Reliability

可靠性 Confiabilidade

موثوقية Fiabilité Affidabilità

信賴性 Αξιοπιστία Zuverlässigkeit

Confiabilidad Niezawodność Надежность

WEIBULL++®

ALTA®

START

THE SYNTHESIS PLATFORM®

Use with: Weibull_ALTA10_QuickStart_Rev1.rsgz10

Quick Start Guide

Weibull++®

Version 10

ALTA®

Version 10

ReliaSoft®

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Weibull++/ALTA 10 Quick Start Guide

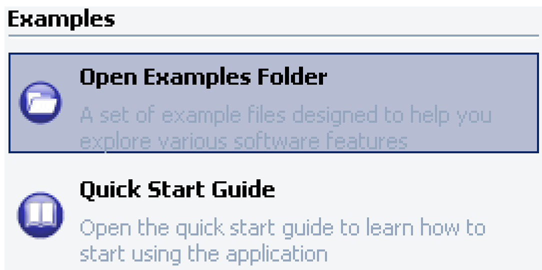
1

Thank you for your interest in ReliaSoft's Weibull++ and ALTA software tools. This quick start guide has been designed to help you explore many of the software's key features by working through step-by-step instructions for some practical application examples.

In order to demonstrate a variety of different applications for the tools available in Weibull++ and ALTA, this guide asks you to imagine that you are a reliability engineer working for a large company with many different product lines, then walks you through the steps you might take to answer a variety of questions from different design groups and customers. Please note that the sample data sets provided are fictional and intended for demonstration purposes. Furthermore, note that although this guide attempts to introduce you to some of the most frequently used tools in the software, Weibull++ and ALTA support many other reliability engineering methods and applications. Within the software, you can choose **File > Help** to access a wide array of resources that will help you explore other software capabilities.

In addition to this introduction, the following chapters are presented in this guide. Note that the examples in chapters 2 through 10 require Weibull++, chapters 11 and 14 can use either ALTA Standard or ALTA PRO and chapters 12 and 13 require ALTA PRO.

The quick start repository that is installed with the software (called "Weibull_ALTA10_QuickStart_Rev1.rsgz10") contains a sample project with completed analyses for all of the examples. To access this file, choose **File > Help**, click **Open Examples Folder**, then browse for the file in the **Weibull** or **ALTA** sub-folder.



Tip: To preserve the integrity of the shipped example files, the software creates a copy of the file each time you access a repository in the Examples folder. The copy has the same name as the original file and is saved in the default documents folder for your computer (e.g., My Documents\ReliaSoft\Files). Use the copy to work on the example projects and save your changes. Any changes you make in the copy will not affect the original file.

All of the folios, plots and other analyses described in this guide are stored in the "Completed Examples -- Weibull++ and ALTA Quick Start" project in the quick start database.When applicable, the instructions in this guide will refer to a completed folio in the quick start project using a notation such as (*"Bulb A - Supplier Data" in the sample project*). While reading any example in this guide, you have the choice to:

- Examine how it was completed in the sample project.
- Follow the instructions to complete the analyses "from scratch."
- Copy data/analyses from the sample project to help you complete the analyses.

IMPORTANT: Note that it may sometimes be necessary to modify the data in the quick start repository to fit updated instructions or new examples in the latest printing of this quick start guide. This printing of the guide was designed for use with **Weibull_ALTA10_QuickStart_Rev1.rsgz10** (where _RevX indicates the database revision). If you try to use a different database revision, the sample projects may not exactly match the instructions printed here. 1) If this guide is older than the latest database revision installed on your computer, you can choose **File > Help > Quick Start Guide** to download the latest printing. 2) If this guide is newer than the latest database revision installed on your computer, you can choose **File > Help > Check for Update** to download the latest software service release.

Life Data Analysis 2

In life data analysis, the goal is to model and understand the failure rate behavior of a particular item, process or product. The models are built by taking the observed "life" data, which can be obtained either from the field or from in-house testing. Because time is a common measure of product life, the life data points are often called *times-to-failure data*. There are two general types of times-to-failure data: *complete* and *censored*.

In this chapter, you will work with these types of data and use the Weibull++ standard folio to perform life data analysis.

In this chapter

- ✓ Standard folios
- ✓ Complete and censored data
- ✓ Confidence intervals
- ✓ QCP, plots and reports

2.1 Complete Data

You receive a request from a team of product engineers who are working on the design of a projector that your company manufactures. You are asked to quantify the life characteristics of the projector bulb in order to understand its reliability. You are given a data set for 10 bulbs that were all tested to failure by the bulb's supplier. The test included shutdown and cooldown periods that were intended to simulate normal use conditions. The failure times were 513, 649, 740, 814, 880, 944, 1009, 1078, 1161 and 1282 hours. These failure times are called *complete data*.

Complete Data: The simplest case of life data is a data set where the failure time of each specimen in the sample is known. This type of data set is referred to as *complete data*, and is obtained by recording the exact times when each unit failed.

Objectives

- Estimate the average life of the bulb (i.e., MTTF or *mean life*).
- Estimate the B10 life of the bulbs (i.e., the time by which 10% of the bulbs will be failed, or the time by which there is a 10% probability that a bulb will fail).
- Estimate the reliability of the bulbs after 200 hours of operation.
- Assuming 1,000 bulbs will be fielded, estimate how many would fail after 200 hours.
- Estimate the warranty time for the bulb if you do not want failures during the warranty period to exceed 2%.

MTTF and MTBF: The terms MTBF (mean time between failures) and MTTF (mean time to failure) have often been interchangeably used to describe the average time to failure. The truth is, these two metrics are not the same and should not be used interchangeably.

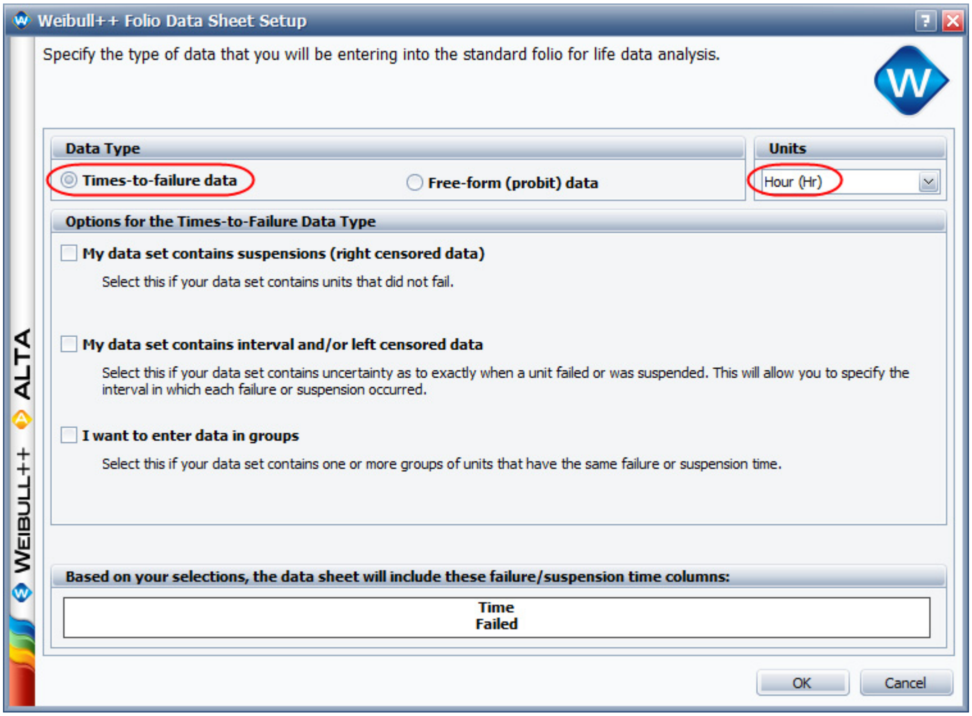
When dealing with non-repairable components (as in the case of life data analysis) the metric sought is the mean time ***to*** failure or MTTF. It is only when dealing with repairable components (where the component may fail and be repaired multiple times during its operational life) that you calculate the mean time ***between*** failures or MTBF. The only time that the MTTF and MTBF are the same is when the failure rate is constant (i.e., when the underlying model is an exponential distribution).

Solution

To answer the questions of interest to the design team, you will perform life data analysis on the complete data set provided by the supplier.

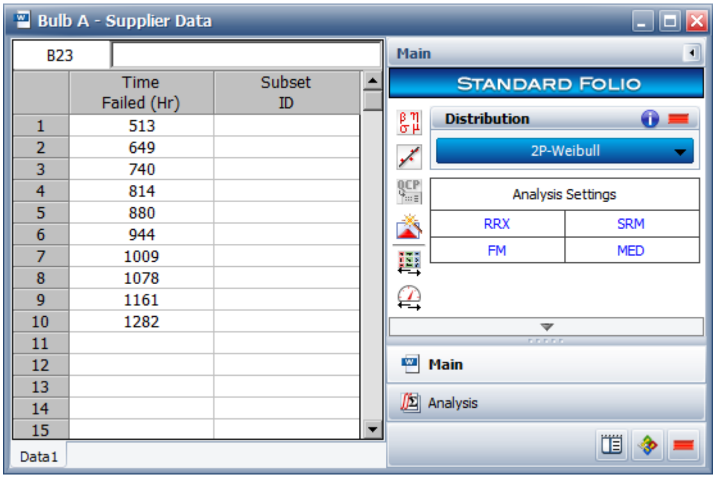
First, you create a new Weibull++ standard folio (*"Bulb A - Supplier Data" in the sample project*) by choosing **Insert > Folios > Weibull++ Standard Folio**.

When prompted to specify the data type, you select **Times-to-failure data** and clear all the other options. You also use the **Units** drop-down list to indicate that the time values in the data sheet will be entered in hours.



Note: By clearing all the other options, you limit the number of columns that require data entry. In this example, there is no need to select any of the other options because your data set contains only complete data.

Once the data folio is created, you enter the data given by the bulb supplier.

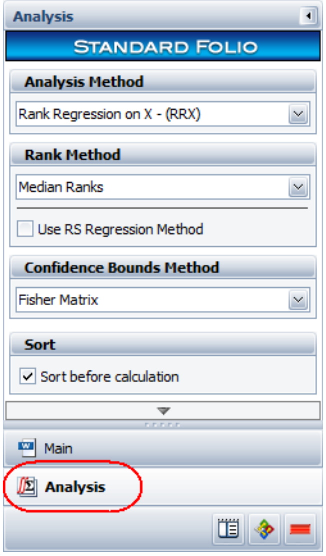


Note: The new folio starts with a single data sheet by default. You can add multiple data sheets to the folio as needed. Think of the data folio as an Excel® workbook that can contain multiple worksheets.

Once the data set is entered, the next step is to set up the analysis. The analysis options are available in the Analysis Settings area of the control panel. This area provides a quick summary of the settings that will be used to fit a distribution to the data set. The current settings on the Main page of the control panel are as follows:

- Rank Regression on X (**RRX**)
- Standard Ranking Method (**SRM**)
- Median Ranks (**MED**)
- Fisher Matrix Confidence Bounds (**FM**)

These settings are also available on the Analysis page of the control panel, which can be accessed by clicking the **Analysis** button, as shown next.



Tip: Instead of switching between control panel pages, you can click the blue text in the Analysis Settings area on the Main page as a quick method for switching between available analysis options.

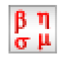
The next step is to set the distribution that you want to fit to the data. In order to determine which distribution will work best with your data, you click the **Distribution Wizard** icon on the Main page of the control panel.

You select to consider all the distributions and then click **Analyze** to see which of the selected distributions best fits the data set, based on the selected analysis method (in this case, it is for the RRX analysis method).

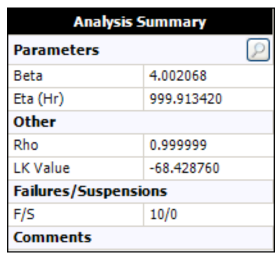
Note: The Distribution Wizard serves only as a guide. You should compare its results with your own engineering knowledge about the product being modeled before making the final decision on which distribution to use for your data set.

The G-Gamma distribution receives the highest ranking, but you know enough about the properties of that distribution to conclude that it is not the best choice for the type of analysis you are performing. You decide to use the 2P-Weibull distribution, which received the second highest ranking. You close the Wizard and then select **2P-Weibull** from the distribution drop-down list on the control panel.

To analyze the data (i.e., fit the selected distribution based on the selected analysis settings), you click the **Calculate** icon on the control panel.



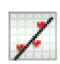
Once the distribution is fitted, the **Analysis Summary** area of the control panel displays the parameters of the distribution and other relevant information. In this case, based on the 2P-Weibull distribution setting, the results are as shown next.



Analysis Summary	
Parameters	
Beta	4.002068
Eta (Hr)	999.913420
Other	
Rho	0.999999
LK Value	-68.428760
Failures/Suspensions	
F/S	10/0
Comments	

This result includes the Rho, which is the correlation coefficient, and the LK Value, which is the value of the log-likelihood function based on the current parameter solution.

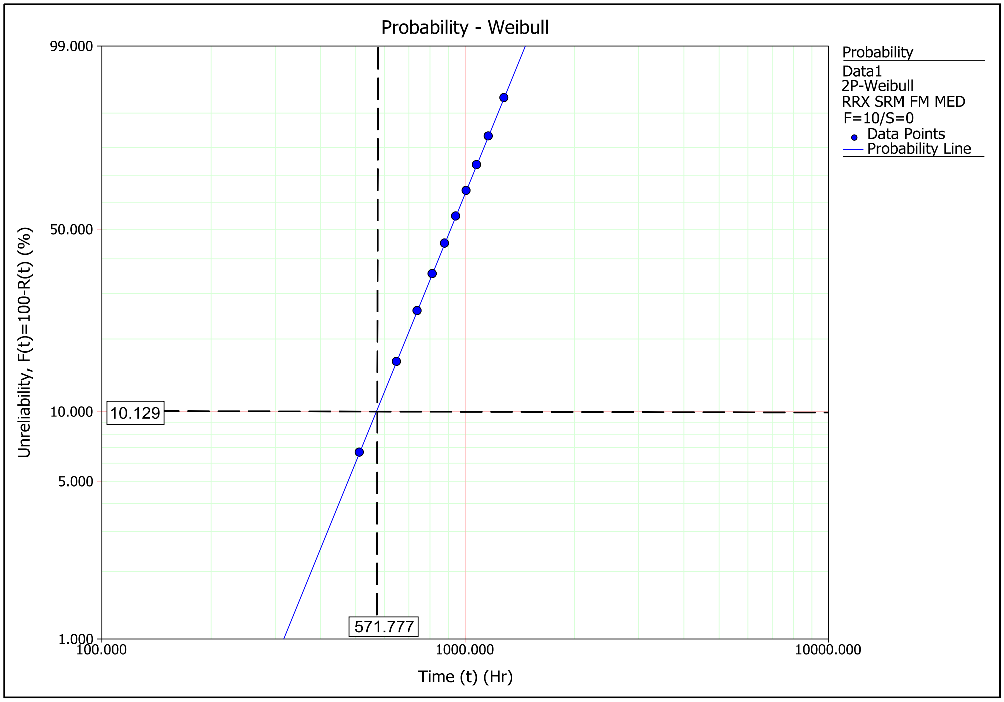
You can now access additional information, obtain metrics and/or view plots. To create a probability plot, you click the **Plot** icon on the control panel.



Probability Plots: The Weibull probability plot is drawn on a "Weibull probability plotting paper" that displays time on the x-axis using a logarithmic scale and the probability of failure on the y-axis using a double log reciprocal scale. From the plot, you can obtain the probability of failure at a given time or vice versa.

To obtain the results from the plot, you click the plot line. This displays crosshairs that show the current location on the line. You can move the mouse pointer to track the coordinates from any position on the line. You click the plot again to return to normal mode.

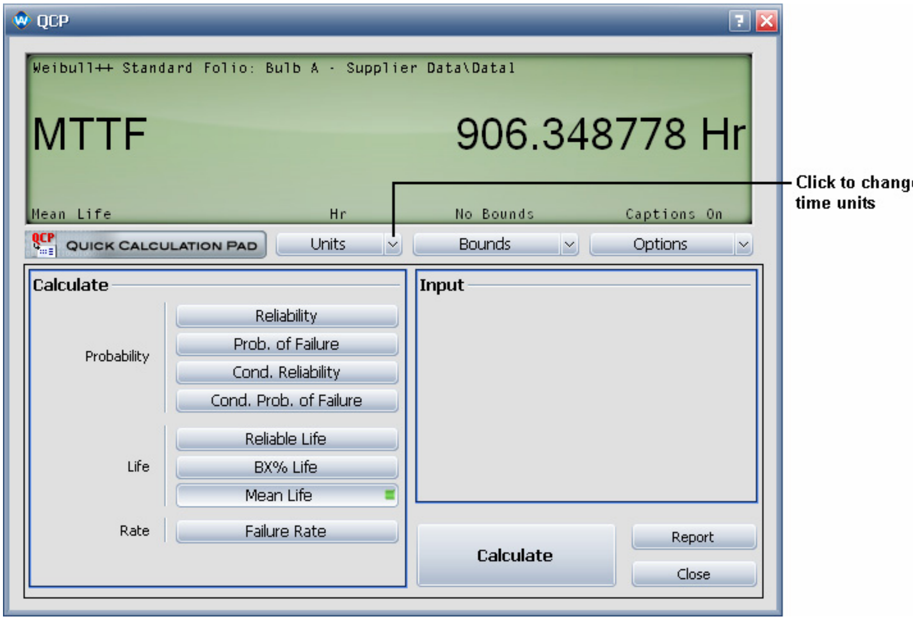
The following example shows the Weibull probability plot with the approximate B10 life of the bulbs (where the x-axis value corresponds to y=10%).



To add a label that displays the coordinates on the plot, you simultaneously press **CTRL** and **ALT**, then click a point on the plot.

You find that one of the disadvantages of reading results off the plot is that it may be difficult to position the pointer at exact values. To get more precise results, you open the Quick Calculation Pad (QCP) by clicking the icon on the control panel.

The QCP provides quick access to a set of commonly needed results. To estimate the MTTF, you select to calculate the **Mean Life** and use the **Units** drop-down list to make sure that the results will be returned in hours. You click **Calculate**. The average time to failure for the bulbs is about 906 hours.



Note: The picture shows the QCP without the optional "Calculation Log" on the right side of the window. To hide or display this log on your computer, click the **Options** button and then toggle the **Show Calculation Log** option.

Similarly, you use the QCP to answer the remaining questions:

- To estimate the B10 life, you select to calculate the **BX% Life** and enter **10** for the **BX% Life At** input. The result is about 570 hours. A B10 of approximately 570 hours means that 10% of the population will be failed by 570 hours of operation.
- You select **Reliability** to calculate the reliability at **200** hours. The result is 0.998406 or 99.84%.
- To determine the number of bulbs out of 1,000 that would fail after 200 hours of operation, you first find the probability of failure at 200 hours by selecting **Prob. of Failure** and entering **200** for

the time. The probability of failure is 0.001594 or 0.16%. You multiply this by the total number of bulbs (1,000). The number of bulbs that would fail is 1.6 or approximately 2.

- To estimate the warranty time during which no more than 2% of the bulbs will fail, you select to calculate the **Reliable Life** and enter **0.98** for the **Required Reliability** input. The result is about 377 hours. (Alternatively, the same result could have been obtained by calculating the B2 life.)

2.2 Censored Data

After analyzing the supplier's data, you decide that you would feel a lot more comfortable if you could validate the results yourself by performing an in-house test.

After putting in the appropriate requests, you are allocated 15 bulbs for testing purposes and have approval to use the lab facilities for a maximum of 40 days. Unfortunately, only five pieces of equipment that are capable of detecting bulb failures are available for you to use. Given this constraint, you decide to test 5 bulbs using the available automated equipment and test the remaining 10 bulbs via manual inspection. You stop by the lab on your way to your office every morning at 8:00 am (except on weekends and holidays) to check the status of the 10 bulbs. When you find that one of the bulbs has failed, the only information you have is that it failed sometime after you last checked on the bulbs (the last inspection) and before now (the current inspection). This information is called *interval censored data*.

Censored Data: Censored data means data with missing information. When a unit has failed between observations and the exact time to failure is unknown, the time intervals in which the failures occurred are referred to as *interval censored data*. On the other hand, for non-failed units that continue to operate after the observation period has ended, the observed operating times of the units are referred to as *right censored* data or *suspensions*.

Once the test is completed (after 40 days or 960 hours), you have the following data:

- For the automated equipment, bulbs 1, 2 and 3 failed at 425, 730 and 870 hours respectively, while bulbs 4 and 5 continued to operate after 960 hours.
- For the manual inspections, you have the log shown on the following page, where ✓ indicates a working bulb and *x* indicates a failed bulb.

Day	Hrs	Bulb 6	Bulb 7	Bulb 8	Bulb 9	Bulb 10	Bulb 11	Bulb 12	Bulb 13	Bulb 14	Bulb 15
1	24	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	48	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	72	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	96	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	120	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6	144	**Weekend**									
7	168										
8	192	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
9	216	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
10	240	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
11	264	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
12	288	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
13	312	**Weekend**									
14	336										
15	360	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16	384	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
17	408	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
18	432	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
19	456	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
20	480	**Weekend**									
21	504										
22	528	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
23	552	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
24	576	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
25	600	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
26	624	✓	✓	✓	✓	✓	✓	✓	**X**	✓	✓
27	648	**Weekend**									
28	672										
29	696	✓	✓	**X**	✓	✓	✓	✓		✓	✓
30	720	✓	✓		✓	✓	✓	✓		✓	✓
31	744	✓	✓		✓	✓	✓	✓		✓	✓
32	768	✓	✓		✓	✓	✓	✓		**X**	✓
33	792	✓	✓		✓	✓	✓	✓			✓
34	816	**Weekend**									
35	840										
36	864	✓	✓		✓	✓	✓	**X**			✓
37	888	✓	✓		✓	✓	✓				✓
38	912	✓	✓		✓	✓	✓				**X**
39	936	✓	✓		✓	✓	✓				
40	960	✓	**X**		✓	✓	✓				

Objectives

- Use a Failure Rate vs. Time plot to ascertain the failure rate behavior of the bulbs. Your expectation is that the bulbs should have an increasing failure rate. Basically, an increasing failure rate implies an underlying degradation mechanism with time, or in other words, the older the bulb the more likely it is to fail.
- Estimate the average bulb life.
- Estimate the B10 life of the bulbs.
- Estimate the reliability of the bulbs for 200 hours of operation.
- Assuming 1,000 bulbs will be fielded, estimate how many would fail after 200 hours.
- Estimate the warranty time for the bulb if you do not want failures during the warranty period to exceed 2%.

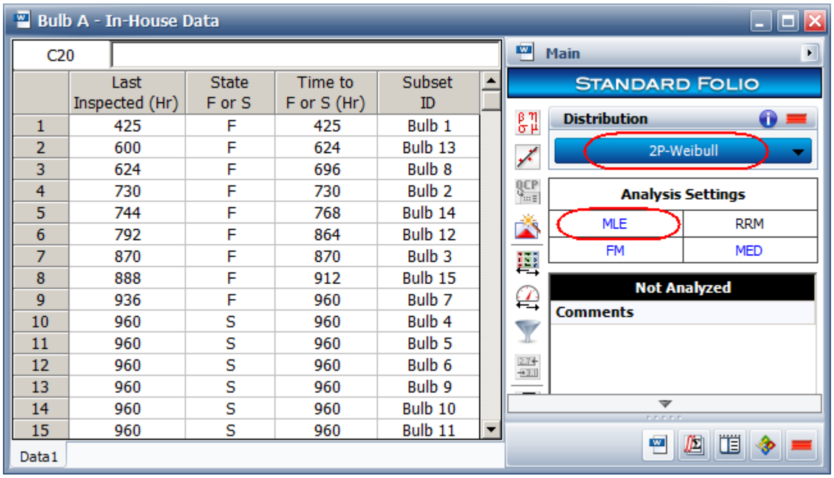
Solution

To answer the questions of interest, you will perform life data analysis on the censored data set that you obtained from both parts of the in-house test (automated equipment and manual inspection).

First, you create a new Weibull++ standard folio (*"Bulb A - In-House Data" in the sample project*). When prompted to specify the data type, you select **Times-to-failure data** and the following check boxes:

- **My data set contains suspensions (right-censored data)**
- **My data set contains interval and/or left censored data**

Once the folio is created, you enter the data obtained from both parts of the test in the data sheet. On the control panel, you choose the **2P-Weibull** distribution and the **MLE** parameter estimation method. The resulting data sheet is shown next.

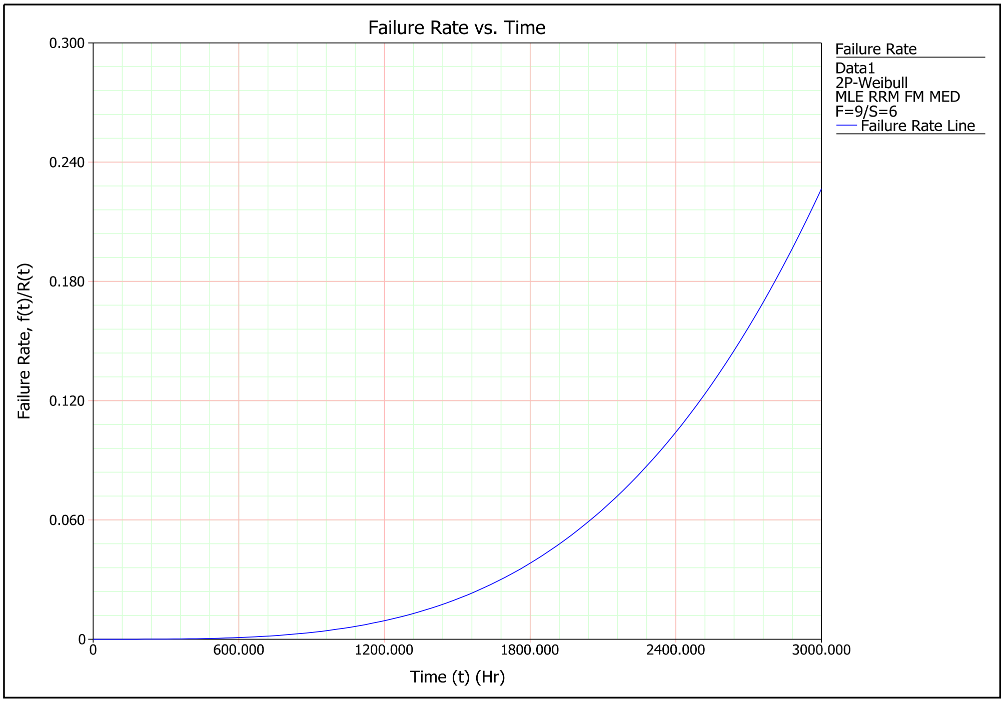


	Last Inspected (Hr)	State F or S	Time to F or S (Hr)	Subset ID
1	425	F	425	Bulb 1
2	600	F	624	Bulb 13
3	624	F	696	Bulb 8
4	730	F	730	Bulb 2
5	744	F	768	Bulb 14
6	792	F	864	Bulb 12
7	870	F	870	Bulb 3
8	888	F	912	Bulb 15
9	936	F	960	Bulb 7
10	960	S	960	Bulb 4
11	960	S	960	Bulb 5
12	960	S	960	Bulb 6
13	960	S	960	Bulb 9
14	960	S	960	Bulb 10
15	960	S	960	Bulb 11

Maximum Likelihood Estimation (MLE): As a rule of thumb, analysts often use the MLE analysis method when dealing with heavily censored data, as in this example. This is because the MLE method is based on the likelihood function, which considers the time-to-suspension data points in the estimate of the parameters, whereas in rank regression (RRX and RRY) the solution is based on the plotting positions of the times-to-failure data.

Next, you click **Calculate** to analyze the data set, and then click **Plot** to create a probability plot.

On the control panel of the plot sheet, you use the **Plot Type** drop-down list to choose the **Failure Rate vs. Time** plot. This displays the failure rate behavior of the bulbs over time. The plot shows an increasing failure rate.



Using the QCP as before, you again answer the rest of the questions:

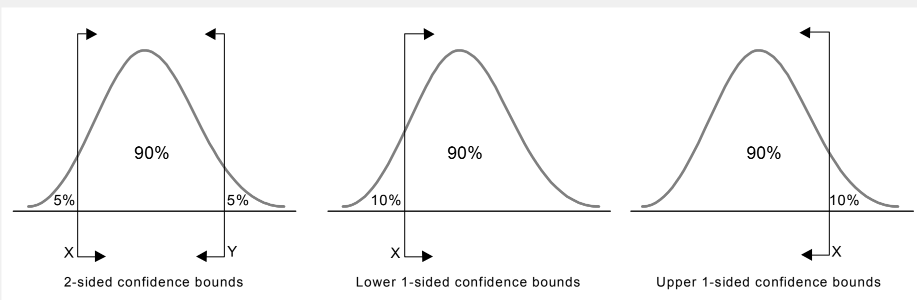
- Mean Life = 893 hours.
- B10 Life = 593 hours.
- Reliability at 200 hours = 0.999194 or 99.92%.
- Probability of failure at 200 hours = 0.000806 or 0.08%. Therefore, when multiplied by 1,000 bulbs, the number of bulbs that would fail is 0.8 or about 1 bulb.
- Warranty time = 410 hours.

2.3 Confidence Intervals

Before you submit the results of the in-house test for the projector bulbs, you want to quantify the error that may be associated with your predictions. After all, the results were based on a sample of only 15 bulbs. If you were to repeat the same experiment with another set of 15 bulbs, you would, in all likelihood, obtain different results. To quantify the error due to sampling, you will use *confidence intervals* (or *confidence bounds*), which may be viewed as the range of probable values that you are likely to obtain if you were to keep repeating the same experiment with different samples of 15 bulbs, all belonging to the same homogeneous population.

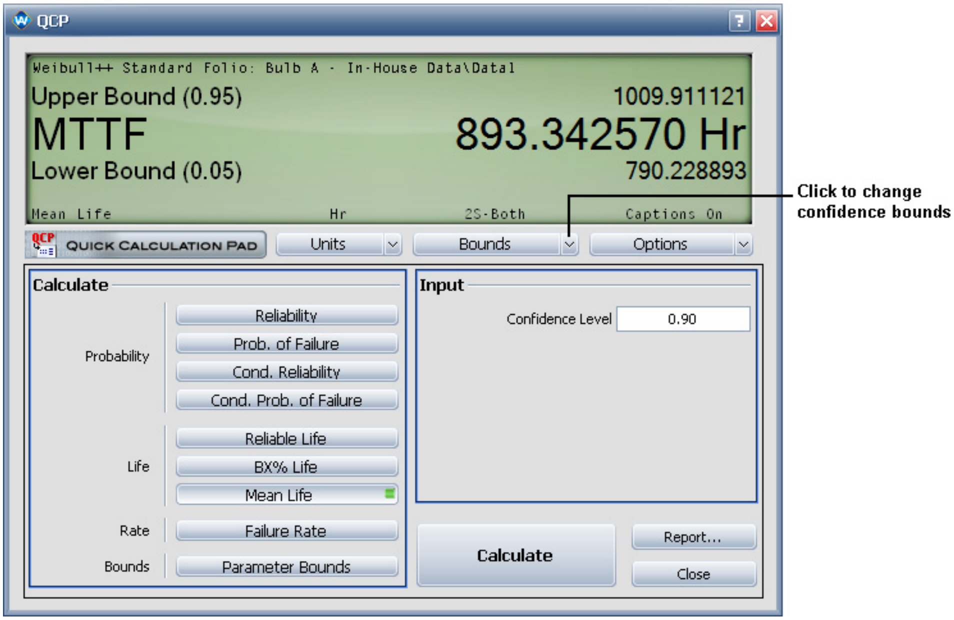
One-Sided or Two-Sided Confidence Bounds: Confidence bounds may be one-sided or two-sided. They are usually around a computed metric, such as the reliability at a given time. Two-sided bounds are used to indicate that the metric of interest is contained within these bounds with a probability equal to the chosen confidence value. For example, 90% two-sided confidence bounds indicate that the metric of interest will be between the bounds 90% of the time, and that 5% of the time it may be above the upper bound and 5% of the time it may be below the lower bound. Another way to express this is to say that the metric of interest will lie between the bounds with a 90% probability.

