ACCELERATED STRESS TESTING

Fundamentals of Accelerated Stress Testing

TABLE OF CONTENTS

INTRODUCTION

This handbook is written to show how greater control can be gained over total product reliability by the utilization of Accelerated Stress Testing techniques (AST). It will examine the concept of AST; how Accelerated Stress Testing compares to Accelerated Life Testing; the technologies used in Accelerated Stress Testing; and the issues involved in properly implementing Accelerated Stress Testing.

General questions relating to the purpose and intent of Accelerated Stress Testing are also addressed in this booklet. However, because Accelerated Stress Testing is product specific, and each product has its own set of variables, it is not possible to cover individual product applications in detail. Sources for assistance of this type are referenced in the Bibliography Section.

NOTE ON TERMINOLOGY

As it is true throughout various industries, terms used to define or describe things in a particular discipline can vary widely. In understanding Accelerated Stress Testing, there are a number of areas where these variations cause confusion. In interest of clarity, this book makes some needed distinctions. It is recommended that readers refer to the Definitions Section for clarification of the terms used in this book.

THE CHANGES

Manufacturing techniques and procedures have changed dramatically over the last twenty years. Products have become much more complex, customers' product expectations have grown, and competition for customers has increased. Additionally national and international quality and reliability standards are continually being published. Because of these changes, most products must now undergo testing to achieve acceptable levels of quality and reliability improvements, and these testing methods can vary greatly. On one hand, there are pragmatic methods based upon sound management and engineering, and the wide use of statistical techniques. On the other hand is a range of methods based largely upon a systems approach in quantification of factors such as yield and failure rates[1].

The requirements for product reliability and testing have undergone major changes in the last few years. Customers are starting to recognize the importance of building reliability into their products. To build in reliability, today's manufacturers need to know as much about "how things fail" as they know "how things work"[2]. The advent of cost-effective computer technology coupled with low testing and test personnel budgets have caused a renewed interest in Accelerated Stress Testing. The number of tools and techniques used to test products has also changed dramatically and will continue to evolve as technology evolves.

AST is a product testing technique that everyone from the management team, to the marketing people, to the product managers, to the product designers, to the manufacturing personnel, to the quality and reliability personnel need to know about. AST can be used quite simply to make better, more reliable product.

DEFINITION OF AST

Accelerated Stress Testing can be simply defined as: applying high levels of stress for a short period of time to a device under test assuming it will exhibit the same failure mechanisms as it would in a longer amount of time at lower stress levels. In contrast to many types of testing – AST is "testing to fail" versus that of "testing to pass" a product. The key here is to understand the failures and their relationship to the applied stresses.

The main purpose of AST is to insure product reliability and accelerate the reliability growth for a given product. The intent is to attain product reliability maturity early in the design phase (see Fig. 1 & 2).

Fig. 1

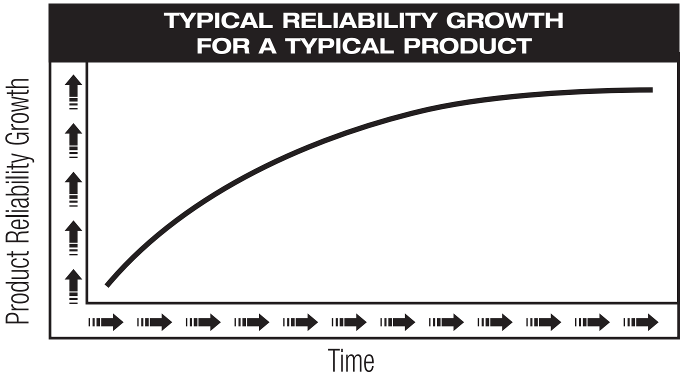
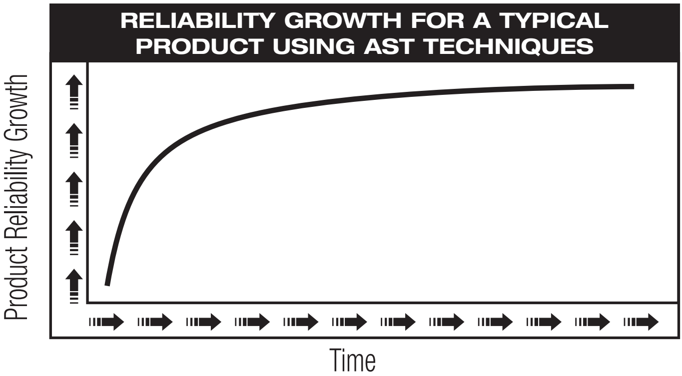


Fig. 2



It is very important to understand that specific types of defects are precipitated or caused to surface by certain stresses or combinations of stresses. ***Remember, each product is unique and there is no one tool or machine that will precipitate all relevant flaws for all products.*** This is not only due to various product dimensions and functions, but more importantly the physics of the product response to various stimuli. Mathematical models used in predicting or counting failures has its place, but when concerned with accelerating the fatigue of products, we must first remember what causes product failures. The main causes of failure, whether in production or in use are[1]:

- *Over-stress* – In which the stress (volts, torque, etc.) exceeds the strength available to withstand it.

- *Wear-out* – Caused by fatigue wear, corrosion, etc.

- *Performance* – Such as resistance value, drift, dimensional change, etc.

- *Variation* – Variation of parameter values (dimensions, environments, etc.) can cause failure to meet specifications; or can lead to failure due to over-stress or wear-out. Variation in the product is the result of manufacturing processes that are not exactly repeatable.

By understanding the product, we can focus on how to accelerate the life of the product and identify potential weaknesses or failures. To accomplish this we must identify what stresses the product can sustain and what stresses precipitate defects. This has long been practiced by skilled Environmental Engineers by applying TAAF (Test, Analyze, And Fix) Procedures.

> ***"One test is worth a thousand expert opinions"***
>
> —Anonymous

ACCELERATED STRESS TESTING– SIMULATION OR STIMULATION?

A great deal of confusion in the area of AST testing can be eliminated if the simple question is asked: Am I trying to ***simulate*** the product's life or am I trying to ***stimulate*** any failure that might occur during the product's life? Although this may sound like the same thing, it is not. In product life ***simulation*** tests, you are trying to simulate a lifetime of actual stresses the product will be exposed to. In product ***stimulation*** you apply stresses to the product that are typically more substantial than what the product would see in its use environment in an effort to induce fatigue, which precipitates failures and reveals product weakness. Both techniques have uses in a well-planned product development program, and when used improperly, both techniques lead to false conclusions and can have costly implications.

