ReliaSoft

Understanding Accelerated Life-Testing Analysis

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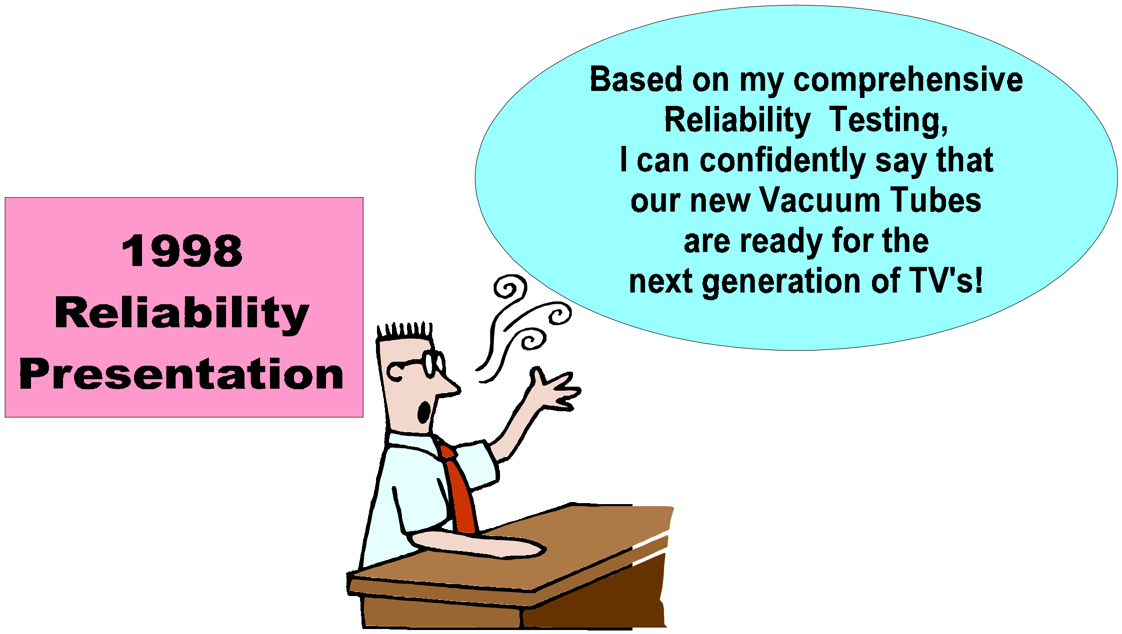
RAMS 2002

Accelerated Testing



- No one can realistically wait years to see how things really turn out.

Types of Accelerated Tests

- ESS and Burn-in
- Qualitative Tests
- Quantitative Tests

ESS (Environmental Stress Screening)

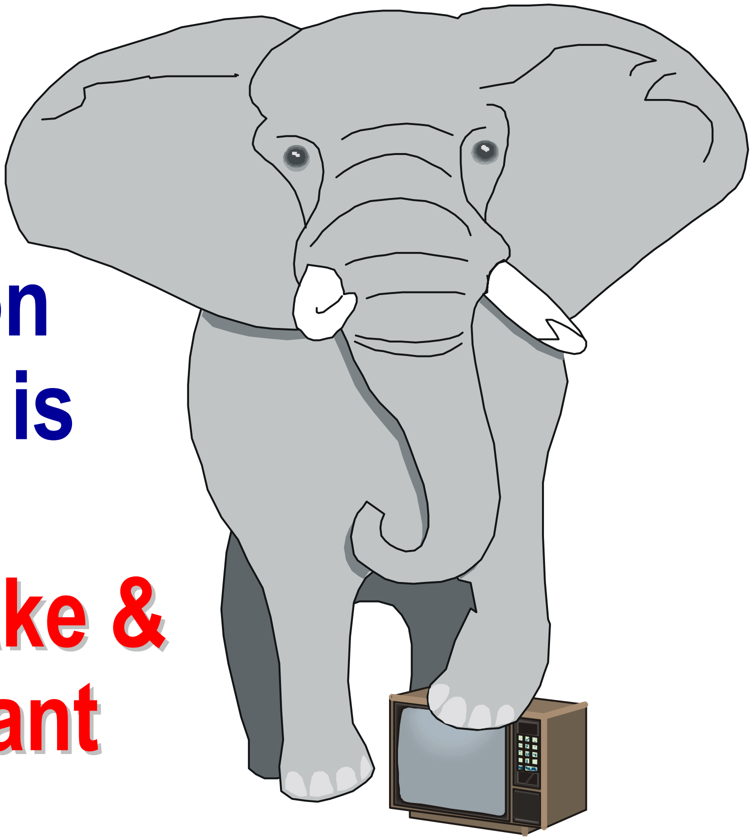
- A process involving the application of environmental stimuli to products
- The goal of ESS is to expose, identify and eliminate latent defects which cannot be detected by visual inspection or electrical testing but which will cause failures in the field.
- ESS is performed on the entire population and does not involve sampling.

Burn-in

- Burn-in can be regarded as a special case of ESS.
- According to MIL-STD-883C, Burn-in is a test performed for the purpose of screening or eliminating marginal devices.
- Marginal devices are those with inherent defects or defects resulting from manufacturing aberrations which cause time- and stress-dependent failures.
- As with ESS, Burn-in is performed on the entire population.

Accelerated Testing: Qualitative Tests

- An accelerated test that yields Failure Information (or Failure modes) only, is commonly called a Qualitative Test (or Shake & Bake Test, HALT, Elephant Test, etc.) .



Accelerated Testing: Qualitative Tests

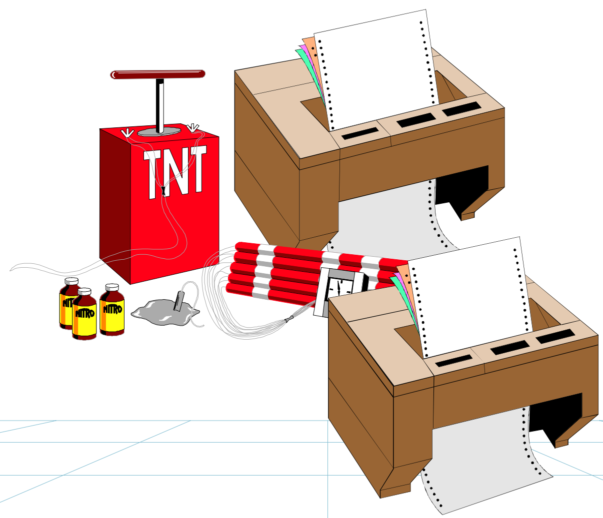
- Overstressing of products to "*quickly*" obtain failures is perhaps the oldest form of Reliability Testing.

No Life (Reliability) Information is usually obtained!

What are Qualitative Tests?

Torture tests are performed on small sample sizes and the specimens are subjected to a harsh environment (i.e. severe levels of stress).

- If the specimen survives, it passes the test.
- Torture test data cannot usually be extrapolated to use conditions.



Qualitative Test

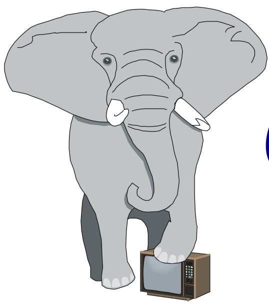
Benefits

- Increase Reliability by revealing probable failure modes.

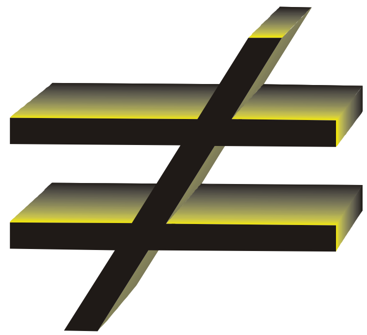
Unanswered Questions

- What is the Reliability of the Product?
- Are the failure modes the same as the ones that will occur during the life of the product under normal use?

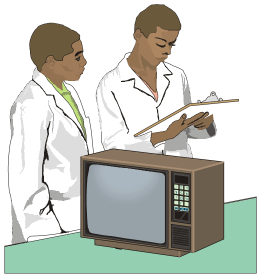
Quantitative Accelerated Life Testing



Qualitative or Torture Test



*Accelerated Life Test**



- Quantitative Accelerated Life Testing, unlike the Qualitative Testing, is designed to provide Reliability Information on the product, component or system.

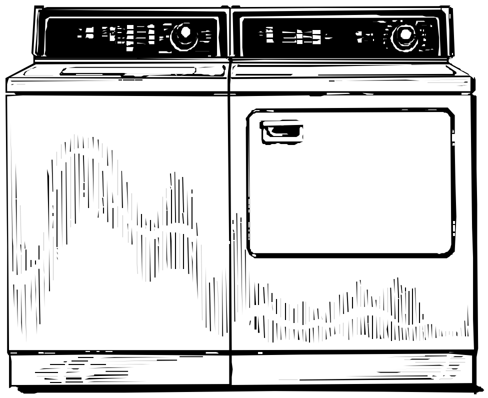
**in the context of this tutorial*

Data Needed: Time-to-failure Data

- Time-to-failure can be in any quantitative measure, such as hours, days, cycles, miles, actuations, etc.

“Usage Rate Acceleration” or “Continuous Use Acceleration”

- Easiest and most common form of Accelerated Life Testing is “Continuous Use Acceleration.”



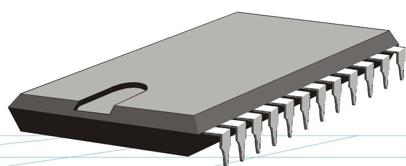
Average Use = 10 hours a week!

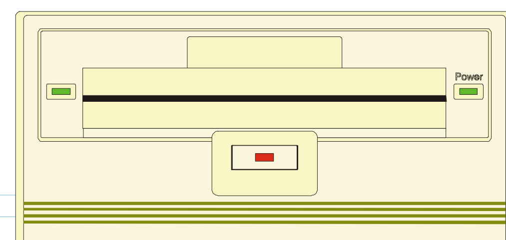
1 Week = 168 hr

Possible Acceleration Factor = 16

The Problem with “Continuous Use Acceleration”

- How do you accelerate “High Usage” products?
  - Many products have a very high (even continuous) usage rate such as TV’s, computers, electronic devices, etc.



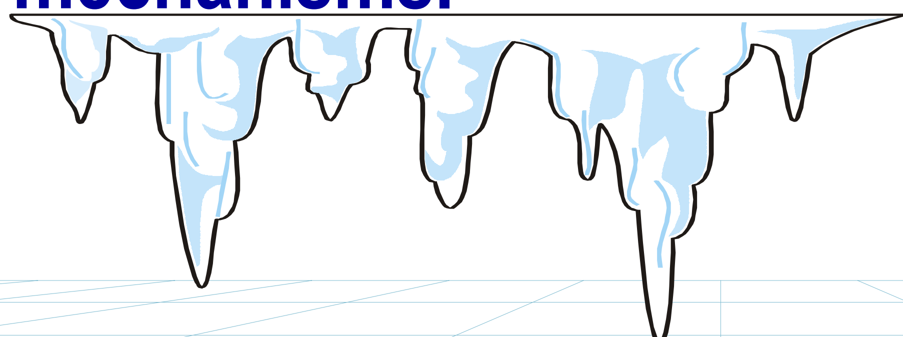


Accelerate High Usage Products?

- Perform a life test in which stress levels exceed the actual use conditions in order to accelerate the cause(s) of failure. **Use this Accelerated Life Test data to extrapolate to use conditions.**

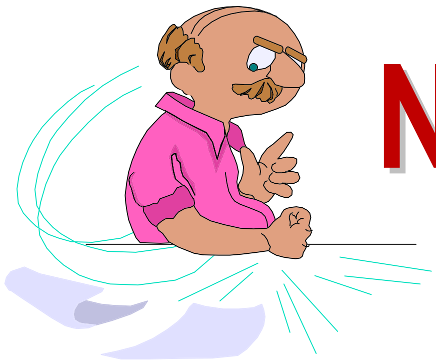
Overstress Acceleration -Acceleration Via Higher Stresses-

- Accelerated tests can be performed at elevated temperature, humidity, voltage, pressure, vibration, etc., or in a combination manner, in order to accelerate the failure mechanisms.



