ReliaSoft's
Weibull++ 7

All the tools you will ever need
for Life Data Analysis,
and more...

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1 Weibull++ 7 Training Guide

1.1 About this Training Guide

This training guide is intended to provide you with many examples to demonstrate the use of the Weibull++ 7 software. It begins with step-by-step examples and then proceeds into more advanced examples. At any time during the training, please feel free to ask the instructor(s) any questions you might have.

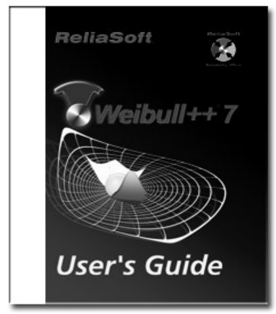
NOTE: If you have a demonstration version of Weibull++, you may not be able to create new project files and enter your own data to perform the examples in this training guide. Therefore, sample files required to perform these examples are provided in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide). The name of the applicable file is provided at the beginning of each example in this training guide.

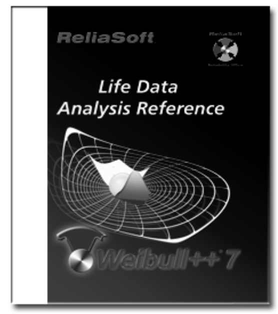
1.2 Other Example Files

In addition to the examples described in this training guide, ReliaSoft provides a large array of example files to demonstrate various types of analyses and product features. These files are located in the "Examples" folder in your application directory (*e.g.* C:\Program Files\ReliaSoft\Weibull7\Examples). The Examples folder is also accessible by clicking the **Open Examples Folder...** link in the What do you want to do? window or by selecting **Open Examples Folder...** from the **Help** menu.

1.3 Weibull++ 7 Documentation

Like all of ReliaSoft's standard software products, Weibull++ 7 is shipped with detailed printed documentation on the product (*Weibull++ 7 User's Guide*) and the underlying principles and theory (*ReliaSoft's Life Data Analysis Reference*). This training guide is intended to be a supplement to those references.





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2 Features Summary

The examples included in this training guide have been designed to introduce you to the features available in Weibull++ Version 7. This section presents a brief summary of these features. If you are already familiar with Weibull++'s features, you can proceed to the examples.

2.1 Intuitive and Flexible Work Environment

The Weibull++ interface is an intuitive, flexible and completely integrated work center designed around the Data Folio (similar to an Excel® worksheet). In Version 7, the interface has been enhanced to allow you to manage multiple analysis folios and related information all together in a single file. Using the "Project Explorer" approach that was first introduced in ReliaSoft's BlockSim software, Weibull++ now provides an intuitive, hierarchical (tree) structure to allow you to view and manage one or many standard folios, specialized folios, plot sheets, reliability block diagrams, spreadsheet reports and/or attached documents per project. At the same time, the new work environment "stays true to its roots" so that users who are familiar with previous versions of the software will be able to enter and analyze data in much the same way as always.

2.2 All the Tools You Need for Standard Life Data Analysis

Weibull++ provides all of the tools that you need for standard life data analysis (Weibull analysis), including flexible options for data type, lifetime distribution and parameter estimation methods.

2.2.1 Support for All Life Data Types and Multiple Lifetime Distributions

Weibull++'s data entry spreadsheets for standard life data analysis support all life data types and all major lifetime distributions. You can analyze time-to-failure (complete), right censored (suspension), left censored, interval censored or free-form data, entered individually or in groups. Available distributions include the 1, 2 and 3 parameter Weibull; 2, 3 and 4 subpopulation Mixed Weibull; 1 and 2 parameter Exponential; Normal; Lognormal and Generalized Gamma. In addition, Version 7 now supports the Gamma, Logistic, Loglogistic, Gumbel and Weibull-Bayesian distributions. With the incorporation of the Weibull-Bayesian model, which considers prior knowledge of the Weibull Beta parameter, Weibull++ now supports methodologies from both Classical and Bayesian statistics.

The Distribution Wizard automatically performs multiple goodness-of-fit tests on the available lifetime distributions and recommends the one that best fits your data set. You can use Monte Carlo simulation to generate sample data sets based on any of the supported lifetime distributions or a user-defined function. This can include complete data, right censored, interval censored and/or left censored data points, according to your specifications.

2.2.2 Choice of Parameter Estimation Methods

Weibull++ allows you to choose the parameter estimation method that is most appropriate for your data set. Options include Maximum Likelihood Estimation (MLE), Rank Regression on X or Rank Regression on Y with Median Ranks, Kaplan-Meier or ReliaSoft ranking methods.

2.3 Results and Plots at the Click of a Button

Always a strength of Weibull++, Versions 7 continues to make it easy to calculate and present your analysis results in ways that effectively support decision-making.

2.3.1 Quick Calculation Pad

The Quick Calculation Pad (QCP) provides a quick, easy and accurate way for you to obtain results for the most frequently asked reliability questions. This includes Reliability or Probability of Failure, Failure Rate, Warranty Time for a given reliability, B(X) Life and Mean Life calculations. The utility also returns the conditional reliability or probability of failure given the starting age.

2.3.2 Plots and Graphics to Showcase Your Analyses

Weibull++ continues to offer unparalleled plotting capabilities to demonstrate your analyses visually. You can generate Probability, Reliability vs. Time, Unreliability vs. Time, *pdf*, Failure Rate vs. Time, Contour and 3-dimensional Likelihood Function Surface plots with the click of a button. In addition, Version 7 now includes histogram, pie and timeline charts to display failures/suspensions data. The Plot Setup allows you to configure the appearance of plot output and the software also provides a Chart Wizard to create your own custom charts. All plot graphics are metafiles that can be pasted or inserted into other reports and presentations.

The Multiple Plot Sheet makes it easy to compare analyses by automatically plotting the results for multiple data sets together in the same plot. The Side-by-Side Plots utility allows you to view (and print) multiple plots for a given data set side-by-side. For example, you may want to show the Probability, Reliability, *pdf* and Failure Rate plots for a given analysis together in the same window. Alternatively, you may wish to compare the Probability or *pdf* plots for a given data set when analyzed with different distributions. Simply select the combination that meets your analysis/reporting needs. You can use RS Draw, ReliaSoft's integrated metafile graphics editor, to edit and annotate the plots generated by Weibull++. This utility allows you to insert text, highlight a point or line, mark the coordinates of a point, and much more!

2.3.3 Confidence Bounds for Parameters and Results

Weibull++ provides confidence bounds for all of the standard life data analysis parameters and results and also for many of the results from related analyses (such as warranty forecasts, recurrence data analyses, etc.). In addition to the Fisher Matrix, Likelihood Ratio and Beta Binomial methods, Bayesian confidence bounds have been added in Version 7. You can choose whether bounds will be displayed and also specify the confidence level and type of bounds.

2.4 A Complete Array of Related Analyses

In addition to the software's unparalleled support for all aspects of standard life data analysis, Weibull++ also supports a comprehensive array of related analyses. Whenever applicable, these analyses can be fully integrated with the standard folio, allowing you to supplement/enhance your basic analysis.

- **Warranty Analysis:** Perform life data analysis and make warranty projections based on sales and returns data, entered in a Nevada, Times-to-Failure or Dates of Failure format.
- **Reliability Block Diagrams:** Use Reliability Block Diagrams (RBDs) that are integrated with calculated data folios to analyze competing failure modes and perform other system analyses.
- **Recurrence Data Analysis:** Use parametric or non-parametric methods to analyze events that are dependent and not identically distributed (such as repairable system data) and/or to model the number of occurrences of an event over time.
- **Degradation Analysis:** Use the Linear, Exponential, Power, Logarithmic, Gompertz or Lloyd-Lipow models to extrapolate the failure times of a product based on its performance (degradation) over a period of time.
- **Non-Parametric Life Data Analysis:** Use Kaplan-Meier, Simple Actuarial or Standard Actuarial techniques for non-parametric life data analysis.
- **Event Log Interface:** Enter data in an event log format (*e.g.* equipment downtime log) and convert the data to times-to-failure and times-to-repair for standard life data analysis or export to BlockSim for system reliability, maintainability and availability analyses.
- **Risk Analysis and Probabilistic Design:** Use the Monte Carlo simulation tool to perform relationship-based simulations. When you specify an equation relating different random variables, you can then determine the joint *pdf* for the simulated data set.
- **SimuMatic:** Automatically perform large quantities of analyses on simulated data sets in order to investigate various reliability questions, including confidence bounds, testing scenarios, etc.

2.5 Additional Tools and Wizards

Weibull++ also provides many additional tools and wizards designed to streamline, enhance and supplement your analyses.

2.5.1 Spreadsheets for Custom Analyses

General Spreadsheets, which can be incorporated into any Weibull++ standard folio, are used just like an Excel® worksheet to perform your own customized analyses. These spreadsheets provide complete in-cell formula support, cell references, over 140 built-in functions and integration with the Function Wizard and the Chart Wizard. You can use the Function Wizard to insert a wide array of calculated results based on your inputs and, when applicable, a referenced data folio. Available results range from basic math/statistical functions to common reliability analysis results, and much more. In Version 7, this now works more like Excel® functions, with the ability to type functions directly into cells and results that are updated automatically when the inputs change. The Chart Wizard leads you through a step-by-step process to create and configure your own custom charts/plots based on a selected data set.

2.5.2 Template-Based Report Generator

The Report Wizard utility allows you to design print-ready reports to showcase your analyses. The template feature makes it easy to apply the same report format to different analyses. This utility has been revised and enhanced in Version 7 and now provides an intuitive spreadsheet-based interface for creating and formatting reports.

2.5.3 References and Wizards

- **Quick Statistical Reference:** Frees you from tedious lookups in tables by returning results for common statistical functions, such as Median Ranks, Chi-Squared values and more at the click of a button.
- **Design of Reliability Tests:** Determine the appropriate sample size, test duration or other variable for a reliability demonstration test. Parametric Binomial, Non-Parametric Binomial and Exponential Chi-Squared methods are available and results are displayed in both tables and plots.
- **Tests of Comparison Wizard:** Compare two data sets to determine whether items from the first set will outlast those of the second.
- **Stress-Strength Wizard:** Compare a data set with strength data against a data set with stress data to determine probability of failure (*i.e.* stress exceeds strength).
- **Parameter Experimenter:** Solve for a parameter of a distribution given the other parameter(s) and one data point (unreliability at a given time) or solve for all parameters of a distribution given two unreliability data points.
- **Non-Linear Equation Fit Solver:** Estimate the parameters of a non-linear equation, given the equation, the minimum, maximum and initial guess values for its parameters and at least two data points.
- **Non-Linear Equation Root Finder:** Iteratively solve for a real root of an unconstrained non-linear function using a variable order improved memory method.

2.6 Data Import and Integration with Other ReliaSoft Software

In addition to providing a variety of data sheet formats designed to fit your particular data and analysis requirements, Weibull++ makes it easy to import data from outside sources, including: Weibull++ 4, 5, 6 or MT; ALTA; Excel® and Tab, Comma, Space or Semi-colon delimited files.

Weibull++ is directly integrated within other ReliaSoft software whenever you need to specify a distribution and parameters based on a calculated data set. Integration is currently available for the following products: ALTA, BlockSim, RENO, RGA, Xfmea and RCM++.

2.7 Configure the Workspace to Meet Individual Needs

Weibull++ makes it easy to configure the interface and analysis settings to meet your specific preferences and needs. For example, the User Setup allows you to specify default options for data sheets, analysis settings, fonts/symbols, etc. The Plot Setup allows you to configure the appearance of the plots that are automatically generated by the software. In addition, you can customize the toolbars and/or adjust the appearance of the workspace by hiding/displaying or changing the position of the Project Explorer and other panels.

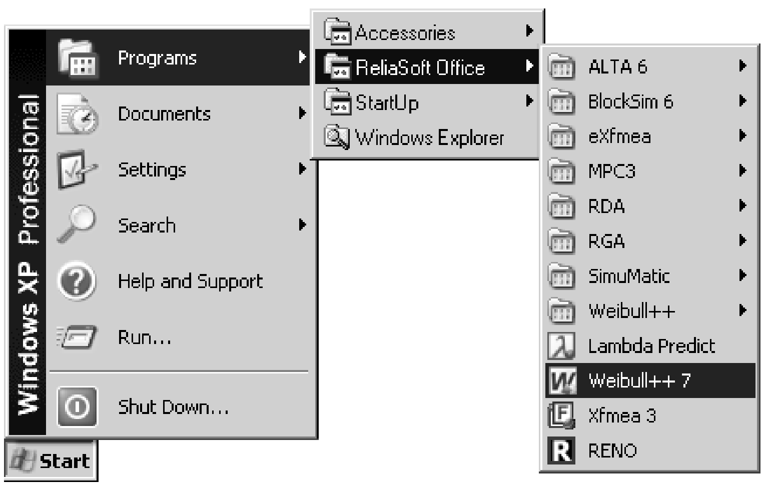
2.8 System Requirements

Weibull++ is compiled and designed for Windows NT, 2000 and XP and takes advantage of the features available in these platforms. Minimum system requirements: 433-MHz Intel Pentium-class processor or equivalent, with 32MB RAM (64MB or more is recommended), SVGA display and at least 80MB of hard disk space.

3 First Steps

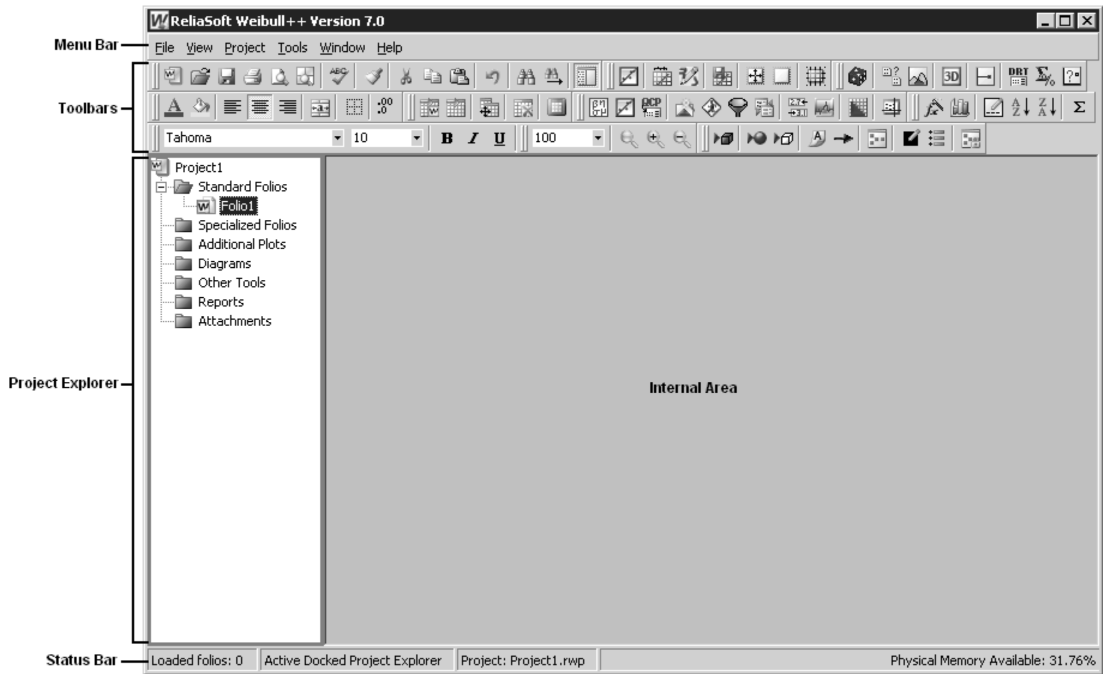
3.1 Starting Weibull++ 7

Weibull++ is a 32-bit application that has been designed to work with Windows NT, 2000 and XP. The internal screens and commands are identical regardless of which operating system you are using, and this training guide is equally applicable. To start Weibull++, from **Start** select **Programs**, **ReliaSoft Office** and then **Weibull++ 7**.



3.2 Multiple Document Interface

Every time you begin a new session in Weibull++, the first window you will encounter is the Multiple Document Interface (MDI). It contains the windows you will use to analyze your data. The MDI serves as the container for the Project Explorer, Standard Folios, Specialized Folios, Special Plots, Diagrams, Other Tools, Reports and Attachments and manages the different active windows. The MDI remains open until you close the program. Closing the MDI has the same effect as terminating the program. The next figure shows the MDI of Weibull++ 7 and its components. The appearance of the MDI will vary depending on the windows that are currently open and the configuration settings of the Project Explorer.



3.3 Getting Help in the Weibull++ Environment

ReliaSoft's Weibull++ includes complete on-line help documentation. This help can be obtained at any time by pressing **F1** or by selecting **Contents** from the **Help** menu.

3.4 First Steps Example

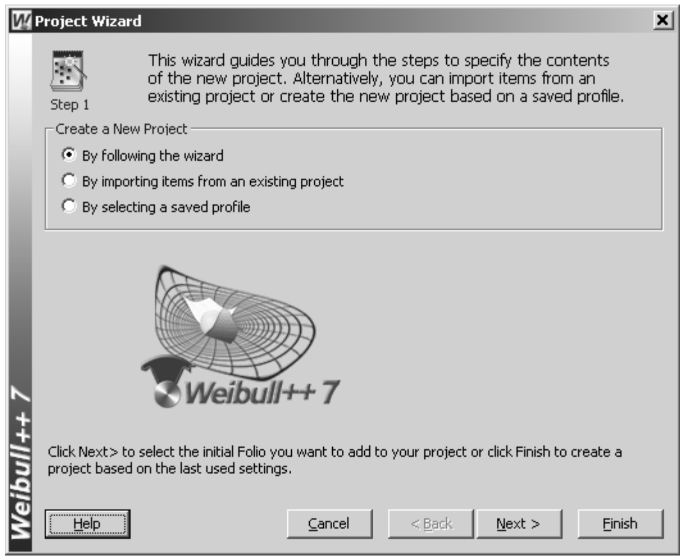
This section presents you with a very simple example and guides you through the solution. The test case for this example: Six units were reliability tested and the following times-to-failure were observed: 46, 64, 83, 105, 123 and 150 hr. You will analyze the data with the 2-parameter Weibull distribution and Rank Regression on X, create the Weibull-Probability plot and estimate the Reliability at 50 hr.

The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "1stSteps.rwp."

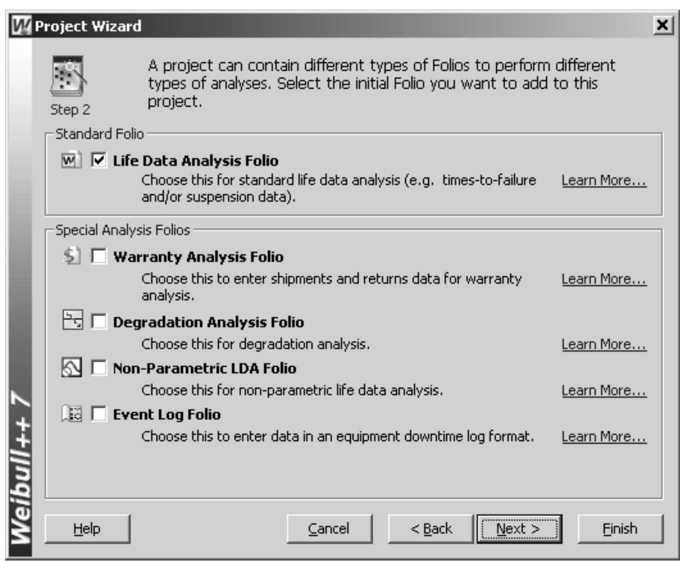
- Create a new project by clicking **Create a New Project** in the initial window that may appear at startup, by selecting **New...** from the **File** menu or by clicking the **New** icon.

The Project Wizard will be displayed. This wizard guides you through the steps required to create a new project that will meet your analysis needs. The steps displayed will vary depending on your selections for each page. Note that you can click **Finish** from the first page of the wizard to create another project with the same settings as the last project you created. You may also choose to create a new project with items imported from an existing project or based on a saved profile.

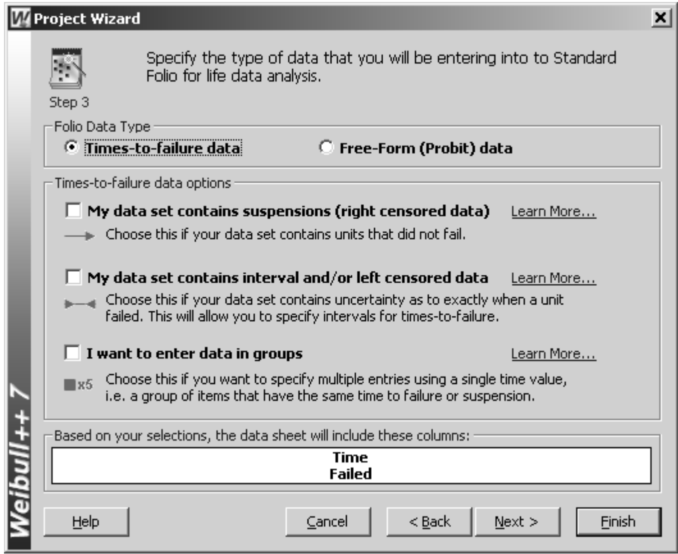
- On the first page of the Project Wizard, select to create a new project **By following the wizard** and click **Next>** to proceed to the next step.



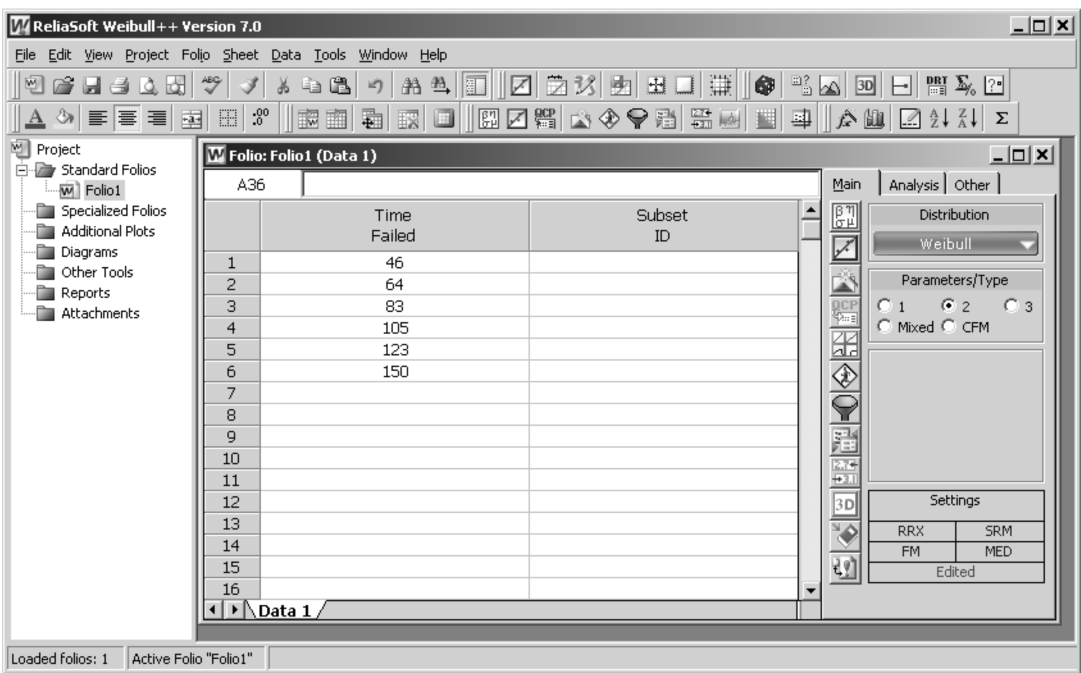
- On the second page of the Project Wizard, make sure that **Life Data Analysis Folio** is selected and click **Next>** to proceed to the next step.



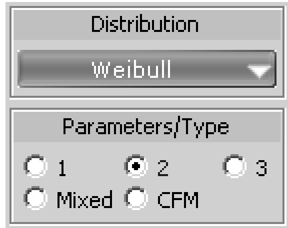
- On the third page of the Project Wizard, select **Times-to-failure data** for the Folio Data Type and make sure that no other options are selected. Click **Next>** to proceed to the next step.



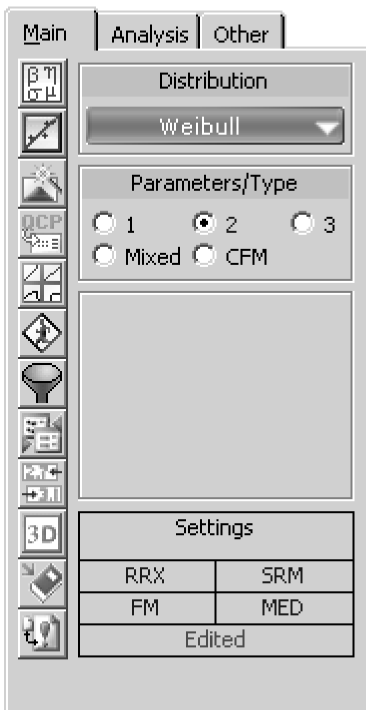
- On the last page, click **Finish** to create the new project according to your specifications. The project will now include one Standard Folio with a data sheet that has been configured to accept the type of data that you will be entering for this example. Enter the times-to-failure into the **Time Failed** column of the data sheet, as shown next.

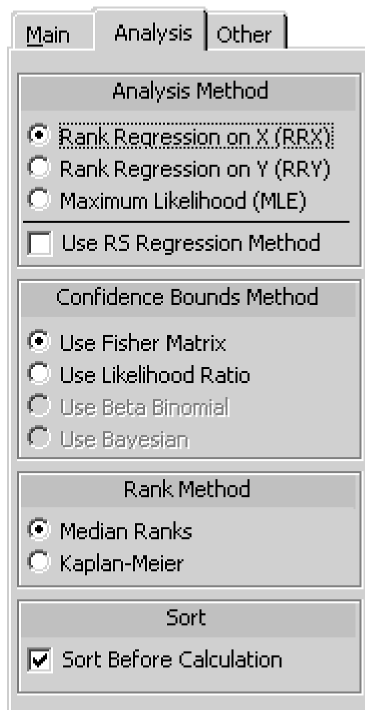


- The next step is to select a distribution and parameter estimation method to calculate the parameters. Select the **Weibull** distribution from the menu on the Main page of the Control Panel. Note that you can activate this menu in two ways: by clicking the blue bar or by hovering the mouse over the bar for a second or two. The Parameters/Type area below the menu will be updated to display the options available for the selected distribution. Select **2** to perform the analysis with the 2-parameter Weibull distribution, as shown next.



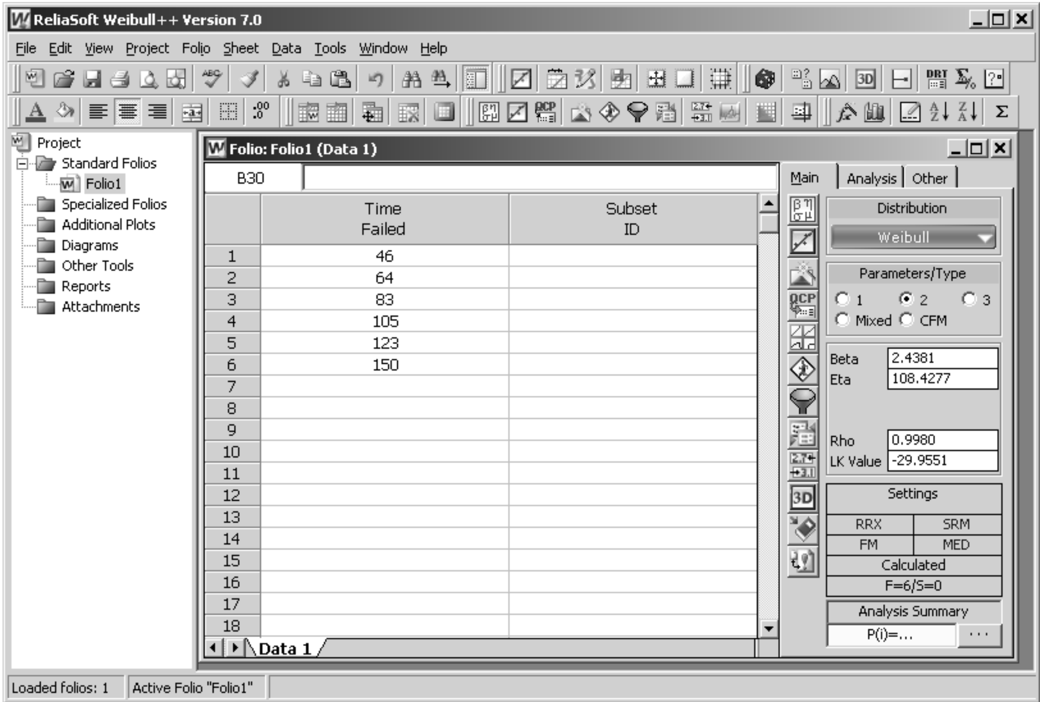
The other analysis settings are set/displayed in two places within the Control Panel: in the Settings area of the Main page and on the Analysis page. For this example, you will use the default settings: **Rank Regression on X (RRX)** with the **Standard Regression Method (SRM)** and **Median Ranks (MED)**; and **Fisher Matrix (FM)** confidence bounds, as shown next.





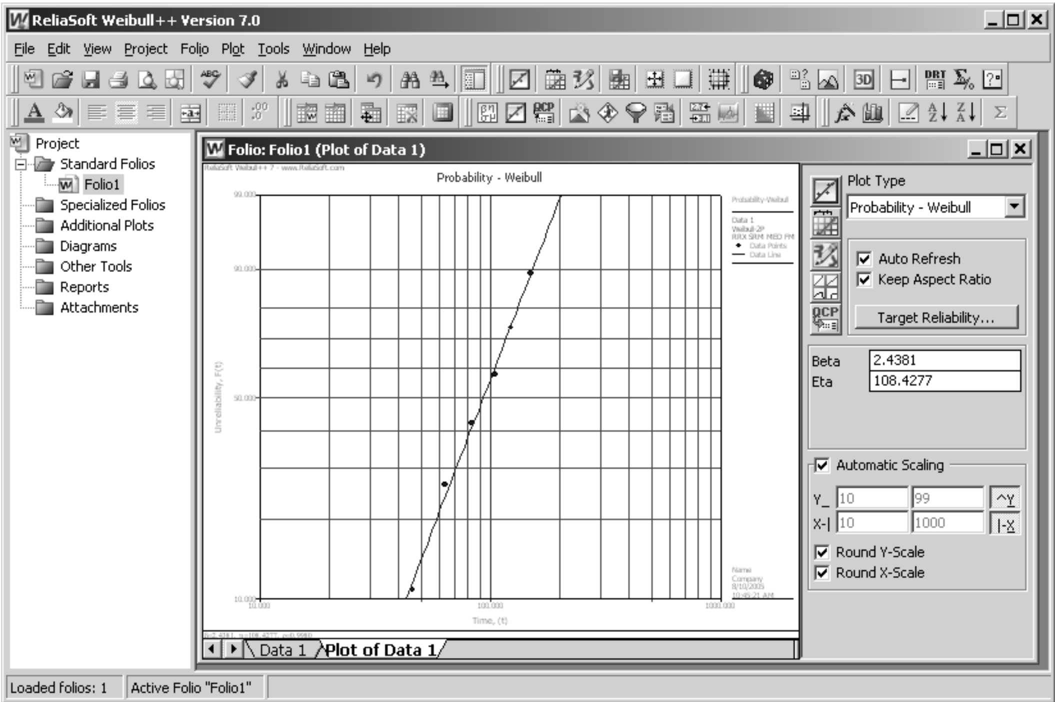
- Make sure that the analysis settings for your Folio are set to the defaults. Note that clicking the options displayed with blue text in the Settings area of the Main page allows you to toggle through the available settings.
- Calculate the parameters by selecting **Calculate** from the **Data** menu or by clicking the **Calculate** icon. This icon is displayed in both the Data Analysis Tools toolbar and in the Control Panel.

The data sheet with its parameters calculated is shown next. The estimated parameters will appear in the Results Area, which is located just below the Parameters/Type options.



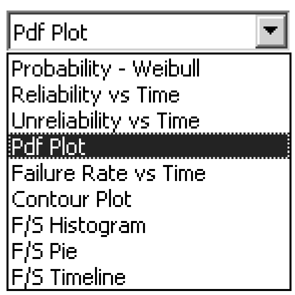
- Plot the data by selecting **Plot** from the **Data** menu or by clicking the **Plot** icon. This icon is displayed in both the Data Analysis Tools toolbar and in the Control Panel.

A new sheet called “Plot of Data 1” will be added to the Folio. The Probability-Weibull plot will be displayed by default, as shown next.[1]



The Plot Sheet provides many options for creating and configuring plots to meet your particular analysis and presentation needs. You may wish to experiment with some of these options at this time. If the **Auto Refresh** command is enabled, the display will be updated automatically to fit your new selections. If not, select **Redraw Plot** from the **Plot** menu or click the **Redraw Plot** icon to implement your selections.

For example, the **Plot Type** menu in the Control Panel allows you to create other types of plots.

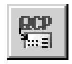


In addition, notice that the analysis settings are displayed in the legend in the top right corner of the plot and the calculated parameters are displayed in the bottom left corner. You can customize these and other display settings from the Plot Setup window. To access the Plot Setup, select **Plot Setup** from the **Plot** menu or click the **Plot Setup** icon.

- When you are finished experimenting with the Plot Setup window, return to the data sheet by clicking the **Data 1** tab.

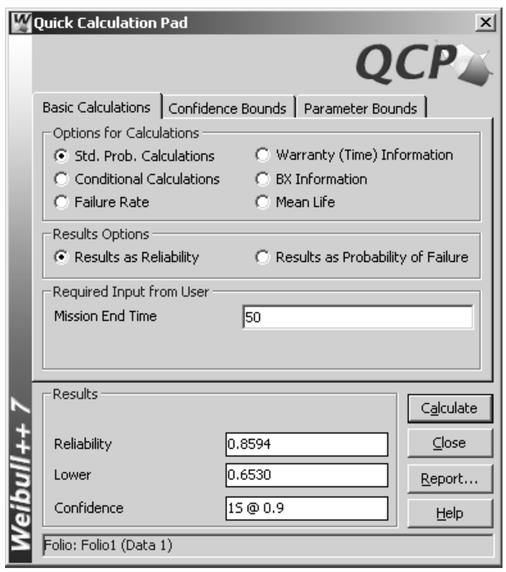
1. If necessary, you may wish to re-size the plot by re-sizing the Folio.