It is worth noting that a test oriented towards evaluating long term effects (fatigue or durability) will almost always take more time than a test oriented towards evaluating short term (limit load or step-stress) effects. This does not mean that one is better than the other; finding one type of problem often requires an approach that is not suited to finding another type of problem. More importantly, it does not mean that substituting a shorter type of test for a longer test will produce equivalent results, regardless of what the test is called. The cheaper test may not always be the right test[3].

SIMULATION TESTING

The intent of product life simulation tests is to identify relevant failure mechanisms that would occur, *and correlate these with the point in the product's life the failure would occur.* We want to understand the product's performance under the conditions that customers would expect the product to operate.[12] This can be very simple for some types of products and very complex for other types of products.

For example, a keyboard could expect to be used for 5 years. Assuming an operator could type 80 WPM (350 characters per minute), 7 hours a day, 280 days a year, and the highest usage keys were vowels, and the vowels were each used an average of once every five letters typed, then 41.16 million strokes would occur on the highest usage keys. So by striking a key 41.16 million times we would simulate 5 years of operation. This could be done using an X-Y Cartesian robot (so you could strike off center as well), with a set of solenoids that could strike 900 strokes/minute to simulate 5 years of life in 31.7 days. This is an example of time compression using actual simulated life conditions. This can also be done with the dynamic and climactic conditions a product would see. This type of accelerated life testing is very easy to correlate to the actual life of the product.

Unfortunately, not all product simulations are quite this simple. The steps to a product life simulation are as follows:

1. Determine what life your customer expects from the product.

The most important thing to know for any life test, or any test for that matter, is what your customer expects from your product. Each market segment has its own expectation level for what is acceptable. The expectation level varies based on the product's type and price. If the product does not meet the expectation level of its market segment, it will most probably be a failure.

An example of this is comparing a Rolex™ watch with a watch that that you get free when you fill your gas tank. The market segment that the Rolex™ was designed for expects precision, and lifetime operation. If it does not last the customers' lifetime, then it will not meet the customers expectation level, and the customer will be dissatisfied. On the other hand, if the giveaway watch keeps reasonable time for two years, the customer will most likely be very satisfied. It is obvious that the cost to manufacture a product such as the Rolex™is much greater than the cost of the giveaway watch. If we tried to make a watch for the giveaway market with too high a cost, it would also be a failure.

By first determining what the customer expects from your product, you can intelligently put together a life test that helps you meet or exceed the customer expectations.

2. Determine what operating and non-operating environment(s) the product will experience.

The first environments to consider are those the product will experience during transportation (all the modes of transportation used as well the regions the product will be shipped to). The next consideration is storage environments.

The final set of environments are those the product will encounter during its primary use (all the situations where a customer may use the product). After all these conditions are identified, you will have determined the standard and extreme environments the product will see during its life.

3. Determine the frequency and duration of operation the product will experience.

Identifying how often the product will be used and the duration of its uses requires an understanding of statistics and probability, as not all users will use the product the same number of times or for the same length of time.[11] It is best to assume worst case use of the product for life test purposes.

Once the number of uses and the duration is determined, we can look for ways to compress the time. This is done by cycling the product on and off the total number times the product would see during its life. As for duration of use, it is applicable for some products but not others. For example, for most electronic equipment duration applies to the amount of time it takes to bring the product to temperature. After that point, the stress incurred is minimal. However, for some mechanical devices, the length of operation does apply and must be taken into consideration.

4. Determine the frequency the product will see particular use environments.

A. Determine the extreme stress levels and how many times the product will experience these.

We now need to consider the extremes that were decided earlier to determine how many times the product will see these in its life, assuming the worst case (again, this will vary from user to user). Once the frequency of cycles is determined, we can look at compressing the time period. We do need to differentiate the number of cycles and extremes the product will see during transportation, storage, and operation. It has been shown that once the product reaches a temperature condition, the majority of the fatigue has been incurred. This means that typically once the product reaches a targeted temperature a dwell period is not required and we can continue to the next target temperature condition. Humidity extremes are affected by duration due to breakdowns that can occur in coatings and seals as well as corrosion growth. In vibration testing, how often a product experiences extreme vibration levels directly relates to the total amount of stress that the product is subjected to, and needs to be addressed.

B. Determine transitions and how many times the product will see these.

Chances are, there will be cases in a product's life where an extreme change in temperature will occur. Even office equipment that typically resides in air-conditioned comfort will most likely experience extreme changes in temperature, humidity, and vibration levels during transportation. We need to identify the maximum transitions and incorporate the worst case number into our accelerated life test.[11]

5. Put together the life test.

Now that we know the stress conditions, the frequency of use and exposure, and the maximum transitions, we can create a profile that represents a particular product's life. One of the easiest ways to formulate this test is to break the product's life down into two sections.

The first section represents the product transportation and storage environments, and the second section represents the product use environment. During the transportation and storage section, because the product experiences vibration extremes before it experiences climactic extremes, we apply the vibration conditions first. That is, the greater stresses will be applied first. A good reference for the transportation vibration profiles is MIL-STD-810 or SAE J-1211. These specifications detail environmental profiles for different modes of transportation. After the vibration extremes are tested, the climactic extremes with transition rates are applied. Finally the use environment tests are applied; we have already determined the extremes and frequency of variation.

While applying the environmental and dynamic stress conditions, remember to exercise and continually monitor the product. ***It is extremely important to document failures and at what condition they occur.*** This information is critical to identify the failure mechanisms so the proper corrective action can be taken.

STIMULATION TESTING

The intent of environmental stimulation is to induce product fatigue by applying higher levels of stress than the product would experience in normal use. This type of testing is based on the concept that higher stresses applied to a product accelerate the rate at which relevant failures would become evident in the product's life. The key is that the failures caused during stimulation must be *relevant* to failures that the product would experience sometime during its expected life. Predicting the life of parts stressed above the endurance limit is at best a rough procedure[4]. For many mechanical and electronic parts subjected to randomly varying stress cycle intensity, the prediction of fatigue life is further complicated. The procedure referenced here for addressing this situation was proposed by Palmgren of Sweden in 1924 and, independently, by Miner of the United States in 1945. The procedure is often called the *linear cumulative-damage rule*. Palmgren and Miner very logically proposed the simple concept that if a part cyclically loaded at a stress level causing failure in 10^5 cycles, then each cycle of this loading consumes one part in 10^5 of the life of the part. If other stress cycles are interposed corresponding to a life of 10^4 cycles, each of these consumes one part in 10^4 the life, and so on. When, on this basis, 100 percent of the life is consumed, fatigue failure is predicted[4]. Miner's equation for damage at failure is:

$$\frac{n_1}{Nf_1} + \frac{n_2}{Nf_2} + \ldots + \frac{n_k}{Nf_k} = 1$$

Where n_1, n_2...n_k represent the number of cycles at specific overstress levels, and N_1, N_2...N_k represent the life (in cycles) at these overstress levels, as taken from the appropriate S-N curve.

