THE NASA EUVE SATELLITE IN TRANSITION: FROM STAFFED TO AUTONOMOUS SCIENCE PAYLOAD OPERATIONS

B.A. Stroozas, D. Biroscak, M. Eckert, F. Girouard, A. Hopkins, G.C. Kaplan, F. Kronberg, K.E. McDonald, P. Ringrose, C.L. Smith, J.V. Vallerga, L.S. Wong, & R.F. Malina
Center for EUV Astrophysics, 2150 Kittredge Street,
University of California, Berkeley, CA 94720-5030, USA

ABSTRACT

The science payload for NASA's Extreme Ultraviolet Explorer (EUVE) satellite is controlled from the EUVE Science Operations Center (ESOC) at the Center for EUV Astrophysics (CEA), University of California, Berkeley (UCB). The ESOC is in the process of a transition from a single staffed shift to an autonomous, zero-shift, "lights out" science payload operations scenario (a.k.a., 1:0). The purpose of the 1:0 transition is to automate all of the remaining routine, daily, controller telemetry monitoring and associated "shift" work. Building on the ESOC's recent success moving from three-shift to one-shift operations (completed in Feb 1995), the 1:0 transition will further reduce payload operations costs and will be a "proof of concept" for future missions; it is also in line with NASA's goals of "cheaper, faster, better" operations and with its desire to out-source missions like EUVE to academe and industry. This paper describes the 1:0 transition for the EUVE science payload: the purpose, goals, and benefits; the relevant science payload instrument health and safety considerations; the requirements for, and implementation of, the multi-phased approach; a cost/benefit analysis; and the various lessons learned along the way.

Keywords: Extreme Ultraviolet Explorer (EUVE) satellite, artificial intelligence (AI), telemetry monitoring, autonomous operations, satellite operations, zero-shift operations

1. INTRODUCTION

In today's environment of reduced NASA budgets additional pressures have been put on existing satellite missions to reduce costs. Mission operations costs, by far, dominate all others and have rightly become the prime target. In response to these budgetary pressures and to NASA's goals of "cheaper, better, faster," the EUVE project at CEA has led the way in changing the typical NASA mission operations paradigm. In Feb 1995 CEA successfully implemented a transition from 24-hour, three-shift human operations to a single-shift scenario (Malina 1994; Biroscak et al. 1995) for the EUVE science payload. This transition was accomplished using augmented intelligence software (Lewis et al. 1995; Wong et al. 1995) and has been extremely successful.

CEA is now following up on this success with a transition from one- to zero-shift payload operations. We have been able to follow this course of action for two main reasons: (1) EUVE has successfully completed its prime mission and fulfilled the associated science objectives; and (2) the flight hardware was designed with built-in, on-board safety mechanisms that have proved very reliable on orbit. For these reasons we can accept increased levels of risk in order to reduce operations costs, which will help to further extend the mission's lifetime. Through the so-called three-to-one (3:1) and, now, one-to-zero (1:0) transitions we have significantly reduced operations costs, while at the same time incurring no significant additional risks to the payload instruments or negative impacts on the quality and quantity of the science return.

2. WHY 1:0?

A variety of factors contributed to the decision to further build upon the success of the 3:1 transition with a move to a zero-shift science payload operations environment. The following subsections discuss these factors in detail.

2.1 GOALS AND BENEFITS

The goal of the 1:0 transition is to automate or eliminate all of the routine controller "shift work," defined as those routine tasks that must be done on a specific time basis. Under this definition shift work mainly comprises the routine, daily "on-line" controller activities: the human monitoring of science payload telemetry during real-time contacts with the satellite (i.e., console duty); the daily console support maintenance activities; and routine payload commanding. In addition to this routine shift work, controllers are responsible for a variety of non-routine "off-line" activities (e.g., anomaly response and special commanding).

A transition to a zero-shift environment reaps many benefits. In addition to further reducing ESOC costs for routine operations, the 1:0 transition is in line with NASA's goals of "cheaper, faster, better," and with the recent NASA decision to out-source the EUVE mission to CEA (in part, a direct result of the 3:1 transition). The 1:0 transition will also serve as a "proof of concept" for future missions, and will provide CEA with additional opportunities for innovation, collaboration, and technology transfer.

