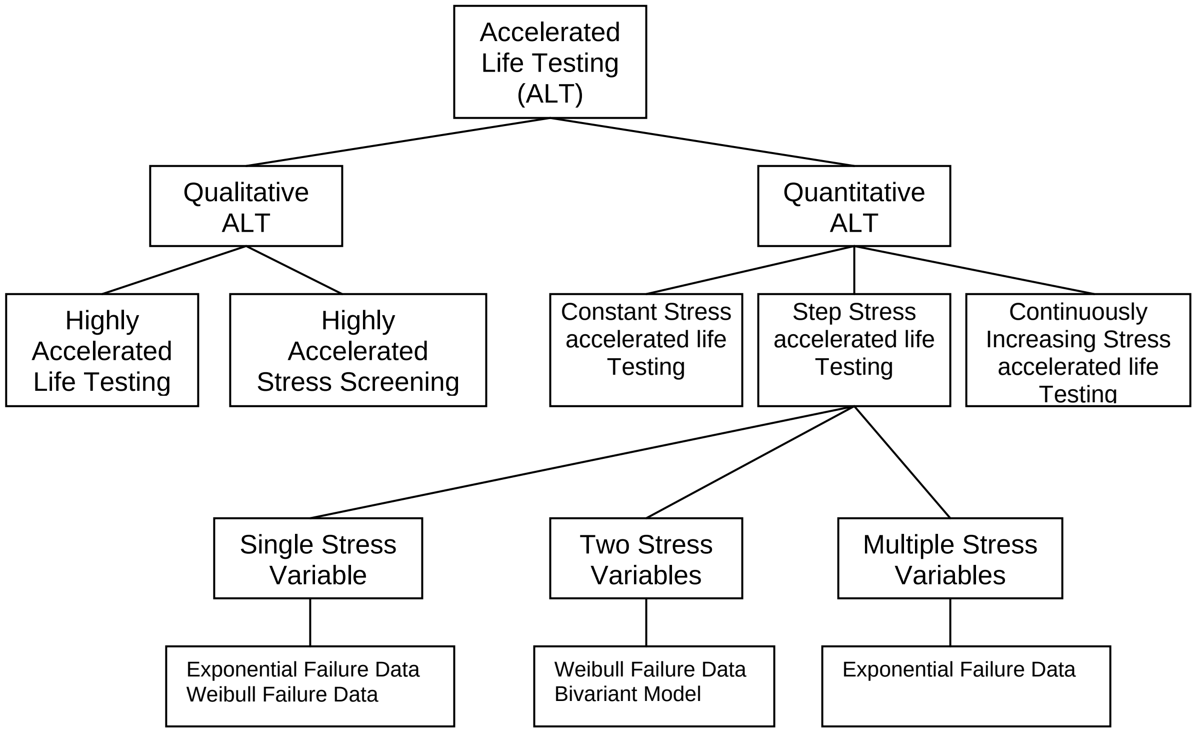
CHAPTER 14

STEP STRESS TESTING (SST)

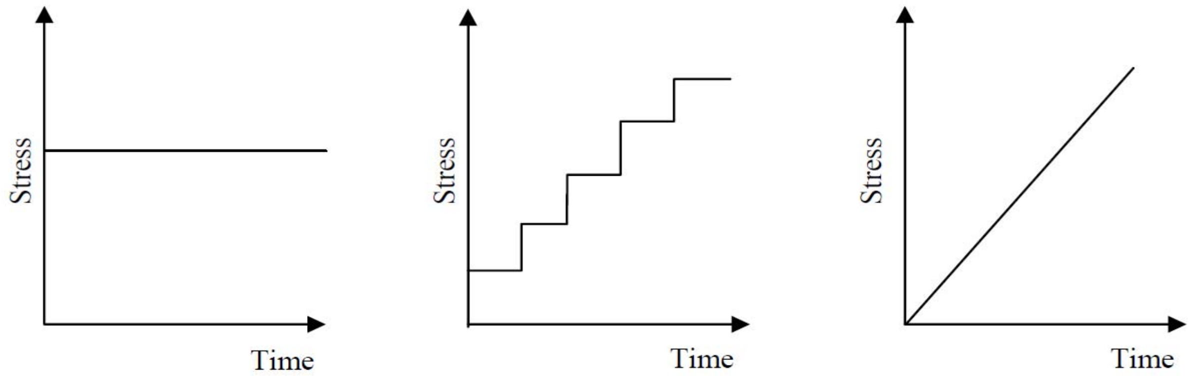
CONTENTS

1. INTRODUCTION

1.1 Accelerated testing is an approach for obtaining more information from a given test time than would normally be possible. It does this by using a test environment that is more severe than that experienced during normal equipment use. Step Stress Testing (SST) is one method of accelerated testing. The diagram below illustrates how SST aligns with other forms of accelerated life testing.



