Advanced Satellite Workstation

An Integrated Workstation Environment for Operational Support of Satellite System Planning & Analysis

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Abstract

This paper describes a prototype integrated environment, the Advanced Satellite Workstation (ASW), that has been developed and delivered for evaluation and operator feedback in an operational satellite control center. The current ASW hardware consists of a Sun Workstation and Macintosh II Workstation connected via an ethernet Network Hardware and Software, Laser Disk System, optical Storage System, and Telemetry Data File Interface. The central mission of ASW is to provide an intelligent decision support and training environment for operator/analysts of complex systems such as satellites. There have been many workstation implementations recently which incorporate graphical telemetry displays and expert systems. ASW is a considerably broader look at intelligent, integrated environments for decision support, based upon the premise that the central features of such an environment are intelligent data access and integrated toolsets. A variety of tools have been constructed in support of this prototype environment including: an automated pass planner for scheduling vehicle support activities, architectural modeler for hierarchical simulation and analysis of satellite vehicle subsystems, multimedia-based information systems that provide an intuitive and easily accessible interface to Orbit Operations Handbooks and other relevant support documentation, and a data analysis architecture that integrates user modifiable telemetry display systems, expert systems for background data analysis, and interfaces to the multimedia system via inter-process communication.

Executive Summary

The Advanced Satellite Workstation (ASW) project was conceived as a mechanism for demonstration of advanced information technology as applied to satellite support activities. Initial prototypes concentrated on providing graphical telemetry displays ("electronic strip-charts") and very specific expert system modules for anomaly diagnosis. As experienced was gained with the technology, and the technology itself grew in capability, it became apparent that the definition of an intelligent environment for decision support systems such as a satellite workstation encompasses more than expert systems and displays. Central to the evolving ASW concept is a robust multimedia data architecture and an integrated, communicating set of tools. Interation with this ASW prototype system is providing a method for exploring operational questions relating to satellite support activities.

ASW has recently been installed in an active Mission Control Complex. The current hardware is composed of Sun and Macintosh II workstations. These two workstations are connected via ethernet, and can interface to data products within the operational environment over this network. The technologies being applied are expert systems, graphical user interfaces, graphical data visualization, hypermedia and multimedia information systems, and hierarchical design and modeling environments. The specific applications that are being targeted as part of the current ASW implementation are: Automated Pass Plan Generator, Electronic Orbit Operations Handbook, Telemetry Data Graphical Display System, Telemetry Data Trend Analysis System, Vehicle Subsystem Hierarchical Modeler, and On-orbit Event Scheduler. Prototypes of the first four have been integrated and delivered. Major emphasis is on communication and data sharing among these applications to provide an integrated environment for decision support.

Introduction

ASW Project History

The Advanced Satellite Workstation project was initiated in 1985. The primary initial focus of the project was the technology transfer of expert systems to satellite support activities. By mid-'85 an prototype system was completed on a Symbolics computer. This first prototype was designed to solve anomalies in the attitude control system of the DSCS III spacecraft. The initial system was useful in demonstrating the utility of rule-based systems as applied to spacecraft system anomaly resolution.

Further work on this project resulted in the development of a lisp-based satellite architecture browser. The browser was conceived as a tool that would allow engineers to enter (in a hierarchical manner) schematics and subsystem documentation related to the space vehicle. This information could be browsed by the user in a structured fashion, and provide insight into any component of the satellite subsystem to the finest level of detail installed in the browser. By 1986 the satellite architecture browser incorporated diagnosis and simple simulation capabilities. This provided the user with the ability to simulate the operation of the hierarchical models installed into the browser; while comparing the simulated output with actual telemetry data from the satellite vehicle.

1986 also saw the development of an expert system for anomaly resolution in the GPS spacecraft. Again, the attitude control system was the focus of the effort. Specifically, the system did long term trend analysis of the telemetry data representing the spin-rate of the reaction control wheels. Upon analysis of this data, the expert system could determine if upon exit from an eclipse the vehicle would tend to exhibit excessive roll and pitch. Recommendations from the expert system would alert the operators to the condition of the vehicle prior to exit from eclipse so that the vehicle attitude could be closely monitored. This system demonstrated the value of expert systems for long-term, automated monitoring of telemetry data not practical for human operators.

In 1987 development was initiated on hypermedia-based information system that would provide the satellite operators with access to documentation. This system was also used as a tool to rapidly develop and test (in conjunction with satellite operators) different user displays and interfaces.

The concept of an integrated architecture that would combine the electronic documentation system with the expert system based analyst, selectable telemetry displays, and the architecture modeler was developed in 1987. By 1988 the entire ASW prototype was migrated from the Symbolics lisp processor into a general purpose workstation. By moving to a more general purpose workstation the project would be able to target delivery into operational programs. 1989 efforts focused on the integration of general purpose tools within the evolving environment that comprised the ASW satellite analyst's workbench. In 1990 the first operational prototype system was fielded and is currently being tested by satellite operators.

Problem

Mission planning, analysis, and command and control functions for military systems have increased significantly in complexity and can be expected to become still more demanding as systems themselves become larger, more complex, and more highly automated. This trend is especially true for large space systems. Future Air Force satellites may have tens of processors onboard, with increased onboard autonomy and higher telemetry and payload data rates. The number of vehicles in a satellite constellation is also increasing. At the same time, budget pressures and shifting of operations from the development community to the user community means fewer, less well trained operators and analysts. To deal with this set of circumstances, we must use new ground station technology to provide operators with a better environment. Intelligent tools for decision support and training can provide significant leverage both in terms of functionality and user friendly support to less experienced operators. The following technical areas are being explored as part of the ASW prototype activity:

