FATIGUE CRACK GROWTH DATABASES FOR THRESHOLD BEHAVIOR IN ROTORCRAFT MATERIALS

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Dr. Dy Le, Monitor, FAA William J. Hughes Technical Center
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OBJECTIVES OF RESEARCH WORK

- **Conduct crack-growth tests from threshold to fracture on:**

  - 7075-T651 (LT; B = 0.225 in.; W = 3 in.; MSU)
  - Ti-6Al-4V (β-STOA; B = 3/8 in.; W = 3 in.; Sikorsky)
  - 4340 Steel (B = 1/4 in.; W = 2 in.; Boeing)

- **Generate the ΔK_{eff}-rate curves for:**

  - 7050-T7451 (LT)
  - Ti-6Al-4V (β-STOA)
  - Mg AZ91E

  being tested at NASA Langley (A. Newman & M. James)

- **Develop proposed annex to ASTM E-647 on compression precracking constant amplitude (CPCA) and load-reduction (CPLR) threshold testing**

THRESHOLD TEST METHODS

- Load-Reduction (LR) Procedure (ASTM Standard)
- Compression Pre-cracking Constant-Amplitude (CPCA) Testing Procedure
- Compression Pre-cracking Load-Reduction (CPLR) Testing Procedure
- Compression Pre-cracking Constant-ΔK Loading (CPCK) Procedure (not used)
- K_{max} (equal constant) Test Procedure (not used)

EXPENDITURES (as of May 31, 2006)

	Budget	Expended	Available
FAA	312,000	210,846	101,154
MSU Share	224,530	198,394	26,136
Salaries	162,675*	96,551	66,124
Fringe	33,496	21,899	11,597
Tuition	8,998	5,597	3,401
Travel	16,700	15,119	1,581*
Contractual	31,272	29,845	1,427
Equipment	176,487	169,503	6,984
Indirect	106,902	70,726	36,176
Total	536,530	409,240	127,290

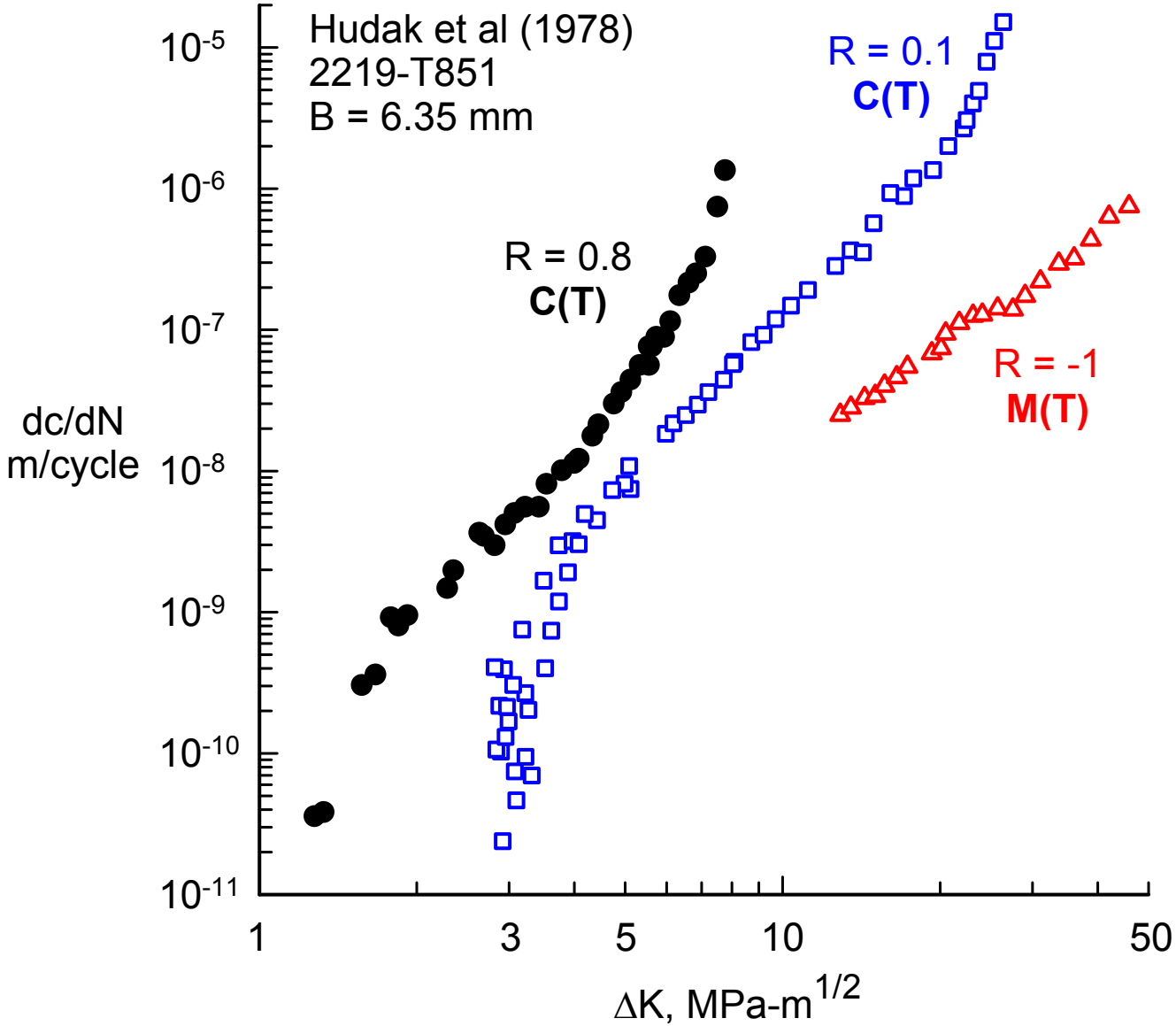
***Salary changed to equipment (J. Schneider left project) and to travel**

CRITICAL ISSUES AND CONCERNS

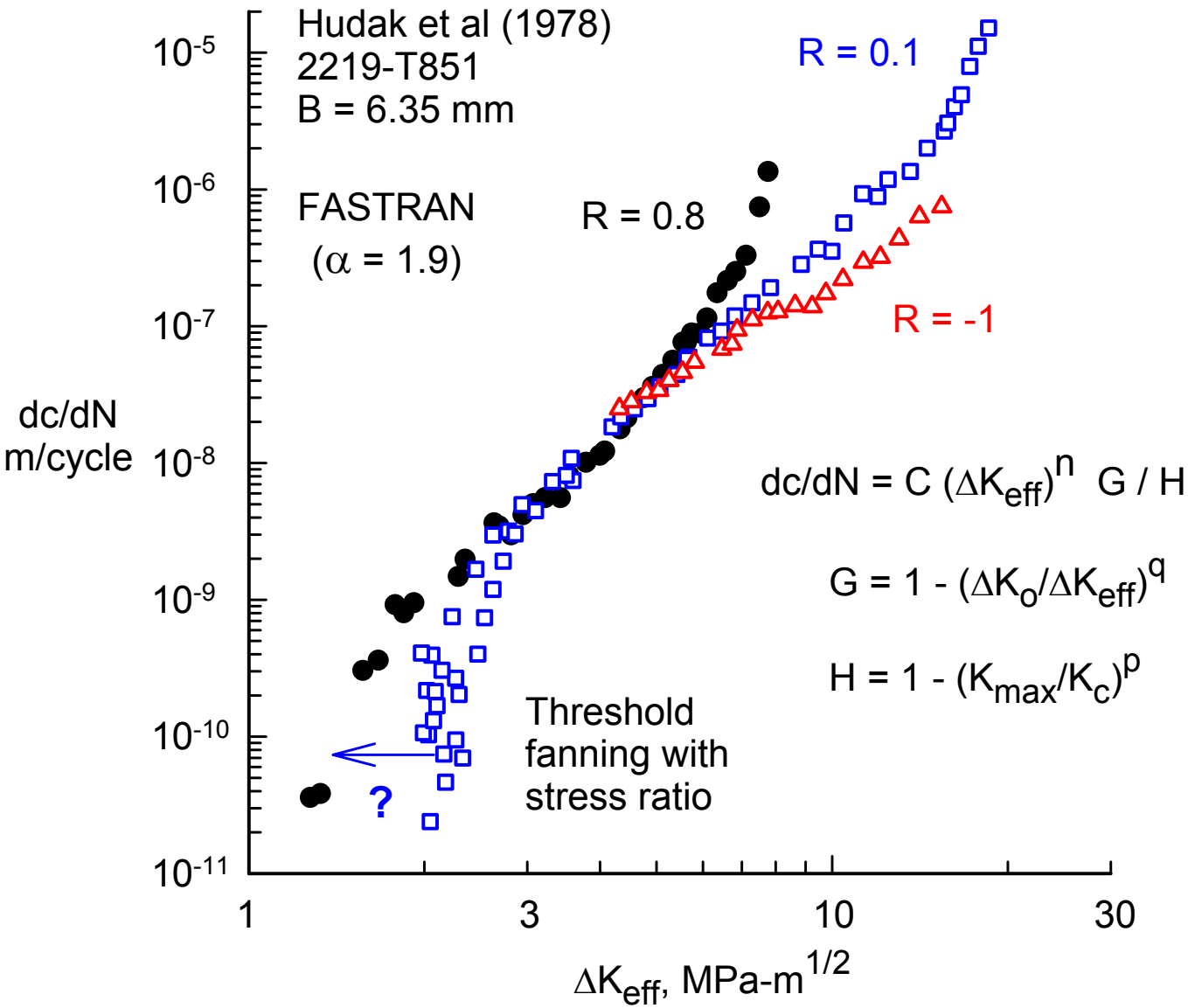
- Overheating and equipment failures have delayed testing, only 2 test machines have been fully operational, but a new pump (additional MSU cost-share funds, $22k) will allow the use of 4 test machines for the remaining 9-months of the grant

