Special Feature

Advances in Reliability Testing

A Look Under the Hood of HALT and HASS

Although HALT and HASS methodologies have become widely accepted in military programs, not enough attention is paid to what is actually happening to hardware in those test environments.

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The Future Combat Systems (FCS) and Joint Strike Fighter (JSF) Programs have set goals for reduced maintenance costs through high-reliability requirements and application of prognostics for electronic systems. There is a long history of using HALT/HASS for development of military electronics. Military experience has found some electronic products often fail to meet the reliability targets. Even worse, when redesign is requested due to reliability shortfalls, often the redesigned products have even lower reliability levels.

If military experience has found that currently used reliability methods often fail to meet goals, how can these same methods meet the higher goals of FCS or accurately predict remaining life for prognostic approaches in FCS and JSF (Figure 1)? With that in mind, it's helpful to examine the vibration test equipment commonly used in reliability of electronics and look at some tests specially conducted to numerically quantify capabili-

Figure 1

The Joint Strike Fighter (JSF) is among the programs that have set goals for reduced maintenance costs through high-reliability requirements and application of prognostics for electronic systems. The challenge now is to accurately predict remaining life for prognostic approaches in such programs. Shown here an F-35 Lightning II Joint Strike Fighter takes off for its first flight as part of system development testing in Fort Worth, Texas.

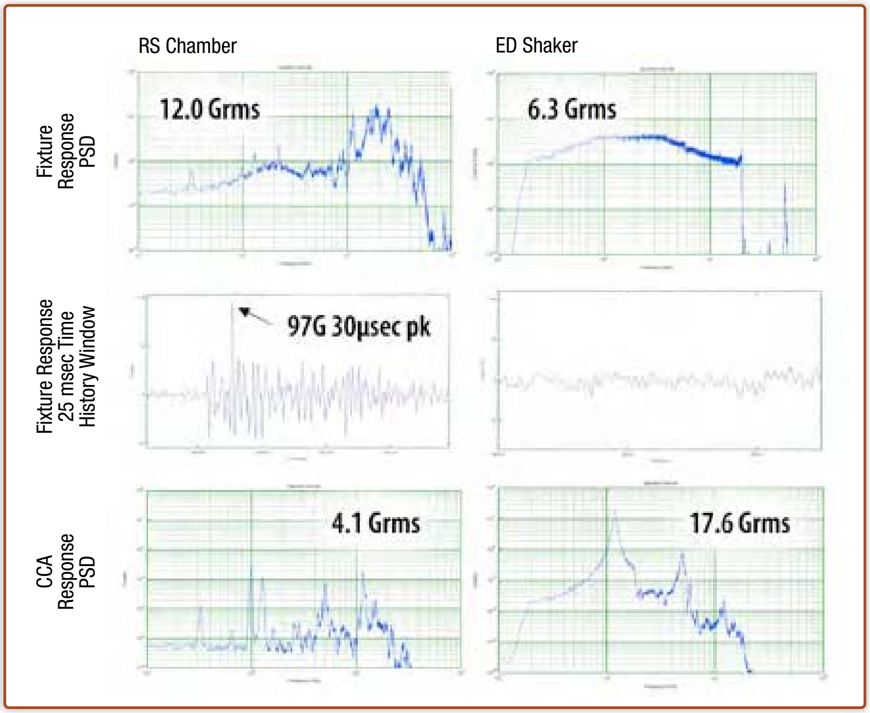

Figure 2

Shown here are the control and response comparisons for the ED Shaker and RS Chamber tests. The primary mode of the CCA was excited on the ED Shaker resulting in an overall 17 Grms response level with the primary mode peaking at 120 Hz. CCA response levels on the RS Chamber varied from 3.3 Grms to 5.9 Grms, depending on the location of the test unit, showing quasi random excitation response.

ties that are critical to effective reliability testing of electronics.

Electronics Reliability: A Little History

In 1979 the Navy Manufacturing Screening Program Document NAVMAT P-9492 was introduced. In the 1980s there were working groups, papers and various societies all working to advance techniques and methodologies of ESS. At the time, there was at least one common thread amongst all of this activity—understand what you are doing to your hardware.