Technical Area	Questions Being Explored
Expert Systems	*What areas within satellite support activities are best suited towards implementation using expert systems? Can experience on a specific satellite subsystem for one program improve the efficiency of a similar expert system development for a different program?*
Telemetry Processing and Display Systems	*Efficiency of user configurable telemetry display systems. Graphic display of telemetry versus numeric display of measurands. Local processing of telemetry data as needed versus batch processing. User interface and control mechanisms.*
Hypermedia and Multimedia Systems	*Can an interface to satellite vehicle documentation be developed that is intuitive for all users of the system? Does having random access to as-built photographs of the satellite vehicle assist the operator in normal operations or during anomaly resolution procedures? How should multimedia data be structured to provide scalable systems with efficient user and programmed data access and query capabilities? What procedures will streamline the development of electronic multimedia data systems?*
Modeling and Visualization	*What modeling and simulation techniques can be used most effectively in an operational environment? How can advanced visualization techniques be used in conjunction with modeling to improve operator understanding?*
Artificial Neural Networks and Fuzzy Logic Systems	*By developing system models of space vehicle subsystems using techniques that are based on examples of real world data, can a decision support system be developed that provides good recommendations under conditions that can include incomplete or inconsistent data?*

Solution

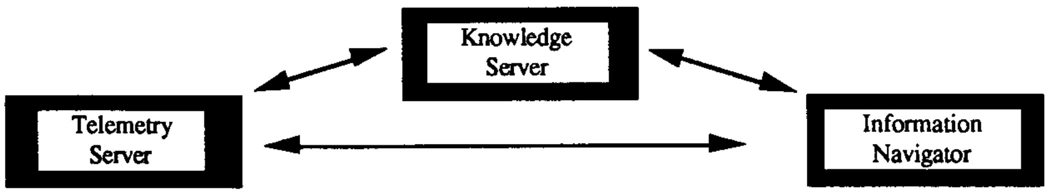
A significant number of projects to address the above issues are underway at Space Systems Division, government labs, and contractors, focusing on workstation environments for satellite commanding and control. Graphical telemetry displays and simple use of expert systems for anomaly resolution have been demonstrated in support of satellite programs, including DSCS, DMSP, IUS, GPS, and many others. Expert systems are being used operationally by NASA at JSC and by JPL in support of current satellites. Based upon our early prototypes, in ASW we are extending this expert system and display metaphor to include a number of technologies such as fuzzy logic, advanced visualization techniques, simulation, and multimedia/hypermedia. While each of these technologies is a powerful approach to specific tasks, the integration of these technologies in a unified support environment provides a new paradigm for operations support.

Some space vehicle anomalies can be avoided if accurate and persistent trend analysis of telemetry data is performed. ASW uses expert systems to encode the satellite subsystems' operational structure. The rule-based system makes use of objects for modeling elements of the subsystem such as batteries, high-power amplifiers, solar arrays, reaction control wheels, and thermocouples. This object-based representation of components works well for system components that can be defined by a set of equations or transfer functions. When a system component is best described by examples of its operation under varied conditions, then mechanisms such as artificial neural network models can be used to construct an object model. Object-based models of system components are integrated into the rule-based system and together these elements form the knowledge processing system for a specific space-craft subsystem. These knowledge processing systems interface to telemetry server agents that provide data required for trend analysis and health and status processing. All of these activities occur in background as multiple processes and provide high-level messages to a user modifiable graphics display system for operator interpretation. In addition to the messages that are provided to the operator, an on-line documentation system is integrated into the architecture to provide ready access to vehicle-specific data. This documentation system can be automatically oriented to appropriate "chapters" according to the context of the analysis being performed with the workstation.

System Architecture

The system architecture of the Advanced Satellite Workstation is composed of three principal components. These components (shown in Figure-1) are the Knowledge Server, Information Navigator, and Telemetry Server. The implementation of these components and their integration with each other is a continually evolving process. In addition, ASW includes a modeling and visualization system and more specific tools for satellite pass planning, on-orbit event scheduling, etc. A fourth important component currently being defined is an object-oriented data server to provide uniform access to multimedia information.

Figure-1.
ASW System Architecture



Telemetry Server

The present telemetry server provides buffered telemetry data both for user displays and for use by the expert system. Since the current system is designed for post-pass analysis, a telemetry data file is created in shared memory with pointers to individual parameter streams. The server also controls the user interface, handling input events and using toolbox calls to provide selectable telemetry displays. The telemetry server forks a Unix process which activates the expert system, and passes pointers to shared memory to give the expert system access to telemetry. The expert system uses Unix pipes to send diagnostic messages to the telemetry server for display to the operator. Modifications to this architecture are currently being designed to provide control of digital real-time telemetry streams provided by a dedicated preprocessor interfaced to wideband analog satellite data.

Information Navigator

The Information Navigator's primary function is presenting information to the satellite operator in an intuitive fashion. A vast amount of supporting documentation accompanies most satellite programs. Developing familiarity with the satellite program through accessing this data is an inefficient, labor intensive process. The supporting documentation that can be of particular importance during anomaly resolution procedures is often difficult to locate, and may be in the archives of the satellite vehicle's prime contractor or associated subcontractors. Accessing this information would pose a considerable challenge if it were even delivered as part of the contract, and chances are that if delivered in its most popular form (paper) it would probably find a nice dark out-of-the-way storeroom in which to reside.

Simply moving this information into electronic form is not sufficient. Standard databases are powerful tools for structured data and provide flexible query capabilities, but do not provide adequate methods for dealing with implicitly related information. The data of potential interest to the satellite operator is not just alphanumeric data, but includes engineering schematics, program schedules, animated models, and video. Object-oriented databases offer the promise of dealing with such multimedia data, but are not yet a mature technology. ASW currently deals with these different forms of information using an Information Navigator able to provide automated access to video and still data on laser disk as well as graphical and text data stored on optical and magnetic media. The Information Navigator permits hypermedia techniques to be employed to link data explicitly for user-directed browsing, and this approach has been used to develop an online Orbital Operations Handbook (OOH) for a satellite program (See Appendix-A for sample screens of the Information Navigator OOH). The Information Navigator also provides the capability to perform text searches to locate implicitly related data without explicit predefined links. The Information Navigator is currently based on the Macintosh workstation, and can communicate with the processes on the Sun via a defined 2-way communication protocol. This architecture permits both user and expert system control of the information display, as well as the passing of information from the electronic database to processes running on the Sun workstation.

