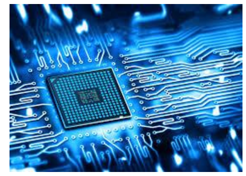
ZEST PAGA / MBS RELIABILITY

TDS-030 Issue 01 Ziztel Technical Bulletin



Ziztel are a UK based manufacturer of PAGA / MBS and Intercom products. Our systems are mainly designed for use in the Military, Marine, Hazardous Oil, Gas and Petrochemical industries.

Maintaining reliability and providing reliability engineering is an essential part of the Ziztel package. Reliability engineering for electronic equipment requires a means for a quantitative baseline, or a reliability prediction analysis. The MIL-217 standard was developed for military and aerospace applications; and has become widely used for industrial electronic equipment applications throughout the world. Using the Mil-217 standard for reliability prediction produces calculated Failure Rate and Mean Time Between Failures (MTBF) numbers for the individual components, equipment and the overall system. The final calculated prediction results are based on the roll-up, or summation, of all the individual component failure rates.

RELIABILITY MIL-HDBK-217

Background

The PAGA / MBS system is a safety critical package and as such reliability is a key part of Ziztel product development. To obtain highest product reliability, consideration of reliability issues are integrated from the very beginning of the design phase. This establishes the philosophy of *reliability prediction*. Historically, this term has been used to denote the process of applying mathematical models and component data for the purpose of estimating the field reliability of a system before failure data are available for the system. The objective of reliability prediction is not limited to predicting whether reliability goals, such as MTBF, can be reached. It is also used for:

- Identifying potential design weaknesses
- Evaluating the feasibility of a design
- Comparing different designs and life-cycle costs
- Providing models for system reliability/availability analysis
- Establishing goals for reliability tests
- Aiding in business decisions such as budget allocation and scheduling

Ziztel use an industry recognised predicative reliability software package to assess reliability metrics early in the design process. The benefit of this is that during the design process reliability can be built into the fibre of our products. Analysis is performed for a chosen environmental condition and mission profile. Analysis is undertaken in accordance with MIL-HDBK-217 Military Standard.

Key benefits and capabilities:

Analysis of components to predict and calculate the rate at which a product will fail – enabling our products to be designed with high reliability ratings as a pre requisite.

ZIZTEL LIMITED
email: sales@ziztel.com web: www.ziztel.com tel: +44 (0) 115 9202888
mail: 96 Rolleston Drive, Arnold, Nottingham, NG5 7JP United Kingdom

Calculation of MTBF (Mean Time Between Failures)

Prediction calculations are based on established globally accepted models

Mission profile modelling, reliability allocation methods and the ability to model both active and dormant states

Derating analysis possible

Compliance with industry standard models

Once the prototype of a product is available, tests are utilized to obtain more accurate reliability predictions. Accurate prediction of the reliability of electronic products requires knowledge of the components, the design, the manufacturing process and the expected operating conditions. Several different approaches have been developed to achieve the reliability prediction of electronic systems and components. Each approach has its unique advantages and disadvantages. Among these approaches, three main categories are often used: empirical - standards based, physics of failure and life testing.

Empirical (or Standards Based) Prediction Method MIL-HDBK-217

Empirical prediction methods are based on models developed from statistical curve fitting of historical failure data, which are collected in the field, in-house or from manufacturers. These methods tend to present good estimates of reliability for similar or slightly modified parts. Some parameters in the curve function can be modified by integrating engineering knowledge. The assumption is made that system or equipment failure causes are inherently linked to components whose failures are independent of each other. MIL-HDBK-217 Predictive Method

The MIL-HDBK-217 predictive method consists of two parts; one known as the *parts count* method and the other called the *part stress* method [1]. The parts count method assumes typical operating conditions of part complexity, ambient temperature, various electrical stresses, operation mode and environment (called *reference conditions*). The failure rate for a part under the reference conditions is calculated as:

$$\lambda_{b,i} = \sum_{i=1}^{n} (\lambda_{ref})_i$$

Where:

- λ_{ref} is the failure rate under the reference conditions
- i is the number of parts

Since the parts may not operate under the reference conditions, the real operating conditions will result in failure rates that are different from those given by the "parts count" method. Therefore, the part stress method requires the specific part’s complexity, application stresses, environmental factors, etc. (called *Pi factors*). For example, MIL-HDBK-217 provides many environmental conditions (expressed as π_E) ranging from "ground benign" to "cannon launch." The standard also provides multi-level quality specifications (expressed as π_Q). The failure rate for parts under specific operating conditions are calculated thus:

ZIZTEL LIMITED
email: sales@ziztel.com web: www.ziztel.com tel: +44 (0) 115 9202888
mail: 96 Rolleston Drive, Arnold, Nottingham, NG5 7JP United Kingdom

$$\lambda = \sum_{i=1}^{n} (\lambda_{ref,i} \times \pi_S \times \pi_T \times \pi_E \times \pi_Q \times \pi_A)$$

where:

- π_S is the stress factor
- π_T is the temperature factor
- π_E is the environment factor
- π_Q is the quality factor
- π_A is the adjustment factor

Figure 1 shows an example using MIL-HDBK-217 to predict the failure rate of a ceramic capacitor. According to the handbook, the failure rate of a commercial ceramic capacitor of 0.00068 μF capacitance with 80% operation voltage, working under 30 degrees ambient temperature and "ground benign" environment is 0.0217 / 10^6 hours. The corresponding MTBF (mean time before failure) or MTTF (mean time to failure) is estimated to be 4.6140 / 10^7 hours.