• Open the Quick Calculation Pad (QCP) by selecting **Quick Calculation Pad...** from the **Data** menu or by clicking the icon. This icon is displayed in both the Data Analysis Tools toolbar and in the Control Panel.



This tool allows you to obtain commonly requested reliability results based on your analysis and any required inputs. To estimate the reliability at 50 hr for this example, do the following:

• On the Basic Calculations page, make the following selections/inputs:
    • Options for Calculations: **Std. Prob. Calculations**
    • Results Options: **Results as Reliability**
    • Required Input from User: Mission End Time = **50**
• Click **Calculate** to obtain the results, as shown next.



• Click **Close** to close the QCP.
• Save the project by selecting **Save** from the **File** menu or by clicking the **Save** icon.

• When prompted to specify the name and location for the file, browse to the directory of your choice and type “1stSteps” for the File name.[2] Accept the default type (*.rwp) and click **Save** to close the window and save the file.
• Close the project by selecting **Close** from the **File** menu.

[2] By default, files will be saved in the “My Documents” directory on your computer. You can select a different directory, if desired, and Weibull++ will “remember” the directory for the next time that you save a file.

4 Step-by-Step Examples

4.1 List of Examples

This chapter provides the following step-by-step examples, which are designed to introduce you to the features of the Weibull++ software:

4.2 Example 1: Life Data Analysis with Complete and Suspended Data

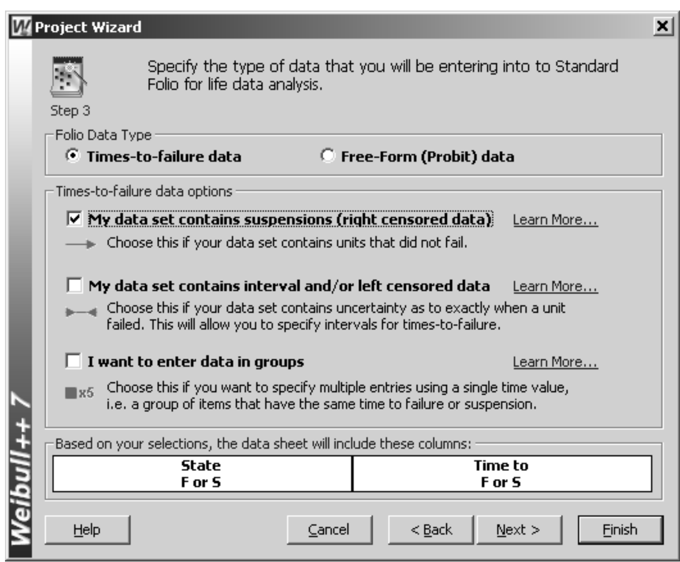
Ten identical units were reliability tested at the same application and operation stress levels. Six of these units failed during the test after operating for the following times, T_j : 16, 34, 53, 75, 93 and 120. Four other units were still operating, *i.e.* right censored or suspended, after 120 hr. Determine the parameters of the Weibull *pdf* that represents this data set and create the Probability and *pdf* plots.

The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Training Examples.rwp." Use Folio1.

Solution

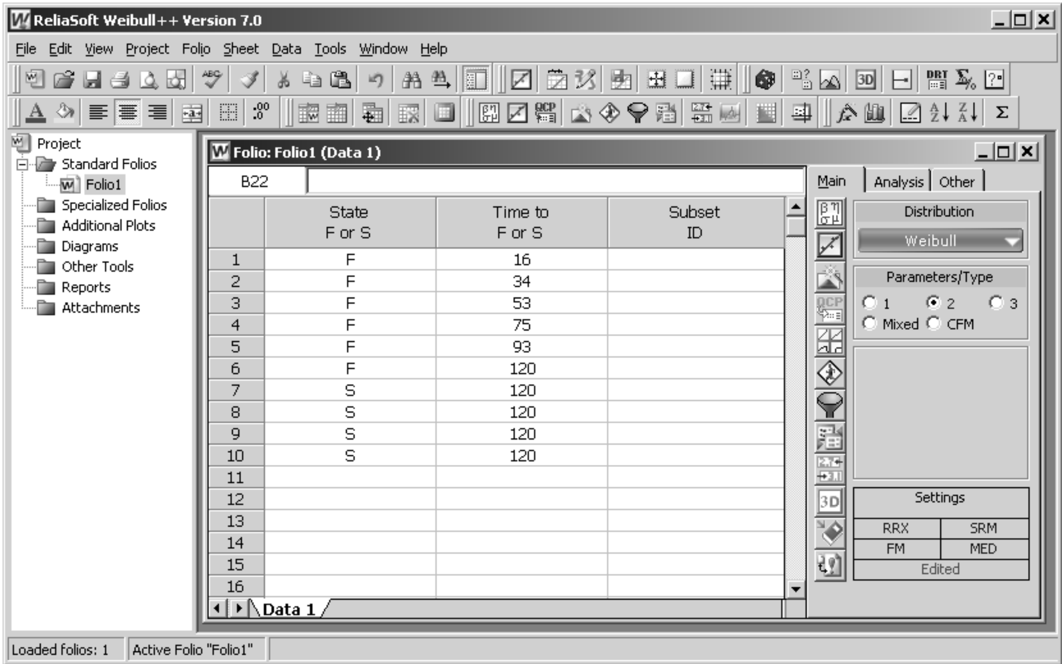
- Create a new project by clicking **Create a New Project** in the initial window that may appear at startup, by selecting **New...** from the **File** menu or by clicking the **New** icon.

- Select **By following the wizard** on the first page of the Project Wizard and **Life Data Analysis Folio** on the second page.
- On the third page, select **Times-to-failure data** for the Folio Data Type and select **My data set contains suspensions (right censored data)**, as shown next.

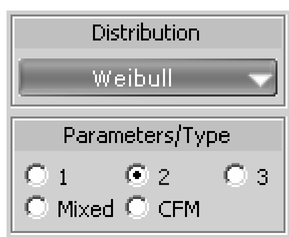


- Click **Finish** to create the new project with the appropriate Standard Folio. In this type of data sheet, the first column ("State F or S") contains an F to indicate that the data point entered in the second column ("Time to F or S") is a failure or an S to indicate that the data point is a suspension. Note that if you type a positive value in the "Time to F or S" column, an F will be assigned automatically by the software and if you type a negative value, an S will be automatically assigned.

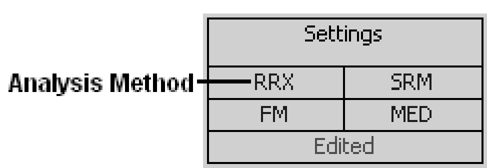
- Enter the data for this example, as shown next.



- The 2-parameter Weibull distribution and Rank Regression on X (RRX) will be used to calculate the parameters. If these are not the default analysis options on your computer, select **Weibull** from the Distribution menu and **2** from the Parameters/Type area on the Main page of the Control Panel, as shown next.

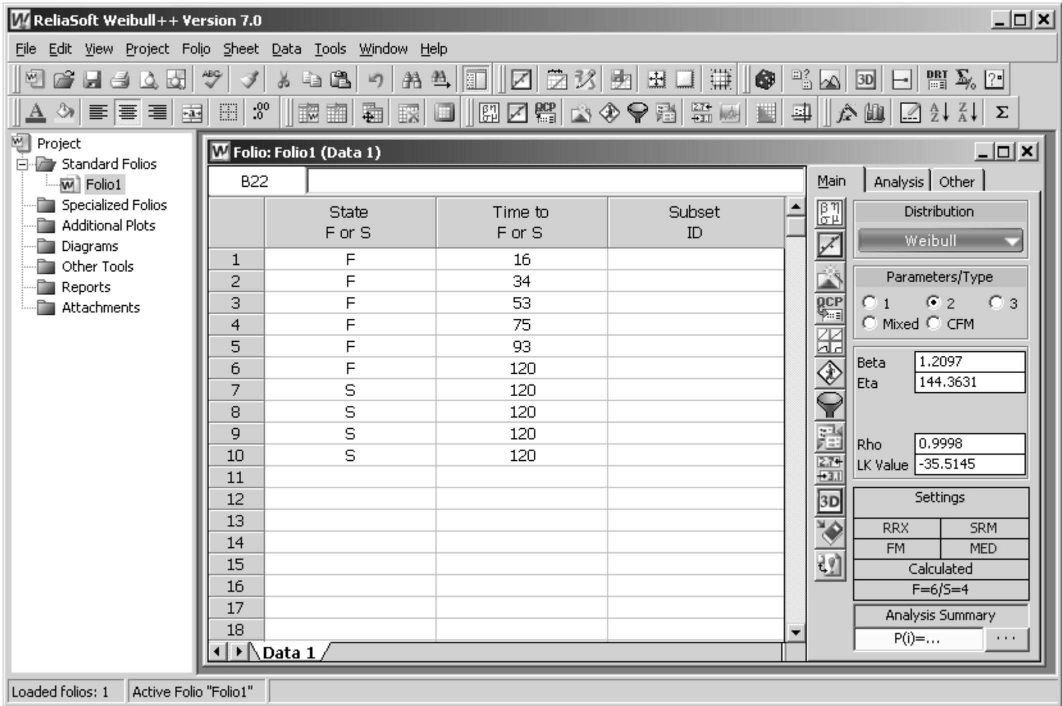


- There are two ways to set the Analysis Method: select **Rank Regression on X (RRX)** from the Analysis page of the Control Panel or click the **Analysis Method** box on the Main page of the Control Panel until **RRX** is displayed, as shown next.



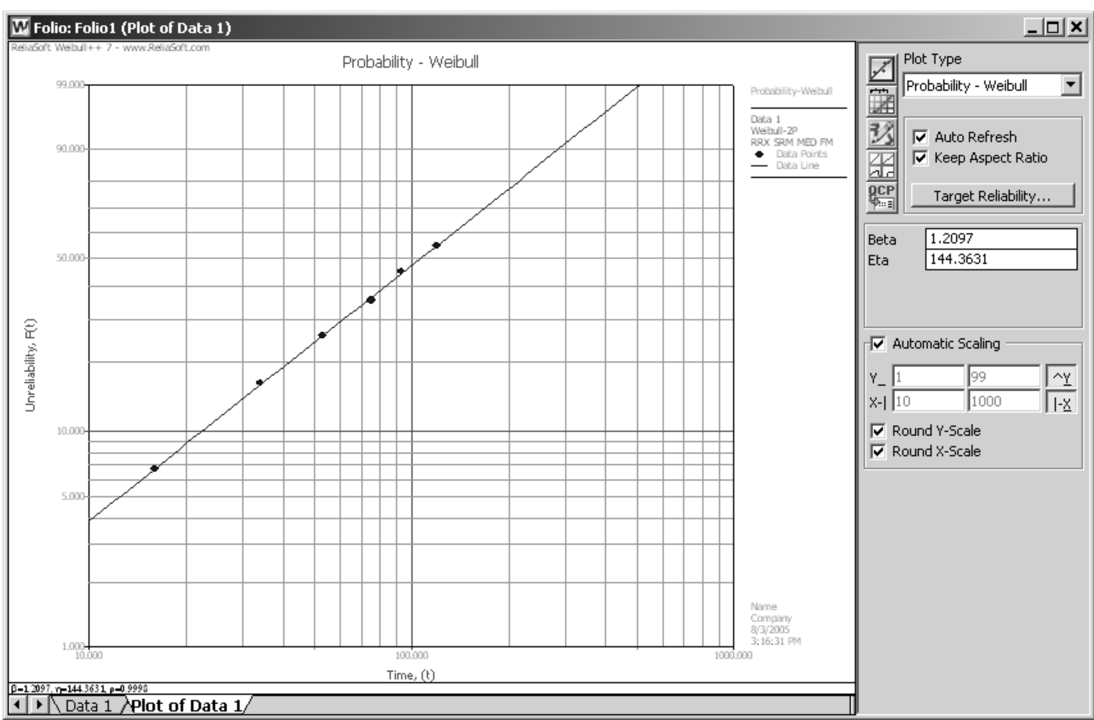
- Calculate the parameters by selecting **Calculate** from the **Data** menu or by clicking the **Calculate** icon. This icon is displayed in both the Data Analysis Tools toolbar and in the Control Panel.

The results will appear in the Control Panel, as shown next.



- Plot the data by selecting **Plot** from the **Data** menu or by clicking the **Plot** icon. This icon is displayed in both the Data Analysis Tools toolbar and in the Control Panel.

The Weibull Probability plot for this data set is shown next.



Note that the plotted line represents the unreliability, $Q(T)$, which is defined as:

$$Q(T) = 1 - R(T)$$

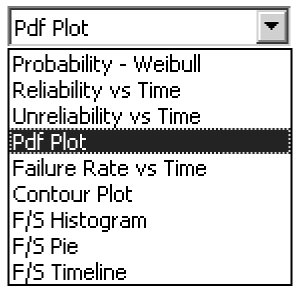
where $R(T)$ is the reliability. If desired, the 2-parameter Weibull *pdf* representing this data set can be written as:

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

or

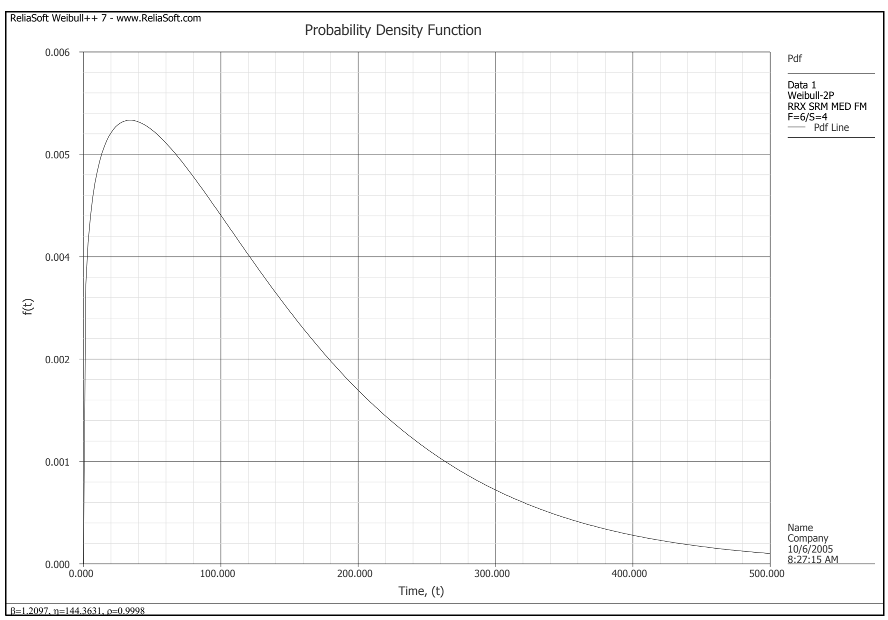
$$f(T) = \frac{1.2097}{144.3631}\left(\frac{T}{144.3631}\right)^{0.2097} e^{-\left(\frac{T}{144.3631}\right)^{1.2097}}$$

- You can also plot the Weibull *pdf* by selecting **Pdf Plot** from the Plot Type menu on the Control Panel.



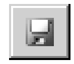
- If the Auto Refresh option is selected, the Plot Sheet will be updated automatically to display the new plot type that you have selected. If the option is not selected, click the **Redraw Plot** icon or select **Redraw Plot** from the **Plot** menu to update the display.

The *pdf* plot is shown next.



- Return to the data sheet by clicking the **Data 1** tab at the bottom of the Folio.

- Save the project by selecting **Save** from the **File** menu or by clicking the **Save** icon.



- When prompted to specify the name and location for the file, browse to the directory of your choice and type “Training Examples” for the File name.[1] Accept the default type (*.rwp) and click **Save** to close the window and save the file.
- Leave the project and Folio open and proceed to the next example.

4.3 Example 2: Obtain the Unreliability for a Given Operating Time

What is the unreliability of the units in Example 1 for a mission duration of 227 hr, starting the mission at $T = 0$?

The file for this example is located in the “Training Guide” folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named “Training Examples.rwp.” Use Folio1.

Solution

There are several methods of solution for this problem. The first and more laborious method is to extract the information directly from the plot. It is possible to extract the information from a plot within Weibull++ or from a printed copy. For this example, let's obtain the information from within the application. This can be done using ReliaSoft Draw (RS Draw).[2]

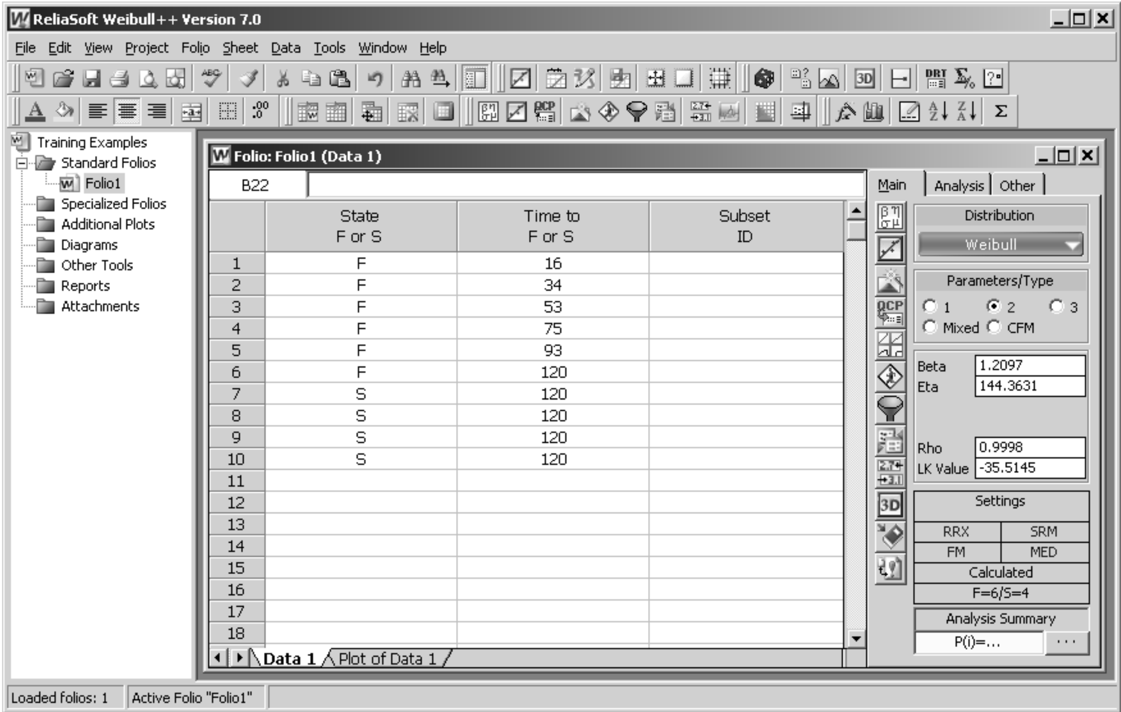
- If Folio1 from the “Training Examples.rwp” project file that you created in the first example is not already active, open the project by selecting **Open** from the **File** menu or by clicking the **Open** icon.

- Browse for the “Training Examples.rwp” file and click **Open**.

1. By default, files will be saved in the “My Documents” directory on your computer. You can select a different directory, if desired, and Weibull++ will “remember” the directory for the next time that you save a file.

2. RS Draw is presented in detail in Chapter 28 of the *Weibull++ User's Guide*.

- Click the "plus" (+) to the left of the Standard Folios branch in the Project Explorer on the left side of the Weibull++ MDI to display a list of the standard life data analysis folios in the current project. Double-click **Folio1** to open it. The MDI will now look like the figure shown next.

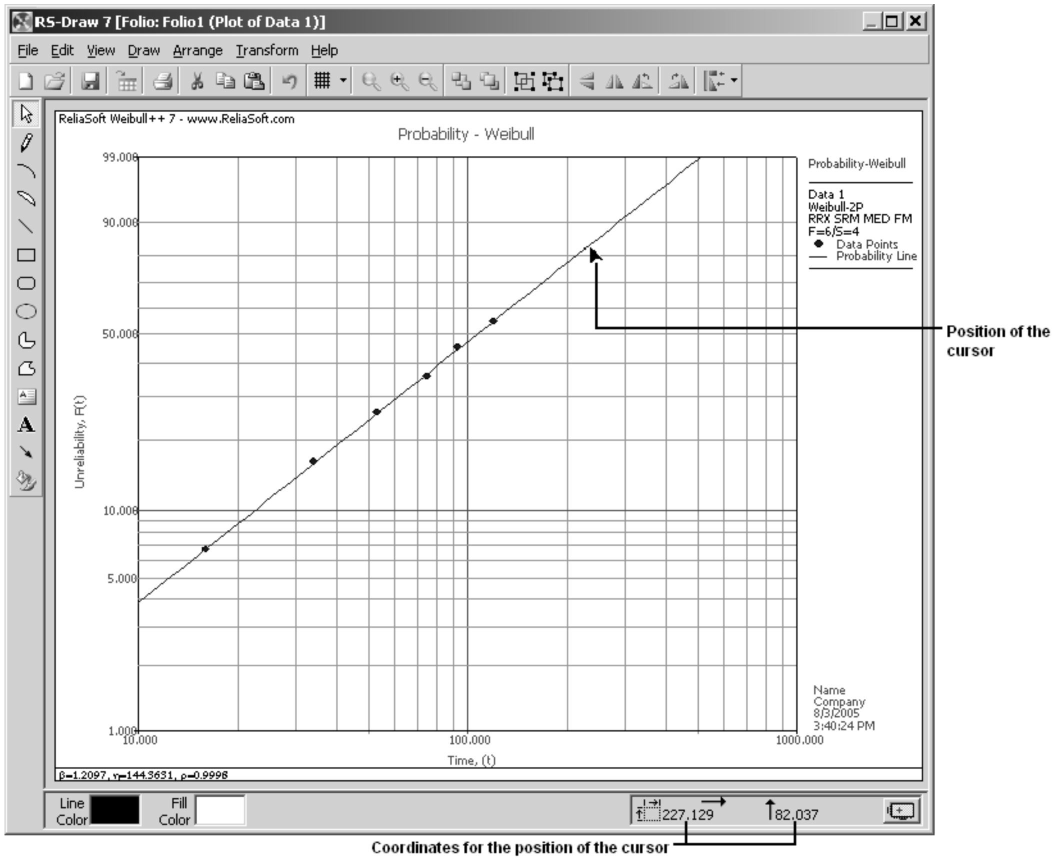


- Click the **Plot of Data 1** tab at the bottom of the Folio to display the Plot Sheet. Select **Probability-Weibull** from the Plot Type menu and refresh the display, if necessary.

- Open RS Draw by selecting **Edit with RS Draw...** from the **Plot** menu or by clicking the **Edit with RS Draw** icon. This icon is displayed in both the Plot Tools toolbar and in the Control Panel.

- RS Draw can automatically track the position of the mouse cursor and translate the coordinates for you. Obtain the unreliability at $T = 227$ hr by placing the cursor at the intersection of the plotted line and $T = 227$. The position of the cursor is indicated by the Position Indicator located in the lower right corner of the RS Draw window. The x-coordinate (time) is displayed on the left and the y-coordinate (unreliability) is displayed on the right. When the x-coordinate reads approximately 227, read off the value of the y-coordinate. You may not be able to obtain the value of the unreliability at exactly 227 hr.

This is one of the disadvantages of reading the value off the plot. The position of the cursor at the intersection of the plotted line and approximately $T = 227$ is shown next.



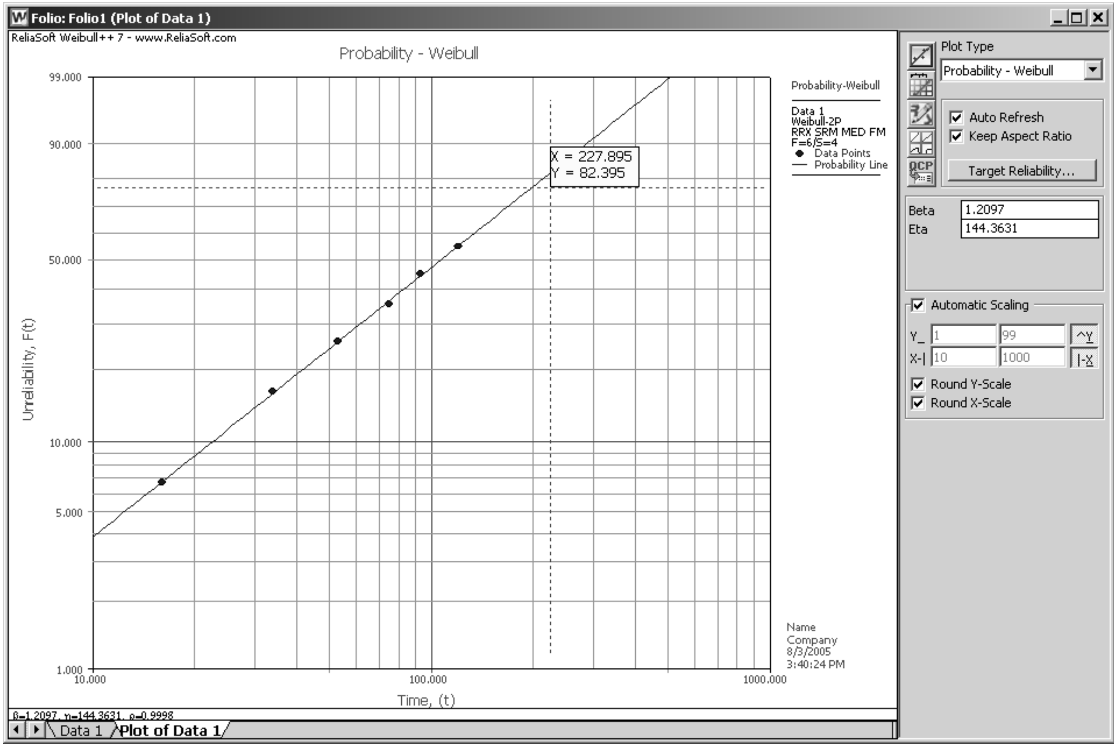
The value of the y-coordinate from the Position Indicator, the unreliability $Q(T)$, is such that $Q(T) \cong 82\,\%$. Therefore, a good estimate of the probability of failure (unreliability) at 227 hr is 82%. The reliability is then:

$$R(T) = 1 - Q(T) = 1 - 0.82$$

$$= 0.18 \text{ or } 18\,\%$$

- Close RS Draw and return to the Plot Sheet by selecting **Exit** from the **File** menu or by clicking the **Close** button (**X**) in the top right corner of the window.

You can also read the coordinates from within the Plot Sheet. To do this, position the mouse pointer over the plot line, press **Shift** and click the plot. The X and Y coordinates for the current position of the mouse on the line will be displayed in a yellow box. If you continue to hold down the **Shift** key while moving the mouse, the pointer will track the plot line, allowing you to read the coordinates for any position on the line. The next figure shows the Plot Sheet with the coordinates marked at approximately 227 hr.



• Return to the data sheet by clicking the **Data 1** tab.

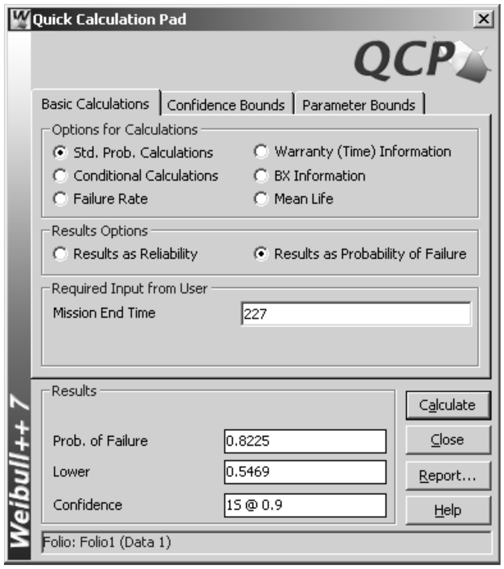
The second method to obtain the unreliability for a given time involves the use of the Quick Calculation Pad (QCP).[3]

• Open the Quick Calculation Pad by selecting **Quick Calculation Pad...** from the **Data** menu or by clicking the **Quick Calculation Pad** icon. This icon is displayed in both the Data Analysis Tools toolbar and in the Control Panel.

• On the Basic Calculations page, make the following selections/inputs:
    • Options for Calculations: **Std. Prob. Calculations**
    • Results Options: **Results as Probability of Failure**
    • Required Input from User: Mission End Time = **227**

3. The Quick Calculation Pad is presented in detail in Chapter 8 of the *Weibull++ User's Guide*.

- Click **Calculate** to obtain the results, as shown next.



The QCP returns a result of $Q(T) = 0.8225 \cong 82\,\%$. This agrees with the result found using the plot. However, using the QCP is more accurate and easier to use.

- Close the QCP, save any changes, leave the project and Folio open and proceed to the next example.

4.4 Example 3: Calculate Conditional Reliability and Warranty Time

Using the analysis from Example 1, what is the reliability for a mission duration of t = 30 hr, starting the mission at T = 30 hr? Also, what is the warranty time for a reliability of 85%?

The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Training Examples.rwp." Use Folio1.

Solution

- If Folio1 from the "Training Examples.rwp" project file that you created in the first example is not already active, open the project and Folio now.

The functions used to find the reliability are shown next.

$$R(T,t) = \frac{R(T+t)}{R(T)}$$

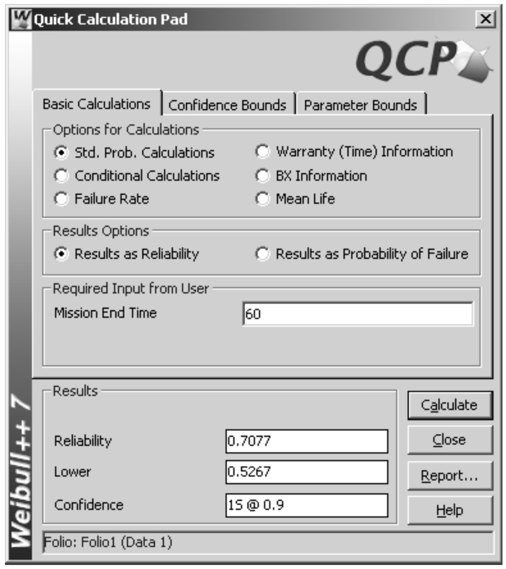
$$\hat{R}(30hr, 30hr) = \frac{\hat{R}(30hr + 30hr)}{\hat{R}(30hr)} = \frac{\hat{R}(60hr)}{\hat{R}(30hr)}$$

- Open the Quick Calculation Pad by selecting **Quick Calculation Pad...** from the **Data** menu or by clicking the **Quick Calculation Pad** icon.

- On the Basic Calculations page, make the following selections/inputs:
    - Options for Calculations: **Std. Prob. Calculations**
    - Results Options: **Results as Reliability**

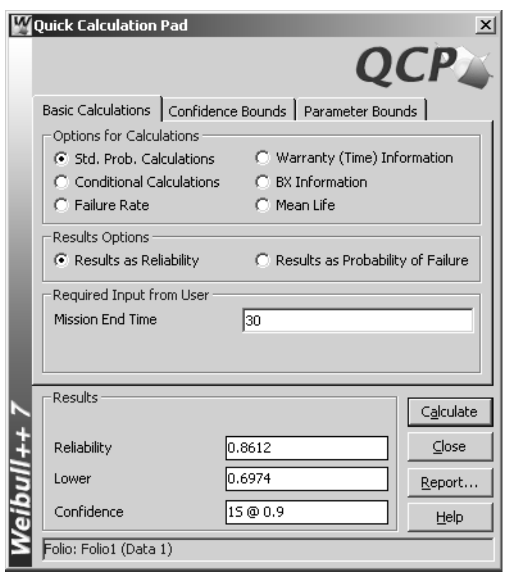
- Required Input from User: Mission End Time = **60**

- Click **Calculate** to obtain the results, as shown next.



$$\hat{R}(60hr) = 0.7077$$

- Still using the QCP, enter a Mission End Time = **30** and click **Calculate** to obtain the reliability at t =30 hr, as shown next.



$$\hat{R}(30hr) = 0.8612$$

- Divide the reliability at 60 hr by the reliability at 30 hr and you will obtain the conditional reliability for this example.

$$\hat{R}(30hr, 30hr) = \frac{0.7077}{0.8612} = 0.8218$$

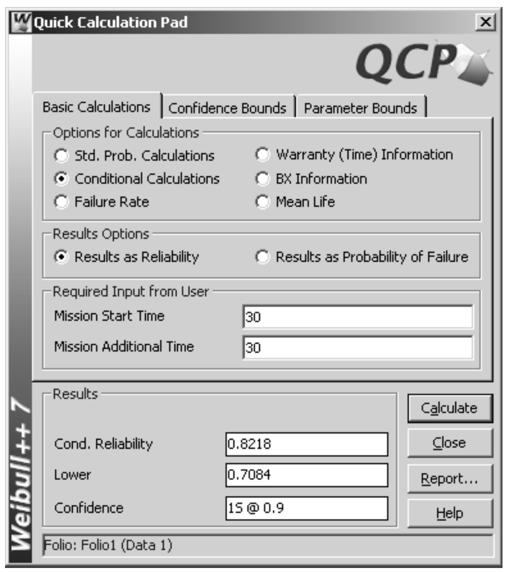
$$\hat{R}(30hr, 30hr) = 82.18\%$$

However, the Quick Calculation Pad can provide this result directly and more efficiently. The Std. Prob. Calculations are based on a starting mission time, *T*, equal to zero. This example had a starting mission time equal to T = 30 hr. A starting mission time greater than zero can be accounted for using Conditional Calculations.

- Still on the Basic Calculations page of the QCP, make the following selections/inputs:
  - Options for Calculations: **Conditional Calculations**
  - Results Options: **Results as Reliability**
  - Required Input from User:

    Mission Start Time = **30**

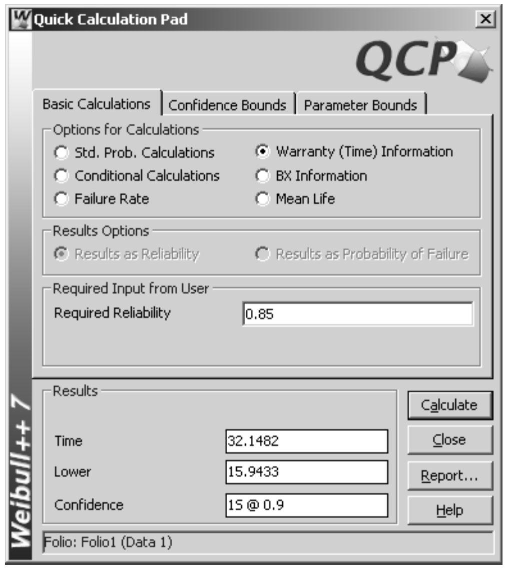
    Mission Additional Time = **30**
- Click **Calculate** to obtain the results, as shown next.