Stress Levels

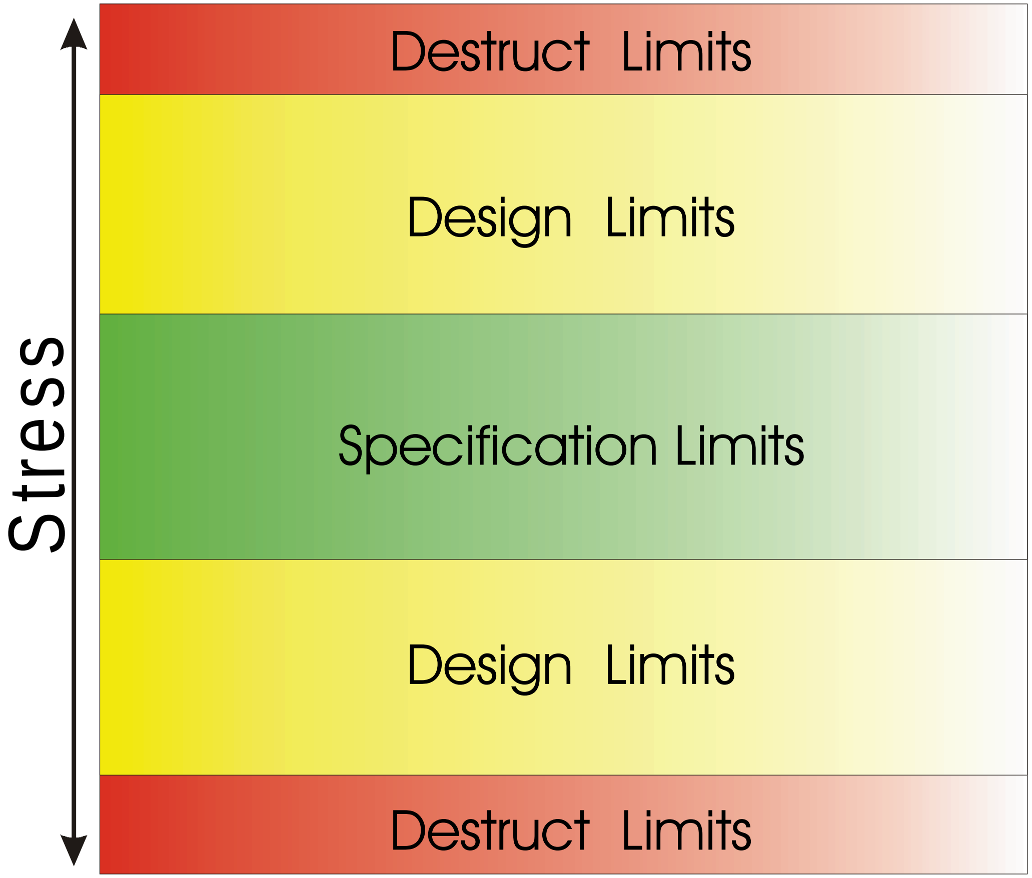
- The test stresses should be chosen so that they accelerate the failure modes under consideration.
- Test stress levels should be chosen so that they do not introduce failure modes that would never occur under use conditions (i.e. material phase change).



No Free Lunch

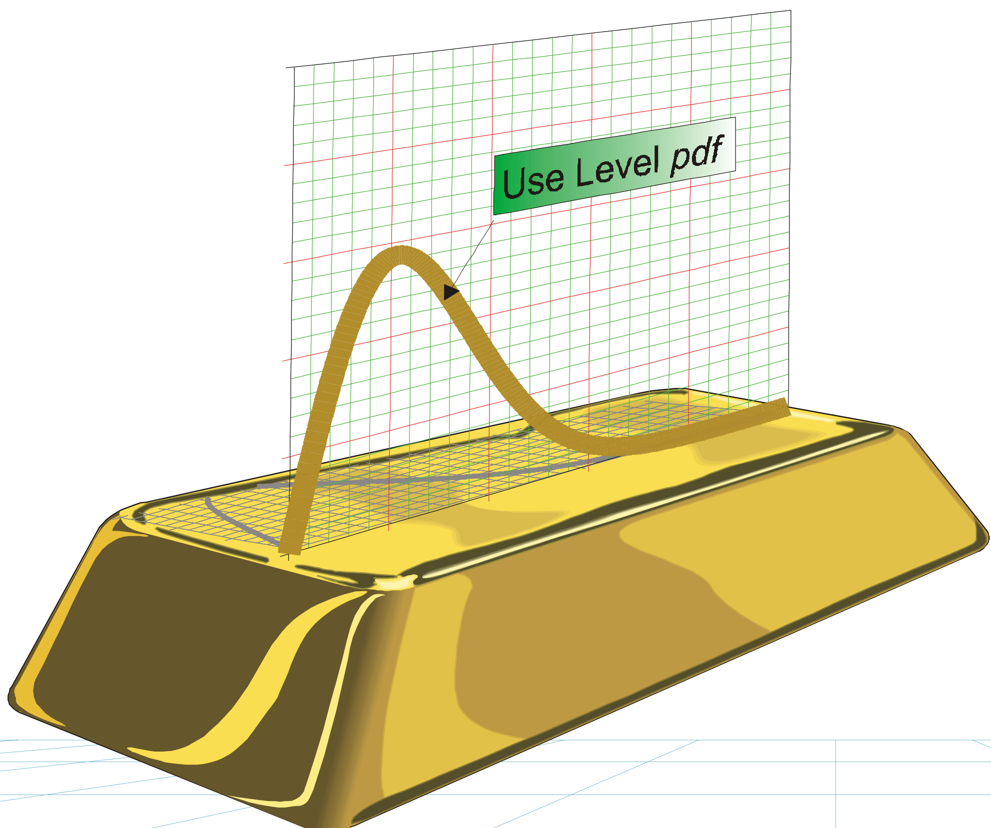
- Stress levels must be high “enough” so that enough failures are observed within the allowable testing time.
- The higher the accelerated stress from the operating stress, the greater the uncertainty of the extrapolation.

Stress Levels



Understanding Accelerated Life Test Analysis

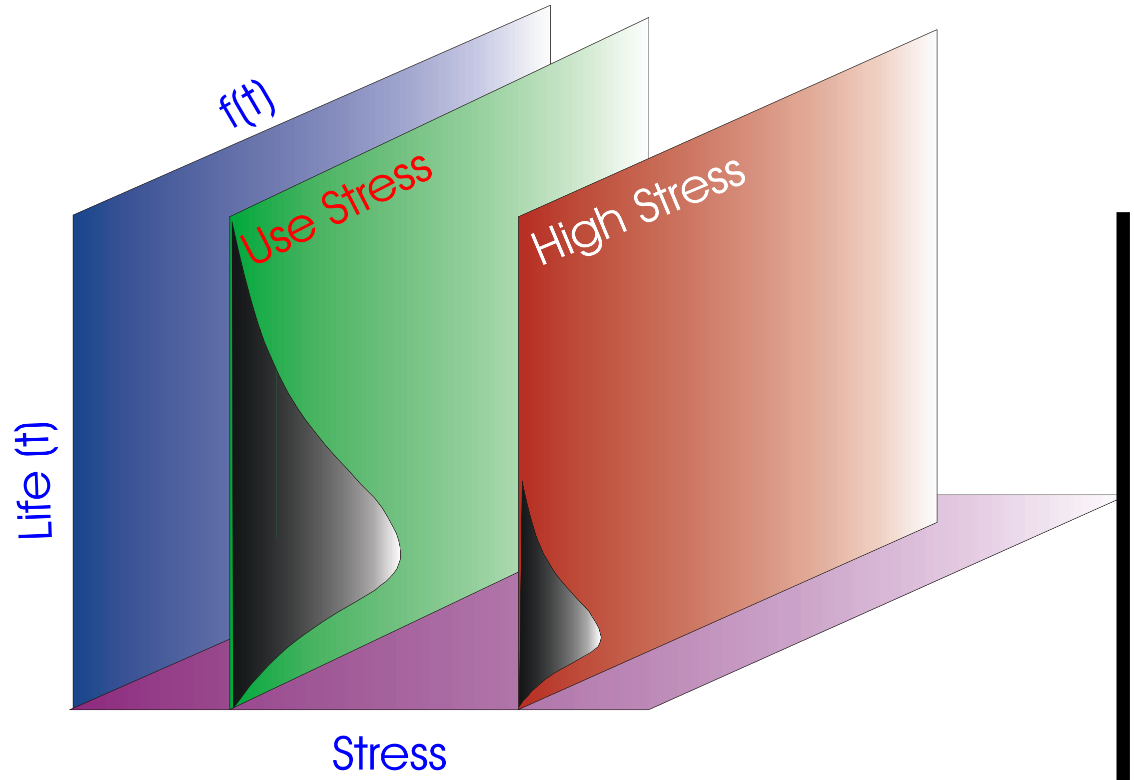
- Estimate life distribution of the product in a shorter time.

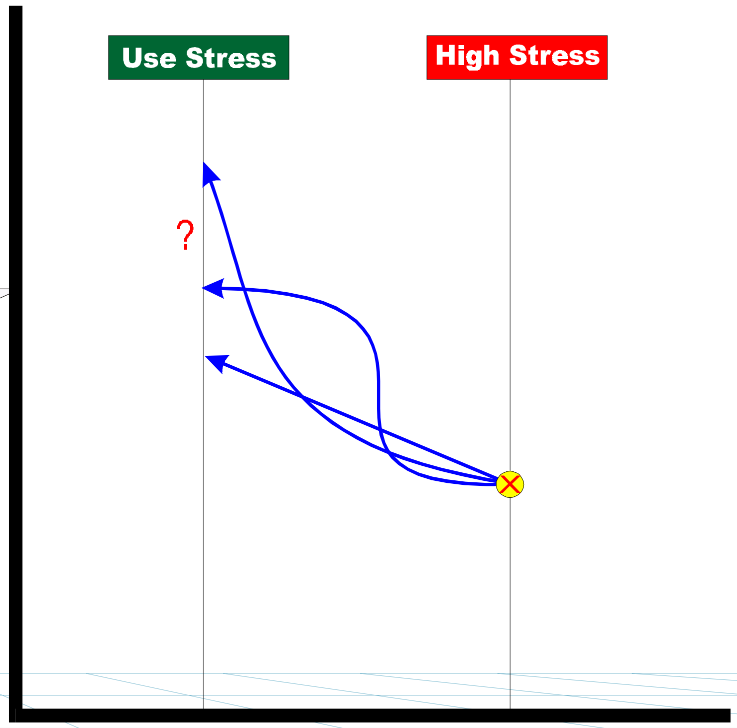


- •Percent failing under warranty
- •Assess risk
- •Compare designs
- •Determine wear-out period (product performance degradation)

Understanding ALT

-Looking at a Single Constant Stress ALT-

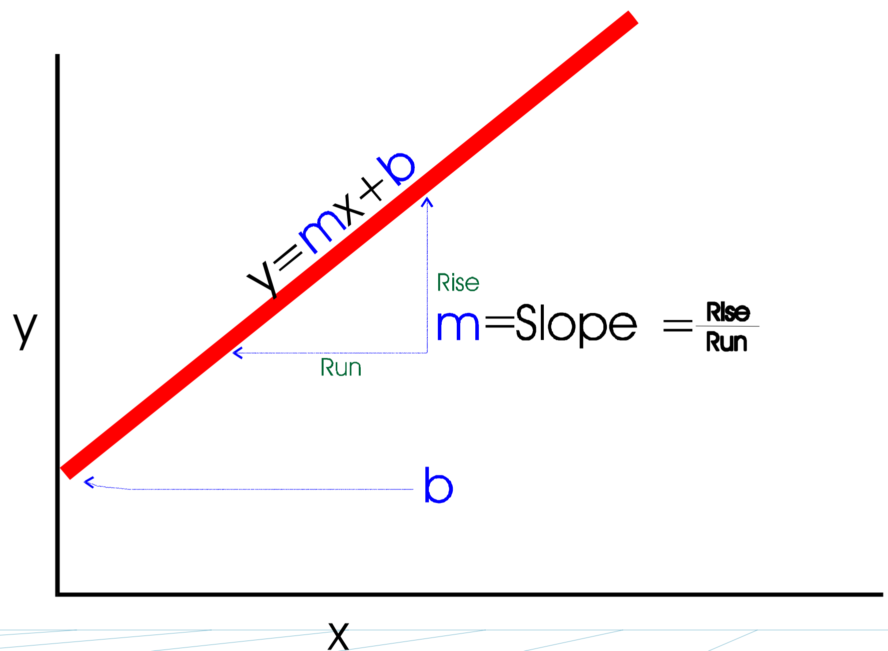




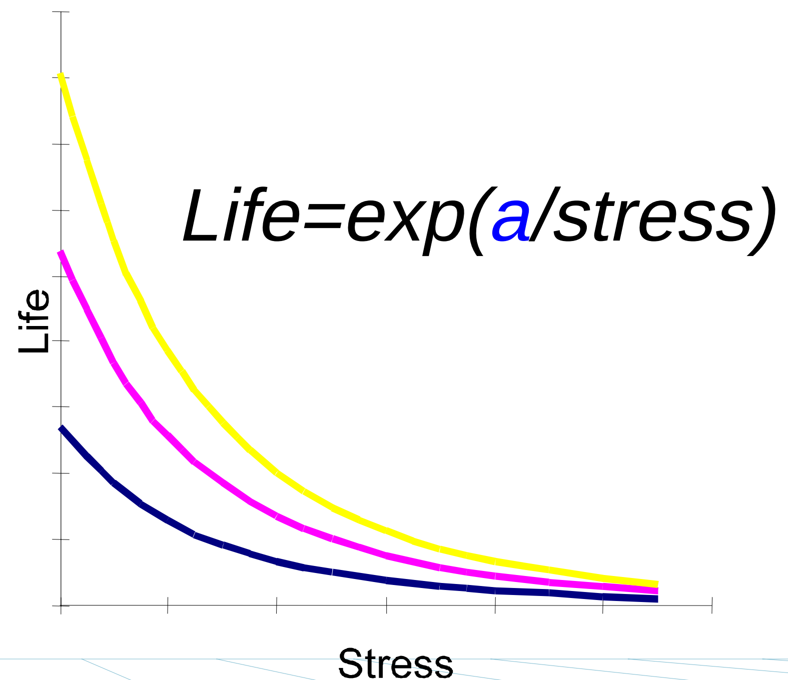
Determine a Relationship between "Test Stresses" and the "Use Stresses"

