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THE MECHANICAL PROPERTY DATA BASE FROM AN AIR FORCE/INDUSTRY COOPERATIVE TEST PROGRAM ON ADVANCED ALUMINUM ALLOYS

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This report contains a mechanical property data base on aluminum-lithium alloys 2091, 8090, IN905XL, AL905XL, and Weldalite 2095 and a data base on powder metallurgy alloys 7064 and CW67. Basic mechanical property data consist of tension, compression, shear, bearing and fracture toughness properties. Fatigue data were generated from both smooth and notched specimens. Constant amplitude fatigue crack growth rate data and spectrum fatigue test data were generated. Other tests performed on a select number of alloys were ballistic, hardness and conductivity.

14. SUBJECT TERMS

Weldalite™	8090	Tension	Fatigue	2095
Aluminum-Lithium	AL905XL	Compression	Spectrum	
2091	IN905XL	Shear	Crack Growth	
		Bearing	Fracture Toughness	

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PREFACE

This report was prepared by the Materials Engineering Branch (WL/MLSE), Systems Support Division, Materials Directorate, Wright Laboratory, Wright Patterson Air force Base, Ohio, under Project 2418, "Metallic Structural Materials, "Task 241807, "Systems Support, " Work Unit 24180703, Engineering and Design Data."

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SECTION 1

INTRODUCTION

High performance aerospace systems are dependent on materials that are lighter, have improved mechanical properties, and/or offer a cost savings. Aluminum alloys that met these criteria were the newly developed aluminum-lithium alloys and the second generation powder metallurgy alloys.

In 1985, the Air Force along with the aerospace community found it important to investigate the potential of these promising aluminum alloys. A cooperative program was formed by the Wright Laboratory Materials Directorate, Systems Support Division, and a number of aerospace industries. The Air Force would obtain the test material from the producers, compile the test data, and submit reports to the participants. The participants agreed to support the program by performing mechanical property tests which include tension, compression, bearing, shear, fracture toughness, and fatigue related properties (S/N, da/dn). The Air Force elected to perform spectrum fatigue crack growth testing on most alloys. The following table contains the participants who volunteered to test a particular material. The X's that have a circle around them indicate the participants that submitted their data to the Air Force. Some participants were unable to test due to funding cuts or decrease in material interest.

This report contains aluminum-lithium alloys 2091, 8090, 2095, IN905XL and AL905XL, and powder metallurgy (P/M) aluminum alloys 7064 and CW67. Comparisons to other materials and ranking of materials are generally avoided, since each potential application may be based on different evaluation criteria.

TABLE

Participants and Advanced Aluminum Alloys in the Cooperative Test Program

	ALUMINUM LITHIUM ALLOYS													P/M ALUMINUM ALLOYS					
	PECHINEY				ALCAN		IncoMAP		ALCOA				REYNOLDS	KAISER		ALCOA			
PARTICIPANTS	2091–T3 Sheet (0.063"T)	2091–T351 Plate (0.420"T)	2091–T8 Forging	8090–T851 T Extrusion	8090–T851 Extrusion	8090–T87T1 Plate (1.75"T)	PM IN9003L Forging	PM AL9003L Forging	2091–T3 Sheet (0.063"T)	2091–T3 Sheet (0.144"T)	2091–T8 Plate (0.50"T)	8090 Extrusion	Weldalite 049 RX815 Plate (0.5"T)	7064–T74511 Extrusion	7064–T74 Forging	CW67 Sheet (0.063"T)	CW67 Plate (0.40"T)	CW67 Extrusion	CW67 Forging
Air Force WPAFB, OH		●			●	x	●	●	●	●	●		●	●	●			●	●
Army, MA												●	●						
AVCO, TN									x										
Boeing, WA	●	●	●	●															
Douglas Aircraft, CA								x	x	x	x	x	x						
General Dynamics, CA	●	●							x	x	x		●						
General Dynamics, TX	●	●	●	●			●		x	●	x	x							
Grumman Aerospace, NY	●	●			●		x							x	x			x	x
Jet Propulsion, CA								x					x						
Lockheed, CA	x			x				x	x		x								
Lockheed, GA			●		x				x	x					●				x
LTV, TX	●			●			●	●	x			x		●	●			●	
Martin Marietta, LA	●	●	●	x	●	●	●	●	●	●	●	●		●	●	●	●	x	●
McDonnell Douglas Astro, CA										●			●						
McDonnell Douglas Helicopter, AR								●											
McDonnell Douglas Missile Sys, MO													●						
McDonnell Aircraft, MO	●						●	●	●						●	●			●
NASA, VA					●		●	●					●						
Naval Air Development Center		●		●				x			x								x
Northrop, CA	●	●	●		●	x	●	●	●	●	x	x	●						
Sikorsky, CT							●		x						x		x		x
Sundstrand, IL													●						
Wyman–Gordon								x											

SECTION 2

MATERIALS AND TESTS

The advanced aluminum alloys were received on various dates. shown below are the aluminum alloys and approximate dates received.

Producer	Aluminum Alloy	Date Received
Alcan	8090-T651 Extrusion	Feb 86
	8090-T8771 Plate	May 91
Pechiney	2091-T3 Sheet	Jul 86
	2091-T351 Plate	Jul 86
	2091-T6 Forging	Jul 86
	8090-T651 Extrusion	Oct 86
Alcoa	2091-T3 Sheet (0.063")	Oct 88
	2091-T3 Sheet (o.144")	Mar 88
	2091-T8 Plate	Mar 89
	8090 Extrusion	Sep 91
INCO	IN905XL Forging	Jan 87
	AL905XL Forging	May 89
Reynolds	2095 Plate	Feb 91
Kaiser	7064 Extrusion	Dec 86
	7064 Forging	Dec 86
Alcoa	CW67 Sheet	Apr 89
	CW67 Plate	Apr 89
	CW67 Extrusion	Aug 87
	CW67 Forging	Oct 88

The aluminum-lithium alloys shown in the table above are shown in the as received condition. Some aerospace companies heat treated the alloys to T8 tempers.

Mechanical properties, (tension, compression, bearing, shear and fracture toughness) fatigue, and constant amplitude fatigue crack growth tests were tested according to ASTM standards, unless otherwise specified. Spectrum tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

SECTION 3

PRESENTATION

Each participant compiled a data package which contained the data they generated. Some of these data packages contained discussions and in other cases, only the data were provided. The tensile, compression, bearing, and shear data were put in tabular form. Fracture toughness, fatigue, fatigue crack growth, and spectrum fatigue crack growth data were put in tabular and graphical form.

SECTION 4

RESULTS AND DISCUSSION

The data generated by the participants are contained in the appendices. The following table lists the producer, aluminum alloy, form and the appendix that the data can be found.

Table
Contents of Appendices

		Form	Appendix
Pechiney	2091	Plate	A
Pechiney	2091	Sheet	B
Pechiney	2091	Forging	C
Pechiney	8090	Extrusion	D
Alcan	8090	Extrusion	E
Alcan	8090	Plate	F
INCO	IN905XL	Forging	G
INCO	AL905XL	Forging	H
Reynolds	2095	Plate	I
Alcoa	2091	Sheet (0.063")	J
Alcoa	2091	Sheet (0.144")	K
Alcoa	2091	Plate	L
Alcoa	8090	Extrusion	M
Kaiser	7064	Extrusion	N
Kaiser	7064	Forging	O
Alcoa	CW67	Sheet	P
Alcoa	CW67	Plate	Q
Alcoa	CW67	Extrusion	R
Alcoa	CW67	Forging	S

SECTION 5

CONCLUSIONS

Nineteen aerospace laboratories participated in generating data on the advanced aluminum alloys for the Air Force/Industry Cooperative Test Program Advanced Aluminum Alloys. The data contained in this report provides an extensive data base on the aluminum-lithium and P/M aluminum alloys.

APPENDIX A

PECHINEY 2091-T351 AND 2091-T8X PLATE (0.42" X 39" X 39")

INTRODUCTION

The Pechiney 2091-T351 0.42-inch plates were received the second quarter of 1986. Three participants heat treated the plate to a T8X temper; Northrop - T8 condition was achieved by aging the 2091 plate at 275° for 12 hours, Grumman (-T8X) at 275°F for 12 hours, and General Dynamics TX (-T851) at 335° F for 16 hours.

TESTING

Basic mechanical properties (tension, compression, bearing, etc.) were tested according to ASTM standards, unless otherwise specified.

Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 standard. The growth rate a-N data that was generated by the participants (Northrop, Grumman, General Dynamics CA, and Air Force) were reduced using a seven-point incremental polynomial method. This involves fitting a second-order polynomial (parabola) to sets of seven successive data points. The data are also checked against requirements per ASTM E647, Section 7.2. General Dynamics TX performed constant amplitude fatigue crack growth tests using a K-increasing (load increasing) method.

Spectrum tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

PECHINEY

2091-T351 PLATE

TABLE A1

TENSILE RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
BOEING, WA	RT	LONG	64.5	51.3		17.0	
			64.5	51.2		16.0	
			64.6	51.4		17.0	
GENERAL DYNAMICS, CA	RT	LONG	64.3	51.3	10.2	20.2	10.8
			63.8	53.7	12.4	23.1	10.9
			63.9	51.0	12.5	25.8	10.9
			64.3	50.8	10.2	20.0	11.4
NADC	RT	LONG	68.2	55.5	15.0		11.2
			67.9	57.0	16.0		10.4
			68.2	55.2	15.0		11.7
			67.9	56.5	16.0		10.7
NORTHROP	RT	LONG	66.7	54.7	10.6	18.5	11.3
			67.3	55.2	11.0	18.1	11.3
			66.9	54.8	11.3	19.5	11.7
MARTIN MARIETTA, LA	RT	LONG	64.9	52.1	15.0	15.0	
			64.5	52.7	14.0	14.0	
			64.7	52.3	15.0	13.0	
		AVERAGE	65.9	53.6	13.2	18.6	11.1
	STANDARD DEVIATION		1.7	2.1	2.2	3.8	0.4

TABLE A2

TENSILE RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
BOEING, WA	RT	L TRANS	64.5	44.8		20.0	
			65.3	45.6		18.0	
			64.8	45.5		19.0	
GENERAL DYNAMICS, CA	RT	L TRANS	64.7	46.3	13.8	21.9	11.0
			64.4	46.5	13.4	24.4	11.1
			64.6	46.7	15.9	22.1	10.9
			65.2	47.2	14.2	22.2	11.2
NADC	RT	L TRANS	67.9	50.9	15.0		10.3
			66.2	49.9	16.0		11.7
			67.3	49.9	16.0		12.2
			66.2	49.9	15.0		10.7
NORTHROP	RT	L TRANS	67.2	49.1	12.1	23.4	11.7
			67.7	49.1	12.4	22.0	11.7
			67.6	49.0	12.8	24.8	12.3
MARTIN MARIETTA, LA	RT	L TRANS	65.8	46.6	16.0	15.0	
			65.4	46.0	20.0	17.0	
			65.2	46.6	18.0	15.0	
		AVERAGE	65.9	47.6	15.0	20.4	11.3
	STANDARD DEVIATION		1.2	1.9	2.2	3.3	0.6