The second part of this example involves determining the warranty time for a reliability of 85%.

- Still on the Basic Calculations page of the QCP, make the following selections/inputs:
  - Options for Calculations: **Warranty (Time) Information**
  - Required Input from User: Required Reliability = **0.85**

- Click **Calculate** to obtain the results, as shown next.



The time required for a reliability of 85% is equal to 32.1482.

- Close the QCP by clicking **Close**.
- Close the Folio by clicking the Close button (X) in the top right corner.
- Save any changes, leave the project open and proceed to the next example.

4.5 Example 4: 3-Parameter Weibull Analysis

The 3-parameter Weibull analysis option calculates the correct γ and adjusts the points by this value, such that they fall on a straight line, and then plots both the adjusted and the unadjusted points.

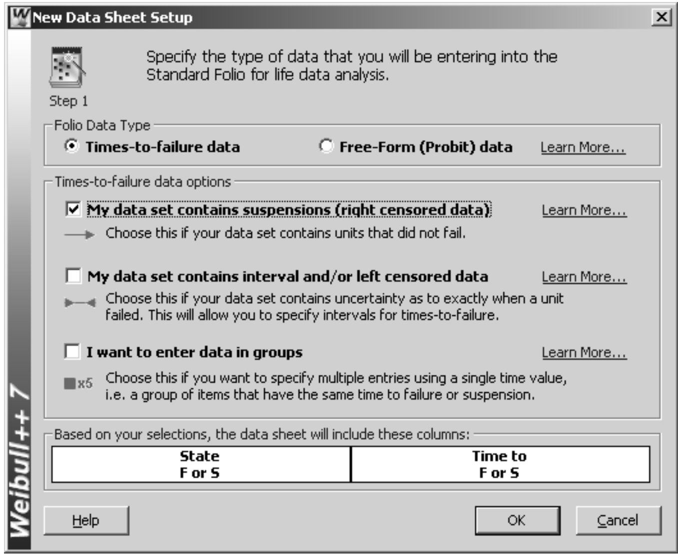
Ten identical units, $N = 10$, were reliability tested at the same application and operation stress levels. Six of these units failed during the test after operating for the following times, T_j: 46, 64, 83, 105, 123 and 150. The four other units were suspended after operating for 150 hr. Using the 3-parameter Weibull distribution and Rank Regression on X (RRX), find the parameters of the Weibull *pdf* that represents these data points.

The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Training Examples.rwp." Use Folio2.

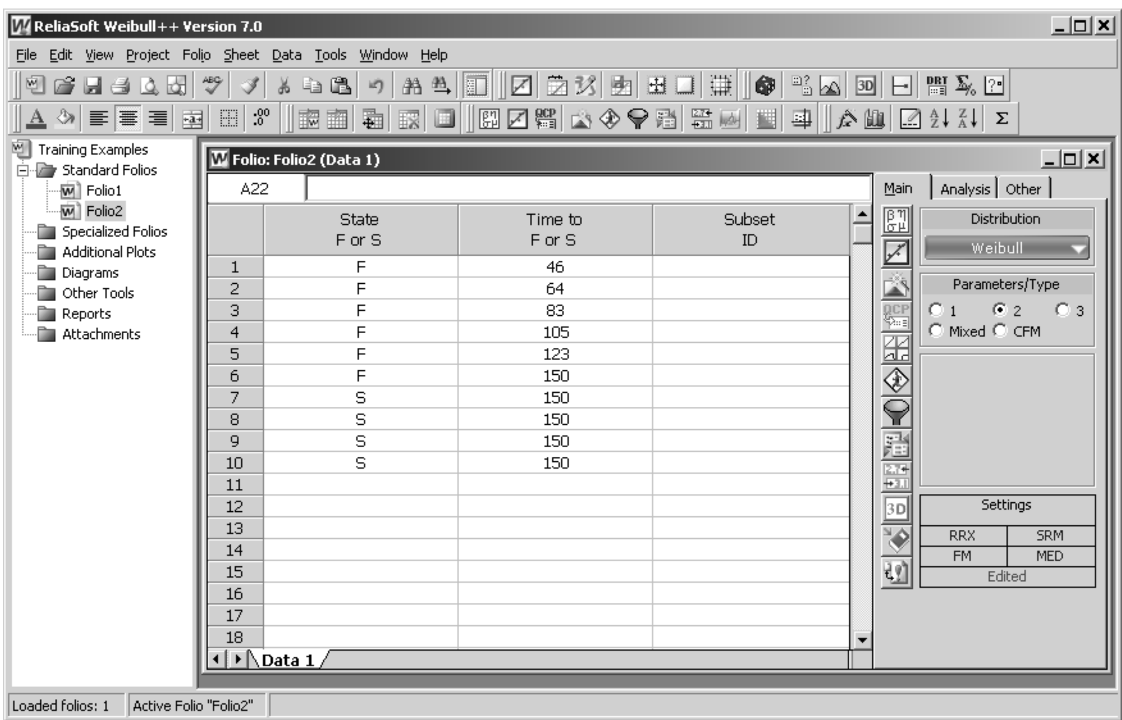
Solution

- With the "Training Examples.rwp" project open, create a new Standard Folio by selecting **Add Standard Folio...** from the **Project** menu or by right-clicking inside the Project Explorer and selecting **Add Standard Folio...** from the shortcut menu.

- In the New Data Sheet Setup window, select **Times-to-failure data** for the Folio Data Type and select **My data set contains suspensions (right censored data)**, as shown next.

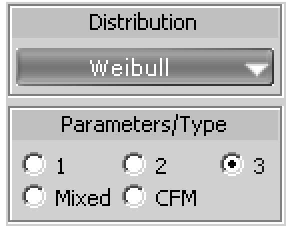


- Click **OK** to create the new Standard Folio with the data sheet that you have specified.
- Enter the data in the same way as in Example 1. The MDI with the data entered into the new Folio is shown next. Note that the Project Explorer now displays two standard data analysis folios, Folio1 and Folio2.[4]



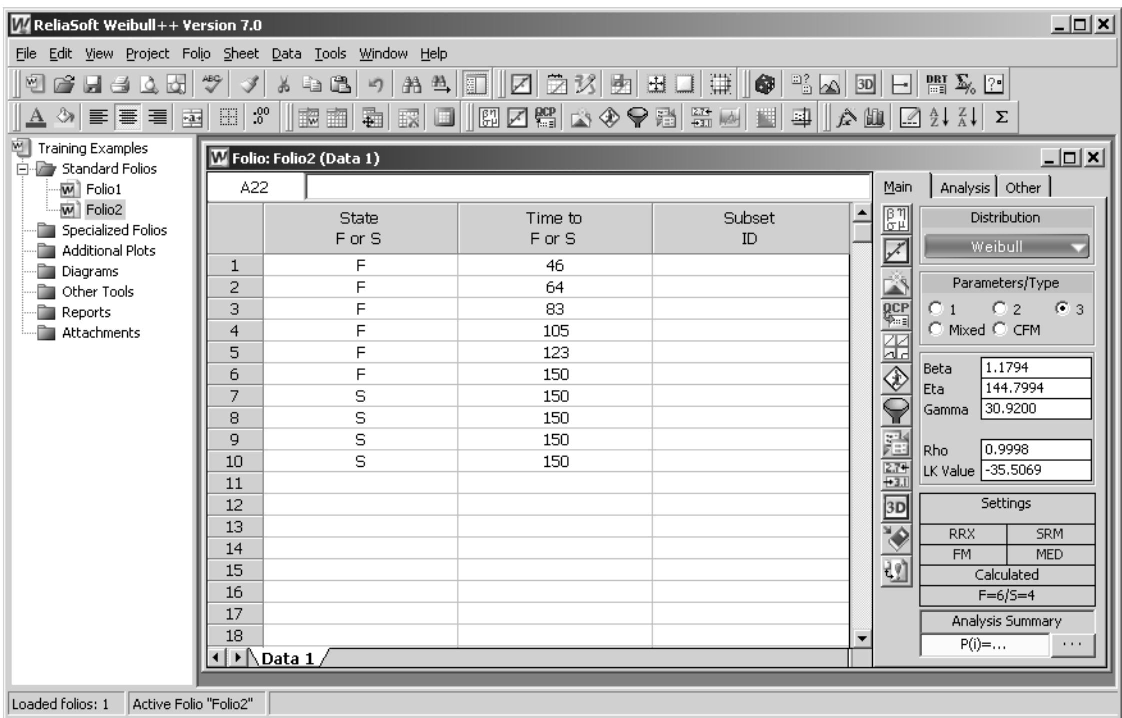
4. Although the default Folio names have been used for these examples, you can rename Folios to be more descriptive, if desired. To rename an item in the Project Explorer, right-click the item and select **Rename Item** from the shortcut menu or select the item and press **F2**.

- Select **Weibull** from the Distribution menu and **2** from the Parameters/Type area on the Main page of the Control Panel, as shown next.



- Set the Analysis Method to **Rank Regression on X (RRX)** from the Analysis page of the Control Panel or by clicking the option in the Settings area of the Main page until RRX is displayed.
- Calculate the parameters by selecting **Calculate** from the **Data** menu or by clicking the **Calculate** icon.

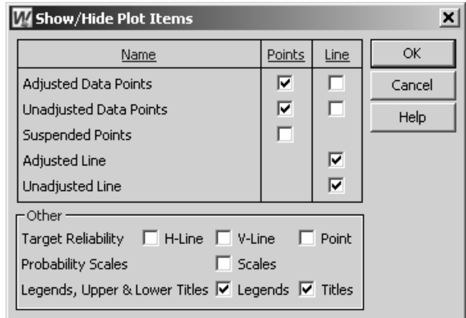
The calculated parameters are shown next.



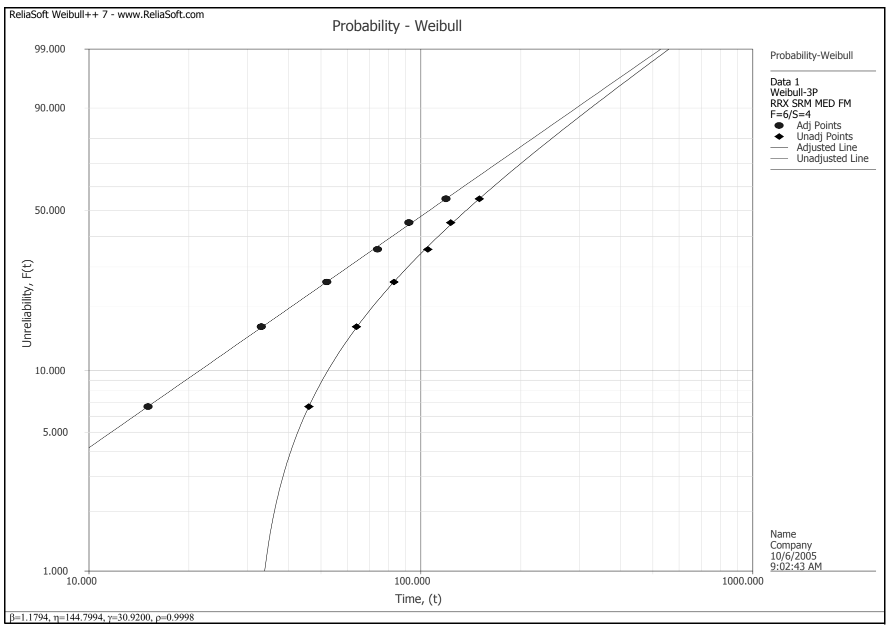
- Plot the data by selecting **Plot** from the **Data** menu or by clicking the **Plot** icon.

- Select **Probability-Weibull** from the Plot Type menu (if it is not already selected).
- When the plot has been refreshed, select **Show/Hide Items...** from the **Plot** menu or right-click inside the plot and select the command from the shortcut menu. In the Show/Hide Plot Items window, select to

display both the line/points that have been adjusted for Gamma and the line/points that have not been adjusted for Gamma, as shown next.



- Click **OK** to close the window and refresh the plot with both the adjusted and unadjusted plot lines displayed, as shown next.



Note that the original data points, plotted along the curved line, were adjusted by γ = 30.92 hr to yield the straight line. Also note that the x-axis for the plot is $T - \gamma$. Therefore, to obtain the time (T) required for a given unreliability level using the straight line, you must add the value of γ to the x-axis value found at ($T - \gamma$). Alternatively, you can read the results from the unadjusted line.

- Close the Folio, save any changes, leave the project open and proceed to the next example.

4.6 Example 5: 2-Parameter Exponential Analysis and Plots

Twenty units, $N = 20$, were reliability tested with the following times-to-failure: seven units failed at 100 hr, five units failed at 200 hr, three units failed at 300 hr, two units failed at 400 hr, one unit failed at 500 hr and two units failed at 600 hr.

Do the following:

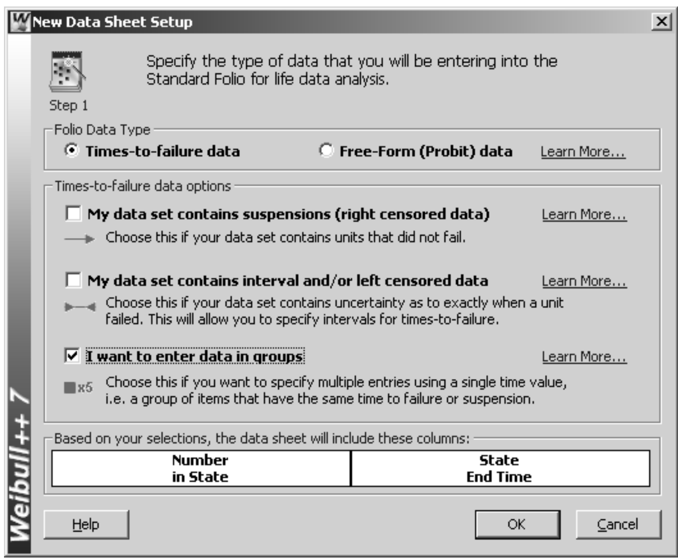
- Enter the data. Use the 2-parameter exponential distribution and Rank Regression on X as the parameter estimation method.

- Obtain the Exponential Probability plot.
- Obtain the Reliability vs. Time plot.
- Obtain the *pdf* plot.
- Obtain the Failure Rate vs. Time plot.

The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Training Examples.rwp." Use Folio3.

Solution

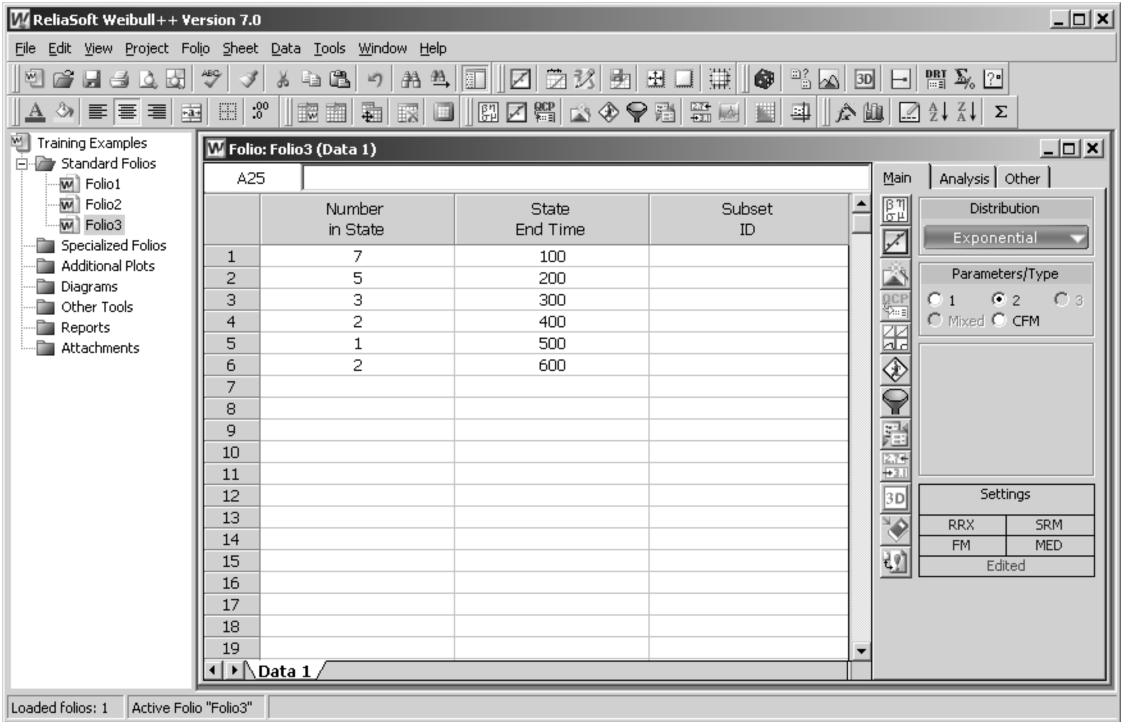
- With the "Training Examples.rwp" project open, create a new Standard Folio by selecting **Add Standard Folio...** from the **Project** menu or by right-clicking inside the Project Explorer and selecting **Add Standard Folio...** from the shortcut menu.
- In the New Data Sheet Setup window, select **Times-to-failure data** for the Folio Data Type and select **I want to enter data in groups**, as shown next.



- Click **OK** to create the new Standard Folio with the data sheet that you have specified.

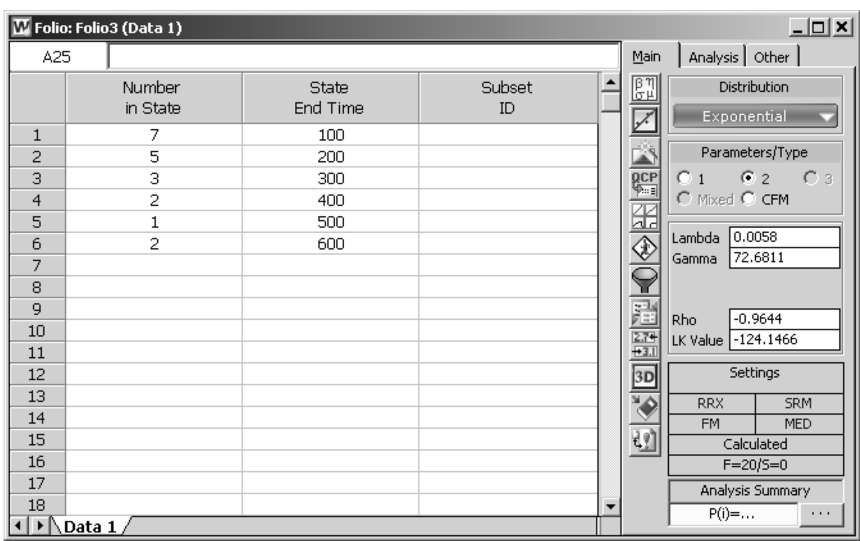
In this type of data sheet, the first column ("Number in State") contains the quantity of units that failed at a given time and the second column ("State End Time") contains the time-to-failure.

- Enter the data into the new Folio and select the 2-parameter exponential distribution with RRX, as shown next.

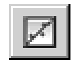


- Calculate the parameters by selecting **Calculate** from the **Data** menu or by clicking the **Calculate** icon.

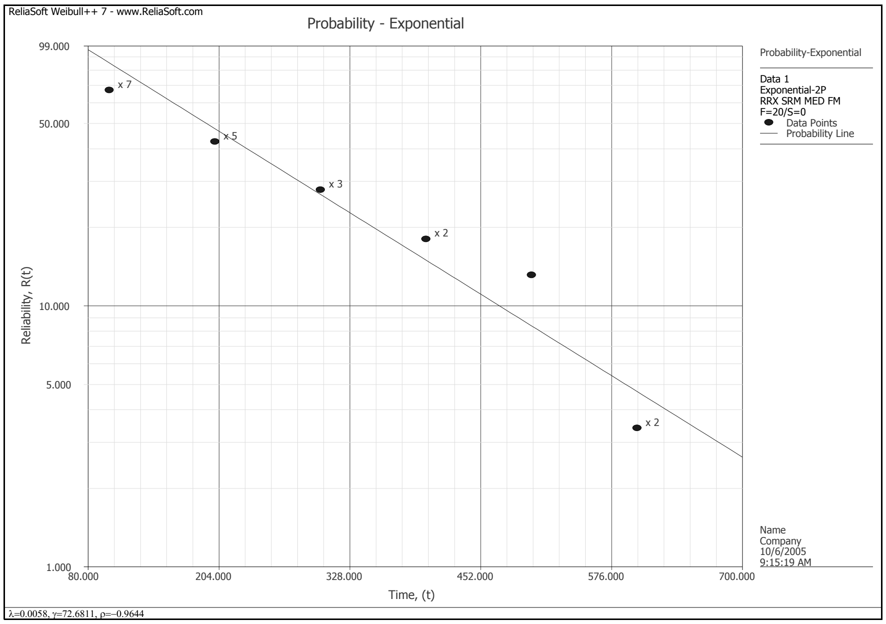
The calculated parameters are shown next.



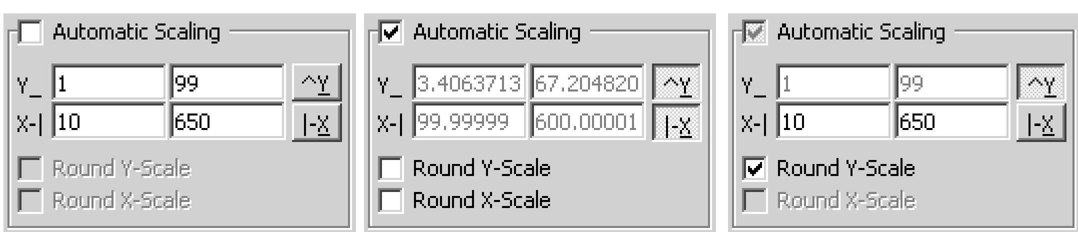
- Plot the data by selecting **Plot** from the **Data** menu or by clicking the **Plot** icon.



- Select **Probability-Exponential** from the Plot Type menu and refresh the display if necessary. The Exponential Probability plot is shown next.

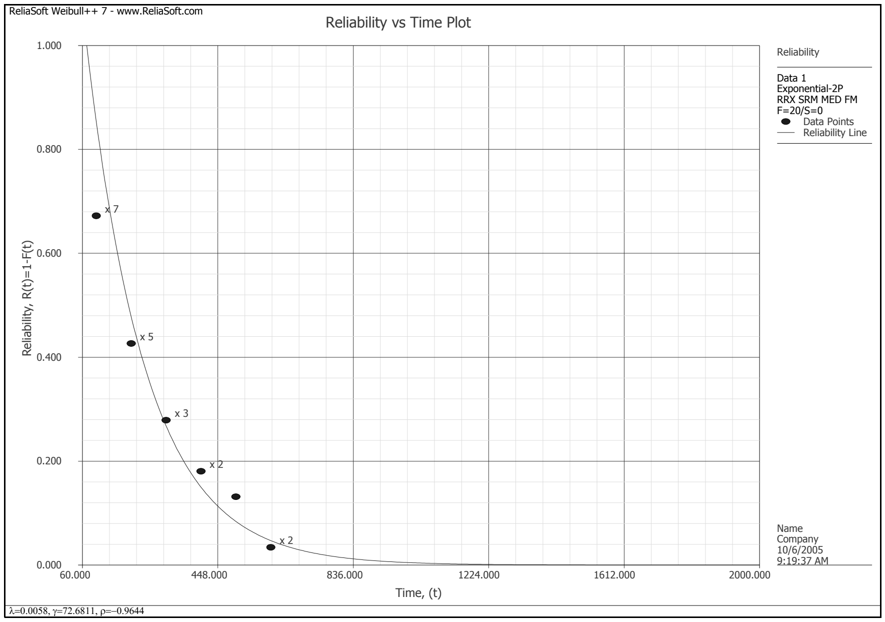


Note that this plot is displayed with automatic scaling and rounding on both the Y-Scale (vertical axis) and X-Scale (horizontal axis). These are the default plot display options in Weibull++. If you de-select the **Round Y-Scale** and **Round X-Scale** options and refresh the display, the scales will be set automatically based directly on the data. If you de-select the **Automatic Scaling** option, you can manually set the starting and ending values for both scales. Finally, the **^Y** and **|-X** buttons allow you to set one scale manually and the other automatically. Changes to the scaling do not take effect until you refresh the plot display. As an example, the figures shown next demonstrate manual scaling for both axes, automatic scaling without rounding and automatic scaling with rounding on the Y axis but manual scaling on the X axis. Other combinations are possible to meet your specific scaling requirements.

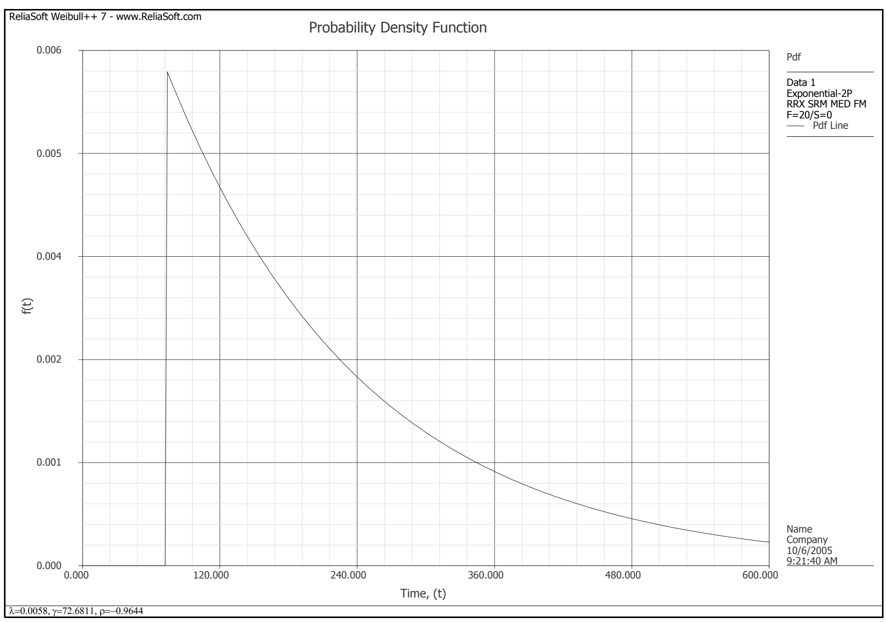


- After you have finished experimenting with the scaling options, return to the default settings (with Automatic Scaling, Round Y-Scale and Round X-Scale selected) before creating the rest of the plots.

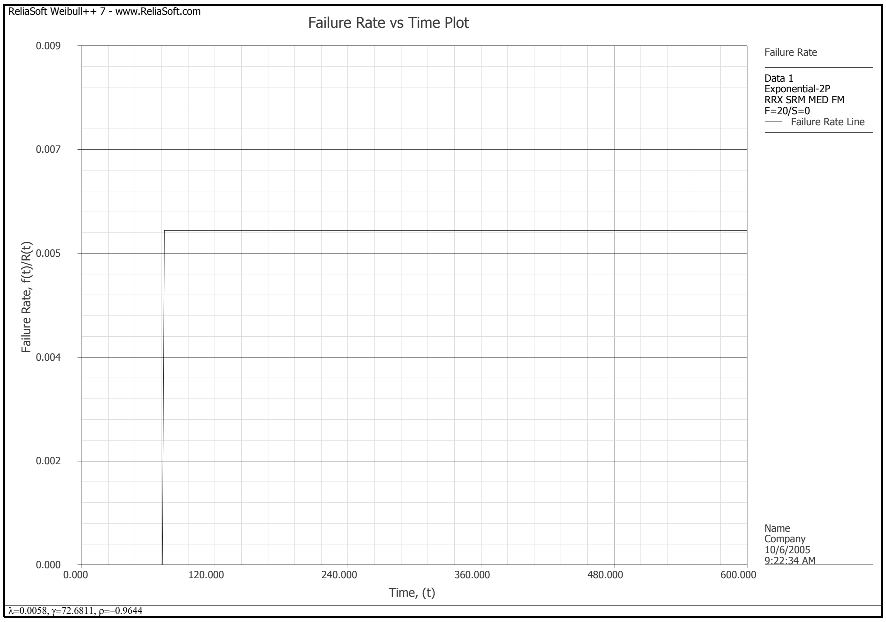
- Select **Reliability vs. Time** from the Plot Type menu and refresh the display if necessary. The plot is shown next.



- Select **Pdf Plot** from the Plot Type menu and refresh the display if necessary. The plot is shown next.



- Select **Failure Rate vs. Time** from the Plot Type menu and refresh the display if necessary. The plot is shown next.



- Close the Folio, save any changes, leave the project open and proceed to the next example.

4.7 Example 6: Normal Probability Plot with Confidence Bounds

Six units were tested to failure and the following times-to-failure were observed: 11,260; 12,080; 12,125; 12,825; 13,550 and 14,670 hr. Assume the data are normally distributed.

Do the following:

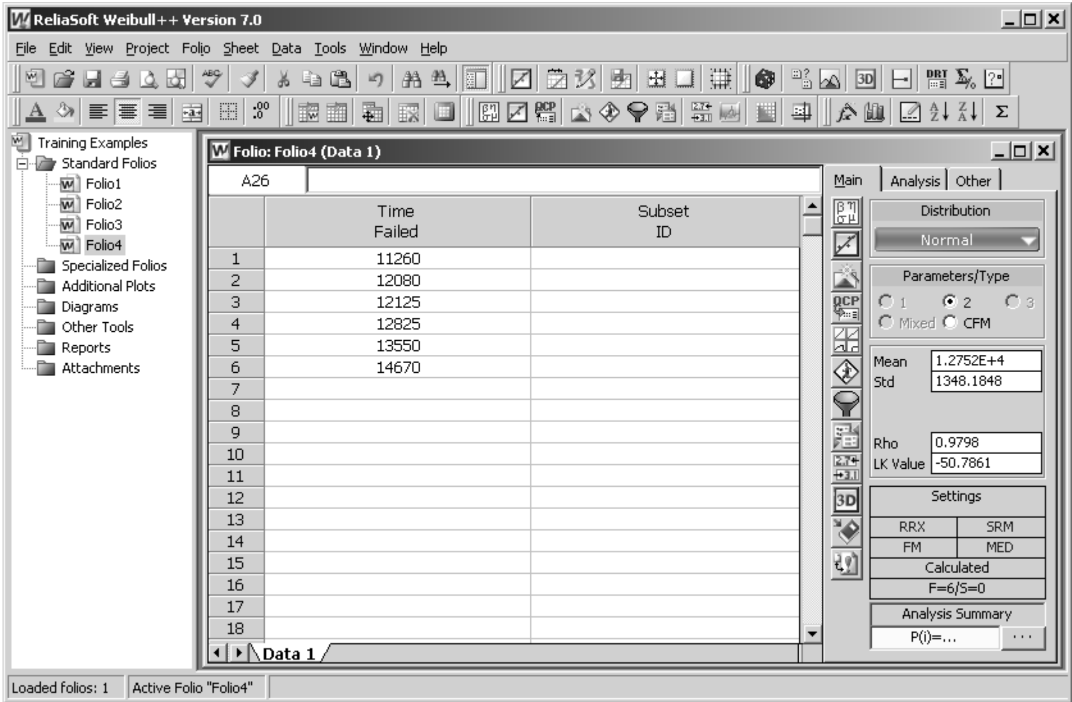
- Determine the parameters for the data using the normal distribution and Rank Regression on X as the parameter estimation method.
- Obtain the Normal Probability plot for the data with 90%, 2-sided Time (Type 1) confidence bounds.
- Obtain the *pdf* plot.

The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Training Examples.rwp." Use Folio4.

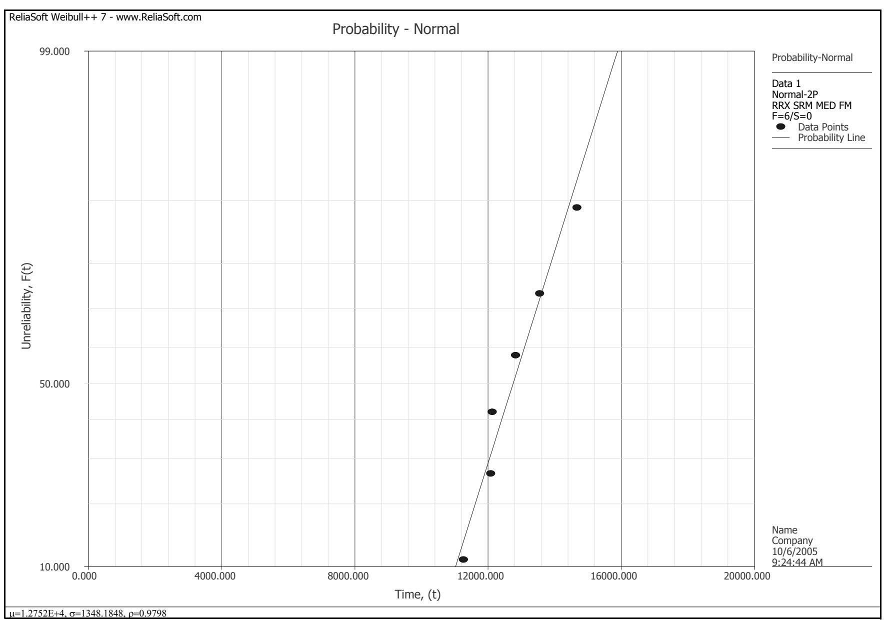
Solution

- With the "Training Examples.rwp" project open, create a new Standard Folio by selecting **Add Standard Folio...** from the **Project** menu or by right-clicking inside the Project Explorer and selecting **Add Standard Folio...** from the shortcut menu.
- In the New Data Sheet Setup window, select **Times-to-failure data** for the Folio Data Type and de-select all other options. Click **OK** to create the new Standard Folio with the data sheet that you have specified.

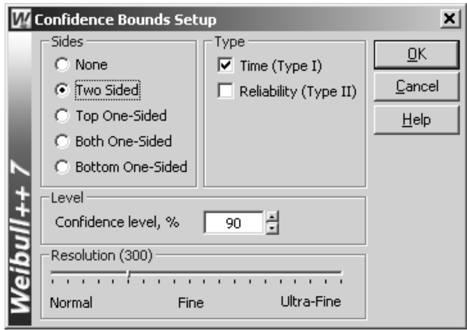
- Enter the data into the new Folio, select the normal distribution with RRX and calculate the parameters, as shown next.



