Analysis of air conditioning system failures in Boeing aircraft

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AIR CHECK CONSULTING

OUTLINE

01

Inhomogeneous Poisson process (IPP)

1- The IPP is a mathematical model used to count failures over time

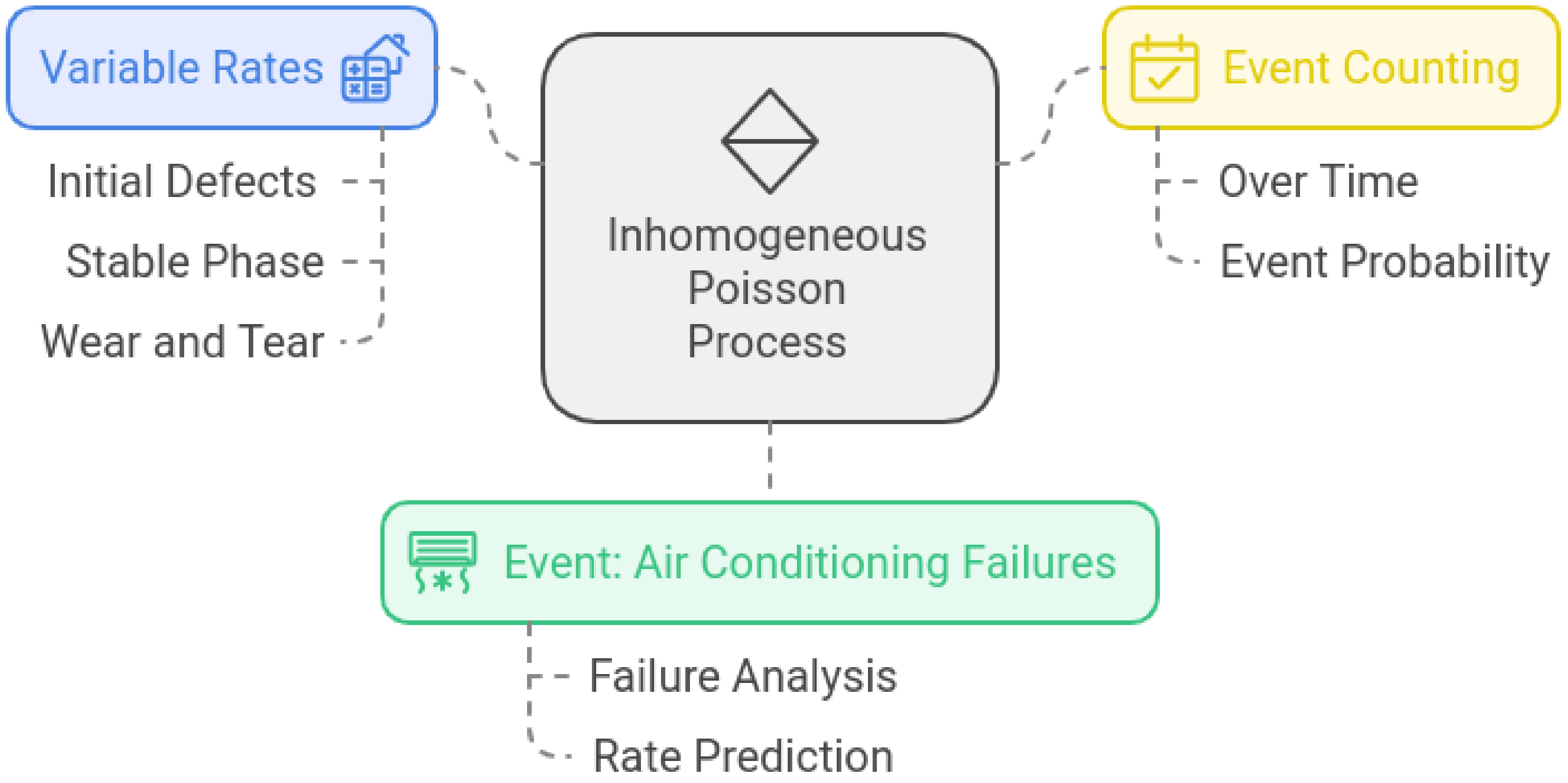
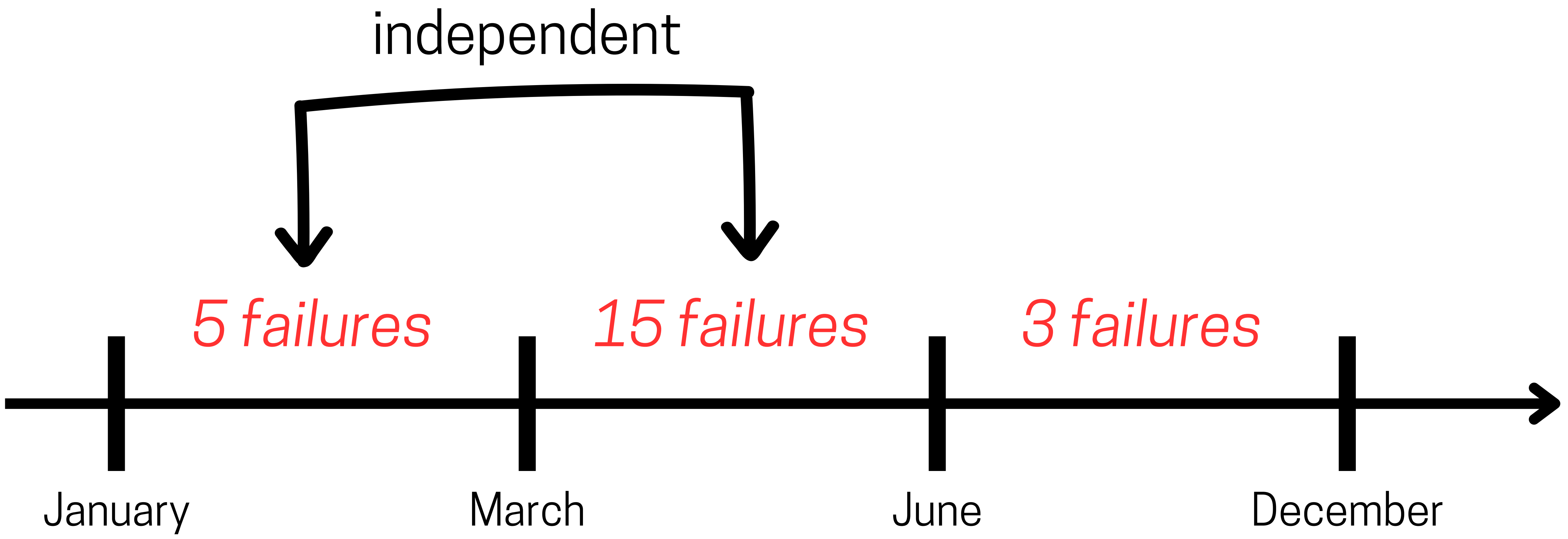


Figure 1: Illustration of an IPP

01

Inhomogeneous Poisson process (IPP)

2- We suppose that we have independent events



01

Inhomogeneous Poisson process (IPP)

3- The intensity function λ(t) is time varying

What is the intensity λ(t)?