Knowledge Server

In the context of ASW, a Knowledge Server encapsulates domain-specific knowledge and uses this knowledge to provide advisory messages, suggest actions, and direct the operator to documentation. Initial implementations have been limited to expert systems for specific satellite subsystems such as electrical power. In a fully operational system, multiple concurrent knowledge agents will independently process telemetry related to separate subsystems, under the control of an executive process. In ASW, expert system processes run in the background, reading telemetry from the shared memory buffer created by the Telemetry Server. These processes use Unix pipes to send messages to the operator’s screen. Since messages may be voluminous under certain conditions, these message are read in a scrollable window by the operator. The Telemetry Server-Knowledge Server interface permits to operator to automatically jump to telemetry data related to messages by simply mousing on a button. At the operator’s discretion, the Knowledge Server may also signal the Information Navigator to provide automatic access to documentation relevant to a current area of concern.

A more robust system could use standard expert systems for the capture of high-level knowledge and heuristics regarding system operation, while drawing on additional techniques such a fuzzy logic for approximate reasoning and dealing with continuous data with inexact boundaries. Real-world events can often be grouped into a continuous spectrum of values that are termed fuzzy sets. Fuzzy inferencing on such data can provide robustness to uncertainty and “common-sense” reasoning.

Artificial Neural Networks (ANN) can provide another technique for extending the capability of intelligent systems such as a knowledge server process. While system models can often be defined using a set of equations that precisely describe the behavior of the system, at times it is not practical to model behavior based on a set of equations. In such cases the application of an artificial neural network can provide a model that behaves like the real subsystem, provided the ANN model is developed using data from real world systems. An example of such a system would be an ANN model of a spacecraft battery. Given specific inputs reflecting the state of the space environment, loading from the spacecraft subsystems, and past charge/discharge profiles, an ANN battery model could provide predictions of power system performance. These predictions would be based on a model that was developed with real-world data. An expert system making assessment of the state of spacecraft subsystems could use such models for hypothesis exploration.

Additional Capabilities

A realistic satellite support environment must provide many additional capabilities, and these capabilities should be integrated into a consistent overall environment. At present, ASW has developed tools for automated pass planning support, mission scheduling, and systems modeling and browsing.

Pass Planner

The pass planning capability was specifically requested by operators to automate the repetitive, labor intensive process of creating detailed pass plans used to control satellite commanding and data recording during real time contacts. This tool uses many of the same toolbox calls as the telemetry server display process to provide a consistent interactive user interface. Based on input data the pass planner interrogates data files to create a consistent plan. A specialized planning language was developed to provide flexible programmatic control of this process so that it can be generalized to multiple satellite families.

Satellite Architecture Modeler

Another important tool is the Satellite Architecture Modeler (SAM). SAM is written in Smalltalk™, and runs on both the Sun and Macintosh computers. It provides a way to graphically display color diagrams representing the functional structure of a system, identifying the modules, interfaces, and communication routes. The user can navigate through the system by pointing at the object he wants to move to, and the display then changes to the part of the system centered on that object. In addition, the Modeler provides a discrete-event simulation capability. The simulation of the entire system is determined from the simulation of each fundamental component in the hierarchical structure, organized and coordinated as specified in the diagrams. The simulation of a fundamental component is specified purely locally, without reference to external entities, and the structure of the system joins these independent parts into a cooperative whole. The simulation capability was recently extended to include time, allowing feedback loops and time-varying behavior: this has greatly increased the range of possible simulations. Work is underway to fully integrate SAM with ASW.

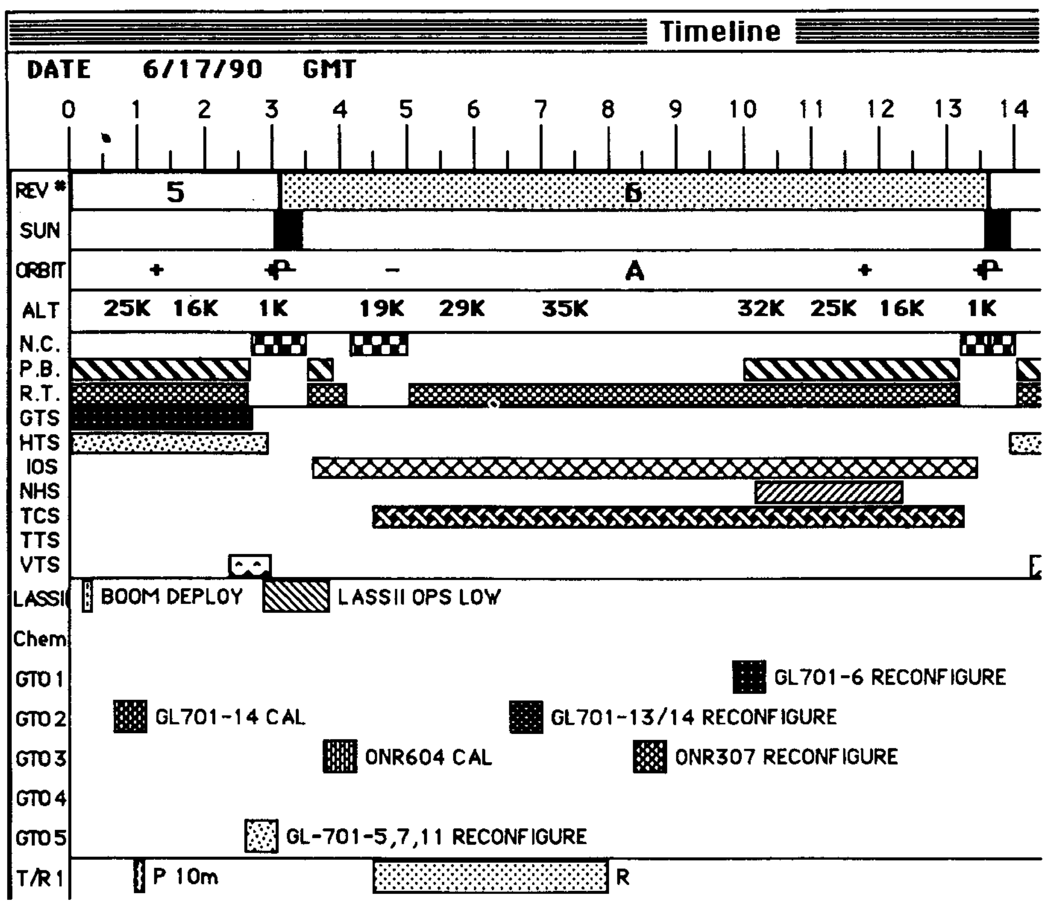
In addition, future versions of SAM will provide advanced visualization capabilities. Current space systems are deeply structured, complex mechanisms. Dealing with that complexity is straining the capacity of even trained and experienced personnel, while there is a high learning curve for new spacecraft operators. Simulation and modeling, combined with graphical output showing the unfolding development of the system being simulated, can be of significant benefit in understanding complex systems, as evidenced by the growing interest in scientific visualization. Viewing the time-varying behavior of a simulation conveys far more information to a user than static displays. For clarity, these displays must be composed according to a consistent metaphor, focusing on a particular subset of the system's behavior. This subset could be qualified by structural, functional, or dynamic considerations. There will often be multiple valid views of a system, which may range from small to large, simple to intricate, static to dynamic, independent to completely dependent. Multiple metaphors are necessary to provide appropriate views to heterogeneous subsystems. Links to neighbor systems must enable rapid browsing through associated concepts with possibly widely varying views. The user must be able to expand or contract his focus of interest, or to easily redirect his inquiries to related subjects. Since so much of the character of a system is shown through its dynamic behavior, the user must be able to easily examine and change the state of the simulation, using " what-if" strategies to explore alternative behaviors.

