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Paper Session II-A - Predictive Health & Reliability Management (PHARM)

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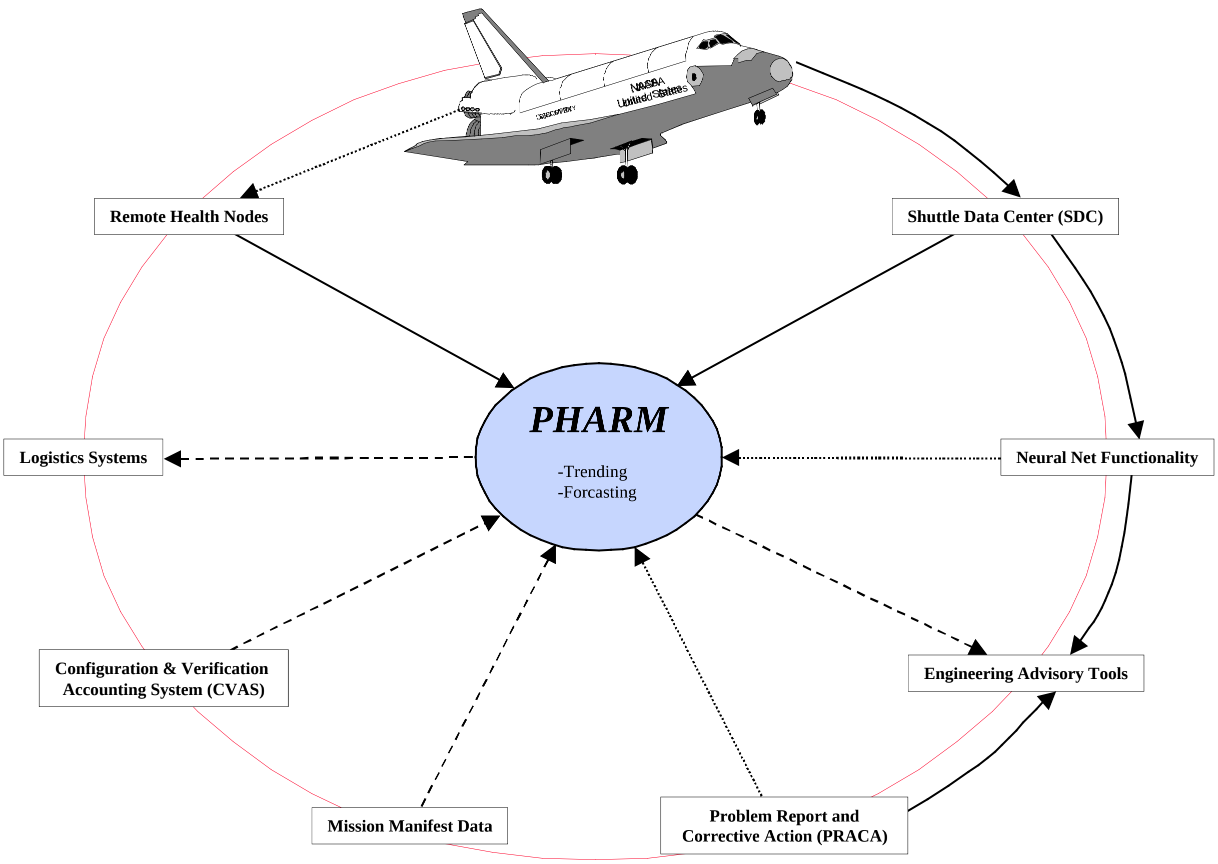
Predictive Health And Reliability Management

(PHARM)



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Acronyms and Definitions:

BRSS	Boeing Reusable Space Systems
CVAS	Program's Configuration Verification Accounting System
D/A	Data Acquisition
ECS	Environmental Control System
FMEA	Failure Modes and Effects Analysis
FD	Function Designator
GMT	Greenwich Mean Time
IR&D	Internal Research & Development
LETF	Launch Equipment Test Facility
LCL	Lower Control Limit
OMS	Orbital Maneuvering System
PHARM	Predictive Health And Reliability Maintenance
PRACA	Problem Reporting And Corrective Action
RCS	Reaction Control System
SDC	Shuttle Data Center
SPC	Statistical Process Control
SSAV	Space Station Accounting and Verification
STAT	Spacecraft Telemetry Analysis Tool
TCID	Test Configuration Identification Document
UCL	Upper Control Limit
VHM	Vehicle Health Management

1.0 Introduction:

PHARM was developed to address operational costs associated with Space Shuttle component failures, repair, and/or replacement processes by identifying components trending toward failure. Thus PHARM mitigates impacts to operational testing and mission performances by providing realistic need dates and historical performance data for component repair/replacement decisions and logistic provisioning. BRSS developed under an IR&D and NASA contract an OMS Vehicle Health Management testbed using qualification hardware in flight configuration. The testbed performs a complete and total automated checkout of an OMS Helium pressurization system. In the course of the automated checkout, key component performance data is saved, correlated and used to develop, prove, and demonstrate PHARM technologies. Via data acquisition, PHARM provides trending and forecasting capabilities for mission scheduling. Figure 1 illustrates the inter-relationship between various activities and PHARM.

