SATELLITE GROUND OPERATIONS AUTOMATION – LESSONS LEARNED AND FUTURE APPROACHES

John Catena
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

Lou Frank
Honeywell Technology Solutions, Inc.
Greenbelt, MD 20771

Rick Saylor
Honeywell Technology Solutions, Inc.
Greenbelt, MD 20771

Craig Weikel
Computer Sciences Corporation
Lanham, MD 20706

ABSTRACT

Reducing spacecraft ground system operations costs is a major goal in all missions. The Fast Auroral Snapshot (FAST) flight operations team at the NASA/Goddard Spacecraft Flight Center developed in-house scripts and procedures to automate monitoring of critical spacecraft functions. The initial staffing profile of 16x7 was reduced first to 8x5 and then to "lights out". Operations functions became an offline review of system performance and the generation of future science plans for subsequent upload to the spacecraft. Lessons learned will be applied to the challenging Triana mission, where 24x7 contact with the spacecraft will be necessary at all times.

KEY WORDS

Small Explorer, Fast Auroral Snapshot (FAST) Explorer, Ground Operations Automation and Lights-out Operations

INTRODUCTION

After a two-year delay due to launch vehicle problems, the Fast Auroral Snapshot (FAST) Explorer spacecraft was launched from Vandenburg Air Force Base on August 21, 1996. Its primary mission was a one-year observation of the Earth's magnetic field above the polar regions. The highly successful mission was extended and continues to perform its scientific program today. Ground operations support was provided by NASA at the Small Explorer (SMEX) control center facility at the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. Because of budgetary constraints and a desire to transfer spacecraft operations to the Principal Investigator (PI) home facility at the University of California at Berkeley (UCB), FAST operations personnel developed automation concepts and techniques to eliminate the need for man-tended passes and simplifying operations as much as possible.

OPERATIONS CONCEPT

Because of the volume of science data generated by the FAST complement of instruments and the limited amount of on-board data storage, frequent contacts with the ground are required. These circumstances drive the requirement to have a ground contact every orbit resulting in 9 to 11 passes per day. The result is approximately 2 to 3 Gigabytes (GB) of telemetry downlinked every day. Because most of this data is acquired in "real-time" with limited ability to save it, it is important that ground contacts succeed in retrieving as much of this data as possible.

The original operations concept established a 16x7 level of staffing for the flight operations team (FOT) to ensure the success of each FAST pass transfer of science data to the ground network. This resulted in a staffing level at the FAST mission operations center (MOC) of 3 console-level personnel per shift, 2 shifts per day for the life of the mission. In addition, a mission planner supported operations 5 days a week on a half-time basis. After the critical first six months of the mission when a northern winter science campaign was conducted, manned staffing hours were reduced to an 8x5 level.

After the completion of two years of successful FAST science operations combined with budgetary limits at NASA, there was a desire to reduce control center staffing levels as much as practical to limit costs while not jeopardizing the science mission. There was enough confidence in the spacecraft and ground system to operate the mission with one 8-hour shift, five days a week with no science commanding occurring over weekends. In addition, ground network personnel at the Wallops Flight Facility provided 24x7 anomaly support and Barker commanding on weekends. These operations changes resulted in a FOT staffing level of 2 console personnel and a part-time mission planner.

With the approach of the Y2K initiative, a new ground system architecture was developed for the FAST control center. This architecture included the introduction of the Integrated Test and Operations System (ITOS) for spacecraft command and control

functions in March 1999. In addition, NASA GSFC's Spacecraft Emergency Response System (SERS) was under development to provide automated spacecraft monitoring functions and paging of personnel in the event of anomalous conditions. The combination of ITOS and SERS provided an opportunity to automate routine operation functions and notify off-duty personnel in the event a spacecraft or ground anomaly which threatened the loss of science data or the spacecraft itself. FAST operations milestones and corresponding adjustments to FOT staffing are presented in Table 1.

