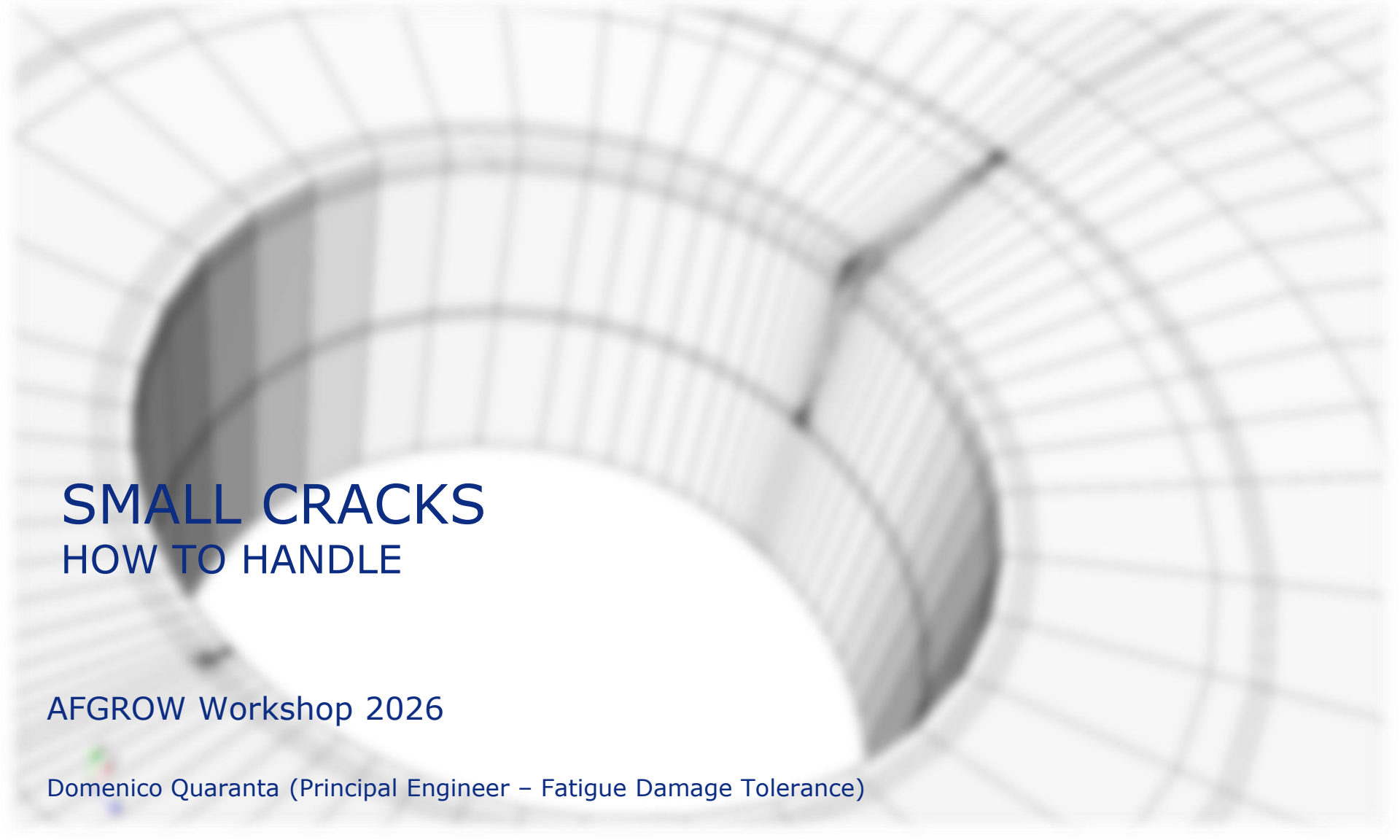


SMALL CRACKS
HOW TO HANDLE

AFGROW Workshop 2026

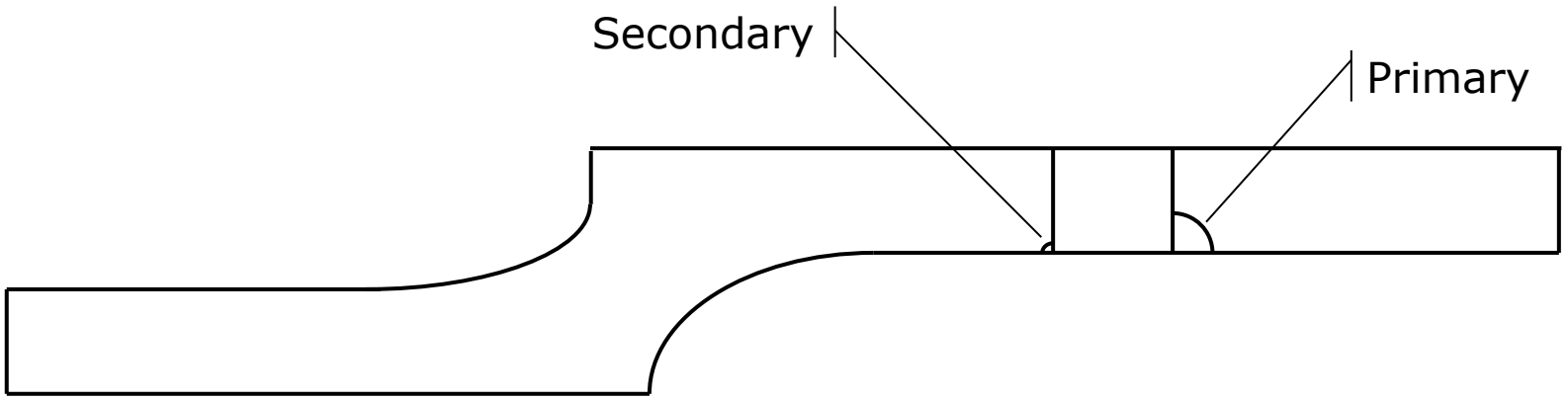
Domenico Quaranta (Principal Engineer – Fatigue Damage Tolerance)

OUTLOOK

- Typical problem
- Small Cracks
- Proposed Solution
- Total Fatigue problem

TYPICAL PROBLEM

- Typically we need to address models where we have a conventional ‘primary’ crack, initial size 0.05 inch, and a ‘secondary’ manufacturing flaw of 0.005 inch.



- We generally do a ‘continuing damage approach’ so after the Primary crack goes through the ligament, we keep propagating the secondary crack.

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TYPICAL PROBLEM

- While the primary crack grows, also the secondary crack grows, at a slower rate, being characterized by smaller SIFs.
- For this analysis, using models allowing a single crack, a 2 stages approach can be used:
  - Stage one: only Primary crack in the model.
    - This is considered as appropriate because the primary crack is assumed to be negligibly influenced by the presence of the secondary crack.
  - Stage two: only Secondary crack in the model with ligament simulated as a slot.
    - The secondary crack IS influenced by the primary and grows, slower, simultaneously with the primary.
    - Problem: what is the size, at ligament failure, of this secondary crack?

TYPICAL PROBLEM

- Today we can simulate the model with two simultaneous crack (e.g. Advanced model in AFGROW) however the question is:

- Is the da/dN model that we generally use, derived from tests with ‘conventional’ cracks, applicable?

- In other words, is the CG solution coming from AFGROW or whatever other SW correct when we use a da/dN model for all scales of crack lengths?

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- The following charts are the results of studies performed by the Australian DSTG (L. Molent).

