Accelerated Life Tests
Design Guidelines

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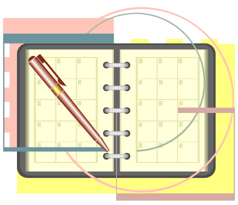
Gertron Ltd.

Agenda

- *Motivation*
- *Example Overview*
- *Preface*
- *System Investigation*
- *Test Design*
- *Test Setup*
- *Test Parameters*
- *Test Procedure*
- *Analysis*
- *Flow Chart*
- *Summary*
- *Questions*



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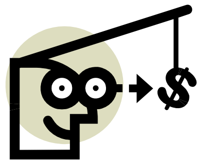

Motivation

- The time spent from the conceptual stage to the final product development stage needs to be short in order to be competitive in today's market
- Industrial competitiveness in terms of innovation, time of development, and field reliability expectations leads to more efficient strategies to develop a mature product
- Early failures have adverse effect on both the image and the market share of the manufacturer

Motivation (cont.)

- In order to reduce test time, accelerated life testing can be useful
- Accelerated Life Test (ALT) is also useful in identifying Potential Failure Modes of products at the design stage, before the products are put in the field

Motivation (cont.)

"To call in the statistician after the experiment is done may be no more than asking him to perform a post-mortem examination: he may be able to say what the experiment died of."

Ronald Fisher

Motivation (cont.)

- An *experiment* deliberately imposes a *treatment* on a group of objects or subjects in the interest of observing the response
- Because the validity of an experiment is directly affected by its construction and execution, attention to *experimental design* is extremely important

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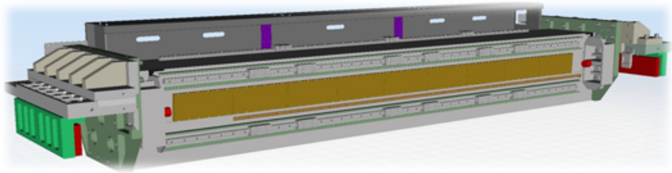
Example Overview

- The UUT is part of a system that is used to check the perfection of the printed glass intended to be part of an LCD TV or monitor
- Due to the size of the working glass the system is very large in size

Example Overview (cont.)

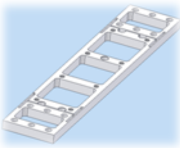
- Cameras are mounted on a gantry which is motorized by linear motors on both sides



- The gantry beam was originally made of a very low thermal expansion coefficient compound material
- Due to design for cost reasons it was later changed to aluminum with a very high thermal expansion

Example Overview (cont.)

- This change raises a concern regarding the mechanical stresses that will be built up during transportation, due to the high fluctuation in temperature that the system might be exposed to (up to a 100 Deg. C. change)
- This thermal expansion will exert large forces on the linear bearings and may destroy them
- To reduce the forces applied on the linear bearings, a Flexure (set of springs) is used to connect between the gantry and the linear motors



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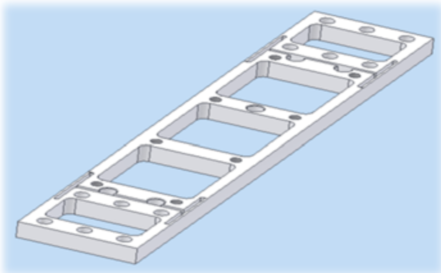
- Test Rational
- Test Objectives
- Part Number of the UUT
- UUT Disposal Manner
- Key Persons

Test Rationale

- Describe the rationale of the test (e.g., Cost reduction, Obsolete, New design, etc.)
- **Example:**
  - **Test Rationale**: New design of Flexure (UUT)



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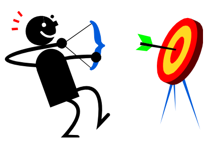

Test Objectives

- The specific questions that the experiment is intended to answer must be clearly identified before carrying out the experiment
- Goal-setting ideally involves establishing Specific, Measurable, Attainable, Realistic and Time-bounded (S.M.A.R.T.) objectives
- The 'Measurable' attribute dictates using the ALT for a life test (as a **quantitative** test) rather than other **qualitative** tests (commonly called shake and bake tests, HALT, HAST, MEOST, elephant tests, etc.)

Test Objectives (cont.)

- Quantitative accelerated life testing, unlike qualitative testing, is designed to provide reliability information on the product, component or system through data obtained during the accelerated test
- When stating the reliability test objectives, it is important to take into consideration the amount of UUTs in the system, as well as the redundancy level (if there is one)
- List the test quantitative objectives – verify/find reliability (e.g., MTTF (Mean Time To Failure), Expected Life – B(10), etc.), failure distribution, etc.)

Test Objectives (cont.)

- **Example**:
  - **Test objectives:** The object of the test is to verify the minimal Flexure reliability:
    - The probability that the Flexure remains functional after transportation and storage
    - The probability that the Flexure remains functional during system useful life
    - The expected reliability of the flexure is 99.9% after 30 cycles of transportation and storage and 20 cycles of useful life.
    - In other words, 1 out of 1000 systems will require flexure replacement due to failure after transportation and/or storage or during system life.

