An Overview of Weibull Analysis

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Introduction

Weibull provides engineers with an understanding of life data analysis. Where aircraft maintenance is concerned, the Weibull plot is extremely useful for maintenance planning, particularly where reliability centred aircraft maintenance is concerned.

Weibull tells the engineer/analyst whether or not scheduled inspections and overhauls are needed.

For wear out failure modes, if the cost of an unplanned failure is much greater than the cost of a planned replacement, there is an optimum replacement interval for minimum cost. Using Weibull failure forecasting, quantitative trade-offs can then be made between:

- Scheduled and unscheduled maintenance,
- Forced retrofit and convenience retrofit,
- Non-destructive inspections versus parts replacement,
- Corrective action versus "do nothing,"
- Different times-between-overhauls (TBO),
- Optimal replacement intervals.

Planned aircraft maintenance has a habit of inducing cyclic or rhythmic changes in failure rates. This 'rhythm' is affected by the interactions between the characteristic lives of the failure modes of the system(s), the inspection periods, and parts replacement.

Where operators of aircraft are concerned, Weibull through reliability reporting also presents commercial as well as technical opportunities. For example good analysis using Weibull can also provide information for warranty purposes, as well as determining life-cycle cost, materials properties and production process control. Early examples of the application of Weibull involved the utilization of the analysis technique by Pratt & Whitney in the mid-50's.

Weakest Link in the Chain Concept

If a part has multiple failure modes, it is recommended that the time to first failure is best modelled by the Weibull distribution. This is called the "weakest-link-in-the-chain" concept, and, works with extremely small samples, even two or three failures for engineering analysis.

This characteristic is important with aerospace safety problems and in development & testing with small samples.

Applications of Weibull Analysis

Typical Applications of Weibull in aviation and aerospace may include the following scenarios:

Scenario 1

An aircraft maintenance engineer reports three failures of a component's in service operations during a three-month period. The Aircraft Maintenance Manager asks,

- How many failures will we have in the next quarter, six months, and year?
- What will it cost?
- What is the best corrective action to reduce the risk and losses?

Scenario 2

To order spare parts and schedule maintenance labour, how many avionics units will be returned to the AMO for overhaul for each failure mode month-by-month next year?

The Aircraft Maintenance Manager wants to be 95% confident that he will have enough spare parts and labour available to support the overall program.

Scope

Weibull Analysis includes:

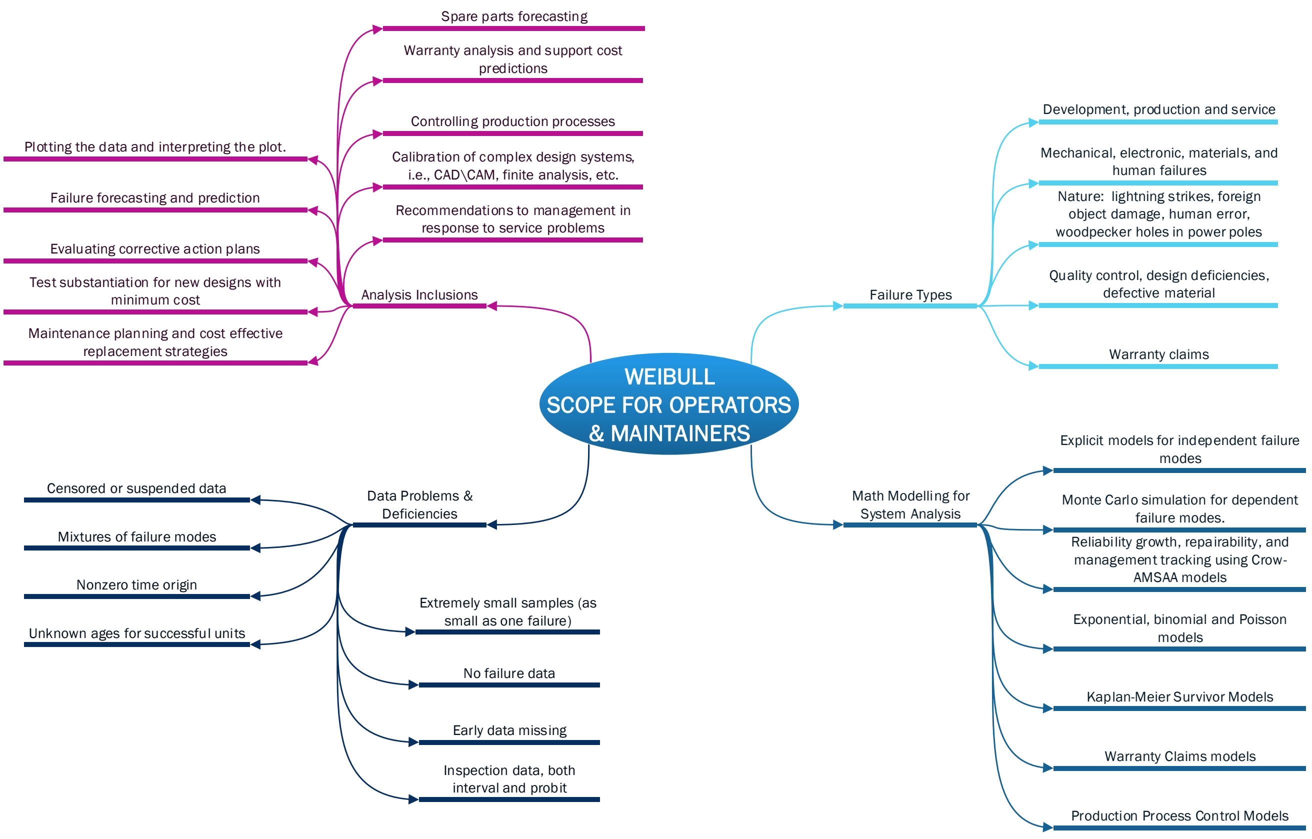

Figure 1 - Weibull Analysis - Scope

Advantages of Weibull Analysis

1. The ability to provide reasonably accurate failure analysis and failure forecasts with extremely small samples.
2. Small samples also allow cost effective component testing.
3. Provides a simple and useful graphical plot of the failure data.
4. Weibull analysis may still be useful even with inadequacies in the data. (Even bad Weibull plots are usually informative to engineers trained to read them.)

Weibull Data Plot - Description

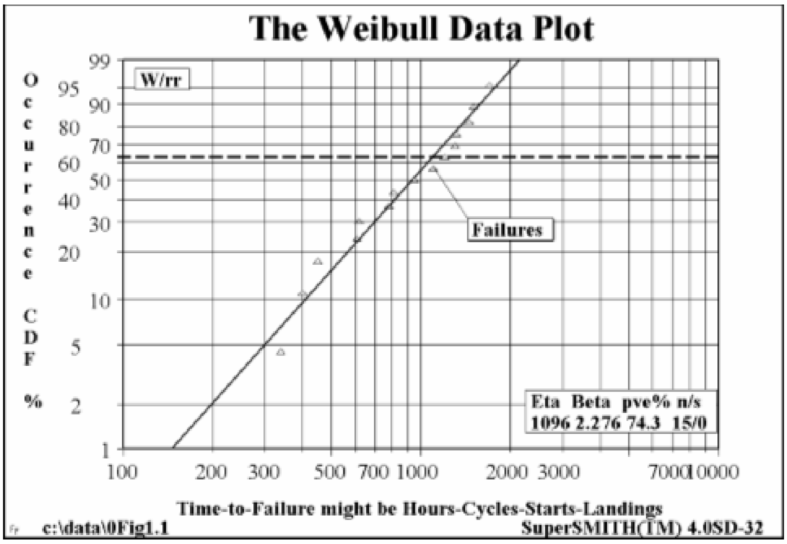

Figure 2 - Typical Weibull Data plot

The horizontal scale is a measure of life or aging. (For example - Start/stop cycles, mileage, operating time, landings or mission cycles).

The vertical scale is the Cumulative Distribution Function (CDF), describing the percentage that will fail at any age.

Reliability = 100 - CDF

The two defining parameters of the Weibull line are:

- The slope, β (beta), and the characteristic life, eta.

- The slope of the line, β, is particularly significant and may provide a clue to the physics of the failure. Not least, the class of failure present:
  - β < 1.0 indicates infant mortality
  - β = 1.0 means random failures (independent of age)
  - β > 1.0 indicates wear out failures

- The characteristic life, η, is the typical time to failure in Weibull analysis.

- It is related to the mean time to failure (MTTF).