- Use a Mathematical Model to describe the relationship *(Y=mx+b is a simple Linear Model).*

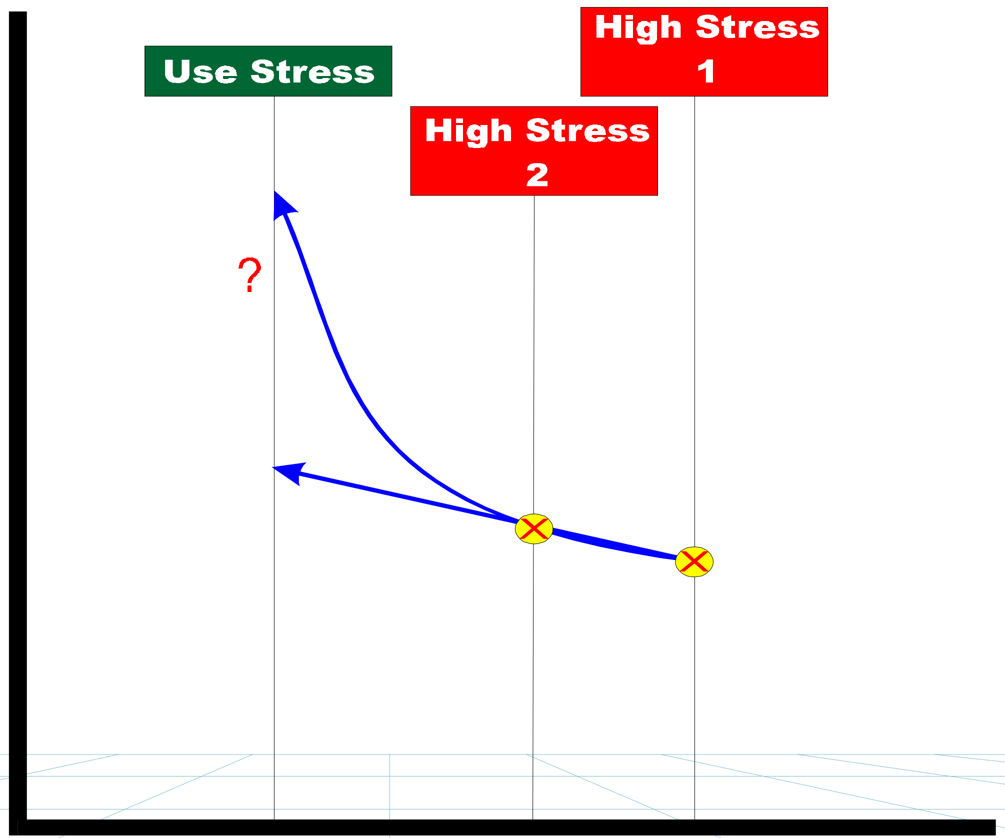
A Linear Relationship



An Exponential Relationship



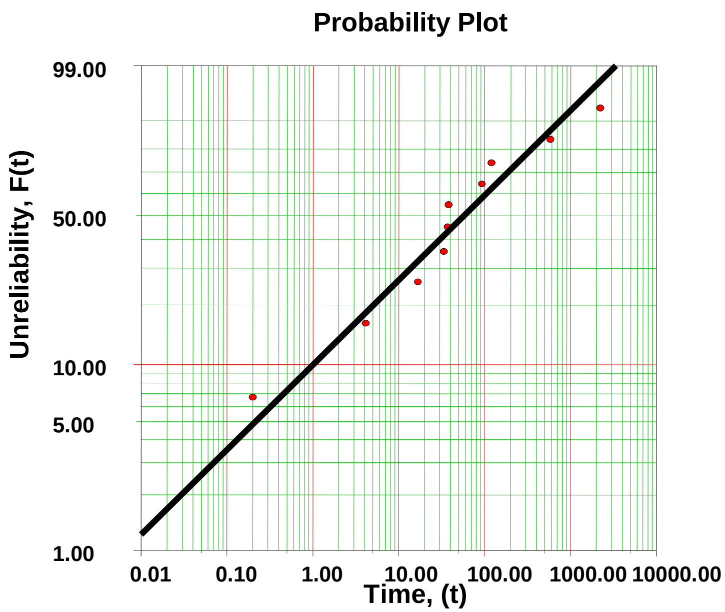
- The more points we have, the better off we are in correctly determining the Life-Stress relationship (fitting the model to our data).

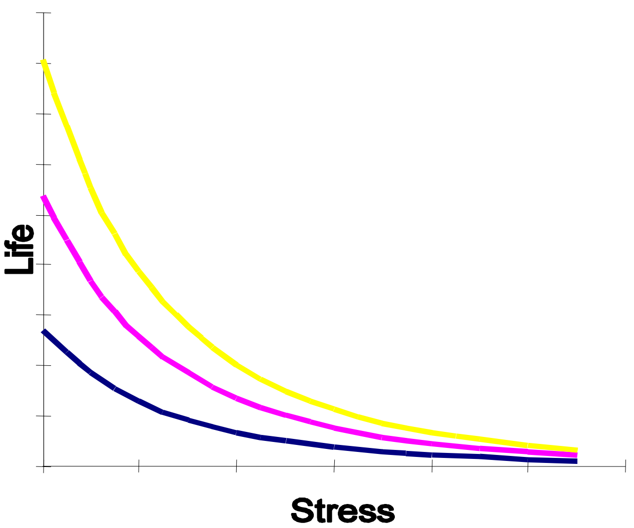


Overview of the Analysis Steps

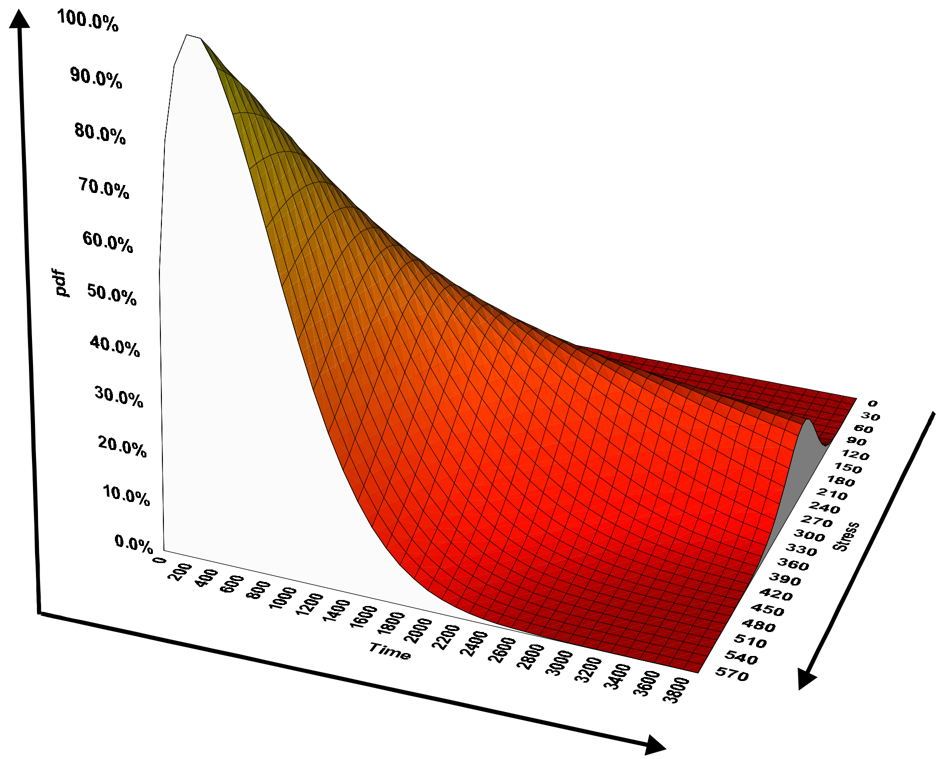
Accelerated Life Models usually consist of:

- A Life Distribution (i.e. Weibull)
- Life-Stress Relationship(s).





pdf vs. Time vs. Stress Relationship

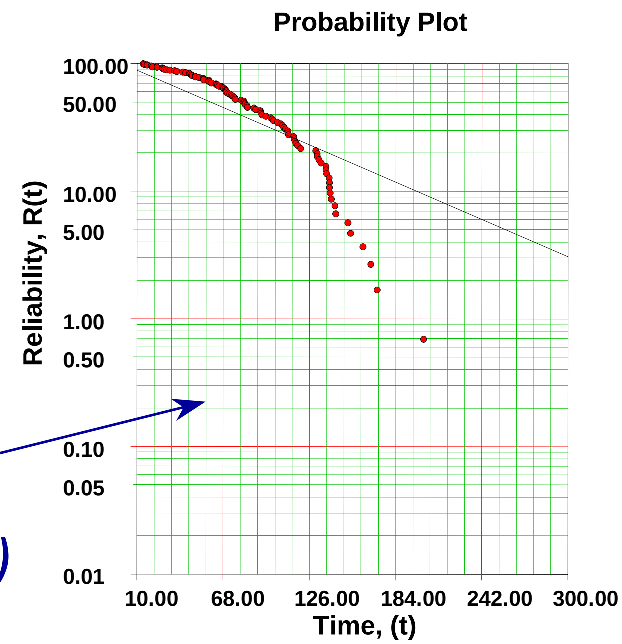


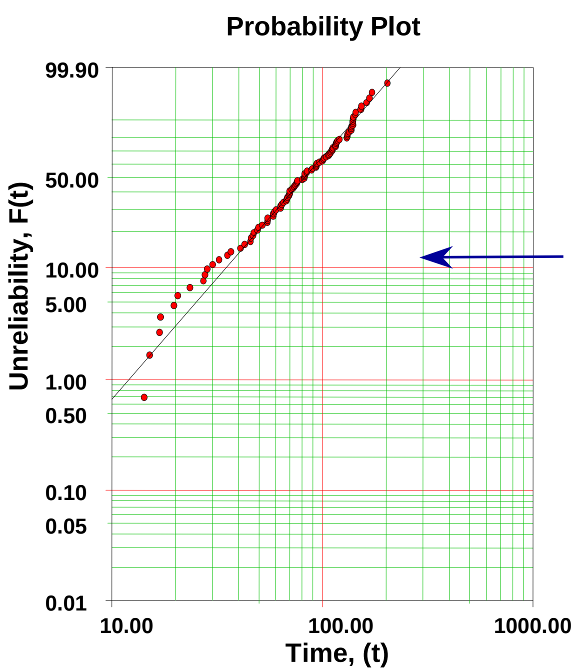
Data

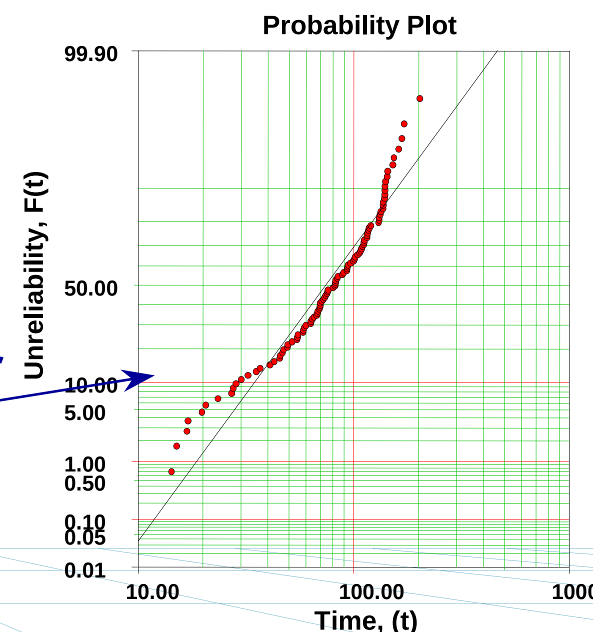
- Life (times-to-failure) data is obtained from in-house accelerated testing.
- Obtain data on the stress(es) used.
- Obtain data on the stress(es) the product will encounter under normal use conditions.