- Travel funds are low, but remaining contractual funds will be used to cover any shortfalls or one additional trip

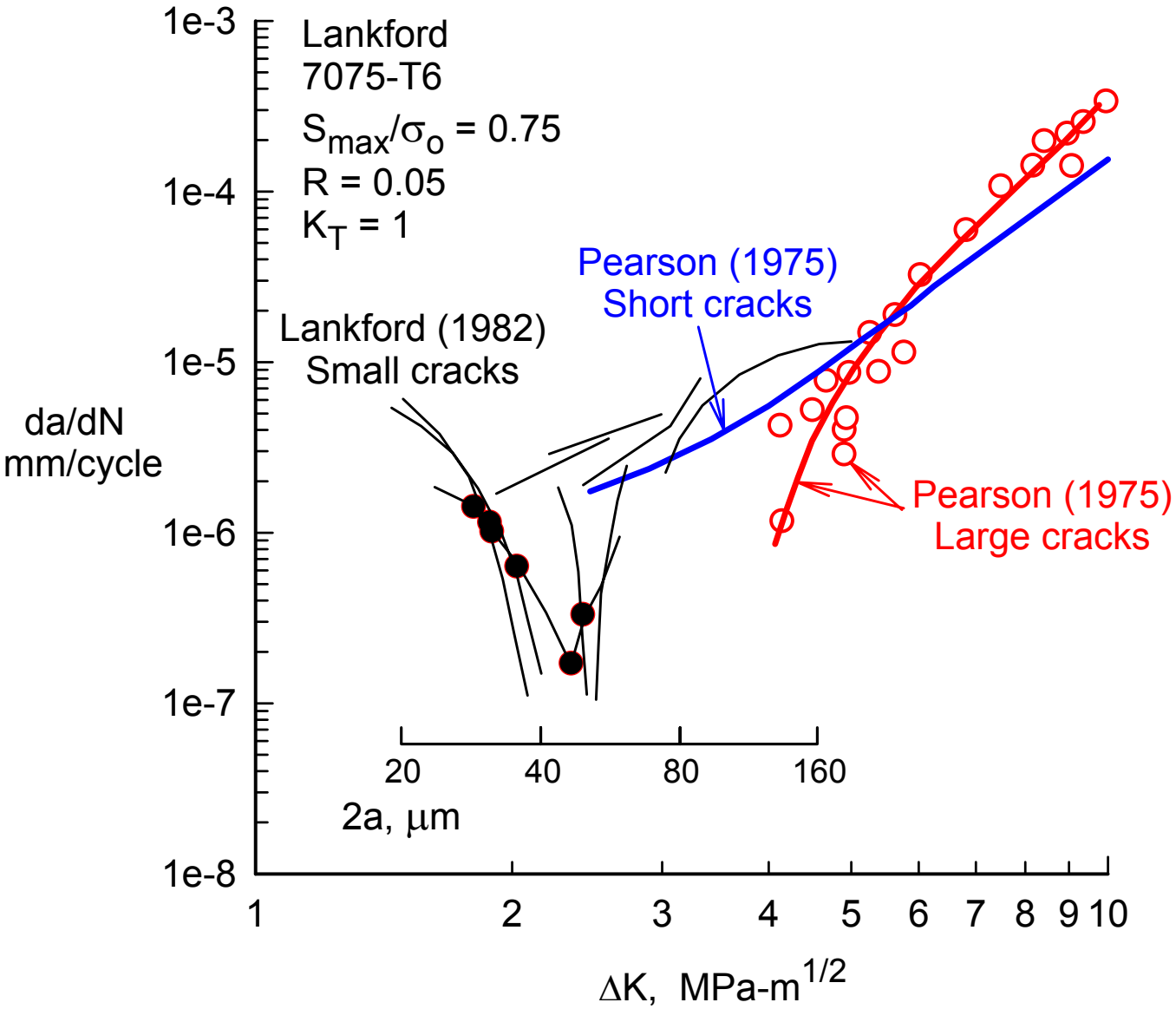
DATA USED IN ORIGINAL DEVELOPMENT OF ASTM LOAD-REDUCTION TEST PROCEDURES



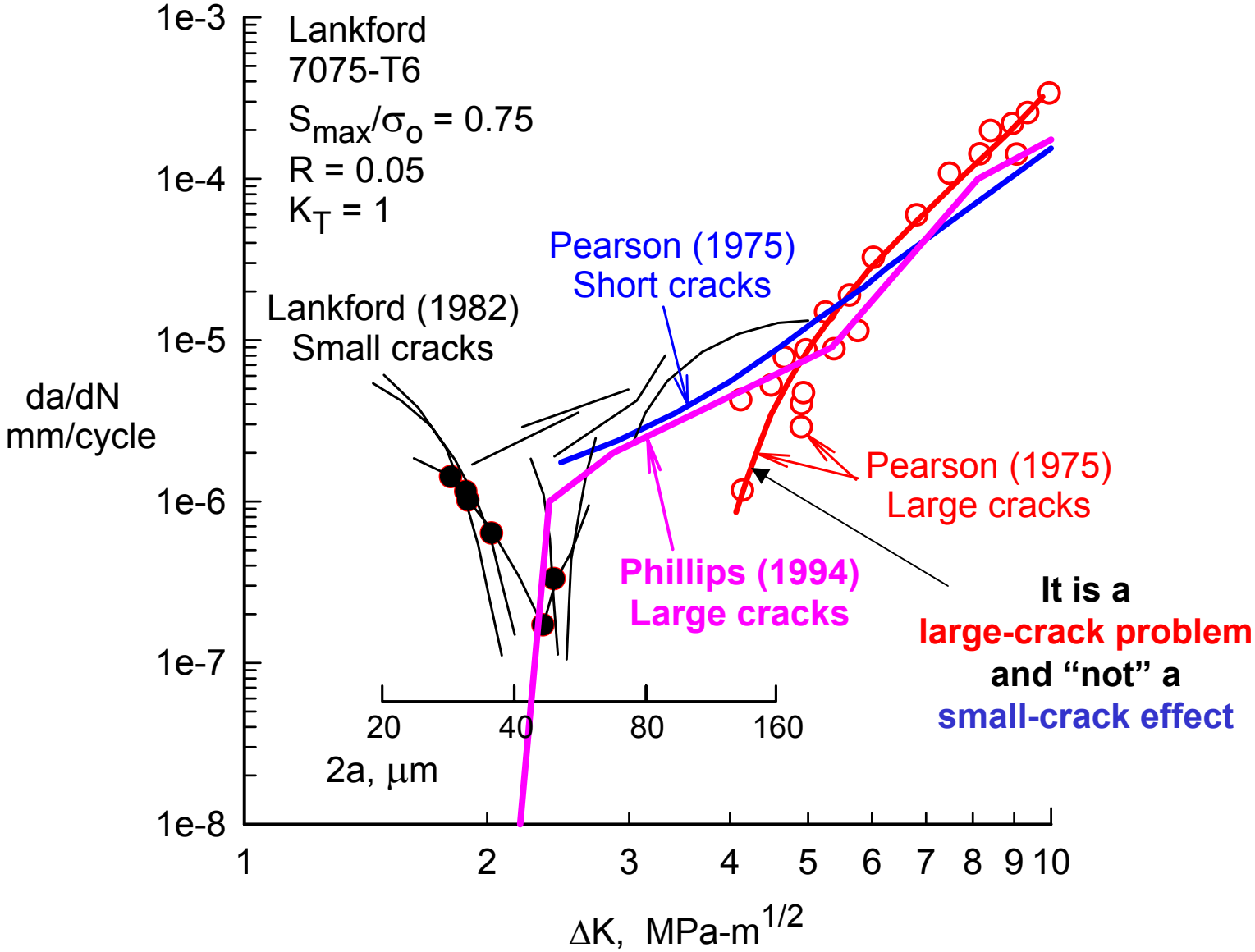
THRESHOLD DATA FANNING WITH R VALUES



COMPARISON OF SHORT/SMALL- AND LARGE-CRACK DATA



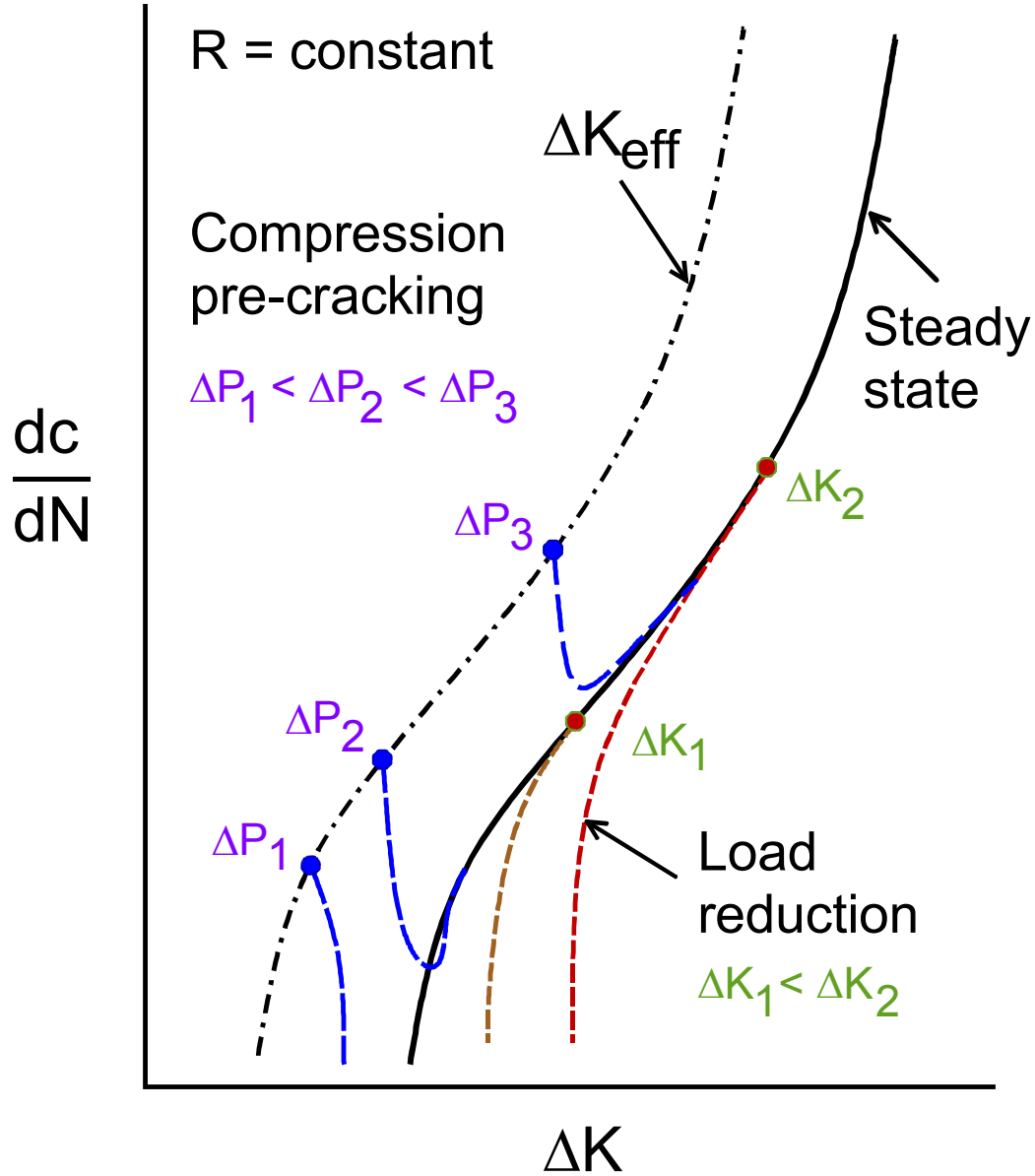
WHAT ARE THE SHORT- OR SMALL-CRACK EFFECTS ?



THE OPENING OF PANDORA'S BOX

- M(T) produce lower thresholds than C(T)
- M(T) show less threshold fanning with R than C(T)
