SUMMARY OF HALT AND HASS RESULTS AT AN ACCELERATED RELIABILITY TEST CENTER

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BIOGRAPHY

Mike is an experienced leader in reliability improvement through analysis and testing. He has also led numerous quality system development programs. He has 20 years of reliability and quality experience, the majority in start-up companies. Mike is also an expert in accelerated reliability techniques, including HALT and HASS. He set up and ran an accelerated reliability test lab for 5 years, testing over 300 products for 100 companies in 40 different industries. Mike is founder and managing partner at Ops A La Carte, a Professional Business Operations Company that offers a broad array of expert services in support of new product development and production initiatives. Through Ops A La Carte, Mike has had extensive experience as a consultant to high-tech companies, and has consulted for over 100 companies including Cisco, Ciena, Siemens, Intuitive Surgical, Abbott Labs, and Applied Materials. He has consulted in a variety of different industries including telecommunications, networking, medical, semiconductor, semiconductor equipment, consumer electronics, and defense electronics. Mike has authored and published 7 papers on reliability techniques and has presented these around the world including China, Germany, and Canada. He has also developed and currently teaches 8 courses on reliability techniques. Mike has a BS degree in Electrical and Computer Engineering from the University of Colorado at Boulder, and is both a Certified Reliability Engineer and a course instructor through the American Society for Quality (ASQ), IEEE, Effective Training Associates, and Hobbs Engineering. Mike is a member of ASQ, IEEE, SME, ASME, PATCA, and IEEE Consulting Society.

ABSTRACT

Accelerated reliability testing is one of the fastest growing segments of the testing industry because it enables the user to determine the reliability of a product quicker, therefore being able to affect the design quicker. HALT and HASS are special types of accelerated reliability techniques that are very effective and are being used by companies around the world from many different industries. HALT is used at the design stage of a project to quickly expose the weakpoints of a design so that the product can be re-designed to remove these weakpoints, thereby expanding the margins of the design. All of this can be achieved at a minimal cost increase, if any at all. HASS is used at the manufacturing stage of a project to quickly expose any manufacturing flaws that a particular sample may have. The two principle stresses used during HALT and HASS are rapid temperature transitions and six degree-of-freedom repeated shock vibration.

This paper analyzes HALT and HASS data from 33 different companies from a variety of industries and illustrates the following concepts:

1) HALT can be applied to a wide variety of electrical and electro-mechanical products.
2) Products today are much more robust than in the past and, therefore, these methods are necessary to improve product reliability.
3) Random vibration is much more effective than temperature cycling for accelerating defects, and the combined environment of random vibration and temperature cycling is even more effective still.
4) The types of failures that HALT and HASS discover are the same types of failures that are found in the field.

KEY WORDS

HALT	Acronym for Highly Accelerated Life Test, was developed by Dr. Gregg K. Hobbs of Hobbs Engineering Corporation.[1] In HALT, stresses such as six degree-of freedom repeated shock vibration, rapid temperature transitions, voltage margining, frequency margining, and any other stresses that are appropriate are used to find the weak links in the design and fabrication processes of a product. HALT is performed during the design phase.
POS	Acronym for Proof-of-Screen. The process of showing that a screen does not damage good hardware and that the screen is effective in finding all of the defects present in a product.

HASS	Acronym for Highly Accelerated Stress Screen, was developed by Dr. Gregg K. Hobbs of Hobbs Engineering Corporation.[1] In HASS, the highest possible stresses are used in order to reduce the time of the screen. The screen must be proven using the Proof-of-Screen Process prior to using it in manufacturing.
LOL	Acronym for the Lower Operating Limit. The point at which the product stops operating or a specification is no longer being met, but returns to normal after the temperature is increased.
LDL	Acronym for the Lower Destruct Limit. The point at which the product does not return after the temperature is increased.
UOL	Acronym for the Upper Operating Limit. The point at which the product stops operating or a specification is no longer being met, but returns to normal after the temperature is decreased.
UDL	Acronym for the Upper Destruct Limit. The point at which the product does not return after the temperature is decreased.
VOL	Acronym for the Vibration Operating Limit. The point at which the product stops operating or a specification is no longer being met, but returns to normal after the vibration level is decreased.
VDL	Acronym for the Vibration Destruct Limit. The point after which the product does not return after the vibration level is decreased below the operating limit.
FLT	Acronym for the Fundamental Limit of Technology. An operational or destruct limit in which corrective action cannot be performed because the design or manufacturing process for the particular part of family of parts is at the technological limit at the present time. Only after a technological breakthrough can the limit be expanded further. If the limit is not satisfactory, a change in technology may be in order.