Table 1. FAST Operations Milestones

Date	Operational Milestone
August 1996-March 1997	Commence 16x7 manned operations
March 1997	Transition to 8x5 manned operations
March 1999	Transition to ITOS command and control system
June 1999	Start development of lights-out automation concepts
August/September 1999	Conduct operations testing of automation operations
October 1999	Transition FAST operations to PI facility

AUTOMATION CONCEPT

In June 1999, the FAST control center operations team developed a two-phased automation concept. The first phase was to automate the activities performed during a FAST space-to-ground contact including the sending of commands. The second phase was to devise a method to monitor critical spacecraft and payload telemetry and notify operations personnel when anomalous conditions were evident. Figure 1 provides a system level perspective on the automation concept.

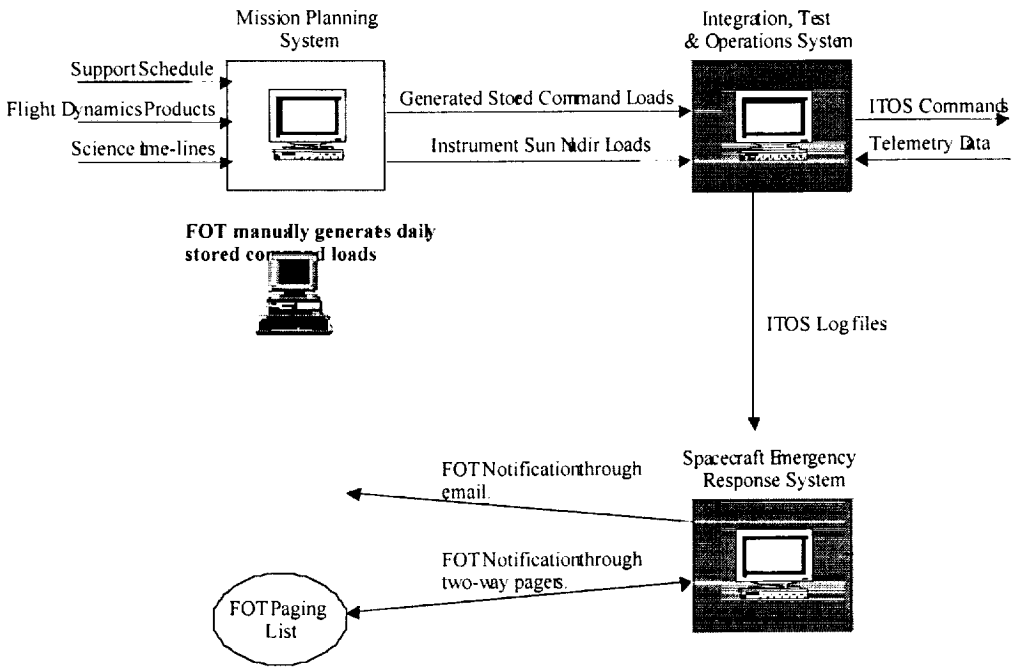

Figure 1. FAST System Level Automation Concept

The automation of routine space-to-ground activities with ITOS was achieved in seven steps. First, a schedule-driven approach was adopted. A weekly ground contact schedule was ingested into ITOS from the ground network scheduling system. This schedule provided ITOS with the acquisition of signal (AOS) and loss-of-signal (LOS) times for each ground contact. Second, at 20 minutes prior to AOS, ITOS would setup the pass configuration, listen for telemetry and command connection requests from the designated ground station, open a new spacecraft events log file for the coming pass, and activate mnemonic monitoring scripts for the pass. Third, at AOS, ITOS would determine what command activities to perform using a pre-determined, prioritized list of activities. These activities were uploading the daily spacecraft functions (e.g., transmitter on/off times, science observation timeline, recorder dumps of science and/or spacecraft event message, etc.), uplinking the Solar ephemeris files, spacecraft clock adjustment commands, and watch dog commands. Fourth, at LOS, after ground station connections were dropped or ground station information denoted the end of the spacecraft transmission, ITOS would perform close out pass log files and disable monitoring schemes. Fifth, at around LOS+1 minute, ITOS would produce a pass summary of all the spacecraft event activities that had transpired during the pass as well as any problems or failures, i.e., daily load not received by the spacecraft for example. These failure notices were sent to the SERS event log file as well. Sixth, If a once-a-day activity was successfully concluded during a pass (uplink of the daily load file), ITOS would automatically flag this function so it would not be performed again for the rest of the operational day. Finally, in the seventh step ITOS would notify SERS via the event log file if the pass had a severe anomaly such as no telemetry received or having uplinked commands not acknowledged by the spacecraft.