HALT and HASS methodologies using Repetitive Shock (RS) vibration systems for ruggedizing and screening electronic hardware have become widely accepted in both commercial and military programs. This approach has often eliminated analytical modeling, structural analysis, measuring hardware response characteristics and understanding interactions of subsystem modes within a system. Estimates of damage imposed on the product are often quantified by a measurement of Grms (Gs root mean square) of full band spectrum. That said, circuit card damage is usually dominated by the lower response modes of the card, and full band Grms does not define modal response damage. The question is what is actually happening to hardware in a RS environment? Is it important anymore to care about response characteristics of critical CCAs and components? And what about damage or life consumption of hardware subjected to ESS processes?

Military programs are very eager to use the HALT/HASS methodologies for both cost and schedule reasons. Customers understand and often require the turnkey process, and the techniques are now widely accepted. Hardware is simply run through step by step procedures using RS stimuli, functional tests are made, weak points are ruggedized, HASS levels are determined and the product is ready for production screening. This is all accomplished with little or no understanding of how the actual product is responding during the HALT and HASS process. Many questions go unanswered in these processes. Questions like: What is the actual vibration input spectrum? What are the hardware response characteristics? How repeatable is the stimulus? What are the system gradients?

Complexities of Vibration Test

Vibration of electronics is very complex. Every component in every assembly is subjected to a unique stress history. Since there is no existing reliability database for component vibration life, each assembly's vibration life capabilities must be determined during the development cycle, unique to the specific product. There are two parts critical to development of a reliable electronic product. First, the electronics must be rugged enough for the expected life load conditions. And second, the product must be free of production flaws / defects that could result in premature failure.

Ruggedness of an assembly can be verified by accelerated life testing (ALT), subjecting the product to equivalent damage of a life time of service life in a time compressed test. Electrodynamic (ED) shakers (applying ALT) and RS Chambers (applying HALT) are common means of determining assembly fragilities. RS Chambers can find weak points but, due to lack of excitation control in response frequency ranges common to electronic circuit card assemblies (CCAs) and inherent gradients that are common in RS chambers, cannot accurately quantify the failure level. However, HALT test fragility levels can be numerically defined using some of the methods discussed here.

Production defects are found by proper application of an Environmental

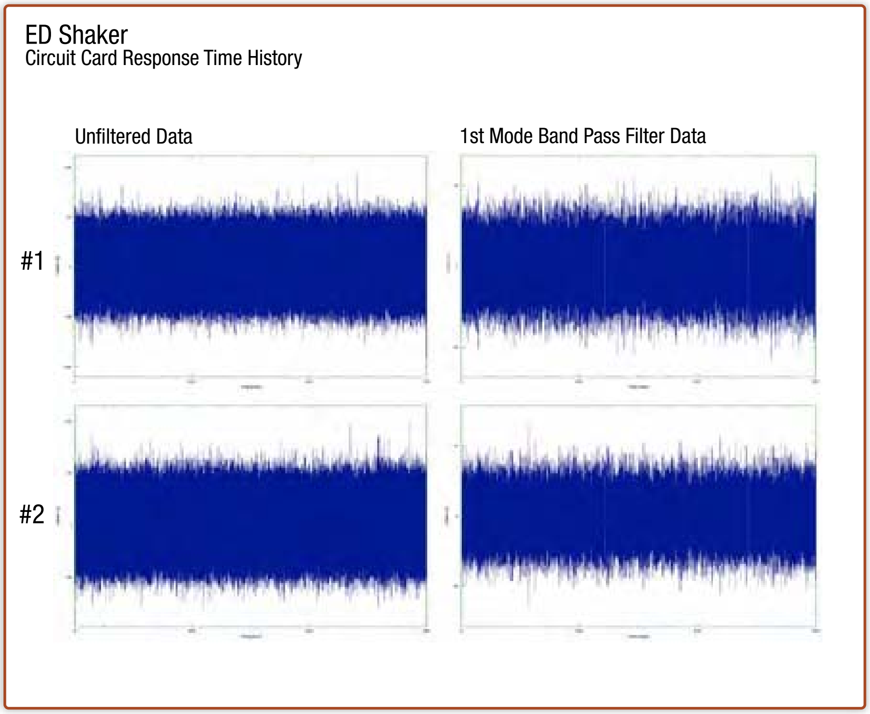

Figure 3

Depicted here is the ED Shaker CCA Acceleration time history for the unfiltered data and first mode response.

Stress Screening (ESS) process. ED shakers (applying ESS) and RS Chambers (applying HASS) are common means of screening. ESS and HASS are "processes" because they are part of the production build and are adjusted during the production life to increase the efficiency of preventing failures during service life. Field failures can be the result of ESS under-test (failure to find existing flaws) or ESS over-test (using excessive product life). ESS must be customized to the product to be effective. Avoiding under-test and over-test can best be accomplished with a thorough understanding of both product damage experienced under test and the test equipment control capabilities.