TABLE A3

COMPRESSION RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
BOEING, WA	RT	LONG	42.7	
			42.8	
			42.6	
GENERAL DYNAMICS, CA	RT	LONG	42.0	11.4
			41.7	11.6
			41.6	11.7
NADC	RT	LONG	44.7	
			44.7	
			42.3	
			43.9	
			45.5	
			47.3	
			47.3	
MARTIN MARIETTA, LA	RT	LONG	44.5	12.4
		AVERAGE	43.8	11.8
		STANDARD DEVIATION	1.9	0.4

TABLE A4

COMPRESSION RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
BOEING, WA	RT	L TRANS	48.7	
			48.6	
			48.8	
GENERAL DYNAMICS, CA	RT	L TRANS	41.1	11.4
			48.4	11.6
			48.0	11.7
NADC	RT	L TRANS	50.9	
			49.9	
			49.4	
			47.2	
			52.8	
			47.7	
			51.7	
MARTIN MARIETTA, LA	RT	L TRANS	51.6	12.5
		AVERAGE	48.9	11.8
		STANDARD DEVIATION	2.8	0.5

TABLE A5

RIVET SHEAR RESULTS FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
GENERAL DYNAMICS, CA	LONG	34.3
		33.9
		33.4
	AVERAGE	33.9
	STANDARD DEVIATION	0.5

TABLE A6

RIVET SHEAR RESULTS FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
GENERAL DYNAMICS, CA	L TRANS	32.6
		36.6
		33.0
	AVERAGE	34.1
	STANDARD DEVIATION	2.2

TABLE A7

AMSLER DOUBLE SHEAR RESULTS FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
BOEING, WA	L-S	35.2
		35.3
		35.2
	AVERAGE	35.2
	STANDARD DEVIATION	0.1
BOEING, WA	L-T	38.2
		38.0
		37.9
	AVERAGE	38.0
	STANDARD DEVIATION	0.2
BOEING, WA	T-S	34.4
		34.0
		34.5
	AVERAGE	34.3
	STANDARD DEVIATION	0.3
BOEING, WA	T-L	38.0
		38.0
		37.9
	AVERAGE	38.0
	STANDARD DEVIATION	0.1

TABLE A8

BEARING RESULTS FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING, WA	LONG	1.5	88.0	66.4 *
			87.0	67.2
			90.0	67.2 *
GENERAL DYNAMICS, CA	LONG	1.5	90.8	81.6
			89.4	72.0
			89.4	70.5
		AVERAGE	89.1	70.8
		STANDARD DEVIATION	1.4	5.7

(*): INDICATES SHEAR TEAR OUT FAILURE

TABLE A9

BEARING RESULTS FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR (KSI)
BOEING, WA	L TRANS	1.5	90.9	66.1
			90.0	66.4
			90.9	67.7
GENERAL DYNAMICS, CA	L TRANS	1.5	91.9	72.3
			92.5	71.7
			89.7	71.8
		AVERAGE	91.0	69.3
		STANDARD DEVIATION	1.1	2.9

TABLE A10

BEARING RESULTS FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING, WA	LONG	2.0	111.0	79.8
			111.8	81.0
			110.3	81.5
GENERAL DYNAMICS, CA	LONG	2.0	113.9	90.6
			115.8	85.8
			113.5	86.4
		AVERAGE	112.7	84.2
		STANDARD DEVIATION	2.1	4.1

TABLE A11

BEARING RESULTS FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING, WA	L TRANS	2.0	114.8	82.3
			112.6	82.3
			115.2	83.2
GENERAL DYNAMICS, CA	L TRANS	2.0	113.0	87.6
			114.2	95.1
			114.6	87.4
		AVERAGE	114.1	86.3
		STANDARD DEVIATION	1.0	4.9

TABLE A12

FRACTURE TOUGHNESS RESULTS FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
GENERAL DYNAMICS, CA	L-T		37.0	(1,2,3)
			34.5	(1,2,3)
			35.4	(1,2,3)
NADC	L-T		42.6	(1)
			42.6	(1)
			40.6	(1)
			36.6	(1)
	AVERAGE		38.5	
	STANDARD DEVIATION		3.4	

(1): INVALID DUE TO Pmax/Pq > 1.10

(2): INVALID DUE TO a < 2.5(KQ/Fty)^2

(3): INVALID DUE TO B < 2.5(KQ/Fty)^2

TABLE A13

FRACTURE TOUGHNESS RESULTS FOR PECHINEY

2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
GENERAL DYNAMICS, CA	T-L		38.7	(1,2,3)
			36.5	(1,2,3)
			33.0	(1,2,3)
	AVERAGE		36.1	
	STANDARD DEVIATION		2.9	

(1): INVALID DUE TO Pmax/Pq > 1.10

(2): INVALID DUE TO a < 2.5(KQ/Fty)^2

(3): INVALID DUE TO B < 2.5(KQ/Fty)^2

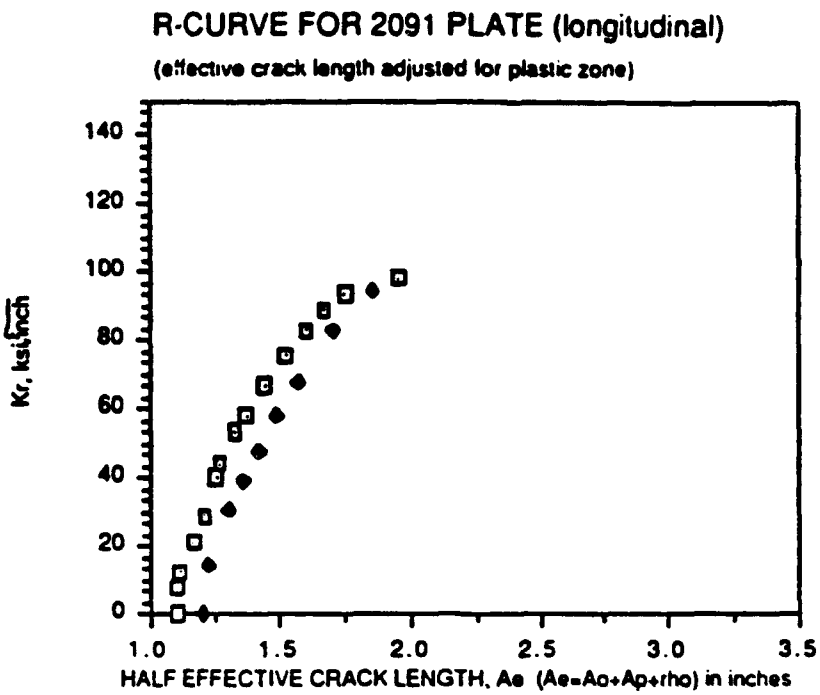


Figure A1 R-Curve Results for 2091-T351 0.42" Plate (longitudinal). Martin Marietta LA.

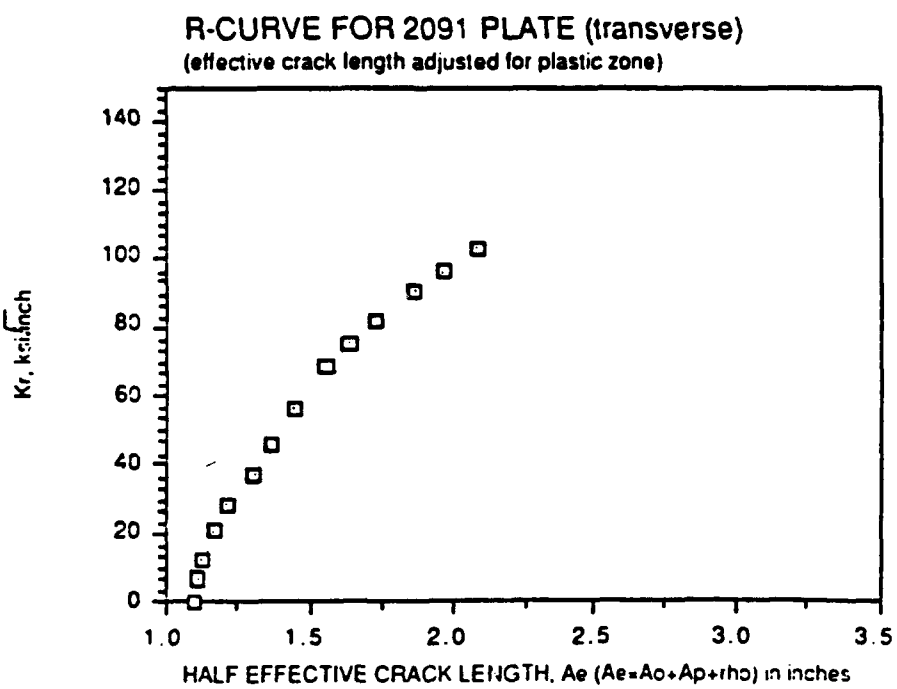


Figure A2 R-Curve Results for 2091-T351 0.42" Plate (transverse). Martin Marietta LA.

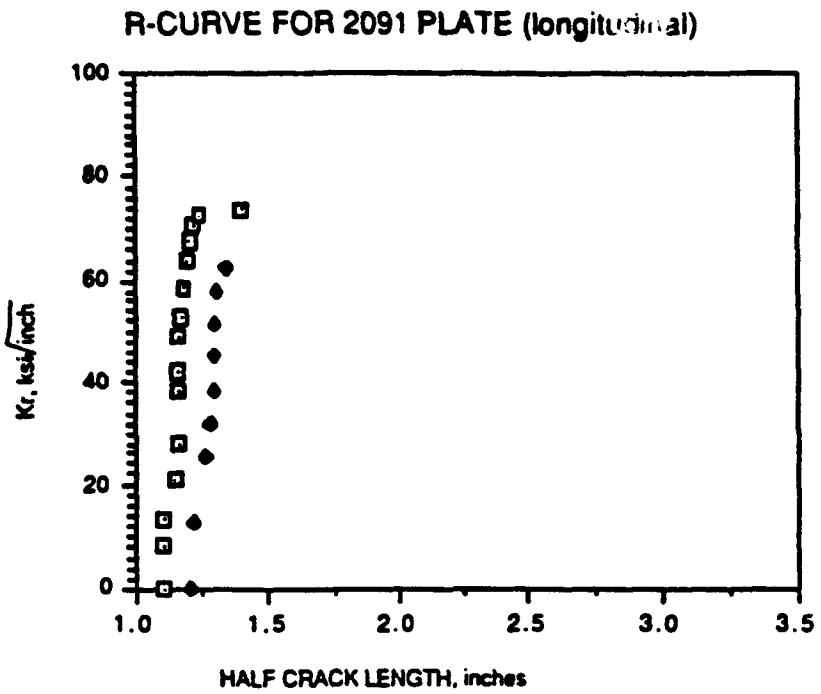


Figure A3 R-Curve Results for 2091-T351 0.42" Plate (longitudinal). Martin Marietta LA.

