Accelerated Test: Reasons, Methods and Concerns

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HALT/HASS

- Management must truly want to improve quality and reliability.
- Without the desire the necessary actions cannot be made.
- HALT/HASS will not become a reality.

HALT

- Upper and Lower Operating Limits
  - » Assess Design Margins
- Upper and Lower Destruct Limits
  - » Find Design Limits
  - » Select Subsequent HASS Environment Confidently

HALT

- At Each HALT Limit Level Detected:
  - » Accurate Data Collected
  - » Failure/Flaw Determined
  - » Failure Analysis Assessment of Cause
  - » Corrective Action Decision Made
    - – Design Limitation
    - – Harden Product

Monitor

- 50% of all flaws discovered by ESS are intermittent.
- Under an effective level of stress and monitoring, a flaw is generally repetitive and relatively obvious.
- A monitor must be evaluated for both functionality and stability.
- With an effective level of stress, computer time monitoring can be made to perform as well as real time continuous monitoring.
- A jitter test circuit is used to identify intermittent electronics.

HALT Diagnostic Procedure

❶ Problem Identified

❷ Objective Defined

❸ Determine/Modify Stress Protocol

❹ Apply Stress(es)

❺ Objective Achieved? If yes, continue. If no, go back to 3.

❻ Minimum Stress Identified? If yes, continue. If no, reduce stress(es) and go back to 4.

❼ Broad Results

❽ Document Results

Shock Response Vibration

Accumulated Fatigue Solution For Total of Random Excitation

- Since the PPDF gives the complex totals of all stressing peaks of a random excitation, either Gaussian or non-Gaussian, by solving each PPDF bar and summing, the total fatigue rate is determined.

$$AFDF = \sum(n_1\sigma_1{}^b + \ldots n_n\sigma_n{}^b)$$

Therefore:

$$D = (f_n)(T)\left(\frac{\sigma^\beta}{\subset^\beta}\right)$$

Where:

σ = rms stress level (MPa:ksi)

$\subset$ = strength parameter (MPa:ksi)

β = slope parameter

Papoulis' Rule

And its Implications To Screening

- Mechanical components, when excited by an input, act as narrowband filters, resonating at their own frequencies regardless of the nature of the input. Furthermore, their fatigue is related only to this self resonance.
- The principal compression functions of the RS machine are:
  - » Multi-vectored stimulation excites more modes in less time.
  - » Higher average intensity forces higher response, hence, more fatigue per unit time.
  - » Wider bandwidth may provide stimulus to smaller components.

Inverse Power Law

$$N_1 S_1^{\beta} = N_2 S_2^{\beta}$$

$$N_1 = N_2 = (S_2^{\beta} / S_1)$$

$$\beta = [\mathrm{LOG}(N_1 / N_2) / \mathrm{LOG}(S_2 / S_1)]\text{:Slope}$$

$S_1 =$ Low Level Stress

$S_2 =$ High Level Stress

$N_1 =$ Time to Failure at Stress S_1

$N_2 =$ Time to Failure at Stress S_2

Working with Product Designers

- HALT - Efficient/effective purposeful stressing of the design limits for identification, documentation and evaluation.
- Concerns for avoiding physical damage to a unit to allow for an investigation of the product's actual strengths.
- Iterative investigation and subsequent corrective elimination of surfaced flaws allows for an eventual highly robust design.
- HALT is not a test. HALT is a design development tool - ideally performed on new designs during pre-production evaluation.

Conclusion

If our design and fabrication is robust enough, we can use very high stress levels compared to field environments and therefore shorten the screens to a cost effective time.