ZIZTEL LIMITED
email: sales@ziztel.com web: www.ziztel.com tel: +44 (0) 115 9202888
mail: 96 Rolleston Drive, Arnold, Nottingham, NG5 7JP United Kingdom

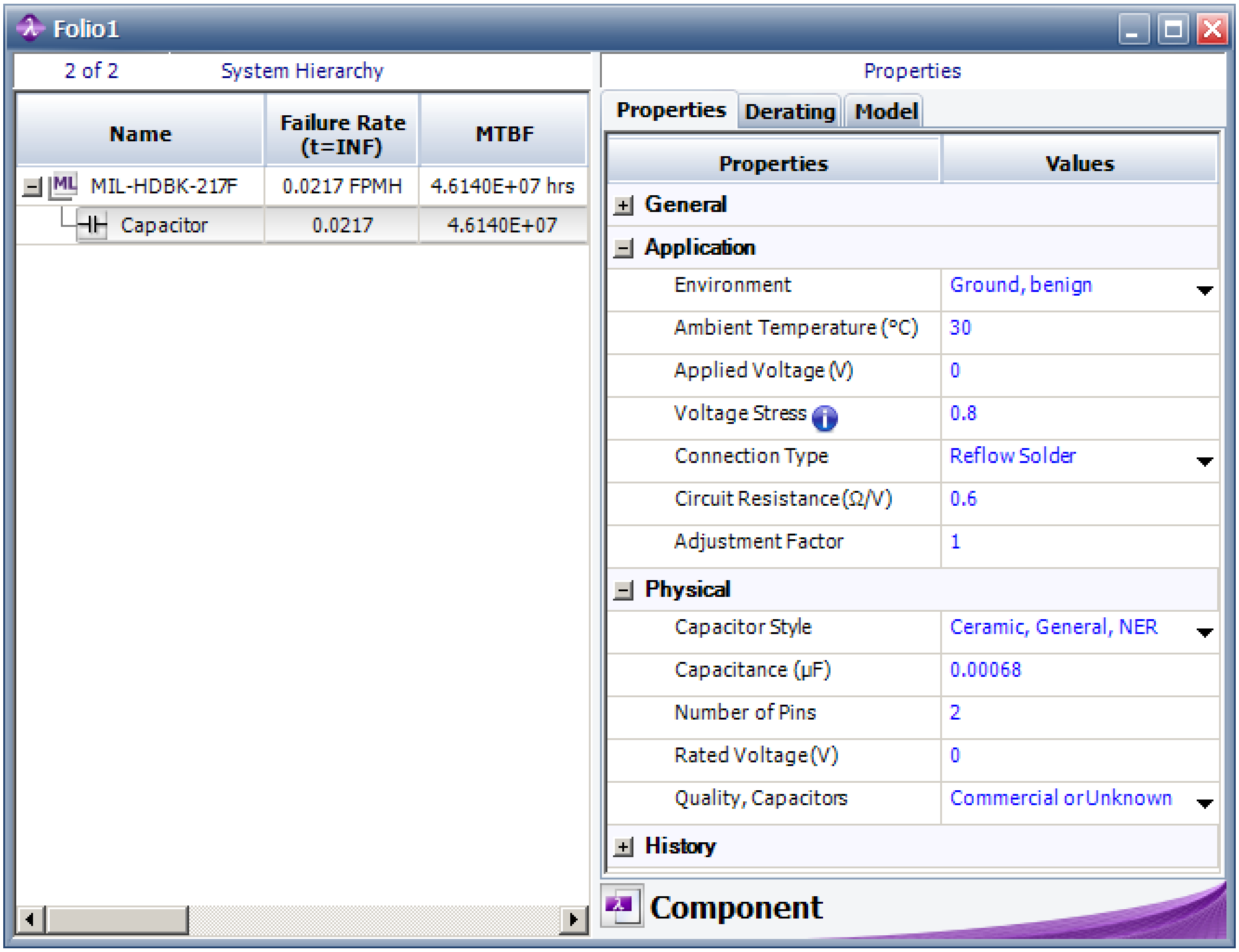


Figure 1: MIL-HDBK-217 capacitor failure rate example

Advantages of empirical methods:

1. Easy to use, and a lot of component models exist
2. Relatively good performance as indicators of inherent reliability
3. Provide an approximation of field failure rates

Disadvantages of empirical methods:

1. Failure of the components is not always due to component-intrinsic mechanisms but can be caused by the system design
2. The reliability prediction models are based on industry-average values of failure rate, which are neither vendor-specific nor device-specific
3. It is hard to collect good quality field and manufacturing data, which are needed to define the adjustment factors, such as the Pi factors in MIL-HDBK-217

Physics of Failure Method

In contrast to empirical reliability prediction methods, which are based on the statistical analysis of historical failure data, a physics of failure approach is based on the understanding of the failure mechanism and applying the physics of failure model to the data.

Arrhenius's Law

One of the earliest and most successful acceleration models predicts how the time-to-failure of a system varies with temperature. This empirically based model is known as the *Arrhenius equation*. Chemical reactions are accelerated by increasing the system temperature. Since it is a chemical process, the aging of a capacitor (such as an electrolytic capacitor) is accelerated by increasing the operating temperature. The model takes the following form.

$$L(T) = A \exp\left(\frac{E_a}{kT}\right)$$

Where:

- $L(T)$ is the life characteristic related to temperature
- A is the scaling factor
- E_a is the activation energy
- k is the Boltzmann constant
- T is the temperature.

