HALT AND HASS
THE NEW QUALITY AND RELIABILITY PARADIGM

Gregg K. Hobbs, Ph.D., P.E.
13 August 2002

INTRODUCTION

This brief paper is a condensation of the methods taught by the author and inventor of the methods in the seminar **HALT and HASS**. This paper is not intended to be complete, but to be an introduction to the concepts and to allow one to determine if the seminar would be useful. Complete training is necessary in order to successfully use the techniques. Attempting to use the methods with only this brief introduction would be less than successful.

The new methods are aimed at finding and fixing weak links in the product in the design phase and then finding and fixing process flaws during production. This is testing to find problems or testing to failure. The old paradigm of qualification testing was one of trying to pass by discounting any failures as unusual and not relevant. This is called success testing by the author. The HALT and HASS techniques represent a paradigm shift of major proportions compared to the old techniques of success testing.

HALT is an acronym for Highly Accelerated Life Tests that was coined by the author after having used the term "Design Ruggedization" for several years. In these tests, every stimulus of potential value is used to find the weak links in the design and fabrication processes of a product during the **design phase**. These stimuli may include vibration, thermal cycling, burn-in, voltage, humidity, and whatever else makes sense. The stresses are not meant to simulate the field environments at all, but to find the weak links in the design and processes using only a few units and in a very short period of time. The stresses are stepped up to well beyond the expected field environments until the "fundamental limit of the technology" is reached in robustness. Reaching the fundamental limit generally requires fixing everything relevant found even if found at above the "qualification" levels! HALT, or its predecessor, has, on many occasions in the last 33 years, provided substantial (5 to 1000 times) MTBF gains even when used without production screening, reduced the time to market substantially and also reduced the total development costs. It is noted in passing that STRIFE (STRESS plus LIFE), as used by Hewlett-Packard, is a subset of HALT and that the basic philosophy of HALT has been in use by the author since 1969 and has been used by the author on hundreds of products. Some attendees of the author's seminars have, in addition, used the techniques on thousands more, so the methods are not new, but have not been publicized very much due to the advantages that they provide. Development of the methods and equipment continues with significant advances in 1991, 1992, 1996, 1998, 1999, 2000 and 2001. As of this writing, more advances in equipment for performing HALT and HASS are in the development stages. HALT and HASS are therefore still emerging technologies.

HASS is an acronym for Highly Accelerated Stress Screens that was also coined in 1988 after using the term "Enhanced ESS" for some years. These screens use the highest possible stresses (frequently well beyond the "QUAL" level) in order to attain time compression in the screens. Note that many stimuli exhibit an exponential acceleration of fatigue damage accumulated with stress level, and so a drastic reduction in screening equipment and manpower is obtained by the use of higher stress levels. The screens must be, and are proven to be, of acceptable fatigue damage accumulation or lifetime degradation using Safety of HASS techniques. HASS is generally not possible unless a comprehensive HALT has been performed as, without HALT, fundamental design limitations will restrict the acceptable stress levels to a very large degree and will prevent the large accelerations that are possible with a very robust product. It has been proven that HASS generates extremely large savings in screening costs because much less equipment (shakers, chambers, monitoring systems, power and liquid nitrogen) is necessary due to time compression in the screens. HASS, too, is failure testing as compared to success testing.

THE PHENOMENA INVOLVED

Several phenomena are involved when screening occurs. Among these are electromigration, chemical reactions and mechanical fatigue damage. Each of these has a different mathematical description and responds to different stimuli.

Chemical reactions and some migration effects proceed to completion according to the Arrhenius model or some derivative of it. It is noted that many misguided screening attempts assume that the Arrhenius Equation **always** applies; that is, that higher temperatures lead to higher failure rates, but this is just simply not an accurate assumption. MIL-HDBK 217 is based on these concepts and therefore is quite invalid for predicting the field reliability of the products built today. MIL-HDBK 217 is even less valid and completely misleading when used as a reverse engineering tool to improve reliability, as it will lead one to make changes such as cooling that may well reduce reliability.

The fatigue damage done by mechanical stresses due to temperature, rate of change of temperature, vibration, or some combination of them can be modeled in many ways, the least complex of which is the Miner's Criterion. This criterion states that fatigue damage is cumulative, is non-reversible, and accumulates on a simple linear basis which in words is "The damage accumulated under each stress condition taken as a percentage of the total life expended can be summed over all stress conditions. When the sum reaches unity, the end of fatigue life has been reached and failure occurs". The data for percentage of life expended is obtained from S-N (number of cycles to fail versus stress level) diagrams for the material in question. A general relationship based on the Miner's Criteria follows:

$D \approx n\sigma^{\beta}$, where:
D is the fatigue damage accumulated,
n is the number of cycles of stress,
σ is the mechanical stress (in pounds per square inch, for example), and

ß is an exponent derived from the S-N diagram for the material. ß ranges from 8 up to 12 for most materials in high cycle fatigue (low stress and many cycles to failure).

