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As cost effectiveness and time to market have become higher priorities during the developmental process, more and more companies are turning to Computer Aided Engineering (CAE) to achieve these goals while ensuring that next generation products continue to meet customer expectations. In order to meet these expectations, it is important to understand how customers use the product. In some cases, usage estimation is sufficient, however, collecting actual customer usage data will allow for more accurate predictions.

In this article, we will combine ReliaSoft Weibull++ and nCode DesignLife to perform a two-step analysis to estimate product life. The first step will involve fitting a distribution to existing customer usage data to obtain the 50th and 90th percentile usage levels. The second step will involve applying those levels within DesignLife to a virtual model of our product to obtain life estimates for both the average user (50TH percentile) and the high-end user (90th percentile).

CUSTOMER USAGE PROFILE

After designing the door hinge on the next generation refrigerator, the team has now been tasked to estimate the life expectancy of the hinge using CAE prior to the process going into the prototype phase. This is to ensure that the new design will meet the expected life of 1,000,000 cycles for the average user and will also last 75,000 cycles for a high-end user. Thankfully for the design team, they have access to customer usage data collected by a third-party customer survey company. This data was collected using an accelerometer to measure the Peak g-levels on various showroom refrigerators upon the door being closed.
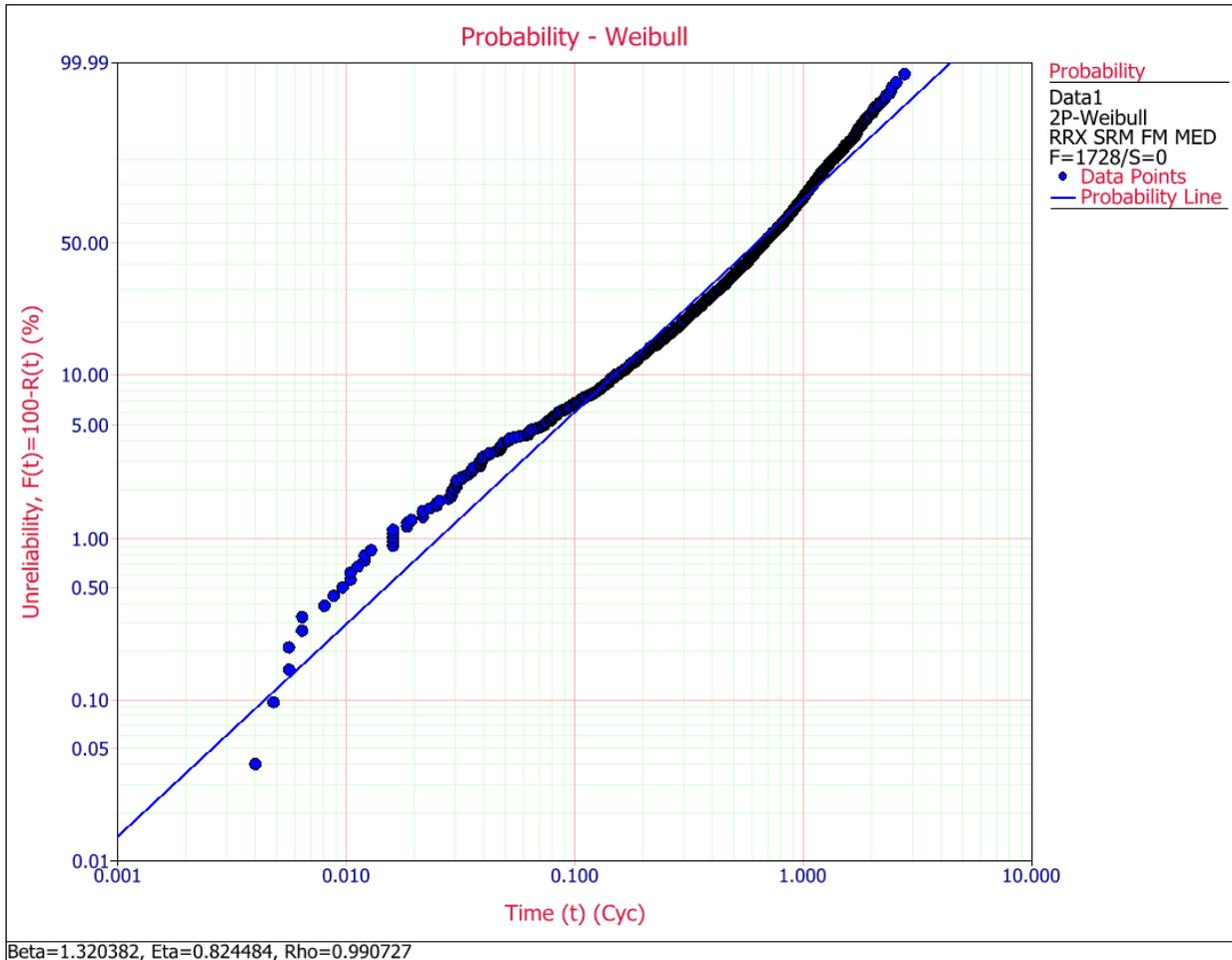
The first step of the analysis involves taking the usage data collected and fitting it with a distribution. A sample below:

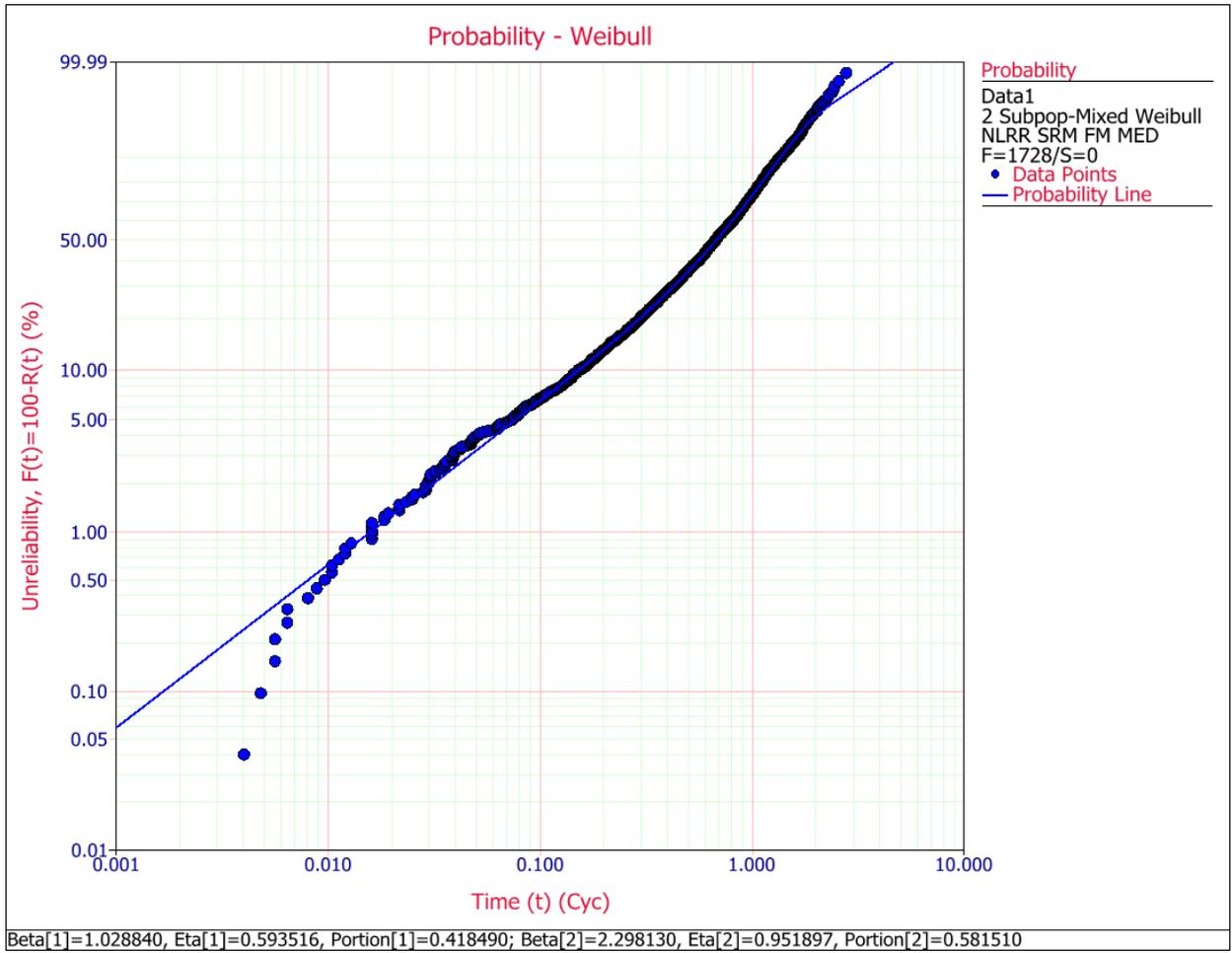|	Peak Accel (g)	Door Close Number
1	0.0105	1
2	0.5041	2
3	0.07189	3
4	0.5372	4
5	0.004846	5
6	0.8628	6
7	0.5647	7
8	0.09855	8
9	0.9064	9
10	0.622	10
11	0.02908	11
12	1.381	12
13	0.1858	13
14	1.059	14
15	0.04766	15
16	0.5008	16
17	0.4378	17
18	1.163	18
19	0.2092	19
20	0.4766	20
21	0.534	21
22	0.4346	22
23	0.1341	23
24	0.5889	24
25	0.513	25
26	0.971	26
27	0.07432	27
28	0.6963	28
29	0.0307	29
30	1.566	30
31	1.507	31
32	1.183	32
33	0.8603	33
34	0.9767	34
35	0.1381	35
36	0.5574	36
37	0.3667	37
38	0.9621	38
39	0.7004	39
40	1.034	40
41	0.5235	41
42	0.702	42
43	0.2108	43
44	0.7755	44
45	0.5937	45
46	1.103	46
47	0.8531	47
48	1.382	48