- Thinner specimens produce lower thresholds
- Smaller width specimens produce lower thresholds
- Lower humidity produces lower thresholds
- Threshold behavior is complex interaction between configuration, loading, environment, and crack-front shielding mechanisms

WHAT IS THE CONCERN?



CRACK-GROWTH EXTENSION CRITERIA

Valid crack-growth-rate data for **CPCA** loading:

- $\Delta c = \mathbf{3}\,(1 - R)\,\rho_c$
- $\Delta c = 0.5$ mm for $\theta \leq 60$ degrees

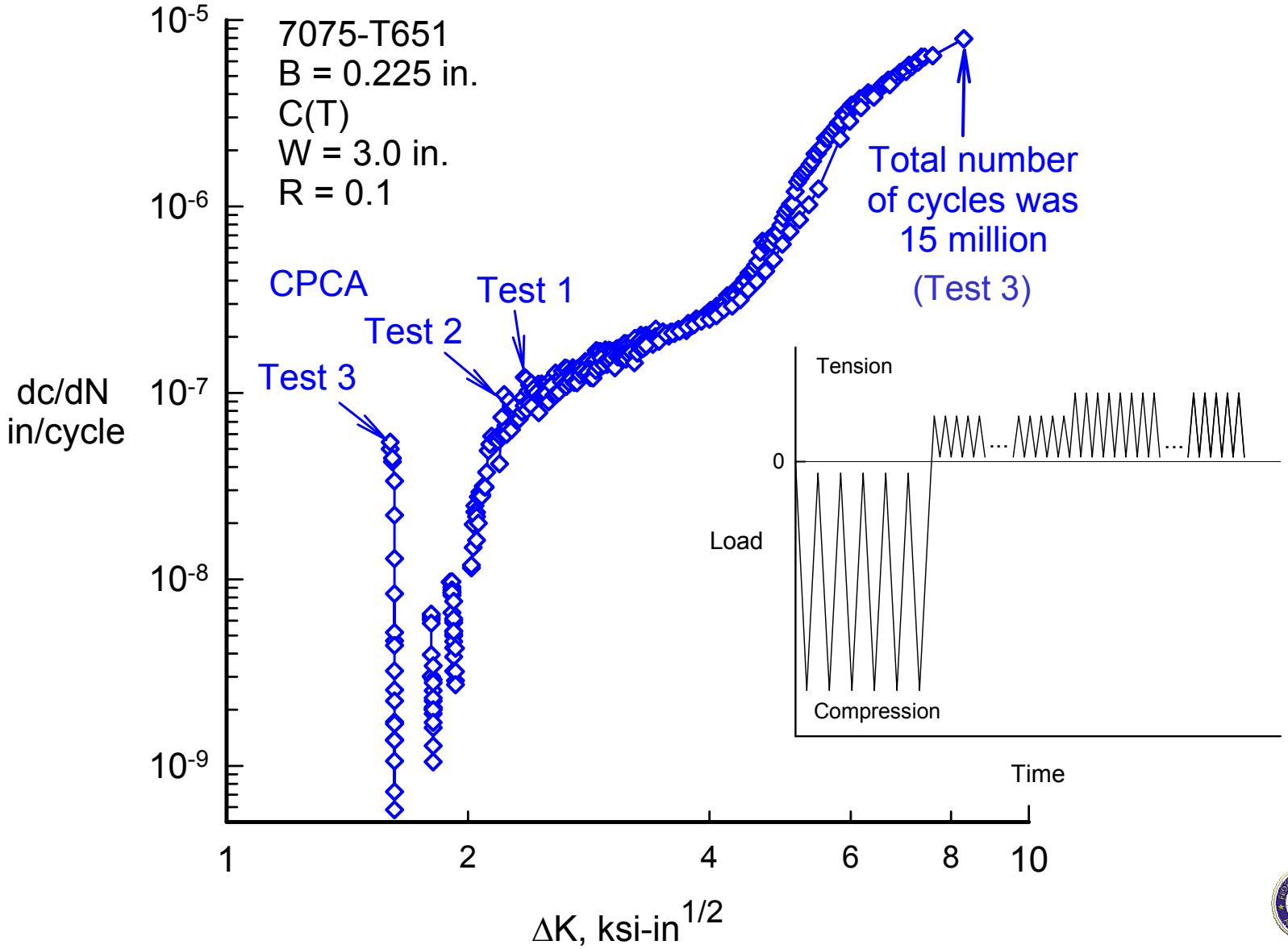
whichever is larger.