The diagrams below illustrate how the test stresses for the three main quantitative accelerated life testing methods are applied.



(a) CSALT (b) SSALT (c) CISALT

(a) CSALT = Constant Stress Accelerated Life Testing
(b) SSALT = Step Stress Accelerated Life Testing

(c) CISALT = Continuously Increasing Stress Testing

1.2 The primary purpose of SST is to identify at what point under a certain type of stress something fails. This principle can be applied to Banking and Internet systems as well as physical objects. For physical objects SST employs similar techniques to those used in Environmental Stress Screening (ESS), applying thermal, vibration, electrical, compression and tensile stress loads to components and assemblies. (See Part C Chapter 45 Environmental Stress Screening for the application and benefits of ESS).

1.3 Within the discipline of Reliability, SST can be used to explore functional performance beyond the specific boundaries i.e. the agreed or accepted maximum that the item will experience during its operational life. Understanding how tolerant the item is beyond the specific boundaries will provide a measure of confidence that the items will perform even if the manufacturing tolerances, material qualities etc. are all at the lower end of their performance parameters. The use of discreet steps will reveal if the part under test is able to withstand a level of stress or not. These results can then be used to inform reliability assessments. The need to understand failure or success beyond a specific boundary usually occurs when Robustness Testing reveals that there is only a small margin beyond a specific requirement. SST will help to inform if that margin is adequate enough to compensate or allow for manufacturing, assembly and usage margins (tolerances) therefore delivering a product that has a robust level of reliability.

Critical assumption – *the same failure mechanisms will be present at the higher stress levels and will act in the same manner as at normal stress levels.*

2. APPLICATION AND USE OF SST

2.1 This section discusses the argument for SST as a cost effective stage in developing reliable products. Like all stress screening techniques SST is expensive. The use of Highly Accelerated Life Testing (HALT) and Highly Accelerated Stress Screening (HASS) helps to reduce some of the associated costs. However, the benefits of SST need to be compared with the cost of testing and correcting, where necessary, a finished product. When the product is something like a complex weapon the process of testing the finished product can be a considerable proportion of the development cost (The cost of the test, the cost of the weapon itself and cost of the test facility – often a large test range). Therefore if there is a high degree of confidence in the product from design through to manufacture then end product testing will be more for validation and verification rather than product reliability growth.

2.2 The processes used in SST can vary but essentially one or a number of product samples are exposed to stress levels beyond their intended operating boundaries. If the product survives the test then it is exposed to a higher level of stress. This process is repeated as necessary to establish the stress value at which the product fails. The test can be terminated without any failures occurring (Fully Censored Test) once a level of confidence has been reached however, it is failure data that is required if extrapolations of product performance at normal stress levels is to be achieved. Variations in the SST process will create different arguments against the results. For example, if the SST process initially samples a number of items with those surviving the test going on to a higher stress test then the resultant findings will be different from testing new samples at the higher stress levels. The test procedures adopted and their value should be considered for each application.

2.3 For a fully censored test stress testing is based on pass or fail against a desired reliability goal. The test is designed around an hypothesis that a product has a given reliability with a given level of confidence. By calculation the number of test subjects that should fail at particular stress steps is determined before the test. The test can be stopped even if failures do not occur at or before the predicted levels. The precision of the test is determined by the number of items tested and number of failures during test.

2.4 The results obtained from SST can be used to predict the failure rate at normal operating conditions using a life-stress relationship model. The Arrhenius model can be used for temperature related prediction. Chemical reactions and changes vary with temperature. The Swedish chemist Svante Arrhenius developed a model that can be used to predict performance at a given temperature given the data for performance at elevated temperatures. This can and is used to predict temperature dependant failure mechanisms in semiconductor devices. A table of some of the models employed is provided below. Before using any of the models further research should be undertaken so that a full understanding of what the models inform on and their limitations is fully known.