Life Distribution

- Choose an appropriate Life Distribution
  - **Exponential** *(rarely appropriate but easy to use!)*
  - **Weibull** *(appropriate for most uses)*
  - **Lognormal** *(appropriate for most uses)*

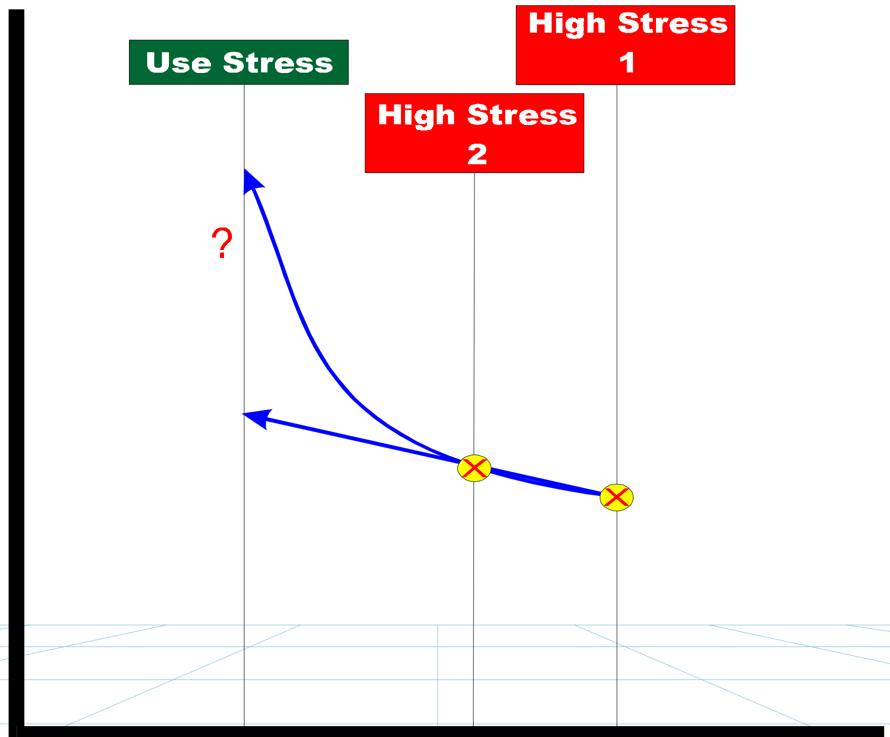






Stress-Life Relationship

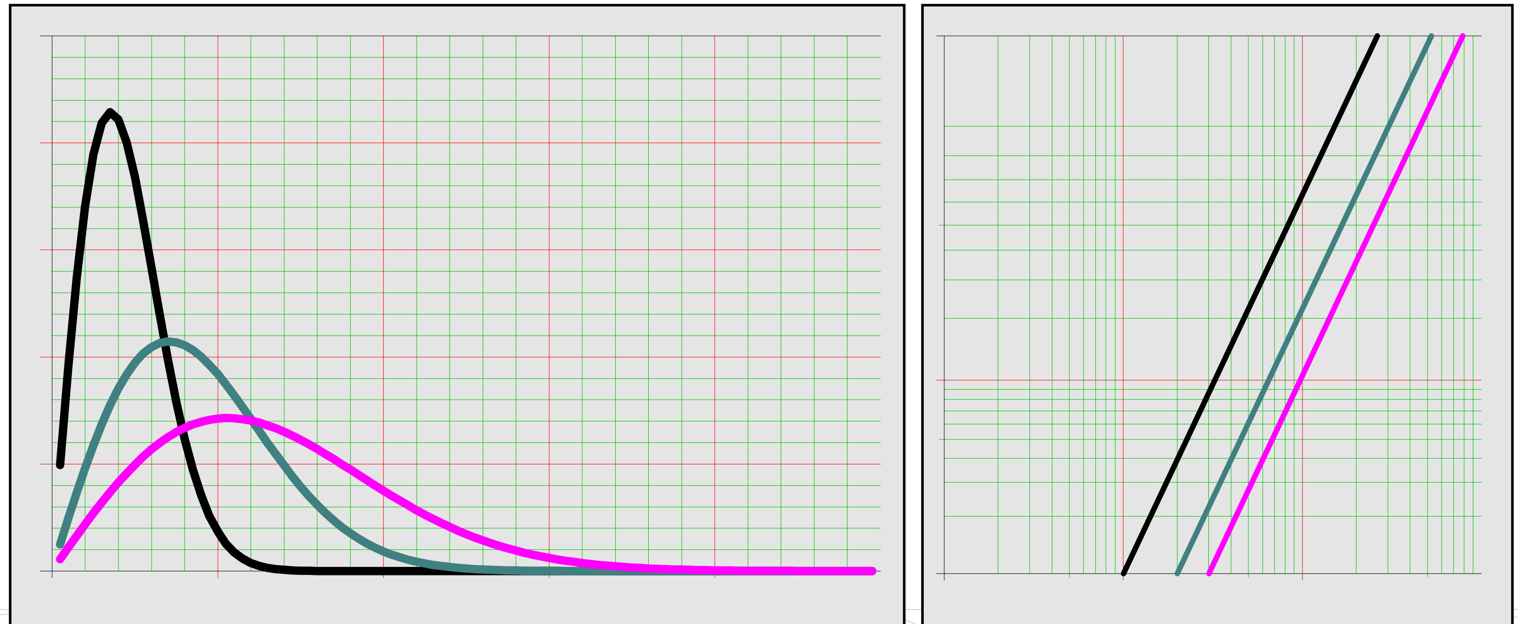
- Select (or create) a model that describes a characteristic of the distribution from one stress level to another.



What Distribution Characteristic?

- **Life Characteristic, Distribution Parameter, etc.** *(Mean, Median, R(x), F(x)*, ***λ, β, η, μ, σ)***

*Weibull Distribution with **η(s)** as a function of stress*

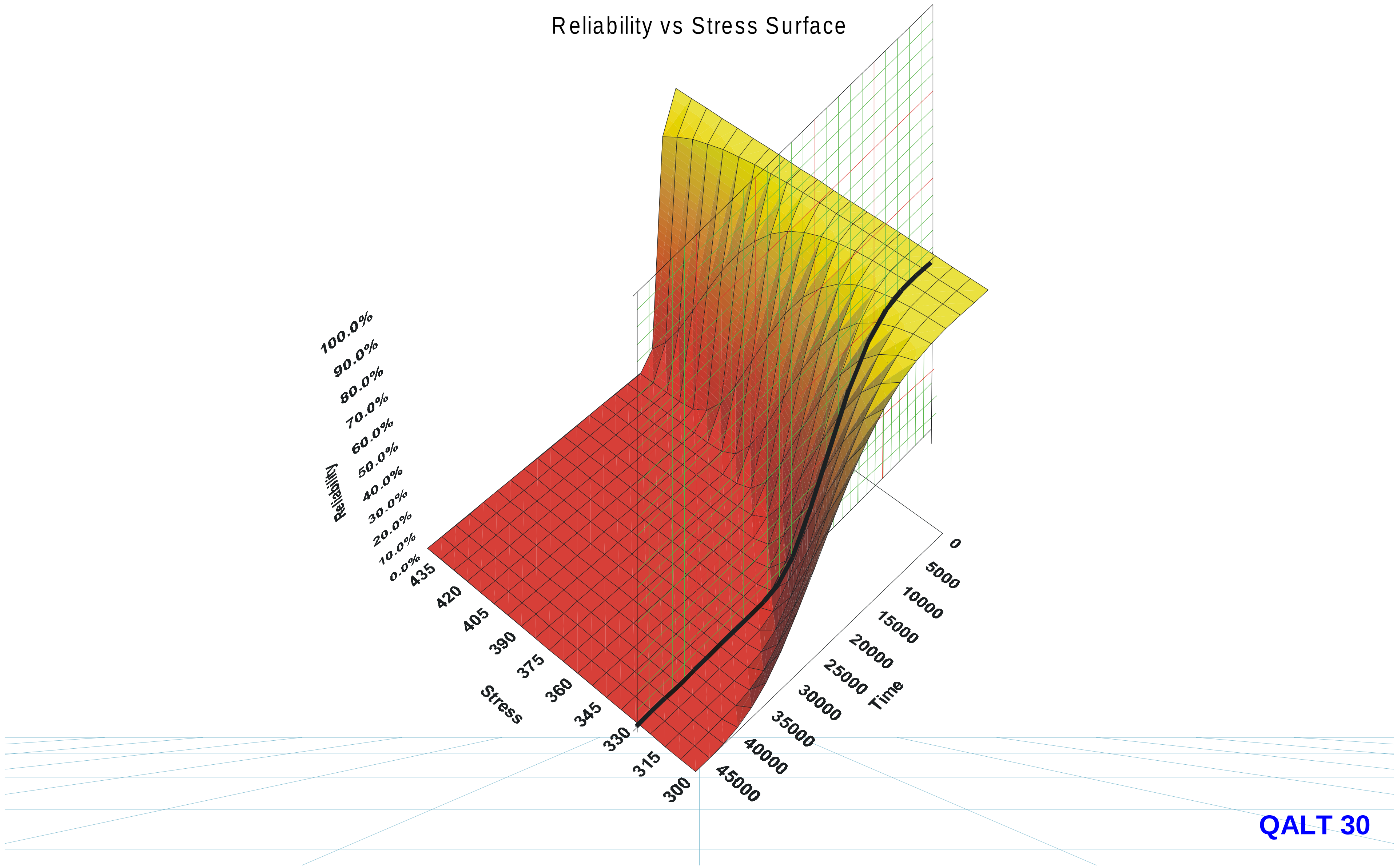


Parameters commonly used as a Function of Stress for different life distributions

- Exponential (Mean or Failure Rate)
- Weibull (Scale Parameter)
  - Shape parameter usually assumed to be constant!
- Lognormal (Ln-Mean or Median)
  - Ln-Std parameter usually assumed to be constant!

Reliability vs. Time vs. Stress Relationship

Using a Weibull Distribution and an Exponential Life Relationship



Overview of some Simple Stress-Life Relationships

- Arrhenius Relationship
  - Commonly used for analyzing data for which temperature is the accelerated stress.

$$L(V) = C \cdot e^{\frac{B}{V}}$$

Eyring Relationship

- Commonly used for analyzing data for which temperature is the accelerated stress.

$$L(V) = \frac{1}{V} \cdot e^{-\left(A - \frac{B}{V}\right)}$$

Inverse Power Law Relationship

- Commonly used for analyzing data for which the accelerated stress is non-thermal in nature.

$$L(V) = \frac{1}{K \cdot V^{n}}$$

Temperature-Humidity Relationship

$$L(U,V) = A \cdot e^{\left(\frac{\phi}{V} + \frac{b}{U}\right)}$$

Temperature-Humidity Relationship

$$L(U,V) = \frac{C}{U^n e^{-\frac{B}{V}}}$$

Parameter Estimation

- Parameter estimation can vary from being trivial (with ample data, a single constant stress, a simple distribution and simple model) to being an impossible task.
  - Available Methods
    - Graphical
    - Least Squares
    - MLE

Reliability Information

- Once the parameters of the underlying life distribution and stress-life relationship have been estimated, a variety of reliability information about the product can be derived such as:
  - Warranty time.
  - The instantaneous failure rate, which indicates the number of failures occurring per unit time.
  - The mean life which provides a measure of the average time of operation to failure.

Stress Loading

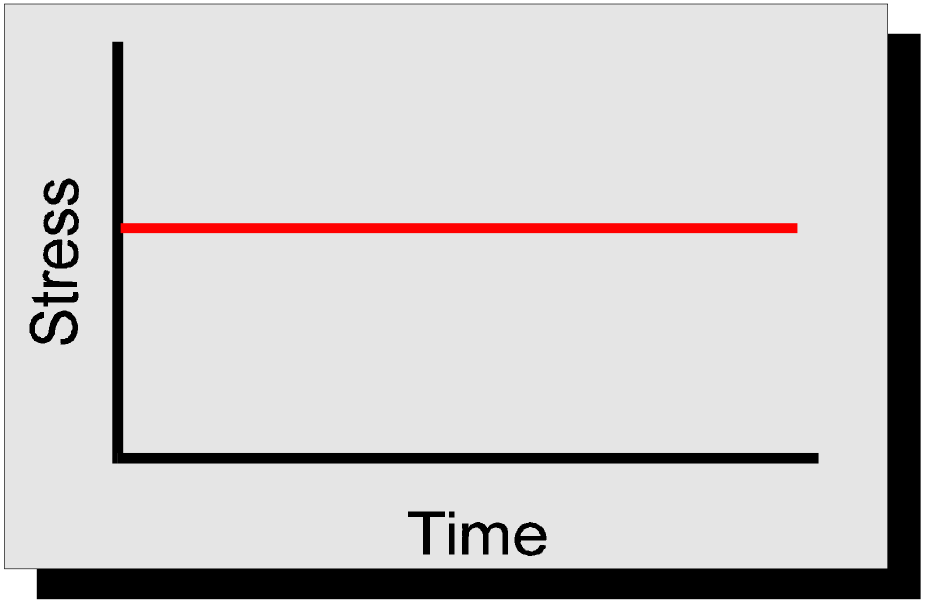
- Must be Able to Quantify the Stresses Applied
- The application of stresses must be done in some logical and controlled fashion.
- Accurate data on the stresses applied as well as the observed behavior of the test specimens must be kept.

Types of Stress Loading

- Two possible stress loading schemes.
  - Stress is Time Independent.
  - Stress is Time Dependent.
    - Stress is Quasi-Time Independent
    - Stress is Continuously Time Dependent.

