PRE-HOST HIGH TEMPERATURE CRACK PROPAGATION

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The Pre-HOST activities in High Temperature Crack Propagation are described in detail in NASA CR-167896, "Fracture Mechanics Criteria for Turbine Engine Hot Section Components." What follows is a brief recap of the highlights of that contract.

This was a 14-month contract awarded in late 1980 to Pratt & Whitney Aircraft. The principal investigator was G. J. Meyers. The program consisted of five technical Tasks.

In Task I, the Contractor was to "establish the locations, characteristic geometry, temperature levels, and stress levels in hot section components of typical advanced turbine engines which present crack initiation and crack propagation conditions that may significantly impact engine operational safety or engine maintenance costs." "The suitability and the limitations of the currently available methods for correlation and generalization of crack propagation data such as linear elastic fracture mechanics parameters" were to be evaluated. The key results of this Task are shown in the first two figures.

In Task II, the Contractor was to identify "the empirical crack growth predictive methods and data necessary for effective design involving the potential cracking conditions identified in the preceeding Task I" and also "the test specimen designs and the facility requirements which can provide the required data under suitably controlled thermomechanical crack propagation conditions." A suitable testing program was to be developed.

In Task III, The Contractor was to "conduct an analysis to identify and define the nature and magnitude of the crack initiation and propagation mechanisms at the sites identified in Task I." "An analysis of the corresponding test specimen geometry and loading" was also to be made. The component which received the greatest amount of analysis is the combustor liner shown in Figure 3-1. A finite-element analysis had already been performed under another contract, and the results are shown in Figure 5.2-3. The louver lip (location 1) is the area of interest and contains strong thermal gradients. A more detailed model, Figure 5.3-8, was constructed for J-integral analysis using the MARC program (note the three contours). The calculated J-integral was found to be very sensitive to material property variations within the contour of integration (Figures 5.3-9 and 5.3-10). The results of this analysis indicate that the J-integral calculation resident in the MARC program is not satisfactory for this kind of problem. The specimens that were to be tested in Task IV were analyzed using a modified Shih-Hutchinson approach.

Task IV consisted of the actual testing. The specimens used were tubular specimens with short circumferential through-thickness cracks as shown in Figure 6.2-1, with the initial EDM slot being about 0.040" long. The external-ridge specimens were used for the isothermal tests, the internal-ridge for TMF tests. The TMF cycles that were used are shown in Figure 6.2-2. Cycle I and Cycle II are linear, the "Faithful Cycle" is an approximation to the calculated louver-lip cycle shown earlier. The test matrix is shown in Tables 6-I and 6-II.

The data are correlated and generalized in Task V. As shown in Figures 7.4-2 and 7.4-3, The J-integral was not entirely successful in correlating the data. One should note, however, that all calculations were effectively based on the assumption that the crack began to open at maximum compressive load. If all cracks opened at the same percentage of max. load, then all calculations are in error by the same constant factor. Based on data spread, the crack tip opening displacement (which was calculated from the J-integral) gave a somewhat better correlation.

There are two significant points to be noted. First, the J-integral calculation resident in the MARC computer program is not satisfactory for problems involving thermal gradients. Second, the specimens tested here were sparsely instrumented, and therefore we can only guess at how they actually responded to the thermal and mechanical cycling.

DOCUMENTATION OF DAMAGE RESULTS IN JT9D COMBUSTOR LINERS
(Outer and Inner)

Figure Number	Time (% of Calculated B-50	Cycles (% of Calculated B-50	Calculated Temperature (°F)	Calculated Strain Range (%)	Nature of Damage
			COMBUSTOR OUTER LINERS		
3-2	38	20	1780	0.45	o Lip Collapse o Coating Spallation o Burning o Extensive Cracking
3-3	84	85	1810	0.45	o Cracking and Burning (Similar to Figure 3-2)
3-4	51	88	1780	0.45	o Extensive Cracking o Localized Distress
3-5	81	51	1780	0.45	o Extensive Cracking (One Severe Crack)
			COMBUSTOR INNER LINERS		
3-6	27	10	1730	0.25	o Erosion and Burning o Axial and Circumferential Cracking o Dilution Air Hole Cracking
3-7	53	34	1730	0.37	o Mild Dilution Air Hole Cracking o Cracking in Aft End

NOTES:

Cooling Type: Film Cooled Material: Hastelloy-X Coating: Metallic-Ceramic Thermal Barrier

Crack Initiation Location: Outer Liner: End of louver lip
Inner Liner: End of louver lip and circumferential seam weld

Liners must be weld-repaired or eventually replaced.