One-sided bounds, on the other hand, are used to indicate that the metric of interest is above the lower bound with a probability equal to the chosen confidence value. For example, a 90% lower one-sided confidence bound indicates that the metric of interest will be higher than the lower bound with a 90% probability.



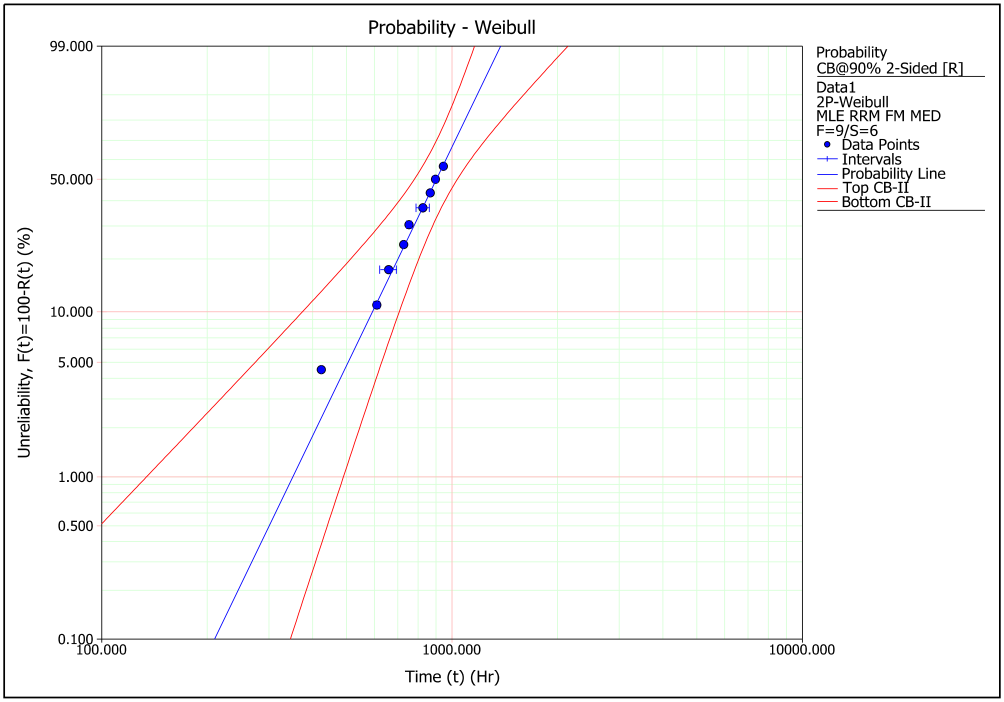
An estimated metric that is obtained without the use of confidence bounds is said to be at the 50% confidence level, or the error is equal on both sides.

You use the QCP to calculate the MTTF of the bulb. To obtain the desired confidence bounds, you choose **Two-Sided** from the **Bounds** drop-down list and enter **0.90** for the **Confidence Level** input. The calculated results are shown next.



Therefore, with a 90% probability, the true value of the MTTF is estimated to be between 790 and 1,010 hours. While unlikely, there is still a 5% probability that the MTTF is less than 790 hours and a 5% probability that it is greater than 1,010 hours.

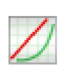
To visualize the confidence bounds, you create a Weibull probability plot. To show the bounds, you right-click the plot sheet and select **Confidence Bounds**. You then select to display the **Two-sided** bounds. The following plot shows the 90% two-sided confidence bounds on the Weibull probability plot (with the scaling adjusted to Y = 0.1 to 99 and X = 100 to 10,000).



2.4 Comparing Data Sets

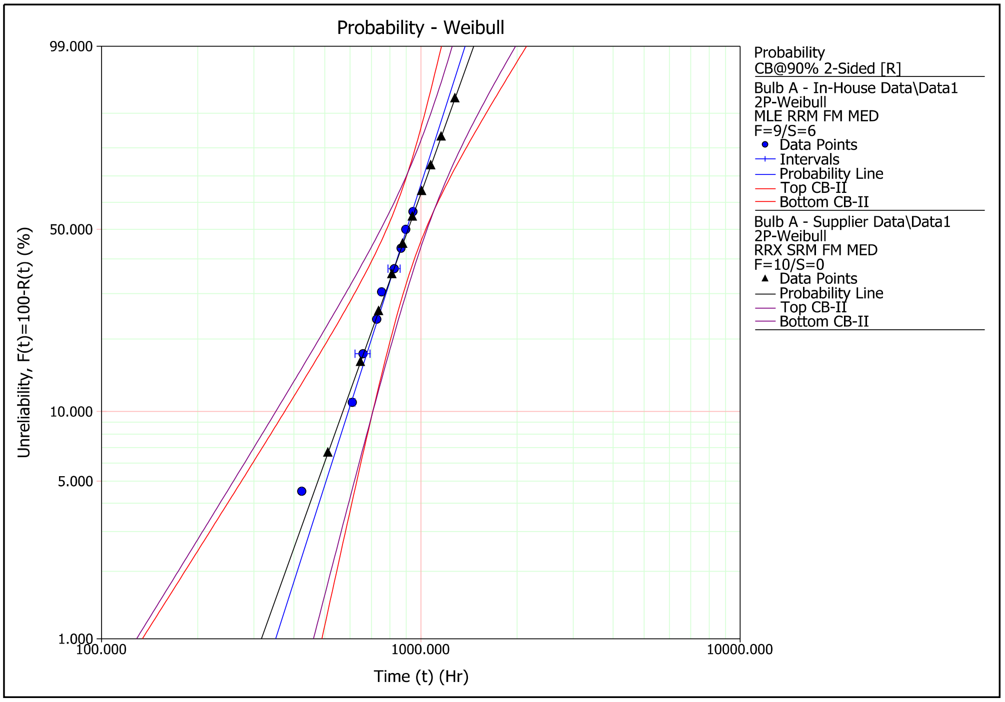
After analyzing the data from the bulb supplier and the in-house test, a reasonable question would be, how do they compare? Specifically, you want to understand how the data and analysis from the in-house test compare to the data and analysis provided by the bulb supplier. One way to do this is to use an overlay plot that displays both data sets and analyses on the same plot.

You create the overlay plot (*"Bulb A - Supplier vs. In-House" in the sample project*) by choosing **Insert > Reports and Plots > Overlay Plot**.



When prompted to select which data sets to plot, you select the folio containing the data set from the supplier and the folio containing the data set from the in-house test. (*"Bulb A - Supplier Data" and "Bulb A - In-House Data" in the sample project.*)

The following overlay plot shows the two data sets plotted on the same Weibull probability plot (and both with 90% two-sided confidence bounds):

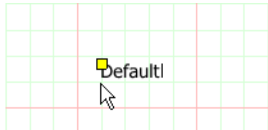


The overlay plot shows that the probability lines of the two data sets have similar slopes. Furthermore, there is a significant overlap in the confidence bounds of both sets, which suggests that both data sets exhibit the same reliability characteristics.

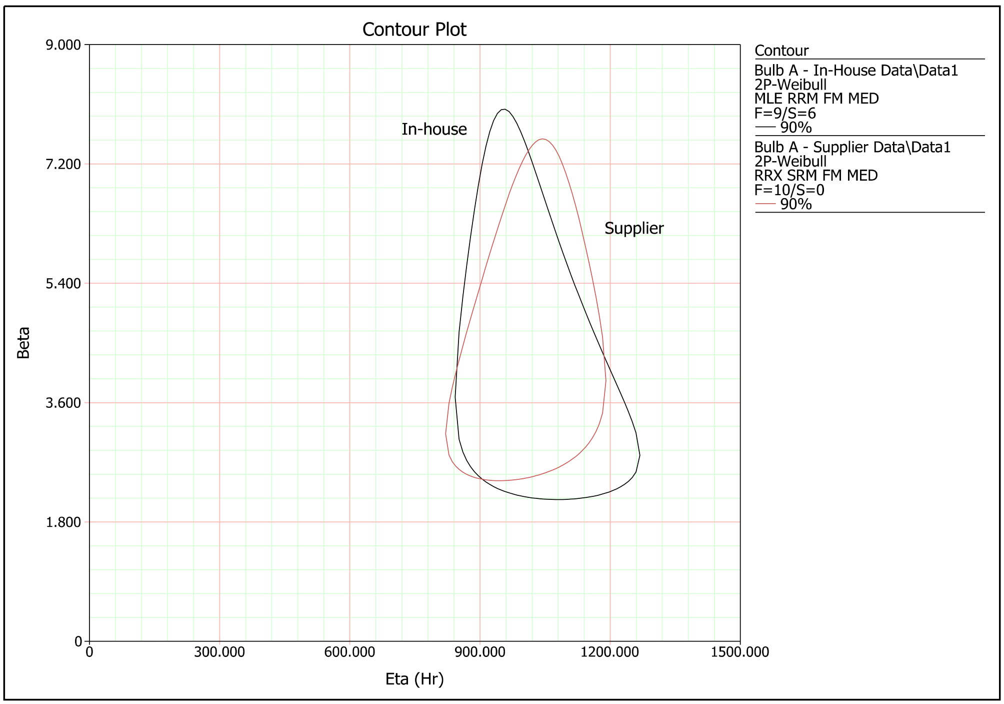
Another way to determine whether there is a statistically significant difference between the two data sets at a given confidence level (say 90% confidence level for this example), is to switch the plot type to a **Contour Plot**. When prompted to specify the contour lines, you select the **2nd Level, 90%** check box.

Tip: To add contour lines (confidence levels) to the plot or change the confidence level associated with a contour line, click the **Contours Setup** link on the control panel of the plot sheet.

You add labels to the plot by holding down the **CTRL** key and then clicking in the plot. You then edit the text by double-clicking the labels. To position the text on the plot, you click the label and then drag it by its handle (i.e., the small box on the upper left corner of the label).



The annotated plot is displayed next (with the scaling adjusted to Y = 0 to 9 and X = 0 to 1,500). The contour plot shows that the two data sets overlap at the 90% confidence level; therefore, they do not show a statistically significant difference at that confidence level.



Tip: For more extensive annotations you can use the RS Draw utility, which is a metafile graphics editor that allows you to insert text, draw objects, paste another picture into the plot and rearrange the objects in the plot. You can open the utility by clicking the **RS Draw** icon on the control panel.

2.5 Reports

For presentation to the rest of the team, you will prepare a report that summarizes the results of your analyses. Weibull++'s built-in reporting tool, the Synthesis Workbook, combines two reporting modules: spreadsheet and word processing.

Objectives

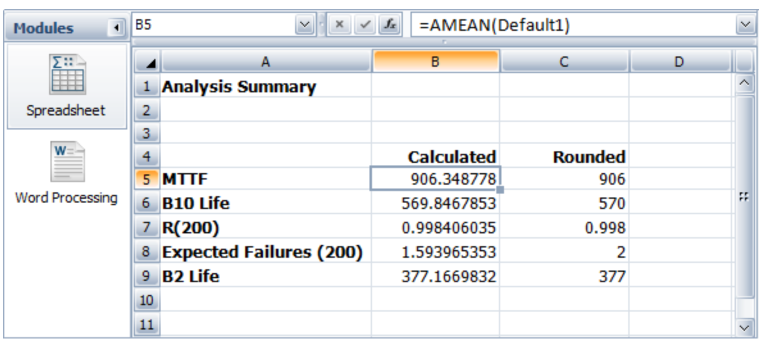
- Use the spreadsheet module to calculate all of the results that you obtained individually from the QCP.
- Use the word processing module to create a document that presents the key results, along with a plot of the failure rate vs. time.

2.5.1 Spreadsheet Module

You create a Synthesis Workbook ("*Synthesis Workbook - Bulb A*" in the sample project) by choosing **Insert > Reports and Plots > Synthesis Workbook**.

When prompted to specify a default data source, you choose the folio containing the bulb supplier's data ("*Bulb A - Supplier Data*" in the sample project) and click **OK** to create a blank workbook.

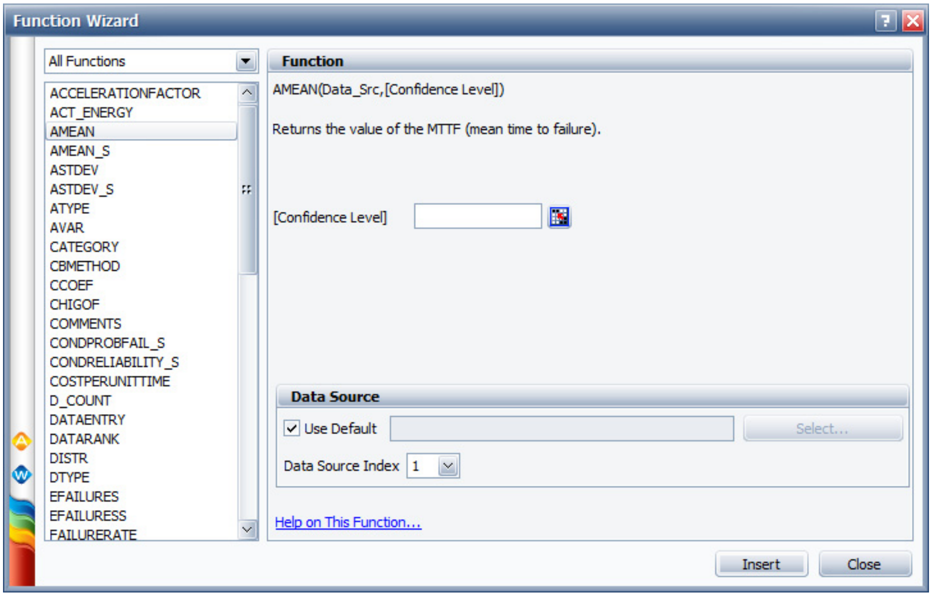
In the workbook, you click the **Spreadsheet** button in the Modules panel and build a worksheet like the one shown next. You use the Function Wizard to build functions that automatically insert calculated results based on the specified data source.



	A	B	C	D
1	**Analysis Summary**			
2				
3				
4		**Calculated**	**Rounded**	
5	**MTTF**	906.348778	906	
6	**B10 Life**	569.8467853	570	
7	**R(200)**	0.998406035	0.998	
8	**Expected Failures (200)**	1.593965353	2	
9	**B2 Life**	377.1669832	377	
10				
11				

For example, to build the function that is highlighted in the picture, you open the Function Wizard by choosing **Home > Report > Function Wizard**.

You select the **AMEAN** function from the list.



The confidence level input is optional (as indicated by the brackets that enclose the label) and not applicable in this example. So you simply specify the data source by selecting the **Use Default** check box. From the **Data Source Index** drop-down list, you select the number **1** (i.e., the first default data source, which you selected when you created the workbook), then you click **Insert**.

The MTTF for the specified data set will be automatically computed and displayed in the workbook. You continue to use the Function Wizard to build the rest of the report:

- To calculate the B10 life, you select the **TIMEATPF** function and enter **0.1** for the **Unreliability** input.
- To calculate the reliability at 200 hours, you select the **RELIABILITY** function and enter **200** for the **Age** input.

- To calculate the expected number of failures after 200 hours of operation, you first calculate the probability of failure and then multiply that number by the total number of bulbs (1,000 bulbs in this example). To do this, you enter the following formula directly into the appropriate cell: **=(1 - B7)* 1000**, where B7 is the cell reference of the reliability at 200 hours, as shown in the picture on page 21.
- To calculate the B2 life (which is equivalent to the warranty time during which no more than 2% of the bulbs will fail), you select the **TIMEATPF** function and enter **0.02** for the **Unreliability** input.

To round the numbers to the nearest integer, you use a math function. You choose **Formulas > Function Library > Insert Function**.

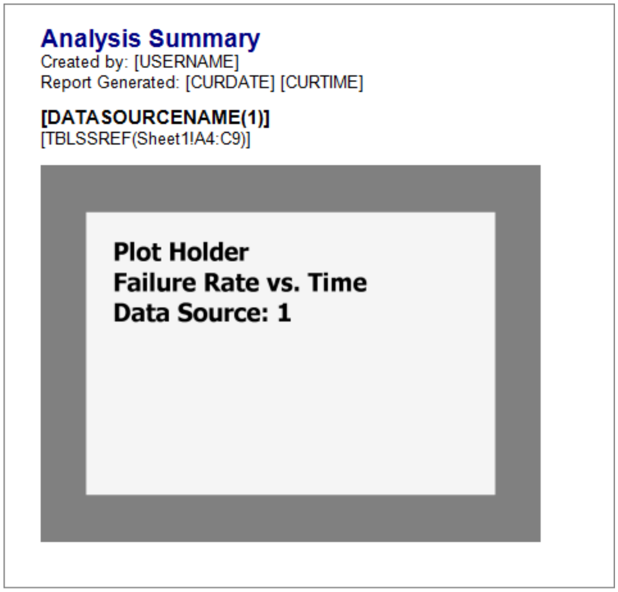
You select **ROUND** from the list and click **OK**. When prompted to define the function arguments, you enter **B5**, which is the cell reference to the first calculated result; and **0** (zero), which indicates that you will be rounding the number to the nearest integer.

In the worksheet, you copy this formula by clicking inside cell C5 and then dragging the fill handle (small black square on the lower right of the cell) down the column of cells.

You review the resulting worksheet and notice that the value in cell C7 appears to be equal to 1. To change its rounding precision, you double-click the cell and edit its function to use three decimal places: **= ROUND(B7,3)**. You press **ENTER** to save the changes.

2.5.2 Word Processing Module

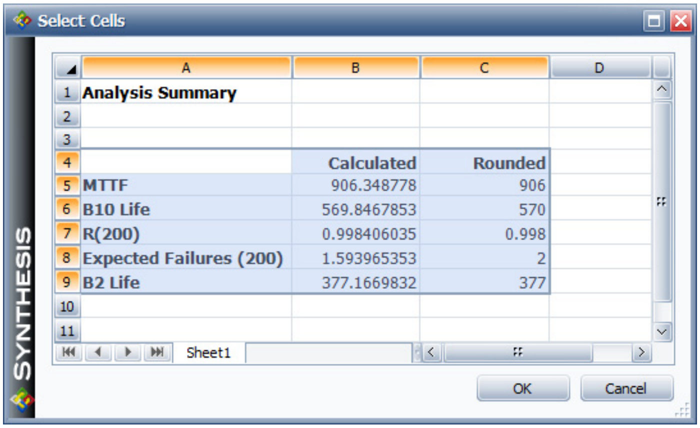
Next, you click the **Word Processing** button in the Modules panel and build a report template like the one shown next. You use the Function Wizard and Plot Wizard to insert functions into the desired locations.



For example, to insert the display name of the person who generates the report, you open the Function Wizard and select the **User Name** function from the list. You continue to use the Function Wizard to build the rest of the report:

- To insert the date and time that the report is generated, you select the **Current Date** and **Current Time** functions.
- To insert the name of the standard folio and data sheet that the results will be pulled from, you select the **Data Source Name** function. You also select the number **1** for the data source index.
- To insert the results that you created in the spreadsheet module, you select the **Spreadsheet Reference** function. You then click the **Select** button next to the Cell Reference field and, when

prompted to select cells, you highlight the table that contains the calculated results (cells A4 to C9) and click **OK**.



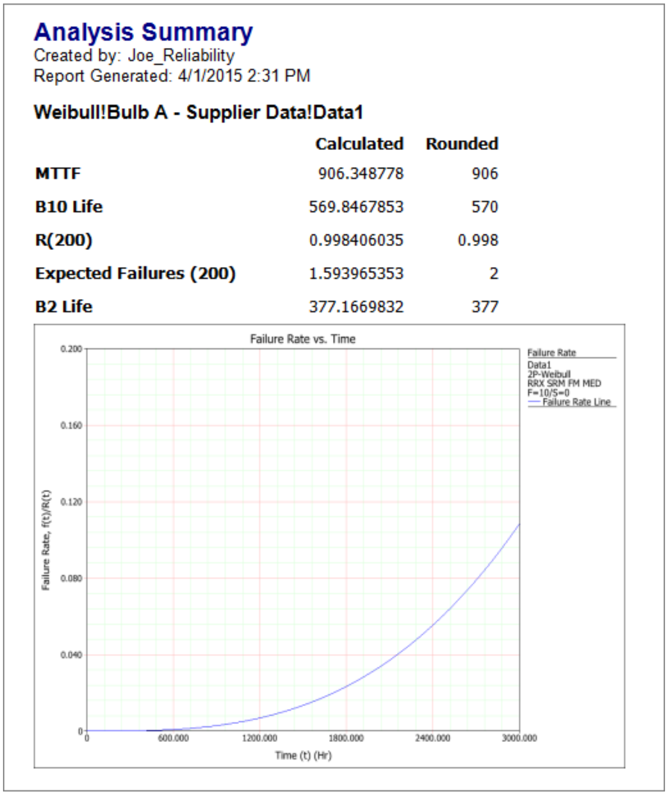
Tip: You can also access the Spreadsheet Reference function from the ribbon while in the word processing module by choosing **Home > Report > Spreadsheet Reference**.

To insert the Failure Rate vs. Time plot, you open the Plot Wizard by choosing **Home > Report > Plot Wizard**.

You select the **Failure Rate vs. Time** plot from the list. You also select the number **1** for the data source index. You then click **Insert** to add a placeholder for the plot.

To resize the plot, you select its placeholder, and then click and drag the resize handles (i.e., the small circles that appear within the corners of the selected placeholder).

When you have finished building the report template, you click the **Review** tab at the bottom of the window. This generates a preview of the report, with all the data and plots inserted.



Analysis Summary

Created by: Joe_Reliability
Report Generated: 4/1/2015 2:31 PM

Weibull!Bulb A - Supplier Data!Data1

	Calculated	Rounded
MTTF	906.348778	906
B10 Life	569.8467853	570
R(200)	0.998406035	0.998
Expected Failures (200)	1.593965353	2
B2 Life	377.1669832	377

You generate the final report in Microsoft Word by returning to the design view and choosing **Home > Report > Send to Word**.

Tip: If you want to create the same reports for the bulb's in-house data set, you could simply change the first default data source assigned to the workbook (**Home > Report > Associate Data Sources**). Alternatively, if you want to compare both data sets in the same report, you can add a second default date source and then duplicate/ modify the functions. For example, use **=RELIABILITY(Default1, 200)** to return the reliability from the supplier data set and create a new function **=RELIABILITY(Default2, 200)** to return the reliability from the in-house data set.

Degradation Analysis 3

Degradation analysis is useful for tests performed on highly reliable products that (a) cannot feasibly be tested to complete failure under normal operating conditions, (b) are associated with a measurable performance characteristic (e.g., the wear in brake pads) and (c) are not destroyed upon inspection. This analysis consists of two steps. First, the failure times of the units on test are extrapolated using measurements of their degradation over time. (A unit is considered failed when its degradation reaches a specified critical level.) Second, once these failure times are obtained, life data analysis is used to estimate the reliability of the product.

In this chapter

- ✓ Degradation folios
- ✓ Analyzing extrapolated failure times
- ✓ QCP and plots

In this chapter, you will use a degradation analysis folio to analyze the measurements of an LED lamp's decreasing light output.

3.1 Simple Degradation Analysis Using Luminosity Measurements

After completing the life data analysis for the projector's incandescent bulb, you learn that the R&D group is working on perfecting an LED lamp to replace the bulb. The product engineers would like to obtain reliability information for the new lamp. However, while it is relatively easy to test incandescent bulbs to failure (given their low life in hours), testing LEDs to failure is not feasible given their long life characteristics. Based on the failure mode under consideration for the LEDs, you know that the failure is gradual and preceded by a decrease in light output of the lamp over time. As a result, the R&D group concludes that in lieu of a long failure test, it is preferable to perform a degradation analysis where they will monitor the decrease of light output over time and use this information to extrapolate failure times.

According to the formal test plan, the light intensity of 10 lamps will be recorded at 400, 600, 800 and 1,000 hours of operation. This data set will be used to predict the lamp's life. Furthermore, the engineers agree that the lamp should be considered failed when its output reaches 50% of its design output of 1,000 lumens.

The following measurements were obtained in the test:

Luminosity Measurements (in Lumens) of 10 LED Lamps

Inspection Time (Hr)	Lamp 01	Lamp 02	Lamp 03	Lamp 04	Lamp 05	Lamp 06	Lamp 07	Lamp 08	Lamp 09	Lamp 10
400	960	950	990	840	880	800	930	870	870	910
600	890	900	890	730	760	770	890	810	800	850
800	850	860	830	670	710	730	840	760	730	800
1,000	810	820	780	615	670	700	820	730	690	770

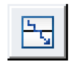
Degradation Analysis Assumptions: Degradation analysis can be used for analyzing this data set because, according to the underlying physics, the luminosity will continue to decrease with time. The main assumption in this kind of analysis is that the degradation mechanism and observed measurements will continue the same behavior throughout operation. In other words, this analysis assumes that the measurements will monotonically decrease (or increase) with time.

Objectives

- Use a Degradation vs. Time plot to see how the luminosity of the lamps degrades over time.
- Estimate the following metrics:
  - The average lamp life (i.e., MTTF or *mean life*)
  - The B10 life (i.e., the time by which 10% of the lamps will be failed)
  - The reliability for 200 hours of operation
  - The number of lamps (out of 1,000) that can be expected to fail after 200 hours
  - The warranty time on the lamp if you do not want failures during the warranty period to exceed 2%

Solution

You start by choosing **Insert > Folios > Weibull++ Degradation** (*"Degradation - LED Lamp" in the sample project*) to create a new degradation analysis folio.



Then, you enter degradation measurements into the folio's data sheet and enter **500** for the lamp's **Critical Degradation** (i.e., the luminosity level at which a lamp is considered failed).

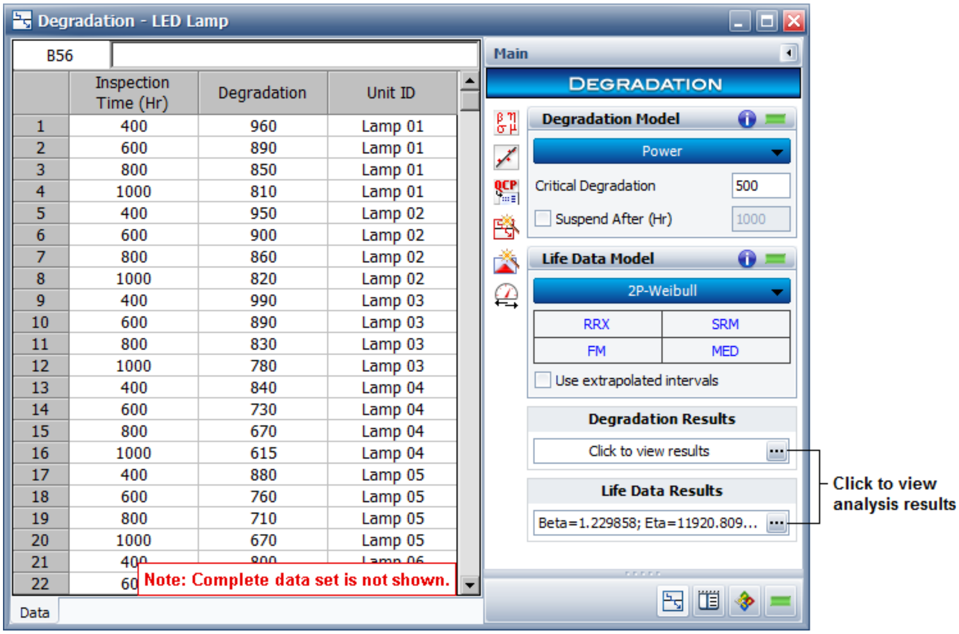
First, you need to specify how failure times will be extrapolated from the luminosity measurements. The failure mode under consideration is metal fatigue, and you know the underlying degradation model for this failure mode is the power model, so you select **Power** from the drop-down list in the **Degradation Model** area. Next, you need to specify how the extrapolated failure times will be analyzed. Based on your engineering knowledge, you select **2P-Weibull** from the **Life Data Model** area.

In the **Settings** area of the control panel, you click the blue text to switch between the available analysis options. (Note that these settings are also displayed on the Analysis page.) You select the following:

- Rank Regression on X (**RRX**)
- Standard Ranking Method (**SRM**)
- Median Ranks (**MED**)
- Fisher Matrix Confidence Bounds (**FM**)

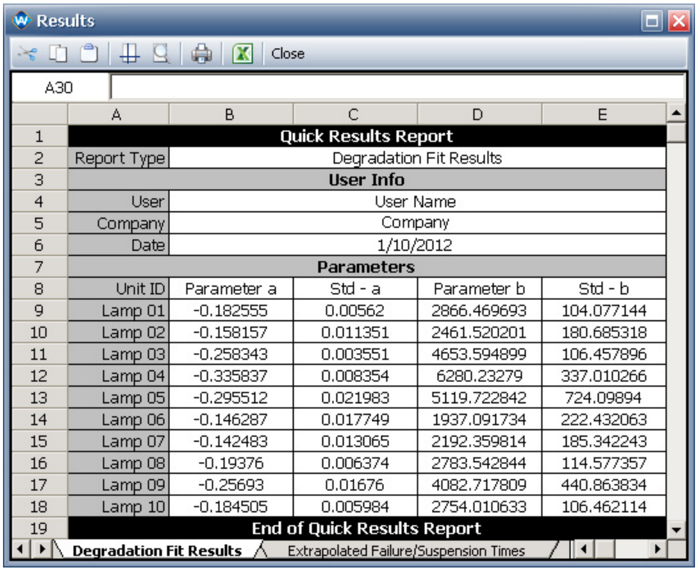
Next, you click the **Calculate** icon to analyze the data.

The folio appears as shown next.



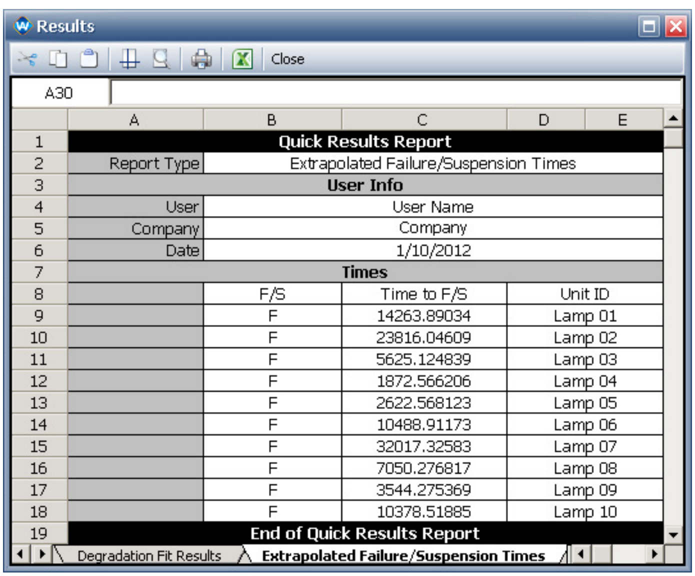
Before you continue, you decide to quickly review the results of the software's calculations. To see how the failure times were extrapolated, you click the **Degradation Results (...)** button. You look at the

Degradation Fit Results tab (shown next) to see the parameters of the degradation model that was fitted to each lamp.



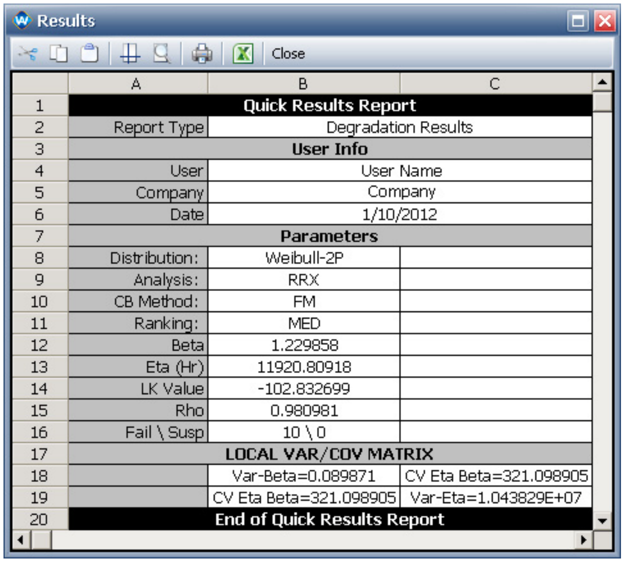
	A	B	C	D	E
1	Quick Results Report				
2	Report Type	Degradation Fit Results			
3	User Info				
4	User	User Name			
5	Company	Company			
6	Date	1/10/2012			
7	Parameters				
8	Unit ID	Parameter a	Std - a	Parameter b	Std - b
9	Lamp 01	-0.182555	0.00562	2866.469693	104.077144
10	Lamp 02	-0.158157	0.011351	2461.520201	180.685318
11	Lamp 03	-0.258343	0.003551	4653.594899	106.457896
12	Lamp 04	-0.335837	0.008354	6280.23279	337.010266
13	Lamp 05	-0.295512	0.021983	5119.722842	724.09894
14	Lamp 06	-0.146287	0.017749	1937.091734	222.432063
15	Lamp 07	-0.142483	0.013065	2192.359814	185.342243
16	Lamp 08	-0.19376	0.006374	2783.542844	114.577357
17	Lamp 09	-0.25693	0.01676	4082.717809	440.863834
18	Lamp 10	-0.184505	0.005984	2754.010633	106.462114
19	End of Quick Results Report				

Then you look at the Extrapolated Failure/Suspension Times tab to see the failure times that were extrapolated.



