31st Annual INCOSE international symposium

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You Don’t Save Money by Doing Less Testing – You Save Money by Doing More of the Right Testing!

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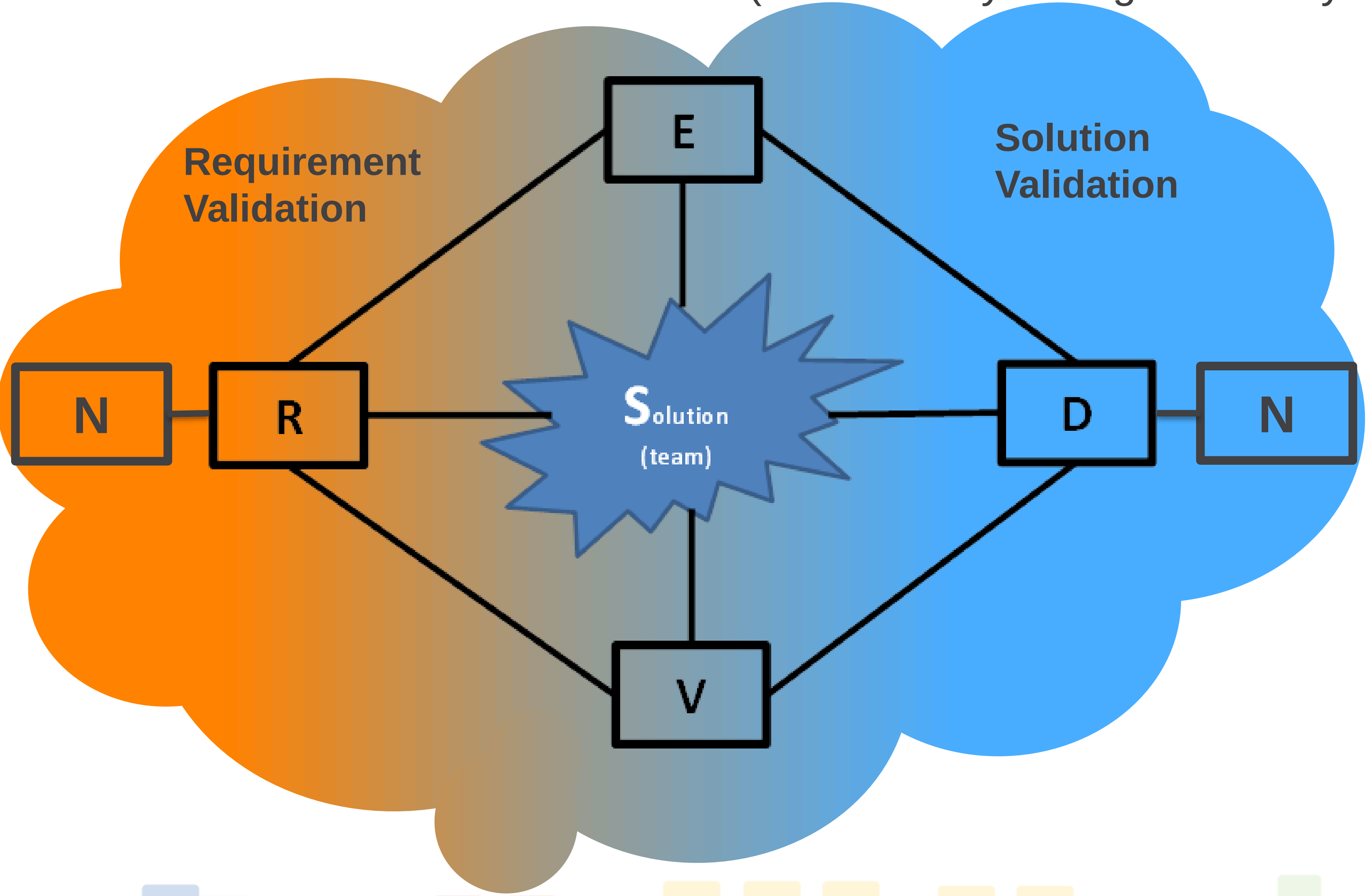
Introduction

- Some Background
- Validation – What Does it Mean?
- Why do we test things?
- An Example – Critical Part Fatigue Life Prediction
- Discussion – Databank Fatigue Life Prediction
- Discussion – What Tests Should I Plan?
- Conclusions