L. Molent, S.A. Barter / International Journal of Fatigue 29 (2007) 1090–1099

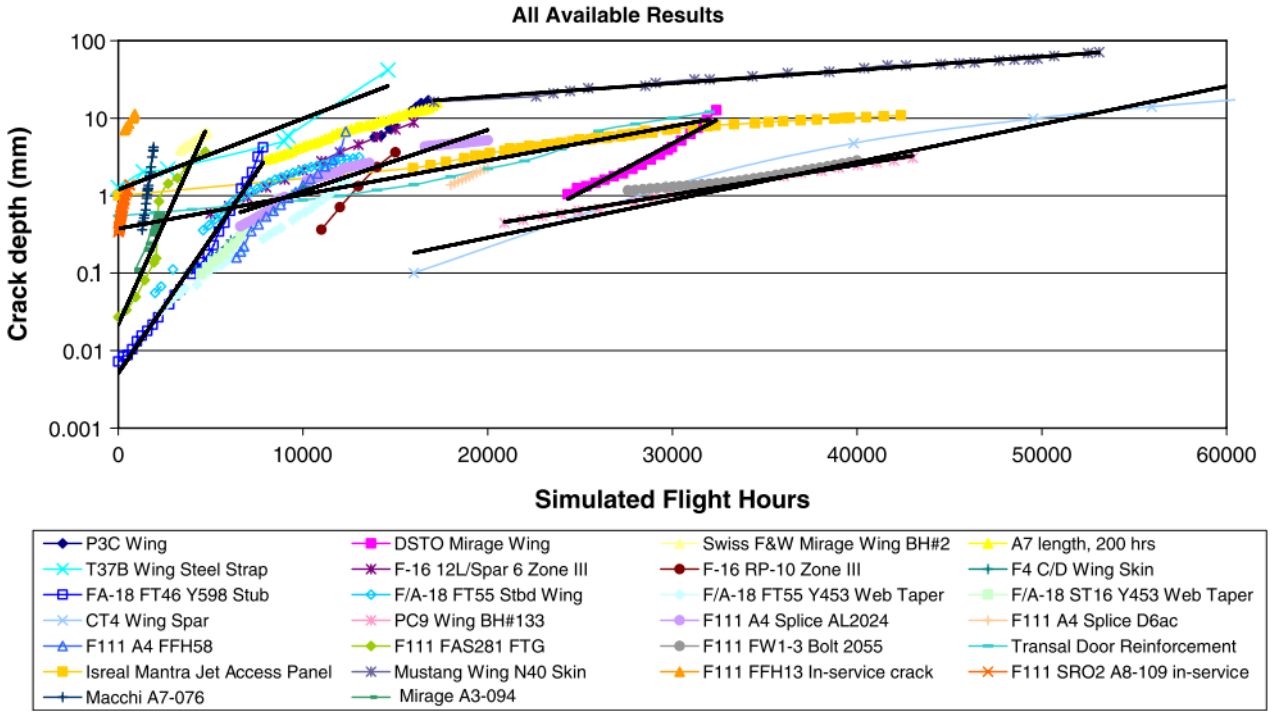

Fig. 4. Available FSFT and in-service crack growth history data (with some trendlines).

SMALL CRACKS

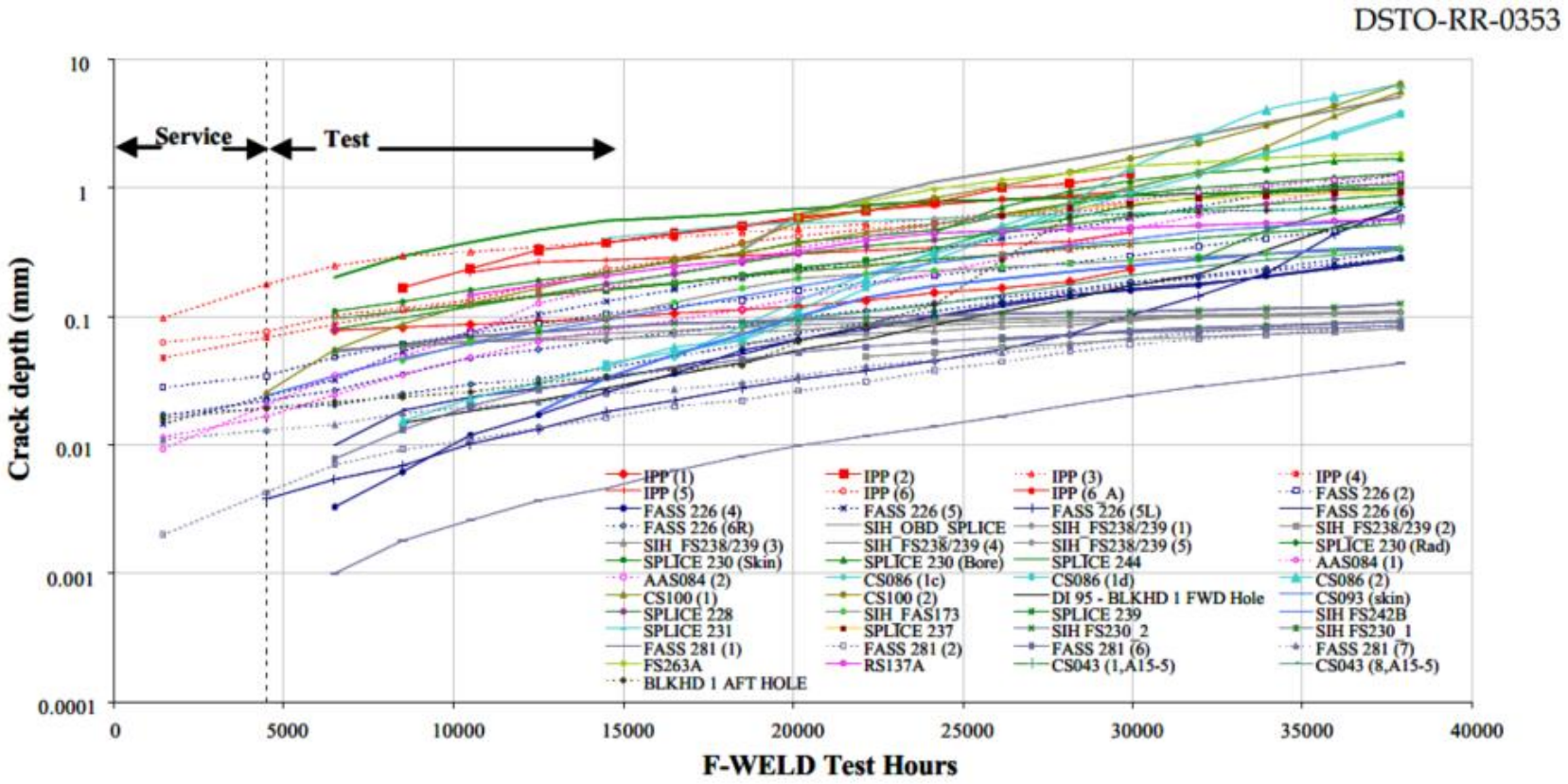

Figure 1: Sample of FCG curves from different locations in the aluminium alloy (AA) 2024-T851 lower wing skin of an F-111 test article removed from service [17]. CS = central spar, BLKHD = bulkhead, FASS = Forward Auxiliary Spar Station inches, IPP = Inner Pivoting Pylon, RS = Rear Spar.