Timeliner

The *TIMELINER* program is a prototype stand-alone application developed in SuperCard™ for the Macintosh. It is a graphically-based scheduling tool for the development and manipulation of event timelines that correspond to events that must be scheduled onboard the space vehicle. The current version of the *TIMELINER* program was tuned towards a specific satellite program, but future extension of this work will address a more general tool for spacecraft event scheduling and management. This tools is included as part of the ASW tool set for satellite support and is hosted in the Apple Macintosh workstation.

TIMELINER has three parts: the *TIMELINER* application, the timeliness and the activity cards. Activities are defined when the user enters information pertaining to an activity on an Activity Card. These activity cards are stored in an Activity file which the user creates during his or her first session with the program. Timelines are generated by the user by choosing a time scale and scheduling activities from the Activity file. Timelines are stored in a Timeline file which is also created by the user during the first session with *TIMELINER*. A snapshot of a *TIMELINER* screen is shown in Figure-2.

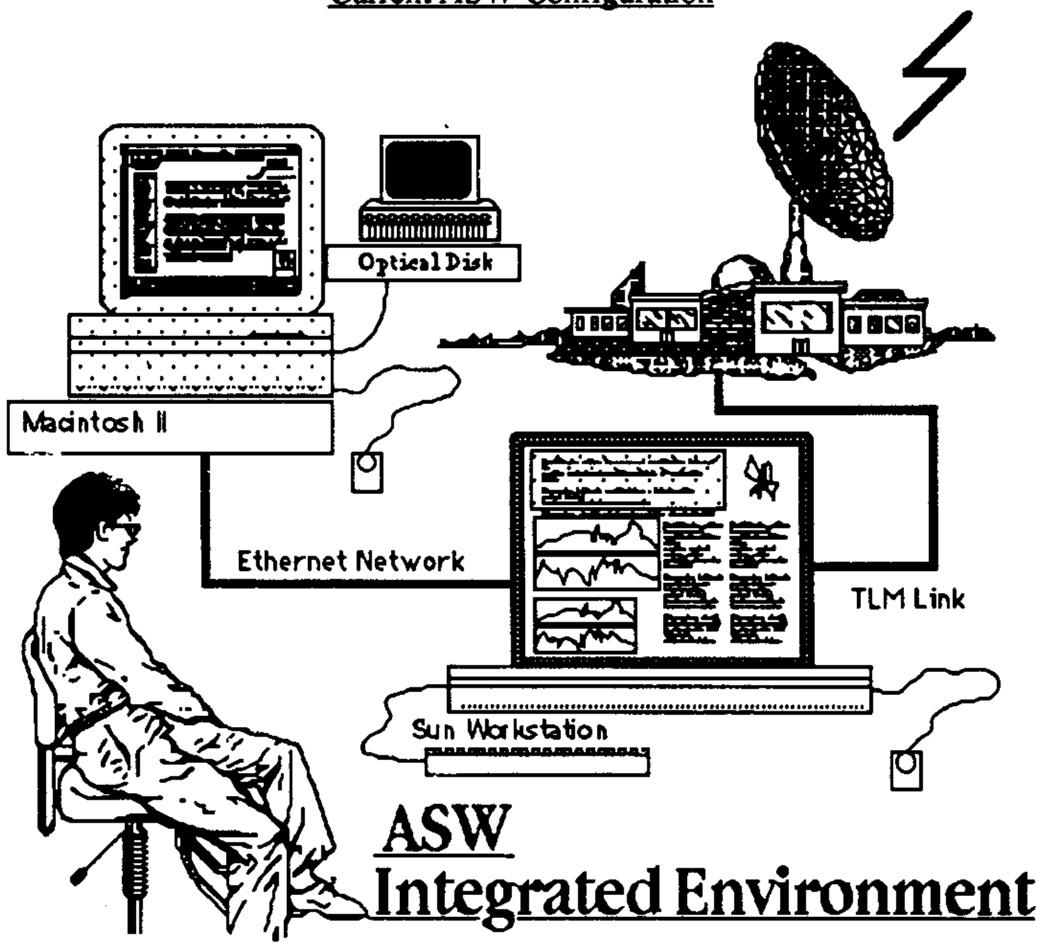
Figure-2.



