Overview of PHMBIT

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ABSTRACT

Abstract —Many Wooden Rounds or generic complex systems that are currently fielded or operational, have limited if any maintenance performed, have no routine tests performed, however, most of these systems typically execute a Built-In-Test (BIT) just prior to being expected to perform with a high degree of reliability. This innovative PHMBIT technique provides the system and design engineers pertinent raw data on re-occurring hardware design (or software) BIT failures for trend analysis and prognosis. PHMBIT provides a closed loop feedback from fielded complex systems to the engineering authority for design change implementation, which enables a more robust and reliable wooden round or generic complex system to be manufactured.

1 Introduction

For this paper, Power on Self Test (POST) and BIT are synonymous and only BIT will be used. The concept of deriving prognostic health information from existing Wooden Round BIT data has been performed for decades; this paper describes an innovative technique as the result of the author's independent research on a Prognostics and Health Management (PHM) effort. Also for this paper, Wooden Round and complex system are synonymous and only the Wooden Round terminology will be use.

This innovative PHMBIT feedback method can be implemented on any generic complex system that executes BIT during the various system development stages, even on already fielded production units without any additional hardware (H/W) or embedding of sensors. Before we can adequately define any PHM needs, we should answer the question of "What is meant by the Wooden Round philosophy and PHM?"

Wikipedia defines the Wooden Round as: A sealed round (A.k.a a "Wooden Round") is a munition which is typically stored in some kind of container (usually a cylinder or box, but the container may in fact be the outside of the munition), so that the munition does not require any sort of maintenance and is stored in this container right up until the point that it is used. The advantage of this type of system is that such munitions can be stored for long periods without needing to be periodically checked and possibly repaired. Typically these, like all munitions, still do have a shelf-life — but it is often quite long. Bullets have been sealed rounds ever since the cartridge case was invented.

The Wooden Round philosophy has been used in the Defense Industry for decades which describes their definition of a theoretical tactical weapon mainly used on military aircraft. As applied to the missile defense industry, the Wooden Round concept was developed in the late 1960's and early 1970's and has been almost exclusively the province of solid propellant weapon systems (i.e., Harpoon, Phoenix or AMRAAM missile)[1].

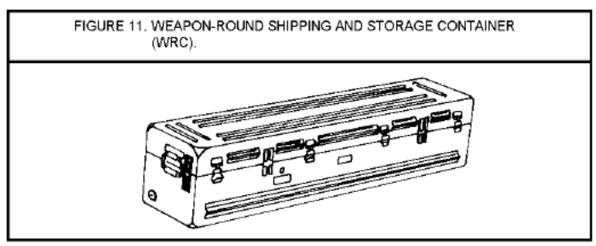

Figure 1: Wooden Round Shipping and Storage Container

A prime Wooden Round example is the Advanced Medium Range Air-to-Air Missile (AMRAAM), which has a 10 year bumper-to-bumper warranty. The missile warranty cost is tacked on the price of the missile. Raytheon used historic reliability and repair data to estimate this warranty price. AMRAAM is basically a Wooden Round with limited field-level maintenance repair. If field personnel induce a failure (e.g. broken radome, etc), then the missile repair is not covered under the manufacturer's warranty and any repairs will be charged against the Contract Logistics Support (CLS) contract[2].

PHM is a combination of prognostics and diagnostics which is defined as follows: diagnostics is the process of determining the state of a component to perform its function; prognostics is the predictive diagnostics, which usually includes determining the remaining life or time span of proper operation of a component or system, but not necessarily in this paper's context. Therefore, the health management of a Wooden Round, is the capability to make appropriate design change decisions based on the limited diagnostic and prognostics information available, thus enabling a more robust design to meet current operational demands.

This PHMBIT technique is developed to obtain specific raw BIT data/variables to help prognosis BIT failure trend data on specific recurring BIT test failure parameters. This trend data aids in the Root Cause and Corrective Analysis (RCCA) of potential systemic issues to improve upon an already capable and proven Wooden Round.