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UUT Disposal Manner at test termination

- Indicate what should be done with the UUT after completion of the ALT (both the working and the failed parts)
- Discarding is one option, but returning it to the R&D for further analysis of the failed parts (e.g., X-Ray) for in depth understanding of the Physics Of Failure, is a more reasonable option
- It is recommended additionally to check the items that did not fail to see if there is a degradation in performance

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Key Persons

- List the name of the key persons involved in the ALT, both from the customer side (e.g., R&D, Engineering, etc.) and those who are responsible to conduct the test and analyze it
- Key persons of subcontractors who will be responsible for the setup design and/or production should also be included

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  - UUT Utilization
  - UUT Failure Modes
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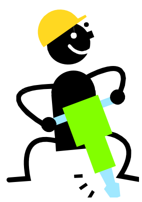

System Investigation

- To assure that the ALT will be a good predictor to the expected system failures in the field, we have to fully understand how the UUT will be used in the system

Operating modes of the UUT in the system

- Data that will be gathered at this stage will include:
  - number of UUTs that are included in the system
  - how many of them are needed for system functionality (is there a redundancy configuration)
  - the different operating modes (e.g., off, init, standby, running, etc.)
  - the operating phases (e.g., transportation, storage, operation, maintenance, etc.)
  - the operating duty cycle at each operating mode and phase
  - stress level (e.g., voltage, force/moment, 50/60Hz, etc.) – for each operating mode and phase

Operating modes of the UUT in the system (cont.)

- Data that will be gathered at this stage will include:
  - environmental condition (e.g., temperature, humidity, VOC, vibration, shock, dust, etc.)
  - Preventive Maintenance (PM) procedure
  - interfaces between the UUT and the rest of the system
- If the influential parameters are not fully understood, it might be good practice to conduct a Design Of Experiment (DOE[4]) before defining the test bench

Operating modes of the UUT in the system (cont.)

- Example:
  - UUT transfers motion from the Gantry Beam linear motor in the Y axis direction to the Gantry Beam while enabling the Gantry Beam expansion and shrinking in the X axis direction
  - The UUT is operated in two modes
    - Transportation and storage – due to major temperature changes the UUT is deflected ± 1mm in a cycle time of 24 hours
    - System useful life – due to small temperature changes the UUT is deflected ± 0.18mm in a cycle time of 3 months (3 months is PM time)

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UUT utilization in the system

- At this step one has to collect all the data regarding the way the UUT(s) is going to be utilized during the expected life time of the system
- One aspect of the utilization is the system utilization by the user. For example:
  - the system might be used only during night time (e.g., street lights)
  - 24/7 (e.g., industrial furnaces)
  - 15,000 miles per year (e.g., average family car travel)
  - 60% of the time (e.g., red junction light)
  - 10 hours per week (e.g., washing machine)

UUT utilization in the system (cont.)

- In cases where the 'non-operating' condition is dominant (e.g., fire hydrant), this period has to be accounted for as other failure mechanisms might be involved in causing a failure, for example:
  - rust that may build up in a non-operating car engine
  - fungus that may build up in a water filter where water stops flowing through for a long period of time

UUT utilization in the system (cont.)

- Example:
  - UUT is utilized in the system in two modes:
    - Transportation and storage
    - System useful life
  - Expected number of cycles during the life-time of the system is as follows:
    - Mode 1, Transportation – up to 30 cycles with velocity of 11mm/hour, cycle time = 24 hours
    - Mode 2, System useful life – up to 20 cycles, with velocity 11mm/hour, cycle time = 3 months (during 5 years)

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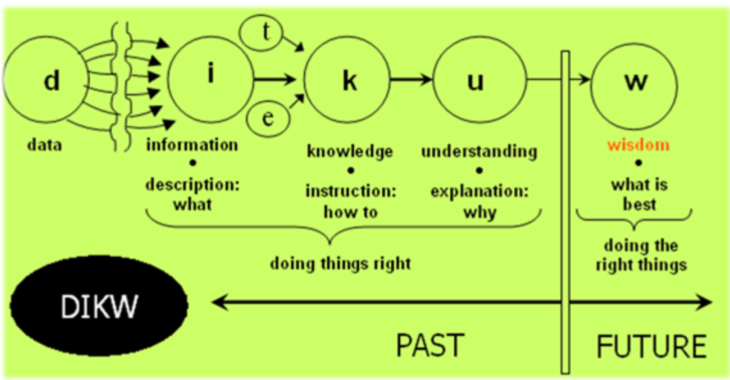
UUT failure modes

> *"To design systems that work correctly we often need to understand and correct how they can go wrong"*
>
> Dan Goldin, NASA Administrator, 2000

http://en.wikipedia.org/wiki/File:DIKW.png



UUT failure modes (cont.)

- A definition of a failure can be very broad and versatile. Different dictionaries define “failure” as:
  - Concise Oxford English Dictionary:
    - *"Lack of successes. Action of ceasing to function or state of not functioning."*
  - Wikipedia English:
    - *"In general, failure refers to state or condition of not meeting desirable or intended objective, may be viewed as opposite of success."*
  - Telecommunication Standard Terms:
    - ***"****Temporary or permanent termination of ability of an entity to perform its required function."*

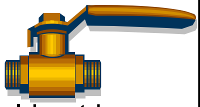
UUT failure modes (cont.)

- Mariam Webster:
  - *"Omission of occurrence or performance; specifically: a failing to perform a duty or expected action“*

- From the above definitions it is clear that when a function is not performed when it should be, or it is performed when it should not (Snake Circuits[1]), either permanently or temporarily, we can say that a failure occurred

UUT failure modes (cont.)