The flaws (design or process) that will cause field failures usually, if not almost always, will cause a much higher than normal stress to exist at the flaw than at a position without the flaw. Just for illustrative purposes, let us assume that there is a stress that is twice as high at a particular spot that is flawed due to an inclusion or void in a solder joint. According to the equation above, the fatigue damage would accumulate about 1,000 times as fast at the position with the flaw as it would at a non-flawed position. This means that we can fatigue and break the flawed area and still leave 99.9% of the life in the non-flawed areas. Our goal in environmental stress screening is to do fatigue damage to the point of failure at the flawed areas of the structure. With the proper application of HALT, the design will have several, if not many, of the required lifetimes built into it and so an inconsequential portion of the life would be removed in a HASS. This would, of course, be verified in SAFETY OF HASS. Note that the relevant question is "How much life is left after HASS?" not "How much did we remove in HASS?" Also note that **all screens remove life from the product.** This is a fundamental fact that is frequently not understood by those unfamiliar with the correct underlying concepts of screening.

EQUIPMENT REQUIRED

The application of the techniques mentioned generally is very much enhanced by, if not impossible without, the use of environmental equipment of the latest design such as all axis broadband random vibration and ultra rate thermal chambers (70°C/min. or more **product** rate). Both of these techniques, HALT and HASS, have been in use by some of the author's consulting clients for some time, using the early all axis shakers for about 23 years and the more modern and more effective systems in later years. Any of the pneumatically driven shakers do fatigue damage much more rapidly at the same GRMS level than do "classical" shakers which usually are set to clip acceleration peaks at 3 sigma and therefore prevent cost effective screening.

Note that **we are trying to do fatigue damage in a screen; and the more rapidly we do it, the sooner we can stop and the less equipment we need to do the job.** It is not unusual to reduce equipment costs by orders of magnitude by using the correct stresses and accelerated techniques. This comment applies to all environmental stimulation and not just to vibration. An example given in the seminar “HALT and HASS” shows a decrease in cost from $22 million to $50 thousand on thermal chambers alone (not counting power requirements, monitoring equipment and personnel) by simply increasing the rate of change of temperature from 5°C/min to 40°C/min! Another example shows that increasing the RMS vibration level by a factor of 2 times would decrease the vibration system cost from $100 million to only $100 thousand for the same throughput of product. The use of an all axis shaker would further reduce the cost ratio. With these examples, it becomes clear that HALT and HASS, when combined with modern screening equipment, provide quantum leaps in cost effectiveness, which is precisely why most of the leaders in screening techniques are not publishing.

Some typical results of these screening techniques applied to product design and manufacturing are as follows:

(1) Nineteen years ago, an electro-mechanical product's MTBF was increased approximately 1000 times when HALT (in its primitive form as it existed then) was applied. A total of 340 design and process problems were identified in the several HALTs that were run, and all of these identified problems were removed from the product before production began, resulting in an **initial production system** MTBF of 55 years! This product is about the size of two PCs and has many mechanical parts. It is interesting that the MTBF never got better than it was at initial product release, but it did get worse when something went out of control. The out of control conditions were spotted by the 5% sample HASS called HASA. The reason there was no reliability growth is that the system was born an adult due to HALT. The equipment and techniques available today are far superior to those of the early 80's, so results today are much better!

(2) A power supply that had been in production for four years by 1983 with conventional (IES Guidelines) low rate, narrow range thermal screening had a plug and play of 94%. This means that 6% failed essentially out of the box. After HALT and HASS were applied using a six-axis impact shaker and 20°C/minute air ramp rates, the plug and play jumped to 99.6% within four months. A subsequent power supply, which had the benefit of HALT and HASS before production began, had a plug and play of 99.7% within two months! This company has been able to simultaneously increase sales and to reduce the QA staff from 60 to 4 mostly as a result of HALT and HASS and the impact it had on perceived quality and reliability. The company also reported that the cost of running REL-DEMO has been reduced by a factor of about 70 because all relevant attributable failures were found in HALT. Since HALT has been in use, all products have gone through REL-DEMO with **<u>ZERO</u>** failures. Current plug and play is 100% and has been so for 19 years!