A point to be taken into consideration is that once a product is fatigued, a portion of its life is consumed, and this damage is irreversible. We need to temper this fatigue accumulation equation with the fact that *all products are unique*. This statement was proved very conclusively by showing the order in which vibration and temperature cycling is applied does affect time to failure[5]. To calculate a particular material's accumulated fatigue damage in relationship to the stress cycles at various stress levels, we find a form of the Miner's rule using idealized S-N curves Crandell and Mark[10] suggested. The relationship can be stated as:

$$AFD = n\sigma^{\beta}$$

AFD is the accumulated fatigue damage; n is the number of stress cycles; σ is the mechanical stress; and β is the exponential drive from the SN Diagram for the material this is typically between 6 and 25.

This illustrates that by increasing the amount of stress, you can reduce the number of cycles. This principle applies for a single type of material and does not work blindly on products that contain many different types of materials and the interactions that occur when various stresses are applied.

It has been proven that relevant latent (hidden) defects can be precipitated by exaggerated stress levels utilizing a smaller number of cycles. The reasons for stimulation testing are quite simple. First, it allows you to quickly gauge the overall ruggedness of a product early in the design phase by identifying operation failure limits. Next, it produces failures which can be judged as relevant or irrelevant by the design team, and the corresponding corrective measures can be implemented quickly with minimal rework. Finally, it provides invaluable information regarding how the system reacts to various stress environments and operating conditions, and this information can help close the design feedback loop.

ACCELERATED STRESS TESTING (AST) VS. ACCELERATED LIFE TESTING (ALT)

As discussed earlier there is quite a difference between *simulation* testing and *stimulation* testing. This is the difference between AST and ALT. Even if you are using accelerated models with higher levels of stress for time compression, the intent of life testing is to be able to determine not only that a failure will occur during the products expected lifetime but also when in the product's life the failure will occur. AST on the other hand, is based on the assumption that an item will exhibit the same failure mechanisms in a short time under high stress conditions that it will exhibit in a longer time under low stress conditions[2]. With AST you must examine and review all failures, determine relevance, and decide what, if any, corrective action is required.

ACCELERATED SCREEN TESTING IS NOT ENVIRONMENTAL STRESS SCREENING (ESS)

There is sometimes confusion between AST and ESS. This is because both technologies use *stimulation* as a means of precipitating latent defects. AST, however, is a test applied to a sample of the production, while ESS is a process applied to every unit that is produced. AST is typically used in the product development phase to identify design weaknesses, while ESS is used primarily to identify weaknesses in materials and processes.

The most important thing to recognize when implementing AST is that *your product* determines the test. The first consideration when implementing AST is the type of stresses to apply. This can be determined by reviewing typical field failure data on related products (if possible) to gauge expected early failure mechanisms. The concept is to apply stresses that precipitate all the latent flaws that would occur during a product's lifetime.[14] There are many sources to familiarize yourself with the various screens and the types of defects that they precipitate. See Table 2 (on pages 20 and 21) for examples. If you have no past related field data, a Step Stress or a HALT test needs to be performed to identify a product's potential weaknesses. Ideally, when considering what types of stresses to apply to the product, you should use as many relevant stressing environments as possible. By incorporating multiple stressing environments, a synergistic stress effect is produced.

The next consideration is the proper levels of stress to apply. This can be determined by applying a step stress procedure to determine the destruct and operational limits of a product. Stress level determination is very product dependent. While applying the stresses, it is important to apply TAAF (Test, Analyze And Fix) techniques to identify product weakness and implement any required corrective actions. To do this requires that the product be exercised and monitored. This cannot be overstated.

The final major consideration is stress duration. This is determined by the nature of the AST test and the time required to be properly electrically or mechanically operated and tested.

MODES OF STRESS TESTING[6]

There are several modes of using AST: design qualification, manufacturing qualification, production sampling, and ongoing AST. These are presented in order; from the most effective in increasing product reliability to the least.

Design Qualification AST: The product is tested near the end of the design stage to see if it is robust with respect to stress levels in excess of those likely to be encountered in the use environment. If deficiencies are found, the root cause is determined and corrective actions are taken to fix the underlying causes of the problem. This is the most productive mode of doing AST because the benefits are realized over the whole life of the product.

Manufacturing Qualification AST: A representative sample of product is subjected to AST during manufacturing ramp-up to identify deficiencies in component quality or manufacturing processes. In addition, design margin deficiencies that did not show up in design qualification AST may be found. The emphasis again is on Failure Mode Analysis (FMA) and corrective action, so that deficiencies in the product can be quickly eliminated before production volumes become large.

Production Sampling AST: For products requiring high reliability, it is useful to continue to perform AST on a sampling basis to monitor the production process for manufacturing or component quality variations, even after satisfactory qualification has been achieved. The emphasis continues to be on determining the root cause of any problems found and taking corrective action to fix them.

Ongoing AST: It sometimes occurs that AST is performed with the intention of doing good FMA and correcting any problems found, but because of a lack of sufficient resources, quality problems persist. In this case, it may still be economically feasible to continue doing AST on an ongoing basis, with some degree of FMA and corrective action to achieve a high reliability product. However, this mode is certainly less desirable than the approaches mentioned above.

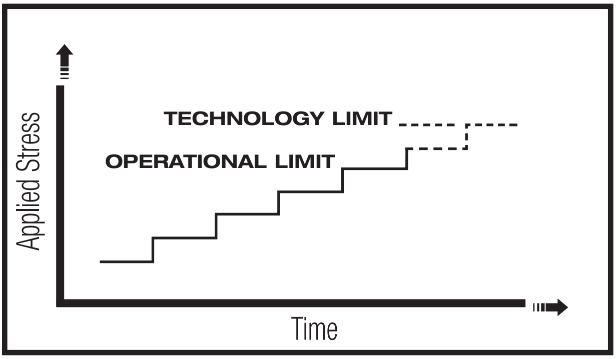
Step-stressing has been used since the early days of the space program. It is basically a process of starting at a known stress level, then increasing the "stress" levels in controlled "steps". The stress applied can be temperature, vibration, electrical, or other stresses, and the stresses can be applied separately or in various combinations (see Fig. 3).