Types of Stress Loading

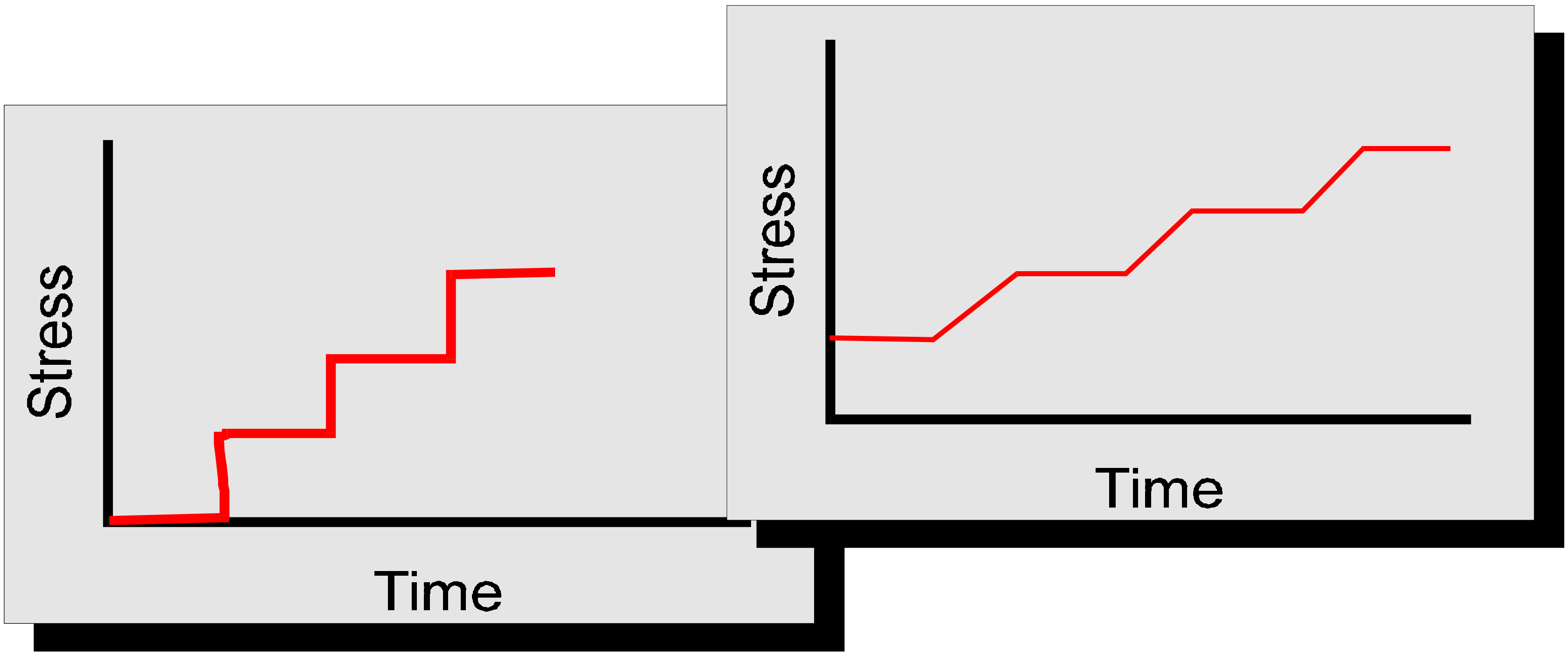
Time-Independent



$s \neq f(t)$

Stress is time independent!

Types of Stress Loading
Time-Dependent (Quasi Time-Dependent)

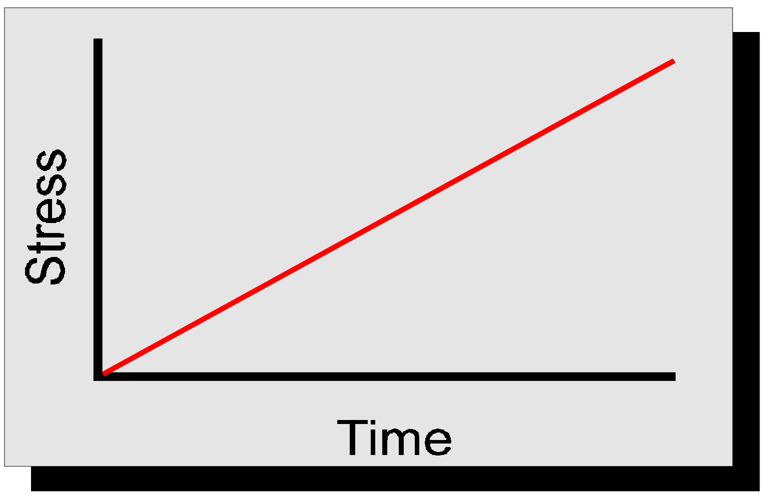


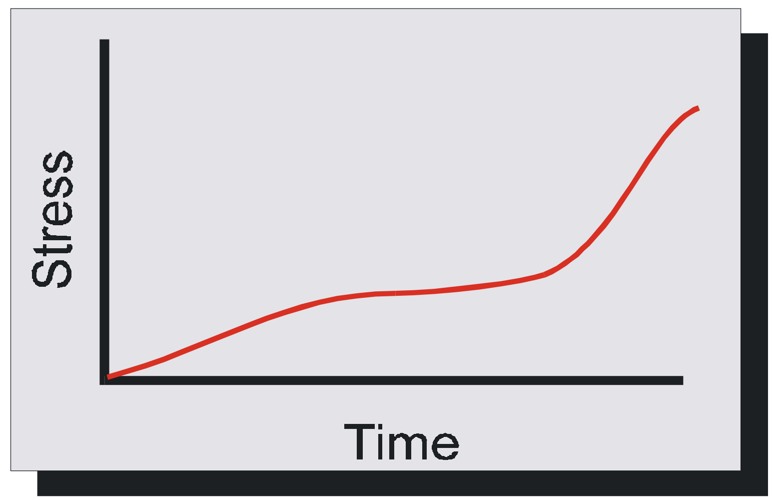
Stress is time dependent!
(Quasi time independent)

$$s = f(t)$$

Types of Stress Loading

Time-Dependent (Continuously Time-Dependent)





Stress is time dependent!

$$s = f(t)$$

An Introduction to the Arrhenius Relationship

- The Arrhenius model (or relationship) was originally formulated for accelerated life testing, where the acceleration variable (or stress) is thermal (i.e., temperature). It can also be used for other stress variables.
- The life at use stress level is estimated from life data obtained at different stress levels.

The Arrhenius model is given by,

$$L(V) = C \cdot e^{\frac{B}{V}} \qquad (1)$$

where,

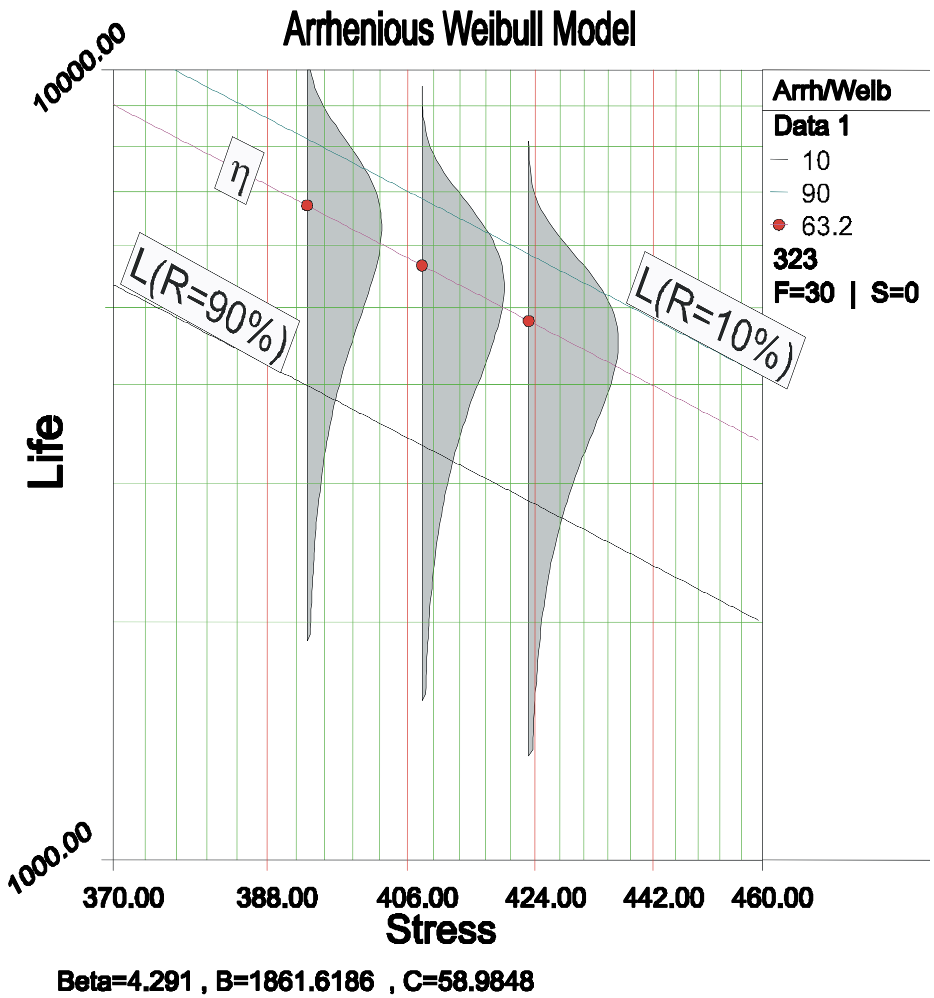
- L represents a quantifiable life measure, such as mean life, characteristic life, median life, or B(x) life, etc.
- V represents the stress level,
- C is one of the model parameters to be determined, (C>0)
- B is another model parameter to be determined.

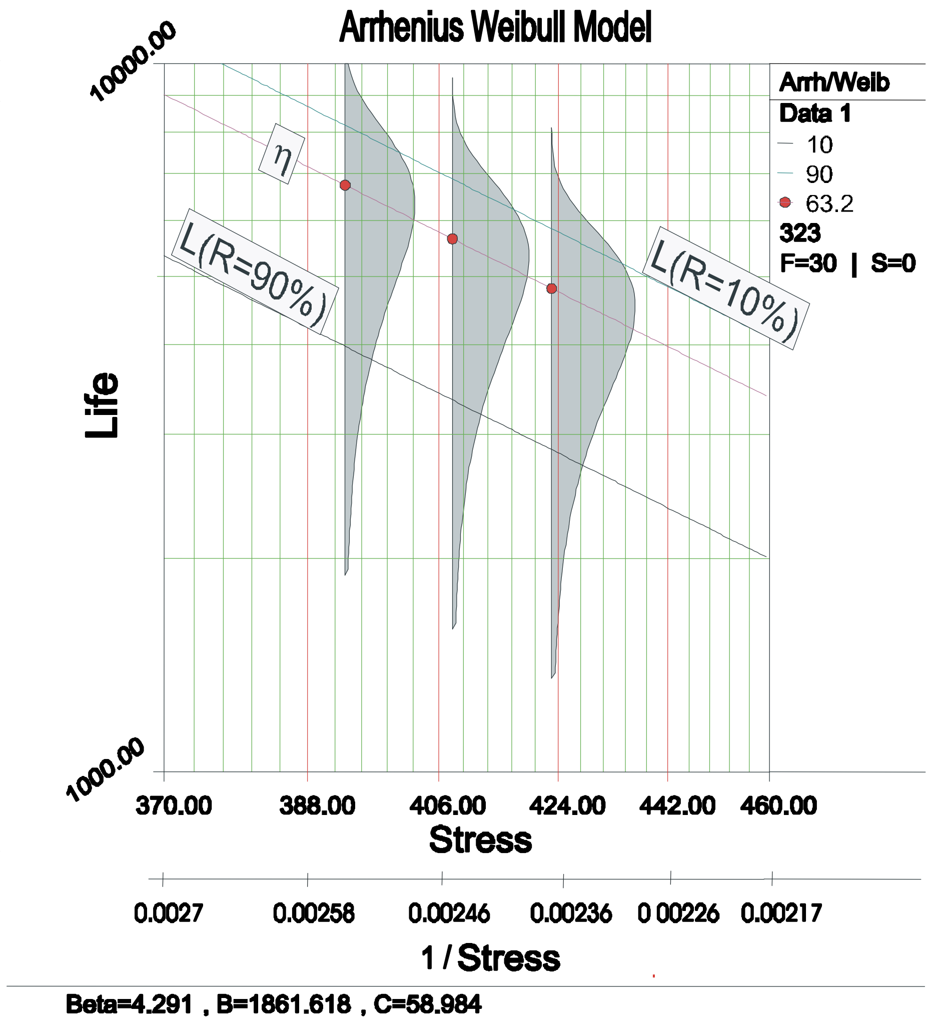
Arrhenius Relationship, cont.

