Introduction to Reliability Analysis Using Weibull Engineering

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What Weibull Engineering Empowers Users to Do

- Select and fit a variability model for most measurements
- Interpret non-linear data patterns on probability scaling
- Forecast risk using the selected model with added usage rate
- Simulate random samples to answer difficult questions
- Choose between graphical and non-graphical solution
- Form a database of previous results to improve accuracy
- Plan a test to demonstrate life, capability, or reliability
- Evaluate test results (standard, accelerated, or step-stress)
- Establish lower and/or upper confidence bounds for results
- Apply simple related probability models when needed
- Perform general trend analysis for tracking progress
  - NOTE: This trending is called “Crow/AMSAA” or “Reliability Growth”

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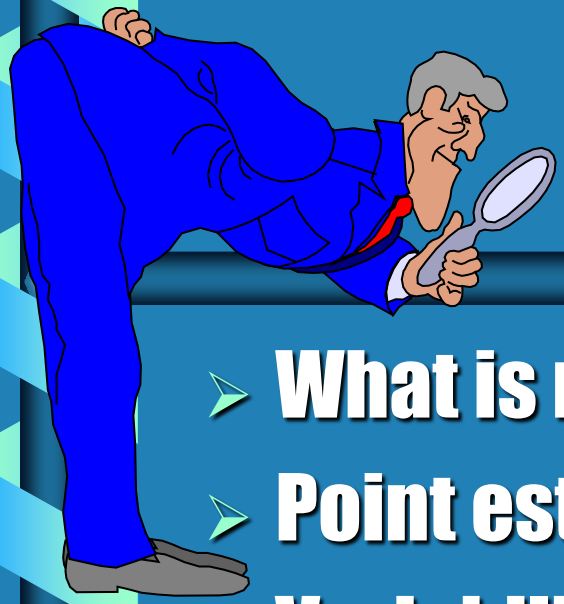

To Begin

- What is reliability?
- Point estimates related to reliability
- Variability vs. Point estimates
- Standard variability distributions
- New product development techniques
- Service data analysis … warranty data
- ***The most important thing***

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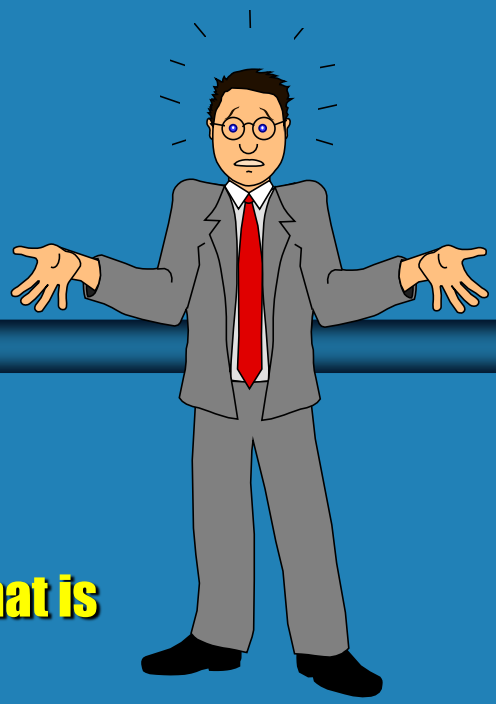
Reliability?



- Reliability (R) = probability of success
- Or … R = 1 - (probability of failure)
  - To be useful, need a good specification of what is acceptable and what is not
- Actual reliability can change:
  - With different design or different assembly
  - With different length of service required
  - With different duty cycle, different loading
  - With different environments
  - With changes in quality
  - With changes in maintenance practice
- *So … reliability is a moving target ! ! !*

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Point Estimates Related to Reliability

- R estimate = (successes) / (trial quantity)
- Mean time between failure … "MTBF"
  - Meaningful for repairable items
  - Cumulative MTBF (easy!) = (total time) / (total failures)
  - Instantaneous MTBF … get from "Crow/AMSAA"
- Mean time to failure – "MTTF"
  - Meaningful for non-repairable items
  - 1st moment of life distribution … "expected life"
- Availability = (total up-time) / (total time)

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Variability Vs. Point Estimates

- Trials (go/no-go) without failure … point estimate.
  - 100 trials … R = 100%.
  - 1 trial … R = 100% … same! … Is this point estimate useful?
- Binomial w/90% confidence … variability estimate.
  - 100 trials … R >= 97.7 %.
  - 1 trial … R >= 10 % … so! They are different.
- Variability estimates can often be more useful.
- Which type of variability model to use?
  - Non-parametric: 1st moment, 2nd, … (e.g. mean, median, range)
  - Parametric: Weibull, lognormal … (y=Par1(x) +Par2)
- ***Parametric accuracy is much better than non-parametric … if model selected is the correct one.***