INTRODUCTION

The examples in this study were obtained between May 22, 1995 and March 31, 1996. The study is comprised of data on 47 products from 33 companies across 19 different industries. The majority of products were electrical, but several of the products had mechanical components as well. No specific data about any one product is presented so that confidentiality is maintained between the lab and its customers. The industries participating are shown in Table 1.

TABLE 1 - DISTRIBUTION OF COMPANIES BY INDUSTRY

	Industry Types	Number of Companies	Product Type
1	Networking Equipment	6	Electrical
2	Defense Electronics	4	Electrical
3	Microwave Equipment	4	Electrical
4	Fiberoptics	2	Electrical
5	Remote Measuring Equipment	2	Electrical
6	Supercomputers	2	Electrical
7	Teleconferencing Equipment	1	Electro-mechanical
8	Video Processing Equipment	1	Electrical
9	Commercial Aviation Electronics	1	Electrical
10	Hand-held Computers	1	Electrical
11	Hand-held Measuring Equipment	1	Electrical
12	Monitors	1	Electrical
13	Medical Devices	1	Electro-mechanical
14	Personal Computers	1	Electrical
15	Printers and Plotters	1	Electro-mechanical
16	Portable Telephones	1	Electrical
17	Speakers	1	Electro-mechanical
18	Telephone Switching Equipment	1	Electrical
19	Semiconductor Manufacturing Equipment	1	Electro-mechanical
	TOTAL	33	

Environmental testing in the past was a simulation of what the product was expected to experience in the field. Therefore, most commercial manufacturers used burn-in at the upper product specification as the sole accelerated reliability technique. Today, stimulation has proven to be much more effective than simulation in finding defects quickly. With the stimulation approach, products are stress tested well beyond their specifications in order to uncover weaknesses and ultimately improve their reliability. The majority of companies included in this data have products that are intended for the office environment. The product's end-use environments are shown in Table 2.

TABLE 2 - DISTRIBUTION OF PRODUCTS BY ENVIRONMENT TYPE

Environment Type	Number of Products	Thermal Environment (1)	Vibration Environment (1)
Office	18	0 to 40°C	Little or no vibration
Office with User	9	0 to 40°C	Vibration only from user of equipment
Vehicle	8	-40 to +75°C	1-2 Grms vibration, 0-200 Hz frequency
Field	7	-40 to +60°C	Little or no vibration
Field with User	4	-40 to +60°C	Vibration only from user of equipment
Airplane	1	-40 to +75°C	1-2 Grms vibration, 0-500 Hz frequency
TOTAL	47		

Note 1 All values are approximates based on a combination of data from individual customers and from Bellcore and military specifications.

HALT PROCESS

The HALT process applied at the test center consisted of temperature step stress, rapid temperature transitions, six degree-of-freedom repeated shock vibration and combined environment of temperature and vibration. For each of these stimuli, the operating and destruct limits were determined (if possible).

The HALT process alone will not improve the reliability of the product. The root cause of the failures noted need to be determined and the problems corrected until the fundamental limit of the technology for the product can be reached. This process will yield the widest possible margins between product capabilities and the environment in which it will operate, thus increasing the product's reliability, reducing the number of field returns and realizing long-term savings.

During the temperature and vibration stressing, other product specific stresses were added, such as power cycling, voltage margining, frequency margining, and varying input line voltages in order to further accelerate the testing to uncover defects.

For the modular products tested, it was not unusual for one or more subsystems to have a very low tolerance for stress due to their inherent characteristics. In this case, testing began by using the complete product until those weak subsystems were identified and characterized. They were then removed from the chamber through the use of extended connections to allow testing to continue at higher levels on the remainder of the system. This prevented the weakest link from blocking access to weak links in other areas. The key to remember is that in HALT, the goal is stimulation not simulation.

The common stimuli used for all products evaluated in the test center were temperature step stress, rapid temperature transitions, vibration step stress, and combined environment. Below is a brief description of the process used for each stimuli applied.

1. Temperature Step Stress

During this phase of the testing, ducting was designed to allow for maximum airflow across the product. Thermocouples were attached to the product to measure the actual product temperature versus chamber setpoint. This information was then used to adjust the thermal ducting in order to maximize the thermal energy from the chamber into the product while maintaining thermal uniformity across the product.