2 BIT Background

First, we must understand some of the logistical shortfalls that presently exist in any Wooden Round which perform BIT. The goal of BIT is to test as much of a Wooden Round's functionality or health (typically more than 75 percent of hardware and software functionality) as possible in an extremely short amount of time, usually less than 5 seconds. Again, using AMRRAM as a prime example, as depicted on the wing of an Aircraft in Figure 2, the Aircraft applies

Figure 2: AMRAAM as Wooden Round

power to AMRAAM (or any typical Wooden Round Weapon) for approximately 5 seconds and then power is removed. AMRAAM performs BIT upon power up, unless commanded to launch via the Release Consent discrete signal. This is a typical Wooden Round Weapon scenario.

Introducing any type of active PHM technique into a Wooden Round's BIT would prove to be an extremely challenging task. This paper will reference historical BIT data from a program that's been in production for many years with over 1,000 Wooden Rounds produced and in use by the customer. This program has an extremely successful flight test rate of approximately 97 percent. One might ask, how much better can PHMBIT improve on such a high flight test success rate? The answer is probably none. PHMBIT may not improve any program's flight test success rate, as its not designed to, however, PHMBIT can make the Wooden Round more reliable, thus having fewer Wooden Rounds returned for repair, which results in a significant cost savings to the customer and/or manufacturer.

2.1 BIT Analysis

The key issue is that programs have too many fielded Wooden Rounds returned for BIT failures. Every failed system returned from the field has to be tested (verify failure), disassembled, repaired, tested, reassembled into a Wooden Round, final test performed and then shipped back out into the field. All of this touch labor, troubleshooting and testing to repair the Wooden Round, costs either the customer or manufacturer money. This adds program risk by having fewer fielded systems and having to perform repair work on every fielded Wooden Round returned.

Even if Reliability Engineering performs a Root Cause Corrective Analysis on every piece of hardware that failed BIT, which costs money whether it's a circuit card assembly (CCA) or subassembly, the true underlying cause of the failure might not be revealed due to lack of the raw test data/variables needed surrounding the BIT failure. This PHMBIT technique can be applied to any system that performs BIT, or any tests like BIT. The Pareto chart in Figure 3 illustrates a program's BIT failure analysis over several years' worth of BIT historical data. The Pareto chart has had sanitized by removing the BIT failures actual test names.

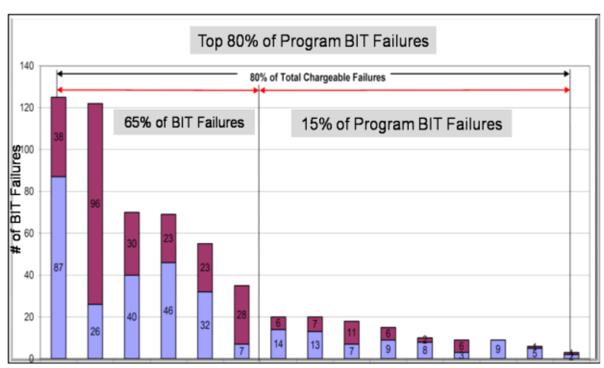

Figure 3: BIT Failure Pareto

Analysis of the Pareto chart shows the top 15 BIT failures make up the top 80 percent of all recorded BIT failures, and the top 6 BIT failures make up 65 percent of all recorded failures.

Further analysis reveals these top six BIT failures were all electromechanical failures and it takes the next nine BIT failures to represent the remaining 15 percent of the top 80 percent BIT failures. Overall, this indicates the Wooden Round BIT has been extremely effective at testing the Wooden Round’s performance and hardware functionality. Analysis also indicates that BIT is testing the hardware (and software) sufficiently to prevent the Wooden Round weapon from presenting a potential threat of failure to the launching Aircraft when commanded to launch (BIT tests all of the launch critical safety hardware). This sophisticated balance of system testing and performance has led to a highly successful flight test success rate.