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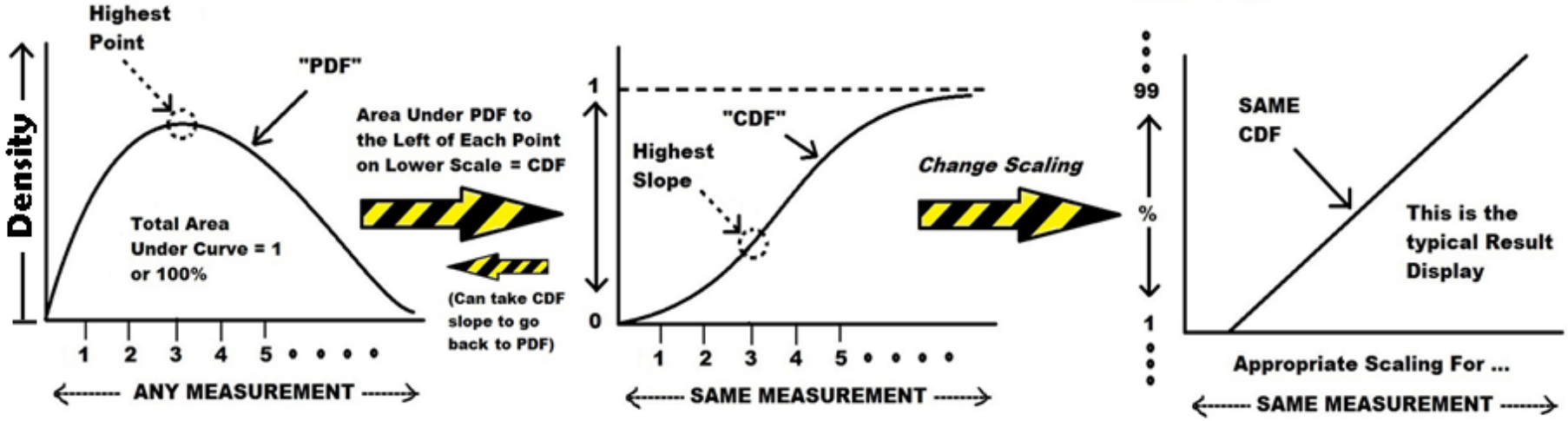
Different Ways of Viewing Any Probability Distribution Model

... like Weibull, or Normal, or Lognormal, or Gumbel ...



* Highest Slope for CDF occurs at same measurement value as Highest Point for PDF

* CDF: Cumulative Distribution Function

* HDF: Hazard Distribution Function ... OR ... Rate

* PDF: Probability Density Function

* RDF: Reliability Distribution Function

NOTE: Can also get this from Crow-AMSAA trend analysis

$$\text{"HDF"} = \frac{\text{PDF}}{1 - \text{CDF}} = \frac{\text{PDF}}{\text{"RDF"}} = \text{HAZARD RATE} = \text{INSTANTANEOUS OCCURRENCE RATE} = \underline{\text{CONDITIONAL PROBABILITY}}$$

NOTE: Can add HDF's together for series system analysis even with different models used for each component.

NOTES: (1) Other CONDITIONAL PROBABILITY methods include Bayesian, and Remaining Life, and Negative t0 (prior damage) 3P Weibull.
(2) "ACH" (Aggregate Cumulative Hazard) is also useful for evaluating how well model matches actual data.

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Standard Parametric Variability Distributions and Their Relationship

- Binomial … for discrete outcomes … only two choices.
- Poisson … for discrete outcomes … events occurring vs. Operating time, wire length, inspection area, etc.
- Exponential … first term of the Poisson.
- Normal… aka "Gaussian" or "bell curve."
- Lognormal… log-values of data have normal distribution.
- Extreme value … every individual data value is the smallest (or largest) from a group of samples.
- Weibull … extreme value type III smallest … can be 1-parameter, 2-parameter (standard), or 3-parameter
  - NOTE: Mixtures could have even more parameters (4, 5, 7)

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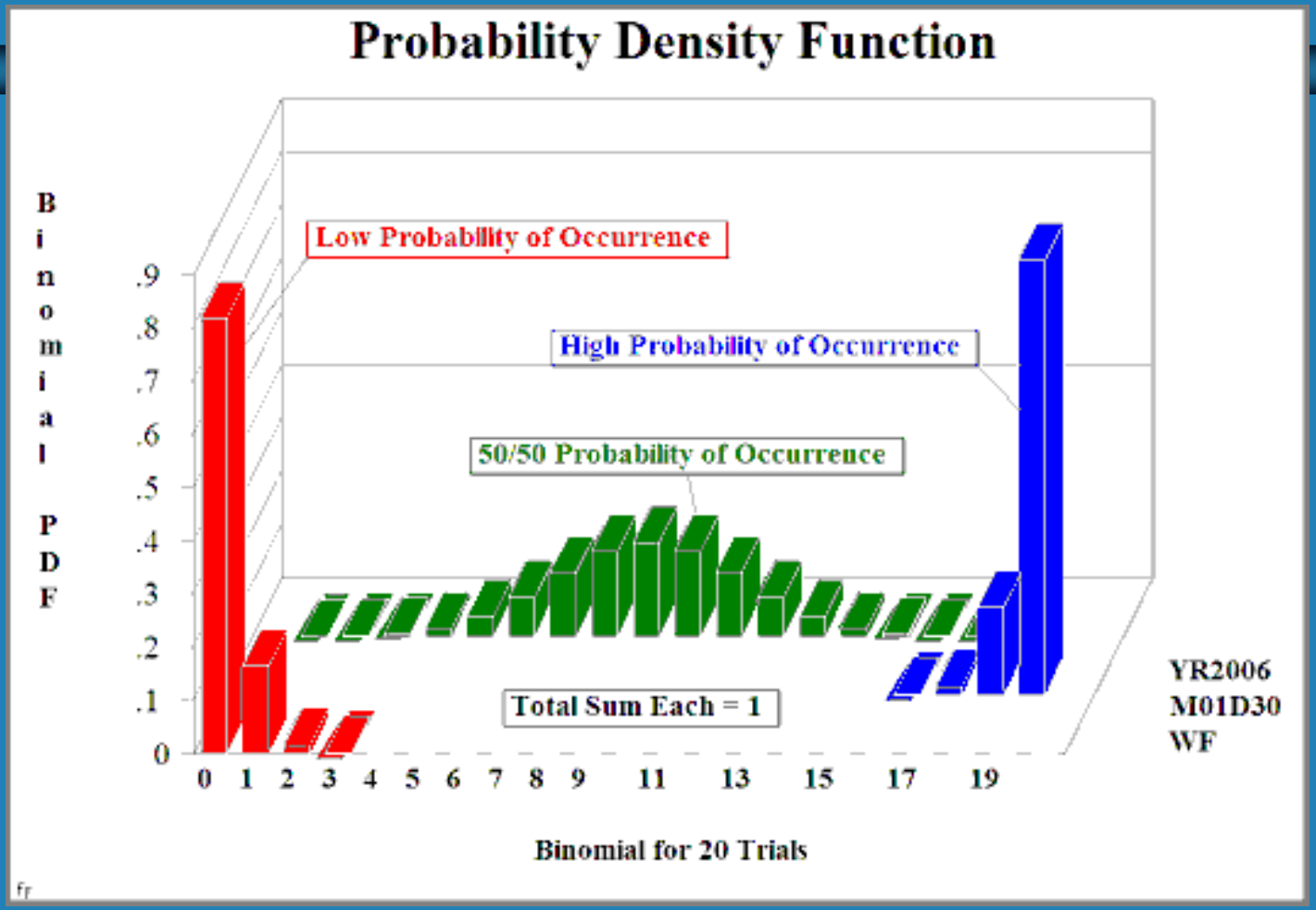
Binomial Distribution



