UARS AND TOMS-EP PROJECT OPERATIONS CONTROL CENTERS COLLOCATED AND REENGINEERED

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Abstract

At NASA's Goddard Space Flight Center (GSFC), we are reengineering Project Operations Control Centers (POCCs) based on workstation network technologies and lessons learned from the current complex Upper Atmosphere Research Satellite (UARS) mission and the impending generation of low-cost satellites such as the Total Ozone Mapping Spectrometer-Earth Probe (TOMS-EP) mission. UARS is supported in a multimission institutional environment by Concurrent Computer Corporation computers; TOMS-EP is supported independently by networked workstations using embedded processing techniques tailored to small systems. To maintain data continuity until follow-on instruments can be launched, NASA wants to extend the UARS mission (currently in its fourth year of operation) until the year 2002 and expects to extend the TOMS-EP mission, designed for 2 years of operation, to 5 years. The relocation of UARS mission operations to the Earth Observing System Data and Information System (EOSDIS) building, in the same mission operations room with the TOMS-EP mission, offers a unique opportunity. We can evaluate these two disparate systems with the goal of reducing extended lifespan operational costs without increasing risks to the spacecraft or compromising data to the scientists. This paper addresses postlaunch life-cycle costs, plans for extended UARS mission operations, increased automation of TOMS-EP, cost savings from shared UARS/TOMS-EP mission resources, and application of lessons learned to new spacecraft mission operations.

Introduction

GSFC has been the home of UARS operations since the observatory was launched by the Shuttle Discovery on September 12, 1991, and placed into a 57-degree inclined orbit at an altitude of 585 km. The UARS observatory mission objective is to collect information that will improve our scientific understanding of the processes that control upper atmosphere structure and variability, the response of the upper atmosphere to natural and human-induced changes, and the role of the upper atmosphere in climate and climate variability.

UARS flight operations is a joint effort that involves instrument operations personnel, GSFC institutional support elements, mission planning, and the Flight Operations Team (FOT), which operates the observatory.

The UARS FOT has achieved mission objectives in day-to-day operations, in special operations, and in response to anomalous observatory and ground system situations. Coordinated operations with the individual instrument teams have been a key factor in scheduling observatory instruments and reporting spacecraft health and safety status. The data capture rate is better than 99.9 percent of the data recorded during the mission.

The UARS FOT, located in the POCC, is currently supported by the Multisatellite Operations Control Center (MSOCC), the GSFC institutional facility that provides shared computer resources for up to nine simultaneous Tracking and Data Relay Satellite (TDRS) missions. To reduce development and operations costs, GSFC is developing new mission control centers and rehosting current MSOCC POCCs on a workstation environment that integrates GSFC-developed generic building blocks with commercial off-the-shelf (COTS) solutions. As a result, in 1996, the UARS mission may be the only MSOCC mission supported, an unplanned event in a planned closure of the multimission facility.

The UARS science mission extension (desired until the year 2002), the planned phase-out of MSOCC-supported missions (Table 1), and the decision to collocate UARS with TOMS-EP have introduced discussion concerning the best course of action for UARS as a single MSOCC user on a decreasing operations budget.

Table 1. MSOCC-Supported Spacecraft

1995	1996	1997	1998
UARS	UARS	UARS	UARS
ERBS	ERBS		
GOES	GOES		
GRO			
EUVE			

The Mission To Planet Earth (MTPE) budget (which includes the UARS funding) is under continuous scrutiny, and cancellation or termination of both TOMS-EP and UARS has been discussed. Scientists have fought to preserve UARS, and it continues to operate, providing science data that are otherwise unavailable until the Earth Observing System (EOS) Chemistry Mission, scheduled for the year 2002. As the gap in global ozone data monitoring increases, the TOMS-EP mission is waiting for a launch vehicle.