FAILURE CONSEQUENCES:

Outer Liner: Axial cracks link together, resulting in liner deformation. This deformation may affect combustor exit temperature distribution with an ultimate effect on turbine performance and durability.

Inner Liner: Intersection of large axial and circumferential cracks can result in liberation of pieces of the liner, causing secondary damage to turbine blades and vanes.

TABLE 3-II

IMPORTANT DAMAGE MECHANISMS FOR
JT9D HIGH-PRESSURE TURBINE AIRFOILS

Airfoil	Damage Mechanisms
First-Stage Turbine Vane	o Cracking (oxidation-assisted) of leading edge and pressure-side wall. o Burning around leading edge cooling holes.
Second-Stage Turbine Vane	o Leading edge cracking (early models). o Coating oxidation and impact damage (later models).
First-Stage Turbine Blade	o Radial cracking of pressure- and suction-side walls. o Blade tip oxidation. o Stress rupture. o Impact damage.
Second-Stage Turbine Blade	o Impact damage. o Stress rupture (early models).

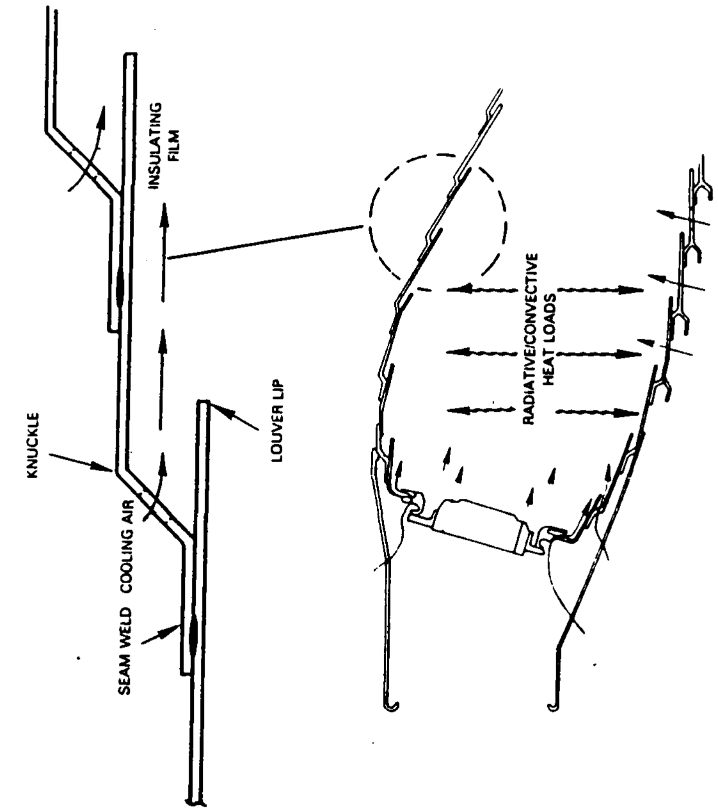


Figure 3-1 Typical Combustor Liner Louvered Construction.