	A	B	C	D	E
1	Quick Results Report				
2	Report Type	Extrapolated Failure/Suspension Times			
3	User Info				
4	User	User Name			
5	Company	Company			
6	Date	1/10/2012			
7	Times				
8		F/S	Time to F/S	Unit ID	
9		F	14263.89034	Lamp 01	
10		F	23816.04609	Lamp 02	
11		F	5625.124839	Lamp 03	
12		F	1872.566206	Lamp 04	
13		F	2622.568123	Lamp 05	
14		F	10488.91173	Lamp 06	
15		F	32017.32583	Lamp 07	
16		F	7050.276817	Lamp 08	
17		F	3544.275369	Lamp 09	
18		F	10378.51885	Lamp 10	
19	End of Quick Results Report				

To see the results of the life data analysis that was performed on the extrapolated failure times, you return to the control panel and click the **Life Data Results (...)** button.



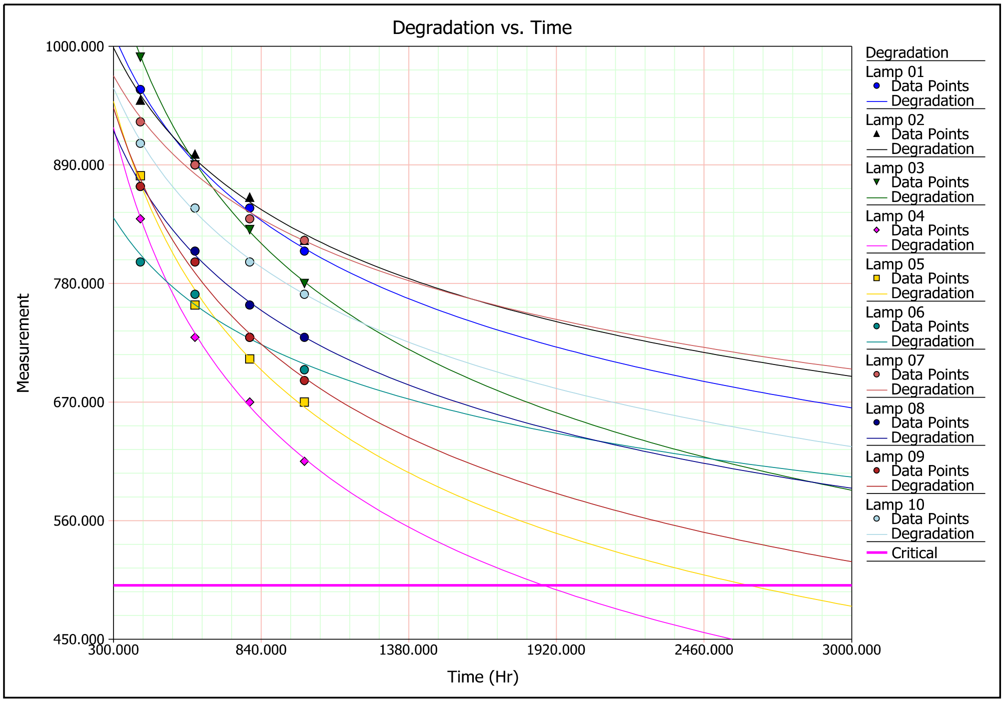
	A	B	C
1	Quick Results Report		
2	Report Type	Degradation Results	
3	User Info		
4	User	User Name	
5	Company	Company	
6	Date	1/10/2012	
7	Parameters		
8	Distribution:	Weibull-2P	
9	Analysis:	RRX	
10	CB Method:	FM	
11	Ranking:	MED	
12	Beta	1.229858	
13	Eta (Hr)	11920.80918	
14	LK Value	-102.832699	
15	Rho	0.980981	
16	Fail \ Susp	10 \ 0	
17	LOCAL VAR/COV MATRIX		
18		Var-Beta=0.089871	CV Eta Beta=321.098905
19		CV Eta Beta=321.098905	Var-Eta=1.043829E+07
20	End of Quick Results Report		

Next, to view a plot that shows how the luminosity for each unit on test degraded over time, you click the **Plot** icon on the control panel and select the **Degradation vs. Time (Linear)** plot. This shows you the degradation lines for each LED lamp.

To improve the appearance of the plot, you clear the check boxes in the **Scaling** area and enter the following ranges:

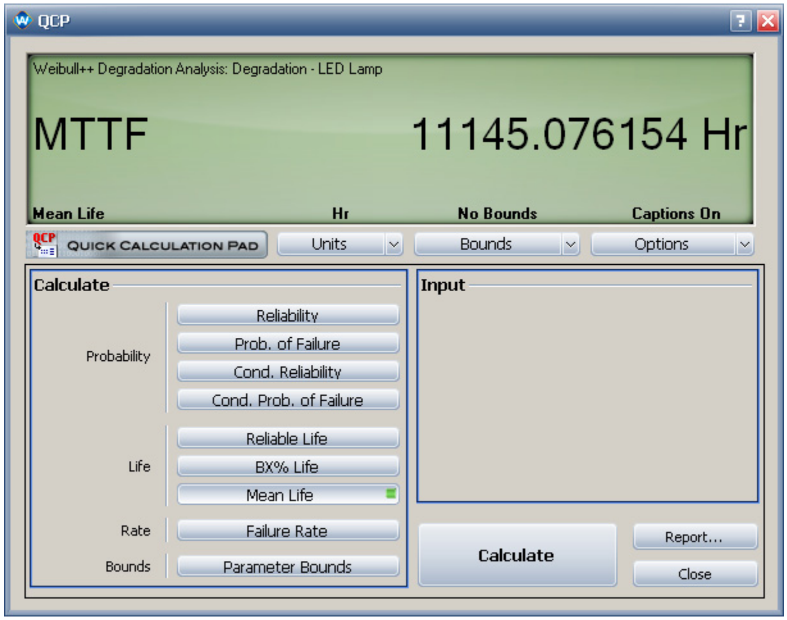
- Y-axis: 450 to 1,000 lumens
- X-axis: 300 to 3,000 hours

The resulting plot is shown next. The horizontal line towards the bottom of the plot marks the luminosity level at which the lamp is considered failed.



Next, to solve for the requested reliability metrics, you open the Quick Calculation Pad by clicking the **QCP** icon on the control panel.

You select to calculate the **Mean Life** and use the **Units** drop-down list to make sure the results will be returned in hours. The mean life of the lamp is estimated to be about 11,145 hours.



You continue to use the QCP to solve for the remaining reliability metrics:

- You select **BX% Life** to calculate the time by which 10% of the lamps will be failed. The result is about 1,913 hours.
- You select **Reliability** to obtain the reliability at 200 hours of operation. The result is 0.993465, or 99.3465%.
- To solve for the upper bound on the number of LED lamps (out of 1,000) that would fail after 200 hours, follow these steps:
  - Select **Prob. of Failure** and enter **200** for the mission end time to calculate the probability of failure at 200 hours.
  - The probability of failure at 200 hours is estimated to be 0.006535 or 0.65%. Now multiply this by the total number of lamps (1,000). The number of lamps that will fail is 6.5, or approximately 7.
- To estimate the warranty time during which no more than 2% of the lamps will fail, you select to calculate the **Reliable Life**, and then enter **0.98** for the **Required Reliability** input. The result is about 499 hours. Alternatively, the same result could have been obtained by calculating the B2 life.

Design of Reliability Tests 4

Weibull++ includes a number of test design tools that provide ways to design reliability tests and evaluate/compare proposed test designs. In this chapter, you will work with the three tools available in the Test Design folio, starting with the Reliability Demonstration Test tool, which you will use to design a zero-failure test intended to demonstrate a specified reliability for bulb A.

Afterwards, you'll examine ways to compare the reliability of bulb A and a less expensive bulb B. To do this, you'll use the Difference Detection Matrix to determine what test times are required to demonstrate a difference in reliability between the two bulbs. Then you'll use the Expected Failure Time Plot to compare the failure times that are expected from a design with a specified reliability to the actual failure times that are observed during a test.

In this chapter

- ✓ Zero-failure demonstration test
- ✓ Detecting differences in reliability
- ✓ Predicting expected failure times

4.1 Combining the Test Data for Bulb A

Before you can use the test design folio, you need to estimate the life distribution followed by bulb A. You already have data from two tests for the bulb, and you established previously that there is no significant difference between the two data sets (*see Chapter 2*). You decide to combine the data sets and analyze them in a separate standard folio (*"Bulb A - Combined Data" in the sample project*).

The analysis shows that the failure behavior of bulb A follows a 2-parameter Weibull distribution with beta = 4.219615. Using the Quick Calculation Pad, you also see that the estimated B10 life of the bulb is about 581 hours.

4.2 Reliability Demonstration Test Design

Based on your experience with analyses for bulb A, which is currently being used in the projector, you are asked to design a demonstration/validation test to show that the bulb has the required B10 life.

More specifically, your objective is to demonstrate that bulb A has a B10 life of at least 500 hours with 80% confidence. You are allocated 10 bulbs for the test and decide on a zero-failure reliability demonstration test. In other words, you decide to design a test that uses the available sample size of 10 and will demonstrate the target metric if no failures occur before a certain time (i.e., you design a test where the number of “allowable” failures is zero).

Zero-Failure Tests: A zero-failure test is appropriate in this case because you only want to know, with a given confidence level, whether the life metric is greater than the specified requirement. This sort of test provides a quick and efficient way of accomplishing this. Note, however, that zero-failure tests generally cannot be used to determine the actual value of a product’s life metric. (In some special cases, the 1-parameter Weibull or 1-parameter exponential distribution can be suitable for analyzing a data set containing few or no failures.)

Objectives

- Determine the test time for a zero-failure test that would demonstrate the target metric with a sample size of 10.
- Compare the test times that would be required given different sample sizes and different numbers of “allowable” failures.

Solution

To create a new test design folio (*“Zero-Failure Test - Bulb A” in the sample project*), you choose **Insert > Tools > Test Design**.

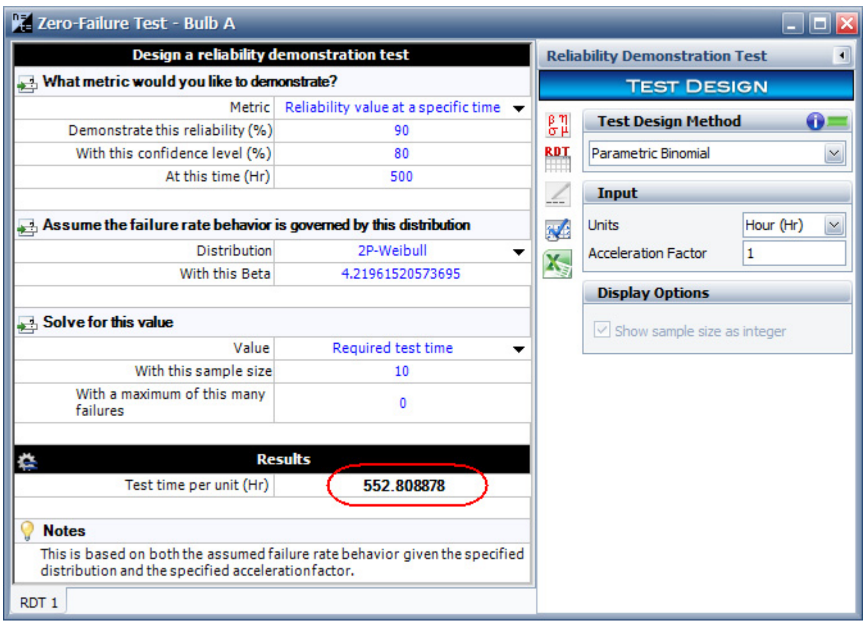
In the Test Design Assistant window, you select **Reliability Demonstration Test Design**. Since you are able to make reasonable assumptions about the life distribution that describes bulb A’s failure rate behavior, you select the **Parametric Binomial** test design method on the control panel of the folio. To specify the metric that you wish to demonstrate, you choose **Reliability value at a specific time** from the **Metric** drop-down list on the RDT sheet. Then you enter **90** for the reliability and **80** for the confidence level. (The B10 life is equivalent to the time at which reliability reaches 90%.)

Next, you click the **Get Distribution** icon and select the standard folio that analyzed the combined data sets for bulb A (*"Bulb A - Combined Data" in the sample project*).

This copies the life distribution from the standard folio into the **Distribution** and **With this Beta** fields of the tool, and it calculates the time at which bulb A would reach the specified reliability with the specified confidence level (i.e., the B10 life). The calculated time is about 581 hours, and it appears in the **At this time** field.

You check to make sure the B10 life is equal to or greater than the B10 life you wish to demonstrate (i.e., 500 hours). Since it is greater, you know a demonstration test is possible, and so you continue planning the test by changing the value in the **At this time** field to **500**.

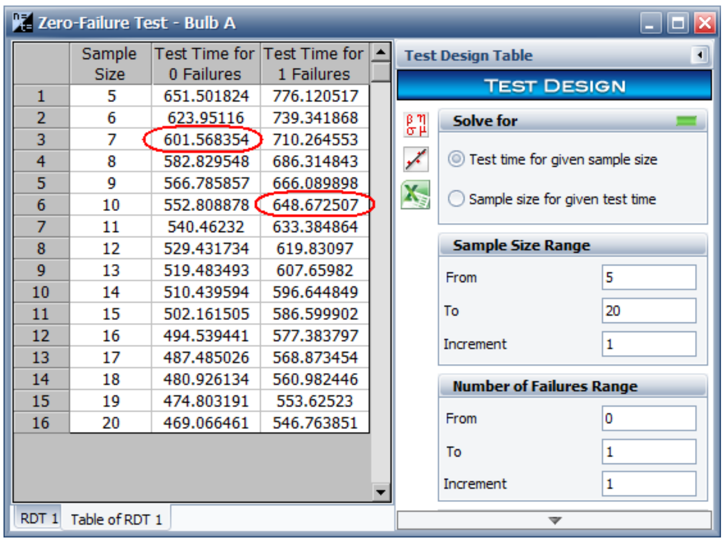
In the **Solve for this value** area, you select to solve for the **Required test time** for a test with a sample size of **10**. To specify that this will be a zero-failure test, you enter **0** for the maximum number of failures. Finally, you click the **Calculate** icon. The inputs and results appear as shown next.



Based on this calculated result, you need to test the 10 bulbs for at least 553 hours each. If no failures occur during that time, you will have demonstrated that the bulb has a B10 life of at least 500 hours with 80% confidence (i.e., if no failures occur before about 553 hours, then there is an 80% probability that the B10 life is greater than 500 hours).

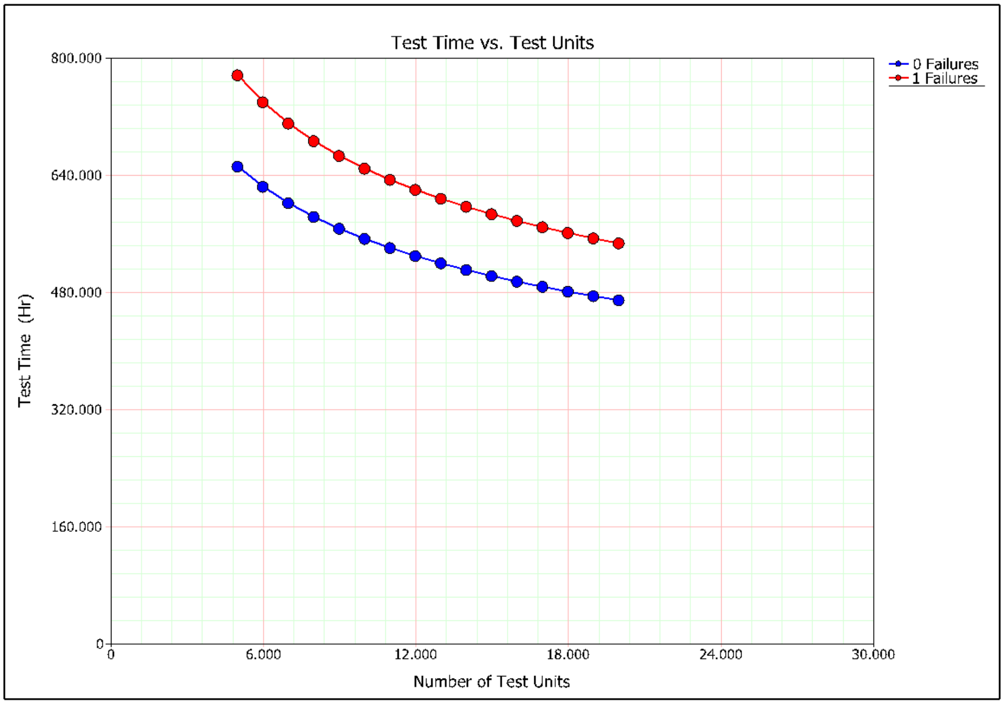
You would also like to explore the possibility of using a different sample size and examining the sample size's effect on test time. This may allow you to find a better combination of sample size and test time. So you click the **Show RDT Table** icon on the control panel.

A sheet called "Table of RDT" is added to the folio. You select to solve for the **Test time for given sample size** and specify that you want to see the required test times for sample sizes that range from 5 to 20, using an increment of 1. Then, because you want to view test times for zero-failure and 1-failure tests, you specify that you want to consider numbers of failures that range from 0 to 1. Finally, you click **Calculate** and see the results shown next.



This table uses the target metric and life distribution information you provided earlier to calculate the test times needed under many different scenarios. For example, the first highlighted cell shows that you could reduce the sample size to 7 and test to 602 hours instead of 553 (with zero failures). The second highlighted cell shows that if you were to stay with your current sample size of 10, you could demonstrate the target metric even if 1 failure occurred. However, the required test time in that case would increase to 649 hours.

To more easily see how sample size, test time and number of failures are related, you generate a plot of this information by clicking the **Plot** icon.



4.3 Difference Detection Matrix

The Reliability Demonstration Test tool is used to plan a test that is intended to demonstrate that a product's reliability exceeds a specified target. Sometimes, however, tests will be performed just for comparative purposes (e.g., to show that one product's B10 life is greater than another product's). The Difference Detection Matrix calculates how much test time is required before it is possible to detect a statistically significant difference in a reliability metric (e.g., mean life) of two product designs by analyzing the data from a reliability life test.

The purchasing group has located a less expensive bulb B from another manufacturer. Based on the extremely attractive pricing of bulb B, you are asked to evaluate and propose plans to compare the B10 life of bulb B to the life of bulb A. You are also informed that you only have 5 units of bulb B available for testing. The goal of the comparison is to determine if there is a significant difference between the B10 lives of the bulbs at a specified confidence level. Because of the smaller sample size, you decide to use a confidence level of 70%.

You realize that you could simply test bulb B and compare the results to the results obtained from testing bulb A. However, given that only 5 units of bulb B are available for testing, you decide to first explore the capability of a test (and the available sample sizes) to show any difference. In other words, you will be evaluating various test durations to determine which durations are capable of demonstrating a difference in B10 life between the two bulbs.

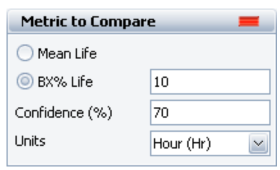
Objective

- Determine how long you must test the 5 units of bulb B to be able to detect a difference in the B10 life of the two designs.

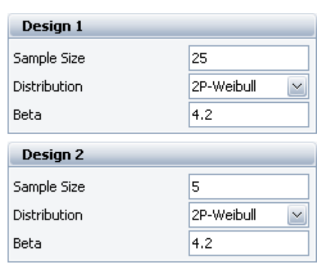
Solution

You start by choosing **Insert > Tools > Test Design** and then selecting **Difference Detection Matrix** in the Test Design Assistant. The new matrix (*"Difference Detection - Bulb A vs. Bulb B"*) will allow you to see what test times will be required to show a difference between the bulbs, given a range of different B10 life values.

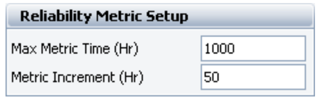
On the control panel of the new folio, you specify that you will be comparing the B10 life by choosing **BX% Life** and entering **10** in the **Metric to Compare** area. You enter **70** for the confidence level and choose **Hour (Hr)** for the time units.



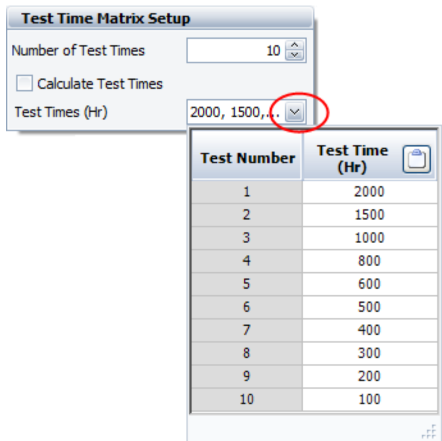
You provide information about the sample size and life distribution of bulb A in the **Design 1** area, and you provide this information for bulb B in the **Design 2** area. The results from combining and analyzing the 25 data points from the in-house test and the supplier's data (*"Bulb A - Combined Data" in the sample project*) show that bulb A has a 2P-Weibull distribution with a beta of about 4.2. Since you will be testing the assumption that bulb A and bulb B have a similar reliability, you assume the same life distribution information for both products.



The fields in the **Reliability Metric Setup** area define the range of reliability metric values in which you want to see the results. Given that bulb A has a B10 life of about 600 hours, a reasonable range may be from 0 to 1,000, so you enter **1000** in the **Max Metric Time** field. To specify that you would like to see the results spread out over 50-hour increments, you enter **50** in the **Metric Increment** field.



The inputs in the **Test Time Matrix Setup** area define the test durations that you want to explore. After reviewing the analyses of bulb A, you set the range to have a maximum of 2,000 hours of test time and decide to have the software give you results at 9 other intervals. You do so by entering **10** in the **Number of Test Times** field, and then you clear the **Calculate Test Times** check box and enter the specific test times shown next.



With these settings, the software will evaluate test plans with ten different durations: 2,000 hours, 1,500 hours, and so forth.

With all the inputs provided, you click the **Calculate** icon to generate the matrix. Part of the matrix is shown and explained next.

Design 2 BX% Life	Design 1 BX% Life: 550
50	10
100	9
150	8
200	8
250	7
300	6
350	5
400	0
450	0
500	0
550	0
600	0
650	0
700	4
750	4
800	4
850	4
900	4
950	4
1000	4

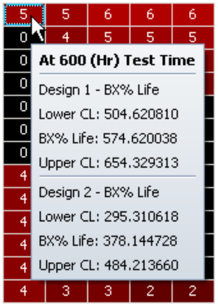
Legend

0	Difference cannot be detected using current setup, existing sample size, and test time of <= 2000 (Hr).
1	Difference can be detected with 2000 (Hr) of testing.
2	Difference can be detected with 1500 (Hr) of testing.
3	Difference can be detected with 1000 (Hr) of testing.
4	Difference can be detected with 800 (Hr) of testing.
5	Difference can be detected with 600 (Hr) of testing.
6	Difference can be detected with 500 (Hr) of testing.
7	Difference can be detected with 400 (Hr) of testing.
8	Difference can be detected with 300 (Hr) of testing.
9	Difference can be detected with 200 (Hr) of testing.
10	Difference can be detected with 100 (Hr) of testing.

Since the B10 life of Design 1 (bulb A) was estimated to be 581 hours, you can focus on either the 550 column or the 600 column. You choose to focus on the 550 column, as shown above. (You decide not to change to a 10-hour increment to view the 581 hours column, since that would make the matrix quite large.)

You do not know what the life of Design 2 is; thus, you are interested in the range of life values that you specified on the control panel. The legend assigns an index number to each of the 10 test durations you specified in the **Test Time Matrix Setup** area. In this case, the index number represents the test time that would be needed to detect a difference in B10 life with 70% confidence.

For example, suppose Design 2 has a B10 life of 350 hours. The index number in row 350 is 5, which corresponds to a test time of 600 hours. According to this result, if Design 2 has a B10 life that is equal to or less than 350 hours (and failure rate behavior that is similar to Design 1; in other words, behavior that follows a Weibull distribution with beta = 4.2), then if you tested 5 bulbs from Design 2 using the indicated test time, you would detect a difference between the designs 70% of the time (i.e., the difference would be demonstrated with 70% confidence). You click the cell to view the required test time and the confidence bounds that were used to determine that the test time demonstrate a difference.



Similarly, if Design 2 has a B10 life of 700 hours, then the index number is 4, which means that testing 5 of the bulbs for 800 hours would demonstrate a difference in B10 life with 70% confidence.

Furthermore, if the B10 life of Design 2 is greater than 350 hours but less than 700 hours, then the index assigned is 0, which means that even a test of 2,000 hours is incapable of demonstrating, at the specified confidence level, a statistically significant difference between the two designs.

Tip: The granularity of the results is based on the test times specified in the **Test Time Matrix Setup** area. If needed, you can iteratively adjust the test times and recreate the matrix in order to arrive at an optimal granularity.

4.4 Expected Failure Time Plot

Before performing a reliability life test, you can use the Expected Failure Time Plot to provide an overall expected timeline and sequence of events for the test. This in turn can be used during the actual test to monitor its progress for any early warnings that indicate a deviation from the original assumptions or expectations.

After a discussion with management, you are asked to go ahead and run the life test on the five bulbs.

Objectives

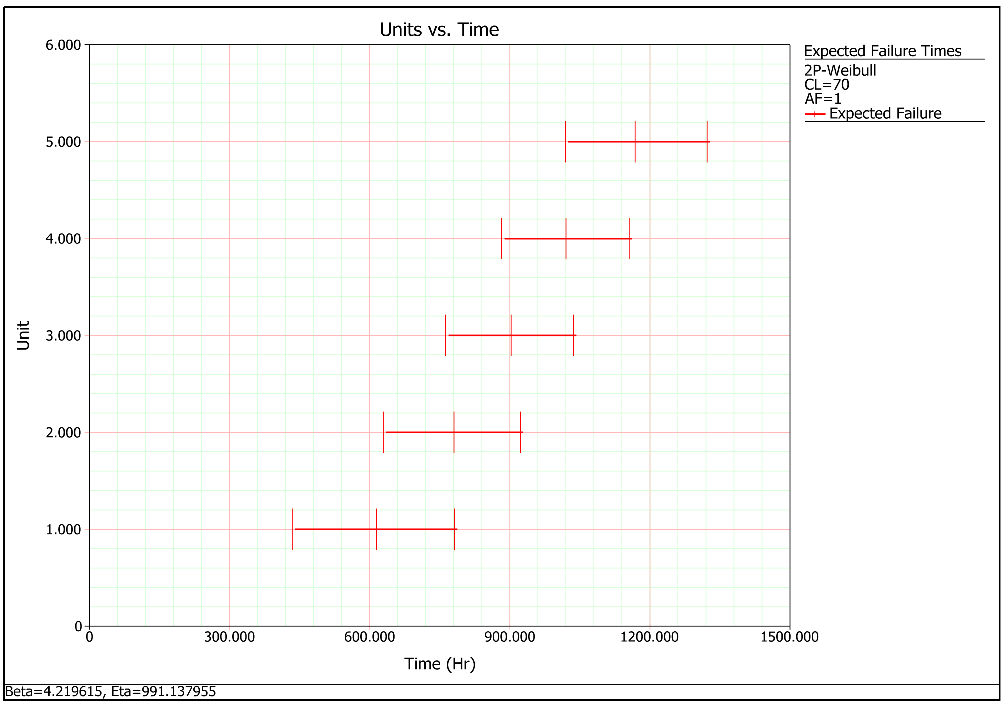
- Use the Expected Failure Time Plot to determine what range of failure times you can expect to observe on each unit of bulb B during this test. Assume that bulb A and bulb B have the same reliability.
- As the units of bulb B fail during the test, compare the failure times to the expected times. If the bulbs appear to differ in reliability, determine which has a greater B10 life.

Solution

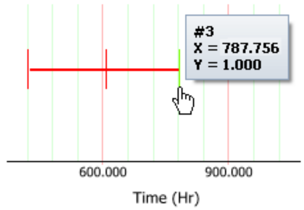
To create the plot, you choose **Insert > Tools > Test Design** and select **Expected Failure Time Plot** in the Test Design Assistant. In the **Plot Setup** area on the control panel, you enter **5** for the sample size and **70** to specify that you wish to see 70% two-sided confidence bounds for each expected failure time. You enter **1** for the acceleration factor because the units will be tested under normal stress conditions.

You need to associate the plot with the combined data for bulb A. To do this, you click the **Get Failure Model** icon on the control panel and select the calculated data sheet that contains the combined data from the manufacturer (*"Bulb A - Combined Data" in the sample project*).

The information in the **Expected Failure Model** area of the control panel is now updated with the distribution and parameters that were calculated from the selected data sheet. You click the **Redraw Plot** icon to display the ranges of expected failure times (*"Expected Failure Times - Bulb B" in the sample project*), and then you adjust the x-axis range so the maximum value is 1,500.

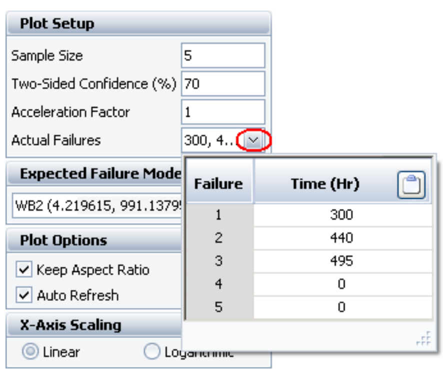


This plot uses the failure number on the y-axis (1 = the first failure, and so on) and time on the x-axis. Based on the plot, you expect the first failure to occur sometime between 440 and 787 hours of testing, the second between 635 and 928 hours, and so forth. You view the actual time bounds by pointing to the first or last tick mark on a line, as shown next for the first failure.

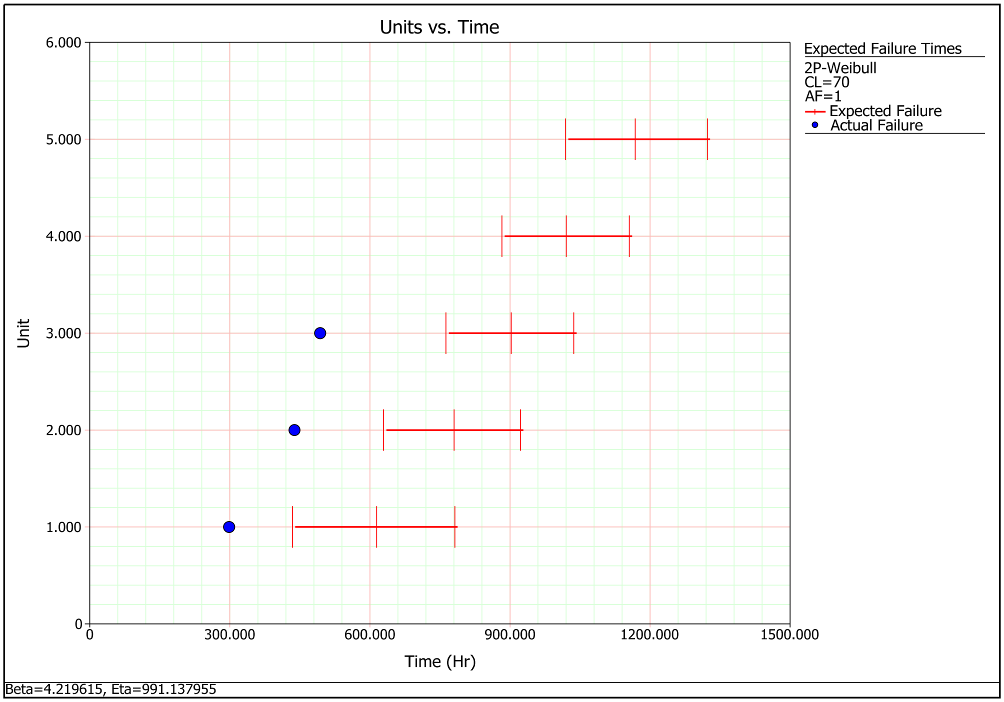


The Expected Failure Time Plot: In general, this plot tells you that, based on the assumed distribution, you can expect the observed failure times to be within the ranges shown. If any sequential observed time is outside this range, then the distribution (and thus the reliability) of the observed units should no longer be assumed. (The plots results are only valid, however, for the confidence level chosen.) Moreover, if any of the observed failure times is earlier than its predicted interval, then you can infer that the reliability will be less than what was assumed. Similarly, if any of the actual failure times is greater than its predicted interval, then you can infer that the reliability is greater than what was assumed (at the specified confidence level).

