

A decorative graphic on the left side of the slide, consisting of a network of light blue lines and small circles, resembling a circuit board or a stylized tree structure.

PRACTICAL USE OF STRESS-STRENGTH MODELS TO DEVELOP SPECIFICATIONS

ROB SCHUBERT, SSBB, CRE

AGENDA

- Introduction 5 min
- Target setting/predicted failure rate 5 min
- Stress – Strength basics 5 min
- Nozzle attachment strength with single comparator
 - With Excel 10 min
 - With Reliasoft 5 min
- Brush attachment strength with 8 comparators 15 min
- Cable pull – both ends – 3 comparators 10 min
- Questions 5 min

INPUTS FOR RELIABILITY TARGET SETTING

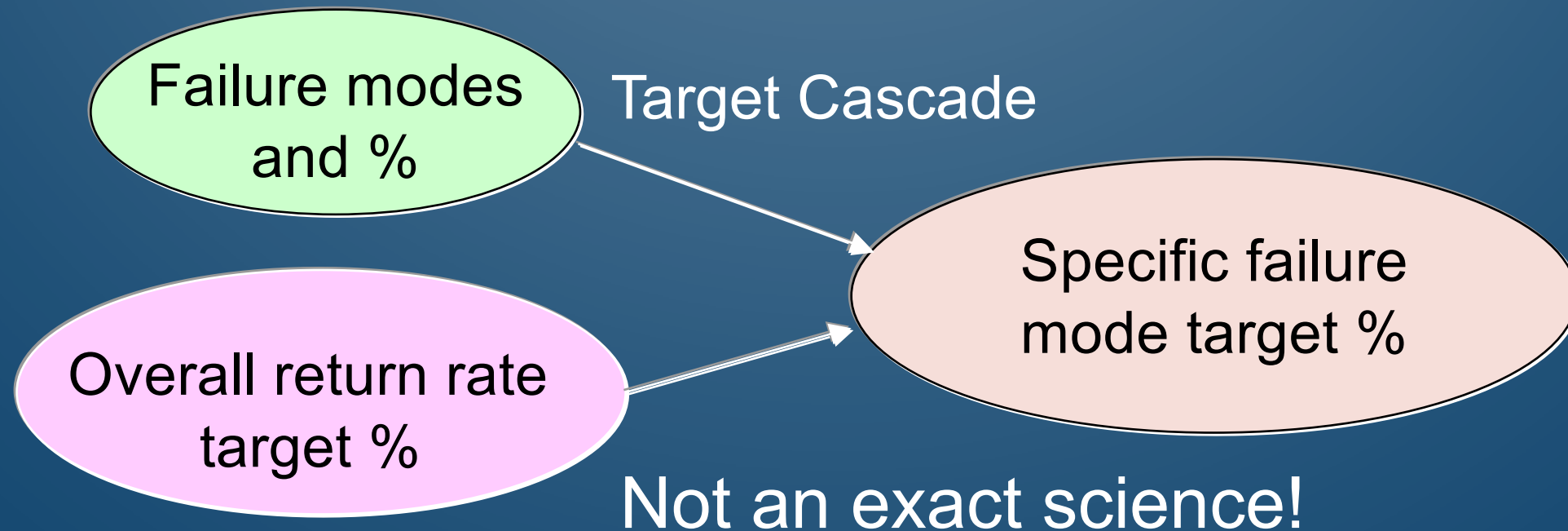
- Overall return rate target percentage for specific time frame

Company warranty requirements, warranty financial targets, achievable

Example: 3% for 2 year warranty period

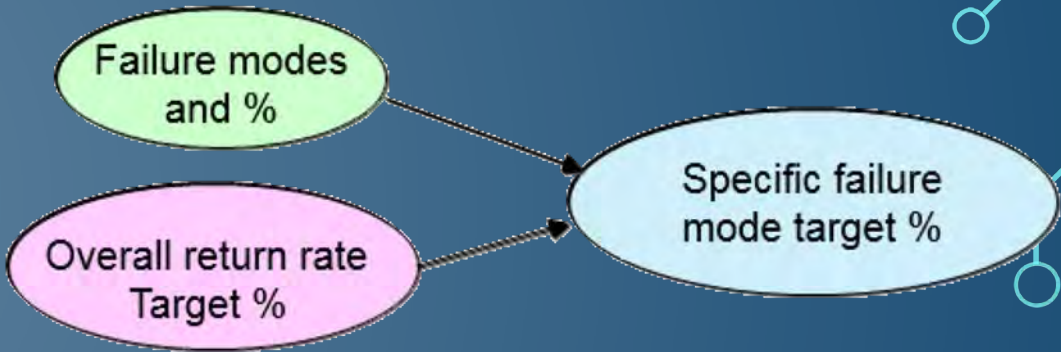
List of potential failure modes

- DFMEA
 - Percentage return expectations
- Previous shipping products
 - Percentage return actuals (historical data)



TARGET CASCADE EXAMPLE

- If 3% is set for the overall:



Blanket reduction

Failure mode	Current percent	Target percent
Clip Break	3.13%	1.10%
Brush Break	2.23%	0.79%
Battery Failure	1.94%	0.68%
Failure 4	1.10%	0.39%
All else	0.11%	0.04%
TOTAL	8.51%	3.00%

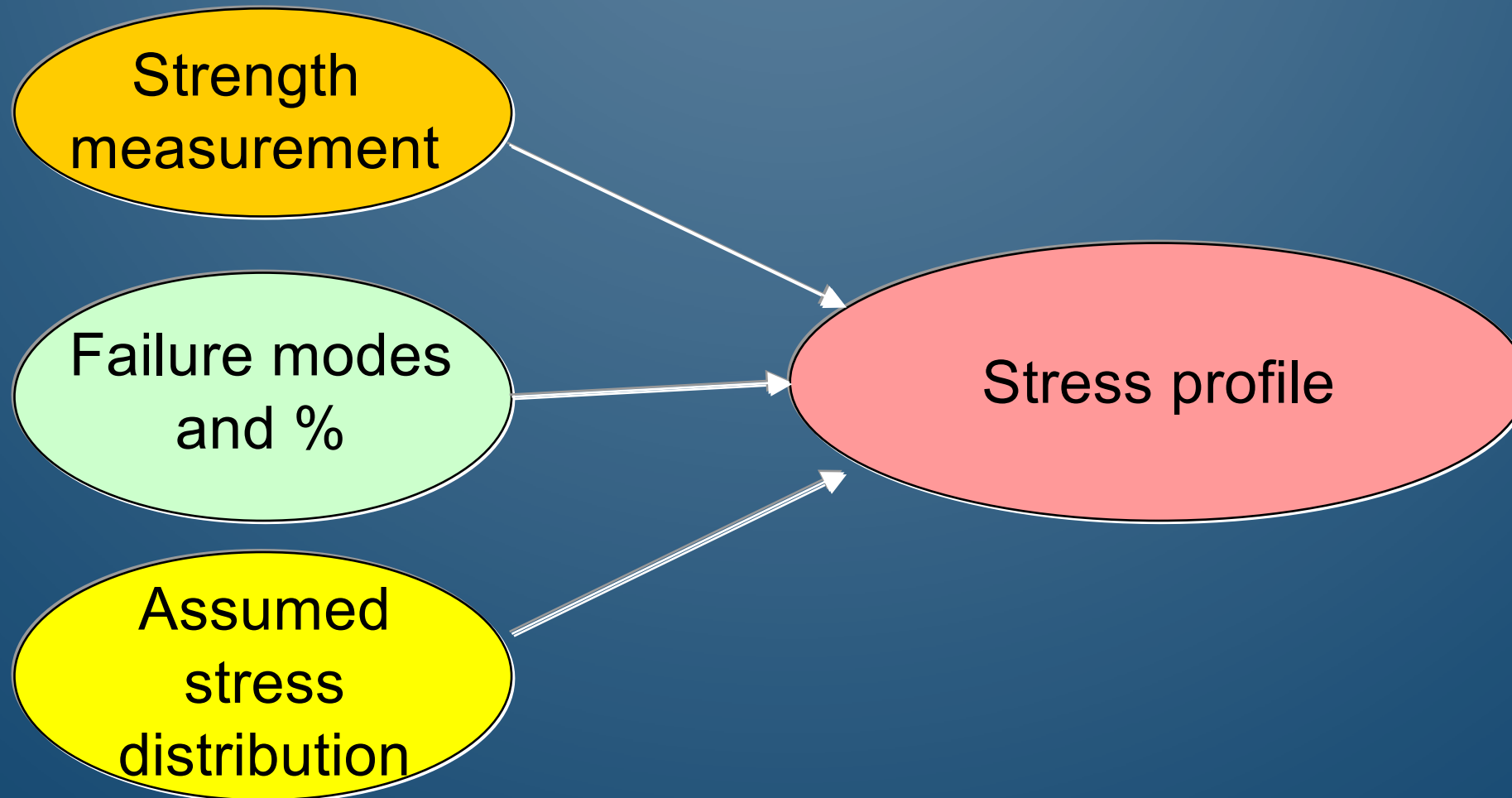
Specific actions

Failure mode	Current percent	Target percent	Action
Clip Break	3.13%	0.30%	Improve clip strength
Brush Break	2.23%	0.30%	Improve Brush strength
Battery failure	1.94%	1.94%	
Failure 4	1.10%	0.35%	Action ...
All else	0.11%	0.11%	
TOTAL	8.51%	3.00%	



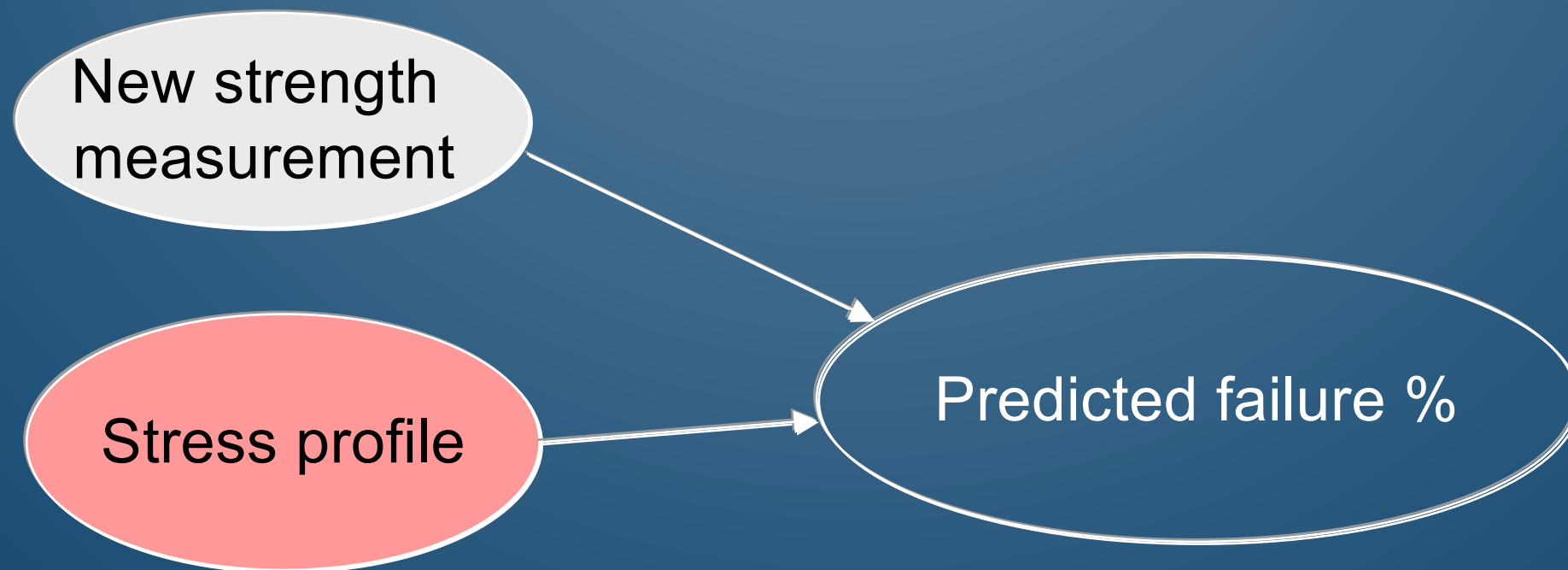
CONVERTING TARGET % TO STRESS PROFILE

- Choose a comparator (or several) with a similar or identical use case
- Measure strength of the comparator
- Choose an assumed stress distribution



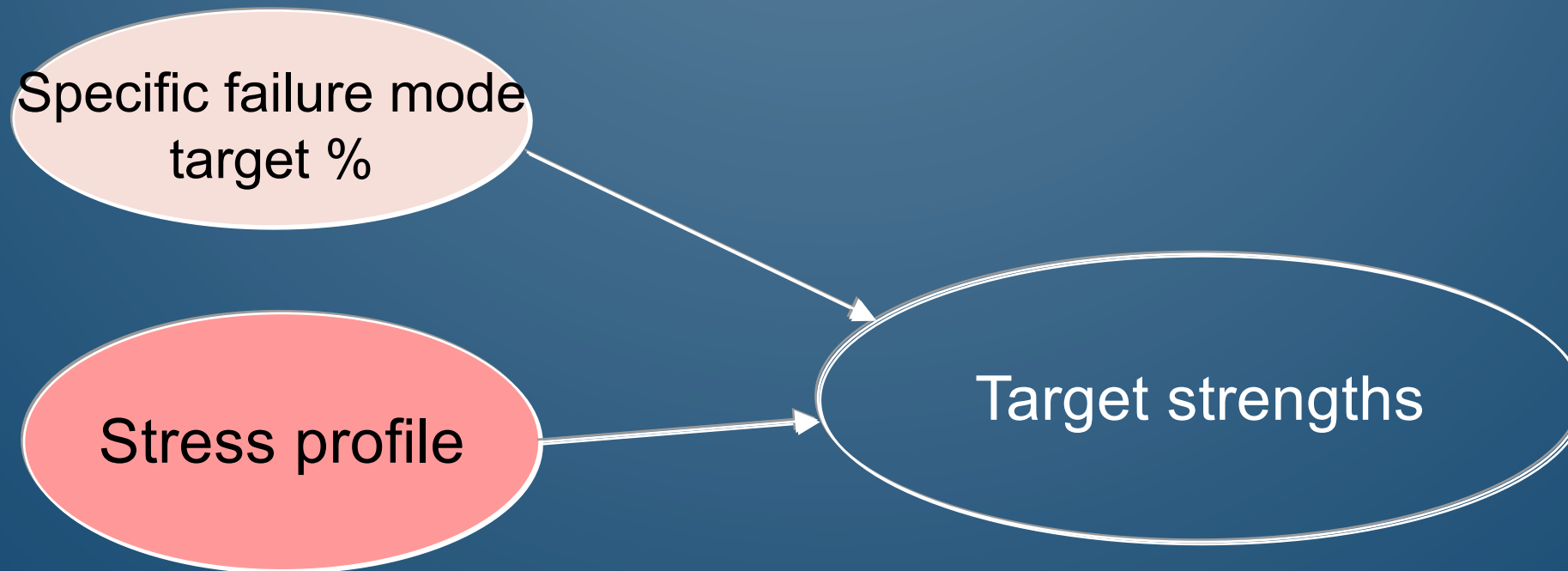
CALCULATE PREDICTED FAILURE RATE

- Use stress profile
- Use new product's strength measurement
- Calculate predicted failure rate



OR...CALCULATE TARGET STRENGTHS

- Use stress profile
- Use specific failure mode target
- Calculate target strengths

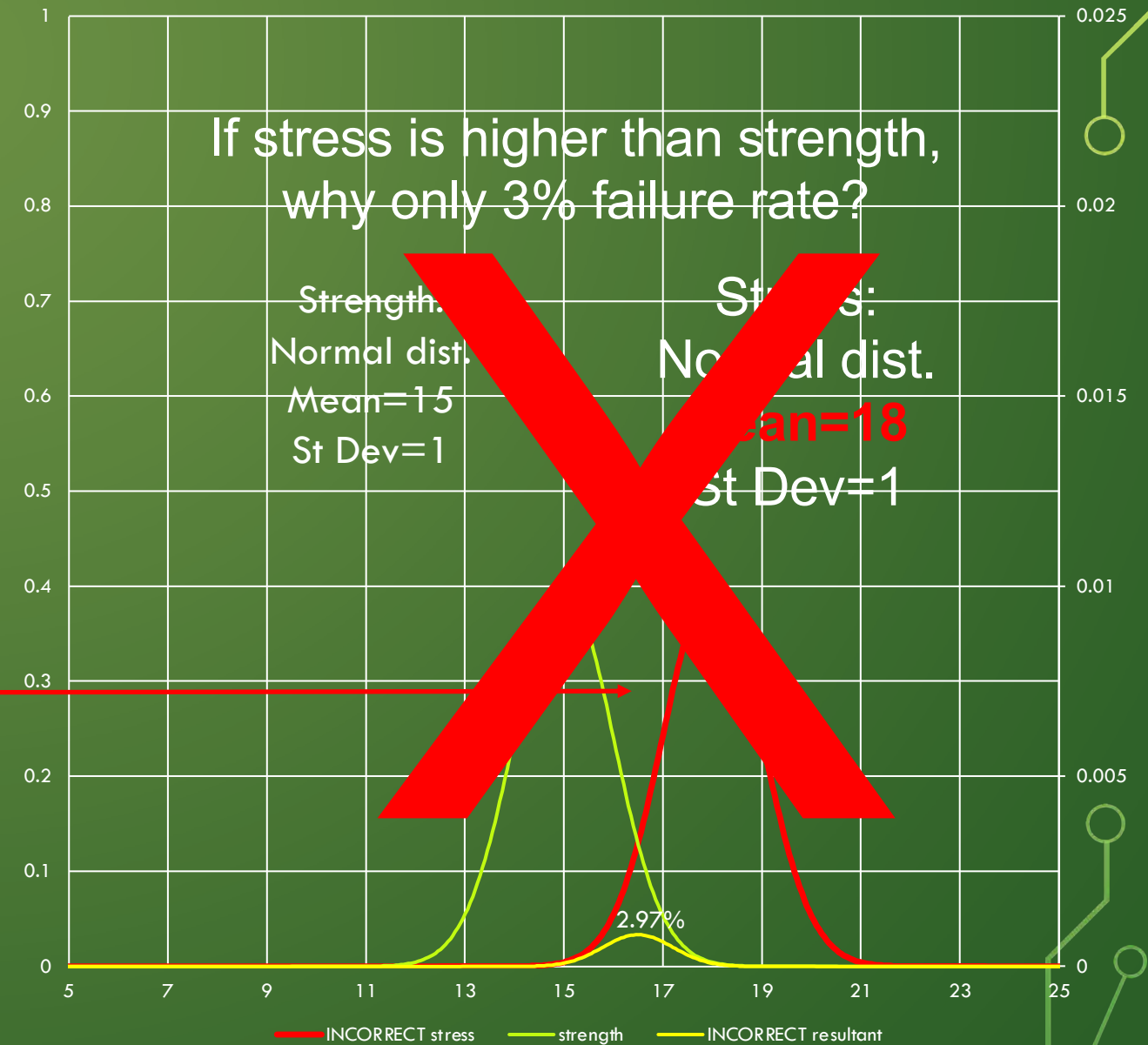
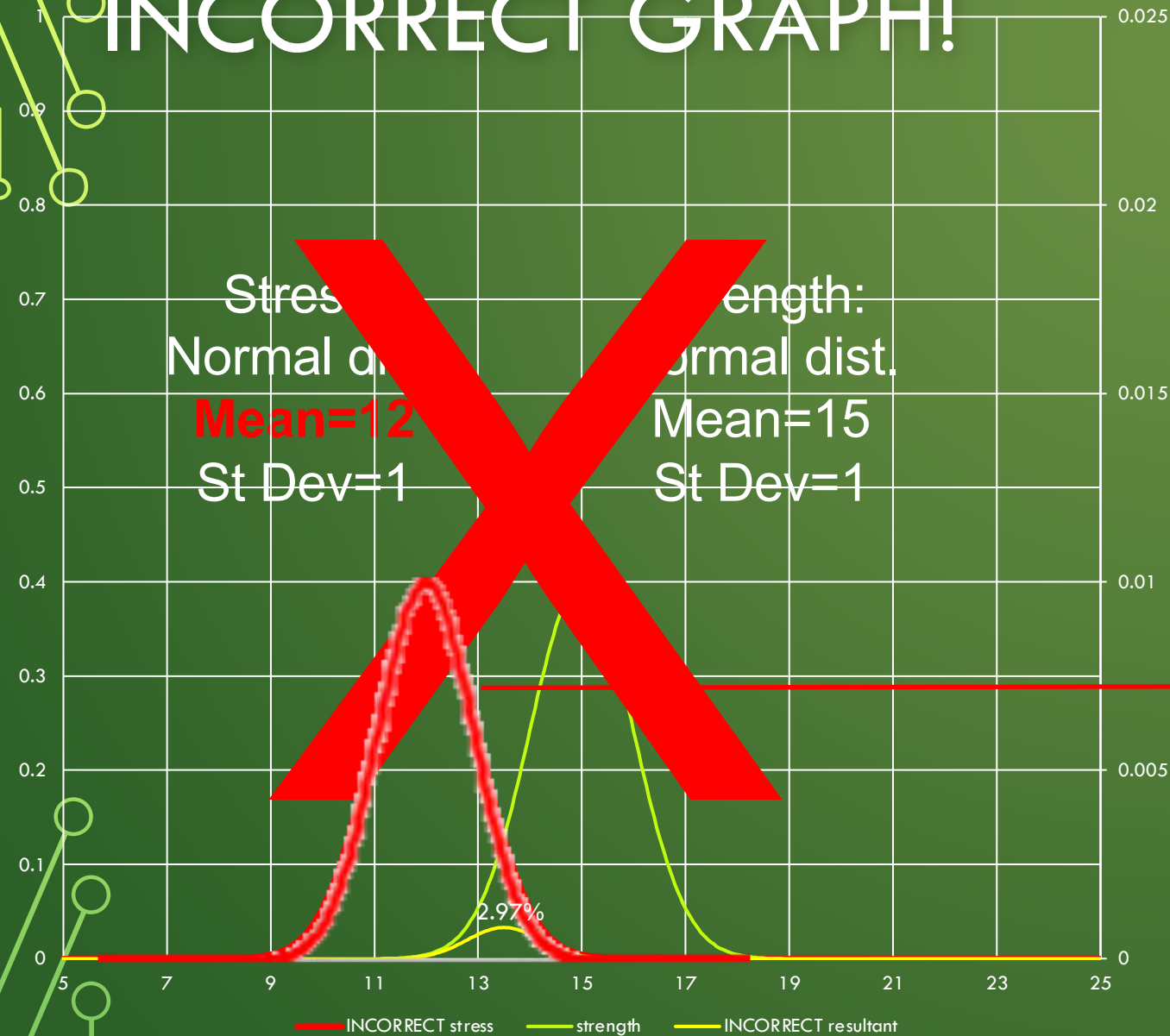


STRESS-STRENGTH BASICS

- Stress* is the (generic) forces applied in the field
- Strength is the (similar) forces the product can withstand
- When stress exceeds strength, failure occurs

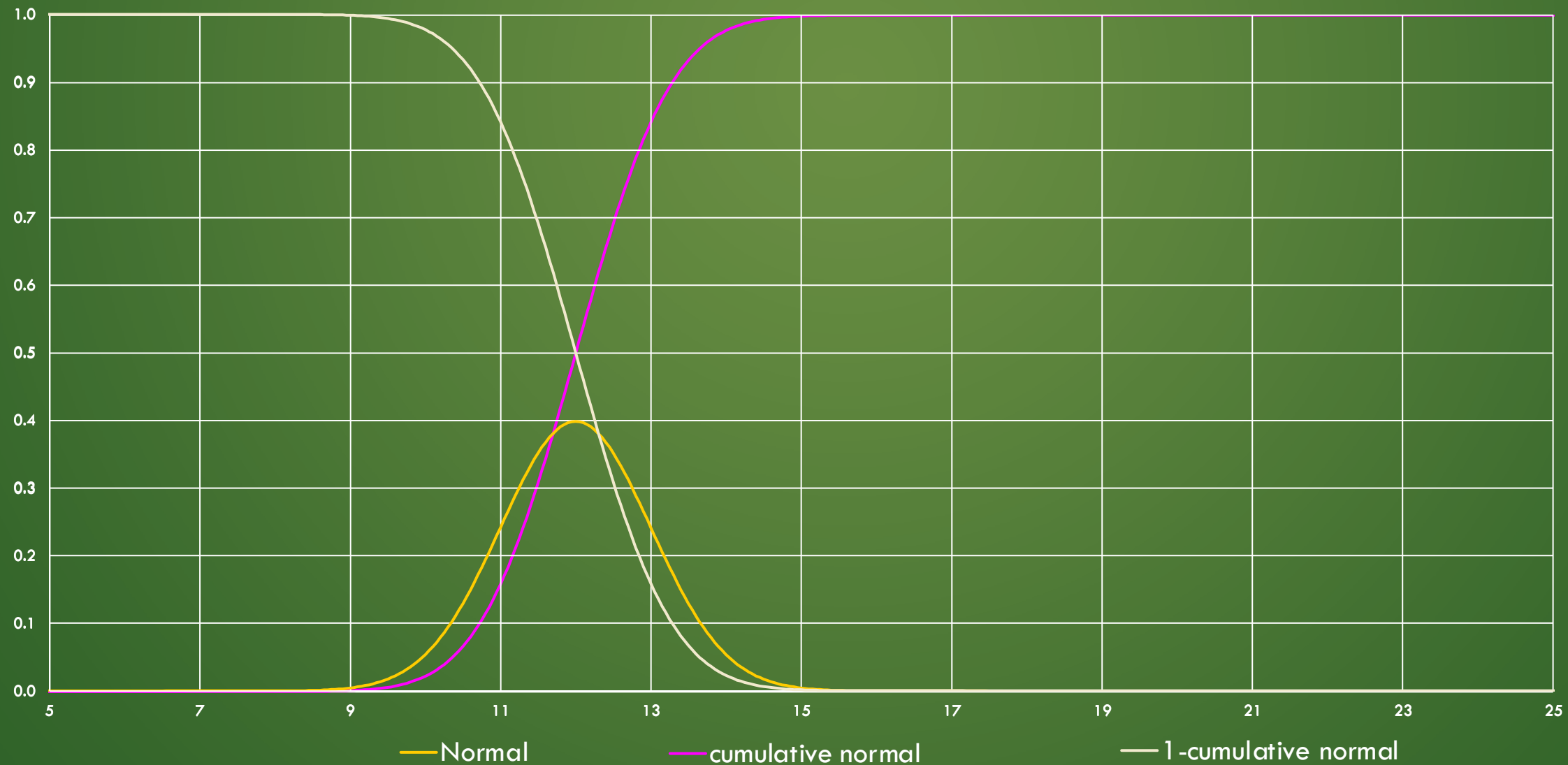
*This is a generic stress, not the engineering stress [force/area]

MOST REFERENCE MATERIALS SHOW AN INCORRECT GRAPH!