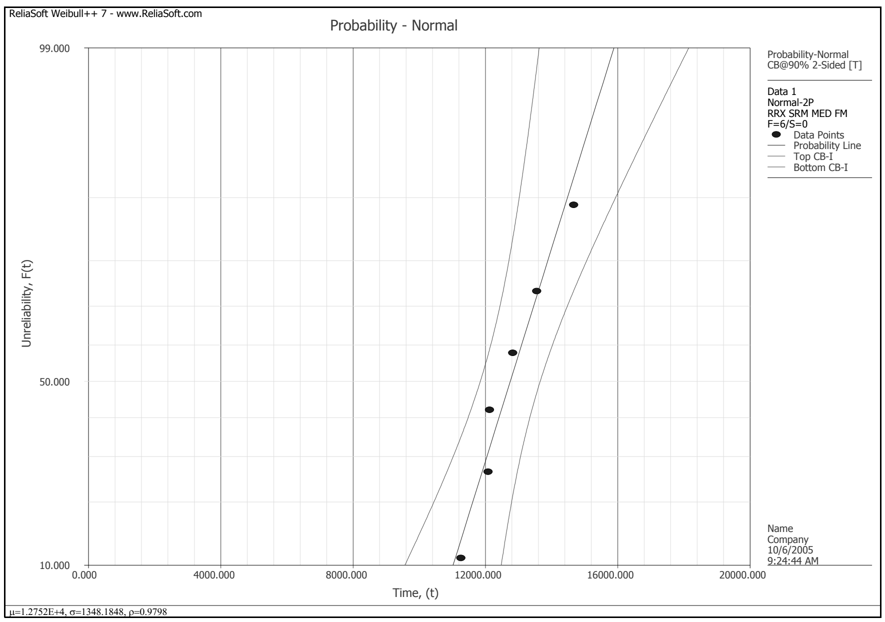
- Create the Normal Probability plot, as shown next.



- Select **Confidence Bounds...** from the **Plot** menu or shortcut menu to open the Confidence Bounds Setup window. Specify **Two-Sided**, **Time (Type I)** and Confidence Level = **90**, as shown next.

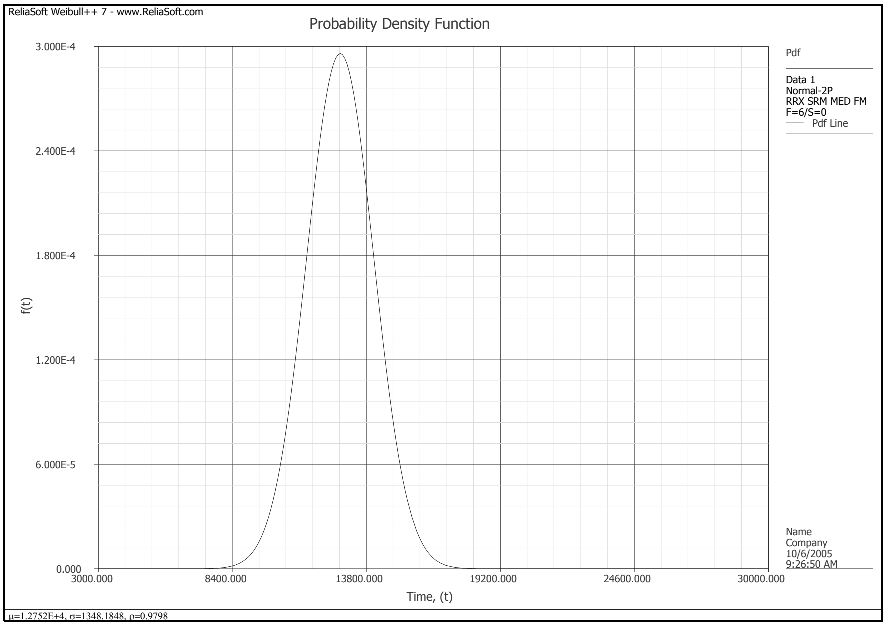


- Click **OK** to close the window and display the confidence bounds on the plot, as shown next.



Note that the plot legend now contains information about the confidence bounds that have been plotted.

- Plot the *pdf* plot, as shown next.



- Click the **Data 1** tab at the bottom of the Folio to return to the data sheet.
- Save the changes, leave the project and Folio open and proceed to the next example.

4.8 Example 7: Calculate Reliability and MTBF with Confidence Bounds

Using the data and analysis from the previous example, do the following:

- Determine the reliability for a mission of 11,000 hr, as well as the two-sided 90% confidence bounds on this reliability.
- Determine the MTTF, as well as the two-sided 90% confidence bounds on this MTTF.

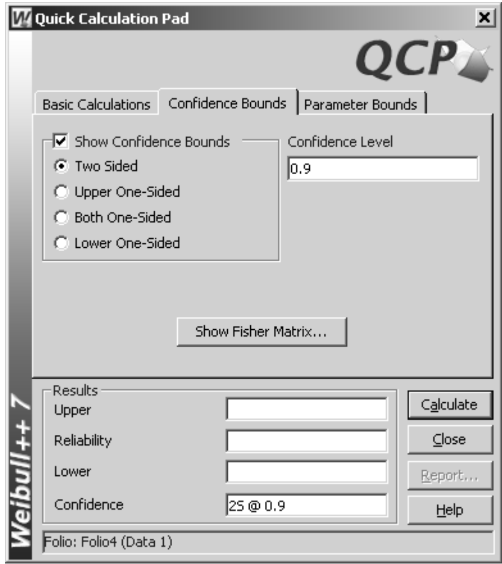
The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Training Examples.rwp." Use Folio4.

Solution

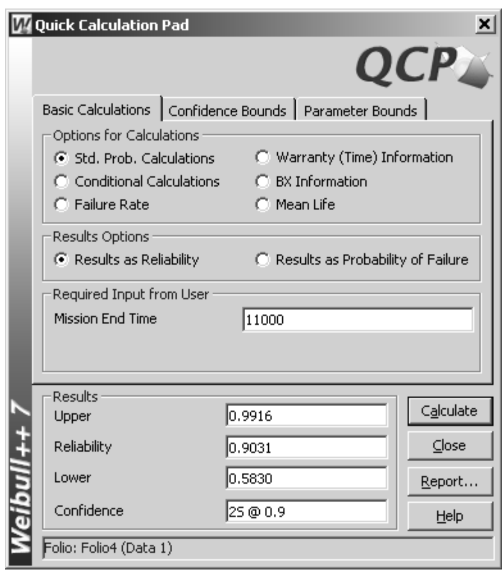
- If Folio4 from the "Training Examples.rwp" project is not already active, open the project and Folio now.
- Open the Quick Calculation Pad by selecting **Quick Calculation Pad...** from the **Data** menu or by clicking the **Quick Calculation Pad** icon.

- On the Basic Calculations page, make the following selections/inputs:
    - Options for Calculations: **Std. Prob. Calculations**
    - Results Options: **Results as Reliability**
    - Required Input from User: Mission End Time = **11000**

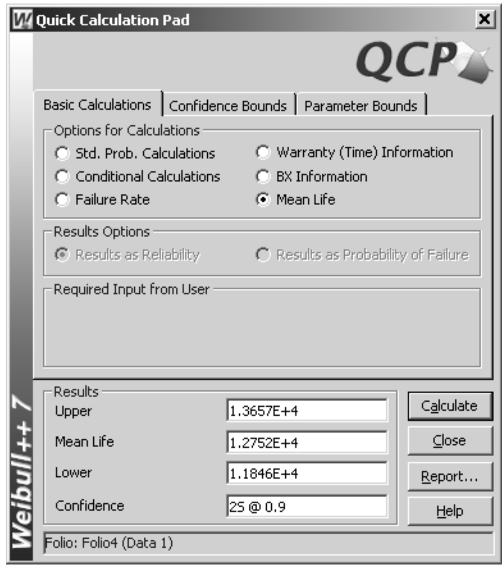
- On the Confidence Bounds page, select **Show Confidence Bounds** to enable the confidence bounds options. Select **Two Sided** and type **.90** for the Confidence Level, as shown next.



- Return to the Basic Calculations page and click **Calculate** to obtain the result with confidence bounds, as shown next.



- To obtain the MTTF, select **Mean Life** under Options for Calculations on the Basic Calculations page. Since the confidence bounds options are already set, click **Calculate** to obtain the results, as shown next.



- Return to the Confidence Bounds page and de-select **Show Confidence Bounds**.
- Click **Close** to close the QCP, leave the project and Folio open and proceed to the next example.

4.9 Example 8: Use the Function Wizard and General Spreadsheet

Using the data from Example 6, obtain tabulated values for the failure rate for ten different mission end times. The mission end times are 1,000 to 10,000 hr, incremented by 1,000 hr.

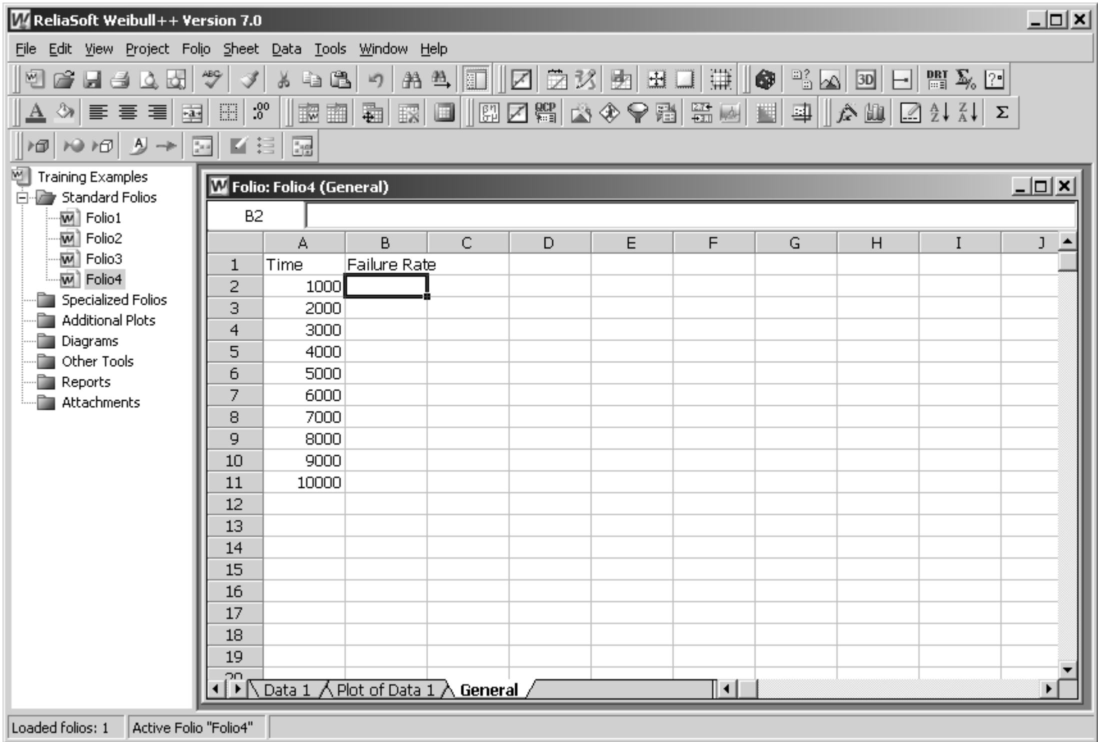
The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Training Examples.rwp." Use Folio4.
Solution

You can easily accomplish this via the use of the Function Wizard within the General Spreadsheet.[5] The General Spreadsheet is very similar to an Excel® spreadsheet. You can input formulas and edit the cells in a similar manner. The Function Wizard allows you to insert a wide array of calculated results based on your inputs and, when applicable, a referenced data sheet.

- If Folio4 from the "Training Examples.rwp" project is not already active, open the project and Folio now.
- Insert a General Spreadsheet by selecting **Insert General Spreadsheet** from the **Folio** menu or by clicking the icon in the Folio Tools toolbar.

[5] The General Spreadsheet is presented in detail in Chapter 20 of the *Weibull++ User's Guide* and the Function Wizard is presented in Chapter 22.

- Type “Time” in cell A1 and “Failure Rate” in cell B1. Then enter 1000 through 10000 in cells A2 to A11.[6] Finally, place the cursor into cell B2, as shown next.

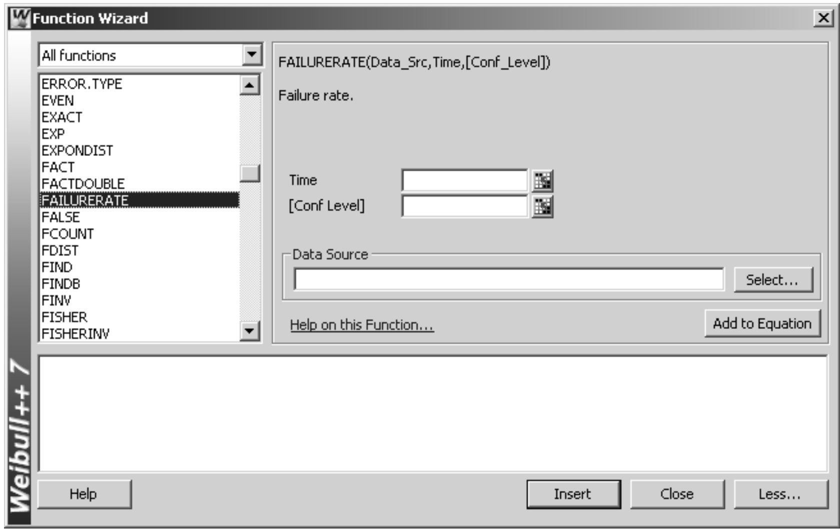


- Open the Function Wizard by selecting **Function Wizard** from the **Data** menu or by clicking the **Function Wizard** icon.

- Select **FAILURERATE** from the list of functions. Note that the functions are in alphabetical order and if you click inside the list and start typing the name of the function, the selection will automatically move to the first function in the list that matches the letters you have typed. Also note that the menu

[6] To save time, you could also type the equation “=A2+1000” into cell A3 and then copy/paste the equation through cell A11.

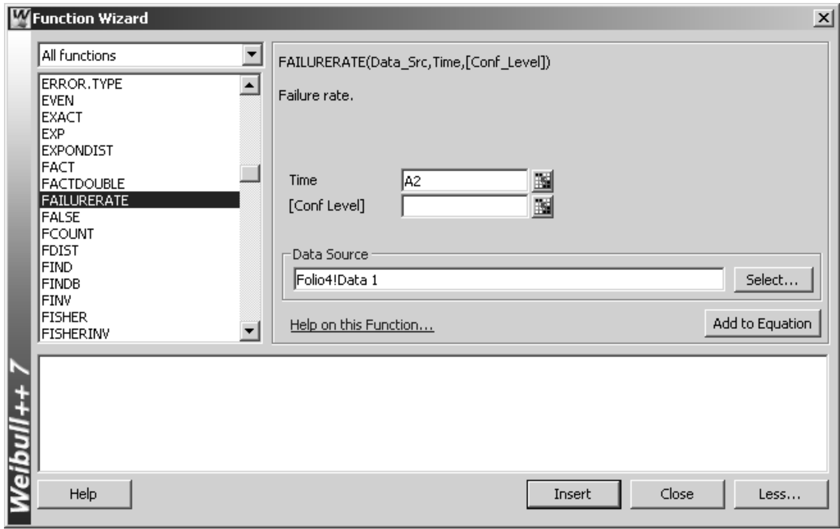
above the list allows you to filter the list to display only those functions of a specific type. With the failure rate function selected, the wizard will look like the figure shown next.



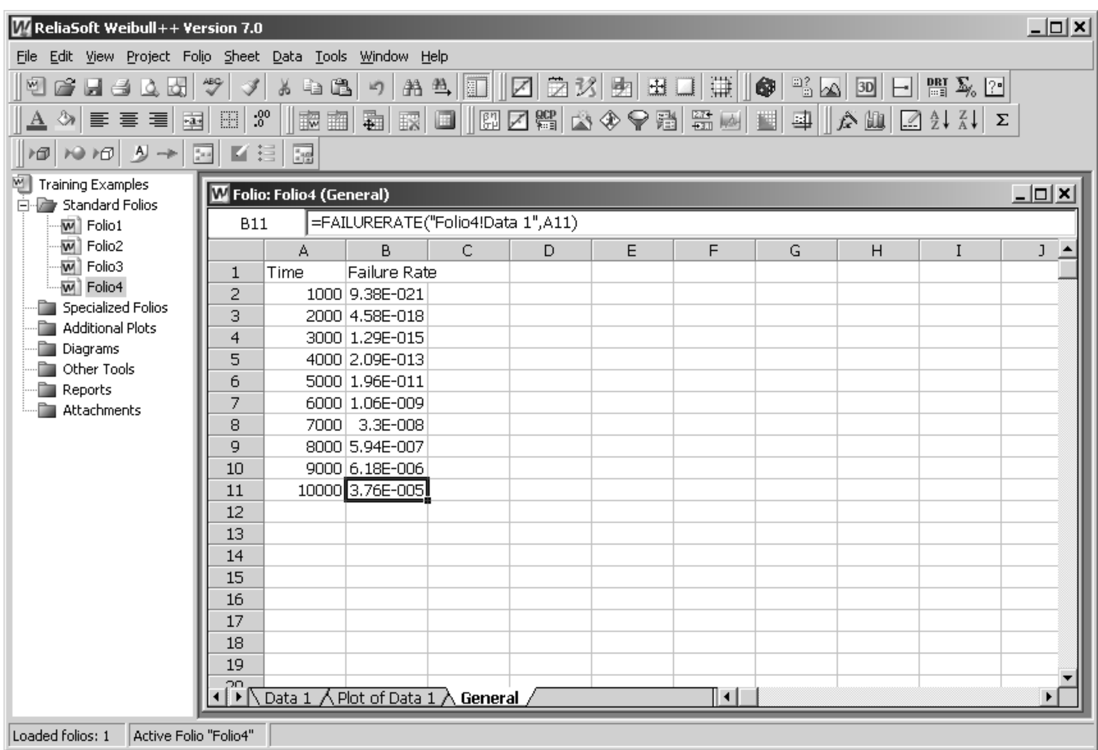
The inputs required for the selected function are displayed on the right side of the window. The text box at the bottom of the window allows you to build the function that will be inserted into the spreadsheet.

- Enter **A2** for Time. This indicates that the time input for the equation will be obtained from the specified cell in the worksheet.
- To specify the existing Weibull++ analysis that the function result will be based on, click **Select...** to open the Select Folio/Data Sheet window and then navigate to the desired sheet. If you have been performing all of the examples in the Training Examples.rwp project as specified in this training guide, this will be Data 1 in Folio4, as shown next.

- Click **OK** to close the window and return to the Function Wizard. The wizard will look like the figure shown next.



- Click **Insert** to close the window and insert the function code into the General Spreadsheet. Functions are inserted into the cell that was active when you opened the Function Wizard.
- Copy the function into cells B3 through B11. One way to do this is to position the mouse over the bottom right corner of cell B2 and when the cursor turns into a plus symbol (+), click and drag the mouse to cell B11.
- By selecting one of the cells that you copied the function into, you can see that the cell reference was updated to match the current row, as shown next with cell B11 selected.



The table that you have created displays the failure rate for each time in column A, based on the analysis in the associated data sheet.

- Close the Folio, save any changes, leave the project open and proceed to the next example.

4.10 Example 9: Analyze Interval Data

Consider the interval data given below. The data set contains the inspection times of 167 identical parts in a machine and the number of them found cracked at the end of each inspection time.

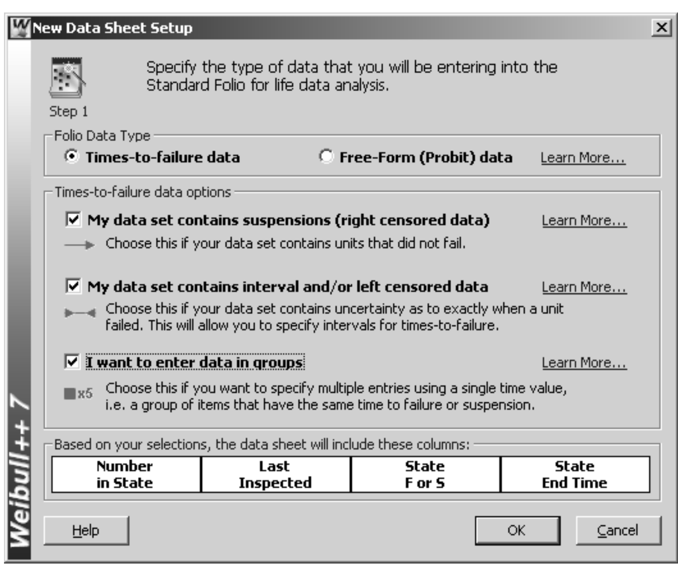
Number in State	Last Inspected	State	State End Time
5	0	F	6.12
16	6.12	F	19.92
12	19.92	F	29.64
18	29.64	F	35.40
18	35.40	F	39.72
2	39.72	F	45.24
6	45.24	F	52.32
17	52.32	F	63.48
73	63.48	S	63.48

Determine the parameters of the 2-parameter Weibull distribution using Maximum Likelihood Estimation and obtain the 3D Log-Likelihood Function surface plot.

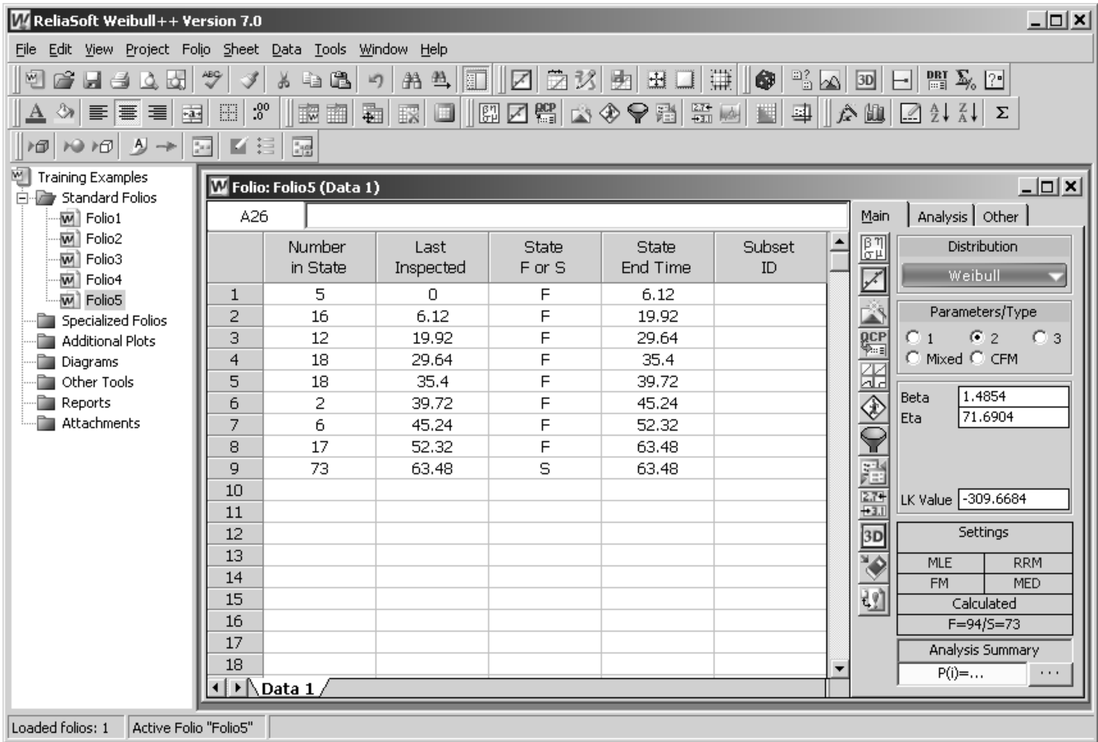
The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Training Examples.rwp." Use Folio5.

Solution

- With the "Training Examples.rwp" project open, create a new Standard Folio by selecting **Add Standard Folio...** from the **Project** menu or by right-clicking inside the Project Explorer and selecting **Add Standard Folio...** from the shortcut menu.
- In the New Data Sheet Setup window, select **Times-to-failure data** for the Folio Data Type and select all of the options under Time-to-failure data options, as shown next.

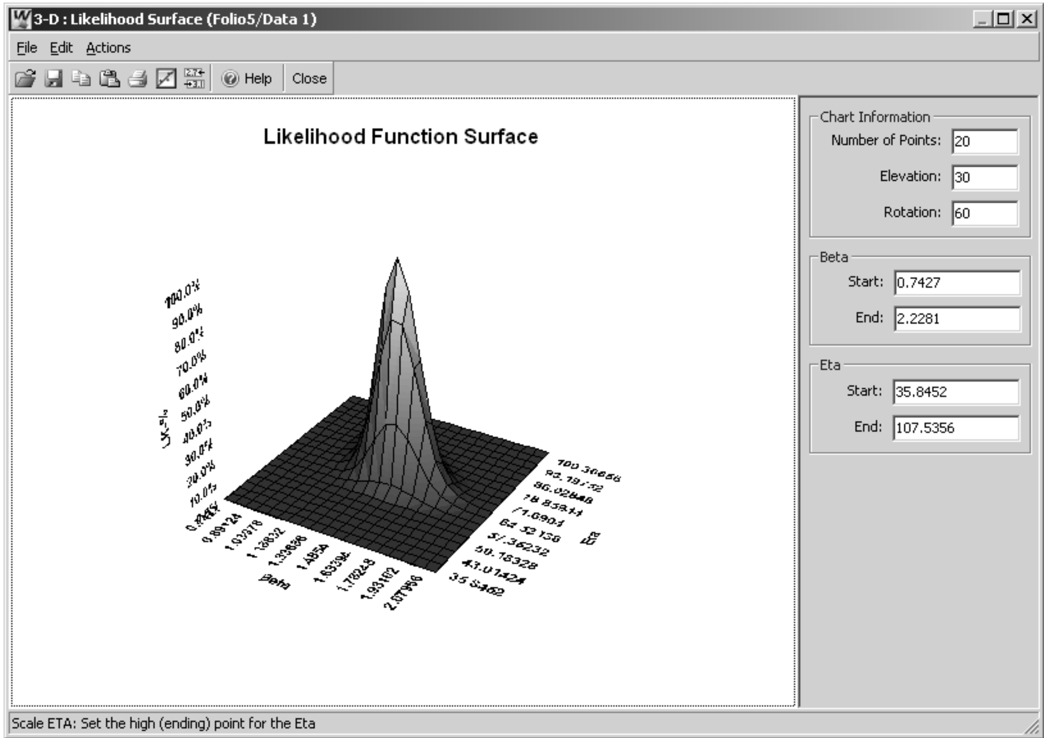


- Click **OK** to create the new Standard Folio with the data sheet that you have specified.
- Enter the data and calculate the parameters with the 2-parameter Weibull distribution and MLE, as shown next.



- Create the 3D Likelihood Function Surface plot by selecting **ReliaSoft 3D (LK Function)...** from the **Tools** menu or by clicking the icon in the Control Panel or the General Tools toolbar.

The plot is shown next.



To rotate the plot, click the plot then press the **Ctrl** key while holding down the left mouse button and moving the mouse. Note that the peak of the surface is at the center of the beta-eta plane.

- When you are finished experimenting with the 3D plot utility, close the window by selecting **Close** from the **File** menu or by clicking the **Close** button in the toolbar.
- Close the Folio and save any changes to the project.
- Close the project by selecting **Close** from the **File** menu and proceed to the next example.

4.11 Example 10: Analyze Accelerated Test Data

A new product was reliability tested. Since the life of this product under operating conditions is expected to be more than 15,000 hr, testing under these conditions is not time-wise feasible. For this reason, it was decided to run an accelerated test for this product. The operating temperature for this product is 323K (50°C) and temperature is the only acceleration variable. A table of the data obtained from the test for three different operating stress levels is given below.

Stress Level, K	393K	408K	423K
Times-to-failure, hr	3850	3300	2750
	4340	3720	3100
	4760	4080	3400
	5320	4560	3800
	5740	4920	4100
	6160	5280	4400
	6580	5640	4700
	7140	6120	5100
	7980	6840	5700
	8960	7680	6400

Do the following:

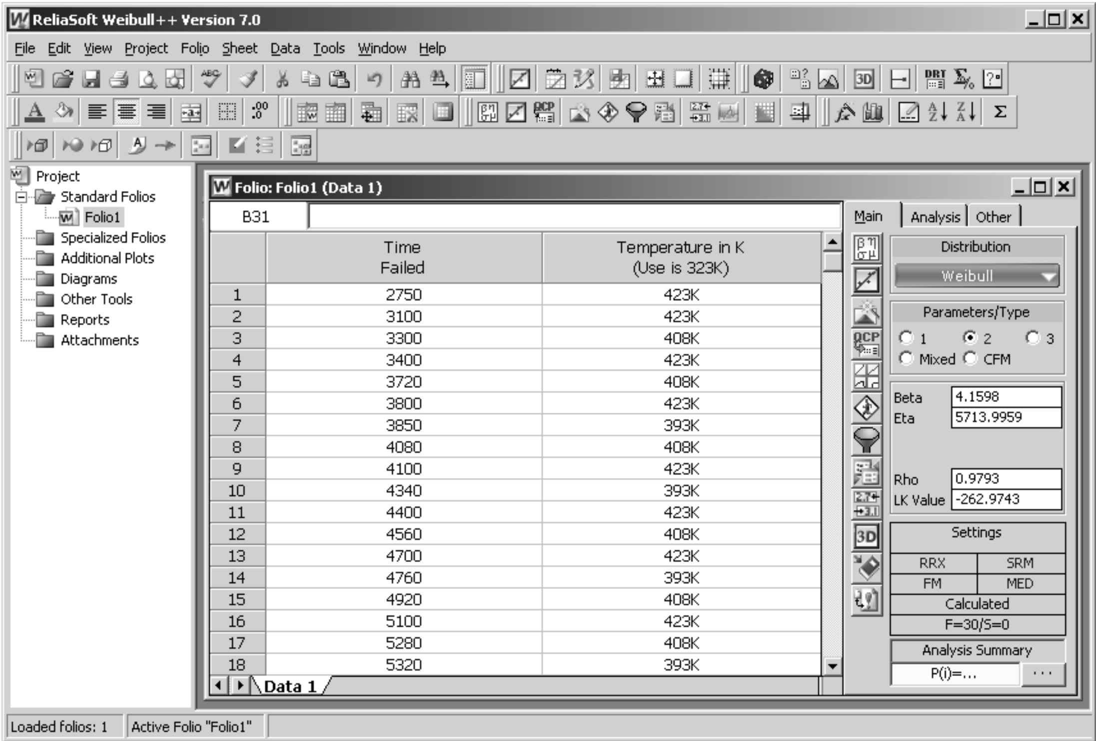
- Determine the parameters of the 2-parameter Weibull distribution at each stress level using Rank Regression on X.
- Estimate the parameters for the Eyring model.
- What is the reliability of the unit for a mission duration of 9,000 hr, starting the mission at $T = 0$ and at the operating temperature (323K)?

The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Accelerated Analysis.rwp."

Solution

- Create a new project with a new Standard Folio for time-to-failure data.
- The Subset ID column will be used to identify the stress level at which each failure time was observed. To rename this column, double-click the column header, type "Temperature in K (Use is 323K)" in the Change Heading window and click **OK** to update the data sheet. Note that you can edit all column headings, row headings and tab names in a similar manner.

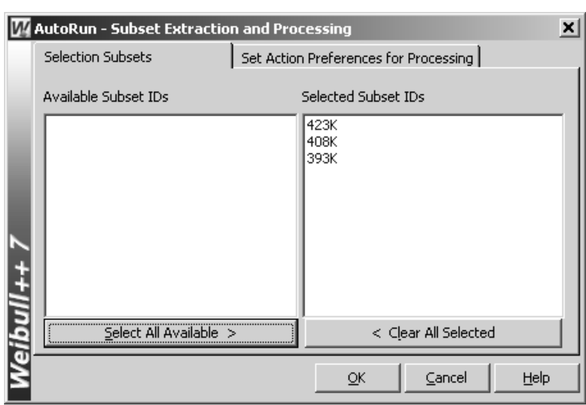
- Enter the data and calculate the parameters with the 2-parameter Weibull and RRX, as shown next (with only the first 18 data points visible in the picture).



The Batch Auto Run feature allows you to break down the original data set into three different data sets based on the different operating temperatures. The Batch Auto Run uses the Subset IDs to extract the data.[7]

- Open the AutoRun window by selecting **Batch Auto Run...** from the **Data** menu or by clicking the **Batch Auto Run** icon in the Control Panel or Data Analysis Tools toolbar.

- Click **Select All Available>** to apply the Batch Auto Run process to all three of the Subset IDs in the current data set. The window will look like the figure shown next.



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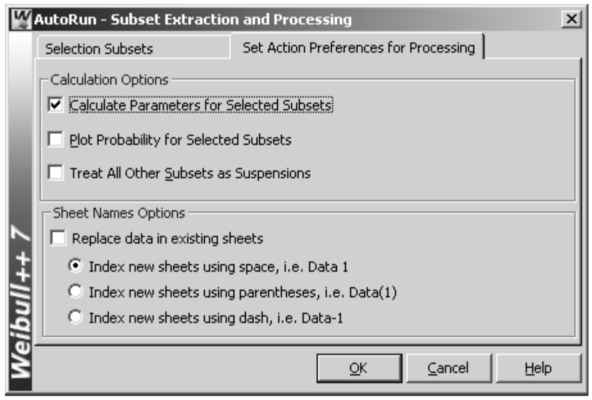
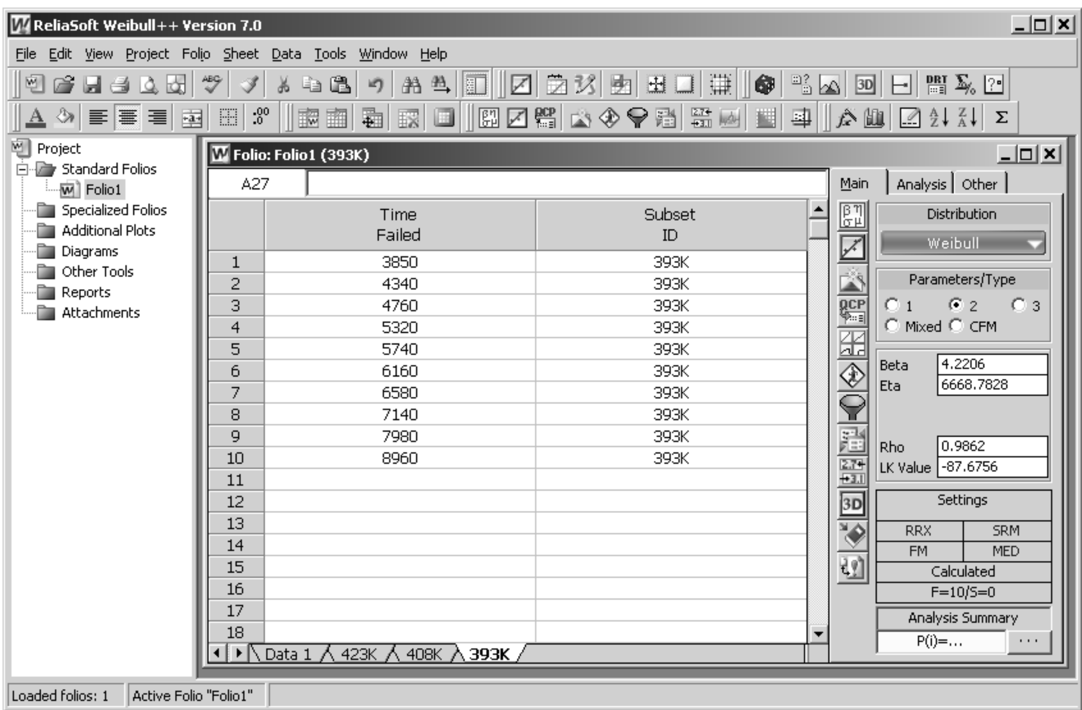
[7] Batch Auto Run is presented in detail in Chapter 6 of the *Weibull++ User's Guide*.