THE ARRHENIUS MODEL

$$r = r_o e^{\frac{E_a}{kT}}$$

- where
  - » r is the reactive rate
  - » r_o is a constant
  - » E_a is the activation energy, in electron-volts (1 eV = 23 kcal/mole)
  - » k is Boltzmann's constant (8.617 x 10-5 eV/^{O}K)
  - » T is the reaction temperature (^{O}K)
- At two different temperatures, T_1 and T_2, $r_1 t_1 = r_2 t_2$, and $t_f \ oc \ \frac{1}{r} \ oc \ e^{\frac{E_a}{kT}}$
- The acceleration factor is

$$AF = \frac{t_u}{t_t} = exp\left[\frac{E_a}{k}\left(\frac{1}{T_u} - \frac{1}{T_t}\right)\right]$$

THE INVERSE POWER LAW

- The general form of the inverse power law is

$$\tau = \frac{A}{S^n}$$

- Where

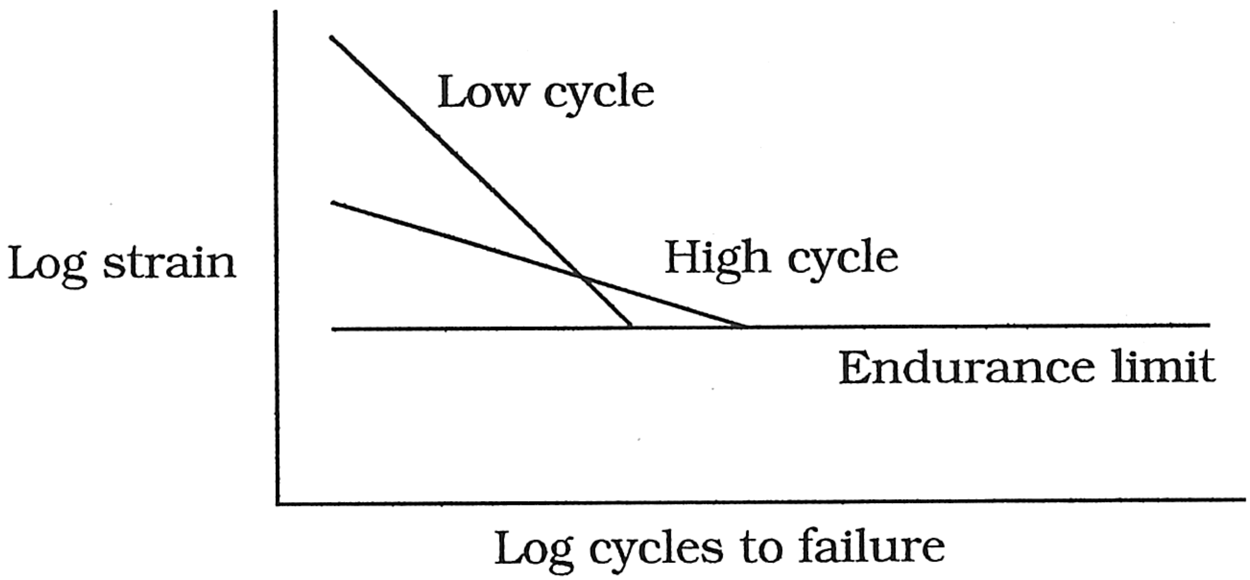
» τ is a measure of product life

» A is a constant characteristic of the product

» S is the applied stress

» n s an exponent characteristic of the product

THE S-N CURVE



Low cycle
Log strain
High cycle
Endurance limit
Log cycles to failure

AN INVERSE POWER LAW EXAMPLE

- Ten microcircuit samples with gold wires bonded to aluminum bond pads are temperature cycled between -55 and +125°C, with failures at 100, 120, 150, 170, and 170 cycles. What is the estimated time to 1% failure in an operating environment of +40 to +85°C?

- t_{01} is obtained graphically, and is equal to 53 cycles. The acceleration factor for this failure mechanism is

$$AF = \frac{N_{fu}}{N_{ft}} = \left(\frac{\Delta T_t}{\Delta T_u}\right)^B = \left(\frac{180}{45}\right)^5 = 1{,}024$$

- and t_{01} under use conditions is

53 x 1,024 = 54,272 cycles

AN EYRING MODEL EXAMPLE

- 10 microelectronic samples are tested at 85°C-85% RH, with failures at 620, 1000, 1100, 1150, 1700, 1800, 1800, 2000, 2600, and 4000 hours. What is the MTTF (mean time-to-failure) at 40°C-60% RH?

$$AF = \left(\frac{60}{85}\right)^{-3.0} exp\left[\frac{0.9}{8.617 \times 10^{-5}}\left(\frac{1}{313} - \frac{1}{358}\right)\right] \approx 182$$