- From that, a comprehensive yet concise description of all of the functions the UUT is responsible for should be noted.



- For example:
  - ☺ A valve's pressure drop, while in open state, should not be higher than x PSI and leak rate, while in close state, should be lower than y LPM
  - ☺ Bearing friction should not be higher than x NM while its clearance should be under y microns

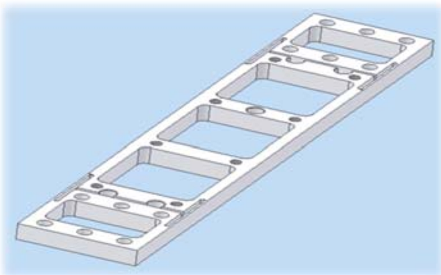
  - ☺ A definition of a function like "the valve's pressure drop should be as low as feasible" does not help defining the failure

UUT failure modes (cont.)

- Make a list of all the UUT functions
- For each function, a list of parameters and their normal operating values should be noted, E.g.:
  - A valve's pressure drop, while in open state, should not be higher than x PSI and leak rate, while in close state, should be lower than y LPM
- Each parameter should be measurable either directly (with a measuring means) or indirectly (e.g., calculating the height of a building by measuring its shadow)

UUT failure modes (cont.)

- Example:
  - The failure of the UUT is the presence of cracks in one of the spring areas



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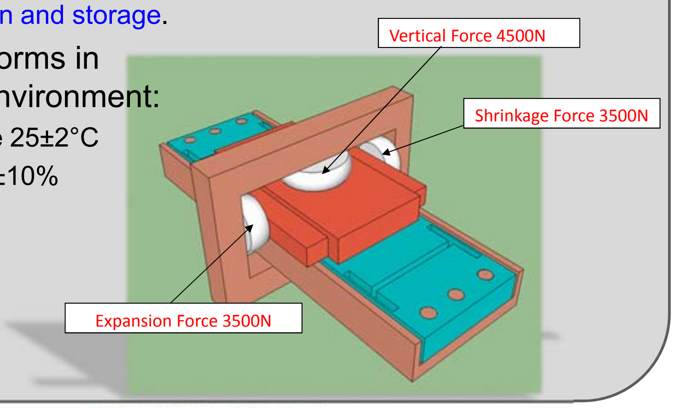
Operating conditions of the UUT during the test

- Based on the data gathered earlier (*Operating modes of the UUT in the system* and *UUT utilization in the system*) we can now configure the test details regarding how the UUT(s) will be operated during the test
- This will include:
  - operating modes and how much time the UUT will be running in each operating mode
  - operating phases (e.g., transportation, storage, operation, maintenance, etc.)
  - the operating duty cycle at each operating mode and phase
  - stress levels (e.g., voltage, force/moment, 50/60Hz, etc.
  - environmental conditions during the test should be established as well

Operating conditions of the UUT during the test

- Example:
  - The picture below shows the forces acting on the UUT during the test. The forces are equivalent to those expected during the transportation and storage.
- The test performs in laboratory environment:
  - Temperature 25±2°C
  - Humidity 50±10%



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Defining Accelerating Factor

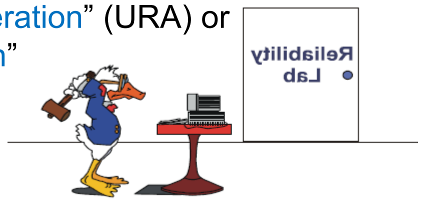
- The term *acceleration factor* is used to describe the ratio of the life characteristic at the use and accelerated test conditions, or:

$$A_F = \frac{L(Use)}{L(Accelerated)}$$

- Thus, if the life characteristic (i.e., MTTF) during the test is half of what it is at use conditions, then the acceleration factor is 2

Accelerating the test

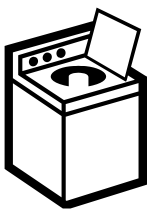
- Acceleration may be obtained through usage rate acceleration and/or overstressing
- In both methods, the test can run till failures are observed or using the degradation method
- In quantitative ALT, even though failures are needed, one must assure that the conditions that created the failure can be quantified with respect to the use condition
- The easiest and most common form of accelerated life testing is "Usage Rate Acceleration" (URA) or "Continuous Use Acceleration"



Usage Rate Acceleration (URA)

- Assuming we would like to verify or evaluate the reliability of a washing machine, assuming that:
  - average usage is 10 hours per week
  - we will be operating it 24/7 during the test
- then the accelerated factor will be

$$\frac{7 * 24[\frac{hour}{week}]}{10[\frac{hour}{week}]} = 16.8$$



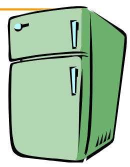
Usage Rate Acceleration (URA)

- The same concept will applies for testing car reliability
  - Assuming the average usage is 14,000 miles per year and we would like to evaluate the reliability after 3 years, we can accelerate the test by continuously operating the car 24/7
  - Based on the average speed of 50 miles per hour, the accelerated factor will be:

$$\frac{8{,}760[\frac{hous}{year}] * 50[\frac{mile}{hour}]}{14{,}000[\frac{mile}{year}]} = 31$$

