Benefits and Costs of Overstress Testing (HALT)

Nahum Meadowsong & Edmond L. Kyser
Cisco Systems, Inc.

The partnership of Design and Manufacturing is central to the process of bringing a product to market. The impact of problems in either of these stages can increase exponentially if they go unnoticed until after the product reaches the customer. Overstress Test (tests using stresses beyond the design limit of the product) is successful at uncovering such faults in both product design and the manufacturing process and insures the overall robustness of the product. The benefits of Overstress Test include:

- Rapid design and process maturation
- Reduced total engineering time and cost
- Reduced production and warranty costs
- Earlier and mature product introduction (yields stabilized)
- Higher MTBF
- Greatly reduced manufacturing screening costs
- Faster corrective action for design and process problems
- Delighted Customers

HALT

HALT is a 'step-stress to fail' destruct test which gradually increases the environmental stresses to determine the operational limits and to find any **d**esign faults. The process is one of test, fail, and corrective action to prevent possible field failures. HALT is not a compliance test, and is not limited by component or product specifications. All products are candidates for HALT. In the case of systems**,** the HALT test will find defects in the weakest subsystem. Production should be delayed until HALT results are satisfactory. HASS testing, which is a non-destructive Manufacturing screen or process, will be discussed in a following article.

HALT Stress Overview

The following stresses are capable, both alone and in corporation, of identifying product weaknesses. When available, each of these stresses should be used in HALT test design.

- **Temperature**

Operation under prolonged elevated temperatures can uncover marginal design, bad components, or process problems inherent in the product. Temperature cycling detects weak solder joints, IC package integrity, TCE mismatch, and PCB processing and mounting problems; problems that will show up over time once a product is in the field.

- **Vibration**

Vibration is useful for testing a product's robustness during shipping and poor solder conditions. Cold / Insufficient solder connections can be stressed to failure with vibration levels which will not harm good connections.

- **Voltage Margining**

Voltage margining can be useful in the identification of marginal components and marginal design, especially when used in conjunction with temperature.

- **Frequency Margining**

Frequency margining is not always an option but if the circuit under test allows for it, it can be useful in identifying marginal components.