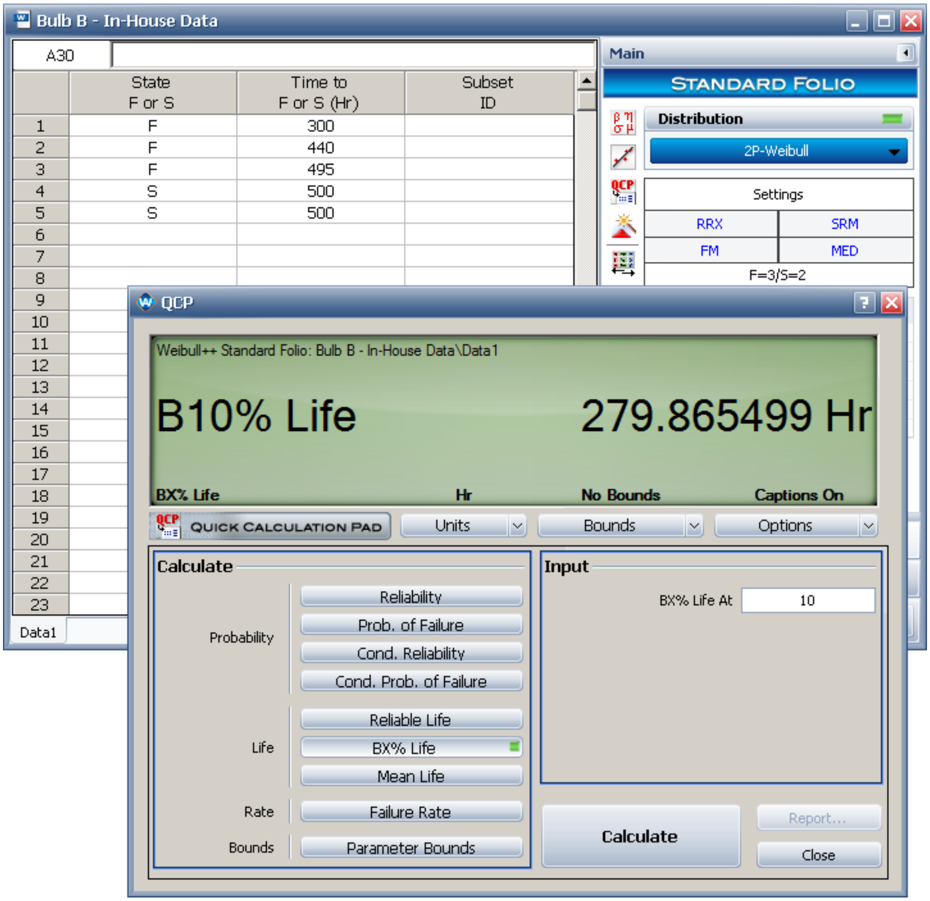
As the test progresses, you observe the first failure at 300 hours, which is earlier than the associated starting interval. You conclude that, at the specified confidence level, bulb B's reliability is less than what was assumed. In order to estimate the bulb's B10 life, you continue the test to collect more data. The next 2 failures are observed at 440 and 495 hours. As these failures occur, you display them on the plot by clicking inside the **Actual Failures** field on the control panel and entering them into the table that appears. After recording these 3 failures, the table appears as shown next.



The plot appears as shown next. With three failure times observed, you end the test at 500 hours and calculate the data.



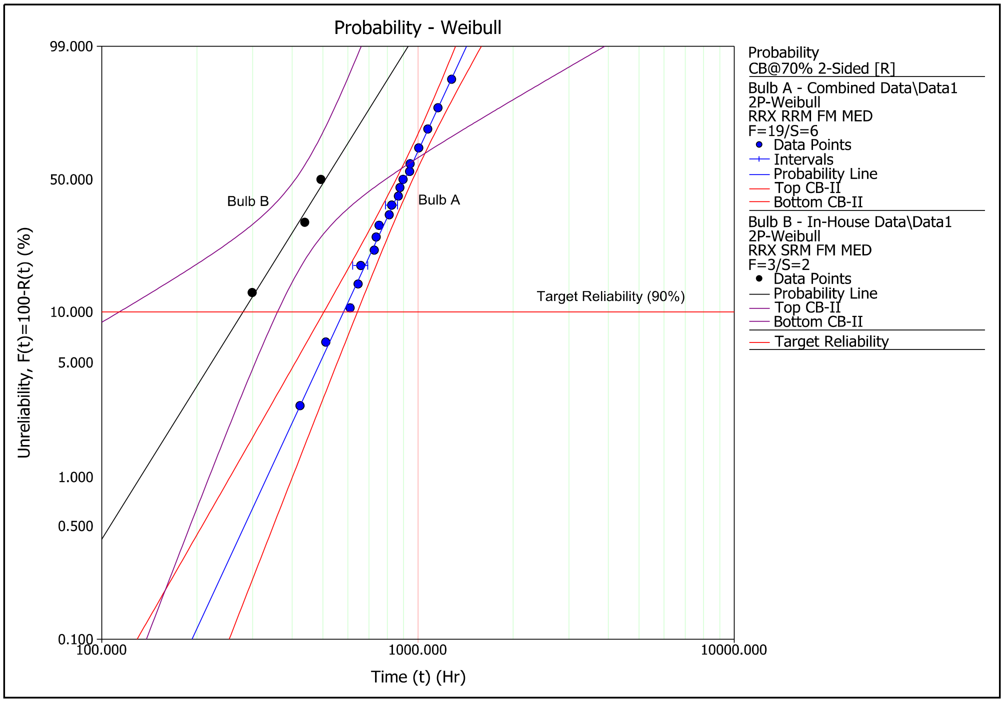
You create a standard folio for the bulb B data (*"Bulb B - In-House Data" in the sample project*) and use the QCP to calculate the B10 life.



The estimated B10 life for bulb B is about 280 hours, which is clearly less than the 575-hour B10 life that was calculated for bulb A using the combined data.

You decide to perform further analysis to determine whether this is a statistically significant difference. To do this, you choose **Insert > Reports and Plots > Overlay Plot** (*"Bulb A vs. Bulb B" in the sample project*) and select to compare the data sheets for the two bulbs. On the control panel of the overlay plot, you click **Confidence Bounds** and then select to view the 70% two-sided bounds on reliability. Finally, you click **Target Reliability** on the control panel and select to display the target reliability value of 90%.

This will mark the time at which reliability equals 90%, which is equivalent to the B10 life. The plot appears as shown next (with annotations added via RS Draw to make the plot easier to interpret).



The horizontal line marks the target metric, and you can see that bulb B's B10 life is lower than that of bulb A, and that the confidence bounds on the B10 life for both products do not overlap. Thus, you conclude that bulb B indeed has a lower B10 life. You show the plot to the design team and recommend that they use bulb A in the projector.

Note: In the difference detection matrix you created in Section 4.3, you can see that if the B10 life of bulb B is 300 hours and the B10 life of bulb A is approximately 550 hours, then a 500-hour test with a sample size of 5 would be sufficient to detect a difference (at a 70% confidence level) between the designs. Notice that the results in this section are consistent with the prior results and that a difference was detected on this 500-hour test.

Warranty Analysis 5

Development testing allows you to uncover and correct reliability problems before a product is deployed; however, there are instances when a problem is not discovered until the product is in the customer's hands. Data obtained from field failures can provide valuable information about how a product actually performs in the real world.

In this chapter, you will extract life data from warranty returns records, and then compare the results obtained from the field data to the results obtained from an in-house reliability test.

In this chapter

- ✓ Warranty data analysis
- ✓ Nevada chart format
- ✓ Forecasting product returns

5.1 Warranty Data Analysis

Based on your prior analyses, you recommended bulb A because of its higher reliability; however, bulb B is lower-priced, and so a decision was reached by management to use bulb B for production. The projectors with bulb B were then released to market with a 12-month warranty.

Soon after the product introduction, due to excessive returns (as you predicted), management decided to discontinue the use of bulb B and return to bulb A, which you originally recommended. Specifically, bulb B was used in production for twelve months. After that, any projectors released in the 13th month and beyond were modified to use bulb A. Six months after this change, you are asked to forecast the warranty returns due to bulb failures for the next six months. The returns data are available and shown in the following table. The data set is organized in Nevada chart format and it includes all 18 months of service (12 with bulb B and 6 with bulb A).

Returns Period (columns) / **Sales Period** (rows)

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1		6	13	20	32	38	62	82	97	78	112	113	76	0	0	0	0	0
2			5	9	20	35	52	76	64	76	114	112	89	77	0	0	0	0
3				4	12	19	31	58	56	77	94	87	114	93	76	0	0	0
4					5	13	20	31	39	70	69	104	81	104	108	112	0	0
5						6	10	22	39	48	56	68	89	97	109	92	88	0
6							4	12	22	36	54	61	52	88	101	97	89	94
7								4	10	23	35	53	58	65	68	76	107	78
8									5	10	25	38	33	50	57	79	100	105
9										6	9	22	20	40	41	75	75	80
10											6	12	11	17	29	48	67	67
11												6	4	9	22	40	57	67
12													0	0	1	2	3	8
13														0	0	1	2	5
14															0	0	1	2
15																0	0	1
16																	0	0
17																		0
18																		

In this format, the columns represent the warranty returns periods and the rows represent the sales periods. This chart indicates, for example, that a total of 18 units were returned during the 3rd month (column 3), and that 13 of those units were sold in the first month (row 1) while 5 units were sold in the 2nd month (row 2). The rest of the chart can be read in a similar manner.

Objectives

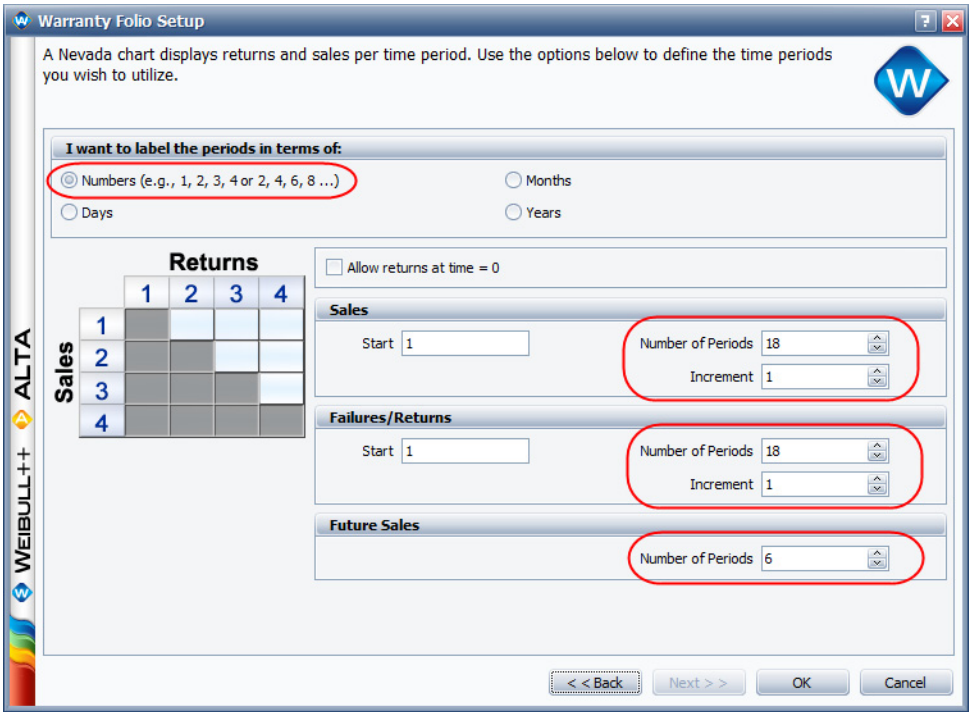
- Assuming an average sales of 1,000 projectors per month, estimate the number of warranty returns due to bulb failures that will occur in the next six months (i.e., months 19 to 24).
- As a side analysis, verify whether an assumption of a usage rate of 50 hours/month per projector holds true for bulb B. Do this by comparing the record of warranty failures to the data from the in-house test of the bulb. *See page 43 in Chapter 4*.

Solution

You create a warranty analysis folio (*"Warranty - Bulbs" in sample project*) by choosing **Insert > Folios > Warranty**.

When prompted to specify the data format, you select **I want to enter data in the Nevada chart format**, and then click **Next**.

Currently, there are **18** sales periods (i.e., the projectors with bulb B were sold in the first 12 months and the projectors with bulb A were sold in the following 6 months) and **18** returns periods. You are asked to forecast the returns for the next 6 months, so you include the forecasted future sales for the next **6** months. Note that because all new projectors have bulb A in them, the future sales will be of projectors with this type of bulb. You set up your Nevada chart with the following settings:



Note: In the Warranty Folio Setup window, you could select to label the periods in terms of months instead of numbers; however, the setup will require you to specify the calendar year. This example does not analyze several years of data, so we will simplify the data entry process by labeling the periods in terms of numbers instead of months.

Once the folio is created, you click the **Change Units** icon on the control panel.

You then specify that the time units of the sales and returns periods will be in terms of months.

Next, you enter data in the Sales data sheet. You use the assumption of a constant rate of sales of 1,000 projectors per month, and use the subset ID column to specify the type of bulb that was used in the projectors that were sold that month.

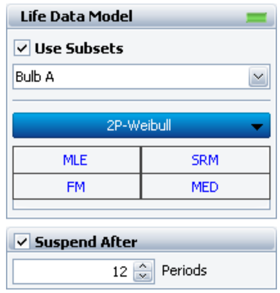
> **Note:** Subset IDs allow you to separate the full data into different homogeneous data sets. In this example, there are two products, bulb A and bulb B. Separating the data by product will allow you to fit different models (distribution and parameters) to each one.

The resulting Sales data sheet is shown next.

Period (Mon)	Quantity In-Service	Subset ID
1	1000	Bulb B
2	1000	Bulb B
3	1000	Bulb B
4	1000	Bulb B
5	1000	Bulb B
6	1000	Bulb B
7	1000	Bulb B
8	1000	Bulb B
9	1000	Bulb B
10	1000	Bulb B
11	1000	Bulb B
12	1000	Bulb B
13	1000	Bulb A
14	1000	Bulb A
15	1000	Bulb A
16	1000	Bulb A
17	1000	Bulb A
18	1000	Bulb A
19	1000	Bulb A
20	1000	Bulb A
21	1000	Bulb A
22	1000	Bulb A
23	1000	Bulb A
24	1000	Bulb A

You then enter the data from the Nevada chart on page 50 to the Returns data sheet of the folio.

On the control panel, you select the **Use Subsets** check box, as shown next.



This setting tells the software to look at the information in the subset ID column and separately analyze the data based on their subset IDs. In addition, it allows you to use the drop-down list to switch between subset IDs and alter the analysis settings for each one, if appropriate. As a general rule, however, the recommendation is to use the same analysis settings for all subsets. You select the following analysis settings for each subset ID:

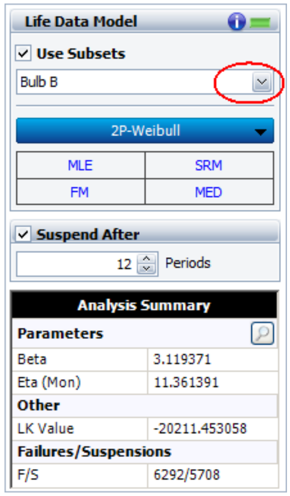
- **2P-Weibull**
- Maximum Likelihood Estimation (**MLE**)
- Standard Ranking Method (**SRM**)
- Median Ranks (**MED**)
- Fisher Matrix Confidence Bounds (**FM**)

Next, you select the **Suspend After** check box and enter **12** periods.

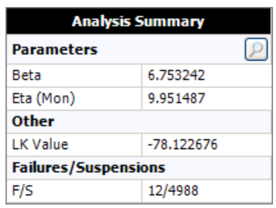
> **Note:** In many cases, data after the warranty period are incomplete or unreliable. The Suspend After setting allows you to ignore any failure times after the specified period and treat them as suspensions (i.e., all we know is that the units had not failed by that time).

Once the settings are finalized, you analyze the data sheet by clicking the **Calculate** icon on the control panel.

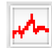
The **Analysis Summary** area of the control panel will display two sets of parameters (because the data sheet contains two subsets IDs). You view the parameters of each set by choosing the subset ID from the drop-down list, as shown next. The following picture shows the 2P-Weibull parameters of bulb B.



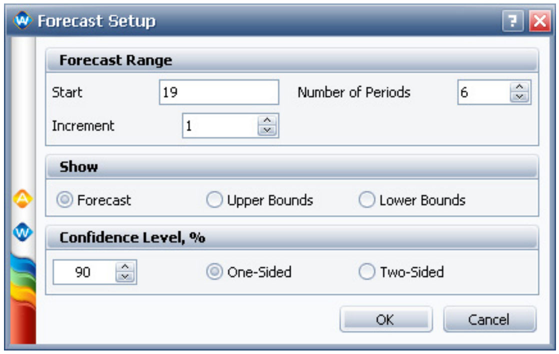
The following picture shows the 2P-Weibull parameters of bulb A.



With the analysis completed, the next step is to generate the forecast. You do so by clicking the **Forecast** icon on the control panel.



In the setup window, you set the forecast to start on the **19**th month and show **6** periods.

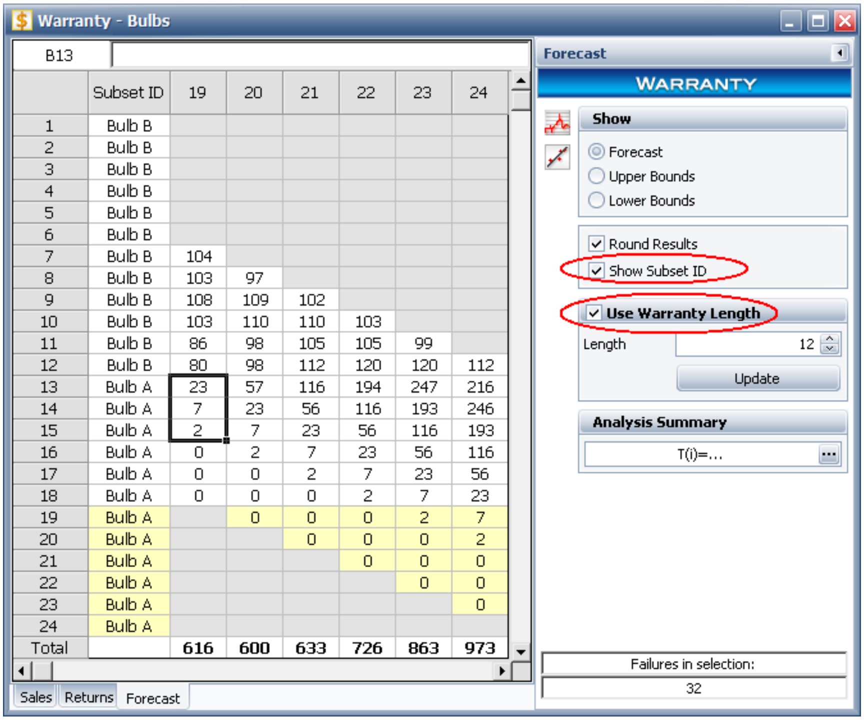


The forecast is then generated within the folio and displayed in the data sheet called "Forecast."

On the control panel of the Forecast sheet, you select the **Show Subset ID** check box in order to identify which type of bulb the expected failure will be. You also select the **Use Warranty Length** check box, enter **12** periods and click **Update**.

Note: By default, the software assumes an infinite warranty period. The Use Warranty Length check box allows you to limit the length of the warranty period. In this example, the warranty length is 12, which means that any units that fail after 12 months of operation are not counted in the returns as they are assumed to be out of warranty.

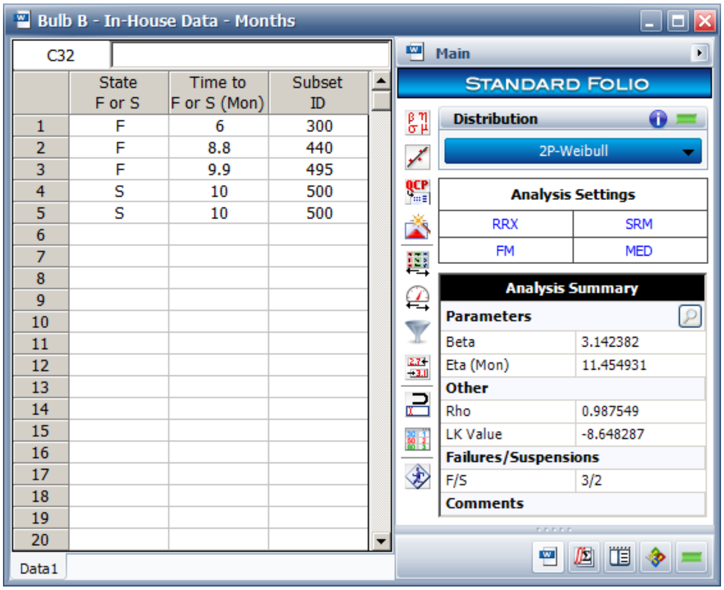
The following Forecast sheet shows the results of your analysis, with the Show Subset ID and Use Warranty Length options selected.



The columns represent the warranty returns periods and the rows represent the sales periods. The results indicate, for example, that you would expect to see a total of 616 bulb failures in the 19th month (column 19), and that 32 of those failures will be from bulb A (as shown in rows 13 to 15), while the remaining failures will be from bulb B. The rest of the forecast can be read in a similar manner.

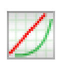
As a side analysis, you want check whether the assumption of a usage rate of 50 hours/month is valid. The data from the in-house test of bulb B are in terms of hours, so you first convert the data for bulb B according to the hour-to-month ratio (by dividing the failure and suspension times by 50).

You create a new Weibull++ standard folio (*"Bulb B - In-House Data - Months" in sample project*) and manually enter the converted data. You analyze the data sheet using the same analysis settings that were used on the in-house test data (i.e., 2P-Weibull and RRX). The following picture shows the result of the analysis (for reference, the subset ID column shows the failure times in terms of hours).



You can now compare the results from the warranty analysis to the results from the in-house test and verify the assumption of the usage rate. One way to do this is to display the contour plot of both data sets and analyses on the same plot.

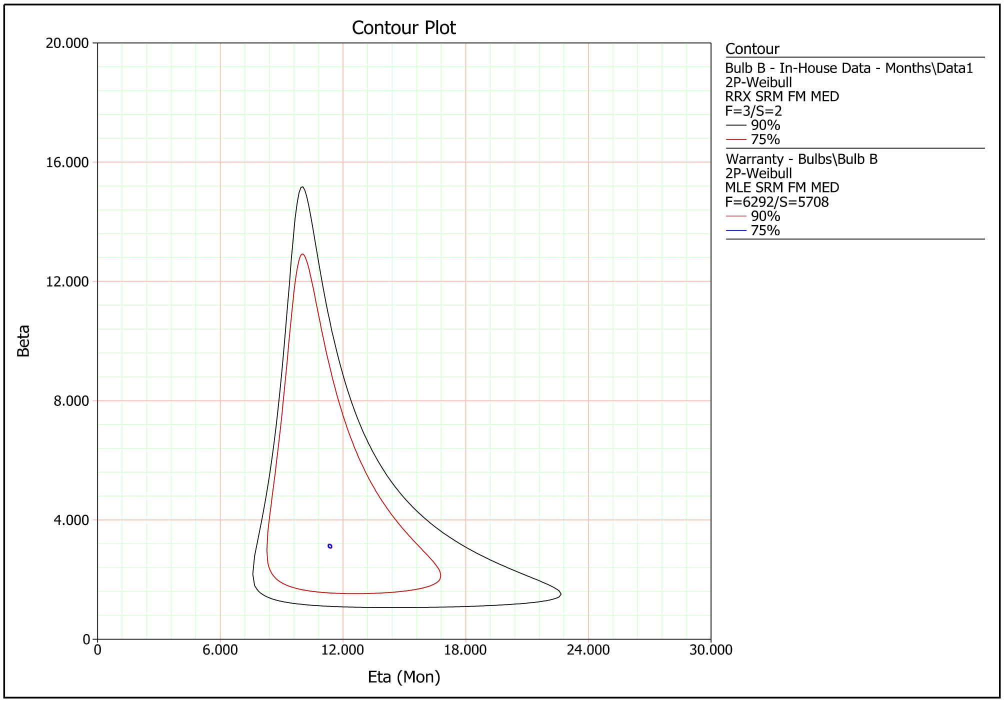
You create an overlay plot (*"Bulb B - Warranty vs. In-House" in sample project*) by choosing **Insert > Reports and Plots > Overlay Plot**.



When prompted to select which data sets to plot, you select the converted data set from the in-house test and the data set from the warranty analysis of bulb B (*"Bulb B - In-House Data - Months" and "Warranty - Bulbs" in the sample project*).

On the control panel of the plot sheet, you switch the plot type to a **Contour Plot**. When prompted to specify the contour lines, you select the **2nd Level, 90%** and the **5th Level 75%** check boxes.

The following overlay plot shows that all the contours overlap; therefore, the two data sets do not show a statistically significant difference in the life, and the 50 hour/month assumption is valid. (This assumes that the only factor is the hour-to-month ratio and that there is no differentiation between the test and use conditions.)



Target Reliability Estimation

6

Deciding on a reliability goal/target involves trade-offs. This is because higher reliability typically correlates with higher production costs, lower warranty costs and higher market share. With Weibull++'s Target Reliability tool, you can generate plots that help you visualize and estimate a target reliability that will minimize cost, maximize profit and/or maximize your return on an investment in improving the product's reliability.

In this chapter, you will use cost factors to estimate the target reliability for a product and calculate the return on an investment intended to reach that reliability.

In this chapter

- ✓ Estimating target reliability
- ✓ Calculating the return on an investment in reliability

6.1 Reliability and Return on Investment

Based on their benchmarking and market research, the marketing group believes the company will become the market share leader if it offers a highly reliable projector coupled with a one-year warranty period. Specifically, their research shows that if the company maintained the current sale price of $1,500 per unit, used a one-year (600 hours) warranty and managed to provide a projector with a 99% reliability over the warranty period, its current 20% market share would increase to 45%. On the other hand, a highly unreliable product (more than 50% returns under warranty) would virtually eliminate the company's market share (i.e., reduce it to about 1%).

The projector bulb is covered under the warranty and is the projector's primary cause of failure. Based on the prior in-house analyses of bulb A and bulb B (*see Chapter 2 and Chapter 4*), if the company were to use bulb A, it is expected that 12% of the projectors would fail during the warranty period. Furthermore, if the company decided to use the lower priced bulb, bulb B, it is expected that 67% of the projectors would fail under warranty. Moreover, after looking at additional manufacturers, you learn that more reliable bulbs are available, but at a higher cost. You identify one manufacturer that offers a highly reliable bulb (1% failures during the warranty period).

The cost of producing a projector without a bulb is $400. The additional cost for the bulb varies depending on which bulb is used.

- The least expensive bulb (bulb B): $50 each.
- The moderately reliable bulb (bulb A): $175 each.
- The bulb with the highest reliability: $450 each.

Finally, each warranty claim costs $200 to process in addition to the replacement cost of the bulb, and the maximum market potential is estimated to be 120,000.

Objectives

- Estimate the target reliability for the projector bulb based on the one-year warranty period.
- Assume that a redesign is required to achieve the target reliability and that such a redesign effort is estimated to require an initial investment of $10 million. Estimate the return on this investment.

Solution

You open the Target Reliability tool (*"Bulb B - Target Reliability" in sample project*) by choosing **Insert > Tools > Target Reliability**.

In the **Target Estimation Inputs** area, you use the information given above to describe the following three scenarios, all of which assume a one-year warranty:

- Best Case: Purchase the most expensive, most reliable bulb.
- Mostly Likely: Purchase bulb A, the modestly reliable bulb.
- Worst Case: Purchase bulb B, the least expensive and least reliable bulb.

The following picture shows your inputs:

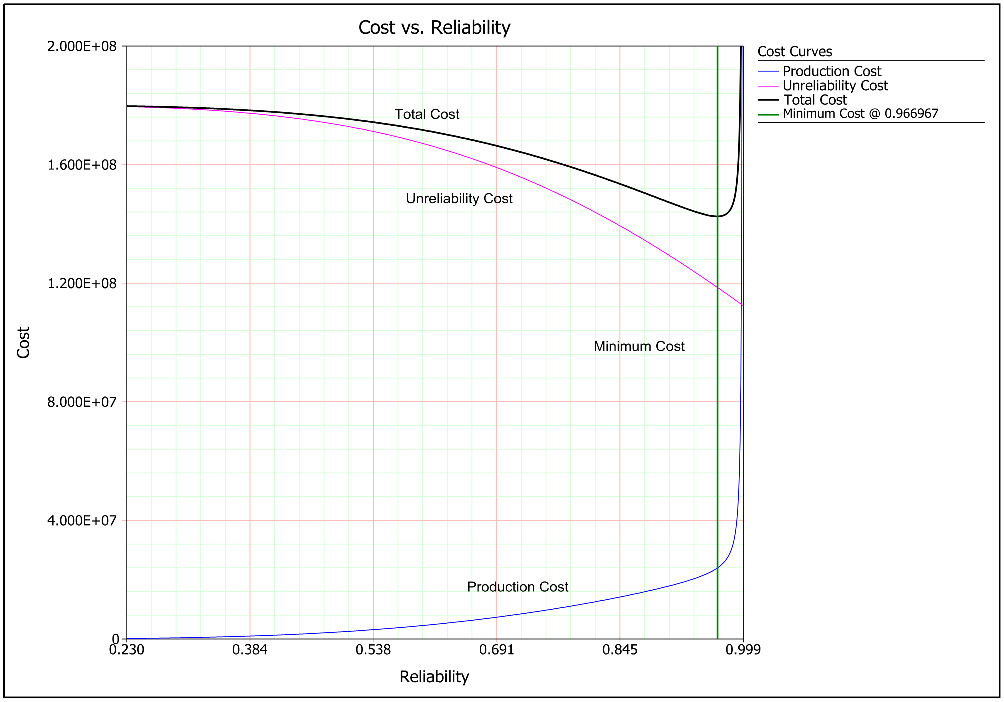
Target Estimation Inputs			
Estimate each scenario with the below factors:	**Best**	**Most likely**	**Worst**
Expected failures/returns per period (as % of sales)	1	12	67
% of market share you expect to capture	45	20	1
Average unit sales price	1500	1500	1500
Average cost per unit to produce	850	575	450
Other costs per failure (in addition to replacement cost)	200	200	200

Here is a more detailed breakdown of the inputs:

- **Expected failures/returns per period (as % of sales)**: With the most expensive bulb, 1% of the projectors would be returned during the warranty period. With bulb A, 12% of the projectors would be returned. With bulb B, 67% would be returned.
- **% of market share you expect to capture**: Your market share in the projector market is 20% with bulb A. This could be increased to 45% with the most reliable bulb or reduced to 1% with bulb B.
- **Average unit sales price**: The sales price of the projector will be fixed at $1,500, regardless of the type of bulb used.
- **Average cost per unit to produce**: Each projector costs $400 to produce, plus $450 for the most expensive bulb, $175 for bulb A and $50 for bulb B.
- **Other costs per failure**: Additional costs are assumed to be fixed at $200, regardless of which bulb is used.

