START
Selected Topics in Assurance Related Technologies
Volume 6, Number 4

Accelerated Testing

Introduction

To meet increasing competition, get products to market in the shortest possible time, and satisfy demanding customer expectations, industry is turning to sophisticated methods and techniques of testing. Many of today's products are capable of operating under extremes of environmental stress and for thousands of hours without failure. Traditional test methods are no longer sufficient to identify design weaknesses or validate life predictions.

Accelerated testing is an approach for obtaining more information from a given test time than would normally be possible. It does this by using a test environment that is more severe than that experienced during normal equipment use. Since higher stresses are used, accelerated testing must be approached with caution to avoid introducing failure modes that will not be encountered in normal use. Accelerating factors used, either singly or in combination, include:

- More frequent power cycling
- Higher vibration levels
- High humidity
- More severe temperature cycling
- Higher temperatures

Accelerated testing falls into two main categories, each with a specific purpose:
- Accelerated Life Testing - life estimation
- Accelerated Stress Testing - problem/weakness identification (or confirmation) and correction

The differences between these two categories, although subtle, are significant and include the underlying assumptions upon which the test is based, the models utilized in constructing the test, the test equipment and chambers used, the way in which the test itself is conducted, and the manner in which the resulting data is analyzed and interpreted. Table 1 compares the two main categories of accelerated testing.

Table 1: The Two Main Categories of Accelerated Testing

Test	Purpose and Approach	Comment
Accelerated Life Testing (ALT)	Uses a model relating the reliability (or life) measured under high stress conditions to that which is expected under normal operation to determine length of life	Requires: • an understanding of the anticipated failure mechanism(s) • a knowledge of the magnitude of the acceleration of this failure mechanism, as a function of the accelerating stress
Accelerated Stress Testing (AST)	Uses accelerated environmental stresses to precipitate latent defects or design weaknesses into actual failures to identify design, part or manufacturing process problems which could cause subsequent failures in the field.	Requires a thorough understanding, or at least a workable knowledge, of the basic failure mechanisms. Estimation of item life may, or may not, be a concern.

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The level at which accelerated test is performed is very important. Some accelerating techniques are appropriate only for part level testing, while others can be used only for higher levels of assembly, and a very few techniques may be applicable for both part level and assembly level. The underlying assumptions and modeling approaches which may be perfectly legitimate at the part level may be totally invalid for tests performed on higher level equipment and vise-versa. Table 2 provides information on testing at the two major levels; equipment and component.

Table 2: Levels at which Accelerated Testing is Performed

Level	Limitations	Comment
Equipment Level	Usually quite limited; seldom performed. Creating a valid model relating rate of equipment failures at a high stress to that at normal operating conditions is extremely difficult. Also, it is very difficult to formulate stress conditions that do not change the failure mechanisms occurring within the equipment.	One example of an accelerated test that can be used effectively on equipment is that of increasing the duty cycle, e.g., for a system normally running only during one shift, or avionics equipment operating only a few hours before and during a flight. In such cases a higher duty cycle could easily be used during the test. the system undergoing test could be operated continuously for three shifts a day or the avionics equipment might be cycled continuously, with only enough time between simulated flights to permit the temperature within the equipment to stabilize to non-operating conditions. Although the failure rate per operating hour does not change, the number of failures accrued per day is increased. This type of accelerated testing is commonly done in reliability qualification test, and although it is not usually recognized as such, this is actually a form of accelerated testing.
Component Level	Components (parts) tend to have fewer failure modes than equipment. Thus, it is far easier to identify a stress which can effectively accelerate the rate of failure without seriously changing the failure mechanism.	There are usually one or more dominant failure mechanisms accelerated by a given stress, e.g., dielectric breakdown of capacitors as a function of voltage, or corrosion as a function of humidity. In this case it is usually relatively easy to find an acceleration model relating failure rate as a function of operating stress. For this reason accelerated life testing is used extensively for components and the technique is highly recommended for most types of parts and for most part applications.

Accelerated Test Models

Accelerated test models relate the failure rate or the life of a component to a given stress such that measurements taken during accelerated testing can then be extrapolated back to the expected performance under normal operating conditions. The implicit working assumption here is that the stress will not change the shape of the failure distribution.