Once the data has been entered into the tool, it is fitted with a normal distribution based on the assumption that the usage profile should follow a Gaussian curve. The probability plot of the data versus the model can be seen below:
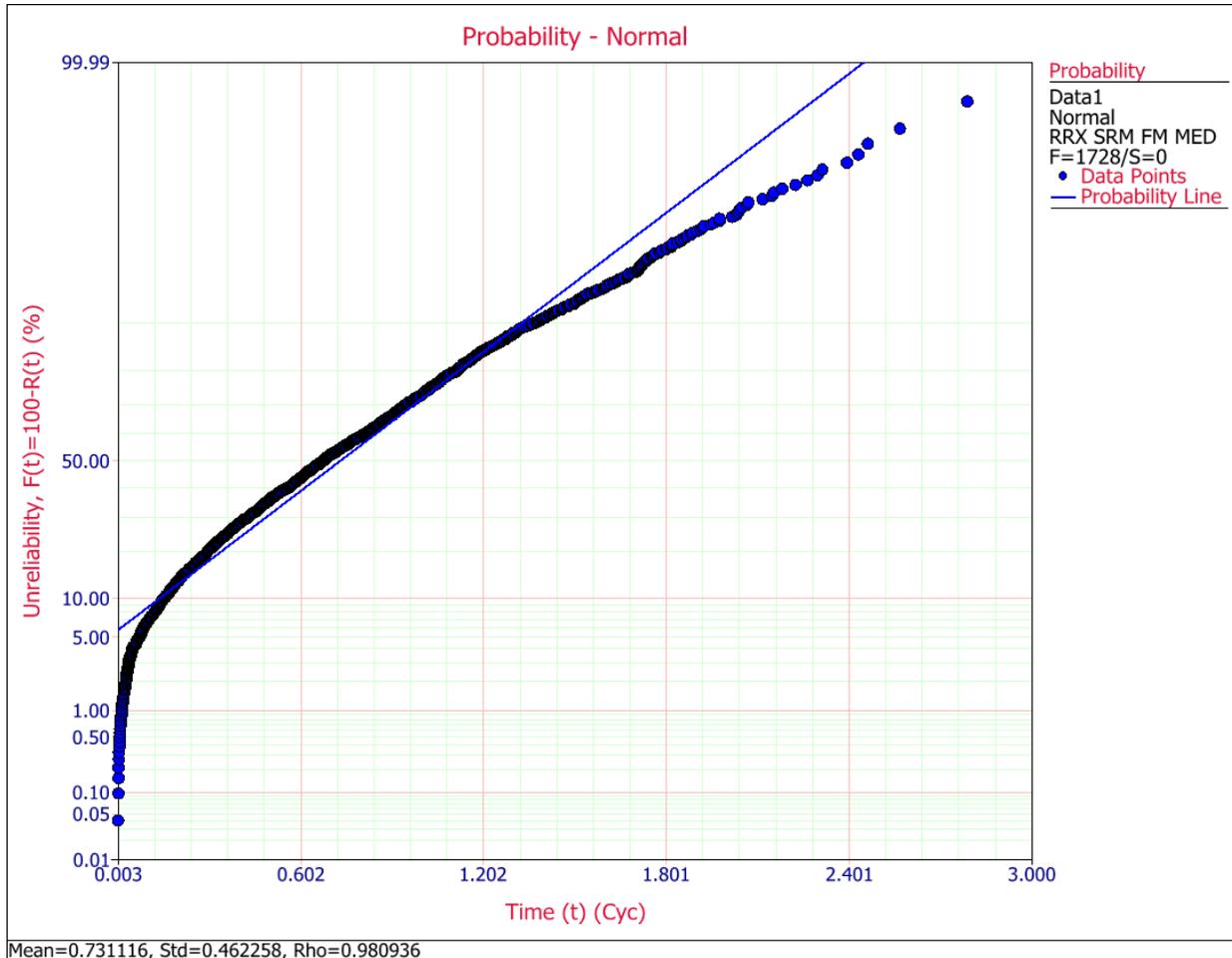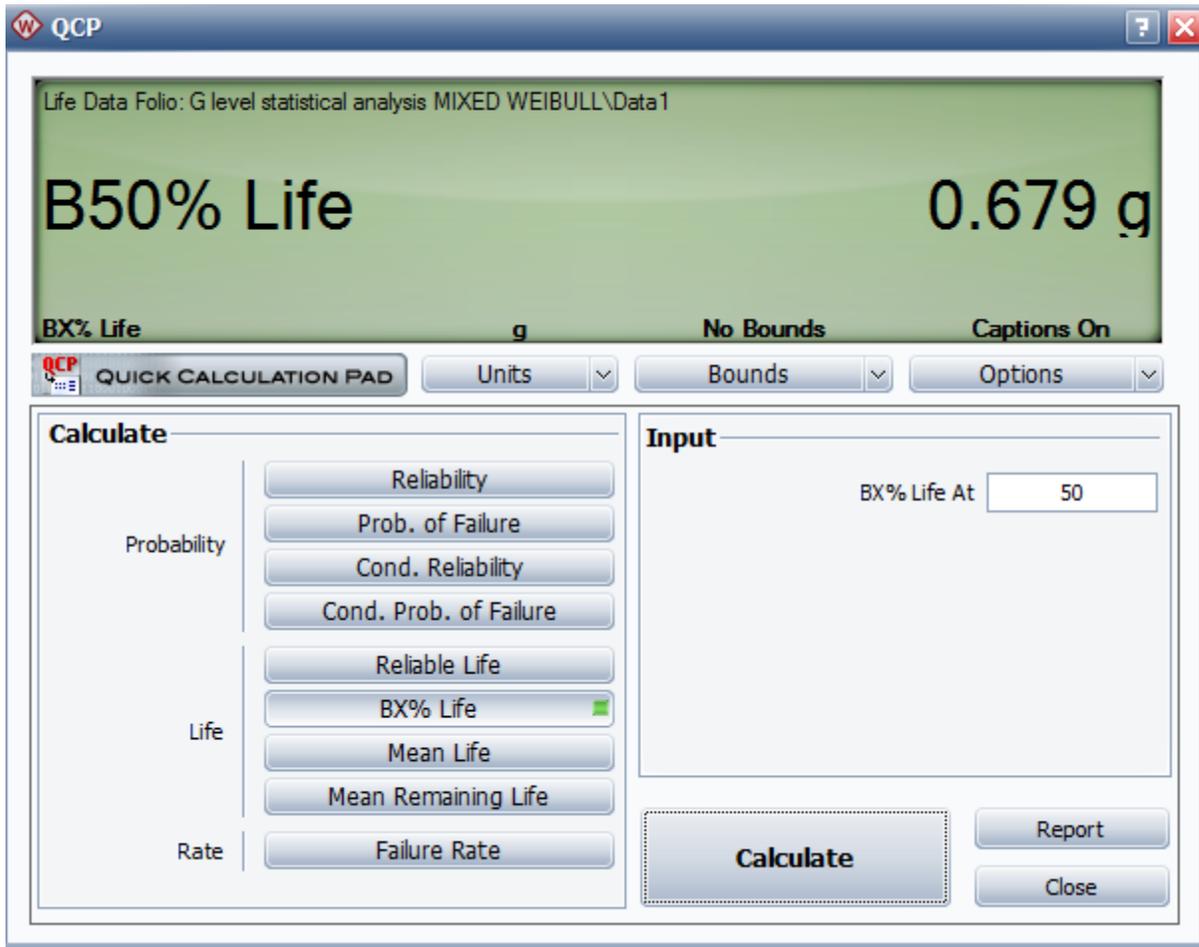