2.2 SCIENCE PAYLOAD HEALTH AND SAFETY CONSIDERATIONS

The maturity of the EUVE mission played a major role in allowing CEA to reduce operations staffing. The satellite's built-in safety mechanisms have always worked on-orbit as designed, providing EUVE with the ability to autonomously safeguard itself in anomalous situations. Although on-console controllers are good at detecting unexpected failures and at providing instantaneous response, this type of emergency human response to a payload anomaly is limited to realtime contacts with the satellite and has never actually been necessary during four years of on-orbit operations. Moreover, we have discovered that automated monitoring of telemetry can detect expected anomalies better than on-console controllers.

EUVE has four levels of payload instrument health and safety (H&S) monitoring, each with its own associated response timescale:

1. On-board safety monitors (e.g., detector high voltage shutdown in response to high counting rates) provide instantaneous detection and response.
2. Engineering monitor out-of-limit conditions (e.g., instrument electric current readings) are detected on the ground during realtime contacts or hours later via review of production data (i.e., tape recorder dump).
3. Detector anomalies (e.g., distorted detector images) are detected hours after the fact by human review of production data images.
4. Instrument degradation (e.g., detector gain sag) is detected over periods of weeks to months via special tests and calibrations.

The 1:0 transition has little effect on the above response timescales, introducing a significant increase (of up to a few days) only for discovering detector anomalies. However, this delay is acceptable because of the low risk of such an occurrence (none so far in four years of flight operations) and because the impact would not compromise instrument safety, but would only result in a small degradation of the science return. Based on these instrument H&S considerations, we are convinced that a zero-shift operations scenario with 24-hour automated telemetry monitoring will maintain virtually the same level of instrument H&S with only a slight and acceptable increase in risk, mainly in the form of slower response to detector anomalies.

2.3 SUCCESS OF 3:1 TRANSITION

Before going into the details of the 1:0 transition implementation, the enormous success of its predecessor is worth noting. The 3:1 transition changed the operations paradigm for the way NASA will run missions in the future by demonstrating an innovative, low-cost, and low-risk methodology. As NASA Administrator Dan Goldin (1994) stated, "…[EUVE] employed artificial intelligence and expert systems and, instead of having three shifts operating the spacecraft, with people going around the clock, [they] changed the paradigm… Less is more, and we're getting more reliable operations of the spacecraft with one shift instead of three."

The 3:1 transition, which has been extremely successful, has been described in previous publications (Malina 1994; Lewis et al. 1995; Biroscak et al.1995; Kronberg et al. 1995; Wong et al. 1995). The implementation of an artificial intelligence (AI) telemetry monitoring system, which uses two major components, formed the basis of the transition. The first component, "Eworks," is an EUVE-specific adaptation of a commercial AI telemetry monitoring package called RTworks from Talarian, Corp. The second, "sepage," is a UNIX-based paging utility, invoked by Eworks, that generates pages to an on-call Anomaly Coordinator for EUVE (an ACE). This software system has performed exceptionally well.

3. HOW 1:0?

The 1:0 transition was implemented in a phased approach based on an established set of requirements and ground rules. The following sections describe the implementation in detail.

3.1 REQUIREMENTS AND GROUND RULES

The first item of business for 1:0 was establishing the following relevant requirements: (1) science payload instrument H&S will not be compromised; (2) all console telemetry monitoring duty will be human independent; (3) all routine console support duties will be automated or, where appropriate, eliminated; and (4) information exchange in the ESOC will be centralized, simplified, and effective.

In order to meet the above requirements, a number of ground rules were established. First and foremost, instrument H&S will remain the primary focus of science payload operations in the ESOC. Second, CEA is willing to sacrifice some science data return in order to reduce costs. Third, the “20-hour rule” will remain in effect; this rule states that all detector high voltage units will be turned off in the event that CEA is unable to receive payload H&S status information within any contiguous 20 hour period (i.e., we completely trust the payload to be on its own for up to 20 consecutive hours). Fourth, the on-call ACE system will remain in effect.

After outlining the above requirements and ground rules we began the planning, design, and implementation efforts for the 1:0 transition.

3.2 A PHASED APPROACH TO ZERO-SHIFT OPERATIONS

To implement the 1:0 transition we adopted the following methodology of a multi-phased approach:

- Phase 1. Minimal Zero-Shift Scenario — Automate all essential console telemetry monitoring duties.
- Phase 1.5. Semi-Operational Zero-Shift Scenario — Eliminate ESOC support on weekends and holidays as a first step to the full operational zero-shift scenario.
- Phase 2. Operational Zero-Shift Scenario — Automate all daily console support activities.