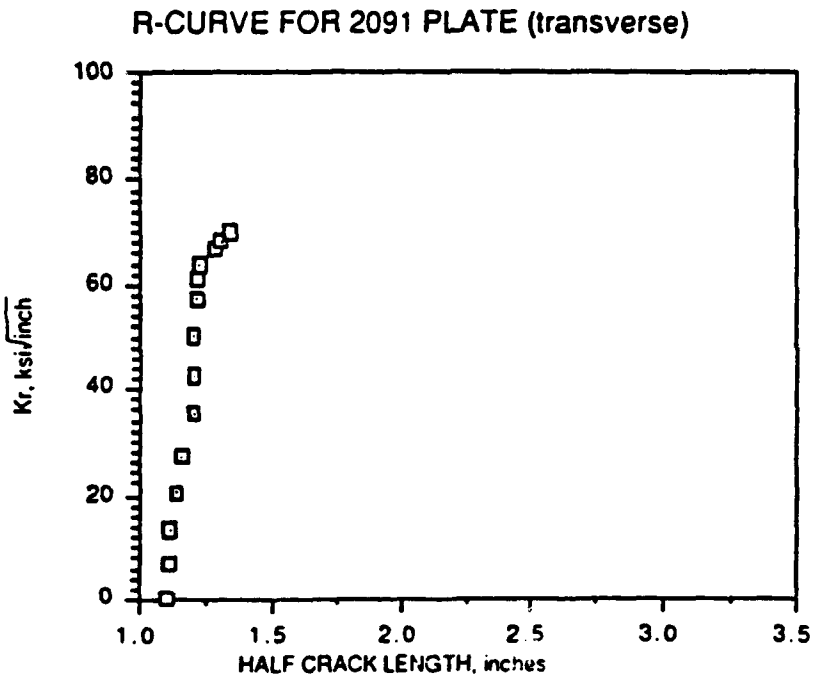


Figure A4 R-Curve Results for 2091-T351 0.42" Plate (transverse). Martin Marietta LA.

TABLE A14

DATA FOR SPECIMEN NO. 1, 2091

LONGITUDINAL PLATE

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{inch}$	
			Not Adjusted	Adjusted for Plasticity
0.00	1.202	1.202	0.0	0.0
20.14	1.217	1.229	12.44	14.57
40.32	1.257	1.310	25.41	30.34
50.22	1.282	1.369	32.05	38.8
60.00	1.292	1.422	38.48	47.34
69.98	1.297	1.491	44.99	57.88
79.84	1.297	1.567	51.33	68.3
89.98	1.312	1.711	58.28	82.93
94.90	1.342	1.857	62.38	94.28

Thickness = .420 inch
Yield = 52.4 ksi
Specimen Width = 7.00 inch

TABLE A15

DATA FOR SPECIMEN NO. 2 2091

LONGITUDINAL PLATE

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{inch}$	
			Not Adjusted	Adjusted for Plasticity
0.0	1.100	1.100	0.0	0.0
12.54	1.100	1.104	8.45	7.93
20.3	1.100	1.110	13.68	12.84
30.09	1.145	1.171	20.80	21.06
40.17	1.165	1.213	28.08	28.71
54.79	1.165	1.257	38.30	39.89
60.10	1.165	1.278	42.06	44.16
69.79	1.165	1.329	48.79	53.14
75.44	1.175	1.375	53.03	58.74
83.47	1.180	1.440	58.84	66.95
90.09	1.190	1.522	63.86	75.72
95.15	1.200	1.600	67.82	82.82
98.00	1.215	1.673	70.43	88.90
99.15	1.245	1.750	72.43	93.30
93.49	1.400	1.958	74.14	98.06

Thickness = .420 inch
Yield = 52.4 ksi
Specimen Width = 7.00 inch

TABLE A16

DATA FOR SPECIMEN NO. 3, 2091

TRANSVERSE PLATE

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0.0	1.100	1.100	0.0	0.0
9.93	1.110	1.113	6.73	6.31
19.81	1.115	1.127	13.46	12.61
20.65	1.135	1.167	20.38	20.69
39.73	1.160	1.220	27.70	28.46
49.74	1.205	1.307	35.50	37.13
59.86	1.210	1.364	42.90	45.68
69.86	1.210	1.444	50.08	56.26
79.58	1.215	1.561	57.39	68.41
85.32	1.215	1.639	61.32	75.71
88.14	1.230	1.728	63.87	82.05
91.82	1.280	1.872	66.82	90.59
91.79	1.305	1.973	68.35	96.81
90.86	1.340	2.090	69.83	103.00

Thickness = .420 inch
Yield = 42.4 ksi
Specimen Width = 7.00 inch

TABLE A17

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR

PECHINEY 2091-T351 PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
NADC	LONG	60.0	28.300
		60.0	29.600
		50.0	72.400
		50.0	87.000
		45.0	395.500
		45.0	779.200
		40.0	1.47E+06
		40.0	2.00E+06
		35.0	1.11E+07
		32.5	1.00E+08 *

(*): RUN OUT

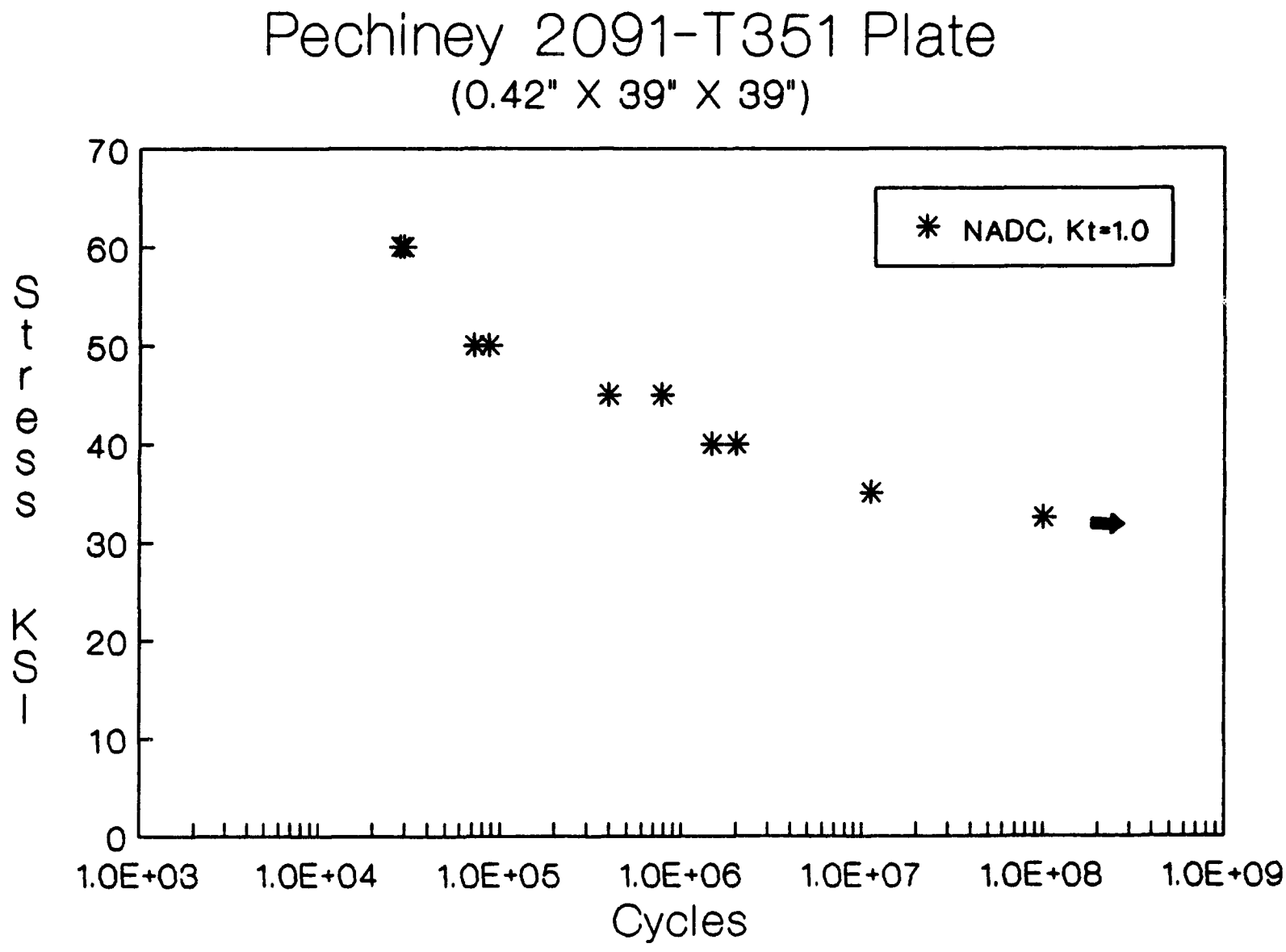


Figure A5 Fatigue Results for 2091-T351 0.42" Plate (R=0.1, Kt=1.0). NADC.

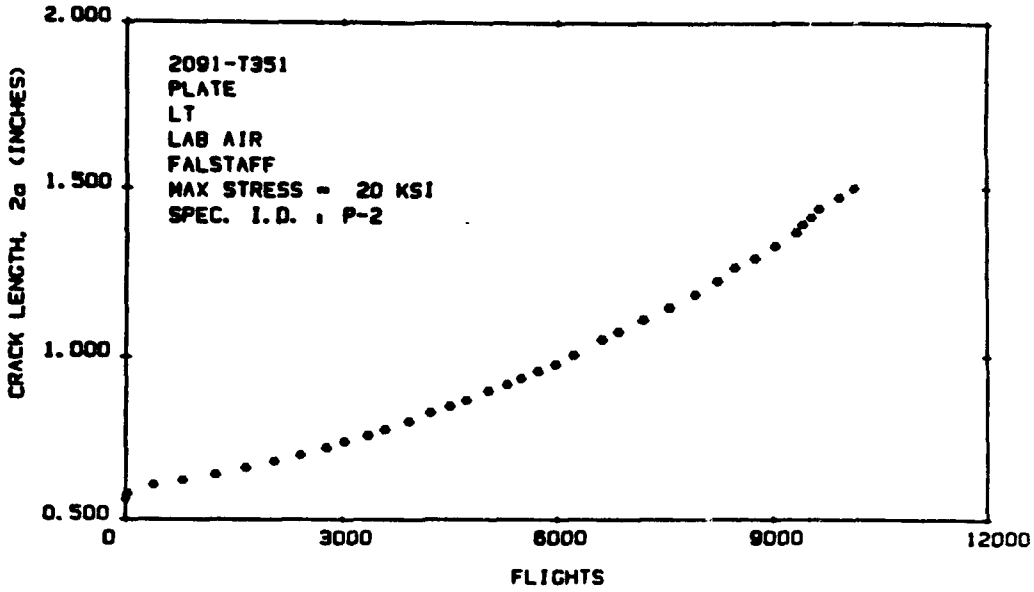


Figure A6 Crack Length Versus Flights for 2091-T351 Plate Under FALSTAFF Loading, Max Stress = 20 KSI.