Data Requirements for the Ideal Weibull Plot

Ideally,

1. A Weibull plot should depict a single failure mode.
2. Be able to determine failure time precisely. To do this:
    a. A time origin must be unambiguously defined.
    b. A scale for measuring the passage of time must be agreed to.
    c. The meaning of failure must be entirely clear.

3. The age of each part is required, both failed and unfailed.
4. The units of age depend on the part usage and the failure mode.
5. For example, low cycle and high cycle fatigue may produce cracks leading to rupture.
6. The age units 'would be' fatigue cycles.
7. The age of a starter may be the number of starts. Burner and turbine parts may fail as a function of time at high temperature or as the number of cold to hot to cold cycles.

Usually, knowledge of the physics-of-failure will provide the age scale.

When there is uncertainty, several age scales are tried to determine the best fit. This is not difficult with good software.

Remember uncertainty usually indicates the presence of inferior data will increase the uncertainty. Regardless, the resulting Weibull plot may still be accurate enough to provide valuable analysis. *The data fit will tell us if the Weibull is good enough.*

Failure Forecasts and Predictions

When failures occur in service, a prediction of the number of failures that will occur in the fleet in the next period of time is desirable, (say six months, a year, or two years). A typical failure forecast is shown opposite.

Cumulative future failures are plotted against future months. This process provides information on whether the failure mode applies to the entire population or fleet, or to only one portion of the fleet, called a batch.

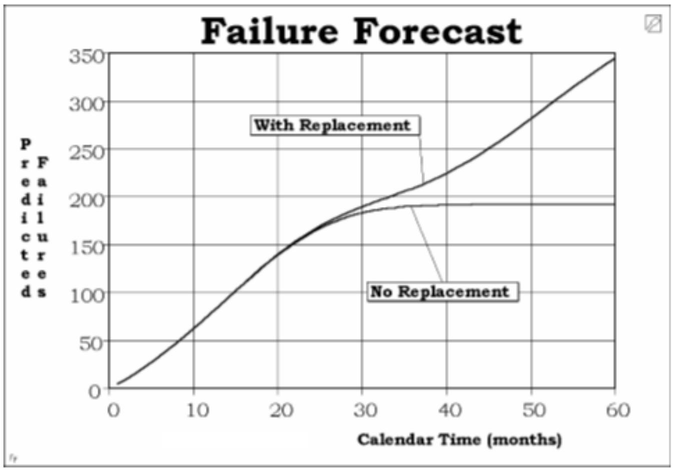

Figure 3 - Failure Forecast

After alternative plans for corrective action are developed, the failure forecasts are repeated.

The decision-maker will require these failure forecasts to select the best course of action, based on the plan with the minimum failure forecast or the minimum cost.

In most cases in aviation, if a part fails it is likely to be replaced with a serviceable item, as such the failure forecast is generally higher than without replacement. In these circumstances, Prediction intervals, (which are analogous to confidence intervals), may be added to the plot.

Establishing the Weibull Line & Choosing the Fit Method

The standard engineering method for establishing the Weibull line is to plot the time to failure data on Weibull probability graphs using median rank plotting positions.

Statisticians, however, prefer an analytical method called maximum likelihood. The likelihood calculations require a computer. Both methods have advantages and disadvantages.

The Weibull distribution usually provides the best fit of life data. This is due in part to the broad range of distribution shapes that are included in the Weibull family. Many other distributions are included in the Weibull family either exactly or approximately, including

- the normal,
- the exponential,
- the Rayleigh, and
- the Poisson and the Binomial.

Remember, that choice of distribution is also dependent on the best fit. Therefore:

- If the Weibull fit is poor, other distributions should be considered.
- The data may be plotted utilizing other forms of probability to determine which distribution best fits the data.

Use of Log Normal

The Log Normal is the best choice for some material characteristics (although not a member of the Weibull family), for crack growth rate, and for non-linear, accelerating system deterioration.

Log Normal & other distributions versus Weibull – Which to choose.

Weibull-Log Normal comparisons are much easier with appropriate software. If there is engineering evidence supporting another distribution, this should be weighed heavily against the Weibull.

Moderate size samples, twenty or more failures, are needed to accurately discriminate between the Weibull and other distributions.

*With less than 20 failures the Weibull is the best choice, and therefore, **best practice**.*