Plane stress: $\rho_c = \pi/8\,(|K_{cp}|/\sigma_o)^2$

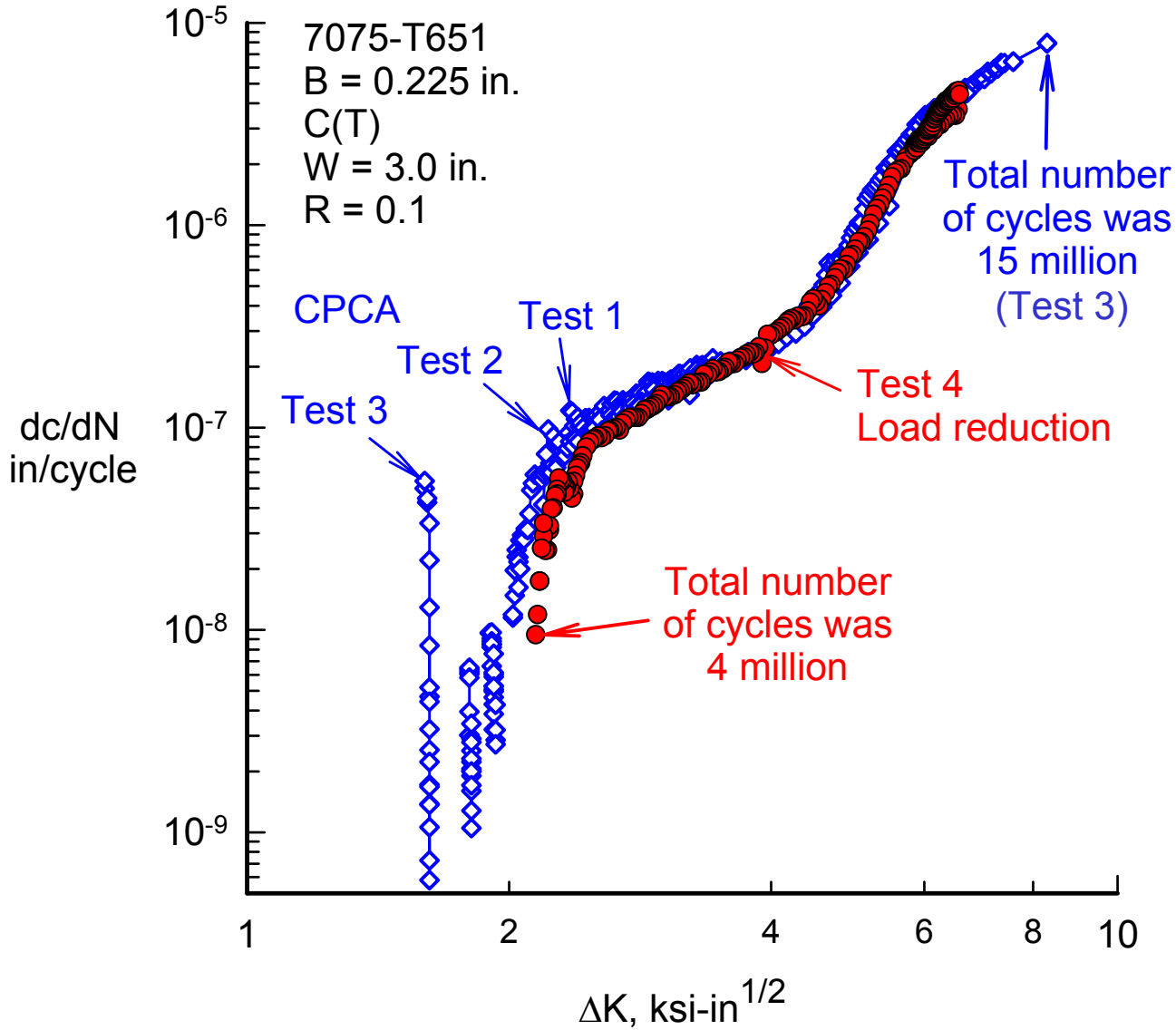
MATERIALS BEING TESTED

- MSU – Aluminum alloy – 7075-T651
- Sikorsky – *Dr. John Wang* – Ti-6Al-4V (β-STOA)
- Boeing – *Dr. Ashok Sane* – 4340 Steel

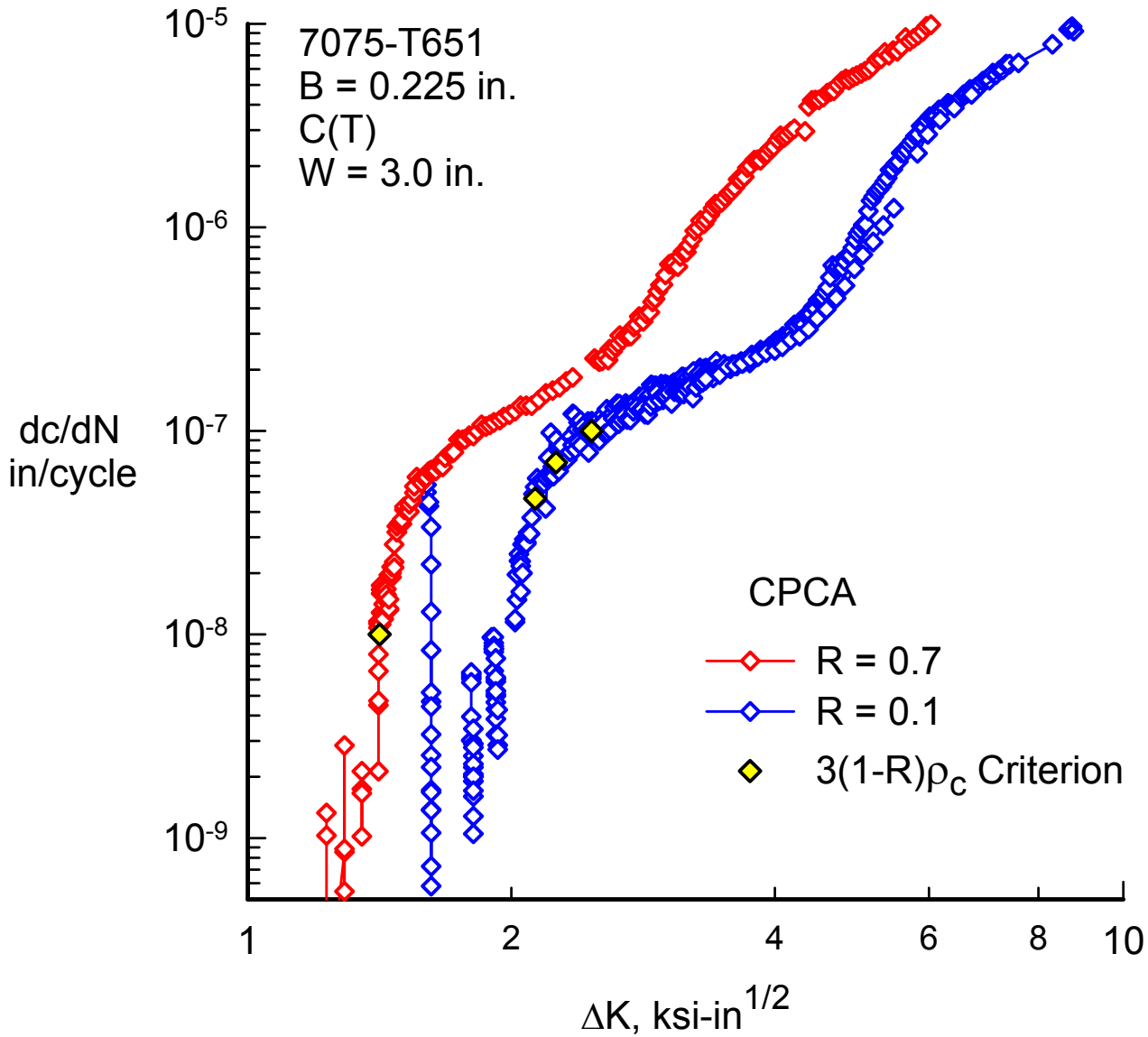
CPCA THRESHOLD TESTING ON 7075-T651 AT R = 0.1 CONDITIONS



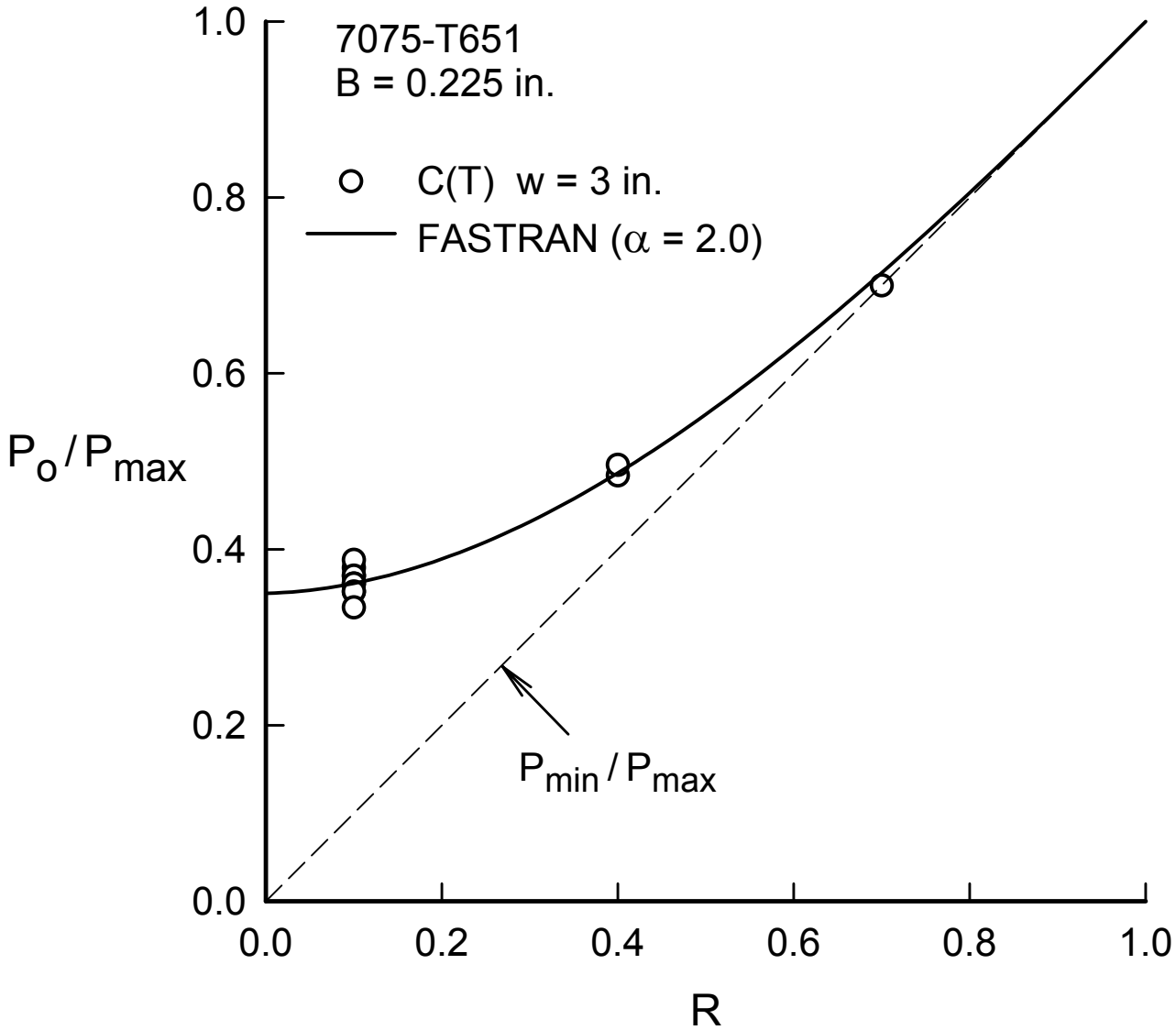
CPCA AND LOAD-REDUCTION THRESHOLD TESTING ON 7075-T651 ALLOY



