Bulgarian Academy of Sciences. Space Research and Technology Institute.
Aerospace Research in Bulgaria. 34, 2022, Sofia

DOI: https://doi.org/10.3897/arb.v34.e11

IDENTIFYING BATCH PROBLEMS IN AIRCRAFT FIELD RELIABILITY ANALYSIS

Kolyo Kolev, Angel Tanev

Aviation Faculty, Air Force Academy, Dolna Mitropoliya
e-mail: ang_tanev@abv.bg

Keywords: *Aircraft, Aviation safety, Batch problems, Reliability*

Abstract

In practice, a very important task is to monitor the field reliability of aircraft systems, especially the ones related to aviation safety, and to take relevant actions to prevent from potential consequences. Zooming in that task, one can state that a very important step in that analysis is to identify batch problems where the failure mode only affects a subset of the fleet. The Weibull distribution typically provides the best fit of life data obtained either from test or from field. This is due in part to the broad range of distribution shapes that are included in the Weibull family. As well as, there are many other distributions which are included in the Weibull distribution's family either exactly or approximately- for example, the normal, the exponential, the Rayleigh, and sometimes the Poisson and the Binomial. This paper presents a practical approach for those aviation professionals dealing with monitoring and analyzing the aircraft field reliability.

Introduction

Weibull distribution has been invented by Waloddi Weibull in 1937. His statement was that this distribution can be applied to a large variety of engineering problems. And, on other hand, his first experience showed that it had not always worked. In fact, history has shown that Waloddi Weibull was correct in both of these statements [10]. The author found a very important advantage that the Weibull method works with extremely small samples, even two or three failures for engineering analysis (in engineering practice such situation often happens). This characteristic is important and very useful in different domains including aerospace safety problems and in development testing with small samples (one should note that, for statistical relevance, larger samples are needed). In aircraft operation, the presence of defects and occurrence of failures may have a potential impact on flight safety. Today, with the increasing number of flight objects (e.g. unmanned aerial vehicles), the problem with the operational reliability becomes even more complex [12–14], especially for batch issues identification and detection [16–18].

Theoretical Background

From the reliability engineering theory [1, 2], it is well-known that a product/component failure rate often exhibits 3 periods in the usage/field (Fig. 1).

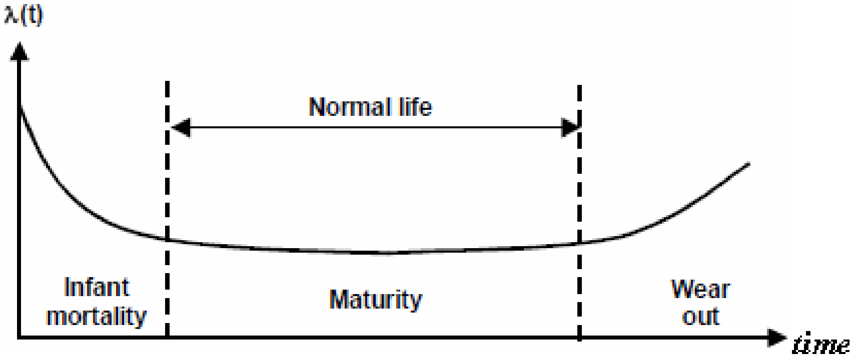

Fig. 1. Failure rate over product/component lifetime

One of the most flexible distributions which may adequately describe the bathtub curve (Fig. 1) is the Weibull distribution. Let's review some of the most basic characteristics of the Weibull distribution. Suppose the random variable *X* has Weibull distribution with scale parameter and shape parameter. The Weibull probability density function is defined by the following expression [5–9]:

(1) $$f(t) = \frac{\beta t^{\beta-1}}{\alpha^{\beta}} exp\left(-\left(\frac{t}{\alpha}\right)^{\beta}\right), t \geq 0,\ \ \alpha, \beta > 0$$

where: the two defining parameters of the Weibull line are:

- The slope, β (beta: shape parameter), and the characteristic life, alpha (scale parameter, where 63.2% of cumulative failures will occur up to this point).