Eyring and Other Models

While the Arrhenius model emphasizes the dependency of reactions on temperature, the Eyring model is commonly used for demonstrating the dependency of reactions on stress factors other than temperature, such as mechanical stress, humidity or voltage.

The standard equation for the Eyring model [10] is as follows:

$$L(T,S) = AT^{\alpha} \exp\left[\frac{E_a}{kT} + \left(B + \frac{C}{T}\right)S\right]$$

Where:

- $L(T,S)$ is the life characteristic related to temperature and another stress
- A, α, B and C are constants
- S is a stress factor other than temperature
- T is absolute temperature

According to different physics of failure mechanisms, one more term (i.e., stress) can be either removed or added to the above standard Eyring model. Several models are similar to the standard Eyring model. They are:

Two Temperature/Voltage Model:

$$L(T,V) = Ae^{\frac{E_a}{kT}}V^{-\beta}$$

Three Stress Model (Temperature-Voltage-Humidity):

$$L(T,V,H) = Ae^{\frac{\Delta H}{kT}}V^{-\beta}RH^{-\tau}$$

Corrosion Model:

Electronic devices with aluminium or aluminium alloy with small percentages of copper and silicon metallization are subject to corrosion failures and therefore can be described with the following model [11]:

$$L(RH,V,T) = B_0 \exp[(-a)RH] f(V) \exp\left(\frac{E_a}{kT}\right)$$

Where:

- B_o is an arbitrary scale factor
- α is equal to 0.1 to 0.15 per % RH
- $f(V)$ is an unknown function of applied voltage, with empirical value of 0.12 to 0.15

Hot Carrier Injection Model:

Hot carrier injection describes the phenomena observed in MOSFETs by which the carrier gains sufficient energy to be injected into the gate oxide, generate interface or bulk oxide defects and degrade MOSFETs characteristics such as threshold voltage, transconductance, etc. [11]:

For n-channel devices, the model is given by:

$$L(I,T) = B(I_{sub})^{-N} \exp\left(\frac{E_a}{kT}\right)$$

Where:

- B is an arbitrary scale factor
- I_{sub} is the peak substrate current during stressing
- N is equal to a value from 2 to 4, typically 3

- E_a is equal to -0.1eV to -0.2eV

For p-channel devices, the model is given by:

$$L(I,T) = B(I_{gate})^{-M} \exp\left(\frac{E_a}{kT}\right)$$

Where:

- B is an arbitrary scale factor
- I_{gate} is the peak gate current during stressing
- M is equal to a value from 2 to 4
- E_a is equal to -0.1eV to -0.2eV

Since electronic products usually have a long time period of useful life (i.e., the constant line of the bathtub curve) and can often be modelled using an exponential distribution, the life characteristics in the above physics of failure models can be replaced by MTBF (i.e., the life characteristic in the exponential distribution). However, if you think your products do not exhibit a constant failure rate and therefore cannot be described by an exponential distribution, the life characteristic usually will not be the MTBF. For example, for the Weibull distribution, the life characteristic is the scale parameter *eta* and for the lognormal distribution, it is the *log mean*.

Black Model for Electro-migration

Electro-migration is a failure mechanism that results from the transfer of momentum from the electrons, which move in the applied electric field, to the ions, which make up the lattice of the interconnect material. The most common failure mode is "conductor open." With the decreased structure of Integrated Circuits (ICs), the increased current density makes this failure mechanism very important in IC reliability.

At the end of the 1960s, J. R. Black developed an empirical model to estimate the MTTF of a wire, taking electro-migration into consideration, which is now generally known as the *Black model*. The Black model employs external heating and increased current density and is given by:

$$MTTF = A_0(J - J_{threshold})^{-N} \exp\left(\frac{E_a}{kT}\right)$$

Where:

- A_o is a constant based on the cross-sectional area of the interconnect
- J is the current density
- $J_{threshold}$ is the threshold current density
- E_a is the activation energy
- k is the Boltzmann constant
- T is the temperature

- N is a scaling factor

The current density (J) and temperature (T) are factors in the design process that affect electro migration. Numerous experiments with different stress conditions have been reported in the literature, where the values have been reported in the range between 2 and 3.3 for N, and 0.5 to 1.1eV for E_a. Usually, the lower the values, the more conservative the estimation.

Coffin-Manson Model for Fatigue

Fatigue failures can occur in electronic devices due to temperature cycling and thermal shock. Permanent damage accumulates each time the device experiences a normal power-up and power-down cycle. These switch cycles can induce cyclical stress that tends to weaken materials and may cause several different types of failures, such as dielectric/thin-film cracking, lifted bonds, solder fatigue, etc. A model known as the (modified) *Coffin-Manson model* has been used successfully to model crack growth in solder due to repeated temperature cycling as the device is switched on and off. This model takes the form [9]:

$$N_f = Af^{-\alpha}\,\Delta T^{-\beta}\,G(T_{max})$$

Where:

- N_f is the number of cycles to failure
- A is a coefficient
- f is the cycling frequency
- ΔT is the temperature range during a cycle
- A is the cycling frequency exponent
- A is the temperature exponent
- $G(T_{max})$ is equal to:

$$\exp\left(\frac{E_a}{k} \times \frac{1}{T_{max}}\right)$$

Which is an Arrhenius term evaluated at the maximum temperature in each cycle.

Three factors are considered for testing: maximum temperature (T_{max}), temperature range (ΔT) and cycling frequency (f). The activation energy is usually related to certain failure mechanisms and failure modes, and can be determined by correlating thermal cycling test data and the Coffin-Manson model.

