GM WORLDWIDE ENGINEERING STANDARDS	Test Procedure	GMW8758

Calibrated Accelerated Life Testing (CALT)

1 Scope

The Calibrated Accelerated Life Testing (CALT) process is applicable to a wide array of failure mechanisms and applies to a wide range of components. Failure mechanisms such as fatigue, wear, thermal degradation, corrosion, color-change, voltage effects, and other cumulative damage processes are good candidates for CALT. Generally the failure mechanisms should be addressed "one at a time", however, the process can model the effect of two failure mechanisms occurring simultaneously. Two (2) stress CALT processes increase the cost and time demands of the CALT process. The following discussion will describe a single stress analysis only, and can be performed without specialized software tools. Specialized software tools are available (see reference section) to increase the accuracy and speed of this process.

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

1.1 Purpose. The Calibrated Accelerated Life Test methodology describes the design and analysis of a test process that allows time compression in life testing while retaining correlation in resulting life predictions for components. This standard is intended for use as a guideline in planning, executing, and analyzing Calibrated Accelerated Life Tests (CALT) where a significant reduction in test time is desirable as well as quantification of reliability. Special situations involving rubber isolators and mixed failure modes are addressed and are the result of component testing experience.

1.2 Foreword. The CALT methodology proposed by Larry Edson in the following text leverages the previous work of Wayne Nelson, William Meeker, and Pantelis Vassiliou. The CALT method focuses on situations needing extensive time compression, thus requiring significant extrapolation. The desire to combine "fast learning cycles" in testing with "calibration to reality" is the fundamental underlying objective. This methodology is especially well suited for situations where a very high level of quantified reliability is required, thus being ideal for Reliability Design for Six Sigma.

1.3 Applicability. CALT can be applied to a wide range of components, and is useful to determine life predictions and reliability for any components that may experience failure mechanisms such as such as fatigue, wear, thermal degradation, corrosion, color-change, voltage effects, and other cumulative damage.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

GMW8287

2.3 Additional References.

Accelerated Testing – Wayne Nelson, John Wiley & Sons, 1990

ALTA Testing Reference, ReliaSoft Corporation, Reliasoft Publishing, 2001

ALTA 6.0, Reliasoft Corporation

Component Technical Specification (CTS)

Failure of Materials In Mechanical Design - Second Edition, Jack A. Collins, John Wiley & Sons, 1993

Statistical Methods For Reliability Data, William Q. Meeker and Luis A. Escobar, John Wiley & Sons, 1998

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Subsystem Technical Specification (SSTS)

Vibration Analysis For Electronic Equipment - Second Edition, Dave S. Steinberg, John Wiley & Sons, 1988

3 Resources

3.1 Facilities. The test facility shall be capable of providing the environmental conditions needed to determine the failure mechanisms being evaluated.

3.2 Equipment. The test equipment must be calibrated properly. Test data recording equipment must be capable of identifying the failure mechanism precisely when it occurs.

3.3 Test Vehicle/Test Piece. The test property is typically a component.

3.4 Test Time. Test time varies based on the Test Plan and focus of the failure mechanism.

3.5 Test Required Information. Not applicable.

3.6 Personnel/Skills. Not applicable.

4 Procedure

4.1 Preparation.

4.2 Conditions.

4.2.1 Environmental Conditions.

4.2.2 Test Conditions. Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

4.3 Instructions.

4.3.1 Description of Basic CALT Method.

Note: The following method assumes a single failure mode will be dominant. If more than one failure modes appear, then refer to paragraph 4.6.2 for alternative test sequencing. The Characteristic Life value is to be used as the metric for plotting in the following description. Refer to paragraph 4.4 for a graphic representation of the CALT Process. In special circumstances, when access to software tools is not available, the average value can be used as a replacement for the Characteristic Life value.

The CALT test design and analysis method is as follows:

1. Identify the maximum level of stress that can be applied that represents a non-foolish extreme. It should be expected that this maximum level will be well in excess of the normal stress level or the specification.
2. Apply a stress level (Highest Stress Level) that is slightly reduced from the foolish extreme level (approximately 90% of the foolish limit can be used as a general starting point).
3. Test two devices to failure at this highest stress level and record the cycles or time to failure for each device.
4. Identify failure modes. If both parts fail in the same way (same failure mode), then proceed with confidence. If different failure modes are experienced, then proceed cautiously and with expectations of a common failure mode becoming dominant at the next lower stress level. The abnormal failure mode can later be treated as a suspended item in the analysis.
5. Apply a lesser stress level (The Middle Stress Level) that is slightly reduced from the Highest Stress Level (a reduction of 10% of the Highest Stress Level is reasonable).
6. Test two devices to failure at the middle stress level and record the cycles or time to failure for each device.
7. Identify failure modes and confirm relevancy to stresses applied in the “real world”.
8. Obtain the Characteristic Life value for each set of two parts tested at each stress level (alternatively use the average). If there were different failure modes at the highest stress, then use the cycles to failure value for the relevant failure mode and treat the abnormal failure mode as a suspension. The Characteristic Life values (alternately, the average values) form the metric for plotting and extrapolation. The Characteristic Life values can be obtained from Weibull analysis of each set of failure data.