Multiplying 2 probability distribution functions yield incorrect results

THEN WHAT IS THE CORRECT GRAPH?

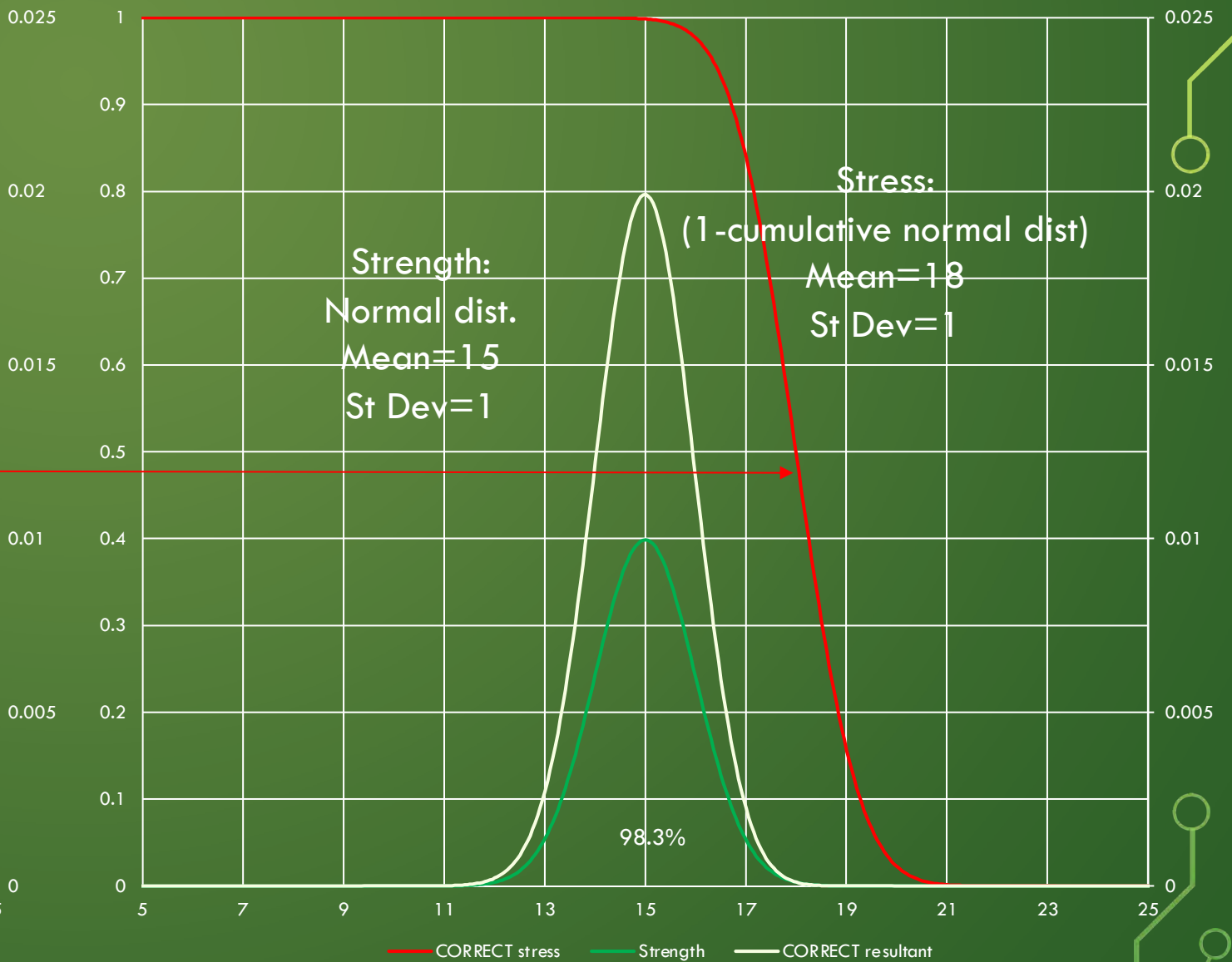
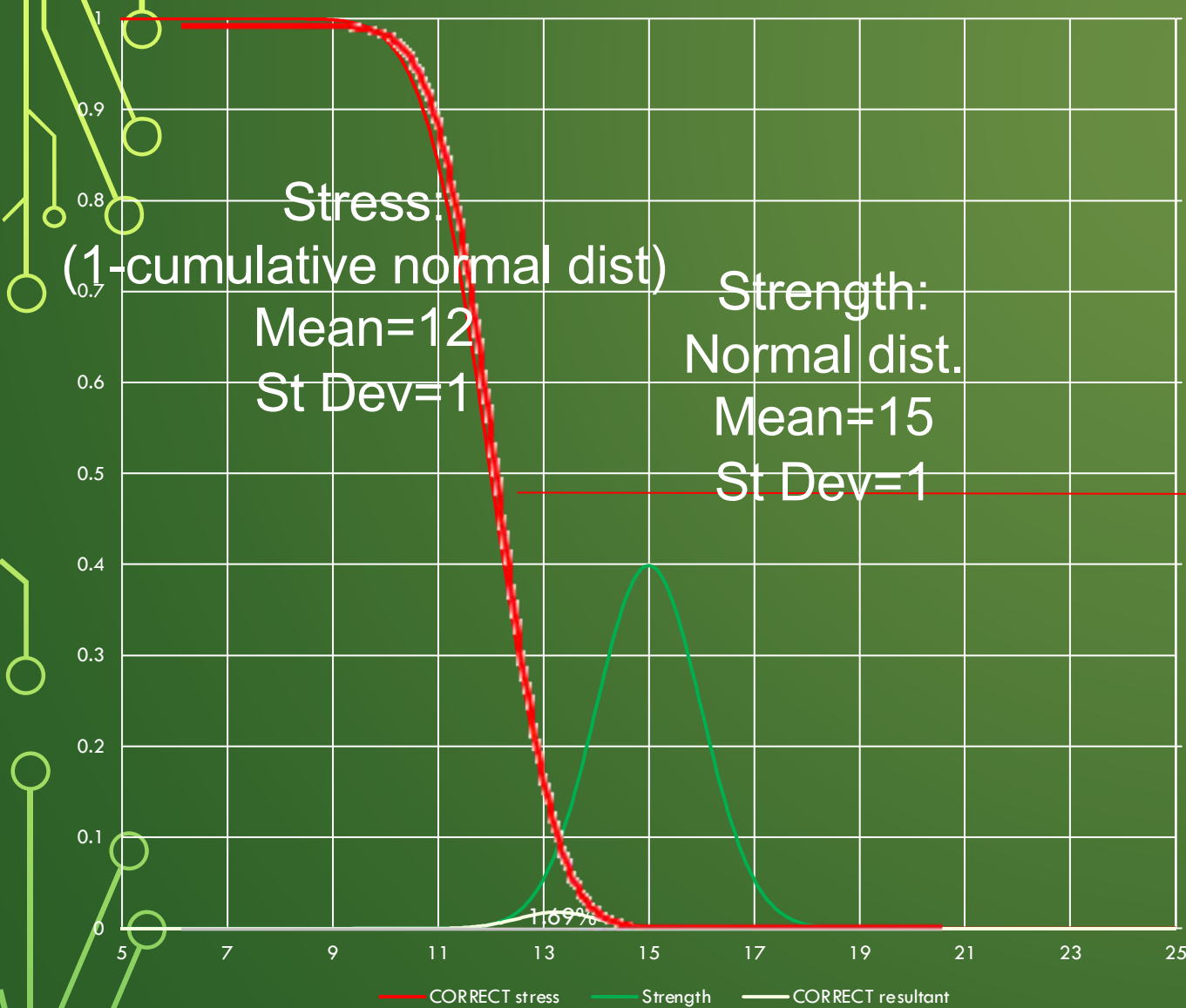


The PDF is the relative likelihood that the value of the stress would **equal** that force

The CDF is the likelihood that the value of the stress would **be less than** that force

The 1-CDF is the likelihood that the value of the stress would **be greater than** that force

Correcting the Paradigm



Corrected graph shows correct result !

CALCULATE ON AN EXCEL SPREADSHEET

$$\int_0^{\infty} STRESS(x) * Strgth(x) dx$$

=100%-NORM.DIST(stress level,Stress Mean,Stress StDev,TRUE)

=NORM.DIST(Stress level,Strgth Mean,Strgth StDev,FALSE)

Enter force in Lbs

Mean	12	15	Sum
st dev	1	1	1.695%
Stress level (Force)	stress (%)	Strength(%)	Resultant(%)
1.0	100%	1.09661E-43	1.09661E-43
2.0	100%	7.99883E-38	7.99883E-38
3.0	100%	2.14638E-32	2.14638E-32
4.0	100%	2.11882E-27	2.11882E-27
5.0	100%	7.6946E-23	7.6946E-23
6.0	100%	1.02798E-18	1.02798E-18
7.0	100%	5.05227E-15	5.05227E-15
8.0	100%	9.13472E-12	9.13443E-13
8.1	100%	1.83033E-11	1.83024E-12
8.2	99.99%	3.63096E-11	3.6307E-12
8.3	99.99%	7.13133E-11	7.13056E-12
8.4	99.98%	1.38668E-10	1.38646E-11
8.5	99.98%	2.66956E-10	2.66894E-11
8.6	99.97%	5.08814E-10	5.08643E-11
8.7	99.95%	9.60143E-10	9.59679E-11
8.8	99.93%	1.79378E-09	1.79255E-10
8.9	99.90%	3.31788E-09	3.31467E-10
9.0	99.87%	6.07588E-09	6.06768E-10

=Stress%*Strength%*(Change in stress level)

=SUM(entire column)

Any distributions can be used:

Gamma
Exponential
Lognormal
Weibull
Etc

Practically every function is in Excel

NOZZLE ATTACHMENT STRENGTH EXAMPLE

The goal was to find a specification for the Nozzle attachment Strength

Units would be returned with broken Nozzles (no explanation)



NOZZLE ATTACHMENT STRENGTH EXAMPLE (SINGLE PRODUCT COMPARATOR)

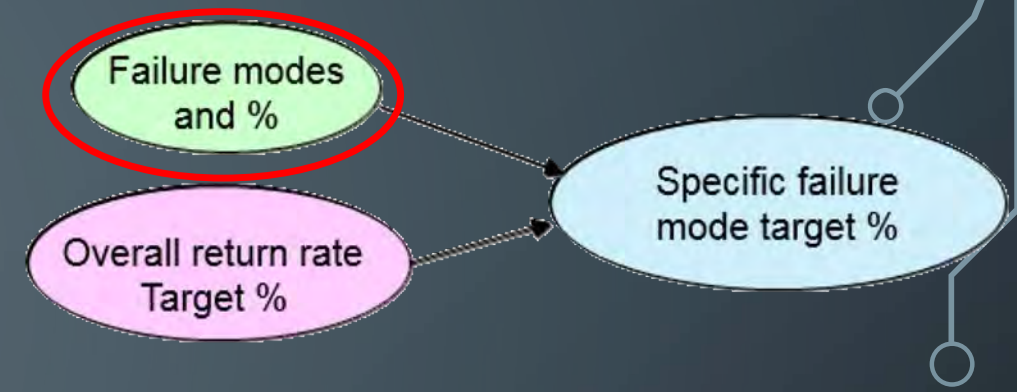


Test Method – fixture and pull up until failure



Stress doesn't have to be identical to the field stress, but should be related

CALCULATE SPECIFIC RETURN RATE

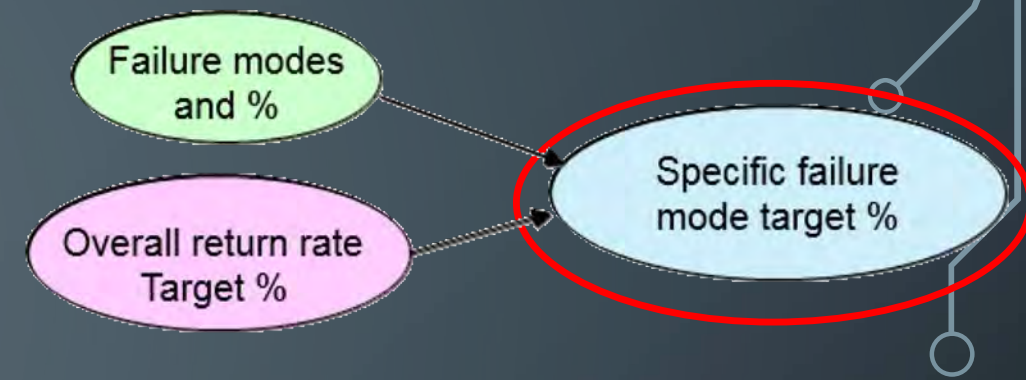


- In lieu of better measures, a simple return rate vs manufacture date can make for decent estimates.

$$= \text{Returns} / \text{Total Manufactured}$$

- Be sure to use mature data
 - 2 year warranty data w/ corresponding manufactured quantities
- For this example, this calculates to 0.78% for 2 year warranty period

CREATE SPECIFIC TARGET



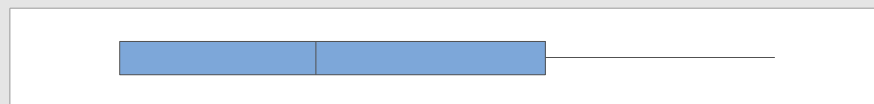
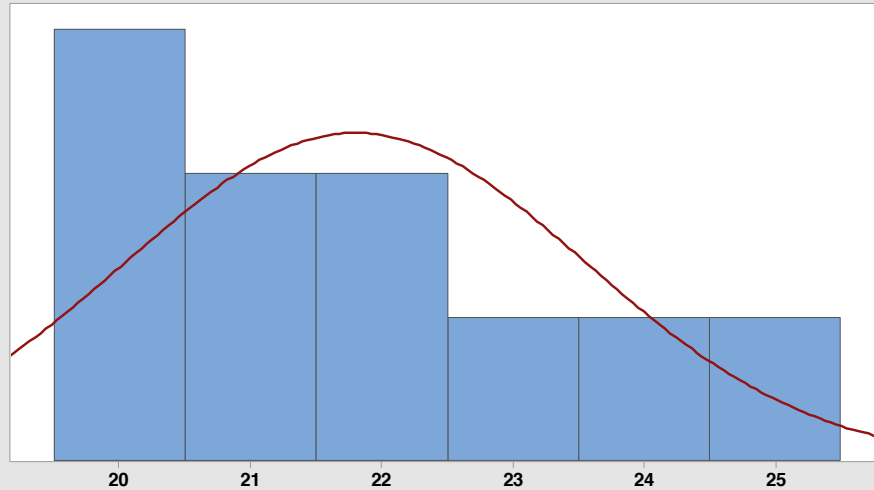
- Is there an overall target?
- What percentage is this failure mode? Or what is it expected to have?
- Example:

	Failure Mode Percentage
Good	<0.75%
Borderline	0.75%-1.00%
Unacceptable	>1.00%

- With 1 comparator, this is pretty rough

MEASURE NOZZLE STRENGTH OF CURRENT COMPARATOR

Summary Report for nozzle strength



95% Confidence Intervals



Anderson-Darling Normality Test

A-Squared	0.39
P-Value	0.312

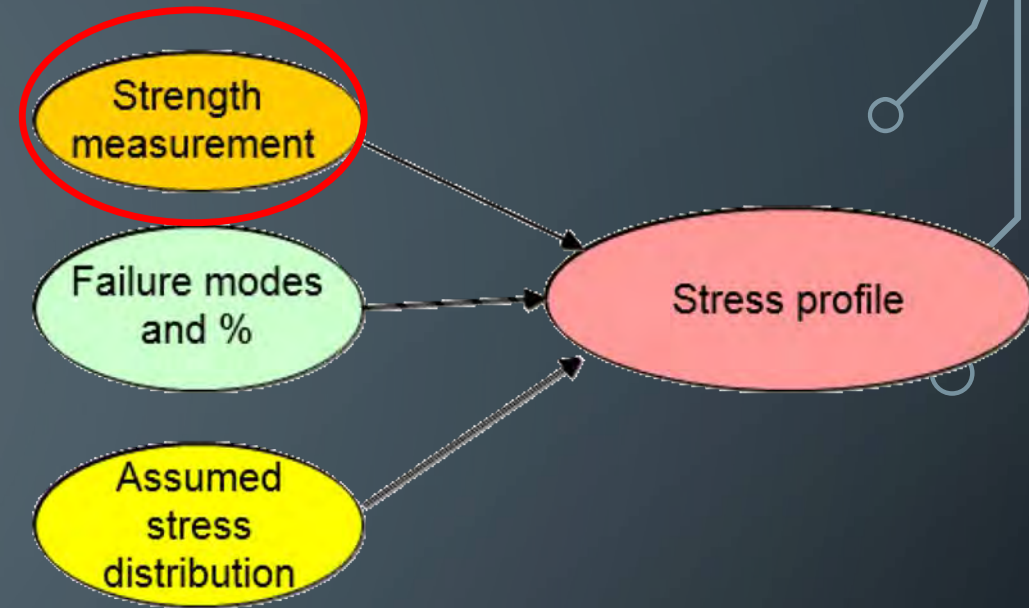
Mean	21.800
StDev	1.751
Variance	3.067
Skewness	0.688972
Kurtosis	-0.564070
N	10

Minimum	20.000
1st Quartile	20.000
Median	21.500
3rd Quartile	23.250
Maximum	25.000

95% Confidence Interval for Mean	
20.547	23.053

95% Confidence Interval for Median	
20.000	23.342

95% Confidence Interval for StDev	
1.205	3.197



Use Mean and Standard Deviation from the actual measurement

WHAT DISTRIBUTION TO USE FOR STRESS?

- Random forces/stresses applied to product in the field

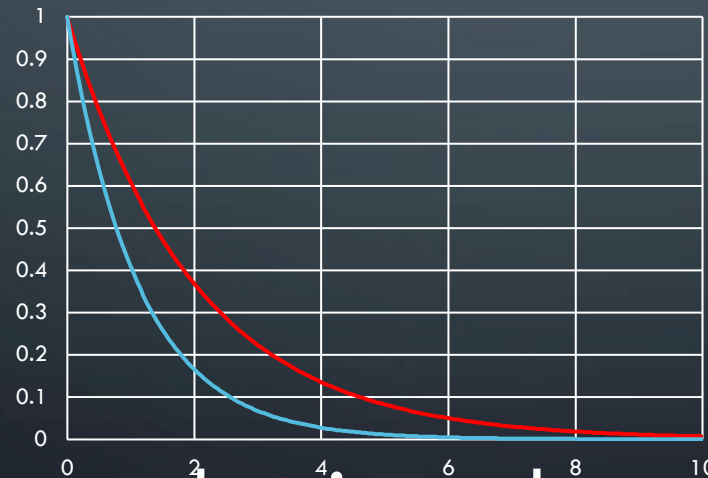
- Small force (<1 lb) is much more often than large forces (>10 lbs)

- For instance, many products will see multiple 1 lb forces, few will see 10 lb forces, less will see 20 lb forces, etc

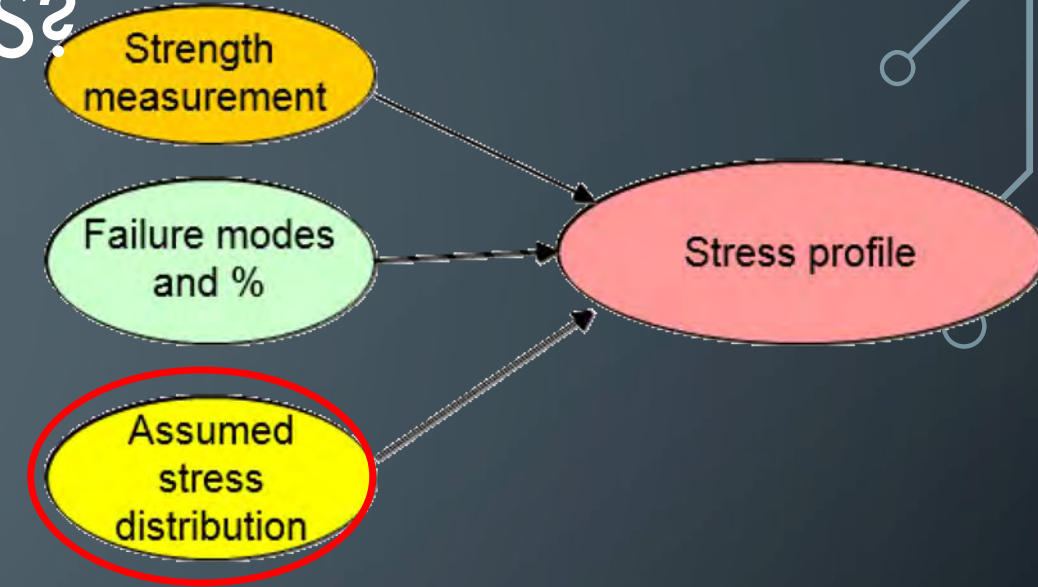
- Forces generally occur *continuously* and *independently* at constant average rate

- This equals a Exponential Distribution

$1-F(x)$
 $\lambda = 0.5$
 $\lambda = 0.9$



- Same forces to each product in each use case



$$f(x; \lambda) = \begin{cases} \lambda e^{-\lambda x} & x \geq 0, \\ 0 & x < 0. \end{cases}$$

$$F(x; \lambda) = \begin{cases} 1 - e^{-\lambda x} & x \geq 0, \\ 0 & x < 0 \end{cases}$$

$$\text{Mean: } \lambda^{-1} (= \theta)$$

USE A SIMPLE “GOAL SEEK” TO CALCULATE LAMBDA FOR THE STRESS PROFILE

$$\int_0^{\infty} STRESS(x) * Strgth(x) dx$$

=EXP (-Lambda * stress level)

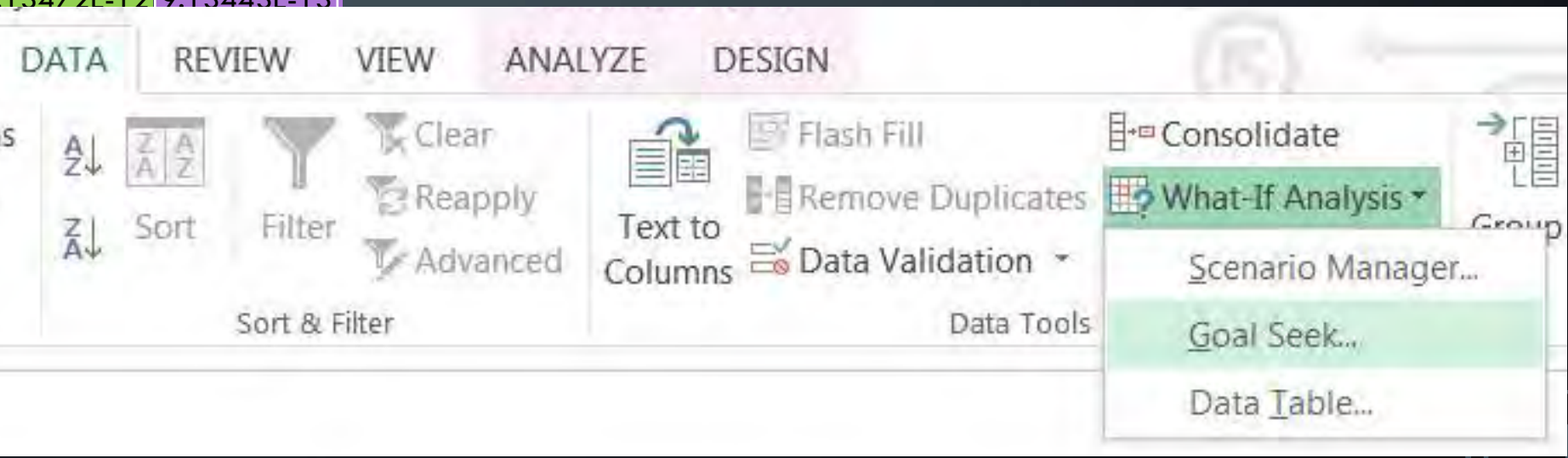
=NORM.DIST(Stress level,Strgth Mean,Strgth StDev,FALSE)

Enter force in Lbs

Lambda/ Mean	0.22	15	Sum
st dev			1.695%
Stress level (Force)	stress (%)	Strength(%)	resultant
1.0	100%	1.09661E-43	1.09661E-43
2.0	100%	7.99883E-38	7.99883E-38
3.0	100%	2.14638E-32	2.14638E-32
4.0	100%	2.11882E-27	2.11882E-27
5.0	100%	7.6946E-23	7.6946E-23
6.0	100%	1.02798E-18	1.02798E-18
7.0	100%	5.05227E-15	5.05227E-15
8.0	100%	9.13472E-12	9.13443E-13
8.1	100%	1.	
8.2	99.99%	3.	
8.3	99.99%	7.	
8.4	99.98%	1.	
8.5	99.98%	2.	
8.6	99.97%	5.	
8.7	99.95%	9.	
8.8	99.93%	1.	