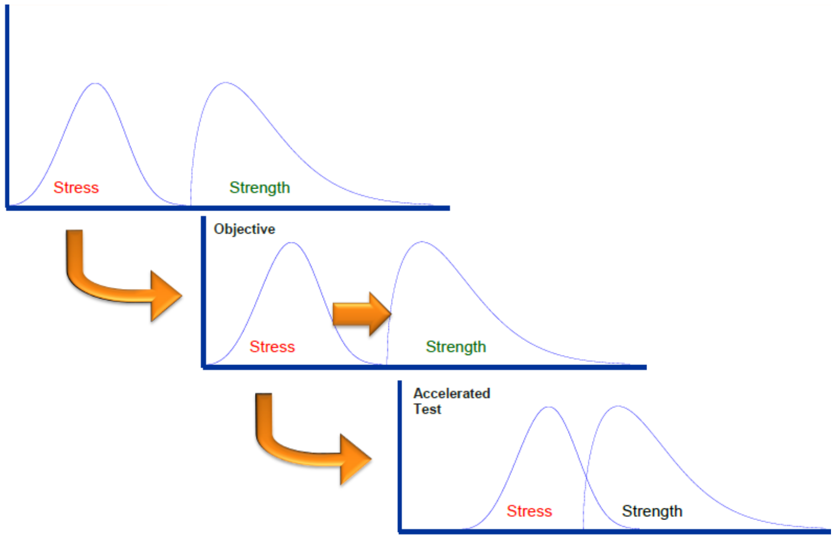
  - ***Note**: Accelerated factor does not, by itself, indicate what will be the test duration*
  - *Some other factors are needed to calculate the test duration including number of UUTs in the test and known reliability distribution*

Stress Acceleration



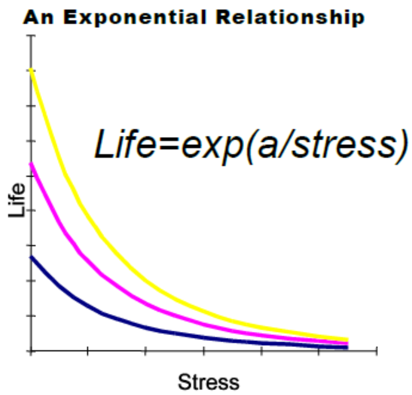
- Many products have a very high (even continuous) usage rate such as TVs, computers, refrigerators, electronic devices, etc.
- In these cases, perform a life test in which stress levels exceeds the actual use conditions in order to accelerate the cause(s) of failure
- Use this accelerated life test data to extrapolate to use conditions
- UUTs failure is a must unless the life-stress relationship is known.

Objectives of increasing the Stress in ALT



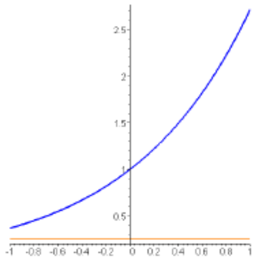
Life Stress Relationship

- Use a mathematical model to describe the relationship
  - e.g., $f(x) \equiv Y = m * X + b$ *is a simple linear model normally used for Usage Rate Acceleration*



Life Stress Relationship

- In choosing a life-stress relationship verify that it is:
  - Strictly Monotonic Function
    - It is a function that is increasing on its entire domain or decreasing on its entire domain.
  - One-to-One Function
    - The function should be a one-to-one function (i.e., for each y value in the range of f there exists exactly one value of x in its domain.)



Common Life-Stress Relationship

- Found widely in literature and used in ALT application (for constant stresses):
  - Arrhenius
  - Eyring
  - Inverse Power Law
  - …
  - Others…

Arrhenius Relationship

Exponential Relation

- Commonly used for analyzing data for which temperature is the accelerated stress
  - $R(T) = Ae^{-\frac{E_A}{K*T}}$
- Where R is the speed of reaction, A is a non-thermal constant, E_A is the activation energy (eV), K is Boltzmann's constant (8.617385E-5 eV/K) and T is the absolute temperature, K
- The activation energy is the energy that a molecule must have to participate in the reaction. In other words, the activation energy is a measure of the effect that temperature has on the reaction rate

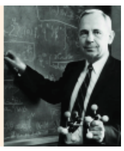
The model is derived from the Arrhenius reaction rate equation proposed by the Swedish physical chemist Svante Arrhenius in 1887.

Eyring Relationship

Exponential Relation

- Commonly used for analyzing data for which temperature or humidity is the accelerated stress. It is a 2 parameter model (A and B in this formulation)
  - $L(V) = \frac{1}{V} * e^{-\left(A-\frac{B}{V}\right)}$

The Eyring model was formulated from quantum mechanics principles and is most often used when thermal stress (temperature) is the acceleration variable. However, the Eyring relationship is also often used for stress variables other than temperature, such as humidity.