Finally, to specify the maximum market potential, you enter 120,000 in the **Max. Market Potential (Units)** field on the control panel.

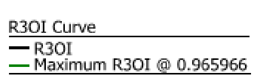
As reliability increases, your production costs will increase, but your unreliability cost will decrease. The Cost vs. Reliability plot allows you to visualize the relationship between reliability and cost, as well as estimate the reliability that minimizes total cost (i.e., production cost + cost due to unreliability). After you enter all the inputs specified above, you select the **Cost vs. Reliability** plot in the **Plot Setting** area and click the **Redraw Plot** icon on the control panel. The plot appears as shown next (with annotations added via RS Draw to make the plot easier to interpret).



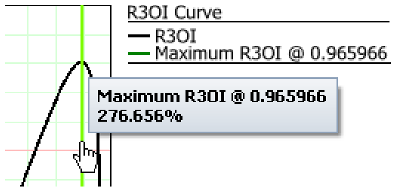
As the legend in this plot shows, the reliability that is estimated to minimize cost is 96.7% at the end of the warranty period.

Next, you select to view the **R3OI vs. Reliability** plot so you can estimate the reliability target that has the highest ROI using ReliaSoft's Reliability Return on Investment (R3OI) equation.

According to the legend of this plot, if your goal is to maximize the return on investment, then your target reliability should be about 96.6% at the end of the warranty period (which is obviously very close to the 96.7% reliability needed to maximize cost). With this reliability for maximizing ROI, you can expect 3.4% of the units sold to be returned under warranty.



Lastly, you wish to determine the return on a $10 million investment to reach the target reliability. So you enter 10,000,000 in the **Initial Investment** field and click the **Redraw Plot** icon. After the plot refreshes, you point to the vertical green line to display the expected return on investment at the target reliability.



This calculation indicates that the return rate on a $10 million reliability investment would be about 276.7%

Stress-Strength Comparison

7

Generally, the reliability of a product is calculated based on its ability to perform without failure for a specified period of time. In some cases, however, you may need to obtain the reliability of a product based on its ability to withstand an applied stress without failure, rather than the length of time it continues to operate. In this chapter, you will estimate the reliability of a product based on the strength of the material and the stress it will experience.

In this chapter

- ✓ Stress-Strength tool
- ✓ Reliability Demonstration Test (RDT) tool

7.1 Stress-Strength Analysis

A different design group in the company needs your assistance in selecting and qualifying a steel component for a new product. Their main concern is the ability of the component to withstand the tensile stresses in its intended application. The estimated median (50th percentile) tensile stress is 75 megapascals (Mpa). The worst case load (defined as the 99th percentile case) is estimated to be 150 Mpa. The reliability requirement for the component is a probability of failure of 1 in 100,000 due to tensile loads (or a reliability of 99.999%).

The group had previously conducted a test on six specimens. They send you the following data set, which shows the stress values at which each of the specimens failed: 212, 236, 248, 254, 271 and 287 Mpa. They have 10 more specimens available for testing if the current information is not sufficient to demonstrate the reliability target.

Objectives

- Determine whether it is possible to demonstrate the required reliability with the information provided.
- If not, design a test for 10 specimens that will demonstrate that the component meets the required reliability if all specimens pass the test.

Solution

The first step is to obtain a distribution for the tensile stress that the component will experience in the field. You create a Weibull++ standard folio (*"Steel Component Data" in the sample project*) by choosing **Insert > Folios > Weibull++ Standard Folio**.

When prompted to specify the data type, you select **Free-form (Probit) data**.

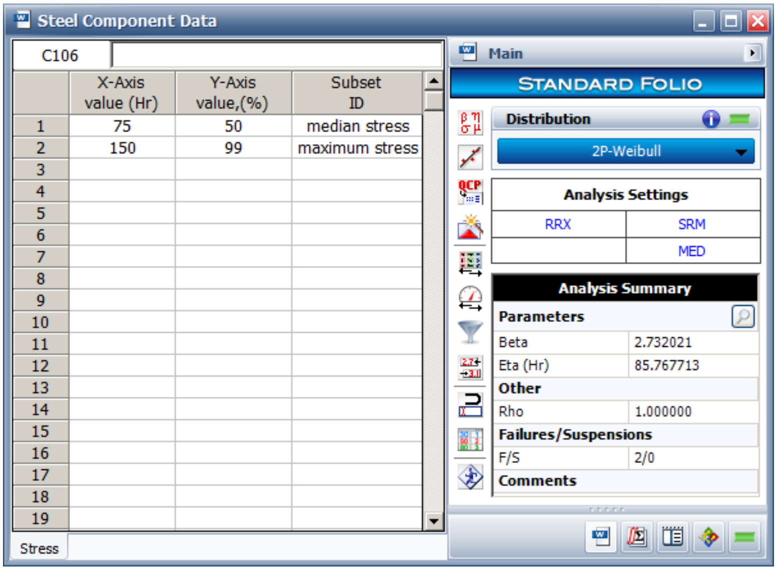
Note: Because the data set you are analyzing is in terms of stress rather than time, you have two choices. You can set the units for the data sheet to "Hours" and then remember throughout the analysis that any inputs and results given in "Hours" really means Mpa. Alternatively, if you have administrative permissions in the Synthesis repository (**File > Manage Repository > Manage Units**), you can define a new unit for Mpa that will then be available in the Units drop-down list for any analysis performed within the database. For the purposes of this analysis, it is not necessary for the software to be able to convert Mpa to some other unit so we will use the simpler approach of interpreting "Hours" as "Mpa."

Once the folio is created, you double-click the name of the data sheet (located at the bottom of the window) and rename "Data1" to "Stress." You then enter the estimates for the tensile stress in the data sheet. On the control panel, you choose the following analysis settings:

- **2P-Weibull**
- Rank Regression on X (**RRX**)
- Standard Ranking Method (**SRM**)
- Median Ranks (**MED**)

You click the **Calculate** icon on the control panel to analyze the data set.

The following picture shows the result of your analysis. It shows that the stress distribution is a 2P-Weibull distribution with beta = 2.732021 and eta = 85.767713 Mpa.



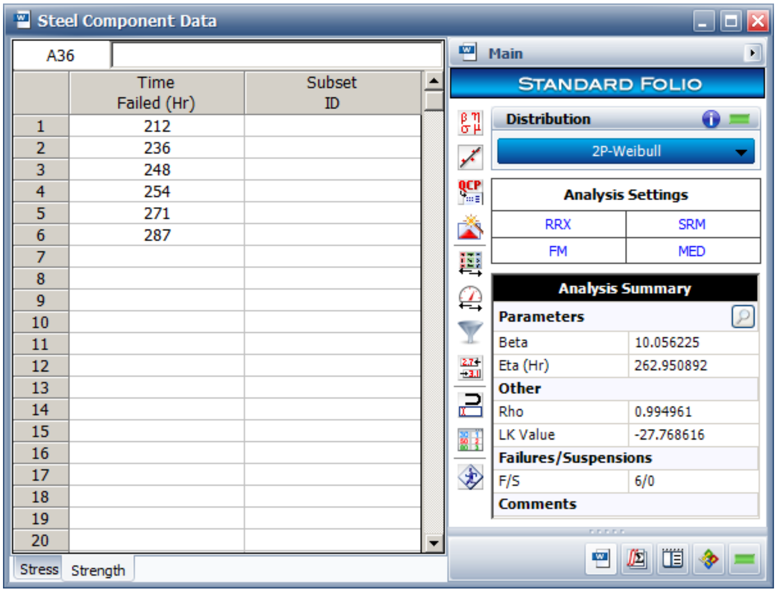
Tip: Because you have two probability points (i.e., the unreliability is estimated to be 50% at 75 Mpa and 99% at 150 Mpa), you could also use the Quick Parameter Estimator (QPE) to obtain the parameters of the distribution. To access the utility, choose **Home > Tools > Quick Parameter Estimator (W++)**.

In the QPE, select the **Two Unreliability Points** option and the **2P-Weibull** distribution. Enter the stress values (Mpa entered as time) and unreliability values (percentile), and click **Calculate**. You will obtain the same estimates for the parameters.

The next step is to obtain the strength distribution. You create a second data sheet in the folio by right-clicking the data sheet tab area (the area at the bottom of the window that shows the name of the data sheets) and choosing **Insert Data Sheet** on the shortcut menu. This time, you select **Times-to-Failure data** as the format and clear all the other options.

You rename the second data sheet to “Strength,” and then enter the failure “times” from the test (i.e., the stress value at which each specimen failed).

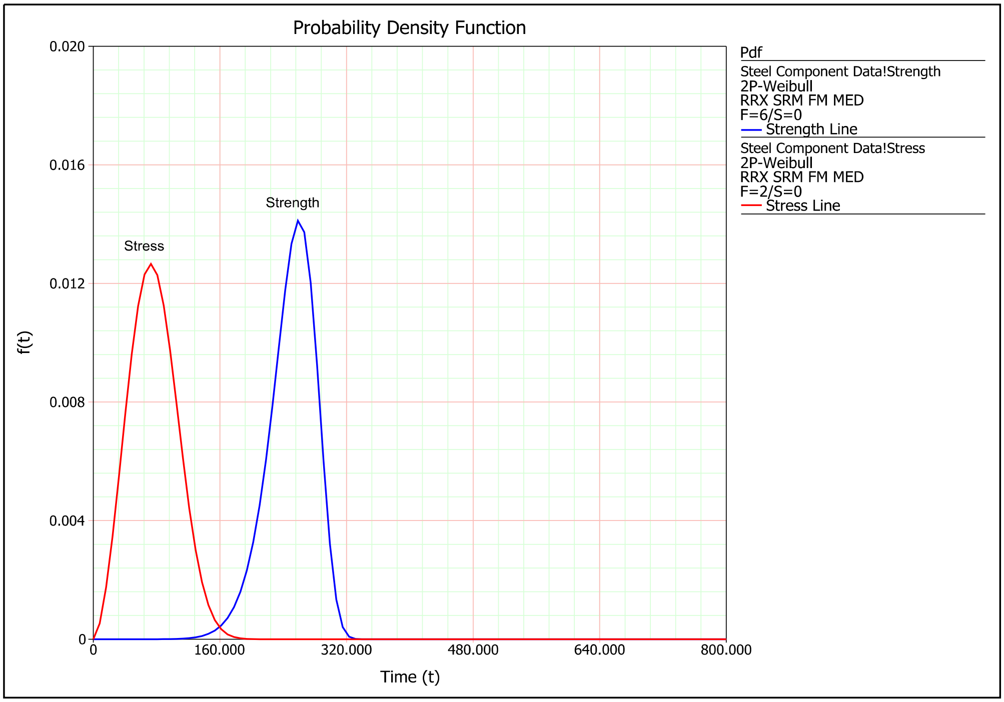
On the control panel, you select the same analysis settings, and then click **Calculate** to analyze the data. The following picture shows the result of your analysis. It shows that the strength distribution is a 2P-Weibull with beta = 10.056225 and eta = 262.950892 Mpa.



The next step is to compare the stress and strength distributions. You open the Stress-Strength tool (*“Stress-Strength - Steel Component” in the sample project*) by choosing **Insert > Tools > Stress-Strength Comparison**.

You select the “Stress” and “Strength” data sheets, and click **OK**.

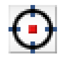
The Stress-Strength tool shows the following plot (with annotations added via RS Draw to make the plot easier to interpret).



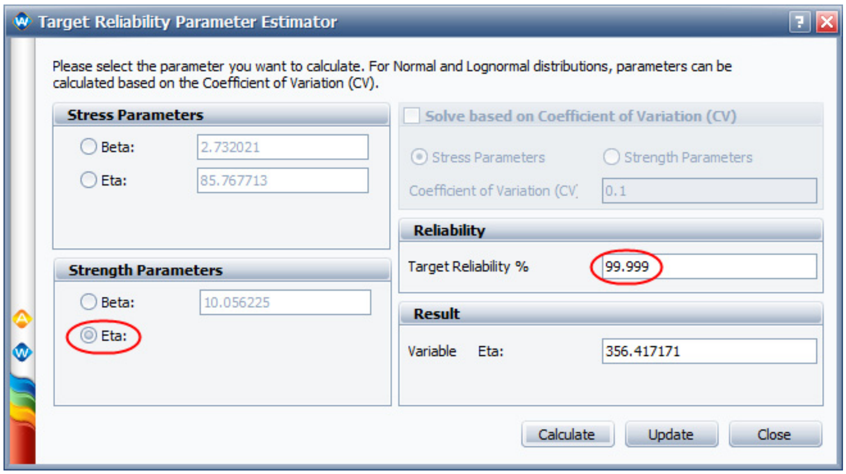
In addition, the result on the plot's control panel tells you that the reliability of the component is estimated to be 99.980787%. This value is close to the target reliability, but not close enough.

You know that the design group has 10 more specimens that they could use to test against the tensile loads. You want to use a *zero-failure test* (also called *reliability demonstration test* or *RDT*), which will demonstrate that the component meets the required reliability if all specimens pass the test. To design the test, first you need to determine how "strong" the component needs to be in order to meet a reliability target of at least 99.999%. This means that you need to determine the parameters for the strength distribution that, when compared against the stress distribution in the Stress-Strength tool, would result in the required reliability.

To find out, you click the **Target Reliability Parameter Estimator** icon on the control panel.

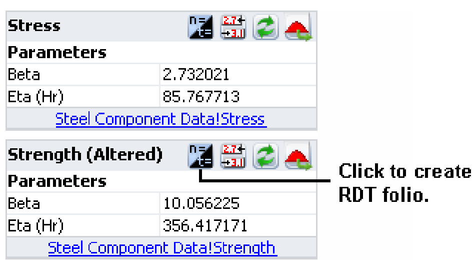


You select to estimate a new eta parameter for the strength distribution, and then you enter the target reliability, which is 99.999%. When you click **Calculate**, the result tells you that in order to meet the reliability target, the value of eta needs to be 356.417171.



Based on this result, you can now design a zero-failure test plan. To do this, you click **Update** to transfer the new eta value to the Stress-Strength tool. You can see that in the control panel, the parameters of the strength data set are now labeled "(Altered)."

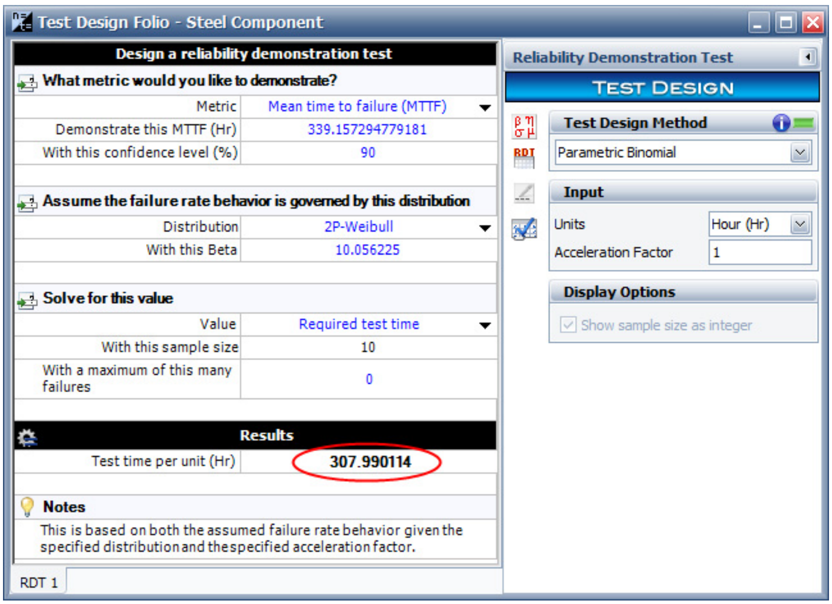
You click the **Reliability Demonstration Test** icon of the strength data set.



This automatically creates a new RDT folio (*"Test Design Folio - Steel Component" in the sample project*) and populates the test plan with the MTTF of the strength distribution that you want to be able to demonstrate. The software also automatically populates all of the Parametric Binomial test plan inputs, including the company's standard 90% confidence level for demonstration tests, so you just need to choose the following settings in the **Solve for this value** area:

- Value: **Required test time**
- Sample size: **10**
- Maximum number of failures: **0**

In this analysis, the required test "time" is the tensile stress that the specimens must experience without failure. You compute the results and it shows a "test time" (i.e., tensile stress) of 307.990114 Mpa.



You inform the group of your findings and show them the test plan you created. You explain that if they test 10 specimens at a tensile stress of 307.990114 Mpa and there are no failures, then this will demonstrate that the component meets the required reliability with a 90% probability.

Competing Failure Modes Analysis 8

Competing failure modes analysis is a method of analyzing the reliability of a product that has more than one cause of failure. The analysis uses the following assumptions: a) the failure modes are independent, meaning that the occurrence of one mode does not affect the probability of occurrence of the other modes, b) the system will fail if any of the modes occur (i.e., series configuration) and c) the failure rate behavior for each failure mode is known and can be described with a life distribution and parameters.

In this chapter

- ✓ Competing failure modes analysis
- ✓ Batch auto run
- ✓ Reliability block diagrams

In this chapter, you will work with a product that experiences multiple failure modes and explore two ways to perform the analysis.

8.1 Competing Failure Modes

Based on your prior work, your reputation for reliability analysis work has reached other divisions within the company. Another division requests your assistance on a classified project, but because you do not have the required security clearance to access classified information, you have no specific knowledge about the product. The only information that can be shared with you is that the product has three failure modes (A1, A2 and A3), and that it would fail if any one failure mode occurs.

Thirty identical units were tested. The failure times (in hours) for the test units, along with the failure mode responsible for the failure, are given next.

	Time Failed (Hr)	Subset ID
1	17	A2
2	74	A2
3	107	A2
4	164	A2
5	246	A2
6	263	A1
7	345	A2
8	395	A2
9	402	A1
10	425	A1
11	465	A1
12	466	A1
13	514	A2
14	525	A1
15	571	A1
16	590	A1
17	594	A1
18	640	A1
19	653	A1
20	671	A1
21	726	A1
22	747	A1
23	750	A1
24	817	A1
25	856	A1
26	879	A2
27	903	A1
28	905	A3
29	1010	A3
30	1223	A3

Objectives

- Use the built-in Competing Failure Modes (CFM) analysis method in the Weibull++ standard folio to perform the analysis and estimate the median time to failure of the product (i.e., B50 life).
- Perform the analysis again using a reliability block diagram (RBD), and estimate the B50 life again to show that the results are the same.
- Determine whether the product can meet a required B10 life of 350 hours. If it cannot be achieved, determine which failure mode will need to be addressed in order to meet the requirement.

Solution

First, you create a new Weibull++ standard folio (*"Competing Failure Modes" in the sample project*) by choosing **Insert > Folios > Weibull++ Standard Folio**.

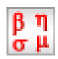
When prompted to specify the data type, you select **Times-to-failure data** and clear all the other options because your data set only contains complete data. You also use the **Units** drop-down list to indicate that the time values in the data sheet will be entered in hours.

Once the folio is created, you enter the failure times and the associated subset IDs that identify the failure modes. On the control panel, you choose **Competing Failure Modes > CFM-Weibull**.

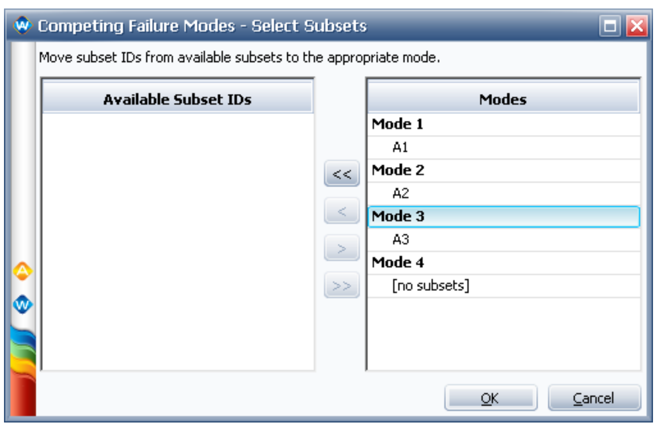
You select the following analysis settings on the control panel:

- Rank Regression on X (**RRX**)
- Standard Ranking Method (**SRM**)
- Median Ranks (**MED**)
- Fisher Matrix Confidence Bounds (**FM**)

Next, you analyze the data (fit the selected distribution to each failure mode) by clicking the **Calculate** icon on the control panel.



When you select to use CFM analysis, the software prompts you to define up to four failure modes for the analysis. Each "mode" can be associated with one or more of the subset IDs of the data sheet. You move each subset ID (on the left) under a different mode (on the right).



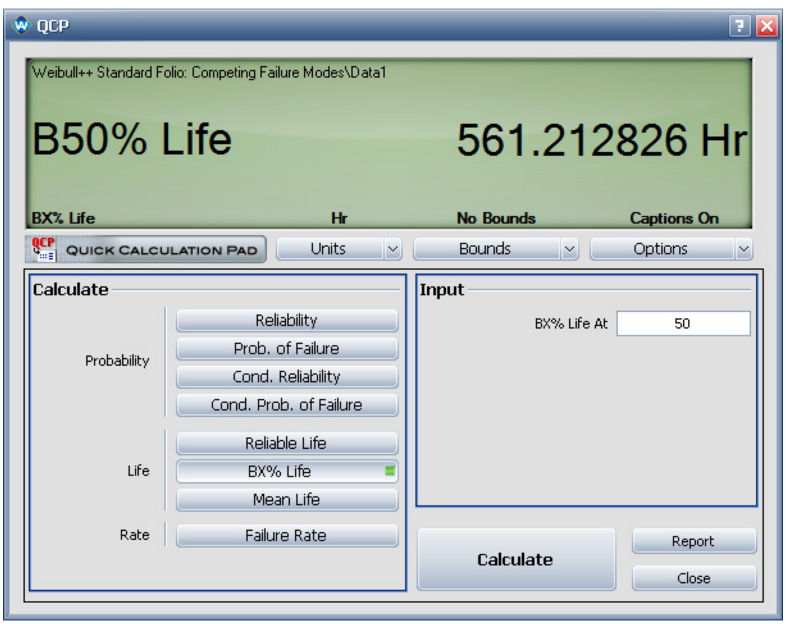
You click **OK** to begin the analysis. When the data set has been analyzed, the **Analysis Summary** area of the control panel displays the estimated parameters of the failure distribution for each mode.

Analysis Summary	
Parameters	
Beta[1]	3.484255
Eta[1] (Hr)	762.644611
Beta[2]	0.785394
Eta[2] (Hr)	2330.987042
Beta[3]	5.444704
Eta[3] (Hr)	1123.507536
Other	
Rho [1]	0.992106
Rho [2]	0.996776
Rho [3]	0.974761
Comments	

Next, you open the QCP by clicking the icon on the control panel.

To calculate the B50 life, you select **BX% Life** and use the **Units** drop-down list to make sure that the results will be returned in hours. You enter **50** for the **BX% Life At** input and click **Calculate**.

The result shows a B50 life of approximately 561 hours. This means that 50% of the population will have failed by 561 hours of operation.

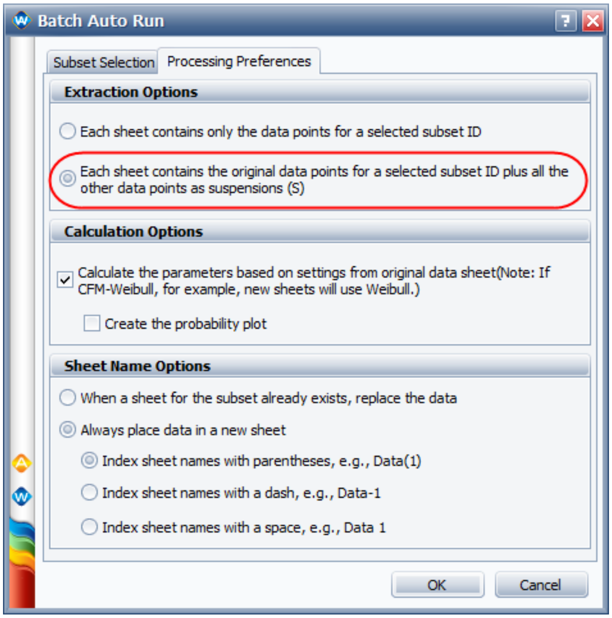


Because some members of the design team are not familiar with the built-in CFM analysis method available in Weibull++ standard folios, your next step is to perform the analysis again using the more familiar RBD approach to demonstrate that both methods return identical results when all of the settings and assumptions are the same.

Before you create a diagram, you first need to segregate the data sets of the failure modes so that each mode can be represented by a single block in the diagram. You click the **Batch Auto Run** icon on the Main page of the control panel.

When prompted to select the subset IDs, you select them all.

You click the **Processing Preferences** tab. In the **Extraction Options** area, you select the option shown next.



This option allows you to extract the data sets that are required for the CFM analysis. For example, when you extract the data points of mode A1, the Batch Auto Run utility will retain all the data points due to mode A1 as failures but mark all other data points due to modes A2 and A3 as suspensions. They are suspensions because the units in the sample would have continued to operate for some unknown amount of time if they had not been removed from the test when they failed due to those modes.

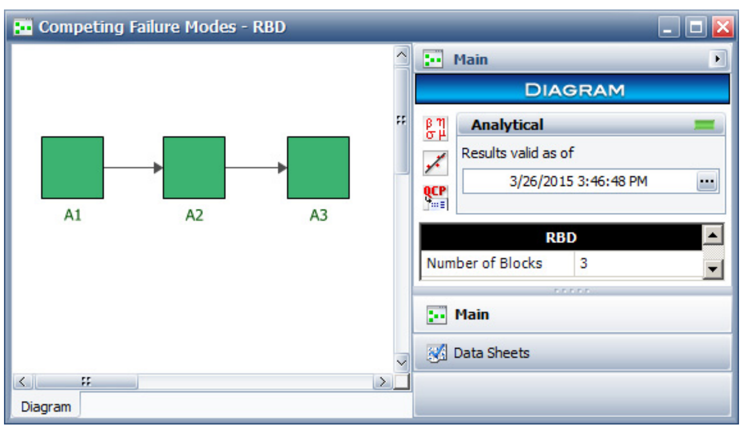
In the **Calculation Options** area, you select to calculate the parameters of each data set based on the selected distribution, which is the 2P-Weibull for this analysis. When you click **OK**, the data sets are extracted to separate data sheets in the folio and automatically calculated.

You then create a diagram (*"Competing Failure Modes - RBD" in the sample project*) by choosing **Insert > Tools > Diagram**.

Once the diagram is created, you add a block by right-clicking the diagram and choosing **Add Block** on the shortcut menu. When prompted to select the data sheet of the failure mode that the block will represent, you select the data sheet for mode A1. You use the same approach to add the blocks that will represent failure modes A2 and A3.

Next, you connect the blocks in an appropriate configuration to describe the relationships between the failure modes. You add a connector by right-clicking the diagram sheet and choosing **Connect Blocks** on the shortcut menu. You click the source block, hold down the left mouse button and then drag a line from the source block to the destination block. When the crosshairs are located above the destination block, you release the mouse button to create a connector.

The following diagram shows the modes connected in a series configuration. This indicates that the product will fail if any of the modes occurs.



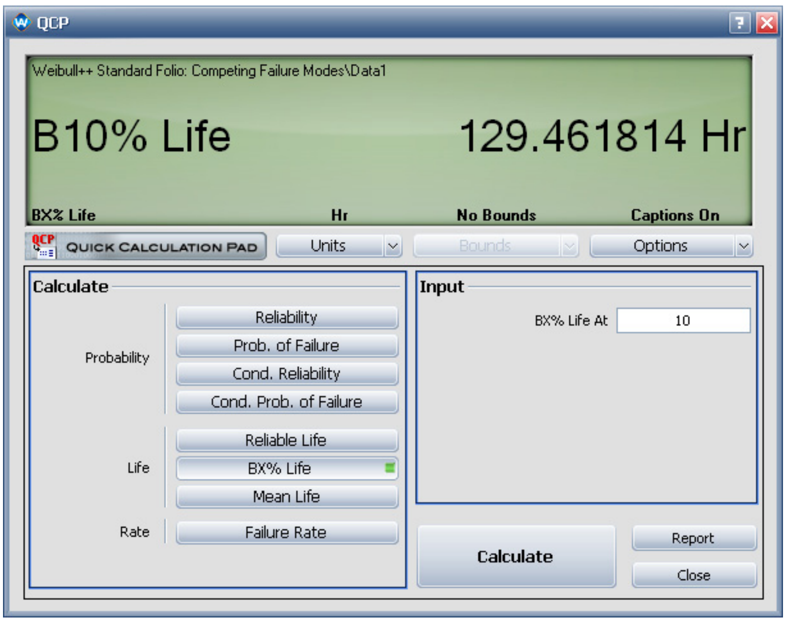
To analyze the diagram and calculate the product's overall reliability, you click the **Calculate** icon on the diagram's control panel.

To estimate the B50 life of the product, you use the QCP. The result is about 561 hours, which is identical to the result you obtained when you performed the CFM-Weibull analysis in the Weibull++ standard folio.

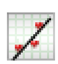
Tip: The RBD approach can also be used for more complex analyses that are not supported by the CFM analysis methods built into the Weibull++ standard folio. Specifically, you will need to use the RBD approach if: a) the analysis involves more than four failure modes, b) the failure modes are described by different life distribution and/or c) the relationships between the modes do not follow a series configuration.

You return to the CFM-Weibull analysis in the Weibull++ standard folio (*"Competing Failure Modes" in the sample project*), and use the QCP to calculate the B10 life of the product.

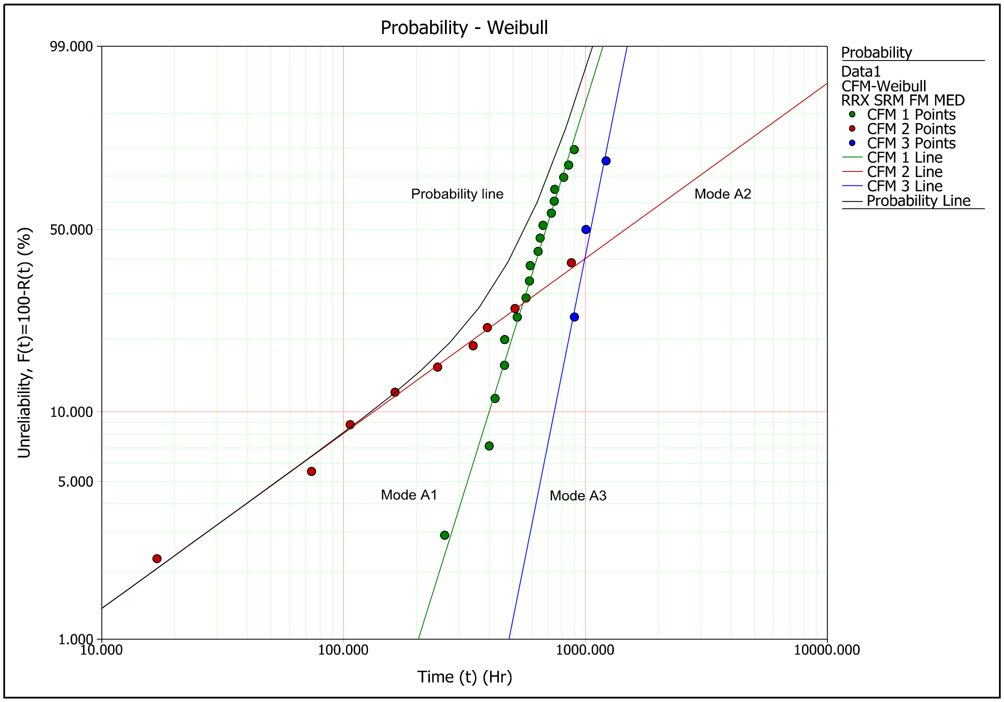
The required B10 life is 350 hours, but the result is about 129 hours.



To visualize how each of the failure modes contribute to the overall reliability of the product, you click the **Plot** icon on the control panel.