Cold Step Stress: With each product, cold thermal step stress was performed because it is usually the least destructive of all stimuli applied. The cold step stressing began at 20°C and then the temperature was decreased in 10°C steps until the lower operating and destruct limits were determined (whenever possible). When possible, modifications were made to the product as failures were encountered to increase these limits and ruggedize the product. If modifications could not be made because the failure wasn't easily correctable, thermal barrier material was used so that the sensitive areas were kept at a lower stress level than the rest of the product while the temperature was decreased. The dwell time at each step was approximately 10 minutes to allow time for component temperatures to stabilize plus the time needed to check the functionality of the product under test.

Hot Step Stress: The hot step stressing began at 20°C and then the temperature was increased in 10°C steps until the upper operating and destruct limits were determined (whenever possible). When possible, modifications were made to the product as failures were encountered to increase these limits and ruggedize the product. If modifications could not be made because the failure wasn't easily correctable, thermal barrier material was used so that the sensitive areas were kept at a lower stress level than the rest of the product while the temperature was increased. The dwell time at each step was approximately 10 minutes to allow time for component temperatures to stabilize plus the time needed to check the functionality of the product under test.

2. Rapid Temperature Transitions

During this phase, continuous hot and cold ramps were applied to the product as fast as the chamber and the product would allow. The temperature extremes chosen, were based on the operating limits determined during the thermal step stress.

3. Vibration Step Stress

During this stimulus, the product under test was secured to the vibration table (typically aluminum channel over the product held down to the table with threaded rods). Accelerometers were placed on the product to measure the vibration response of the product. This information was then used to tune the fixture in order to maximize the vibration energy from the chamber into the product while maintaining vibration uniformity across the product. The step stress process began at 3-5 Grms and increased in 3-5 Grms increments until the operating and destruct limits were determined (whenever possible). When possible, modifications were made to the sample as failures were encountered to expand these limits and ruggedize the product. If modifications could not be made because the failure wasn't easily correctable, epoxy or RTV was used between the body of the component and the board/product surface or between two adjacent components to help remove stress from the leads of the component so that the rest of the product could be taken to a higher level of vibration. The dwell time at each step was approximately 10 minutes. The product was functionally tested during each dwell. When the product response reached levels of 30 Grms and above, the functionality of the product was checked at the current stress level and at a lower stress level in the event that the higher vibration level precipitated a failure which was only detectable at the lower vibration level.

4. Combined Environment

After the individual stimuli were applied, the product was subjected to a combined environment of vibration and thermal stress with fast temperature transition rates. A thermal profile was developed with upper and lower temperature extremes close to the operational limits determined during temperature step stress. The profile for most of the products tested were approximately 30 minutes in length (dependent on maximum operational thermal transition rates and on the length of the functional tests). At each temperature extreme, 10 minute dwells were applied to allow time for temperature stabilization and to run the test routines using the same test conditions described for thermal step stress. Vibration was applied to the product throughout the profile starting at 3-5 Grms, and was increased in 5-10 Grms increments after each run of the profile. Stepping the vibration during thermal stress was found to be important because the vibration response of many products changed as the temperature changed. Operational and destruct limits (if possible) were determined for this combined environment stimulus.

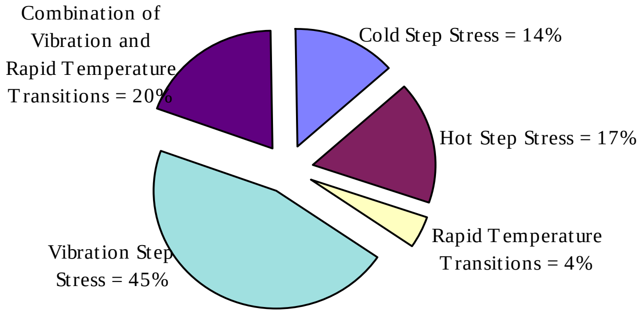
HALT RESULTS

The results for all of the products tested have been combined and summarized. Individual product results are not presented so that the confidentiality of each customer is preserved.

The average time to complete a HALT was 4 days. The majority of customers completed the HALT in one visit, correcting the problems at their facility after the end of the HALT. Some, however, decided to divide the HALT into 2 or more visits, verifying corrective actions before implementing them on production versions of the product.