=Stress%*Strength%*(Change in stress level)

=SUM(entire column)
Target Sum 0.78%



USE A SIMPLE “GOAL SEEK” TO CALCULATE LAMBDA FOR THE STRESS PROFILE

$$\int_0^{\infty} STRESS(x) * Strgth(x)dx$$

=EXP (-Lambda * stress level)

=NORM.DIST(Stress level,Strgth Mean,Strgth StDev,FALSE)

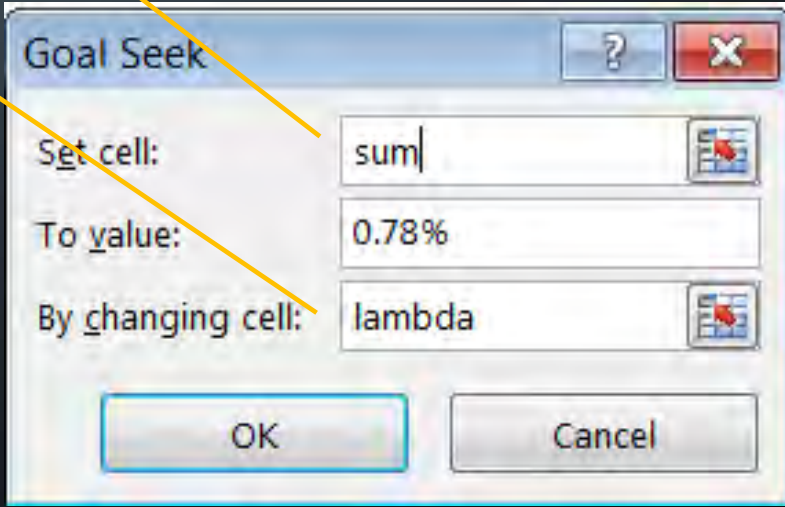
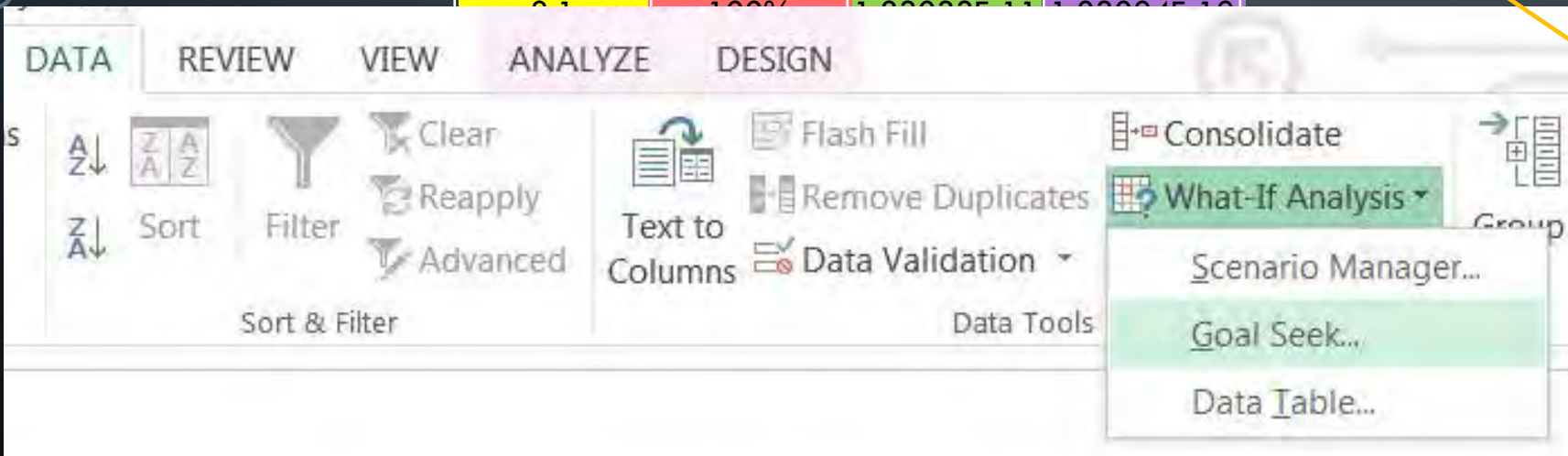
Enter force in Lbs

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st dev		1	1.695%
Stress level (Force)	stress (%)	Strength(%)	resultant
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4.0	100%	2.11882E-27	2.11882E-27
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6.0	100%	1.02798E-18	1.02798E-18
7.0	100%	5.05227E-15	5.05227E-15
8.0	100%	9.13472E-12	9.13443E-13

=Stress%*Strength%*(Change in stress level)

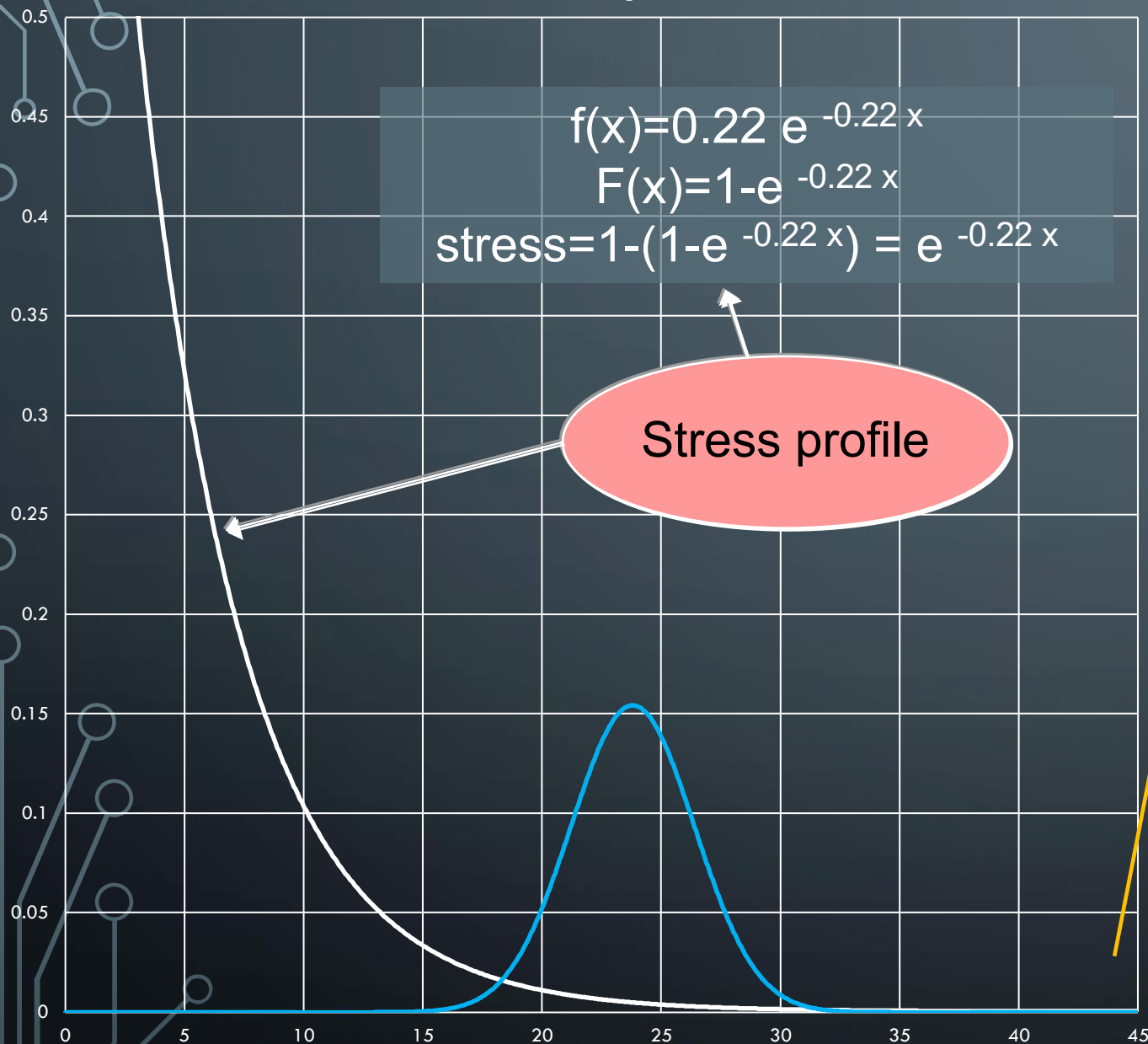
=SUM(entire column)

Target Sum 0.78%

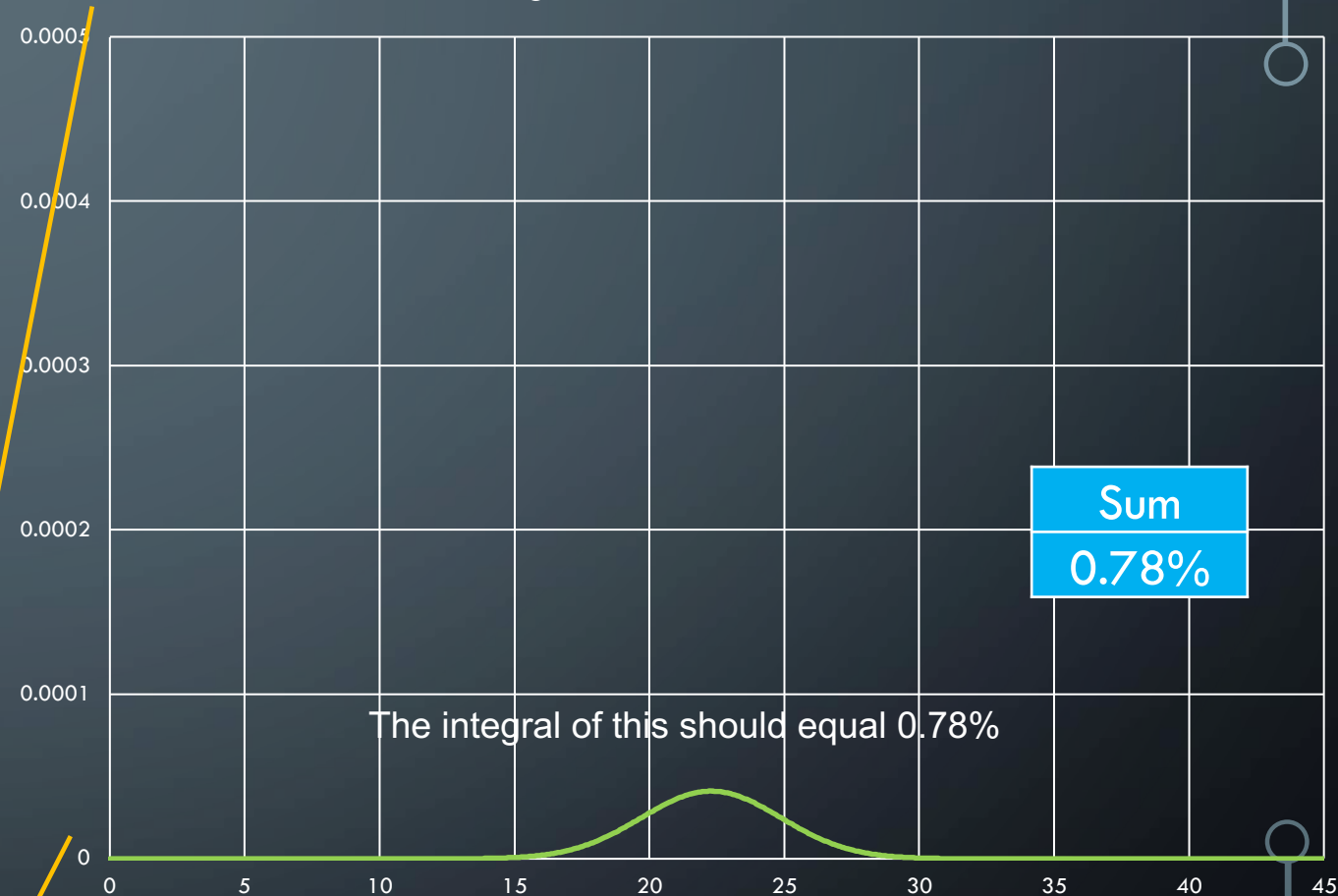


STRESS, STRENGTH, AND RESULTANT

Nozzle stress - strength Distributions

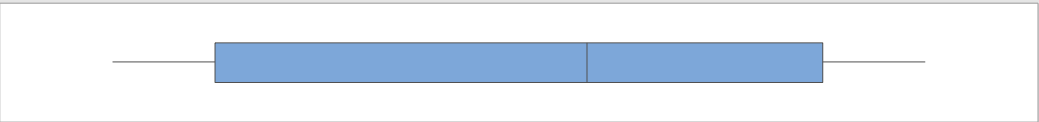
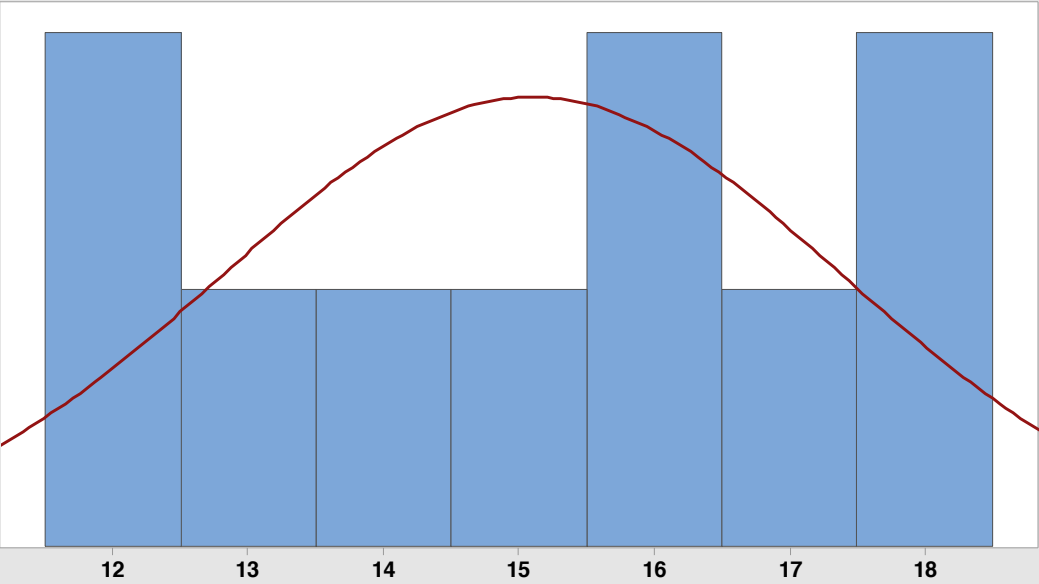


Nozzle stress - strength resultant - failure rate calculation



MEASURE NEW PRODUCT

Summary Report for new model



Anderson-Darling Normality Test

A-Squared	0.30
P-Value	0.523

Mean	15.100
StDev	2.283
Variance	5.211
Skewness	-0.15271
Kurtosis	-1.43453
N	10

95% Confidence Interval for Mean

13.467	16.733
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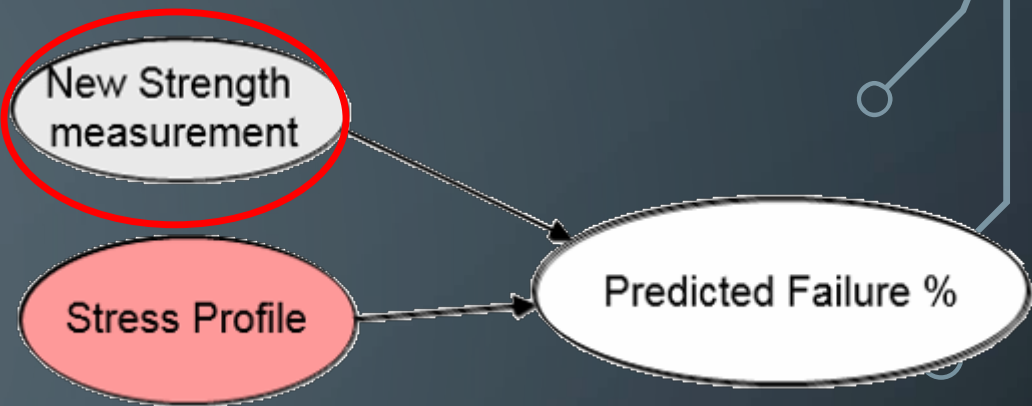
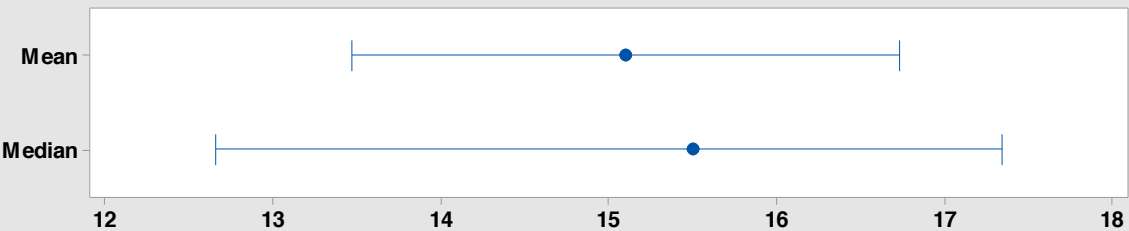
95% Confidence Interval for Median

12.658	17.342
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95% Confidence Interval for StDev

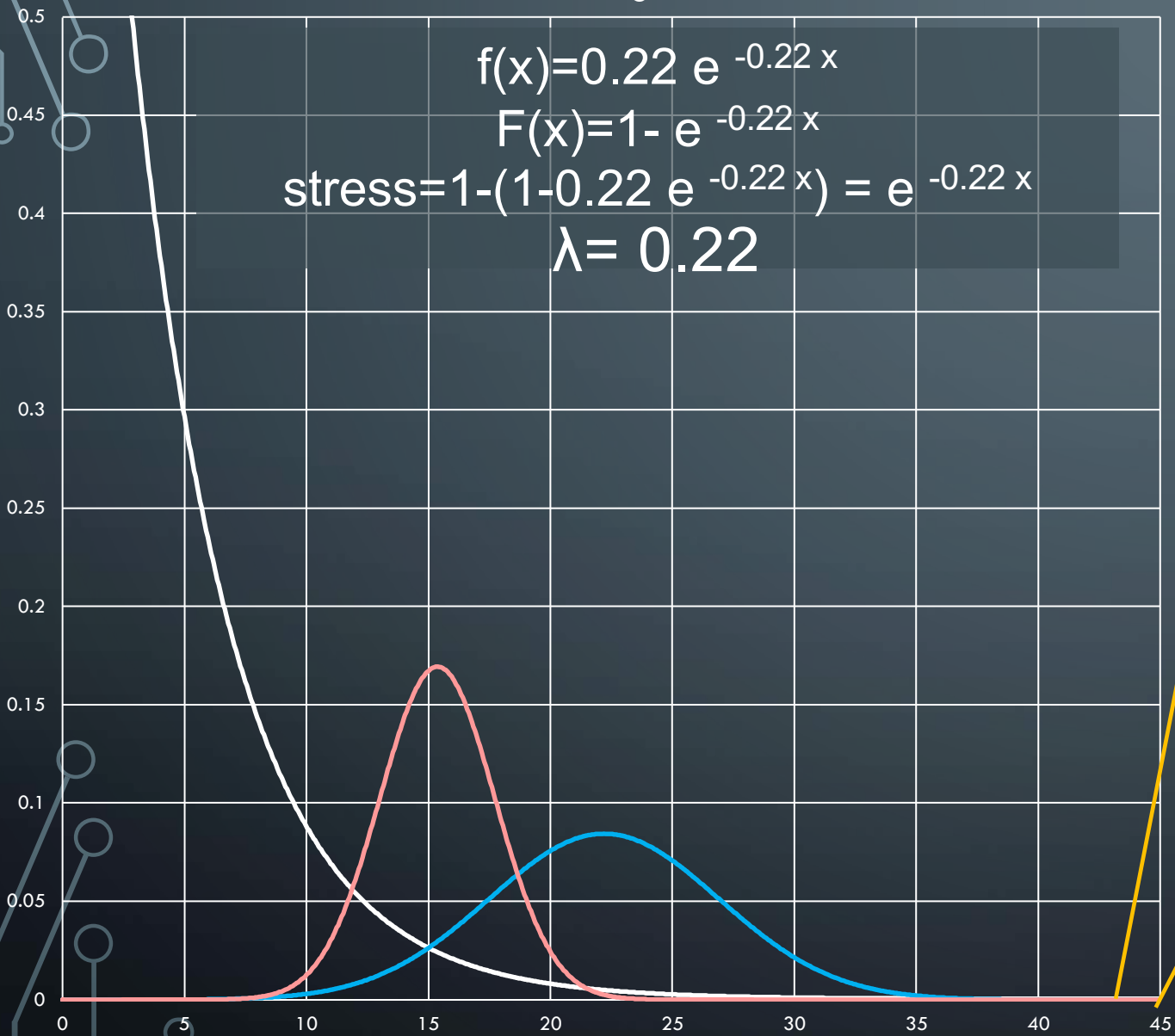
1.570	4.167
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95% Confidence Intervals