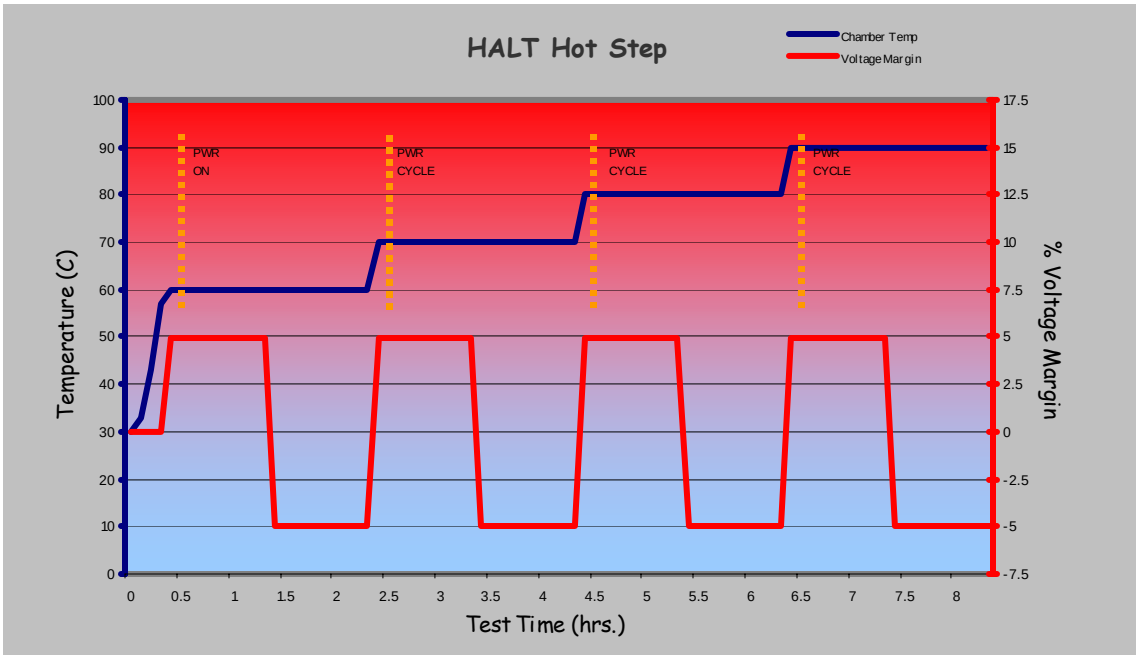
- **Functional Stresses**

The most abstract and sophisticated aspect of HALT test design is the functional test of the product. The goal is to have the product endure the combination of environmental and electrical stress while operating at peak processor utilization, bandwidth etc. Functional test should simulate this 'worse-case real world' as accurately as possible to insure that no product functionality goes untested.

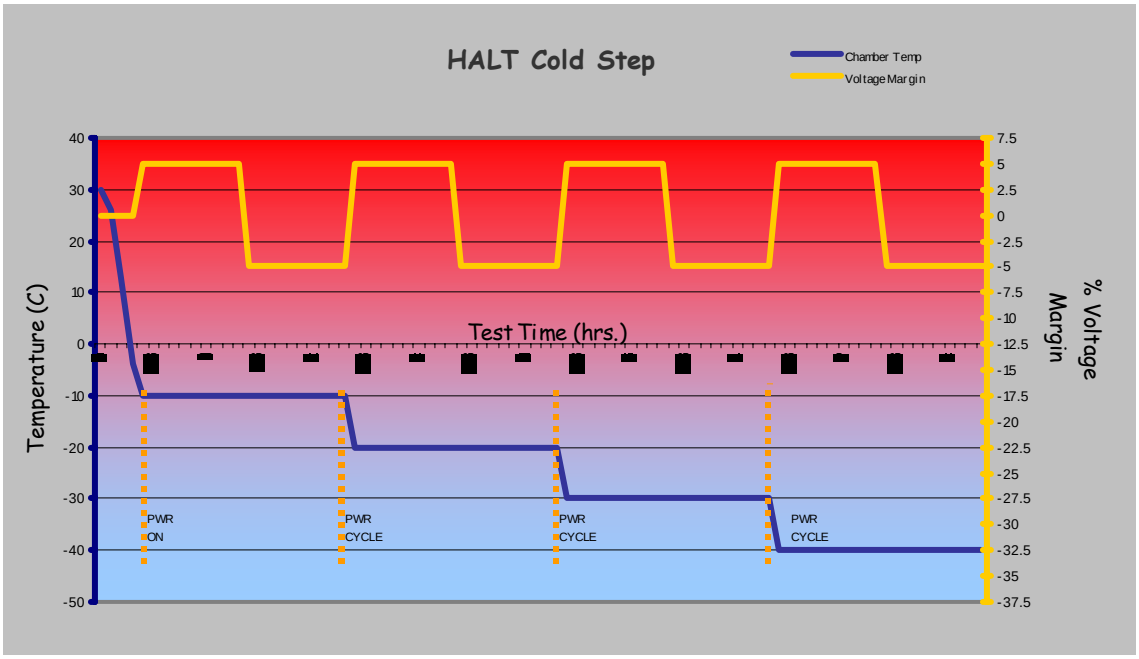
HALT Profile

There exists no industry standard HALT profile. The HALT profile should be tailored to the needs of the specific program. Our experience with testing telecommunications products at Cisco has lead to the design of the following three phase profile.

- **Hot Step**: Two hours at each temperature step; one hour high voltage margin, one hour low voltage margin. Power Cycle after each temperature step. First step is 60°C and last meaningful step is 90°C (The temperature may continue to be stepped however failures become less and less meaningful after a certain temperature. The point of diminishing returns is around 90°C).