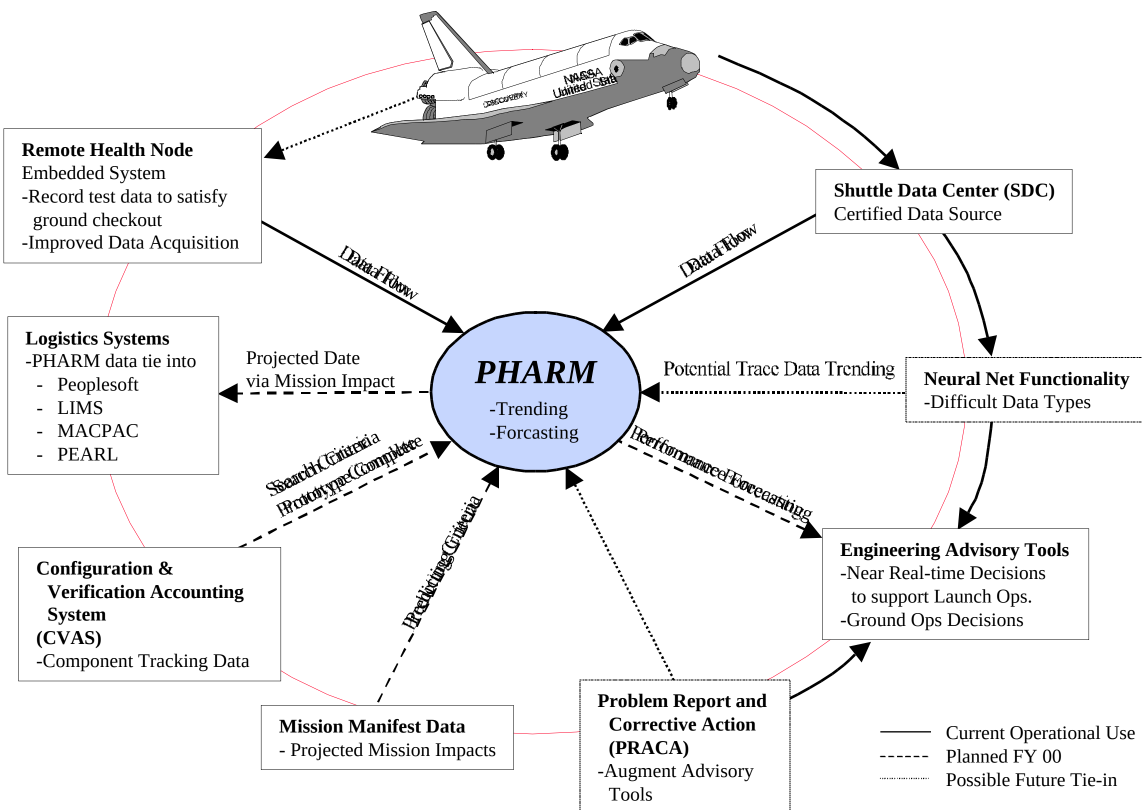

Figure 1 PHARM's Information Cycle

Development of a PHARM approach to operational systems (i.e. Shuttle, X vehicles, and commercial applications) requires some initial steps to verify and validate that a PHARM approach is a viable option. PHARM's foundation is based on applying Statistical Process Controls (SPC) to component performance data to determine present and future component/system health. Therefore the accuracy and reliability of the data is crucial to accurately trend and predict component performance. Another key aspect of PHARM is to have an "apples to apples" data storage and retrieval capability. This is accomplished by tying into a configuration management system where components are tracked through repairs, replacement, relocation etc. PHARM's component performance forecasting is initially based on testing cycles. These cycles will need to be integrated with a scheduling system to provide a realistic mission based need date for integration into the logistics scheduling database for component repair/replacement decisions and logistics provisioning.

2.0 Scope:

This report discusses the PHARM infrastructure, forecasting development, and related databases that make PHARM a total information cycle. Much of the PHARM discussions are centered on the Vehicle Health Management (VHM) OMS He pressurization system testbed located at the Kennedy Space Center's Launch Equipment Test Facility (LETF).