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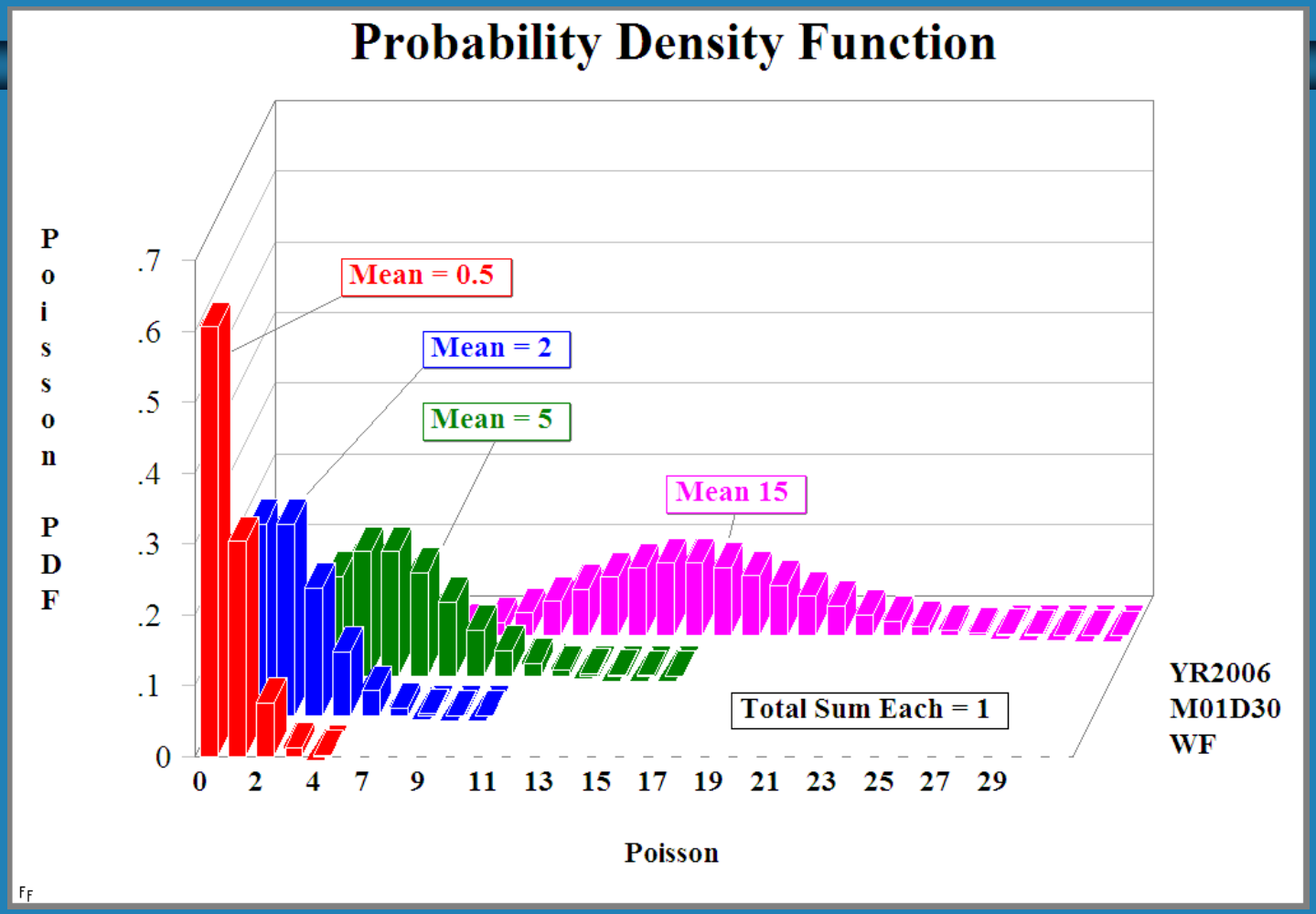
Poisson Distribution