- The MTTF is determined graphically to be approximately 1600 hours. The estimated MTTF at 40°C-60% RH is

$$1{,}600 \times 182 = 291{,}200 \text{ hours} \approx 33 \text{ years}$$

COMBINATIONS OF STRESSES

- Miner's rule for fatigue testing:

$$R = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} + \ldots \frac{n_j}{N_j}, \text{ or } R = \sum_{i=1}^{j} \frac{n_j}{N_j}$$

Where

» R is the ratio of the fraction life that is exhausted at a given point

» nj is the number of cycles at a specific applied stress level

» Nj is the number of cycles to failure at that level

» nj/Nj is the fraction of a product's useful life which is used up at each level of each applied stress

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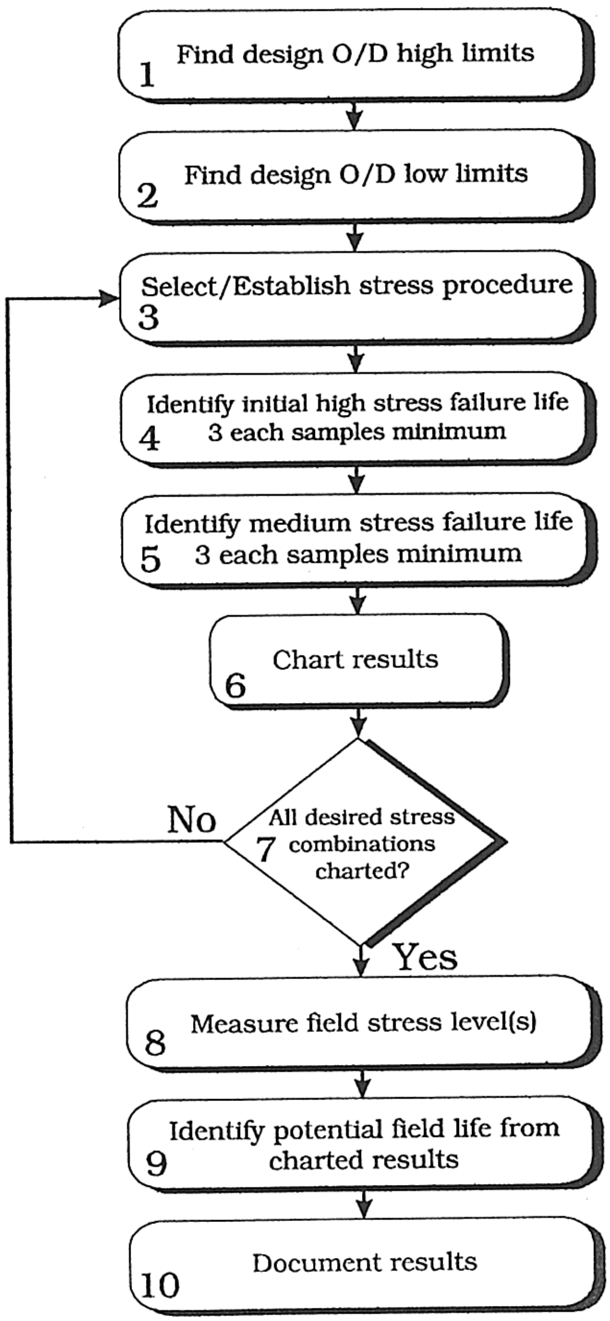
F.A.S.T. (HALT) PREDICTIVE PROCEDURE