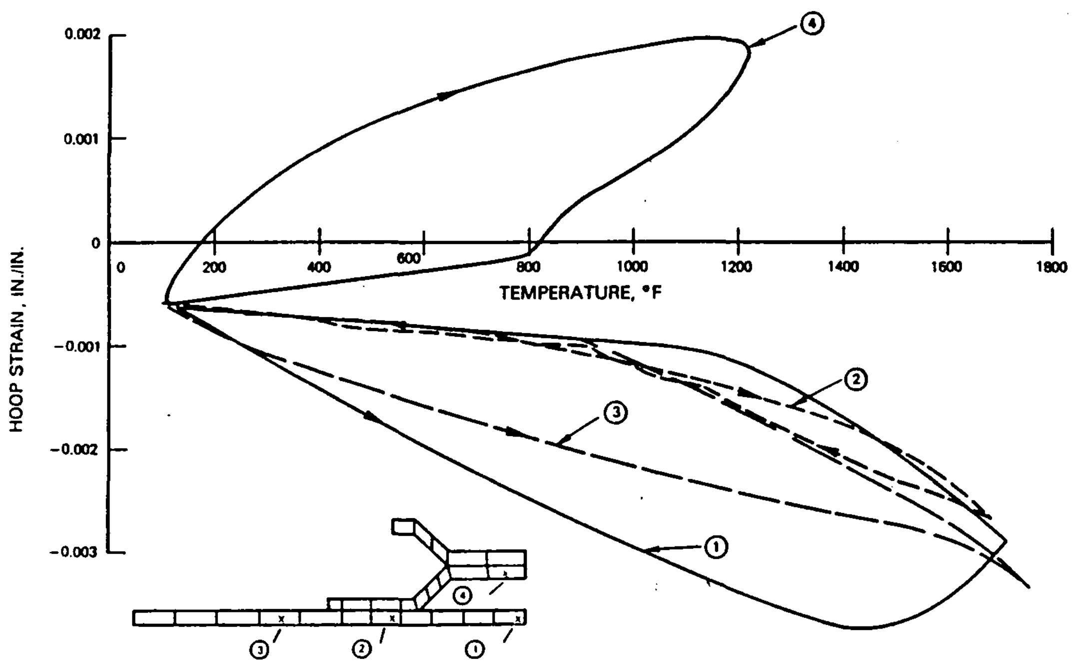


Figure 5.2-3 Strain-Temperature Response at Several Locations Along Combustor Liner Louver.