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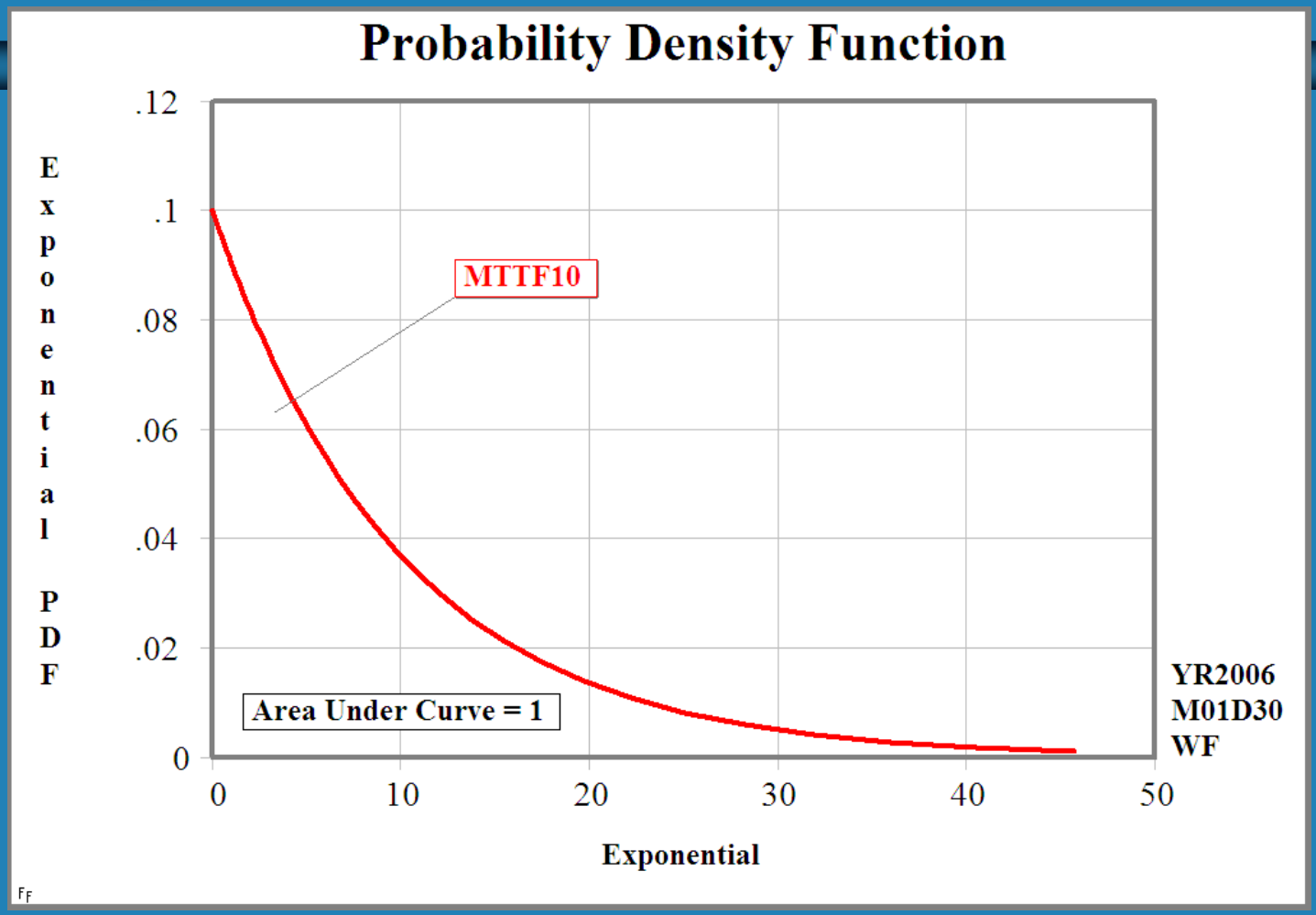
Exponential Distribution