Inverse Power Law

- $N_1 S_1^{\beta} = N_2 S_2^{\beta}$
- $N_1 = N_2 (S_2^{\beta} / S_1)$
- β = [LOG(N_1/N_2)/LOG(S_2/S_1)]:Slope
- S_1 = Low Level Stress
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- N_1 = Time to Failure at Stress S1
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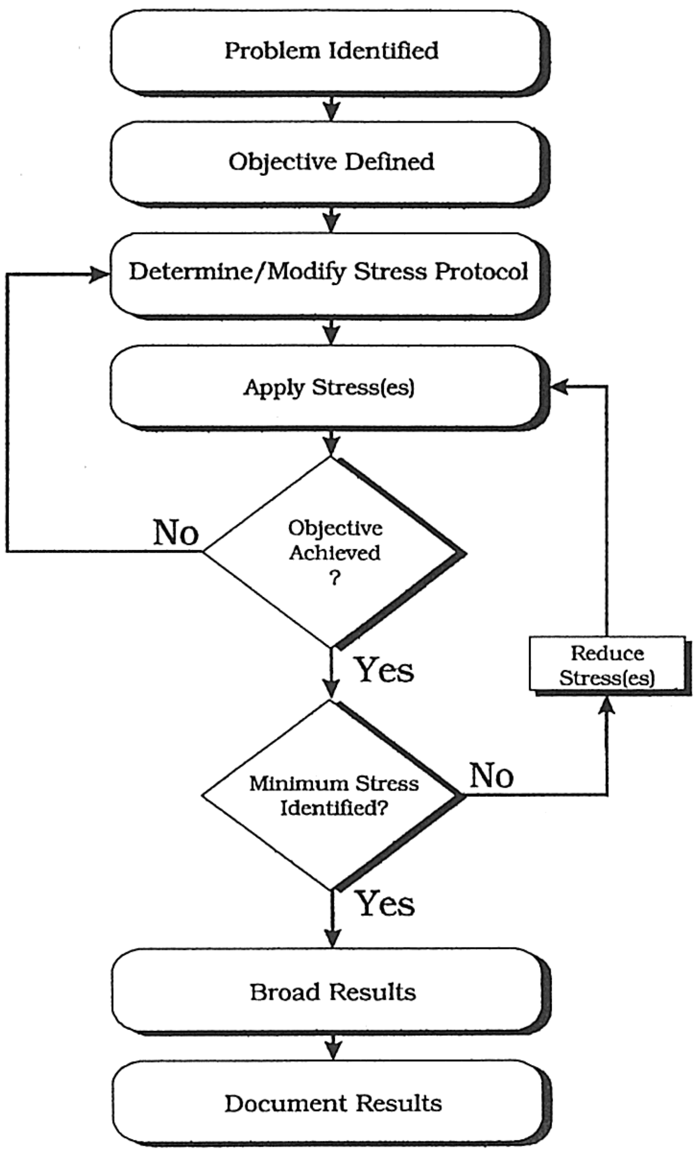
F.A.S.T. (HALT) DIAGNOSTIC PROCEDURE



Identify Problem

Define/State Objective

Determine/Modify the accelerated stress protocol to achieve the defined objective.

Apply selected stress(es) to items in question. Monitor results.

Has the defined objective been achieved/identified?

Return loop. Reduce the applied stress in a search to find the minimum applied stress that will yield the desired objective.

Has the minimum stress been identified? e.g. Further reduction of applied stress will fail to yield the desired result.

With design engineering and using the monitored data, identify "Broadly Defined" results. e.g.

✓Broad failure isolation

✓Broad conclusions of failure

✓Possible components involved

Accelerated Testing HALT Approach

<u>START:</u> Classical Thermal Cycling

Add

6-Axis Vibration

Add

Humidity

Add

Other Accelerating Mediums

- ☑ Salt Spray for Corrosion
- ☑ Oxygen for Fretting Determination
- ☑ Water for Seal Integrity

Note: During testing, all products are powered up and subject to continuous monitoring.

Shock Response Vibration

- Pneumatic Hammers to Vibration Table
- Hammers Bolted to Table
  - » Deliberate but Varied Orientations
  - » Mix of Force Vectors - Shock Waves
- RS Advantageous Over Single Planar Testing
- Effective as a Result of Actual Level Imparted to the UUT
- Fixturing Becomes a Significant Concern

SRS Test Report

GHI SYSTEMS, INC. CAT SYSTEM

DATE / TIME :
Vibration Syst: 9 Hammer Pneumatic
Table Location:

TEST ENGINEER :
RMS Accel. :
Temperature : Room

Sensitivity: Ch. 1: g's/Div. g's/Div.
Filter: None None

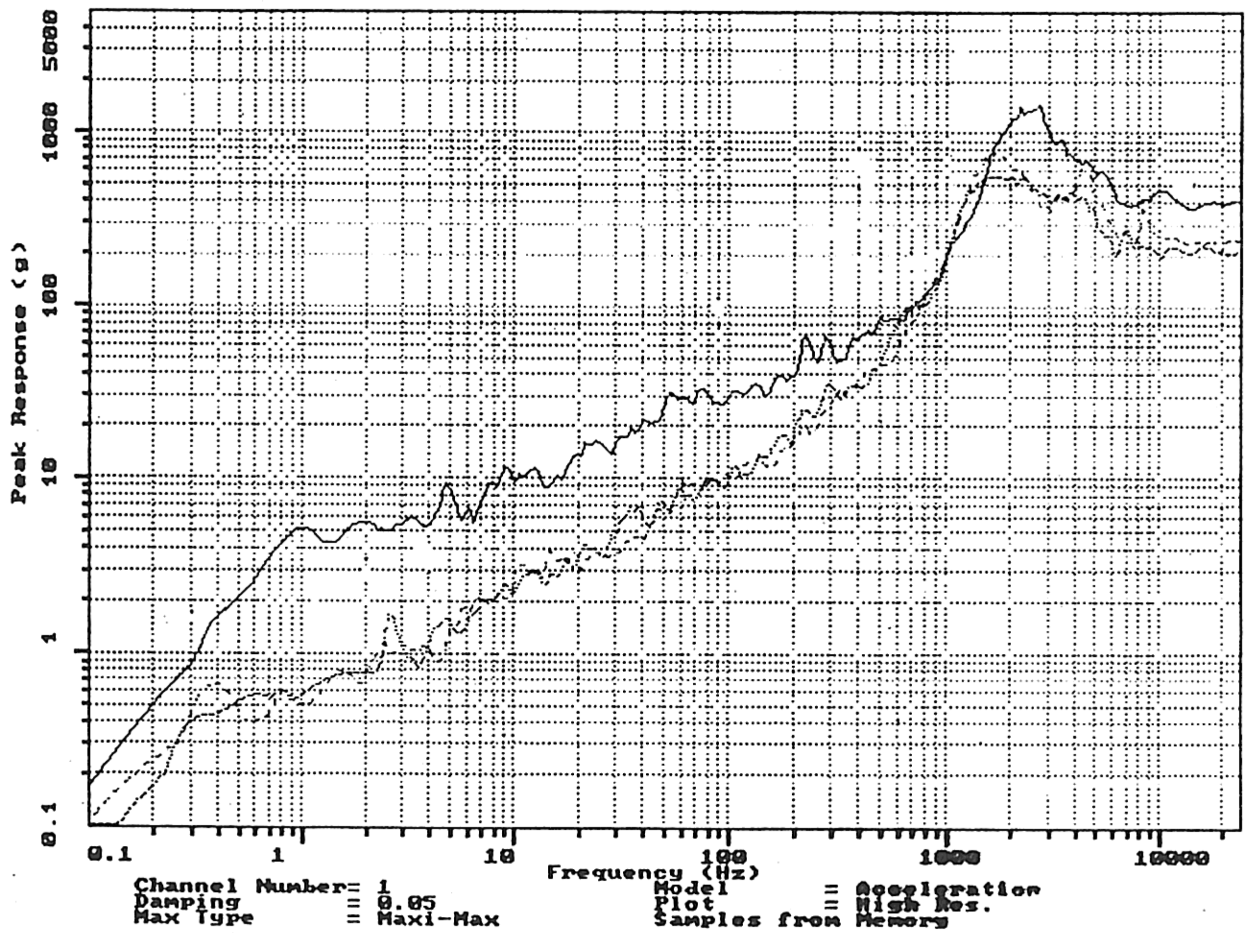


FIG 1

Main Concerns

- Actual Spectral Levels
- Major Bending Modes
- Actual Rate of Fatigue - Time Expended