Extended Mission Operations

Current Operations With Full MSOCC Capability and Institutional Support

The UARS system is NASA's contribution to Phase I of MTPE, preceding the launch of NASA's EOS satellites in 1998. The UARS system includes the flight observatory and ground-based, mission-unique and institutional elements. These elements can be further broken down into communications elements and the ground system elements needed to support flight operations and data capture. Communications with the observatory are normally provided by the Tracking and Data Relay Satellite System (TDRSS).

The UARS observatory is approximately 32 ft long and 15 ft in diameter, and it weighs 15,000 pounds. It comprises 10 science instruments; an Instrument Module that includes mission-unique hardware; and the Multimission Modular Spacecraft (MMS), which provides precision pointing for the science instruments on an Earth-oriented platform, periodic routine maneuvers to maintain a favorable Sun orientation, and the ability to communicate through the Space Network (SN) and the Deep Space Network (DSN) for emergencies. Figure 1 shows the relationship of the UARS observatory to the major system elements.

Ground system facilities for UARS flight operations, shown in Figure 2, include GSFC institutional and project-unique facilities. Several NASA institutional elements provide routine support for UARS. The MSOCC provides the real-time telemetry and command processing computers. The SN provides radio

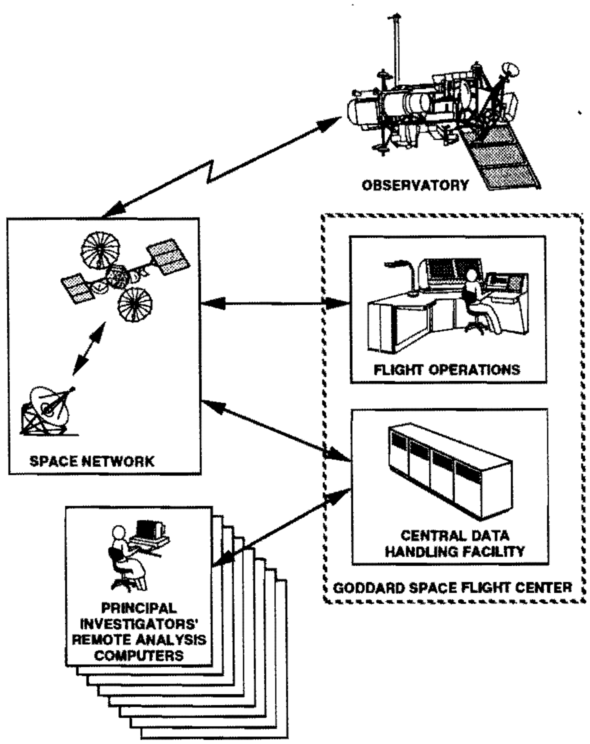

Figure 1. UARS System

frequency communications to and from the orbiting observatory through the TDRS. The NASA Communications network (Nascom) provides communications among all NASA ground elements. The Command Management System (CMS), the primary interface to the science and mission planning personnel for observatory commands, generates the stored command load and instrument microprocessor loads and sends these loads to the POCC for transmission to the observatory. The UARS Test and Training Simulator (UTTS) is available for testing the ground system by validating the flight plan, procedures, and databases and for training the FOT. The Flight Dynamics Facility (FDF) determines observatory orbit and attitude and provides maneuver planning and analysis support. The Data Capture Facility (DCF) collects telemetry data for science-oriented processing, archives playback data, and provides first-level data processing. The Onboard Computer Software Test Facility (OBCSTF), located within MSOCC, is used for on-orbit analysis as well as maintenance and update for spacecraft onboard software.

Other NASA project-unique ground support elements provide special support for the UARS mission. The POCC uses the MSOCC facilities to provide the focal point for on-orbit real-time operations. The Central Data Handling Facility (CDHF) is a project-unique ground data processing system that handles all centralized processing of UARS science data. Members of the UARS science teams analyze data and conduct theoretical studies through the use of remote analysis computers (RACs) located at the principal investigators' (PIs') facilities. The POCC KCRTs located at investigator facilities are connected directly into the POCC computer system through dial-up modem ports and allow users to view observatory telemetry during real-time operations. The PIs use the RACs to submit command sequences and instrument microprocessor loads to the CMS.