Implementation

ASW has been implemented using a Sun 3/470 workstation, Apple Macintosh IIcx workstation, laser disk player, and associated ethernet network hardware. The basic configuration is shown in Figure-3. The operator sits in front of these two workstations that are located side-by-side. The Sun workstation provides the operators primary interface to telemetry data, and data analysis tools. The Telemetry Server is implemented in the C language, using DataViews™ toolbox calls for input handling and graphics displays. In addition, the expert system processes are mostly resident on the Sun workstation. Expert systems are currently implemented using the NEXPERT™ Object expert system shell with C extensions. The Macintosh workstation provides the operator access to hypermedia-based (electronic) documentation that includes schematics, text, sound, and animation. The more exotic forms of information (sound and full-motion random accessed video) are made possible through the use of high-density optical disc, CD ROM, and video disc equipment that interfaces to the Macintosh workstation.

Figure-3.
Current ASW Configuration



The Macintosh workstation and Sun workstation are connected to an ethernet network. Custom protocols based on TCP/IP are used for communication between the Sun and Macintosh computers. This network serves as the primary conduit for transfer of information between each workstation. The telemetry data is currently provided to the Sun workstation via a file system interface with a DEC PDP minicomputer. This pre-processed data is analyzed and displayed on the Sun workstation. In the future, telemetry data may be accepted over the ethernet network in real time from these front-end systems. The Macintosh workstation is connected to the Sun workstation via ethernet and is automatically oriented to the proper documentation screen according to the context of the analysis being performed on the Sun workstation. The user may at any time direct his attention to the Macintosh and via the Information Navigator and explore the data items (text, graphics, and animation) in more detail through a hierarchical browser.

The Orbit Operations Handbook was prototyped using HyperCard™ for the multimedia user interface environment. MacroMind Director™ was used to develop animations that play through the HyperCard environment. Studio/8™ was used to develop color images and to retouch scanned images taken from actual documentation. OmniPage™ was used as the OCR (Optical Character Recognition) package for translating printed text into ASCII files for installation into HyperCard-based text containers (fields). Swivel 3D and Super3D were used to build simple 3D models of the spacecraft and associated subsystem hardware. These 3D models were used to generate different views of the space vehicle. These 3D views were assembled in a HyperCard Stack for manipulation and orientation by the user. Later, higher quality 3D renderings were taken from videotape after being produced on a Silicon Graphics IRIS workstation. These individual views of the spacecraft were captured using Mass Micro's ColorSpace II, and ColorSpace FX video boards. The following diagrams included in Appendix-A illustrate the style of information displayed by the Information Navigator OOH (IN-OOH).

Acknowledgements

The authors would like to acknowledge Thomas E. Bleier of The Satellite Control Network Directorate for continuing support of the development of the ASW architecture from its inception in 1985 to the present. Tom Bleier has kept our perspective focused and continues to provide valuable technical and programmatic assistance. Additional acknowledgements are extended to Pinfun Tsai of The Space Test Department for supporting the development of prototype electronic OOH as well as support of TIMELINER, telemetry display systems, and program specific expert systems.

The following individuals are to be acknowledged for their dedication and long hours in ASW prototype development. Peter Homeier has provided the longest running support to this project and is the principal designer of the modeling and visualization methods used in ASW. Grisel Hlavaty is the developer of the TIMELINER event scheduling support tool for graphical visualization and manipulation of on-orbit events. Thach Le is a co-developer of the expert system architecture as well as principal developer of the initial interface on the Sun workstation. Robert Statsinger is the designer and developer of recent subsystem specific expert systems for ASW as well as a co-architect of the shared memory architecture of the ASW workstation. Candice Yu has participated in the design, development and performed a substantial portion of the implementation of the Information Navigator Orbit Operations Handbook for ASW. Scott Zechiel has been the principal designer and developer of the telemetry display system, and workstation user interface that integrates the expert system environment, hypermedia environment, graphical display

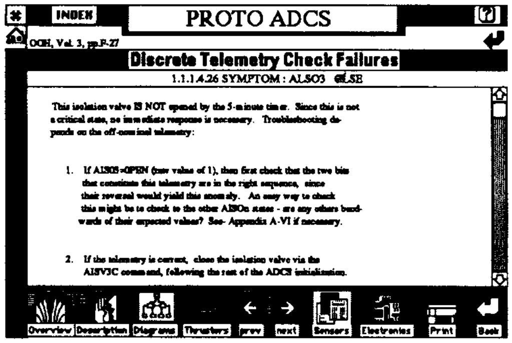
environment, and general tools environment. In addition Mr. Zechiel has been a designer and developer for the workstation interface to the electronic OOH as well as principal developer of the automated pass planner system.

References

[1]. J. D. Bost et al, “Hypermedia and Expert Systems Applied to Space Vehicle Monitoring & Control,” ITC Proceedings, pp. 811 822, 1989.

NOTICE: The material in this appendix is representative of a typical satellite program office. The sample electronic version of this material is for prototype use only, and no claims are made for its correctness.