Upon implementation of this phased approach the ESOC will be operating in a full zero-shift, “lights out” scenario, with all routine duties handled autonomously.

When all of the “required” tasks for the transition were organized and listed, it was clear that CEA had neither the time nor the resources to accomplish them all. This lack of time and resources forced us to reexamine our expectations, and to categorize and prioritize the listed tasks into primary and secondary needs and wants according to the following definitions:

- Primary Need—An issue that, if not addressed, could have negative effects on instrument H&S.
- Secondary Need—A non-H&S issue that, if addressed, would yield significant operations cost savings.

- Primary Want—A non-H&S issue that, if addressed, would yield minor cost savings and/or science benefits.
- Secondary Want—A non-H&S issue of a purely streamlining nature.

By focusing on the primary and secondary needs, we then proceeded to incrementally implement the various tasks, doing the simple things first in order to gain tangible results quickly. This phased, incremental approach also helped us to build an overall robust system in an organized manner, provided sufficient time for testing and validation, and allowed us to reexamine our assumptions based on our experiences along the way. At each transition a review was held with CEA and Goddard Space Flight Center (GSFC) personnel to ensure that everything was in order before proceeding with that particular transition. In all, we believe that this was the right way to proceed: a safe and reasonable implementation strategy.

3.3 PHASE 1 — MINIMAL ZERO-SHIFT SCENARIO

The 1:0 Phase 1 transition aimed to automate all essential payload telemetry monitoring, thereby eliminating human console duty. The development costs for this Phase were relatively minor, and the transition was completed on 15 Nov 1995. The major accomplishment eliminated "bad data" in the monitoring process, which is caused by a lack of quality information in the telemetry files. We had to change Eworks from monitoring realtime data (which do not include quality information) to post-pass realtime data (which do); this change was accomplished in cooperation with the Packet Processor (PACOR) facility at GSFC that packages and sends EUVE data to CEA. During normal one-shift operations the controllers had continued to monitor payload telemetry manually for 2–3 realtime passes each day; during this time Eworks detected all the anomalies that the controllers detected, giving us additional confidence in the Eworks implementation, and serving as a simulation for the 1:0 Phase 1 transition.

3.4 PHASE 1.5 — SEMI-OPERATIONAL ZERO-SHIFT SCENARIO

The goal of the 1:0 Phase 1.5 transition was to eliminate ESOC staffing on weekends and holidays as a first step toward the fully operational zero-shift scenario. This step provided an intermediate near-term goal to push the development efforts in order to complete many of the 1:0 tasks in advance of any EUVE out-sourcing implementation activities. It also allowed for an incremental reduction in weekend and holiday shift support, and provided a time period to begin early validation and simulation of software and personnel activities in preparation for the Phase 2 transition. The development costs for this transition were moderate, and the transition occurred on 26 Jan 1996. Some of the major tasks accomplished for this transition were: the implementation of an automated system to monitor a minimal set of critical ground system equipment, the automation of the daily manual review of engineering limit transitions and alert conditions, and a revision of the internal and external communications flow process. We conducted a simulation over the winter holiday period in which controllers "staffed" the ESOC via remote computer access on weekends and holidays, checking in on the various systems at least twice each day to ensure everything was operating as expected.

3.5 PHASE 2 — OPERATIONAL ZERO-SHIFT SCENARIO

The goal for the 1:0 Phase 2 transition is to automate all daily console support duties. When completed in late 1996, this transition will completely eliminate the need for all routine daily console duty and support activities during normal operations. The development for this transition includes such tasks as supplementing the Eworks rule base to monitor additional engineering monitors, enhancing the existing automated ground system monitoring utilities to incorporate additional capabilities, providing for user-configurable control of the paging process, upgrading and reconfiguring the ground systems for enhanced reliability, automating all routine payload commanding activities, updating and augmenting all ESOC operations procedures, developing a training program to ensure controllers retain operator proficiency with payload activities in a reduced support environment, and ensuring an adequate simulation period.

4. COST/BENEFIT ANALYSIS FOR 3:1 AND 1:0

In Jan 1996, in order to quantify the fiscal effects of the 3:1 and 1:0 transitions, we performed a cost/benefit analysis for both. We calculated costs (actual and projected) by including all development costs for the commercial software (e.g., licenses and maintenance) and for the CEA personnel (programmers, systems, engineers, scientists, and managers) who designed, developed, and integrated the new software into the existing environment. By comparing the post-transition monthly operations costs with those pre-transition, we were then able to calculate a fixed monthly cost savings rate that will be sustained throughout the remainder of the mission. We estimated a break-even date for each transition by comparing development costs with the accumulated monthly cost savings. We then projected the monthly cost savings from the break-even date through the remainder of the mission (currently slated through Sep 1997) to yield total estimated savings.