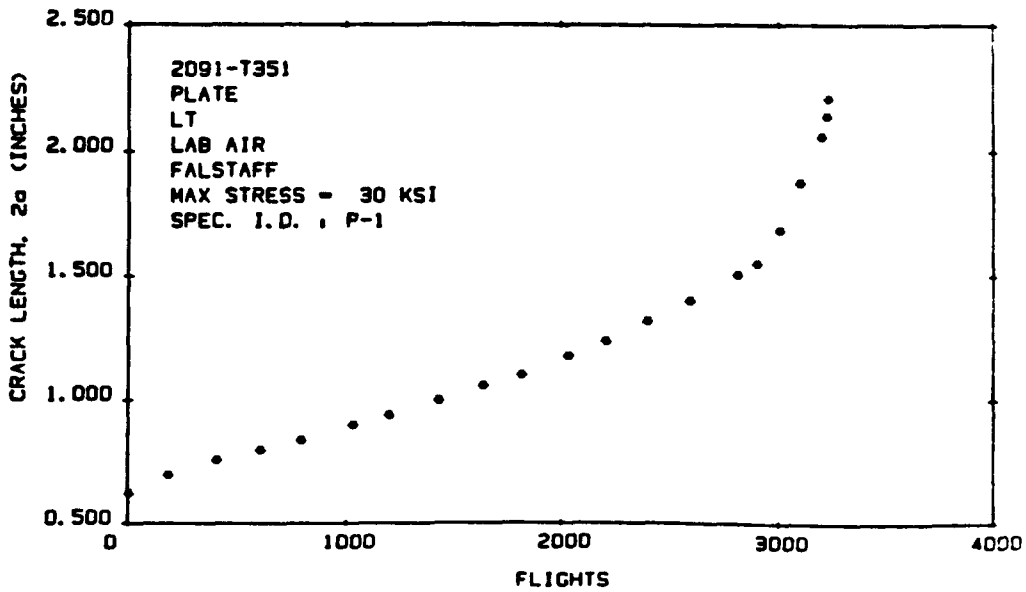


Figure A7 Crack Length Versus Flights for 2091-T351 Plate Under FALSTAFF Loading, Max Stress = 30 KSI.

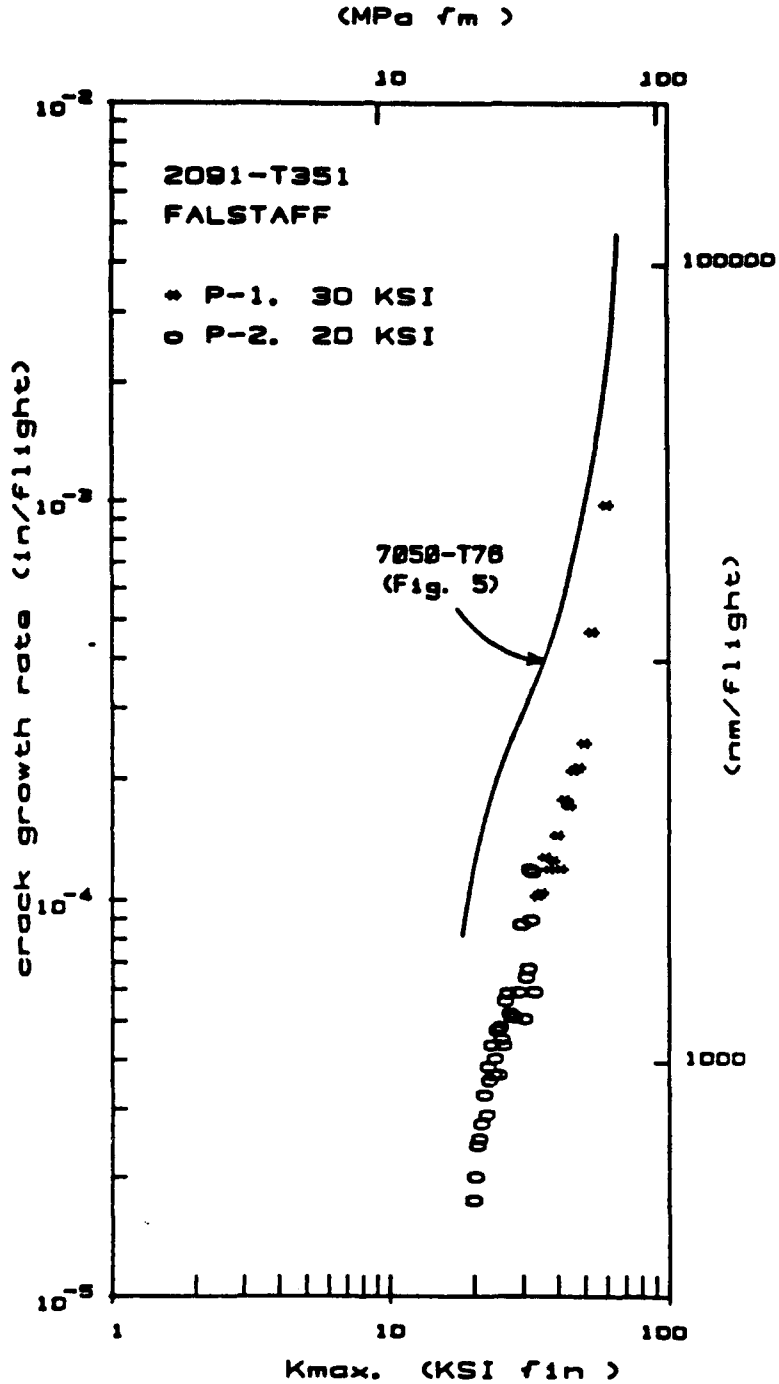


Figure A8 FALSTAFF Spectrum Results for 2091-T351 Reduced in Terms of Growth Rate and Maximum Spectrum Stress Intensity.

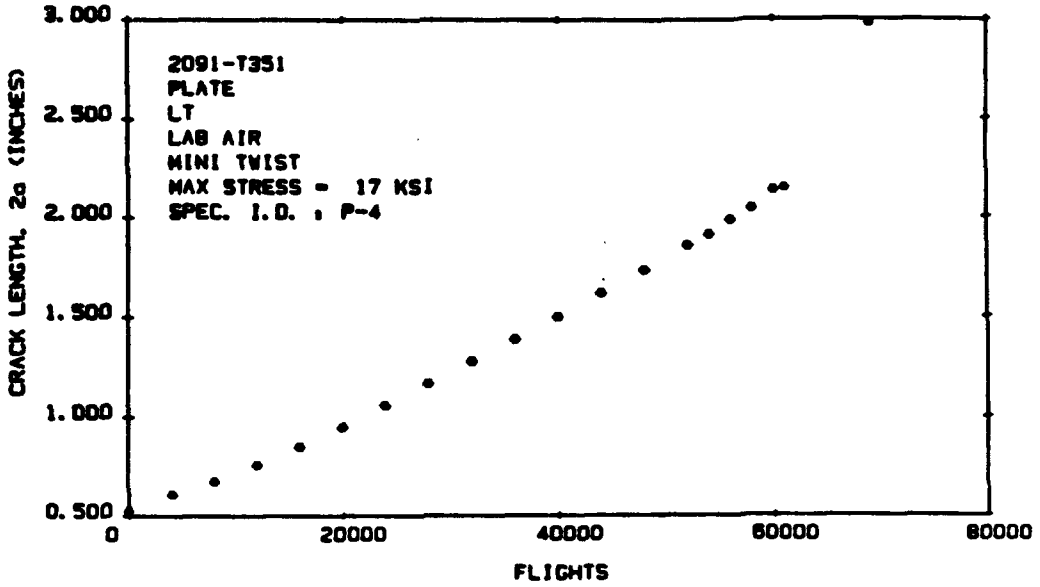


Figure A9 Crack Length Versus Flights for 2091-T351 Plate Under Mini-TWIST Loading, Max Stress = 17 KSI.

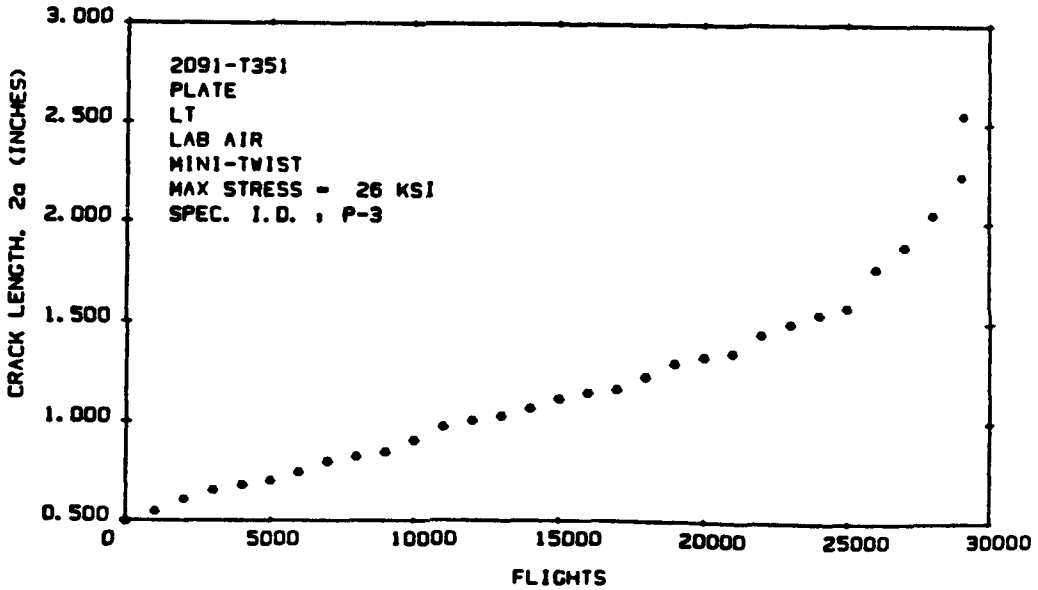


Figure A10 Crack Length Versus Flights for 2091-T351 Plate Under Mini-TWIST, Max Stress = 26 KSI.