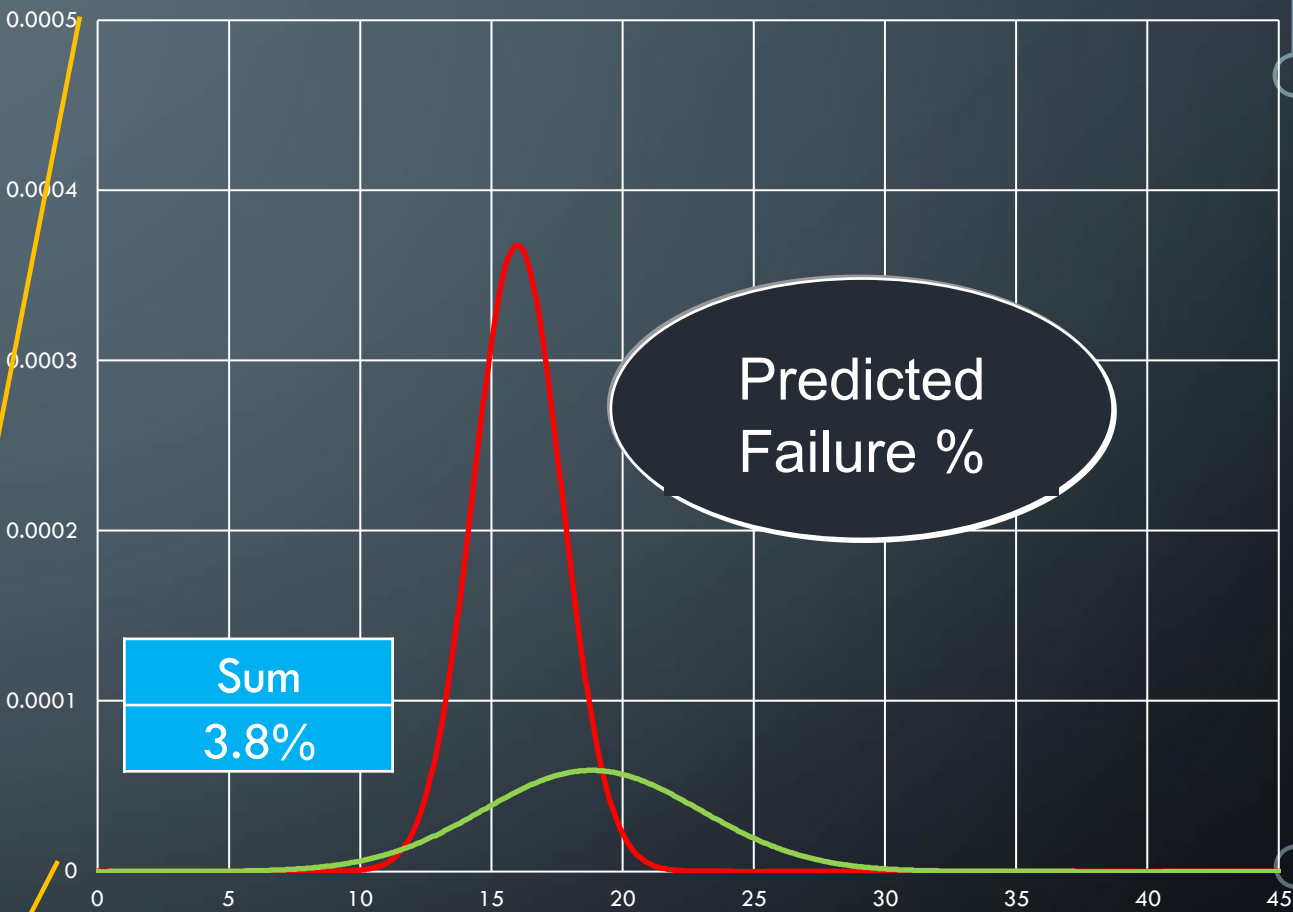


CALCULATE RESULTANT

Nozzle stress - strength Distributions

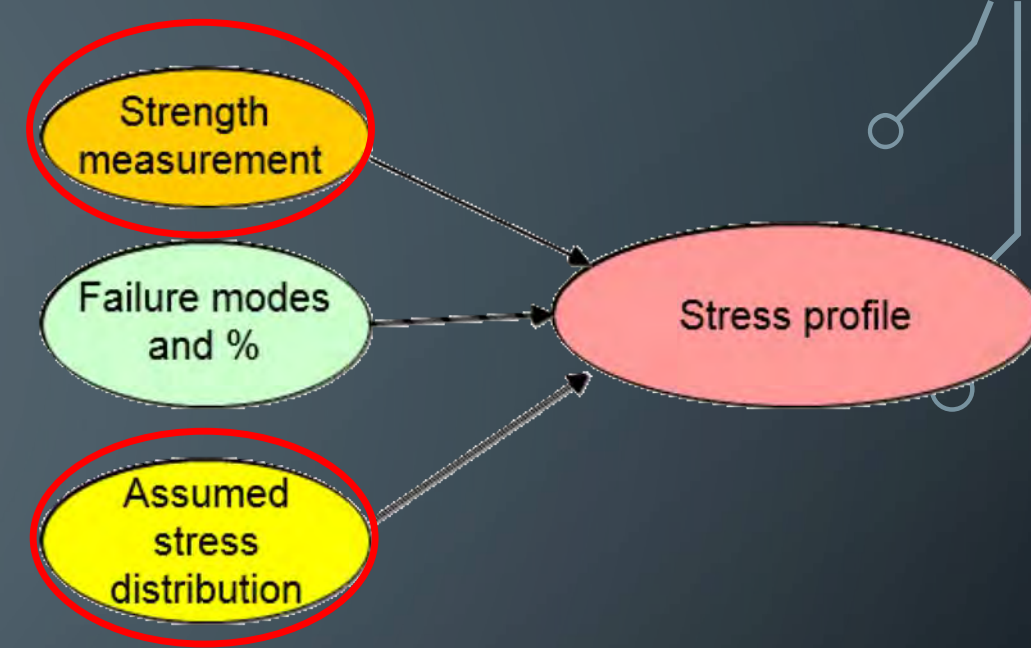
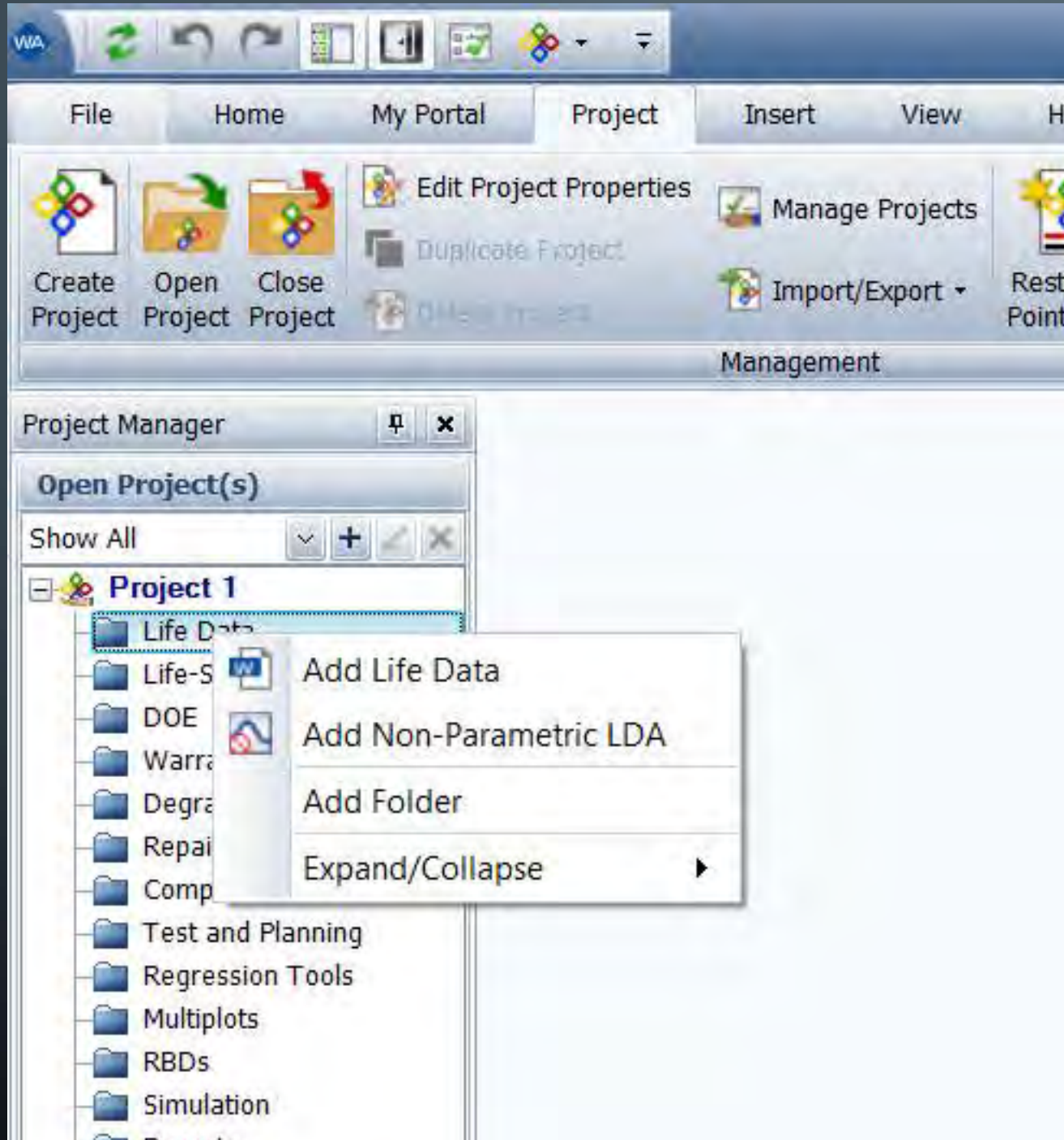


Nozzle stress - strength resultant - failure rate calculation



Failure Mode Percentage	
Good	<0.75%
Borderline	0.75%-1.00%
Unacceptable	>1.00%

IN RELIASOFT (WEIBULL ++)



ADD STRESS AND STRENGTH

WEIBULL++ ALTA

WVA Weibull++ Folio Data Sheet Setup

Specify the type of data that you will be entering into the folio for life data analysis.

Data Type

☒ Times-to-failure data ☐ Free-form (probit) data

Units

Hour (hr)

Options for the Times-to-Failure Data Type

☐ My data set contains suspensions (right censored data)
Select this if your data set contains units that did not fail.

☐ My data set contains interval and/or left censored data
Select this if your data set contains uncertainty as to exactly when a unit failed or was suspended. This will allow you to specify the interval in which each failure or suspension occurred.

☐ I want to enter data in groups
Select this if your data set contains one or more groups of units that have the same failure or suspension time.

Based on your selections, the data sheet will include these failure/suspension time columns:

Time Failed

OK Cancel

Stress:

Random data, starting with about $\frac{1}{2}$ of mean of strength, doesn't matter too much as you'll see soon.

NozzleStrength Stress

A10 20

	Time Failed (hr)
1	25
2	20
3	24
4	21
5	20
6	22
7	21
8	22
9	23
10	20
11	

*Modified data

NozzleStrength Stress Stress-Strength1

A10

	Time Failed (hr)
1	12
2	8
3	6
4	5
5	4
6	3
7	2
8	1

CHANGE DISTRIBUTIONS, GRAPH

W Main

LIFE DATA

Distribution

Normal

Analysis Settings

RRX	SRM
FM	MED

Analysis Summary

Parameters

Mean (hr)	21.800000
Std (hr)	1.830260

Other

Rho	0.959077
-----	----------

W Main

LIFE DATA

Distribution

1P-Exponential

Analysis Settings

RRX	SRM
FM	MED

Analysis Summary

Parameters

Mean Time (hr)	5.110714
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Other

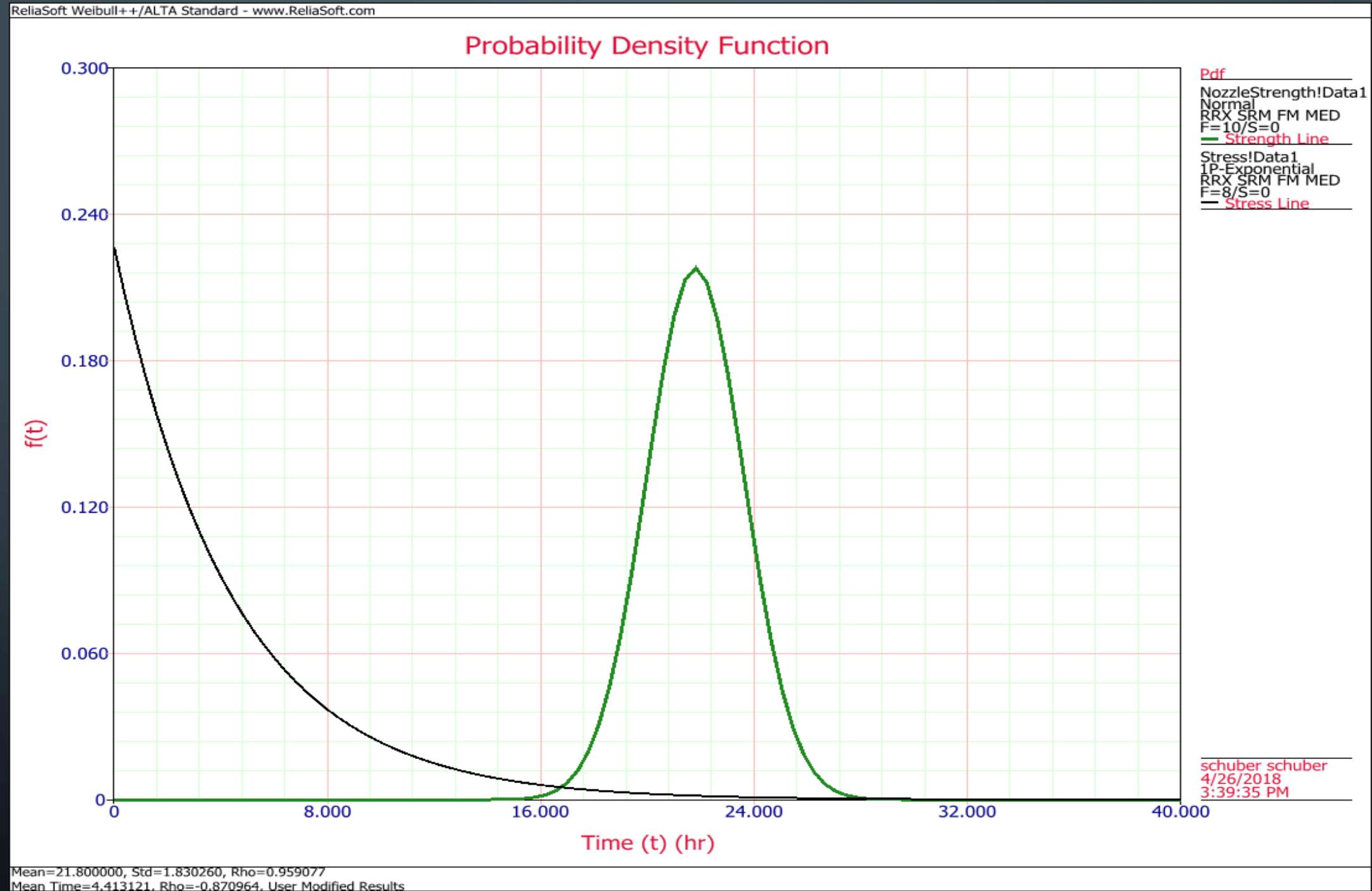
Rho	-0.870964
LK Value	-21.073075

ADD STRESS-STRENGTH COMPARISON

The screenshot shows the WVA software interface. The top menu bar includes File, Home, My Portal, Project, and View. The ribbon contains tabs for Calculate, Plot, Quick Calculation Pad, Distribution Wizard, and 3D Plot. The Project Manager on the left shows a tree structure for 'Project 1' with folders like Life Data, NozzleStrength, Stress, Life-Stress Data, DOE, Warranty, Degradation, and Repairable Systems. A context menu is open over the 'Comp' folder, listing options: Add Stress Strength Comparison, Add Life Comparison, Add One-Way ANOVA, Add Folder, and Expand/Collapse. The main workspace displays a table with columns A10, x, and 20, and rows 1 through 16.

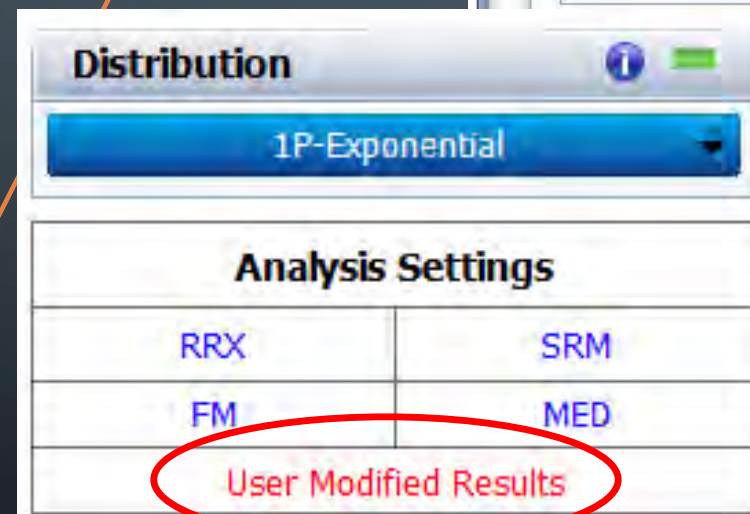
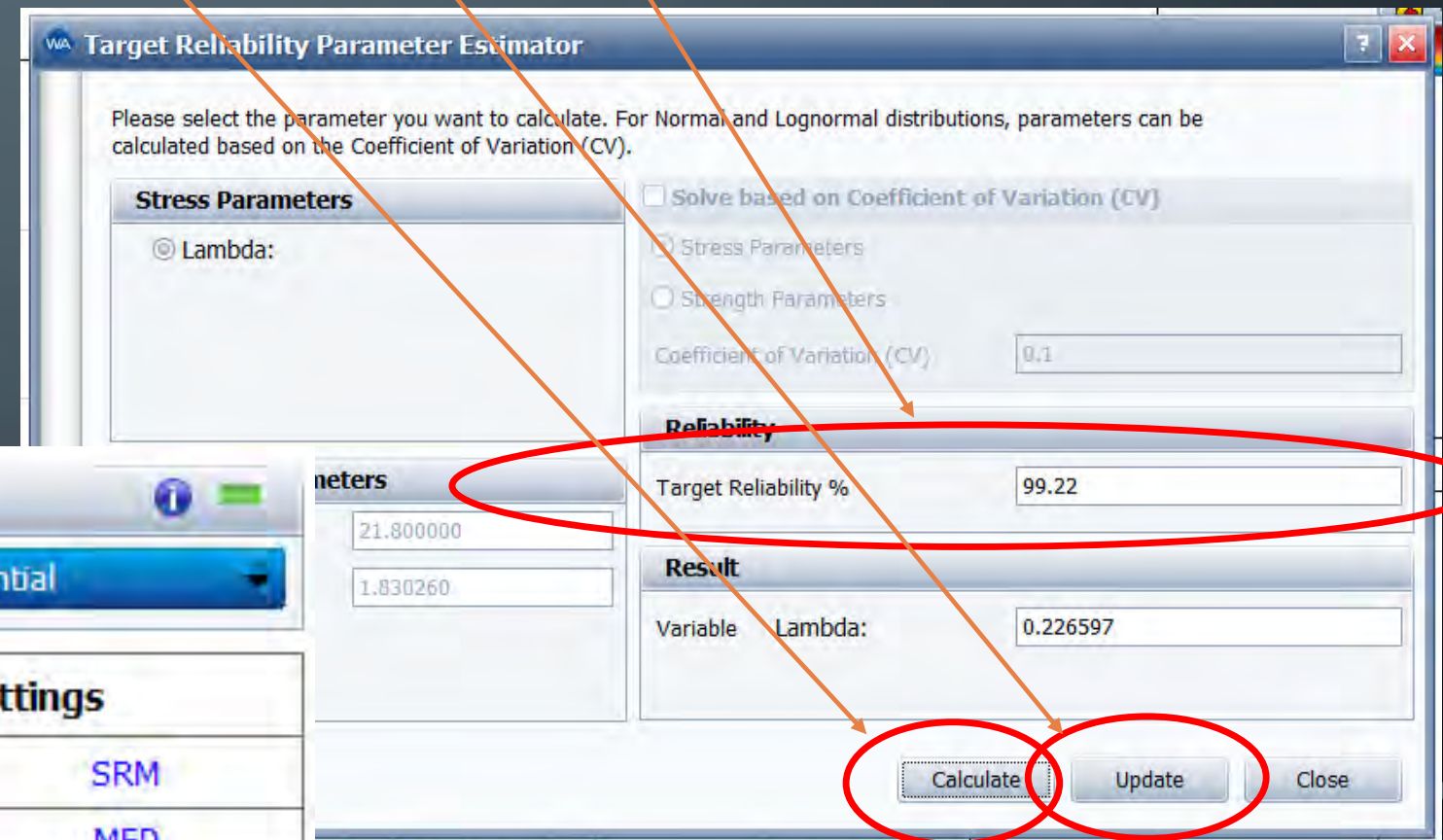
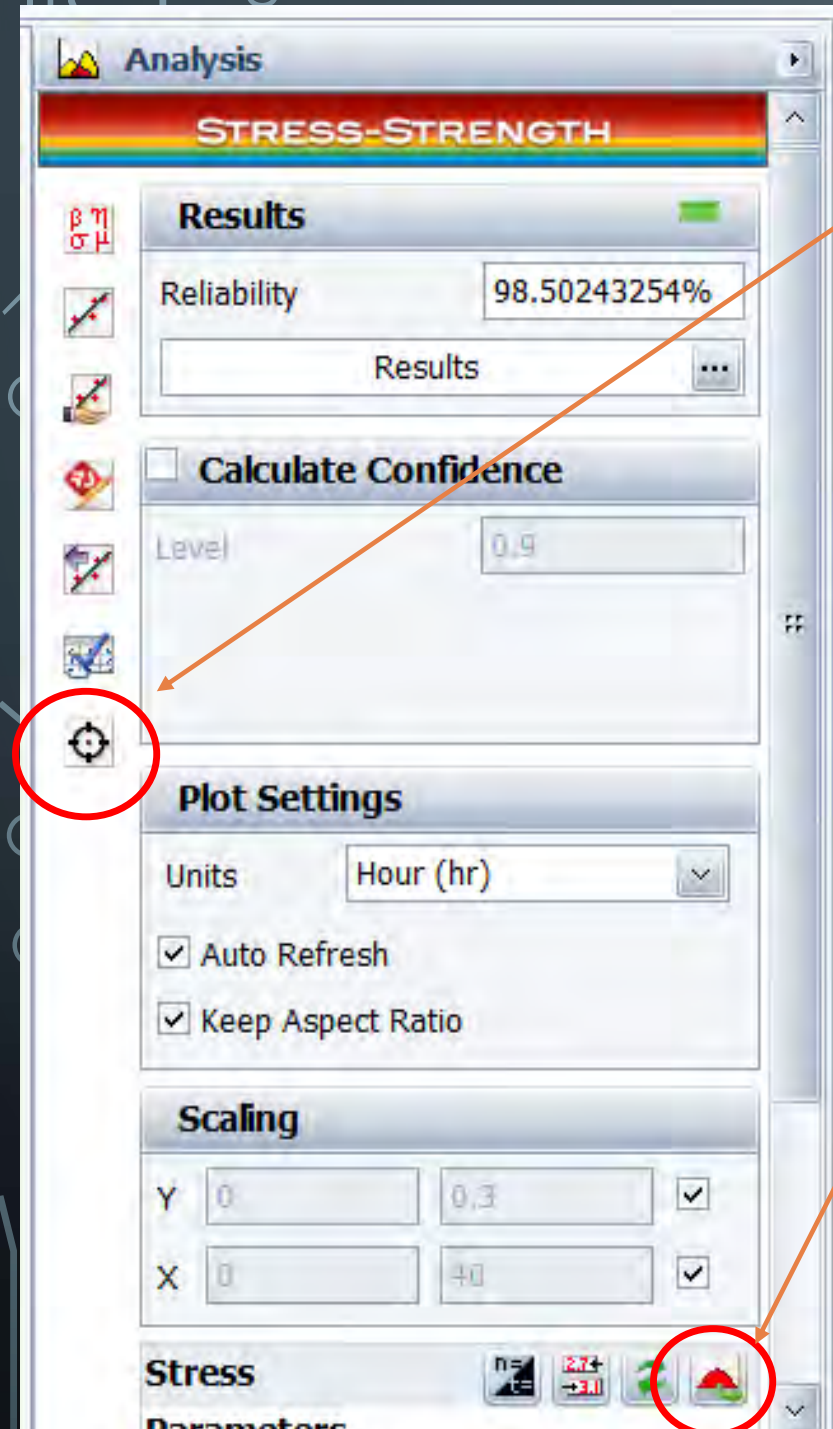
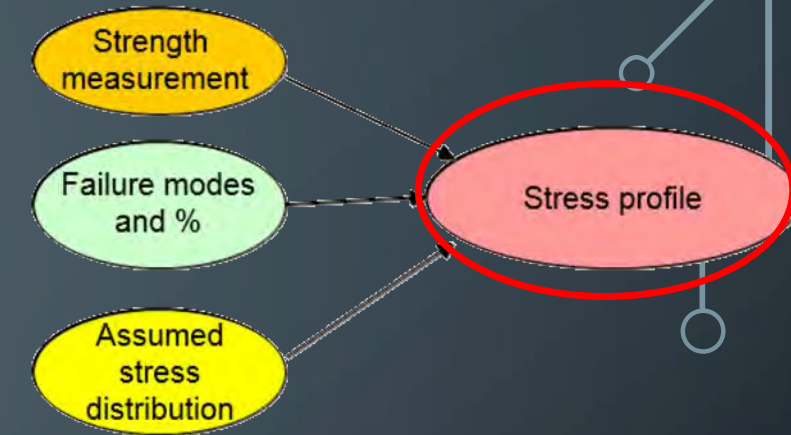
The 'Select Data Sheets' dialog box is shown, with the instruction: 'Select the data sets you want to compare from below. Note that Weibull data sets using CFM or Bayesian-Weibull distributions are excluded.' The dialog has two panels: 'Available Stress Data Sheets' and 'Available Strength Data Sheets'. Both panels show a tree structure with 'Life Data Folios' as the root, containing 'NozzleStrength' and 'Stress'. Under 'NozzleStrength', 'Data1' is selected. Under 'Stress', 'Data1' is also selected. The 'OK' and 'Cancel' buttons are at the bottom right.