First, the product is tested to determine the maximum operational limits of stress the product can withstand. When the product reaches the limits of operation (destruct limits), and no longer works, the failures are analyzed and categorized, and the product is repaired, and it is tested again. This process is repeated until satisfactory results are achieved. To determine when to terminate the step stress test, continue the step-stressing until the following occurs[5]:

- Stress levels well above those expected in service are reached,
- All samples fail, or
- Irrelevant failures begin to appear

By understanding the main cause of failure, we can then identify and address these potential failures. To do this we must first have an idea of what stresses the product can survive. The product is then ruggedized to the level which the company has intended.

Fig. 3



HALT TESTING

Another type of stress stimulation testing is known as HALT testing. HALT is an acronym for Highly Accelerated Life Testing. It was coined by Dr. Greg Hobbs[8]. HALT is really a package of testing techniques, such as aggressive temperature and vibration step-stressing. In the strictest definition, HALT testing also implements repetitive multiple axis vibration, also known as quasi-random, omni-axial, or six-degree-of-freedom vibration. This was developed in the 1970's by Hughes aircraft as a ruggedization tool.

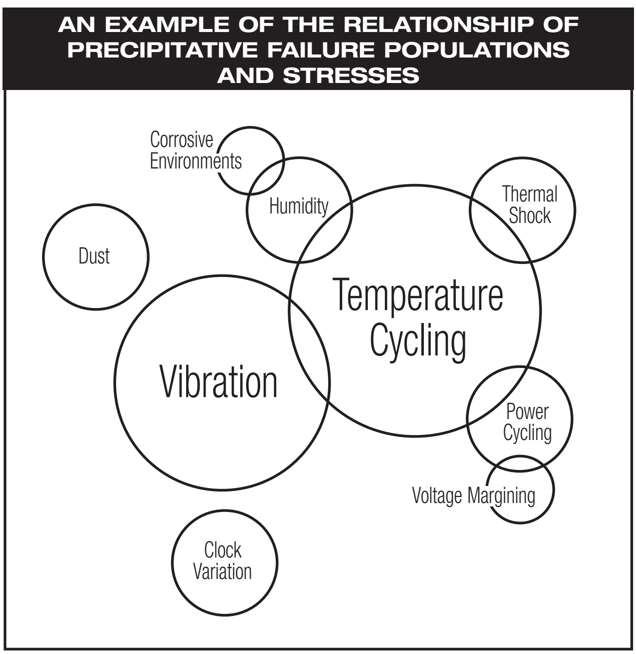
HALT testing offers a convenient step-by-step process which will by its very nature precipitate defects. It induces fatigue, which in turn causes failures that can be analyzed to determine the appropriate corrective action. However, HALT testing does not correlate the failures to the point in time in the product's life that the failure would actually occur. Although HALT testing does stress and fatigue products, the actual amount of time compression is unknown. For this reason, HALT testing should probably be categorized as highly accelerated fatigue testing instead of inferring that it actually accelerates the lifetime of a product by any *measurable* amount of time.

TYPES OF STRESSES USED IN AST

Accelerated Stress Testing consists of exposing a group of products to one or more stressing environments. These environments can include Thermal Cycling, Vibration, Electrical Stress, Thermal Shock, Humidity, and others. The actual detailed product profiles, such as the rates of change, types of stress, stress extremes, etc., must be tailored for each product. In this section we will present some of the commonly used stressing environments, what effects these have on potential failure mechanisms, and a listing of failure mechanisms precipitated by individual stresses.

It is important to remember that each type of stress precipitates certain failure mechanisms.

Fig. 4



TEMPERATURE CYCLING

Temperature Cycling consists of multiple cycles of changing temperature between predetermined extremes. Temperature Cycling can be used in AST for both simulation and stimulation testing. As all the variables in AST screening are product dependent, temperature extremes must be far enough apart to allow for optimum stressing caused by the temperature change between the extremes. It is the constant rate of change that provides the expansion and contraction necessary to sufficiently stress the product.

When we talk about temperature stressing of a product, we are talking about product change rates. Because products have different amounts of surface area, different specific heats, and different coefficients of thermal expansion, we must treat every product as unique. There are three main variables to consider when planning temperature stress tests. These are product temperature change rates, difference between temperature extremes and number of cycles. Other considerations are:

Airflow: For each product, there is an air velocity at which maximum heat transfer is obtained. Exceeding this air velocity can be counter-productive. The correct air velocity and direction for a particular product can be determined through experimentation.

Dwell periods: Once the product has reached the desired temperature, dwell periods at temperature extremes typically do not significantly contribute to stress. Many manufacturers allow the product to remain at temperature extremes only long enough to allow for a functional test of the product.

Thermal Cycling is the most commonly used, and one of the most effective precipitation stresses. Like any stress, it must be properly implemented. Failure rates must be analyzed to determine which latent defects are causing failures; and experimentation must be performed to determine the stress profile best suited to trigger those particular latent defects and their failures.

Vibration involves stimulating a product with a pre-determined force over a frequency spectrum. There are several types of machines used for vibration testing, but in AST, typically two types of vibration are used: Electrodynamic and Repetitive Shock vibration.

The typical Electrodynamic vibration system frequency range is 5-2000 Hertz. The most common type of vibration stress used is broadband random. This is created through simultaneous excitation of all the resident frequencies within a profile range. Random vibration is transferred to the product by fixturing attached to the moving element of the Electrodynamic shaker. The Electrodynamic shaker is controlled by a closed loop vibration control system which is repeatable and will accurately reproduce real world vibration. It can be used for simulation testing as well as stimulation testing. Products may be vibrated on a single axis or multiple axis concurrently or consecutively. Several categories of vibration can be run on Electrodynamic vibration systems such as sine, random, resonance search and dwell, shock, sine on random, random on random, and several others. These stress environments may or may not be applicable depending on the product application.