Operations With Dedicated MSOCC Hardware

With UARS as the only potential major user in 1996 and beyond, MSOCC must continue to operate economically with a reduced capability to support UARS operations. Table 2 shows the MSOCC equipment required for a multimission and a single-user environment and shows frequency of use. With UARS as a single user, MSOCC staffing would decrease by an estimated half of the current staff level.

All MSOCC equipment required for switching between missions, archiving continuity files between spacecraft contacts, and recording data will be greatly reduced or eliminated, leaving a UARS-tailored capability: dedicated prime, back-up, and spare Concurrent Computer Corporation computers for processing real-time telemetry and transmitting commands, serviced by prime and back-up PDP 11/34 Telemetry and Command (TAC) computers interfacing with Nascom. With some modifications, the FOT could control MSOCC computers for operations from the UARS POCC

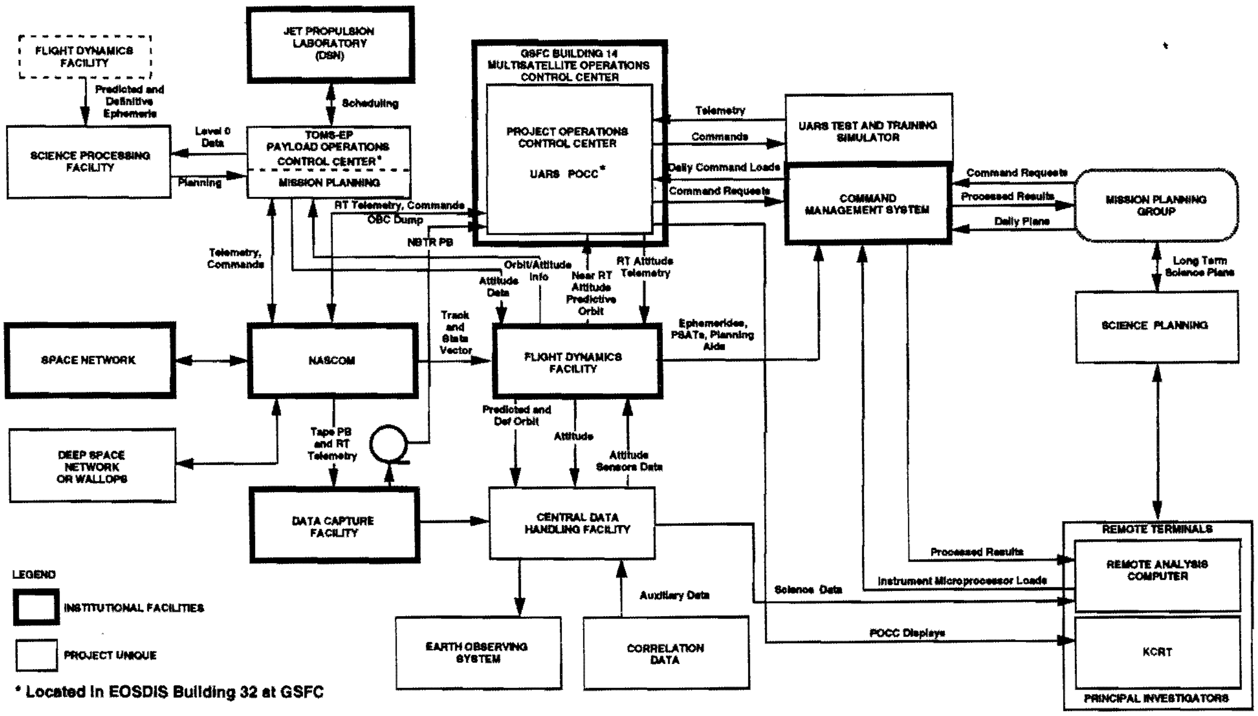

Figure 2. UARS and TOMS-EP Ground System Operational Block Diagram

Table 2. MSOCC Institutional Resources

Multimission Resources	Single User Resources	Use Frequency
8 Applications Processors (6 Concurrent Computer Corporation and 2 PDP-11/70)	3	14 passes/day
8 Telemetry and Command Systems (Front-End PDP 11/34)	2	14 passes/day
4 Recorder Utility Processor Systems	2	1 pass/day to strip FDF data
Data Operations Control System	NA; replace with patch panel	NA
1 User Planning System	1	As needed
Closed-Circuit Television	Yes	As needed
Voice Distribution System	Yes	As needed
MSOCC LANs	Yes	14 passes/day
OBCSTF	1	As required
Dial-back Modems	1	14 passes/day
Nascom Interface	Yes	14 passes/day

remotely collocated with the TOMS-EP Mission Operations Center (MOC) in the EOSDIS building.

Near-Future Operations With Dedicated MSOCC Hardware

The extended UARS mission guidelines are based on these drivers:

- Declining overall budget, reduced by 50 percent
- Science operations desired through 2002
- Parked solar array, reduced power availability, and reduced payload operations
- Reduced tape recorder data capacity
- Dependence on TDRSS to recover science and housekeeping data with the DSN for emergencies
- Dependence on the GSFC institutional environment of MSOCC, FDF, CMS, DCF, and Nascom