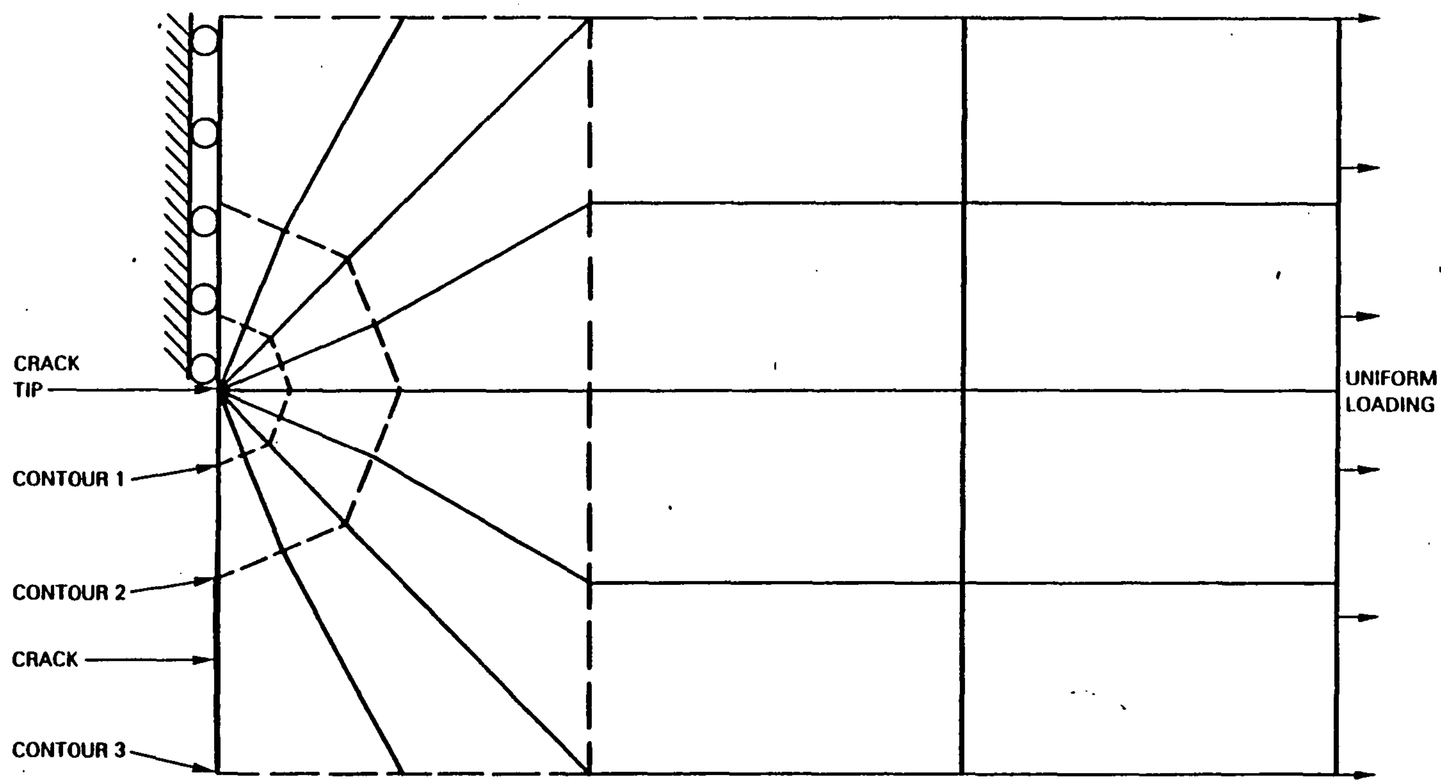


Figure 5.3-8 Coarse Grid Finite Element Mesh for J-Integral Test Cases.

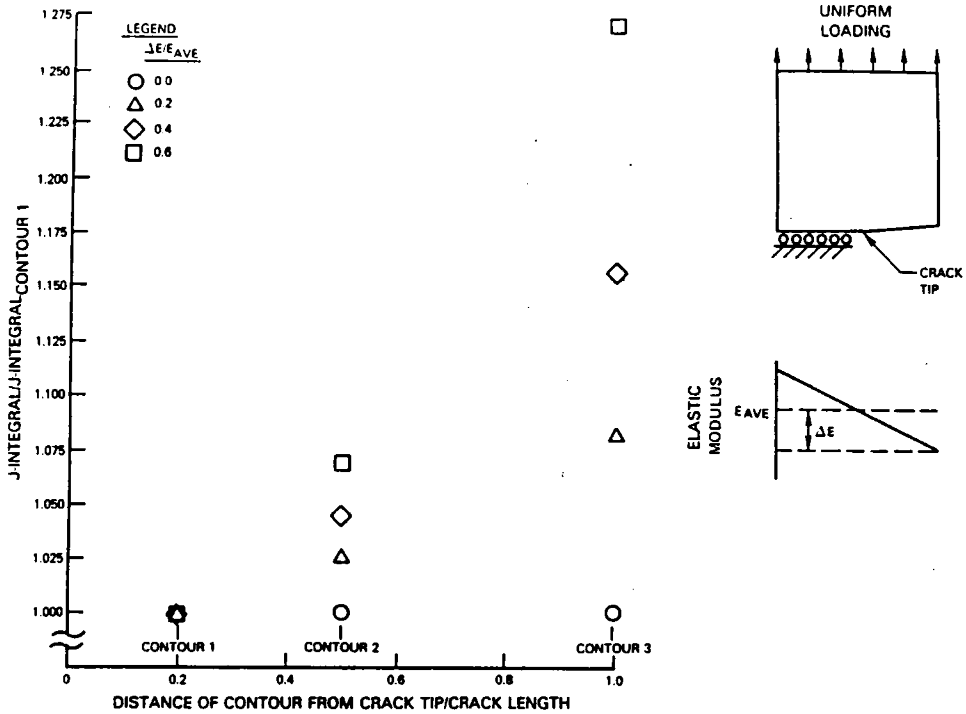


Figure 5.3-9 Effect of Elastic Modulus Variation on J-Integral Calculation using Coarse Grid.