Physics of Failure Methods

A given electronic component will have multiple failure modes and the component's failure rate is equal to the sum of the failure rates of all modes (i.e., humidity, voltage, temperature, thermal cycling and so on). The system's failure rate is equal to the sum of the failure rates of the components involved. In using the above models, the model parameters can be determined from the design specifications or operating conditions. If the parameters cannot be determined without conducting a test, the failure data obtained from the test can be used to get the model parameters.

For example, the life of an electronic component is considered to be affected by temperature. The component is tested under temperatures of 406, 416 and 426 Kelvin. The usage temperature level is 400 Kelvin. The Arrhenius model and the Weibull distribution are used to analyse the failure data in ALTA. Figure 4 shows the data and calculated parameters. Figure 5 shows the reliability plot and the estimated B10 life at the usage temperature level.

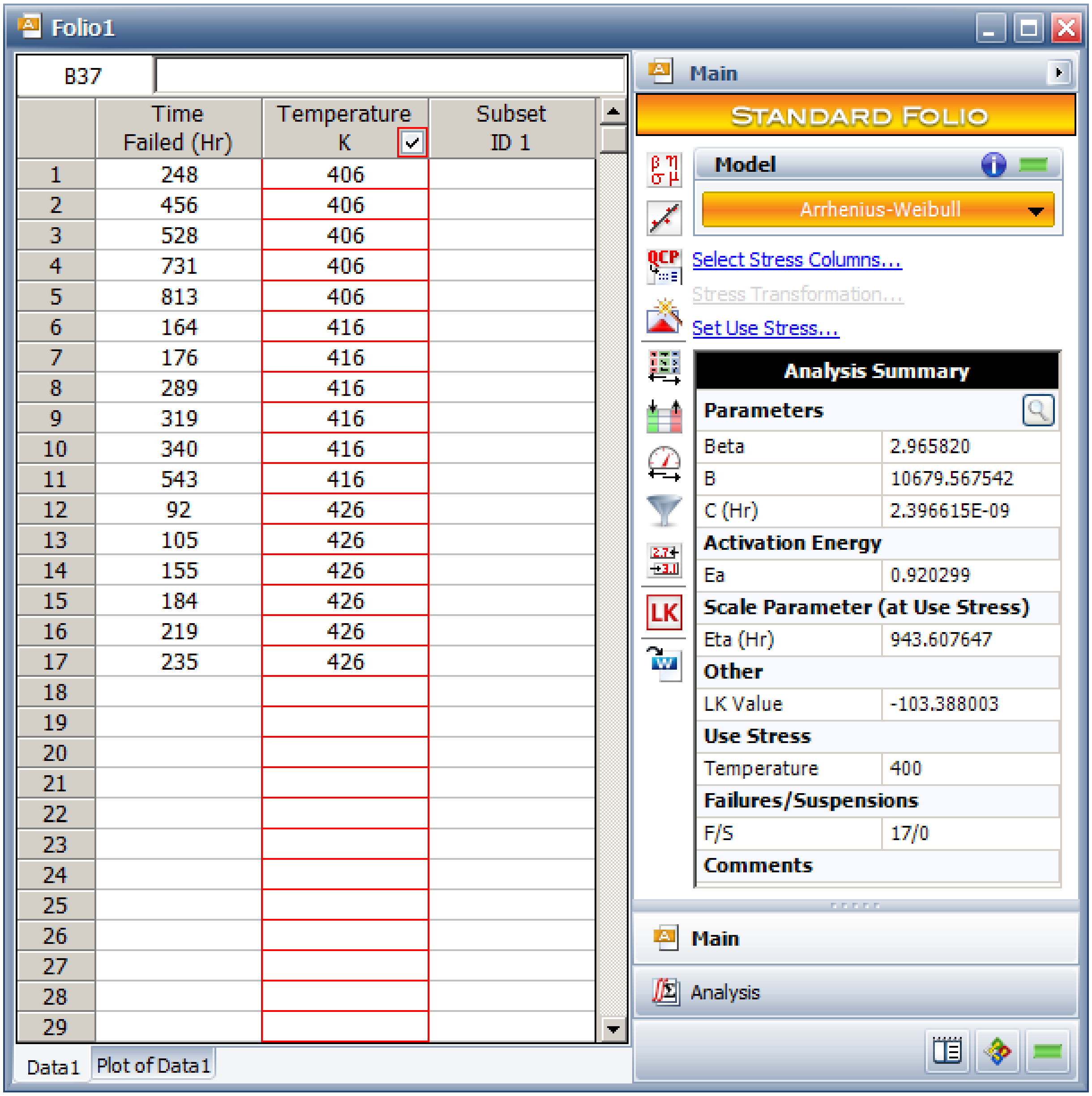
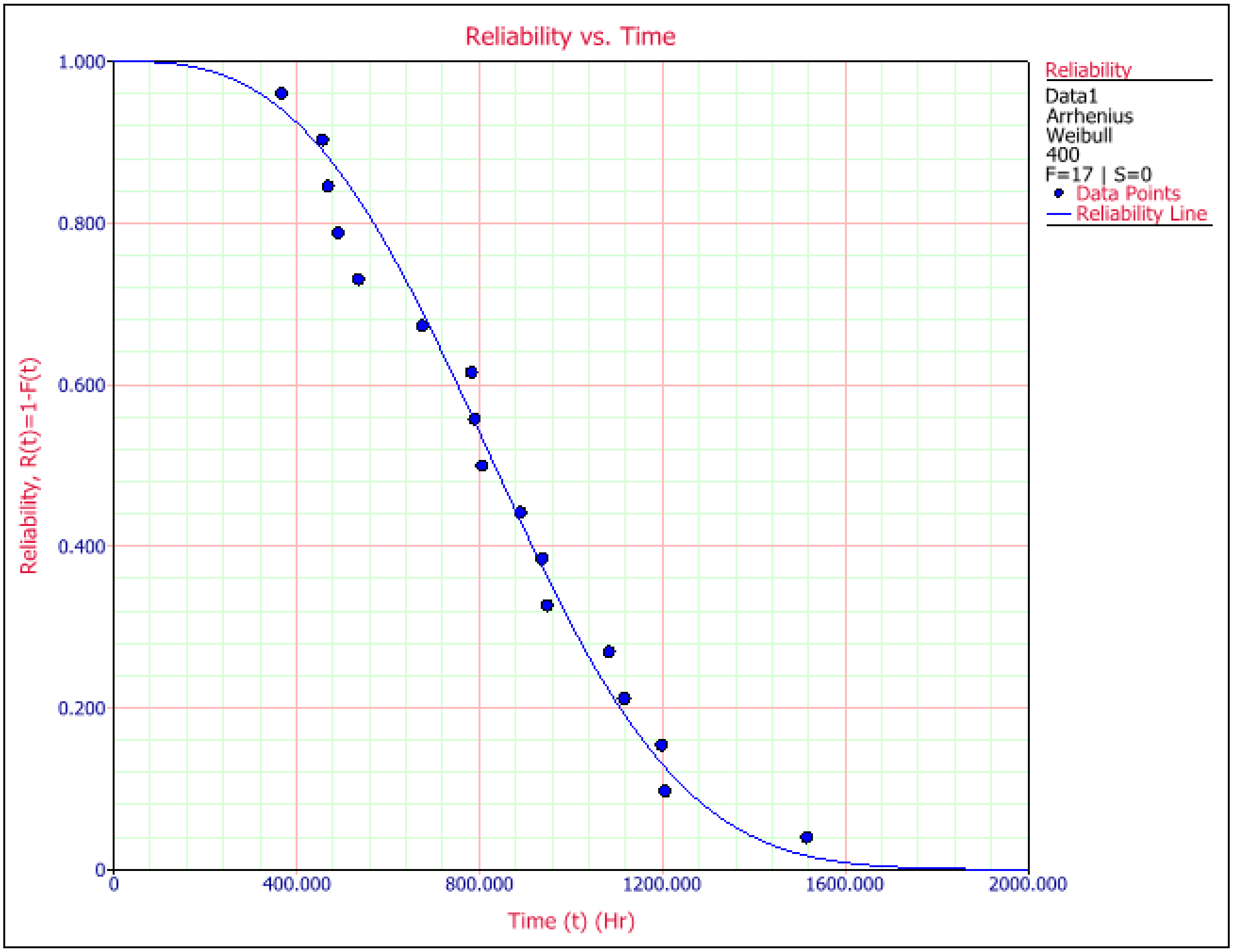