The UARS FOT is responsible for continuous spacecraft health and safety monitoring, maneuvers, and reduced instrument operations. The current system operation demands labor-intensive data analysis to support a degraded spacecraft. The UARS FOT online operations staffing has been downsized from 5 people per shift in 1991 through 1993, to 4 people per shift in 1994. The combined UARS and TOMS-EP operations staffing will be 5 people per shift. The science community has requested a conservative operational approach for all activities associated with the UARS observatory. The current plan to find short-term and long-term cost-effective solutions includes the following:

- Historical trend analysis to anticipate component degradation
- Power management tool to maximize utilization of power available for payload operations with a parked solar array
- Instantaneous graphic modeling with respect to celestial reference points to visualize spacecraft orientation
- Definition and augmentation of current onboard autonomous logic for anomaly detection and reaction
- Anomaly recognition, analysis, and correction on the ground
- Reduced operations risk using COTS software, with a high degree of automation built in to reduce the potential for human error during critical or emergency operations

Long term, we must consider the possibility of rehosting the UARS system by using COTS products. The goal is to preserve scientific data beyond NASA funding by transferring spacecraft operations to a university to achieve some, if not all, aspects of a lights-out operation. Such an operation will include the following goals:

- Monitoring by exception
- Single-shift operations
- Remote monitoring (from home)
- System-provided emergency notification to operations personnel
- Automatic pass and data processing
- Combined resources
- Adjustment of data recovery opportunities
- Redefinition of risks
- Focus on real requirements

Develop Synergistic Operations With TOMS-EP

Lockheed Martin operates the UARS and TOMS-EP FOTs under two separate contracts and periods of performance. The UARS Project Manager, having the responsibility for both mission operations, believes one way to reduce costs is to do more with less by developing a seamless working relationship with operations and support teams.

The complexity of a spacecraft bus, number of instruments, science requirements, and methods of implementation all contribute to overall mission operations complexity and intensity of effort. Table 3 shows the mission profile drivers for each mission.