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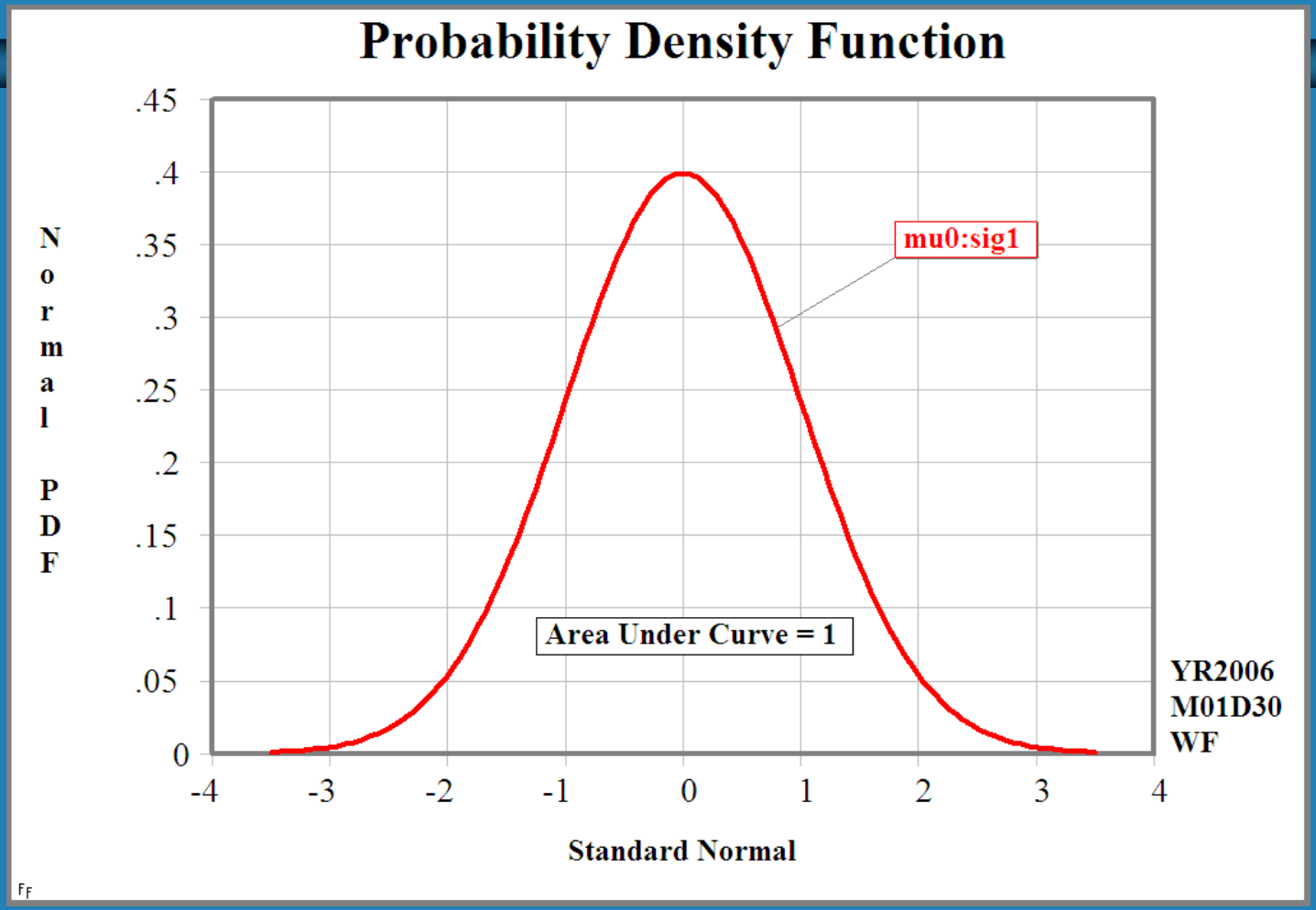
Normal Distribution



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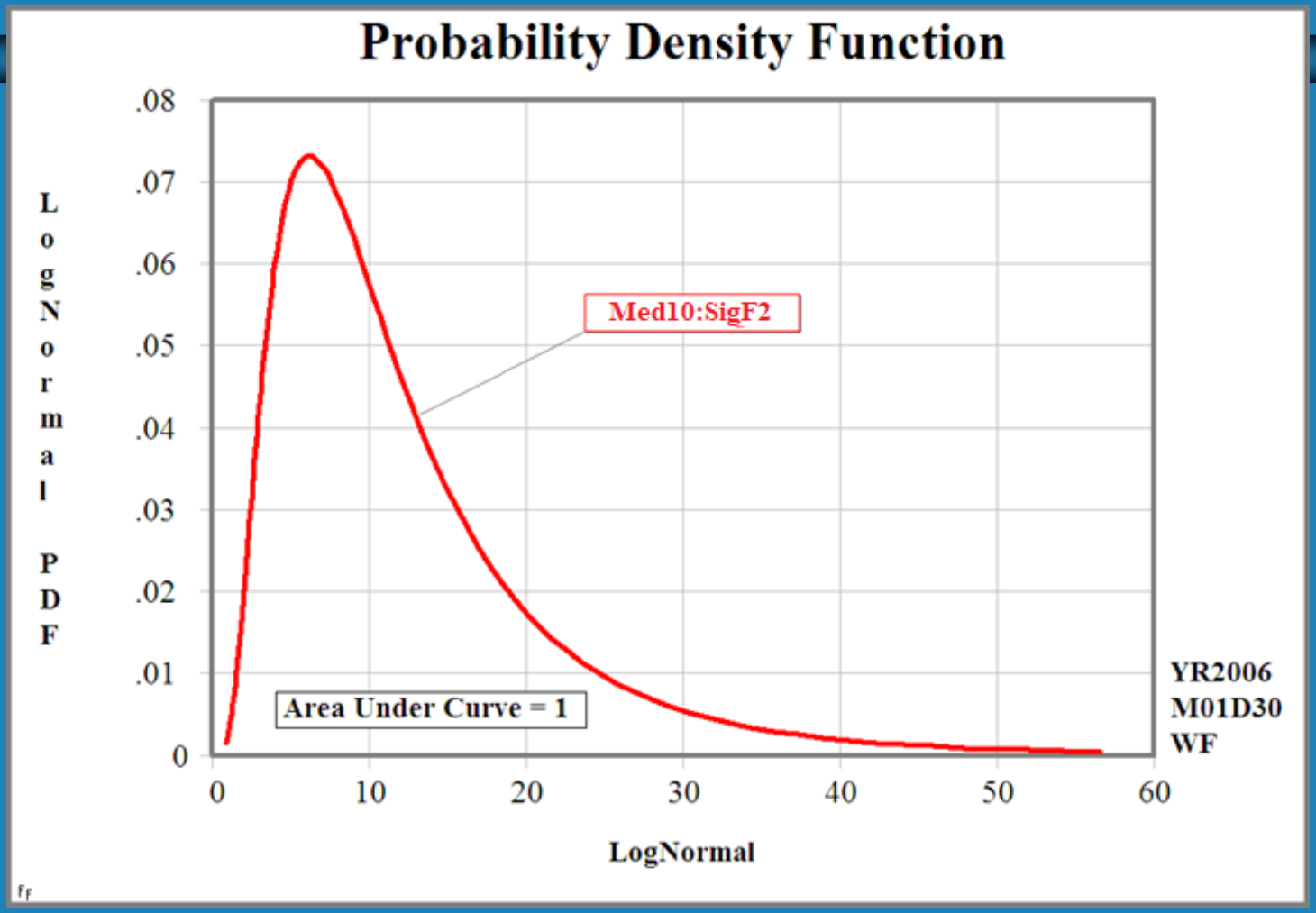
Lognormal Distribution