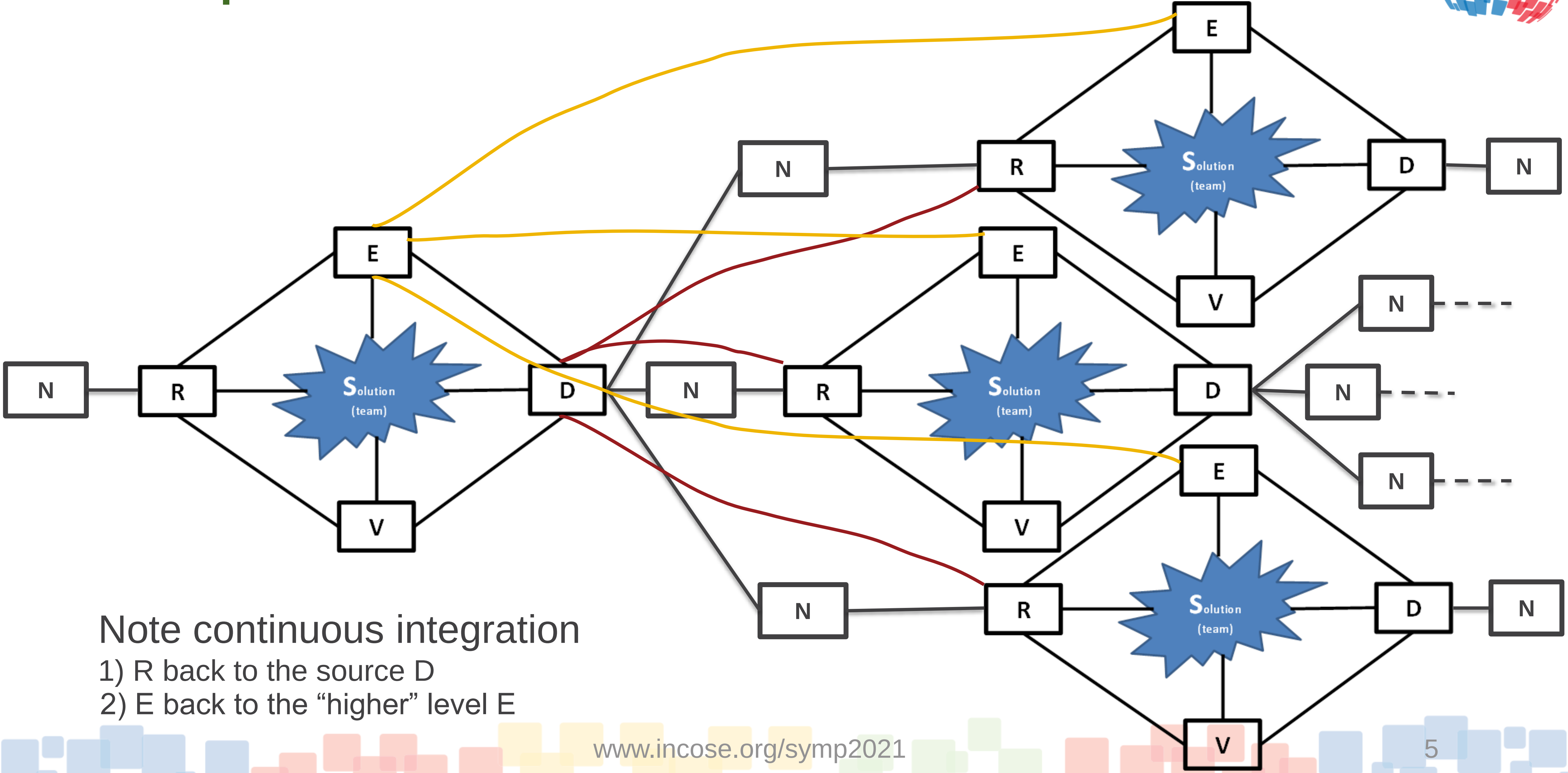
Background – The Updated RED-V Kernel

Validation (continuously through the lifecycle)



- N = Needs
- R = Requirements
- E = Evidence
- D = Definition
- V = Verification
- Validation

The Updated RED-V Kernel - Continued



Note continuous integration

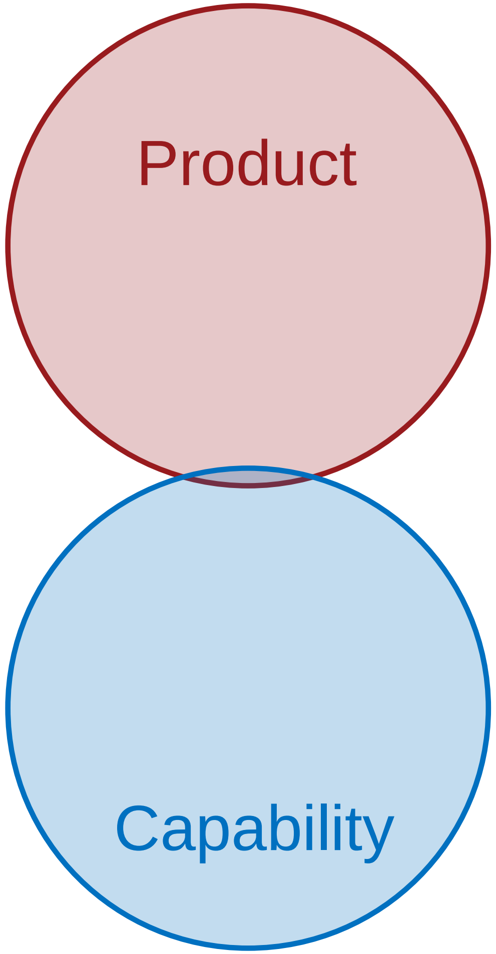
1) R back to the source D

2) E back to the “higher” level E

Validation – What Does it Mean?

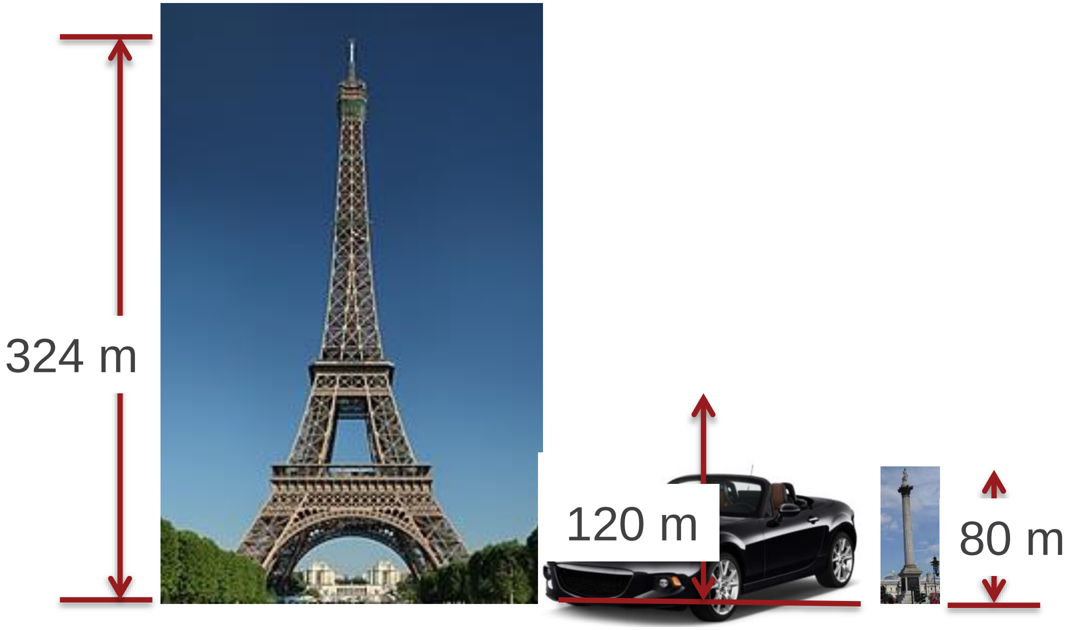
- Confirm that what we will / have delivered to the user is fit for purpose, through the lifecycle
- Confirm that the system is still fit for purpose if the user changes the way they use the system

Why do we Test Things?