GRAPH PLOTTED... "TRADITIONALLY"



USE THE TARGET RELIABILITY PARAMETER

Start the Target Reliability
Parameter estimator
Enter the Target Reliability %
Click Calculate, Update, then
Transfer Parameters



Note: Reliasoft uses "Reliability"
which is 1-Failure rate

PUT IN NEW PRODUCT DATA

NozzleStrength	
Stress	
Stress-Strength1	
NewNozzle	
B6	
	Time Failed (hr)
1	15
2	17
3	16
4	12
5	13
6	16
7	12
8	18

Analysis

STRESS-STRENGTH

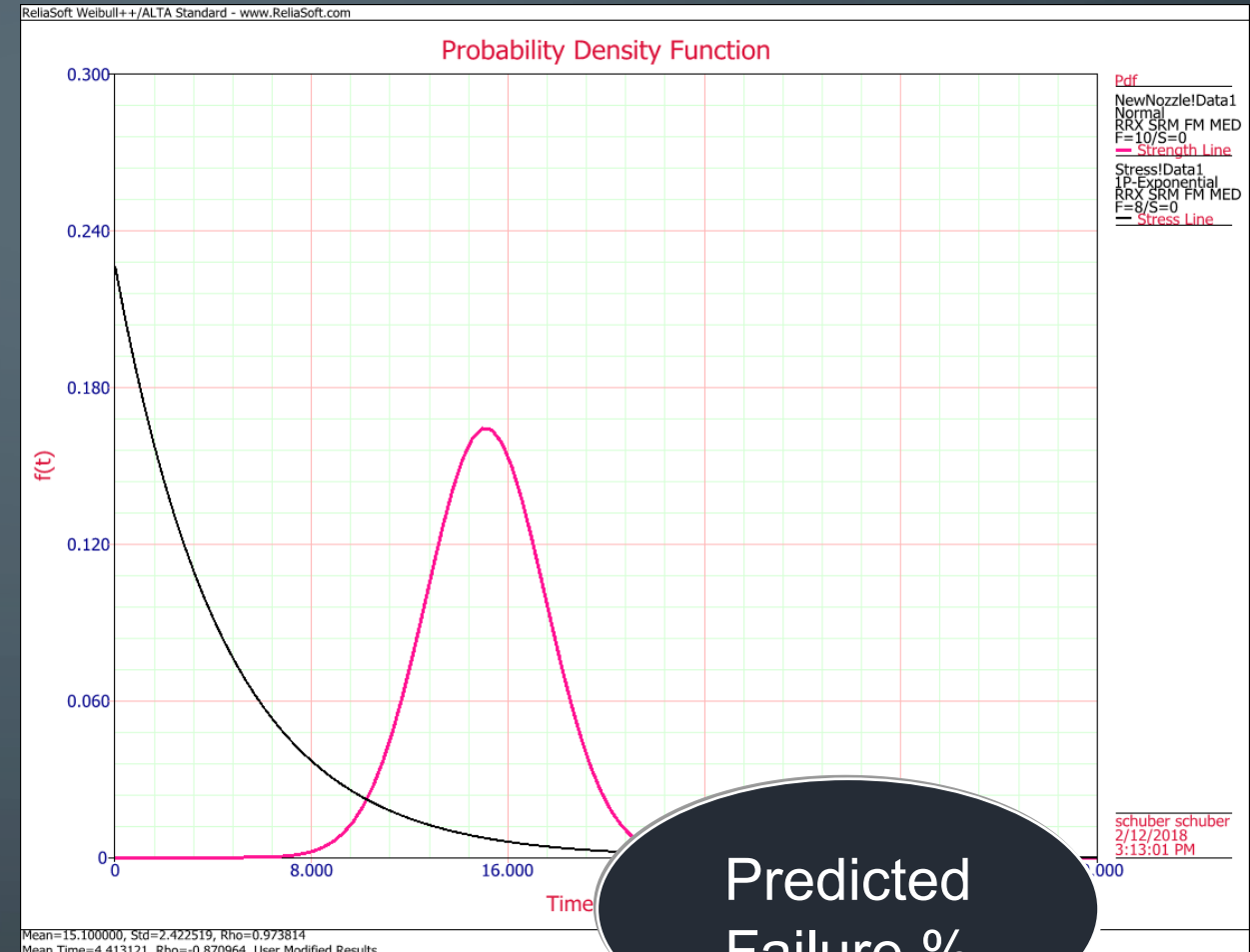
Results

Reliability: 96.20273792%

Results: ...

☐ Calculate Confidence

Level: 9



Answer: 3.8% (=100%-96.2%)

Failure Mode Percentage	
Good	<0.75%
Borderline	0.75%-1.00%
Unacceptable	>1.00%

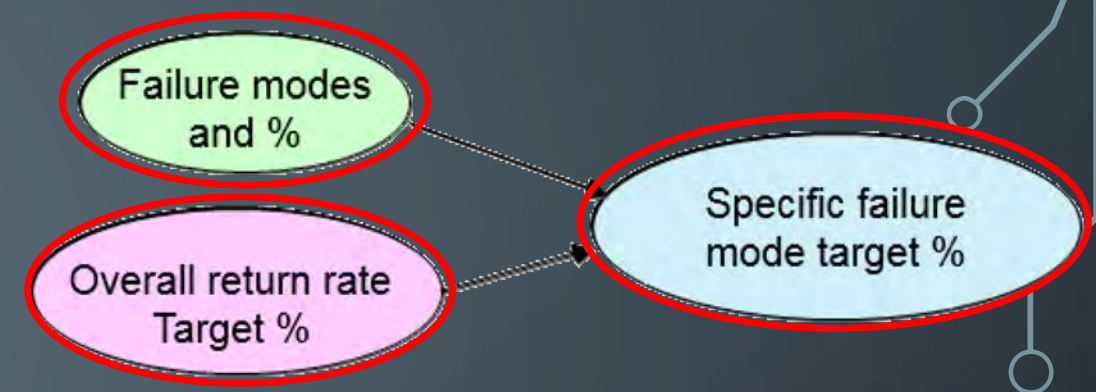
WHAT ARE THE SOME OF THE SOURCES OF ERROR?

- Even with the best data, sales spikes, return delays, people who don't return can all cause percentages to be “out of whack”. Even then, what is returned is likely a sample of the overall totals.
- And, Force data is a distribution based on a sample

Let's Improve the accuracy of profile !

IMPROVED FAILURE MODE TARGET

- **All** current shipping products and their comparable return rates
 - Is there an overall target?
 - What percentage is this failure mode? Or what is it expected to have?
 - Base these on ALL currently manufactured product



	Return percentage (nozzle Strength only)
Vac1	0.39%
Vac2	0.43%
Vac3	0.78%
Vac4	1.85%
Vac5	3.78%
Vac6	3.06%
Vac7	4.25%
Vac8	0.29%

	Failure mode percentage	
BIC	0.10%-	0.25%
Good	0.25%-	0.50%
Borderline	0.50%-	1.00%
Unacceptable	>1.00%	

STRESS PROFILE IMPROVEMENT

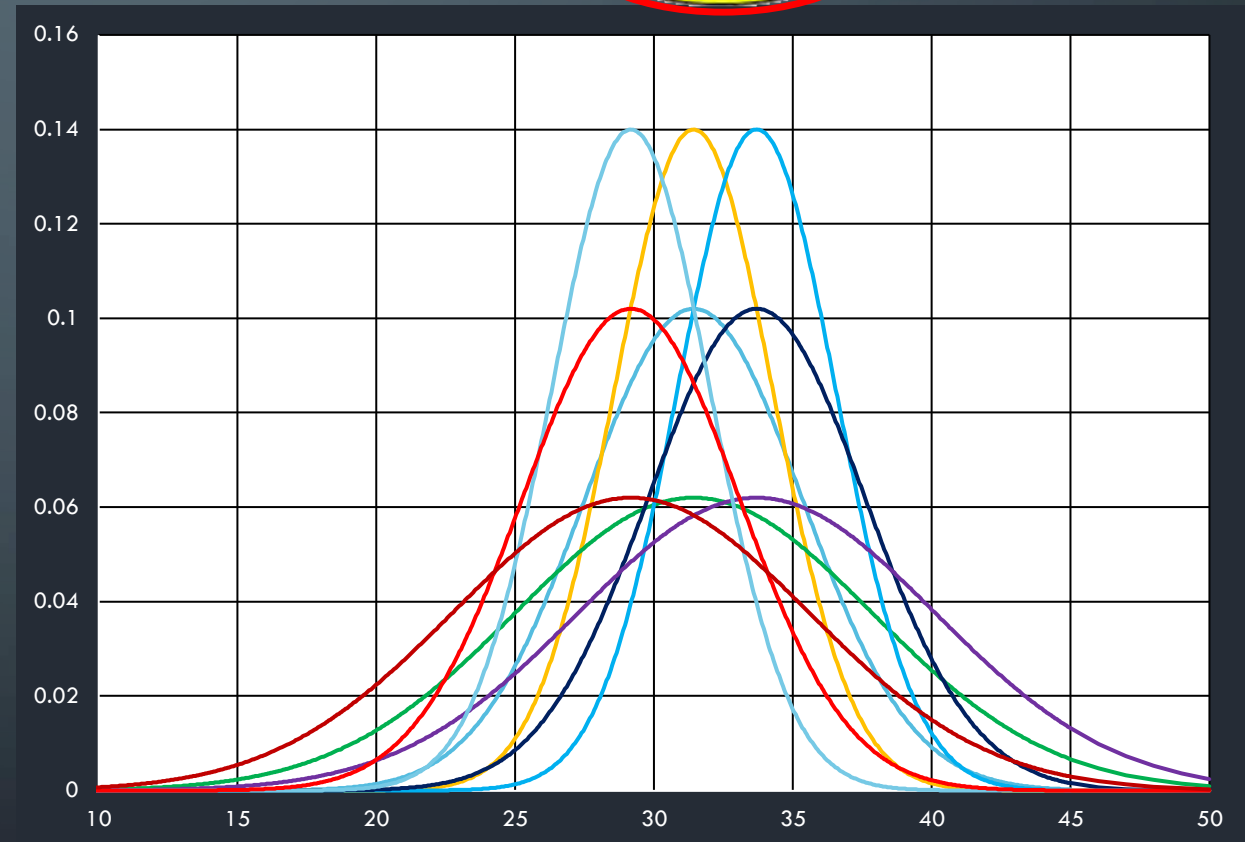
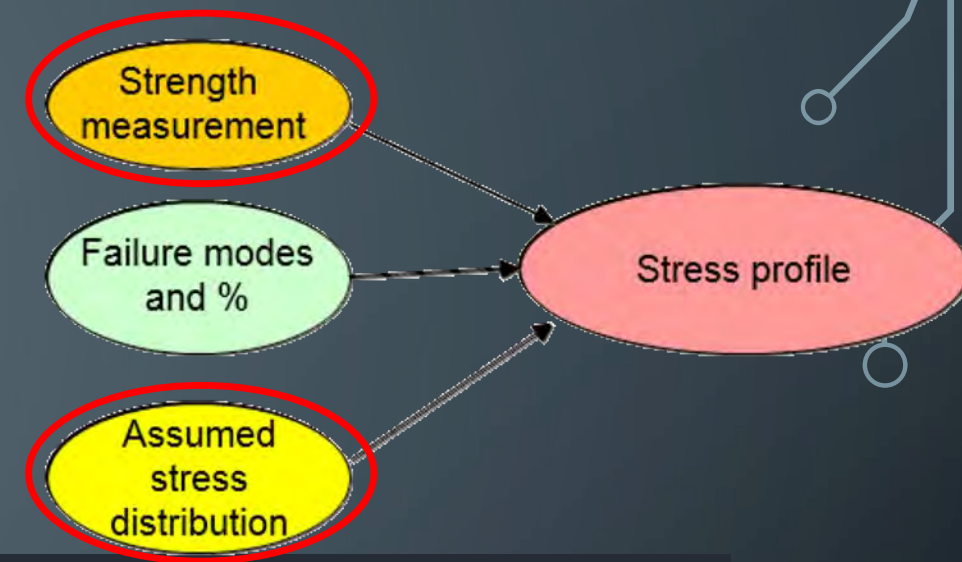
- Calculate 90% confidence bounds
 - Return percentages
 - Force data
 - Mean
 - Standard Deviation

$$\text{Lower limit (P}_L\text{)} = \frac{v_1 * F}{v_2 + v_1 * F}$$

$$\text{Upper limit (P}_U\text{)} = \frac{v_1 * F}{v_2 + v_1 * F}$$

$$\bar{x} \pm z \frac{s}{\sqrt{n}}$$

$$\frac{(n-1)s^2}{\chi^2_{\alpha/2}} < \sigma^2 < \frac{(n-1)s^2}{\chi^2_{1-\alpha/2}}$$



Note that the point estimate for standard deviation is not centered in the bounds

STRESS PROFILE IMPROVEMENT

- Calculate 90% confidence bounds
 - Return percentages
 - Force data
 - Mean
 - Standard Deviation

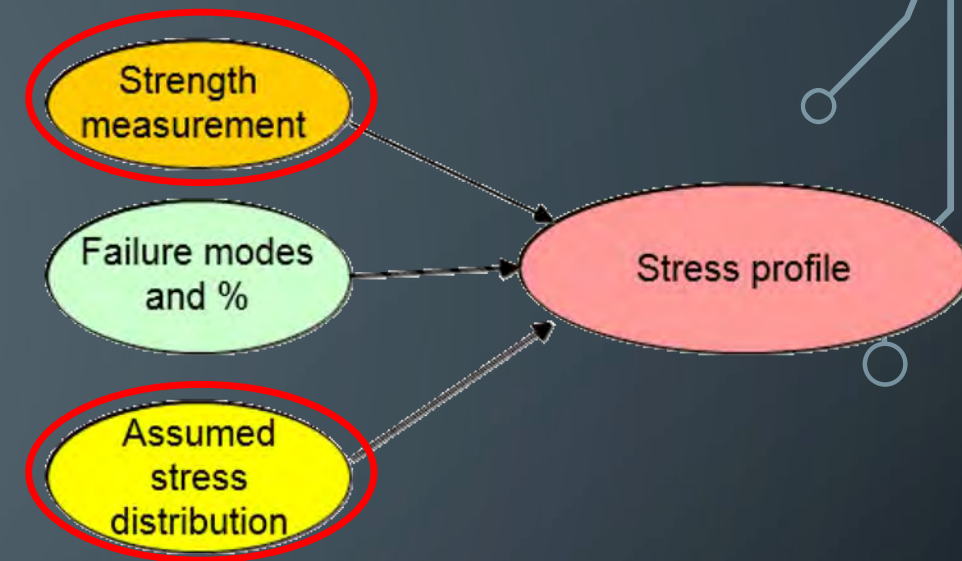
In Excel:

Lower limit (P_L) =

$=((ret*2)*F.INV(0.05,(ret*2),(2*(mfg-ret+1)))) / ((2*(mfg-ret+1))+(mfg*2)*F.INV(0.05,(ret*2),(2*(mfg-ret+1))))$

Upper limit (P_U) =

$=((2*(ret+1))*F.INV.RT(0.05,(2*(ret+1)),(2*(mfg-ret)))) / ((2*(mfg-ret))+(2*(ret+1))*F.INV.RT(0.05,(2*(ret+1)),(2*(mfg-ret))))$



$$\bar{x} \pm z \frac{s}{\sqrt{n}}$$

$=avg \pm CONFIDENCE.NORM(0.10,avg,COUNT(tested))$

$$\frac{(n-1)s^2}{\chi^2_{\alpha/2}} < \sigma^2 < \frac{(n-1)s^2}{\chi^2_{1-\alpha/2}}$$

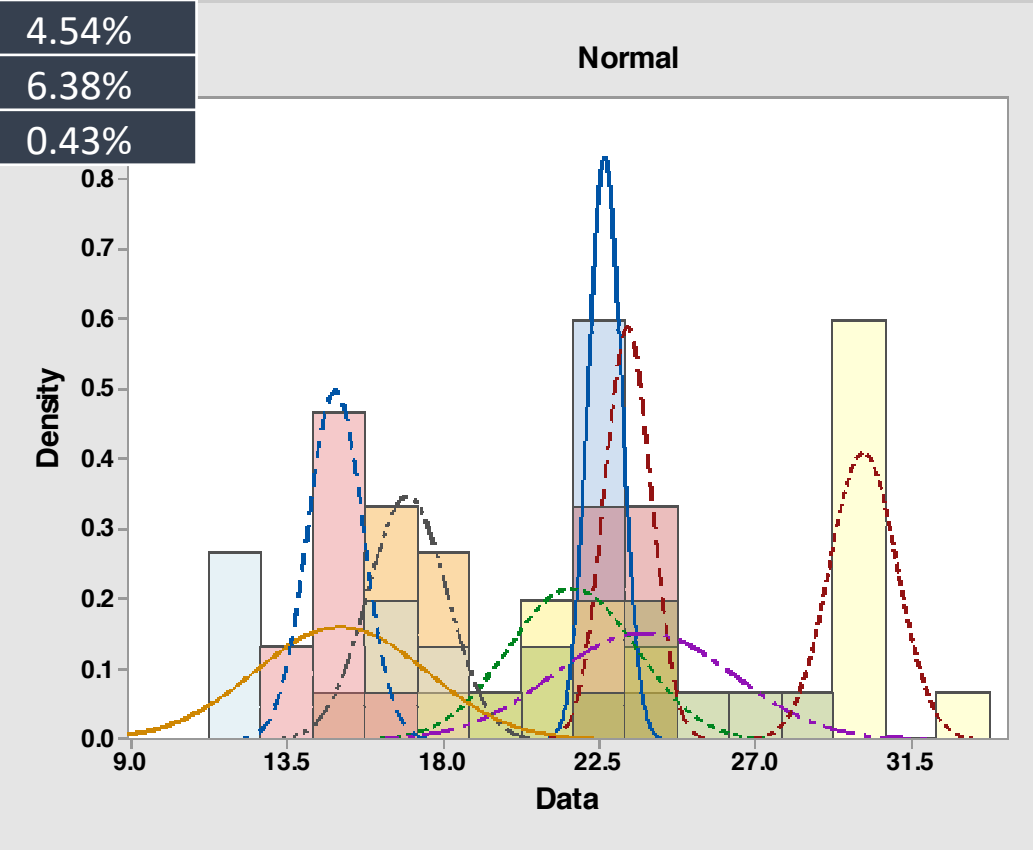
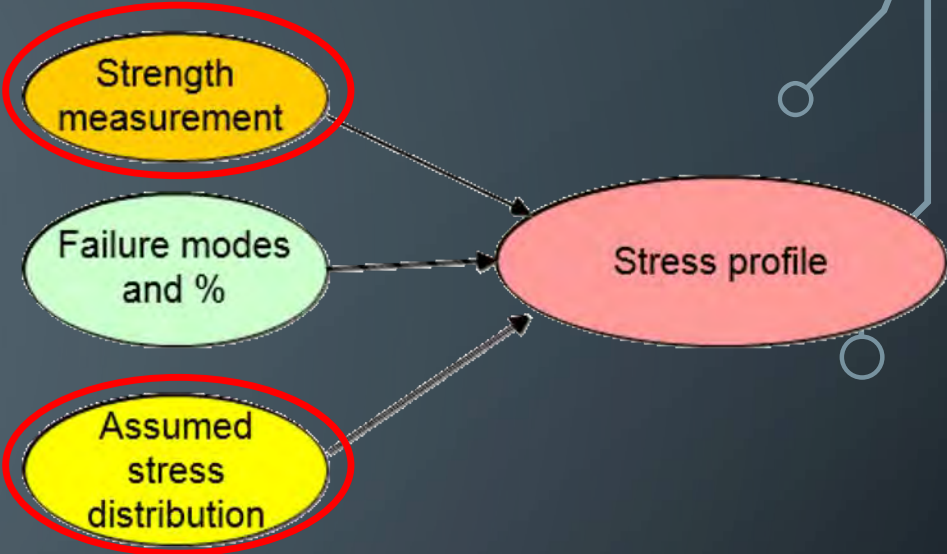
$=SQRT(((COUNT(tested)-1)*stdev^2) / CHISQ.INV(0.05,(COUNT(tested)-1)))$

FOR NOZZLE STRENGTH EXAMPLE

- Calculate 90% confidence bounds
 - Return percentages
 - Force data
 - Mean
 - Standard Deviation

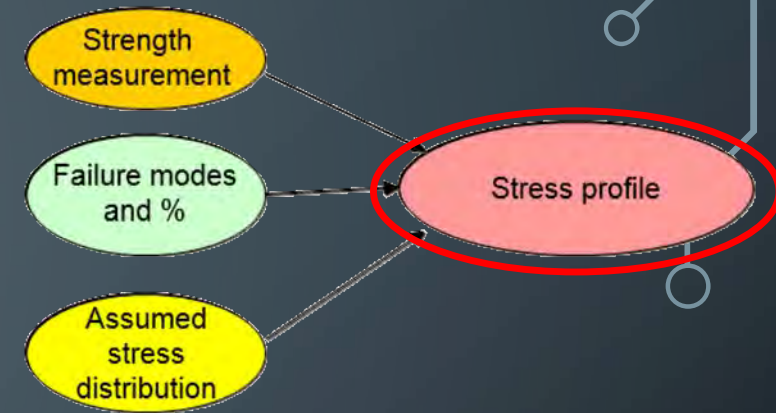
	Nozzle Strength field failure		
Product	percent	% Low	% Up
Vac1	0.39%	0.30%	0.48%
Vac2	0.43%	0.32%	0.54%
Vac3	0.78%	0.28%	1.40%
Vac4	1.85%	1.18%	2.52%
Vac5	3.78%	2.46%	5.10%
Vac6	3.06%	1.58%	4.54%
Vac7	4.25%	2.12%	6.38%
Vac8	0.29%	0.15%	0.43%

Product	Mean	Upper bound Mean	Lower Bound Mean	St Dev	Upper Bound StDev	Lower Bound StDev	N
Vac1	23	35.0	11.0	0.5	0.36	0.82	10
Vac2	23	35.0	11.0	0.7	0.51	1.15	10
Vac3	22	33.4	10.6	1.8	1.31	2.96	10
Vac4	24	36.5	11.5	2.6	1.90	4.28	10
Vac5	17	25.8	8.2	1.1	0.80	1.81	10
Vac6	15	22.8	7.2	2.5	1.82	4.11	10
Vac7	15	22.8	7.2	0.8	0.58	1.32	10
Vac8	30	45.6	14.4	1	0.73	1.65	10



USE THE EXCEL SOLVER TO CREATE THE STRESS PROFILE

- What will you minimize?
 - Error
 - The 1 comparator model provided 1 answer, but 8 products have 8 answers, what is best?
- What will you change?
 - Lambda
 - Force
 - Averages
 - Standard Deviations
- What are the limits?
 - 90% confidence intervals
 - Reasonable Lambda?
 - Greater than zero
 - Less than ??