Relationship	Used Condition	Model
Arrhenius Relationship	Used when the stimulus or acceleration variable (or stress) is thermal (i.e. temperature).	$\ln(L(V)) = \ln(C) + \frac{B}{V}$
Eyring Relationship	Most often used when thermal stress (temperature) is the acceleration variable, but also used for stress variables other than temperature, such as humidity.	$L(V) = \frac{1}{V} e^{-\left(A - \frac{B}{V}\right)}$
Inverse Power Law Relationship	Commonly used for non-thermal accelerated stresses.	$\ln(L) = -\ln(K) - n\ln(V)$
Temperature-Humidity Relationship	Often used when temperature and humidity are the accelerated stresses in a test.	$\ln(L(V,U)) = \ln(A) + \frac{\phi}{V} + \frac{b}{U}$
Temperature-Non thermal Relationship	Used when temperature and a second non-thermal stress (e.g. voltage) are the accelerated stresses of a test.	$\ln(L(U,V)) = \ln(C) - n\ln(U) + \frac{B}{V}$
General Log-Linear Relationship	Used when a test involves multiple accelerating stresses.	$\ln(L) = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \ldots + \alpha_n X_n$
Proportional Hazards Model	Widely used in the biomedical field and recently increasing application in reliability engineering for multiple accelerating variables.	$\lambda(t;\mathbf{X}) = \lambda_0(t) \cdot e^{\alpha_1 x_1 + \alpha_2 x_2 + \cdots + \alpha_m x_m}$

Where L represents a quantifiable life measure, V, U, X_i 's are the stress variables; λ is the failure rate, and $A, B, C, K, n, \phi, b, \alpha_i$ are unknown parameters.

2.5 Single, Two and Multiple stress variables can be employed. The advantages and disadvantages of each are tabled below.

	Advantages	Disadvantages
Single stress applied test	This is the most widely used method as it provide a clear indication of failures caused by the applied stress.	A combination of different stresses may have a greater effect than the results of single stress screening will reveal.

Two stresses applied test	Can provide information on the combined impact of two different stress loads - Interactions	Different stress steps and their interrelationship can make Interpreting results very complex.
Multiple stresses applied test	Cost and time can be reduced. Can provide confidence data for shorter lifted items. Fewer test samples needed	Very difficult to interpret the results to provide item life or reliability at normal stress levels. Requires high levels of rigor to provide quantitative outputs.

3. CONSTRAINTS AND LIMITATIONS OF SST

3.1 Testing will only inform on the performance of products subjected to test parameters. When these results are used in a model to extrapolate performance at different levels of stimulus or time interval the results will only be as good as the model employed. As with all models, they are only a model and not reality itself and therefore the limitations of the model must be understood if the modelling results are to usefully contribute to a product design or development.

3.2 An accelerated test model is derived by testing the item of interest at a normal stress level and also at one or more accelerated stress levels. Extreme care must be taken when using accelerated environments to recognize and properly identify those failures which will occur in normal field use and conversely those that are not typical of normal use. Since an accelerated environment typically means applying a stress level well above the anticipated field stress, accelerated stress can induce false failure mechanisms that are not possible in actual field use. For example, raising the temperature of the test item to a point where the material properties change or where a dormant activation threshold is exceeded could identify failures which cannot occur during normal field use. In this situation, fixing the failure may only add to the product cost without an associated increase in reliability. Understanding the true failure mechanism is paramount to eliminating the root cause of the failure.

4. FURTHER STUDY

4.1 **Publications**

Harris, C.M., Crede, C.E., "Shock and Vibration Handbook," McGraw-Hill, 1961.

Hopf, A.M., "Highly Accelerated Life Testing for Design and Process Improvement," Sound and Vibration, Vol. 27, No. 11, Pages 20-24, November 1993.

Keller, M.E., "HALT/HASS Pays Off in Product Reliability and Lower Costs," Test Technology Newsletter, January-February 1977.

Nelson, Dr. Wayne, "Accelerated Testing," John Wiley & Sons, 1990.

O'Shea, P., "HALT Can Shorten Time to Market," Evaluation Engineering, Vol. 35, No. 12, Pages 42-45, December 1996.

"Product Survey: Environmental Test Equipment - The Baffling World of HALT/HASS," Test & Measurement World, Vol. 16, No. 1, January 1996.

Optimal step-stress plans for accelerated life testing considering reliability/life prediction - Li Chenhua 2009.

4.2 Standards

IEC 60068-2-64: Environmental testing – Part 2-64: Test methods

EN 61163-1:2006 Reliability Stress Screening

BS/EN 60749 Semiconductor devices - Mechanical and climatic test methods -

JEDEC JESD47I Stress-Test-Driven Qualification of Integrated Circuits

MIL-STD-781C Environmental Tests.