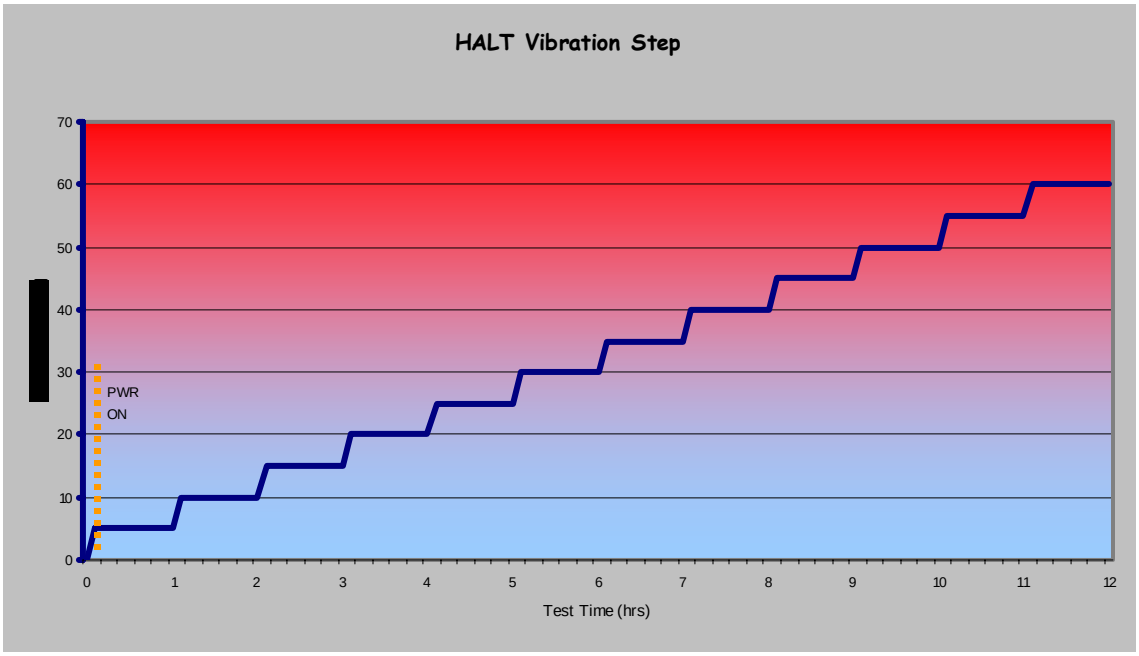


- **Cold Step:** Similar to hot step. First step is at -10°C and last meaningful step is -40°C.



- **Vibration:** Vibration is stepped 5 Grms/hr until the maximum capabilities of the vibration table are reached. For the Qualmark OVS4 chambers we use this value is 60 Grms. Accelerometers should be used in order to determine the amount of vibration incident on the UUT. Generally, and especially when the UUT is part of

a larger system, only a fraction of the table vibration is transmitted to the test subject.



Determinants of HALT Success

For a HALT test to be successful the closed loop corrective action process must be followed. If failure analysis is not carried through to root cause, the benefits of HALT are lost. To be effective, results must be:

- Fed back to design to make a circuit design change, select a different supplier, or improve the existing suppliers process.
- Fed back to manufacturing for a process change.
- Used to determine the production test profile.

Another key for success is the intimate involvement by members of several key areas. These include:

- Management – Management must allocate sufficient resources, time, and funds for HALT testing to take place. They must also provide support during the failure analysis phase in order to get closed loop corrective action in a timely fashion.
- Development / Engineering – Design Engineering needs to be immediately available to troubleshoot failures which can sometimes be beyond the scope of the HALT Test Engineers.