The results were very encouraging, with estimated savings of ~$581,000 for 3:1 (see Figure 1) and ~$25,200 for 1:0 (see Figure 2), a sum total of over ~$606,000 when carried through Sep 1997. Although some of the 1:0 savings will be lost because of the delay in the Phase 2 transition (originally scheduled for mid-1996), this loss will very likely be compensated for if the outsourced EUVE mission continues through Sep 1999 as proposed by CEA.

5. LESSONS LEARNED

Even though we have not yet completed the 1:0 Phase 2 transition, we have learned numerous lessons from what has been accomplished to date, as outlined in the following paragraphs.

Management — As with the 3:1 transition, we continually reexamined our assumptions during the 1:0 implementation. By categorizing tasks into needs vs. wants, and by then focusing on the critical needs, we were better able to meet our deadlines and to make use of our limited programming resources.

Phased approach — A stepped implementation allowed us to phase in changes in an organized and readily controlled manner. This approach made it much easier for everyone involved to adjust to the changes, and allowed us to implement the simple things first and to do so rapidly. Tailoring simulations for each phase of the transition also allowed us to test smaller chunks of software code in a more thorough manner.

Communications — Requiring that users and developers work closely together to ensure a smooth transition minimized internal CEA communications problems related to the 1:0 transition. In addition, consolidation of all CEA EUVE operations functions (payload, science planning, and guest observer/investigator support) into a single integrated/intelligent science operations group under one manager helped to smooth the communications flow. In terms of external communications, we worked directly with GSFC personnel to define and implement an agreement for communications during off-shift hours. We also implemented a weekly operations telecon between CEA and GSFC personnel to ensure that all parties were aware of on-going issues, problems, etc.

Paging — A lesson learned during 3:1 and applied in 1:0 handles “bad data” (i.e., realtime data with no quality information included) by switching Eworks monitoring to post-pass realtime data (with quality information). This change required agreements and work on the part of both CEA and the PACOR facility at GSFC. Future missions are advised to always

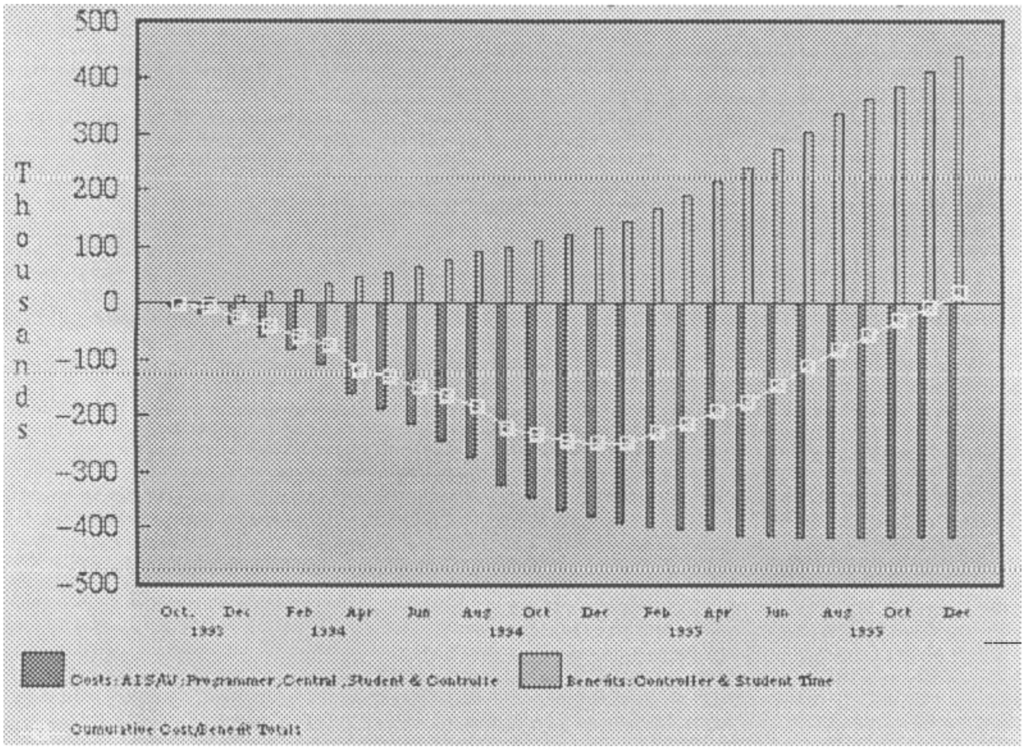

Figure 1: EUVE science payload cost/benefit analysis for the 3:1 transition.