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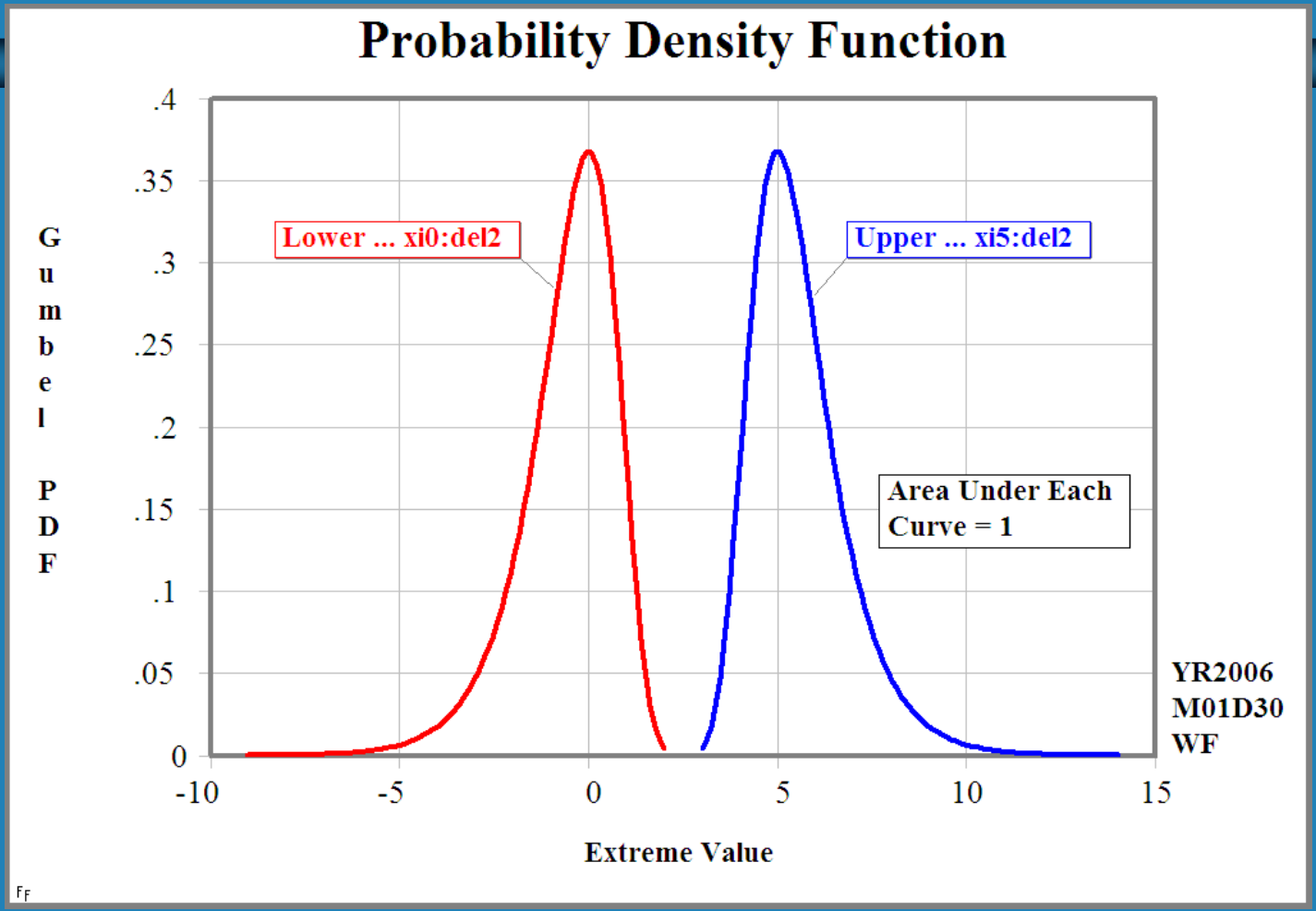
Extreme Value Distribution Type I Only ... (II & III Not Shown)