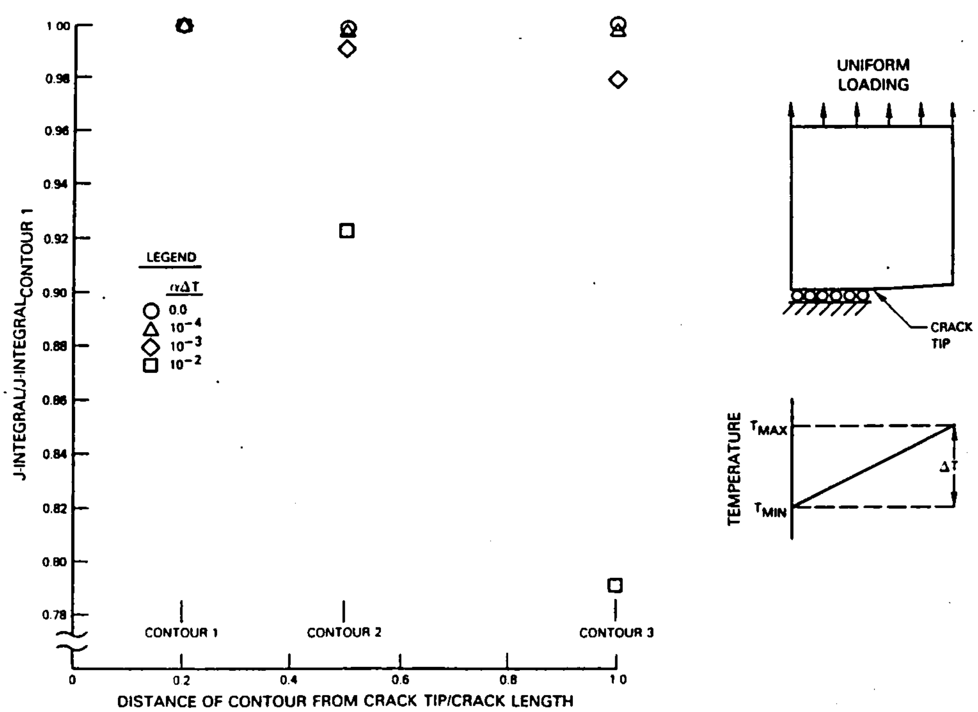


Figure 5.3-10 Effect of Linear Temperature Gradient on J-Integral Calculation Using Coarse Grid.

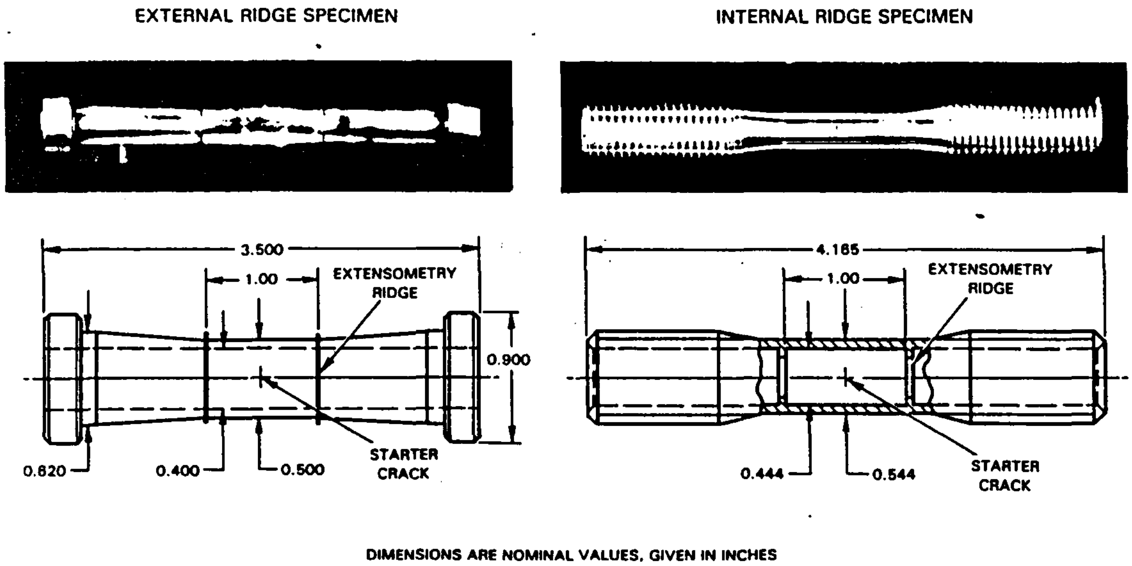


Figure 6.2-1 Tubular Strain-Controlled Crack Propagation Specimens.