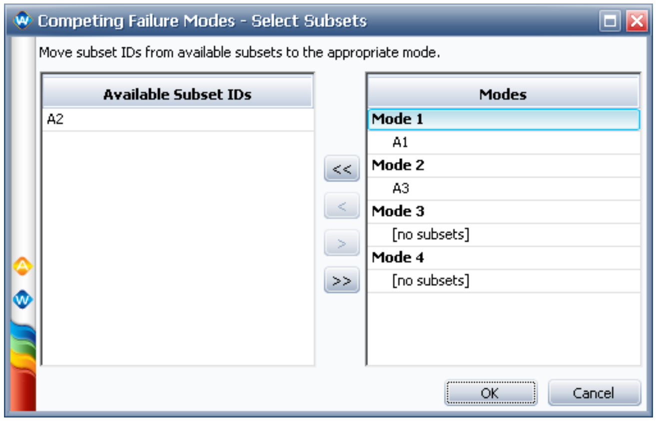
The following probability plot shows the results (with annotations added via RS Draw to make the plot easier to interpret).



The plot tells you that mode A2 has a strong influence on the overall probability of failure of the product.

You decide to perform a "what-if" analysis to see what the B10 life of the product would be if the failures due to mode A2 did not occur. To do this, you create a copy of the data sheet in the folio by right-clicking the data sheet tab area (the area at the bottom of the window that shows the name of the data sheets) and choosing **Move/Copy Sheet** on the shortcut menu. You select the "Data1" data sheet and the **Create a Copy** check box, and then click **OK**.

Once the new data sheet is created, you rename it to "Two Modes." You then click the **Calculate** icon on the control panel to redo the CFM analysis with only two modes. When prompted to select the subset IDs, you remove mode A2 from the list of modes.



After performing the CFM analysis again for only modes A1 and A3, you use the QCP to calculate the B10 life. This time, the result shows 396 hours, which indicates that the product would be likely to meet the requirement if the designers were able to address the A2 failure mode (best case scenario).

Parametric Recurrent Event Data Analysis

9

In life data analysis, it is assumed that the components being analyzed are non-repairable; that is, they are either discarded or replaced upon failure. However, for complex systems such as automobiles, computers, aircraft, etc., it is likely that the system will be repaired (not discarded) upon failure. Failures are recurring events in the life of a repairable system, and data from such a system are known as *recurrent event data*. Weibull++ includes a choice of two methods for analyzing recurrent event data: parametric and non-parametric analysis.

In this chapter

- ✓ Recurrent event data analysis
- ✓ Parametric RDA folios

In this chapter, you will perform parametric recurrent event data analysis in order to estimate the number of spare parts that will be needed to maintain a repairable system.

9.1 Parametric Recurrent Event Data Analysis (RDA)

You are performing consulting work for a customer who uses a piece of equipment that your company manufactures. The customer has 200 such systems, with each system using five bulbs. If any one of the bulbs in a given system fails, the system is considered failed. The customer's maintenance department restores the system by replacing the failed bulb. When maintenance personnel go out to repair a system, the only information recorded is the "use time" of the system as indicated by the Hobbs meter on the equipment. The table on the next page shows the failure logs for 28 of those systems, all recorded between 0 to 1,500 hours of operation. Each log includes the operating hours of the system at the time when each failure occurred (indicated by an F) and the time when the observation period ended (indicated by an E).

Recurrent Event Data: In recurrent event data, the failure time that is recorded is not the observation time when the failure occurred, but rather the age of the system when the failure occurred. System age may be measured in terms of the number of operating hours accumulated, or in terms of accumulated mileage, distance, etc.

1		2		3		4		5		6		7	
F	467	F	543	F	826	F	326	F	322	F	796	F	197
F	792	F	755	F	978	F	571	F	548	F	829	F	624
F	1111	F	1310	F	1003	F	1016	F	641	F	952	F	909
F	1177	F	1369	F	1019	F	1025	F	648	F	1053	F	975
F	1190	F	1388	F	1162	F	1085	F	826	F	1140	F	1012
F	1333	E	1500	E	1500	F	1104	F	1087	F	1375	F	1176
F	1383					F	1119	F	1350	F	1447	F	1370
E	1500					F	1420	F	1482	E	1500	E	1500
						E	1500	F	1489				
								E	1500				

8		9		10		11		12		13		14	
F	825	F	547	F	659	F	343	F	589	F	375	F	714
F	847	F	686	F	913	F	659	F	877	F	413	F	794
F	939	F	820	F	916	F	806	F	912	F	912	F	977
F	995	F	825	F	1309	F	810	F	1051	F	1032	F	1237
F	1209	F	1276	F	1319	F	936	F	1218	F	1182	F	1279
E	1500	F	1368	E	1500	F	1111	F	1343	F	1287	F	1453
		E	1500			F	1262	E	1500	E	1500	E	1500
						E	1500						

15		16		17		18		19		20		21	
F	449	F	370	F	614	F	421	F	564	F	627	F	141
F	582	F	531	F	784	F	721	F	1195	F	734	F	545
F	898	F	547	F	921	F	1169	F	1370	F	971	F	804
F	1101	F	1045	F	1100	F	1212	F	1420	F	978	F	967
F	1154	F	1052	F	1298	F	1279	E	1500	F	1395	F	1096
F	1334	F	1077	F	1475	F	1489			F	1401	F	1154
E	1500	F	1283	E	1500	E	1500			E	1500	F	1199
		F	1394									E	1500
		F	1452										
		E	1500										

22		23		24		25		26		27		28	
F	616	F	657	F	310	F	415	F	578	F	832	F	156
F	791	F	717	F	726	F	559	F	816	F	917	F	505
F	792	F	762	F	868	F	847	F	874	F	1024	F	717
F	923	F	909	F	1009	F	982	F	1082	F	1048	F	764
F	1413	F	1041	F	1017	F	986	F	1148	F	1463	F	855
E	1500	F	1277	F	1292	F	1378	F	1434	E	1500	F	903
		F	1444	F	1310	E	1500	F	1483			F	1299
		E	1500	E	1500			E	1500			F	1371
												F	1493
												E	1500

Objectives

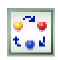
- Estimate the number of bulbs that are expected to fail per system over the next 100 hours.
- Estimate the number of spare parts that the maintenance department will need to cover repairs for all 28 systems in the next 100 hours of operation.

Solution

For this data set, you know that you cannot use life data analysis (e.g., fit a Weibull distribution to the data set) because the failure times of each system are dependent on that system's history of repairs. In other words, all you know is that when a system failed, one of its five bulbs was replaced, but you do not know which one.

In this case, from a system perspective, you are dealing with a repairable system (with the repair being the replacement of one of the five bulbs). Each time a system is repaired, the system is returned to service, but it is no longer in an *as good-as-new* condition nor *as bad-as-old*, but at some stage in between. To analyze the data and answer the questions of interest to the customer, you will perform parametric recurrent event data analysis using the general renewal process (GRP) model.

You create a new Parametric RDA folio (*"Hobbs Readings Data" in the sample project*) by choosing **Insert > Folios > Parametric RDA**.

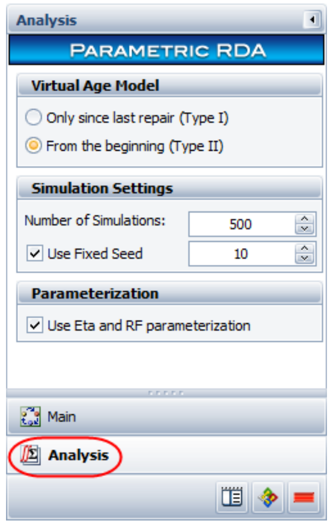


Once the folio is created, you enter the data from the table on page 84 in the data sheet.

After entering the data, the next step is to select the settings that will be used to fit the GRP model to the data. On the control panel, you select **3** parameters and the **Type II** virtual age model.

Virtual Age: The general renewal process model uses the concept of *virtual age* to mathematically capture the effect of the repairs on the subsequent rate of occurrence of failure. The Type I model assumes that the repairs will remove some portion of the damage that has accumulated since the last repair, while the Type II model assumes that the repairs will remove a portion of all the damage that has accumulated since the system was new.

The setting for virtual age is also available on the Analysis page of the control panel, which can be accessed by clicking the **Analysis** button.



On the Analysis page, you make sure that the **Use Eta and RF parameterization** check box is selected.

To fit the general renewal process (GRP) model to the data set, you click the **Calculate** icon on the Main page of the control panel.

Once the model is fitted, the **Analysis Summary** area of the control panel displays the parameters of the GRP model (beta, eta and RF), as well as the LK Value.

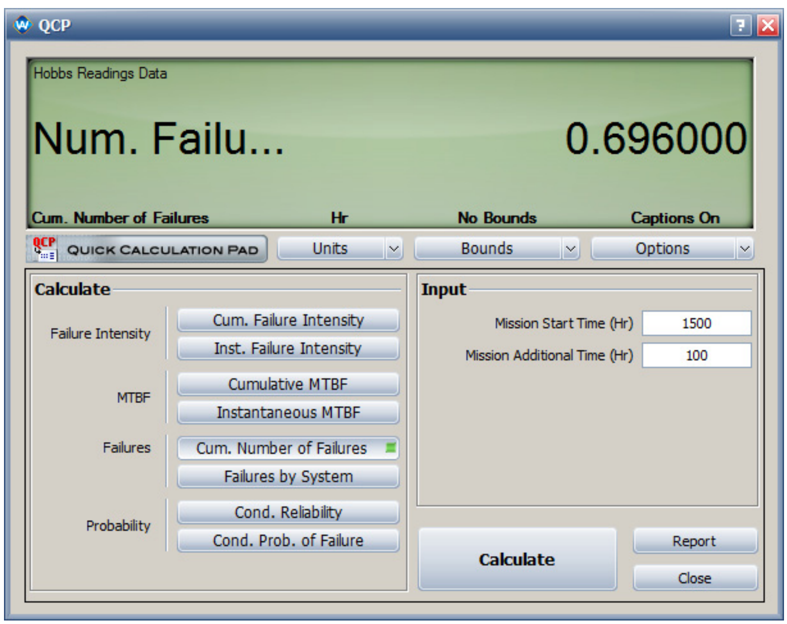
Analysis Summary	
Parameters	
Beta	2.258572
Eta (Hr)	495.260706
RF	0.231669
LK Value	-1109.630979

Restoration Factor (RF): The RF parameter provides an indication of the effectiveness of the repairs as reflected by the data set. An RF = 1 indicates that the system will be "as good as new" after the repair. This is known as a *perfect repair*. An RF value between 0 and 1 indicates that the system will be "better than old but worse than new" after the repair. This is known as an *imperfect repair*. An RF = 0 indicates that the system will be "as bad as old" (i.e., no improvement) after the repair. This is known as a *minimal repair*.

To solve for the number of bulbs that are expected to fail, you open the QCP by clicking the icon on the control panel.

To calculate the number of bulbs that are expected to fail per system over the next 100 hours, you select **Cum. Number of Failures** and use the **Units** drop-down list to make sure that the results will be returned in hours. You enter **1,500** for the **Mission Start Time**, and **100** for the **Mission Additional Time**.

The calculated result shows that 0.696 or about 1 bulb per system will fail in the next 100 hours.



To estimate the number of spare parts that the customer would need to repair all 28 systems in the next 100 hours, you select **Failures by System** and enter **100** for the **Mission Additional Time**. This calculates the number of failures from the time when the observation period for the system ended (which is 1,500 hours as indicated by an E in the folio data sheet).

You click **Calculate** to open the Results window, which shows a detailed report on the number of failures per system. The result indicates that there will be a total of about 20 failures in the next 100 hours. Therefore, the customer will need 20 spare parts.

Quick Results Report			
Report Type	Failures by System		
User Info			
User	User Name		
Company	Company		
Date	2/3/2012		
User Inputs			
Mission Additional Time (Hr)	100		
Individual System Results			
System ID	Current Age* (Hr)	End Age (Hr)	Cum. Number of Failures
1	1500	1600	0.696
2	1500	1600	0.696
3	1500	1600	0.696
4	1500	1600	0.696
5	1500	1600	0.696
6	1500	1600	0.696
7	1500	1600	0.696
8	1500	1600	0.696
9	1500	1600	0.696
10	1500	1600	0.696
11	1500	1600	0.696
12	1500	1600	0.696
13	1500	1600	0.696
14	1500	1600	0.696
15	1500	1600	0.696
16	1500	1600	0.696
17	1500	1600	0.696
18	1500	1600	0.696
19	1500	1600	0.696
20	1500	1600	0.696
21	1500	1600	0.696
22	1500	1600	0.696
23	1500	1600	0.696
24	1500	1600	0.696
25	1500	1600	0.696
26	1500	1600	0.696
27	1500	1600	0.696
28	1500	1600	0.696
Overall System Results			
Total Number of Failures	19.488		
Total (in full units)	20		
End of Quick Results Report			
* - The current age is equivalent to the time when the observation period for the system ended (indicated by an E in the folio data sheet). If you did not enter an end time for a system, then the current age is assumed to be equal to the last failure time for that system.			

Total number of failures for all 28 systems

Event Log Data Analysis 10

Event logs, or maintenance logs, capture information about a piece of equipment's failures and repairs, such as the date/time the equipment failed and the date/time the equipment was restored. This information is useful for helping companies achieve productivity goals by giving insight about the failure modes, frequency of outages, repair duration, uptime/downtime and availability of the equipment.

In this chapter

- ✓ Event log folios
- ✓ Overlay plots

In this chapter, you will learn how to use Weibull++'s event log folio to convert maintenance logs into times-to-failure data, and then perform basic life data analysis.

10.1 Event Log Data

While working with the manufacturing division of your company, you are given the task of analyzing the failure behavior of a critical piece of equipment that operates for 24 hours a day, 7 days a week. The equipment has five different subsystems (subsystems 1, 2, 3, 4 and 5). Furthermore, you learn that:

- When any one of the subsystems fails, the equipment stops operating until the failed subsystem is repaired (thus the remaining subsystems do not age and cannot fail during the repair action).
- A repair action involves replacing the failed subsystem with a new (similar) subsystem.
- An automated data logger automatically captures the equipment failure events and the subsystem responsible for the failure, as well as the date and time when the equipment was restored to operating condition.
- The equipment started operating on January 2, 2013 at 1:00 AM. The log was downloaded on September 16, 2018 at 8:00 PM.

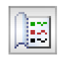
Objectives

- Obtain the times-to-failure and times-to-repair distributions of each subsystem.
- Use overlay plots to compare the failure behaviors and the repair behaviors of the subsystems.

Solution

To obtain the failure distribution and repair distribution of each subsystem, you will use the event log folio to analyze the information downloaded from the data logger.

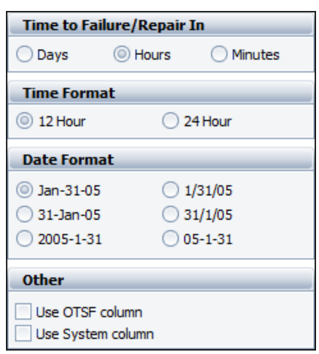
You create a new event log folio (*"Auto Data Event Log" in the sample project*) by choosing **Insert > Folios > Event Log**.



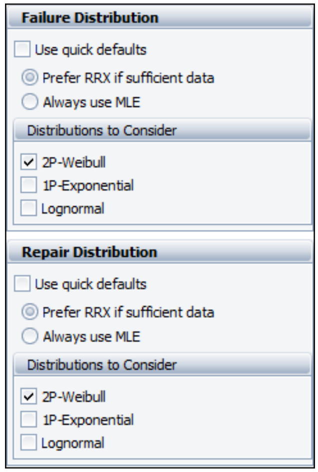
Once the folio is created, the next step is to configure the data sheet.

You click the **Other** page button on the control panel, and then select the following settings:

- In the **Time to Failure/Repair In** area, you select **Hours** so that when the software converts the maintenance logs to failure and repair data, the unit of time will be hours.
- You clear the **Use OTSF column** check box because all of the subsystems will stop accumulating age if the equipment fails for any reason. If this check box were selected, the OTSF (operates through system failures) column would be displayed in the data sheet and you would have the option to specify which subsystem(s) will continue to accumulate age when the system is down due to the failure of another subsystem.
- You also clear the **Use System column** check box because you will be analyzing only one piece of equipment. If this check box were selected, the System column would be displayed in the data sheet and you would have the option to enter events for multiple systems.



You then click the **Analysis** page button on the control panel. For both the failure and repair distributions, you select the **Prefer RRX if sufficient data** option and the **2P-Weibull** distribution. These will be the settings that the software will use to automatically analyze the failure and repair data that are extracted from the event log.



Next, you enter the information from the data logger into the data sheet.

F=Failure/ E=Event	Date Occurred	Time Occurred	Date Restored	Time Restored	Level 1
F	Jan-22-13	4:45:00 PM	Jan-23-13	6:15:00 AM	Subsystem 2
F	Jan-23-13	10:19:00 AM	Jan-24-13	12:01:00 PM	Subsystem 4
F	Feb-09-13	9:53:00 AM	Feb-10-13	6:21:00 AM	Subsystem 3
F	Feb-19-13	7:05:00 PM	Feb-20-13	9:41:00 PM	Subsystem 1
F	Mar-01-13	4:58:00 AM	Mar-02-13	10:35:00 AM	Subsystem 4
F	Mar-07-13	3:48:00 PM	Mar-08-13	11:22:00 AM	Subsystem 1
F	Mar-17-13	2:02:00 PM	Mar-18-13	8:17:00 AM	Subsystem 1
F	Mar-28-13	10:57:00 PM	Mar-30-13	2:22:00 AM	Subsystem 3
F	Apr-10-13	3:08:00 AM	Apr-11-13	12:46:00 AM	Subsystem 1
F	Apr-11-13	1:14:00 AM	Apr-11-13	2:46:00 PM	Subsystem 4
F	Apr-26-13	9:04:00 AM	Apr-27-13	6:48:00 AM	Subsystem 3
F	May-03-13	7:13:00 AM	May-04-13	7:17:00 AM	Subsystem 1
F	May-06-13	1:36:00 PM	May-07-13	10:52:00 AM	Subsystem 2
F	May-23-13	10:00:00 AM	May-24-13	2:38:00 AM	Subsystem 3
F	May-24-13	11:32:00 PM	May-26-13	12:38:00 AM	Subsystem 4
F	Jun-16-13	6:06:00 AM	Jun-17-13	3:48:00 AM	Subsystem 1
F	Jun-18-13	3:11:00 PM	Jun-19-13	12:50:00 PM	Subsystem 4
F	Jun-20-13	10:17:00 AM	Jun-21-13	1:30:00 AM	Subsystem 1
F	Jul-01-[illegible]	[illegible]	[illegible]	[illegible] AM	Subsystem 3
F	Jul-07-[illegible]	[illegible]	[illegible]	[illegible] PM	Subsystem 2

Note: Complete data set is not shown.

Event Log Data Entry: In the event log folio, the "F=Failure/E=Event" column indicates whether the occurrence was a failure event (F) or a general event (E). A general event represents an activity that brings the system down but is not directly relevant to the reliability of the equipment, such as preventive maintenance, routine inspections and the like.

The Level 1, 2, 3 and 4 columns indicate the subsystem or component that was responsible for the event. The level numbers represent the hierarchy of the subsystems, where Level 1 is the highest level in the system configuration at which you might want to perform the analysis.

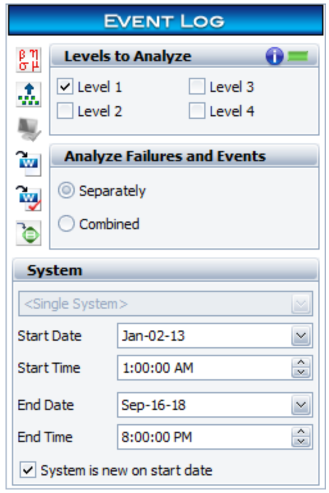
Once data entry is complete, you click the **Main** page button on the control panel and select the following settings:

- In the **Levels to Analyze** area, you select the **Level 1** check box because only one level was recorded in the data set.
- In the **Analyze Failures and Events** area, you select the **Separately** option. This setting tells the software to fit a separate distribution to the E events (if any), instead of combining both types of events together in the same analysis. Because this data set contains only failure events (F), this setting will not affect the analysis results, but it will provide more appropriate labeling for the extracted life data (i.e., will show [F] for failures instead of [C] for combined events).
- In the **System** area, you enter the dates/times when the observation period started and ended. For the start date/time, you enter **January 2, 2013** at **1:00 AM**. For the end date/time, you enter **September 16, 2018** at **8:00 PM**.

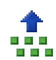
  Because the start date/time is also the exact calendar date that the equipment started operating, you select the **System is new on start date** check box.

System is New on Start Date: The dates/times that you provide in the System area of the control panel are used to determine whether the first event time is recorded as complete or censored data. If the system started operating on the same calendar date as the start date of the observation period (i.e., If the system was new when you started recording data), then the data point is complete (F) because the exact time-to-event is known. If the system was not new, then the data point is censored (S) because you don't know the amount of time that the system operated before the observation period began.

The following picture shows the current settings on the Main page of the control panel.



To specify the shift schedule of the equipment, you click the **Shift Pattern** icon on the control panel.



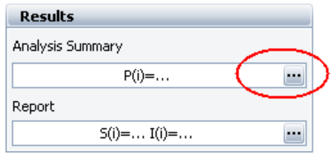
The equipment operates for 24 hours a day, 7 days a week, so you set up the shift schedule as shown next.

Shift Number		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Shift 1	Start Time	12:00:00 AM	12:00:00 AM	12:00:00 AM	12:00:00 AM	12:00:00 AM	12:00:00 AM	12:00:00 AM
	End Time	11:59:59 PM	11:59:59 PM	11:59:59 PM	11:59:59 PM	11:59:59 PM	11:59:59 PM	11:59:59 PM

Shift Schedules: In the case of equipment that does not run on a 24/7 basis, the Shift Pattern feature allows the analysis to take into consideration the periods when your system is not in use. This ensures accurate calculations for the failure and repair times.

Once the settings are finalized, you analyze the data (i.e., convert the logs into failure and repair data, and fit distributions to the data sets) by clicking the **Calculate** icon on the control panel.

After the folio is calculated, you click the **Show Analysis Summary (...)** button on the Main page of the control panel.



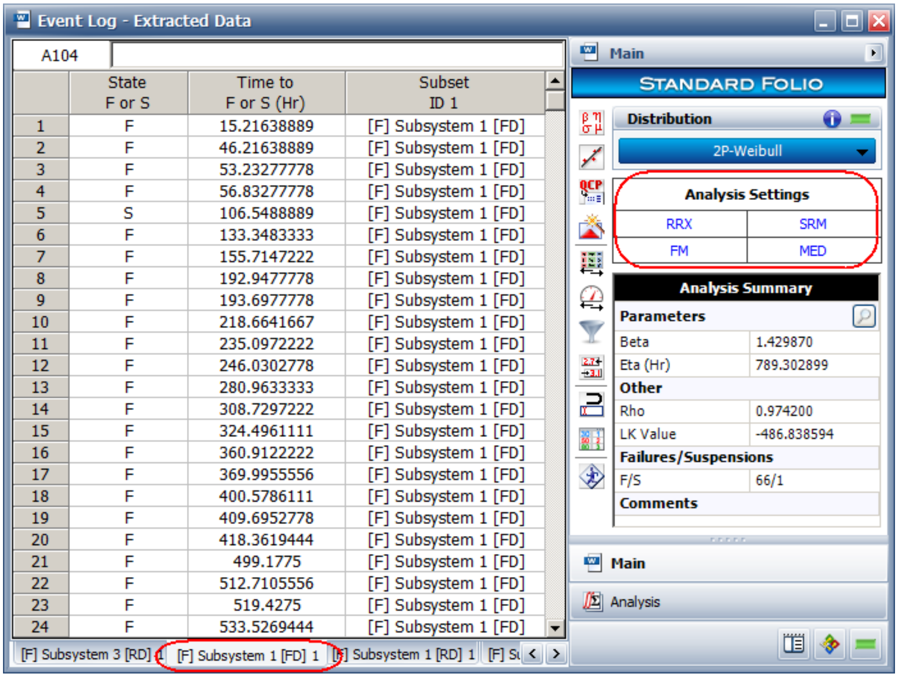
The following report shows the parameters of the failure and repair distributions for each subsystem, as well as the calculated uptime and downtime of each subsystem.

Results							
			Failure Results			Repair Results	
ID	Analysis ID*	Distribution	Parameter 1	Parameter 2	Distribution	Parameter 1	Parameter 2
Subsystem 1	F	Weibull 2-RRX	1.42987	789.302899	Weibull 2-RRX	4.759071	21.06895
Subsystem 2	F	Weibull 2-RRX	1.118264	1204.681946	Weibull 2-RRX	4.181058	20.587052
Subsystem 3	F	Weibull 2-RRX	2.794741	735.393126	Weibull 2-RRX	5.300379	22.820928
Subsystem 4	F	Weibull 2-RRX	4.120462	1004.606124	Weibull 2-RRX	5.694511	21.145348
Subsystem 5	F	Weibull 2-RRX	2.185914	1920.738598	Weibull 2-RRX	4.268986	22.052636
Level	ID	Uptime	Downtime				
1	F-Subsystem 1	45207.3775	1276.133333				
1	F-Subsystem 2	45207.3775	711.516667				
1	F-Subsystem 3	45207.3775	1452.783333				
1	F-Subsystem 4	45207.3775	961				
1	F-Subsystem 5	45207.3775	401.666667				

To compare the probability plots for all subsystems, you transfer the data from the event log folio to a Weibull++ standard folio (*"Event Log - Extracted Data" in the sample project*) by choosing **Event Log > Transfer Life Data > Transfer Life Data to New Folio**.

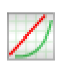
This creates a new folio that contains separate data sheets for the failure and repair data of each subsystem.

You then calculate each data sheet using the 2P-Weibull distribution and the RRX parameter estimation method. The following data sheet shows the analysis of the failure data for subsystem 1.

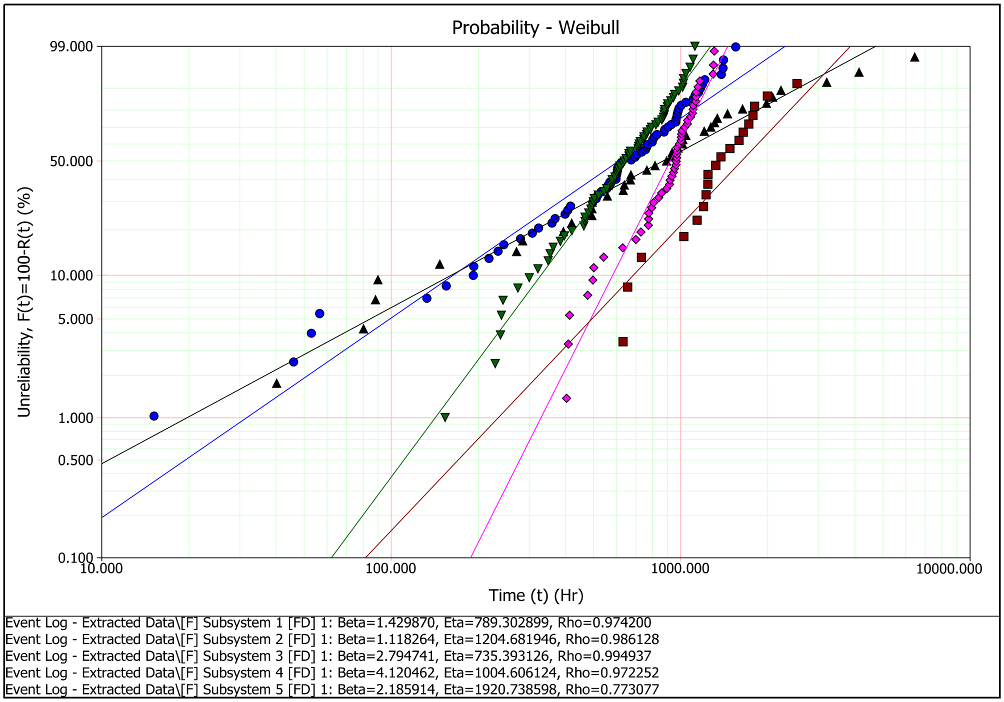


> **Tip:** In the data sheet names, the [F] tag indicates an analysis of the failures, while [E] indicates an analysis of the general events (note that a combined analysis of the F and E events would display [C]). The [FD] tag indicates that the data set is for the failure distribution, while [RD] indicates that the data set is for the repair distribution.

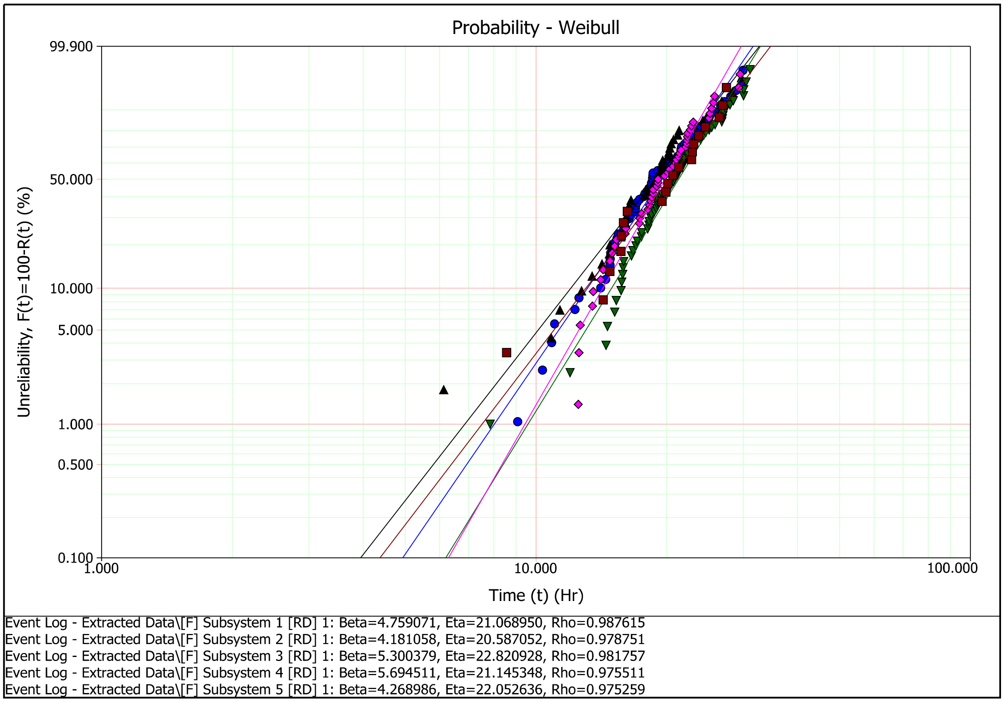
Once all the data sets are calculated, you create an overlay plot (*"Event Log - Failures" in the sample project*) by choosing **Insert > Report and Plots > Overlay Plot**.



When prompted to select which data sets to plot, you select all the data sheets that contain the failure data of the subsystems (i.e., all the data sheets that have the [FD] tag). The following overlay plot shows the failure distributions plotted on the same Weibull probability plot.



You then create a second overlay plot (*“Event Log - Repairs” in the sample project*) that displays all the repair distributions on the same plot (i.e., all the data sheets that have the [RD] tag). The following overlay plot shows the repair distributions plotted on the same Weibull probability plot.



ALTA with One Stress 11

ReliaSoft's ALTA software provides a comprehensive toolset for accelerated life test planning and quantitative accelerated life testing data analysis, plots and reporting. In this chapter, you will use the ALTA standard folio to perform the simplest kind of accelerated life testing data analysis. One accelerated stress will be applied during the test, and you will extrapolate the product's failure behavior at normal conditions from the life data obtained at the accelerated levels.

In this chapter

- ✓ ALTA with one stress type
- ✓ ALTA Quick Calculation Pad (QCP)
- ✓ Overlay plots

After the failure times are fitted to an ALTA model (i.e., a life-stress relationship combined with a lifetime distribution), you will use the model to calculate a variety of reliability metrics (i.e., mean time to failure, B2 life and acceleration factor) and create an overlay plot to compare a product that was tested at the use stress level to a product that was tested at accelerated levels.

11.1 Accelerated Life Testing Data Analysis - One Stress Type

While your company was evaluating bulb A (*see Chapter 2*), the purchasing group found a new supplier that provides a less expensive bulb C. The new supplier claims that the bulb is more reliable, and to support this claim, they have provided data from an accelerated life test using increased temperature. According to the supplier, the tests were done at 40 and 55 degrees Celsius (i.e., 313 and 328 kelvins) and resulted in the failure/suspension times shown in the following table.

