THE EVOLVING TREND IN SPACECRAFT HEALTH ANALYSIS

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ABSTRACT

The Space Flight Operations Center inaugurated the concept of a central data repository for spacecraft data and the distribution of computing power to the end users for that data's analysis at the Jet Propulsion Laboratory. The Advanced Multimission Operations System is continuing the evolution of this concept as new technologies emerge. Constant improvements in data management tools, data visualization, and hardware lead to ever expanding ideas for improving the analysis of spacecraft health in an era of budget constrained mission operations systems. The foundation of this evolution, its history, and its current plans will be discussed.

Key Words: Operations, telemetry, workstations, Unix, vizualization

1. INTRODUCTION

While the goal of space operations is the collection and analysis of scientific data, there is a vast infrastructure required to support that collection. An important part of that infrastructure is the analysis of spacecraft health. Immense volumes of data are tracked by a budget constrained team. An analogous situation is the classic comedy sketch where Hubby goes to get his bowling ball out of the hall closet on bowling night. He opens the door and an avalanche falls on him. The sketch ends by him triumphantly holding up his bowling ball amidst the rubble. Spacecraft analysts have faced their own avalanche by asking for data from their telemetry system. A request for data usually means running a magnetic tape through the telemetry system and handing the results to the requestor who dives in and hopes to emerge triumphantly with the few measurements desired in the first place.

2. HISTORY

The Jet Propulsion Laboratory (JPL) has had several generations of data systems in its support of spaceflight. In the late '60s, IBM 7044s and IBM 7094s comprised JPL's spaceflight data system. About twenty years ago there was a new generation of data system introduced that started a roller coaster of capability for users of these systems.

2.1 Twenty Years Ago

Twenty years ago a new generation of data system was being introduce into JPL's repertoire for spaceflight support. It was comprised of a block redundant IBM 360/75 running a batch orientated operating system modified by the Johnson Spaceflight Center to support real time processing.

While the real time aspects of this data system provided a means of changing which Deep Space Station the data was processed from, there was little to be done to affect the direct processing of the data. Also, while there was a set of displays to choose from, they were hardcoded and required a software delivery for any changes to be incorporated. The only control the users had was which displays were routed to which printers or Digital Television (DTV) Channels (Fig. 1).

There was little in the way of disk storage and the data was written off to magnetic tape to be made into products for the science community. The archive for the engineering community were the printouts and hardcopies of DTV screens that were collected and stored. (Ref. 1) Data reduction of these printouts was comprised of an engineer going through the printouts and either recording or plotting desired values in a journal.

As time went on, the Graphics Display System (GDS) was envisioned and implemented. The GDS allowed individual users to create their own displays with a simple language. They could not control what data flowed through their displays but they could tailor their displays for their own needs. A macro feature was also incorporated into the GDS, called super formats, in which once a set of templates were defined for the display of data, all the user had to do was specify the data and template and not have to get involved with the details.

2.2 Mini-Computers - The Next Generation

In the mid-70s, the arrival of the mini-computer heralded a change to spaceflight support at JPL. It was believed they were so inexpensive that multi-mission systems did not have to be developed anymore, every project could have their own dedicated sets of mini-computers.

It was decided that the Command Subsystem would be moved to mini-computers. About the same time, Voyager decided that they would use their telemetry system that was supporting spacecraft system test for flight support. The result of this move caused the loss of users being able to create their own displays in realtime. This was due too the fact that displays were already hardcoded in the Telemetry System and it was decided to have hardcoded displays in the Command System to reduce cost.

While realtime spacecraft support was regressing, non-realtime was gaining. As flight support was moving off of the IBM 360/75s, they started to be used to make the archive data products. This was the beginning of what has become the Data Records System (DRS). A capability of DRS was to allow a request for a set of data and have that data either printed in a tabular form or plotted. The drawbacks of this system were that it was seven days before the data was available in the DRS, the data usually expired less than thirty days after its receipt on the ground, the request had to be submitted to an operator, and it could take several days to process the request.

2.3 Data Staging

In the early '80s, it was perceived that if data could be kept on disk until processing of it was complete, operations costs could be reduced. Merging files on disk is less labor intensive than hanging magnetic tapes and merging data from magnetic tapes to magnetic tape. Data on disk could be merged from multiple files or data merged into an indexed sequential access method file.

The Multi-Mission Telemetry Transportation Demonstration (MTTD) was a prototyping attempt to design a multi-mission telemetry system that would provide enough disk space to allow data to be kept on disk until the final data products could be generated. Unfortunately, this effort never came to fruition.

After the MTTD had been canceled, the three spacecraft mission Active Magnetosphere Particle Tracer Explorer was approved. For the United States spacecraft it was decided that there would be enough disk space to keep data online until the Master Data Record (MDR) could be generated. The result was that staffing for the creation of MDRs was held to one person. This was in contrast to the estimate of three people during the initial cost estimates for the project. The importance of data staging was realized as a major cost savings when the operational aspects were included in the cost of a project.