Table 3. TOMS-EP/UARS Mission Profiles

TOMS-EP Mission	UARS Mission
1 instrument	10 instruments
Level 0 data processing	DCF
Local software	CMS
Data archive	CDHF & DCF
Local software	User Planning System
Ground Network	TDRSS
4 to 6 passes/day	14 passes/day
584 lbs	15,000 lbs
Solid-state recorder	2 tape recorders
110 watts power output	4200 watts power output
1.125 kbps real-time data	32 and 1 kbps real-time data
50.625 kbps playback (low) 202.5 kbps playback (high)	512 kbps playback
10 real-time commands/ pass	100 real-time commands/day
Infrequent computer loads	7 to 10 instrument computer loads
1 daily stored command load of 25 commands	3 daily stored command loads of 2560 commands plus intrument command loads

Mission planning and scheduling tools and operator assistance systems will be used to resolve conflicts on the collocated systems during intense operational periods. This practice will allow a smaller team to share functionality and provide backup support. Staffing is being reduced by 30 percent, but additional risk will be avoided by requiring that members of each team receive cross-training to become certified for the position.

The combined UARS and TOMS-EP FOTs are being placed in a synergistic environment to demonstrate increased operational efficiency of a simple and a complex mission. This changing environment will require close coordination between the customer and the FOTs to reach consensus on requirements that meet mission objectives within acceptable risks. Combining operations and identifying cost-effective automation tools are challenges that will use FOT and PI lessons learned as a guide to identify issues and proposed solutions.

After the TOMS-EP launch, candidates for automation in support of lights-out operations include level 0 processing; data archival and distribution; mission planning; orbit and attitude determination, routine command and telemetry processing; prepass, on-pass, and postpass procedures; and emergency procedures for anomaly resolutions.

Rehost to an Alternate COTS System

An alternative UARS solution must be quantified by reviewing UARS requirements to extract a realistic, cost-effective, risk-acceptable, relevant requirements set. This requirements set must satisfy extended UARS operations and data capture needs, with the consideration of TOMS-EP operational characteristics that support a launch planned for the late Fall of 1995. UARS operational requirements include the largest set of mission-unique requirements ever implemented in an MSOCC system to the extent that selective data limits were established to stay within memory limits. A recent survey of COTS products indicated that, to date, basic telemetry processing is a common thread, but command processing, onboard computer interaction, and other unique operational tools are not present. The major concerns regarding UARS rehosting are as follows:

- Retention of existing functionality
- Operational risk amplification resulting from reduced functionality
- Magnitude of database transference effort
- Magnitude of the test and validation process

The UARS database software, a major prelaunch software development effort, is unique, generating uniquely formatted and content-specific outputs for ingestion by the CMS, an institutional facility. The evaluation of a COTS database solution that generates a distinct database will include a tradeoff analysis of the time spent in the original effort versus the recovery of costs in development and use.

Testing and validation of a new COTS-based ground system would be a significant and arduous effort. All telemetry and command processing and related functions would be evaluated for validity and equivalency to the existing system. Any functional dissimilarities would have to be compensated for in both machine and operational contingency procedures.

The UTTS, used for maneuver planning validation, observatory command load validation, and operator training, will confirm the feasibility of alternative solutions through prototyping. The evolution of a new system to support the goal of transition to a university could be revolutionary under NASA's pressures to be better, cheaper, and faster. Using the current UARS observatory as an experimental test bed for proof of concept for alternative or COTS products for extended mission operations is too risky. A prototype ground system, using the UTTS as a data source, must be developed in a short period, based on specific requirements and evaluation criteria. A team consisting of the FOT and COTS software integrators will develop the evaluation criteria by using the existing UARS user's guide to define the baseline requirements set for the current operational system.

A separate thrust for lowering satellite operations costs is reduction of operational personnel and limited hours of real-time observation. This objective supports the argument for new, more comprehensive tools and increased autonomy in both the spacecraft and the ground system. A tradeoff analysis, based on costs and risks, between additional tools for the current system and a rehost to an alternate solution would have to be conducted. The addition of automation tools, with the concomitant reduction in staff, would amplify the online operational risk, especially when the satellite is older and the probability of anomalistic behavior is greater.

