THE RELIABILITY ENGINEER PRIMER

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IT IS A TEST OF TRUE THEORIES NOT ONLY TO ACCOUNT FOR BUT TO PREDICT PHENOMENA

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Development Testing

Testing and Modeling are reviewed in the following topic areas:

- **Testing**
  - **Accelerated Life Tests**
  - **Stress Screening**
  - **Qualification Testing**
  - **Degradation Testing**
  - **Software Testing**
- **Modeling**
  - **Block Diagrams**
  - **Physics of Failure**
  - **Failure Models**
  - **Prediction Methods**
  - **Design Prototyping**

Accelerated Life Tests

Accelerated life testing (ALT) is used to obtain performance data on devices or components at a quicker rate through higher stresses than normal. The resulting failure data provides information that is extrapolated to obtain the desired estimate at a future time, t, and at normal operating conditions. This is especially important if a high reliability device is being tested. Very few or no failures will occur at the design stress levels and the duration for failures is quite long.

Elsayed (1996)[11] describes two generic methods for ALT:

- The first is to use the device or unit under test more intensively than in normal use, i.e., a keyboard may be used an estimated 4 hours per day for about 250 days per year. If it is rated for normal use at 5 years, (about 5000 hours), then the ALT would conduct a 5000 hour test within a compressed time frame.

- When time compression is not possible, higher stress levels are used. It is assumed that there will be a linear relationship from the higher stress levels to normal conditions, i.e., if a video monitor has a normal operating temperature of 85°F, an ALT at 200°F will cause components to fail earlier.

The results of ALT are then correlated to normal operating conditions using an appropriate statistical model.

Accelerated Life Tests (Continued)

The *Reliability Toolkit* (1993)[40] provides more benefits for ALT:

- **To save time and money**
- **To quantify the relationship between stress and performance**
- **To identify design and manufacturing deficiencies**

There may be some problems using ALT:

- **The stress data may not match up with normal operating conditions**
- **The devices are damaged by high stress testing**
- **Test failures are not related to field failures (new failure modes)**

It is best to use ALT in the development stage of a new device or component. The design phase is the best time to make easy changes in the device.

***Blueprints for Product Reliability*, RBPR-5 (1996)[6] notes the following necessary assumptions about ALT:**

- **The failure modes uncovered at higher stress must be the same failure modes as at the normal operating levels. If it is not, then the higher stress level testing does not have a valid linear relationship. ALT is, thus, limited to parts and not useful for full product assemblies.**
- **The stress used will accelerate the action of the failure mode that is dominant at the normal operating condition.**
- **The same statistical model of failure will be true for use at the normal and accelerated conditions.**

In ALT, the collection of data at different stresses will provide a means of determining correlation factors. Hopefully, a plot of the data will indicate some correlation. The plots could be exponential, Weibull, lognormal, Rayleigh, or log-log.

Accelerated Life Tests (Continued)

Figure 7.1, illustrates that collected test data will approximate straight lines and are parallel. Several trials may be required to find the proper distribution. Once found, the assumption must be made that there is correlation from the highest stress to the lowest stress levels. A desired life measurement is chosen for plotting. The 10th percentile is often used for the minimum operating life calculation. The plot of these points will extrapolate back to the expected life at normal conditions as shown in Figure 7.2.