- For a Product:
  - To verify that we have met those requirements that can only be verified by test
  - To calibrate models that are specific to that product to validate the use of the model for Verification by Analysis
- For a Capability:
  - To calibrate models that can be used across a range of products to validate the use of the model for Verification by Analysis
- Worst Value?
  - Test every product with test settings that preclude the results supporting calibration of models
- Best Value?
  - Test once and use multiple times via calibrated models

An Example – Fatigue Life Prediction



- Critical Parts in a Gas Turbine
  - Includes all of the rotating discs that hold blades in place (axially and radially) while allowing them to rotate and (compressor) perform work on or (turbine) extract work from the primary gas stream
  - In a typical large gas turbine, fracture of a High Pressure Spool disc results in release of energy equivalent to propelling a 1000kg car up to 120m in the air!

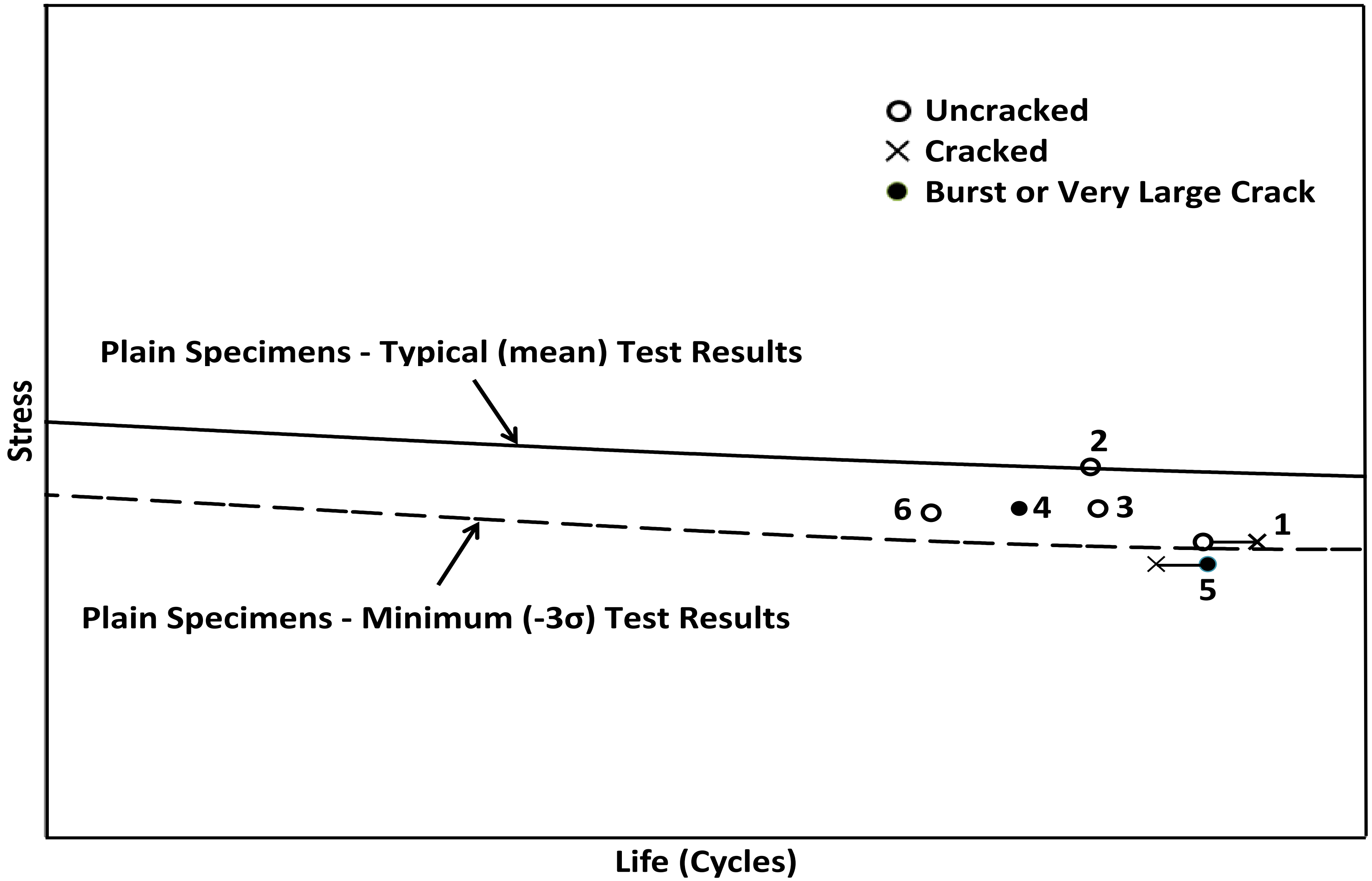
Requirements for Reliable Life Prediction

Avoidance of in-service failure requires a sound knowledge of:

a. The environment and loads to which the component is subjected
b. The macroscopic response of the component to the applied loads and environment
c. The microscopic response of the material
d. Consistency of component manufacturing