Repetitive Shock Vibration (RS Vibration) is generated using one or more pneumatic impact hammer(s) that strike a plate on which the product is attached. Commonly, Repetitive Shock Machines provide vibration in three distinct axes and three rotational axes simultaneously. The frequency in which most of the energy is generated is in the 2 to 5000 hertz bandwidth. Repetitive shock vibration machines cannot simulate real world vibration conditions, so their use is limited to stimulation testing only.

Fixturing for either type of vibration machine needs to be designed to ensure that the stress is transmitted to the product and that the process can be repeatable with reasonable accuracy. Currently there are varying opinions as to which provides a more stressful environment over a particular frequency range. Table 1 provides a comparison.

COMPARISON OF ELECTRODYNAMIC AND REPETITIVE SHOCK (RS) VIBRATION SYSTEM CHARACTERISTICS

TABLE 1

FACTOR	ELECTRODYNAMIC	REPETITIVE SHOCK (RS)
1. Number of Axes per Shaker	One	Six
2. Simultaneous Multiple Axis Capability	One or more shakers per axis (complex control algorithms) or diagonal (skewed) force vector input	Yes
3. Typical Range of Product Mass	Thousands of pounds	Possible: Low hundreds of lbs Practical: Less than 100 lbs
4. Energy Source	Electrical	Pneumatic
5. Typical Frequency Range	< 5 to 2000 Hz	10 to >5,000 Hz
6. Controllable Spectrum	Yes	No
7. Force Limiting Factors	Armature mass, field supply, amplifier cooling capacity	Piston mass, impact velocity, piston/fixture coupling, distance from impact point, modal characteristics of plate
8. Low Frequency Energy	Yes, controllable	Minimal
9. Can be used for Simulation Testing	Yes	No
10. Can be used for Stimulation Testing	Yes	Yes
11. Input Displacement Range	Inches applied to entire fixture and product	Microinches, applied locally to fixture impact points
12. Spectral Characteristics	Continuous control in each filter band; sine, random, shock, sine-on-random, narrowband-on-broadband vibration	Uncontrolled (open loop) spectrum with periodic "holes" and spikes, "quasi-random" vibration only
13. Spectrum Limiting Factors	Fixture resonances, number of filters, ED armature/test mass resonance (~2500 Hz)	Open-loop control, piston repetition rate, fixture resonances and nodes, GRMs control only
14. Product Characterization	Straight forward analysis	Analysis complicated by untailorable spectrum
15. Uniformity On Table	Very uniform	Not uniform
16. Mechanical Shock Pulses	Classical waveform, shock spectrum, pyrotechnic	No control capability
17. Acoustic Noise	Varies with spectrum, fixture and product design, and input force level	Very loud (could affect performance of noise-sensitive products)
18. Electromagnetic Fields	Magnetic fields can affect some products; may require degauss coil	No effects

THERMAL SHOCK

Thermal shock testing involves exposing products to severe temperature extremes in a rapid fashion. For example, the product is transferred either mechanically or manually from an extremely hot environment to an extremely cold environment. This process is repeated several times. Thermal shock is generally considered a cost-effective way to screen defects at the component level; particularly in integrated circuits which require a high degree of stress to experience the rates of change required to force latent defects into failure.

There are two types of Thermal shock test mediums: Air-to-Air and Liquid-to-Liquid. Air-to-Air Thermal shock systems expose the product to preconditioned hot and cold air. Liquid-to-Liquid Thermal shocks immerse a product in high and low temperature inert fluids. These tests can be performed on a variety of Thermal shock machines.

When using Thermal shock for AST testing, consider the following: If the product is manually transferred, the risk of accidental product damage increases. Additionally, it is difficult, or sometimes impractical, to apply product power and monitor the product's operation while the Thermal shock stress environment is being applied. This severely limits opportunities for collecting data for product failure analysis.

HUMIDITY

Humidity testing is typically performed in a chamber that can precisely control wet and dry bulb temperatures. Exposing products to humidity stress precipitates corrosion and contamination defects in products. Humidity can penetrate porous materials, cause leakage between electrical conductors, and is also an important stress when evaluating coatings and seals. Because oxygen is required for oxidation, it limits the use of nitrogen-cooled chambers, which create an inert environment that inhibits corrosion. Typically, humidity tests are of long duration, and certain types of corrosion require minimal airflow, which is not typical of most chambers.

Another type of humidity testing, known as HAST (Highly Accelerated Stress Testing), is done in a pressurized vessel. This type of system is analogous to a pressure cooker or autoclave. The HAST system aggressively forces moisture into potential failure sites.

ELECTRICAL STRESS

Electrical Stress is used to test a product near or at its electrical limits. Exercising circuitry and/or simulating junction temperatures on semi-conductors are both good examples of electrical stress tests. There are two basic types of electrical stress tests: Power Cycling and Voltage Margining.

Power Cycling consists of turning product power on and off at specified levels. Voltage Margining involves varying input power above and below nominal product power requirements. A subset of Voltage Margining is frequency margining.

Typically, electrical stress by itself does not expose the number of defects commonly found through thermal cycling and vibration stress. However, because it is typically necessary to supply power to products in order to find the soft or intermittent failures, it can be relatively inexpensive to implement electrical stress with the other stress environments to increase the overall Accelerated Stress Test effectiveness.

COMBINED ENVIRONMENTS

Depending on product complexity, cost, and other reliability specifications, multiple environmental screens may be used simultaneously. For example, Thermal Cycling and Vibration are often combined in an Accelerated Stress Test program. Many other combinations of stresses can be combined to precipitate latent defects. Keep in mind that each specific stress precipitates specific failure mechanisms, and when used in conjunction with each other, some synergistic effects may be realized.

The primary consideration should be whether the additional stress, applied simultaneously or consecutively, would expose a significant number of additional defects. With all Accelerated Stress Testing programs, the most effective profile is product and application dependent. In general, the proper combination of stresses will produce the greatest number of failures in the shortest amount of time.

