THE LEAD CRACK CONCEPT 30 YEARS ON

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31st ICAF Symposium – Delft, 26-29 June 2023

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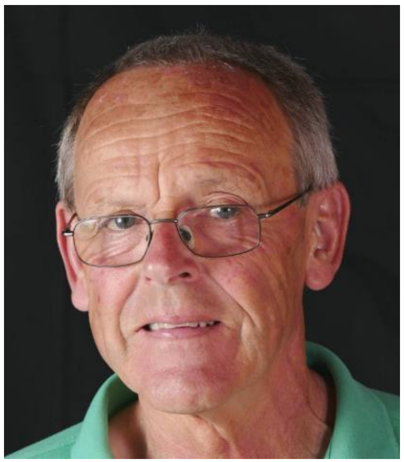

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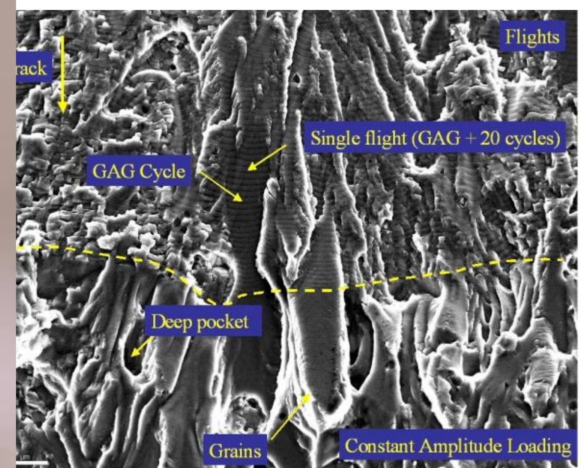


- **Simon Barter**

Metallurgists are Silver!

Quantitative Fractograph

ulau Aur

1999

Acknowledgements

Outline

1. Paris equation re-visited
2. What is fatigue in aircraft metallic structures
3. Some real-world examples of lead cracks
4. Scatter in fatigue
5. Importance of nucleating discontinuities
6. Re-visiting early crack growth models circa 1950
7. Derivatives from the Lead Crack Fatigue Lifing Framework
8. Example. Prediction from limited data
9. Conclusions
10. Bibliography

Ye ol' 1963 Paris Re-Visited [1]

ICF Jun 17

$$\frac{da}{dN} = C(\Delta K)^m \qquad (1)$$

$$ln\left(\frac{da}{dN}\right) = \; ln\, C + m\; lnK \quad (2)$$

Integrating:

$$a_f = a_0 e^{C\pi(\Delta\sigma\beta)^2 N_f}$$ For **m = 2** (3)

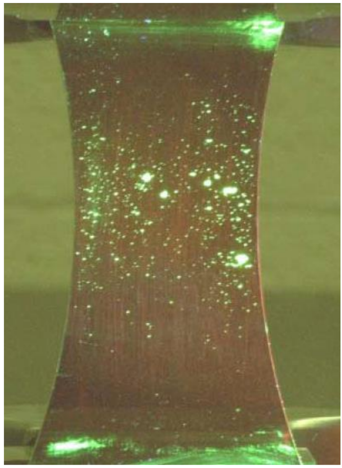
$$a_f = \left[a_0^{\left(1-\frac{m}{2}\right)} + N_f C\left(1-\tfrac{m}{2}\right)\left(\Delta\sigma\beta\sqrt{\pi}\right)^m \right]^{\left(\frac{1}{1-\frac{m}{2}}\right)}$$ For m≠2 (4)

Where a is the crack length at cycle *N*, ΔK is the stress intensity range (or similitude parameter), constant width correction factor β, and *C* and *m* are nominally material constants a_f is the final crack size and σ is the far field stress.

In this presentation, the long-neglected Equation 3 is of most relevance.

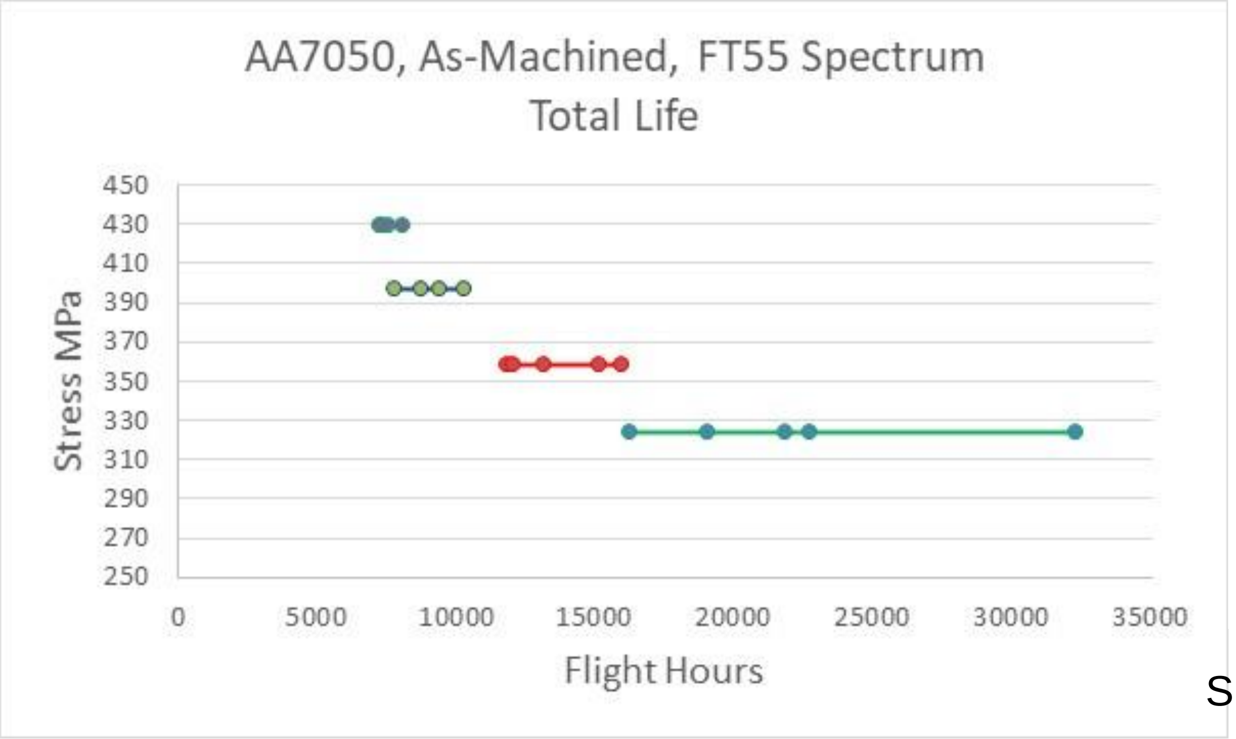
The metal aircraft LC fatigue problem space
Lead Crack Fatigue Lifing Framework