Inverse Power Law

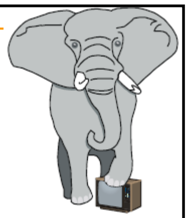
Power Relation

- Commonly used for analyzing data for which the accelerated stress (stimulus) is non-thermal in nature
  - $L(V) = \frac{1}{K * V^n}$

Rule of Thumb Regarding LSRs

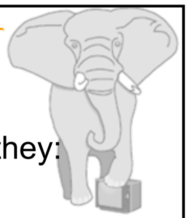
- Use exponential Life-Stress Relationships (LSRs) for thermal stimuli
  - Temperature
  - Humidity
- Use power LSRs for non-thermal stimuli. Voltage
  - Mechanical
  - Fatigue
  - Other…

Stress Acceleration



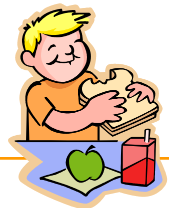
- Typical test acceleration parameters are:
  - Temperature
  - Humidity
  - Voltage
  - Current
  - Vibration
  - Temperature Cycling
  - Power Cycling
  - Contamination Level
  - Force
  - Load
  - Pressure and any combination of the above

Stress Acceleration



- The test stress levels should be chosen so that they:
  - Accelerate the failure modes under consideration
  - Do not introduce failure modes that would never occur under use condition (e.g. material phase change)

- Stress levels must be "high" enough so that enough failures are observed within the allowable testing time
- The more the accelerated stress varies from the operating actual stress, the greater the uncertainty of the extrapolation
- So, no free lunch!



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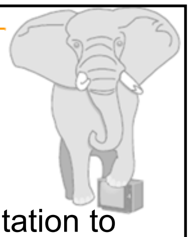
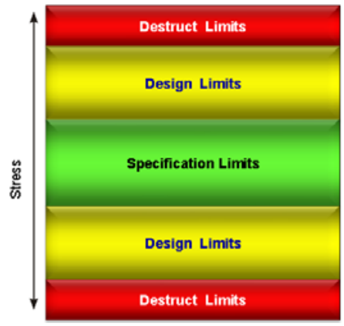
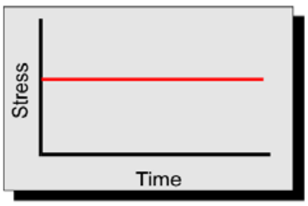


- Picking the appropriate stimuli is crucial
- Prior knowledge, physics of failure or experimentation to identify appropriate stimuli (e.g., DOE[2]) is mandatory
- A possible way to find the destruction limits of the UUT is conducting HALT[3]



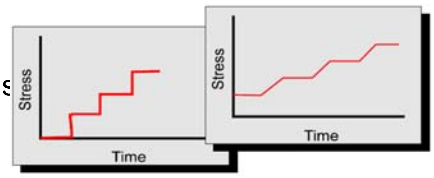
Types of Stress Loading

- Two possible stress loading (or stimulus application) schemes
  - Stress is time-independent
    - The specimens experience the same stress during the test
  - Stress is time-dependent
    - The stress on the specimens changes during the test (normally increases)



$s \neq f(t)$

Stress is time-independent!

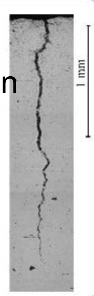


Stress is time-dependent!
(Quasi time-independent)

$s = f(t)$

Degradation ALT

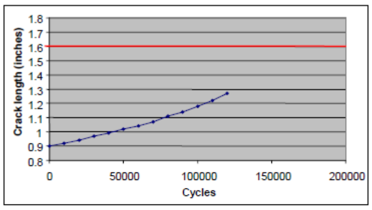
- Products are frequently being designed with higher reliabilities and developed in shorter amounts of time; even accelerated life testing is often not sufficient to yield reliability results in the desired timeframe
- Many failure mechanisms can be directly linked to the degradation of part of the product and degradation analysis allows the user to extrapolate to an assumed failure time based on the measurements of degradation or performance over time

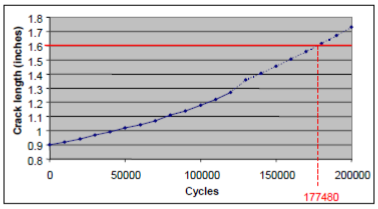


- Degradation analysis involves the measurement and extrapolation of degradation or performance data that can be directly related to the presumed failure of the product in question

Degradation Data – Crack Length Example

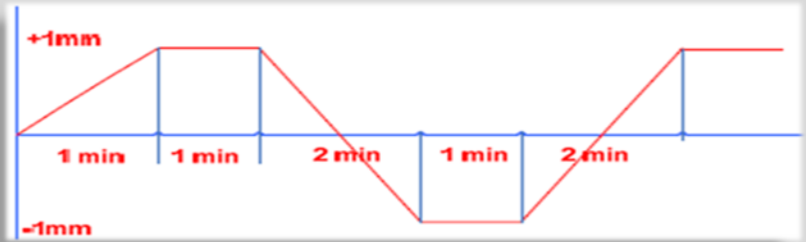
- Example: cracks in turbine blades.
- A failure is defined as a crack length of 1.6 inches or greater.
- A specimen is tested to 120,000 cycles, at which point the crack length is 1.27 inches.
- We can extrapolate the test data to the point at which the degradation would reach the critical level (177,480 cycles)





Usage Acceleration example

- Example:
  - We will use "Usage Rate Acceleration" (URA)
    - One cycle will last 6 minutes instead of 24 hours
  - For Mode 1 the accelerated factor is: 24 hours/6 min= 240
  - For Mode 2 the accelerated factor is: 3 months/6 min= 21600



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- *Motivation*
- *Example Overview*
- *Preface*
- *System Investigation*
- *Test Design*
  - *Operating conditions of the UUT*
  - Accelerating the test
  - *Expected test Duration*
- *Test Setup*
- *Test Parameters*
- *Test Procedure*
- *Analysis*
- *Flow Chart*
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- *Questions*