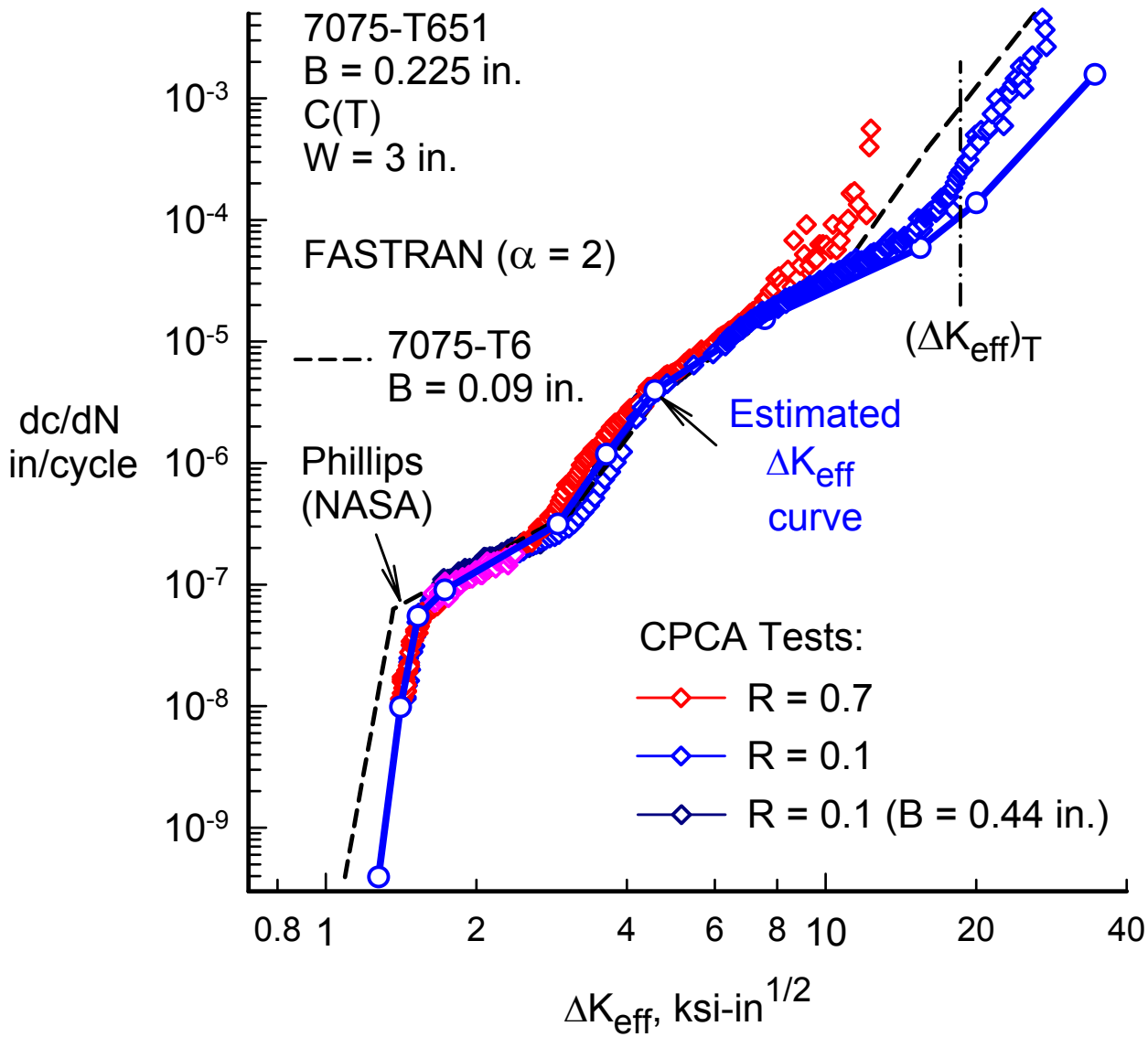
CPCA THRESHOLD TESTING ON 7075-T651 AT LOW AND HIGH STRESS RATIOS



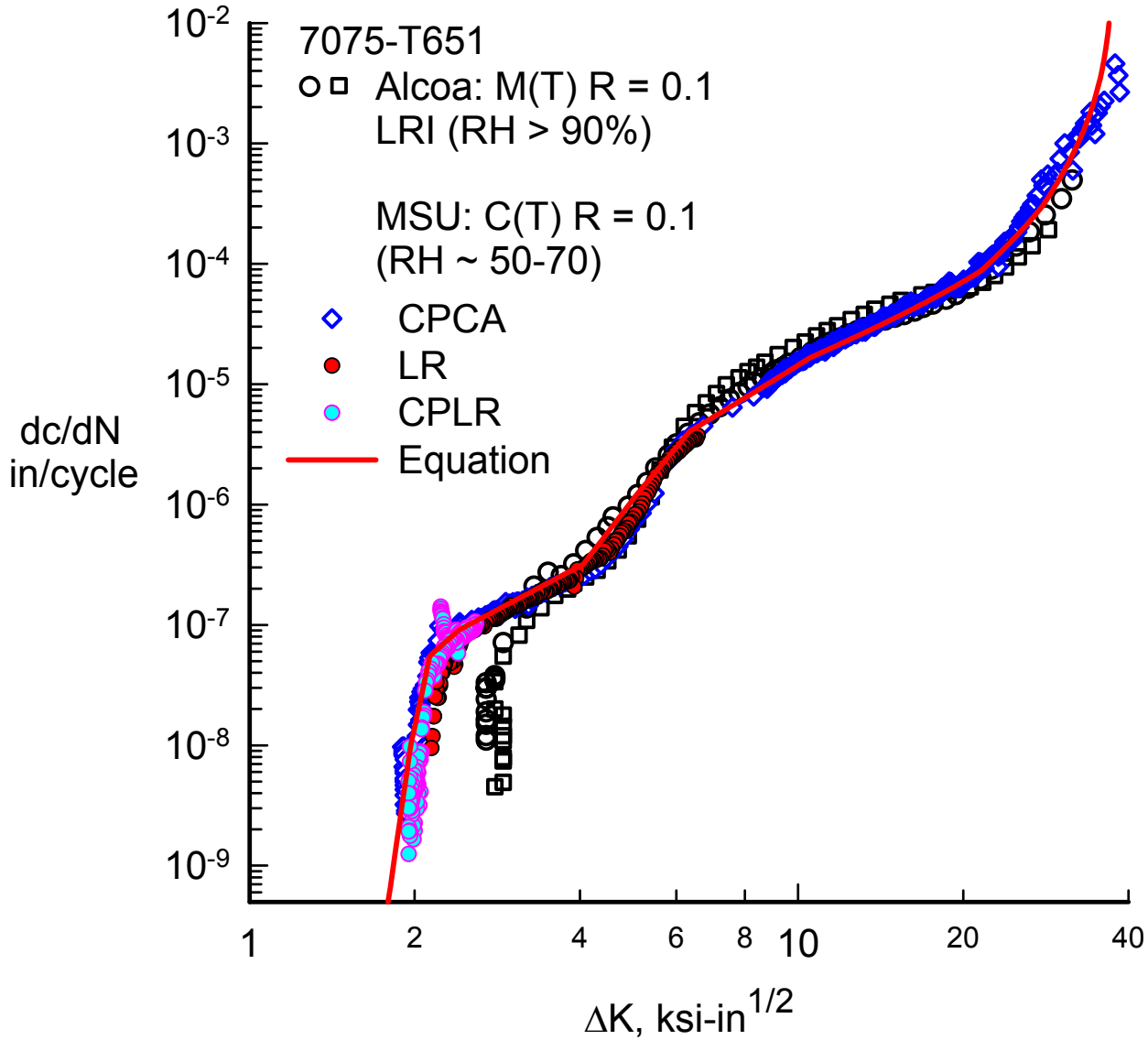
CRACK-OPENING LOAD LEVELS FOR 7075-T651 ALLOY