The slope of the line, β, is particularly significant and may provide an idea about the physics of the failure [3, 4]. From bathtub's point of view, the failure classes present can be split to the following 3 regions (see Fig. 1):

- $\beta < 1$ indicates "infant mortality" (e.g. process issues)
- $\beta = 1$ indicates "random failures" (independent of age; e.g. overstress failures)
- $\beta > 1$ indicates "wear out" failures (e.g. capacitance/resistance drift).

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

Therefore, the failure behavior of a risk system is described by several equally suitable functions: the cumulative distribution function $F(t) = P(T \leq t)$, the Survival function $R(t) = 1 - F(t)$ or failure rate function $\lambda(t)$ [1, 6, 15]. The rate at which failures occur in the interval t_1 to t_2, the failure rate $\lambda(t)$, is defined as the ratio of probability that failure occurs in the interval, given that it has not occurred prior to t_1, the start of the interval, divided by the interval length [7]. Therefore, it is expressed by:

(2) $$\lambda(t) = \frac{R(t_1) - R(t_2)}{(t_1 - t_2)R(t_1)}$$

The Weibull model used for the failure rate modelling is as follows [8]:

(3) $$\lambda(t) = \frac{\beta t^{\beta - 1}}{\alpha^{\beta}}$$

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 [10]. Many other distributions are included in the Weibull family either exactly or approximately, including:

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

One should remember that the choice of distribution is also dependent on the best fit [9]. Therefore, in practice the analyst should follow these rules of thumbs:

- 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.

Methods

In practice, identifying batch problems can be done by applying the following batch analysis methods [11]:

1. Compare Beta MRR (Median Rank Regression) with MLE (Maximum Likelihood).

- MLE Beta is normally steeper (the MLE Bias for small sample-size). If a Batch issue is present, then the MLE Beta will be lower than MRR Beta.

2. Present Risk, calculated on 90% Lower Confidence, should be lower than your current number of defects.
   - If 90% Lower Risk is higher than the Real number of Defects, then this would be a Batch indication
3. The actual number of defects is smaller than the expected number of failures.
   - Aggregated Cumulative Hazard (ACH) plot should show the percentage of the population that is affected by the failure-mode – the Batch size.
4. Other Batch indication clues:
   - Relatively large number of late suspensions; only the youngest units fail.
   - Steep slope followed by shallow.
   - Close serial numbers of the failures.
   - All failures from one supplier (of the multiple suppliers for this unit).
   - All defects after start-up of full production or in a certain timeslot.
   - All failures at one customer/one country.

Practical Application

Next, for our further example showing the practical application of the proposed batch analysis approach, we will focus on the application of the first method- Compare Beta MRR (Median Rank Regression) with MLE (Maximum Likelihood Estimation). For more information on the estimation methods [6, 10].

In our example, we are considering a seal defect with failures and suspensions gathered from the field observations (such seal failure may cause an oil leakage leading to an aircraft oil pollution, cabin odor or visible smoke with the use of bleed air and this might have a potential impact on flight safety). The case study we are considering is the following: the age of the seals is measured in weeks, the total failures number is 10 and the suspensions are 25634. As only the youngest seals are failing, it is suspected that something has recently changed in production. If this is the truth, we might only have a part of the total population that is infected with this “virus”, so the damage will be limited. The defects are summarized in the following format: Failures number vs Time-to-Fail (weeks) and are shown in the table below:

Table 1. Seal Defects vs Time-to-Fail (weeks)

Seal defects	
Time-to-Fail(weeks)	Failures number
14	1
15	1
15	1
20	1
21	1
25	1
26	1
27	1
31	1
31	1
Total	10

Running the analysis by means of specialized software tool, first we create an Occurrence CDF (cumulative distribution function) plot for the two slopes based on MRR (Median Rank Regression) and MLE (Maximum Likelihood Estimation) methods:

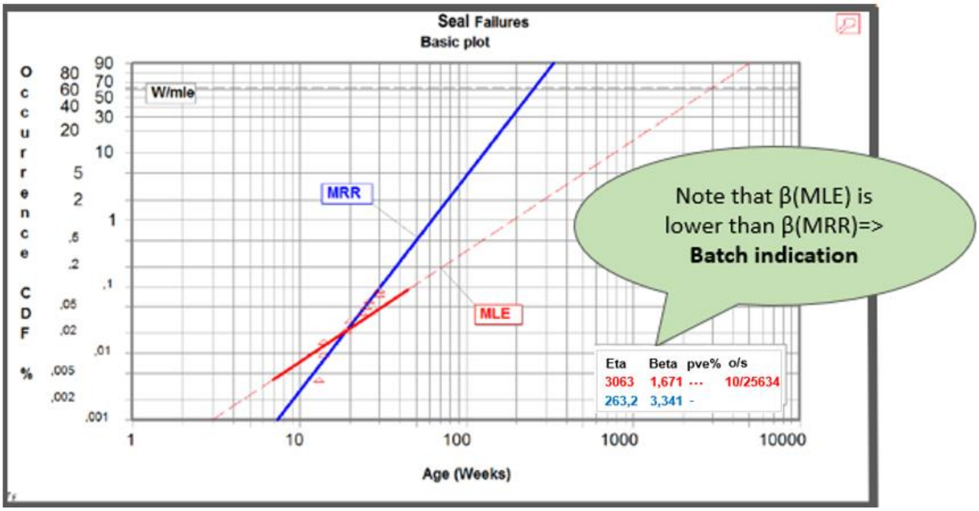

Fig. 2. Occurrence CDF[%] vs Age(weeks)

The analysis clearly shows that the slope related to MLE method is lower than the MRR method (see Fig. 2). Another useful plot: creating a histogram “Quantity vs Age (weeks)” which can confirm the presence of batch issue by plotting the presence of many late suspensions (Fig. 3).

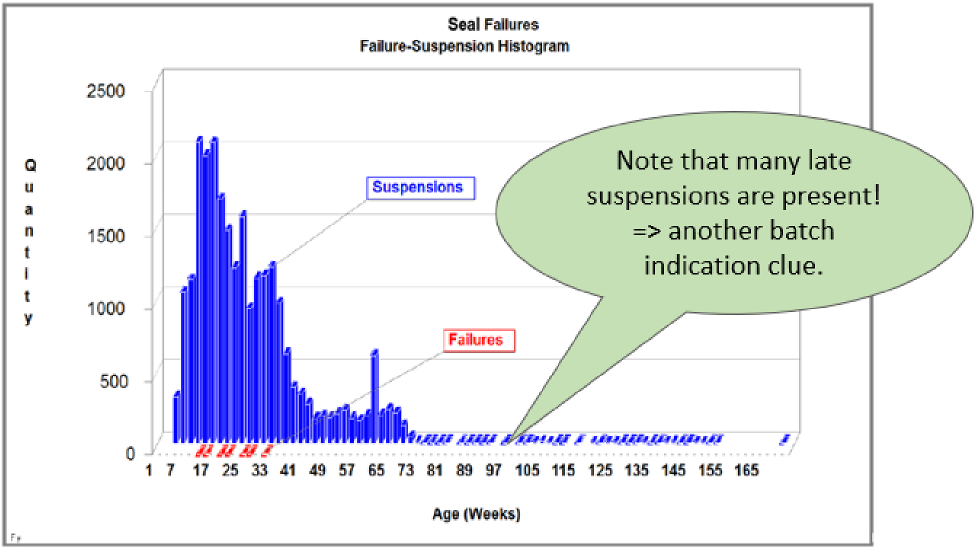

Fig. 3. Quantity (Failures+Suspensions) vs Age(weeks)

In our analysis, the early failures occurrence driven by batch issue has been analyzed and confirmed by the two different methods which are very useful in practical applications.

Conclusion

The following major outcomes can be summarized based on the performed aircraft field reliability engineering analysis:

- In practice, very often problems (e.g. early failures) can be associated with batch issues.
- As a first action, one needs to allocate the batch, find the root-cause and create a solution for the fielded units and the current production.
- After allocating the batch, create a new Weibull analysis plot and then create a failure forecast for the batch only.