Based on the data trend compared to the model, it is clear that the usage profile does not follow a normal distribution as originally assumed. Therefore, the data is reanalyzed using a 2P-Weibull distribution as that distribution is more robust than the normal distribution. The new probability plot using 2P-Weibull can be seen below:

Probability - Weibull

Unreliability, F(t)=100-R(t) (%)

Time (t) (Cyc)

Probability
Data1
2P-Weibull
RRX SRM FM MED
F=1728/S=0
• Data Points
— Probability Line

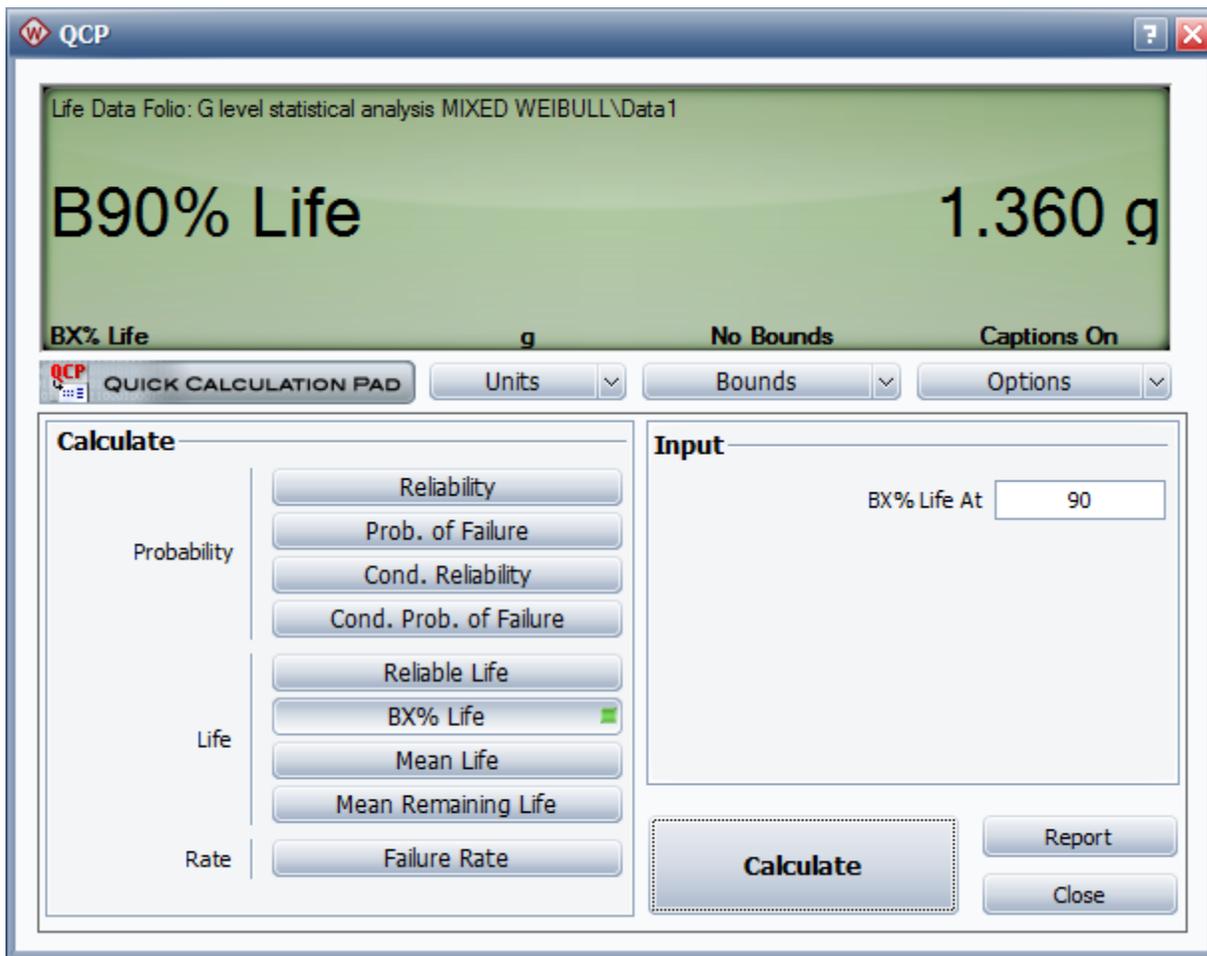Beta=1.320382, Eta=0.824484, Rho=0.990727