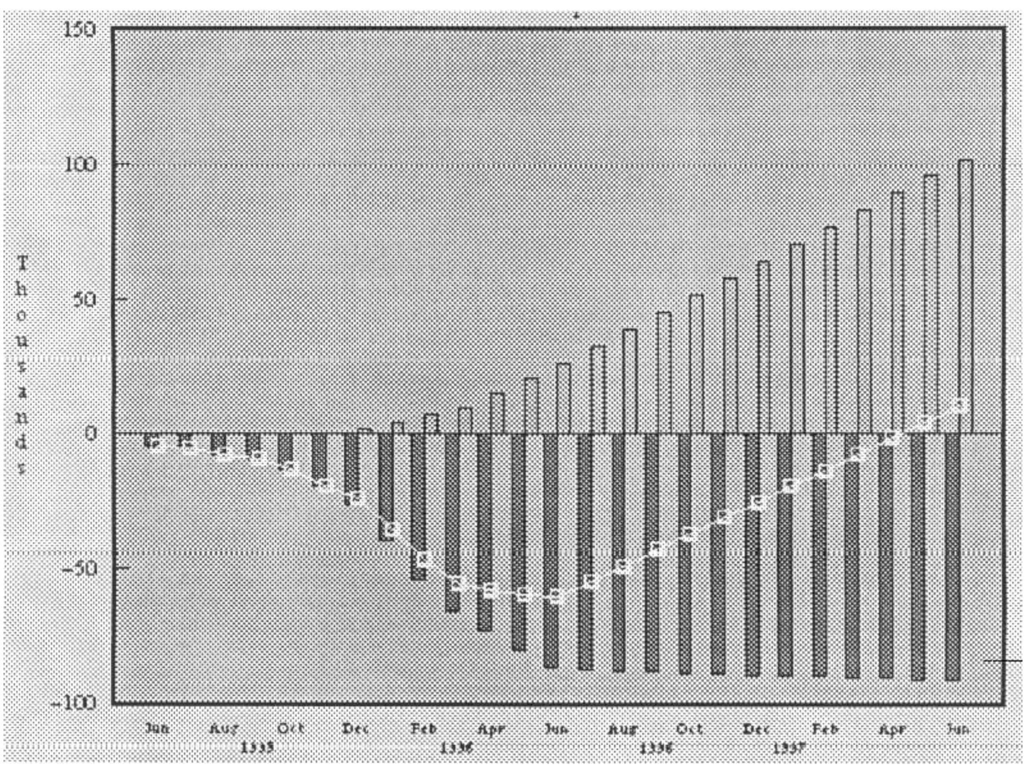

Figure 2: EUVE science payload cost/benefit analysis for the 1:0 transition.

include quality information (e.g., CRCs) in the data used for monitoring. We also learned the usefulness of categorizing anomalies into warnings (those requiring immediate attention) and alerts (those requiring attention during next business day) and paging on each in different ways. Finally, because some expected conditions often generated pages (e.g., certain non-routine observation configurations), it became clear that paging should be user configurable for easy adaptation to varying circumstances.

Ground computer and software systems — Being predominantly concerned about on-board flight anomalies, we underestimated the impact of ground system and software anomalies, which in practice make up the bulk of the anomalous situations that require human intervention. Focusing more from the beginning on these types of anomalies would have yielded a much more robust automated system.

Training — With reduced ESOC staffing one ends up with a shrinking pool of trained controllers and ACEs. Not working in the ESOC on a daily basis makes one rusty when duty calls. This is a difficult problem to solve, and we are exploring a number of ways to deal with it: increased detail in the operations procedures, periodic simulations or re-certifications, training "games" that pit controller vs. controller, etc. Because of the cost inherent in maintaining a high training level, we must be careful to strike a balance between what we need and what we can reasonably provide.