ENVIRONMENTAL STRESSES, EFFECTS AND POTENTIAL RELIABILITY IMPROVEMENT TECHNIQUES

TABLE 2

ENVIRONMENTAL STRESS	EFFECTS	POTENTIAL RELIABILITY IMPROVEMENT TECHNIQUES
High Temperature	Parameters such as resistance, inductance, capacitance, power, dielectric constant will vary; insulation may soften; moving parts may jam due to expansion and finish may blister; thermal aging, oxidation and other chemical reactions may be enhanced; viscosity may be reduced and evaporation of lubricants can arise and structural overloads may occur due to physical expansions.	Thermal Insulation, heat withstanding materials, cooling systems.
Low Temperature	Plastics and rubbers lose flexibility and become brittle; electrical constants vary; ice formation occurs when moisture is present; lubricants and gels increase viscosity; finishes may crack; structures may be overloaded due to physical contraction.	Thermal Insulation, cold withstanding materials, cooling systems.
Thermal Cycling and Shock	Materials may be instantaneously over stressed causing cracks and mechanical failures; electrical properties may be permanently altered. Crazing delamination, ruptured seals can arise.	Combination of techniques for high and low temperature
Shock	Mechanical structures may be over stressed causing weakening or collapse; items may be ripped from their mounts; mechanical functions may be impaired.	Strengthened structural members, reduced inertia and moment, shock absorbing mounts.
Vibration	Mechanical strength may deteriorate due to fatigue or over stress; electrical signals may be erroneously modulated; materials and structure may be cracked, displaced, or shaken loose from mounts; mechanical functions may be impaired.	Stiffening control of resonance.

CALCE Electronic Packaging Research Center, University of Maryland, May 15, 1995

ENVIRONMENTAL STRESSES, EFFECTS AND POTENTIAL RELIABILITY IMPROVEMENT TECHNIQUES

TABLE 2 (CONTINUED)

ENVIRONMENTAL STRESS	EFFECTS	POTENTIAL RELIABILITY IMPROVEMENT TECHNIQUES
Humidity	*Penetrates porous substances and causes leakage paths between electrical conductors; causes oxidation which may lead to corrosion; moisture causes swelling in materials such as gaskets; excessive loss of humidity can cause embrittlement*	*Moisture Resistant materials, dehumidifiers, protective coatings, hermetic sealing*
Contaminated Atmosphere Spray	*Many contaminants combined with water provide good conductor which can lower insulation resistance; cause galvanic corrosion of metals and accelerates chemical corrosion.*	*Non-metal product covers, reduce use of dissimilar metals in contact, of dissimilar metals in contact, heretic sealing, dehumidifiers*
Electromagnetic Radiation	*Causes spurious and erroneous signals from electrical and electronic equipment and components; may cause complete disruption of normal electrical and electronic equipment such as communication and measuring systems.*	*Shielding, radiation hardening*
Nuclear/Cosmic Radiation	*Causes heating and thermal aging; can alter chemical, physical and electrical properties of materials; can produce gases and secondary radiation; can cause oxidation and discoloration of surfaces; damages electrical and electronic components, especially semi-conductors.*	*Shielding, radiation hardening*
Sand and Dust	*Finely finished surfaces are scratched and abraded; friction between surfaces may be increased; lubricants can be contaminated; clogging of orifices; materials may be worn, cracked, or chipped; abrasion, contaminates insulation, corona paths.*	*Air-filtering, wear-proof materials, sealing*
Low Pressure (High Altitude)	*Structures such as containers and tanks, are over stressed and can be exploded or fractured; seals may leak; air bubbles in materials may increase due to lack of cooling medium; insulation may suffer arcing breakdown; ozone may be formed; outgassing is more likely.*	*Increased mechanical strength of containers, pressurization, alternate liquids (low volatility), improved insulation, improved heat transfer methods.*

CALCE Electronic Packaging Research Center, University of Maryland, May 15, 1995

There are two distinct areas in AST that need to be understood: precipitating defects (which we have just discussed), and detecting failures. *These topics are equally important*. Most people involved in testing have a good idea of how to induce failures. Failure detection, on the other hand, usually causes confusion. The most important thing to remember about AST is that *if you precipitate failures without detecting them you have accomplished nothing*.

Due to the cost and complexity involved, many companies do not implement operational Failure Detection Systems (FDS) while testing their products. This can be extremely dangerous and/or counter productive. Remember, whenever you apply any stress you start using up the products fatigue life. A number of published cases have shown that a high percentage of the total failures are soft failures. A soft failure means that a failure occurs at some condition(s) and then normal operation resumes as the condition(s) change. These are the most difficult failures to catch, and they will not be identified unless the product is continuously monitored. Failure detection must also be correlated to the stress levels applied. This also requires continuous monitoring of the product under test.

After a failure is identified, Failure Mode Analysis (FMA) is then performed. This requires knowledge of what failed, why it failed, when it failed, where it failed, and how it failed. After a complete FMA is done, you can apply what you have learned to implement the corrective action.

The corresponding corrective action is the key to closing the loop for a properly designed AST program. *This is where the product improvement is obtained*. Product improvement is gained by first precipitating the hidden flaw(s), identifying the flaw(s), and correcting the flaw(s). None of the three can stand without the others.

TOOLS FOR CONTINUOUS MONITORING

Continuous monitoring requires several considerations regarding the equipment required to do the actual test. To get signals to and from products under test can require fixturing, interconnects, power supplies, product loads, and product stimulus and monitoring instrumentation. Because typically there are a number of interconnects to the product, care must be taken to insure that the interconnect does not fail, producing false failures. To insure reliable interconnect and fixturing the following items should be evaluated:

- Material
- Structural Integrity
- Product/Operator Interface
- Replaceability
- Reliability
- Serviceability
- Adjustability

Remember, everything that is in the stressing environments is subjected to the same stresses as the product under test.

A quality power supply is also essential, especially when considering electrical stress tests. A poor power supply could fluctuate incorrectly and damage your test product. A good power supply should be accurate, programmable, flexible, and reliable. Most commercially available power supplies today have the features that are required for basic AST testing. There are also some supplies today that allow specialized testing such as programmable voltage fluctuations, frequency variations, harmonics, flicker and several other unique functions.

Another very important feature is the operator interface. The proper operator interface makes very complex instrumentation easy to use, as well as easy to implement. Other concerns are the ease of adding additional functions, simplified programming, and interface with the other AST equipment.

The final component required for implementing AST product monitoring is the stimulus and monitoring equipment. *Flexibility* is the key issue when looking for instrumentation for AST. This is because AST tests are typically done during the design phase over a variety of products and functions.

RELIABILITY GROWTH MONITORING

One of the most overlooked areas of product testing is the area of reliability monitoring. Reliability monitoring means keeping a record of successes and failures and creating a database of lessons learned.[17] Reliability monitoring allows you to build on past experiences, which improves overall reliability and helps companies avoid costly mistakes time and time again. This database becomes a reference tool for design engineers to expedite proper design and provides an excellent knowledge-sharing tool.