λ(t): Measure of the instantaneous risk of failure at a given time t.

Air conditioning system failure factors:

- Operational conditions
- Maintenance
- Wear and tear

$\Leftrightarrow$

Figure 2: Hazard rate of a system over time

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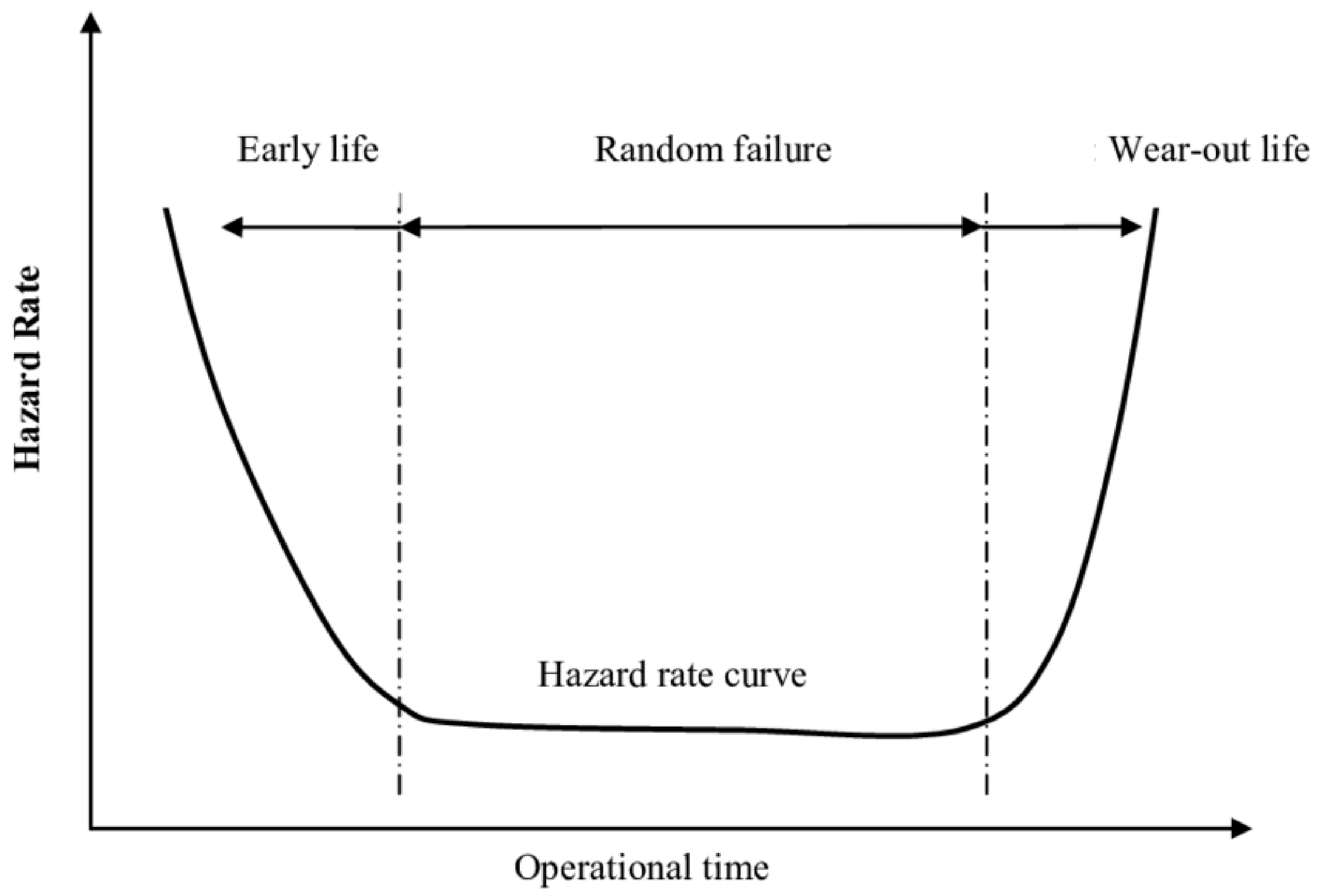


Figure 2: Hazard rate of a system over time

02

Weibull process

1- The Weibull process is a specific IPP

Definition

The Weibull process is an inhomogeneous Poisson process that features independent events and a time-varying intensity.

Intensity formula

$$\lambda(t) = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1}, \quad \alpha > 0 \quad \& \quad \beta > 0$$

- t: time
- α: scale parameter
- β: shape parameter

Use case

- Reliability Engineering: Models failure rates of systems as they age.
- Predictive Maintenance: Forecasts equipment breakdowns for optimized scheduling.
- Product Lifecycle: Evaluates failure trends in products over time.