However, it is summarized that too many Wooden Rounds were failing BIT and being returned for repair. This costs the customer or manufacturer money and decreases the customer’s satisfaction. PHMBIT provides feedback from the fielded failures to the design engineers which will help the company make its product more reliable. Developing this PHMBIT technique transforms the limited Wooden Round BIT Pass/Fail data into a tailored BIT raw data/variables collector. This allows the Reliability analyst to perform detailed prognostic trend analyses on the collected BIT raw data, which aids in the RCCA process, providing BIT knowledge of the most reoccurring BIT failures.

2.2 BIT History

Current Wooden Rounds have embedded system software that performs BIT that is executed on power-up and/or when commanded. BIT executes these specific performance tests and provides a Pass or Fail back to the system controller interface. *Currently, all of the raw test data/variables that BIT used in its algorithms and tests to determine if the UUT passes or fails is lost at the end of commanded BIT or when power is removed* (unless this data is recorded via telemetry data stream, which is not typical for most Wooden Rounds).

If one were to tailor BIT to collect the raw BIT data/variables used during the execution of BIT, this raw data could then be stored in nonvolatile FLASH for future retrieval. The Pareto of the BIT historical data analysis indicated there were nine specific electrical tests failures that make up 15 percent of the top 80 percent BIT of reoccurring failures, it would make the most sense to evaluate these particular nine BIT failures in more detail. These specific individual tests inside of BIT are prime candidates for PHMBIT data collection and feedback implementation.

3 PHMBIT Approach

BIT software is designed and coded to allocate and store individual raw BIT data/variables in nonvolatile FLASH memory, each and every time the Wooden Round executes BIT for these specific individual tests in BIT (pass or fail). Note; due to nonvolatile FLASH memory limitations, there may be a maximum number of BIT collections (pass and fail) possible the BIT system software can store. For illustration purpose, the last 64 BIT data/variables (pass or fail) will be stored in nonvolatile FLASH for future retrieval in the field by ground support equipment. Upon a BIT failure which leads to the Wooden Round being returned to the manufacturer for repair, the PHMBIT data can be retrieved at the factory or depot.

BIT system software now provides extra raw test data/variables (for specific hardware and software tests executed by BIT) on the last 64 BITs performed – pass or fail. Upon the Wooden Round failure and return for repair, specific BIT parameters data/variables can now be downloaded from nonvolatile FLASH. Once downloaded, statistical data analyses and prognostic algorithms can now be performed on the raw test data/variables. The analyst can now perform trend analysis and prognostics on the reoccurring individual test failures of BIT and look for any anomalous behaviors that might have occurred during the execution of any of the BIT results, see example in Figure 4.

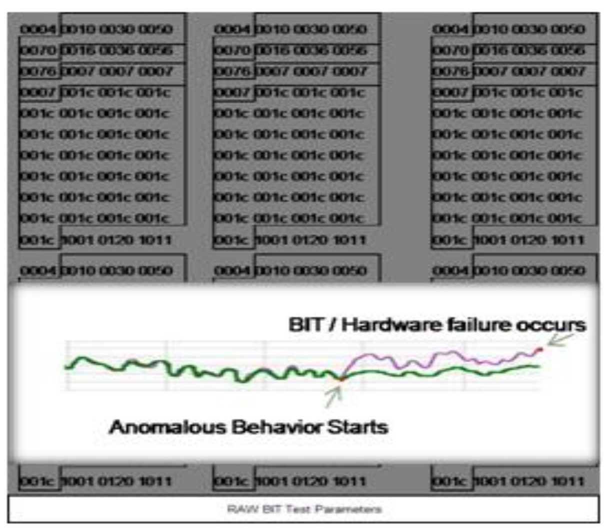

Figure 4: BIT Test anomalous behavior

The fictitious chart above illustrates the individual tests data/variables as stored in FLASH. Each block represents raw data of a particular test of BIT. A plot of the individual test's raw data/variables reveals anomalous behavior starting to occur about 1/2 of the way through the 64 BIT collections. However, it took numerous more BIT tests before this particular test was on its way to permanently failing. Now, the Reliability Engineer has the raw BIT data/variable historical data, indicating anomalous behavior, to aid in the RCCA process of the failed circuit card assembly (CCA) or subcomponent. This new knowledge of the failed subassembly or component will aid in the engineering process of providing a true hardware or software design correction.