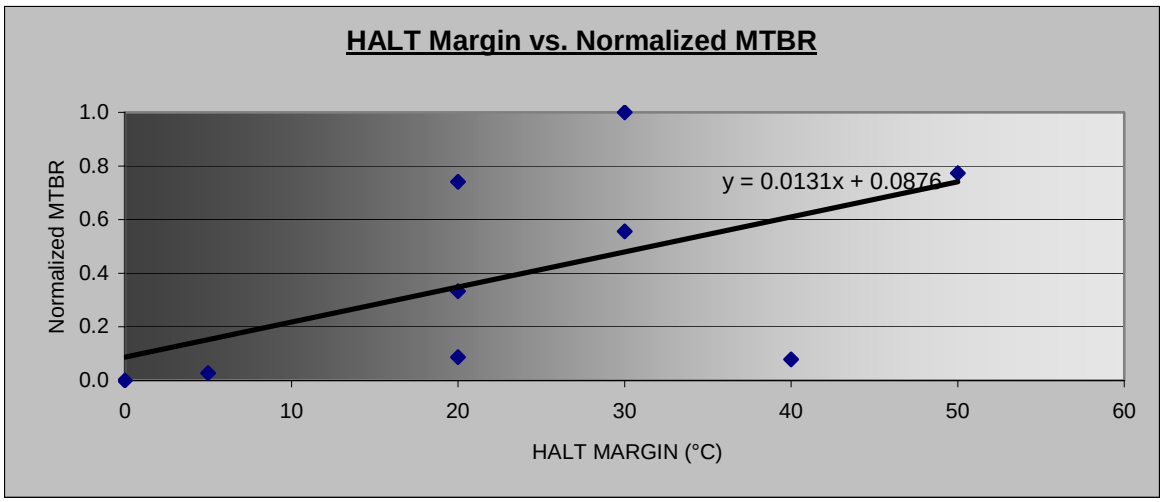
- Suppliers – Suppliers must be willing and able to provide component failure analysis in order to obtain root cause.

Other key factors to success include the placement of HALT in the product development timeline, sample size, the perceived relevance of failures, and failure reporting. A HALT test should begin as soon as HW and SW is available and stable. The testing should use as many units as possible, as the probability of uncovering a defect increases with sample size. Failures that occur during testing should be treated as relevant and pursued to root cause. Finally, failure reporting must be visible enough to prevent the failures and solutions gleaned from HALT from being overlooked.

MTBR Prediction Using HALT Margin

Can HALT be used to predict a product's MTBR? If so, then we are in a good position to estimate the benefits of HALT – and thus also the cost effectiveness of HALT.

The data that follows was collected from multiple HALT tests of similar Cisco telecommunications products. Accurate data collection for MTBR and RMA requires that this quality data be tracked for a year past the completion of the HALT testing. The following chart shows the correlation between MTBR (the actual field performance of the product) and HALT margin. In this data, the HALT margin is the smallest margin in degrees C between operating specifications and any HALT failure. Vibration failures are not considered.



Here the correlation is strong and intuitive. MTBR can be predicted based on the following least squares fit:

MTBR = ((0.0131)(HM) + (.0876))*(NF)

where

- HM = Halt Margin for product
- NF = Normalization Factor used for the above chart

Economic Justification for HALT

Having obtained the relationship between HALT margin and MTBR, we are able to assess the cost effectiveness of HALT. For HALT to be cost effective the cost must be less than the anticipated benefits. HALT requires destruction of at least one prototype at a critical stage, and prototype build is a leading cost item in product development. Also, there are other costs such as the manpower required to conduct HALT, the depreciation of test equipment, consumable costs, and corrective action costs. The cost justification model for HALT follows.

Cost Justification: Improve Reliability

From the above graph of RMA rate vs. HALT margin, if the operating margin is increased **n** °C, the normalized RMA rate is reduced 0.0192 **n**. Also, each RMA costs approximately **WPC** dollars, where **WPC** is the cost of producing the board (whole product cost). The benefit of a HALT test is:

Benefit = (# of RMAs prevented)(cost of an RMA)

= N(0.0192)(RMA intercept)(Pvol)(WPC)$

where

- **Pvol** is the annual production volume.