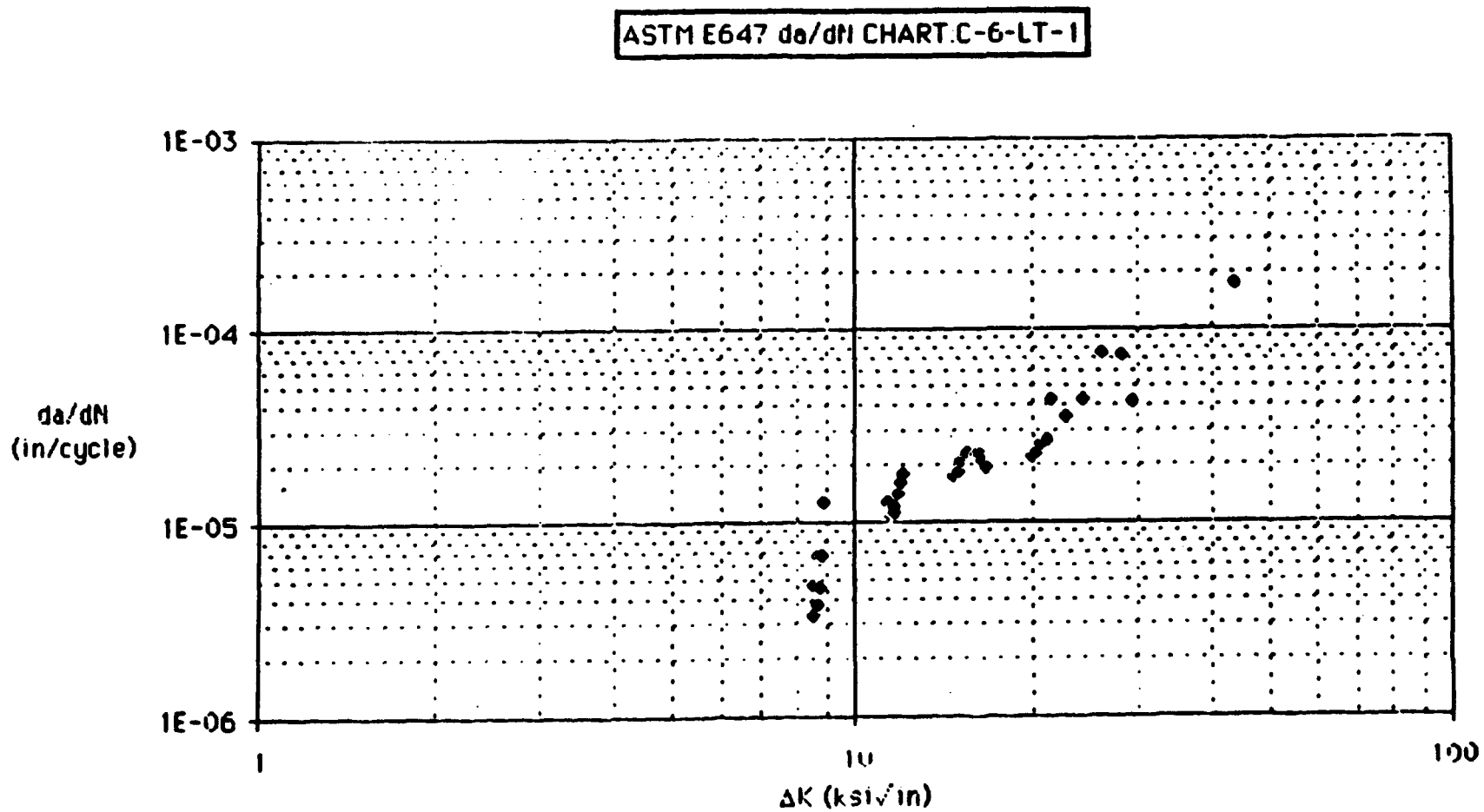


Figure A10A Fatigue Crack Growth Rate Data for 2091-T351 0.42" Plate (L-T Orientation). General Dynamics CA.

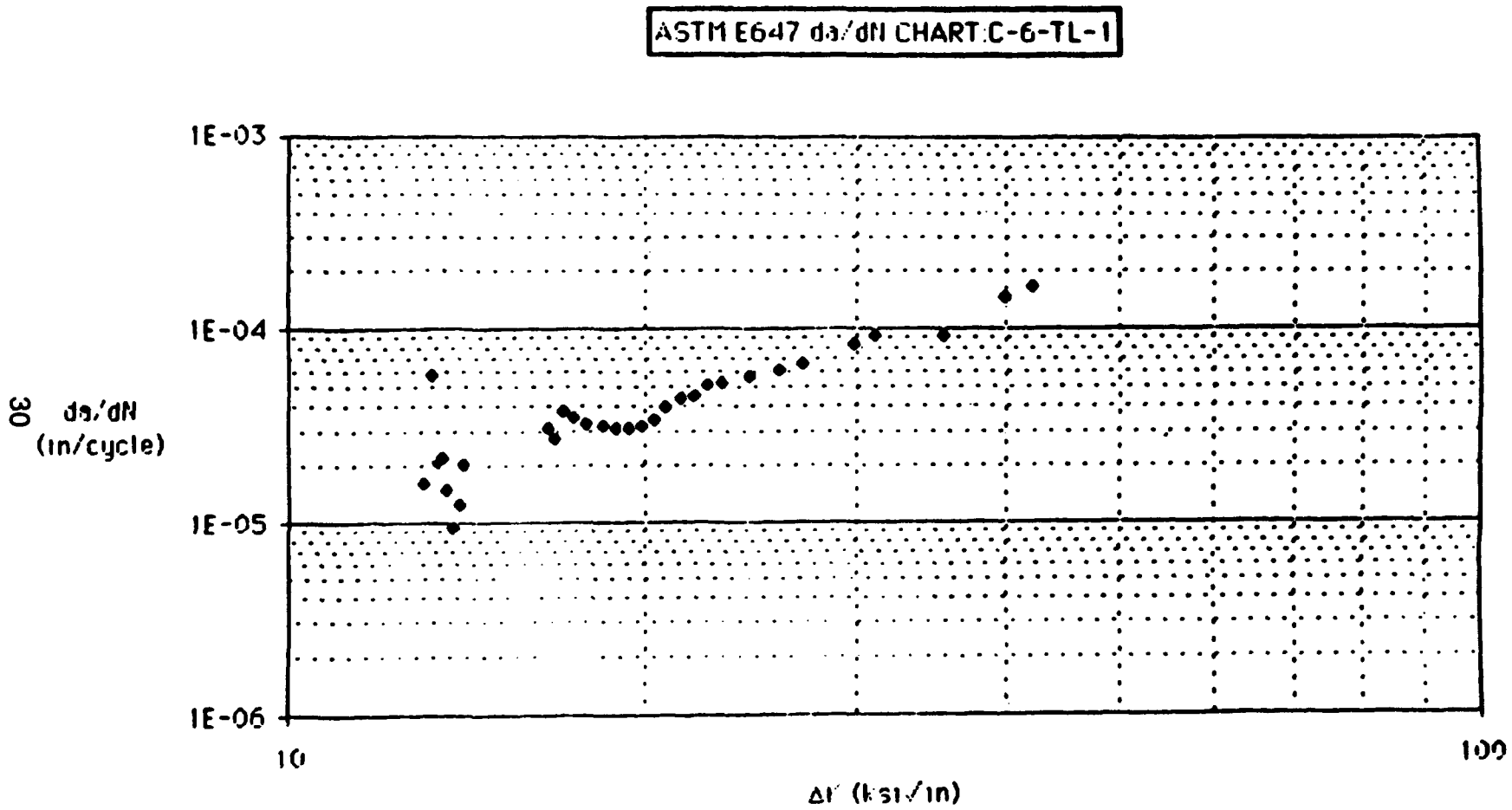


Figure A10b Fatigue Crack Growth Rate Data for 2091-T351 0.42" Plate (T-L Orientation). General Dynamics CA.

PECHINEY

2091-T8X PLATE

TABLE A18

TENSILE RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	LONG	71.4	60.6	10.0	16.0	11.5
			71.5	59.9	12.0	16.0	11.4
			71.8	61.1	11.0	16.0	11.4
			71.5	60.4	10.0		11.4
			72.0	60.4	11.0		11.4
			72.0	60.6	9.0		11.5
GRUMMAN	RT	LONG	68.7	58.2	6.0	6.2	11.8
			70.0	58.2	8.5	9.2	11.9
			67.6	58.4	6.5	6.8	11.1
GENERAL DYNAMICS, TX	RT	LONG	72.8	60.6	8.0		
			72.5	60.8	7.3		
		AVERAGE	71.1	59.9	9.0	11.7	11.5
	STANDARD DEVIATION		1.6	1.1	2.0	4.8	0.2

TABLE A19

TENSILE RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	L TRANS	72.4	54.8	12.0	17.4	11.5
			72.5	55.0	12.0	17.8	11.6
			72.4	55.0	12.0	18.5	11.4
			69.2	51.1	15.0		11.4
			69.5	51.2	17.0		11.2
			69.1	50.9	16.0		11.8
GRUMMAN	RT	L TRANS	69.5	53.0	13.5	22.3	11.5
			69.0	51.1	13.0	16.8	13.0
			69.1	53.0	13.5	17.6	13.4
GENERAL DYNAMICS, TX	RT	L TRANS	71.8	55.9	11.0		
			72.0	55.9	11.0		
		AVERAGE	70.6	53.4	13.3	18.4	11.9
	STANDARD	DEVIATION	1.6	2.0	2.0	2.0	0.8

TABLE A20

TENSILE RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GRUMMAN	RT	45	63.9	45.8	21.0	29.7	11.2
			62.5	45.7	21.5	27.2	11.1
			62.9	45.3	20.5	28.7	11.1
		AVERAGE	63.1	45.6	21.0	28.5	11.1
	STANDARD DEVIATION		0.7	0.3	0.5	1.3	0.1

TABLE A21

TENSILE RESULTS AT t/10 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	LONG	71.6	60.0	10.0		11.3
			71.2	59.9	10.0		11.5
			71.4	60.4	10.0		11.1
		AVERAGE	71.4	60.1	10.0		11.3
	STANDARD DEVIATION		0.2	0.3	0.0		0.2

TABLE A22

TENSILE RESULTS AT t/10 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	L TRANS	69.6	51.2	18.0		11.1
			69.3	51.1	16.0		11.6
			69.7	51.4	15.0		11.4
		AVERAGE	69.5	51.2	16.3		11.4
	STANDARD DEVIATION		0.2	0.2	1.5		0.3

TABLE A23

TENSILE RESULTS AT t/2 LOCATION WITH 100 HOURS EXPOSURE FOR

PECHINEY 2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMP (DEGREES F)	EXPOSURE TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)
NORTHROP	RT	300	LONG	77.7	65.8	9.0	12.3
				77.7	65.9	9.0	11.6
		350	LONG	75.8	70.6	7.0	15.9
				76.1	70.7	7.0	18.9
		375	LONG	71.3	64.7	7.0	18.5
				71.6	64.8	7.0	18.1
		400	LONG	66.9	58.1	7.0	18.5
				66.7	58.0	7.0	18.1

TABLE A24

COMPRESSION RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
NORTHROP	RT	LONG	48.6	
			48.3	
			48.6	
GRUMMAN	RT	LONG	48.1	11.9
			50.5	11.5
			48.4	11.1
GENERAL DYNAMICS, TX	RT	LONG	48.6	
			49.2	
		AVERAGE	48.8	11.5
		STANDARD DEVIATION	0.8	0.4