02

Weibull process

2- The scale parameter α controls the time scale of the intensity process

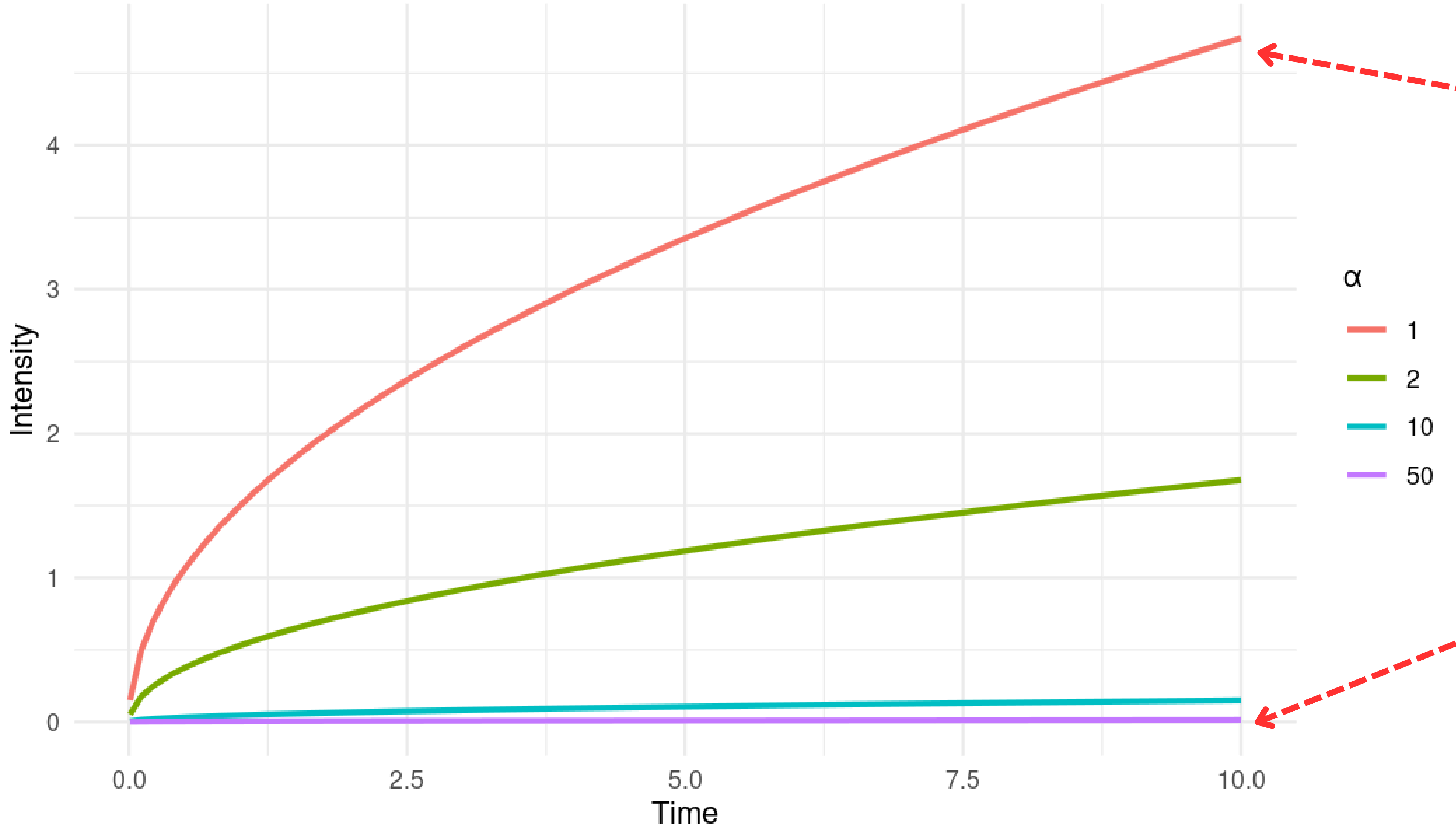


Figure 3: Weibull intensity for differents α and β = 1.5

Interpretation

- Smaller α: Compresses the time scale
  - less reliable system with faster failure occurrences.

- Larger α: Stretches the time scale
  - more robust system with failures spread over a longer period

→ Reflects the expected durability or wear-out rate of components

02

Weibull process

3- The shape parameter β determines the distribution's form

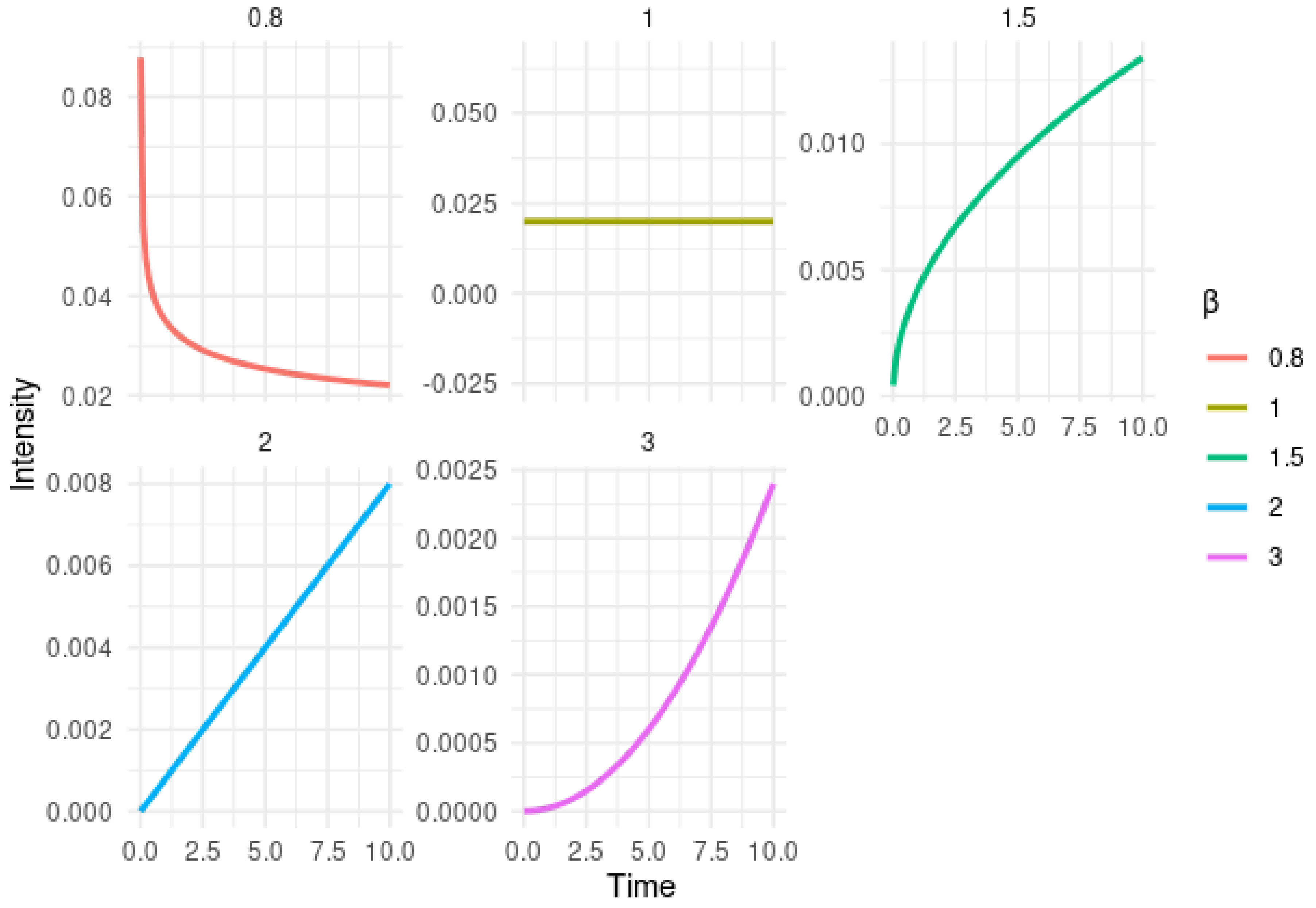


Figure 4: Weibull intensity for differents β and α = 50

Interpretation

- β < 1: intensity function decreases over time
  - Burn-in phase
- β = 1: intensity function is constant = 1/α
  - Operational phase
- β > 1: intensity function increase
  - Wear-out phase

→ Reflects the evolution of the failure rate of a product or system over its entire lifespan.