- Click the **Set Action Preferences for Processing** tab to view/set the calculation and sheet name options. For this example, only the **Calculate Parameters for Selected Subsets** option will be selected, as shown next. This indicates that the parameters will be calculated automatically for each extracted data set.



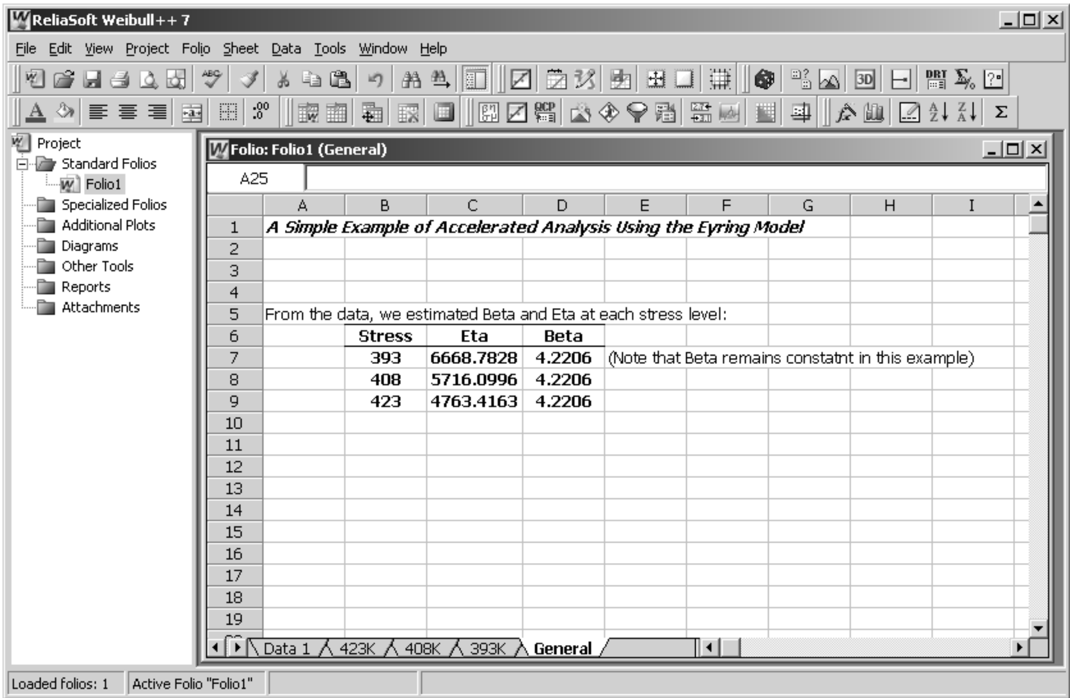
- Click **OK** to initiate the Batch Auto Run process.
- When the process is complete, the Folio will look like the one shown next.



You will notice that three new data sheets labeled 423K, 408K and 393K will appear in the Folio. Each data sheet contains the data that has been extracted for the specified Subset ID (*i.e.* stress level). You can click each tab to view the new data sheets. Notice that the parameters have already been calculated for each stress level.

- Insert a General Spreadsheet by selecting **Insert General Spreadsheet** from the **Folio** menu or by clicking the icon.

- Enter the parameters that have been calculated for each stress level into the spreadsheet. You can type the parameters or use the PARAMETER function in the Function Wizard. If you use the Function Wizard, use **1** for the Param Index to return Beta and use **2** for the Param Index to return Eta.
- With some additional headings and explanations, the spreadsheet will look like the figure shown next.

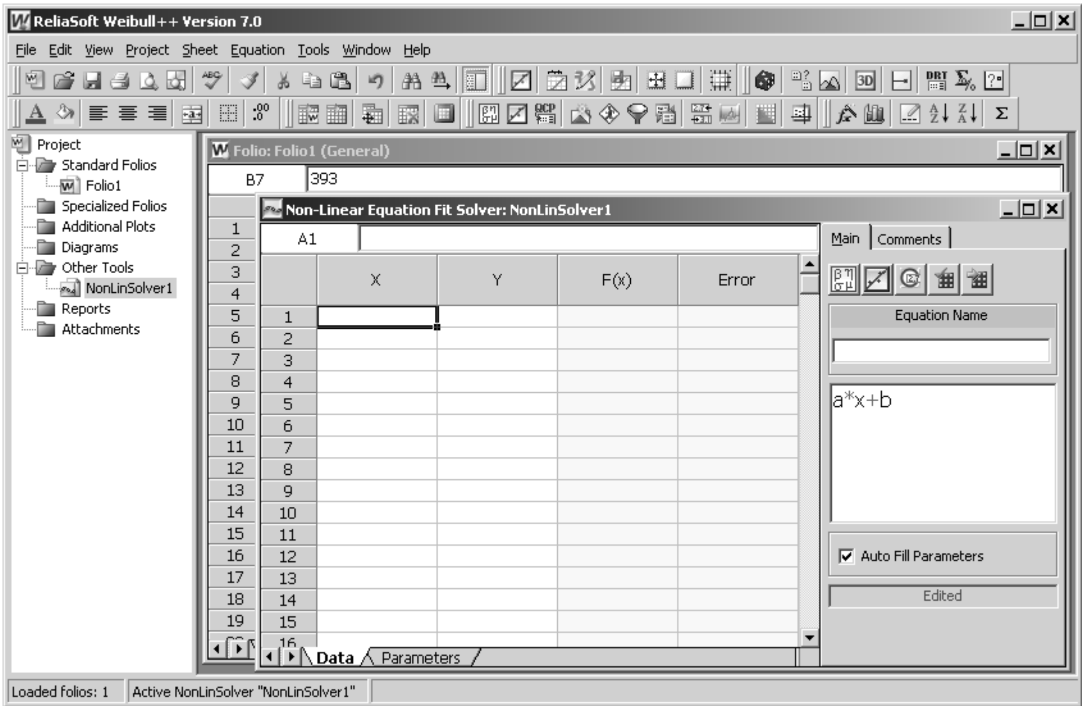


The Non-Linear Equation Fit Solver can be used to estimate the parameters of the Eyring model.[8]

- Highlight the cells containing the stress and eta values (it is assumed that beta remains constant at each stress level, which is the case for this data set). Copy the data to the Clipboard.

8. The Non-Linear Equation Fit Solver is presented in detail in Chapter 17 of the *Weibull++ User's Guide*.

- Open the Non-Linear Equation Fit Solver by selecting **Add Other Tools** then **Add Equation Fit Solver** from the **Project** menu or shortcut menu. This window will now be accessible from the Project Explorer and is currently active within the MDI, as shown next.



- Place the cursor into the first cell in the X column and paste the data that you copied from the General Spreadsheet. Note that if you used the Function Wizard to enter the parameters in the General Spreadsheet, you will need to select **Paste Special** then **Paste Values** from the **Edit** menu, as formulas cannot be pasted into the Non-Linear Equation Fit Solver.

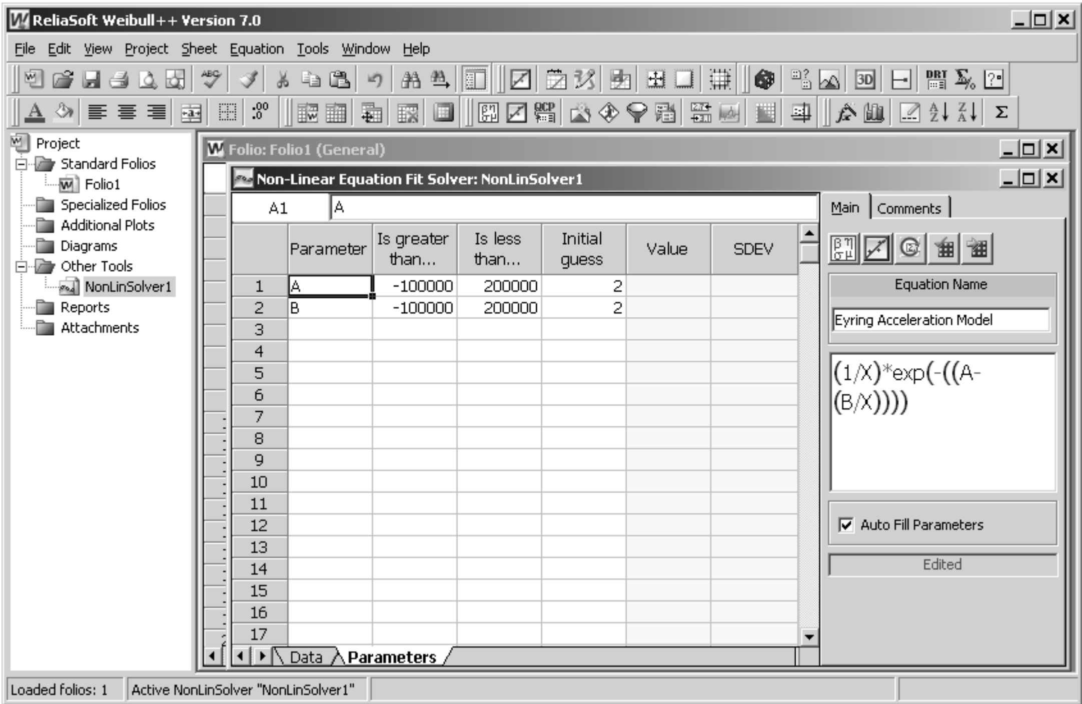
- In the Control Panel on the right, type the following equation for the Eyring model:

$$(1/X)^*\exp(-((A-(B/X))))$$

- Enter **Eyring Acceleration Model** for the Equation Name

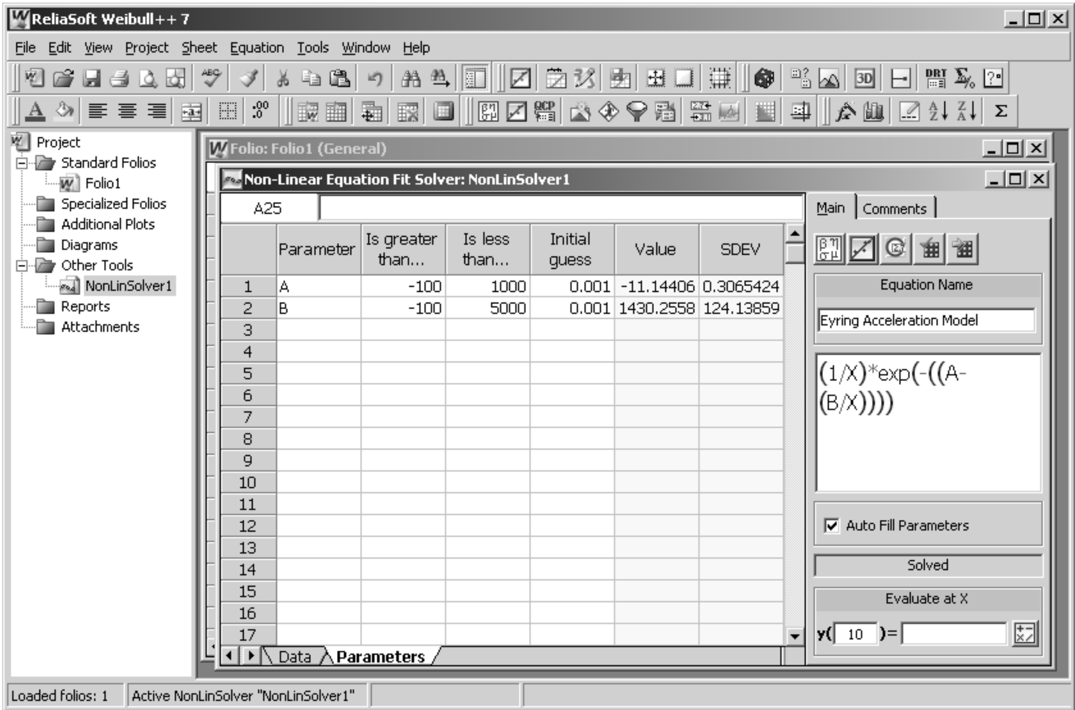
- Click the **Add to Templates** icon to include this equation among the saved equation templates that can be re-used at a later time in other analyses.

- Click **OK** to close the window that confirms that the equation has been saved. The window will now look like the figure shown next. Notice that the focus was switched automatically to the Parameters sheet when you typed the parameters to be solved for (A and B) into the equation.



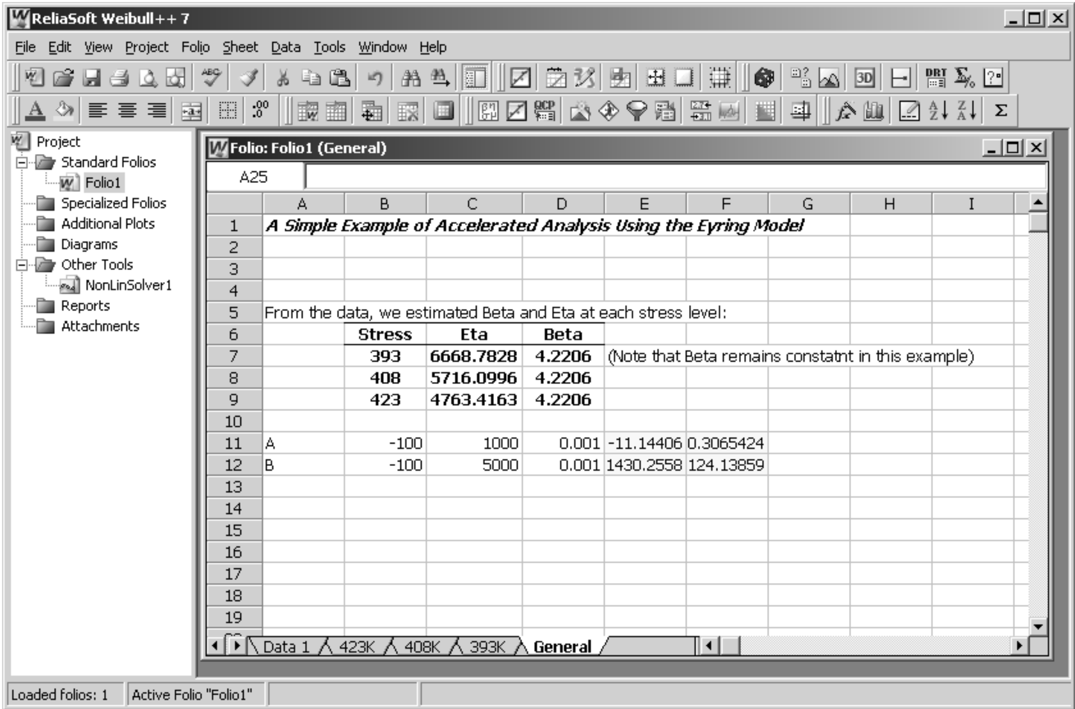
- Enter the following values for the parameter A:
  - Is greater than: **-100**
  - Is less than: **1000**
  - Initial guess: **0.001**
- Enter the following values for the parameter B:
  - Is greater than: **-100**
  - Is less than: **5000**
  - Initial guess: **0.001**

- Select **Calculate** from the **Equation** menu or click the **Calculate** icon. The results are shown next.



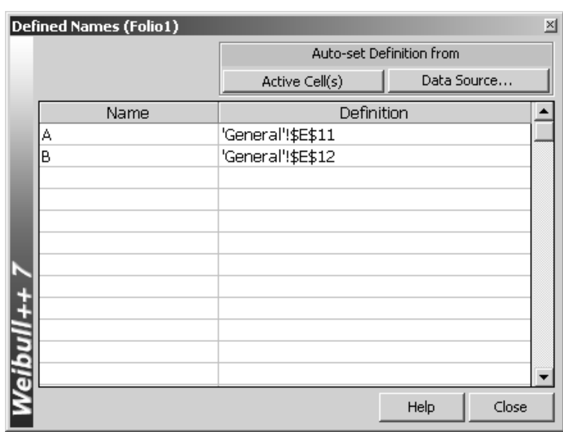
The values for A and B are given within the "Value" column. The standard deviation for each parameter appears within the "SDEV" column. Using the solution of the parameters for the Eyring model, you can calculate the value of eta (η) for any temperature (stress level), particularly in this case for the operating temperature of 323K.

- Copy the solutions for the parameters of the Eyring model and paste them into the General Spreadsheet, as shown next.



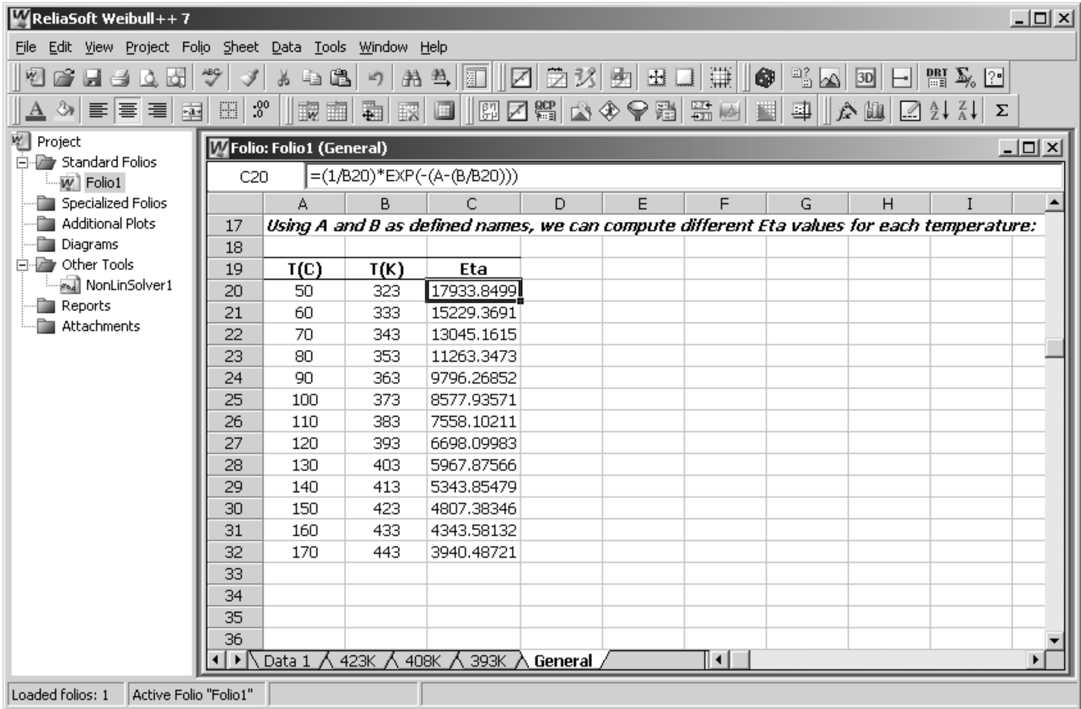
To aid in the process of calculating eta at different stress levels, the parameters A and B will be defined as named variables within the spreadsheet. This allows you to reference these values in a formula without having to input the actual value.

- Click the cell containing the solution of A, in this case cell E11, and select **Define Name...** from the **Sheet** menu to open the Defined Names window. Type “A” in the first row of the **Name** column then click the **Active Cell(s)** button to associate the specified name with the cell that is currently active in the spreadsheet.
- Type “B” in the second row of the **Name** column, go to the spreadsheet and click the cell containing the solution of B (E12), return to the Define Names window then click the **Active Cell(s)** button again. The window will look like the figure shown next.



- Click **Close** to save these variable name definitions and return to the General Spreadsheet.

- Using the Eyring model and the defined parameters, A and B, create a table like the one shown next to calculate the value of eta for a range of temperatures (323K-443K). For example, for cell C20, enter the following formula: **=(1/B20)*exp(-(A-(B/B20)))** and press **Enter**. Be sure to type the formula as it applies to the current structure of your General Spreadsheet.



The value of eta at a stress level of 323K is estimated to be 17933.85.

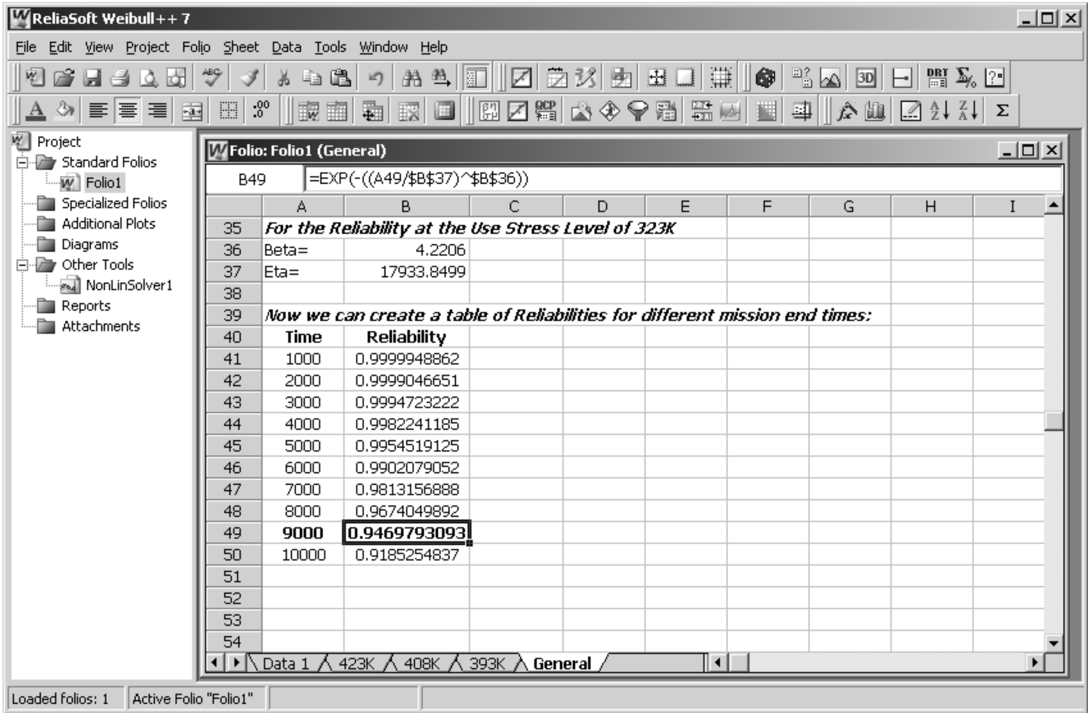
The final part of this example involves estimating the reliability of the product at the operating stress level (323K) for 9,000 hr of operation. The Weibull distribution was used to calculate the values of the parameters eta and beta.

The Weibull reliability function is given by:

$$R(T) = e^{-\left(\frac{T}{\eta}\right)^{\beta}}$$

- Create a table of reliabilities for a range of different end times (1000 - 10000 hr) within the General Spreadsheet using the Weibull reliability function. When referencing the cells containing the values of beta and eta within the formula to calculate the reliability, you must refer to these cells as an absolute reference. This involves inserting a **$** in front of the column letter and the row number. In the next figure, the values of beta and eta are located within cells B36 and B37, respectively. When typing the formula for the Weibull reliability function, these two cells must be referenced using the following format: B36 and B37. In cell B41, enter the following formula: **=exp(-((A41/B37)^B36))**.

Copy the formula down to cell B50. The reliability has now been calculated for all of the end times in question, as shown next.



The reliability at 9,000 hr is estimated to be 94.6979%.

- Save the project as "Accelerated Analysis.rwp" then close the project and proceed to the next example.

4.12 Example 11: Degradation Data Analysis

Five turbine blades were tested for crack propagation. The test units were cyclically stressed and inspected every 100,000 cycles for crack length. Failure is defined as a crack of length 30mm or greater. Following is a table of the test results:

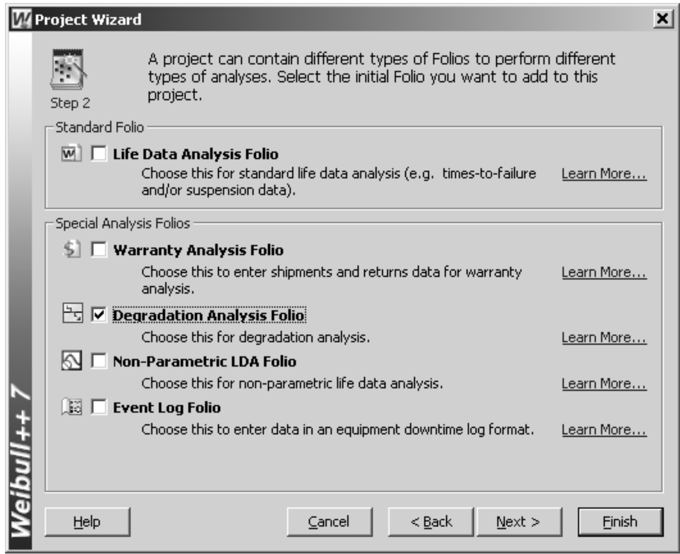
Cycles (x1000)	Unit A	Unit B	Unit C	Unit D	Unit E
100	15mm	10mm	17mm	12mm	10mm
200	20mm	15mm	25mm	16mm	15mm
300	22mm	20mm	26mm	17mm	20mm
400	26mm	25mm	27mm	20mm	26mm
500	29mm	30mm	33mm	26mm	33mm

Using Weibull++'s Degradation Analysis module and the Quick Calculation Pad, determine the B10 life for the blades using degradation analysis with an exponential model for the extrapolation.

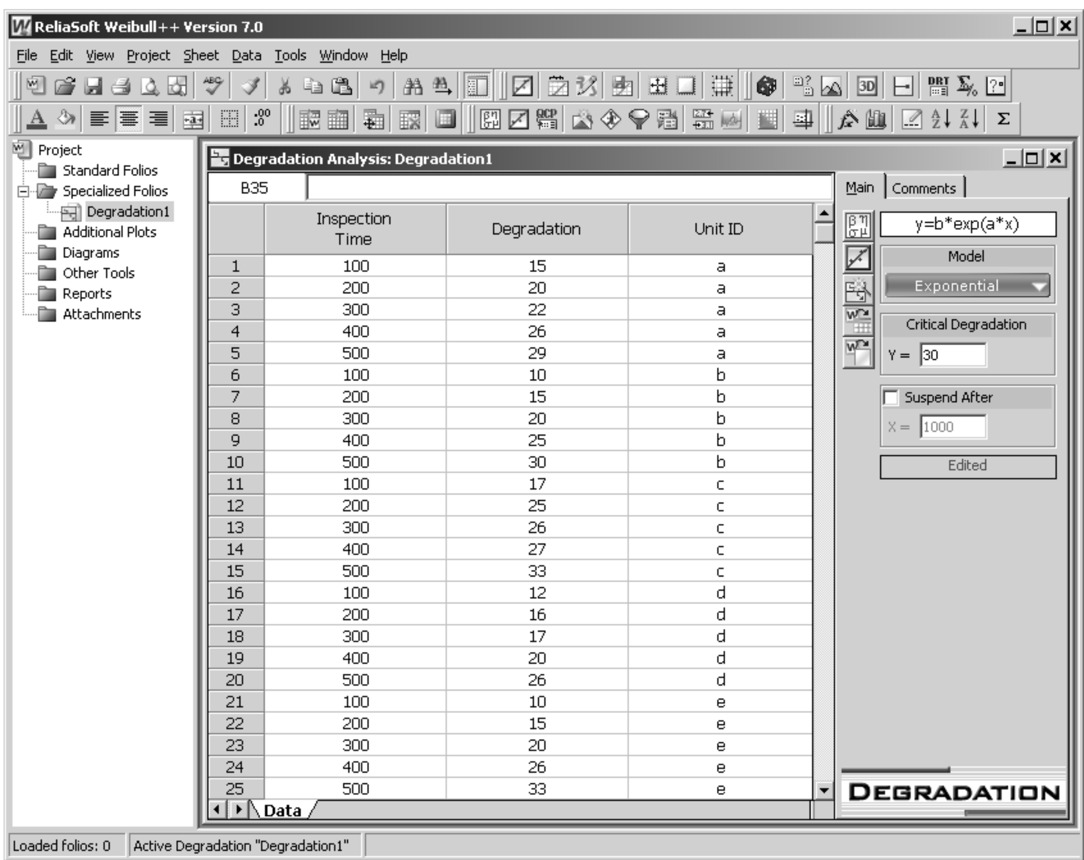
The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Degradation Analysis.rwp."

Solution

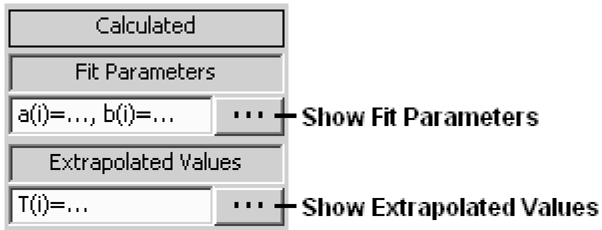
- Create a new project. On the second page of the Project Wizard, select **Degradation Analysis Folio**, as shown next then click **Finish**. This will add a folio to the new project that has been specially designed for degradation analysis.



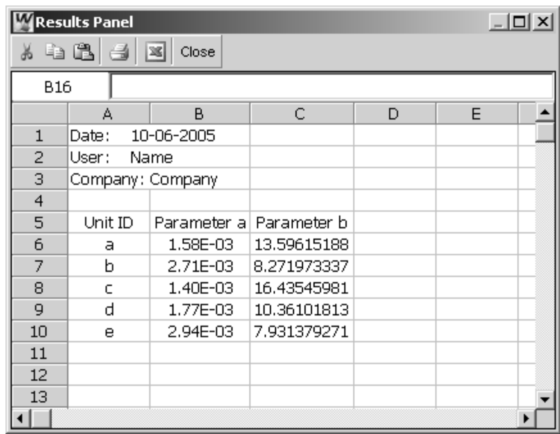
- Enter the data, select **Exponential** for the model and enter **30** for the Critical Degradation, as shown next. There is no suspension time for this example.



- Apply the model to the data set by selecting **Calculate** from the **Data** menu or by clicking the **Calculate** icon.
- To view the calculated parameters, click the **Show Fit Parameters** button in the Control Panel. To view the extrapolated failure times, click the **Show Extrapolated Values** button.

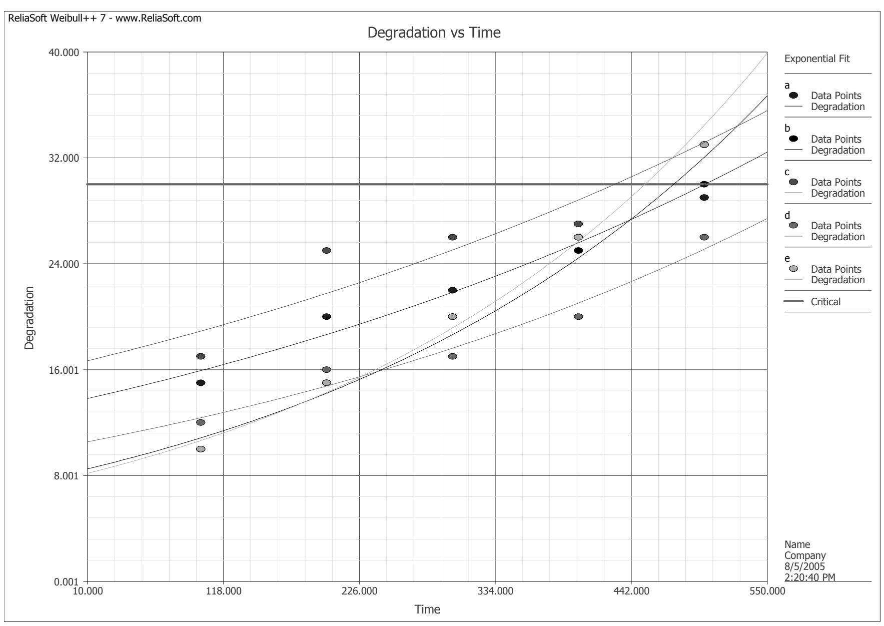


The parameter results are shown next.