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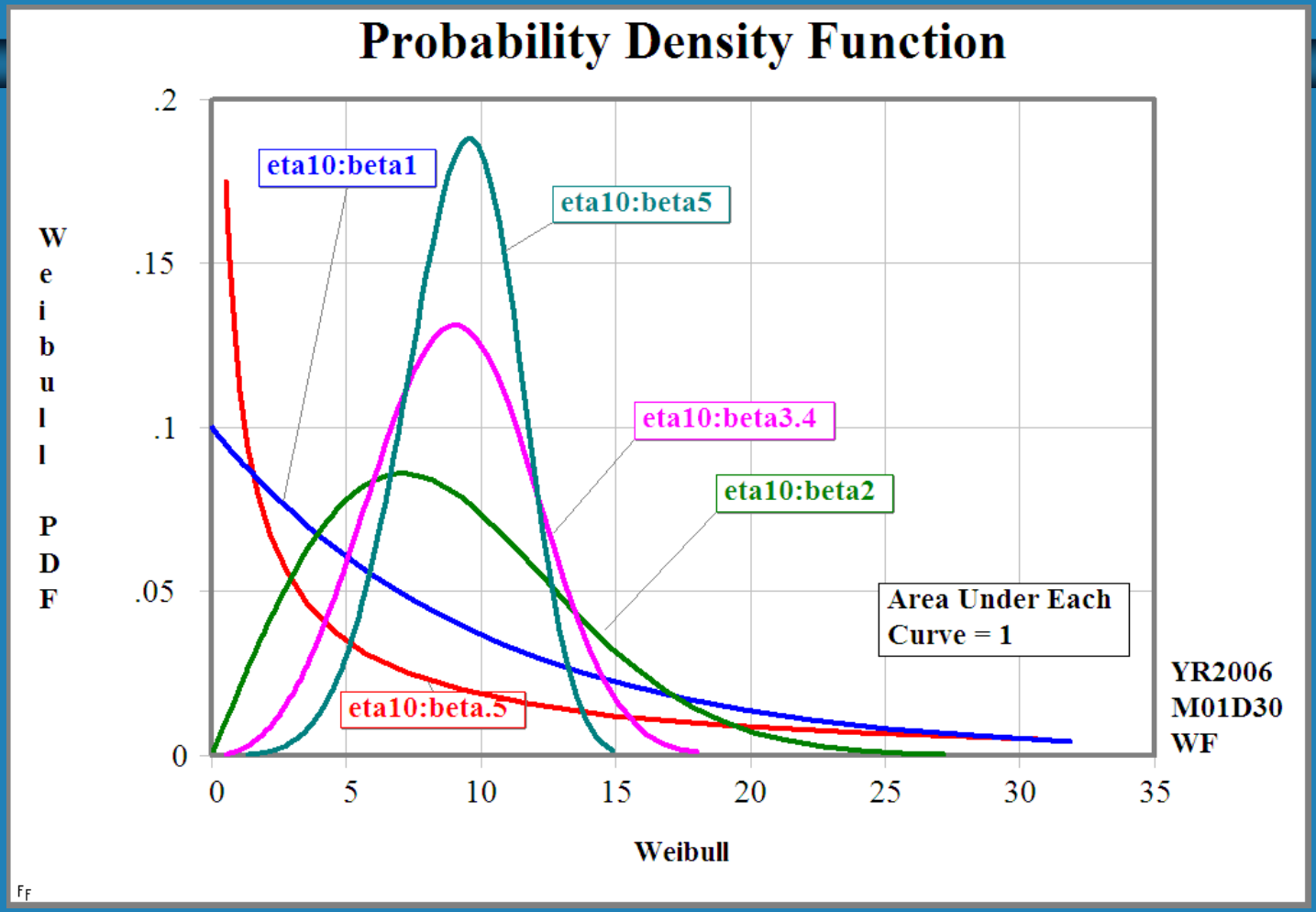
Weibull Distribution … Extreme Value Type III Smallest … USEFUL!



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Experience Data Vs. Age Data

- Experience data is useful for general trends
  - Total accumulated operation of all equipment …
  - … vs. … Total accumulated events
  - Use technique such as Crow/AMSAA to evaluate
- **Age data is useful for more precise Weibull Engineering:**
  - Age = amount of use since new for each equipment
  - For standard analysis each data value is either …
    - "Occurrence" (= age to failure for reliability)
    - "Suspension" [= length of successful operation for reliability)

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New Product Development

- Preliminary models (parts count, R, MTBF)
- 1st principles: physics of failure (POF) … and … probabilistic analysis by Monte Carlo simulation
- Development testing ("Weibayes" substantiation)
- Crow/AMSAA for test, analyze and fix (TAAF) effort
- Accelerated testing (& step-stress)
- Prototypes & lead-the-fleet equipment
- … Weibull library = essential

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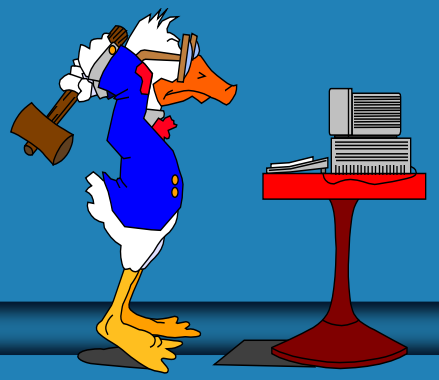
Service & Maintenance Data Analysis