After the successful automation of routine pass operations, the next step was to automate the identification of anomalous conditions and alert operations staff if action needed to be taken. This task was accomplished with the use of the SERS. First, operations personnel identified key telemetry and command engineering data that were critical to the safety of the spacecraft and instruments. If left unchecked, the spacecraft could go into a safehold condition or worse. Once these parameters were identified, the staff determined an acceptable time interval under which such an anomalous condition could exist before corrective action would be required. Next, the type of corrective action was identified for each monitored parameter. These actions included logging the event, issuing a page and/or sending an email to a designated staff member, or even sending a command to the spacecraft autonomously to correct the condition. In the event a page or email was issued, if it was not acknowledged within a pre-determined time interval, additional personnel would be notified according to a priority list. Operations personnel would receive a brief informational message with the page or email to apprise them of the particular problem. Additional information was available via an Internet link which provided detailed spacecraft logs and telemetry. If immediate action was required, the staff member would report to the control center to perform the corrective action. Off-site commanding was not permitted. In addition, previous space-to-ground contact information was viewable by

off-site personnel at any time. Figure 2 provides a graphic representation of the process used to implement the automation concepts.

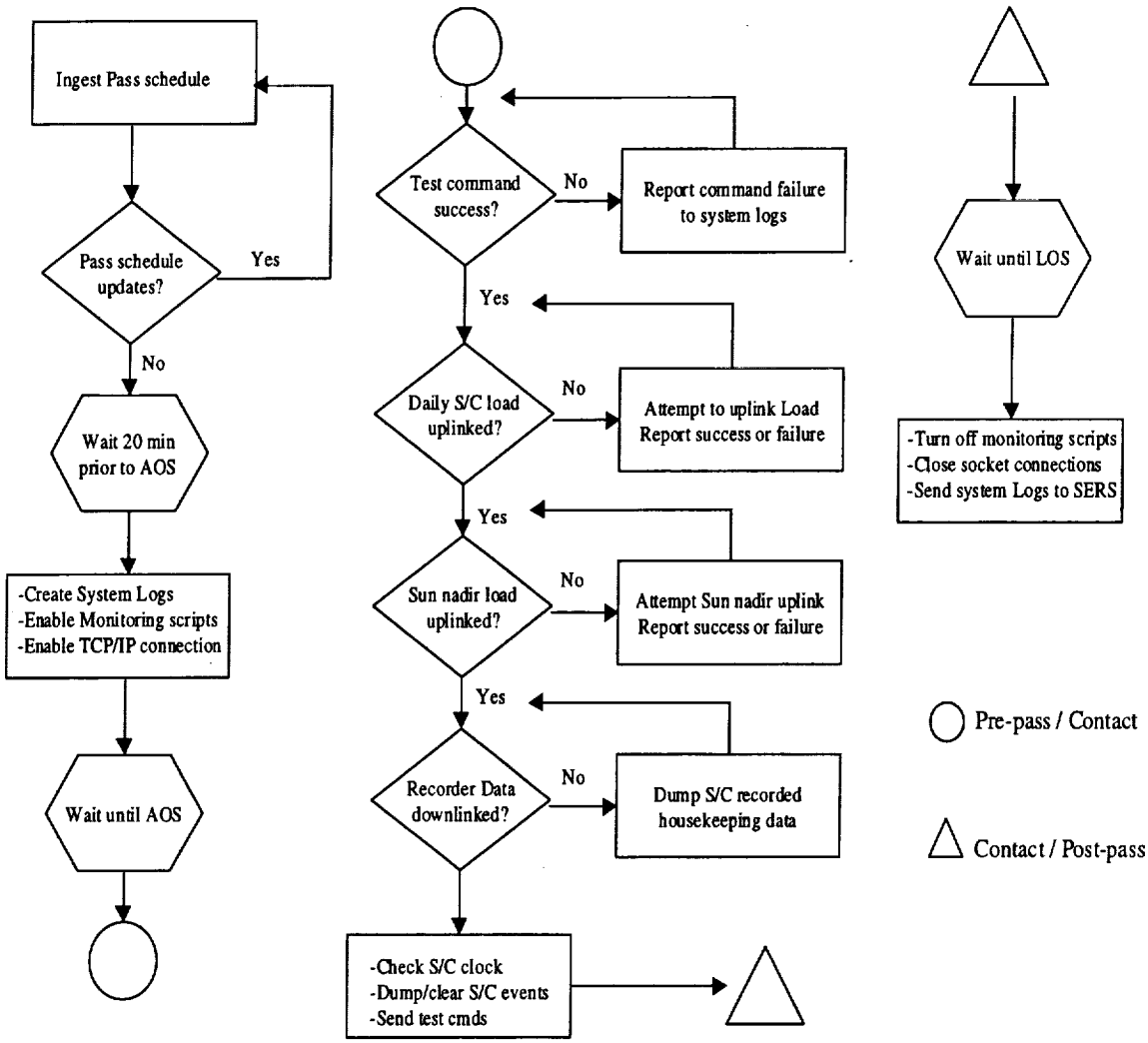

Figure 2. FAST Automation Concept

TRANSITION APPROACH

Transition of the automation concept into operational practice occurred in a very short period of time. In August 1999, the ITOS/SERS configuration was activated during the manned portion of the operational day. Staff members monitored the system and verified

the performance of the system after each spacecraft pass. During various supports, individual automated activities were tested. On August 19, 1999, system level testing started during operational hours. System testing continued to August 26th, 1999 when "lights-out" operations began 24x7. Full-automated operations continued until the operations transitioned to UCB on October 4th, 1999.