The failure percentage by stress type is shown in Figure 1. To review, the order of the testing was 1) cold step stress, 2) hot step stress, 3) rapid temperature transitions, 4) vibration step stress, 5) combined environment consisting of vibration step stress combined with rapid temperature transitions. Since all of the products were subjected to the stressing in this order, it becomes apparent when reviewing Figure 1 why the failure distribution occurred as it did. For instance, since cold and hot step stress were always performed prior to rapid temperature transitions, the majority of the failures occurred during the step stress and were corrected prior to the transitions. Likewise, vibration step stress was always performed prior to combined environment, precipitating and detecting the majority of the failures. But note that it is important to perform combined environment because had it been skipped, 20% of the failures would have remained in the product.

FIGURE 1 - FAILURE PERCENTAGE BY STRESS TYPE



Tables 3a, 3b, and 3c summarize the HALT limits and present them in three different ways. For Table 3a, all of the products were grouped together, and the HALT Limits shown are for the entire set of products. For each limit, the average, most robust, least robust, and median values are given. For Table 3b, the products were grouped by environment using the same environment categories as in Table 2. For Table 3c, the products were grouped by product application using the three product applications of Military, Commercial, and Field.

All products were tested in a state-of-the-art HALT Chamber using six degree-of-freedom repeated shock vibration and LN2 thermal systems. The input vibration consists of broadband energy from 0 to 10 kHz. This was a key factor in the types of failure modes uncovered because the products had a wide range of component sizes and technologies, and each required different frequency bands for excitation, i.e., large mass parts require low frequency (10 Hz to 1 kHz) to excite them while small mass parts require high frequency (> 2 kHz). The thermal data was recorded in °C and is a measure of the average product temperature at the point of failure for each product tested. The vibration data was measured in Grms on the product in a bandwidth from 0 Hz to 3 kHz (even though the system was providing energy up to 10 kHz). The measurement was taken up to 3 kHz because this is traditionally the bandwidth that has been used and is a measure of the maximum product response level at the point of failure for each product tested. For each individual reading in each of the averages, the data point used was the worst case data point if more than one product was tested and was the limit of the product before any corrective actions were implemented.

TABLE 3A - HALT LIMITS BY LIMIT ATTRIBUTE

Attribute	Thermal Data,°C				Vibration Data, Grms	
	LOL	LDL	UOL	UDL	VOL	VDL
Average	-55	-73	+93	+107	61	65
Most Robust	-100	-100	+200	+200	215	215
Least Robust	15	-20	+40	+40	5	20
Median	-55	-80	+90	+110	50	52

The results shown in Table 3A are significant because they indicate that even though the majority of the products were commercial products using commercial grade components for the office environments, the limits achieved were far beyond the limits specified by the component manufacturers. In fact, the majority of the components used in commercial products are rated to operate from 0°C to +70°C with little or no vibration being specified.

TABLE 3B - HALT LIMITS BY ENVIRONMENT

Environment	Thermal Data,°C				Vibration Data, Grms	
	LOL	LDL	UOL	UDL	VOL	VDL
Office	-62	-80	92	118	46	52
Office with User	-21	-50	67	76	32	36
Vehicle	-69	-78	116	123	121	124
Field	-66	-81	106	124	66	69
Field with User	-49	-68	81	106	62	62
Airplane	-60	-90	110	110	18	29

The results shown in Table 3B follow closely with the expected order of limits (although the absolute levels are probably beyond expectations) with the limit for the environments Airplane and Vehicle better than those for the environments Field and User.

TABLE 3C - HALT LIMITS BY PRODUCT APPLICATION

Product Application	Thermal Data,°C				Vibration Data, Grms	
	LOL	LDL	UOL	UDL	VOL	VDL
Military	-69	-78	116	123	121	124
Field	-57	-74	94	115	64	66
Commercial	-48	-73	90	95	32	39

The results shown in Table 3C again follow closely with the expected order of limits with the military products being the most robust.

FAILURE SUMMARIES BY STRESS TYPE

Tables 4 through 8 are failure summaries for each type of stress applied. Note that the failure mode "troubleshooting" dominates many of the stress categories. Troubleshooting indicates that the determination of the root cause of the failure was still being sought at the conclusion of the test.