- Reliability Centered Maintenance (RCM)
- Need **good age-to-failure records** on failed items
  - **Failure type is IMPORTANT to know** for corrective action!
- Also need **age on successful items** ("suspensions")
- Warranty: Failure ages known (but suspensions?)
  - Warranty Data Format = Month of Production (M.O.P.) ... vs ... Months in Service (M.I.S.) ... includes suspension info
- Can convert M.O.P.-M.I.S. data to Weibull or C/A data
- **... Weibull library = essential**

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Small Amount of Input Data

- Biggest issue is small amount of input data
- Input data size depends on occurrence count
  - 20 or less occurrences = “small sample”
- Occurrences for Reliability are “failures”
- Low failure count is good for organizations …
- … but bad for analysis!
- Weibayes is best for small data samples
- Weibayes impossible w/o Weibull Library

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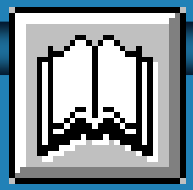
So …
The Most Important Thing Is:



- **The Weibull library.**
- Plan for the future…
- Start and maintain a good Weibull library…
- Save results from every analysis…
  - Type of equipment analyzed
  - Type of usage of analyzed equipment
  - Type of failure under investigation
  - Model type, fit type, parameter values
  - … And other information as appropriate

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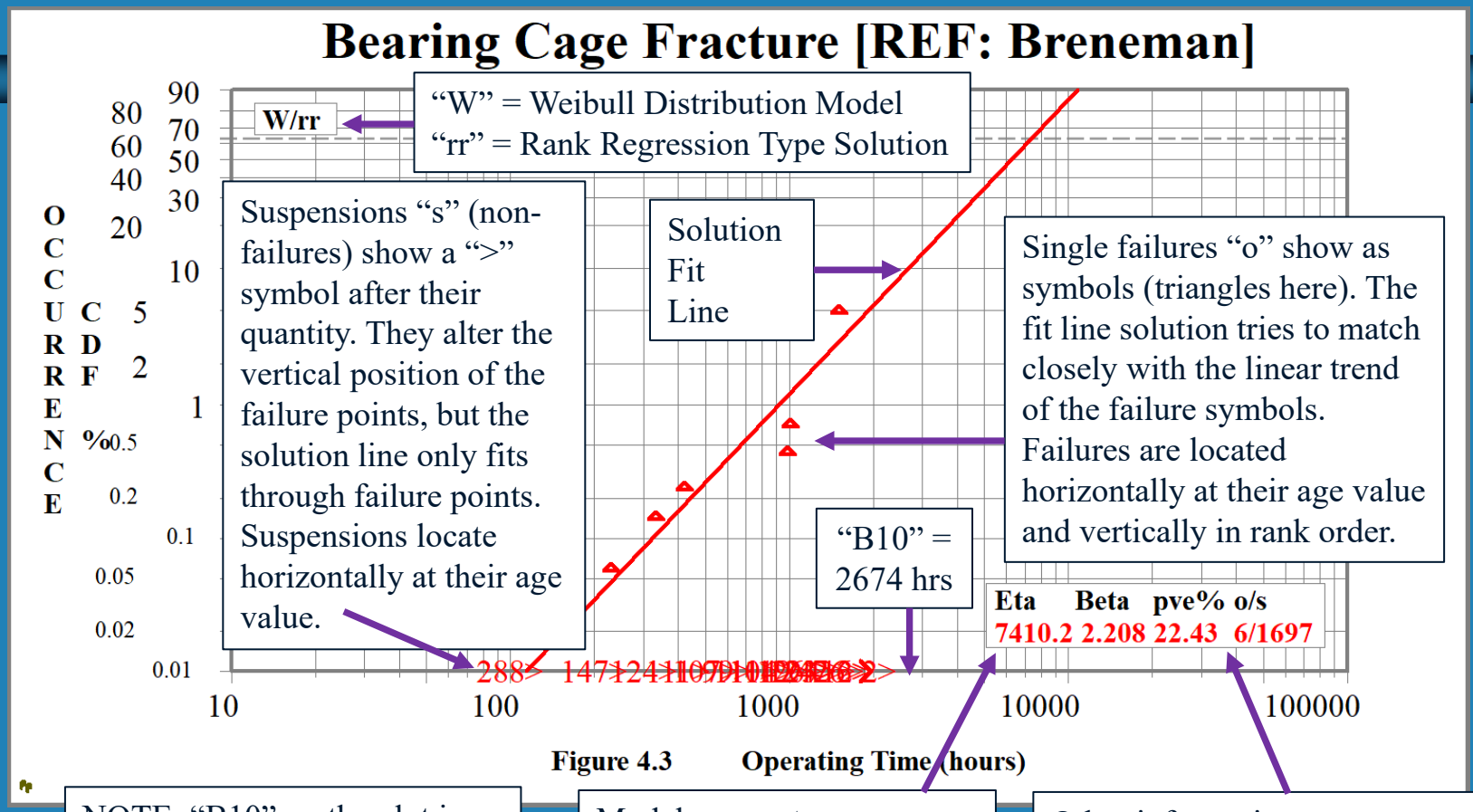
Typical Weibull Plot w/ Answers

For Fighter Aircraft In-Flight Issue



NOTE: "B10" on the plot is the maximum this equipment can age still with failure probability at or below 10%.

Model parameters:
* Eta = Weibull Char. Value
* Beta = Weibull Slope

Other information:
* pve% = Fit Measure (0-100)
* o/s = Data Quantity by Type

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Questions?

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