RESULTS

During the 40 days of "lights-out" operations, the automation procedures encountered only 1 failed attempted at loading a stored command load. The reason for the failed attempt was a ground station uplink problem. The stored command load was successfully loaded on the following support.

ITOS and SERS detected three spacecraft anomalies during the 40-day period. The FOT was notified of all three anomalies by pager and email. Corrective action took place with minimal impacts to operations.

During the operational use of the automation concept, 100% of spacecraft engineering data was recovered along with 99.74% of science data. This reflected the same data recovery statistics when FOT supported passes before "lights-out" automation.

A summary of the activities the FAST automation system performed during September 1999 is presented in Table 2.

Table 2. FAST Automation Events and Anomalies for September 1999

Activity	Frequency	Successful Attempts	Failed Attempts
Stored Command Loads	Once per day between Monday-Friday	29	1
Sun Nadir Loads	Once per day between Monday-Friday	29	0
Engineering Data Operations – Clearing Recorded Data	Twice per day	80	0
Engineering Data Operations – Verifying expected data dump, re-dumping if needed	Every pass	8 re-dump attempts	0
Clock Drift Check	Once per day	40	0
Spacecraft Event Dump verification	Every pass	15 successful event re-dumps	0
No-Op Command	Every pass	N/A	N/A

As evidenced by the table, the system performed extremely well. A total of 520 space-to-ground contacts were supported by the automated system. Four anomalous conditions

were handled without human intervention. As a result of this success, when the flight operations responsibility for FAST was transferred to the PI home facility at UCB the following month, the automated system was transferred intact. Although the system operated at GSFC for a short time, the operations team determined that the new system required only one full-time, 8x5 console position to operate the mission. The duties of this staff member also included the mission planning functions.