For launch, Voyager had used a Univac 1530 to do frame synchronization and error correction. During one of its encounters, the spacecraft data format was changed and could not be accommodated by the Univac 1530 any longer. Also about this time, JPL was to provide a telemetry front end for Ulysses. It was decided that a multi-mission telemetry system would be implemented to do both jobs. The resultant system was the Data Staging and Capture System (DACS). While the DACS was not completely multi-mission, it has been estimated that about 70% of it is common between the two projects. The Voyager DACS provided data to their telemetry system and the Voyager DRS. The Ulysses DACS provides data to their Ulysses

Mission Control System (UMCS) and the Ulysses DRS.

As the name implies, the DACS provided disk for data staging. What the DACS also provides is a data request mechanism. This allows a Voyager Telemetry Operator, a UMCS analyst, or a DRS analyst to request data from one of seven files on disk. As an added value, since data was being loaded in real time, the requesting systems could ask for the file being loaded with real time data and ask for it to be given to them forever. While the controllers of the requesting systems could make data requests of the DACS, the end user, who is the one that really wants to look at the data, still has to make a request to the controllers.

3. SPACEFLIGHT OPERATIONS CENTER

While generations of telemetry systems marched by, technology marched forward. The concept of distributed processing has been used in many parts of the overall ground data system at JPL. These have been in very rigid configurations using point-to-point communication. What had not been done is to distribute that processing to the end user. Not until multi-tasking workstations that could communicate promiscuously with other workstations via a Local Area Network (LAN) were available that the end user could have their own processing to control.

The concept of distributed processing, termed the Space Flight Operations Center (SFOC), communicating over a LAN with data staged and queried by members of the Spacecraft Team from a relational database was developed (Ref. 1,2). Several efforts sprung up in parallel. A Prototype Laboratory was set up to evaluate these new technologies in various combinations. System Engineering developed a System's Concept that utilized the technology that the Prototype Laboratory was to prove.

3.1 The Prototype Laboratory

With the need for new technology to be proven to answer the requirements of a telemetry system, the idea that the concept should be prototyped was developed. Rather than prototyping a specific concept, it was found that the Prototype Laboratory was prototyping prototyping. There was no specific answer that the Prototype Laboratory was looking for because there were so many options to be conceived and tried. However, there were three areas of concept that the Prototype Laboratory proved that were vital to the creation of SFOC.

One of the early problems the Prototype Laboratory help solve was to find a relational database management system that could handle the data loading rates required and support binary data. Database management systems were primarily updated occasionally and the data queried many times. The concept in SFOC was that the engineering data was constantly being load along with many queries. Also, database management systems handled integers and floating point data but not binary data. The solution found by the Prototype Laboratory was Sybase.

At this time many standards for LANs were evolving. Another concept proved by the Prototype Laboratory was Ethernet running TCP/IP.

Finally, the Prototype Laboratory demonstrated that a workstation running Unix could meet the requirements of SFOC, allow the maximum number of vendors for competition, and not be faced with a solution that leads us to a dead end the future.

3.2 Early SFOC

Magellan was the first project supported by SFOC. It incorporated distributed processing based on workstations running Unix communicating a by LAN based on Ethernet and TCP/IP. The end users, i.e., the Spacecraft Team, could view real time engineering data on their workstations using Data Monitor and Display (DMD) displays they had created (Fig. 2,3).

Additionally, thirty days of engineering data was kept online in a Sybase database management system that they could query. Queries of data eventually fell into two categories (Ref. 3). The first and most frequent was the standard queries needed for morning report. These queries were incorporated into scripts that would run at night and have the reports produced automatically by the time the Spacecraft Team arrived in the morning. These scripts were eventually made to create a new script for the next nights query and schedule it to fire off. The other type of query, an ad hoc query, was when a problem or other interesting feature was found in the data and a query to look specifically at that data was created and submitted.

3.3 Current SFOC

Mars Observer and Voyager are currently supported by SFOC. Ulysses and Galileo will be supported by SFOC in the near future. These newer projects to SFOC use workstations based on the SPARC microprocessor. Magellan's workstations are based on the Motorola microprocessor and it did not seem prudent to port them to the new architecture. Thus the current SFOC is a second generation SFOC. Although no major changes in the original concept have occurred, a few lessons have learned and have been applied.

A lesson learned from the Magellan experience is that only the most computer literate of the end users were comfortable with ad hoc queries. This second generation SFOC incorporated a new subsystem, the Telemetry Delivery Subsystem (TDS). TDS provides a single interface for acquiring data to the end user whether the data is resident in the database, stored in the TDS cache, or being broadcast over the LAN in realtime.

Another lesson learned from Magellan was that the extra cost of color workstations could be justified for the end users. Instead of using reverse field in displays for flagging alarms (Fig. 1) red alarms could be displayed in red and yellow alarms displayed in yellow. Also windows could be color coded to enhance grouping of like data.

4. FUTURE

Major development of SFOC has ceased and has entered the sustaining mode. Knowing that there are still capabilities to add and enhancements to be made, SFOC has been renamed the Advanced Multimission Operations System (AMMOS) to indicate the need for these new initiatives to keep the system advanced.