Summary

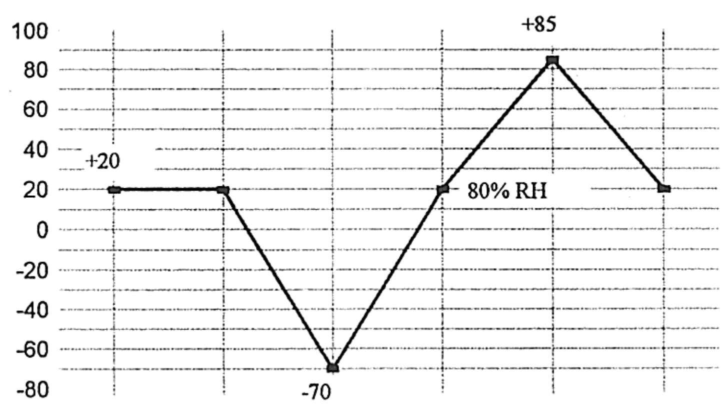
- Identified
  - » Broken Leads
  - » Cracked Solder Joints
  - » Cracked Brackets
- Root Cause/Eliminate

Thermal Cycling

- 60° C/min.
- Concerns for UUT Point of Concern
- Total Mass Monitored
- Change to New Mean Value
- Evidence of Accumulation of Mean Stress Fatigue
- Correlation With Subsequent Follow-Up Tests

Humidity

- Number of Humidity Related Tests Performed
- Fretting Test Example
  - » Compare Materials for Fretting Potential



- At Point of Concern
  - » 5V, 10 ma
  - » Junction R Monitored
  - » All Results 5 to 50 Cycles

Salt Spray Corrosion

- Hypothesis
  - » Identify Salt Spray Corrosion as Primary Cause of Ground Return Failures
- Extensive Matrix:

» Wire Type	vs.	Salt Corrosion
» Lug Type		Temp. Cycling
» Screw Type		Low Current Bias
» Torque		High Current Density

- Hypothesis False
- Corrosion - Contingent Only
- Primary Concerns
  - » Connector Design
  - » Hold-Down Torque