3.0 PHARM Underlying Infrastructure:

Determining the feasibility of applying PHARM to an existing system or new system requires some initial investigations. These investigations require a detailed look into each specific component's failure modes, testing requirements, data acquisition processes, and possible modifications.

3.1 Failure Modes Analysis:

The first and probably the most important tasks were to understand and determine the most common failure modes associated with a system/subsystem. This was accomplished for the components in the OMS helium testbed by reviewing and analyzing the failure modes and shuttle fleet history of each component. To understand the critical failure modes (defined as loss of crew and/or vehicle), a review of the Failure Modes Effects Analysis (FMEA) was performed. Determining the most common failure required an analysis of the Problem Report And Corrective Action (PRACA) data system which contains the failure history and corrective action taken for each of the components. The analysis identified for the OMS/RCS He pressurization systems the most common operational failure modes were associated with internal system leaks. The majority of these leak failures were caused by dried propellant residue, acid etching, contamination, and operational wear. Leak failures associated with dried propellant residue, acid etching, and operational wear appear to lend themselves well to trending, because they can gradually get worse over time. Contamination leak failures are caused by a piece of contaminant flowing through the system causing an instantaneous discrepant condition and therefore is not a good candidate for trending. However a leak rate value outside SPC limit but within requirements might be an indication of a contamination failure and impending problems. The current methods of operational checkout have a high degree of variability and an inefficient method of data recording, storage, and tracking making it extremely difficult to collect and analyze the data for trending.

3.2 Testing Process Analysis:

PHARM relies strongly on applying SPC techniques to trend and forecast component performance. This section will show the importance that accurate and reliable data has on trending of component performance. One of the most basic rules for applying some selective SPC tools (run charts, x-bar charts, trending) states that a process must be in control. Any unique causes of data variations not associated with the process itself needs to be eliminated. This leads us into a discussion on the importance of understanding the testing and data collection process for specific trendable failures and to obtain the most accurate and reliable data possible.

The failure analysis identified leaks to be the most common failure for the components in the OMS/RCS helium pressurization system. Addressing this failure mode would achieve the greatest ground processing savings. The analysis on the testing processs found that the current testing and data collection process had several unique causes of data variations (human biases, additional leak sources, and temperature) that made trending unreliable. These variations were easily addressed using the VHM OMS helium testbed. The testbed uses an expert system tool providing real-time sequencing, analysis, state monitoring and close loop accounting. This tool was built with G2, an expert system shell developed by Gensym Corporation.

3.2.1 Elimination of Human biases:

Current testing and data collection processes on the shuttle OMS/RCS helium pressurization systems are performed manually. The VHM testbed and G2's automated controls provided automated testing procedures and data reading and recording, thus eliminating the human bias factor in testing reading and recording data. The use of G2 eliminates human intervention in reading and recording data, providing a high degree of repeatability and accuracy in data collection.

3.2.2 Reduction in Additional Leak Sources:

Current testing operations require numerous ground QD connections to the OMS/RCS helium pressurization system checkout. Each of these ground QD connections produces a potential leak source, which may mask the actual component leak rate. The testbed was used to develop techniques that use onboard helium instead of ground supplied helium thus eliminating the majority of the required ground QD connections, while also eliminating the additional leak source concerns.

3.2.3 Temperature Variation Accountability:

Current leak check operations are performed with a standard leak stabilization time of 15 minutes with the assumption that temperature is isothermal (constant) for the duration of the leak check. This method of determining leak rates is fairly good, but the isothermal assumption does not accurately represent conditions and at times provides misleading data. For example, an Environmental Control System (ECS) cycling on and off changes the external conditions of system lines and components. This has been proven to produce a sinusoidal effect on the systems temperatures/pressure and thereby influencing the leak rates. The G2 expert system at the testbed uses real-time temperature and pressure data to calculate leak rates. With the real-time leak rate data, the standard leak stabilization time was automated by monitoring leak rates determining real time leak stabilization. This reduced the leak duration time from 15 minutes to approximately 5 minutes. The reduction in stabilization time also reduces the potential effects of an ECS cycling.

3.3 Data Acquisition Process Analysis:

With the elimination of the previous defined variation there still remained a significant 'data toggle' that tended to mask any chance of measuring accurately the components performance. To perform leak checks a running average over the last 60 seconds was used as pressure in the calculation. To eliminate this data toggle and the need to perform a running average the data acquisition system was upgraded from a 12-bit to a 16-bit system. The resultant measurements from the pressure transducers were improved by an order of magnitude or better reducing the data toggles from +/- 2 psi to +/- 0.02 psi. Figure 2 and 3 illustrates the benefits and importance of archiving the most accurate data possible. Figure 2 is a run plot of measurements taken from a common pressure transducer (p5) using the 12 and 16-bit data acquisition systems. Also included is the running average of the 12-bit system. As can be seen the 16-bit system has significantly reduced data toggles. Using the 16-bit system eliminated the need to maintain a running average, greatly simplifying G2's automated procedures.