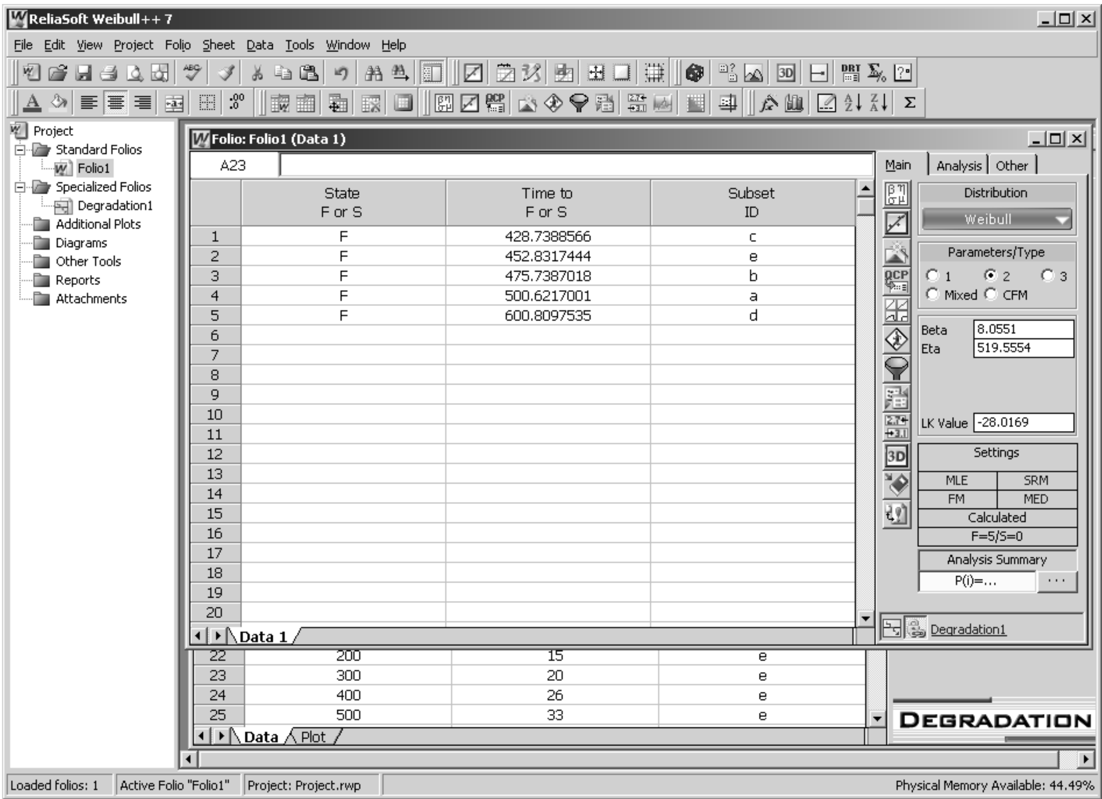
	A	B	C	D	E
1	Date: 10-06-2005				
2	User: Name				
3	Company: Company				
4					
5	Unit ID	Parameter a	Parameter b		
6	a	1.58E-03	13.59615188		
7	b	2.71E-03	8.271973337		
8	c	1.40E-03	16.43545981		
9	d	1.77E-03	10.36101813		
10	e	2.94E-03	7.931379271		
11					
12					
13					

- Click **Close** to close the Results Panel window.
- Plot the results in a new sheet by selecting **Plot** from the **Data** menu or by clicking the **Plot** icon. With all units selected to be displayed, the plot will look like the one shown next.



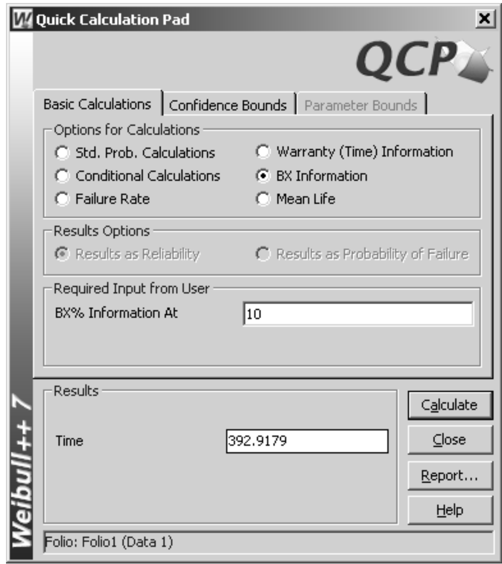
- To transfer the extrapolated failure times to a Standard Folio, return to the Data sheet and select **Transfer Life Data to New Folio** from the **Data** menu or click the icon.

- Double-click **Folio1** in the Project Explorer to open the new Standard Folio that the failure and suspension times were transferred to. Select the 2-parameter Weibull distribution with MLE and calculate the parameters. The estimated parameters for this data set are beta = 8.0551 and eta = 519.5554, as shown next.



Note that the Specialized Folio that you created for the degradation analysis is now associated with the Standard Folio that you transferred the life data to. You can click the link at the bottom of the Control Panel to open the associated Degradation Analysis Folio. In addition, if you change and re-calculate the degradation analysis, the associated Standard Folio will be updated automatically.

- Open the Quick Calculation Pad. Select **BX Information** and enter **10** for the percentage. Click **Calculate**. The results are shown next.



Using the Degradation Analysis utility and the QCP, the B10 life is calculated to be 392,918 cycles.

- Close the QCP.
- Save the project as “Degradation Analysis.rwp” then close the project and proceed to the next example.

4.13 Example 12: Warranty Data Analysis

A company keeps track of its shipments and warranty returns on a month-by-month basis. Following is a table for shipments in June, July and August and the warranty returns through September:

		Returns		
Months	**Shipments**	**July**	**Aug.**	**Sept.**
June	100	3	3	5
July	140	-	2	4
Aug.	150	-	-	4

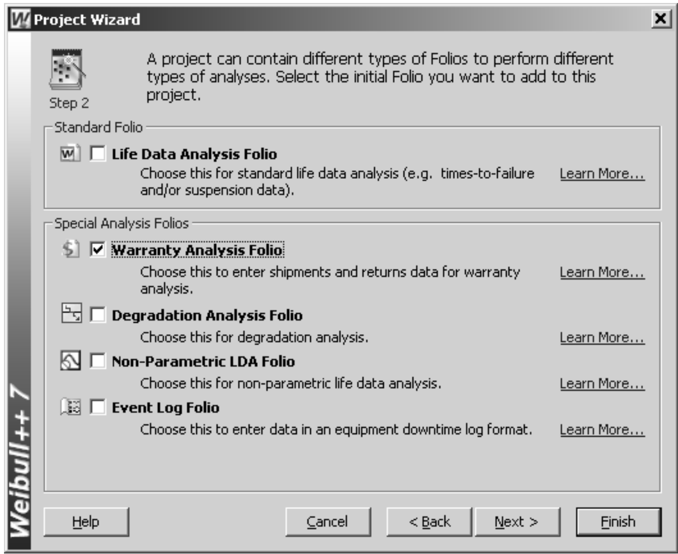
Do the following:

- Using Weibull++'s Warranty Analysis module, convert this information to life data and determine the parameters for a 2-parameter Weibull distribution.
- Predict the number of products from each of the three shipment periods that will be returned under warranty in October.

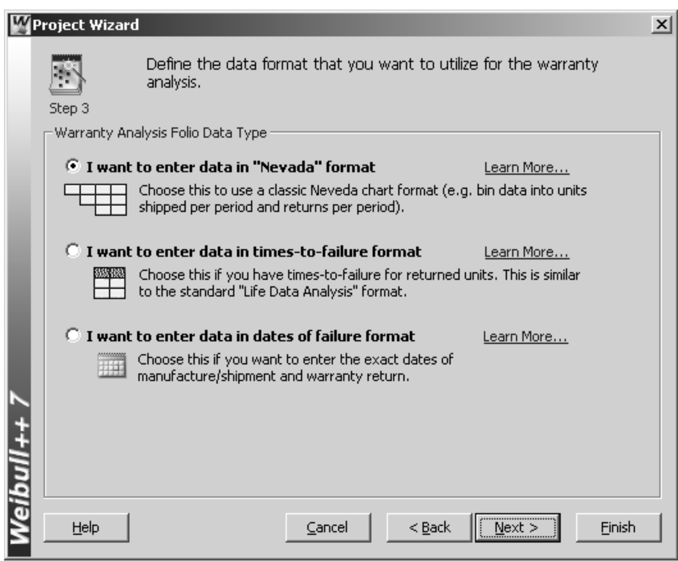
The file for this example is located in the “Training Guide” folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named “Warranty Analysis.rwp.”

Solution

- Create a new project. On the second page of the Project Wizard, select **Warranty Analysis Folio**, as shown next.

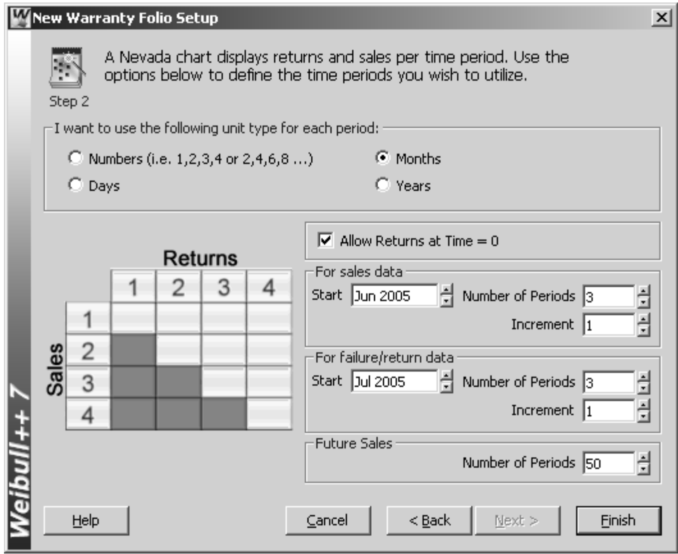


- Click **Next>** to proceed to the next step. Select **I want to enter data in "Nevada" format**, as shown next, and then click **Next>**.

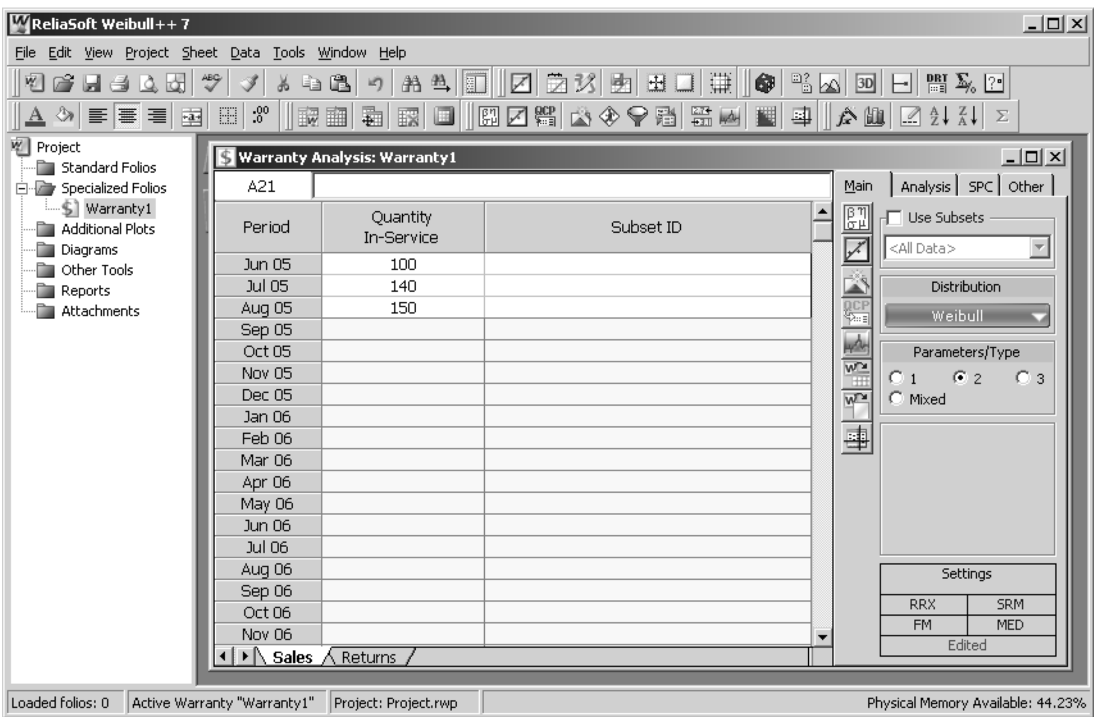


- In the next step:
  - Select **Months** for the unit type.
  - Select **Allow Returns at Time = 0**.
  - Type **June 2005** for the first month of the sales data and specify **3** periods, incremented by **1**.
  - Type **July 2005** for the first month of returns data and specify **3** periods incremented by **1**.

The window will look like the figure shown next.

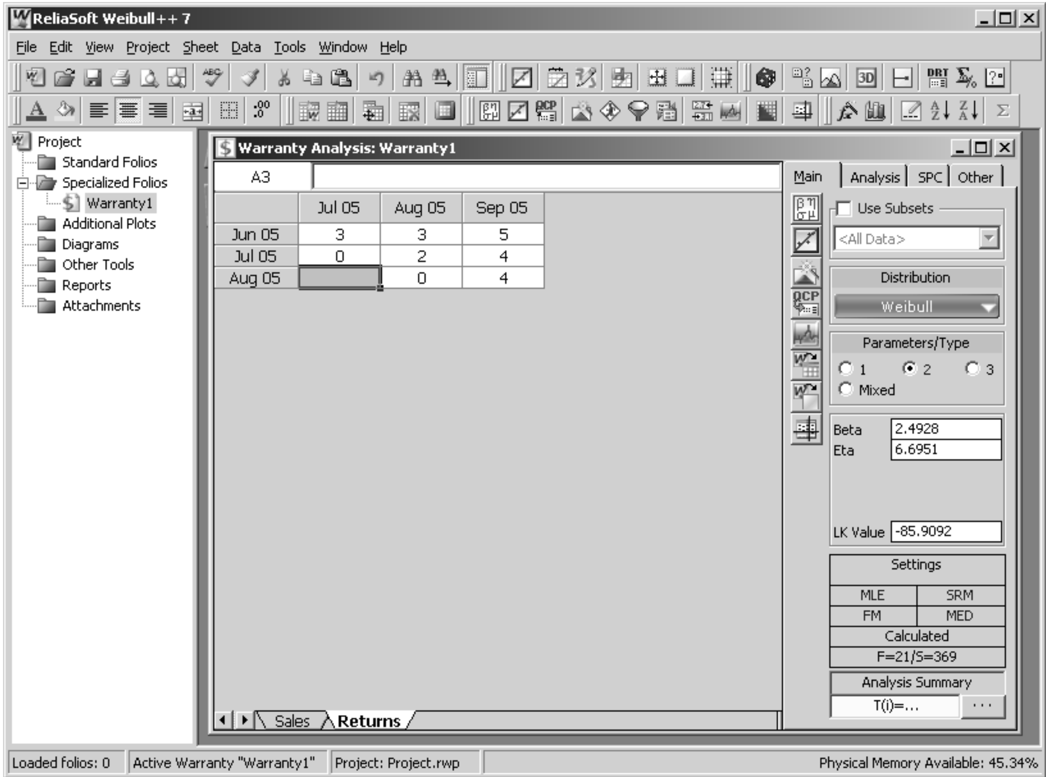


- Click **Finish** to create the Warranty Analysis Folio.
- Enter the shipments data in the **Quantity In-Service** column on the Sales sheet, as shown next.



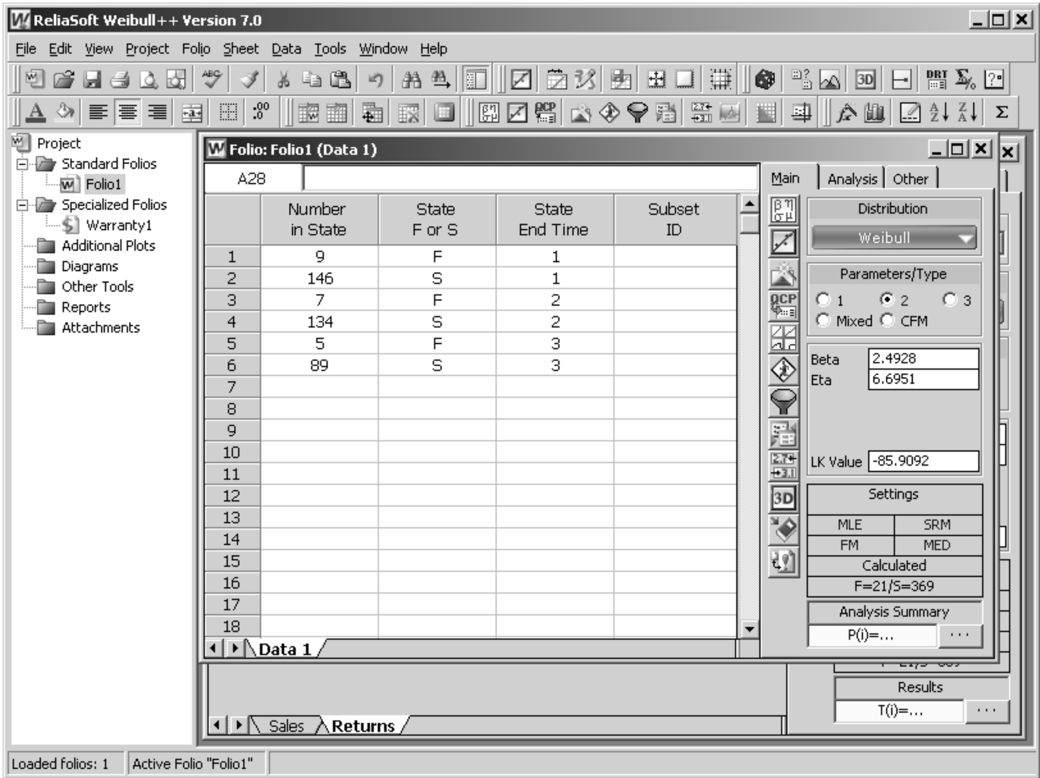
- Enter the returns data in the Returns sheet (where the row represents the shipment month and the column represents the return month).

- Select the 2-parameter Weibull distribution with MLE and calculate the parameters. The window will look like the figure shown next.



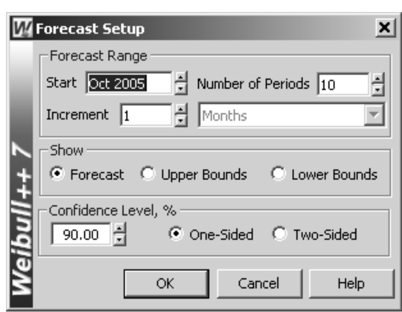
- To transfer the life data to a Standard Folio, select **Transfer Life Data to New Folio** from the **Data** menu or click the icon.

- Double-click **Folio1** in the Project Explorer to open the new Standard Folio that the failure and suspension times were transferred to. The estimated parameters for this data set are beta = 2.4928 and eta = 6.6951, as shown next.

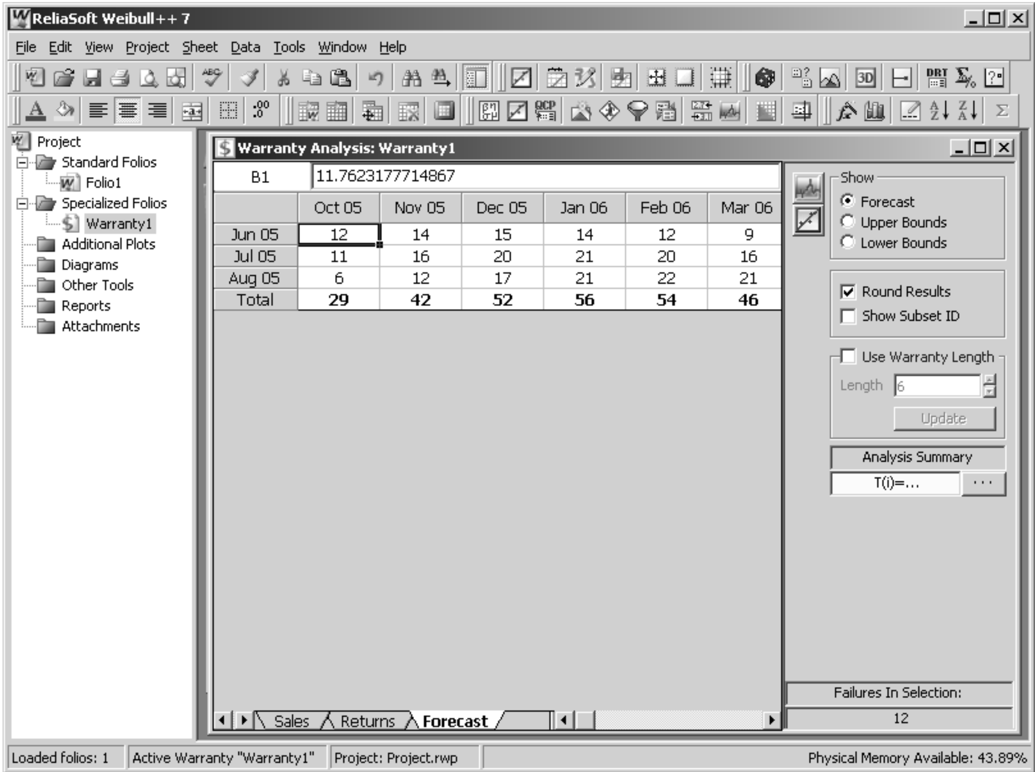


- Return the focus to the Warranty Analysis Folio and select **Generate Forecast** from the **Data** menu or click the icon.

- Accept the defaults in the Forecast Setup window, as shown next, and click **OK**.



A new sheet called "Forecast" will be added to the Folio to display the number of failures that can be expected from each shipment in upcoming months. As shown next, the predicted number of products that will be returned in October are 12 from the June shipment, 11 from the July shipment and 6 from the August shipment for a total of 29 returned units.



• Save the project as “Warranty Analysis.rwp” then close the project and proceed to the next example.

4.14 Example 13: Competing Failure Modes Analysis

This example has been abstracted from Example 15.6 from the Meeker and Escobar textbook *Statistical Methods for Reliability Data*, published by John Wiley and Sons.

An electrical component has two failure modes. One failure mode is due to random voltage spikes, which cause failure by overloading the system. This failure mode is denoted by a V in the table. The other failure mode is due to wear-out failures, which usually happen only after the system has run for many cycles. This failure mode is denoted by a W in the table. The following table shows time-to-failure data for each mode, along with suspension data.

Number in State	Failure Time*	Failure Mode		Number in State	Failure Time*	Failure Mode
1	2	V		1	147	W
1	10	V		1	173	V
1	13	V		1	181	W
2	23	V		1	212	W
1	28	V		1	245	W
1	30	V		1	247	V
1	65	V		1	261	V
1	80	V		1	266	W
1	88	V		1	275	W
1	106	V		1	293	W
1	143	V		8	300	suspended

*Failure times are given in thousands of cycles.

Do the following:

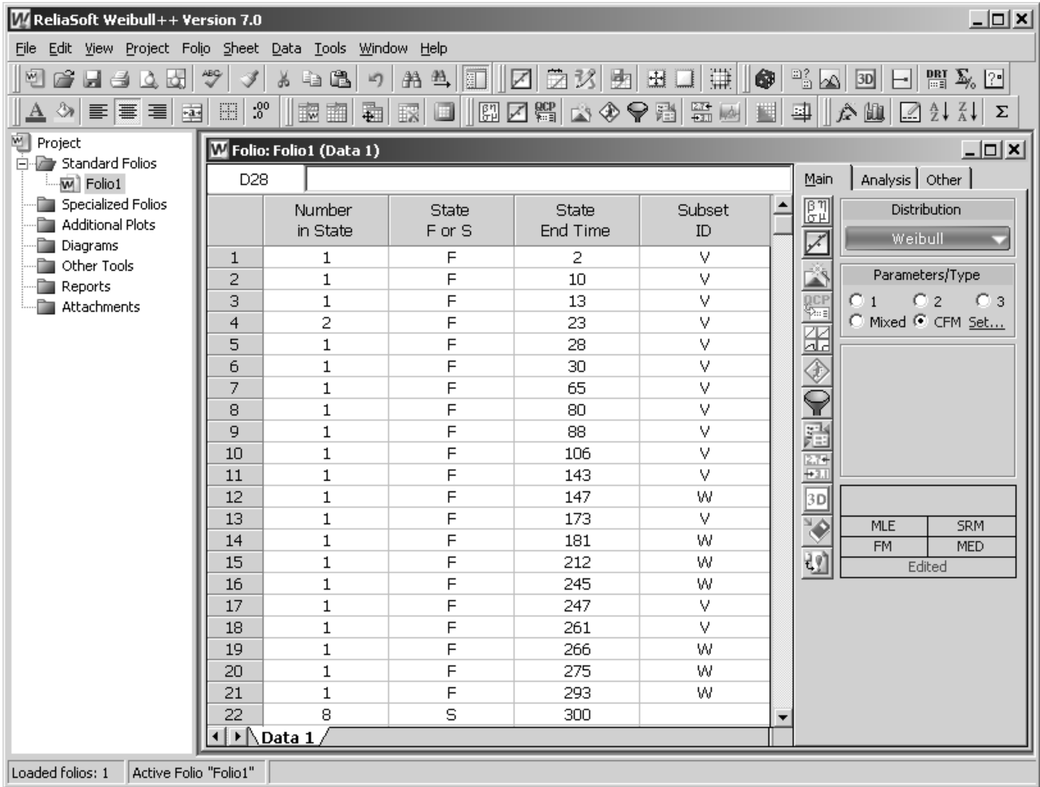
- Determine the overall reliability for the component at 100,000 cycles.
- Plot the competing failure modes.

The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Competing Failure Modes.rwp."

Solution

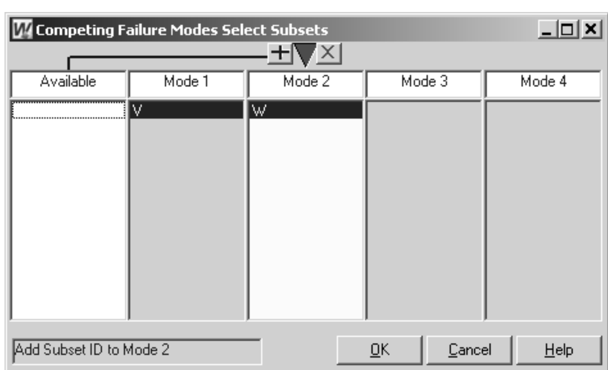
- Create a new project with a Standard Folio for times-to-failure data with suspensions and grouped data.

- Using the Subset ID column to identify the failure mode, enter the data into the Folio. Select the Weibull distribution with Competing Failure Modes (CFM) and MLE, as shown next.

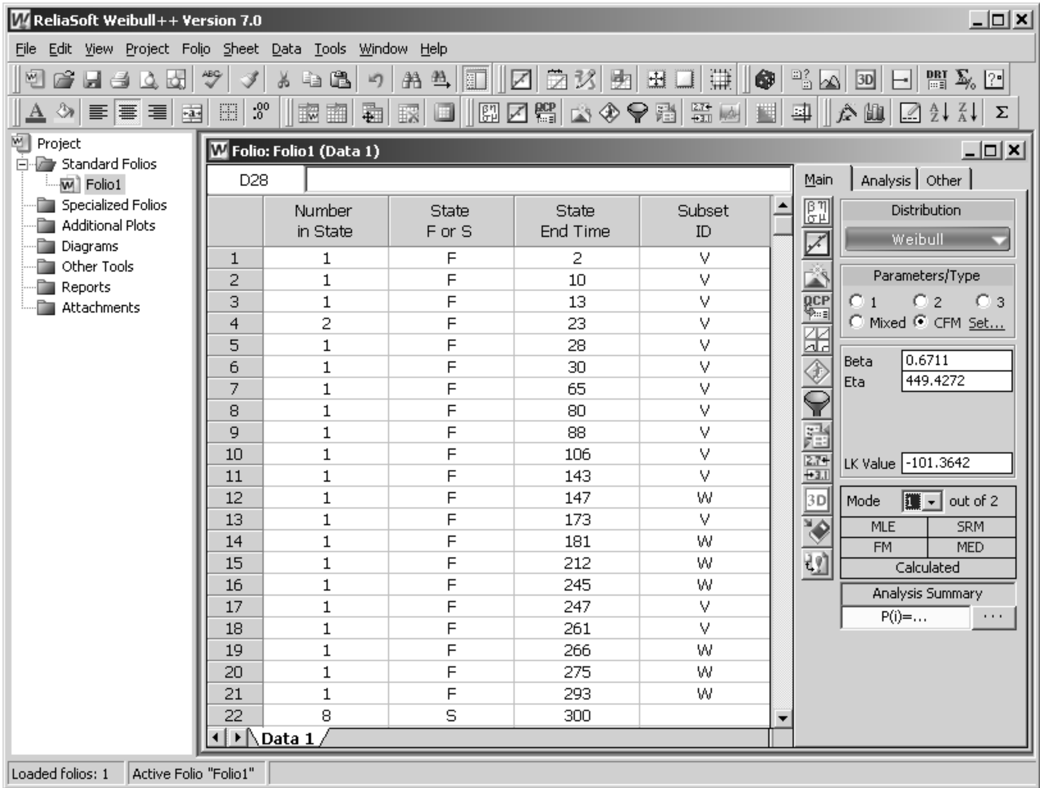


When the CFM option is selected and you click Calculate, the Competing Failure Modes Select Subsets window will appear. This allows you to identify the competing failure modes, based on Subset ID. Note that you can also open this window by clicking the **Set...** link to the right of the CFM option.

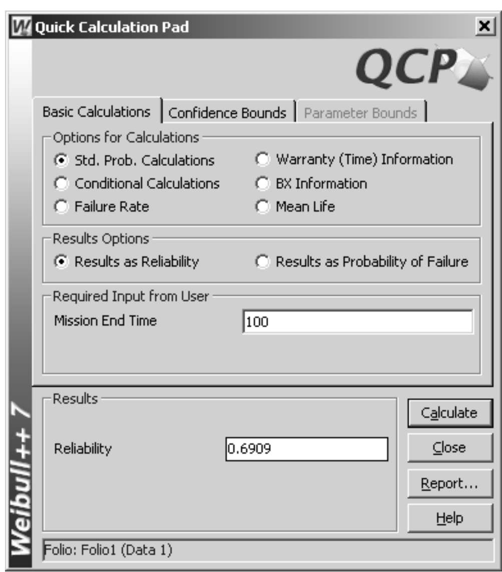
- Place the V failure mode into the Mode 1 column and place the W failure mode into the Mode 2 column, as shown next. To do this, click a subset ID (mode) from the Available panel and select a Mode panel to place the subset ID into. Click (+) to add the selected Subset ID to the Mode panel. Click (**X**) to remove the selected Subset ID from the Mode panel. You can also double-click or drag and drop a Subset ID to add or remove it from a panel.



- Click **OK** to close the window and calculate the parameters for both modes. The results displayed in the Control Panel correspond to the mode currently selected in the menu above the Settings area (Mode __ out of __). The next figure shows the parameters for Failure Mode 1, or the V failure mode.

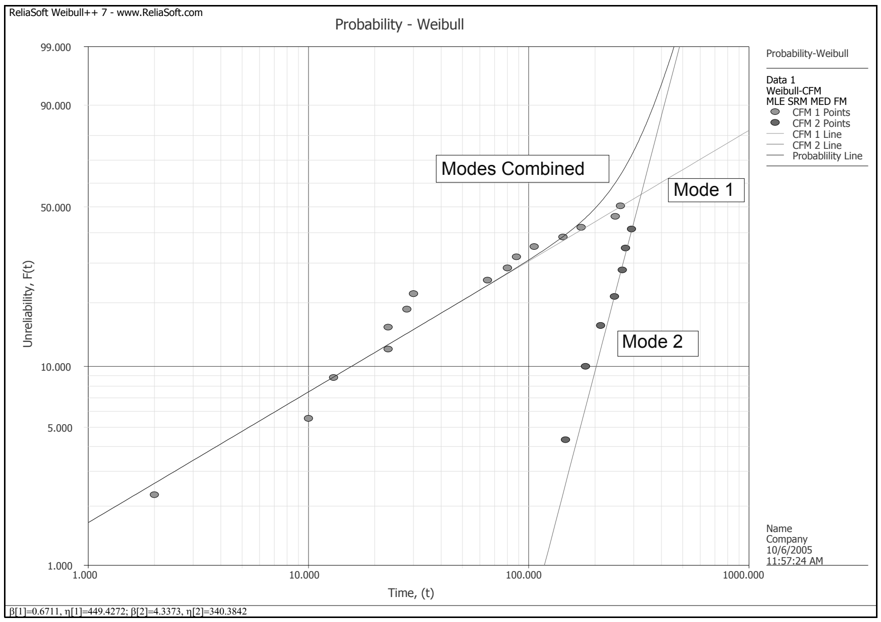


- The estimated parameters for Failure Mode 1 (the random voltage spikes failures) are beta = .6711 and eta = 449.4272. The estimated parameters for Failure Mode 2 (the wear-out failures) are beta = 4.3373 and eta = 340.3842.
- Open the Quick Calculation Pad and determine the overall reliability of the system at 100,000 cycles, as shown next.



Using the Competing Failure Modes and QCP, the overall reliability for the component at 100,000 cycles is estimated to be 69.1%.

- Close the QCP.
- Generate the Weibull Probability plot for this analysis, as shown next with labels added (via RS Draw) to identify the lines for each individual failure mode and for the combined analysis.



- Save the project as "Competing Failure Modes.rwp" then close the project and proceed to the next example.

4.15 Example 14: Weibull-Bayesian Analysis

A redesign is being reliability tested. Test data from the original design is available. The original cycles-to-failure data set (in thousands) is as follows:

11.1	66.1	79.6	106.8
43.9	67.3	93.8	109.9
56.4	73.8	93.9	110.8
59.5	74.6	99.6	119.6
60.8	75.9	104.3	160

The test of the redesign yielded the following data set (in thousands) after 50,000 cycles of testing.