SUMMARY

This booklet is just a quick overview of the area of AST. We have covered what AST is, how it compares to life testing, types of AST, stress environments, and the types of defects that are precipitated. We have also looked at the importance of continuously monitoring the product under test. These are just a few topics a person looking to implement AST should understand. There are several articles listed in the additional reference area that the reader should find helpful.

Accelerated Life Testing – A process, through which a small percentage of products are subjected to stresses at a higher level than they would experience during their use environments during their product lives. This compresses test time. By simulating the product's life, using either actual or accelerated stress, we can determine actually where a particular failure would occur and at exactly what time in a product's life.

Accelerated Stress Testing – Applying high levels of stress to a product for short periods of time assuming it will exhibit the same failure mechanisms as it would in a longer amount of time at lower stress levels. Accelerated stress testing employs various stresses to precipitate failures which in turn need to be analyzed and the proper corrective action implemented. AST is stimulation testing.

AFDF (Accumulated Fatigue damage Factor) – The AFDF uses Minor's Rule to sum fatigue damage. The well known Minor's Rule states that an S-N Curve can be used to compute total fatigue damage. It should be noted that S-N Data is taken using Sign Loading. When applying AFDF to a product, it must be remembered that each product is unique and complex, and that the product consists of more than one type of material. It must also be remembered that each particular stressing machine, the way that the product is placed on the machine, fixture transmissibility, table response, and actual rates of each individual material, all affect any possible AFDF estimate. Therefore, AFDF's estimates are far from accurate.

Aging, Life-Aging or Product Maturing – Simultaneously operating and/or stressing a product in order to advance its maturity through infancy and to uncover latent defects.

Board Level – A level at which circuit boards are tested or screened prior to sub or final assembly. Components are in place and the product can be operated with proper interconnects. The only added complexity is usually in packaging.

Burn-in or Steady-State Burn-in – The process of continuously powering a product; usually at a constant temperature, in order to accelerate the aging process. In burn-in, it is very common to elevate the temperature well beyond normal operation temperatures, to accelerate the process of defect precipitation.

Chamber – A cabinet in which products are placed to subject them to stress or stresses. This usually consists of an insulated unit equipped with air circulation and conditioning equipment.

Component Level – A level at which components are screened or tested before being placed on circuit boards. Components may be screened or tested by the manufacturer or by the user upon receipt.

CA (Corrective Action) – The action taken, after understanding the root cause of a failure, to eliminate the source of the defect in future design and production revisions.

DDT (Device Defect Tracking) – A data base which tracks a product's defects from their discoveries; examines root causes, documents corrective actions, and details methodologies to prevent reoccurrence in the future. Companies can apply this knowledge to products that are being currently developed, so that the same mistakes do not reoccur.

Defect Precipitation – Changing a latent defect to a patent defect; or simply making an undetected failure, detectable.

Design Limits – The operational limit of a product beyond which point the product will not operate correctly and is considered defective.

Design Ruggedization – The process of finding weak links in the design and fixing them so that the design becomes more robust. Stresses used in Design Ruggedization are much greater than field environments.

Destruct Limits (Refer to Design Limits)

DT (Destructive Test) – A test or physical analysis which destroys the product after analysis completion.

DUT – Device Under Test

EMI – Electro-magnetic Interference

Environmental Testing – A process in which a sample of products is subjected to environmental simulation or stimulation. Testing is used in variety of ways. A prototype can be tested using extreme stresses to confirm the range in which it was designed to operate. A randomly selected product can be tested at an extreme temperature range to confirm continuing design and production process compliance. A product can be tested to determine MTBF (Mean Time Between Failures). Testing can be used to simulate the environments in which the products will encounter in transportation and operation. In AST, environmental testing typically applies to the accelerated stresses applied to the product to accelerate potential failure mechanisms.

ESS (Environmental Stress Screening) – Unlike Accelerated Stress Testing, ESS is a process in which 100% of the products are subjected to one or more stresses with the intent of forcing latent defects to precipitate failures. ESS may involve any or all of the following:

- Thermal Cycling
- Vibration
- High Temperature Burn-In
- Electrical Stress
- Thermal Shock
- Humidity
- Low Temperature
- Altitude

Failures – The most common types of failure are:

Critical Failure – A case where the product is unable to operate under the conditions it is expected to.

Non-Critical Failure – A failure that occurs only outside of the normal operating range of the product.

Hard Failure – A case where the product stops and does not resume functioning. These are always designated as Critical Failures.

Soft Failure – A case where the product stops functioning under certain conditions, but then resumes operating under others. For example, when a product is powered, various stresses are applied, a particular stress or a combination of stresses may be the cause of the product to stop operating. When the stress is removed, the product may start functioning again. This type of failure may either be Critical (if the product fails under the condition in which it must operate in the field) or Non-Critical (if the product fails under conditions which the product will never be exposed to in the field).

Infancy Failure – Failures that occur in the early stages of the product life. Generally, most product failures occur at this stage.

Electrical Failures – An electrical malfunction caused by electrical components, connections, switches, or related devices.

Mechanical Failures – A mechanical malfunction caused by cracking, displacement, misalignment, loosening of nuts and bolts, etc.

Process Failures – Failures caused by the manufacturing process. These failures result mainly from mis-loaded components; damage caused by improper handling; or inadequate assembly procedures.

Failure Mode Analysis – A procedure which is used to identify the cause of the defect and understand the defect so that it is not repeated.

Failure Mechanism – The mechanical, physical, chemical or other process that results in failure.

Failure Mode – The manifestation of a failure mechanism at a failure site. The effect by which a failure is observed.

Failure Site – The location of a failure.

Fatigue Life – The amount of time under defined operation conditions that a product is expected to survive.

Fixturing – A device or series of devices used to secure a product within a chamber or on a vibration system, in preparation to running screens or tests.

Frequency Margining – The use of varying frequencies on product input to determine acceptable operational limits of the product.

GRMS – This is acceleration due to gravity in the root mean squared, or the average intensity of the signal.

HALT – Highly Accelerated Life Test

HASS – Highly Accelerated Stress Screens

Latent Defect – A flaw in the part and/or workmanship that is not immediately apparent, but that can result in failures. A defect that is dormant and is not visible, or is undetectable.