State (F=Failed and S=Suspended)	Time (Hr)	Temperature (K)
F	105	313
F	170	313
F	224	313
F	278	313
S	350	313
S	350	313
S	350	313
F	38	328
F	62	328
F	82	328
F	103	328
F	128	328
F	165	328

You are asked to use this data set to compare bulb C to bulb A, assuming a normal operating temperature of 25 degrees Celsius (i.e., 298 K).

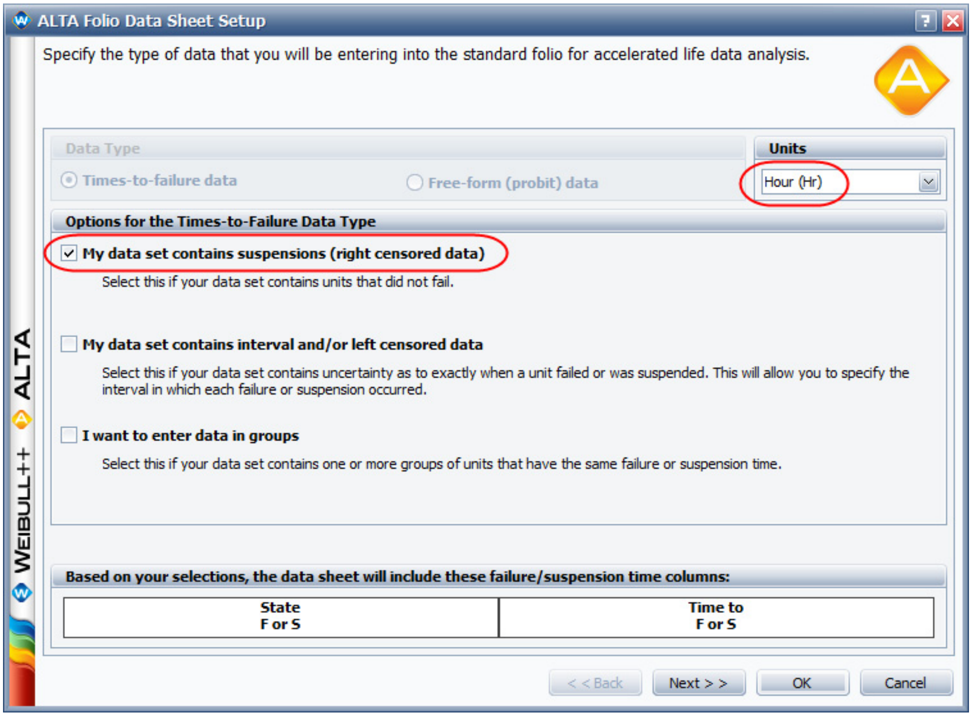
Objectives

- Calculate the mean time to failure and B2 life of the new supplier's bulb.
- Estimate the acceleration factor at 313 K.
- Generate an overlay plot that compares the unreliability vs. time for bulb A and bulb C.

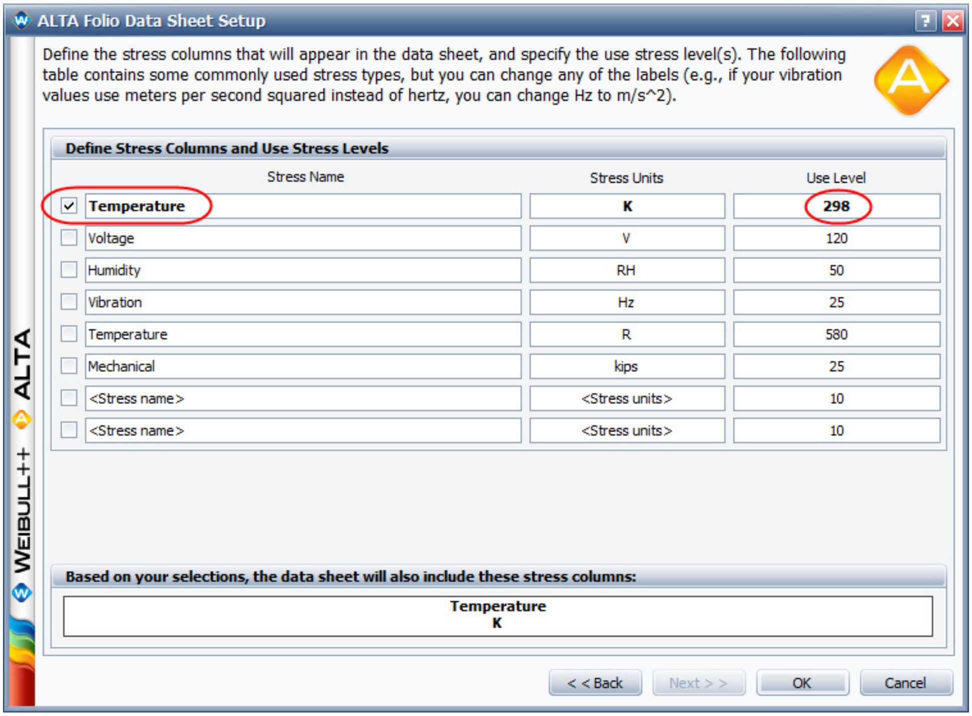
Solution

You create a new ALTA standard folio (*"Bulb C - Supplier Data" in the sample project*) by choosing **Insert > Folios > ALTA Standard Folio**.

When prompted to specify the data type, you select **My data set contains suspensions**. You also use the **Units** drop-down list to indicate that the time values in the data sheet will be entered in hours.

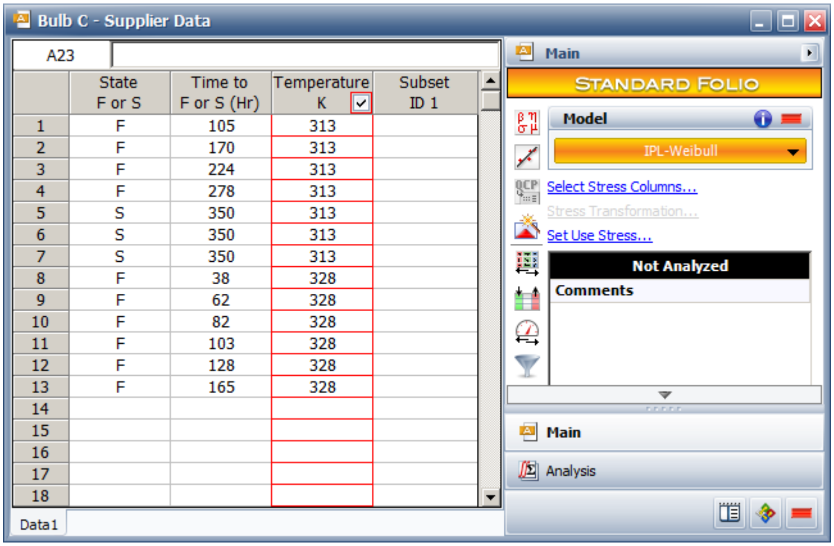


You click **Next**. On the second page of the setup window, you select **Temperature** as the stress type and enter **298** for the use level temperature. The setup is shown next.



After the folio is created, you enter the failure/suspension times and the stress levels at which those times were obtained.

For example, rows 5 through 7 in the data sheet shown next are units that were still operating after 350 hours at a test temperature of 313 K, while row 13 shows the last failure recorded at 165 hours for the units tested at 328 K.



Tip: Temperature values must always be entered in absolute units (e.g., kelvins or degrees Rankine). To convert temperature values in the data sheet that were entered in Celsius or Fahrenheit to absolute units, choose **ALTA > Options > Convert Stress Values**.

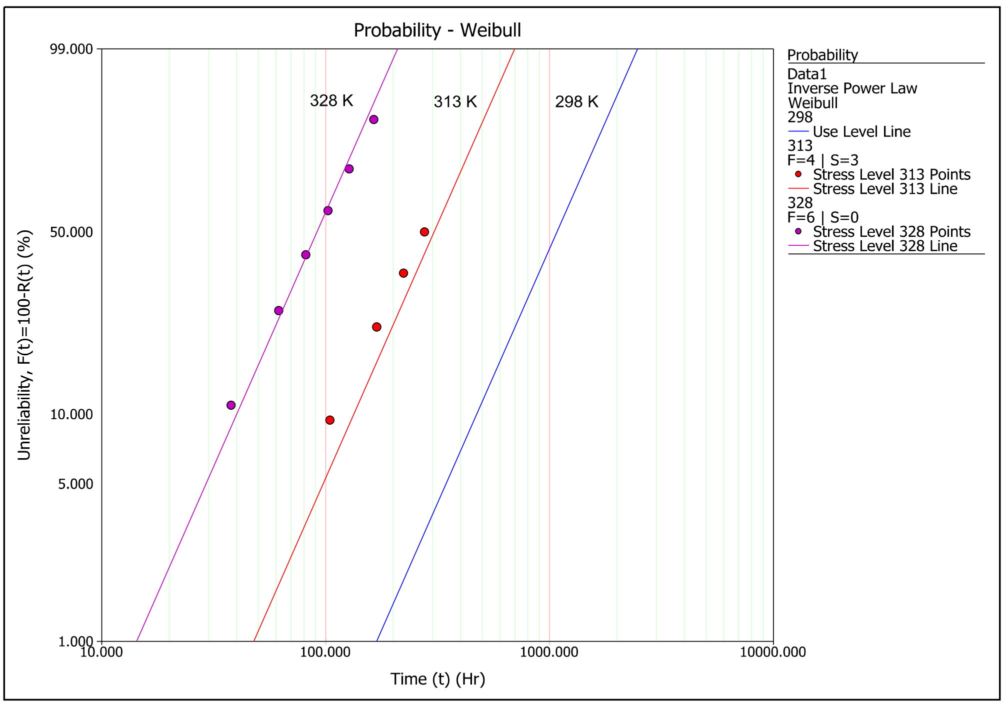
An ALTA model is a combination of a life-stress relationship and life distribution. From the **Model** drop-down list, you select to use the **Inverse Power Law** relationship because the failure mode under consideration is filament burnout. In the submenu that appears, you select **IPL-Weibull** to use the Weibull distribution with the selected relationship.

To fit the selected model to the data, you click the **Calculate** icon on the control panel.

Once the model is fitted, the **Analysis Summary** area of the control panel displays its parameters and other relevant information.

Analysis Summary	
Parameters	
Beta	2.282545
K (Hr)	1.657267E-67
n	25.736616
Scale Parameter (at Use Stress)	
Eta (Hr)	1266.644442
Other	
LK Value	-58.425859
Use Stress	
Temperature	298
Failures/Suspensions	
F/S	10/3
Comments	

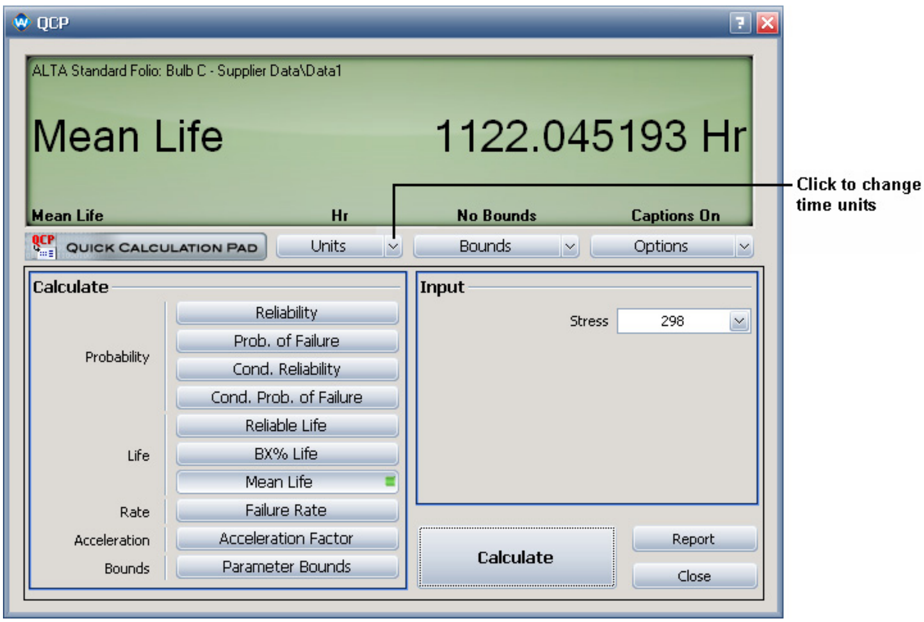
To create a probability plot to visualize the analysis results, you click the **Plot** icon on the control panel. On the control panel of the plot sheet, you choose the **Probability - Weibull** plot, as shown next (with annotations added via RS Draw to make the plot easier to interpret).



The line to the left on this plot shows the unreliability calculated for the data obtained at 328 K. The line in the center shows the unreliability at 313 K, and the line to the right shows the extrapolated unreliability at the specified use stress level (i.e., 298 K).

To calculate the specific results of interest, you open the Quick Calculation Pad (QCP) by clicking the icon on the control panel.

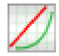
You select to calculate the **Mean Life** and use the **Units** drop-down list to make sure the results will be returned in hours. You also make sure that the correct stress is defined in the **Stress** field.



Bulb C's mean life is approximately 1,122 hours, which is higher than the 906-hour mean life you calculated for bulb A. (*See page 10 in Chapter 2.*) You use the QCP to solve the remaining metrics:

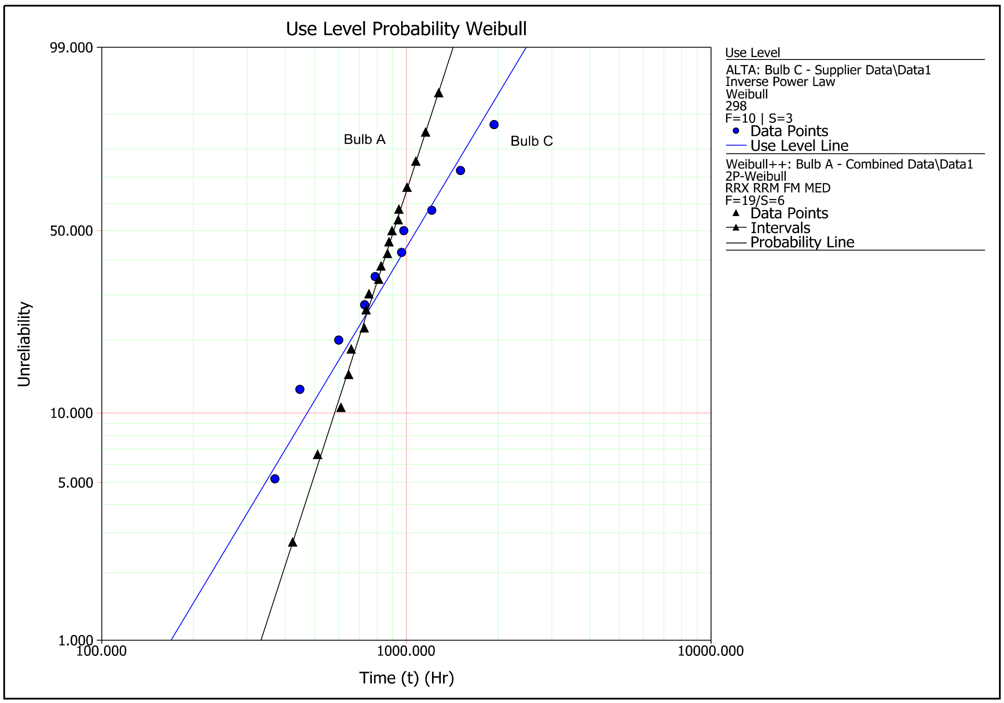
- To estimate the B2 life of bulb C, you select to calculate **BX% Life** and enter **2** for the **BX% Life At** input. The result is approximately 229 hours, which is lower than the 377-hour B2 life of bulb A.
- To estimate the ratio between the life of the bulb at an accelerated stress level to its life at the normal stress level, you select to calculate the **Acceleration Factor**. In the **Stress** field, you enter **298**, while in the **Accelerated Stress** field, you enter **313**. The result is an acceleration factor of 3.539260 or about 3.5. This means that bulb C's life is about 3.5 times longer at the use stress level than it is at a higher stress level of 313 K.

Finally, to compare the unreliability vs. time for bulb A and bulb C, you create an overlay plot (*"Bulb A vs. Bulb C" in the example project*) by choosing **Insert > Reports and Plots > Overlay Plot**.



In the Select Data Sheets window, you select the Weibull++ data sheet with the combined data for bulb A and the ALTA data sheet with the supplier data for bulb C (*"Bulb A - Combined Data" and "Bulb C - Supplier Data" in the sample project*).

In the overlay plot, you switch the plot type to a **Use Level Probability Weibull**, as shown next (with annotations added via RS Draw to make the plot easier to interpret).



As you can see, the slopes of the two lines are different, and they intersect near the middle of the plot. This shows that at earlier times bulb A has a higher reliability than bulb C, but at later times bulb C's reliability is higher.

ALTA with Two Stresses 12

In many practical applications, the life of a product is a function of two or more variables. To support this type of analysis, ALTA PRO includes two-stress models and multivariable models that allow you to analyze multiple accelerating stresses. In this chapter, you will perform a test with two accelerated stresses and use the ALTA standard folio to analyze the resulting data.

In this chapter

- ✓ ALTA with two stress types
- ✓ ALTA QCP and plots

12.1 Accelerated Life Testing Data Analysis - Two Stresses

After analyzing the accelerated life test data provided by the supplier of the new bulb, you begin to investigate further and discover that the primary cause of the bulb failures, which is filament burnout, may be influenced by both temperature and voltage. Therefore, you request permission to perform an in-house accelerated life test for the bulbs, which considers both stress factors.

You are allocated 40 bulbs for testing purposes and have permission to use the lab facilities for a maximum of 400 hours (any failures after 400 hours will be suspended). After studying the design limits of the bulb, you create the following plan:

- 11 bulbs will be tested at 318 K and 120 V
- 10 bulbs will be tested at 318 K and 125 V
- 9 bulb will be tested at 333 K and 120 V
- 10 bulbs will be tested at 333 K and 125 V

You obtain the following data from the test:

Number of Units	State (F - Failure/S - Suspension)	State End Time (Hr)	Temperature (K)	Voltage (V)
1	F	205	318	120
1	F	256		
1	F	259		
1	F	296		
1	F	326		
1	F	352		
1	F	378		
4	S	400		
1	F	103	333	
1	F	130		
1	F	148		
1	F	163		
1	F	176		
1	F	189		
1	F	202		
1	F	216		
1	F	232		
1	F	77	318	125
1	F	97		
1	F	111		
1	F	122		
1	F	132		
1	F	142		
1	F	151		
1	F	162		
1	F	174		
1	F	192		
1	F	33	333	
1	F	42		
1	F	48		
1	F	53		
1	F	57		
1	F	61		
1	F	66		
1	F	70		
1	F	75		
1	F	83		

Objectives

- Calculate the mean time to failure and B2 life of the bulb.
- Estimate the acceleration factor at 318 K and 125 V.
- Generate an overlay plot that compares the use level probability plots of three data sets: combined data on bulb A, supplier data on bulb C and in-house test data on bulb C.

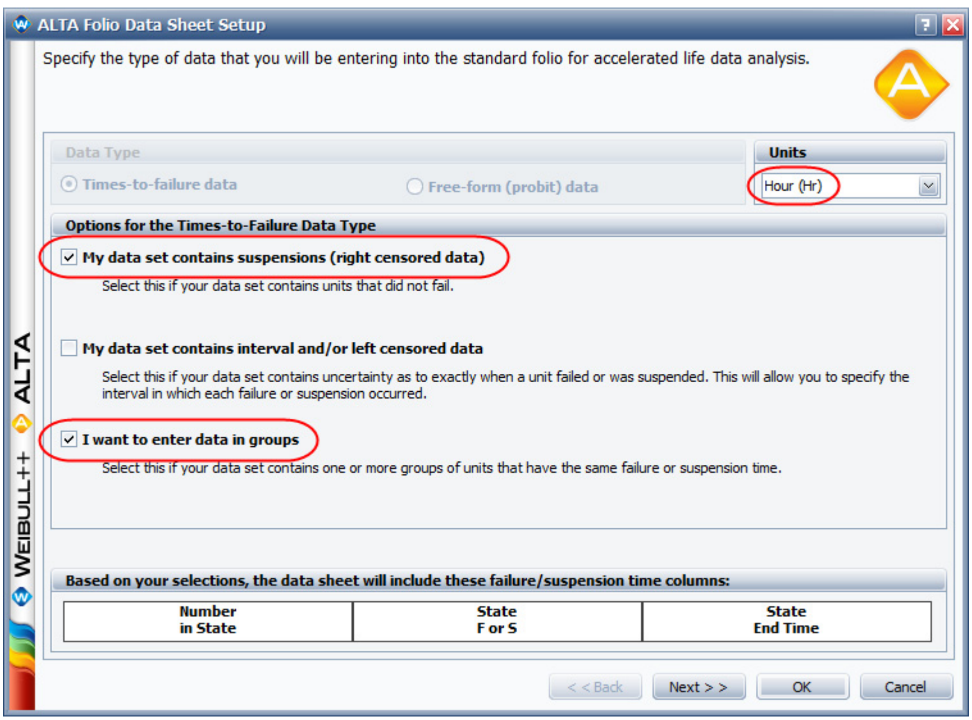
Solution

You start by choosing **Insert > Folios > ALTA Standard Folio** to create a new folio (*"Bulb C - In-House Data" in the sample project*).

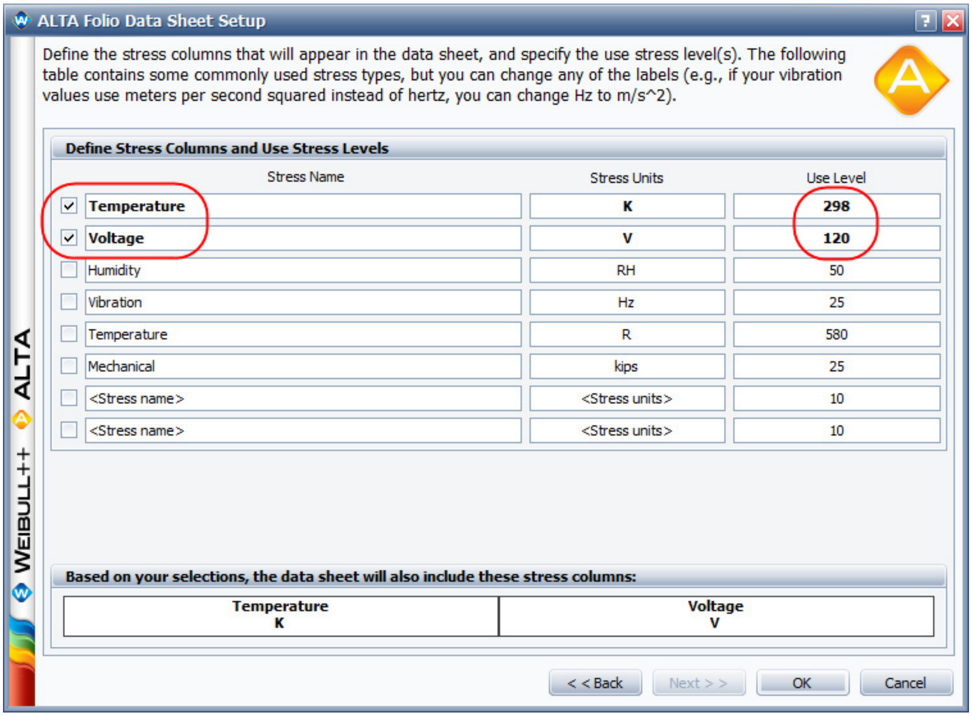
When prompted to specify the data type, you select the following check boxes:

- **My data set contains suspensions (right-censored data)**
- **I want to enter data in groups**

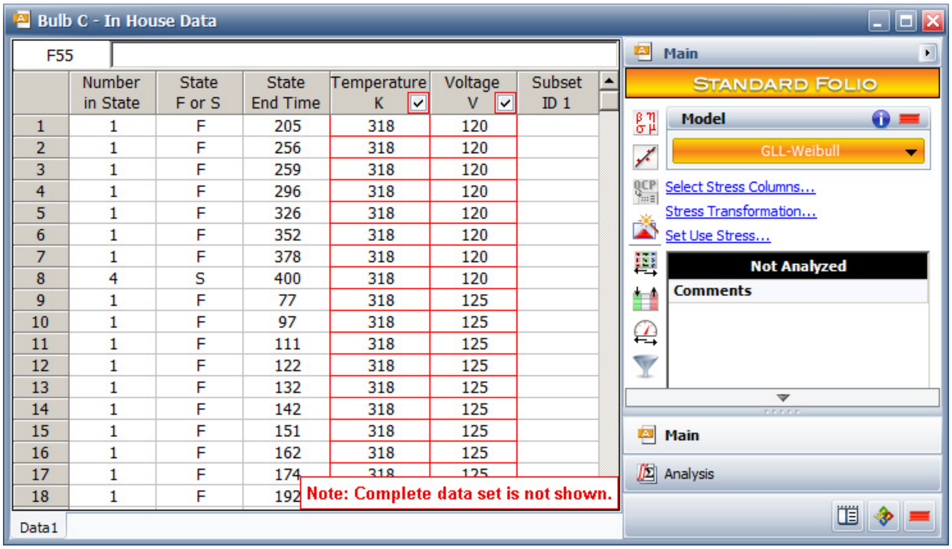
You use the **Units** drop-down list to indicate that the time values in the data sheet will be entered in hours.



You click **Next**. On the second page of the setup window, you select **Temperature** and **Voltage** as the stress types. You enter **298** for the use level temperature and **120** for the use level voltage. The setup is shown next.



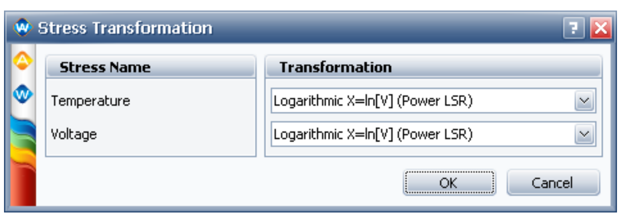
Once the folio is created, you enter the data from the test into the folio data sheet.



The next step is to select the analysis settings. On the control panel, you select the **General Log-Linear** model. In the submenu that appears, you select **GLL-Weibull** to use the Weibull distribution with the selected model.

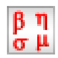
To specify which stress types will be considered in the analysis, you click the **Select Stress Columns** link on the control panel. In the Select Stress Columns window, you select the check boxes for temperature and voltage.

To specify the transformations for the GLL model, you click the **Stress Transformation** link. In the Stress Transformation window, you choose the logarithmic transformation for both temperature and voltage (because the failure mode under consideration is filament burnout).



Stress Transformation: The general log-linear (GLL) model is a multivariable relationship model that supports cases where more than two accelerated stresses need to be simultaneously analyzed. In ALTA, the GLL model can analyze life as a function of up to 8 stress types and, if desired, the relationship may be modified through the use of stress transformations. You have the option to choose one transformation for each stress type that is selected to be used in the analysis. This allows you to modify the GLL model in terms of a life-stress relationship that is appropriate for the stress type.

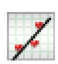
To fit the selected model to the data, you click the **Calculate** icon on the control panel.



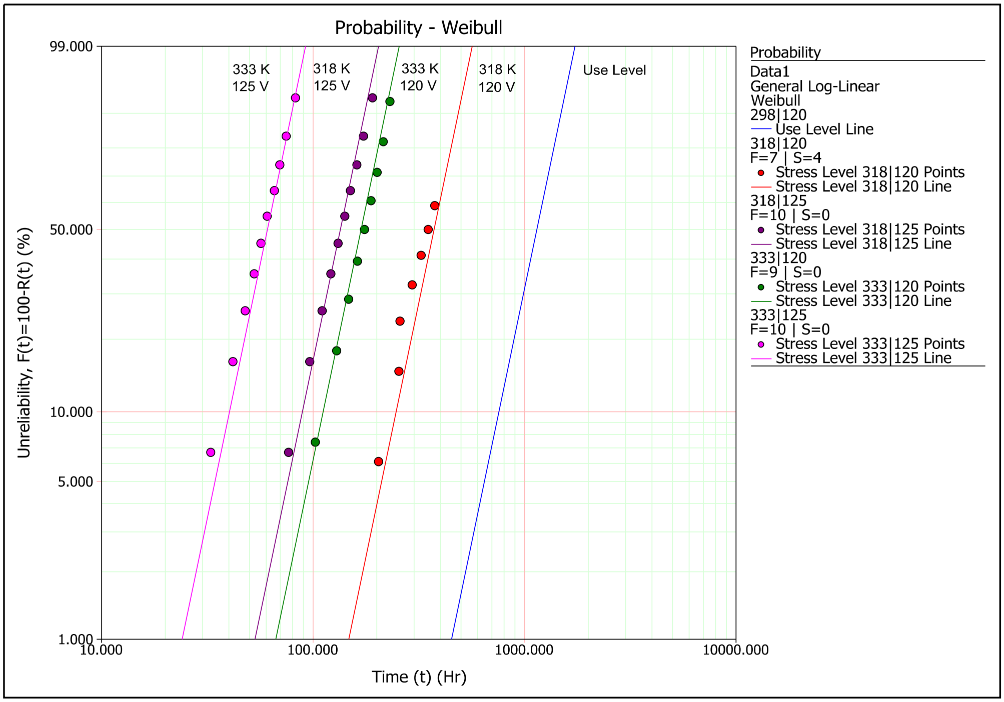
Once the model is fitted, the **Analysis Summary** area of the control panel displays its parameters and other relevant information.

Analysis Summary	
Parameters	
Beta	4.557880
Alpha	
Alpha(0) (Hr)	224.908261
Alpha(1)	-17.239771
Alpha(2)	-24.975493
Scale Parameter (at Use Stress)	
Eta (Hr)	1238.567948
Other	
LK Value	-181.701772
Use Stress	
Temperature	298
Voltage	120
Failures/Suspensions	
F/S	36/4
Comments	

To create a probability plot to visualize the analysis results, you click the **Plot** icon on the control panel.

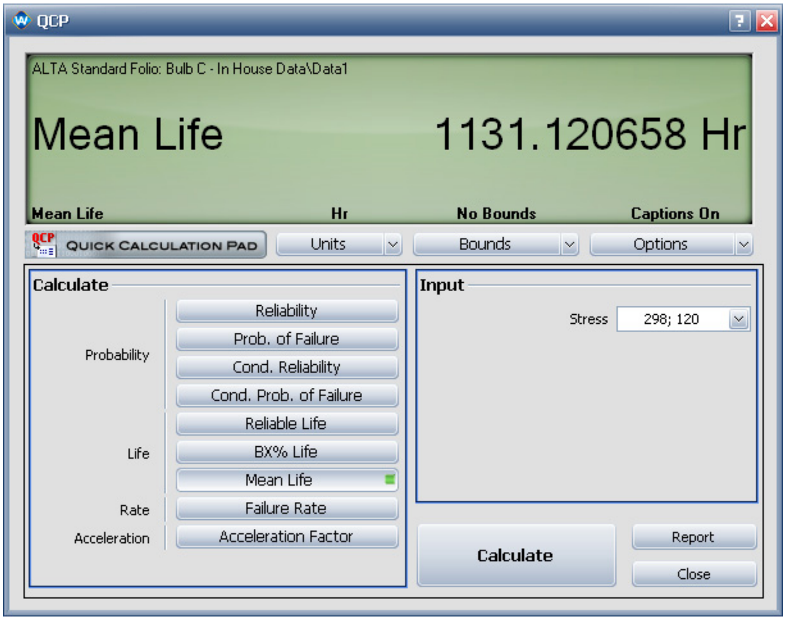


On the control panel of the plot sheet, you choose the **Probability-Weibull** plot. The resulting plot shows the lines for the accelerated stress levels and the line for the use stress level. The lines are parallel, indicating a common beta, as shown next (with annotations added via RS Draw to make the plot easier to interpret).



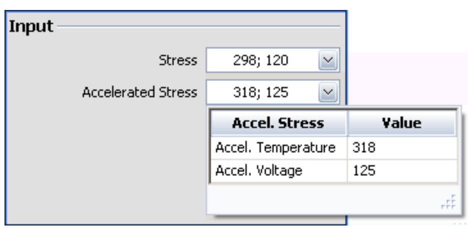
To solve for the requested reliability metrics, you open the Quick Calculation Pad by clicking the **QCP** icon on the control panel.