SMALL CRACKS

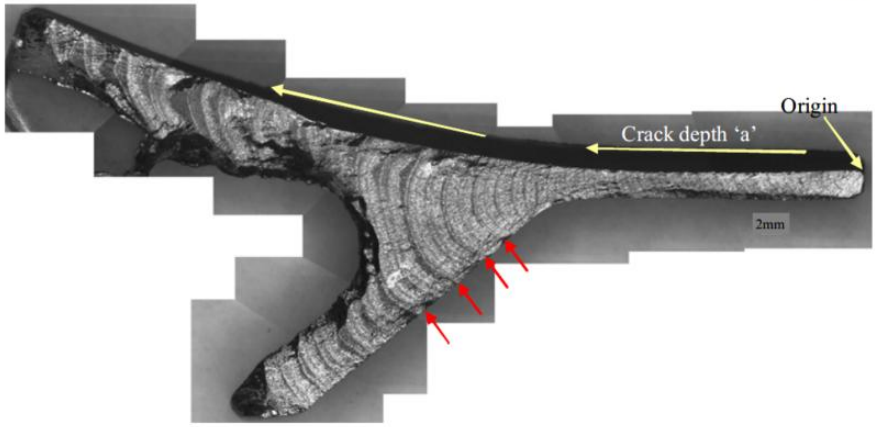

Figure A.2: Optical fractograph of a fatigue crack growing through a major change in geometry, known as the FT46 (AA7050-T7451) Y557 kick-point, under combat aircraft (F/A-18) flight-by-flight block loading [A.3,A.4]. The pattern of the block repeats (some marked by red arrows) was used to generate the FCG curve in Figure A.3. The large arrows indicate the direction of crack measurement.

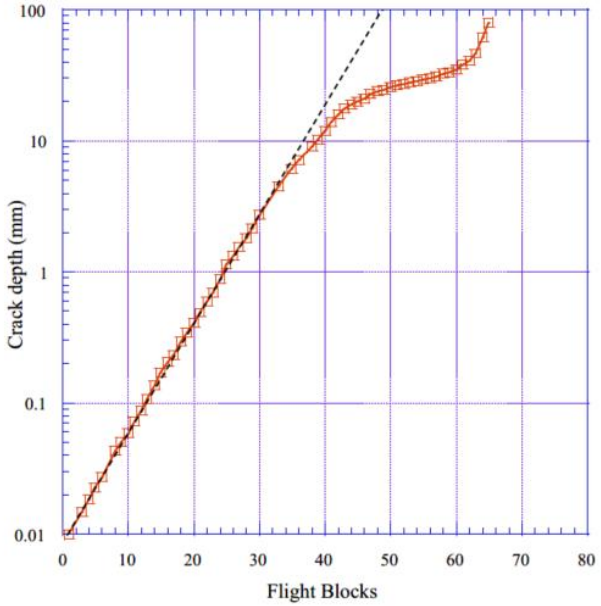

Figure A.3: FCG curve derived for the FT46 Y557 kick-point [A.4]. The commencement of decreasing FCG rates corresponds to the crack entering the 'Y' junction, see Figure A.2. The dashed line represents exponential FCG and would give a conservative estimate of the FCG life.

- **The study shows that in a log-linear chart, there is a linear growth throughout the CG at different length scales,** in absence of residual stress field…