Appendix-A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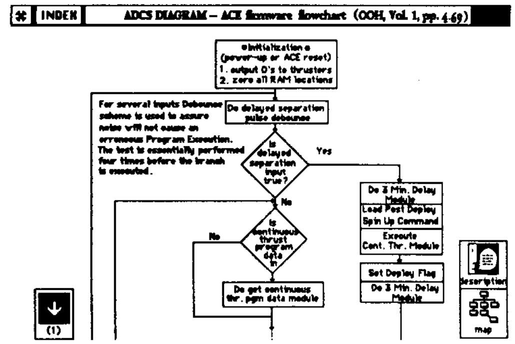
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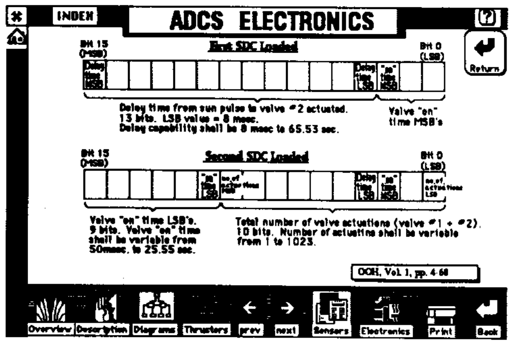
ADCS DIAGRAM – ACE firmware flowchart (OOH, Vol. 1, pp. 4-69)
Set Deploy Flag
Do 3 Min. Delay Module
map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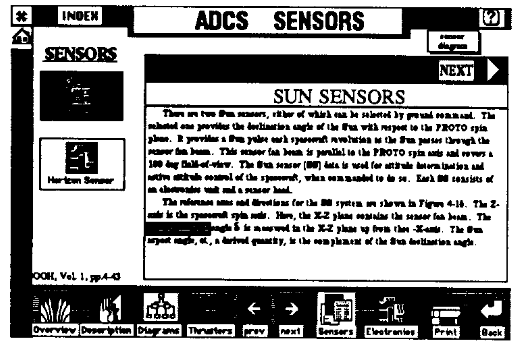
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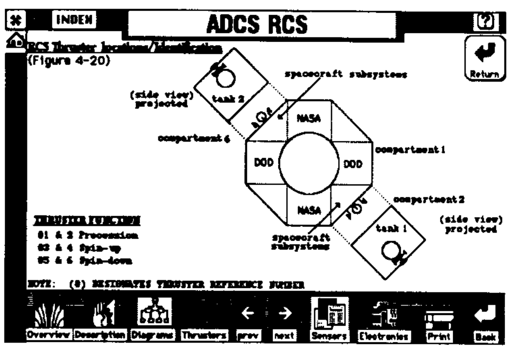
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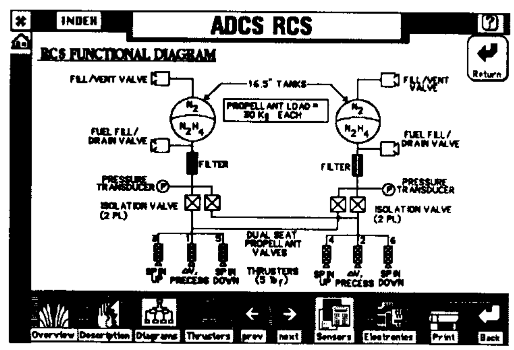
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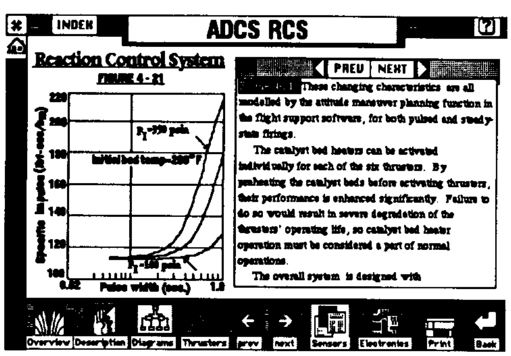
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ADCS RCS
Reaction Control System
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These changing characteristics are all modelled by the attitude maneuver planning function in the flight support software, for both pulsed and steady-state firings.
The catalyst bed heaters can be activated individually for each of the six thrusters. By preheating the catalyst beds before activating thrusters, their performance is enhanced significantly. Failure to do so would result in severe degradation of the thrusters' operating life, so catalyst bed heater operation must be considered a part of normal operations.
The overall system is designed with
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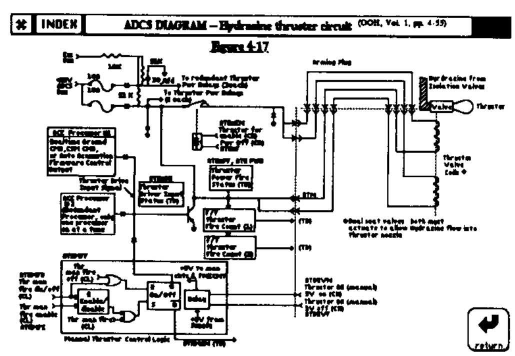
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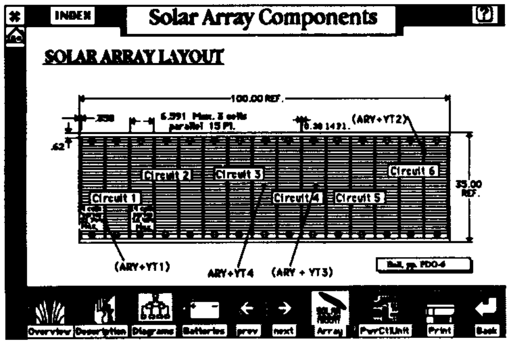
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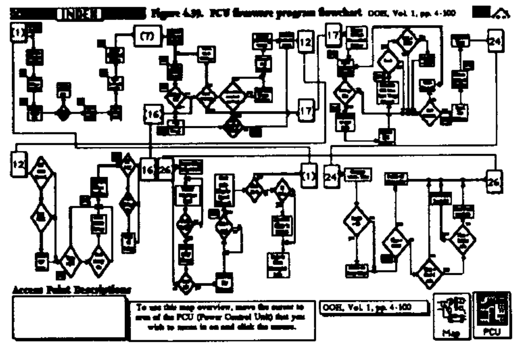
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Figure 4.39. PCU firmware program flowchart OOH, Vol. 1, pp. 4-100
Access Point Descriptions
To use this map overview, move the cursor to area of the PCU (Power Control Unit) that you wish to zoom in on and click the mouse.
OOH, Vol. 1, pp. 4-100
Map
PCU