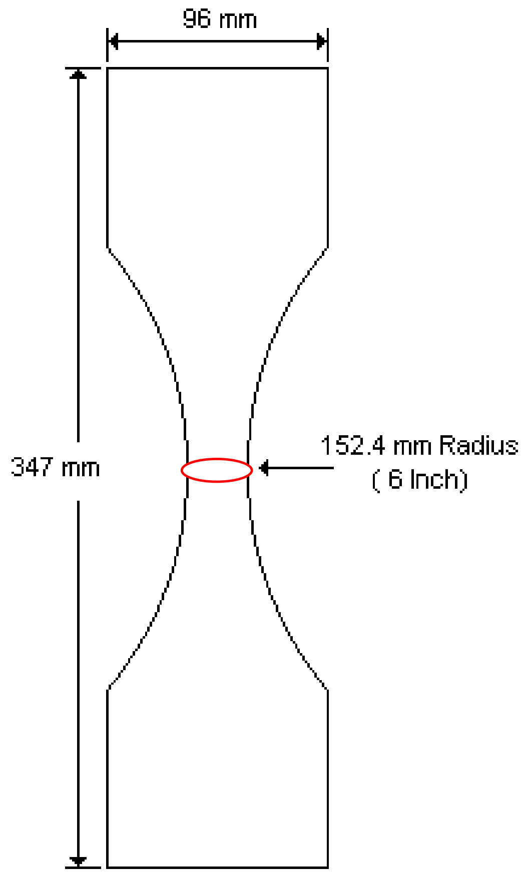
1. The growth of cracks is the only measurable fatigue metric (and thus useful in assessing impact on structural integrity);
2. For production aircraft materials, cracks that will play a role in the fatigue life of a component nucleate from sub-mm surface or near-surface discontinuities at high stress regions (i.e. hotspots);
3. The majority of these cracks commence growing from near-day one of operations (but time dependent damage e.g. corrosion, accidental damage etc may also play a role);
4. Subject to caveats, they grow approximately exponentially;
5. Upwards of two-thirds of the total life spent in growing a detectable crack (» 1mm long). NDI limitations;
6. Thus the physically short-crack at the low ΔK regime is the area of most interest to fleet management & failure analyses; However,
7. Traditionally most data and analysis have been produced using long (> 1mm long) cracks (limitations acknowledged in ASTM E647).



AA7050 specimen; fatigued then loaded to reveal cracks (dye penetrant)