TABLE A25

COMPRESSION RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
NORTHROP	RT	L TRANS	57.6	
			57.4	
			57.5	
GRUMMAN	RT	L TRANS	58.3	11.9
			58.2	11.2
			58.9	11.6
GENERAL DYNAMICS. TX	RT	L TRANS	57.5	
			60.9	
		AVERAGE	58.3	11.5
		STANDARD DEVIATION	1.2	0.3

TABLE A26

COMPRESSION RESULTS AT t/2 LOCATION FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
GRUMMAN	RT	45	49.5	11.3
			48.6	11.4
			49.6	10.8
		AVERAGE	49.2	11.2
		STANDARD DEVIATION	0.6	0.3

TABLE A27

RIVET SHEAR RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	L-S	35.9
		35.9
		35.9
GRUMMAN	L-S	36.4
		38.0
		37.8
	AVERAGE	36.6
	STANDARD DEVIATION	1.0

TABLE A28

RIVET SHEAR RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	T-S	33.5
		33.5
		33.9
GRUMMAN	T-S	34.6
		35.9
		37.2
	AVERAGE	34.8
	STANDARD DEVIATION	1.5

TABLE A29

SLOTTED SHEAR RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
GENERAL DYNAMICS, TX	LONG	41.3
		40.9
	AVERAGE	41.1
	STANDARD DEVIATION	0.3

TABLE A30

SLOTTED SHEAR RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
GENERAL DYNAMICS, TX	L TRANS	42.6
		43.4
	AVERAGE	43.0
	STANDARD DEVIATION	0.6

TABLE A31

BEARING RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	LONG	1.5	93.0	73.0
			89.6	71.8
			92.6	73.7
GRUMMAN	LONG	1.5	92.9	71.9
			93.8	73.0
			93.4	72.1
GENERAL DYNAMICS, TX	LONG	1.5	117.0	93.0
			112.0	91.4
		AVERAGE	98.0	77.5
		STANDARD DEVIATION	10.3	9.1

TABLE A32

BEARING RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	L TRANS	1.5	99.3	75.5
			98.9	76.0
			97.9	74.2
GRUMMAN	L TRANS	1.5	94.9	73.0
			91.9	70.1
			92.8	71.0
GENERAL DYNAMICS, TX	L TRANS	1.5	97.0	79.1
			97.8	80.5
		AVERAGE	96.3	74.9
		STANDARD DEVIATION	2.8	3.6

TABLE A33

BEARING RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	LONG	2.0	119.4	86.8
			118.9	87.8
			118.6	86.4
GRUMMAN	LONG	2.0	113.0	85.6
			115.5	86.9
			114.2	87.1
GENERAL DYNAMICS, TX	LONG	2.0	123.0	91.3
			122.0	94.0
		AVERAGE	118.1	88.2
		STANDARD DEVIATION	3.6	2.9

TABLE A34

BEARING RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	L TRANS	2.0	123.9	90.7
			124.2	94.2
			124.1	92.1
GRUMMAN	L TRANS	2.0	115.6	88.2
			117.5	89.5
			114.9	88.9
GENERAL DYNAMICS, TX	L TRANS	2.0	99.3	82.7
			103.0	85.3
		AVERAGE	115.3	89.0
		STANDARD DEVIATION	9.6	3.7

TABLE A35

FRACTURE TOUGHNESS RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
NORTHROP	L-T	27.0		VALID
		28.0		VALID
GRUMMAN	L-T		40.1	INVALID(1)
			43.2	INVALID(1,2)
			39.5	INVALID(1,2)
GENERAL DYNAMICS, TX	L-T		29.9	INVALID(2,3,4)
			29.0	INVALID(2,3,4)
	AVERAGE	27.5	36.3	
	STANDARD DEVIATION	0.7	6.5	

(1): 2.5(Kq)^2/(YS)^2 > B
(2): Pmax/Pq > 1.10
(3): INSUFFICIENT THICKNESS
(4): CRACK CURVATURE > 5%

TABLE A36

FRACTURE TOUGHNESS RESULTS FOR PECHINEY

2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
NORTHROP	T-L	29.8		VALID
		28.5		VALID
GRUMMAN	T-L		40.5	INVALID(1)
			43.2	INVALID(1,2)
			38.2	INVALID(1,2)
GENERAL DYNAMICS, TX	T-L		27.1	INVALID(2,3)
			27.0	INVALID(2,3,4)
	AVERAGE	29.2	35.2	
	STANDARD DEVIATION	0.9	7.6	

(1): 2.5(Kq)^2/(YS)^2 > B
(2): Pmax/Pq > 1.10
(3): INSUFFICIENT THICKNESS
(4): CRACK CURVATURE > 5%

TABLE A37

General Dynamics, Texas

Pechiney 2091-T8X Plate
(0.42" X 39" X 39")
Results of R-Curve Tests

	K_{R25}, ksi-in$^{1/2}$
L-T	48.3
L-T	50.2
T-L	43.2
T-L	43.2

TABLE A38

SMOOTH FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR

PECHINEY 2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
NORTHROP	LONG	60.0	31,299
		50.0	84,556
		45.0	135,397
		45.0	140,237
		40.0	242,930
		37.5	1,386,890
		37.5	934,697
		35.0	2,000,000 *

(*): INDICATES RUN-OUT TEST

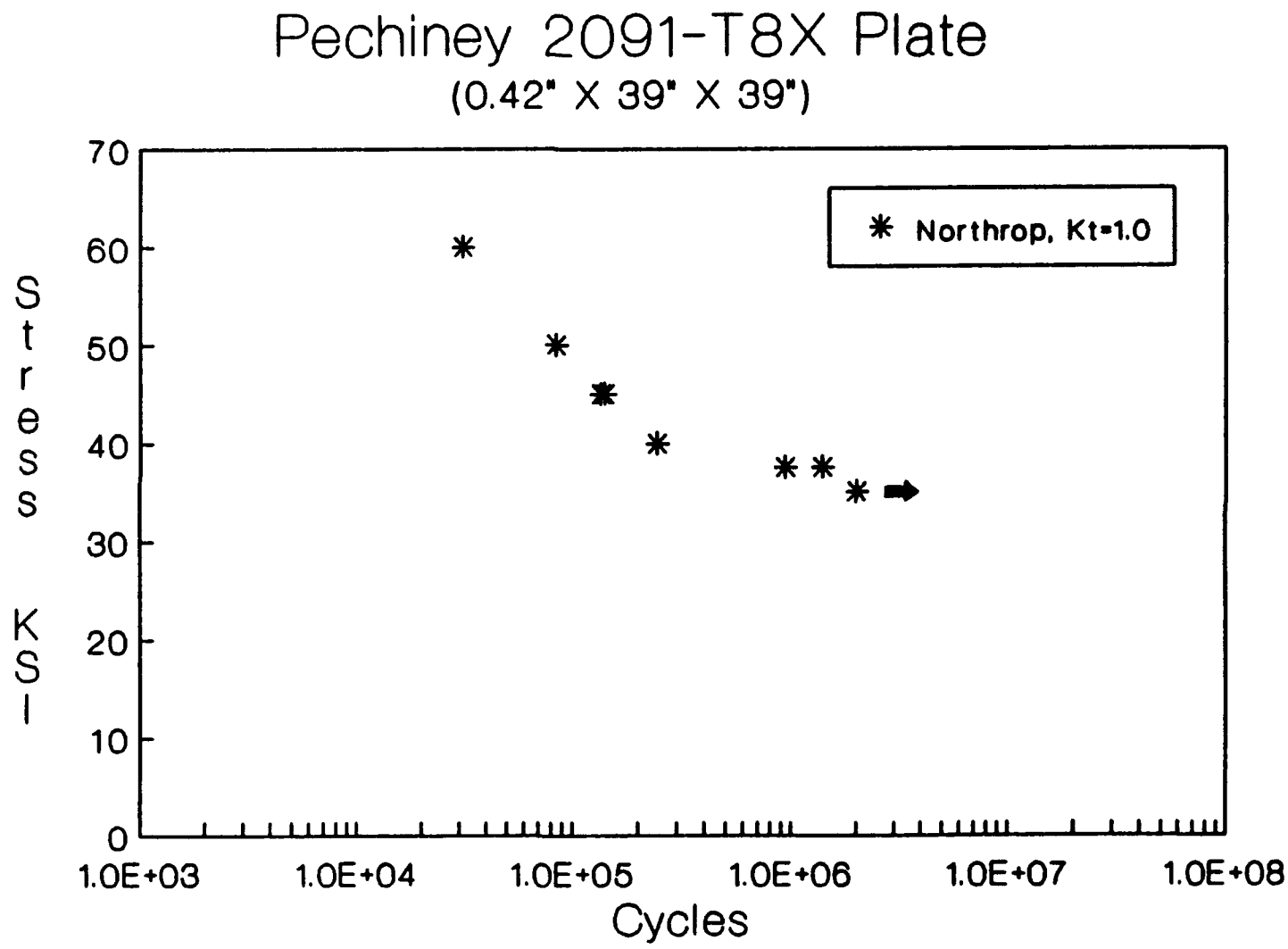


Figure A11 Fatigue Results for 2091-T8X 0.42" Plate (R=0.1, Kt=1.0). Northrop.

TABLE A39

NOTCHED FATIGUE RESULTS WITH R=0.1 AND Kt=3.0 FOR

PECHINEY 2091-T8X PLATE (0.42" X 39" X 39")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
NORTHROP	LONG	45.0	13,635
		40.0	26,179
		35.0	48,930
		30.0	216,536
		27.5	257,234
		27.5	193,418
		25.0	474,737 *
		23.0	940,075