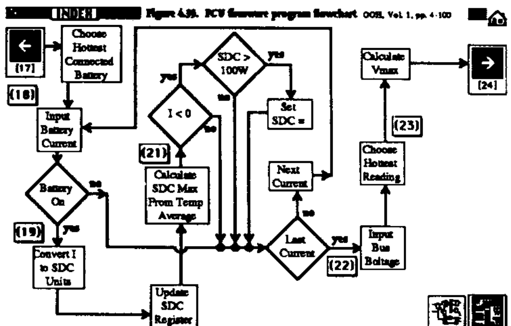
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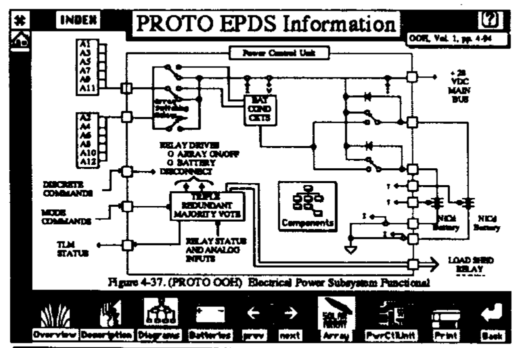
Figure 4.39. PCU firmware program flowchart OOH, Vol. 1, pp. 4-100
(17)
Choose Hottest Connected Battery
(18)
Input Battery Current
SDC > 100W
yes
no
I < 0
Set SDC =
(21)
Calculate SDC Max From Temp Average
Next Current
Calculate Vmax
(24)
(23)
Choose Hottest Reading
Battery On
(19)
Convert I to SDC Units
Last Current
(22)
Input Bus Voltage
Update SDC Register
Map
PCU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BAY COND CKTS
RELAY DRIVES
O ARRAY ON/OFF
O BATTERY DISCONNECT
DISCRETE COMMANDS
MODE COMMANDS
TRIPLE REDUNDANT MAJORITY VOTE
TLM STATUS
RELAY STATUS AND ANALOG INPUTS
Components
+28 VDC MAIN BUS
NiCd Battery
LOAD SHED RELAY
Figure 4-37. (PROTO OOH) Electrical Power Subsystem Functional
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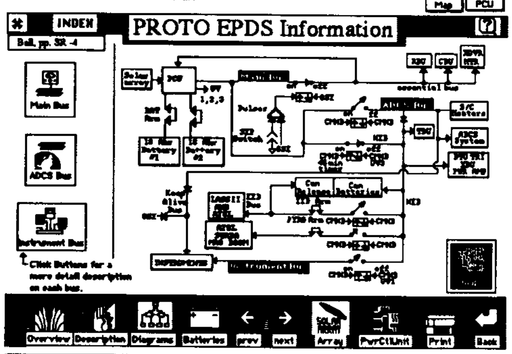
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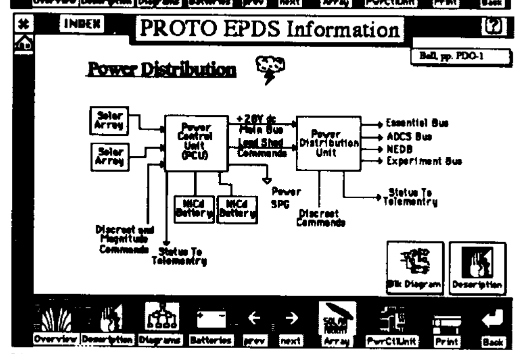
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NiCd Battery
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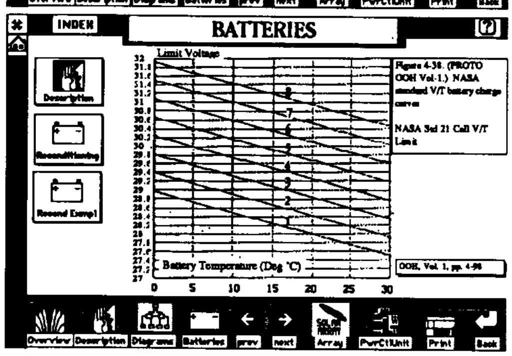
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Recond Exmpl
Limit Voltage
Figure 4-38. (PROTO OOH Vol-1.) NASA standard V/T battery charge curves
NASA Std 21 Cell V/T Limit
Battery Temperature (Deg °C)
0
5
10
15
20
25
30
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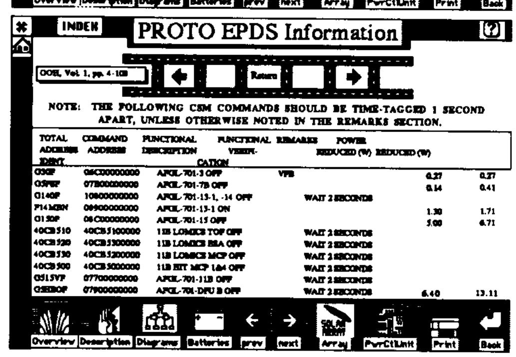
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NOTE: THE FOLLOWING CSM COMMANDS SHOULD BE TIME-TAGGED 1 SECOND APART, UNLESS OTHERWISE NOTED IN THE REMARKS SECTION.
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FUNCTIONAL VERIFI-CATION
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REDUCED (W)
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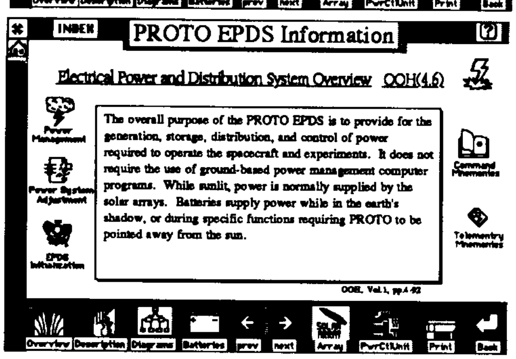
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Electrical Power and Distribution System Overview OOH(4.6)
Power Management
Power System Adjustment
EPDS Initialization
The overall purpose of the PROTO EPDS is to provide for the generation, storage, distribution, and control of power required to operate the spacecraft and experiments. It does not require the use of ground-based power management computer programs. While sunlit, power is normally supplied by the solar arrays. Batteries supply power while in the earth's shadow, or during specific functions requiring PROTO to be pointed away from the sun.
Command Mnemonics
Telemetry Mnemonics
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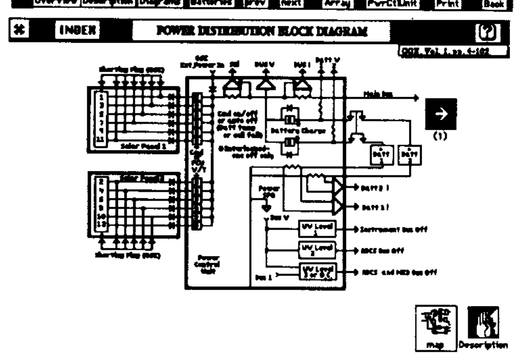
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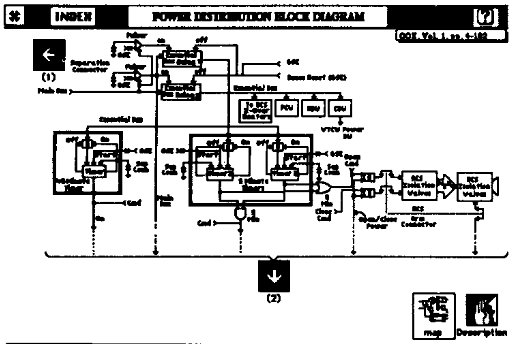
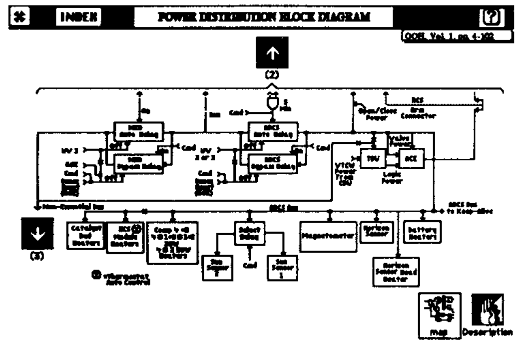
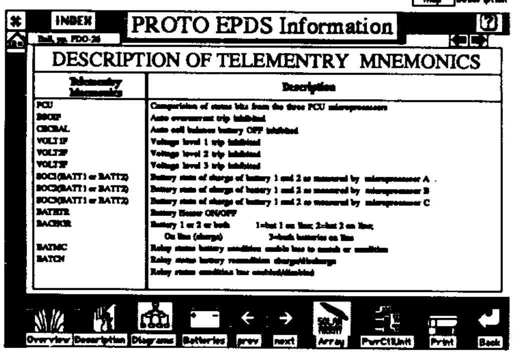
POWER DISTRIBUTION BLOCK DIAGRAM
Main bus
(1)
Solar Panel 1
Solar Panel 2
Battery Charger
Batt 1
Batt 2
Instrument bus off
ADCS bus off
map
Description