Fatigue Coupon S-N Results
Lead Cracks which led to Failure

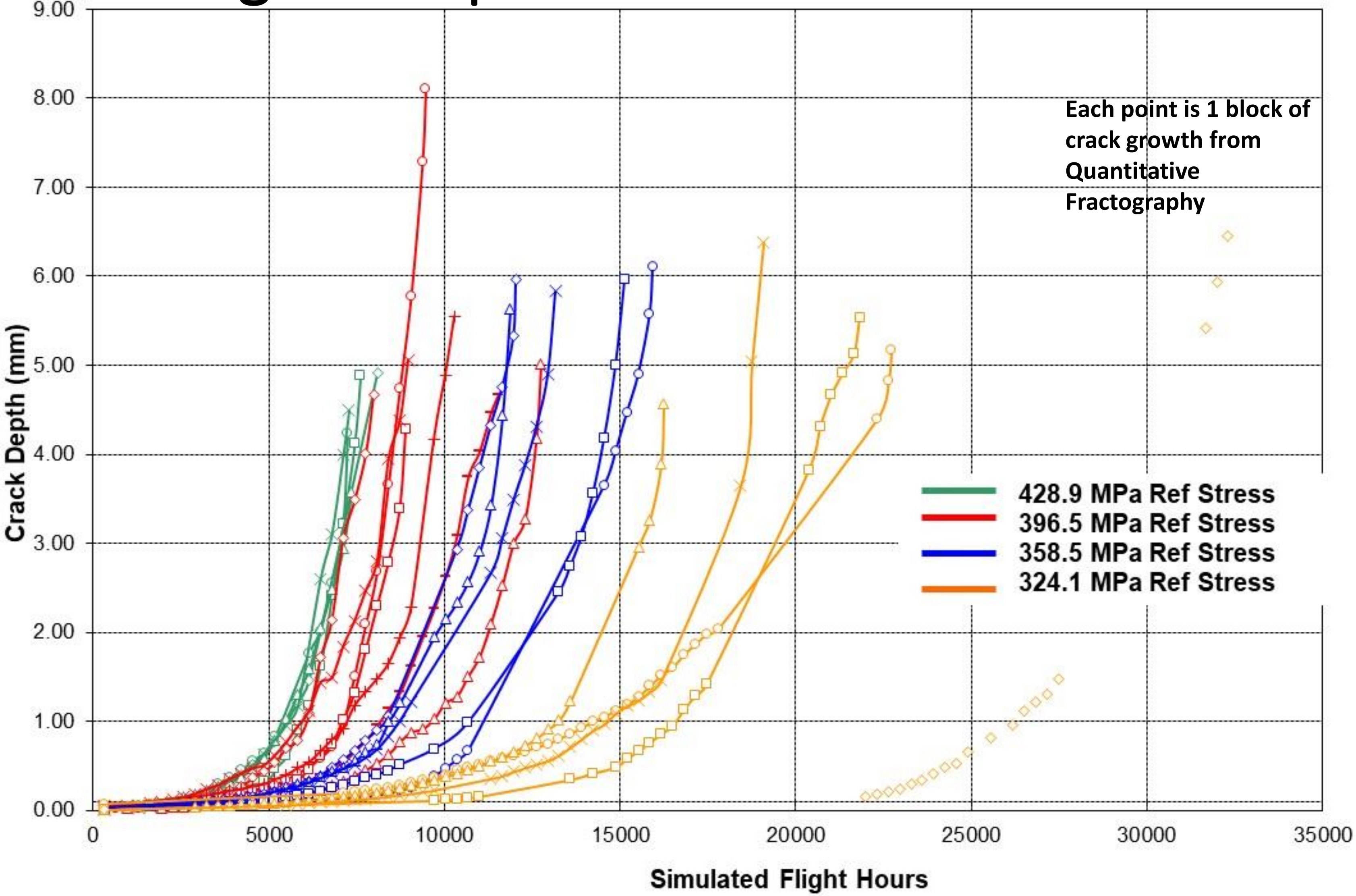




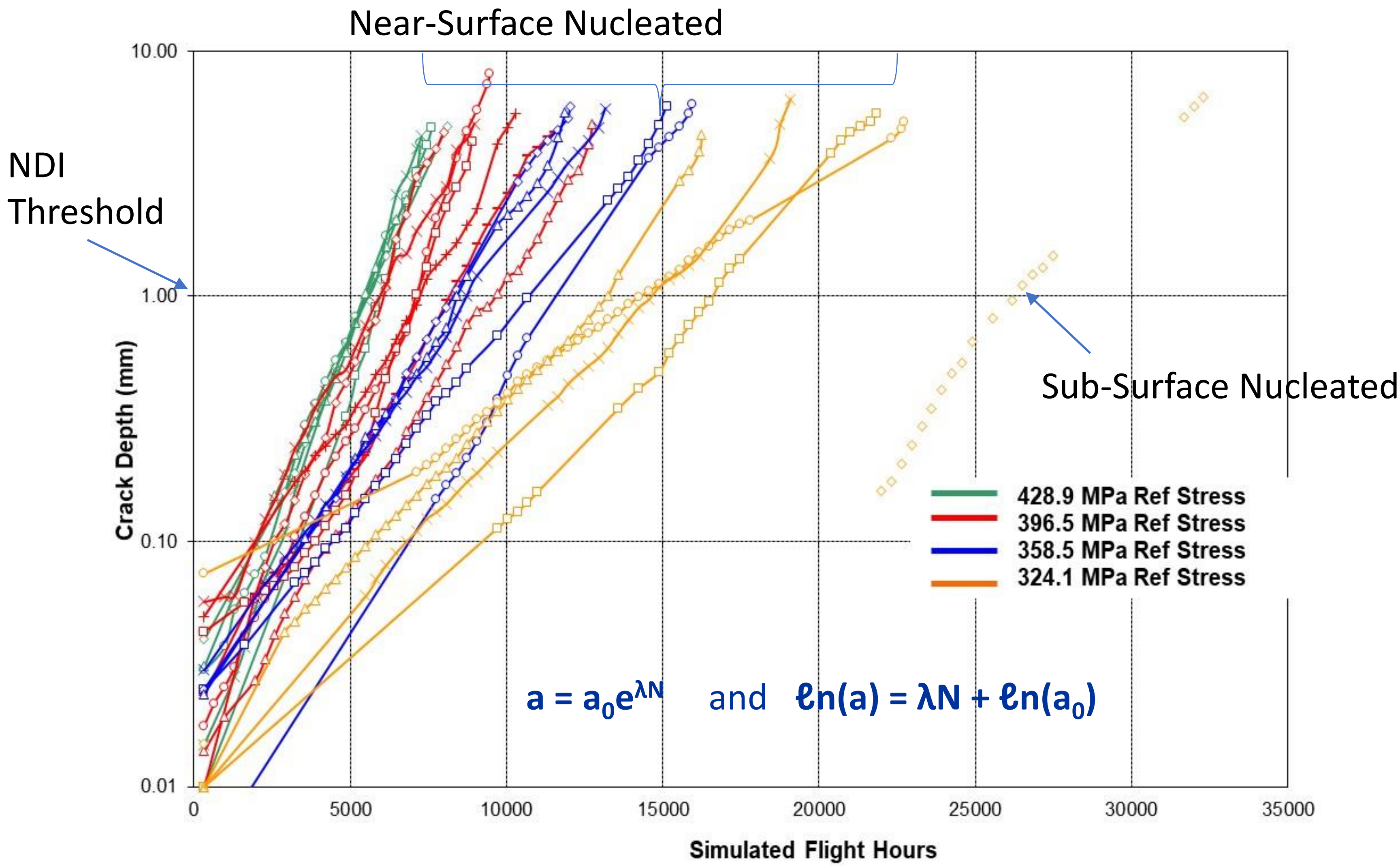
Specimen thickness: 6.25mm

7050-T7451 Aluminum alloy
- Nominal test section is 28mm wide by 6.25mm thick
- Analytical K_t of 1.055
- Four or Five Coupons per Stress level