References

1. MIL-HDBK-338B, (1998), Electronic Reliability Design Handbook.
2. MIL-HDBK-217, (1995), Electronic Reliability Prediction Handbook.
3. IEC 62380, (2003), Electronic Reliability Prediction Handbook.
4. FIDES. (2009), Electronic Reliability Prediction Handbook.
5. Kapur, K., L. Lamberson. *Reliability in Engineering Design*. John Wiley & Sons, New York, 1977.
6. Birolini, A. *Reliability Engineering: Theory and Practice*. Springer-Verlag, 2008.
7. Pham, H. *Handbook of Reliability Engineering*. Springer edition, 2003.
8. Nakagawa, T. *Maintenance Theory of Reliability*. Springer edition, 2005.
9. Gindev, E. *Introduction of Reliability Engineering, Part 1*. “M. Drinov” Academic publishing house, Sofia, 2000.
10. Abernethy, R. *The New Weibull Handbook: Reliability and Statistical Analysis for Predicting Life, Safety, Supportability, Risk, Cost and Warranty Claim, 5th ed.* 2006.
11. Schop, R. Reliability Engineering Life Data Analysis using the Weibull distribution. *PLOT Seminar*, October 2008.
12. Valchinov, I., D. Valchinova, G. Mardirossian, S. Zabunov. The unmanned aviation system for radiation intelligence, aerogamma scanning and mapping. *Proceedings SES 2018*, pp. 420–422, Sofia. (In Bulgarian).
13. Zafirov, D., W. Bo, P. Getsov. Impact of the choice of parameters on an electric multi-rotor unmanned aerial vehicles on their main flight characteristics. *Proceedings SES 2020*, pp. 99–102, Sofia (In Bulgarian).
14. Getsov, P., W. Bo, S. Zabunov, G. Mardirossian. Innovations in the area of unmanned aerial vehicles. *Aerospace Research in Bulgaria*, vol. 29, pp. 111–119, 2017, Sofia.
15. Petrov, N. I. *Reliability’s Investigations of Risk Technical Systems*. Trakia University, Publ. House “Uchkov”, 2nd ed., Bulgaria, 2007.
16. Lee, R., J. Yip, V. Shek. *Knowledge Risk and its Mitigation: Practices and Cases*. Emerald Publishing Limited, 2021.
17. Carroll, T. The Fallacy of MTBUR & MTBF as Reliability Metrics. *DoD Maintenance Symposium*, 25 Oct. 2005.
18. Australian Transport Safety Bureau (ATSB), Aircraft Reciprocating-Engine Failure: An Analysis of Failure in a Complex Engineered System, Transport Safety Investigation Report, 2007.

ИДЕНТИФИЦИРАНЕ НА ПРОБЛЕМИ С ПАРТИДА ПРИ АНАЛИЗ НА ЕКСПЛОАТАЦИОННАТА НАДЕЖДНОСТ НА АВИАЦИОННА ТЕХНИКА

К. Колев, А. Танев

Резюме

В авиационната практика много важна задача е да се следи надеждността на системите на въздухоплавателните средства, особено тези системи, свързани с безопасността на полета, и да се предприемат съответни действия за предотвратяване на потенциални последици. Навлизайки в дълбочина може да се каже, че много важна стъпка в този анализ е да се идентифицират партидни проблеми, при които отказът засяга само една част от авиационната техника. Разпределението на Вайбул обикновено осигурява най-доброто съгласуване на данните за живота на компонентите, получени от провеждане на тест или от експлоатацията. Това се дължи отчасти на широката гама от форми на разпределения, които са включени в семейството на Вайбул. Също така, има много други разпределения, които са включени в семейството на разпределението на Вайбул, точно или приблизително – например, нормалното, експоненциалното, Релей, а понякога и Поасоновото, и биномиалното. Тази статия представя практически подход за онези авиационни специалисти, които се занимават с мониторинг и анализ на надеждността на авиационна техника.