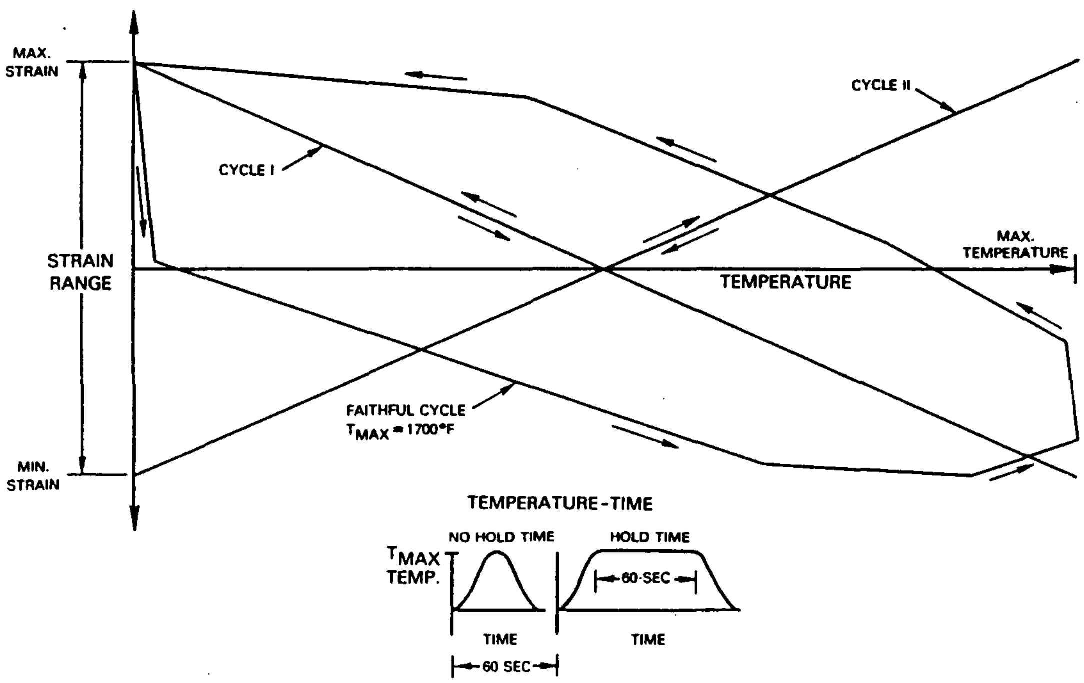


Figure 6.2-2 Strain-Temperature Cycles used in Thermomechanical Fatigue Testing.

TABLE 6-I

CONDITIONS FOR ISOTHERMAL TESTING*

Test No.	Temperature (°C)	Temperature (°F)	Strain Range (%)	Minimum Strain (%)	Maximum Strain (%)	Cyclic Rate (cpm)	Average Strain Rate (in/in)/min	Comments
I-1	427	800	0.15	-0.075	0.075	60	0.18	
I-2	427	800	0.40	-0.20	0.20	10	0.08	
I-3	427	800	0.40	-0.45	-0.05	10	0.08	Mean Strain=-0.25%
I-4	427	800	0.25	-0.125	0.125	10	0.05	
I-6	649	1200	0.15	-0.075	0.075	2.0	0.006	
I-7	649	1200	0.40	-0.20	0.20	1.0	0.008	
I-8	649	1200	0.40	0.05	0.45	1.0	0.008	Mean Strain=+0.25%
I-9	760	1400	0.15	-0.075	0.075	1.0	0.003	
I-10	760	1400	0.25	-0.125	0.125	0.5	0.005	
I-11	760	1400	0.40	-0.20	0.20	1.0	0.004	
I-13	760	1400	0.25	-0.125	0.125	0.5	0.005	1 minute Hold Time
I-14	871	1600	0.15	-0.075	0.075	1.0	0.003	
I-15	871	1600	0.175	-0.0875	0.0875	1.0	0.0035	
I-16	871	1600	0.40	-0.02	0.02	0.5	0.004	
I-18	927	1700	0.15	-0.075	0.075	1.0	0.003	
I-19	927	1700	0.25	-0.125	0.125	1.0	0.005	
I-20	927	1700	0.40	-0.20	0.20	0.5	0.004	
I-21	927	1700	0.25	-0.125	0.125	1.0	0.005	Mean Strain=-0.25%
I-22	927	1700	0.25	-0.125	0.125	0.5	0.005	1 minute Hold Time
I-23	982	1800	0.15	-0.075	0.075	1.0	0.003	
I-23a	982	1800	1.50	-0.75	0.75	1.0	0.030	Large Strain Range
I-24	982	1800	0.25	-0.125	0.125	1.0	0.005	
I-25	982	1800	0.40	-0.20	0.20	0.5	0.004	
I-26	982	1800	0.40	-0.20	0.20	0.5	0.004	Triangular Wave Shape