TABLE 4 - COLD STEP STRESS FAILURES

Failure Mode	Qty
Troubleshooting in progress	18
Failed component, cause unknown	9
Circuit design issue	3
Two samples had much different limits, cause unknown	3
Intermittent component	1

TABLE 5 - HOT STEP STRESS FAILURES

Failure Mode	Qty
Troubleshooting in progress	21
Failed component, cause unknown	11
Circuit design issue	4
Degraded component	2
Warped cover	1

TABLE 6 - RAPID TEMPERATURE TRANSITIONS FAILURES

Failure Mode	Qty
Troubleshooting in progress	6
Cracked component	1
Intermittent component	1
Failed component, cause unknown	1
Connector separated from board	1

TABLE 7 - VIBRATION STEP STRESS FAILURES

Failure Mode	Qty
Broken lead	43
Troubleshooting in progress	17
Screws backed out	9
Socket interplay	5
Connector backed out	5
Component fell off (non-soldered)	5
Tolerance issue	4
Card backed out	4
Shorted component	2
Broken component	2
Sheared screws	1
RTV applied incorrectly	1
Potentiometer turned	1
Plastic cracked at stress point	1
Lifted pin	1
Intermittent component	1
Failed component	1
Connectors wearing	1
Connector making intermittent contact	1
Connector broke from board	1
Broken trace	1

TABLE 8 - COMBINED ENVIRONMENT FAILURES

Failure Mode	Qty
Troubleshooting in progress	23
Broken lead	10
Component fell off (non-soldered)	4
Failed component, cause unknown	3
Broken component	1
Component shorted out	1
Cracked potting material	1
Detached wire	1
Circuit design issue	1
Socket interplay	1

The significance of the data in Tables 4 through 8 is that the majority of failure modes shown are common field failure modes for commercial equipment. The HALT process merely accelerates what will most likely take place over a much longer period of time under field usage. See Table 9 for a summary of all the failures.

TABLE 9 - SUMMARY OF FAILURES

Failure Mode	Qty
Troubleshooting in progress	85
Broken lead	53
Failed component, cause unknown	24
Component fell off (non-soldered)	9
Screws backed out	9
Circuit design issue	8
Connector backed out	5
Socket interplay	5
Card backed out	4
Tolerance issue	4
Broken component	4
Intermittent component	3
Two samples had much different limits, cause unknown	3
Connector broke from board	2
Degraded component	2
Shorted component	3
Broken trace	1
Connector making intermittent contact	1
Connectors wearing	1
Cracked potting material	1
Detached wire	1
Lifted pin	1
Plastic cracked at stress point	1
Potentiometer turned	1
RTV applied incorrectly	1
Sheared screws	1
Warped cover	1

HASS DEVELOPMENT/PROOF-OF-SCREEN/PRODUCTION HASS PROCESS

Many customers only performed HALT to ruggedize their design. In order to ensure that product failures in the field due to process issues are minimized, production screening, or HASS, should be implemented for process monitoring. Approximately 10% of the products brought to the test center to undergo HALT were also submitted to have an effective production screen developed.

The goal during HASS Development and Proof-of-Screen was to provide the most effective and quickest screen possible. The effectiveness of the screen was measured in its ability to find defects in the product without removing significant life from the product.

When possible, all the samples used during HASS Development and Proof-of-Screen were obtained directly from the manufacturing line, not having gone through HALT or other stressing. Before the HASS Development and Proof-of-Screen Process was begun, a special fixture was designed to test numerous units at a time (which was needed in order to met production requirements).

HASS Development

During HASS Development, the stress types were chosen (vibration, thermal, electrical stresses, etc.), including magnitudes, sequences, and dwell times using the limits discovered in HALT. For this reason, it was essential to perform a comprehensive and complete HALT prior to development of the screen to find and understand the design margins of the product. For the products undergoing this process, the screen limits were derived by taking a percentage of the thermal response levels and a percentage of the vibration response levels discovered during HALT. For thermal, a thermal derating of 20% of the operational limit was chosen in most cases. For vibration, a starting level of half the response destruct limit was chosen in most cases. One of the goals during HASS Development for each of the products was to have at least a 100°C delta for the temperature cycling and at least a product response of 20 Grms for vibration.

The production fixture (for both temperature and vibration) was mapped with a product attached to determine the stress levels at each product location. The chamber control system setpoint levels were adjusted until the desired product response levels were achieved. The samples in the fixture were arranged so that the location with the highest and the location with the lowest vibration response level were both populated with working samples (non-functioning samples can be placed in the other locations). The same was done with thermal, using locations with both the highest and lowest thermal rate of change.

If sufficient margins were achieved between the upper operating limit and the upper destruct limit as well as the lower operating limit and the lower destruct limit, the HASS profile was structured so that the temperature profile went beyond the operating limit but below the destruct limit for part of the HASS to precipitate the latent defects, and then within the operating limit for the remainder of the HASS to detect the defects that were precipitated. This is called a “Precipitation/Detection Screen.” During the precipitation portion of the screen, the samples did not meet all specifications. This portion of the screen was useful in bringing out defects that were difficult to uncover in a short period of time when screening only within the operating limits. During the detection portion of the screen, the samples were functional and were being monitored. This portion of the screen was useful in finding the defects brought out in the precipitation portion of the screen.