(3) **HALT** found, using only four units in just a few weeks, 97% of the problems which were later found in an extended life test lasting 16 weeks and involving 12 units run 24 hours per day under normal conditions. The one problem not found in HALT was missed due to a technician reapplying grease to a lead screw every evening without my knowledge! No corrections were made to the product until after the life tests as the designers refused to believe that failures caused by HALT were relevant until these same failures were found under normal operational conditions. This reluctance to address identified problems because they were found by "over spec" stresses is a typical tendency of those unfamiliar with the modern methods, and why a paradigm change and education is necessary for the methods to be effectively applied.

(4) **HALT**, in a three hour demonstration associated with a seminar, detected and allowed solutions to three real design problems in three different pieces of equipment which had been fielded for years and which had had many field failures, one mission critical (safety of flight) and the other two disabling (grounding the aircraft). One major problem found per hour! The manufacturer had not been able to duplicate the field failures, although extensive classical testing had been done, and therefore could not understand the failure mode and conceive the corresponding fix. All three failure modes were found "over spec", two in temperature slightly beyond spec and one in six axis vibration in ten minutes at four times the "spec" GRMS!

(5) In 1993, Storage Technology Corporation reported "savings of hundreds of millions of dollars" in the first two and one half years of HALT and HASS. This was without the benefit of Precipitation and Detection Screens and before Modulated Excitation was invented. These advanced techniques have added several orders of magnitude to the effectiveness of HALT and HASS and are covered in detail in the seminar.

(6) A large farm equipment manufacturer put a new product into their normal verification tests. About 75% of the way to completion, a failure occurred. A fix was implemented and the test started over. After about 75% of the test, another failure occurred. A second fix was implemented and the test again started over. Again, after about 75% of the test, a third failure occurred. At about this time, the company was introduced to HALT and HASS by my seminar at their facility. They then took an original model of the equipment, that is, without fixes, and ran HALT on it. Within hours, all of the weaknesses that had been discovered in days of testing were found.

(7) Thermo King builds air conditioning for trucks such as those that haul meat and other perishables. A program with HALT was compared to a program without HALT. The program without HALT took twice as long to enter production, had many more field failures and cost approximately twice as much in terms of engineering development and field failures. This paper is available free by request. Just ask us for the Thermo King paper and we will send it to you by e-mail.

PRECIPITATION AND DETECTION SCREENS

Correctly done stress screening is a closed loop six step process consisting at least of: Precipitation, Detection, Failure Analysis, Corrective Action, Corrective Action Verification and Database Maintenance.

Precipitation here means changing some flaw in the product from latent (undeveloped or dormant and usually undetectable) to patent (evident or detectable). An example would be to break a nicked lead on a component or to fracture a defective bond or solder joint.

Detection here means to observe in some manner that an abnormality exists, either electrically, visually or by any other means. In the cases illustrated above, we could visually or electrically detect that a lead had broken or a bond or joint had broken. Note that an abnormality may be intermittent in nature and may only be observable under particular conditions such as low temperature and/or low-level impact vibration. **Proven** high coverage in the test system is mandatory. **Software HALT** that determines and then improves the coverage and resolution is covered in the seminar.

Failure Analysis here means to determine the origin or root cause of the flaw. In the illustrations above, we would determine where in the production process and why the lead had been nicked, why the bond had been improperly done or why the solder joint had not been properly done.

Corrective Action here means to implement a change intended to eliminate the source of the flaw in future production. The nicked lead might be prevented by using a correct forming die, the bond might be corrected by using a different pressure or perhaps better cleaning and the solder joint might be corrected by using a different solder or a different temperature.

Corrective Action Verification means to verify that the corrective action taken did indeed solve the problem. Verification is done by repeating the conditions that caused the problem to be exposed before as well as any other appropriate conditions or tests.

Database Maintenance means to collect all of the data from the HALTs in terms of what the weaknesses were and what the corrections were. This last step is extremely important. Without it, the same mistakes will continue to occur over the years. With the knowledge gained by several HALTs, a company can design products that sail right through HALT with no relevant failures, that is, with no weaknesses.

Each of these steps in conjunction with the others is necessary for a comprehensive screening program. Any less than all five will not suffice to provide a truly successful screening program with the entire attendant benefits that all five rigorously done would provide. Specifically, just breaking and then fixing the bad ones, while surely being better than doing nothing, is just the first step in a comprehensive screening program. Unfortunately, many efforts at screening stop here, and therefore attain only small gains in quality, **but entail the majority of the costs.** It must be borne in mind that screening is quite expensive; and, while very cost effective if done correctly, the costs are mostly there even if done incorrectly. In all cases, the obsolete techniques of using single axis vibration instead of all axis vibration and using slow thermal cycling with the attendant many cycles required instead of very high rate with only a few cycles required will be much more expensive than the more effective modern approaches which use the more sophisticated techniques and equipment.