CRACK-CLOSURE ANALYSES ON 7075-T651



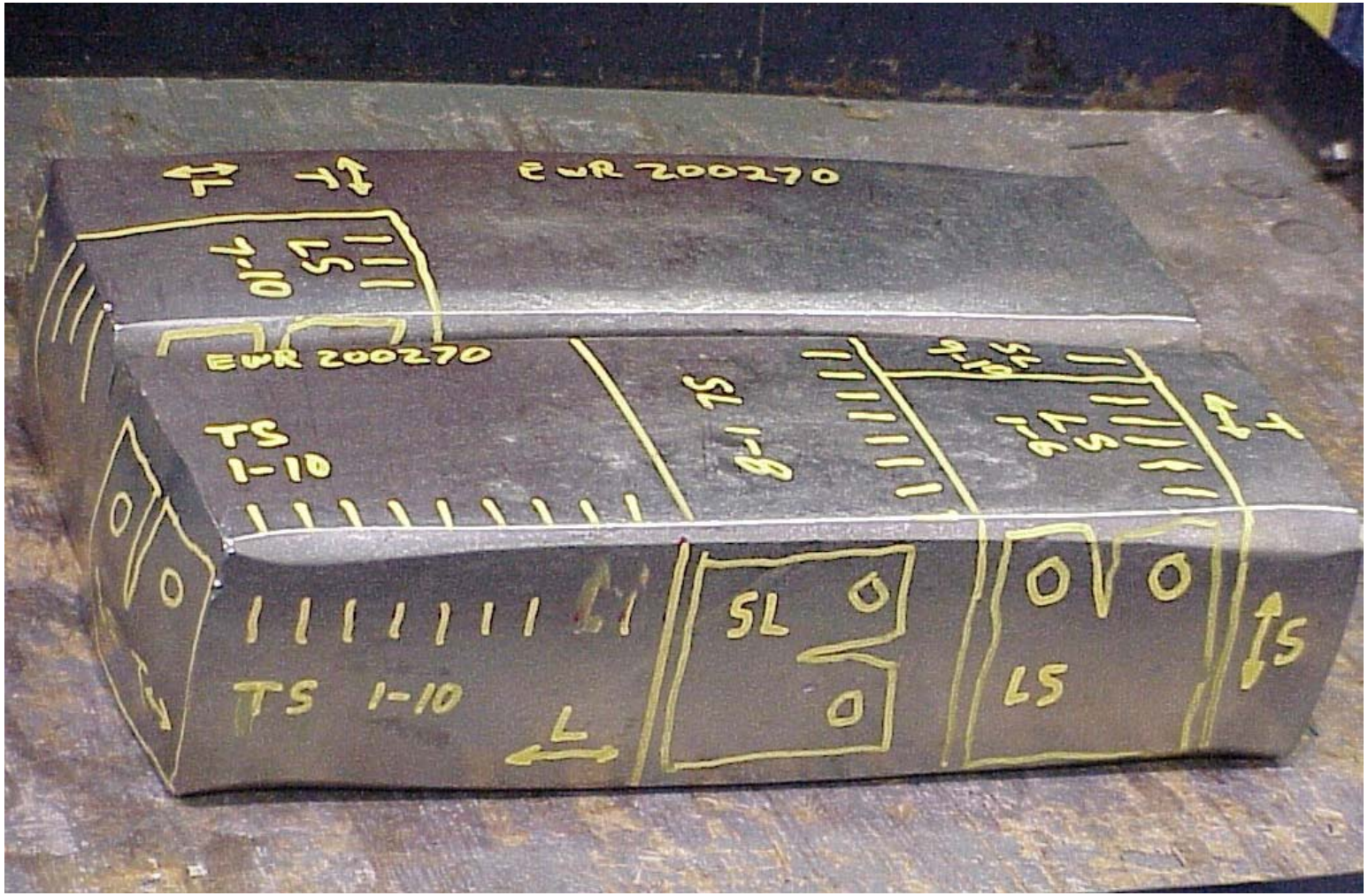
PREDICTED RESULTS AT LOW STRESS RATIO AND COMPARISONS WITH OTHER DATA



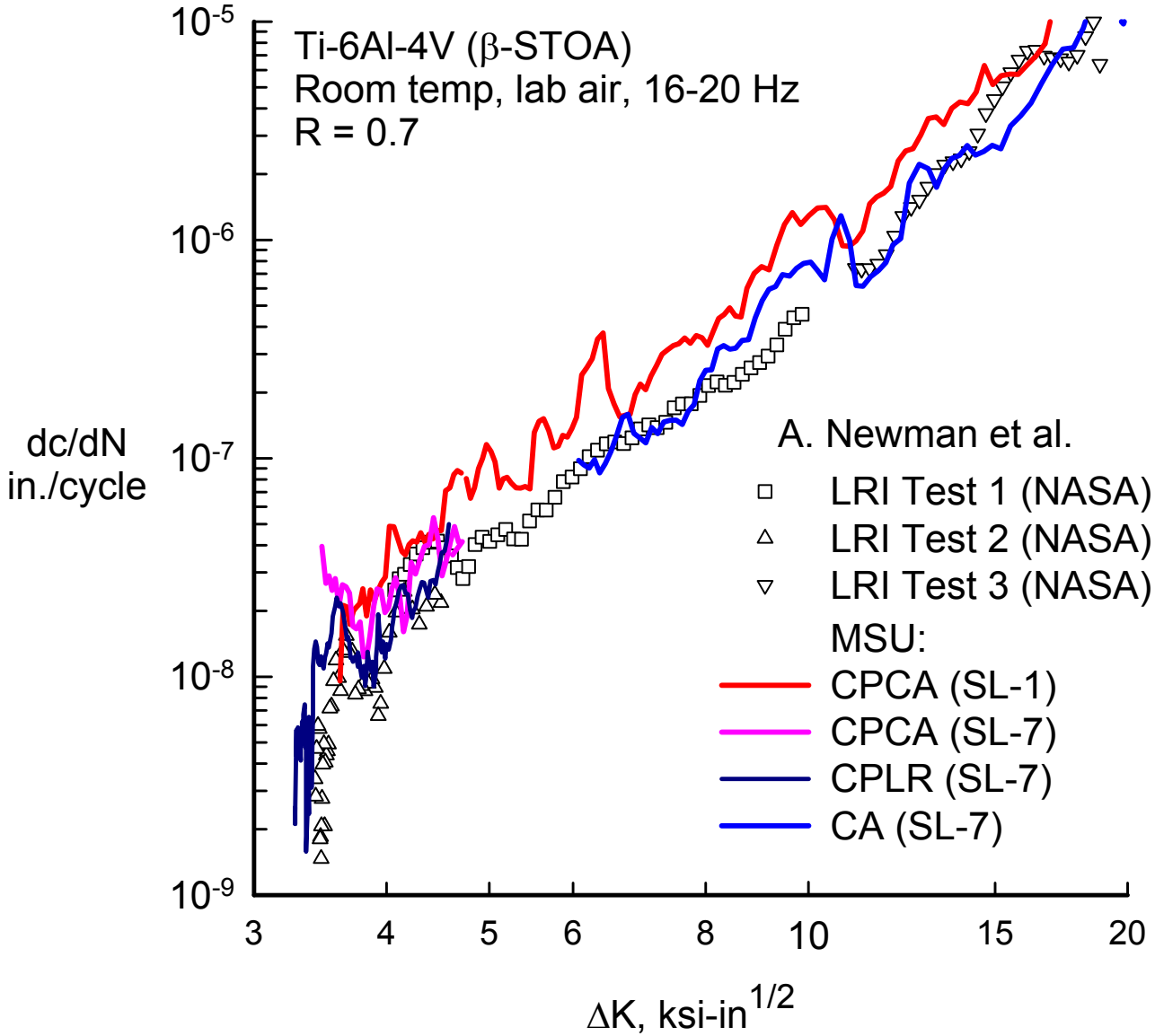
MATERIALS BEING TESTED

- **MSU – Aluminum alloy – 7075-T651**
- **Sikorsky – *Dr. John Wang* – Ti-6Al-4V (β-STOA)**
- **Boeing – *Dr. Ashok Sane* – 4340 Steel**