Modulated vibration and “tickle” vibration were also used. Modulated vibration was useful in finding defects that escaped constant vibration levels. Tickle vibration was useful in finding defects that were precipitated at higher vibration levels, but required lower levels for detection. Whenever either of these methods were effective, they were added into the profile.

Proof-of-Screen

Once the initial HASS profile was created, it was applied to one chamber load of the test articles for a minimum of 30-50 times (i.e., if the HASS profile consisted of 3 combined stress cycles, the articles were submitted to 90-150 combined cycles without any failures occurring). This process is known as "proof-of-screen."

When possible, "seeded samples" were used through the HASS profile in order to determine if and when the profile caught the defects ("Seeded samples" are products induced with problems, such as improperly soldered leads). These types of defects were representative of typical manufacturing defects. Then, depending on when the profile caught the defects, the levels were adjusted accordingly so that they were found in the first cycle, if possible. This ability to prove that the screen can find defects is one of the key aspects of an effective screen.

After the adjustments were made to the HASS profile, previously unstressed samples were re-run through the profile a minimum of 30-50 times in order to determine the effectiveness of the profile.

Production HASS

Once the proof-of-screen process was completed, the product was ready for production screening. The manufacturing screen for each product will continue to be monitored. The profile may need to be changed based upon manufacturing data and field data. However, careful consideration and analysis must be made before each change. If a defect escapes the screen, analysis must be performed to understand why, and if necessary, the screen will be modified. If a high failure rate suddenly occurs during the screening, then analysis must be performed to understand the cause of this to determine if the failures were a result of a process shift. Any changes to any stress will require a repeat of the proof-of-screen.

HASS DEVELOPMENT/PROOF-OF-SCREEN/PRODUCTION HASS RESULTS

Of the 47 products that were subjected to the HALT process, four have gone through the HASS development/proof-of-screen process as well. Two of these are presently going through the production HASS process as well.

Many have elected to implement the HASS process at their own facility using existing environmental equipment, or, if their equipment was not capable of performing at or near the levels (vibration level and temperature transition rate) that the product withstood during HALT, they have purchased new combined environment equipment that could perform at or beyond these levels.

SUMMARY

Poor reliability, low MTBF, frequent field returns, high in-warranty costs, and customer dissatisfaction are often the result of design and/or process weaknesses in products, even if they have successfully passed qualification tests at the design phase and manufacturing tests and burn-in at the production phase. The best method to find these problems quickly is to use HALT and HASS. HALT has been tried and proven on almost every type of electrical and electro-mechanical product, and many purely mechanical products as well. The data from this study represents 19 separate industries.

During the HALT process, a product is subjected to progressively higher stress levels brought on by thermal dwells, rapid temperature transitions (temperature cycling), vibration, and combined environment (rapid thermal transitions and vibration). The stress level for each stimuli applied is raised in small steps well beyond the field environment. The same failures which typically show up in the field over time at much lower stress levels show up quickly in this short term overstress condition. HALT is primarily a design ruggedization process.

In order to improve the product's reliability and increase its MTBF, the root cause of each failure discovered in HALT must be determined and corrective action taken to eliminate them. This process will yield the widest possible margin between the product's capabilities and the environment in which it will operate, thus increasing the product's reliability, reducing the number of field returns and realizing long-term savings. Once corrective actions have been taken and the margins expanded to the product's fundamental limit of technology, the product's operating and destruct limits can be used to develop an effective Highly Accelerated Stress Screen (HASS) for manufacturing which will quickly detect any process flaws or new weak links without removing an appreciable amount of life from the product. This HASS process will ensure that the reliability gains achieved through HALT will be maintained in future production.

REFERENCES

1. Hobbs, Gregg K., "Screening Technology" seminar notes, 1988.

Mike Silverman is Managing Partner of Ops A La Carte LLC, a Professional Consulting Company founded by him in 1999. Ops A La Carte provides a complete range of Reliability Engineering Services employing both Conventional and Accelerated Reliability (HALT) techniques. Mike has pioneered the concept of "Reliability Integration" using multiple Reliability Tools in conjunction with each other to greatly increase the power of Reliability Programs. Please visit www.opsalacarte.com for copies of this paper and other useful resources.