Figure 4: Data and analysis results in ALTA with the Arrhenius-Weibull model



ZIZTEL LIMITED
email: sales@ziztel.com web: www.ziztel.com tel: +44 (0) 115 9202888
mail: 96 Rolleston Drive, Arnold, Nottingham, NG5 7JP United Kingdom

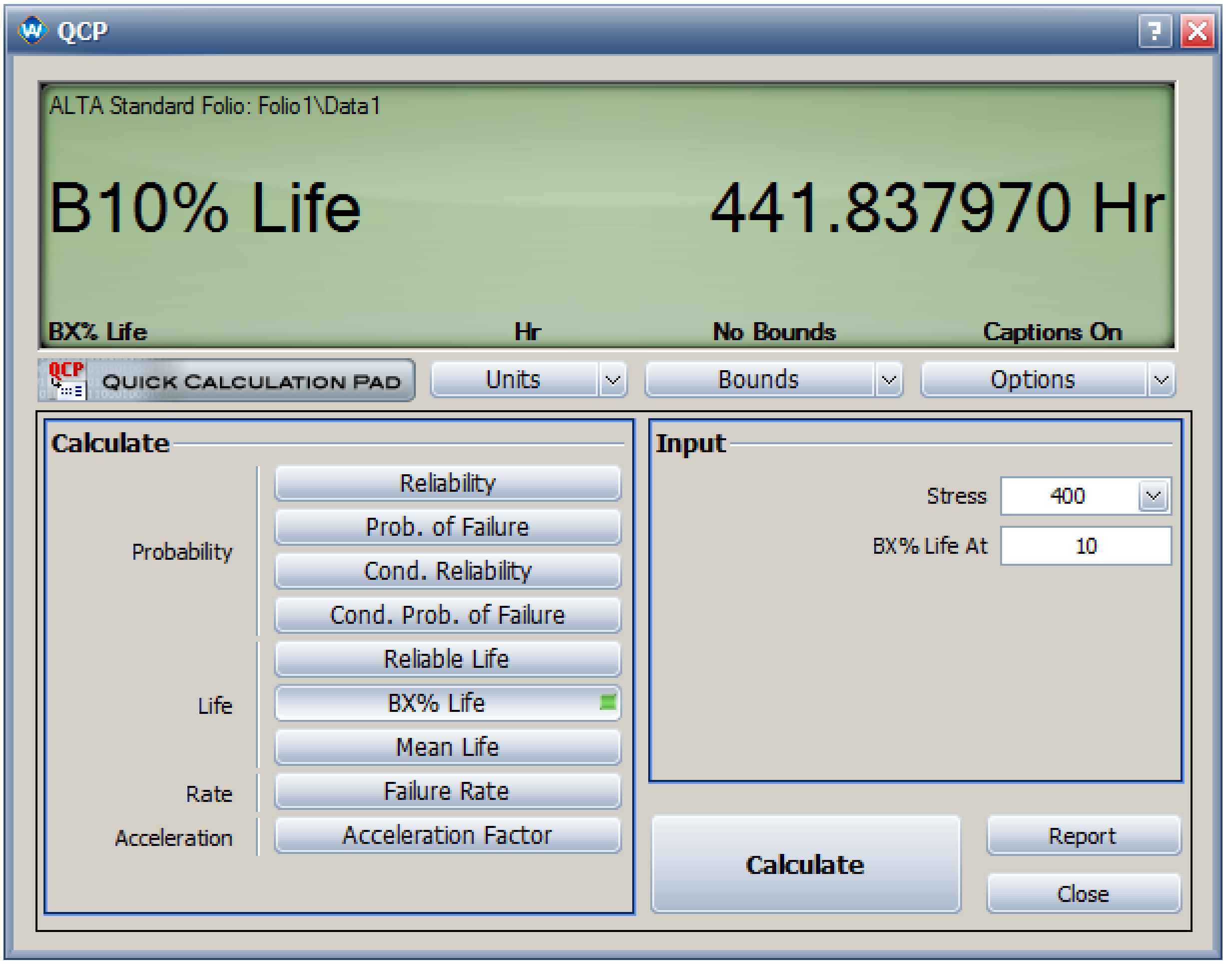


Figure 5: Reliability vs. Time plot and calculated B10 life

From Figure 4, we can see that the estimated activation energy in the Arrhenius model is 0.92. Note that, in ALTA, the Arrhenius model is simplified to a form of:

$$LT = C \exp\left(\frac{B}{T}\right)$$

Using this equation, the parameters *B* and *C* calculated by ALTA can easily be transformed to the parameters described above for the Arrhenius relationship.

Advantages of physics of failure methods:

1. Accurate prediction of wear out using known failure mechanisms
2. Modelling of potential failure mechanisms based on the physics of failure
3. During the design process, the variability of each design parameter can be determined

Disadvantages of physics of failure methods:

1. Need detailed component manufacturing information (such as material, process and design data)

2. Analysis is complex and could be costly to apply
3. It is difficult to assess the entire system

Life Testing Method

With this method, a test is conducted on a sufficiently large sample of units operating under normal usage conditions. Time-to-failure are recorded and then analysed with an appropriate statistical distribution in order to estimate reliability metrics such as the B10 life. This type of analysis is often referred to as *Life Data Analysis* or *Weibull Analysis*.

Example, an IC board is tested in the lab and the failure data are recorded. Figure 6 shows the data entered into Weibull++ and analysed with the 2-parameter Weibull lifetime distribution, while Figure 7 shows the Reliability vs. Time plot and the calculated B10 life for the analysis.