02

Weibull process

4- The parameters are estimated with Maximum Likelihood Estimator

Parameter estimation

Determine the values of α and β to:

- understand the failure behavior of a system
- predict its reliability over time
- plan appropriate maintenance or replacement strategies

Likelihood function

Mathematical expression that represents the probability of observing the given data as a function of the model's parameters

Maximum Likelihood Estimator (MLE)

Measures how likely it is to observe the given data

Estimator of α

$$\log(\hat{\alpha}) = \log(t) - \frac{1}{\hat{\beta}}\log(N(t))$$

Estimator of β

$$\frac{1}{\hat{\beta}} = \log(t) - \frac{1}{N(t)}\sum_{i=1}^{N(t)}\log(T_i)$$

03

Analysis of Boeing data on air conditioning failures

1- The data represents the time between failures

13 aircrafts

Each column represents a Boeing aircraft

Each row represents the amount of time between failures

Focus on 3 aircrafts (B09, B12, B13) as they contain the most data.

Table 1: Sample of Boeing dataset

B07	B08	B09	B10
194	413	90	74
15	14	10	57
41	58	60	48
29	37	186	29
33	100	61	502
181	65	49	12
	9	14	70
	169	24	21
	447	56	29
	184	20	386
	36	79	59
	201	84	27
	118	44	
	34	59	153
	31	29	26
	18	118	326

03 Analysis of Boeing data on air conditioning failures

2- Aircraft B09 is in early life phase

Many failures at the beginning, then it settles down.

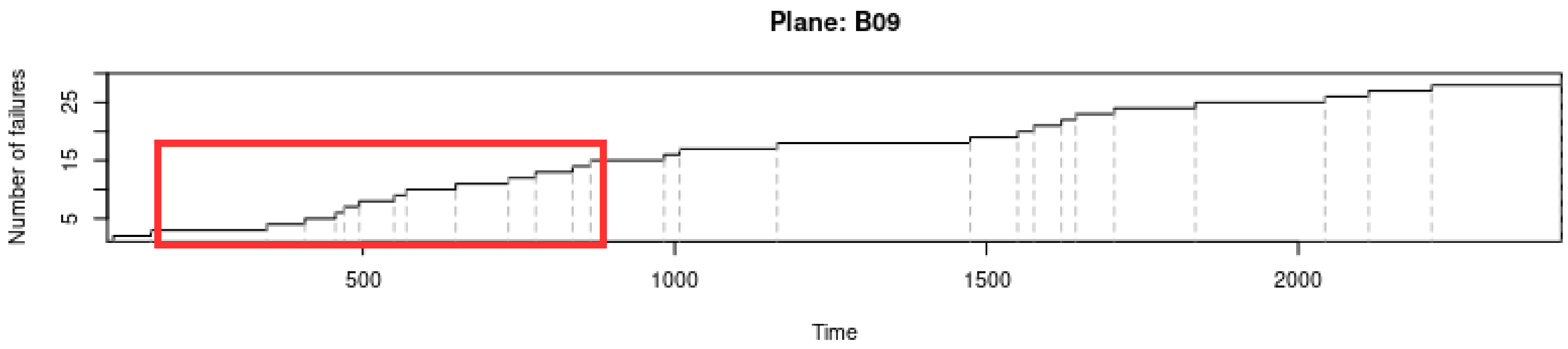
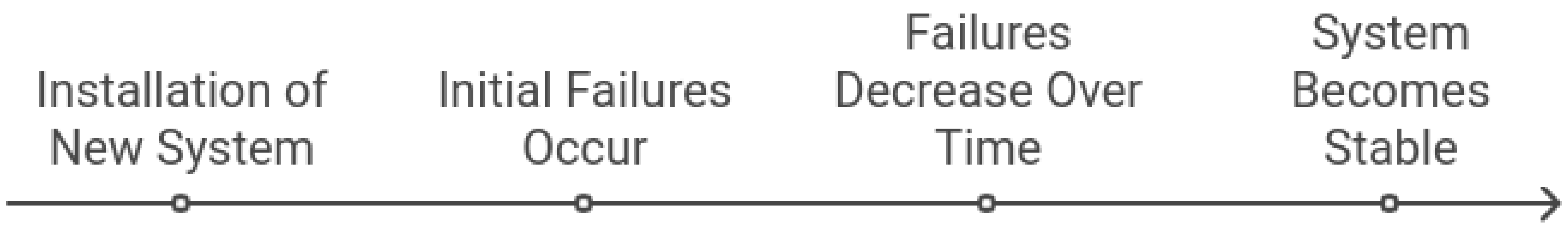
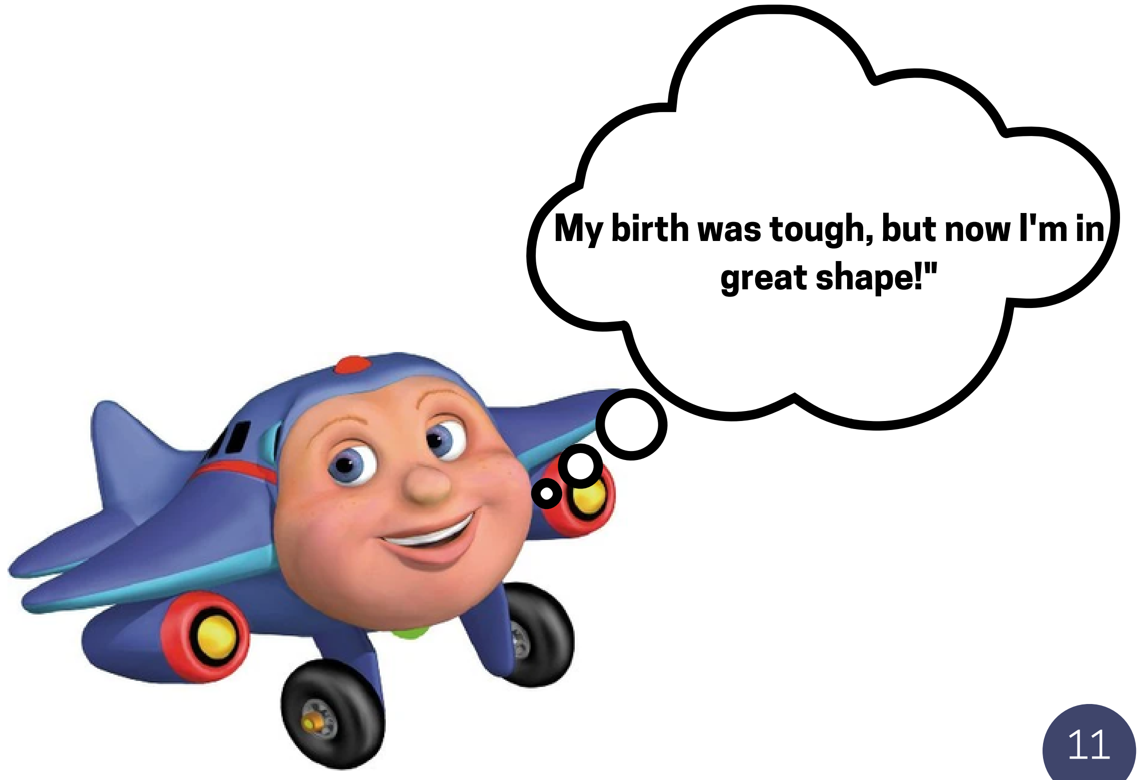


Figure 5: Cumulative failures of B09 air conditioning





03 Analysis of Boeing data on air conditioning failures

3- Aircraft B13 is in operational phase

Everything is running smoothly; it's stable.