Obtaining high reliability is a difficult process. Determination of an equivalent life test for ALT requires an understanding of the expected environment and also an understanding of the product's weakest parts in order to apply the proper stress factors required for time compression. Determination of a proper ESS is even more complex, since it must avoid excessive damage to the product's weakest part while driving flaws to failure—flaws that would be at risk during service life.

Electronics ESS is difficult with well-defined control typical of ED Shakers. With the reduced excitation control associated with RS Chambers, HASS has greatly increased difficulty. In a vibration environment, some parts of an assembly may be capable of infinite life, but the overall product life of a system is still determined by the weakest part.

Reliability Methods: Test Control

Tests were conducted to quantify control. The goal of these tests was to evaluate the response characteristics of a simple circuit card assembly (CCA) mounted inside an electronic

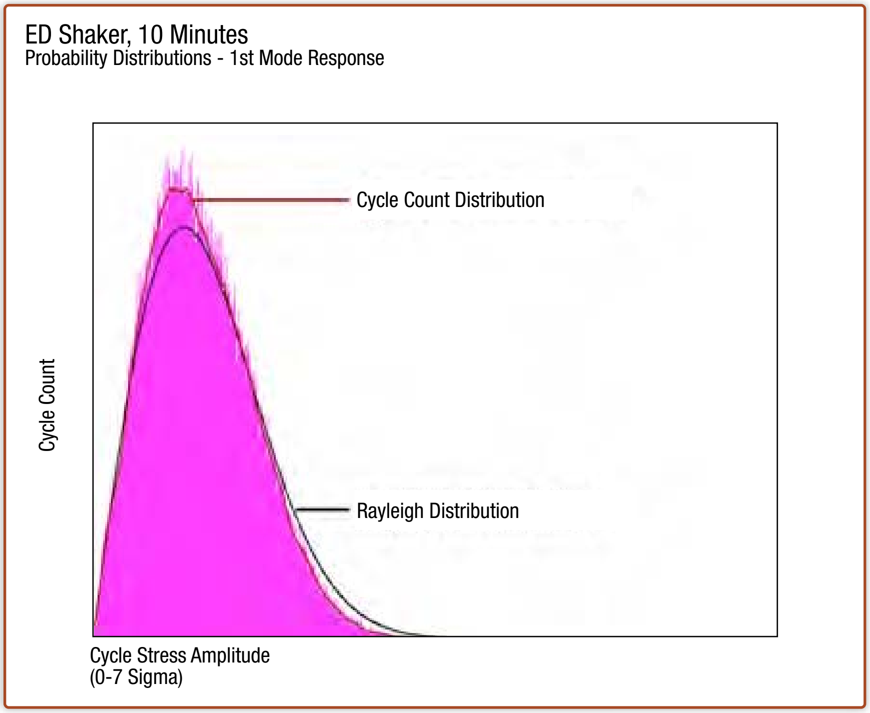

Figure 4

Shown here is the cycle count distribution. The ED Shaker circuit card response closely matches the expected Rayleigh response.

assembly during ED Shaker and RS Chamber vibration environments to determine if either system can effectively and repeatedly screen the CCA without excessive damage to any part within the assembly.

In order to answer this question, CCA damage control was evaluated on both systems, using a 6 Grms 20-2000 Hz NAVMAT spectrum for the ED Shaker and a 6 Grms level for the RS Chamber. To evaluate damage control, the acceleration time history of the CCA was analyzed for stress cycle response in the first mode. Since damage is exponentially related to response level, damage control is highly dependent on the distribution of amplitudes of modal response.

It is well understood that damage is not totally defined by first mode response alone because other modes contribute to failures. Since the first mode dominates stress cycles that define fragility for most CCAs, this was the best means to obtain a numerical understanding of vibration control on damage.

Attributes of fixture and CCA responses varied significantly when collected data from ED and RS vibration systems were compared. Comparison of fixture PSD levels on the ED Shaker was consistent with the input with an overall response level of 6.3 Grms, while fixture levels on the RS Chamber varied greatly with RMS levels measuring from 7.8 to 12.0 Grms, depending on location, with significant Grms contributions above 2 kHz.