Life Cycle Testing – A process through which a small percentage of products are subjected to stresses similar to those that they will experience during their product lives. This process is usually used to determine a product's anticipated life expectancy and its MTBF.

LN2 (Liquid Nitrogen) – Used as a cooling media in some Thermal Cycling Systems.

MTBF – Mean Time Between Failures

Product Monitoring – While applying stress to the product, the product is operated and is monitored to insure it is performing its' intended design functions. This is required to identify many of the failures found during Accelerated Stress Testing. In most cases, it is the only way to catch soft failures.

Power Cycling of Operational Cycling – The process of continuously turning the product on and off at predetermined intervals. Product Cycling adds internal heat and ages the product faster than continuous power on and off.

Operational Limit – The upper and lower limits where the product will not operate with its' intended design functionality.

Parametric Drift – The shift in a known parameter versus time when stress is applied.

Patent Defect – An open or evident defect. Defect precipitation. Changing a latent defect to a patent defect; or simply making an undetected failure detectable.

Product Specification – The specifications of the product manufacturer as communicated to its' customers.

Proof of Screen – This is a process that is used when determining production (ESS) screens for products. It is used to show that the screen is effective in finding defects present in the product, but yet does not damage good hardware.

Random Vibration – A form of stress in which broad band, multiple frequencies are present simultaneously at predetermined power levels. The product is attached to a shaker and vibrated in one or more axis during the stress cycle.

RGDT (Reliability Growth Development Testing) – A test in which normal operating stresses are applied to products. When defects are detected, corrective action is taken.

Root Cause – Understanding what has caused a particular failure. It is important to determine the root cause when a latent defect is precipitated.

RS (Repetitive Shock) Vibration – Vibration which is typically generated using pneumatic hammers striking a plate upon which the product is attached. Commonly, Repetitive Shock Machines provide vibration in three (3) distinct axes and three (3) rotational axis simultaneously.

Screening – The process of stressing products so that defective units may be identified and repaired or replaced.

Step Stressing – Incrementally increasing stress levels in known increments.

Stress – Intensity at the failure site of applied load.

SRS (Shock Response Spectrum) – SRS is a time-domain function sensitive to peaks of excitation. SRS can be a valuable analysis tool when looking at the excitation from RS Vibration Machines (Repetitive Shock).

TAAF (Test/Analyze and Fix) – A test where normal operating environments are stimulated. The problems are identified, analyzed, and corrected.

Thermal Cycling – A process through which a product is subjected to predetermined temperature change rates between established temperature extremes. In Accelerated Life Testing Thermal-Cycling, the ability to develop fast rates of change will determine how many cycles are required to force the greatest number of latent defects into failures.

Voltage Margining – Stress applied to the product by varying voltage, which determines the voltage at which normal operation can be expected.

REFERENCES

[1] O'Conner, P.D. (1993). Quality and Reliability: Illusions and Realities. Quality and Reliability Engineering International, 9:163-168.

[2] Dasgupta, A. (April 1996). Cost-Effective Integrated Product Development. CALCE Accelerated Test Workshop.

[3] Caruso, H. (1996). An Overview of Environmental Reliability Testing. Proceedings, Reliability and Maintainability Symposium, 107.

[4] Juvinall, R.C., & Marshek, K.M. (1991). Fundamentals of Machine Component Design, (2nd ed.). John Wiley & Sons, 288-289.

[5] Dasgupta, A. (April 1996). Physics-of-Failure (PoF) Principles For Accelerated Stress Tests. CALCE Accelerated Test Workshop.

[6] Chan, H.A. (October 1997). Overview of Accelerated Stress Testing Principle. 3rd IEEE Workshop on Accelerated Stress Testing.

[7] Diekema, J. (1987). The ESS Handbook. Thermotron Industries.

[8] Hobbs, G. (May 23-24, 1996). Advanced HALT/HASS Seminar.

[9] Tustin, W. (October 1997). Electrodynamic versus Pneumatic Shakers for Stress Testing. 3rd IEEE Workshop on Accelerated Stress Testing.

[10] Crandell, S.H., & Mark, W.D. (1963). Random Vibration in Mechanical Systems. NY: Academic Press.

[11] Head, R. (February 15, 1997). Test Methodology Interview. Chrysler-Huntsville Electronics.

[12] Darby, B. (February 15, 1997). Test Methodology Interview. Chrysler-Huntsville Electronics.

[13] Kececioglu, D. (1993). Reliability and Life Testing Handbook, (Vol I & II). Englewood Cliffs, NJ: PTR Prentice-Hall, Inc.

[14] Upton, J. (May 3, 1997). AST Implementation. MA/COM.

[15] Barsom, J.M., & Rolfe, S.T. (1987). Fracture and Fatigue Control in Structures, (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

[16] Caruso, H. (1997). Huntsville, AL: TTI Course.

[17] Crowe, D., & Feinberr, A. (1998). Stage-Gating Accelerated Reliability Growth in an Industrial Environment. IEST Proceedings, 246-254.

RECOMMENDED INFORMATION SOURCES

– Anon. (1997). SAE Fatigue Design Handbook. Soc. Auto Eng. Doc. AE-22 (3rd ed.).

– Barsom, J.M., & Rolfe S.T. (1987). Fracture and Fatigue Control in Structures, (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

– IEEE/CMPT TC7 Annual AST Workshops
Contact IEEE at (800) 677-IEEE.
www.cmpt.org/tc/tc7.html

– Institute of Environmental Sciences
940 E. Northwest Highway, Mt. Prospect, IL 60056;
or fax to (847) 255-1699.

– Kececioglu, D. (1993). Reliability and Life Testing Handbook, (Vol I & II). Englewood Cliffs, NJ: PTR Prentice-Hall, Inc.

– Reliability And Maintainability Symposium
www.rams.org

– Wirsching, P.H., Paez, T.L., & Oritz, K. (1995). Random Vibrations. NY: John Wiley & Sons.

THERMOTRON

A Venturedyne, Ltd. Company

Thermotron Industries
291 Kollen Park Drive
Holland, Michigan, USA 49423
Mktg: (616) 393-4580
Main: (616) 392-1491
Fax: (616) 392-5643
Email: info@thermotron.com

Thermotron Industries, U.K.
Newton House
Winch Road
Kent Science Park
Sittingbourne, Kent
ME 9 8EF England
Phone: 01795 436333
Fax: 01795 436777
Email: sales@thermotron.co.uk

Visit us on the Internet
http://www.thermotron.com