Fatigue Coupon Crack Growth Results

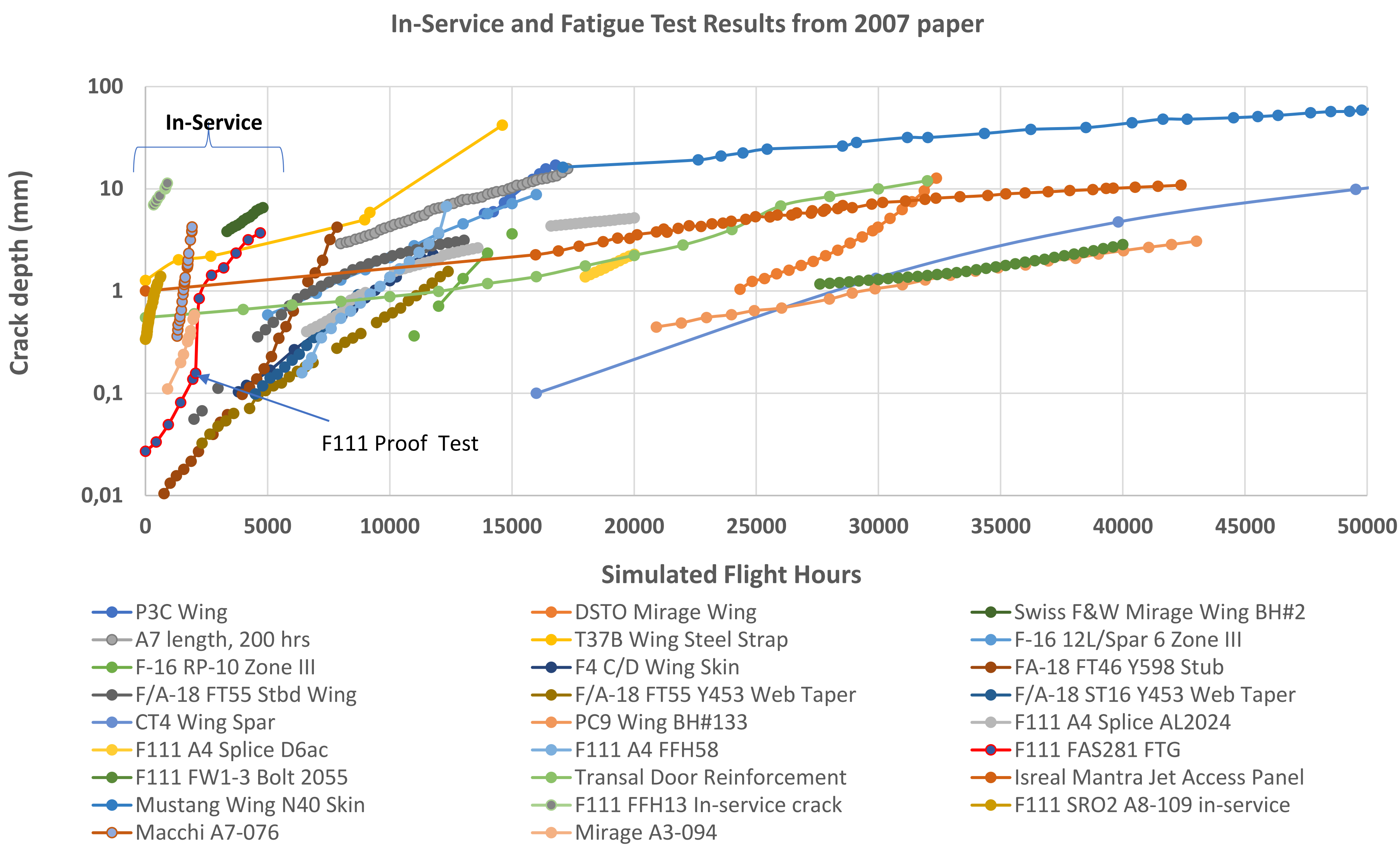


Fatigue Coupon Crack Growth Results – Exponential [2]

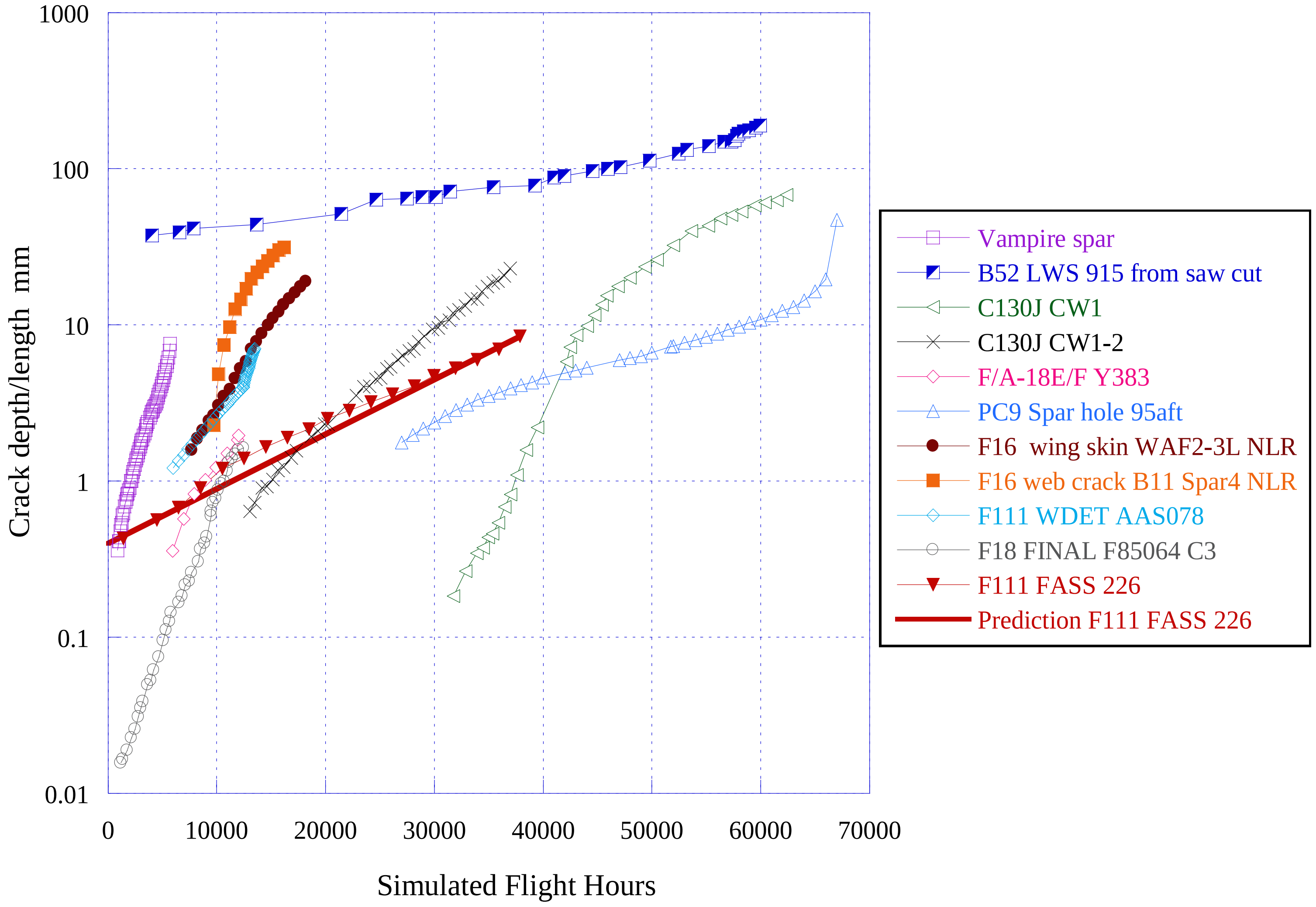


$a = a_0 e^{\lambda N}$ and $\ell n(a) = \lambda N + \ell n(a_0)$

In-Service and Fatigue Test Results (1) [3]