The cost of a HALT test is:

Cost = (WPC + Esalary + DEP + CON + CA)$

where

- Esalary = fully burdened weekly salary
- DEP = Weekly Depreciation of equipment
- COM = Consumable costs
- CA = Corrective action costs

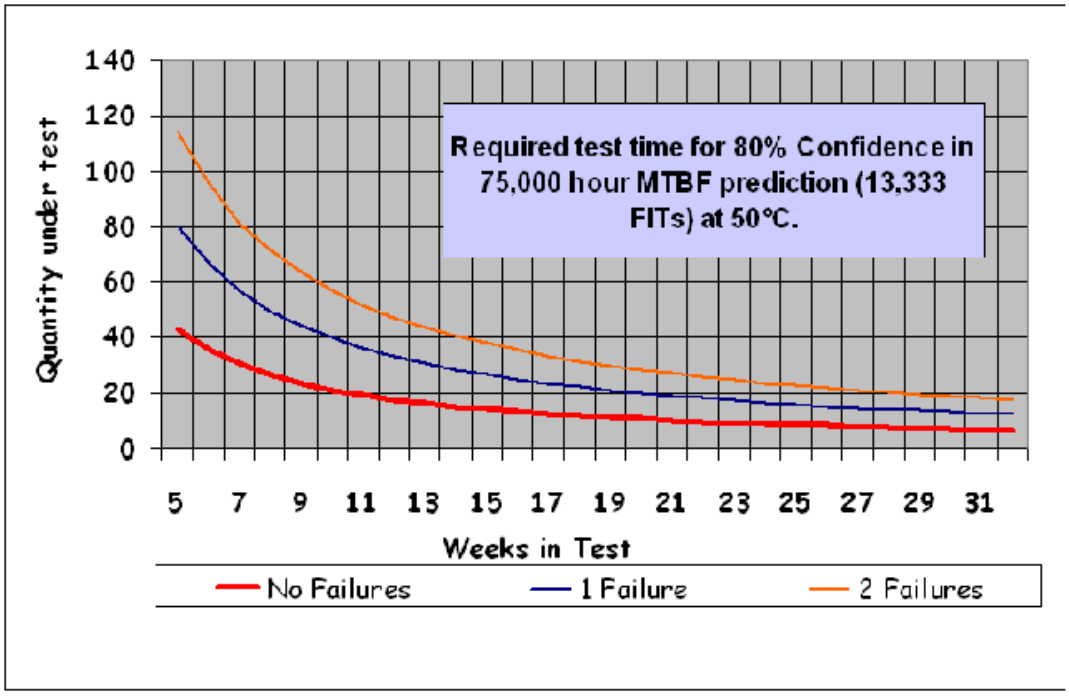
The break-even point is where costs equal benefits. For a HALT test to be cost effective, it must, on average, increase the operating margin **n** °C. Setting costs equal to benefits we can solve for the margin **n** necessary to justify the cost of HALT.

n = (WPC + Esalary + DEP + CON + CA)/[(0.0192)(RMA intercept)(Pvol)(WPC)]