Table 3 summarizes three of the most common accelerated test models. These are not the only models that can be used. In choosing a model, the key criterion is that it accurately models the reliability or life under the accelerated conditions to the reliability or life under normal operating conditions. Great care is essential in choosing the most appropriate model, and in selecting the appropriate range of validity for the chosen model in a specific application. Documenting the rationale for these choices is important.

Table 3: Common Accelerated Test Models

Model Name	Defining Equation
Inverse Power Law	$$\frac{\text{Life at normal stress}}{\text{Life at accelerated stress}} = \left(\frac{\text{Accelerated stress}}{\text{Normal stress}}\right)^N$$ where N is the acceleration factor
Arrhenius Acceleration Model	$$\text{Life} = Ae^{-\frac{E}{kT}}, \text{ where:}$$ Life = a measure of life, e.g., median life of a population of parts A = a constant determined by experiment for the parts involved e = the base of the natural logarithms E = activation energy (electron volts - a measure of energy), which is a unique value for each failure mechanism k = Boltzmann's constant = 8.62×10^{-5} eV/K T = Temperature (degrees Kelvin)
Miner's Rule (Fatigue Damage)	$$CD = \sum_{i=1}^{k} \frac{C_{Si}}{N_i} \leq 1, \text{ where:}$$ CD = cumulative range C_{Si} = number of cycles applied at a given mean stress Si N_i = the number of cycles to failure under stress Si, (as determined from an S-N diagram for that specific material k = the number of loads applied Assumes every part has a finite useful fatigue life and every cycle uses up a small portion of that life. Failure is likely to occur when the summation of incremental damage from each load equals unity. Miner's rule does not extend to infinity, however. It is valid only up to the yield strength of the material; beyond that point it is no longer valid.

Advanced Concepts in Accelerated Testing

Historically, most accelerated testing is done using a single stress and a constant stress profile. This includes cycled stress (e.g., temperature cycling between specified limits) where the cycle (upper and lower temperature limits and rate of change of temperature), rather than the temperature, is fixed. In accelerated testing, however, the stress profile need not be constant and a combination of stresses may also be used. Some common non-constant stress profiles and combined stress profiles include:

- Step Stress Profile Test
- Progressive Stress Profile Test
- Highly Accelerated Life Test (HALT) (Equipment-level)

- Highly Accelerated Stress Screens (HASS) (Equipment-level)
- Highly Accelerated Temperature and Humidity Stress Test (HAST) (Part-level)

Highly accelerated testing is the systematic application of environmental stimuli at levels well beyond those anticipated during product use. Thus, the results need to be carefully interpreted. It is used to identify relevant faults and to ensure that products have a sufficient margin of strength above that required to survive the normal operating environments. Highly accelerated testing attempts to greatly reduce the time needed to precipitate these defects. The approach may be used either for development testing or for screening.

HALT is a development tool and HASS is a screening tool. They are frequently employed in conjunction with one another. They are relatively new, and differ from the classical approach to accelerated testing. Their specific goal is to improve the product design to a point where manufacturing variations and environment effects minimally affect performance and reliability. Quantitative life or reliability prediction is not usually associated with highly accelerated testing.

Step Stress Profile Testing. Using a step stress profile, test specimens are first subjected to a given level of stress for a preset period of time, and then they are subjected to a higher level of stress for a subsequent period of time. The process continues at ever increasing levels of stress, until either all the specimens fail, or the time period at the maximum stress level ends. This approach precipitates failures more rapidly for analysis. However, with this technique it is very difficult to properly model the acceleration and, hence, to quantitatively predict the item life under normal usage.

The amount by which the stress should be increased in any single step is a function of many variables and is beyond the scope of this discussion. However, the general rule to follow in the design of such a test is to eventually exceed the expected environments by a comfortable margin so that all members of the population can be expected to survive both the field environment and the screen environments, assuming of course that they are defect free.

Progressive Stress Profile Testing. A progressive stress profile or “ramp test” is another frequently used approach, where the stress level is continuously increased with time. The advantages and disadvantages are the same as those for step stress testing, but with the additional difficulty of accurately controlling the rate at which the stress is increased.

HALT Testing. The term HALT was coined in 1988 by Gregg K. Hobbs. HALT, sometimes referred to as stress plus life testing (STRIFE), is a development test, an enhanced form of step stress testing. It is typically used to identify design weaknesses and manufacturing process problems, and to increase the margin of strength of the design rather than to predict quantitative life or reliability of the product.