(*): INDICATES SLANT FAILURE

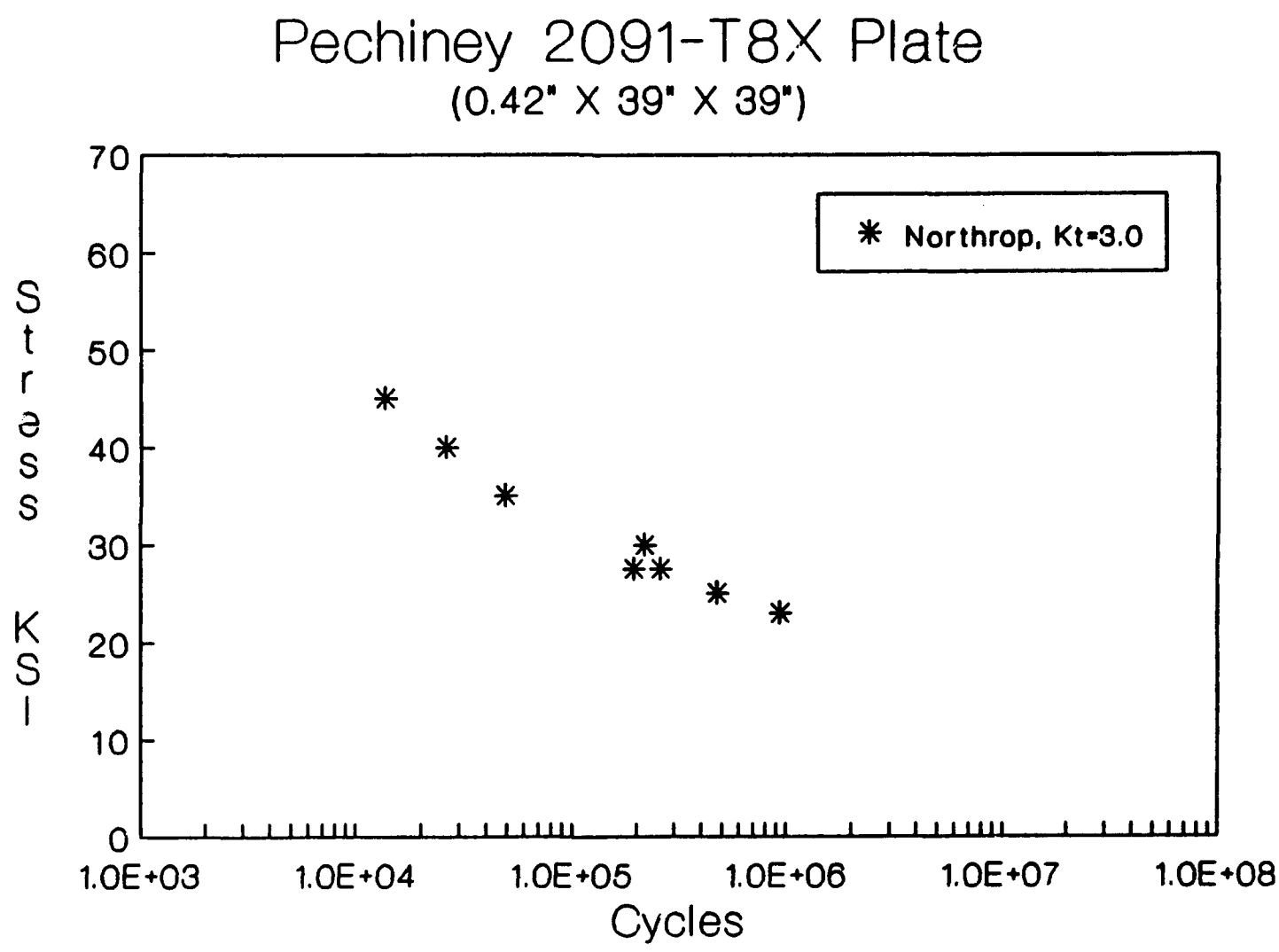


Figure A12 Fatigue Results for 2091-T8X 0.42" Plate (R=0.1, Kt=3.0). Northrop.

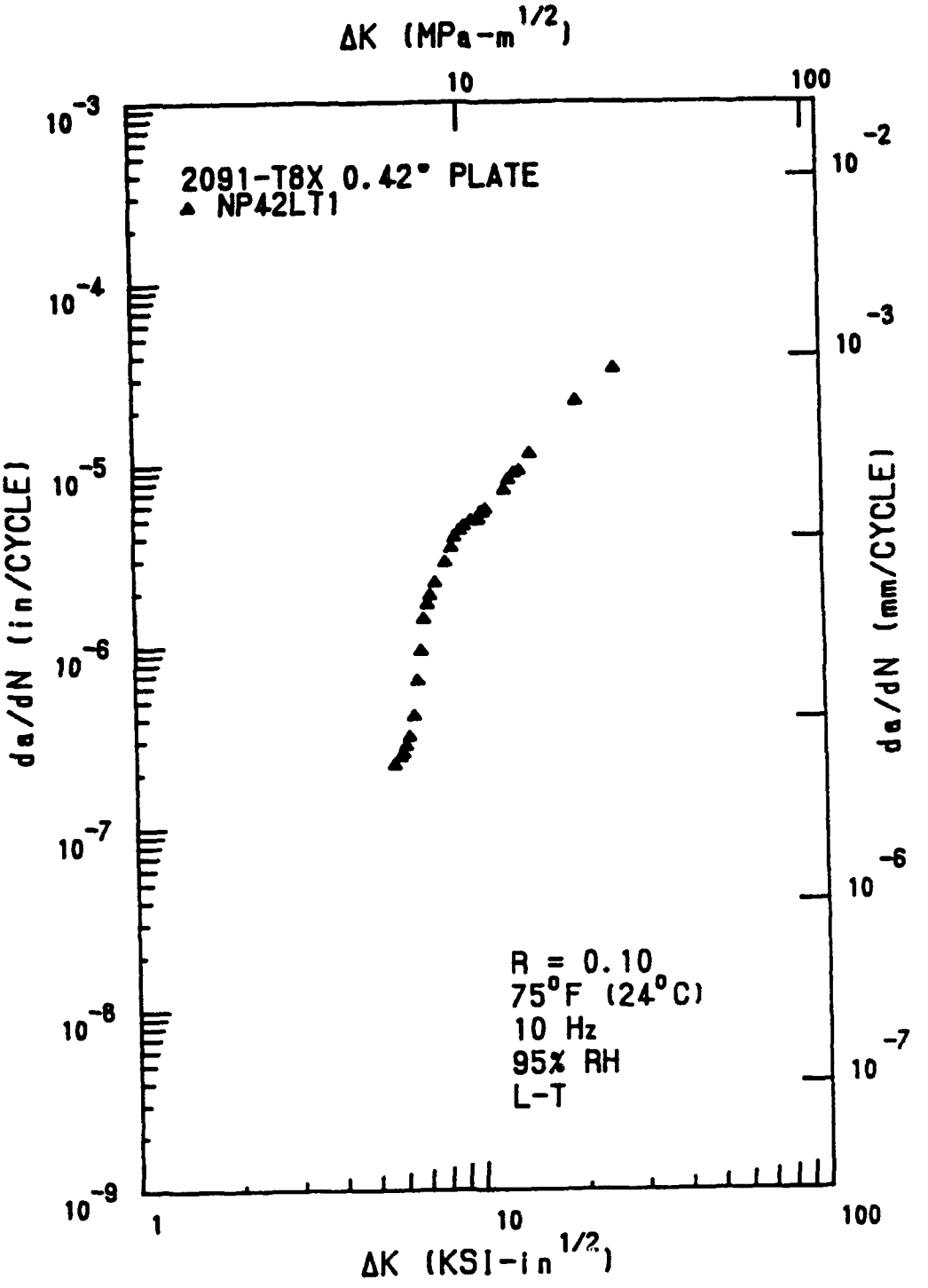


Figure A13 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.42" Plate (L-T Orientation). Northrop.

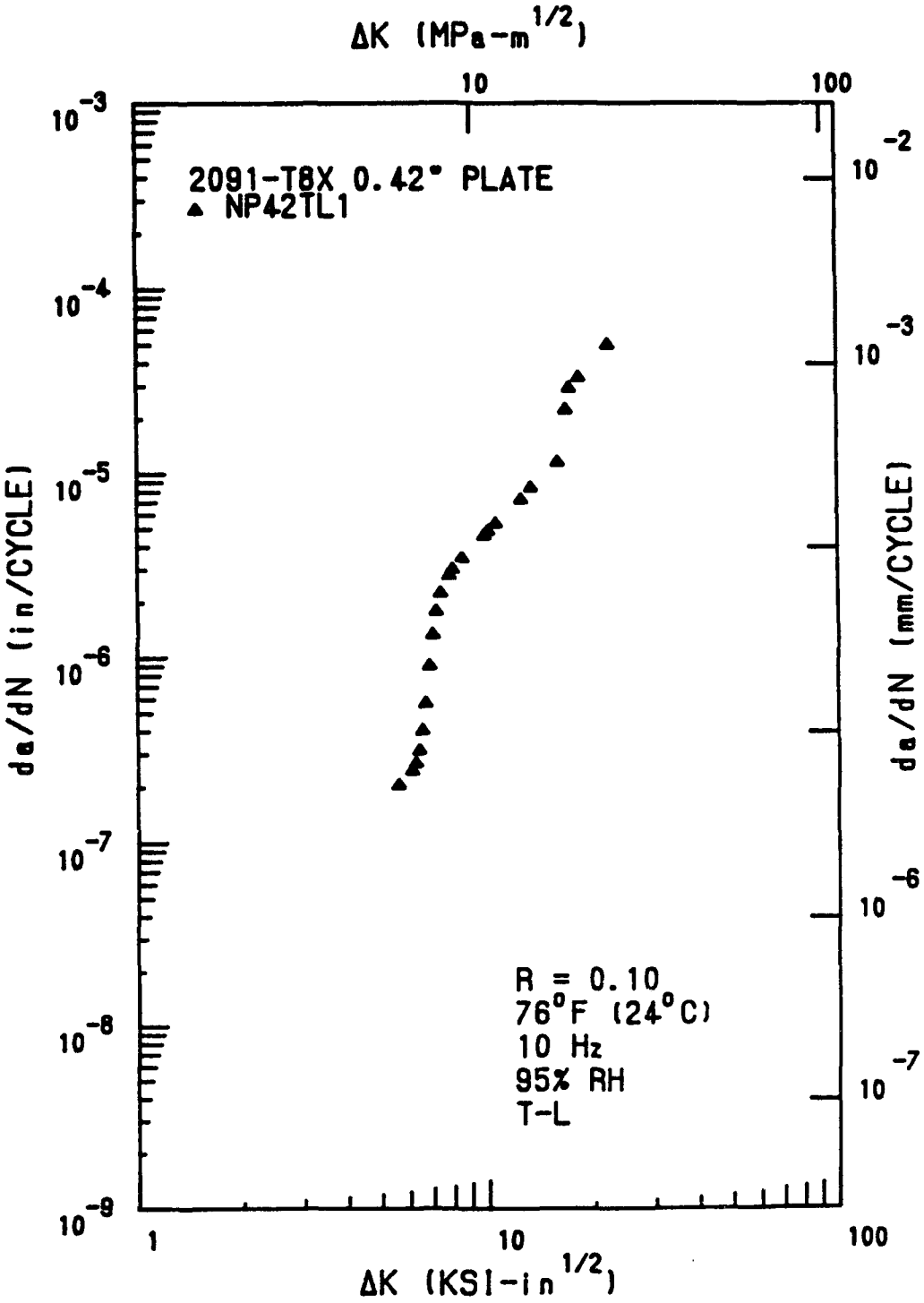


Figure A14 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.42" Plate (T-L Orientation). Northrop.