Expected test duration (accelerated)

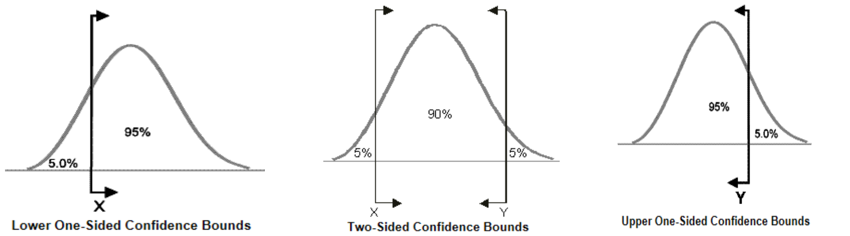
- To calculate the expected accelerated test duration, the following is needed:
  - Test Objectives (e.g. B0.1=30 cycles)
  - Number of UUTs in the test
  - Acceleration factor
  - Failure distribution (e.g., Weibull with β=2)
  - Confidence level (e.g., CL=90)
  - Expected number of failures (e.g., all units)
  - Acceleration method (e.g., Usage Rate Acceleration)

Confidence Level (CL)

- Confidence intervals consist of a range of values (interval) that act as good estimates of the unknown population parameter
- However, in rare cases, none of these values may cover the value of the real parameter
- Heuristically the level of confidence of the confidence interval would indicate the probability that the confidence interval captures this true population parameter

Confidence Level (CL)

- when we say, "we are 90% confident that the true value of the parameter is within our confidence interval"
  - we mean that in 90% of the tests, the observed confidence intervals will hold the true value of the parameter
  - but, in 10% of the tests, the real parameter is out of the confidence interval

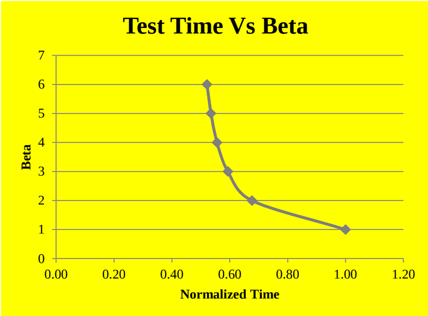


Expected Number of Failures

- When calculating the expected test duration, the number of expected failures has to be selected allready
- Setting the number of failures to zero (no failures, or in other words, the needed 'time' to run the experiment without any failures so that target reliability will be confidently proven), will result in the shortest test
- The drawback of this method is its impreciseness as it was calculated based on the Shape Parameter being known
- It is possible to run a “zero Failures” while conducting a Degradation ALT

Expected Number of Failures (cont.)

- To overcome this drawback it is advisable to use a minimal estimated Shape parameter value to be able to estimate the test 'time' as this will yield the maximal required test time
- Using both minimum and maximum values will yield the range of test 'time' expected



Expected test duration (accelerated)

- Example:
  - Test duration (based on expected reliability of the flexure of 99.9% at confidence level of 90% after 30 cycles and assuming ß=1.5, two flexures under test, no failures during the test):
  - Test duration for Mode 1
    – 3300 cycles
  - Test duration for Mode 2
    – 2200 cycles
  - Test duration for Mode 1 should be about two weeks

$$\frac{3{,}300[cycle] * 6[\frac{minute}{cycle}]}{60[\frac{minute}{hour}] * 24[\frac{hour}{day}]} = 13.75[days]$$

Expected test duration (accelerated)

Design a reliability demonstration test

What metric would you like to demonstrate?

Metric	Reliability value at a specific time
Demonstrate this reliability (%)	99.9
With this confidence level (%)	90
At this time (Cyc)	30

Assume the failure rate behavior is governed by this distribution

Distribution	2P-Weibull
With this Beta	1.5

Solve for this value

Value	Required test time
With this sample size	2
With a maximum of this many failures	0

Results

Test time per unit (Cyc)	3294.328410

Notes

This is based on both the assumed failure rate behavior given the specified distribution and the specified acceleration factor.

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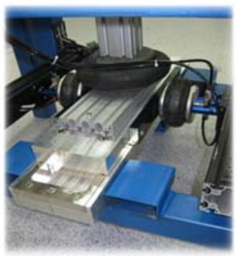


Test Setup

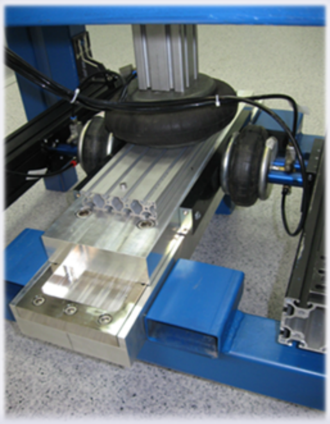
- Test setup comprises of the design and implementation of the test bench for conducting the ALT
- The test bench should include the means to mount the UUT in a way that will emulate the way the UUT is mounted in the system including:
  - Moment
  - Vibration
  - Damping
  - Supply Voltages
  - Temperature
  - Humidity
  - VOC
  - Dust, etc.