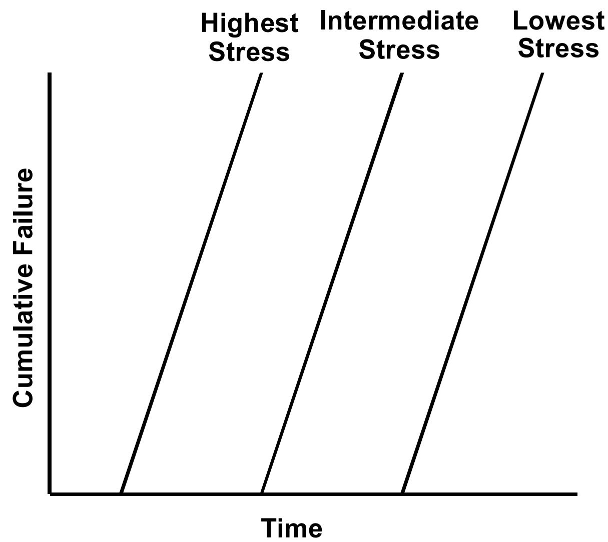

Figure 7.1 A Hypothetical ALT Schematic

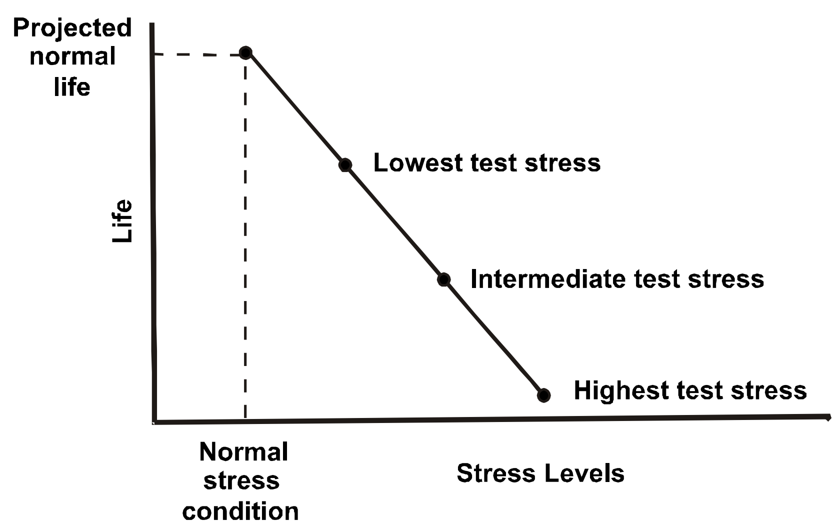

Figure 7.2 A Schematic Showing ALT Extrapolation to a Projected Normal Life

Accelerated Life Tests (Continued)

Blueprints for Product Reliability RBPR- 4 (1996)[6] provides the following additional planning guidelines for ALT:

- Test units must be identical to the final product
- One accelerating stress factor is applied at a time
- Stress levels must cause failure modes identical to those found under normal operating conditions
- Accelerating stress levels do not exceed maximum component design

Meeker (1985)[25] lists these basic ALT concepts:

1. Establish as the high stress the most extreme condition where the model can still hold true.
2. Conduct tests at 2 or more stress levels, where at least 20% of the test units will fail.
3. Conduct tests at the lowest level (as close to the normal operating conditions as possible) which will still yield some failures (at least 5 failures).

Meeker (1982)[25] presents several plans for ALT, which includes different distribution of test units among the stress levels. That is, given 150 units to test, and 3 stress levels, it might be good test sense not to test 50 units at each level, but to allocate more units at the lowest stress level. This allows for more test data to be nearest the normal operating stress level. It should be noted that the number of test units is predetermined by economics, production, schedules, and other considerations.

The *Reliability Toolkit* (1993)[40] recommends that for 20 available test units, a minimum of 3 units should be tested at the highest stress level. If fewer than 10 units are available for testing, design the testing for only 2 stress levels.

Accelerated Life Tests (Continued)

Elsayed (1996)[11] classifies three models for analyzing ALT:

1. **Statistics-based models (parametric and nonparametric). The failure times at each stress level are used to develop or determine the appropriate distribution model. The distribution model is assumed to be the same at all stress levels. When the failure time probability distribution is unknown, nonparametric models are used. Distributions include:**

   Parametric models

   - **Exponential**
   - **Weibull**
   - **Rayleigh**
   - **Lognormal**

   Nonparametric models:

   - **Linear, multiple regression model**
   - **Proportional-hazards (hazard rates are proportional at different stresses)**

2. **Physics-statistics models. The applied stresses have a direct effect on the units under test. i.e., temperature on the physical and chemical properties of the test units. The models include:**

   - **Arrhenius model**
   - **Eyring model**
   - **Inverse power rule model**
   - **Combination model (Arrhenius and inverse power rule)**

3. **Physics-experimental-based models. The failure times can be estimated based on the physics of failure on a theoretical basis or through the conduct of experiments. The reader is referred to Elsayed (1996)[11] for more details. The models include:**

   - **Electromigration model**
   - **Humidity dependence failures**
   - **Fatigue failures**
   - **Degradation models (resistor, laser, hot-carrier)**

Step-Stress Testing

The previous accelerated life tests involved a unit under test at higher stress levels, but at a fixed level. Step-stress testing places the unit at normal level and gradually increases the stress until failure. The stresses are applied in stepwise sequence. The units are operated for a short time span in a sequential progression. The test should include enough time to permit failures. The probability plot of the data can be determined. Multiple incremented stresses can be used in the test. The testing continues until all the units have failed. (*Reliability Toolkit*, 1993)[40]

The step-stress failure plot has a much higher slope than ordinary life data. It also has additional variables compounded into the test, making statistical analysis less meaningful. The design should provide for a failure free stress life greater than the design life. Thus, the test can be used to confirm that the design is correct. The testing should not introduce failure modes not seen at normal or expected operating conditions. Interactions may occur between main stresses that would not have occurred when tested separately. Designed experiments may be required to further probe these interactions. (O'Connor, 2002)[37]

Example 7.1: Nikonx is introducing a new tennis racket. The racket is made of high strength composite materials. A reliability of 95% must be demonstrated under test conditions of minimum power impact (200 ft-lbs) and 10 repetitions for a 20 minute period. A test plan, with n = 10, records the time of failure, stress, and number of repetitions. Table 7.3 summarizes the resulting test information, including the median rank for Weibull plotting.