Time	F/S
24	F
34	F
50	F
50	S
50	S
50	S

Do the following:

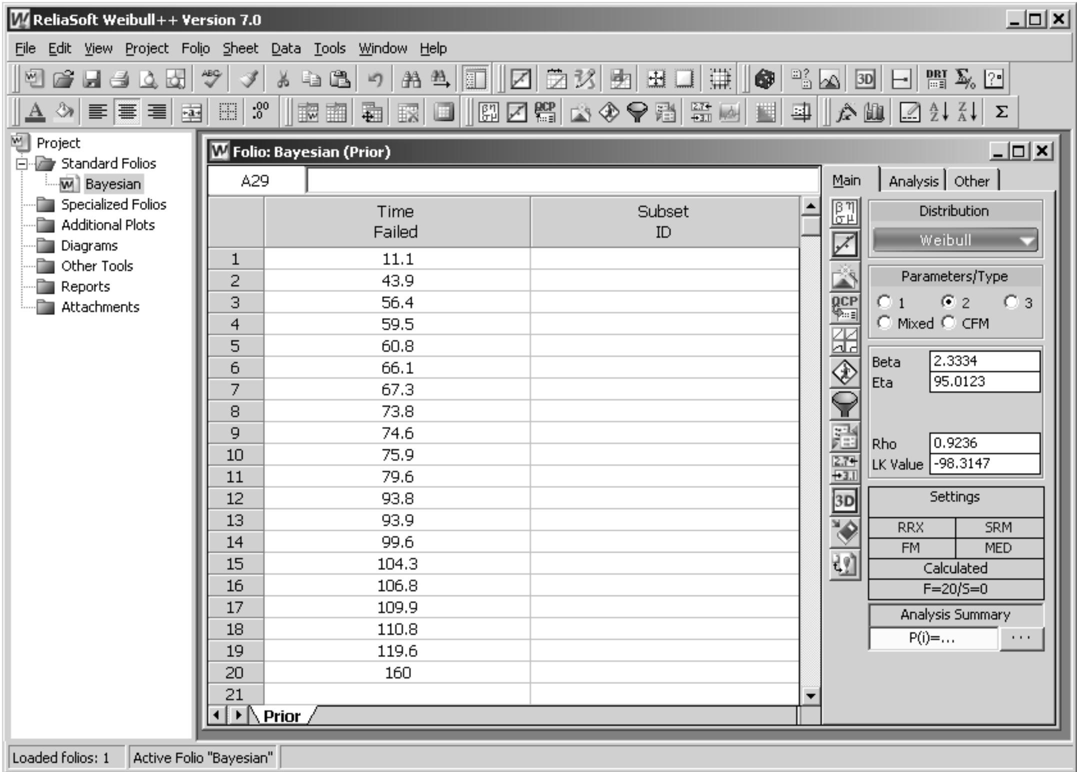
- Using a Weibull-Bayesian approach, compute the demonstrated reliability for the redesign at 10,000 cycles at a 90% lower 1-sided confidence level.
- Repeat this analysis using a standard 2-parameter Weibull approach with Rank Regression on X.
- Compare the results.

The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Weibull-Bayesian.rwp."

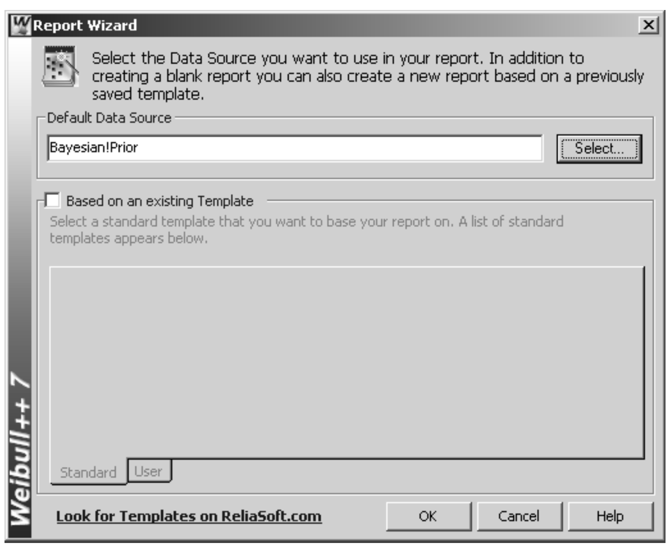
Solution

- Create a new project with a Standard Folio for individual times-to-failure data. Rename the Folio to "Bayesian."
- Rename the data sheet to "Prior" by double-clicking the tab and typing the new name in the Sheet Name window.

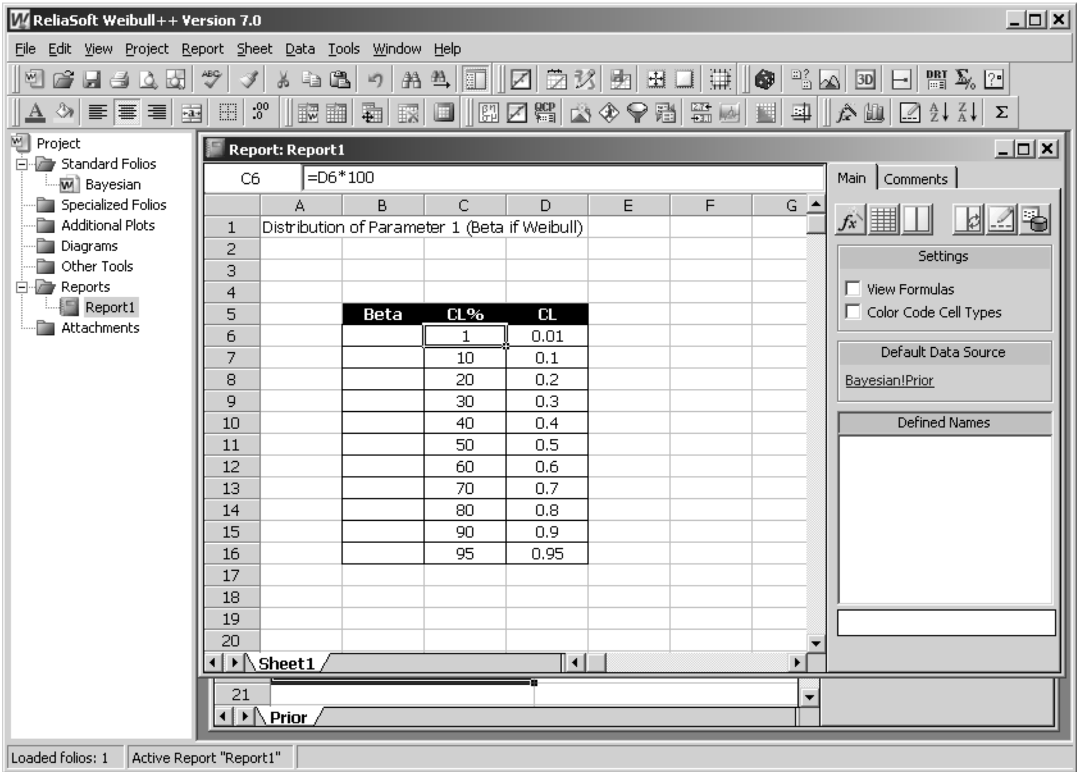
- Enter the data and calculate the parameters with the 2-parameter Weibull distribution and Rank Regression on X, as shown next.



- Select **Add Report...** from the **Project** menu to add a Report to the project.
- In the Report Wizard window, select the “Prior” data sheet as the default data source, as shown next, then click **OK**.



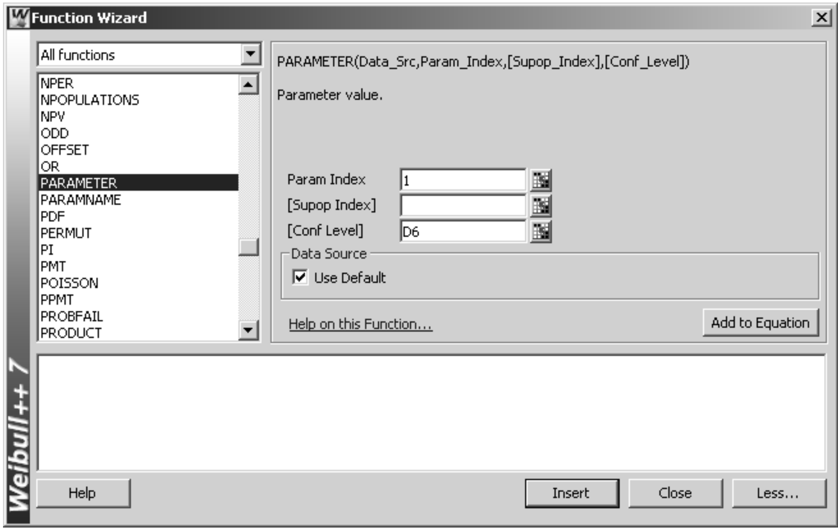
- Build a table like the one shown next, which will contain the Beta parameter values for a range of confidence levels. Note that the confidence level is entered as a decimal in column D and an equation is used to convert the decimal to a percentage in column C (*e.g.* =D6*100).



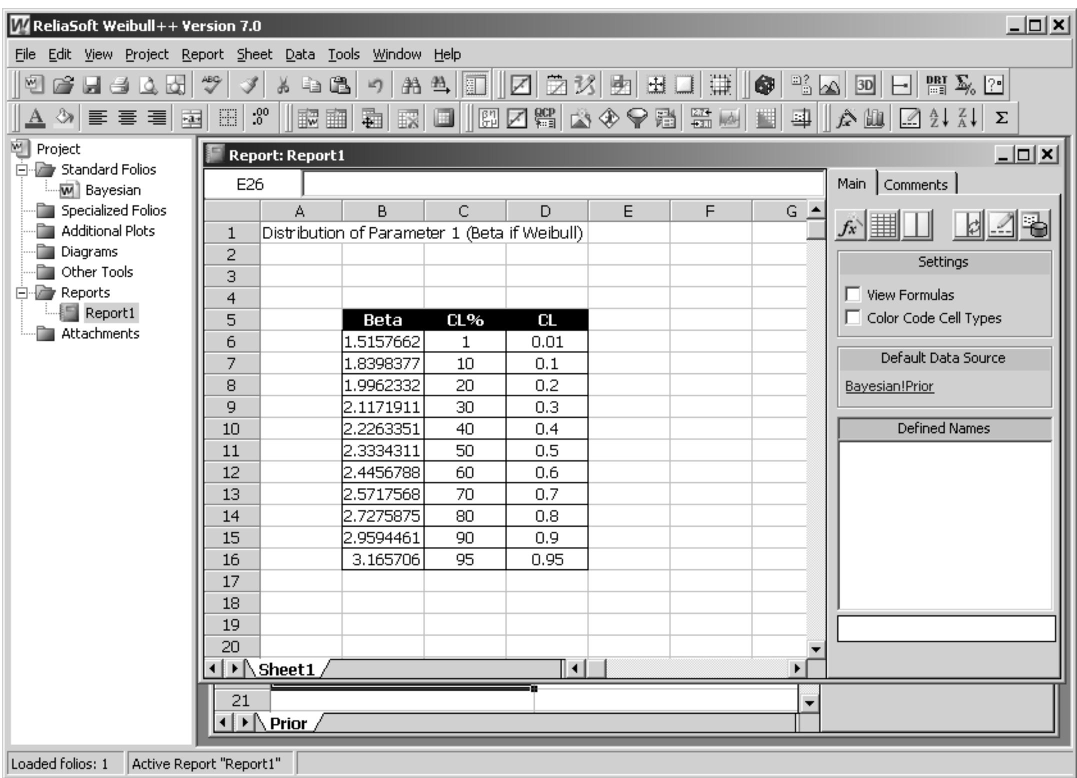
- With the first Beta parameter cell selected (*i.e.* B6), open the Function Wizard by selecting **Function Wizard** from the **Data** menu or by clicking the **Function Wizard** icon.

- Select the **PARAMETER** function then enter **1** for Param Index and **D6** for [Conf Level]. Leave **Use Default** selected for the data source. This indicates that the function will return the first parameter for the analysis in the "Prior" data sheet at the confidence level specified in the referenced cell of the spreadsheet.

The Function Wizard will look like the figure shown next.

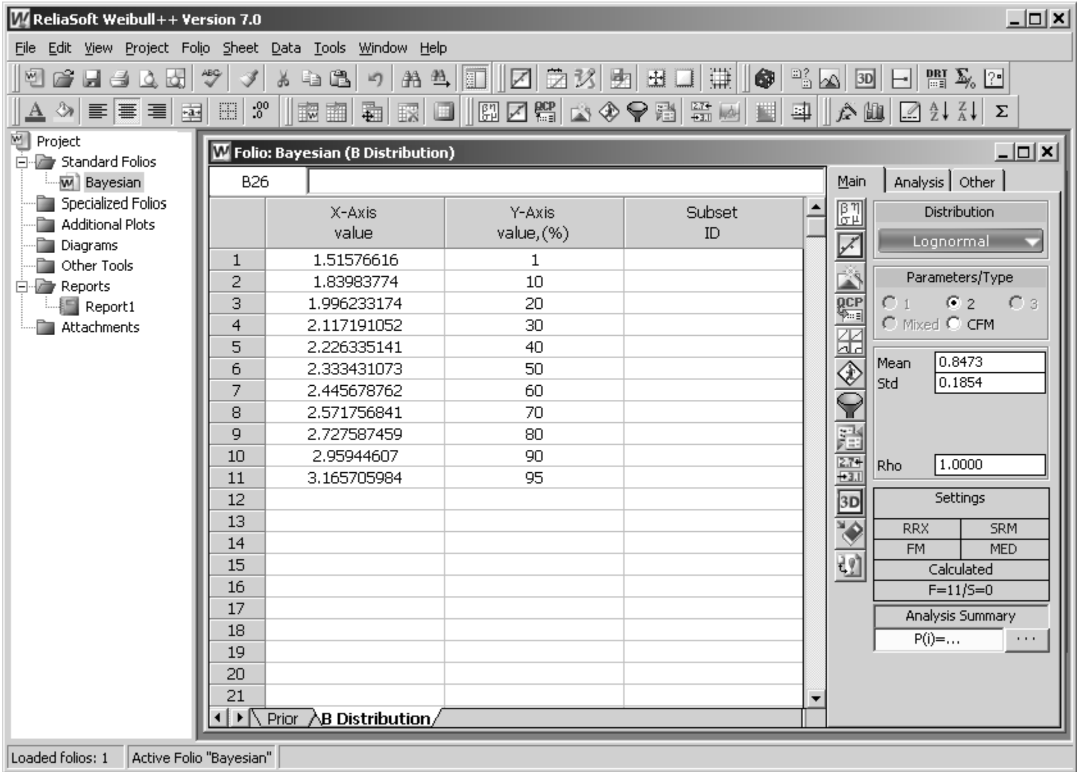


- Click **Insert** to close the Function Wizard and insert the function into the active cell.
- Copy the function from cell B6 to B16 to obtain the Beta values for each confidence level. The table will look like the one in the figure shown next.

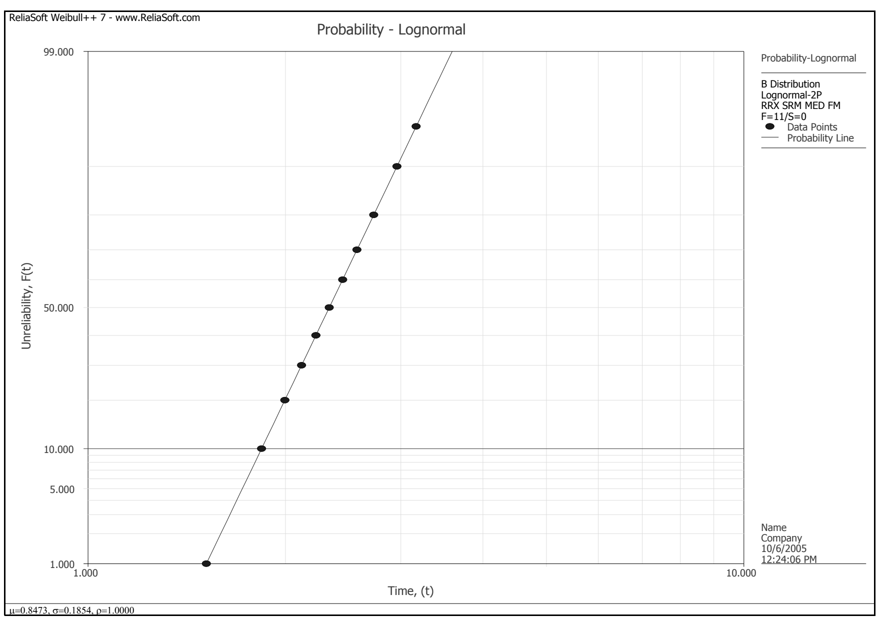


- Copy the first two columns of data (*i.e.* the Beta values and the confidence level percentages) and then return to the Standard Folio.
- Select **Insert Data Sheet** from the **Folio** menu to insert a new data sheet for **Free-Form (Probit) data** called “B Distribution.”

- Use the **Paste Values** command to paste the data into the new sheet and calculate the parameters with the 2-parameter Lognormal distribution and Rank Regression on X, as shown next.[9]



- Generate a probability plot for this analysis, as shown next.



- Insert another new data sheet for individual times-to-failure data with suspensions named "New."

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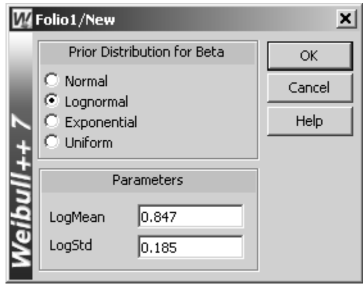
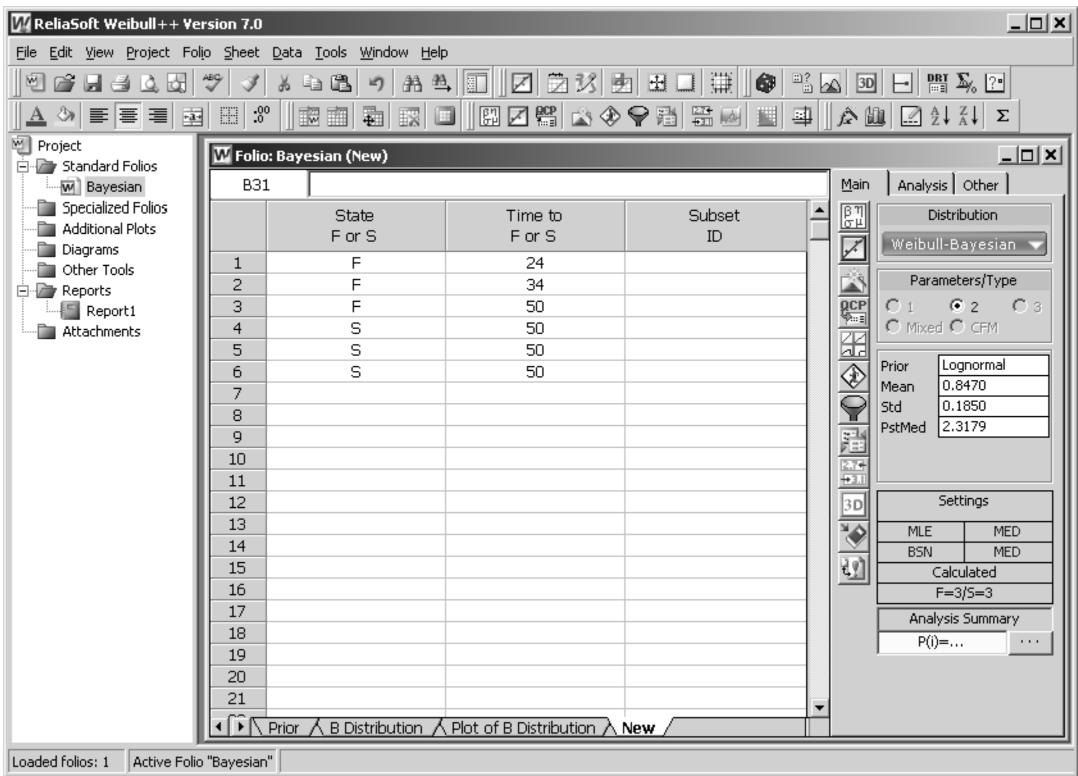
9. The Paste Values command is necessary to paste the confidence level percentage (rather than the formula) copied from the Report spreadsheet. Select **Paste Special** then **Paste Values** from the **Edit** menu.

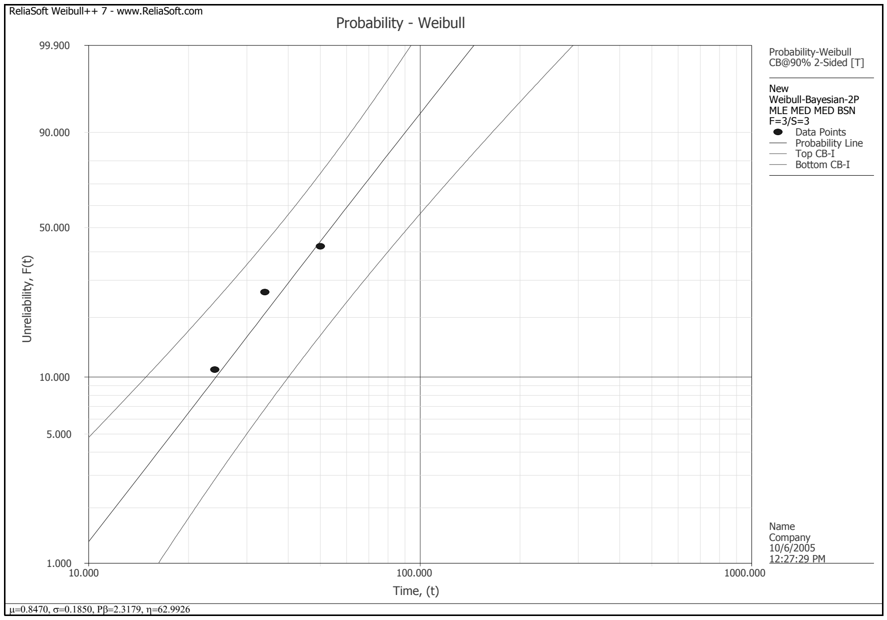
- Enter the data for the redesign (given in the second table of the problem statement) and select the **Weibull-Bayesian** distribution with **MLE**. When you attempt to calculate the parameters, you will be prompted to enter the distribution/parameters for Beta based on prior information. Enter the results from the B Distribution data sheet (rounded to three decimal places), as shown next.



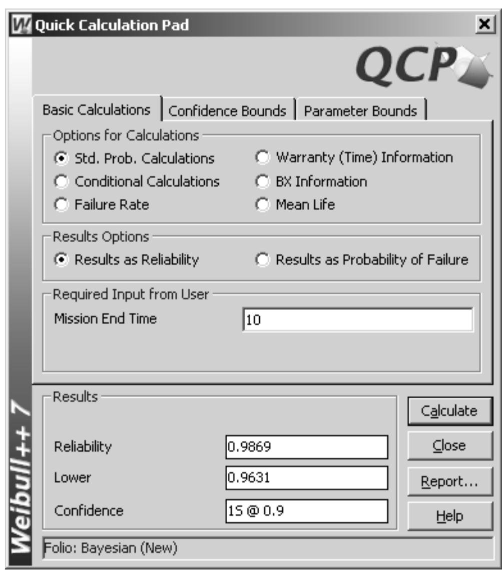
- Click **OK**. The data sheet with the Weibull-Bayesian parameters calculated is shown next.



- Generate a probability plot with 2-sided 90% confidence bounds (Type I), as shown next with the scaling manually adjusted.

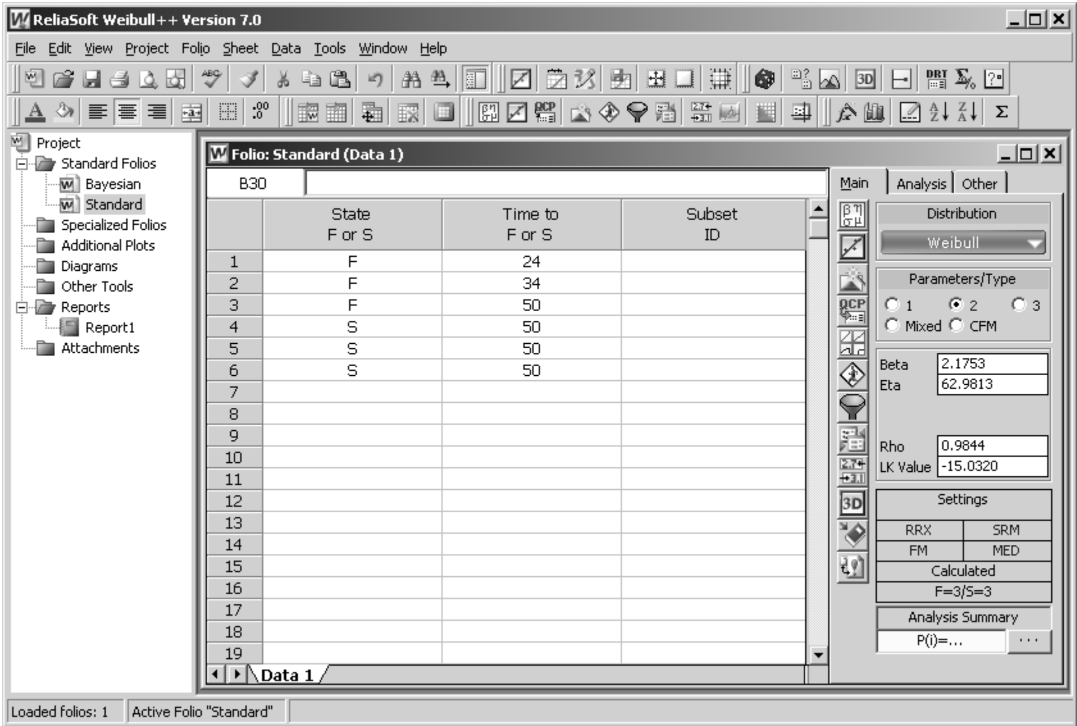


- Return to the "New" data sheet and open the Quick Calculation Pad. Calculate the reliability at 10,000 cycles with 90% lower 1-sided confidence bounds (Type I). Since the data points were entered as thousands of cycles, you will enter **10** for the Mission End Time, as shown next.

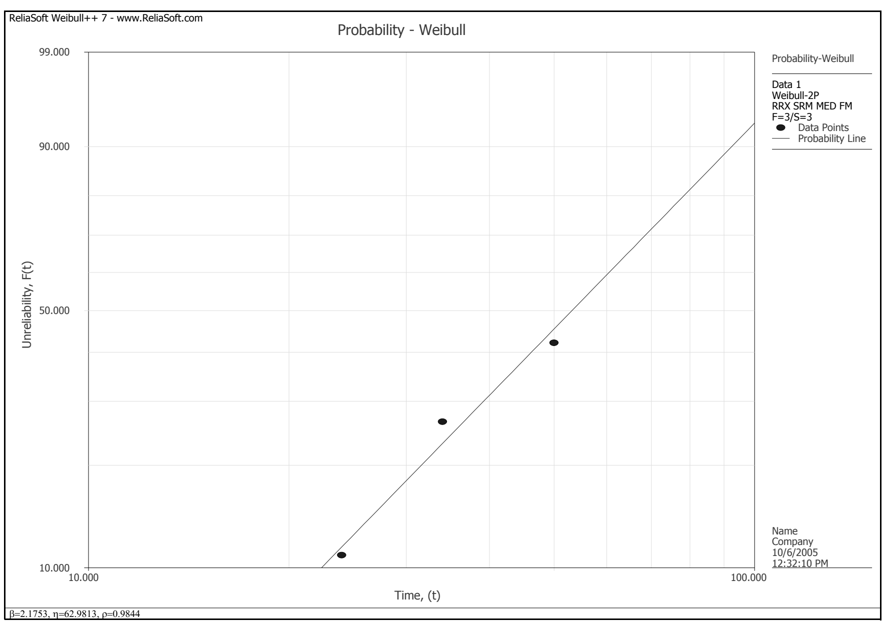


- Create a new Standard Folio for individual times-to-failure data with suspensions.

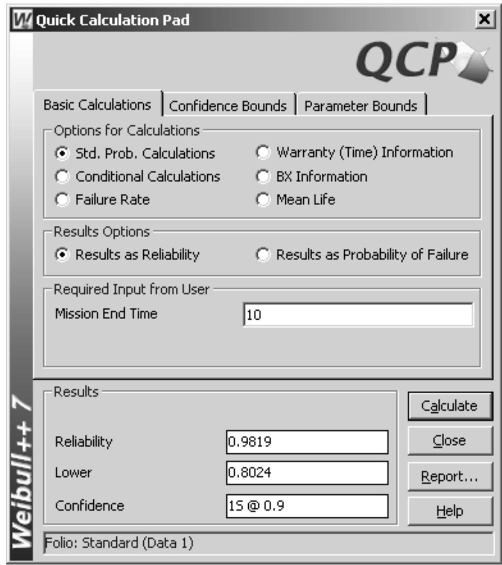
- Enter the redesign data and use the 2-parameter Weibull distribution with Rank Regression on X to calculate the parameters, as shown next.



- Generate a probability plot for the analysis, as shown next.



- Return to the data sheet then use the QCP to calculate the reliability at 10,000 cycles with 90% lower 1-sided confidence bounds (Type I). Again, enter **10** for the Mission End Time since the data points were entered as thousands of cycles, as shown next.



As you can see, the Weibull-Bayesian analysis estimates a reliability of 98.69% with a lower limit of 96.31% while the standard Weibull analysis estimates 98.19% with a lower limit of 80.24%.

- Close the QCP, save the project as “Weibull-Bayesian.rwp” then close the project and proceed to the next example.

4.16 Example 15: Failure Modes RBD Analysis

Assume that a component can fail due to six independent primary failure modes: A, B, C, D, E and F. The component fails if mode A, B or C occurs. If mode D, E or F occurs alone, the component does not fail; however, the component will fail if any two (or more) of these modes occur (*i.e.* D and E; D and F; E and F). The following tables present the time-to-failure data for these modes (in hr). Use the 2-parameter Weibull distribution with MLE to analyze each data set and determine the lower 1-sided 90% confidence interval on the reliability of this component at 100 hr.

Mode A			**Mode B**			**Mode C**		
Number in Group	**State**	**Time**	**Number in Group**	**State**	**Time**	**Number in Group**	**State**	**Time**
1	F	1144	1	F	19	1	F	2221
1	F	1719	1	F	140	1	F	2257
1	F	2129	1	F	292	1	S	2569
1	F	2803	1	F	432	1	F	3029
1	F	3020	1	F	528	1	F	3805
1	F	3082	1	F	552	10	S	5000
1	F	3589	1	F	605			
1	F	3973	1	F	734			
1	F	4337	1	F	779			
1	F	5011	1	F	874			
1	F	5029						
18	S	5500						

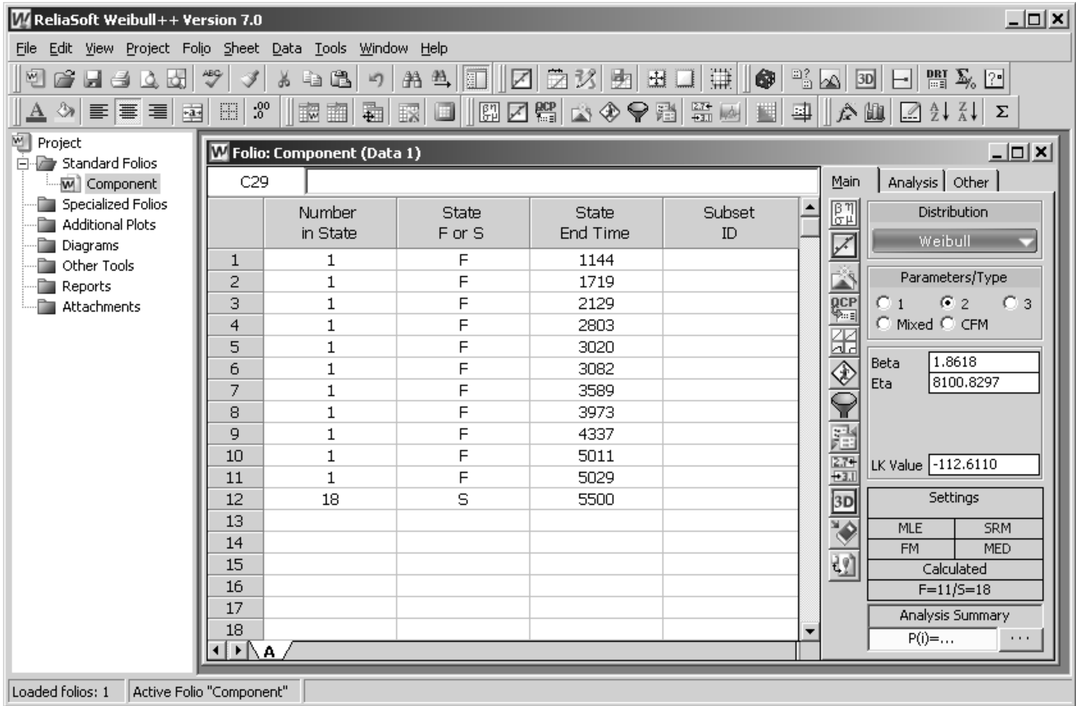
Mode D			**Mode E**			**Mode F**		
Number in Group	**State**	**Time**	**Number in Group**	**State**	**Time**	**Number in Group**	**State**	**Time**
1	F	1063	1	F	1290	1	F	605
1	F	1085	1	F	2261	1	F	760
1	F	1399	1	F	2355	1	F	773
1	F	1445	1	F	3209	1	F	854
1	F	1550	1	F	3284	1	F	890
1	F	2056	1	F	3394	1	F	1165
1	F	4384	1	F	3596	1	F	1220
1	F	4863	1	F	4203	1	F	1320
8	S	5000	1	F	4254	1	F	1967
			1	F	4294	1	F	2606
			1	F	4420	1	F	2834
			10	S	5000	15	S	3000

The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Mode Diagram.rwp."

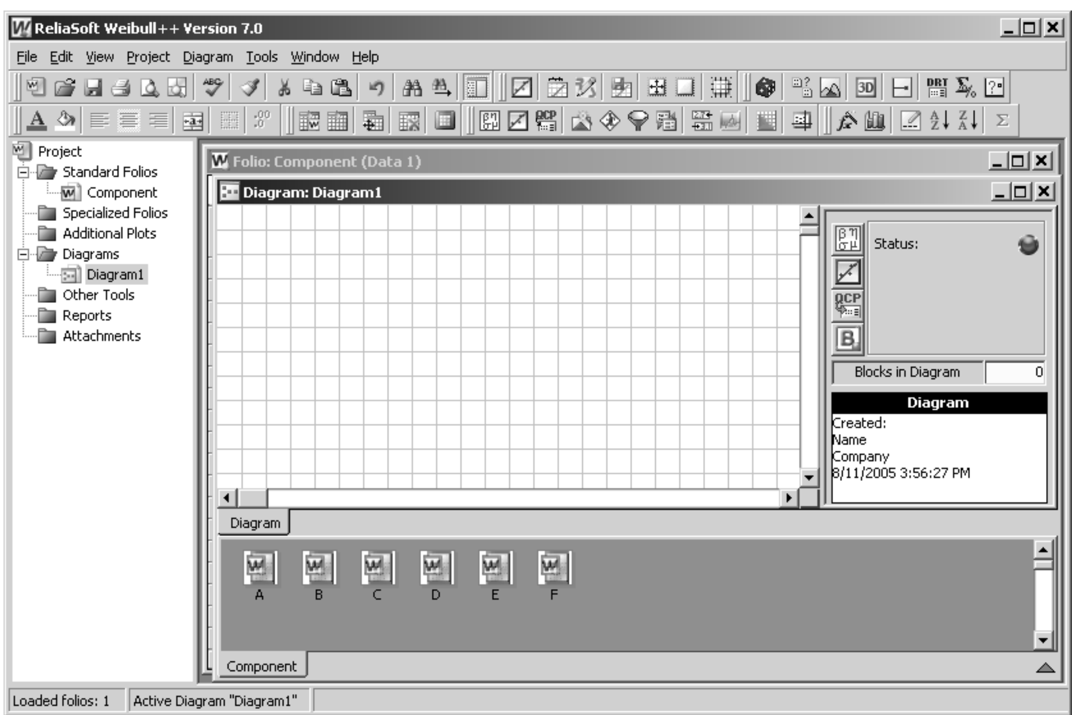
Solution

- Create a new project with a Standard Folio for grouped times-to-failure data with suspensions. Rename the Folio to "Component."