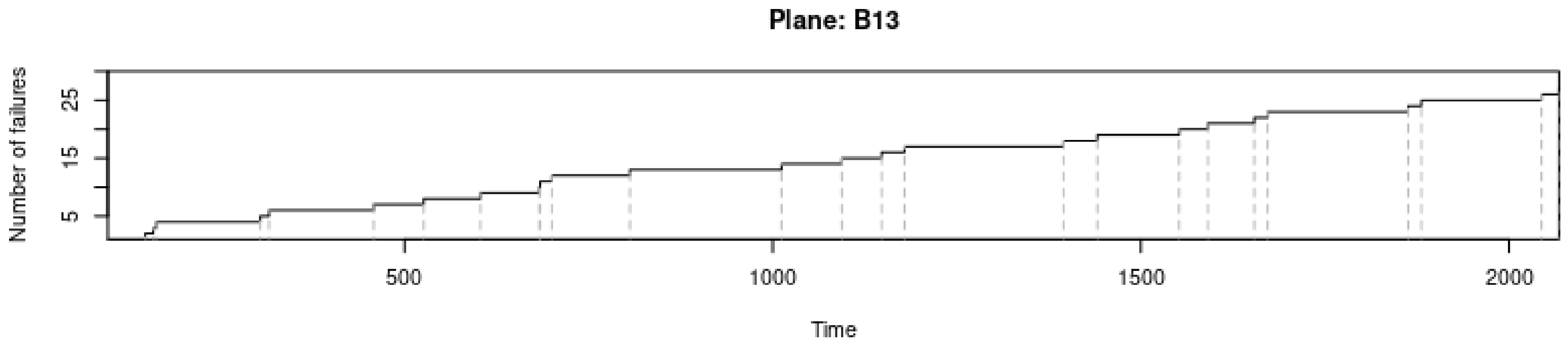
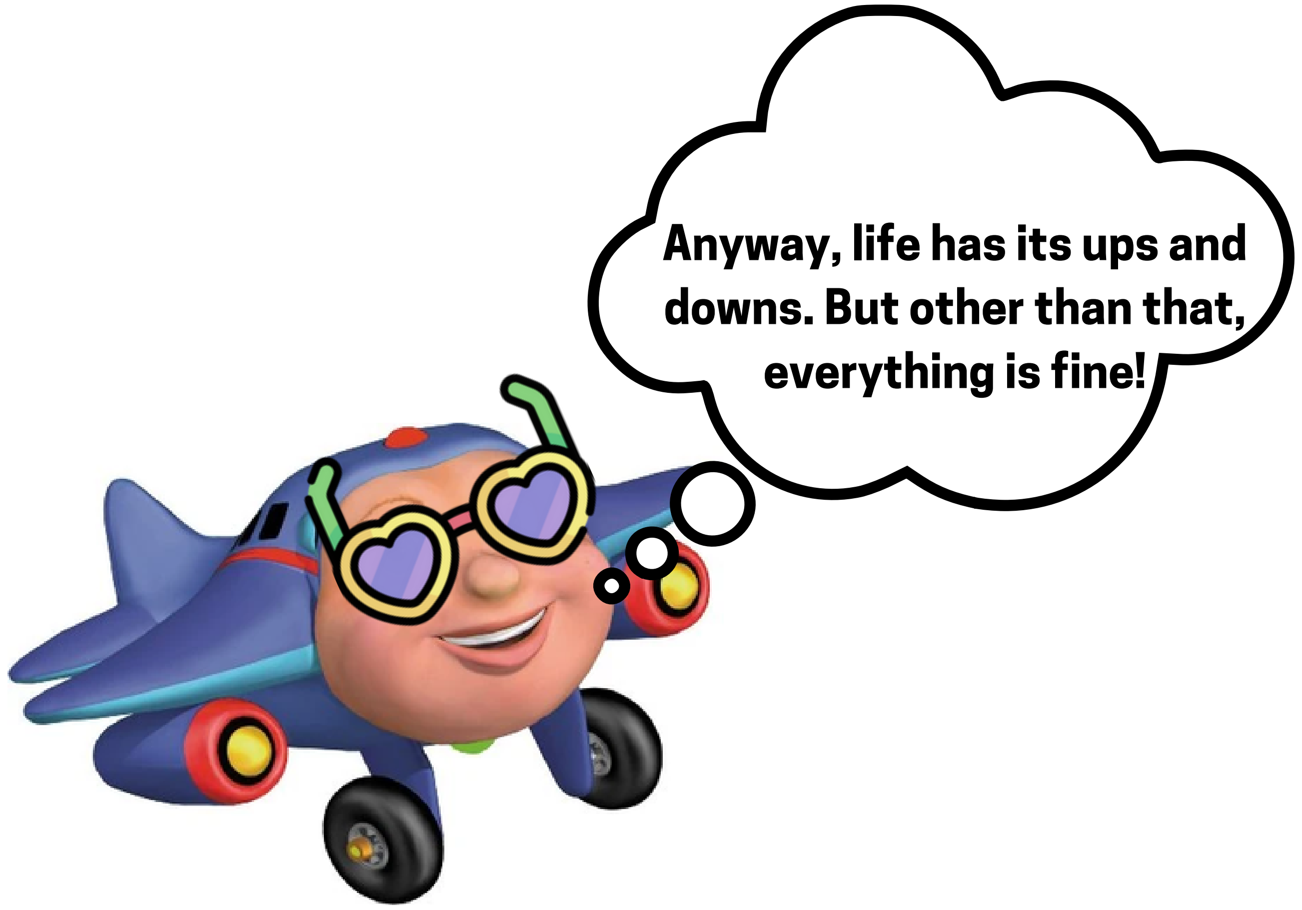


Figure 6: Cumulative failures of B13 air conditioning



Operational stability:

- Regular maintenance
- Robust design

Failure patterns:

- Consistent failures
- Few surprises

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4- Aircraft B12 is in bad condition