* All tests had a sinusoidal wave shape, zero mean strain, and no hold time, except where indicated.

TABLE 6-II

CONDITIONS FOR THERMOMECHANICAL FATIGUE TESTING*

Test No.	Maximum Temperature (°C)	Maximum Temperature (°F)	Strain Range (%)	Minimum Strain (%)	Maximum Strain (%)	Cyclic Rate (cpm)	Average Strain Rate (in/in)/min	Comments
T-1	927	1700	0.15	-0.075	0.075	0.83	0.0025	
T-2	927	1700	0.25	-0.125	0.125	0.83	0.0042	
T-3	927	1700	0.40	-0.20	0.20	0.44	0.0035	
T-4	927	1700	0.25	-0.125	0.125	0.83	0.0042	Cycle II
T-5	927	1700	0.40	-0.20	0.20	0.44	0.0035	Faithful Cycle
T-6	927	1700	0.40	-0.20	0.20	0.30	0.0035	Faithful Cycle; 1.125-minute Hold Time
T-7	982	1800	0.25	-0.125	0.125	0.83	0.0042	
T-8	871	1600	0.25	-0.125	0.125	0.83	0.0042	
T-9	760	1400	0.25	-0.125	0.125	0.83	0.0042	
T-10	649	1200	0.25	-0.125	0.125	0.83	0.0042	
T-11	927	1700	0.40	-0.20	0.20	0.30	0.0035	1.125-minute Hold Time
T-12	871	1600	0.40	-0.20	0.20	0.44	0.0035	

* All tests were Cycle I with no hold time except where indicated.

* All tests had a minimum temperature of 427°C (800°F) and zero mean strain.