Time history fixture data showed that the ED Shaker has a consistent random input and the RS Chamber has repetitive shock bursts with a peak pulse in each burst around 90Gs. The CCA response characteristics were also very different. The primary mode of the CCA was excited on the ED Shaker resulting in an overall 17 Grms response level with the primary mode peaking at 120 Hz. CCA response levels on the RS Chamber varied from 3.3 Grms to 5.9 Grms, depending on the location of the test unit, showing quasi random excitation response. The response spectrum shape follows the chamber input. Of course, overall response Grms does not relate to cycled stress, therefore does not relate to damage. Figure 2 graphically presents this comparison.

ED Shaker and RS Chamber Evaluation

The electronic assembly was tested for two separate 10-minute tests. The measured response on the CCA showed excellent control over time for both tests (Figure 3). Response distributions for the two tests agreed within 7 percent—which is equivalent to two-one control on damage with the exponential stress / damage relationship. Figure 4 shows the first mode response amplitude distribution. The distribution closely matches the expected “ideal” Rayleigh distribution.

The electronics assembly was tested in three different positions on the test table (Locations 1-3). Response of the CCA was continuously recorded for 10 minutes for each of the locations. The CCA showed greater variations in response. The CCA had frequent high amplitude response peaks. In addition, first mode, narrow band filtered data showed that control of board response varied significantly in time and position (Figure 5). CCA first mode response distributions for two test locations are shown in Figure 6, superimposed on identical Rayleigh response distributions (for scaling purposes).

Due to the exponential relationship between stress amplitude and the damage associated with the response cycle, the Location 1 response distribution would be expected to cause higher product damage than the Location 2 response since the distribution exceeds the Rayleigh in the high sigma range. Based on Grms values, Location 1 would be more than 20 times as damaging as the Location 2.

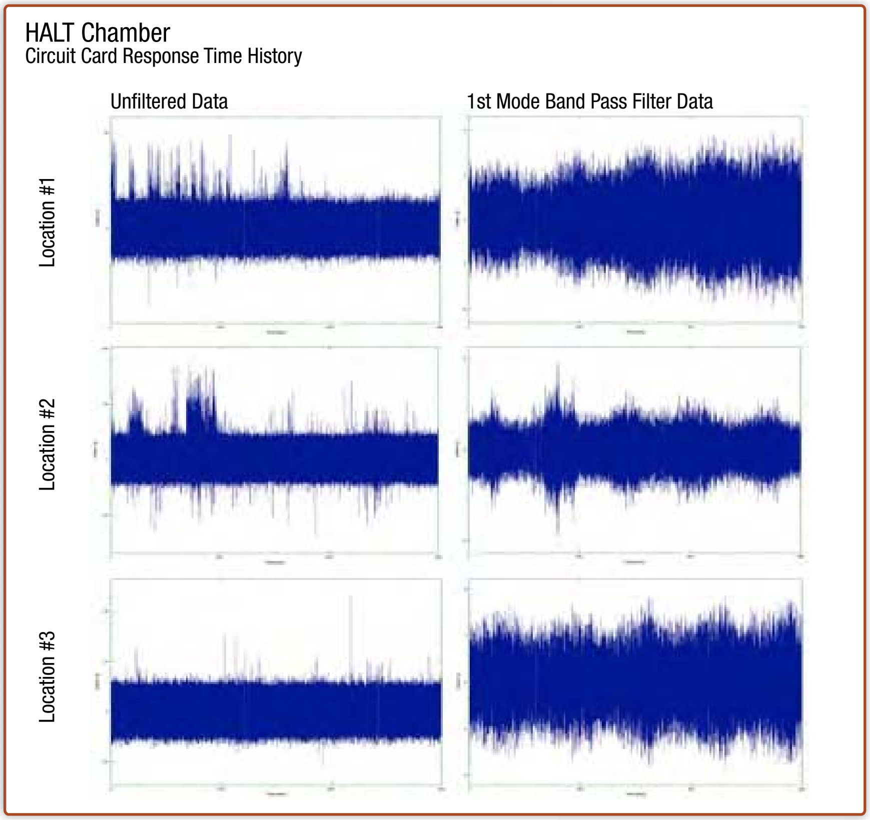

Figure 5

Shown here is the RS Chamber CCA acceleration time history, unfiltered data and first mode response.

RS Chamber Control: Time Variation

Initial inspection of the response distributions of Figure 6 (this would be representative of evaluating the PSD response at the natural frequency) implies that the Location 1 position is more damaging than Location 2. However, when damage is integrated over all response cycles, Location 2 was found to be far more damaging. This results from a significant number of very damaging cycles that occurred during the Location 2 test that cannot be seen in the 10-minute distribution plot. Figure 7 captures response cycles for a 25-second period that dominates damage for Location 2—with many cycles above 3 Sigma response levels—even some above 7 Sigma.