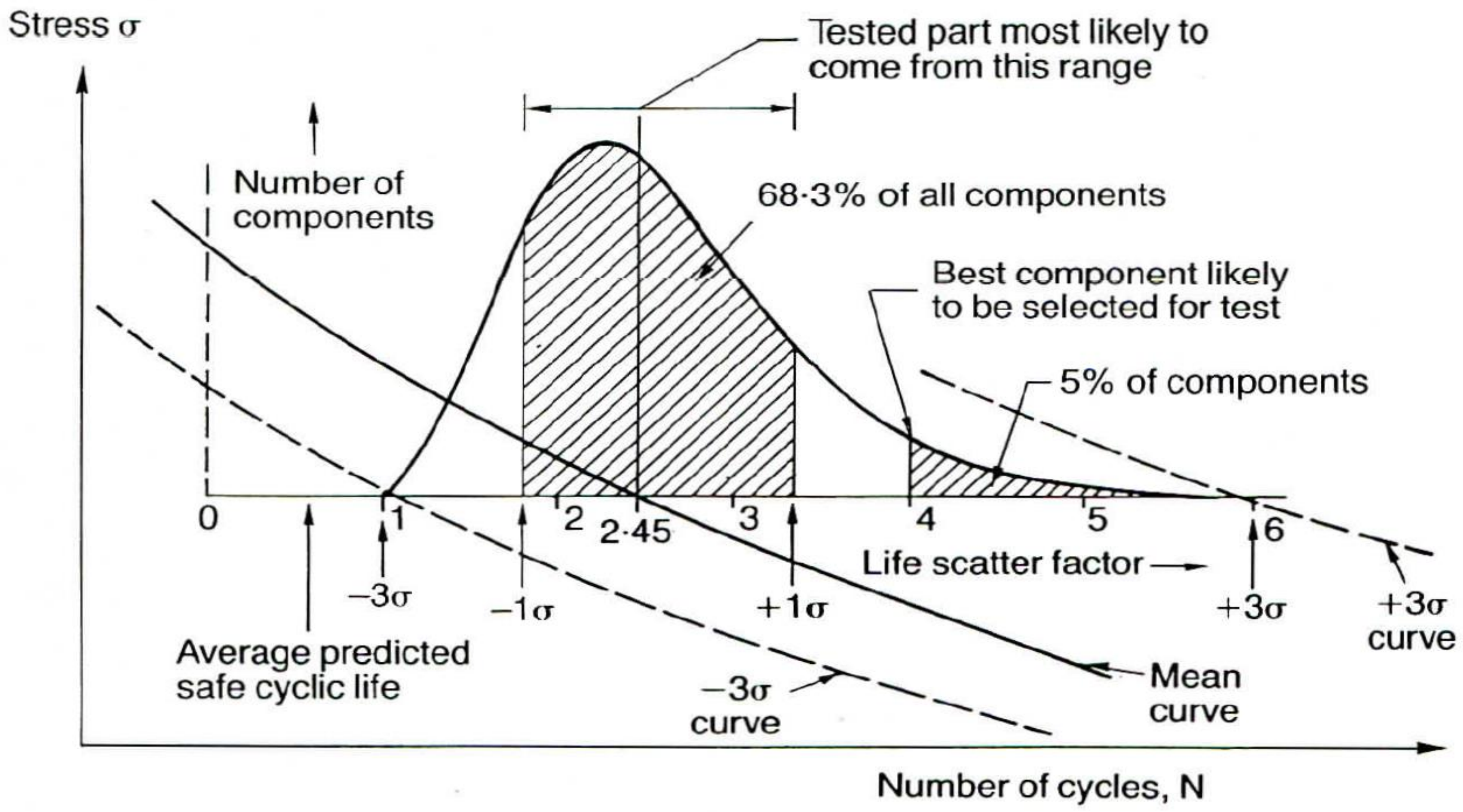
Material	Surface	Residual Stresses	Inspection Techniques
Microstructure	Machining and Damage	Quenching	Repeatability
Homogeneity	Scoring and Burning	Welds	Reproducibility
Defect Content	Dents and bruises	Machining	Detection capability
Defect Type	Fretting		Level of Automation
	Processing		

Traditional Fatigue Life Prediction



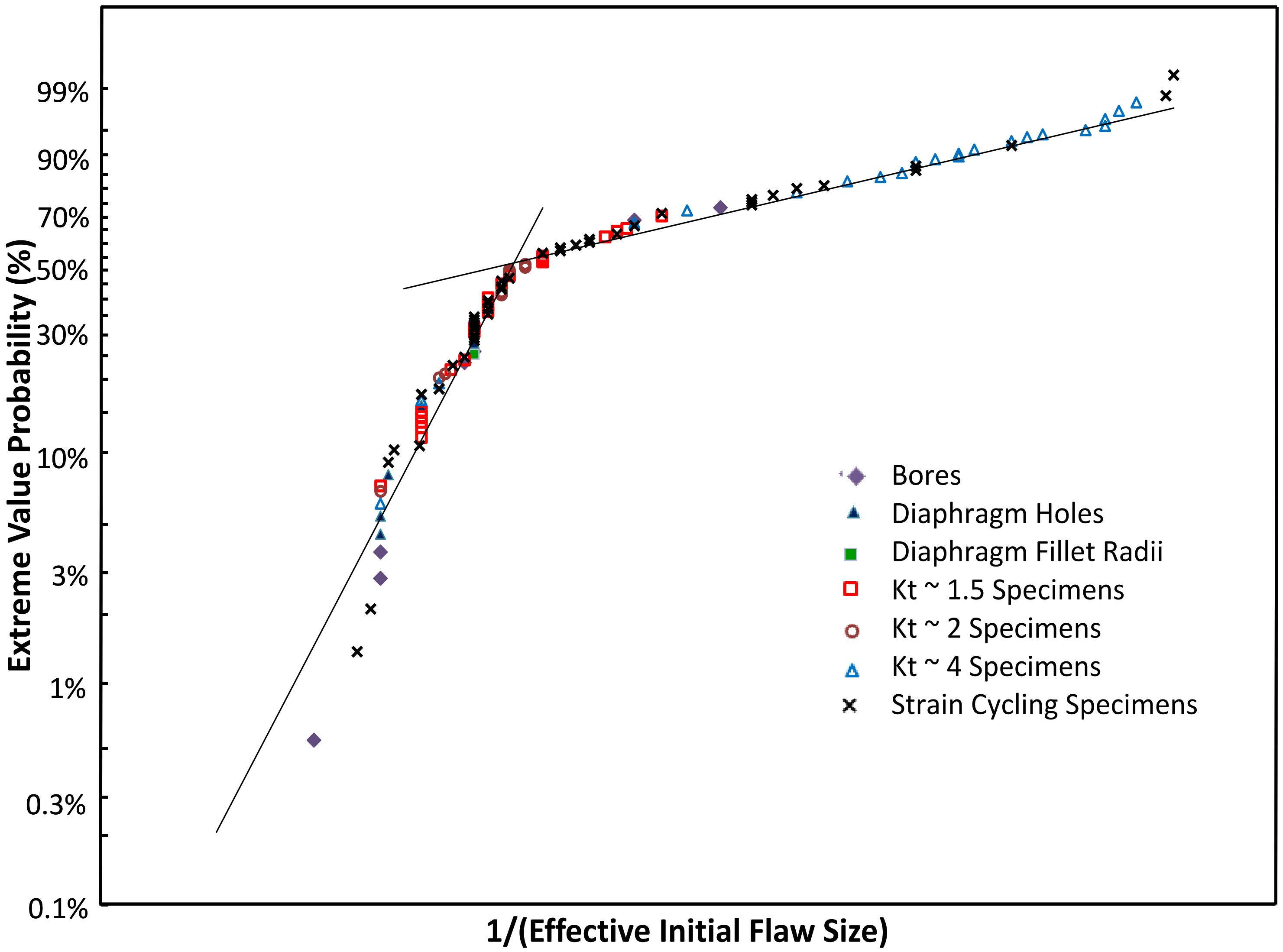
Traditional approach to fatigue life prediction using plain specimen results compared to spin test results on disc bores – Titanium alloy (Ti–6–4) material