While the 2P-Weibull model is a better fit to the data than the normal distribution, the curvature of the data relative to the model suggests that there could be more than one trend within the data set. Upon review of the methodology used by the company collecting the data, it turns out that the data set contains measurements from both people who just pushed the refrigerator door closed and those that actually held on to the door while closing it. Since there is no way to tell which data point came from which type of use, the team decides to use a 2 subpopulation Mixed-Weibull distribution to model the data. The probability plot for the Mixed-Weibull model can be seen below:

Probability - Weibull

Beta[1]=1.028840, Eta[1]=0.593516, Portion[1]=0.418490; Beta[2]=2.298130, Eta[2]=0.951897, Portion[2]=0.581510

As this model appears to follow the trend of most of the data points (except for the two ends), the team uses this model to calculate the usage levels. Using the Quick Calculation Pad found within Weibull++, the 50th percentile usage level (average user) is found to be:

The 90th percentile usage level (high-end user) is found to be:

QCP

Life Data Folio: G level statistical analysis MIXED WEIBULL\Data1

B90% Life   1.360 g

BX% Life   g   No Bounds   Captions On

QUICK CALCULATION PAD   Units ⌄   Bounds ⌄   Options ⌄

Calculate

Probability
- Reliability
- Prob. of Failure
- Cond. Reliability
- Cond. Prob. of Failure

Life
- Reliable Life
- BX% Life
- Mean Life
- Mean Remaining Life

Rate
- Failure Rate

Input

BX% Life At   90

Report

**Calculate**

Close

LIFE ESTIMATION USING CAE

Assessing the fatigue life of a part with CAE requires a few steps. First, the engineer must have a virtual representation of the part. This is usually done in a CAD package. Once this virtual representation, or geometry, is designed the engineer must then use finite element analysis to solve for the "nominal" stress distribution of the part in its environment. The engineer also needs to understand how the part will be used in the field. That is how the part will be loaded and unloaded in the field, causing changes in the nominal stress distribution over time, which is ultimately what drives fatigue damage and ultimately fatigue failure if the stress changes are large enough. Once the static stress distribution and predicted field usage are obtained, the part can then be sent to a CAE fatigue solver such as DesignLife in order to assess the fatigue life of the part.

USING THE RESULTS FROM WEIBULL++ AS INPUT TO THE FATIGUE CALCULATION

So now that we have a good understanding of the field usage of the part, the B50 and B90 results from the Weibull++ analysis are sent to the finite element analysis team along with the solid model created from the design team. The geometry the design team came up with is show below:
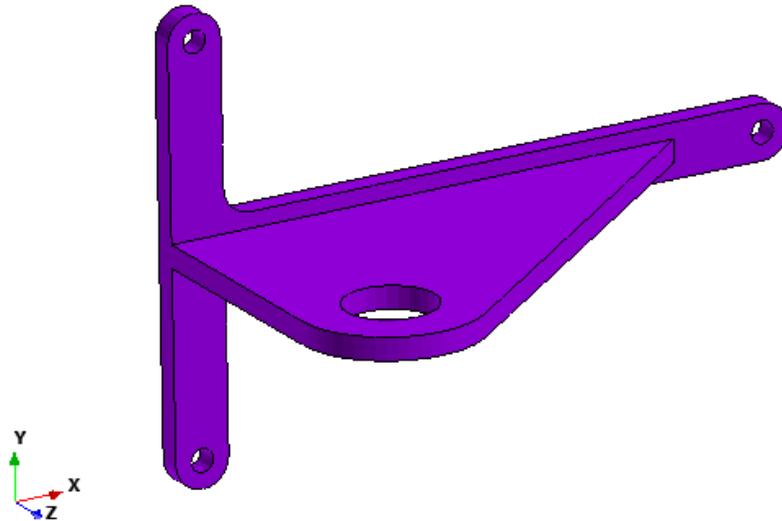
The analysis team applies a simple unit g load to the part to obtain the stress distribution from "nominal" loading. That resulting stress distribution is shown below:
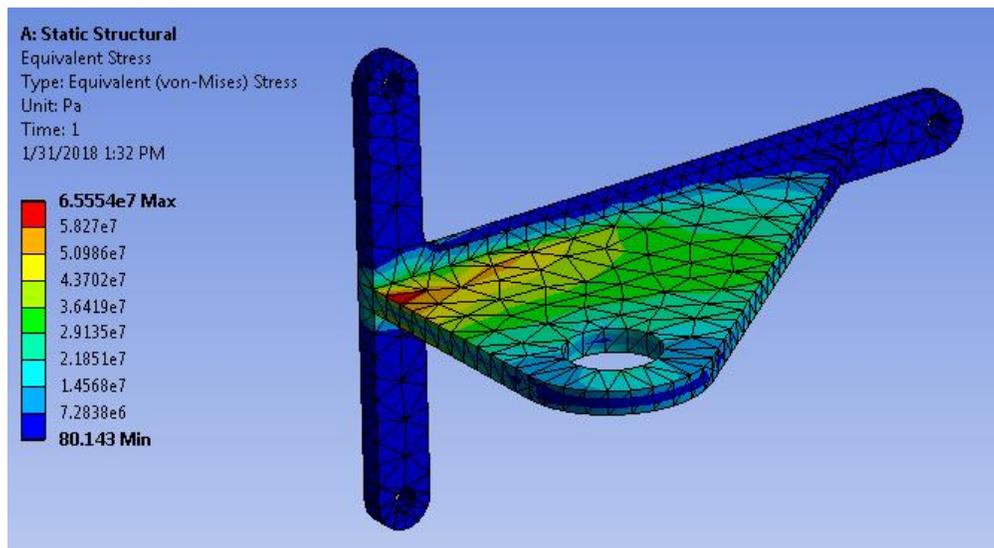