- The Arrhenius relationship can be linearized and plotted on a life vs. stress plot, also called the Arrhenius plot. The relationship is linearized by taking the natural logarithm of both sides in eq (1) or,

$$\ln(L(V)) = \ln(C) + \frac{B}{V}$$

Arrhenius Plot





A Look at the Parameter *B*

- **Depending on the application (and where the stress is exclusively thermal), the parameter *B* can be replaced by,**

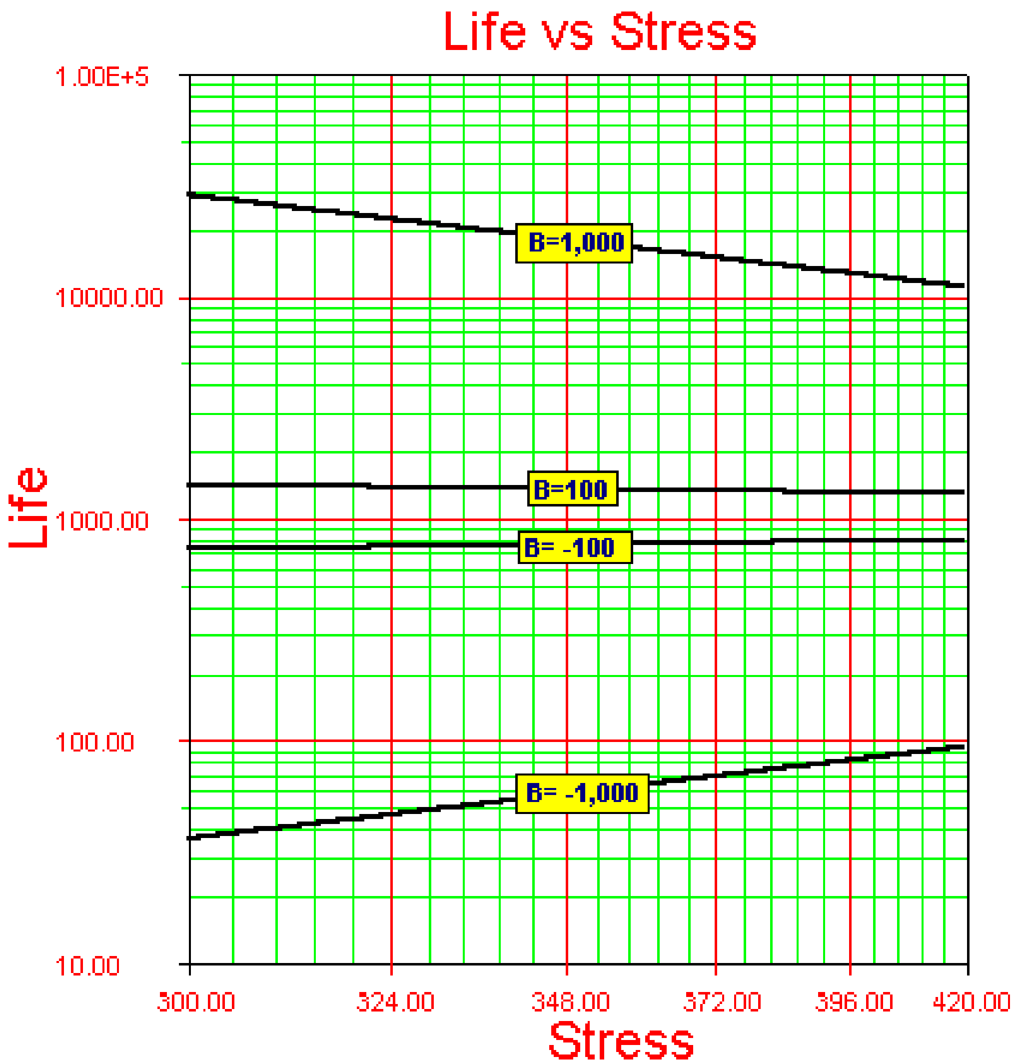
$$B = \frac{E_A}{K} = \frac{\text{activation energy}}{\text{Boltzman's constant}} = \frac{\text{activation energy}}{8.623\times10^{-5}\,\text{eV}\cdot\text{K}^{-1}}$$

A Look at the Parameter *B*, *cont.*

- Note that in this formulation, the activation energy must be known apriori.
- If the activation energy is known then there is only one model parameter remaining, *C*.
- Because in most real life situations this is rarely the case, all subsequent formulations will assume that this activation energy is unknown and treat *B* as one of the model parameters.

Behavior of the parameter B

- *B* is a measure of the effect that the stress (i.e., temperature) has on the life.



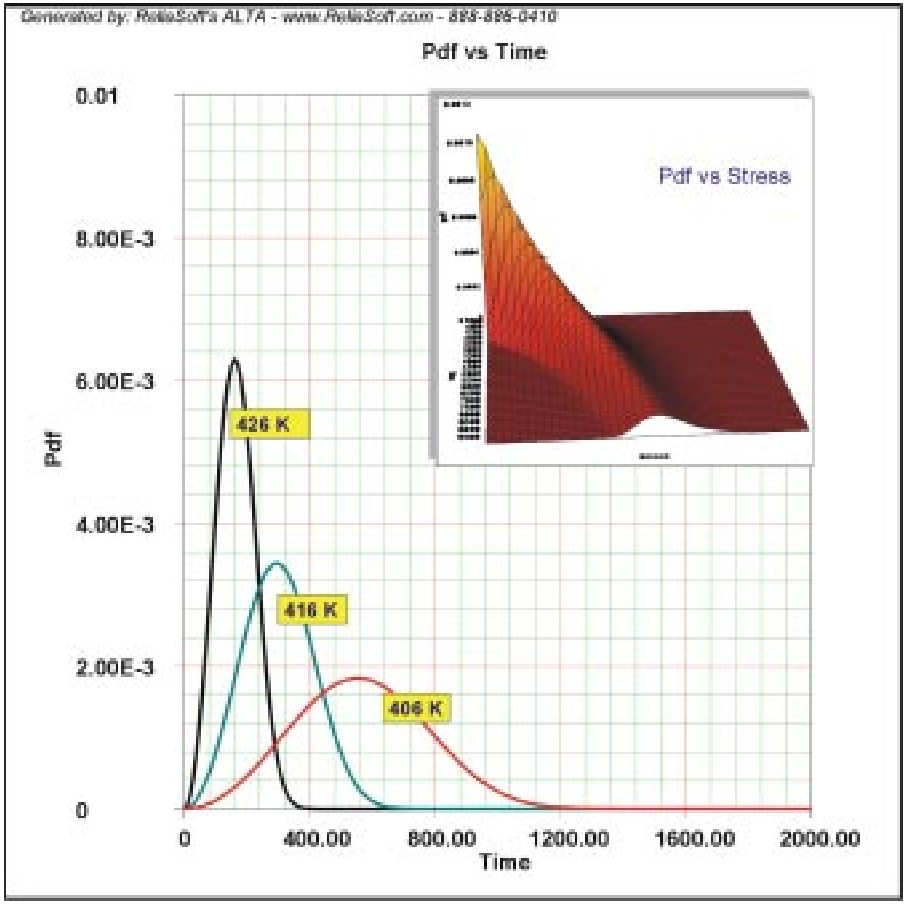
Arrhenius Weibull

$$f(t) = \frac{\beta}{\eta} \cdot \left(\frac{t}{\eta} \right)^{\beta - 1} e^{-\left(\frac{t}{\eta} \right)^{\beta}}$$

$$\eta = L(V) = C \cdot e^{\frac{B}{V}}$$

- Therefore:

$$f(t,V) = \frac{\beta}{C \cdot e^{\frac{B}{V}}} \cdot \left(\frac{t}{C \cdot e^{\frac{B}{V}}} \right)^{\beta - 1} e^{-\left(\frac{t}{C \cdot e^{\frac{B}{V}}} \right)^{\beta}}$$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Pdf vs Time
Pdf vs Stress
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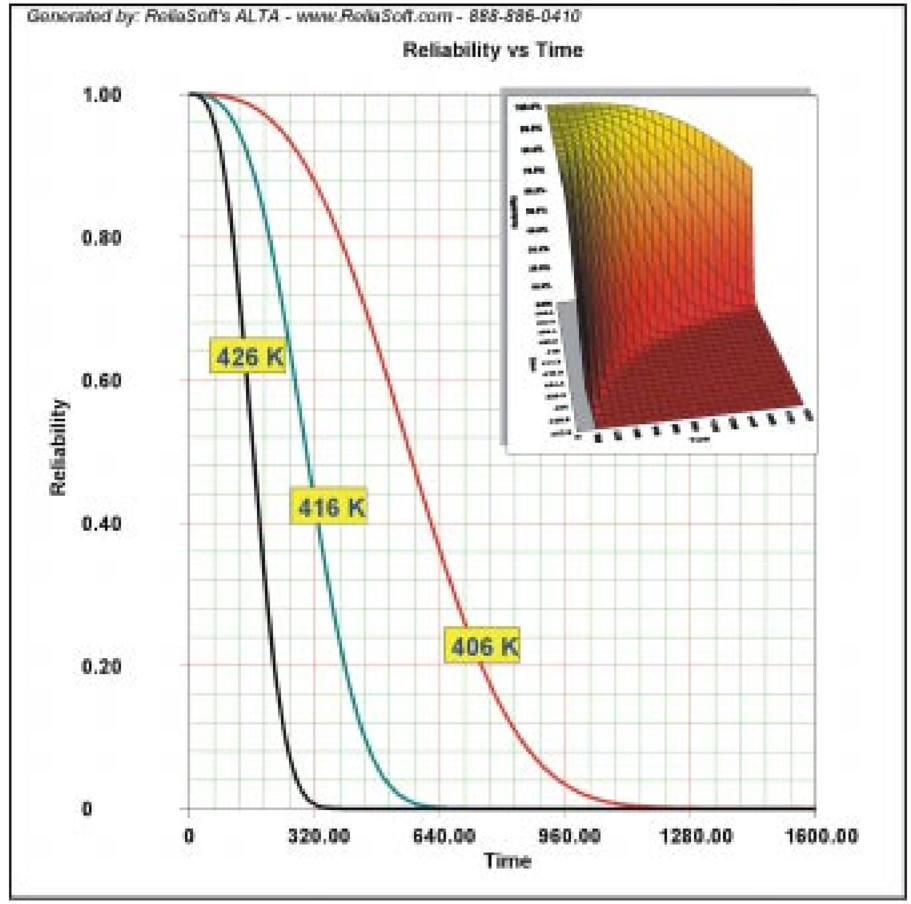
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426 K
416 K
406 K
0
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960.00
1280.00
1600.00
Time

Acceleration Factor

- The ratio of the life (or acceleration characteristic) between the use level and a higher test stress level or,

$$A_F = \frac{L_{USE}}{L_{Accelerated}}$$

- For the Arrhenius model this factor is,

$$A_F = \frac{L_{USE}}{L_{Accelerated}} = \frac{C \cdot e^{\frac{B}{V_u}}}{C \cdot e^{\frac{B}{V_A}}} = \frac{e^{\frac{B}{V_u}}}{e^{\frac{B}{V_A}}} = e^{\left(\frac{B}{V_u} - \frac{B}{V_A}\right)}$$

Example

Stress	393 K	408 K	423 K
Time Failed (hrs)	3850	3300	2750
	4340	3720	3100
	4760	4080	3400
	5320	4560	3800
	5740	4920	4100
	6160	5280	4400
	6580	5640	4700
	7140	6120	5100
	7980	6840	5700
	8960	7680	6400

- The MLE estimates obtained using [10] are:

$$\widehat{\beta} = 4.291$$

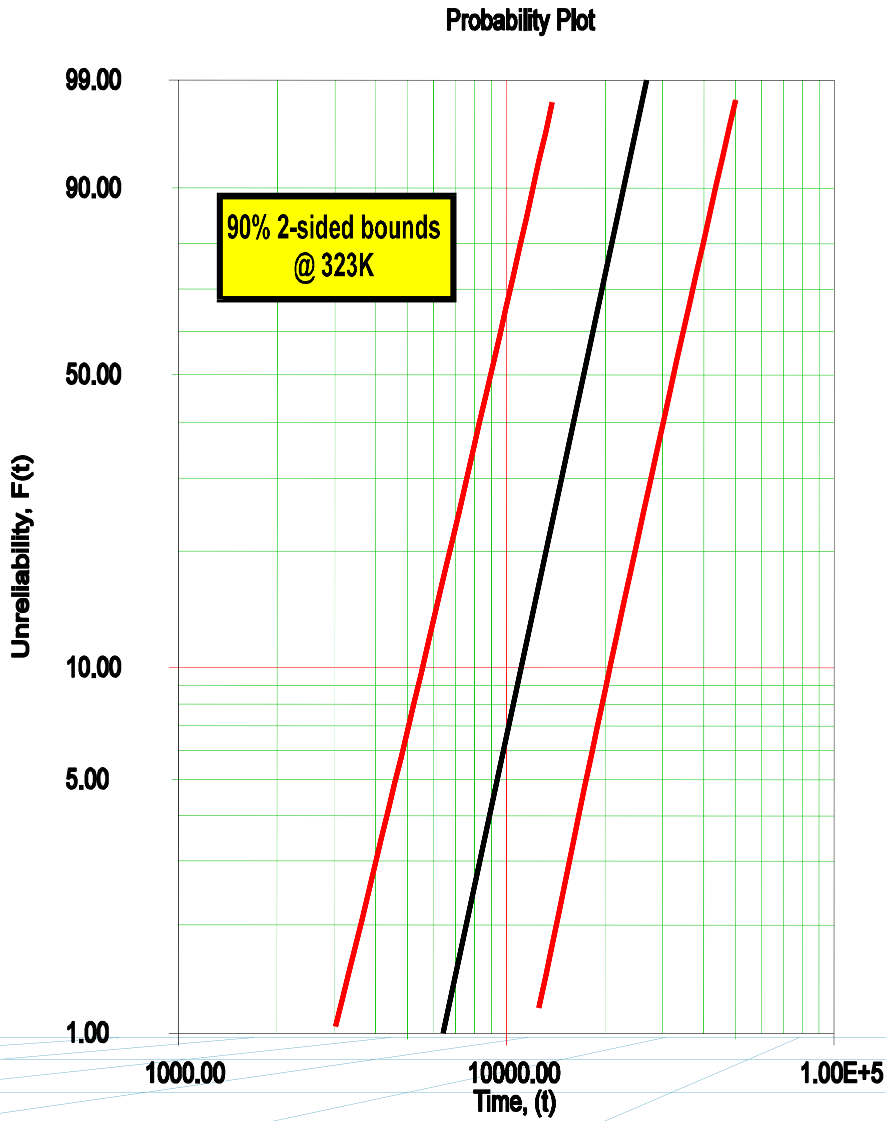
$$\widehat{B} = 1861.618$$

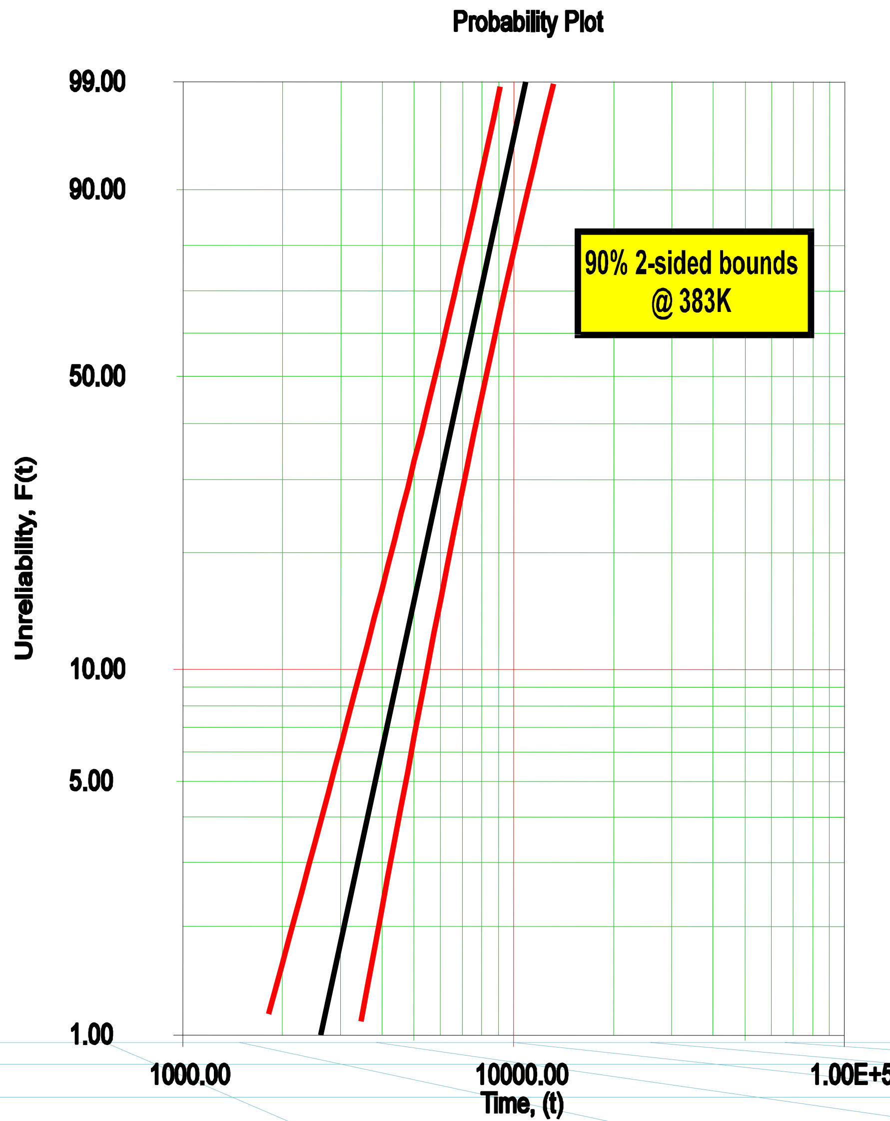
$$\widehat{C} = 58.984$$

Example, cont.

- Once the parameters of the model are estimated, extrapolation and other life measures can be directly obtained using the appropriate equations.
- Using the MLE method, confidence bounds for all estimates can be obtained.
- The more distant the accelerated stress from the operating stress, the greater the uncertainty of the extrapolation. The degree of uncertainty is reflected in the confidence bounds.

Effects of Extrapolation





Other Single Constant Stress Models

- The same formulations can be applied to other models such as the
  - Eyring Relationship (exponential relationship).
  - Inverse Power Law Relationship (power relationship).
  - Coffin Manson Relationship (power relationship utilizing a ΔV for stress).

Other Single Constant Stress Models,cont.

- One must be cautious in selecting a model. The physical characteristics of the failure mode under consideration must be understood and the selected model must be appropriate.
- As an example in cases where the failure mode is fatigue the use of an exponential relationship would be inappropriate since the physical mechanism is based on a power relation, thus a power model would be more appropriate (i.e., Inverse Power Law model).

Introduction to Two-Stress Models

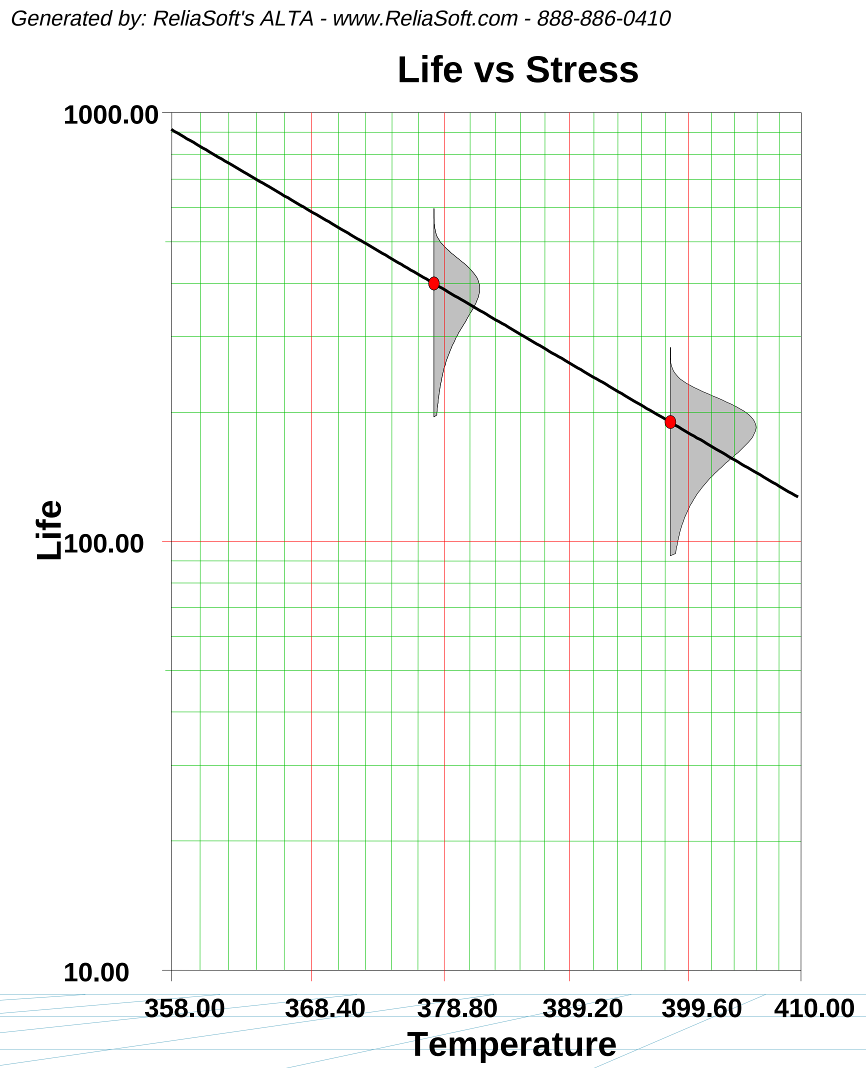
- Temperature-Humidity

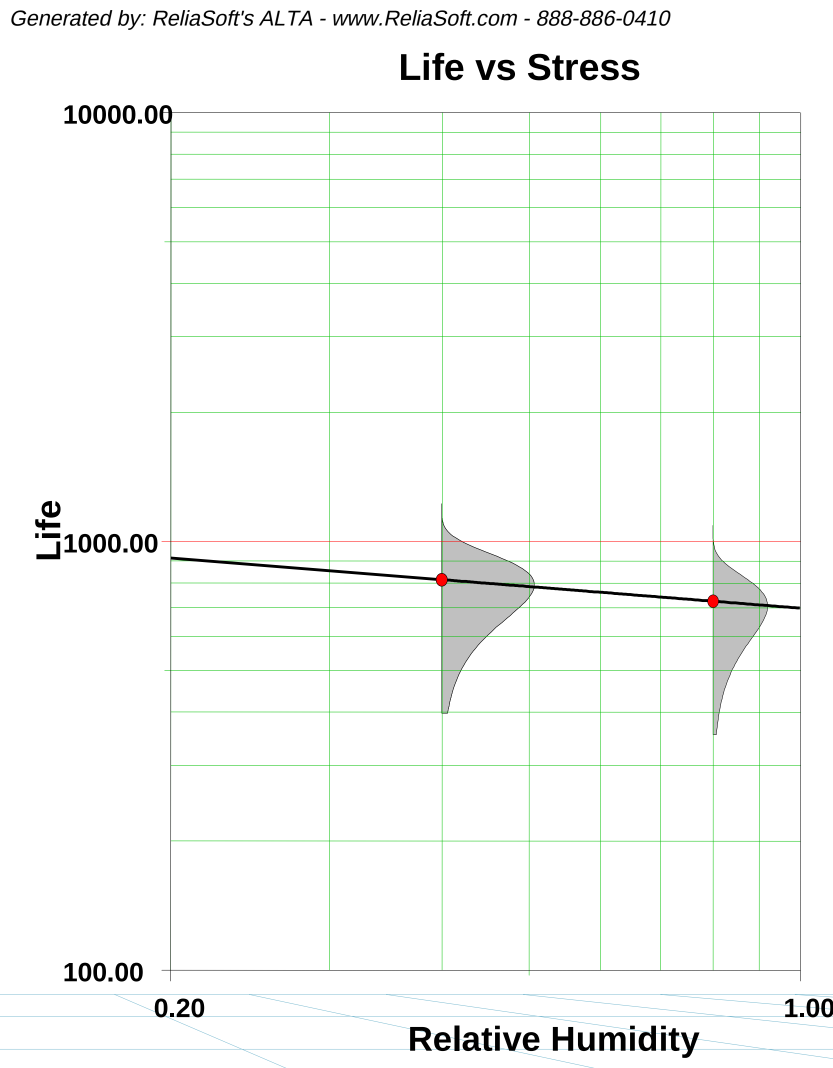
$$L(U,V) = A \cdot e^{\left(\frac{\phi}{V} + \frac{b}{U}\right)}$$