Traditional Fatigue Life Prediction



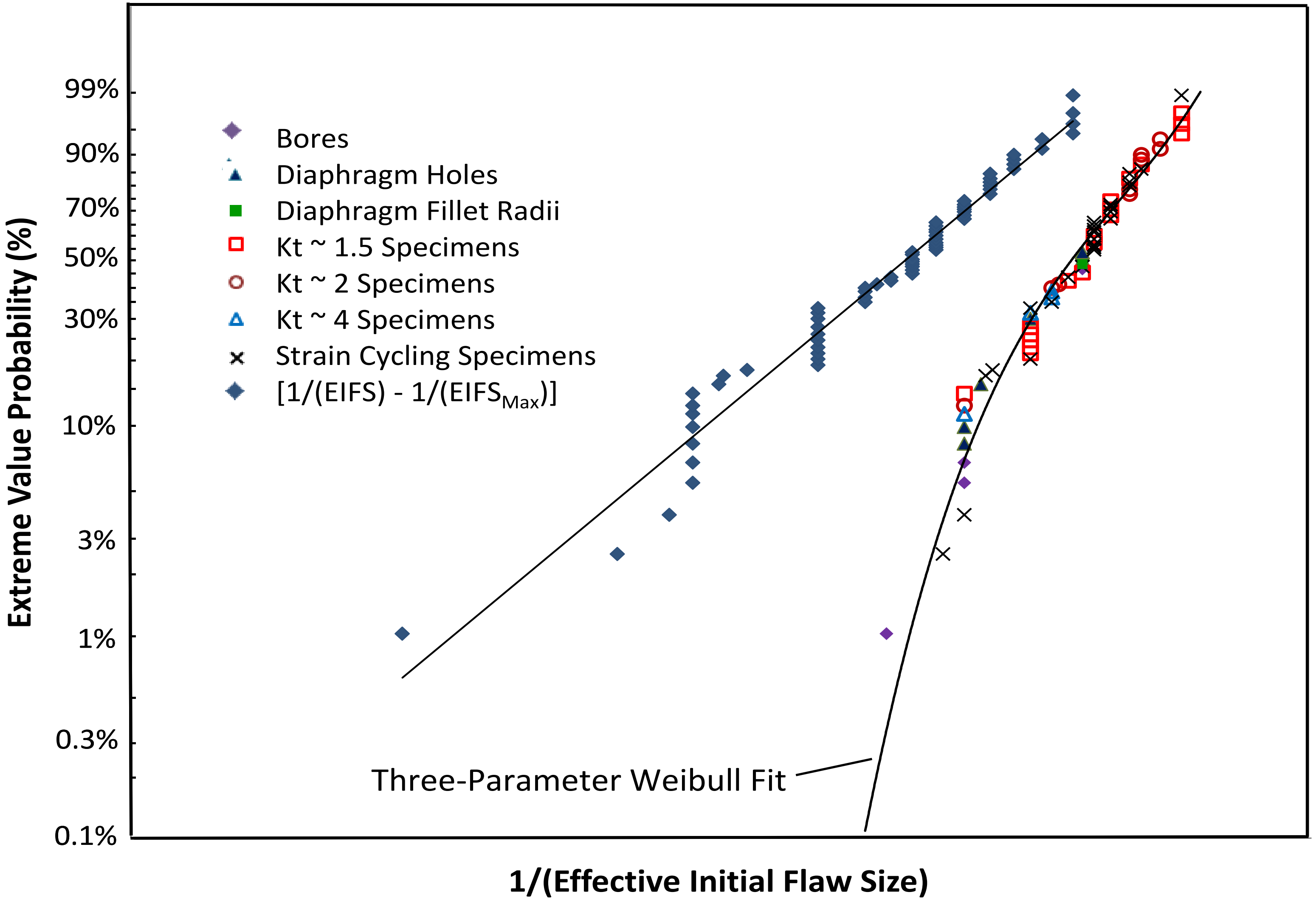
Log-Normal Gaussian Life Distribution – Traditional Fatigue Life Prediction Method