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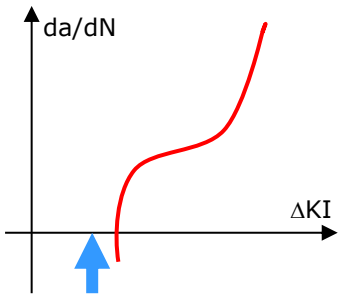
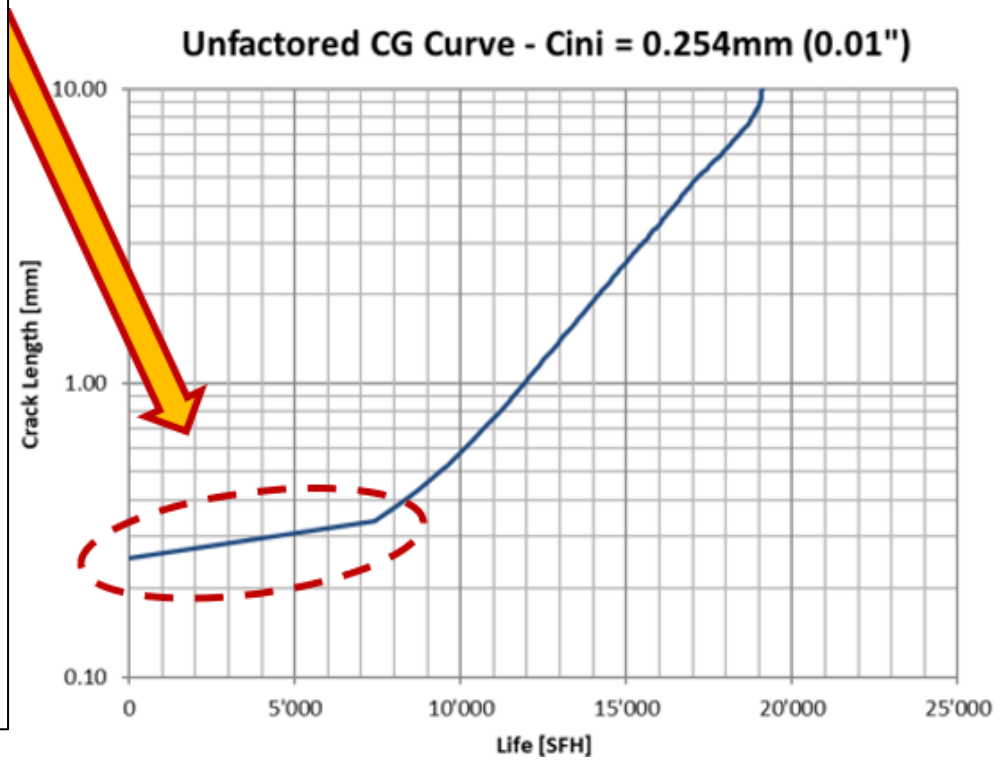
- …however if we would do a CG analysis we generally get something like this, which is unconservative:

At small crack lengths the calculated SIF cycles ΔKI could end up in the threshold region of the da/dN curve, or behind, resulting is a predicted very slow rate. In the semi-Log chart a kink will appear, not reflecting the outcome of the study





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SMALL CRACKS

- Small cracks trigger small Stress Intensity Factors

$$K_I = \beta \cdot S \cdot \sqrt{\pi a_{small}}$$

- When a da/dN curve is used, derived for conventional crack lengths (not small), it is possible that the calculated SIF falls within or below the threshold region.

- **However the da/dN behavior, when the crack is small, is different**: while the crack is within a single crystal grain, the growth rate is much higher than estimated from the usual da/dN(ΔK). Upon encountering a grain boundary, the growth is temporarily retarded.