HASS Testing. HASS is a form of accelerated environmental stress screening. It presents the most intense environment of any seen by the product, but it is typically of a very limited duration. HASS is designed to go to “the fundamental limits of the technology.” This is defined as the stress level at which a small increase in stress causes a large increase in the number of failures. An example of such a fundamental limit might be the softening point of plastics.

HAST (Highly Accelerated Temperature and Humidity Stress Test. With the recent improvements in electronics technology and the speed with which these technology improvements are occurring, accelerated tests which were designed just a few years ago may no longer be adequate and efficient for today’s technology. This is especially true for those accelerated tests intended specifically for microelectronics. For example, due to the improvements in plastic IC packages, the traditional, universally accepted 85°C/85%RH Temperature/ Humidity test now typically takes thousands of hours to detect any failures in new integrated circuits. In most cases, the test samples finish the entire test without any failures. A test without any failures tells us very little. Yet we know that products will still fail occasionally in the field. Thus, we need to further improve our accelerated tests. HAST is intended to replace the older temperature/humidity test.

Caveats

An accelerated test model is derived by testing the item of interest at a normal stress level and also at one or more accelerated stress levels. Extreme care must be taken when using accelerated environments to recognize and properly identify those failures which will occur in normal field use and conversely those that are not typical of normal use. Since an accelerated environment typically means applying a stress level well above the anticipated field stress, accelerated stress can induce false failure mechanisms that are not possible in actual field use. For example, raising the temperature of the test item to a point where the material properties change or where a dormant activation threshold is exceeded could identify failures which cannot occur during normal field use. In this situation, fixing the failure may only add to the product cost without an associated increase in reliability. Understanding the true failure mechanism is paramount to eliminating the root cause of the failure.

For Further Study:

1. Web Sites: Additional information on accelerated testing can be obtained from the following web sites:

    a. http://www.hobbsengr.com/advance_halt_hass.html
    b. http://www.qualmark.com/usergrp.html

2. Publications:

    a. Harris, C.M., Crede, C.E., "Shock and Vibration Handbook," McGraw-Hill, 1961.
    b. Hopf, A.M., "Highly Accelerated Life Testing for Design and Process Improvement," Sound and Vibration, Vol. 27, No. 11, Pages 20-24, November 1993.
    c. Keller, M.E., "HALT/HASS Pays Off in Product Reliability and Lower Costs," Test Technology Newsletter, January-February 1977.
    d. Nelson, Dr. Wayne, "Accelerated Testing," John Wiley & Sons, 1990.
    e. O'Shea, P., "HALT Can Shorten Time to Market," Evaluation Engineering, Vol. 35, No. 12, Pages 42-45, December 1996.
    f. "Product Survey: Environmental Test Equipment - The Baffling World of HALT/HASS," Test & Measurement World, Vol. 16, No. 1, January 1996.

Other START Sheets Available:

94-1	ISO 9000
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95-2	Parts Management Plan
96-1	Creating Robust Designs
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Future Issues:

RAC's Selected Topics in Assurance Related Technologies (START) are intended to get you started in knowledge of a particular subject of immediate interest in reliability, maintainability and quality. Some of the upcoming topics being considered are:

- Mechanical Reliability
- Software Reliability

Please let us know if there are subjects you would like covered in future issues of START.

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Mr. Criscimagna holds a Bachelor's degree in Mechanical Engineering from the University of Nebraska-Lincoln, a Master's degree in Systems Engineering from the Air Force Institute of Technology, and he did post-graduate work in Systems Engineering and Human Factors at the University of Southern California. He completed the U.S. Air Force Squadron Officer School in residence, the U.S. Air Force Air Command and Staff College by seminar, and the Industrial College of the Armed Forces correspondence program in National Security Management. He is also a graduate of the Air Force Instructors course and has completed the ISO 9000 Assessor/Lead Assessor Training Course. Mr. Criscimagna is a member of the Amercian Society of Quality (ASQ) and a Senior Member of the Society of Logistics Engineers (SOLE). He is a certified Reliability Engineer, a certified Professional Logistician, chairs the ASQ/ANSI Z-1 Dependability Subcommittee, is a member of the US TAG to IEC TC56, and is Secretary for the G-11 Division of the Society of Automotive Engineers.

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