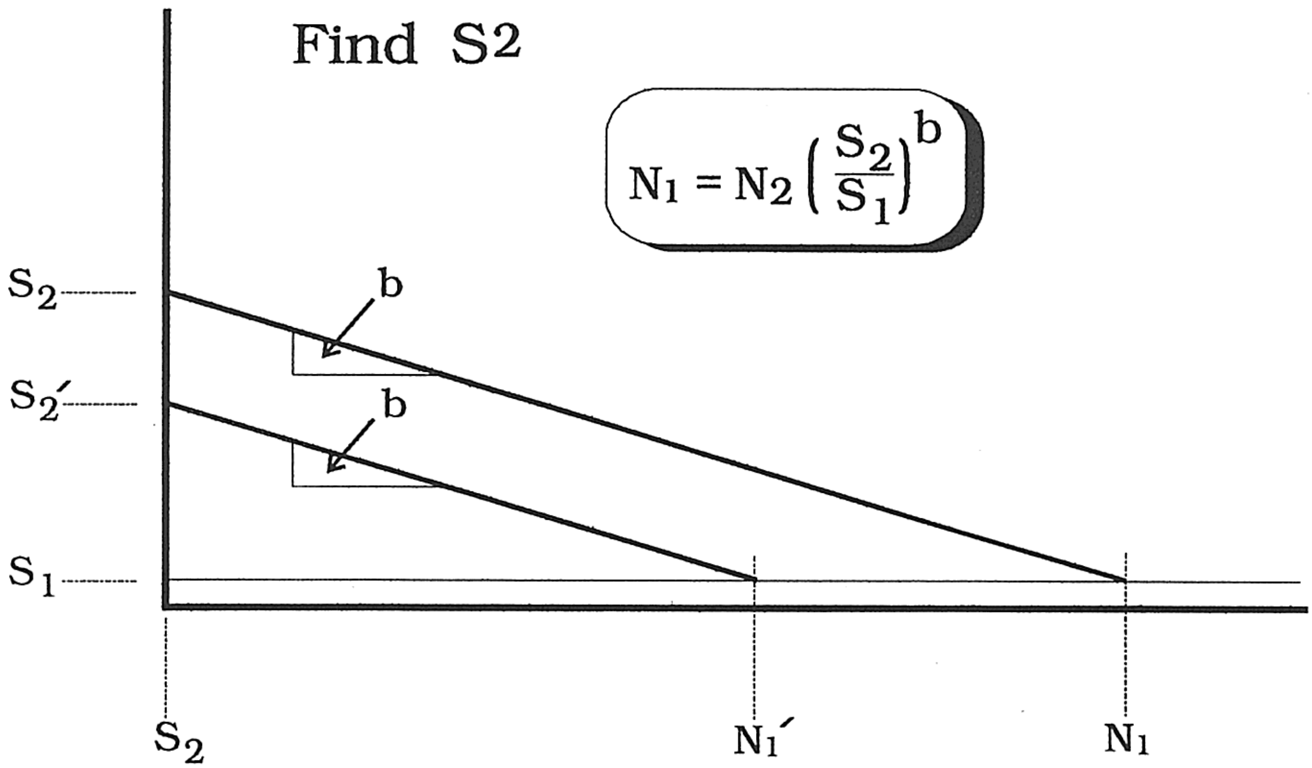
Conclusions

- RS Accelerated Test Chambers Offer Wide Range of Stresses
- Opportunity to Investigate Multiple Environmental Stress Mediums
- With Proper Monitor:
  - » Timely
  - » Concise
  - » Effective

HASS

- "Proof-Of-Screen" must:
  - » Prove the validity of any selected screen regimen
  - » Demonstrate that the regimen can expose design mariginalities or manufacturing defects
  - » Ensure that no damage has been imparted into the product
  - » No useful field life has been removed