More Full-Scale Fatigue Test Results



Metal Fatigue Scatter (in monolithic structure) LCF

		Variable	Contribution to material scatter for lead cracks
1	**Build quality**	Initial discontinuities that lead to fatigue cracking	Most significant
2		Stress concentrations leading to inter-aircraft variations in local stress	Any nominal variation in stress will lead to scatter. Build Quantity Dependent
3		Fit-up or residual stresses	Any nominal variation in stress will lead to scatter. Build Quantity Dependent (significant and should be addressed)
4	**Material property**	Crack nucleation and/or initiation period	Nucleation period insignificant
5		Fracture toughness of the material	Crack tear near end of life.
6		Material cyclic stress intensity threshold	Threshold close to 0 for lead cracks.
7		Crack growth rate of fatigue cracks in the material being examined	Secondary

LCF = Low Cycle Fatigue

Types of Airframe Discontinuities [4]

- Conventional production components have many sources of discontinuities that can cause fatigue cracking e.g.:

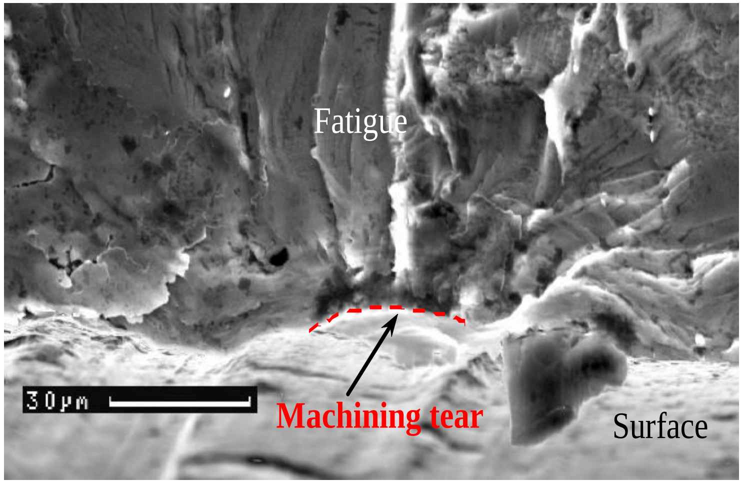
- **Machining damage**:
  - badly drilled holes
  - scratches, grooves, burrs, small tears, nicks
- **Surface treatments** (pickling, anodizing):
  - etch pits, sometimes intergranular attack

- **Constituent particles** (aluminium alloys and steels)
  - particles can be already cracked from production

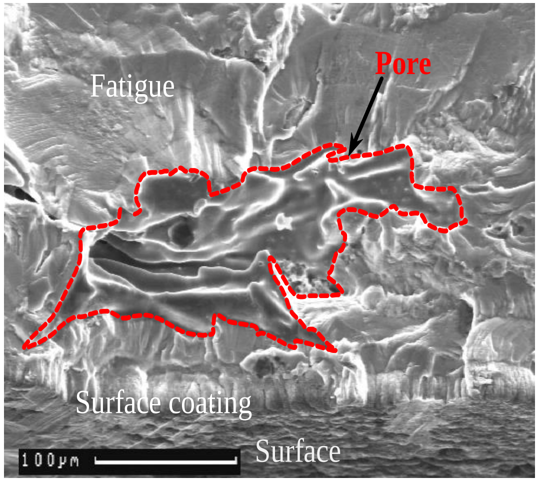
- **Porosity** in thick aluminium alloy plate and castings

N.B: discontinuity depths mostly small, ≈ 0.01mm

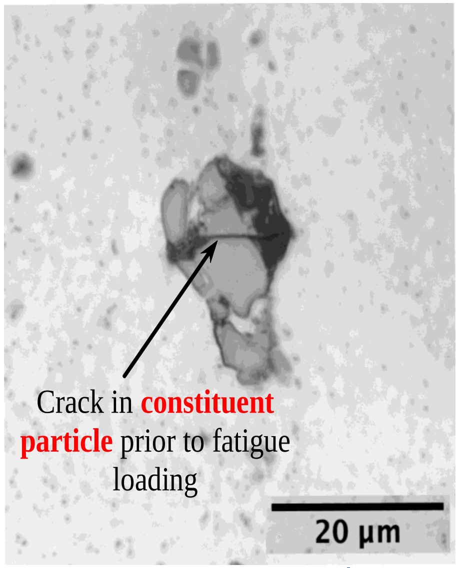
Types of Airframe Discontinuities: Examples