“Databank” Fatigue Life Prediction



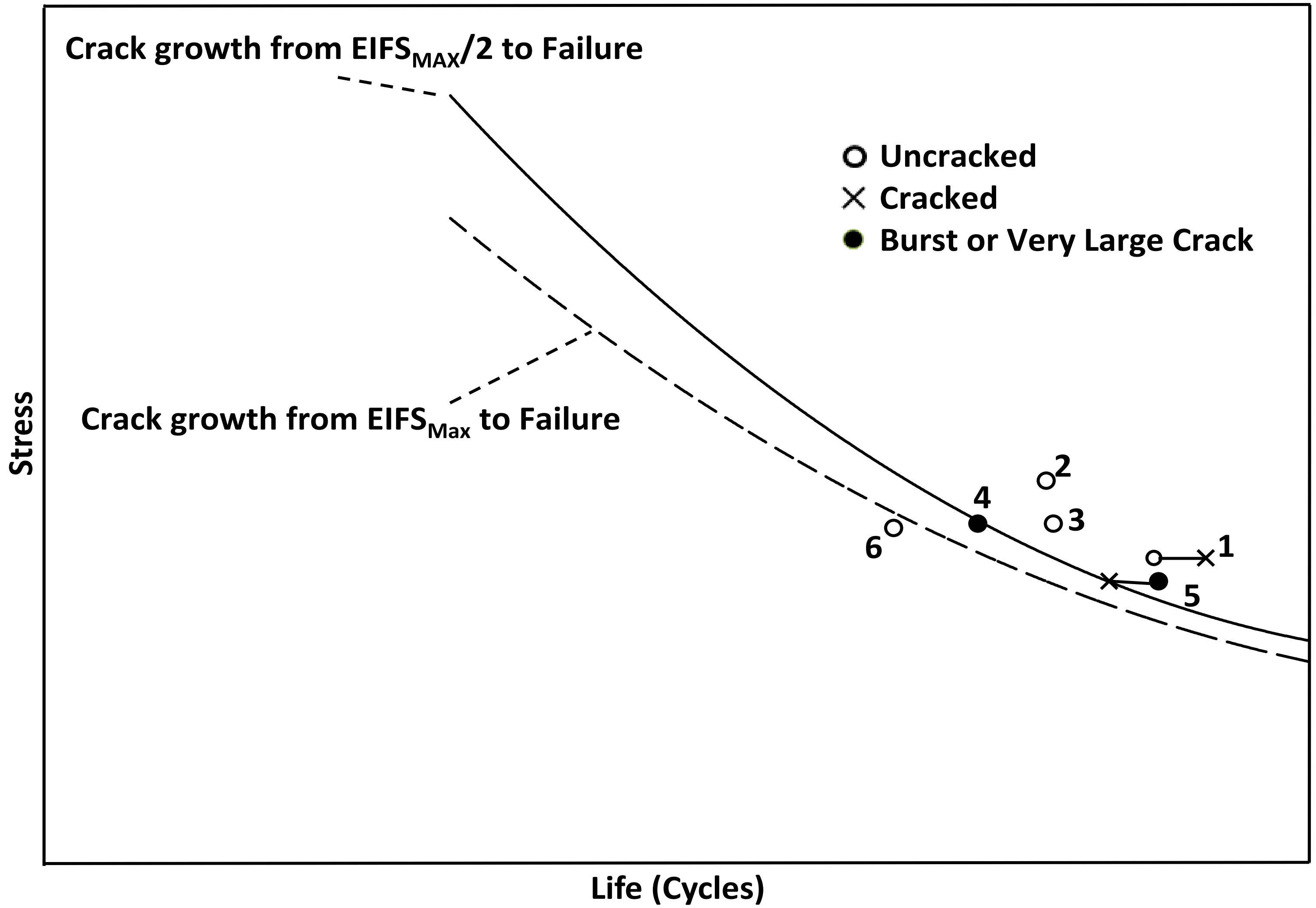
Fracture Mechanics Models were used to derive the distribution of “Effective Initial Flaw Size” – The crack size that would have had to be present from the start of cycling to explain the fatigue life observed (Ti-6-4 material)