4.1 New Initiatives

One way to use the DMD is to produce a file of processed data. Additional information is being added to this data to make it easier for end users to write their own programs in the analysis of spacecraft health with this data.

One data type that is processed by AMMOS is termed status. The values that a status data type can take is the state of something, e.g., for a tape recorder off, on, record, etc. can be status values. Currently status values can only be displayed in tabular or text form. A Change Request has been submitted to be able to plot these values versus time. A user could then see, over a period of time, the states that some device or measurement has been in (Fig. 4).

A new initiative that has been proposed is for the DMD to accept the input of two data sources simultaneously and through some algorithm keep them synchronized with regards to time. In this way an analyst could forecast the behavior of a given channel and have the forecasted and real values displayed together to see if the spacecraft is following the predicted trend.

Now that AMMOS has been around and used for awhile, the various operational teams and users are being surveyed to see how the system is used and how they would like to use it. Out of this effort new initiatives will be developed and funding will be request requested for their implementation.

4.2 Cassini is Next

The next approved flight project that will adapt AMMOS for its ground data system is Cassini which will visit Saturn.

Cassini is planning for their analysts to have a display of the spacecraft and animate it as things are happening. The analyst can rotate the image so that all aspects of the spacecraft can be viewed. Color can be used to indicate where measurements in alarm actually reside on the spacecraft or indicate temperature.

The ability to acquire a set of interesting data is of little use if one is merely left with rows of numbers to peer at. Comprehension has been improved through the use of tailored displays for viewing individual measurements, the use of emerging visualization techniques such as spectrographs, and the use of an analyst's own software. The increased capability of visualizing data is, in large part, again due to the distribution of computing power to the end users. Innovative visualization of data continues to be of importance in the ongoing development of this evolving mission operations system and new technology is being introduced as it becomes available.

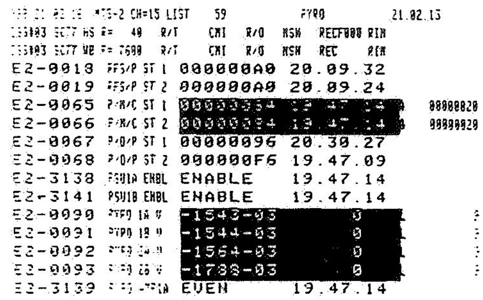
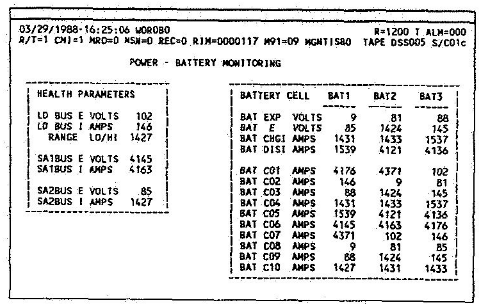


Fig. 1 - DTV Display



HEALTH PARAMETERS	
LD BUS E VOLTS	102
LD BUS I AMPS	146
RANGE LO/HI	1427
SA1BUS E VOLTS	4145
SA1BUS I AMPS	4163
SA2BUS E VOLTS	85
SA2BUS I AMPS	1427

BATTERY CELL	BAT1	BAT2	BAT3
BAT EXP VOLTS	9	81	88
BAT E VOLTS	85	1424	145
BAT CHGI AMPS	1431	1433	1537
BAT DISI AMPS	1539	4121	4136
BAT C01 AMPS	4176	4371	102
BAT C02 AMPS	146	9	81
BAT C03 AMPS	88	1424	145
BAT C04 AMPS	1431	1433	1537
BAT C05 AMPS	1539	4121	4136
BAT C06 AMPS	4145	4163	4176
BAT C07 AMPS	4371	102	146
BAT C08 AMPS	9	81	85
BAT C09 AMPS	88	1424	145
BAT C10 AMPS	1427	1431	1433

Fig. 2 - DMD Fixed Display

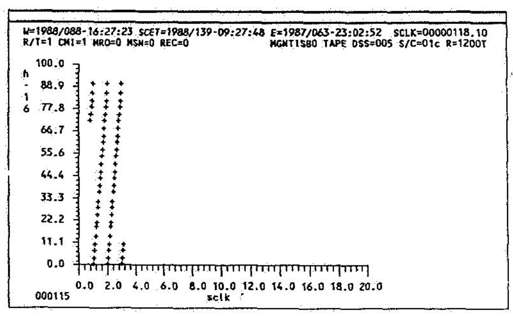


Fig. 3 - DMD Channel vs. Time Plot

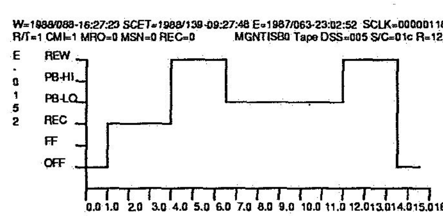


Fig. 4 - Status vs. Time Plot

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