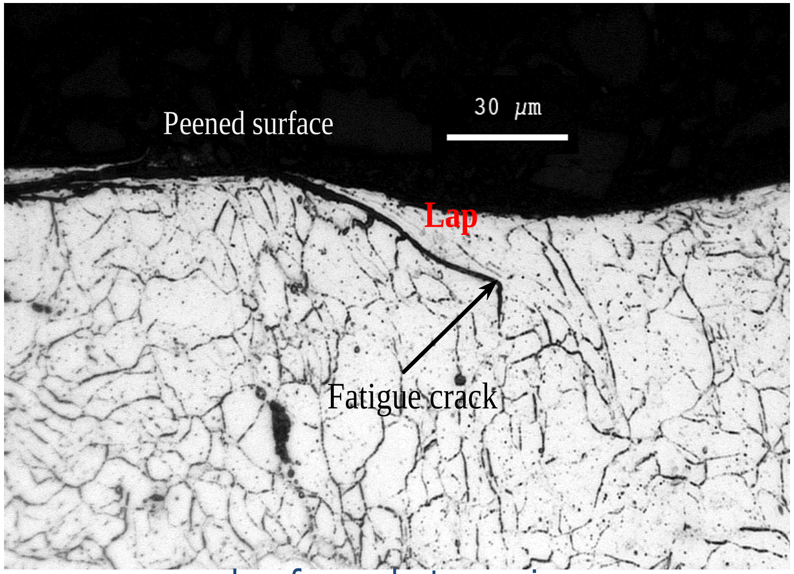
machining damage



porosity



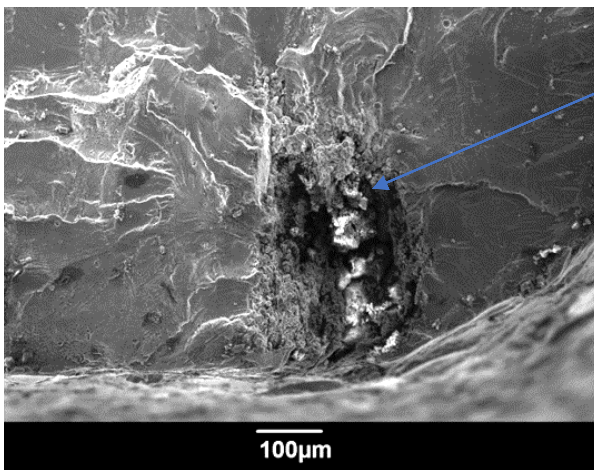
constituent particles



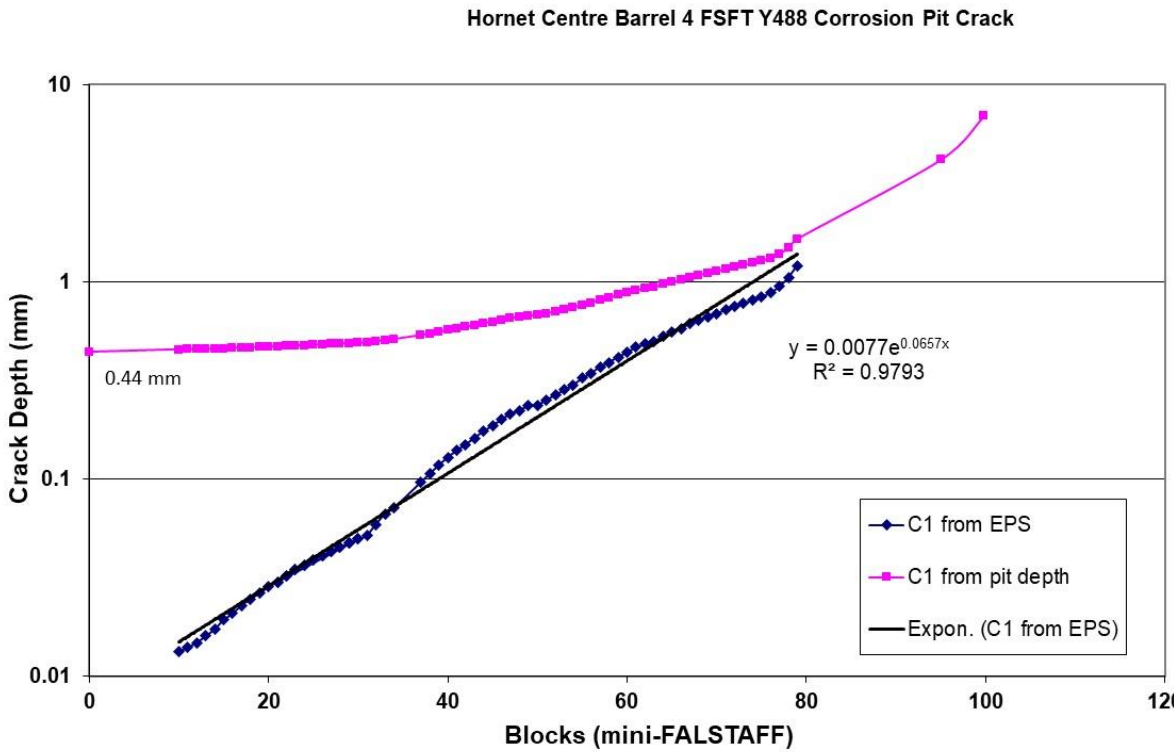
lap from shot peening

Not all Defects are totally Crack-like [5]

e.g. Corrosion Pit in Bulkhead

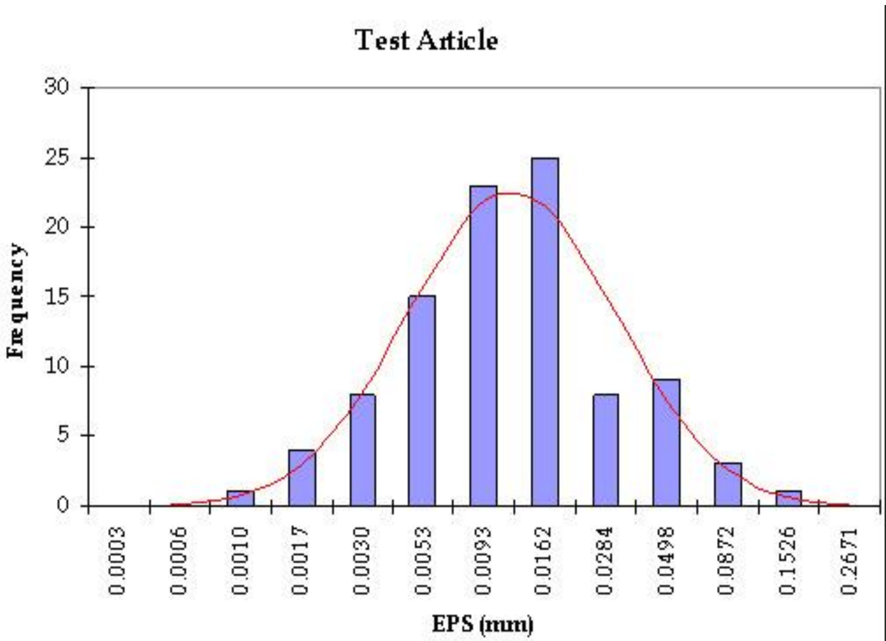


A SEM view of AA7050-T7451 fracture surface showing the corrosion pit at its origin of C1