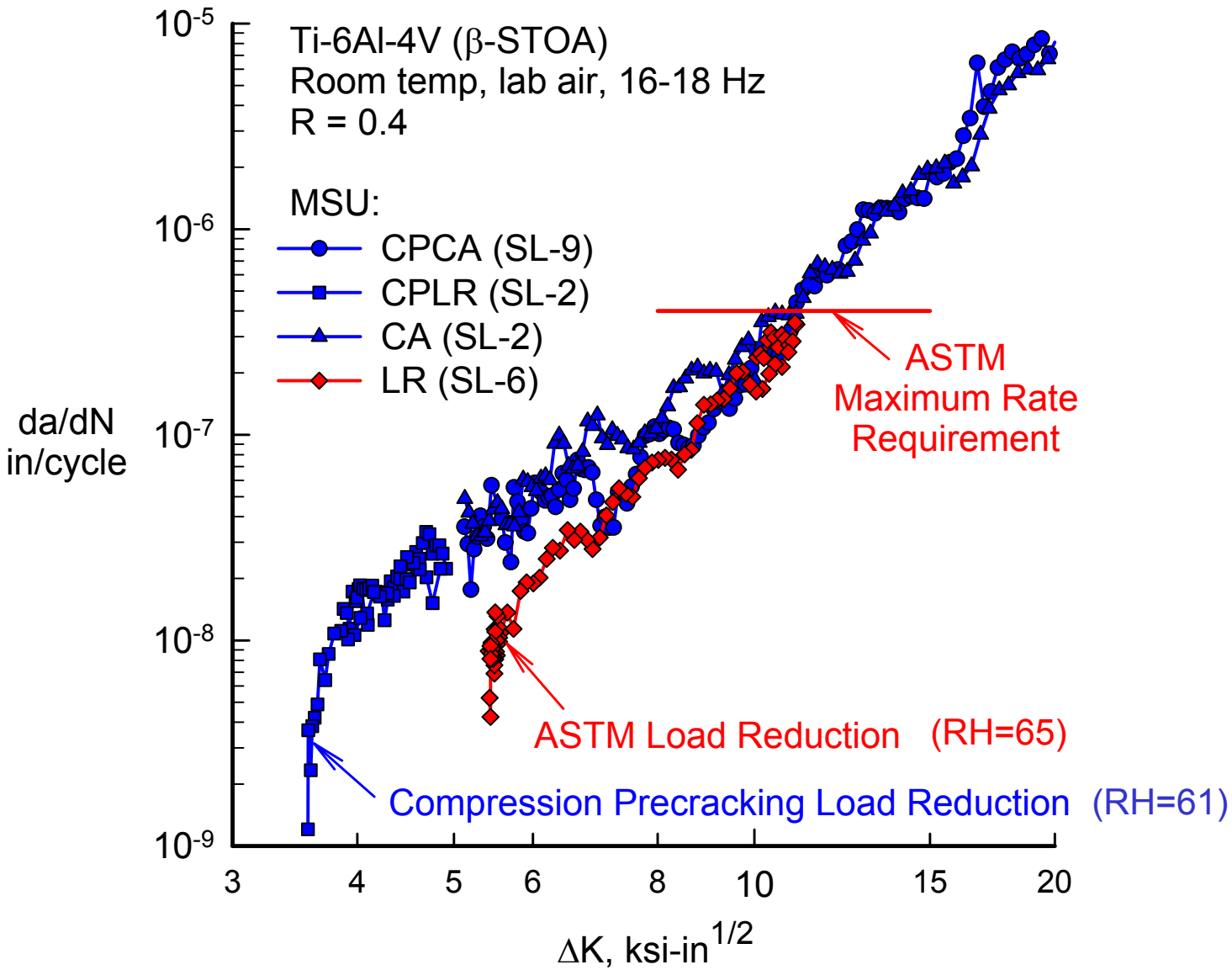
Ti-6Al-4V (β-STOA) Orientations



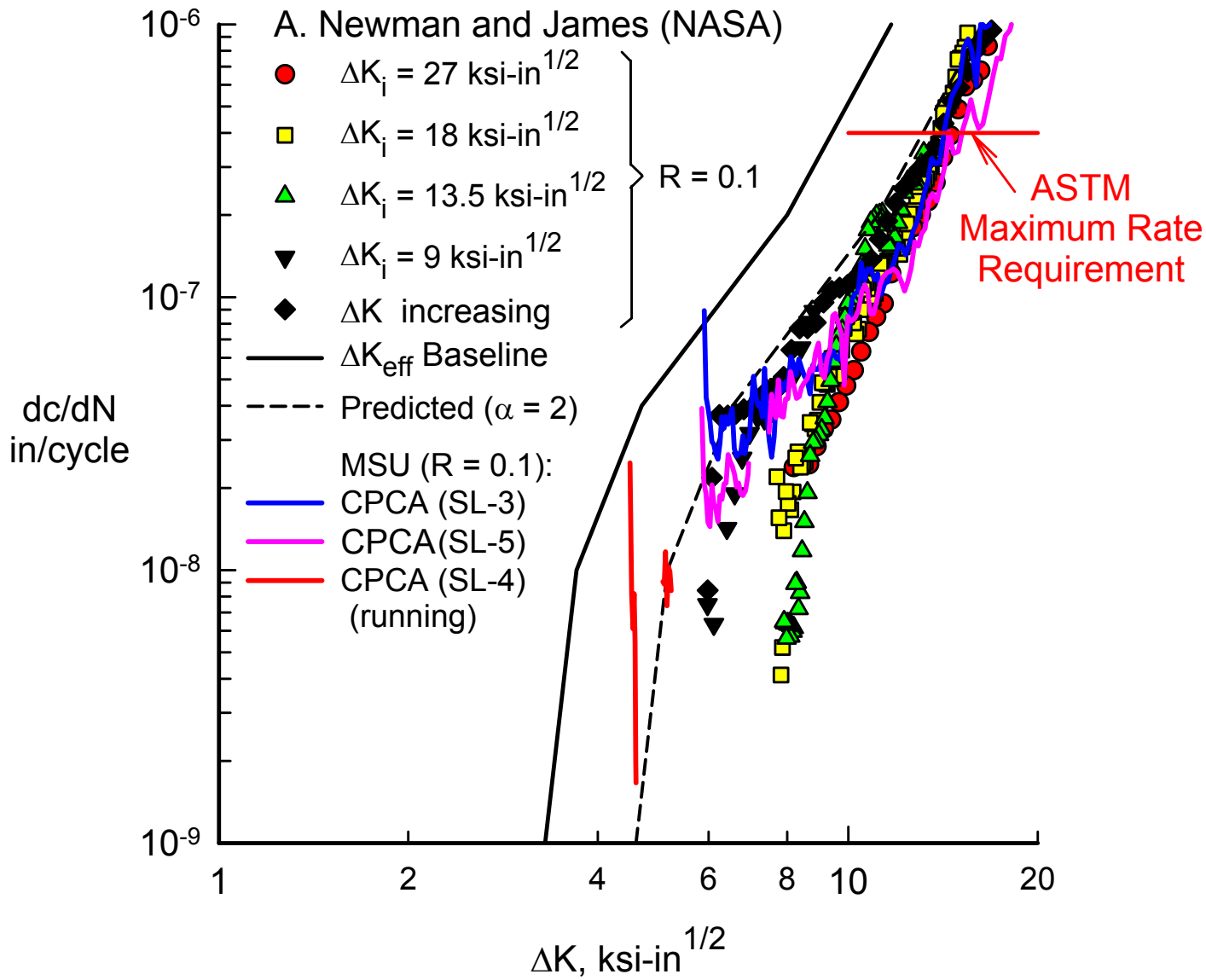
THRESHOLD TESTING AT HIGH STRESS RATIO ON TITANIUM ALLOY



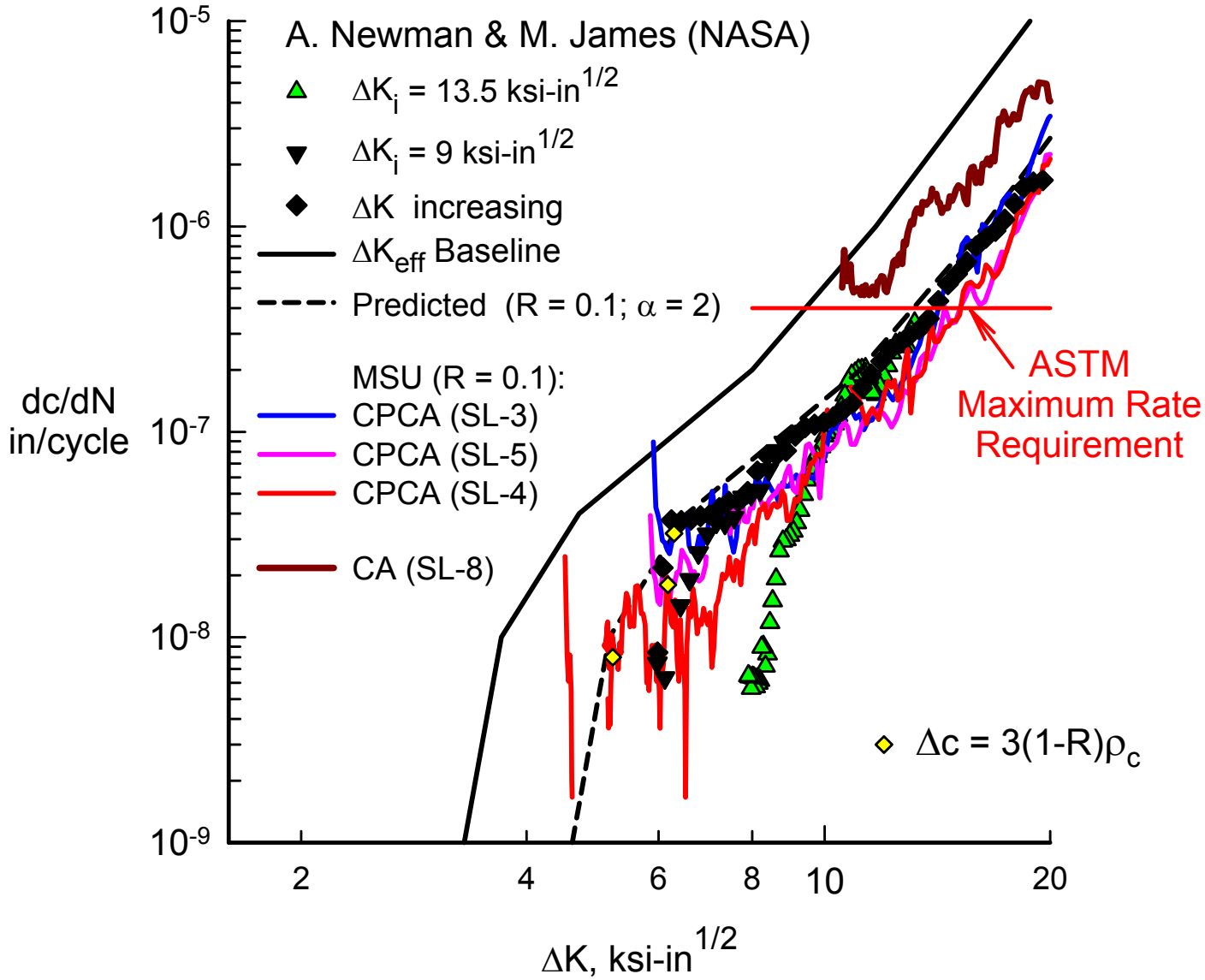
THRESHOLD TESTING AT MEDIUM STRESS RATIO ON TITANIUM ALLOY