Once the static stress distribution is obtained, the results file, along with the B50 and B90 values obtained from the Weibull analysis, can be exported to DesignLife to assess the fatigue life of the part.

Recall from earlier that we've been asked to design a hinge that can survive 1,000,000 cycles at the "average" or B50 loading of 0.679 g, and 75,000 cycles at the high-end user level, or B90 loading of 1.360 g. Let's start by analyzing the B50 life. *(EDIT: This phrase is awkward and unnecessary.)*

As stated earlier, our nominal stress distribution represents the stress of the part under no additional or external user-input loading. So in the case of the B50 loading, the average user causes an acceleration of 0.679 g above nominal. In order to perform the fatigue analysis in DesignLife, we need to define the fatigue cycle. In this case, we will define it as going from nominal to the nominal plus whatever additional acceleration the user imparts on to the hinge. Therefore, our cycle
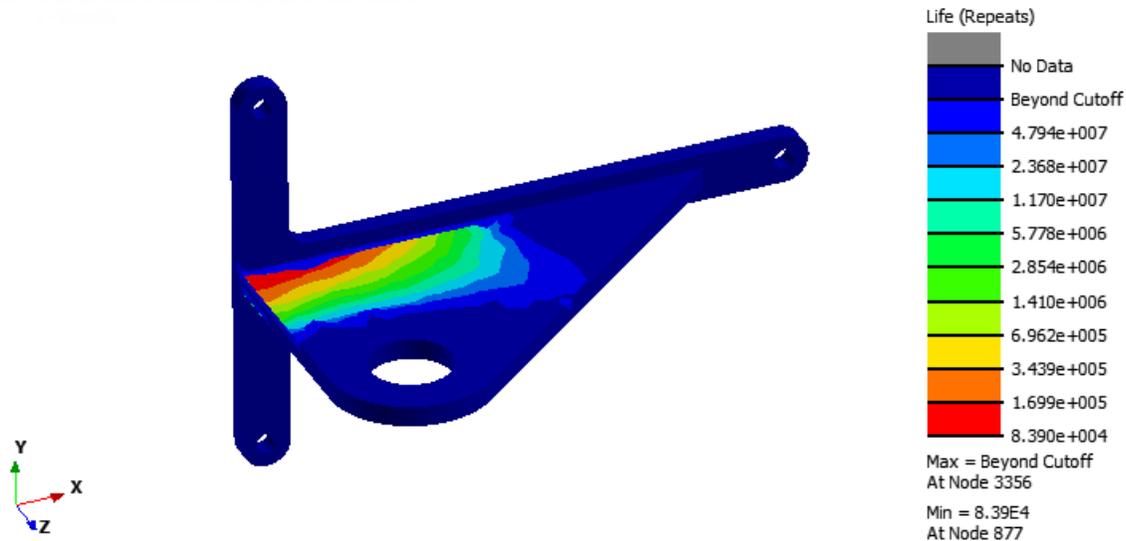
is be defined as going from 1 g to 1.679 g. DesignLife uses this information to calculate the change in stress due to the change in acceleration as every single node in the model. It then calculates the damage associated with that change in stress by looking at the fatigue curve and then calculates how many of those cycles the part can withstand before a crack is predicted to initiate <mark>and every single node in the model</mark>. The result is a contour plot of damage or, inversely, life. That is, how many times can we repeat that 1g to 1.679 g cycle until a crack will initiate. The life contour plot for the B50 case is shown below.