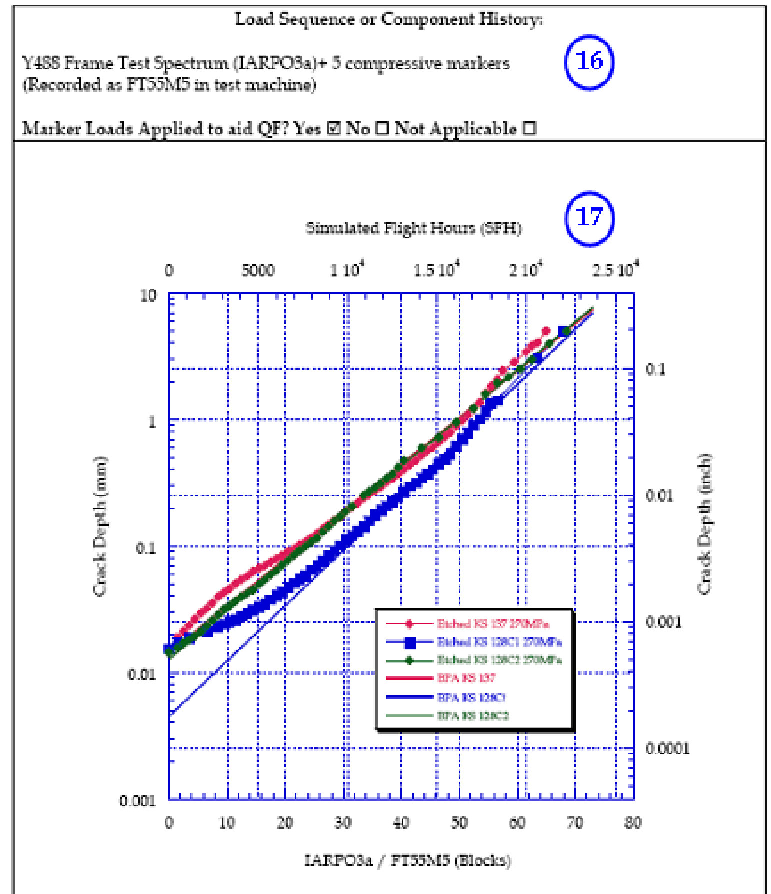


Highly 3D
Multiple origins
Significant period to transition to stable 2D crack

Equivalent Pre-crack Size (example) [6]



EPS distribution from cracks in AA7050 test article nucleating from etch pits (mean ≈ 0.01mm deep). Approx 200 samples.



graphical representation of the QF data and back projected EPS curves

The Past Re-visited

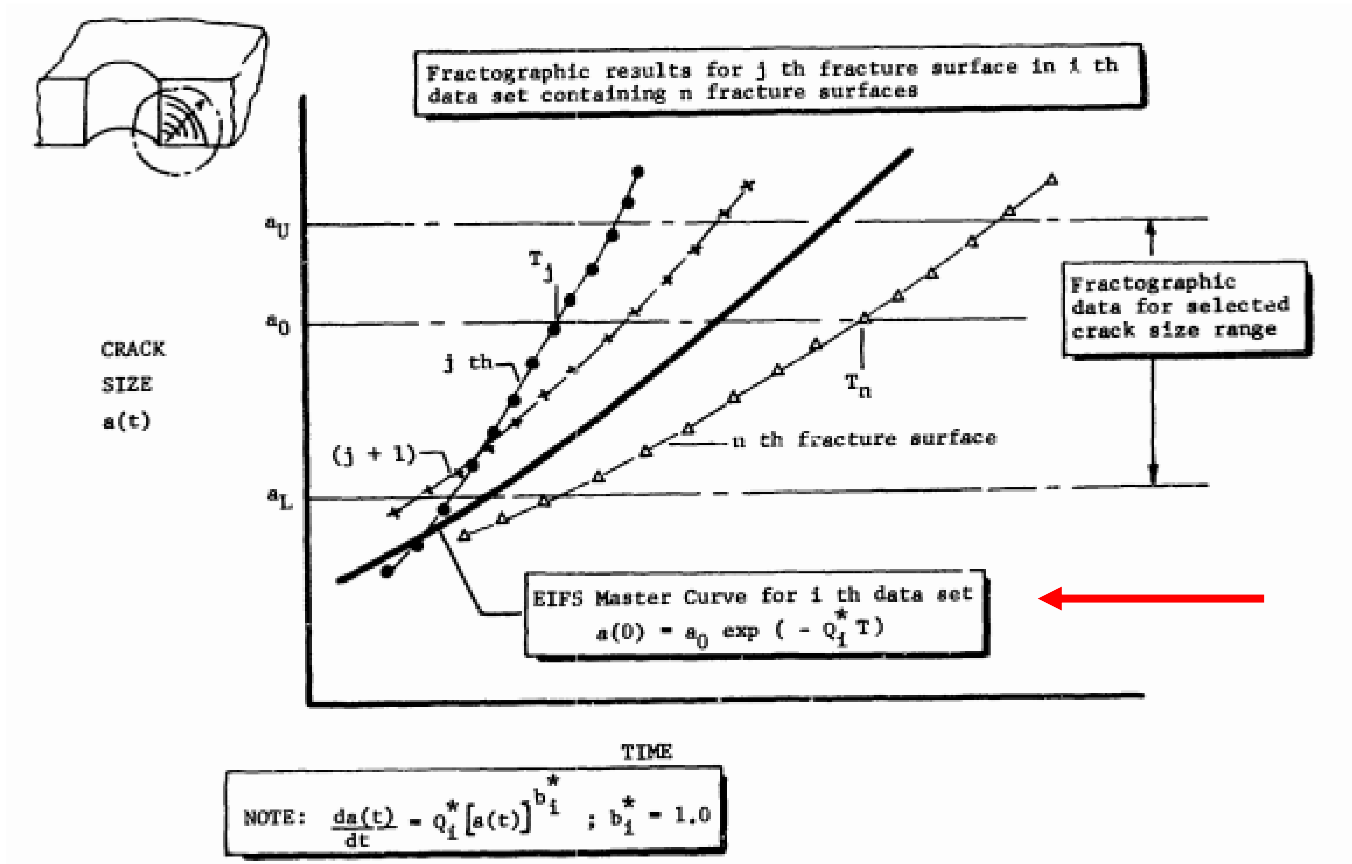


Fig. 4.7 Conceptual Description of Fractographic Data used to Determine Q_i^* for the i th Fractographic Data Set