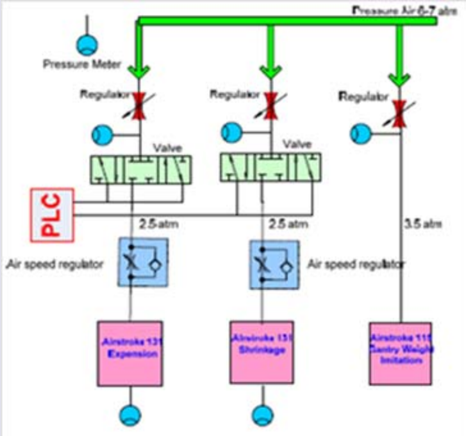
Test Setup (cont.)

- It is recommended to use the same system structure schematics for building the UUT mechanical mounting (to be able to identify any issue of reliability due to over stressing as a cause of bad mounting)
- In cases where the UUT is a motor or when a part of the UUT is a motor, it is advisable to use the same motor driver as in the system
- In general, it is highly recommended to emulate all the UUT interfaces as they might affect the UUT reliability
- Remember to include in the test bench all the measuring means including data loggers, flow meters, etc.

Test Setup (cont.)

- Example:





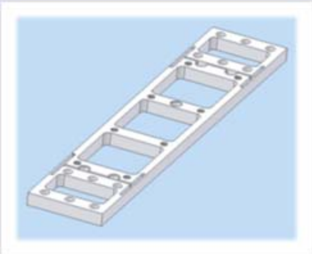
Agenda

Test Parameters

- Based on the failures we need to monitor and their limit values (values that outside them the failure mode takes place), make a list of all the parameters to monitor, concise definitions of the limit values and the means needed to measure them

Test Parameters (cont.)

- Example:
  - During the test, cracks appearance in A, B, C and D spring areas of the UUT should be detected. The UUT is defined as failed if the cracks are detected in at least one spring area of the UUT



Both X-Ray and Fluorescent Color test are Non Destructive tests (NDT), hence, these tests can be conducted during the ALT period without influencing the UUT's health

Agenda

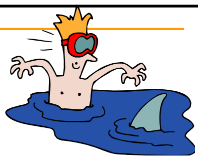
Test Procedure

- Now is the time to determine the timeline of the ALT
- This should include:
  - a list of all the parameters to be monitored
  - their expected correct values range
  - how the parameters are going to be measured
    - e.g., during operation, with no operation, outside the test bench, etc.
  - with what measuring means
    - in-house, outsourcing, etc.
  - at what intervals
    - based on the reliability definition, e.g., time interval, cycles interval, etc.

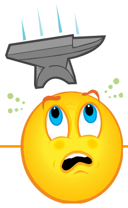
Test Procedure (cont.)

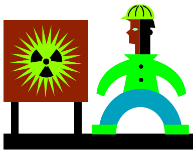
- The timeline should include instructions for when and how to conduct intermediate analysis and actions to take based on the intermediate analysis results
  - continue the test with the original UUTs,
  - replace the failed one with a new one,
  - pause the test and update the 'customer',
  - terminate the test and run final analysis, etc.
- *Important, remember to conduct Preventive Maintenance if applicable*

Test Procedure (cont.)



- *A science or chemistry laboratory can and should be a safe place to perform experiments*
- *Accidents can be prevented if you think about what you are doing at all times, use good judgment, observe safety rules, and follow directions*
- *Each experiment will include comments to alert you to probable hazards, including how to protect yourself and others against injury*





Test Procedure (cont.)

- Example:
  - The test should be performed by Non Destructive Test (NDT)
  - The test includes crack detection in the UUT
  - Cracks detection will be done before test starts and after 100 cycles and then after each 500 cycles
  - Crack detection will be done by X-Rays test and Fluorescent Color test
  - After the test is completed, the probability that the UUT will be functional after transportation and storage, will be calculated

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Analysis

- The most accurate analysis of a test will be obtained after all the UUTs have failed, but…
- …often the customer or the management are impatient and expect to get the result earlier…
- …even in exchange for a higher level of uncertainty

Analysis (cont.)

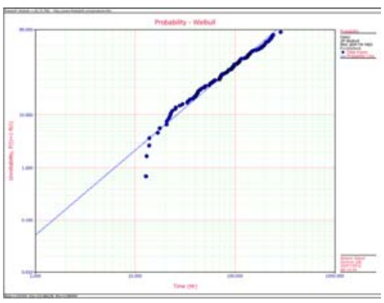
- There are three noticeable test 'periods':
  - the first one is when no failure is observed (from the beginning of the test till the 'moment' when the first failure occurs)
    - → Zero Failures Zone
  - the second one is from the first failure till the one before the last failure
    - → 1 to (n-1) Failures (n=number of UUTs)
  - the last and third 'period' is when all UUTs have failed
    - → n Failures

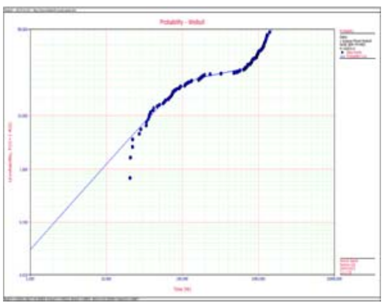
Analysis (cont.)

- To calculate any reliability parameters, first the reliability distribution has to be resolved
- This can be done by using a Weibull application (e.g., Reliasoft Weibull++) and keying in the UUTs 'time' to failure and then let the application reveal the parameters that best fit the test results
- While in the third 'period', all possible failures took place, there is no need to guess the Shape Parameter value as the application will fit one to the results

Analysis (cont.)