Figure 3 shows the improvements the 16-bit system has on SPC using actual tested leak rates. The plot consists of primary A regulator calculated leak rates, which were recorded from both the 12 and 16-bit data acquisition system. As expected the 16-bit data acquisition system has a noticeable improvement to the 12-bit system for the leak rates. The 16-bit system has a 71% reduction in the span between the UCL and LCL as compared to the 12-bit system. The increased fidelity and tighter control limits improves the ability to determine the components performance. The most important issue identified in this chart, and the principal reason why it is so important to obtain the most accurate and reliable data possible, is the difference in the trend lines. The 12-bit trend line shows a downward trend while the 16-bit system show and upward trend. Although the data set is small, the 12-bit system has the potential to lead to an erroneous conclusion.

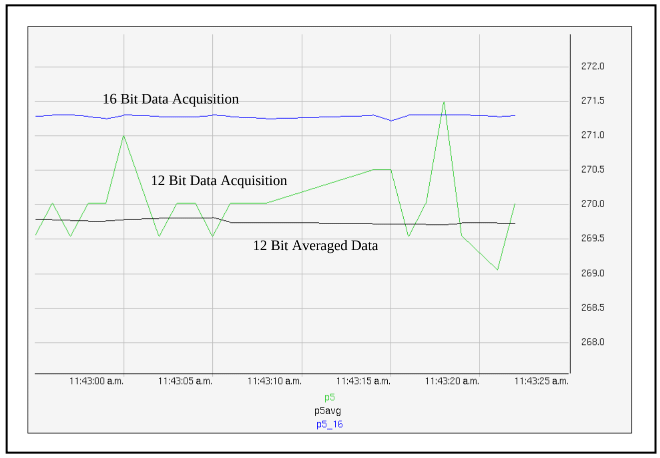

Figure 2 12-bit vs 16-bit Data Acquisition System

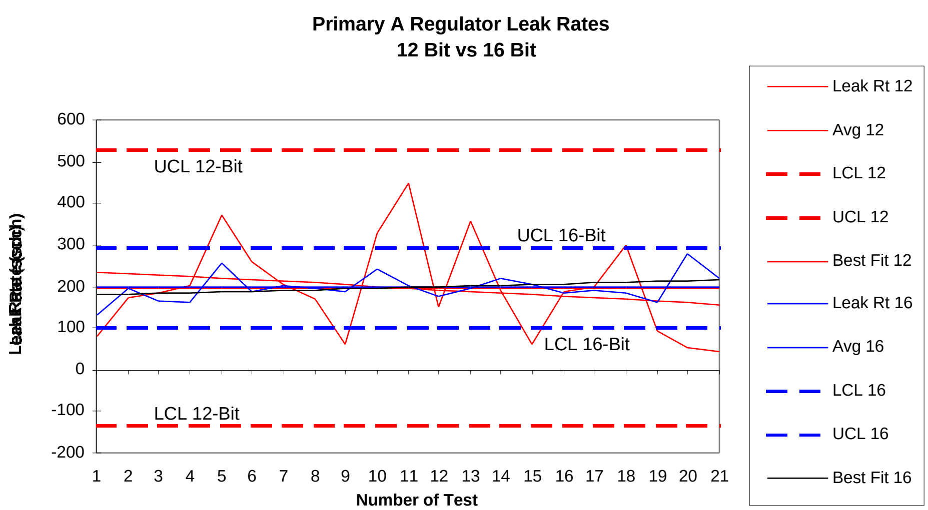

Figure 3 Component Performance Plot 12-bit vs 16-bit Data Acquisition

3.4 Telemetry Data Acquisition Systems:

To augment PHARM applicability to different component failure modes and their particular measurement data requirements, PHARM has developed two data collection systems. One accesses the Shuttle telemetry data stream or the Shuttle Data Center (SDC) for failure conditions that need no measurement data enhancements. The other is an embedded system, which will demonstrate an alternative data collection system where accuracy and high speed data need to be satisfied. The development of the embedded system leveraged off an ongoing Boeing IR&D

effort to develop an automated in-flight checkout system for the VHM OMS helium pressurization system. The embedded system acts as an autonomous remote health node monitoring the system state. When conditions satisfy ground testing requirements it runs algorithms that calculate, collect, and store key measurement data to the hard drive for later download and evaluation. This eliminates the need for ground checkout operations. The improved accuracy in the measured data was achieved by using a 16-bit D/A board with a range of 0 to 10 volts improving the match up between the in D/A board and instrumentation. This year (Calendar Year 2000) PHARM will develop the ability to acquire high speed trace data where neural net applications can be applied to evaluate the health of a component.