Manning and Yang USAF 1984 [7]

Also see Head 1953, Shanley 53, Frost and Dugdale 58, Berens et al. 91

LCFLF Derivatives

1. **Cubic Rule** [8]:
For same spectrum, predict CG rate at new stress (σ_2)

$$a_2 = a_{0_2} e \left(\frac{\sigma_2}{\sigma_1}\right)^3 \lambda_1 N$$

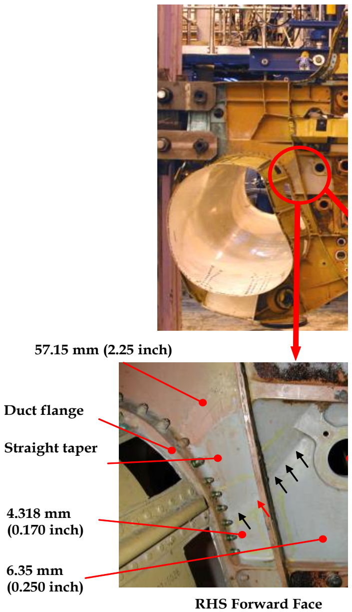
2. The **block-by-block** (or mini-block) approach [9]. Treats a block of CG data (t) as a single cycle

$$\frac{da}{dt} = Aa^j \left(\sigma_{ref}\right)^k$$

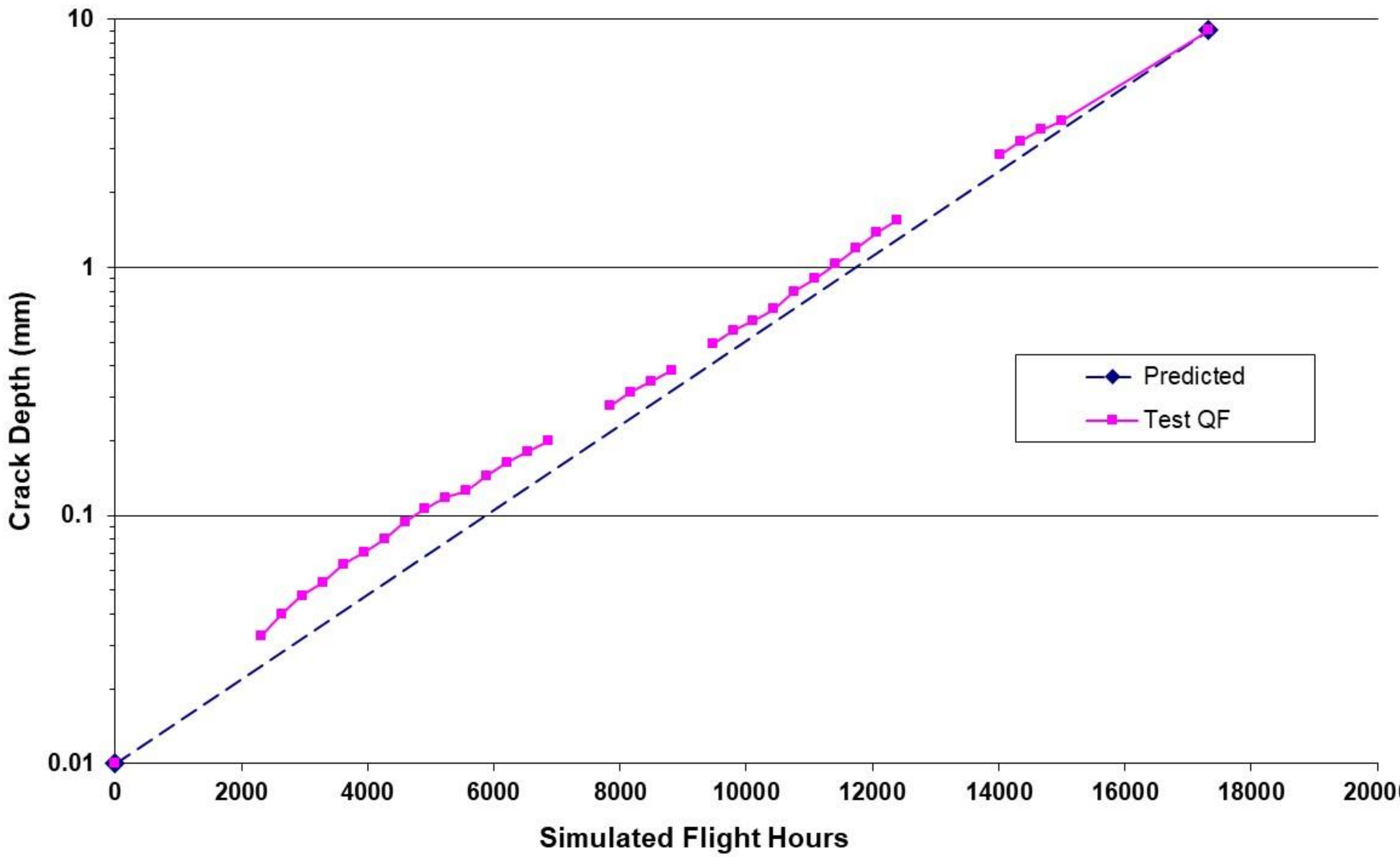
3. The **Hartman-Schijve Variant** [10].
Predictions based on data for ONE stress ratio (R)

$$da/dN = D\,(\Delta K - \Delta K_{thr})^p/(1-K_{max}/A)^{p/2}$$

Example of Prediction (F/A-18 Web-taper)



AA7050



Teardown: At 17326 SFH the crack depth was 9.04mm deep
Initial discontinuity approx. 0.01mm deep

Conclusions

- Cracks that lead to failure grow in an approximately exponential manner commencing shortly after introduction of loads
- These are lead cracks. Lead cracks are the norm.
- Lead crack observations date back to the early 50's
- Short crack growth data should be plotted exponentially
- Crack growth predictions can be made without knowledge of load Spectrum or stress
- A derivative suite of crack growth tools is very useful

Questions?

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