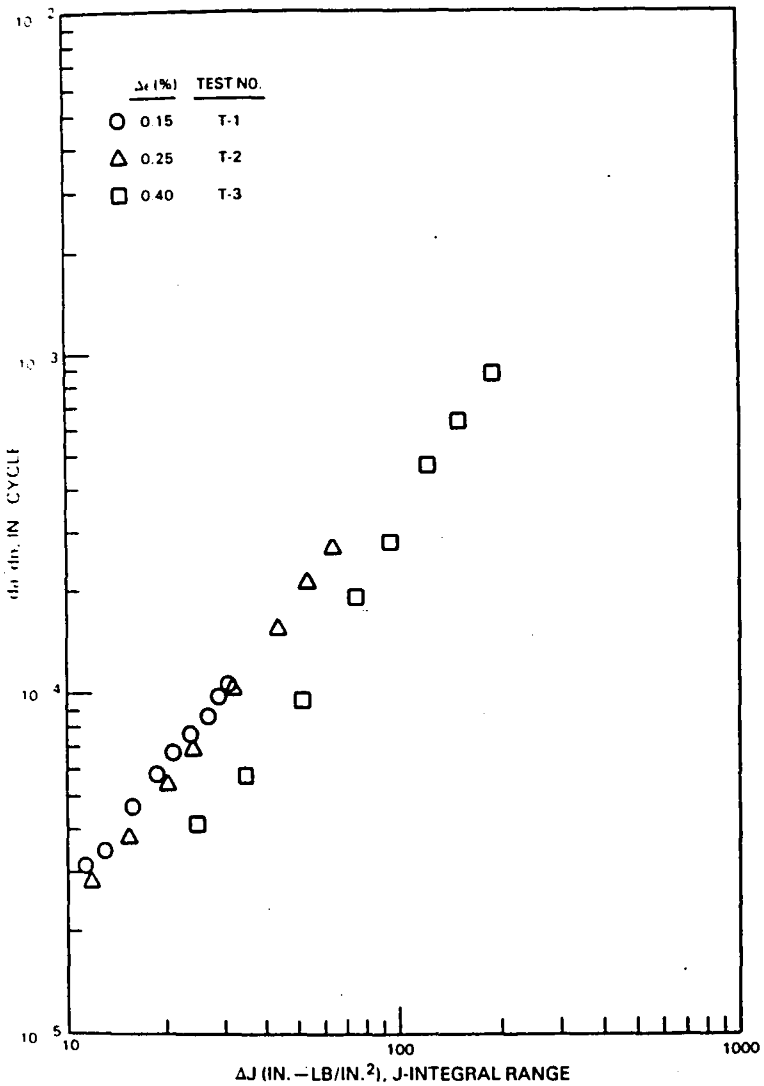
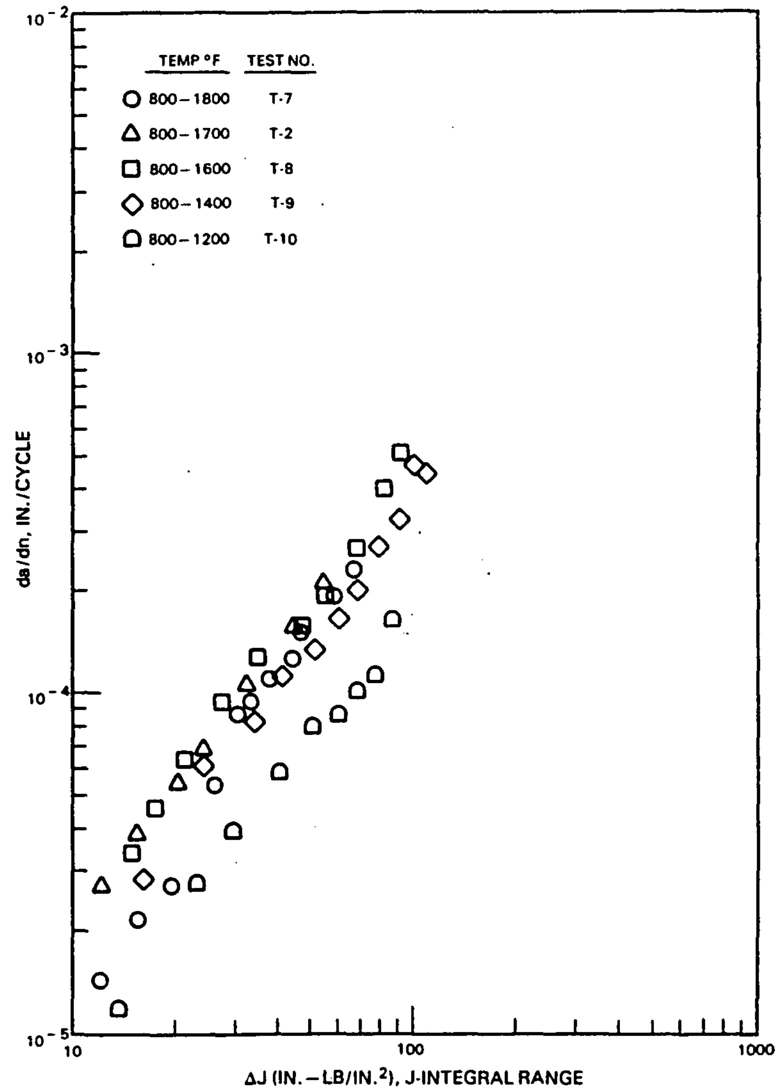


Figure 7.4-2 800 to 1700°F Cycle I Crack Growth Rates Based on J-Integral Range.



re 7.4-3 Cycle I, 0.25 Percent Strain Range Crack Growth Rates Based on J-Integral Range.