For the limited number of tests performed in the RS Chamber, control on damage for test periods was in excess of 600:1. When variations for test time, multiple positions on the test table and combined damage from multi-mode response are considered for HASS, this ratio can grow substantially. For comparison, the ED Shaker had a 2:1 control on damage. This difference is because each component accumulates damage based on the cyclic nature of the combined stresses associated with acceleration and board flexure of each response mode. Components in high curvature regions experience high rates of damage accumulation. Components in low curvature regions can have insignificant rates of damage accumulation. The damage ratio, max-to-min, for all components in this particular assembly / support condition / vibration profile is 743 billion-to-one. Obviously, it is impossible to find an ESS vibration

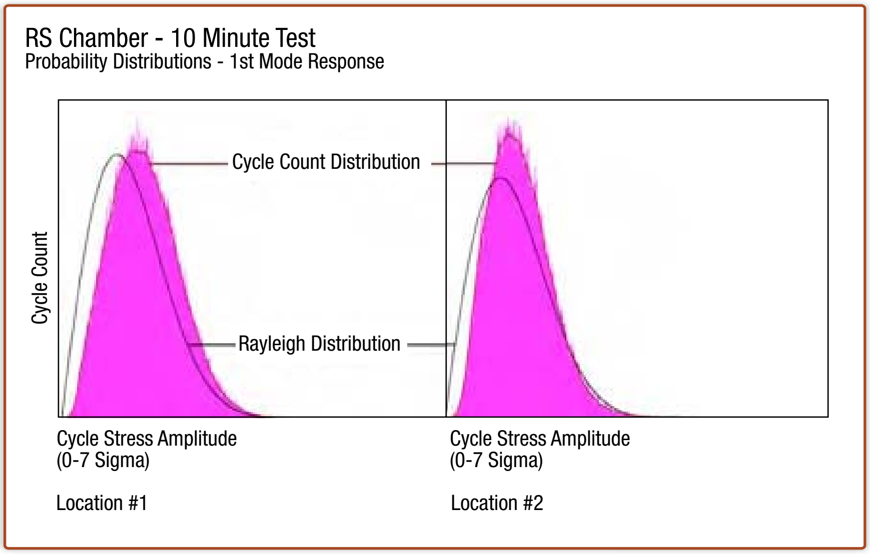

Figure 6

Shown here is RS Chamber CCA first mode response distribution for the 10-minute test. Response distribution, which is critical to damage control, varies significantly with test position.

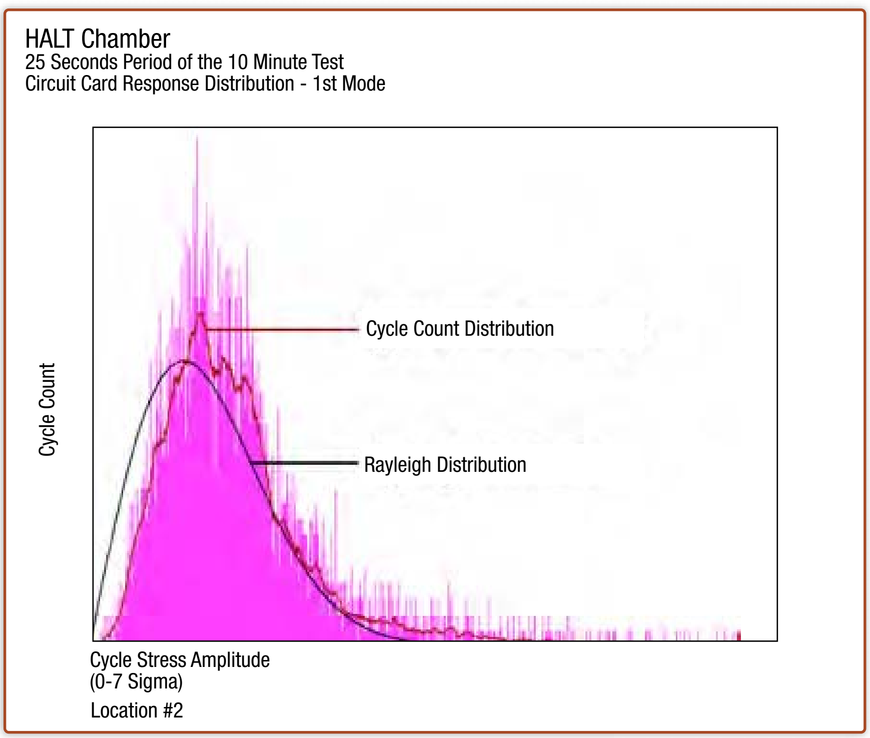

Figure 7

The graph shows the RS Chamber CCA first mode response distribution during a very damaging 25-second period of the Location 2 Test. There are many 3 Sigma to 7 Sigma response cycles.