The screenshot shows the 'Solver Parameters' dialog box in Excel. The 'Set Objective:' field is set to '\$A\$15'. The 'To:' section has 'Min' selected. The 'By Changing Variable Cells:' field is set to '\$A\$2:\$A\$6,\$A\$7:\$A\$13,\$A\$14:\$A\$15,\$A\$16:\$A\$17,\$A\$18:\$A\$19,\$A\$20:\$A\$21,\$A\$22:\$A\$23,\$A\$24:\$A\$25,\$A\$26:\$A\$27,\$A\$28:\$A\$29,\$A\$30:\$A\$31,\$A\$32:\$A\$33,\$A\$34:\$A\$35,\$A\$36:\$A\$37,\$A\$38:\$A\$39,\$A\$40:\$A\$41,\$A\$42:\$A\$43,\$A\$44:\$A\$45,\$A\$46:\$A\$47,\$A\$48:\$A\$49,\$A\$50:\$A\$51,\$A\$52:\$A\$53,\$A\$54:\$A\$55,\$A\$56:\$A\$57,\$A\$58:\$A\$59,\$A\$60:\$A\$61,\$A\$62:\$A\$63,\$A\$64:\$A\$65,\$A\$66:\$A\$67,\$A\$68:\$A\$69,\$A\$70:\$A\$71,\$A\$72:\$A\$73,\$A\$74:\$A\$75,\$A\$76:\$A\$77,\$A\$78:\$A\$79,\$A\$80:\$A\$81,\$A\$82:\$A\$83,\$A\$84:\$A\$85,\$A\$86:\$A\$87,\$A\$88:\$A\$89,\$A\$90:\$A\$91,\$A\$92:\$A\$93,\$A\$94:\$A\$95,\$A\$96:\$A\$97,\$A\$98:\$A\$99,\$A\$100:\$A\$101,\$A\$102:\$A\$103,\$A\$104:\$A\$105,\$A\$106:\$A\$107,\$A\$108:\$A\$109,\$A\$110:\$A\$111,\$A\$112:\$A\$113,\$A\$114:\$A\$115,\$A\$116:\$A\$117,\$A\$118:\$A\$119,\$A\$120:\$A\$121,\$A\$122:\$A\$123,\$A\$124:\$A\$125,\$A\$126:\$A\$127,\$A\$128:\$A\$129,\$A\$130:\$A\$131,\$A\$132:\$A\$133,\$A\$134:\$A\$135,\$A\$136:\$A\$137,\$A\$138:\$A\$139,\$A\$140:\$A\$141,\$A\$142:\$A\$143,\$A\$144:\$A\$145,\$A\$146:\$A\$147,\$A\$148:\$A\$149,\$A\$150:\$A\$151,\$A\$152:\$A\$153,\$A\$154:\$A\$155,\$A\$156:\$A\$157,\$A\$158:\$A\$159,\$A\$160:\$A\$161,\$A\$162:\$A\$163,\$A\$164:\$A\$165,\$A\$166:\$A\$167,\$A\$168:\$A\$169,\$A\$170:\$A\$171,\$A\$172:\$A\$173,\$A\$174:\$A\$175,\$A\$176:\$A\$177,\$A\$178:\$A\$179,\$A\$180:\$A\$181,\$A\$182:\$A\$183,\$A\$184:\$A\$185,\$A\$186:\$A\$187,\$A\$188:\$A\$189,\$A\$190:\$A\$191,\$A\$192:\$A\$193,\$A\$194:\$A\$195,\$A\$196:\$A\$197,\$A\$198:\$A\$199,\$A\$200:\$A\$201,\$A\$202:\$A\$203,\$A\$204:\$A\$205,\$A\$206:\$A\$207,\$A\$208:\$A\$209,\$A\$210:\$A\$211,\$A\$212:\$A\$213,\$A\$214:\$A\$215,\$A\$216:\$A\$217,\$A\$218:\$A\$219,\$A\$220:\$A\$221,\$A\$222:\$A\$223,\$A\$224:\$A\$225,\$A\$226:\$A\$227,\$A\$228:\$A\$229,\$A\$230:\$A\$231,\$A\$232:\$A\$233,\$A\$234:\$A\$235,\$A\$236:\$A\$237,\$A\$238:\$A\$239,\$A\$240:\$A\$241,\$A\$242:\$A\$243,\$A\$244:\$A\$245,\$A\$246:\$A\$247,\$A\$248:\$A\$249,\$A\$250:\$A\$251,\$A\$252:\$A\$253,\$A\$254:\$A\$255,\$A\$256:\$A\$257,\$A\$258:\$A\$259,\$A\$260:\$A\$261,\$A\$262:\$A\$263,\$A\$264:\$A\$265,\$A\$266:\$A\$267,\$A\$268:\$A\$269,\$A\$270:\$A\$271,\$A\$272:\$A\$273,\$A\$274:\$A\$275,\$A\$276:\$A\$277,\$A\$278:\$A\$279,\$A\$280:\$A\$281,\$A\$282:\$A\$283,\$A\$284:\$A\$285,\$A\$286:\$A\$287,\$A\$288:\$A\$289,\$A\$290:\$A\$291,\$A\$292:\$A\$293,\$A\$294:\$A\$295,\$A\$296:\$A\$297,\$A\$298:\$A\$299,\$A\$300:\$A\$301,\$A\$302:\$A\$303,\$A\$304:\$A\$305,\$A\$306:\$A\$307,\$A\$308:\$A\$309,\$A\$310:\$A\$311,\$A\$312:\$A\$313,\$A\$314:\$A\$315,\$A\$316:\$A\$317,\$A\$318:\$A\$319,\$A\$320:\$A\$321,\$A\$322:\$A\$323,\$A\$324:\$A\$325,\$A\$326:\$A\$327,\$A\$328:\$A\$329,\$A\$330:\$A\$331,\$A\$332:\$A\$333,\$A\$334:\$A\$335,\$A\$336:\$A\$337,\$A\$338:\$A\$339,\$A\$340:\$A\$341,\$A\$342:\$A\$343,\$A\$344:\$A\$345,\$A\$346:\$A\$347,\$A\$348:\$A\$349,\$A\$350:\$A\$351,\$A\$352:\$A\$353,\$A\$354:\$A\$355,\$A\$356:\$A\$357,\$A\$358:\$A\$359,\$A\$360:\$A\$361,\$A\$362:\$A\$363,\$A\$364:\$A\$365,\$A\$366:\$A\$367,\$A\$368:\$A\$369,\$A\$370:\$A\$371,\$A\$372:\$A\$373,\$A\$374:\$A\$375,\$A\$376:\$A\$377,\$A\$378:\$A\$379,\$A\$380:\$A\$381,\$A\$382:\$A\$383,\$A\$384:\$A\$385,\$A\$386:\$A\$387,\$A\$388:\$A\$389,\$A\$390:\$A\$391,\$A\$392:\$A\$393,\$A\$394:\$A\$395,\$A\$396:\$A\$397,\$A\$398:\$A\$399,\$A\$400:\$A\$401,\$A\$402:\$A\$403,\$A\$404:\$A\$405,\$A\$406:\$A\$407,\$A\$408:\$A\$409,\$A\$410:\$A\$411,\$A\$412:\$A\$413,\$A\$414:\$A\$415,\$A\$416:\$A\$417,\$A\$418:\$A\$419,\$A\$420:\$A\$421,\$A\$422:\$A\$423,\$A\$424:\$A\$425,\$A\$426:\$A\$427,\$A\$428:\$A\$429,\$A\$430:\$A\$431,\$A\$432:\$A\$433,\$A\$434:\$A\$435,\$A\$436:\$A\$437,\$A\$438:\$A\$439,\$A\$440:\$A\$441,\$A\$442:\$A\$443,\$A\$444:\$A\$445,\$A\$446:\$A\$447,\$A\$448:\$A\$449,\$A\$450:\$A\$451,\$A\$452:\$A\$453,\$A\$454:\$A\$455,\$A\$456:\$A\$457,\$A\$458:\$A\$459,\$A\$460:\$A\$461,\$A\$462:\$A\$463,\$A\$464:\$A\$465,\$A\$466:\$A\$467,\$A\$468:\$A\$469,\$A\$470:\$A\$471,\$A\$472:\$A\$473,\$A\$474:\$A\$475,\$A\$476:\$A\$477,\$A\$478:\$A\$479,\$A\$480:\$A\$481,\$A\$482:\$A\$483,\$A\$484:\$A\$485,\$A\$486:\$A\$487,\$A\$488:\$A\$489,\$A\$490:\$A\$491,\$A\$492:\$A\$493,\$A\$494:\$A\$495,\$A\$496:\$A\$497,\$A\$498:\$A\$499,\$A\$500:\$A\$501,\$A\$502:\$A\$503,\$A\$504:\$A\$505,\$A\$506:\$A\$507,\$A\$508:\$A\$509,\$A\$510:\$A\$511,\$A\$512:\$A\$513,\$A\$514:\$A\$515,\$A\$516:\$A\$517,\$A\$518:\$A\$519,\$A\$520:\$A\$521,\$A\$522:\$A\$523,\$A\$524:\$A\$525,\$A\$526:\$A\$527,\$A\$528:\$A\$529,\$A\$530:\$A\$531,\$A\$532:\$A\$533,\$A\$534:\$A\$535,\$A\$536:\$A\$537,\$A\$538:\$A\$539,\$A\$540:\$A\$541,\$A\$542:\$A\$543,\$A\$544:\$A\$545,\$A\$546:\$A\$547,\$A\$548:\$A\$549,\$A\$550:\$A\$551,\$A\$552:\$A\$553,\$A\$554:\$A\$555,\$A\$556:\$A\$557,\$A\$558:\$A\$559,\$A\$560:\$A\$561,\$A\$562:\$A\$563,\$A\$564:\$A\$565,\$A\$566:\$A\$567,\$A\$568:\$A\$569,\$A\$570:\$A\$571,\$A\$572:\$A\$573,\$A\$574:\$A\$57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SOLVER OPTIONS

Options

All Methods | GRG Nonlinear | Evolutionary

Constraint Precision: 0.0001

☒ Use Automatic Scaling

☐ Show Iteration Results

Solving with Integer Constraints

☐ Ignore Integer Constraints

Integer Optimality (%): 1

Solving Limits

Max Time (Seconds):

Iterations:

Evolutionary and Integer Constraints:

Max Subproblems:

Max Feasible Solutions:

OK Cancel

Options

All Methods | GRG Nonlinear | Evolutionary

Convergence: 0.00001

Mutation Rate: 0.075

Population Size: 100

Random Seed: 0

Maximum Time without improvement: 6000

☒ Require Bounds on Variables

OK Cancel

TO MINIMIZE ERROR, IT FIRST SHOULD BE NORMALIZED

There are 3 parameters being adjusted:

- Averages
- Standard Deviations
- Total Failure Rate %

These need to be “Normalized” so the solver reduces the error of each equally.
(or you can set the weighting)

Error can be measured as a “Distance” from center point (AKA Point estimate)

$$\text{ABS}((\text{Solver Estimate}-\text{Center})/(\text{Bound}_{\text{Upper/Lower}}-\text{Center}))$$

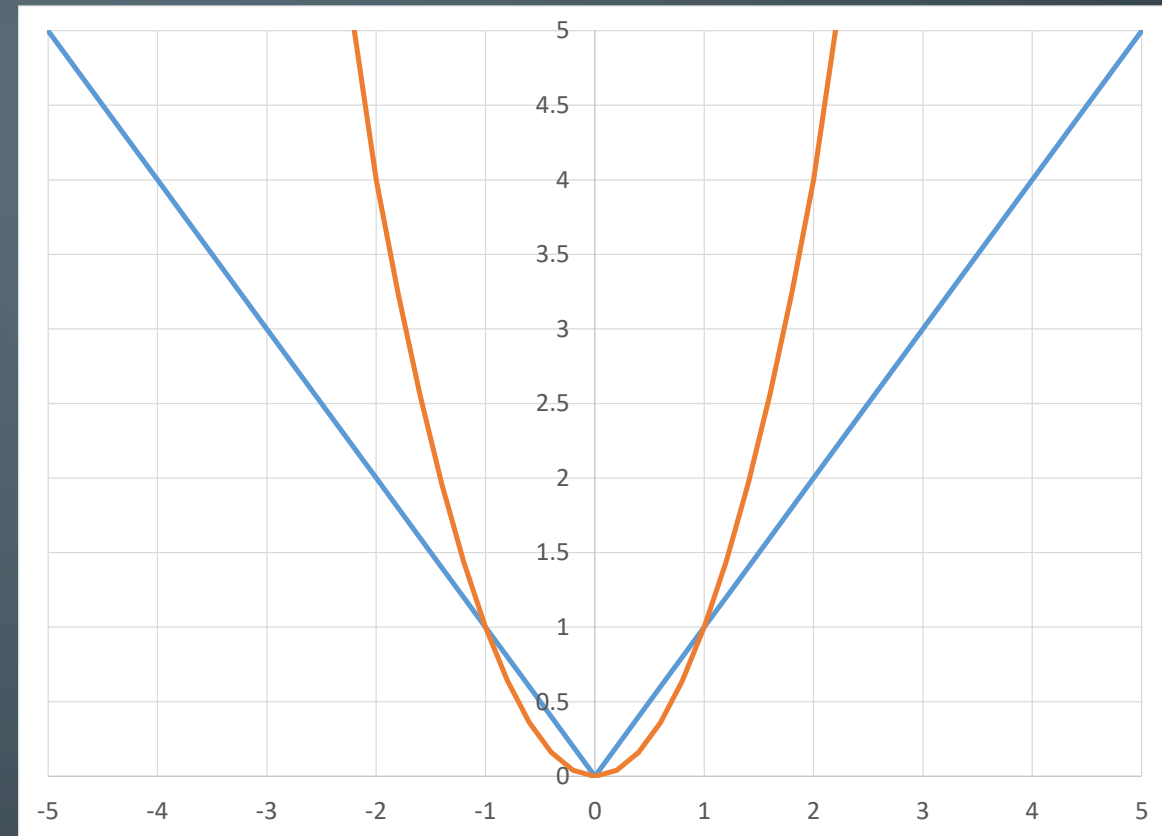


$$\text{Example: Abs}((-2-0)/(-4-0))=50\%$$

THEN, IS HOW IS CENTERING DETERMINED?

Adding up all the Errors

- Linear (abs value)
 - Simple addition
- Least squares
 - Squaring the error
- Combination?



If $\text{ABS}((\text{Solver Estimate}-\text{Center})/(\text{Bound}-\text{Center})) > 100\%$

$\text{ABS}((\text{Solver Estimate}-\text{Center})/(\text{Bound}-\text{Center}))^2$

else

$\text{ABS}((\text{Solver Estimate}-\text{Center})/(\text{Bound}-\text{Center}))$

RUNNING THE SOLVER

After its all entered sit back and wait for your results!



NOZZLE STRENGTH EXAMPLE

	Return Percentage					Nozzle Strength Average			Nozzle Strength Standard Dev		
	Point Est	% Lower	% Upper	Model Estimate	Error	Model Avg	Measured Avg	Error	Model StDev	Measured StDev	Error
Vac1	0.39%	0.30%	0.48%	0.48%	98.0%	23.0	23	0.0%	0.50	0.5	1.3%
Vac2	0.43%	0.32%	0.54%	0.48%	46.4%	23.0	23	0.2%	0.70	0.7	0.0%
Vac3	0.78%	0.28%	1.40%	0.66%	69.2%	22.0	22	0.8%	1.80	1.8	0.0%
Vac4	1.85%	1.18%	2.52%	1.01%	125.8%	22.4	24	99.9%	4.74	2.6	100.0%
Vac5	3.78%	2.46%	5.10%	2.32%	110.5%	16.3	17	99.8%	1.10	1.1	0.1%
Vac6	3.06%	1.58%	4.54%	3.61%	37.4%	15.0	15	0.0%	2.50	2.5	0.0%
Vac7	4.25%	2.12%	6.38%	3.11%	53.6%	15.0	15	0.0%	0.80	0.8	0.0%
Vac8	0.29%	0.15%	0.43%	0.10%	132.2%	29.6	30	62.6%	1.00	1	0.0%

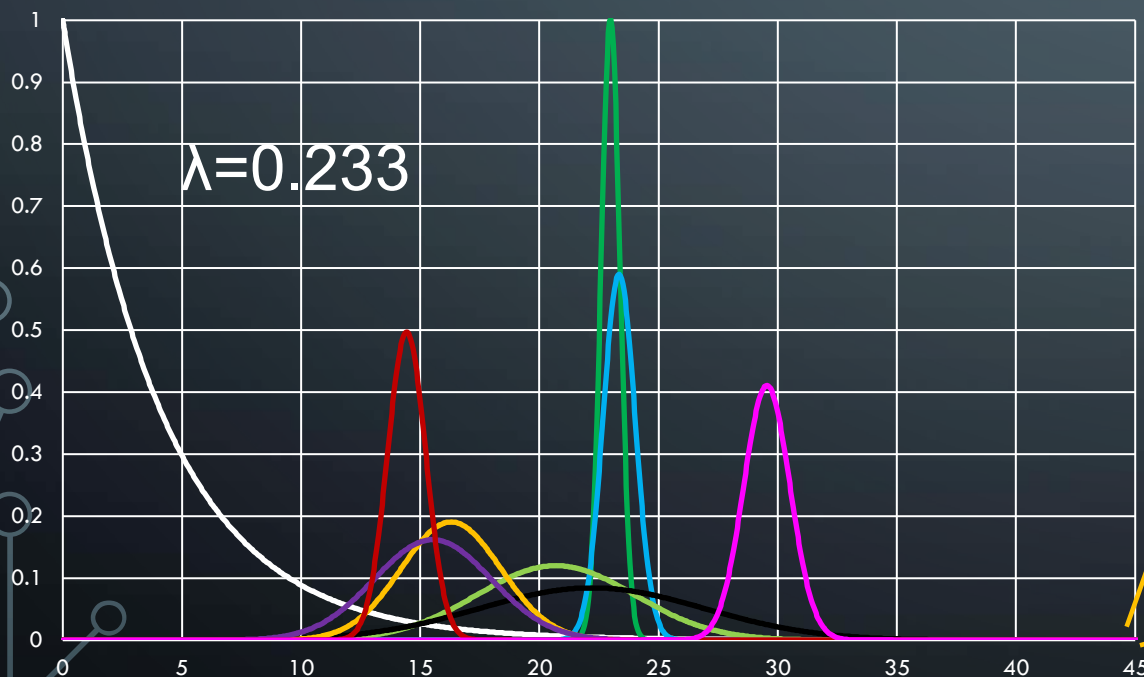
$$f(x) = 0.233 e^{-0.233 x}$$

$$F(x) = 1 - e^{-0.233 x}$$

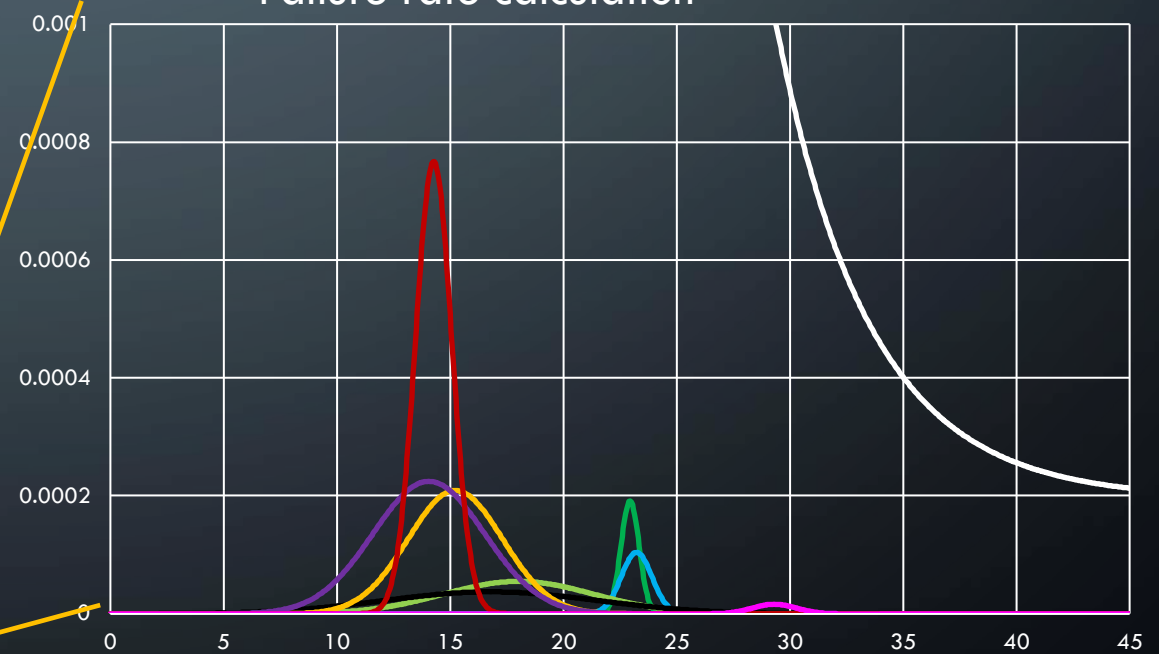
$$\text{stress} = 1 - (1 - e^{-0.233 x})$$

$$= e^{-0.233 x}$$

Nozzle stress - strength Distributions



Failure rate calculation



NOZZLE STRENGTH TARGETS: PLUG AND CHUG

	Return Percentage					Nozzle Strength Average			Nozzle Strength Standard Dev		
	Point Est	% Lower	% Upper	Model Estimate	Error	Model Avg	Measured Avg	Error	Model StDev	Measured StDev	Error
Vac1	0.39%	0.30%	0.48%	0.48%	98.0%	23.0	23	0.0%	0.50	0.5	1.3%
Vac2	0.43%	0.32%	0.54%	0.48%	46.4%	23.0	23	0.2%	0.70	0.7	0.0%
Vac3	0.78%	0.28%	1.40%	0.66%	69.2%	22.0	22	0.8%	1.80	1.8	0.0%
Vac4	1.85%	1.18%	2.52%	1.01%	125.8%	22.4	24	99.9%	4.74	2.6	100.0%
Vac5	3.78%	2.46%	5.10%	2.32%	110.5%	16.3	17	99.8%	1.10	1.1	0.1%
Vac6	3.06%	1.58%	4.54%	3.61%	37.4%	15.0	15	0.0%	2.50	2.5	0.0%
Vac7	4.25%	2.12%	6.38%	3.11%	53.6%	15.0	15	0.0%	0.80	0.8	0.0%
Vac8	0.29%	0.15%	0.43%	0.10%	132.2%	29.6	30	62.6%	1.00	1	0.0%

$$f(x) = 0.233 e^{-0.233 x}$$

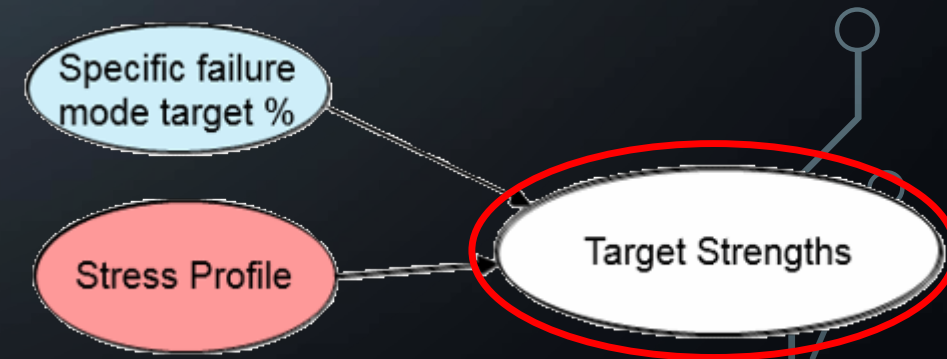
$$F(x) = 1 - e^{-0.233 x}$$

$$\text{stress} = 1 - (1 - e^{-0.233 x})$$

$$= e^{-0.233 x}$$

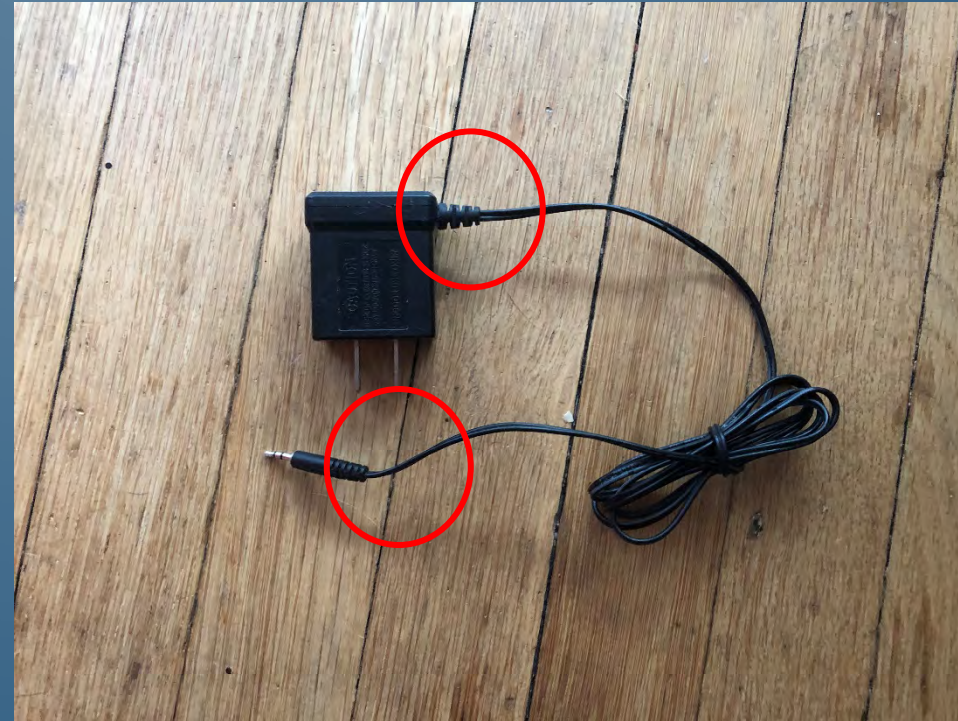
Since there are 2 parameters, average and standard deviation, one will have to be selected. Looking at the measured standard deviation, 1.0 lbs seemed reasonable. Targets became:

	Total percentage (estimate)	Average (lbs)	St Dev (lbs)
BIC	0.10% - 0.25%	26.0	1.0
Good	0.25% - 0.50%	23.0	1.0
Borderline	0.50% - 1.00%	20.0	1.0
Unacceptable	>1.00%		



EVEN MORE COMPLEX MODEL – CABLE PULL

The goal was to find a pull force specification for a power supply



- Cable failures can happen on either end (Wall or Connector)
- Mostly binned by “broken cable”, limited information as to which end
- 3 power supplies had significant field data