LESSONS FOR TRIANA

The Triana spacecraft currently in development will be operated on-orbit in the SMEX control center. Operationally it is a demanding mission because it will be transmitting telemetry to Earth continuously, 24x7 for 2 years or more.

The most important lesson learned from the FAST experience was that round-the-clock nominal operations could be performed automatically without requiring human intervention. Staffing hours for the mission have been aligned with the SMEX concept of 8x5 operations. Utilizing the FAST automation experience staffing levels for Triana are targeted for two full-time personnel.

Three new approaches have been taken in the development of the automation concepts for Triana. The first is that more extensive use will be made of SERS capabilities to access insight into spacecraft events and the performance of the ground network used for Triana. The Universal Space Network (USN) has installed ITOS at its ground station sites. This will enable SERS to determine the results of commanding activities and notify operations of problems related to the network as well as the spacecraft. This will be a powerful tool for the mission. Second, a formal automation plan is under development for Triana. Automation scripts and procedures are being tested and verified with the spacecraft today during its integration and test phase. The results of these tests will help refine the final procedures put into operations after the spacecraft has reached its observation location at Lagrange point 1 and begins nominal mission activities. The third approach concerns ITOS. In addition to the Triana MOC and USN using ITOS in the telemetry and command flow, the Triana Science and Operations Center (TSOC) located at the Scripps Institution of Oceanography in San Diego will be operating an ITOS component. It will receive the Triana science from the MOC. The TSOC ITOS will provide event logs for access by the MOC SERS, which in turn will alert TSOC operations, personnel to system anomalies. This framework of ITOS and SERS components throughout the Triana ground system lays the groundwork for powerful automation capabilities in the future.

CONCLUSIONS

Significant automation of the FAST ground system was achieved in a relatively short period of time at little cost. Because of the evolutionary approach of FAST operations automation, implementation costs to a total "lights-out" system incurred by the operations

staff were minimal. There were no additional software costs associated with the automation effort. ITOS and SERS software were provided by NASA/GSFC.

Overall system performance of the FAST ground system exceeded expectations with almost no loss of science data while maintaining a healthy spacecraft. The reduction in staffing achieved was 50% from the pre-automation levels. With an estimated investment of three man-months of work to develop, install and monitor the automation concepts in operations, the savings returned in subsequent staffing costs was well worth the effort. In addition, the success of the automated system made possible the transfer of FAST operations to the PI facility.

Leveraging the FAST experience for Triana has resulted in realistic staffing plans supported by proven automation techniques and the development of more ambitious automation schemes and procedures verified with the Triana spacecraft prior to launch. Finally, the infusion of software systems and tools throughout the ground system will support future advancements in the automation of Triana operations.

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BIOGRAPHIES

John Catena is the Ground System Project Manager (GSPM) of the Triana mission at NASA GSFC since 1998. He has over 23 years of government service. John was the GSPM for the first five SMEX missions starting in 1989 and completing that assignment in 1999. Previously he was involved in launch vehicle activities including the Atlas-Centaur and the Pegasus proof-of-concept initiative.

Lou Frank is the ground operations system engineer responsible for control center infrastructure, communications and system configurations. He was the principal implementation lead for the FAST automation concepts. An employee of Honeywell Technology Solutions, Inc, Lou has over five years of spacecraft operations experience including two years with SMEX and Triana missions.

Rick Saylor has been a member of the SMEX flight operations team at GSFC since 1994. A six-year employee of Honeywell Technology Solutions, Inc., he has been involved in SMEX spacecraft integration, test and launch operations for the FAST, the Transition Region and Coronal Explorer (TRACE) and Triana missions. He currently leads the flight operations contingent for the Triana project.

Craig Weikel is the lead ground systems engineer for the Triana mission. He has been a member of the ground system engineering team since the FAST mission. He has previously performed software development and system engineering duties for five earlier missions at GSFC in his twenty-eight year career with Computer Sciences Corporation.

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