Resistance to change — As with the 3:1 transition, resistance to change was a factor. CEA payload controllers have traditionally been trained to ensure maximal instrument H&S and science return. This has resulted in a group of very caring and dedicated, yet conservative (by design) personnel. Changing this mind set has sometimes proved difficult. The 1:0 transition has resulted in changing job responsibilities and in fewer highly trained individuals. The key lesson has been to effectively discuss and explain the changes with the affected individuals in order to gain from the outset their understanding, involvement, and support.

Plan early — As evident from the cost savings presented above, the 3:1 and 1:0 transitions have been very successful; one can only imagine what the savings would have been had the EUVE mission been designed from the beginning with the idea of zero-shift operations instead of requiring major re-engineering efforts along the way. Future missions can save significant expenses by planning from the beginning for reduced staffing.

6. SUMMARY

By Jan 1996 CEA was operating the EUVE science payload in a semi-operational zero-shift “lights out” scenario, one in which all payload telemetry monitoring is performed by AI software, and the ESOC is not staffed on weekends and holidays; the transition to the full Phase 2, operational zero-shift scenario, is scheduled for late 1996. We implemented the 1:0 transition in a phased approach, doing the simple things first in order to gain tangible results quickly and to build an overall robust system in an organized manner; other papers in these proceedings (Eckert, 1996; Kronberg, 1996) discuss particular issues related to this transition. The results have been extremely positive, with cost savings for 3:1 and 1:0 projected at $600,000 (and probably much more depending on the length of the out-sourced EUVE mission).

Throughout, we have taken a conservative approach to the 1:0 transition. We have carefully weighed and accepted the additional risks, and have tried to focus and build upon our successes and to learn from our mistakes. We believe that our methodology has resulted in the right approach—one both safe and reasonable.

First and foremost the authors would like to thank the entire EUVE operations team for its assistance and support in the 1:0 transition efforts. At CEA we would particularly like to thank all of the ESOC controllers and aides, the operations programmers and systems support personnel, and the duty scientists. At GSFC we thank Ron Oliversen; Kevin Hartnett, Hun Tann, and Bill Guit and his EUVE Explorer Platform Flight Operations Team; Darnell Tabb, and Don Davenport and his crew at PACOR; and the relevant personnel at NASA Communications (NASCOM) and in the Flight Dynamics Facility. Second, we’d like to thank Mel Montemerlo of NASA Code X, Dave Korsmeyer of NASA Ames Research Center, and Peter Hughes of GSFC for their support of the EUVE technology testbed. Third, we’d like to thank the EUVE Program Manager Dr. Guenter Riegler for being a strong “friend of change” within NASA. Finally, this work has been supported by NASA contract NAS5-29298 and NASA Ames grant NCC2-838.

REFERENCES

Biroscak, D., Losik, L., and Malina, R.F. “Re-Engineering EUVE Telemetry Monitoring Operations: A Management Perspective and Lessons Learned from a Successful Real-World Implementation,” Re-Engineering Telemetry, 1995, 388–395

Eckert, M., et al. "EUVE Telemetry Processing and Filtering for Autonomous Satellite Instrument Monitoring," these proceedings

Goldin, D. from a speech entitled "The Next Frontier," Commonwealth Club of California, 19 Aug. 1994

Malina, R.F. "Low-Cost Operations Approaches and Innovative Technology Testbedding at the EUVE Science Operations Center," SAG #614, 45th International Astronautical Congress, IAA Symposium on Small Satellite Missions," Jerusalem, Israel, October, 1994

Lewis, M., et al. "Lessons Learned from the Introduction of Autonomous Monitoring to the EUVE Science Operations Center," 1995 Goddard Conference of Space Applications of Artificial Intelligence and Emerging Information Technologies," NASA CP-3296, GSFC, Greenbelt, MI, 1995, 229–235

Kronberg, F., et al. "Re-engineering the EUVE Payload Operations Information Flow Process to support Autonomous Monitoring of Spacecraft Telemetry," Re-Engineering Telemetry," 286–294, 1995

Kronberg, F., et al. "Document Retrieval Triggered by Spacecraft Anomaly: Using the Kolodner Case-Based Reasoning (CBR) Paradigm for a Fault-Induced Response System," these proceedings

Wong, L., et al. "Development and Deployment of a Rule-Based Expert System for Autonomous Satellite Monitoring", Proceedings of the Fifth Annual Conference on Astronomical Data Analysis Software and Systems, Oct. 22–25, 1995, Tucson, AZ