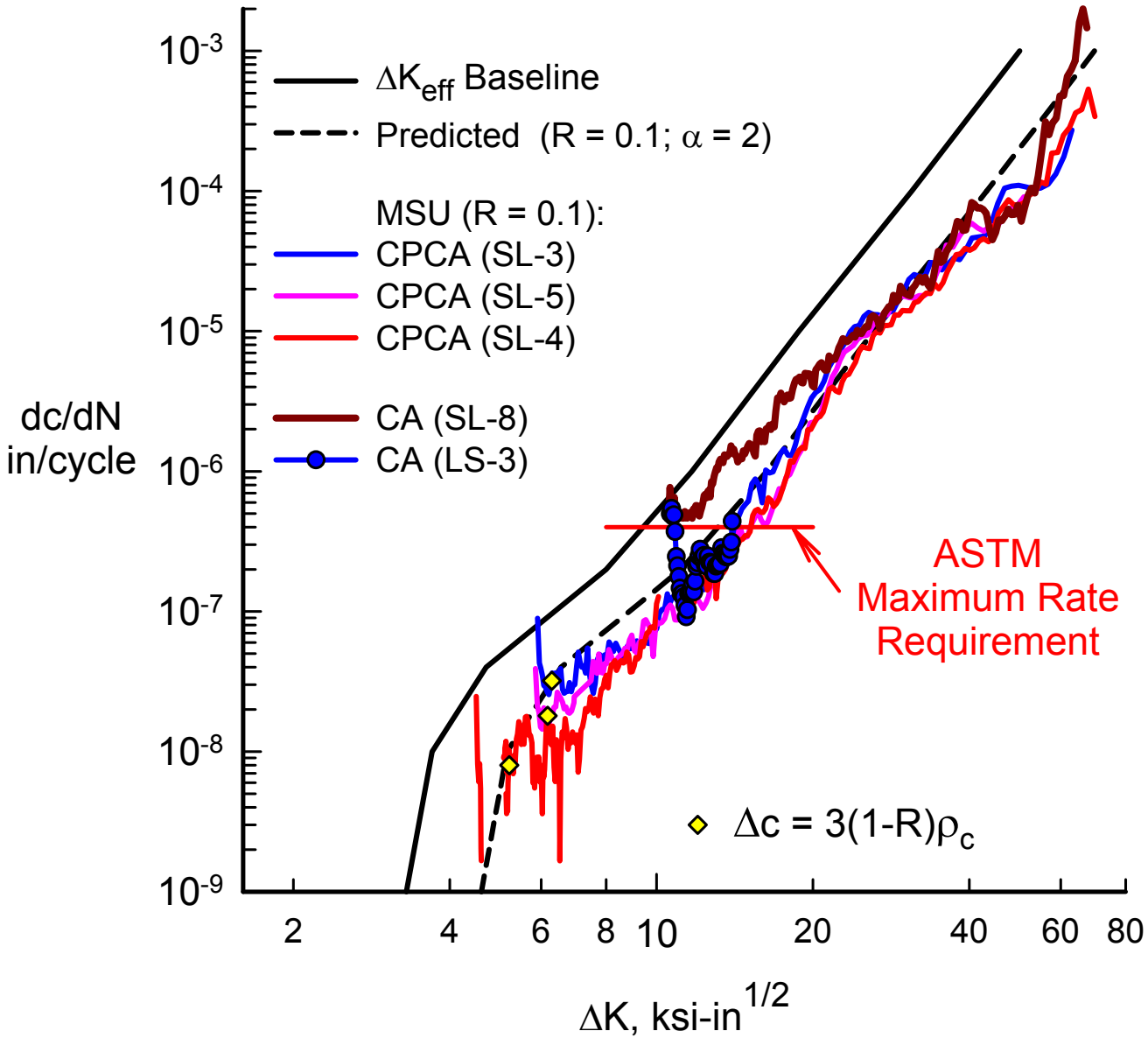
THRESHOLD TESTING AT LOW STRESS RATIO ON TITANIUM ALLOY (Ti-6Al-4V β-STOA)



HUMIDITY AND LOAD-LEVEL(?) EFFECTS AT R = 0.1



ORIENTATION AND/OR RESIDUAL-STRESS EFFECTS AT R = 0.1



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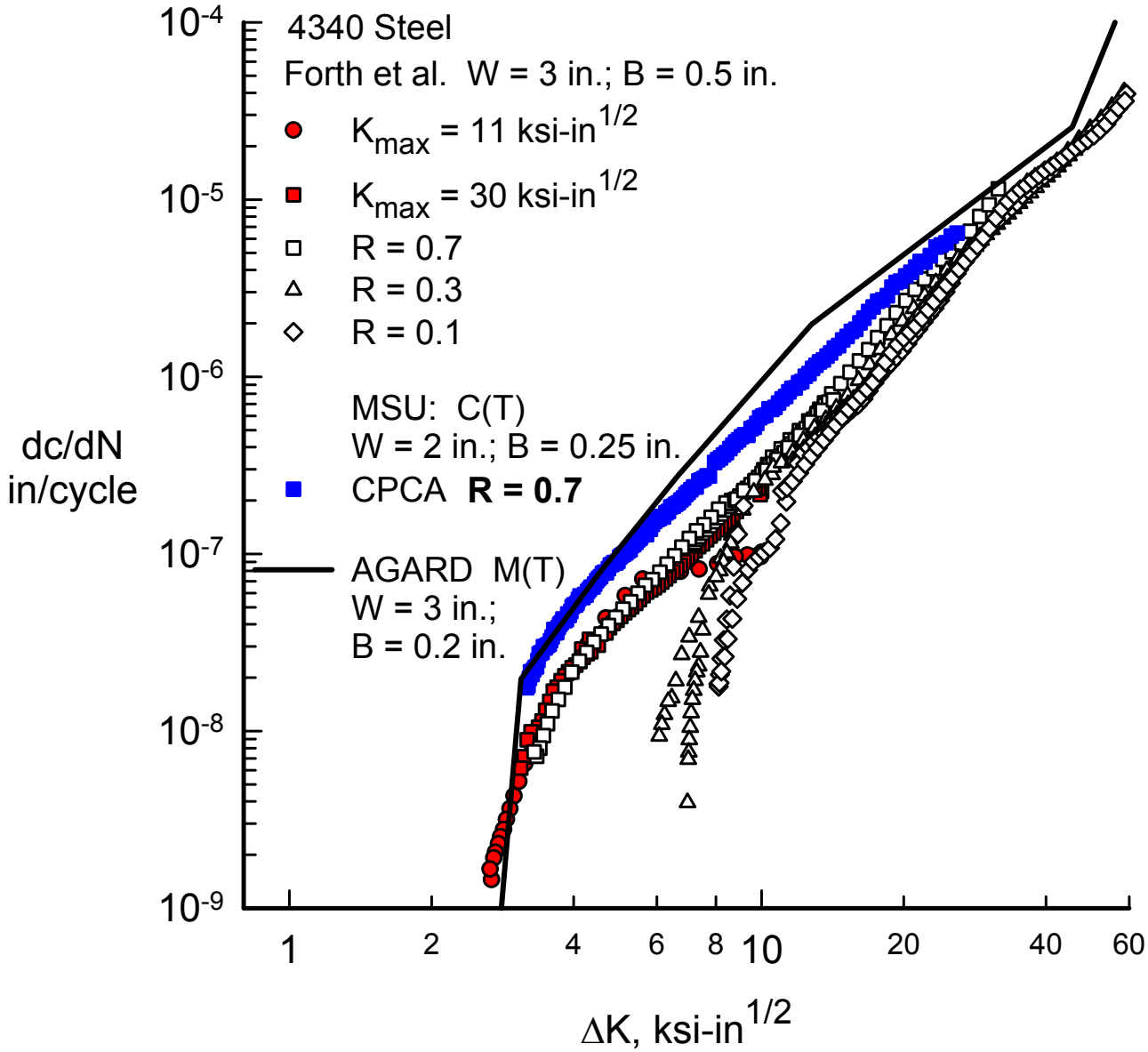
COMPARISON OF CRACK-GROWTH RATE DATA ON 4340 STEEL FROM NASA AND MSU



CONCLUDING REMARKS

- For 7075-T651 alloy, ASTM load reduction (LR) and compression precracking (CPCA, CPLR) threshold testing gave essentially the same results in the threshold regime.
- For Ti-6Al-4V (β-STOA) alloy, ASTM load-reduction tests produced higher thresholds and slower rates than compression precracking (CPCA, CPLR) threshold testing for R = 0.1 and 0.4. (Forging residual stresses may be present in the specimens.)
- For 4340 steel, the R = 0.7 results produced results on C(T) specimens that agreed well with the AGARD test data on M(T) specimens, but was significantly higher than NASA data on a lower strength steel and thicker C(T) specimens.
- Compression pre-cracking constant-amplitude loading (CPCA) and load reduction (CPLR) tests provide <u>alternative</u> methods to generate "steady-state" fatigue-crack-growth rates in the near threshold regime, after some crack extension $\Delta c > \mathbf{3}(1\text{-}R)\,\rho_c$ or $\Delta c > 0.5$ mm (60-degree V-notch).