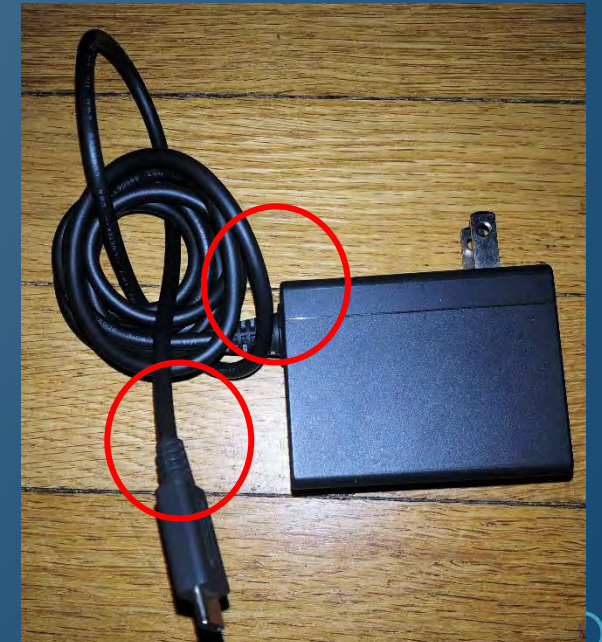
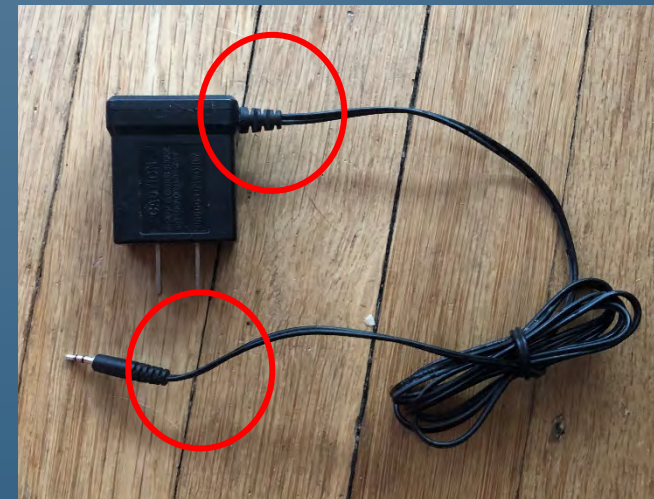
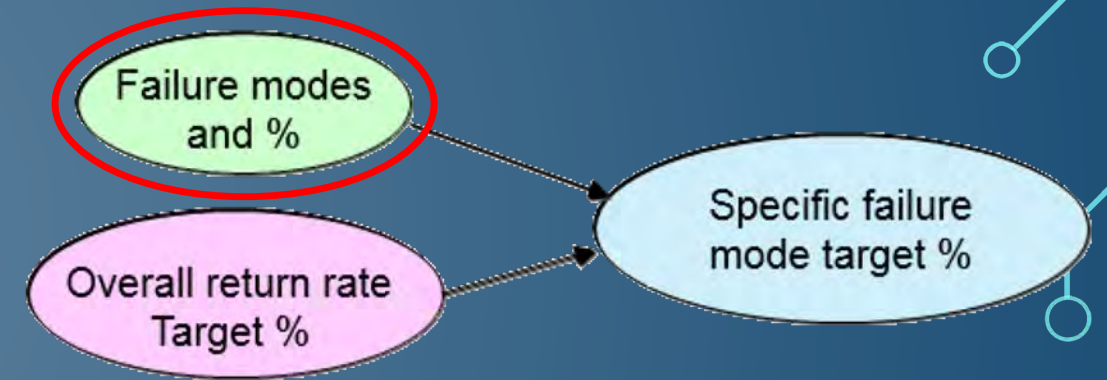
RETURN RATE FOR BROKEN CABLE

- PS 1 – 0.45%
- Lav 2 – 0.07%
- Lav 3 – 0.13%

Additionally, from the verbatims, the Wall end fails
(at a minimum)

- PS 1 – 0.01%
- PS 2 – 0.00%
- PS 3 – 0.02%

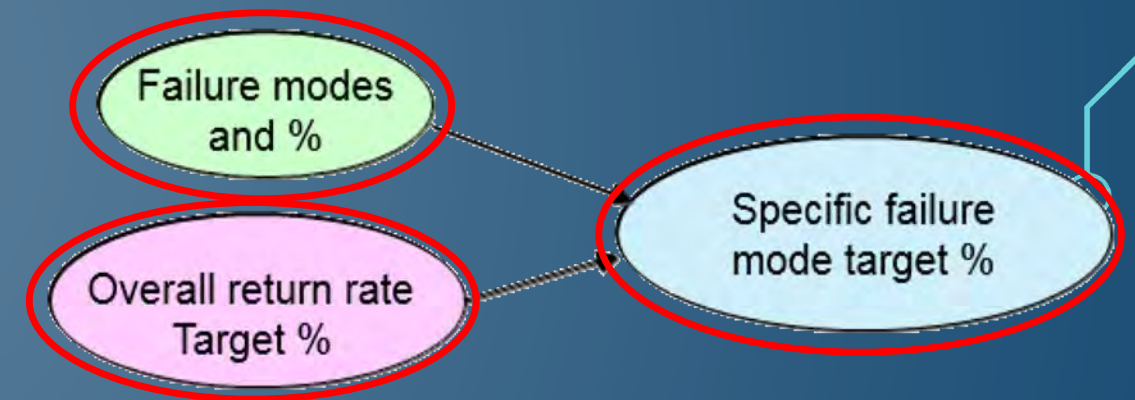
- Since we don't have good data on the wall end, we will set the limits as:
- Upper limit = mic estimate minus total upper limit
- Lower limit = the above data



CREATE A SPECIFIC FAILURE MODE TARGET

Estimate what returns are
due to cable (~10%):

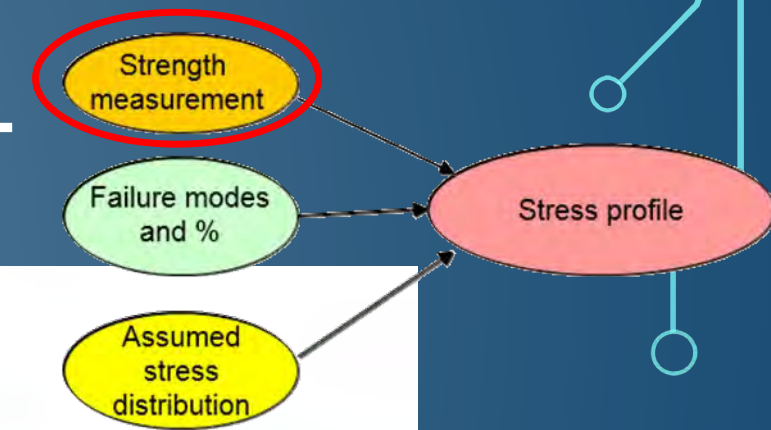
Product	cable returns % of total returns
PS 1	15%
PS 2	8%
PS 3	7%



Using Overall return rate Target at less than 1%, Total cable failure rate should be 0.1%:

	Total cable pull failure rate
Best in class	<0.05%
good	<0.10%
borderline	0.10%-0.20%
unacceptable	>0.20%

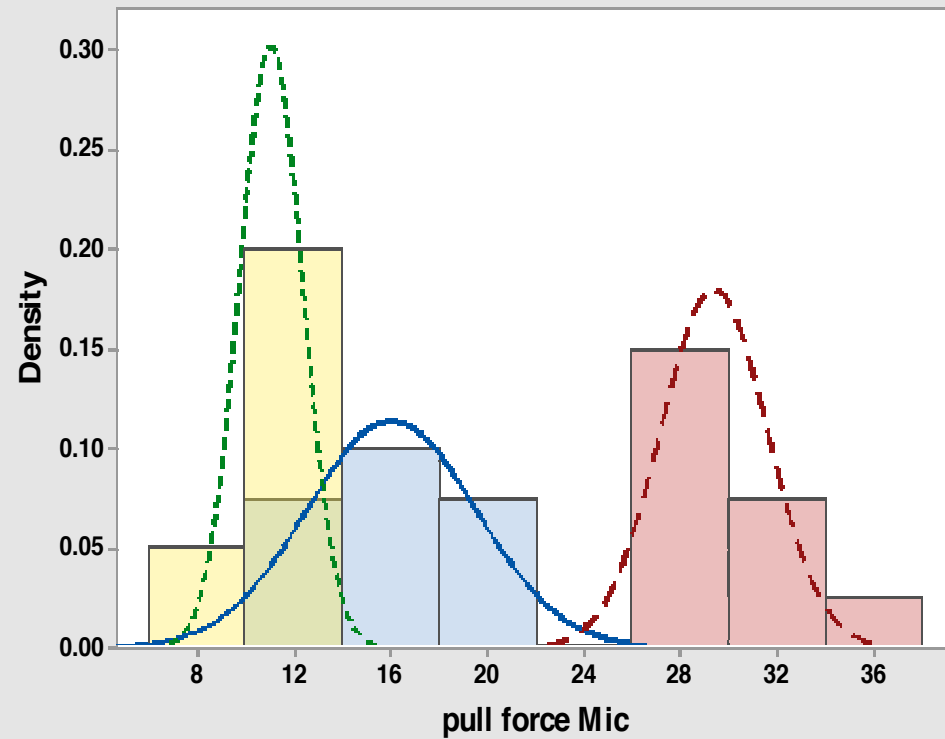
MEASURE THE STRENGTH OF EACH PRODUCT



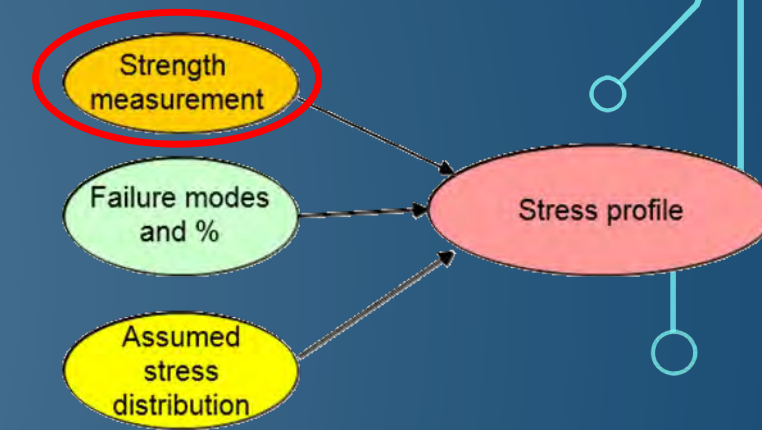
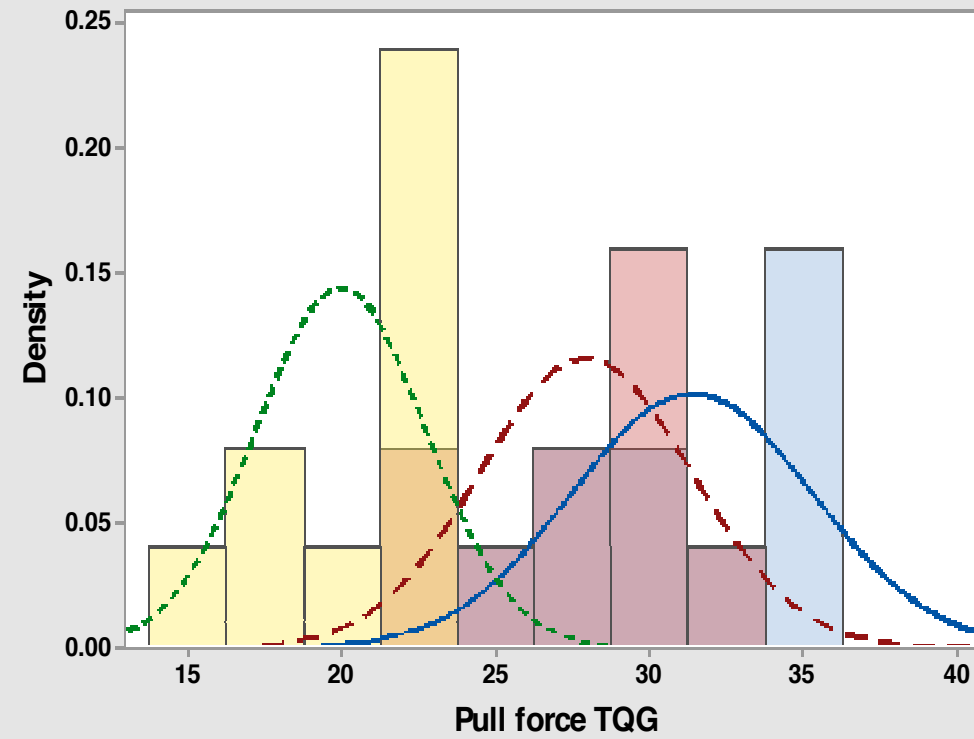
Pull Each End to Failure

CALCULATE LIMITS

Histogram of pull force Wall
Normal



Histogram of Pull force Connector
Normal



	Total Failure mode (Actuals)	Upper Bound	Lower Bound
PS1	0.47%	0.62%	0.35%
PS2	0.07%	0.10%	0.04%
Lav 3	0.13%	0.17%	0.10%

		Wall Side			connector		
		PS1 Wall	PS2 Wall	PS3 Wall	PS1 connector	PS2 connector	PS3 connector
mean	point est	28	16	11	27	31	20
	lower bound	26	14	10	25	29	18
	upper bound	30	18	12	29	33	22
st dev	point est	2.2	3.5	1.3	3.4	3.9	2.7
	lower bound	1.6	2.5	0.9	2.5	2.9	2
	upper bound	3.6	5.5	2.1	5.6	6.4	4.5

NOTE: ULTIMATE STRENGTH IS PROPORTIONAL TO CYCLIC STRENGTH

S-N CURVES SHOW STRENGTH VS CYCLES

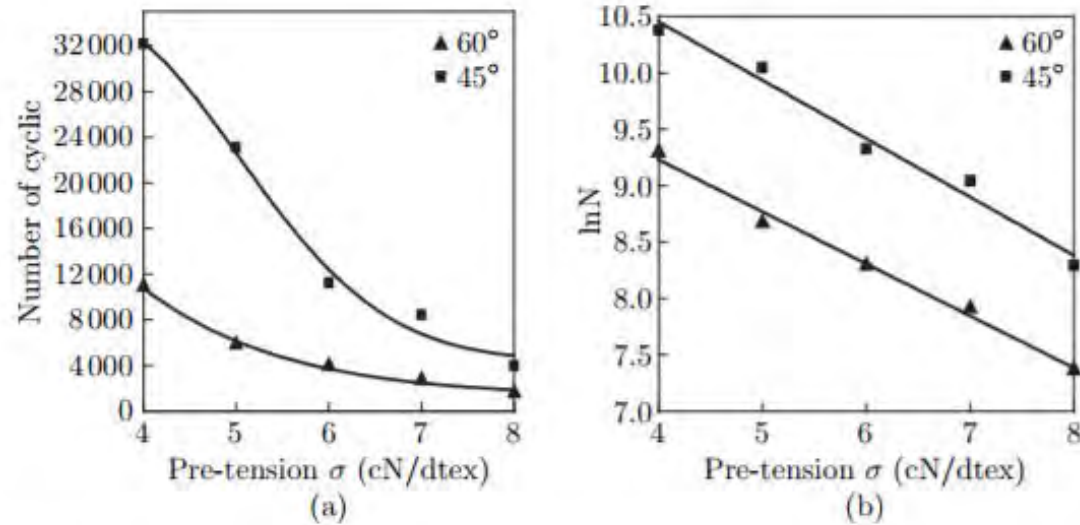


Fig. 8: (a) is the S-N curve of Kevlar 49 fiber; (b) is S-lnN curve of Kevlar 49 fiber

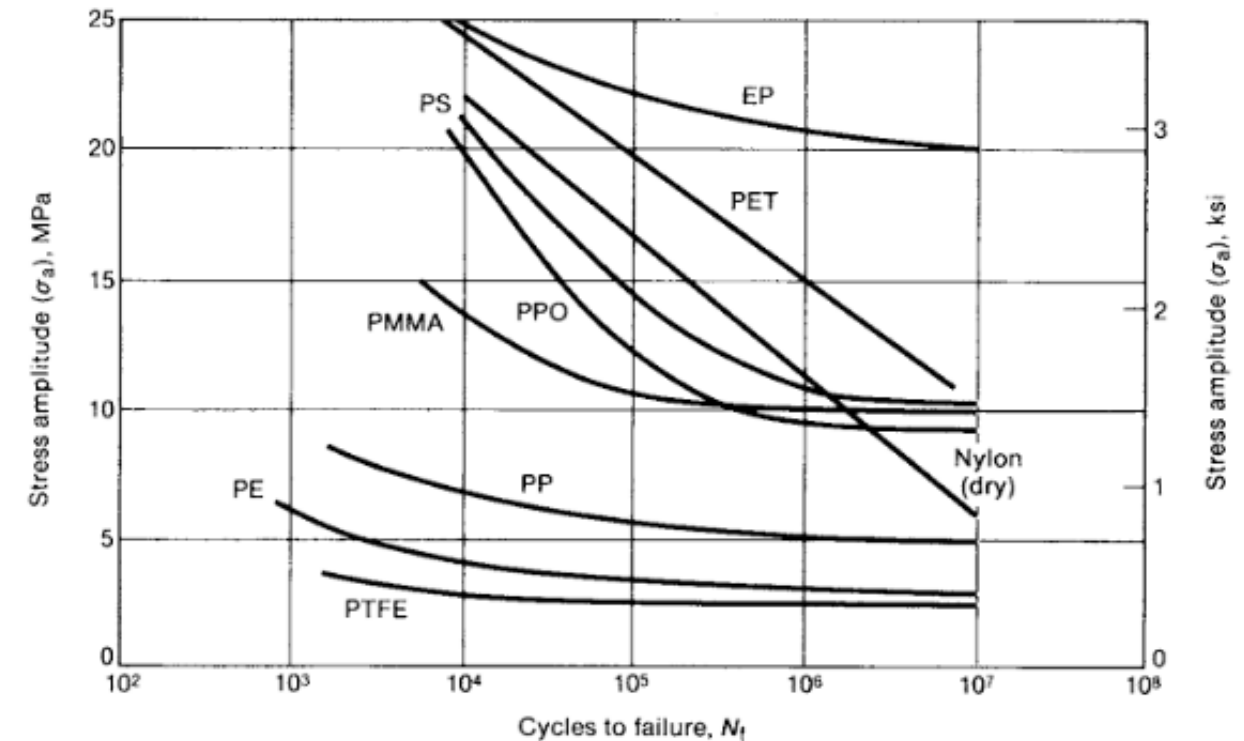


Fig. 1 Stress amplitude versus cycles-to-failure curves for several polymers tested at a frequency of 30 Hz. PS, polystyrene; EP, epoxy; PET, polyethylene terephthalate; PMMA, polymethyl methacrylate; PPO, polyphenylene oxide; PE, polyethylene; PP, polypropylene; PTFE, polytetrafluoroethylene. Source: Ref 5

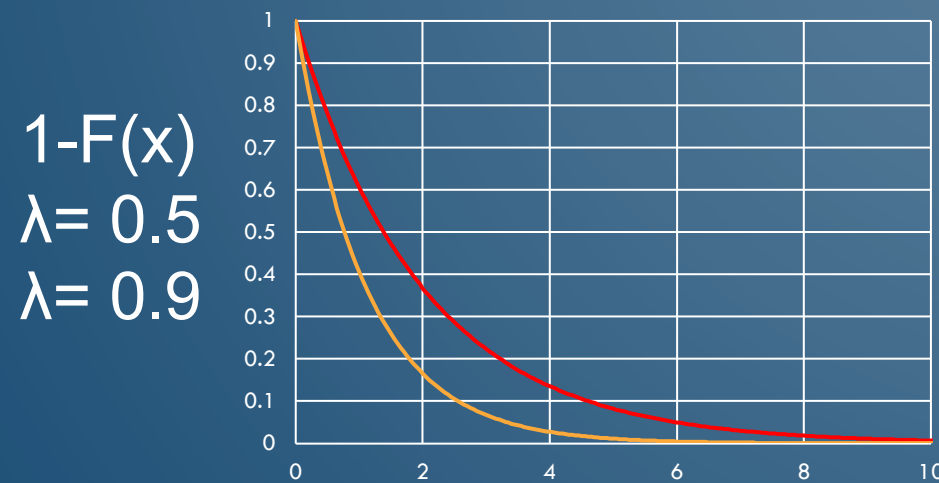
***Characterization and Failure Analysis of Plastics**
By ASM International, Steve Lampman, Pg 250

(note: strength is referred to as stress [force/area] in engineering texts, this is a different stress than the generic stress referenced previously)

ASSUMED DISTRIBUTION

- Random forces/stresses applied to product in the field
 - Forces generally occur *continuously* and *independently* at *constant average rate*

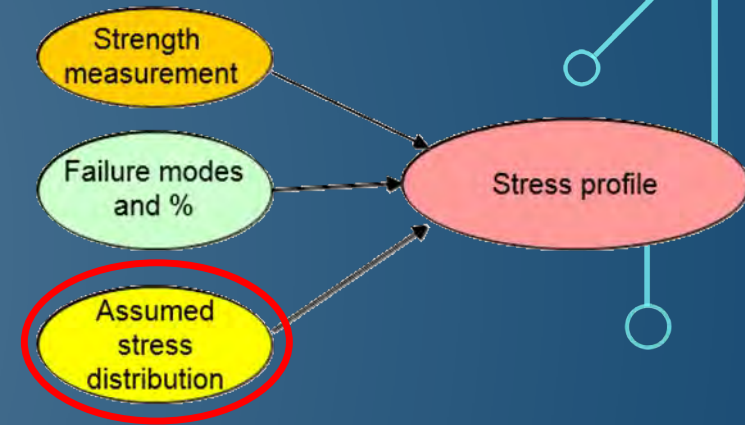
Exponential Distribution



$$f(x; \lambda) = \begin{cases} \lambda e^{-\lambda x} & x \geq 0, \\ 0 & x < 0. \end{cases}$$

$$F(x; \lambda) = \begin{cases} 1 - e^{-\lambda x} & x \geq 0, \\ 0 & x < 0 \end{cases}$$

$$\text{Mean: } \lambda^{-1} (= \theta)$$



- Same forces to each product in each use case
- **BUT! Wall end is different than Connector end**
 - Connector end is attached to gaming consoles, phones, etc.
 - Wall end attached to ... the Wall
 - Evident in the data

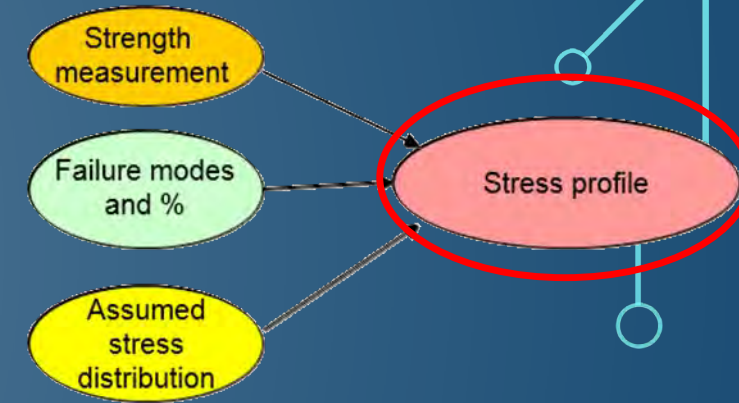
STRESS PROFILE

Use excel solver to best fit:

Wall Stress Profile: $e^{-\lambda_{\text{Wall}}}$

Connector Stress Profile: $e^{-\lambda_{\text{Conn}}}$

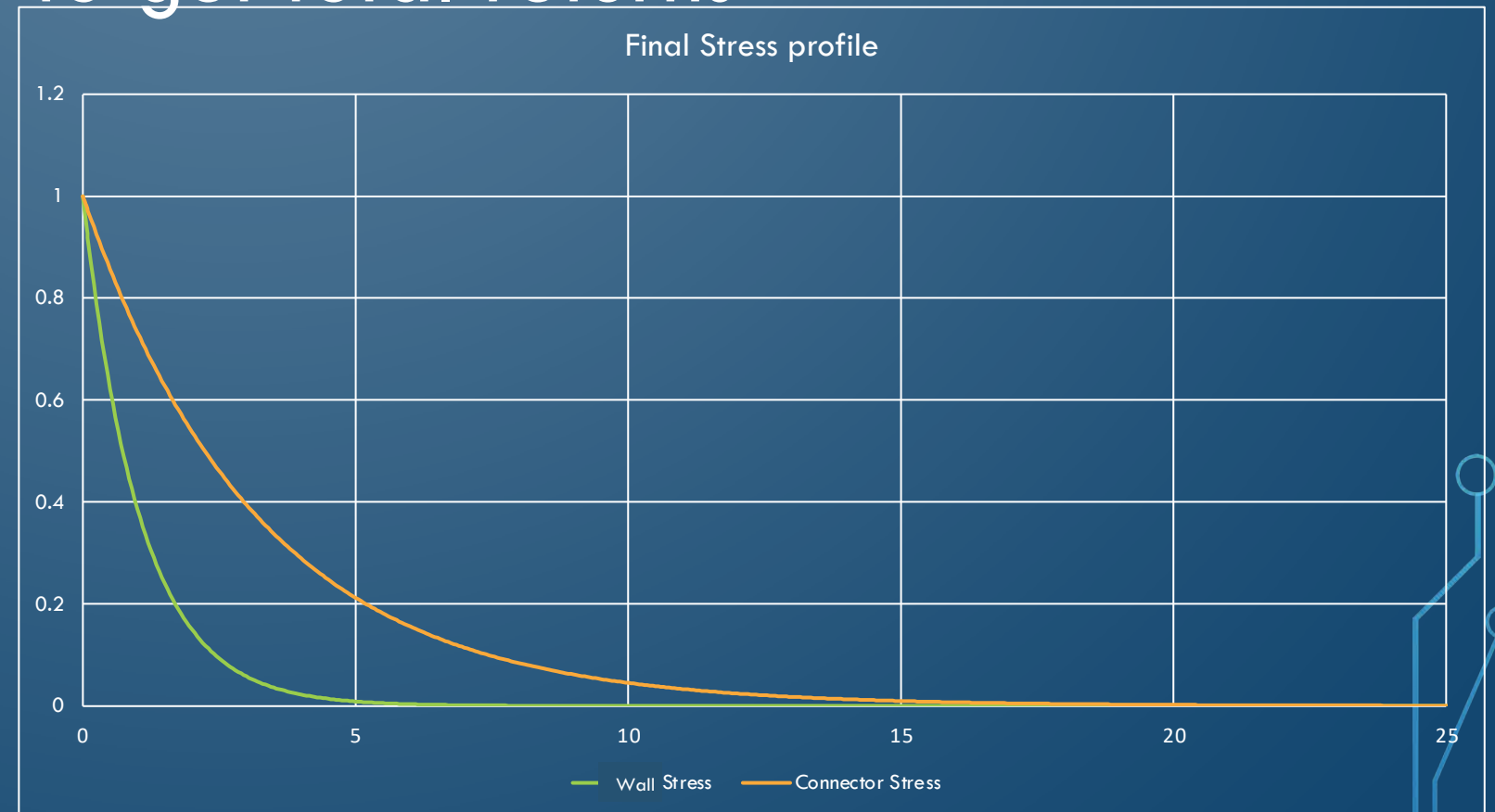
Add both together to get total returns



$(1 - \text{Wall cumulative stress force}) \times (\text{Wall strength}) +$
 $(1 - \text{Conn. cumulative stress force}) \times (\text{Conn. strength})$
= total failure rate

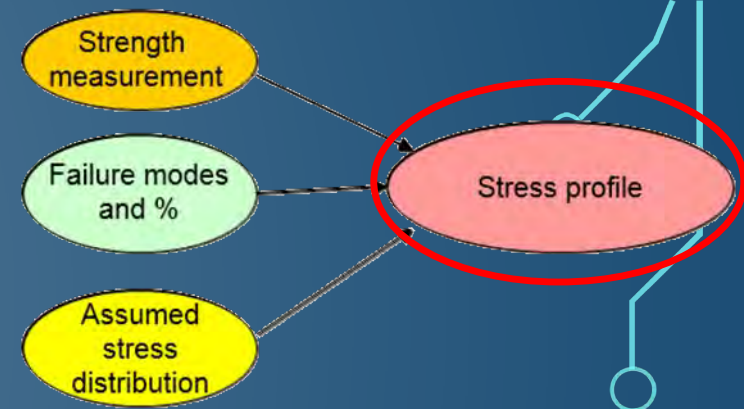
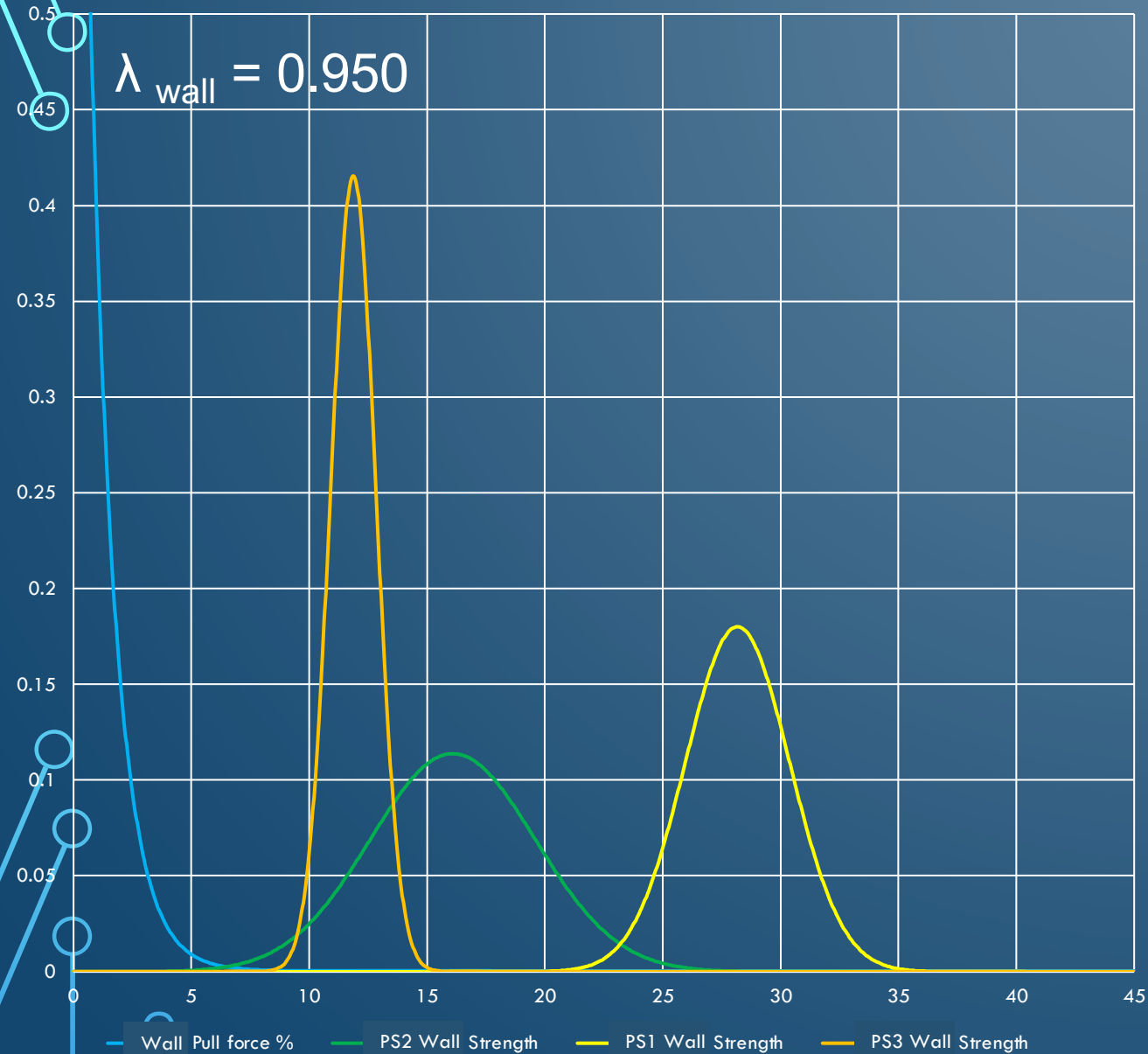
$$\lambda_{\text{Wall}} = 0.950$$

$$\lambda_{\text{Conn}} = 0.310$$

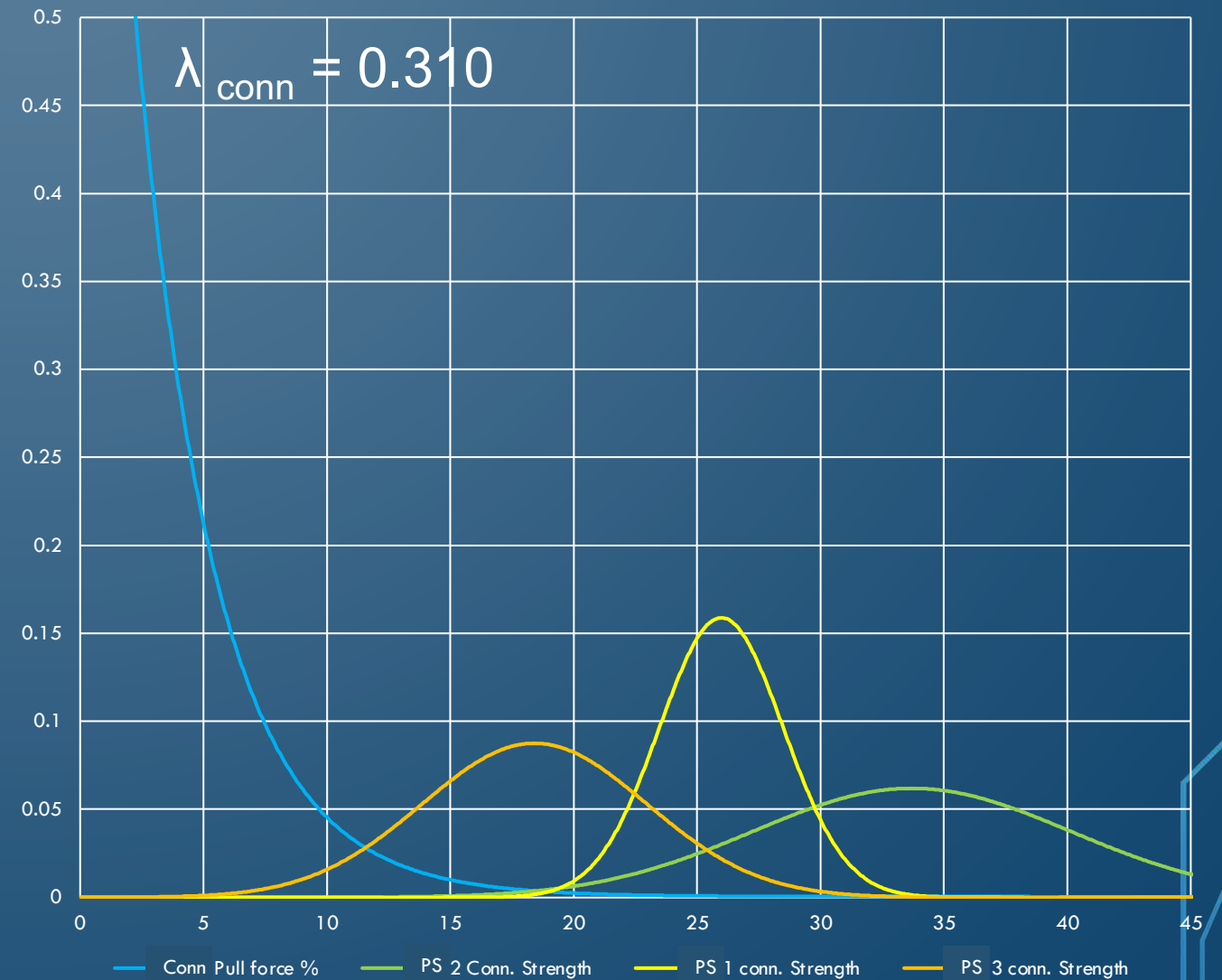


COMPARE TO STRESS PROFILE

Wall stress - strength Distributions

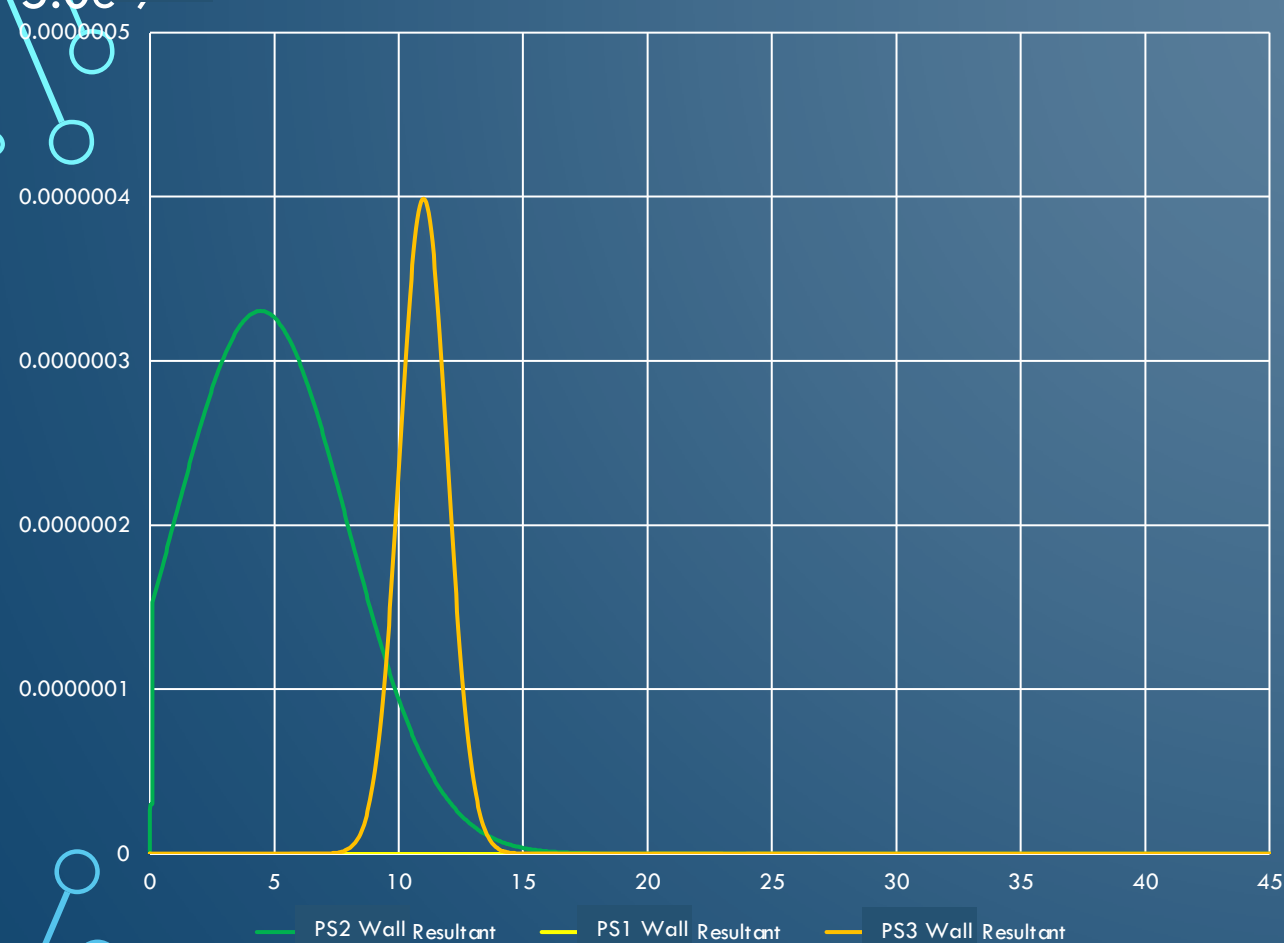


Conn. stress - strength distributions

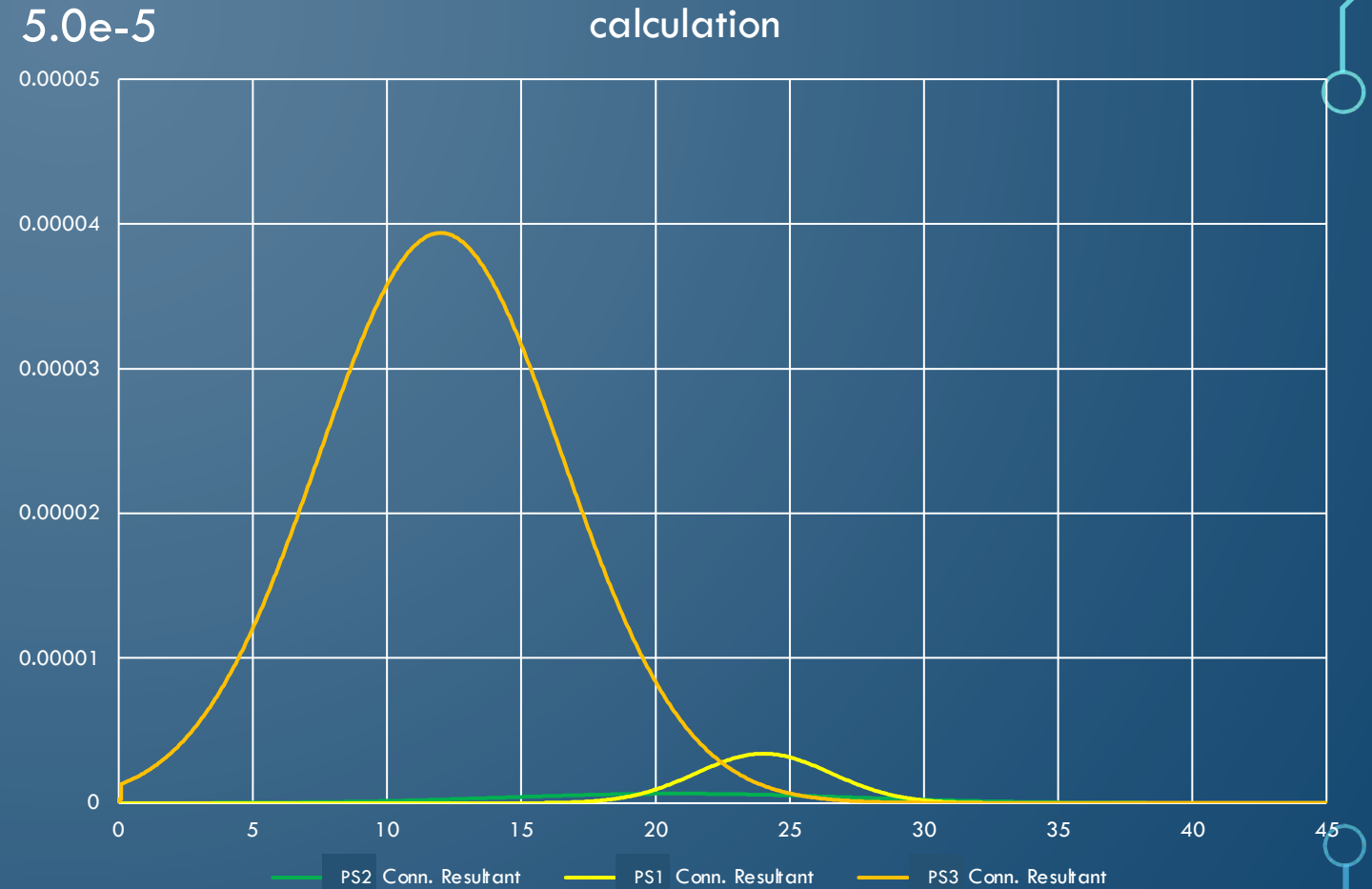


CALCULATE FAILURE RATE DISTRIBUTIONS

Wall stress - strength resultant - failure rate calculation



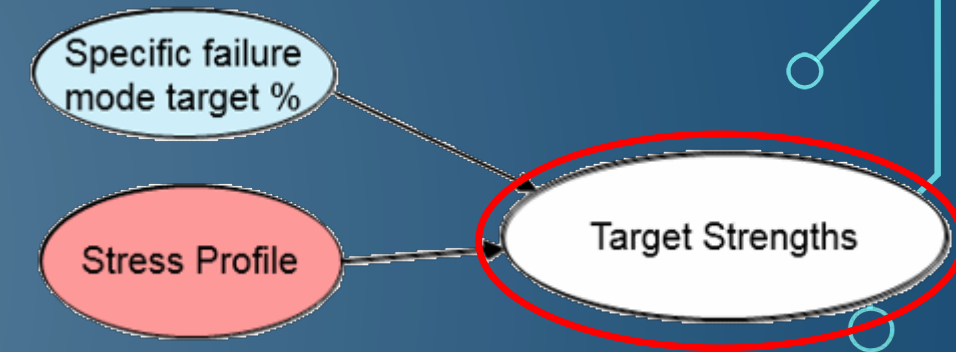
Connector stress - strength resultant - failure rate calculation



	Total Failure mode (Actuals)	Upper Bound	Lower Bound	Total Failure Mode (Calculated)	error	Calculated Wall End	Calculated Conn End
PS 1	0.47%	0.62%	0.35%	0.15%	285.87%	0.000%	0.148%
PS 2	0.07%	0.10%	0.04%	0.02%	162.89%	0.003%	0.021%
PS 3	0.13%	0.17%	0.10%	0.15%	50.65%	0.002%	0.149%

COMPARE TO FAILURE RATE TARGETS

	Total cable pull failure rate
Best in class	<0.05%
good	0.05%-0.10%
borderline	0.10%-0.20%
unacceptable	>0.20%



More inputs required – 4 unknowns:

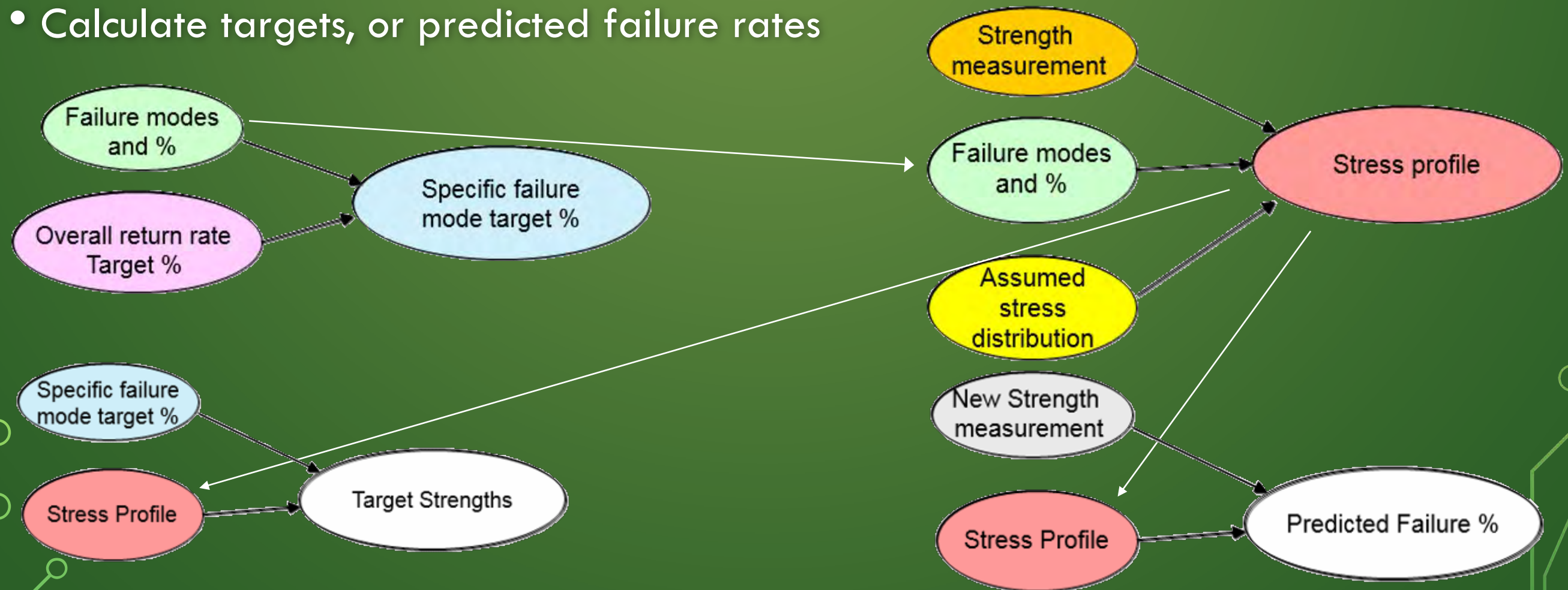
1. Standard deviation – once again, a standard deviation needs to be selected (both mic/connector)
2. Mic or connector average needs to be selected, or a relationship established:
Mic is usually approximately 50% strength of connector

	Avg (lbs)	max Stdev(lbs)		Predicted FR	total
Wall	12.5+	3	BIC	<0.035%	<0.05%
connector	24.5+	3	BIC	<0.016%	
Wall	12 to 12.5	3	good	Max 0.054%	0.05% - 0.10%
connector	22.5 to 24.5	3	good	Max 0.045%	
Wall	11 to 12	3	borderline		>0.20%
connector	19.5 to 22.5	3	borderline		
Wall	<11	3	unacceptable	>0.97%	
connector	<19.5	3	unacceptable	>0.103%	

Use the model with actual results of products to find the failure rate and final “Rating”

SUMMARY

- Pull comparator product Failure modes and rates
- Set specific failure mode targets
- Choose assumed stress distribution
- Measure strength of comparators
- Calculate targets, or predicted failure rates



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Master's in Acoustical Engineering, Penn State

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Quality/Reliability Engineer, 6 Sigma Black belt, Noise & Vibration Engineer, Ford Motor Company - 13 years

Previous presentations:

2 Parameter vs. 3 Parameter Weibull with a Cable Flex Test — ARS 2015

Overview of Reliability Functions for Life Testing in Minitab — Minitab Insights 2016

Practical Use of Stress-Strength Models to Develop Specifications — ARDC 2018



QUESTIONS

Thank you for your attention.

Let me know your questions