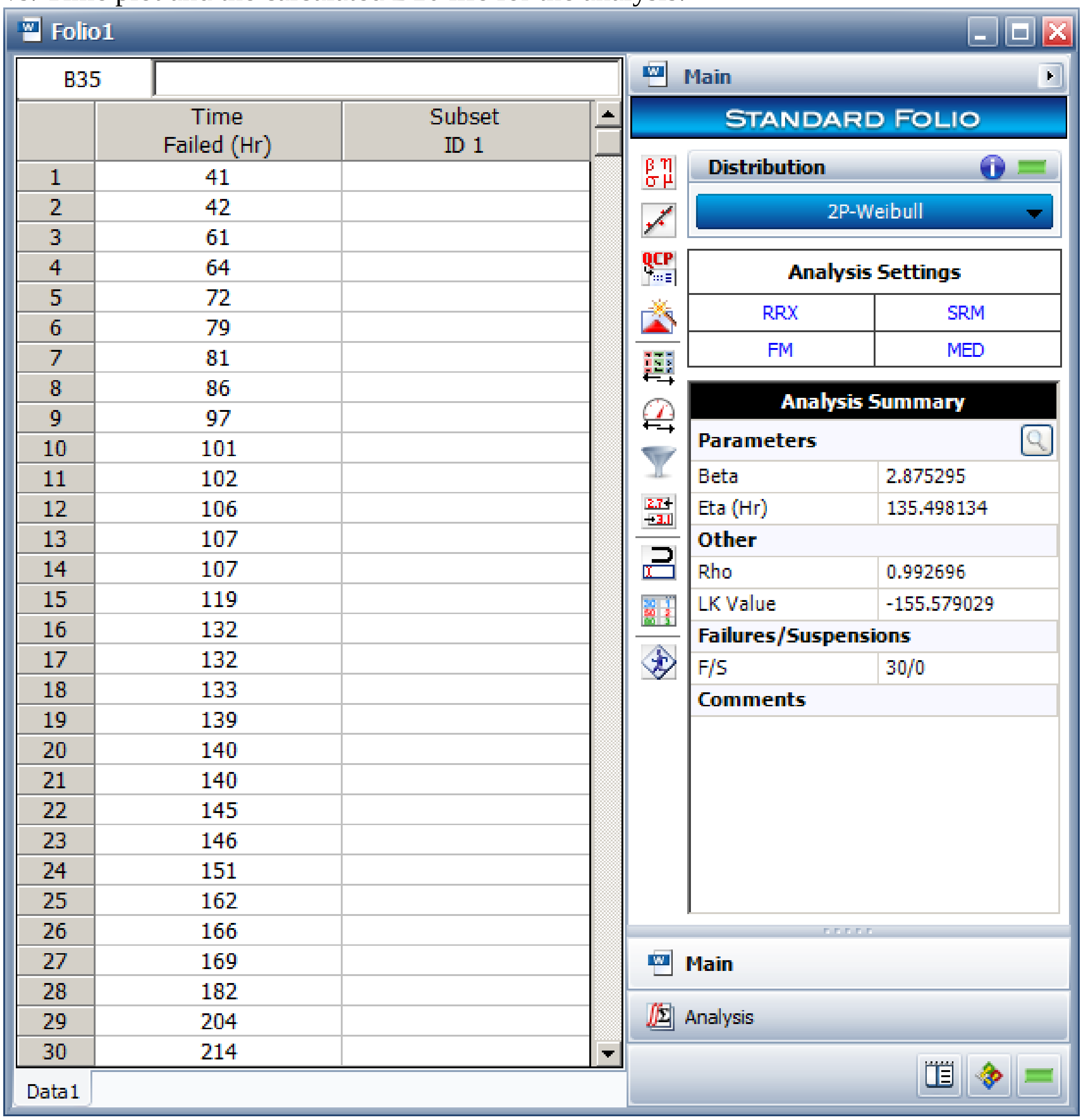
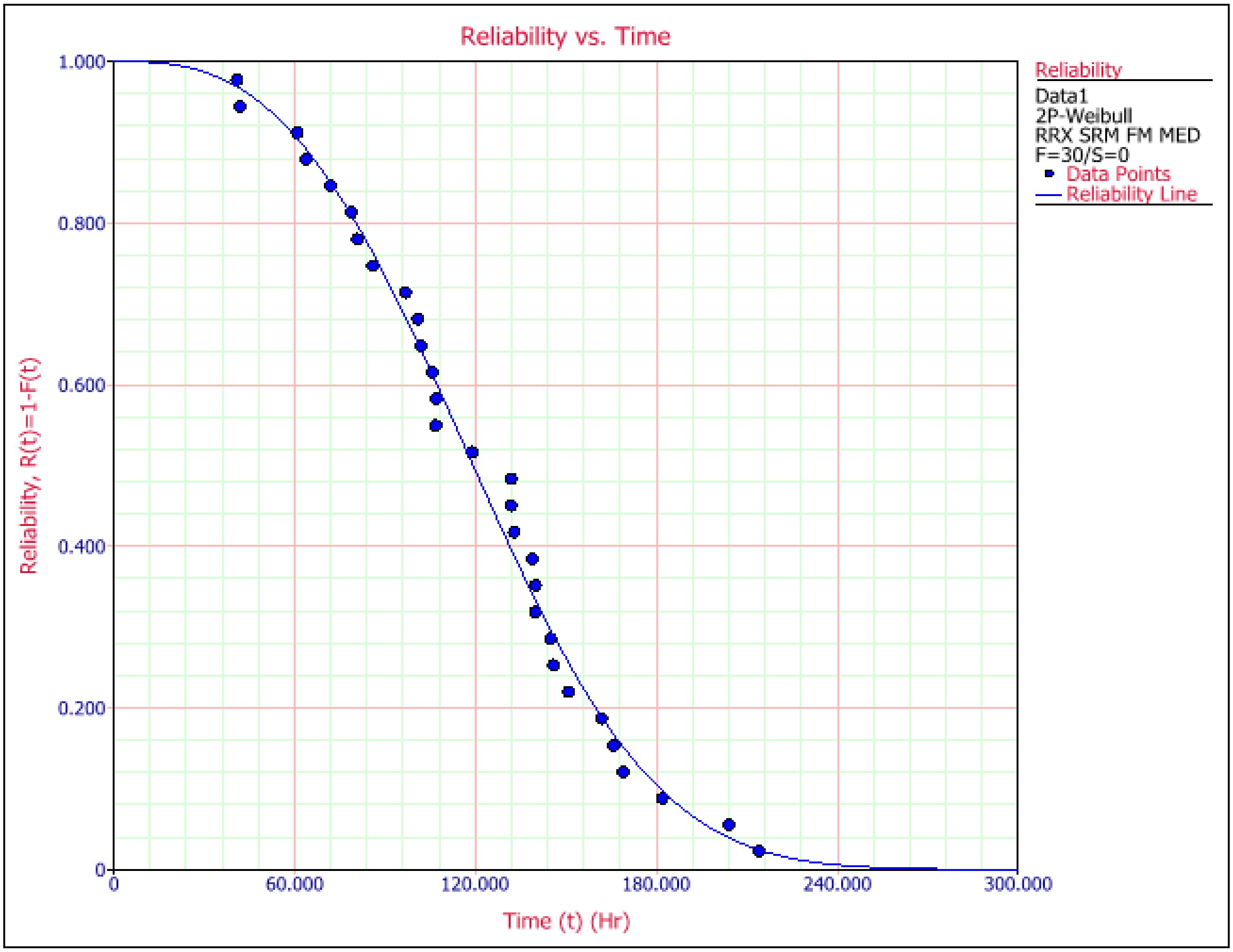