Turn Over to Nongovernment Operations

Privatization, with budget cuts as the driver, is the main emphasis. The current UARS system is not ideally configured to hand over to another entity, unless it were done in place here at GSFC. In the event of deactivation, universities and PIs have expressed interest in taking over the system. As the UARS reengineering continues, serious effort will be placed on a cooperative NASA and university team approach. NASA will operate the observatory and ground system as long as funding is provided. Decommissioning of the UARS observatory does not obviate the funding still required for the 2 years needed after turnoff to process the UARS data captured. Until the current generation of operational NASA spacecraft is deactivated, NASA, working with the PIs, must decide the level of risk it is willing to assume to reduce the cost of current operations.

In summary, NASA's mandate for faster, better, and cheaper dictates a philosophical change in how NASA will support future spacecraft. NASA can no longer afford separate engineering efforts like UARS, in which the spacecraft design drives the ground software requirements, which in turn drive the operations. Spacecraft design, ground software requirements, and operations must be an integrated design effort; decisions made in each engineering segment must be analyzed for the cost impact on the other segments and the lifetime of the entire system. A total integrated engineering solution for future systems must have the goal of reducing the cost of data returned; the UARS requirement for recovery of 99.9 percent of the data has been a significant cost driver. Similarly, the goal of transferring UARS to a university will involve an integrated effort of operations personnel, PIs, and software developers to evaluate acceptable hardware and software solutions to decrease the cost of data.

Biographies

E. J. Macie is the NASA Project Manager for the Upper Atmosphere Research Satellite (UARS). He is also the NASA Mission Support Manager for the Interplanetary Physics Laboratory (WIND) satellite and the Polar Plasma Laboratory (POLAR) satellite. He has over 30 years of professional experience working on NASA, National Oceanic and Atmospheric Administration (NOAA), and Department of Defense programs. In addition to UARS, WIND, and POLAR, he has also worked on other NASA satellite programs, including Landsat 7; Total Ozone Mapping Spectrometer-Earth Probe (TOMS-EP); Television Infrared Observation Satellite (TIROS); the Applications Technology Satellite program for ATSs 1, 3, and 6; Earth Radiation Budget Experiment (ERBE); and Geostationary Observational Satellites (GOES). His roles in these programs have ranged from program management through operations management and spacecraft/ground systems integration and test. His extensive experience on the GOES and TIROS programs also includes all phases of development and operations. He has been a member of the Institute of Electrical and Electronics Engineers (IEEE) for many years and has an AST degree in specialized technology from Ryder Technical Institute.

Abigail H. Maury, a project manager for Computer Sciences Corporation (CSC), has 20 years' experience in implementing and managing the development of software for NASA/Goddard Space Flight Center (GSFC) real-time spacecraft telemetry and command operations control centers, including International Sun Earth Explorer (ISEE-A, B, C), Solar Maximum Mission (SMM), Earth Radiation Budget Satellite (ERBS), and Gamma Ray Observatory (GRO) control center software, as well as the Hubble Space Telescope (HST) Optical Telescope Analysis software for NASA/Marshall Space Flight Center. In 1994, Ms. Maury was the CSC project manager, under subcontract to Space Software Italia, for the development of software for the X-Band Synthetic Radar (X-SAR) real-time telemetry and command control center at Johnson Space Center, a NASA/European Space Agency cooperative effort that supported the Space Radar Laboratory (SRL) part of NASA's Mission to Planet Earth (MTPE), flown on the STS-59 and STS-68 shuttle missions. Currently, she is providing systems engineering support for reengineering the Upper Atmosphere Research Satellite (UARS) control center software and managing the rehosting of the GRO and Extreme Ultraviolet Explorer (EUVE) control center software to the NASA/GSFC Transportable Payload Operations Control Center (TPOCC) environment. Ms. Maury has an undergraduate degree in chemistry from Emory University, a master's degree in microbiology from the University of Georgia, a master's degree in computer science from The Johns Hopkins University, and a master's degree in technical management from The Johns Hopkins University.