There is a great difference between precipitation and detection screens, yet almost nothing is found in the literature regarding the difference. Again, the seminar covers these in great detail.

PRECIPITATION SCREENS

A precipitation screen is intended to convert a relevant defect from latent to patent. Precipitation screens tend to be more stressful than detection screens. An example of a precipitation screen would be high level all axis vibration, which accumulates fatigue damage extremely rapidly, particularly in areas at a relevant flaw, where stress concentrations usually exist, combined with high rate, broad range thermal cycling, which is intended to create low cycle fatigue in the most highly stressed areas, which, fortunately, are usually found (if the design is proper) at a flaw and finally, combined with power on-off switching, which is intended to generate electromigration at areas of very high current density, usually at a flaw, and to generate rapid temperature swings which force low cycle fatigue in areas of high stress, usually near a flaw. In using HASS correctly, one uses the highest possible stresses that will leave non-defective hardware with a comfortable margin of fatigue life above that damage which would be done by remaining screens and the shipping and in use environments. This approach demands the application of HALT techniques and design ruggedization in order to be able to rapidly and effectively precipitate flaws. Without using these techniques, the application of HASS is usually not possible due to weaknesses that will not allow the high stresses.

Note that precipitation screens may well be run at above an upper design operating limit (or below a lower design operating limit) where the system cannot perform normally and therefore cannot be tested during stimulation. In this case, more than 90% of the defects could be expected to be missed when tested under quiescent conditions; i.e., without any stimulation at all. This is where the detection screen comes in.

DETECTION SCREENS

Detection screens are usually less stressful than precipitation screens and are aimed at making the patent defects detectable. It has been found in the author's investigations that many patent defects are not observable under full screening levels of excitation even when the screen is within the operational limits of the equipment. What is required is **Modulated Excitation**, which subjects the article under test to a search pattern in temperature and all axis vibration looking for the conditions under which the product will exhibit intermittents. Modulated excitation and how to design, prove and tune screens is covered in the seminar. Screen Optimization results in a minimum cost screen regimen that is safe and effective.

For example, it has been found on several products that plated through hole solder joint cracks could only be detected by a Modulated Excitation. In an experiment utilizing 13 samples, all thirteen exhibited intermittents at some (all different) combination of stresses but at no others. This implies that no defects at all would have been found if Modulated Excitation were not used.

Detection screens should be used on equipment returned from the field as defective, as we (must) assume that a patent defect is present or the equipment would not have been returned. It is noted in passing that non-defectives are frequently returned from the field for various reasons caused usually by the press of time to "get it running ASAP!" Field repair people are inclined to replace whole sets of boards or boxes, when maybe only one of the set truly has a problem. A full blown precipitation screen may not be necessary on field returns as the patent defect(s) present may be exposed by a much more gentle detection screen. If the detection screens do not suffice, then a precipitation screen followed by a detection screen would be in order. In the case of field returns, it may be prudent to **simulate** the field conditions under which the failure occurred if these could be ascertained. These conditions might include temperature, vibration, voltage, frequency, humidity and any other relevant conditions. The military, airlines, auto manufacturers and others too, would be well advised to follow this course of action as No Defects Found account for about 50% of field returns. Stimulation is not necessarily called for in this case, as simulation and/or detection screens are probably the more effective approach on field returns.

SUMMARY

Every weakness found in HALT is an opportunity for improvement as large margins translate into high reliability. Today, HALT is required on an ever-increasing number of commercial and military programs. Many of the leading companies are using HALT and HASS techniques combined with all axis vibration and moderate to ultra rate thermal systems successfully, however, most are being quiet about it because of the phenomenal improvements in reliability and vast cost savings attained. The basic philosophy is, simply stated, "find the weak spots however we can and then make them more robust." A new paradigm!

A WORD TO THE WISE

Caution is suggested when reading published papers on accelerated testing as many users are not fully trained and do not know all of the best techniques. Several cases have been observed lately wherein companies tried to use the methods without complete training and the result was that essentially all of their mission critical hardware failed very early in field service due to damage done during screens. Consistently, completely and correctly used HALT and HASS **always** work to the benefit of the manufacturer and the end user. Incorrectly used, nobody wins and some may loose more than reputation and money. Do it correctly, or do not do it at all!

Hobbs Engineering Corporation
4300 W 100th Avenue
Westminster, CO 80031-2481
Phone: 303-465-5988 FAX: 303-469-4353
e-mail: learn@hobbsengr.com
web: hobbsengr.com