profile that could screen well-positioned (low-stress) components without damaging the worst position component. The goal of a screen for this board would be to determine what portion of the board could be screened without damaging the weakest part.

A structurally optimized CCA would have a substantially reduced max-to-min life ratio for components. However, for any CCA, the same question of what fraction of the board can be effectively screened without damaging the weakest part must be answered. This question gets very complicated when tests to define fragility (HALT) and screens (HASS) suffer from lack of control. When damage control is lowered, it increases the risk of over-test or under-test for ESS.

Test Experience Counter Arguments

Those with extensive test experience with ESS of electronics without supporting response measurements and PoF analysis might argue that control of the first vibration mode alone does not define screen effectiveness. It might be argued that chambers excite all vibration modes and can combine thermal cycles to ensure an effective screen. Driving all modes and adding thermal does compensate for lost effectiveness or lost repeatability. In addition, control on response of higher modes is likely to be lower than control on the first mode.

A flaw is a product weakness that requires some level of exposed damage to bring it to failure. A part that fails in one week of service life experienced one week of imposed damage. Screens are not magic processes that automatically apply damage to flaws. Screens apply damage to the whole product. The thermal cycle portion of a screen is highly damaging to all parts since temperature differences are usually high stress conditions. For CCAs, vibration is very important since the high number of response cycles, even at low stress amplitude, can drive near failure conditions to detectable faults. There are a number of components that are stress dominated by the primary mode response, others dominated by higher modes. The control of response for each mode determines the repeatability and effectiveness of the screen for the associated parts.

Reliability Applied to Military Electronics

A typical means of defining an initial screen level is to first determine the fragility level of an assembly by accelerated life testing (ALT or HALT). The initial screen level is typically set at half of the fragility level. In the commercial industry, low cost of assemblies typically allows failure testing on many units to accurately define a failure distribution. However, military electronics rarely have the luxury of testing more than a single unit. It becomes very difficult to accurately define fragility of an electronic assembly with a low number of test units and the damage control expected for a HALT chamber.

The practice of a two-to-one reduction in excitation level from HALT to HASS offers high risk for screens of off-the-shelf electronics considering the lack of control when defining fragility and the lack of control during a life of screening. Effective screening of electronic assemblies for high reliability using HASS might be possible, but it cannot be accomplished without in-depth understanding of the product damage and test equipment control capabilities early in the process.

Often, proof-of-screen is a means of assuring that the product is not being excessively damaged and that it can find flawed product. Properly performed, proof-of-screen should demonstrate that it can find “seeded flaws” and also be shown to be non-damaging to good product by passing repeated screens (usually 20). It can be improperly used. If control is poor, passing a screen 20 times may be no more damaging than passing the worst of the 20. Finding seeded flaws is part of the proof-of-screen that is rarely performed—it can be difficult.

Customize Test Processes

Enhanced reliability and accurate prognostics require advanced development methods that include Physics of Failure (PoF) analysis and Reliability Enhanced Testing (RET). Best Practices should be upgraded to customize ALT/HALT test and ESS/HASS process to each product with a full PoF understanding of the test control capabilities and PoF expected damage distribution in the product. For HASS, it is critical to determine if the test equipment is capable of an effective, repeatable screen of the product—in other words, consistent control on damage, avoiding under-test and over-test.

This study quantified first mode response control, but as the mode number increases, the control of response is expected to decrease for both RS Chambers and ED Shakers since higher modes are more difficult to excite. HASS may be capable of an effective screen of an electronic assembly—screws, wires, cables and so on—but it is not likely to be an effective screen of the complex parts (CCAs). Creating an effective screen of a CCA for FCS high reliability with HASS may be impossible or at best, extremely difficult. When CCAs need to be screened, unless the HASS chamber being used can be proven to have proper control, the process should use ESS on ED Shakers where control is capable of an effective screen.

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