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9. Plot these two Characteristic Life values (alternately, the averages) versus the stress levels used on log-linear (Arrhenius Model) or log-log paper (Inverse Power Model).
10. Extrapolate the line through these two plotting points (the characteristic life values or the averages) in the direction of the normal level of stress.
11. Identify the Lowest Stress Level from this plot that relates to a “time to failure value” that balances the following conditions “a” and “b” for the specific situation.
    a. Make the Lowest Stress Level as close to the normal stress level as possible to minimize risk in extrapolation.
    b. Make the Lowest Stress Level as high as possible to reduce test time and meet program-timing requirements.
12. Test two devices to failure at the Lowest Stress Level and record the cycles or time to failure for each device.
13. The optional testing of additional samples should occur at the Lowest Stress Level as compared to the other possible stress levels.
14. A consistent failure mode is expected. If different failure modes occur at the highest and lowest stress levels then refer to Section 4.6.2.
15. Obtain the Characteristic Life value (alternately the average) for this third set of two devices tested to failure through Weibull Analysis.
16. Plot all three Characteristic Life values (or all three averages) versus stress level on log-log paper.
17. Superimpose a “best fit” linear regression line through the three Characteristic Life values (or averages) and extrapolate the line back to the normal stress level.
18. Identify the expected Characteristic Life value (or average) for the reliability of the component for this failure mechanism at the normal stress level.
19. Solve for the missing parameters in the Stress-Life Model from the regression line generated previously. See Section 4.5.
20. Utilize the parameters solved for in the previous step to complete the Acceleration Factor Equation.
21. Transpose the six individual data points obtained by accelerated testing to the expected time to failure at the normal stress level using the Acceleration Factor Equation.
22. There will be a different Acceleration Factor for each accelerated stress level used (three stress levels results in 3 different acceleration factors).
23. The remaining analysis of the transposed data should be viewed as if all six devices were tested to failure at the normal stress level.
24. Apply Weibull Analysis to the six transformed data values and include the “best fit” Weibull plot line.
25. Identify the Reliability of the component for this failure mechanism at the cycle or time requirement.
26. Additionally, confidence bands can be applied to the Weibull plot to express the statistical uncertainty of the Reliability estimate. Generally, General Motors uses the reliability value identified by the best-fit line. This is often referred to as the 50% lower-one-sided confidence value. Higher values of confidence will require the plotting of confidence lines. Seventy percent (70%) confidence is often used as “good engineering judgment”.

This process can be performed using appropriate software, which simplifies and quickens the analysis process. ALTA by ReliaSoft is a recommended software tool.

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4.4 Graphics Describing the Process.