Figure 6: Data and analysis results in Weibull++ with the Weibull distribution


Reliability vs. Time
Reliability, R(t)=1-F(t)
1.000
0.800
0.600
0.400
0.200
0
0
60.000
120.000
180.000
240.000
300.000
Time (t) (Hr)
Reliability
Data1
2P-Weibull
RRX SRM FM MED
F=30/S=0
Data Points
Reliability Line

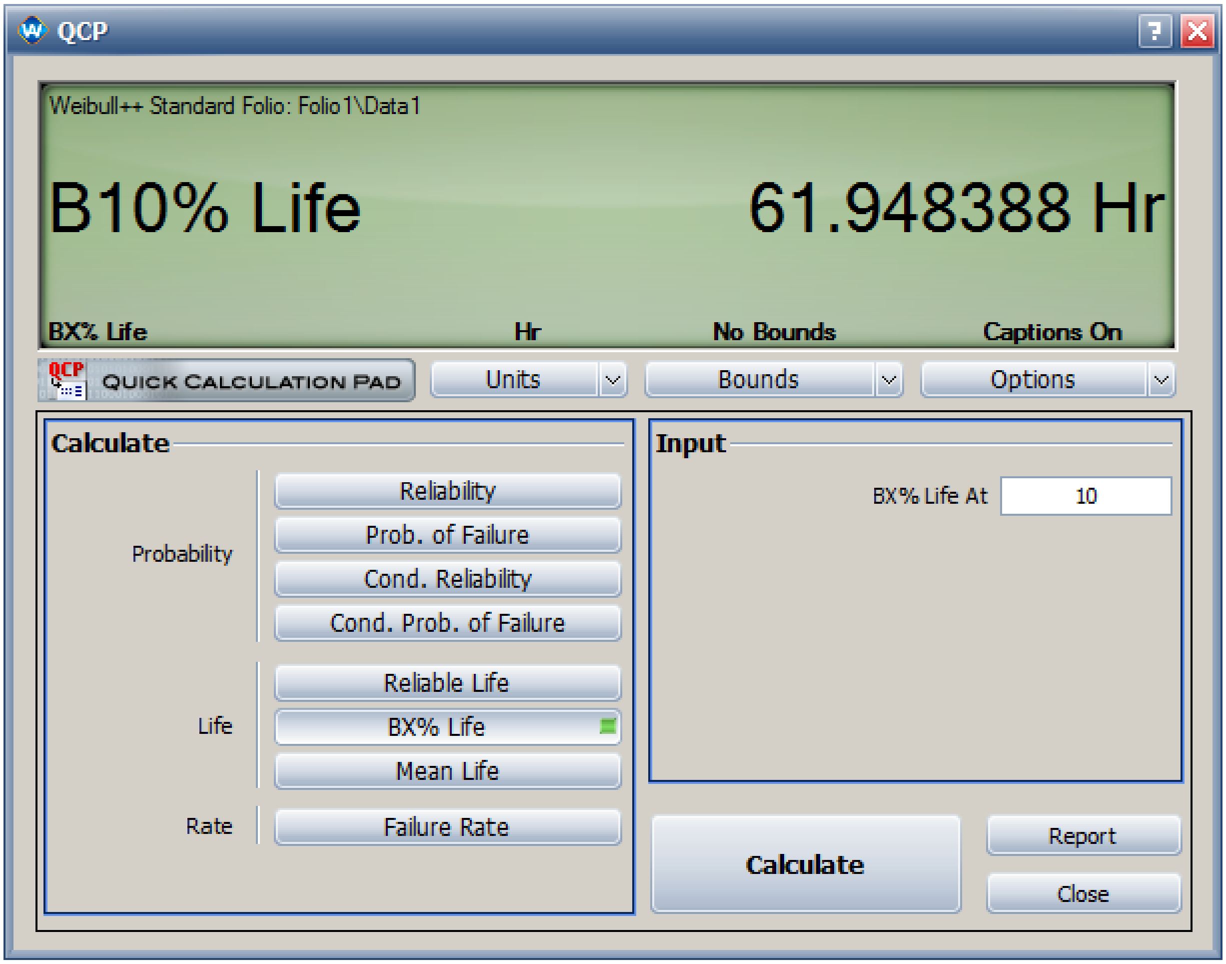


Figure 7: Reliability vs. Time plot and calculated B10 life for the analysis

Life Testing Method

The life testing method can provide more information about the product than the empirical prediction standards. Therefore, the prediction is usually more accurate, given that enough samples are used in the testing.

The life testing method may also be preferred over both the empirical and physics of failure methods when it is necessary to obtain realistic predictions at the system (rather than component) level. This is because the empirical and physics of failure methods calculate the system failure rate based on the predictions for the components (e.g., using the sum of the component failure rates if the system is considered to be a serial configuration). This assumes that there are no interaction failures between the components but, in reality, due to the design or manufacturing, components are not independent. (For example, if the fan is broken in your laptop, the CPU will fail faster because of the high temperature.) Therefore, in order to consider the complexity of the entire system, life tests can be conducted at the system level, treating the system as a "black box," and the system reliability can be predicted based on the obtained failure data.

Conclusion

The empirical (or standards based) methods are used in the design stage to quickly obtain a rough estimation of product reliability.

The physics of failure and life testing method is used in both design and production stages. In physics of failure approaches, the model parameters can be determined from design specifications or from test data.

Life testing method is more accurate than those from a general standard or model since it is based on the performance of the actual hardware.

ZIZTEL LIMITED
email: sales@ziztel.com web: www.ziztel.com tel: +44 (0) 115 9202888
mail: 96 Rolleston Drive, Arnold, Nottingham, NG5 7JP United Kingdom