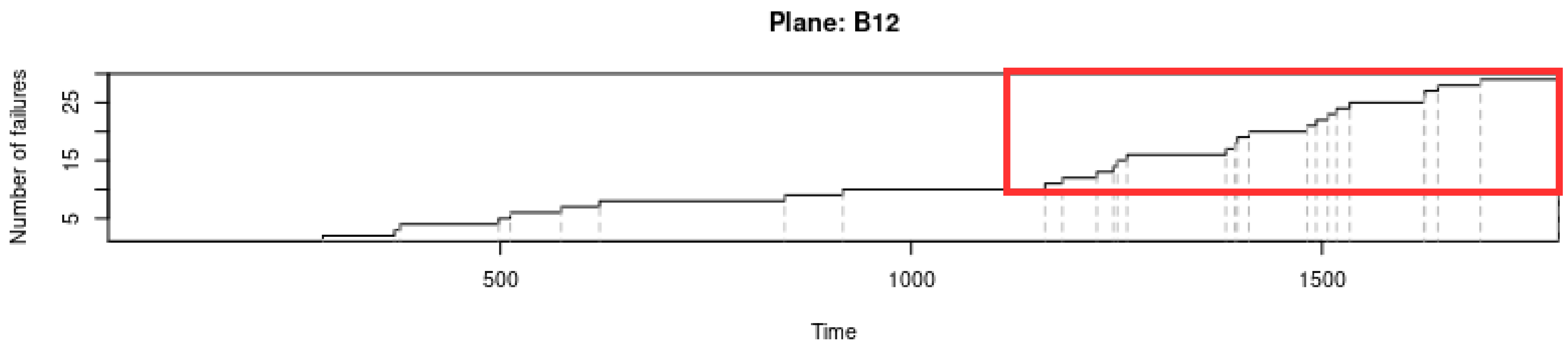
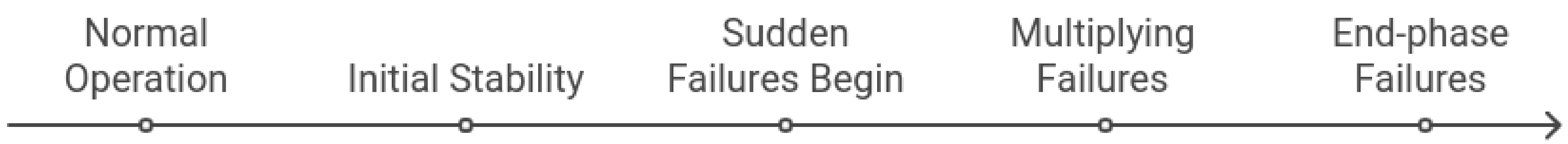
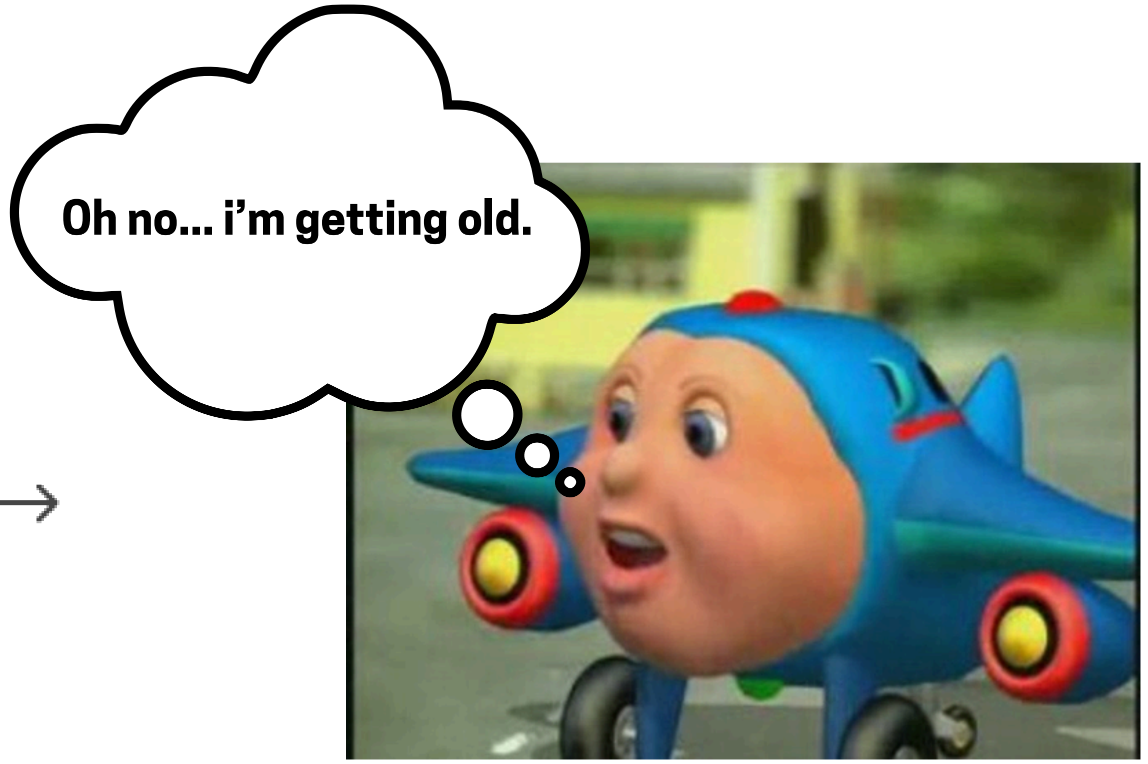


Figure 7: Cumulative failures of B12 air conditioning

Calm periods followed by major issues toward the end.





Analysis of Boeing data on air conditioning failures

5- The parameter estimations confirms our first hypothesis

Interpretation

- B09 (α = 57.62, β = 0.9): Early failures but stabilizes over time
- B12 (α = 186.85, β = 1.51): Requires more maintenance
- B13 (α = 72.94, β = 0.99): Remains relatively stable with moderate failure distribution

→ The differences in α highlight the varying time scales over which these systems fail.