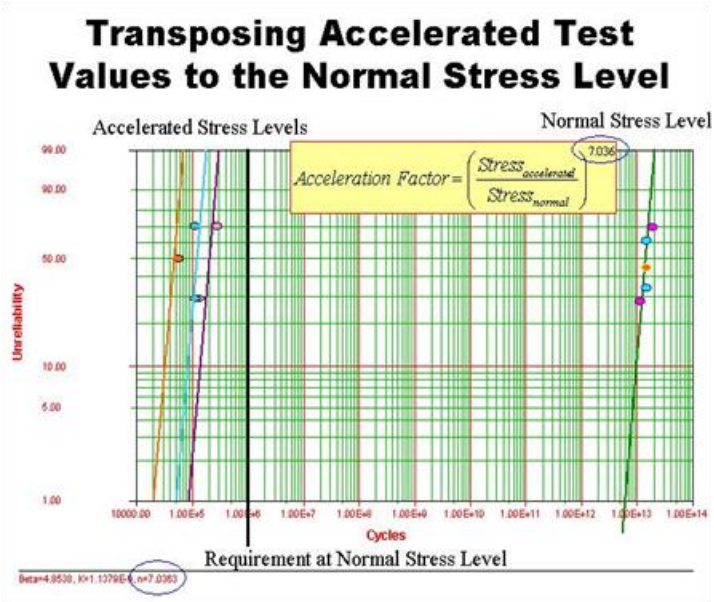

Figure 1: Use of Acceleration Factor

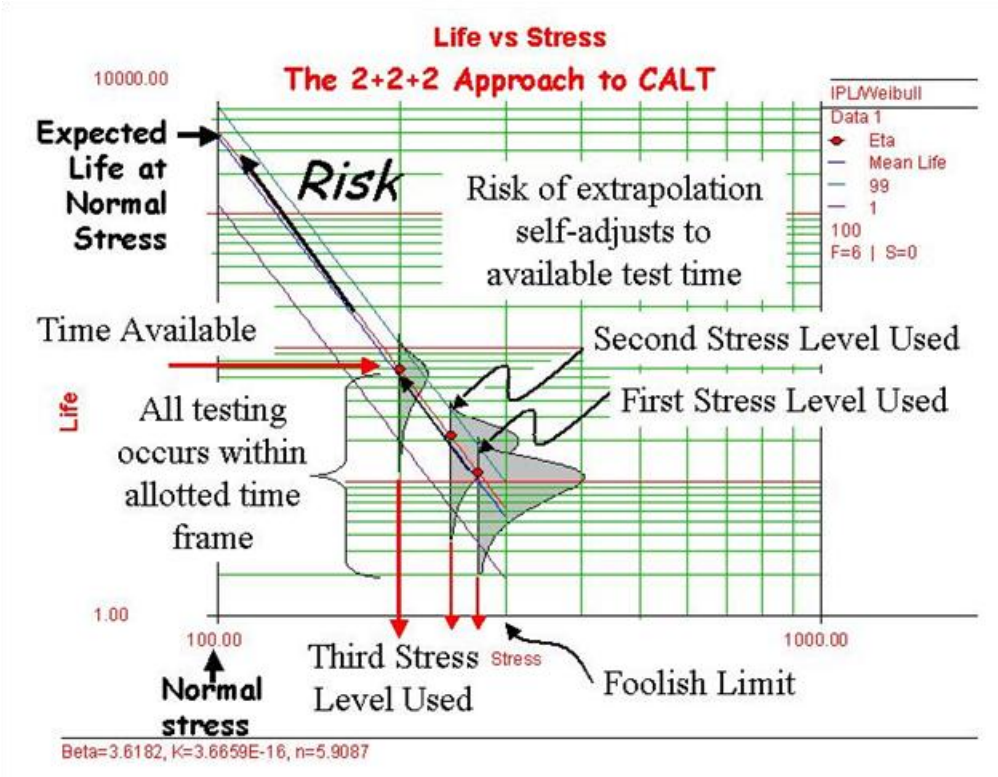

Figure 2: Extrapolating from Higher Stress Testing to Expectations at Normal Stress

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4.5 Parameter Solutions. The two basic Stress-Life models being considered are the Arrhenius model and the Inverse Power Law model. There are other models, which will not be discussed.

4.5.1 The Arrhenius Relationship. The Arrhenius Relationship is a physics based model where temperature induced diffusion-based phenomena is accelerated through manipulation of temperature. The Arrhenius life-stress model assumes that life is proportional to the inverse reaction rate of the process.

The basic equation is given as follows:

$$L(s) = C \times e^{\frac{B}{s}}$$

Where:

s = Stress (if temperature, then it must be in Kelvin)

***L*(*s*)** = Life as a function of stress

C = Unknown parameter

B = Unknown parameter

Taking the natural log of both sides of this equation yields the following:

$$\ln(L(s)) = \ln(C) + B \times \left(\frac{1}{s}\right)$$

This linearized relationship yields (B) as the slope of the stress-life line with ln(C) as the life axis intercept. The slope of the line (B) will appear negative on the plot (sloping downward to the right) even though in this equation it looks to be positive. This occurs because the x-axis variable is the reciprocal of the stress.

The plot of the Characteristic Lives (y-axis) versus one over temperature (x-axis) on log-linear graph paper will produce this linearized relationship. The y-axis is logarithmic (life) and the x-axis is linear (1/T). Quantifying the slope of the line on this plot will provide the value of (B).

The equation for the acceleration factor is used to translate the individual failure data points to a normal stress level. The acceleration factor and translating equation is as follows:

$$AF = e^{\left(\frac{B}{s_n} - \frac{B}{s_a}\right)}$$

$$Life_{normal} = AF \times Life_{accelerated}$$

Where:

S_n = Normal stress level

S_a = Accelerated stress level

The life value of each accelerated test data point is multiplied by this appropriately composed acceleration factor to perform the transpose process.

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