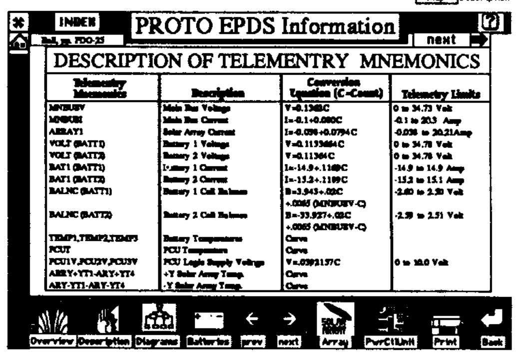






DESCRIPTION OF TELEMENTRY MNEMONICS

Telemetry Mnemonics	Description
PCU	Comparision of status bits from the three PCU microprocessors
BSOIF	Auto overcurrent trip inhibited
CBCBAL	Auto cell balance battery OFF inhibited
VOLT1F	Voltage level 1 trip inhibited
VOLT2F	Voltage level 2 trip inhibited
VOLT3F	Voltage level 3 trip inhibited
SOC1(BATT1 or BATT2)	Battery state of charge of battery 1 and 2 as measured by microprocessor A
SOC2(BATT1 or BATT2)	Battery state of charge of battery 1 and 2 as measured by microprocessor B
SOC3(BATT1 or BATT2)	Battery state of charge of battery 1 and 2 as measured by microprocessor C
BATHTR	Battery Heater ON/OFF
BACHGR	Battery 1 or 2 or both On line (charge) 1=bat 1 on line; 2=bat 2 on line; 3=both batteries on line
BATMC	Relay status battery condition enable bus to match or condition
BATCN	Relay status battery recondition charge/discharge
	Relay status condition bus enabled/disabled



DESCRIPTION OF TELEMENTRY MNEMONICS

Telemetry Mnemonics	Description	Conversion Equation (C=Count)	Telemetry Limits
MNBUSV	Main Bus Voltage	V=0.1368C	0 to 34.73 Volt
MNBUSI	Main Bus Current	I=-0.1+0.080C	-0.1 to 20.3 Amp
ARRAY1	Solar Array Current	I=-0.038+0.0794C	-0.038 to 20.21Amp
VOLT (BATT1)	Battery 1 Voltage	V=0.1133464C	0 to 34.78 Volt
VOLT (BATT2)	Battery 2 Voltage	V=0.11364C	0 to 34.78 Volt
BAT1 (BATT1)	Battery 1 Current	I=-14.9+.1169C	-14.9 to 14.9 Amp
BAT1 (BATT2)	Battery 2 Current	I=-15.2+.1189C	-15.2 to 15.1 Amp
BALNC (BATT1)	Battery 1 Cell Balance	B=3.943+.02C +.0065 (MNBUSV-C)	-2.60 to 2.50 Volt
BALNC (BATT2)	Battery 2 Cell Balance	B=-33.927+.02C +.0065 (MNBUSV-C)	-2.59 to 2.51 Volt
TEMP1,TEMP2,TEMP3	Battery Temperatures	Curve	
PCUT	PCU Temperature	Curve	
PCU1V,PCU2V,PCU3V	PCU Logic Supply Voltage	V=.0392157C	0 to 10.0 Volt
ARRY+YT1-ARY+YT4	+Y Solar Array Temp.	Curve	
ARY-YT1-ARY-YT4	-Y Solar Array Temp.	Curve