“Databank” Fatigue Life Prediction

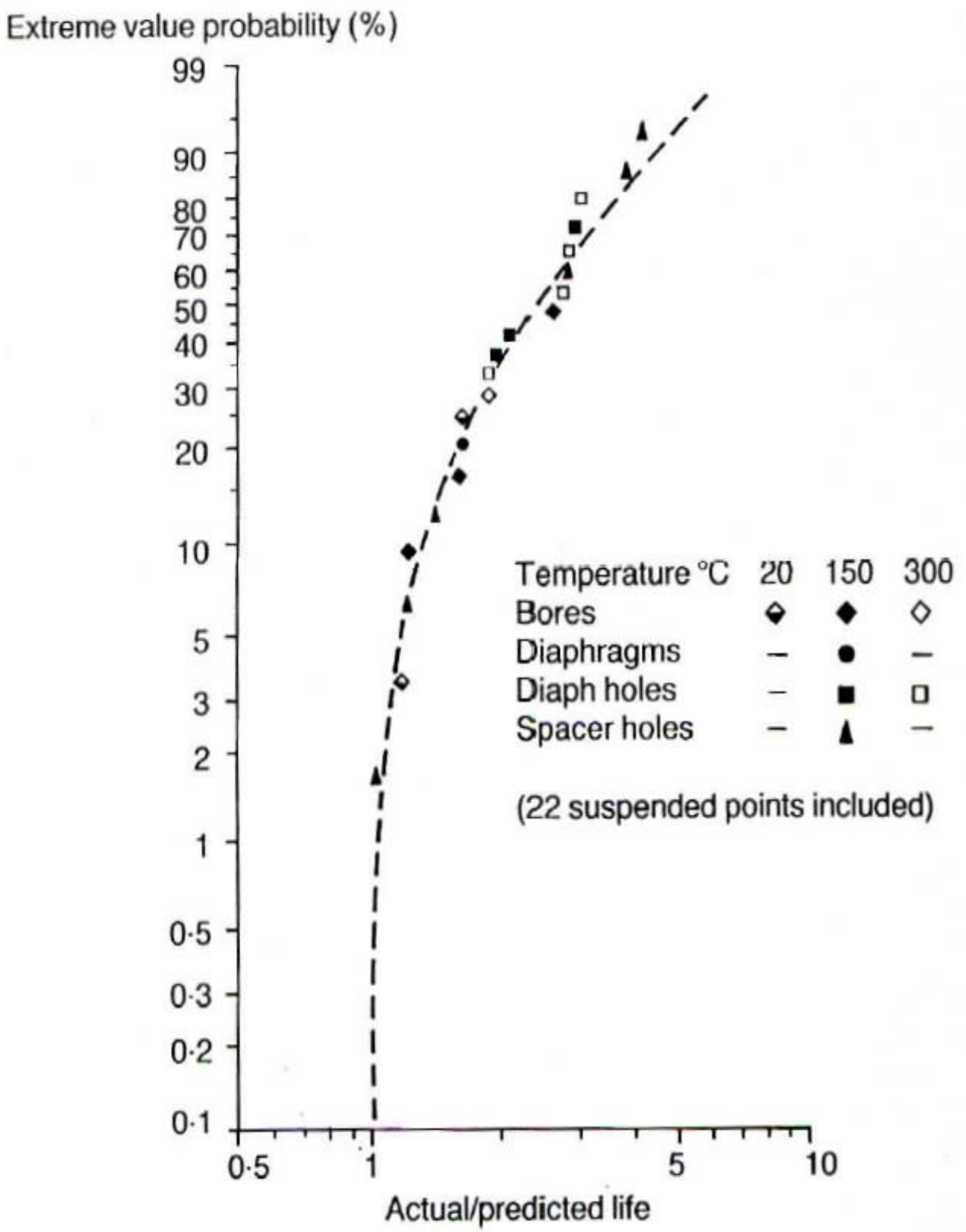


Lower branch (largest effective initial flaw size) statistical distribution – Three Parameter Weibull fit used to identify largest effective initial flaw size (gamma value of the distribution)

“Databank” Fatigue Life Prediction



Fracture Mechanics based prediction of disc bore fatigue lives (Ti-6-4 material)

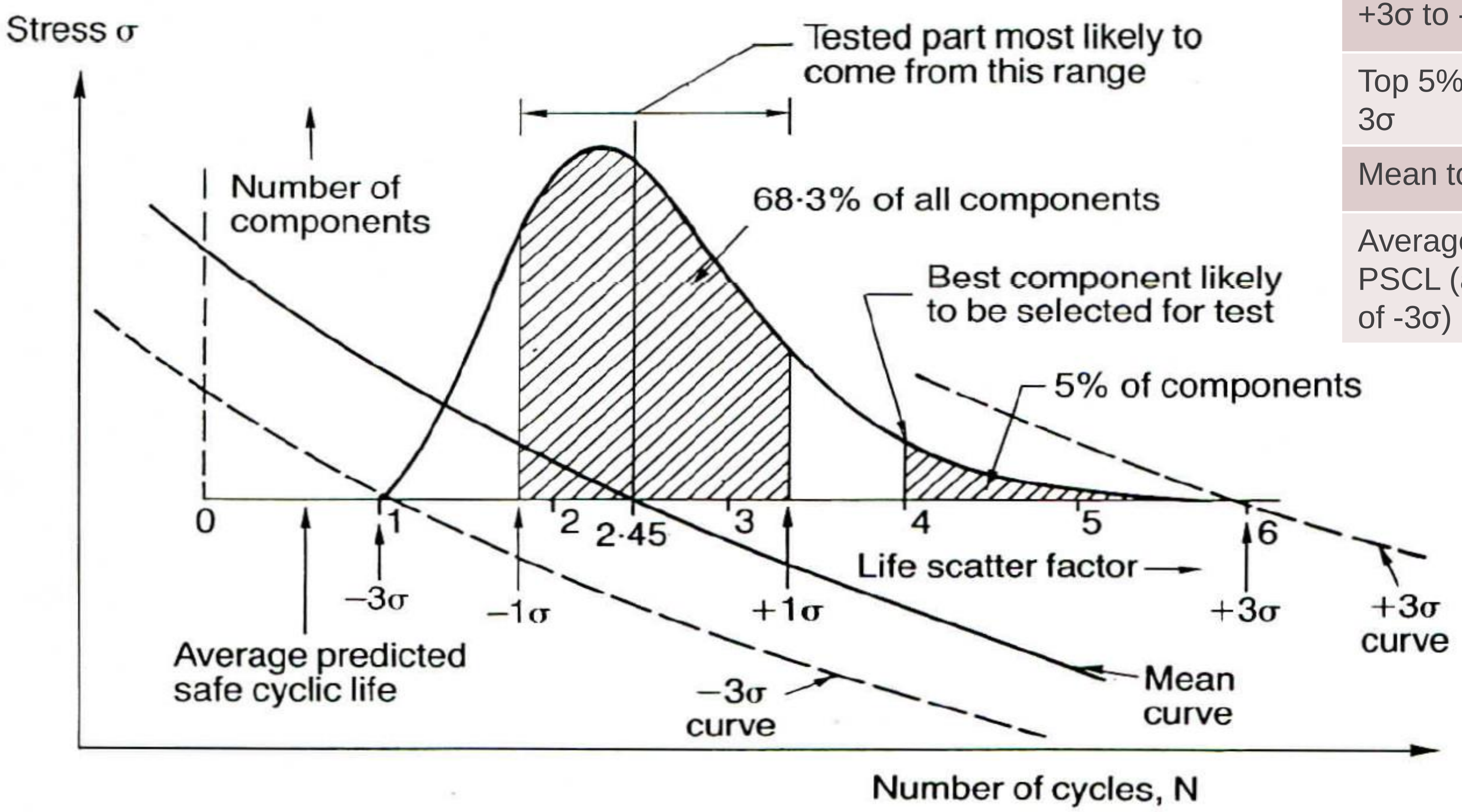


Model Calibration

Databank model calibration – Ti-6-4 material

Use of this model-based databank approach was subjected to rigorous review by the regulatory authorities; acceptance by the UK Civil Aviation Authority and the US Federal Aviation Authority took over two years of review and discussions.