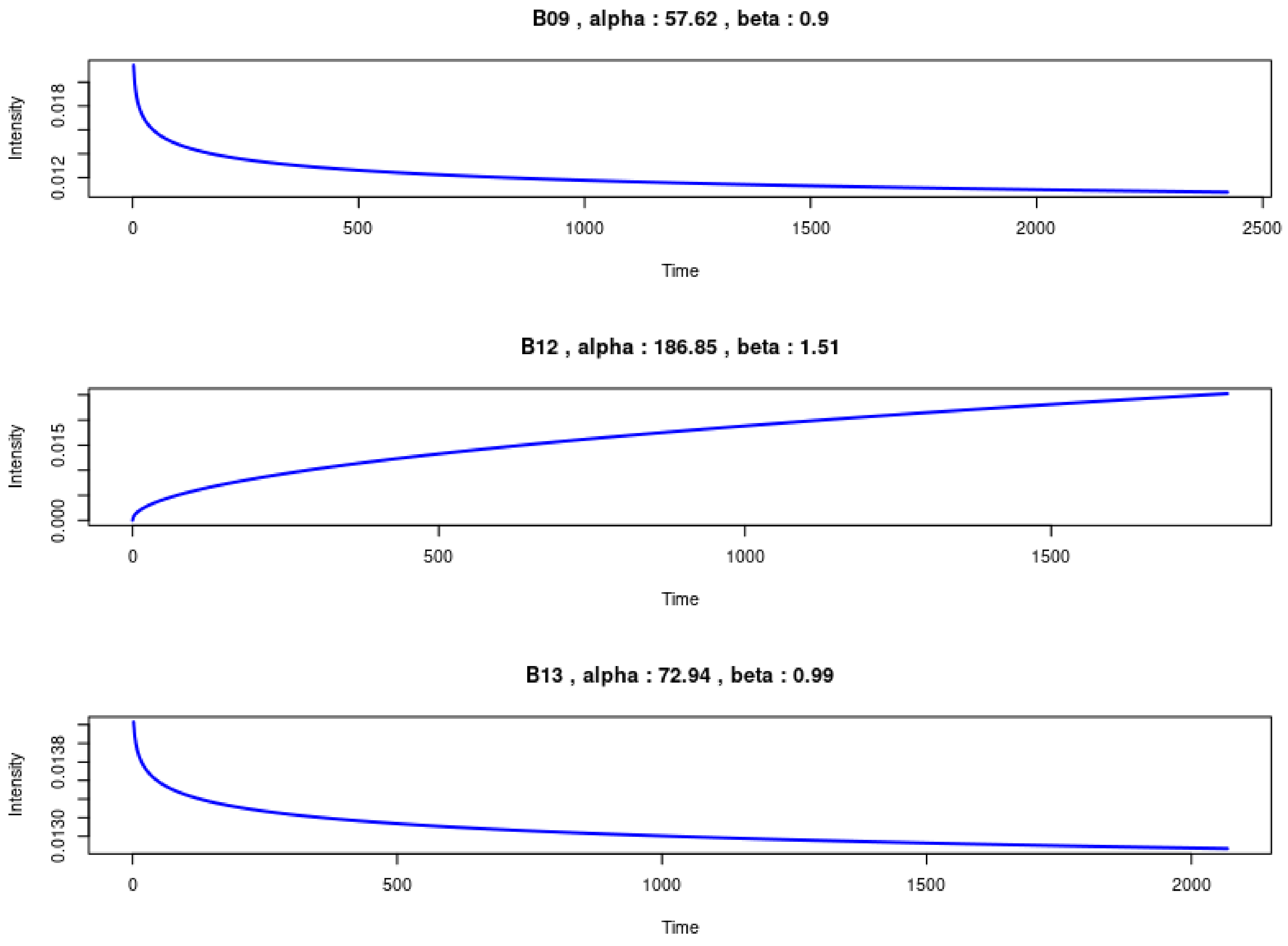


Figure 8 : Weibull intensity with estimated parameters

04

Analysis of Boeing data on air conditioning failures

1- Some planes have undergone major repairs

Major overhaul

Complete inspection and restoration of critical aircraft components to ensure safety and compliance.

EASA European Aviation Safety Agency

Federal Aviation Administration

We take into account a major overhaul for the aircrafts B08 and B09.

Can we evaluate the efficiency of the repairs through the Weibull process analysis?

Analysis of Boeing data on air conditioning failures

2- For B08, the overhaul doesn't improve the system reliability

In 1/5 of the time: same number of failures as before the overhaul

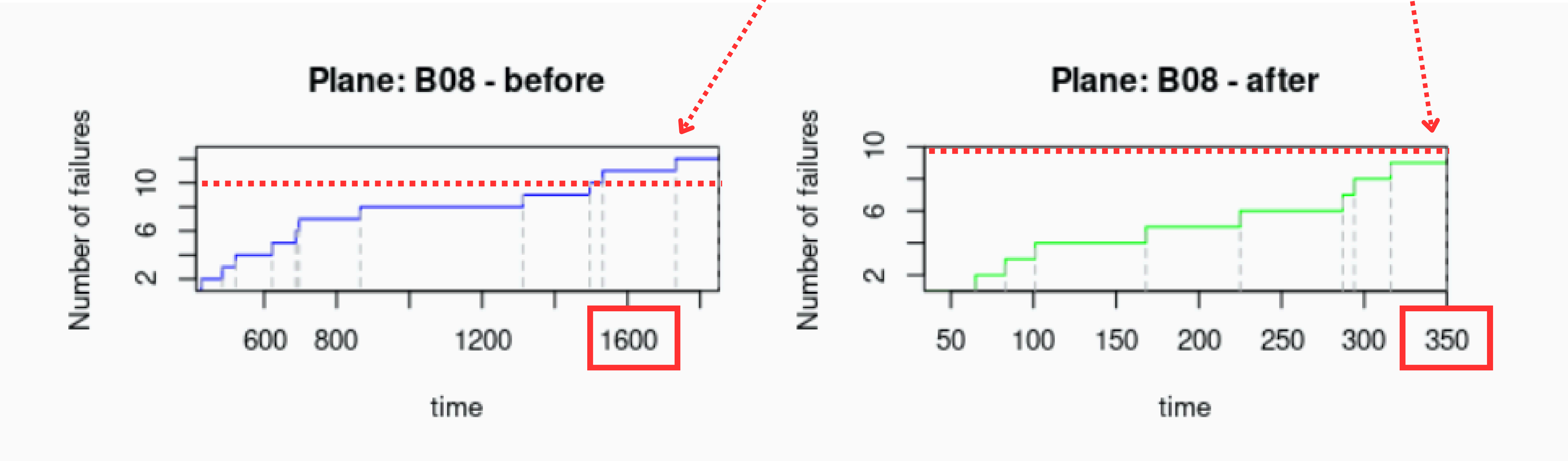


Figure 9 : Cumulative number of failures before and after a major overhaul over time for plane B08

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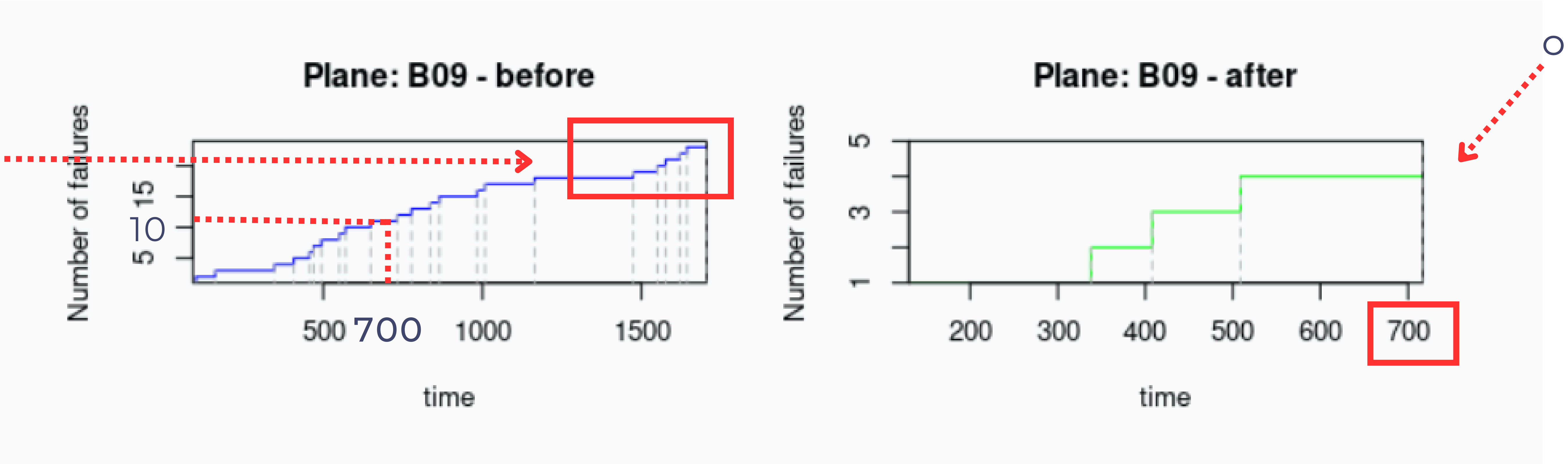
3- For B09, the overhaul improves the system reliability