- Temperature-Non Thermal

$$L(U,V) = \frac{C}{U^{n} e^{-\frac{B}{V}}}$$

Effect of each stress on product life





Note on Two-Stress Type Testing

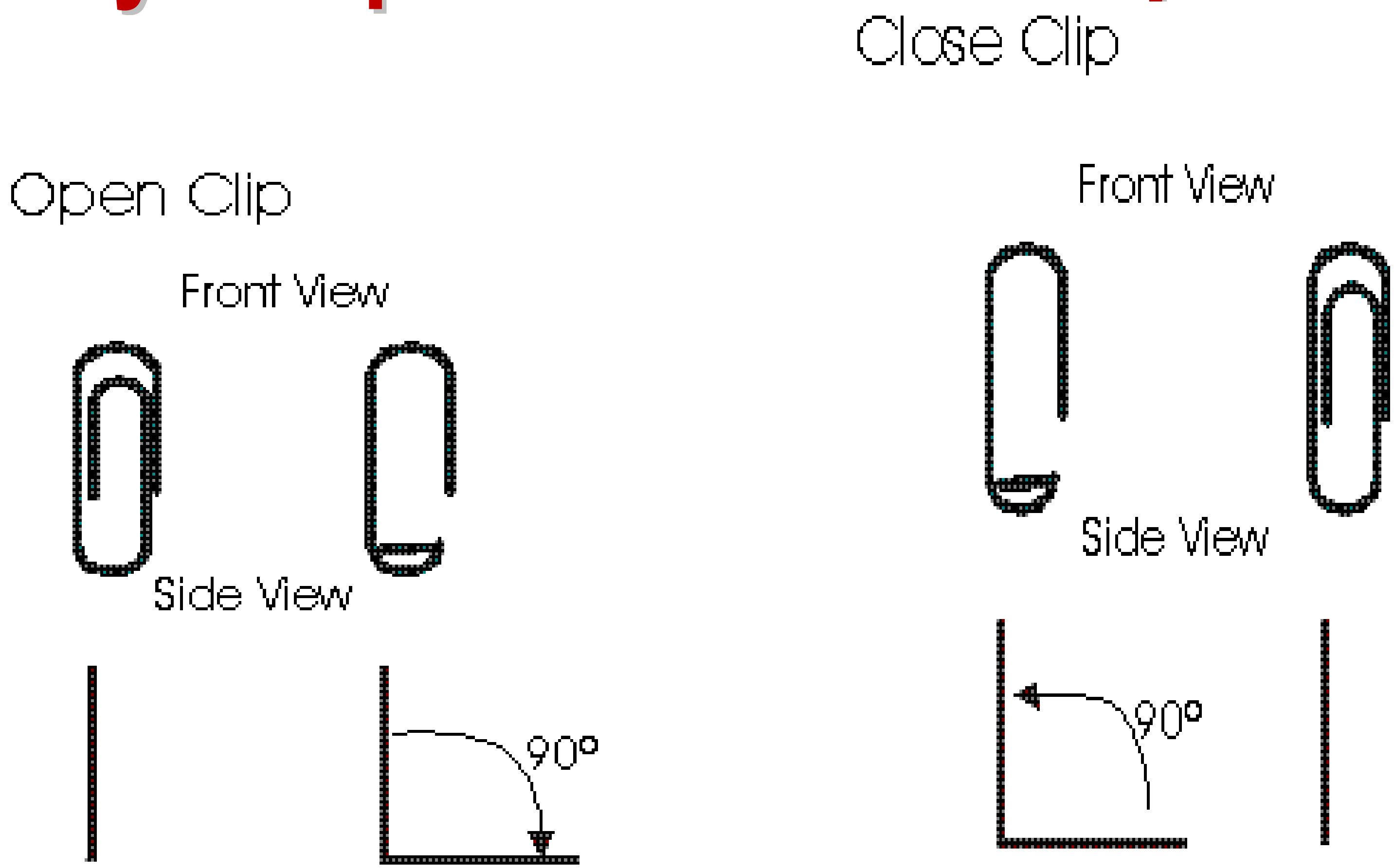
- When using two-stress relationships, the effect of both stresses on life is sought.

- For this reason, the test must be performed in a combination manner between the different stress levels of the two stress types.

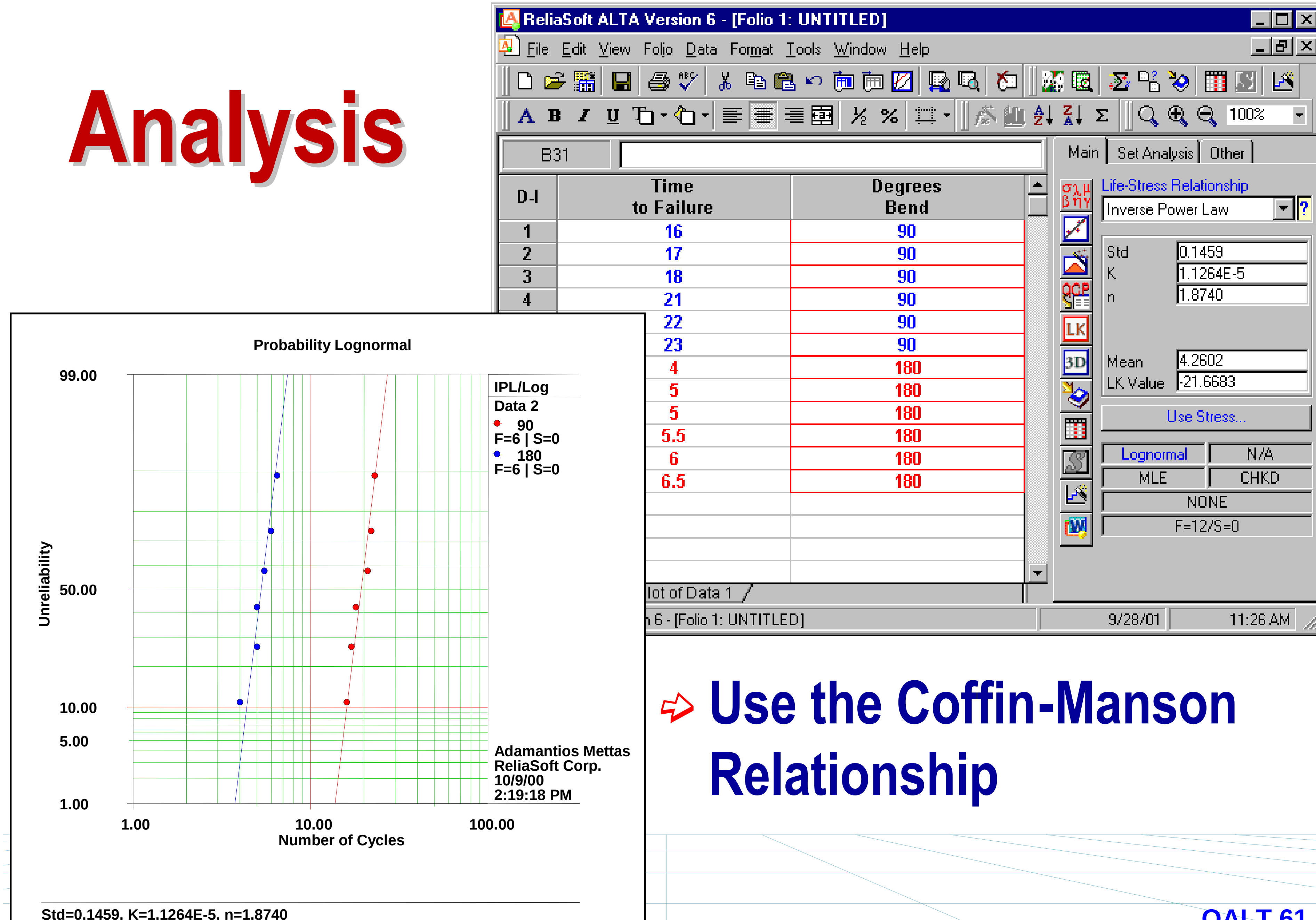
Note on Two-Stress Type Testing, cont.

- For example, assume that an accelerated test is to be performed at two temperature and two humidity levels. The two temperature levels were chosen to be 300K and 343K. The two humidity levels were chosen to be 0.6, and 0.8. It would be wrong to perform the test at (300K, 0.6) and (343K, 0.8).
- Doing so would not provide information about the temperature-humidity effects on life.
- This is because both stresses are increased at the same time and therefore it is unknown which stress is causing the acceleration on life.

A Very Simple Tutorial Example

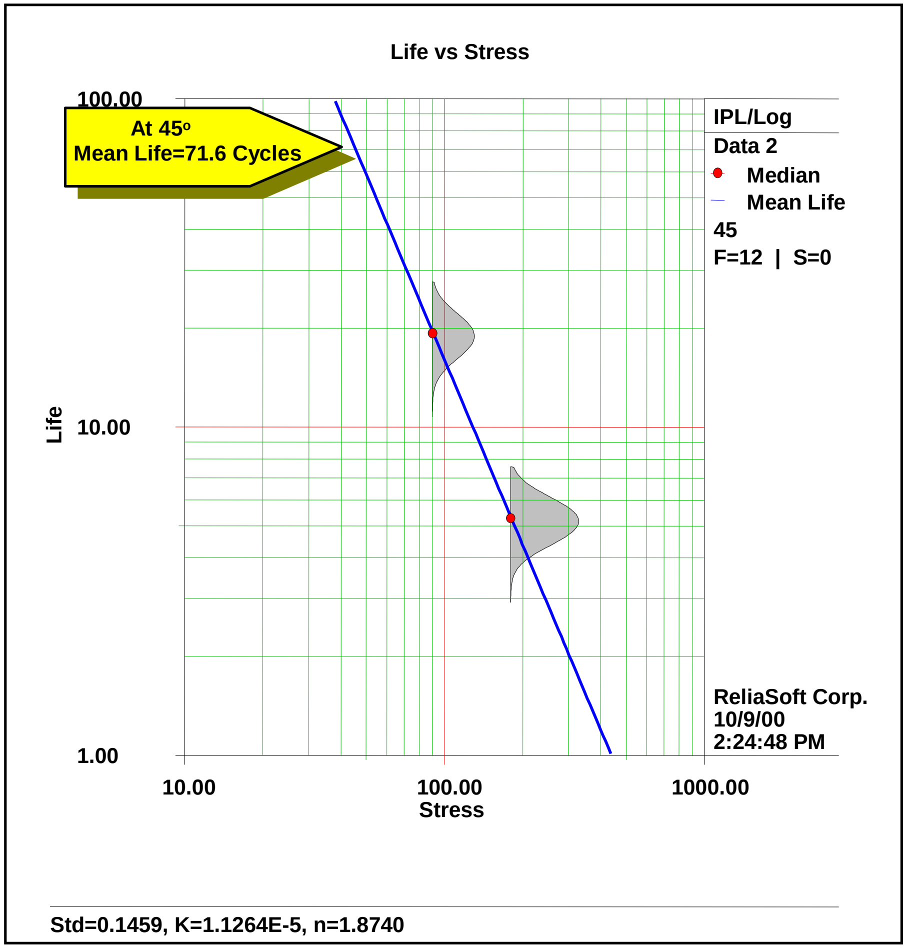


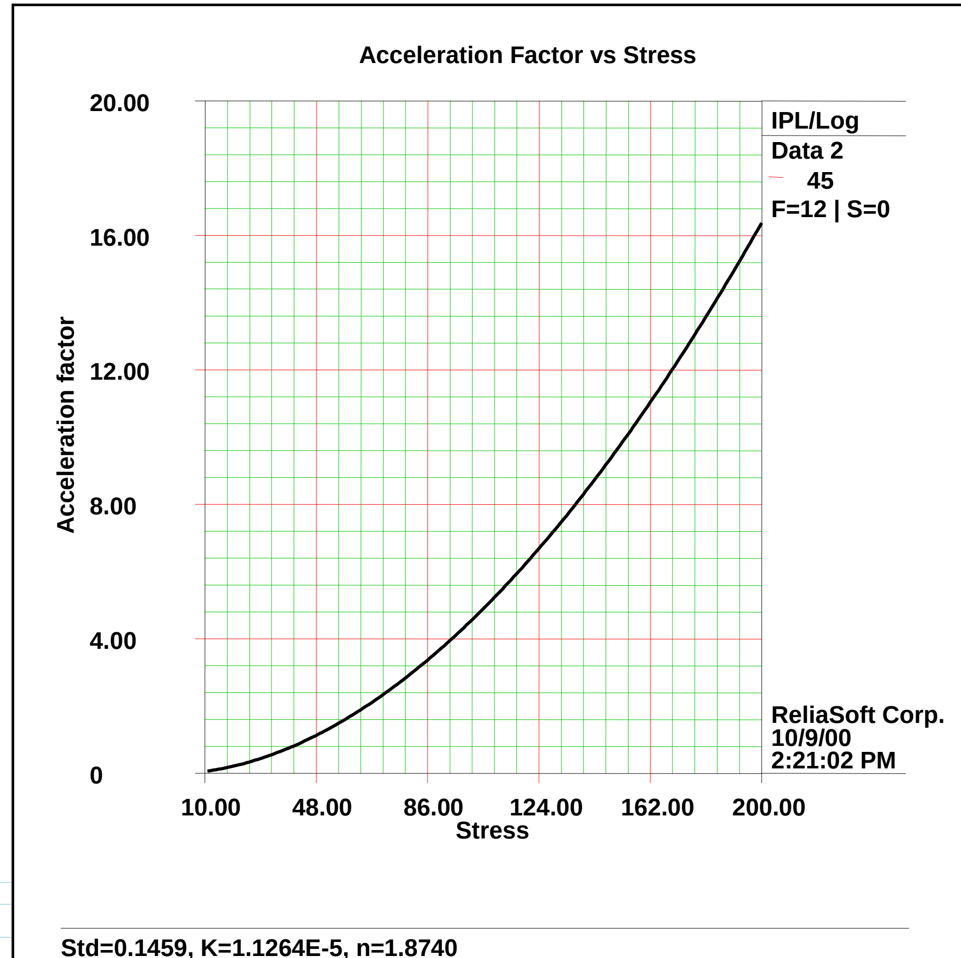
Analysis



- Use the Coffin-Manson Relationship

Analysis, cont.





Note that the base 45° data yielded an MTTF estimate of 70.33 cycles (utilizing a lognormal distribution).

Advanced Concepts…

- More complex and/or generalized life-stress relationships may be utilized:
  - Generalized Log-Linear Model

$$L(\underline{X}) = e^{\left(a_0 + \sum_{i=1}^{m} a_i X_i\right)}$$

– Where a reciprocal transformation on X, or X=1/V will result to an exponential life stress relationship, while a logarithmic transformation, X=ln(V) results to a power life stress relationship.

Advanced Concepts…

- Extending the concept to time varying stresses
  - As an example consider an exponential life stress relationship utilizing a time varying stress:

$$L(V(t)) = Ce^{\left(\frac{B}{V(t)}\right)}$$

    – Treatment and analysis of time varying stresses requires further assumptions and more complex analysis techniques.

More Infromation

- Online eTextbook at:

  www.weibull.com/acceltestwebcontents.htm

- Or for case studies see

  ALTA.ReliaSoft.com