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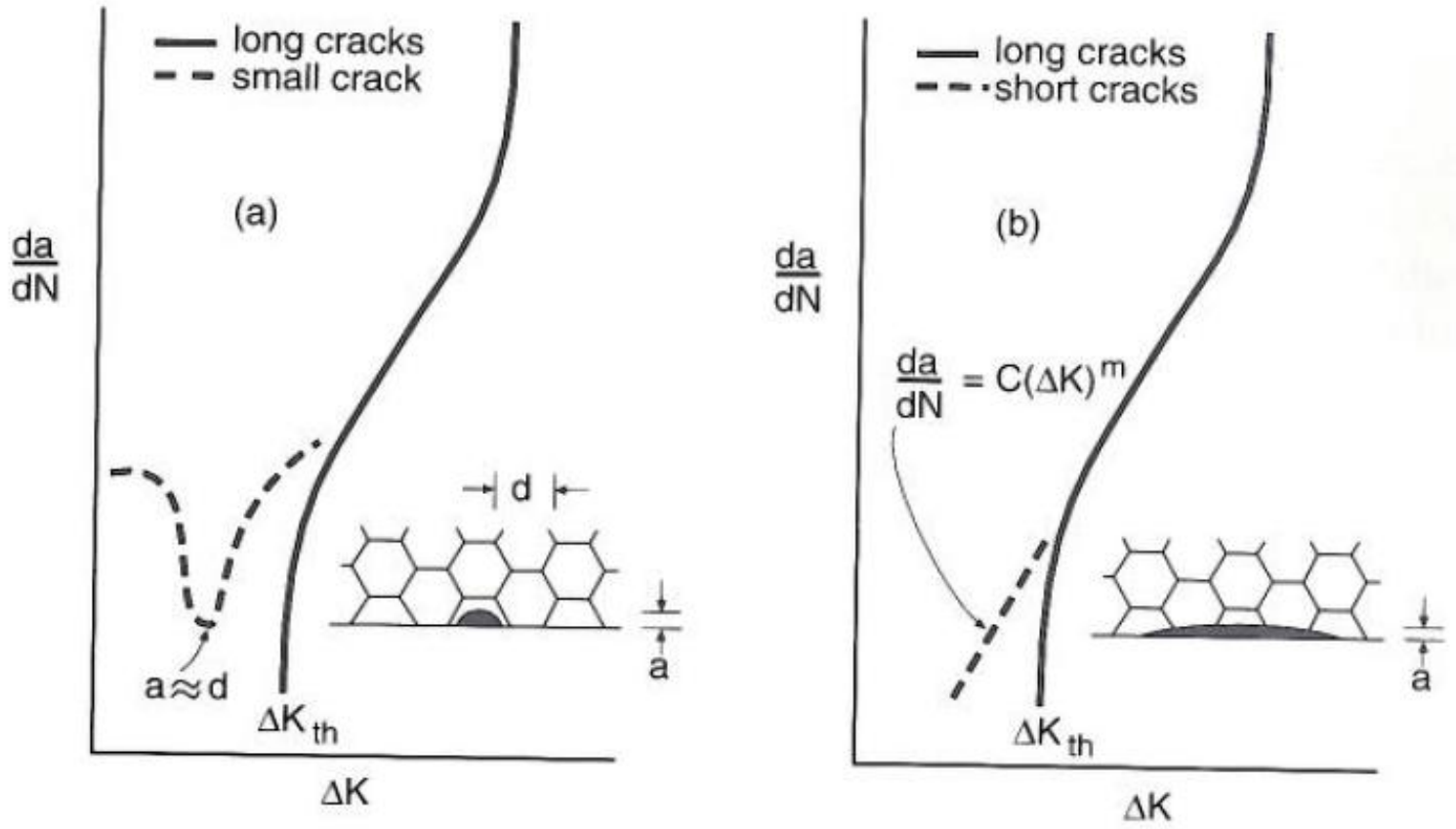
- From Dowling and other sources:



SMALL CRACKS

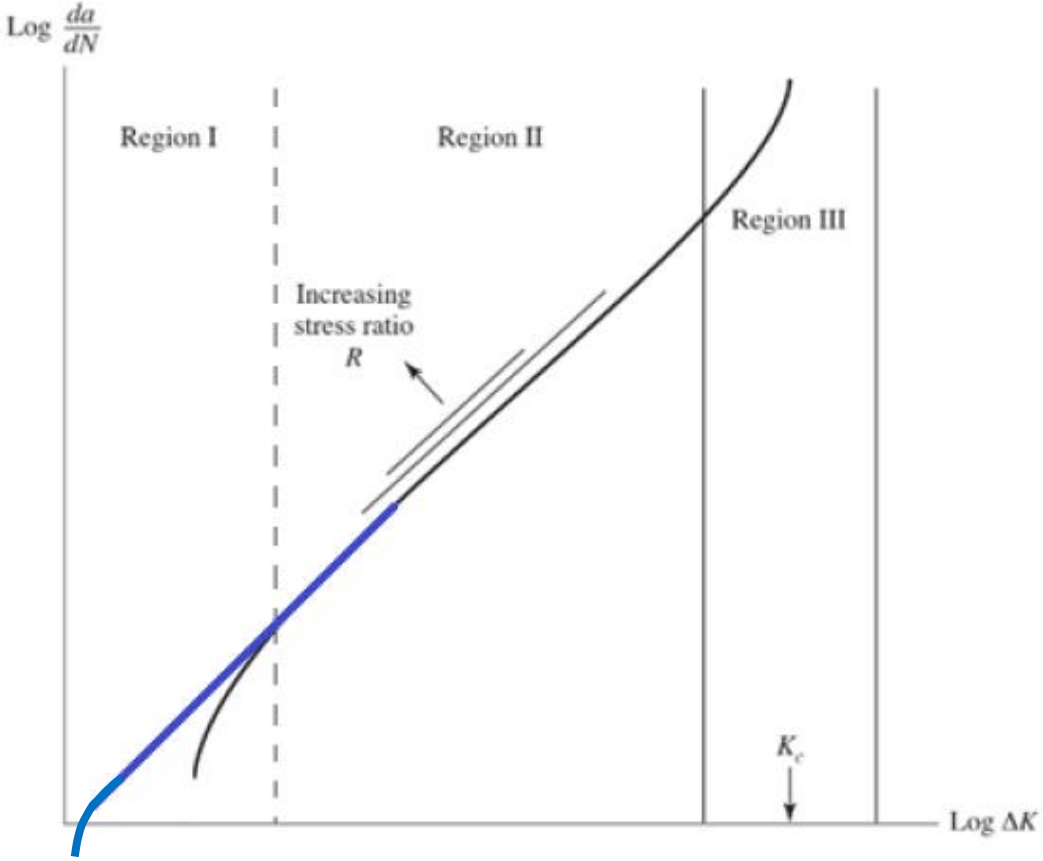
- From Dowling:

- "A less drastic effect occurs if the crack is short in one dimension and large compared with the microstructure in the other dimension. Growth rates for such cracks in metals are similar to the estimated da/dN(ΔK), apart from the threshold region, where a reasonable estimate of the behaviour can be obtained by extrapolation."