- Rename the data sheet to "A," enter the data given for Failure Mode A and use the 2-parameter Weibull distribution with MLE to calculate the parameters, as shown next.



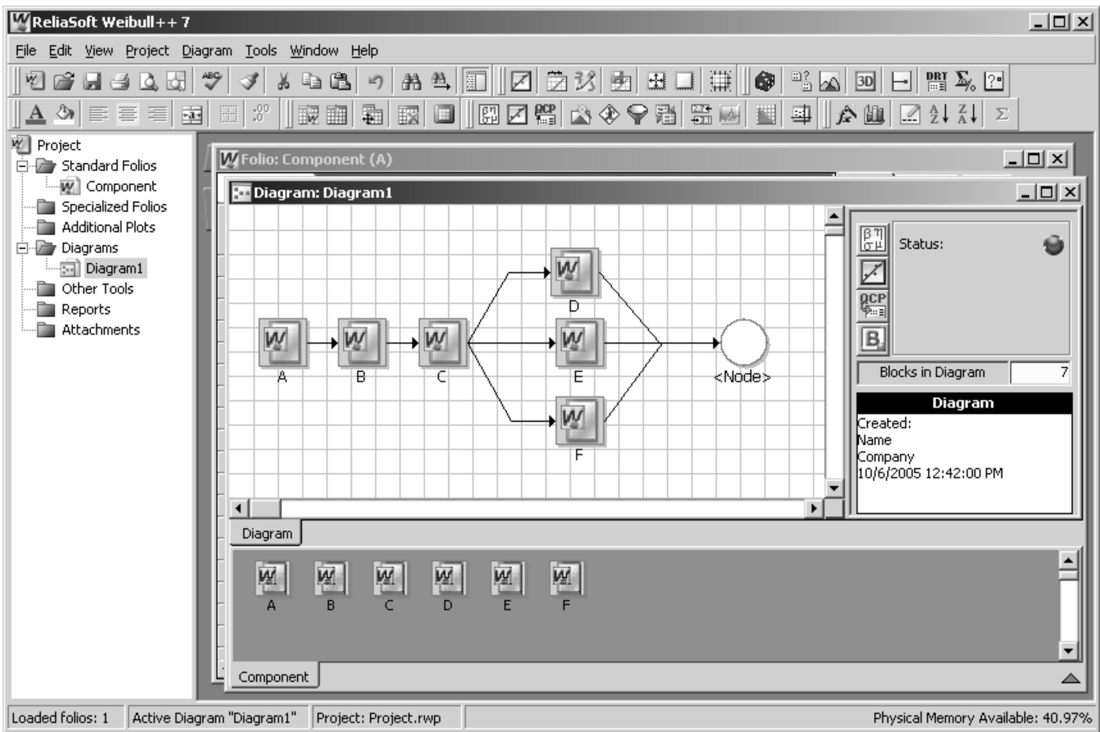
- Insert another data sheet of the same type named "B," enter the data given for Failure Mode B and calculate the parameters. Repeat the procedure for the remaining failure modes.
- After you have entered and calculated the data for all six failure modes, select **Add Diagram** from the **Project** menu to add a Diagram to the project that contains a template block for each data sheet in the project, as shown next.



- Build the RBD that describes the reliability-wise configuration of the failure modes.

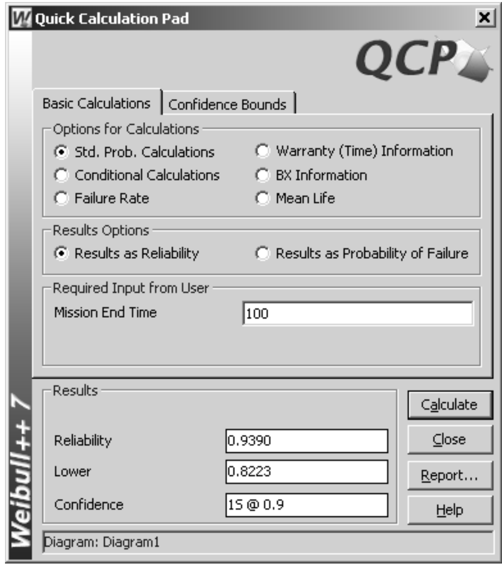
To add a block representing a calculated data set, drag the block from the template and drop it into the diagram. To add the node, select **Add Node** from the **Diagram** menu or shortcut menu. Double-click the node to specify the number of paths leading into the node that must succeed (*i.e.* 2 out of the 3 paths for this example). To add the relationship lines, select **Join Blocks** from the **Diagram** menu or shortcut menu then drag lines between blocks to connect them. After you are finished connecting blocks, right-click inside the diagram to return the cursor to the normal mode.

The diagram will look like the one shown next.



- Select **Calculate** from the **Diagram** menu or click the **Calculate** icon to analyze the diagram.

- Select **Quick Calculation Pad...** from the **Diagram** menu or click the icon to open the QCP. Calculate the reliability at 100 hr with the lower 1-sided 90% confidence bound, as shown next.



The lower bound is estimated to be 82.23%.

- Close the QCP, save the project as "Mode Diagram.rwp" then close the project and proceed to the next example.

4.17 Example 16: Determine Optimum Burn-In Time

An electronic component is undergoing burn-in testing. During burn-in, the following cumulative percent failed is observed:

- 5% failed by 10 hr
- 6% failed by 50 hr
- 7% failed by 100 hr

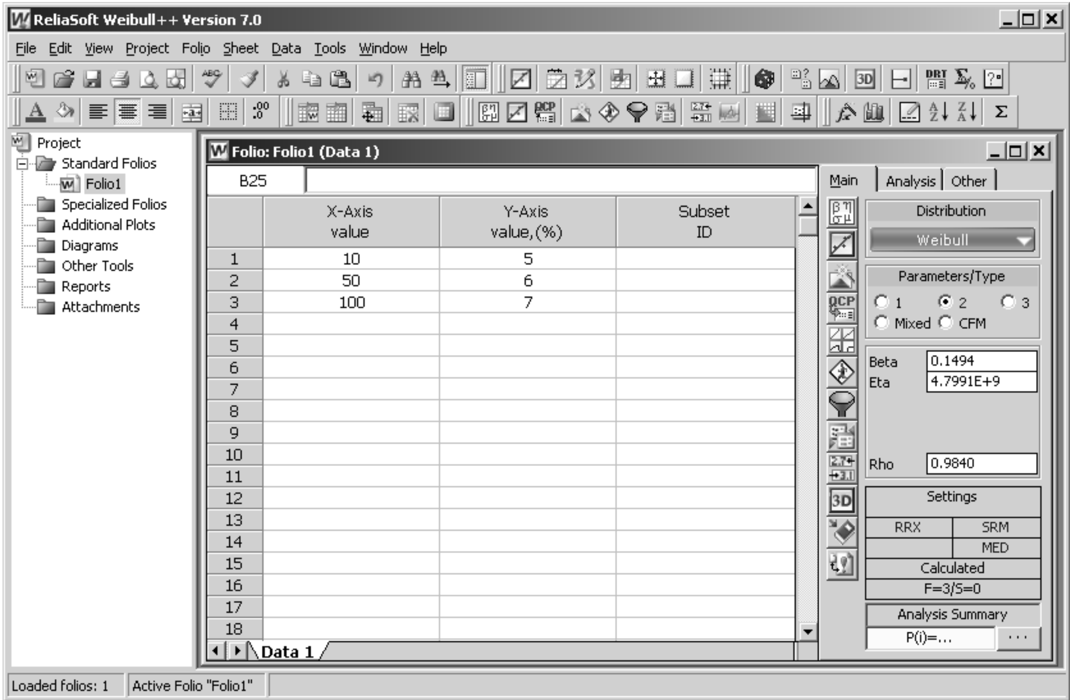
Assume that the cost per hour of burn-in is $10. Additionally, each discovered failure during burn-in costs $50. If a unit fails in the field, the cost is $4,000. Determine the optimum burn-in time.

The file for this example is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Optimum Burn-in.rwp."

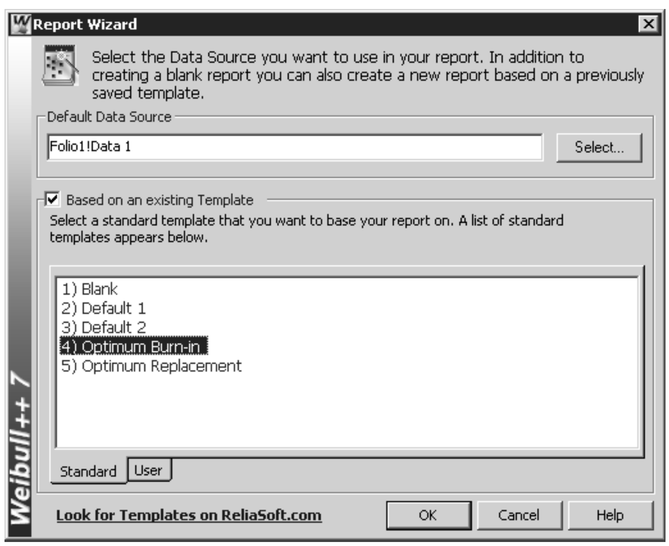
Solution

- Create a new project with a Standard Folio for free-form data.

- Enter the data and use the 2-parameter Weibull distribution with Rank Regression on X to calculate the parameters, as shown next.

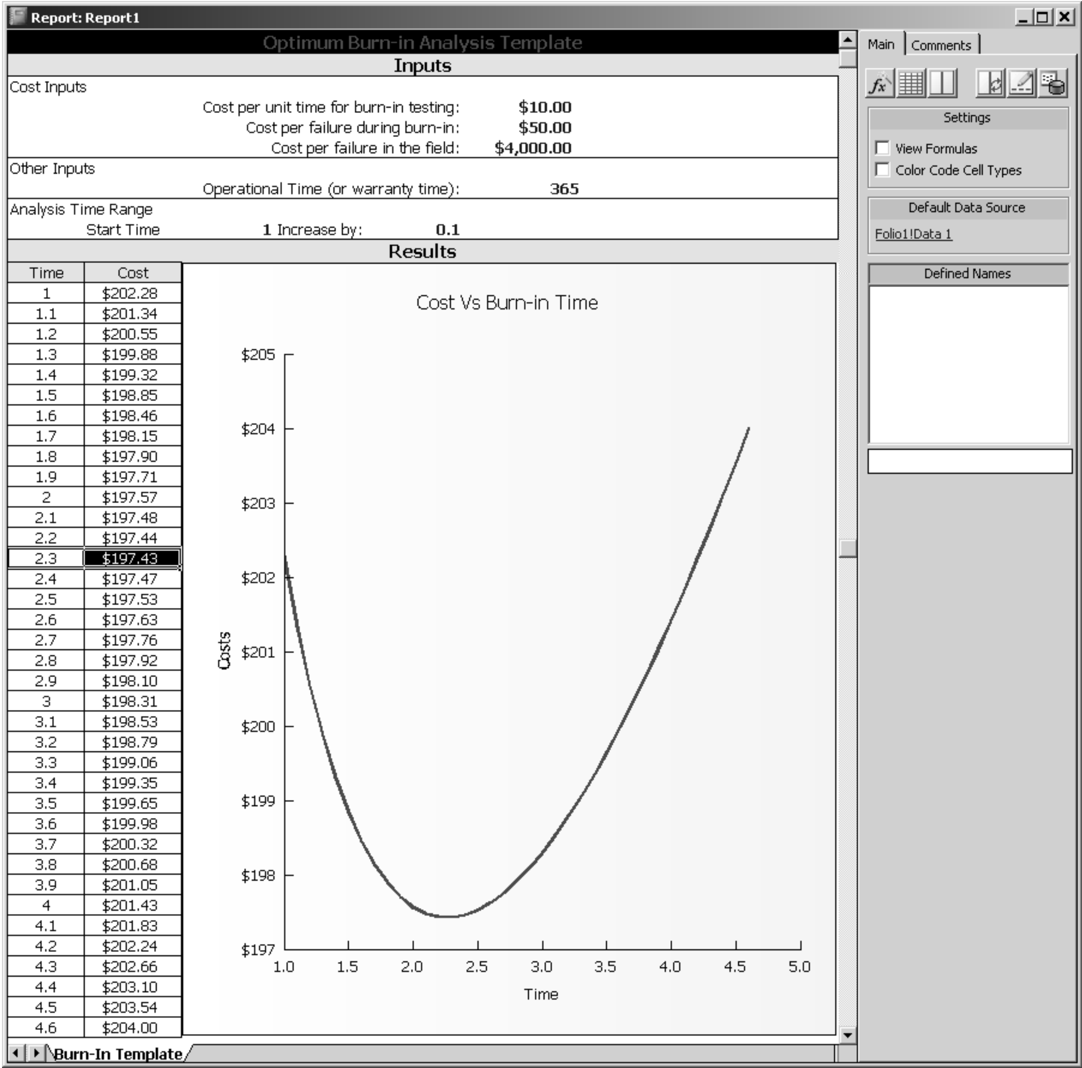


- Select **Add Report...** from the **Project** menu. In the Report Wizard, specify the calculated data sheet as the default data source and select to create the report based on the **Optimum Burn-in.wrt** report template that is shipped with the software, as shown next.



- Click **OK** to create the report.

- Enter the costs for this example in the Cost Inputs area at the top of the template (shown in bold blue text) and accept the other default inputs. The window will look like the figure shown next.



The optimum burn-in time is 2.3 hr.

- Save the project as “Optimum Burn-in.rwp” then close the project.

5 Practice Questions

This section contains some additional practice questions. The next section presents solutions to these examples. *The file for these examples is located in the "Training Guide" folder in your application directory (e.g. C:\Program Files\ReliaSoft\Weibull7\Training Guide) and is named "Practice Questions.rwp."*

5.1 Practice Question 1

Six units were reliability tested and the following times-to-failure were observed: 48, 64, 83, 105, 123 and 150 hr. Do the following:

1. Determine how you would classify this data set, *i.e.* individual, grouped, suspended, censored, uncensored, etc.
2. Create a new project and Standard Folio for individual times-to-failure data with no censoring, named "Question1."
3. Enter the data and select Rank Regression on X as the parameter estimation method.
4. Determine the parameters for this data set using the following distributions and plot the data for each distribution. From the plot, note how well you think each distribution tracks the data, *i.e.* how well does the fitted line track the plotted points?
   i. 2-parameter Weibull
   ii. 3-parameter Weibull
   iii. Normal
   iv. Lognormal
   v. 1-parameter Exponential
   vi. 2-parameter Exponential

5. Use the Distribution Wizard to determine the distribution that best fits your data. Compare with what you have observed.
6. Save the project as “Practice Questions.rwp.” Close the Folio but leave the project open.

5.2 Practice Question 2

ACME manufacturing implemented a reliability tracking program for a recent product. A total of 96 units were released in a small test market. 10 units failed sometime between 0 - 68 hr, 10 units failed between 68 - 90 hr, 10 units failed between 90 - 120 hr and 7 failed between 120 - 130 hr. 59 units were still in the field after successfully operating for 153 hr. Do the following:

1. Create a new Standard Folio for grouped times-to-failure data with suspensions and interval censoring, named “Question2.”
2. Enter the data and determine the parameters of the 2-parameter Weibull distribution using Rank Regression on X.
3. Obtain the probability plot for this data set.
4. Plot the 90%, 2-sided confidence bounds (Type II). Export the plot graphic as MyPlot1.wmf.
5. Experiment with annotating the plot while in RS Draw.
6. From the plot, determine:
   i. The reliability of these units for a mission of 50 hr, R(50hr).
   ii. The 90%, 2-sided confidence bounds on the reliability for a mission of 50 hr (Type II).
   iii. The mission duration for these units if ACME Inc. requires a 90% reliability at the 50% confidence level.
   iv. The mission range if ACME Inc. requires a 90% reliability at the 90% confidence level (Type I).
7. Using the Quick Calculation Pad, determine:
   i. The reliability of these units for a mission of 50 hr, R(50hr).
   ii. The 90%, 2-sided confidence bounds on the reliability for a mission of 50 hr.
   iii. The mission duration for these units if ACME Inc. requires a 90% reliability at the 50% confidence level.
   iv. The mission range if ACME Inc. requires a 90% reliability at the 90% confidence level.
   v. The 2-sided confidence bounds on the parameters.
8. Obtain the Reliability vs. Time plot for these units.
9. Obtain the *pdf* plot for these units.
10. Obtain the Failure Rate vs. Time plot for these units. From the plot, what is the failure rate of these units at 100 hr?
11. Save your changes to the project and close the Folio.

5.3 Practice Question 3

1. Create a new Standard Folio for individual times-to-failure data with no censoring, named “Question3.”
2. Rename the data sheet to “MLE” then copy and paste the data from “Question1.” Use the 2-parameter Weibull distribution and Maximum Likelihood Estimation to calculate the parameters.
3. Insert a new data sheet named “RRX” and paste the data set into the new sheet. Use the 2-parameter Weibull distribution and Rank Regression on X to calculate the parameters.
4. Plot both data sets individually.
5. Customize both plots to your liking.

6. Add a Multiple Plot Sheet to the project (named “Question3”) and select both data sets to be displayed. (Note that both are made up of the same data. Do you see a difference? Why?)
7. Save your changes to the project and close the Folios and Multiple Plot Sheet.

5.4 Practice Question 4

ACME Manufacturing is preparing to purchase a new component for one of its products. Two competing manufacturers presented ACME with the following test data. Each manufacturer tested 8 units to failure with the following results:

Manufacturer A Time to failure, hr	Manufacturer B Time to failure, hr
1900	2000
2600	4250
1400	1300
1300	600
800	3000
2650	6600
1850	9000
2400	12000

1. Create a new Standard Folio for individual times-to-failure data with no censoring, named “Question4.”
2. Enter the data for each manufacturer into separate data sheets (named “A” and “B”) and determine the parameters of the 2-parameter Weibull distribution using Rank Regression on X.
3. Use the Tests of Comparison utility to calculate the probability that Manufacturer A is better than Manufacturer B. Which design would you choose?
4. Save your changes to the project, close the Comparison Wizard and close the Folio.

5.5 Practice Question 5

As you may have noticed, plotting the data points and seeing how well the line runs through the points is an indication of how well the calculated parameters fit the data (or how correct the calculation is). However, when you use Maximum Likelihood Estimation, the data points do not, in general, track the plotted line. The reasons lie in the way the parameters are estimated. One way to view this convergence, since MLE maximizes the Likelihood Function, is to view the 3D plot of the Log-Likelihood Function. Weibull++ lets you do just that.

1. Duplicate the “Question1” Folio and name the copy “Question5.”
2. Calculate the parameters using the 2-parameter Weibull distribution and MLE as the parameter estimation method.
3. Plot the Log-Likelihood Function using 3D Plot.
4. Press **Ctrl** and click the plot. Move the mouse simultaneously in the direction you would like to rotate the plot.
5. Rotate the plot and view the maximum beta.
6. Rotate the plot again and view the maximum eta.
7. Close 3D Plot and insert a General Spreadsheet into the Folio.
8. Use the Function Wizard to create a table of Reliabilities with 90% 2-sided confidence bounds for a time range of 10 to 100, incremented by 5. Note: To get the 2-sided bounds, create one function for the CL at .05 (lower bound) and a second function for the CL at .95 (upper bound).

9. Save your changes to the project and close the Folio.

5.6 Practice Question 6

The Monte Carlo Data generation is a useful tool when dealing with simulations. You can use it to generate values for any distribution or function. This example will take you through such a scenario.

1. Create a new Standard Folio for times-to-failure data with no censoring, named “Question6.”
2. Select **Generate Monte Carlo Data...** from the **Tools** menu or click the icon.
3. Generate a data set using the 2-parameter Weibull distribution with beta = 2 and eta = 1500 hr. Select to put the data points into the current Folio and Sheet.
4. Calculate the parameters.
5. Are the parameters equal to the ones used in the Monte Carlo tool? Comments?
6. Generate another Monte Carlo data set using the same distribution and parameters. Select to put the data points into the current Folio and a new Sheet.
7. Compare the two sets. Are they the same?
8. Save your changes to the project and close the Folio.

5.7 Practice Question 7

Your new manager has to be convinced that product X has an MTBF of 1000 hr with a 95% confidence level. You know from past experience that the shape parameter for this product is 1.5. Due to time constraints, you are allowed to test the units for no more than 500 hr. Using ReliaSoft's Design of Reliability Tests (DRT) utility, find the number of units that have to be tested if:

1. No failures are allowed.
2. One failure is allowed.
3. Experiment with the other cases using the DRT.

5.8 Practice Question 8

The next table presents a data set corresponding to the times-to-failure for two samples of the same product, samples A and B. Both samples are assumed to be identical, so the times-to-failure were entered together in the same data sheet, utilizing the Subset ID column to identify each sample.

Time-to-failure, hr	Subset ID
49	A
71	A
80	A
85	A
93	A
100	A
16	B
18	B
30	B
34	B
50	B
201	B

Using the Batch Auto Run feature, extract two different data sets. Do the following:

1. Create a new Standard Folio for times-to-failure data with no censoring, named "Question8."
2. Calculate the parameters for each data set using the 2-parameter Weibull distribution with Rank Regression on X.
3. Compare the two sets using the Tests of Comparison utility.
4. Create a Multiple Plot Sheet (named "Question8") and plot the two data sets together.
5. Save your changes to the project and close the Folio.

5.9 Practice Question 9

For this example, design a test to demonstrate a reliability of 90% at t = 100 hr, with a 95% confidence. Assume a Weibull distribution with a shape parameter beta = 1.5. No failures will be allowed on this test, or f = 0.

Using the DRT (Design of Reliability Testing) utility, determine the following:

1. The number of units to test for 48 hr (in integers).
2. The test time for 20 units.

6 Answers to Practice Questions

This section provides answers to the Practice Questions in Chapter 5.

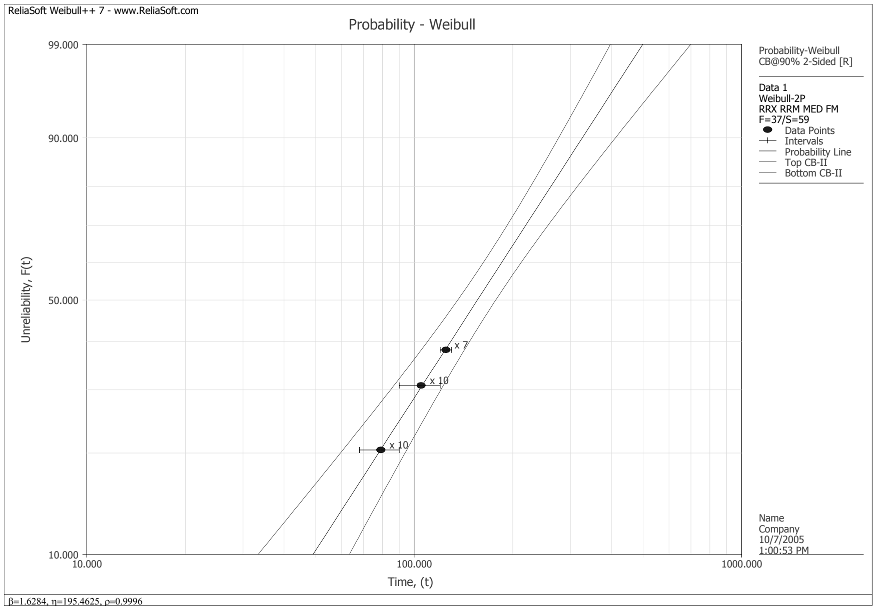
6.1 Practice Question 1

1. Individual times-to-failure (complete)
4. Parameter values for each distribution:
   i. 2-parameter Weibull $\beta = 2.5147$, $\eta = 108.5178$
   ii. 3-parameter Weibull $\beta = 1.8021$, $\eta = 86.0358$, $\gamma = 21.2200$
   iii. Normal $\mu = 95.5000$, $\sigma = 42.8050$
   iv. Lognormal $\mu = 4.4876$, $\sigma = 0.4767$
   v. 1-parameter Exponential $\lambda = 0.0119$
   vi. 2-parameter Exponential $\lambda = 0.0196$, $\gamma = 48.0000$
5. The Distribution Wizard suggests the 3-parameter Weibull distribution.

6.2 Practice Question 2

1. 2-parameter Weibull $\beta = 1.6284$, $\eta = 195.4625$

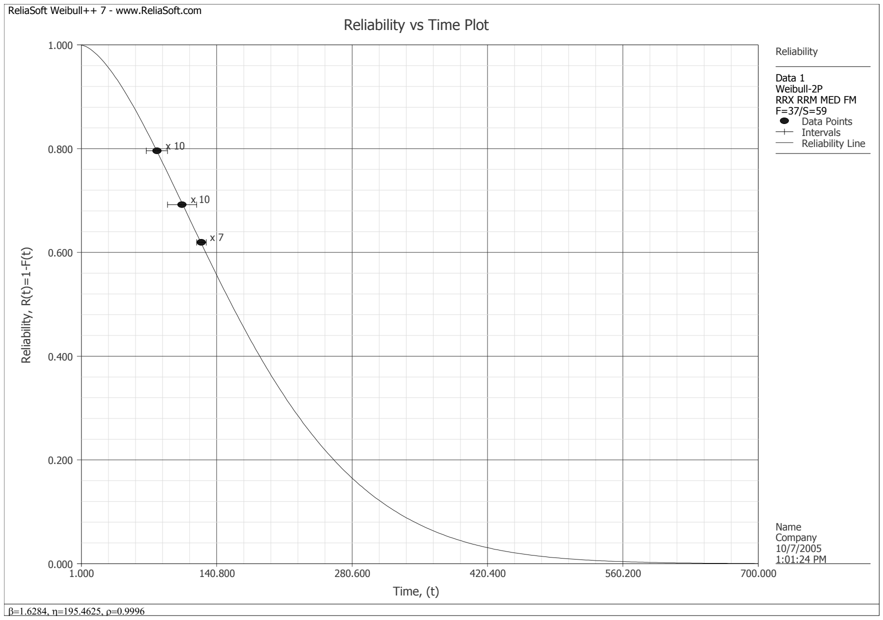
4. Probability plot with confidence bounds:



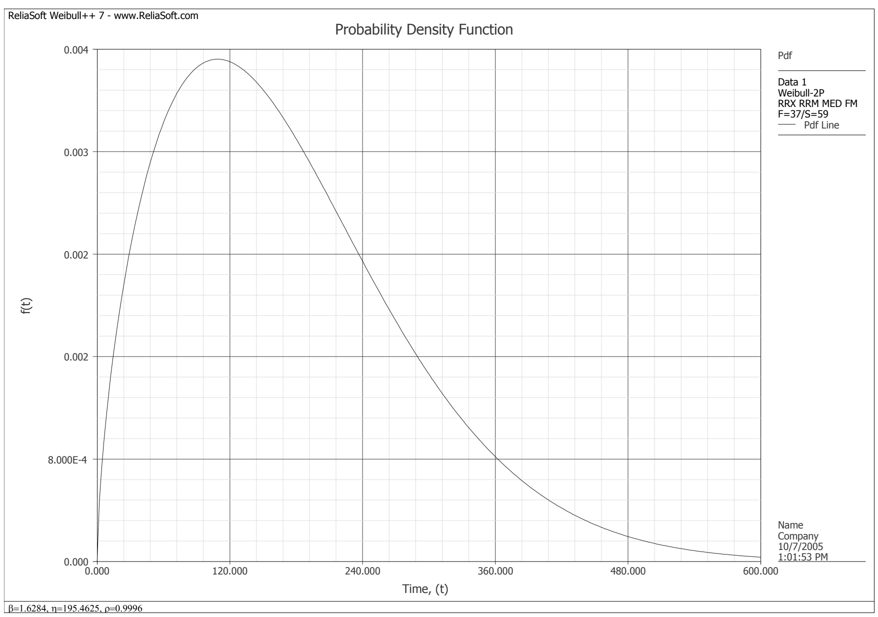
6. From the plot:
   i. R(50 hr) @ 89%
   ii. Upper CL @ 93.6%, Lower CL @ 83%
   iii. Mission Duration @ 50 hr
   iv. Requires a mission range of approximately 37-68 hr
7. From the QCP:
   i. R(50 hr) = 89.71%
   ii. Upper CL = 93.58%, Lower CL = 83.71%
   iii. Mission Duration = 49.0802 hr
   iv. Requires a mission range of 36.1255 - 66.6805 hr
   v. For β : 1.3039, 2.0337

      For η : 171.3340, 222.9889

8. Reliability vs. Time plot:



9. *pdf* plot:

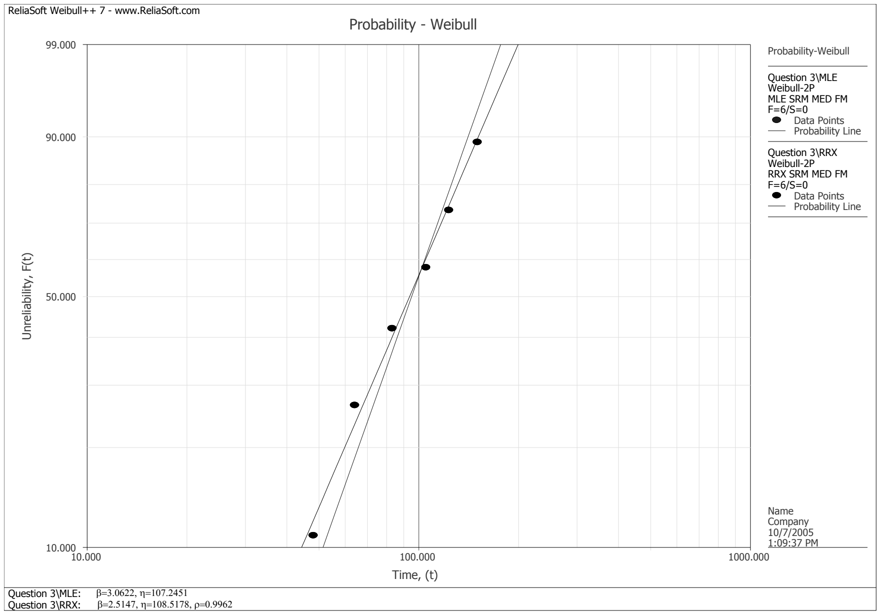


10. Failure Rate at 100 hr = .0055

6.3 Practice Question 3

2. For MLE: $\beta = 3.0622$, $\eta = 107.2451$
3. For RRX: $\beta = 2.5147$, $\eta = 108.5178$

6. MultiPlot for MLE and RRX:



6.4 Practice Question 4

2. Manufacturer A: $\beta = 2.7017$, $\eta = 2107.2287$

   Manufacturer B: $\beta = 1.0796$, $\eta = 5322.1346$

3. Manufacturer B is better with a 73% probability

6.5 Practice Question 5

2. $\beta = 3.0622$, $\eta = 107.2451$
8. Reliability for time increments from 10 to 100 with a 2-sided confidence level at 90%:

Time	Lower CL	Reliability	Upper CL
10	0.9557	0.9993	1.0000
15	0.9217	0.9976	0.9999
20	0.8834	0.9942	0.9997
25	0.8419	0.9885	0.9992
30	0.7982	0.9800	0.9982
35	0.7529	0.9681	0.9963
40	0.7065	0.9524	0.9932
45	0.6596	0.9324	0.9883
50	0.6125	0.9079	0.9811
55	0.5654	0.8786	0.9711
60	0.5187	0.8446	0.9575
65	0.4725	0.8059	0.9398
70	0.4271	0.7628	0.9174
75	0.3825	0.7157	0.8901
80	0.3390	0.6653	0.8576
85	0.2968	0.6122	0.8202
90	0.2559	0.5573	0.7782
95	0.2169	0.5016	0.7325
100	0.1799	0.4461	0.6840

6.6 Practice Question 6

5. The parameters are not equal because the data set was generated via simulation.
7. The two data sets are not the same because they were generated via simulation.

6.7 Practice Question 7

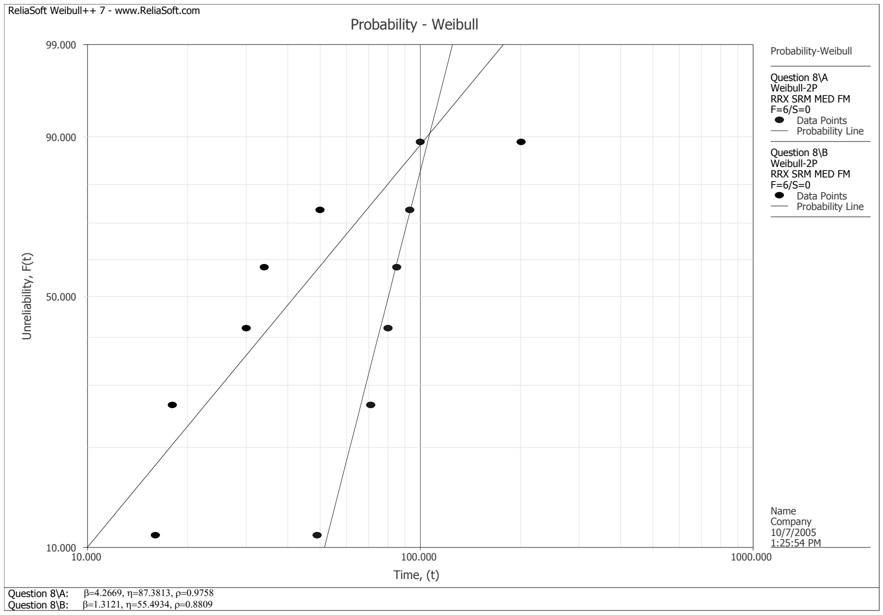
1. 10 units
2. 17 units

6.8 Practice Question 8

2. Product A: $\beta = 4.2669$, $\eta = 87.3813$

   Product B: $\beta = 1.3121$, $\eta = 55.4934$

4. Probability plot for both data sets:



6.9 Practice Question 9

1. 86 units
2. 126 hr