Depending on the type of raw BIT data/variables being stored in nonvolatile FLASH, one or more of these extra bits of raw data could even aid in the diagnosis of a mechanical or electromechanical failure. If a temperature or vibration sensor is available, it could also be stored in FLASH at the time of BIT execution. This could also provide invaluable additional data for complete RCCA diagnosis. *Together, this combined BIT history data collected and hardware RCCA report should provide true failure knowledge to determine if the failure is one of a kind or a potential systemic failure that needs immediate engineering attention to enhance the overall system's reliability.*

3.1 PHMBIT Commonality

This PHMBIT technique of collecting raw test data/variables being stored in nonvolatile FLASH can also be incorporated at various lower levels of subassembly level of testing. It may not be necessary to store the lower subassembly test data/variables in nonvolatile FLASH (could be for continuous test history), but rather in the test equipment performing the following tests:

- Circuit card assembly (CCA)
- Circuit card stack
- System level tests

The PHMBIT prognostic algorithms developed for analyzing the Wooden Round individual tests of BIT, could also be re-used on lower level subassemblies or vice versa, if the prognostic algorithms were first developed for circuit card assembly (CCA) and system level testing. Performing trend analysis and looking for any anomalous behaviors at the lowest level of testing possible, maximizes the opportunity to catch potential system design problems at the earliest possible level of testing, before the Wooden Round makes its way out in the field.

3.2 Accelerated Life Testing

The PHMBIT technique could also be extremely useful during accelerated life testing (ALT) which test UUT at higher stress levels or until UUT failure. The typical various types of ALT are:

- Environmental stress screening (ESS)
- Highly accelerated life tests (HALT)
- Highly accelerated stress screening (HASS)
- Design of experiments (DOE)

Using the PHMBIT data collection technique to help obtain raw test data/variables in sufficient quantity and quality on specific BIT data/variables can provide valuable insight into ALT testing and/or failures. The *PHMBIT technique could be tailored during ALT or DOE to collect any specific raw test data/variables (not necessarily specific tests of BIT) in nonvolatile FLASH memory that could be thoroughly analyzed for diagnostic and prognostic purposes*.

4 CONCLUSION

Many Wooden Rounds utilize BIT or some variation thereof, to test as much of the Wooden Round or complex system's functionality (typically 75 percent or more) as possible before being committed to perform its function. This PHMBIT technique can be implemented on any Wooden Round or complex system which executes BIT, or any similar type of test, without any additional hardware or embedding of sensors.

The advantage of the innovative PHMBIT technique is the acquisition and storage of very specific/tailored raw test data into nonvolatile FLASH, in sufficient quantity and quality, on a complex system without altering the current system's BIT performance. *PHMBIT can be tailored to provide raw test data/variables on the top 80 percent (or more), or of any specific signal of interest, of any Wooden Round or complex system. Trend analyses and prognostic algorithms can be exercised on this data to aid in the Root Cause and Correction Analysis (RCCA) process and determination of the hardware or software BIT failure. This provides a closed loop data feedback from the fielded systems failures to the design engineering center to produce a more robust and reliable Wooden Round or complex system*

Therefore, if any Wooden Round's reoccurring BIT failures (hardware or software) can be isolated and fixed sooner rather than later (thus reducing the program's production risk), this will increase the Wooden Round's mean time between failure, causing fewer Wooden Rounds being returned from the field, thus reducing the overall program costs. The bottom line is this PHMBIT technique could benefit any Wooden Round or complex system, which increases the customer's satisfaction and ultimately increases the overall system's reliability and performance.

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REFERENCES

[1] Raymond Smith, "Development of the First Wooden Round Turbine Engine" figures and notes used in unpublished presentation at Society of Automotive Engineering Aerospace Vehicle Conference, Washington, D.C. 8-10 June 1987. National Air and Space Museum Archives, Washington, D.C.

[2] Missile_Mx_tom.doc, (Unpublished)

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