You select to calculate the **Mean Life** and use the **Units** drop-down list to make sure the results will be returned in hours. The mean life of the bulb is estimated to be 1,131 hours.

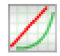


You use the QCP to solve the remaining metrics:

- To estimate the B2 life, you select to calculate the **BX% Life** and enter **2** for the **BX% Life At** input. The result is about 526 hours.
- To estimate the ratio between the life of the bulb at accelerated stress levels to its life at the normal stress level, you select to calculate the **Acceleration Factor**. In the **Accelerated Stress** field, you enter **318** for the temperature and **125** for the voltage. The result is a ratio of about 8.494413.



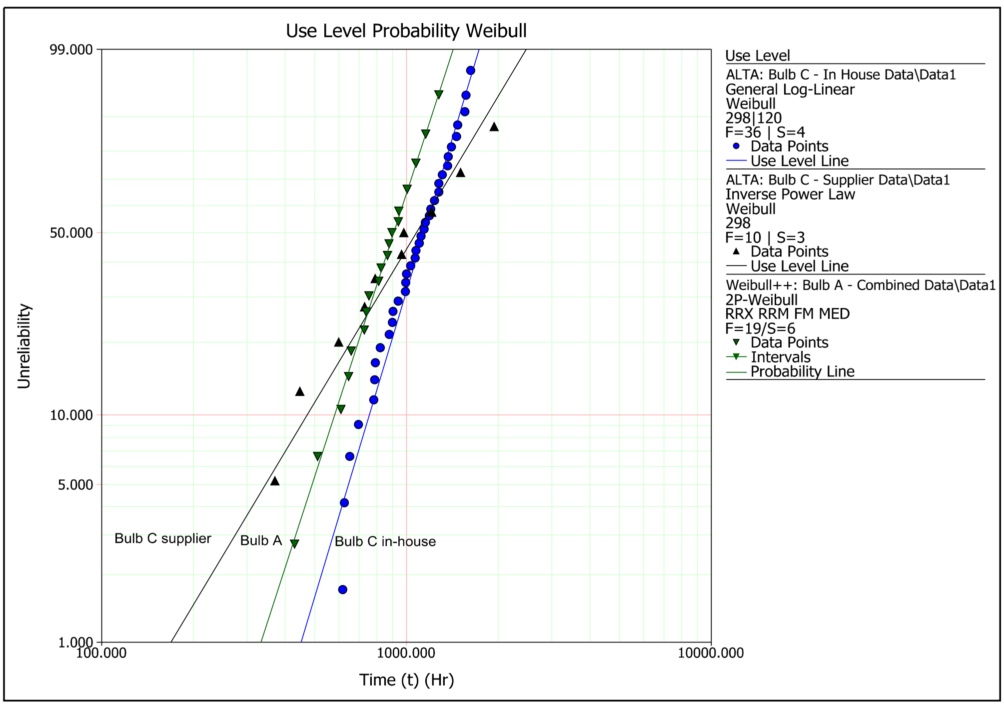
Next, you compare the current analysis to two other analyses. You create an overlay plot (*"Bulb A vs. Bulb C (In-House and Supplier)" in the sample project*) by choosing **Insert > Reports and Plots > Overlay Plot**.



When prompted to select which data sets to plot, you choose the following:

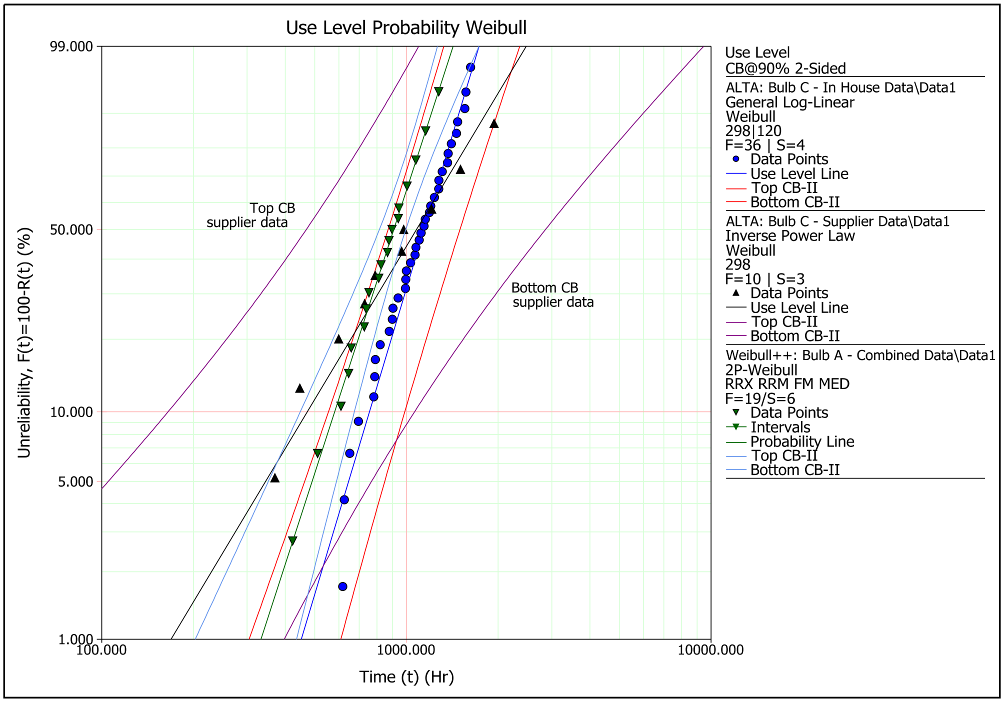
- The ALTA folio data sheet containing the data set for bulb C from the in-house test. (*"Bulb C - In-House Data" in the sample project.*)
- The ALTA folio data sheet containing the data set for bulb C from the supplier. (*"Bulb C - Supplier Data" in the sample project.*)
- The Weibull++ folio data sheet containing the combined data set for bulb A. (*"Bulb A - Combined Data" in the sample project.*)

The following overlay plot shows the analyses plotted on the same **Use Level Probability Weibull** plot (with annotations added via RS Draw to make the plot easier to interpret).



As you can see, the lines for bulb C based on the in-house test and bulb A are parallel, while the line for bulb C based on the supplier's data has a different slope.

To show the confidence bounds, you right-click the plot sheet and select **Confidence Bounds**. You then select **Two-Sided** bounds and enter **90** for the confidence level. The result shows that the bounds on the supplier's analysis are much wider compared to the bounds on the in-house analysis.



This indicates that the results of the in-house analysis may provide more precise estimates, allowing you to perform a better assessment of bulb C's reliability against bulb A.

ALTA with Time-Dependent Stress Profiles 13

With ALTA PRO, you can analyze data obtained from products whose stress levels vary with time. The software allows you to define *stress profiles* that describe how stress levels increase/decrease with time. When you select to use the Cumulative Damage (CD) life-stress relationship, which takes into account the cumulative effect of the applied stresses, the profiles you've defined become available for use in your analysis. In this chapter, you will perform accelerated life testing data analysis on a product with time-dependent use stress conditions.

In this chapter

- ✓ ALTA with time-dependent stress types
- ✓ Stress profiles

13.1 Time-Dependent Stress

Thus far, your analysis of the accelerated life test data for the new bulb C has assumed a constant stress level under normal use conditions. (*See Chapter 11 and Chapter 12*.) You later learn from the design team that the actual usage conditions are more likely to vary with time. You record the actual operating conditions of the bulb for a period of 72 hours. Specifically, you notice the following patterns:

- The temperature alternates between 290 K and 305 K every 12 hours.
- The voltage switches between 119 V and 123 V in the following pattern:

Operating Hours	Voltage
0 to 10th hour	119 V
10th to 12th hour	123 V
12th to 22nd hour	119 V
22nd to 25th hour	123 V
At 25th hour until end of observation period	123 V

Objectives

- Calculate the mean time to failure and B2 life of the bulb, when the analysis considers the time-dependent use stress conditions.
- Use the B2 life of the bulb to estimate the acceleration factor at 318 K and 125 V.
- Generate an overlay plot that compares the new analysis (time-dependent use stress levels) versus the previous analysis (constant stress levels).

Solution

The first step is to create stress profiles in ALTA that reflect the time-dependent operating conditions that the bulb will experience.

Stress Profiles: A stress profile describes how stress levels vary with time. It consists of a series of time segments, each with a specified constant or time-dependent stress level. Stress profiles are used with the cumulative damage life-stress model to perform an analysis that takes into account time-dependent stress levels under testing and/or during normal use.

You create a stress profile (*"Use Temperature" in the sample project*) by choosing **Insert > Tools > ALTA Stress Profile**.

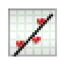
Once the profile is created, you change its default name to "Use Temperature" by right-clicking the new profile in the current project explorer and choosing **Rename** on the shortcut menu. This will make the profile easier to recognize when you need to select it within the analysis.

In the data sheet of the stress profile folio, the start time for the first segment is always set to zero. The start times for subsequent segments are calculated automatically by the software. Thus, you will enter only the segment end times and corresponding temperature values. After entering the data, you select the **Repeat cycle** option on the control panel. This tells the software to treat the entire pattern of segments as a repeating cycle.

The following picture shows the completed setup.

To save your changes and validate the profile, you click the **Validate Stress Profile** icon on the control panel.

To generate a plot that shows the pattern of the segments, you click the **Plot** icon on the control panel.

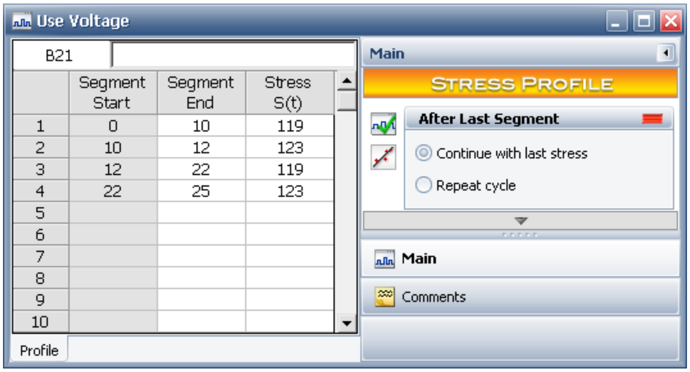


The following plot shows the stress profile for temperature (with the scaling adjusted to Y = 0 to 400 and X = 0 to 100). It illustrates how the normal usage temperature varies with time.

Next, you create a second stress profile for voltage (*"Use Voltage" in the sample project*) and rename it to "Use Voltage."

In the data sheet of the new stress profile, you enter the segment end times and corresponding voltage values. After entering the data, you select the **Continue with last stress** option on the control panel. This tells the software that all the times after the last segment will use the stress value defined in the last segment. In other words, once the projector reaches 123 V for the second time, it stays at that value for as long as the projector continues to operate.

The completed setup is shown next.



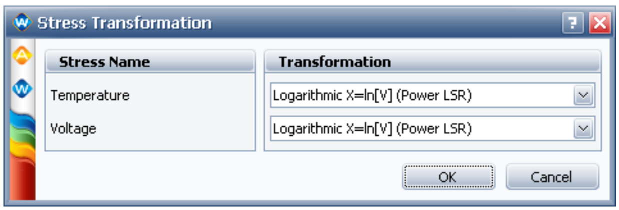
As before, you click the **Validate Stress Profile** icon on the control panel to validate the data sheet entries and save your changes.

You also generate a plot to show how the normal usage voltage varies with time, as shown next (with the scaling adjusted to Y = 0 to 150 and X = 0 to 30).

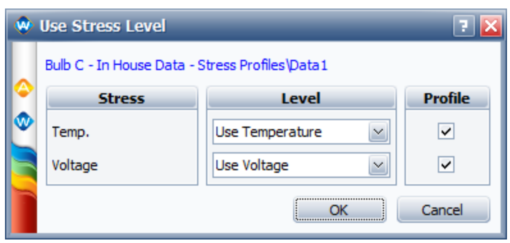
Next, you duplicate the folio that contains the in-house data for Bulb C (*“Bulb C - In House Data” in the sample project*). You do this by right-clicking the folio in the current project explorer and choosing **Duplicate** on the shortcut menu. Once the duplicate folio is created, you rename it to distinguish it from the original folio (*“Bulb C - In House Data - Stress Profiles” in the sample project*).

For this analysis, you change the ALTA model to the cumulative damage model in order to use the time-dependent stress profiles to analyze the data. On the control panel, you choose **Cumulative Damage > CD-Weibull**. You then click the **Select Stress Columns** link and make sure that the check boxes for temperature and voltage are still selected.

As with the general log-linear model in ALTA, the cumulative damage model allows you to define the transformation that will be used for each stress type. You click the **Stress Transformation** link and make sure that the transformations are still set to logarithmic for both stress types (because the failure mode under consideration is filament burnout).



To change the constant values that were defined in the previous analysis to the time-dependent stress profiles, you click the **Set Use Stress** link. In the Level window, you select the **Profile** check box next to each stress and choose the corresponding stress profile from each drop-down list.

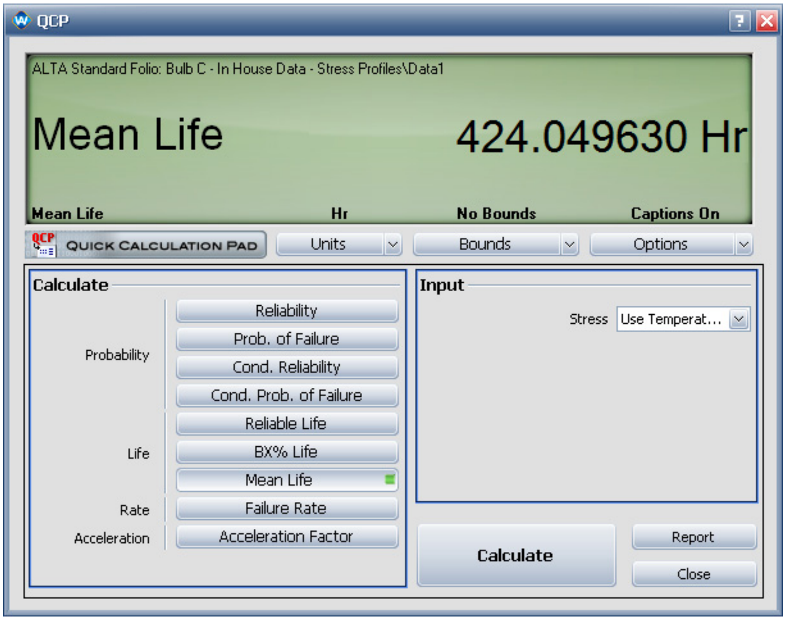


You click the **Calculate** icon on the control panel to analyze the data.

To solve for the requested reliability metrics, you open the Quick Calculation Pad by clicking the **QCP** icon on the control panel.

You select to calculate the **Mean Life** and use the **Units** drop-down list to make sure the results will be returned in hours. In the **Stress** field, you make sure that the use stress is obtained from the stress profiles.

The mean life of the bulb is then estimated to be 424 hours.

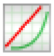


You continue using the QCP to solve the remaining metrics:

- To estimate the B2 life, you select to calculate the **BX% Life**. In the **Stress** field, you select the **Profile** check box next to each stress and select the corresponding stress profile from each drop-down list. Next, you enter **2** for the **BX% Life At** input. The result is about 205 hours.
- You select to calculate the **Acceleration Factor**.
  - In the **Stress** field, you make sure that the **Profile** check box next to each stress is selected.
  - In the **Accelerated Stress** field, you clear the **Profile** check boxes because the accelerated stress values are constant. You then enter **318** for the temperature and **125** for the voltage.
  - In the **Mission End Time** field, you enter **205**.

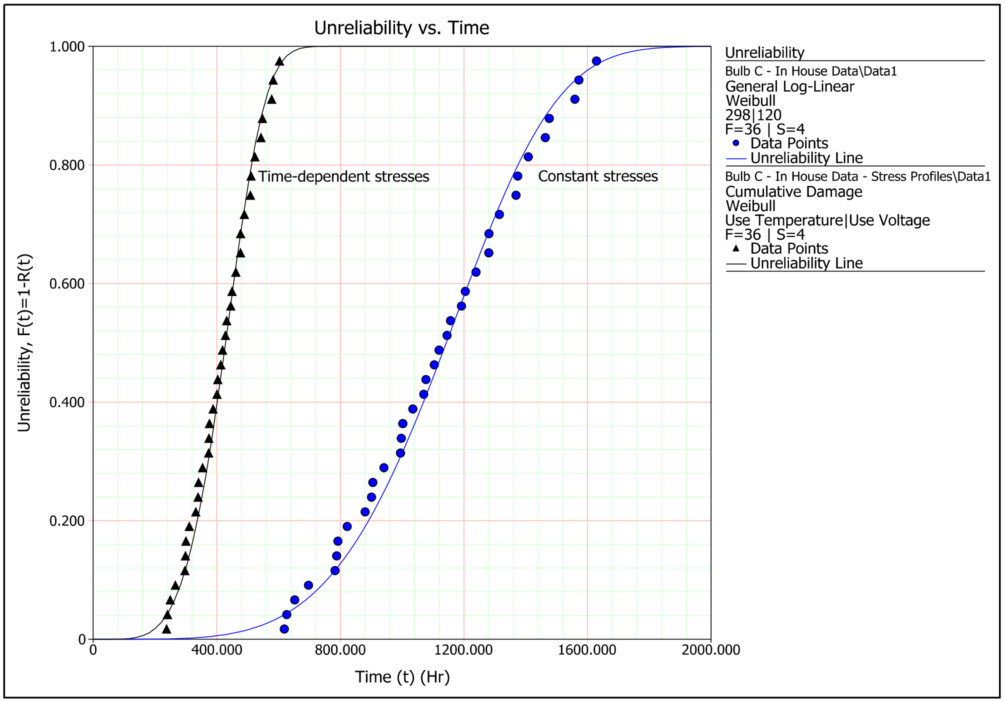
  The result is a ratio of 7.328811. This means that bulb C's life is about 7.33 times longer at the use stress level than it is at higher stress levels of 318 K and 125 V.

Next, you compare the new analysis with the previous analysis. You create an overlay plot (*"Time-Dependent Stress vs. Constant Stress" in the sample project*) by choosing **Insert > Reports and Plots > Overlay Plot**.



When prompted to select which data sets to plot, you choose the data sheet with the time-dependent stresses and the data sheet with the constant stresses (*"Bulb C - In House Data - Stress Profiles" and "Bulb C - In House Data" in the sample project*).

On the control panel of the plot sheet, you select the **Unreliability vs. Time** plot. The following overlay plot shows the result of the assumption of a constant stress against time-dependent stress (with annotations added via RS Draw to make the plot easier to interpret).



If the usage conditions of the bulb vary with time, then the assumption of a constant stress over-estimates the life of the bulb. In this case, the analysis with the time-dependent stress profiles provides a more accurate model of the operating conditions of the bulb and, therefore, more precise estimates.

Accelerated Degradation Analysis 14

In Chapter 3, we illustrated how degradation analysis can reduce the time required to obtain a product's life data. To reduce testing time even further, the degradation can be measured at accelerated stress levels. This type of approach is known as *accelerated degradation analysis*. In this chapter, you will work with degradation measurements obtained at accelerated stress levels and use the ALTA degradation folio to estimate the product's life characteristics under normal stress conditions.

In this chapter

- ✓ ALTA Degradation folios
- ✓ Overlay plots

14.1 Accelerated Degradation Analysis

The LED lamp designers that you worked with before (*Chapter 3*) want to perform another test to capture data about the degradation in the light output over time. But this time, instead of 2 months, they can reserve the lab for only 2 weeks (336 hours) so they decide to use an accelerated test. For reference, they give you the following information:

- The normal stress level of the lamp is 120 volts, but higher voltage levels are known to accelerate the progression of the same failure modes that occur under normal use conditions.
- The degradation of the lamp is measured in terms of how the light output decreases over time.
- The lamp is considered failed when its light output reaches 50% of its design output of 1,000 lumens.

The plan is to test 10 lamps at 128 volts and another 10 at 138 volts. The highest voltage level is expected to accelerate the degradation in the light output without introducing "foolish failures" (i.e., failures that would never occur under normal use conditions). The light intensity of the lamps will be recorded at 100, 150, 200 and 250 hours.

You obtain the following measurements from the test.

Luminosity Measurements at 128 Volts

Inspection Time (Hr)	Lamp 01	Lamp 02	Lamp 03	Lamp 04	Lamp 05	Lamp 06	Lamp 07	Lamp 08	Lamp 09	Lamp 10
100	979	969	1010	857	898	816	949	887	887	928
150	908	918	908	745	775	785	908	826	816	867
200	867	877	847	683	724	745	857	775	745	816
250	826	836	796	627	683	714	836	745	704	785

Luminosity Measurements at 138 Volts

Inspection Time (Hr)	Lamp 11	Lamp 12	Lamp 13	Lamp 14	Lamp 15	Lamp 16	Lamp 17	Lamp 18	Lamp 19	Lamp 20
100	768	760	792	672	704	640	744	696	696	728
150	712	720	712	584	608	616	712	648	640	680
200	680	688	664	536	568	584	672	608	584	640
250	648	656	624	492	536	560	656	584	552	616

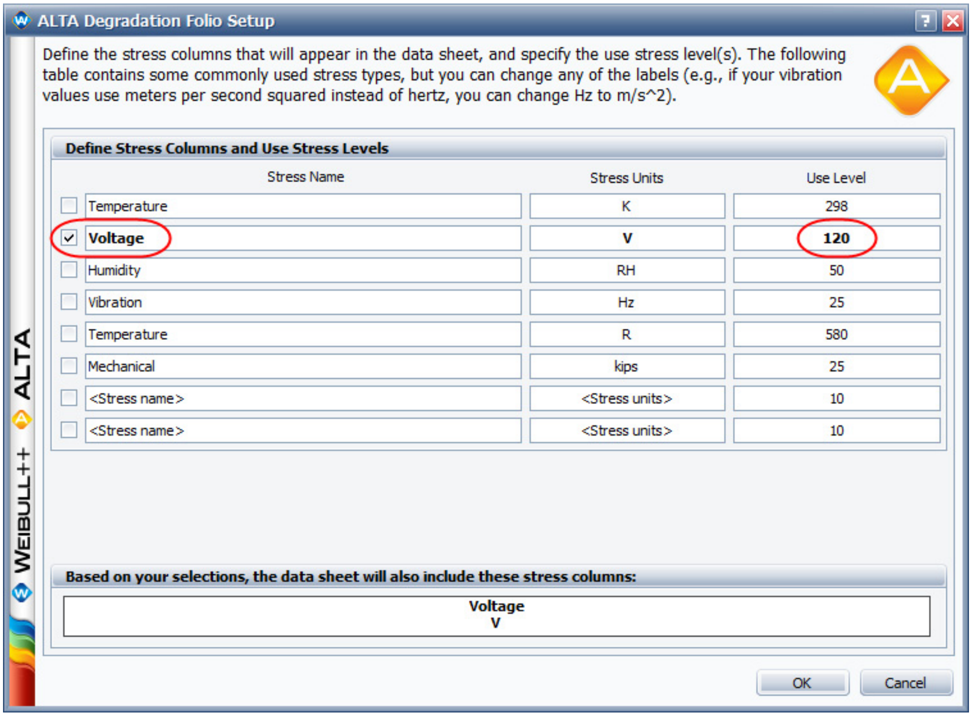
Objectives

- Use a Degradation vs. Time plot to see how the luminosity of the lamps degrades over time.
- Generate an overlay plot that compares the probability plots for the accelerated degradation analysis and the standard degradation analysis in Chapter 3.

Solution

You create an ALTA degradation folio (*"Accelerated Degradation - LED Lamp" in the sample project*) by choosing **Insert > Folios > ALTA Degradation**.

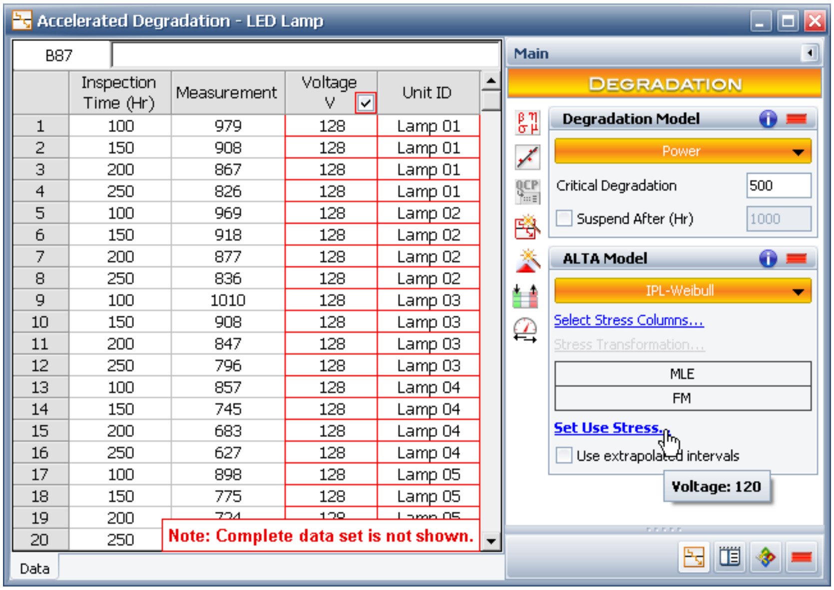
When prompted to define the stress, you select **Voltage** and then enter **120** for the use stress level.



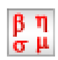
Once the folio is created, you enter the degradation measurements into the folio's data sheet.

The next step is to specify how the failure times will be extrapolated from the luminosity measurements. Based on your engineering knowledge, you select **Power** from the drop-down list in the **Degradation Model** area. For the lamp's **Critical Degradation** (i.e., the luminosity level at which a lamp is considered failed), you enter **500** lumens.

Next, you need to specify how the extrapolated failure times will be analyzed. In the **ALTA Model** area, you choose **Inverse Power Law > IPL-Weibull**. The following picture shows the completed setup.

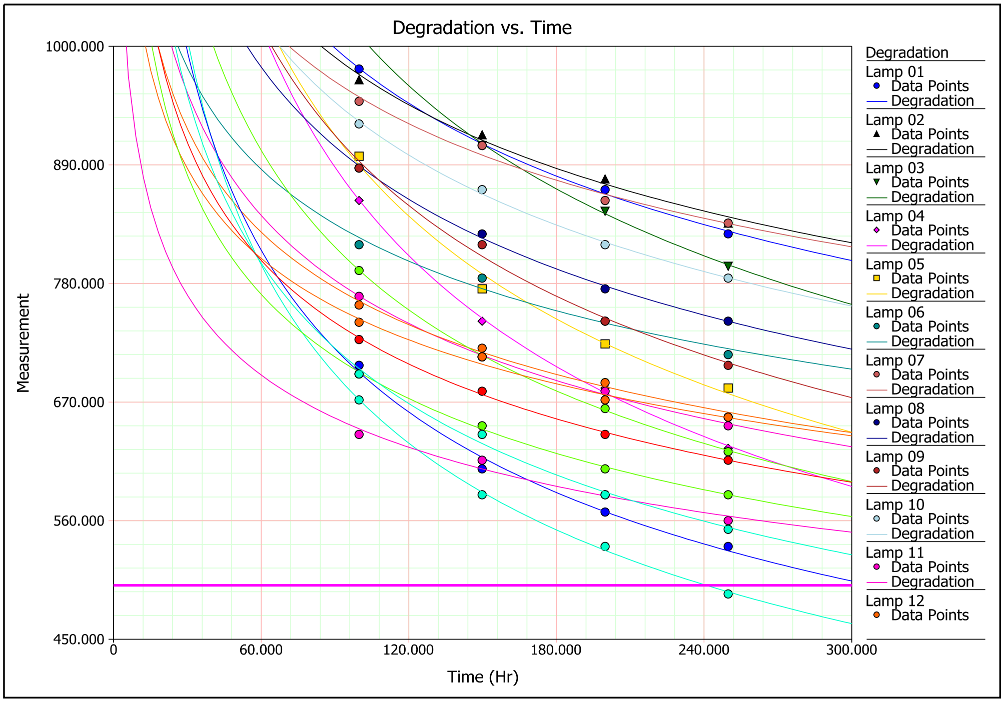


To analyze the data set, you click the **Calculate** icon.

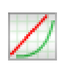


The software will first extrapolate the times at which the degradation measurements will reach the point of critical degradation at the accelerated levels, and then it will perform a separate accelerated life testing data analysis on the extrapolated data.

To view a plot that shows how the luminosity for each unit in the sample degrades over time, you click the **Plot** icon on the control panel and select the **Degradation vs. Time (Linear)** plot. The resulting plot is shown next (with the scaling adjusted to Y = 450 to 1,000 lumens). The horizontal line near the bottom of the plot marks the luminosity level at which the lamp is considered failed.

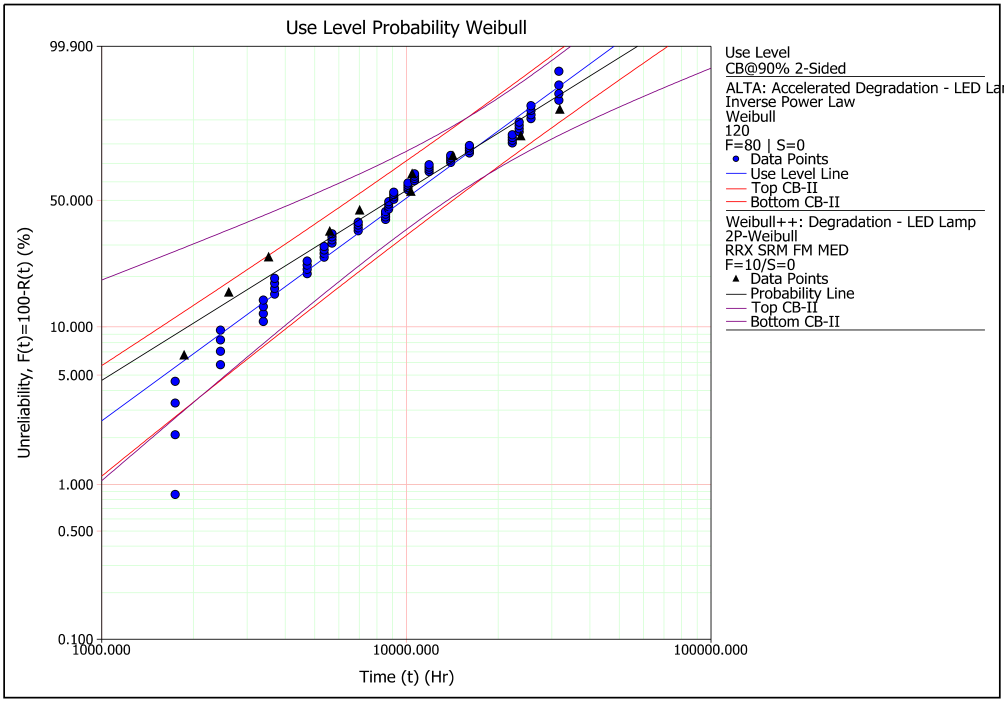


You know that in accelerated life testing data analysis, the farther the accelerated stress level is from the normal stress level, the greater the uncertainty in the extrapolation. To compare the results obtained from the accelerated degradation test to the results obtained from the standard degradation test, you generate an overlay plot (*"Degradation Analysis Comparison" in the sample project*) by choosing **Insert > Reports and Plots > Overlay Plot**.



When prompted to select which data sets to plot, you select the data sheet containing the ALTA degradation analysis and the data sheet containing the Weibull++ degradation analysis (*"Accelerated Degradation - LED Lamp" and "Degradation - LED Lamp" in the sample project*).

On the control panel of the plot sheet, you switch the plot type to a **Use Level Probability Weibull** plot. The following overlay plot shows the results of the two analyses on the same plot (with 90% two-sided confidence bounds on reliability).



The overlay plot shows that the probability lines have similar slopes; however, the bounds on the accelerated degradation analysis are much wider compared to the bounds on the standard degradation analysis. Nevertheless, you were able to obtain reasonable results within the allotted test time.

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12.7 This License Agreement is personal to you and you may not assign, transfer, sub-contract or otherwise part with this License or any right or obligation under it without the Licensor's prior written consent.