The Actual Life Distribution

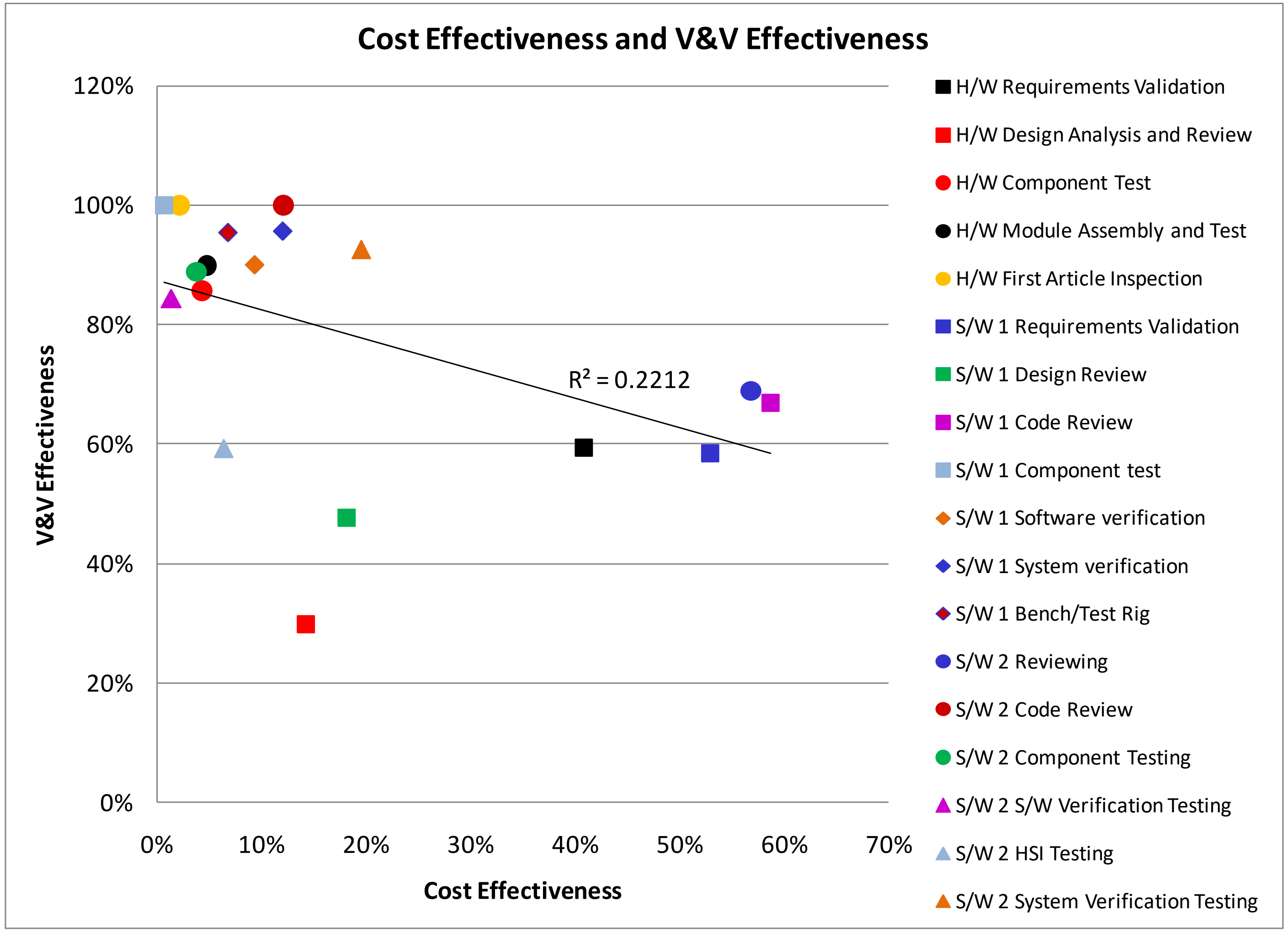


Factors	Traditional	Databank
+3σ to -3σ	6:1	7.1:1
Top 5% to -3σ	4:1	4.1:1
Mean to -3σ	2.45:1	1.86:1
Average PSCL (as % of -3σ)	61%	47%

Discussion – Databank Fatigue Life Prediction

- The Databank Critical Part Fatigue Life Prediction approach was developed in the mid 1980's
- It was made feasible by component and specimen testing performed in the mid 1970's to early 1980's called the Life and Methods Program (LAMP)
- The component tests in this program were designed to reach a finite end-point (cracking or burst) – the right tests!
- Many previous Engine Project-funded component tests were run at low overstress factors to "clear life" and did not reach finite end-points, making them of limited value in developing a predictive model
- A Linear Elastic Fracture Mechanics model was used to correlate the specimen and component tests, via the "Effective Initial Flaw Size" approach
- Databanks were developed for three materials; they have subsequently been extended to more materials and component features and are still in use.
- And there's more! The example model based approach to critical part life prediction helps when creating new designs and introducing new design features.

Discussion – What Tests Should I Plan?



- Selection of approaches for Validation and Verification
  - If not dealing with safety critical systems, there may be more options
  - Consider doing more reviews to reduce undetected escapes when some escapes are acceptable

Pickard, AC and Nolan, AJ 2013 "How Cost Effective is Your V&V?", INCOSE-2013-12, 23rd Anniversary INCOSE International Symposium, Philadelphia, 2013, ISBN 978-1-937076-03-0

Conclusions

- Use of model based approaches to reduce costs is nothing new – the example shown was introduced in the mid – 1980's.
- The approach depends on a change in behavior – don't test at engine stress levels to clear life, as in the traditional fatigue life analysis methods, but test with overstress factors to achieve finite (cracked or failed) component test results.
- Consider alternatives to testing to reduce the cost to develop products – but for Safety Critical systems, make sure that any model-based approaches are calibrated using a databank of test results, including representative full-scale component tests.
- You don't save money by doing less testing – you save money by doing more of the right tests!

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