Peak of failures over a short amount of time right before the overhaul



Only few failures

Figure 10 : Cumulative number of failures before and after a major overhaul over time for plane B09

04

Analysis of Boeing data on air conditioning failures

4- Numerical verification for B08

Before Repair	After Repair
α=247.17, β=1.27	**α=51.2 β=1.2**
Typical behavior of a system experiencing **wear and aging**.	**Failures occur faster post-repair.**

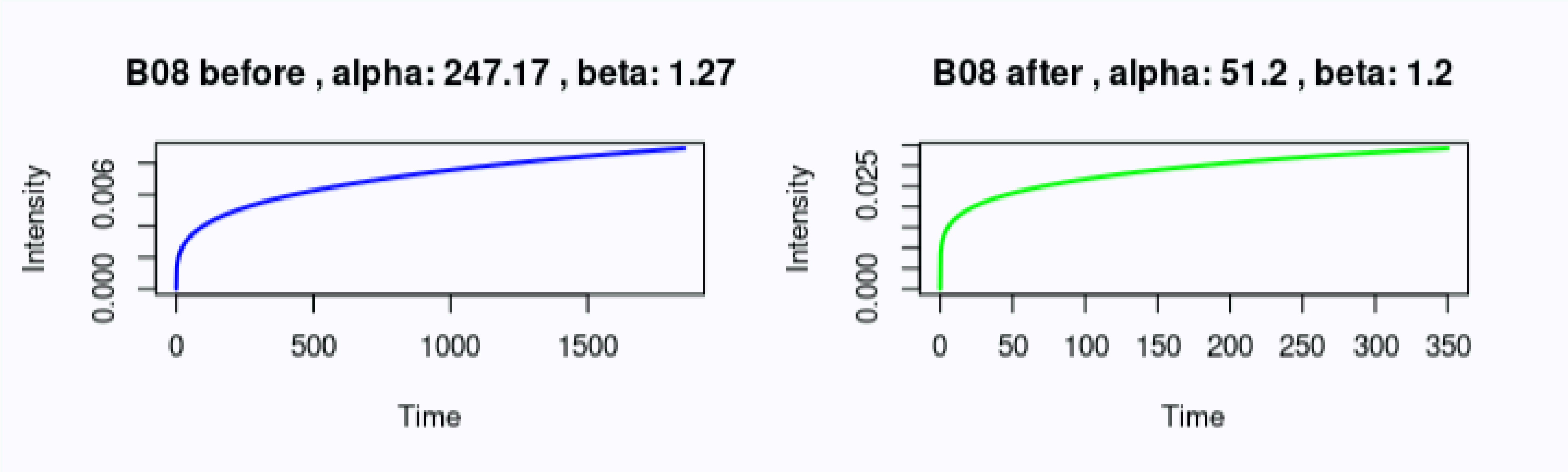


Figure 11 : Weibull intensity with estimated parameters

04

Analysis of Boeing data on air conditioning failures

5- Numerical verification for B09

Before Repair	After Repair
α=80.06, β=1.04	**α=242.65 β=1.49**
Failure rate remains **stable with minimal degradation**.	Repair **stabilized** system **temporarily**, but accelerated degradation follows.

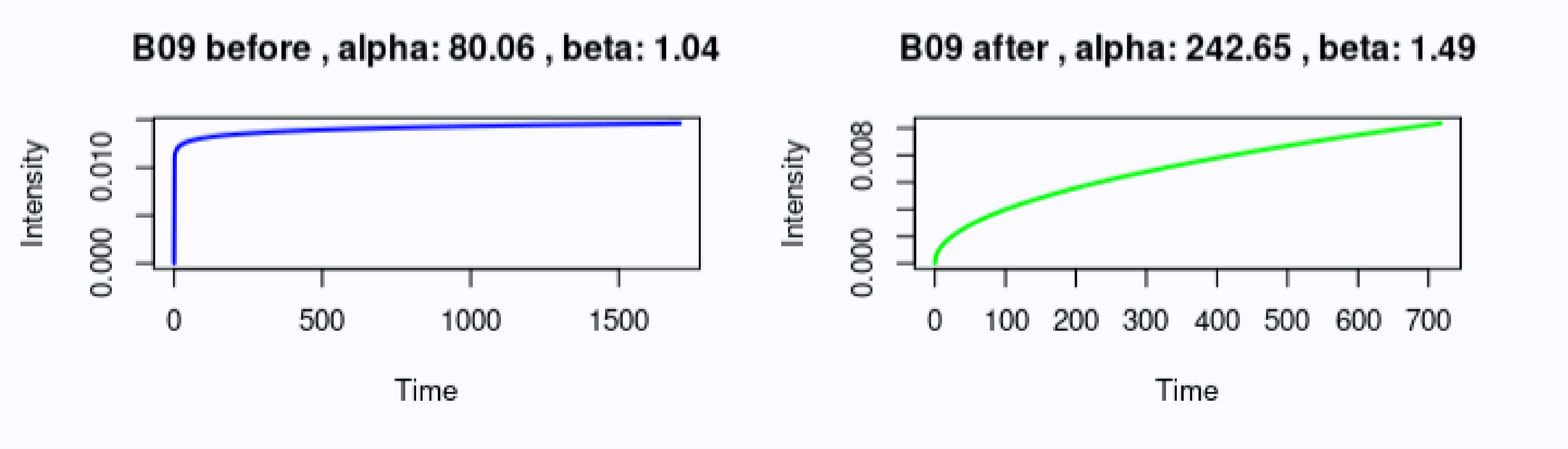


Figure 12 : Weibull intensity with estimated parameters

05

Why partnering with us is the right choice ?

What we achieved:

- apply a mathematical approach to model an industrial system
- analyze air conditioning system's lifecycle to predict failures

By working with us you will get:

- unparalleled expertise
- proven reliability
- commitment to delivering solutions that enhance safety

CONTACTS

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