Additional potential HALT benefits

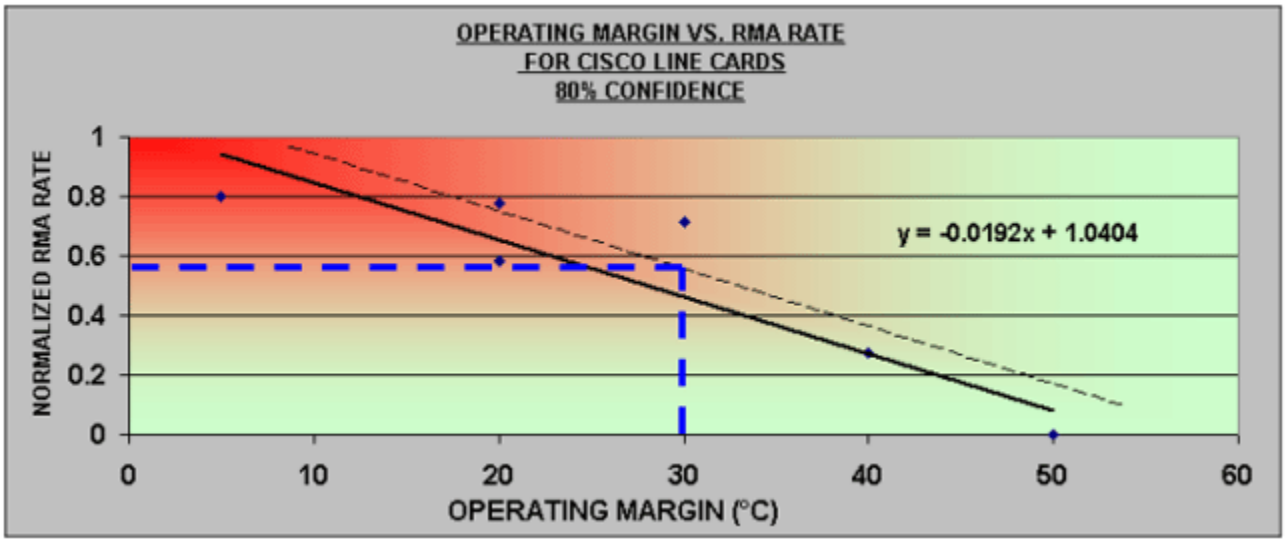
A HALT test is not a highly accelerated life test. In fact, it is not a life test at all. There is no appropriate acceleration algorithm or acceleration factor. The deliverables of a HALT test are operating margin and failure modes. However, operating margin is an indicator of field performance. Low margins indicate poor performance (short life) and high margins indicate good performance (long life). A HALT program with few tests under it's belt does not have the data necessary to correlate HALT performance to field performance. That is not to say that a correlation does not exist – quite the contrary. A seasoned HALT program which has conducted multiple tests on similar products **could** possibly predict MTBR more accurately than current predictors in use such as those based on component count and individual component field data. This may be because current predictors do not factor in any aspects of the actual product design into their calculations whereas HALT margin is specific to the product under test.

Consider the following comparison of RDT using traditional methods and RMA as predicted by HALT margin.



This chart shows the required test time for an 80% confidence level in an MTBF prediction greater than 75000 hours. The dashed blue line shows that RDT requires 40 boards tested for 10 weeks (assuming 1 failure and Arrhenius acceleration due to 50°C test temperature). RDT is a very time consuming test and requires equipment and labor that would otherwise be used for production.

The same prediction using HALT margin requires as little as 1 board for 1 week. In the following chart showing RMA rate vs. HALT margin the dashed blue line shows an 80% confidence for an operating margin of 30°C indicating normalized RMA rate below 0.55.



The traditional MTBF predictor may be improved by factoring HALT margin into the MTBF calculation. This will be the subject of a paper soon to be published.

Conclusions

In this paper we have shown the benefits obtained from a well designed HALT program:

- HALT process is adept at finding and correcting design faults and determining design margins
- The costs of HALT can be justified in terms of improved margin
- HALT margin may also be used to estimate MTBR (and thus obviate traditional RDT) and to improve traditional MTBF prediction

Acronyms

AST - (Accelerated Stress Test) - Overstress Test

HALT - Highly Accelerated Life Test
HASS - Highly Accelerated Stress Screen
HW - Hardware
IC - Integrated Circuit
MTBF - (predicted) Mean Time Between Failures
MTBR - Mean Time Between Returns
ORT - Ongoing Reliability Testing
PCB - Printed Circuit Board
RDT - Reliability Determination Test
RMA - Return Material Authorization
SW - Software
TCE - Temperature Coefficient of Expansion
UUT - Unit Under Test

Acknowledgments

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References

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