Failure No.	Median Rank	Time (min)	Stress	
			ft-lbs	reps
1	6.73%	7	270	170
2	16.35%	9	290	190
3	25.96%	9	290	190
4	35.58%	10	300	200
5	45.19%	11	310	210
6	54.81%	12	320	220
7	64.42%	14	340	240
8	74.04%	15	350	250
9	83.65%	16	360	260
10	93.27%	17	370	270

Table 7.3 Nikonx Test Plan

Step-Stress Testing (Continued)

Example 7.1 (Continued):

The median rank is determined via the Erto formula:

$$\text{median \%} = \frac{i - 0.3}{n + 0.4} \times 100\% \qquad \text{(McLinn, 1996)}^{24}$$

Where: I = failure rank and n = total number of failures. Using Weibull probability paper, a plot can be made of the median ranking percent versus the stress. The resulting computer generated plot, Figure 7.4, follows.

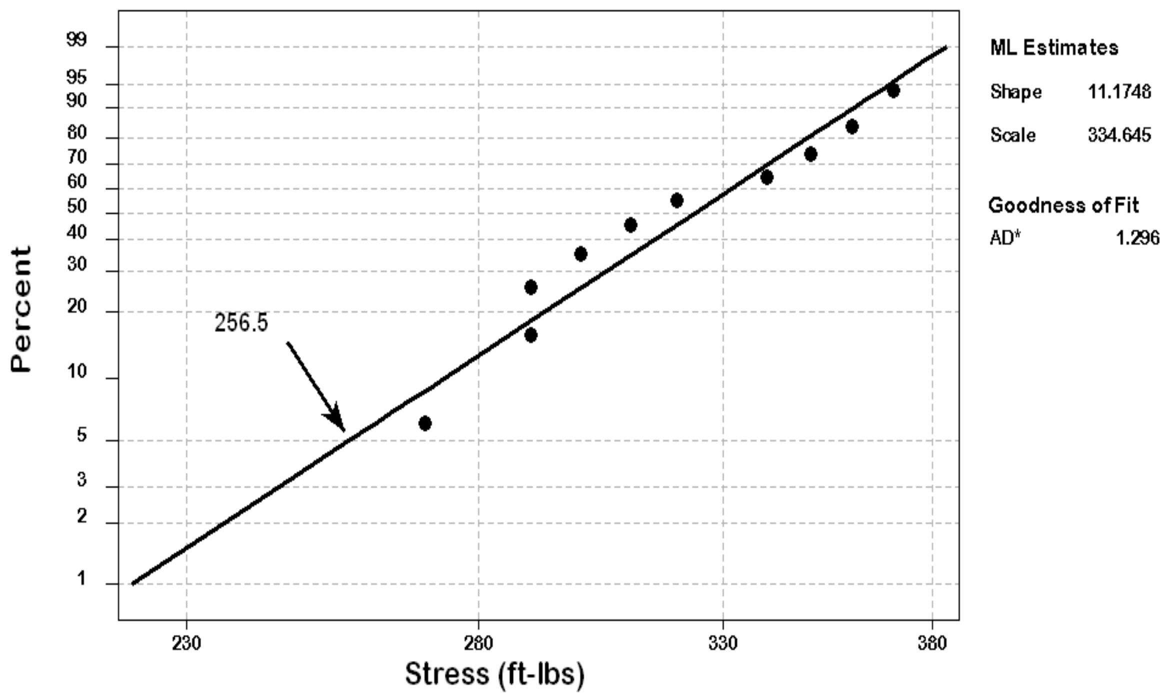

Figure 7.4 Weibull Distribution Plot

The maximum likelihood estimates line has a steep slope. The shape, beta, is 11.1748, indicating the test was conducted in the failure range (which was desirable). An Anderson-Darling test (AD)* for data point fit is 1.296, which is relativity small and acceptable. The 5% life data point is at 256.5 ft-lbs (from the Minitab printout). The scale, alpha, is at 334.645 ft-lbs (where 63.2% of the failures have occurred). The desired reliability is at least 95%. Thus, the tennis racket design meets the desired stress conditions.

Discovery Testing

Discovery testing involves those tests that are used to "discover" the weak links in a unit or assembly. It is typically used early in development cycle. Weaknesses are discovered through the use of aggressive conditions above those expected in service. This is a powerful way to improve unit reliability by aiding the design effort. Discovery testing is not used to determine MTTF as no significant data is generated about typical service conditions. Discovery testing techniques include the following:

- Margin tests
- Sample size of 1
- HAST (highly accelerated temperature and humidity stress test)
- HALT (highly accelerated life testing)
- HASS (highly accelerated stress screening)

Information on HASS is presented later in this Section.

Margin Tests

Safety margins have been used for centuries to attempt to account for variability in materials and service stress conditions. Margin tests are used to verify that a safety margin is actually present.

One early example of a safety margin test was the proof firing of cannons. It was an accepted practice to test fire cannon after casting using a greater load of powder than the cannon would expect in later service. Unfortunately, early cannon designers didn't understand the concept of crack propagation and sometimes cannons exploded in service anyway. Nevertheless, a test of design safety margins is a valuable and accepted practice.

Margin tests are usually performed on a limited number of samples using one variable at a time. For instance, if the variable under test is temperature, the test would involve operating the unit(s) at a temperature equal to the maximum temperature plus some safety margin. This is typically done for only a short period of time.

If the unit survives and operates during the elevated temperature test the design/safety margin has been demonstrated. Note that it is not necessary to drive the variable until the unit fails.