- While analyzing the results, pay attention to whether the results represent only one failure mode (the same Shape parameter) or it might point to competing or mixed failure modes (several Shape Parameters)





Analysis (cont.)

- The same method applies for the **second** 'period' but with lower level of confidence as there are less number of failed UUTs
- When there is a need to conduct an intermediate analysis when no failures have been observed (the **first** 'period'), a value for the Shape Parameter has to be assumed.

Analysis (cont.)

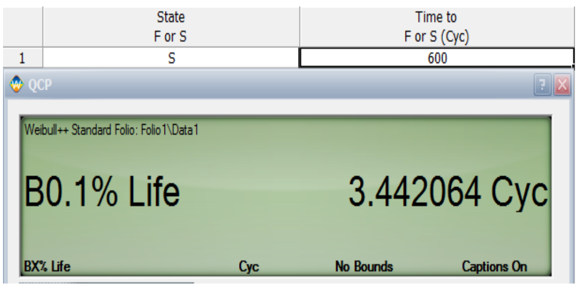
- Example:
  - Based on no failure found after 600 cycles (mode 1) and assuming ß=1.5, we can say that with 90% confidence the flexure will not fail in the first 3 cycles – B(0.1)=3.4.
  - We cannot say when it will fail; it might fail at the 4^{th} cycle or after more than 4 cycles

Analysis (cont.)

- *Note*: in this example, we can refer to the UUT either as a black box, one unit that can fail (ignoring the fact that it is composed of four independent flexures) or as a white box, a system built up of four flexures
- Now we can see the importance of the exact definition of the UUT failure; As stated in the example , "…cracks presence in one of the spring…"; this is a white box definition. In both cases the expected reliability calculation should be, as expected, the same

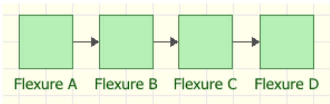
Analysis (cont.)

- *Calculating as a black box*
  - As a black box, the unit was exposed to 600 cycles. Calculating the number of cycles after which we can guarantee reliability of 0.999, or B(0.1%), assuming ß=1.5, will yield 3.4 at CL=90%:



Analysis (cont.)

- *Calculating as a white box*
  - As a white box, the four flexures were exposed to 600 cycles
  - First we have to allocate the desire reliability of the UUT ($R_{30\ cycles} = 0.999$) to each of the four flexures
  - To do the allocation, based on the failure definition, we can draw the four flexures in series



  - That means that the UUT reliability is the product of the four flexures reliability, or:

$$R_{UUT} = \prod_1^4 R_{flexure}, \text{ or, } R_{felxure} = \sqrt[4]{R_{UUT}}$$

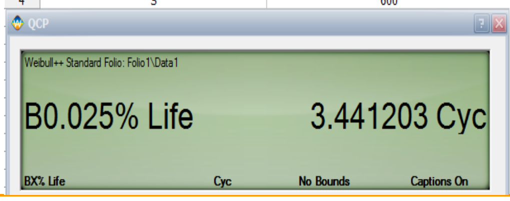
Analysis (cont.)

- *Calculating as a white box*
  - Therefore:

$$R_{flexure} = \sqrt[4]{0.999} = 0.99975, \text{ or, } B(0.025) = 30[cycles]$$

  - Calculating the number of cycles after which we can guarantee reliability of 0.99975, or B(0.025), assuming ß=1.5, will yield 3.4 at CL=90%

	State F or S	Time to F or S (Cyc)
1	S	600
2	S	600
3	S	600
4	S	600



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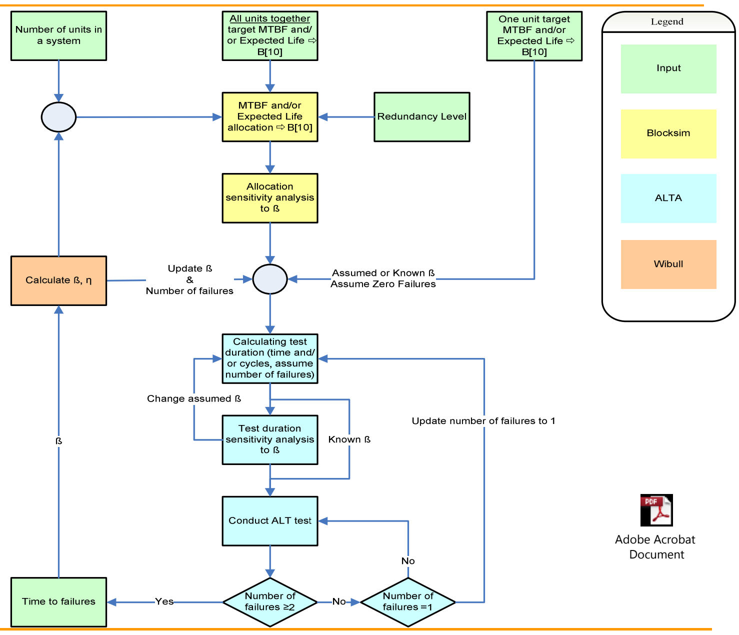
Flow Chart



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Agenda

Summary

- Accelerated Life Tests are most often expensive and time consuming
- It is important to design the test very carefully and decide on UUT quantity vs. Level of Confidence vs. expected test duration
- Following this procedure will assure the optimal test design regarding time, money and results confidence

Agenda

Questions?

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