- Based on the above the proposal comes to consider, in case of small cracks, a modified material with extended Paris region in the Threshold region

PROPOSED SOLUTION

- During integration of da/dN we check the current crack size ‘c’ and compare to a ‘threshold’ length $C_{\Delta Ko}$:
  - If $c > C_{\Delta Ko}$ then the conventional da/dN is used
  - If $c < C_{\Delta Ko}$ a modified da/dN is used
- If the NASGRO equation is used we could ‘alter’ $\Delta K0$ parameter to extend artificially the curve



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PROPOSED SOLUTION

- In case of tabular lookup material, the material curve can be adjusted such to extend the Paris region to the Threshold region.

- Eventually the CG run is performed defining TWO materials:
  - One, conventional, to be used when the crack is above a defined length $C_{\Delta Ko}$
  - One, modified, to be used when the crack is below $C_{\Delta Ko}$

- Jim Harter proposal: for $c < C_{\Delta Ko}$ use a single material curve at R=Rhi (≈0.7) with modified threshold ($\Delta K_{th,short} < \Delta K_{th,long}$). The reasoning behind this is that short cracks are not affected much by the stress ratio R and can be considered as being always in open mode, see next page.

PROPOSED SOLUTION

International Journal of Fatigue 142 (2021) 105980

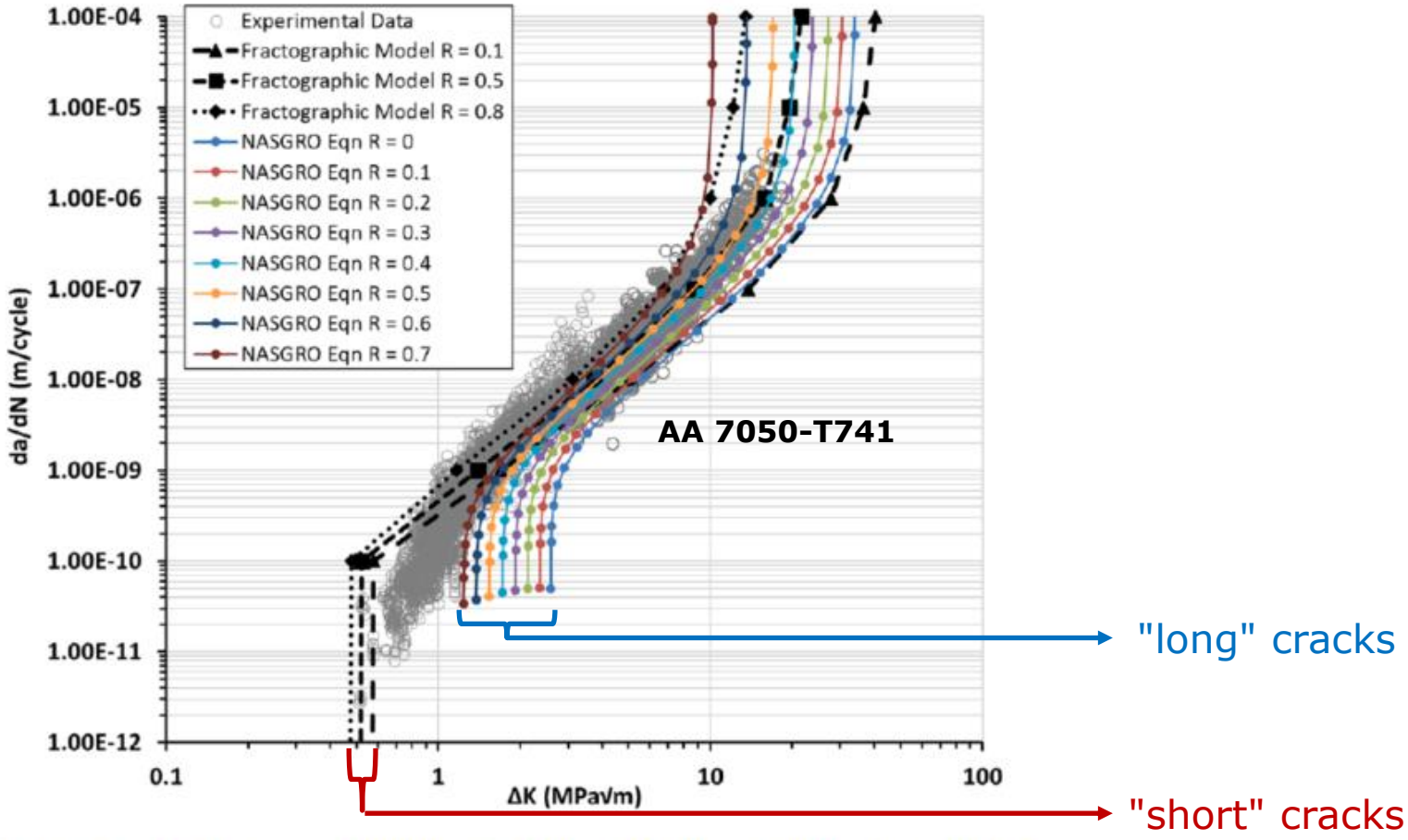


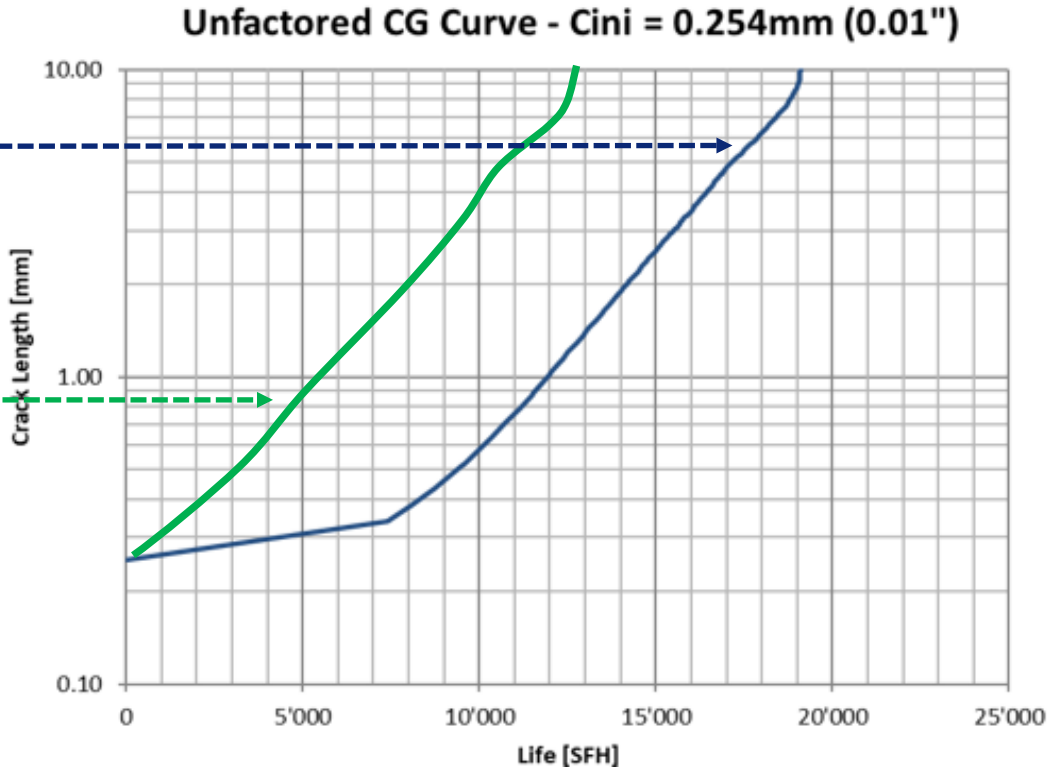
Fig. 8. Two FCGR material models – the NASGRO Equation as implemented in AFGROW [7] at eight R-ratios and a fractography based short crack model at three R-ratios [38,39]. A cloud of QF measured CA data points upon which the fractography based model was developed is shown in grey.

PROPOSED SOLUTION

- The result of such a modification eliminates the kink in the resulting CG, moves the CG curve related to the long length scale to the left and eventually delivers a 'linear' response in the semi-Log scale.

with long crack data…

With modified ΔK0



TOTAL FATIGUE PROBLEM

- The proposed method helps also to cope with Total Fatigue problems, i.e. in situations where the calculation of CI + CG life is required.
- Example:
  - We have an accidental crack in a location where in the FSFT article no artificial damages were introduced.
  - We need to define an inspection regime for this location
- The CG analysis for the inspection definition must be calibrated with a CG analysis which considers an initial Equivalent Pre-crack Size (EPS). For etched aluminum, the EPS is typically around 0.01 mm, see pages 6 & 7.
- In the past we did a mixed strain-Life and CG assessment but now with the proposed approach we can tackle the problem with a single CG analysis.