To demonstrate PHARM applicability using certified Shuttle telemetry data from the SDC, a multi mission web based data mining and analysis tool was developed called Spacecraft Telemetry Analysis Tool (STAT). The telemetry data is acquires based on Test Configuration Identification Document (TCID), Greenwich Mean Time (GMT), and Instrumentation address or Function Designator (FD). STAT has the search functionality to acquire component performance data in several ways. One is to specify the exact time when the event occurred. Another is to identify a range in which the event was to occur where the engineer can zero in on events. And lastly uses an event based algorithm that looks for related component states and when they satisfy some defined condition the needed data is then collected. Once the performance data has been collected, STAT uses Java based plotting features to display the data. STAT applies SPC and trending to aid in performance evaluations.

4.0 Data Analysis Trending and Predicting:

Once the underlying infrastructure has been investigated and the required data collection process has been defined, the next step is to develop techniques to plot component health along with trending and performance prediction. As seen in Figure 3, plotting a component's performance applies common SPC tools X-Bar Charts with SPC limits and a trend or regression line. The difficult part is forecasting and providing a need date for repair/replacement and logistic provisioning decisions. Preliminary investigations indicate that forecasting performance is not as trivial as first thought. It appears that component failure mode and failure characteristics play an important role in the development of prediction techniques. It is hypothesized that there is basic set of trendable failure characteristics for a wide range of components and/or component failure modes where a common set of prediction techniques can be applied. Some expected failure characteristics are:

- The data has a linear trend to a hard limit and the data maintains constant variation over time.
- The data has a linear trend to a hard limit but the data diverges over time.
- The data is linear at first but the failure characteristic is exponential.
- The data does not trend to a hard limit and diverges over time.

5.0 Database Integration:

For PHARM to be a complete informed maintenance cycle the ability to integrate with other databases is needed. Component tracking through its life cycle is essential for PHARM to retrieve and store a particular component performance data. PHARM developed a web based application that integration with the Space Shuttle Program's Configuration Verification Accounting System (CVAS) database. This system tracks the configuration of the orbiter's systems and components. The application can query for a component's mission history and installation information using part and serial number or query for component's part/serial number using mission history and component location. This technology was used to develop SSAV, the configuration management system for the Space Station Program.

Predicting component health for logistics provisioning and repair/replacement scheduling required the ability to convert test cycle predictions to a usable mission based need data. Access to a mission manifest database will provide the needed mission scheduling information to support logistics operations.

The established need date and historical performance data along with SPC and trending provided by PHARM can be used to help mitigate impact to logistic operations in several key ways. First, PHARM can assist in logistics provisioning decisions, which are primarily based on component failure rates. PHARM can assist in this provisioning decision by providing evidence that the component is not trending toward failure and thus provisioning decisions can be differed. Or the opposite may be true. PHARM may provide evidence that the component is trending toward failure earlier than expected and a provisioning decision needs to be expedited. Logistics repair/replacement decision and scheduling again is primarily based on component failure rates. PHARM again can provide evidence that the scheduling decisions to repair/replaceme a component can either be expedited or differed.

PHARMs integration into the mission manifest and logistics scheduling databases is slated for this year (2000) and this will complete the information cycle.

6.0 In Summary:

PHARM was primarily developed to help mitigate operational costs associated with Shuttle component failures, logistics provisioning and repair/replacement processing. The full capability of PHARM has yet to be seen, however some of the fallout technology is currently being implemented and used in Shuttle, Space Station, and Spaceport Florida operations. One of the key advantages that rose out of PHARM's development was STAT and its capabilities are an excellent near real time engineering advisory tool, which is currently being used during Shuttle launch and ground processing operations.

For PHARM to be applied effectively to any program, system, subsystem, and/or component the following key factors need to be addressed.

1) Component failure analysis and feasibility study.
2) Obtain the most accurate measurement data possible
3) Acquire data from alternate data sources
4) Integrate with Configuration Management databases for an "apples to apples" comparison of the data
5) Integrate with scheduling databases to mitigate provisioning, repair/relpacement decisions
6) Make PHARM capability available so all potential users may benefit

PHARM is the integration of information across a project so every entity can make decisions based on actual component performance.