(EDIT: the transition is clumsy and the meaning is unclear)
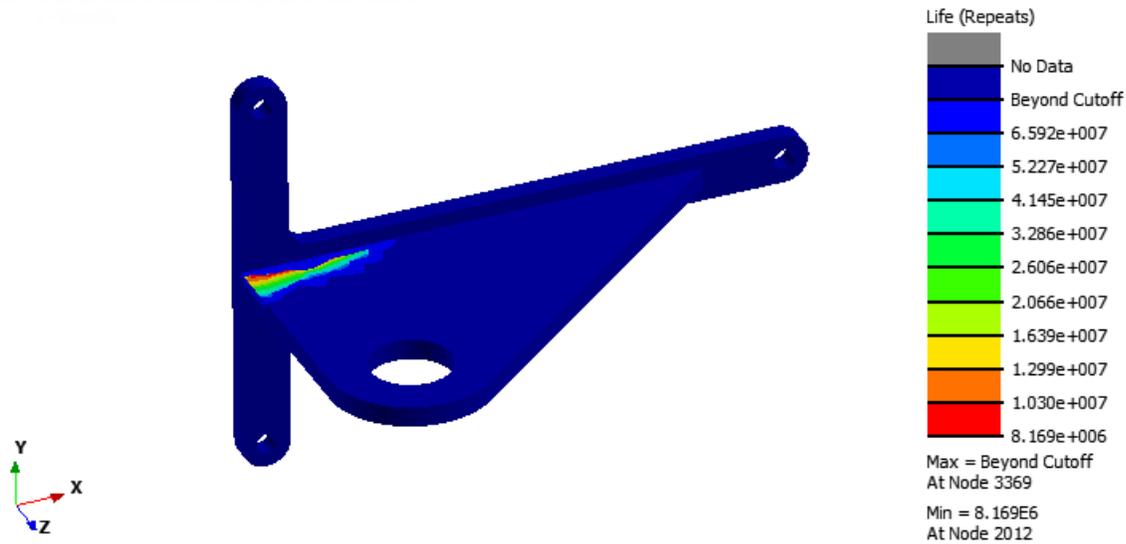
The minimum life seen in the plot is 8,196,000 cycles. This is well above the requirement of 1,000,000 cycles so it's safe to say that this design is sufficient for surviving the B50 loading requirement. Now let's turn our attention to the B90 requirement.

The B90 loading was found to be 1.36 g. That is, 1.36 g in addition to the nominal 1 g. Therefore, our loading for the B90 case is defined as 1 g to 2.36 g. Re-running our fatigue analysis with this loading definition results in the following life contour plot:

Life (Repeats)

	No Data
	Beyond Cutoff
	4.794e+007
	2.368e+007
	1.170e+007
	5.778e+006
	2.854e+006
	1.410e+006
	6.962e+005
	3.439e+005
	1.699e+005
	8.390e+004

Max = Beyond Cutoff
At Node 3356

Min = 8.39E4
At Node 877

The minimum life seen in the plot is 83,900 cycles. This is also above the requirement of 75,000 cycles so it is also safe to say that this design if sufficient for surviving the B90 loading requirement as well.

CONCLUSION

This demonstration walked through two very important concepts of life estimation. First, we discussed and gave examples of how to use Weibull++ to analyze actual in-field customer usage, which is a very important aspect of fatigue life estimation. When designing a new part, it's important to have a good sense of what kind of loadings you need to design against and there is no better way to do this than to collect actual costumer usage data and then fit appropriate distributions to this data. Secondly, we walked through how we can use a CAE fatigue analysis tool called DesignLife to predict the full model fatigue characteristics of our part. Together, Weibull++ and DesignLife provide a very powerful set of tools that enable you create very accurate fatigue life predictions.

(EDIT: Suggest "highlighted" instead of "walked through". People "walk through," not demonstrations.)