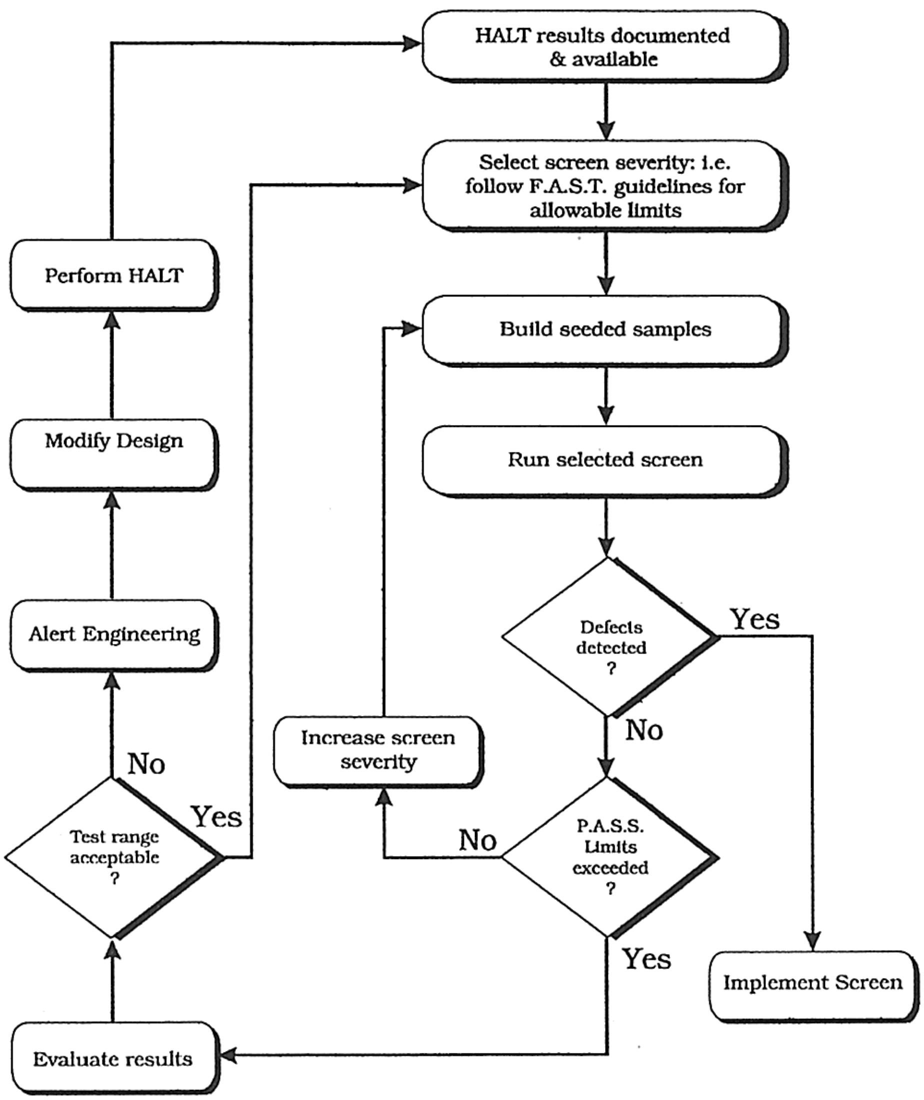
First Failure Prediction



$$N_1 = N_2 \left(\frac{S_2}{S_1} \right)^b$$

$$S_2' = \text{ANT.} \left[\frac{\log\left(\frac{N_1}{N_2}\right)}{b} + \log S_1 \right]$$

P.A.S.S.


HALT results documented & available
Select screen severity: i.e. follow F.A.S.T. guidelines for allowable limits
Build seeded samples
Run selected screen
Defects detected ?
Yes
No
P.A.S.S. Limits exceeded ?
No
Yes
Increase screen severity
Implement Screen
Evaluate results
Test range acceptable ?
Yes
No
Alert Engineering
Modify Design
Perform HALT

Conclusion

If our design and fabrication is <u>robust</u> enough, we can use very high stress levels compared to field environments and therefore shorten the screens to a cost effective time.

ARRHENIUS

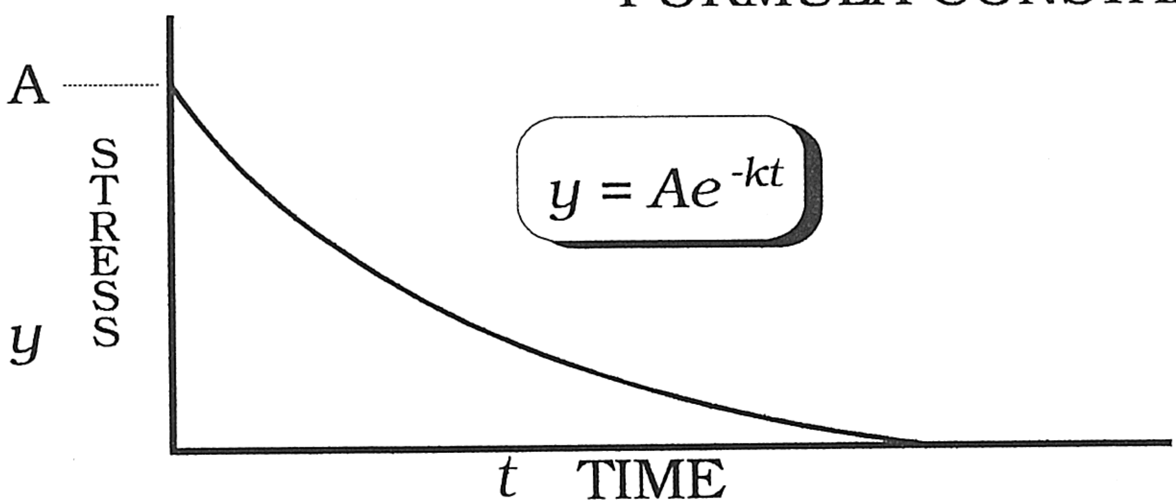
$$t_U = t_t \ exp\left[\frac{E_a}{k}\left(\frac{1}{T_u} - \frac{1}{T_t}\right)\right]$$

$$E_a = k\left[\frac{ln\left(\frac{T_u}{T_t}\right)}{\frac{1}{T_u} - \frac{1}{T_t}}\right]$$

$\left(\frac{t_u}{t_t}\right)$

Activation Energy E_a

EXAMPLE FORMULA CONSTANT



$$y = Ae^{-kt}$$

$$k = \frac{-ln\left(\frac{y}{A}\right)}{t}$$