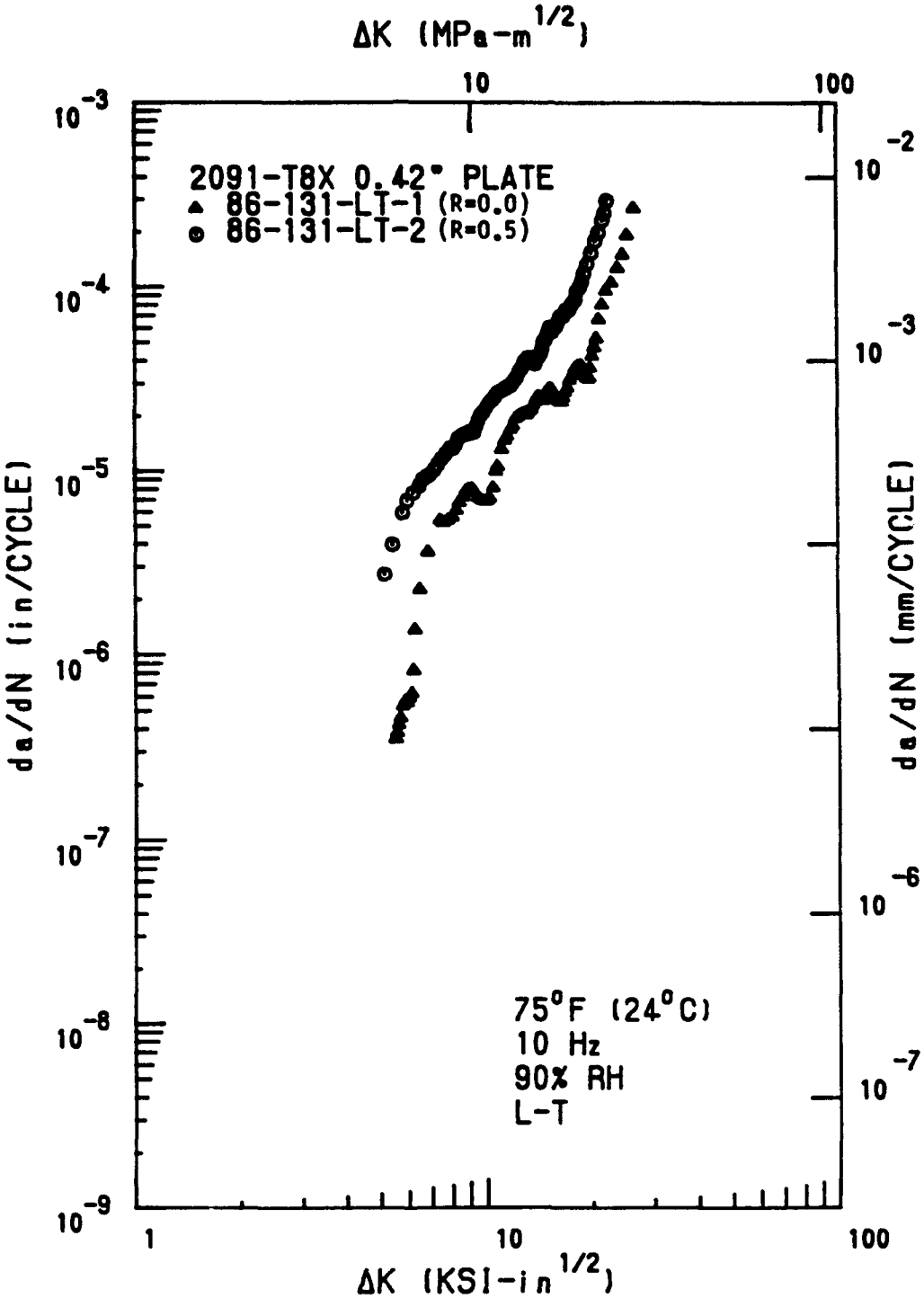


Figure A15 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.42" Plate (L-T Orientation). Grumman.

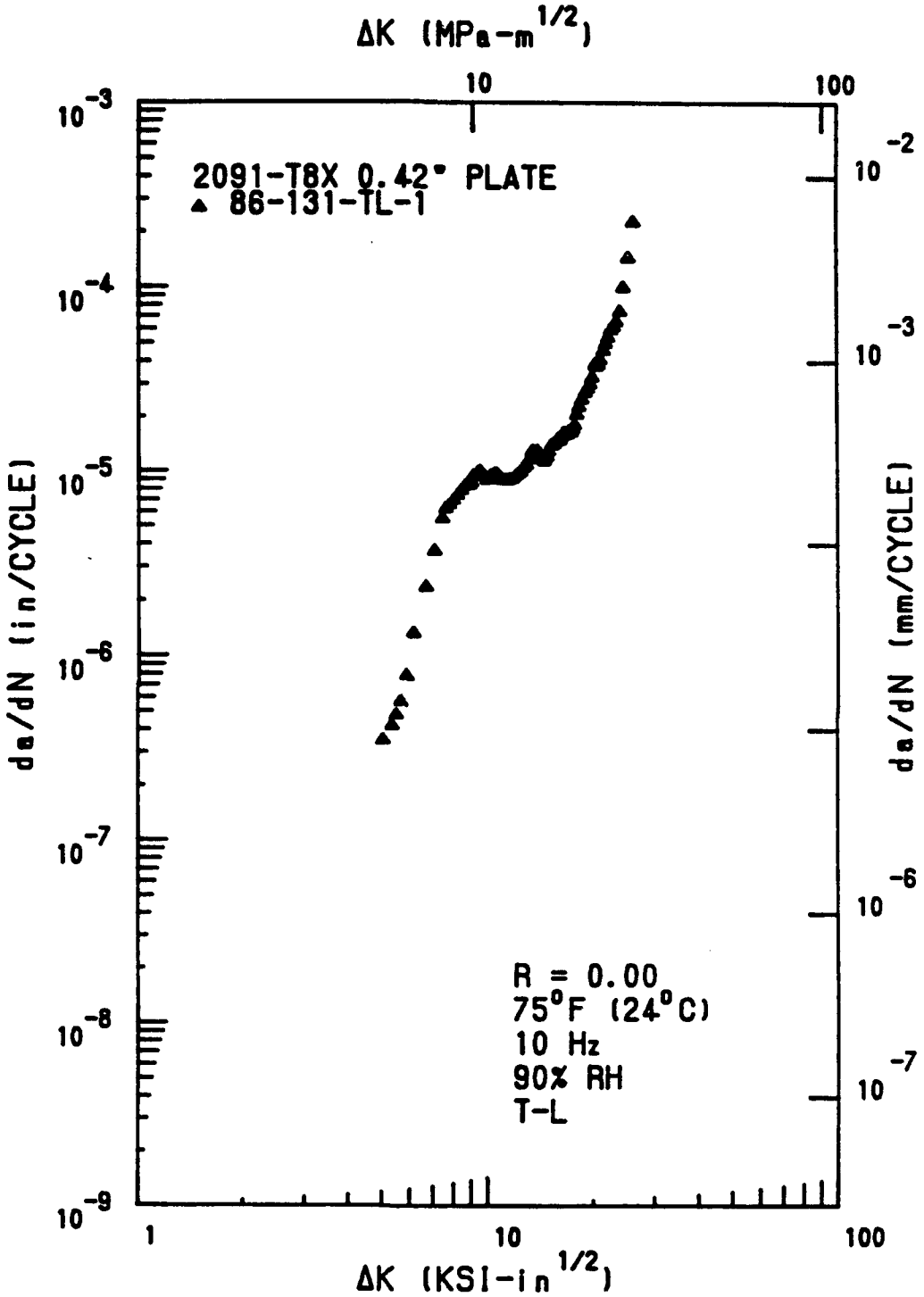


Figure A16 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.42" Plate (T-L Orientation). Grumman.

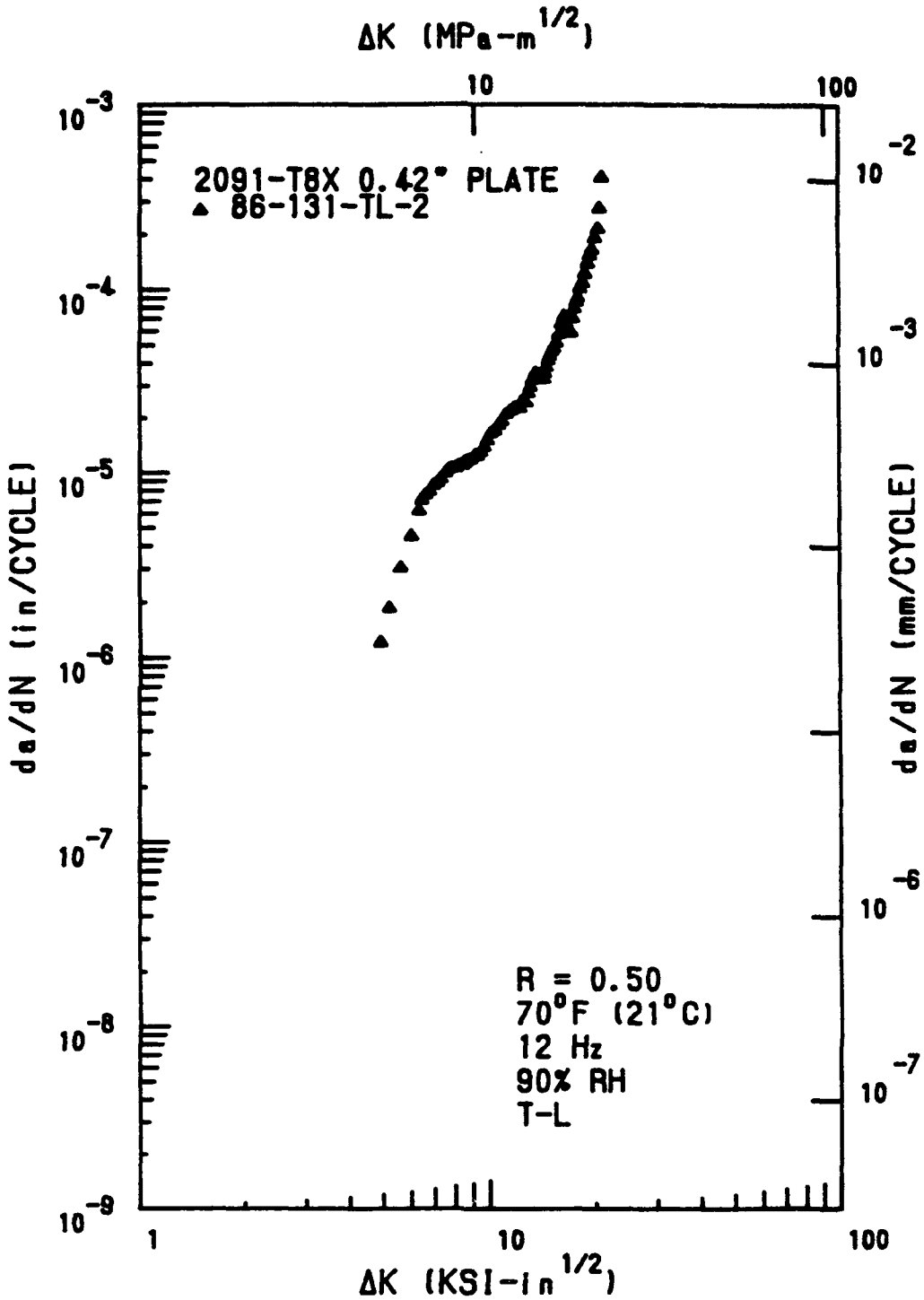


Figure A17 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.42" Plate (T-L Orientation). Grumman.

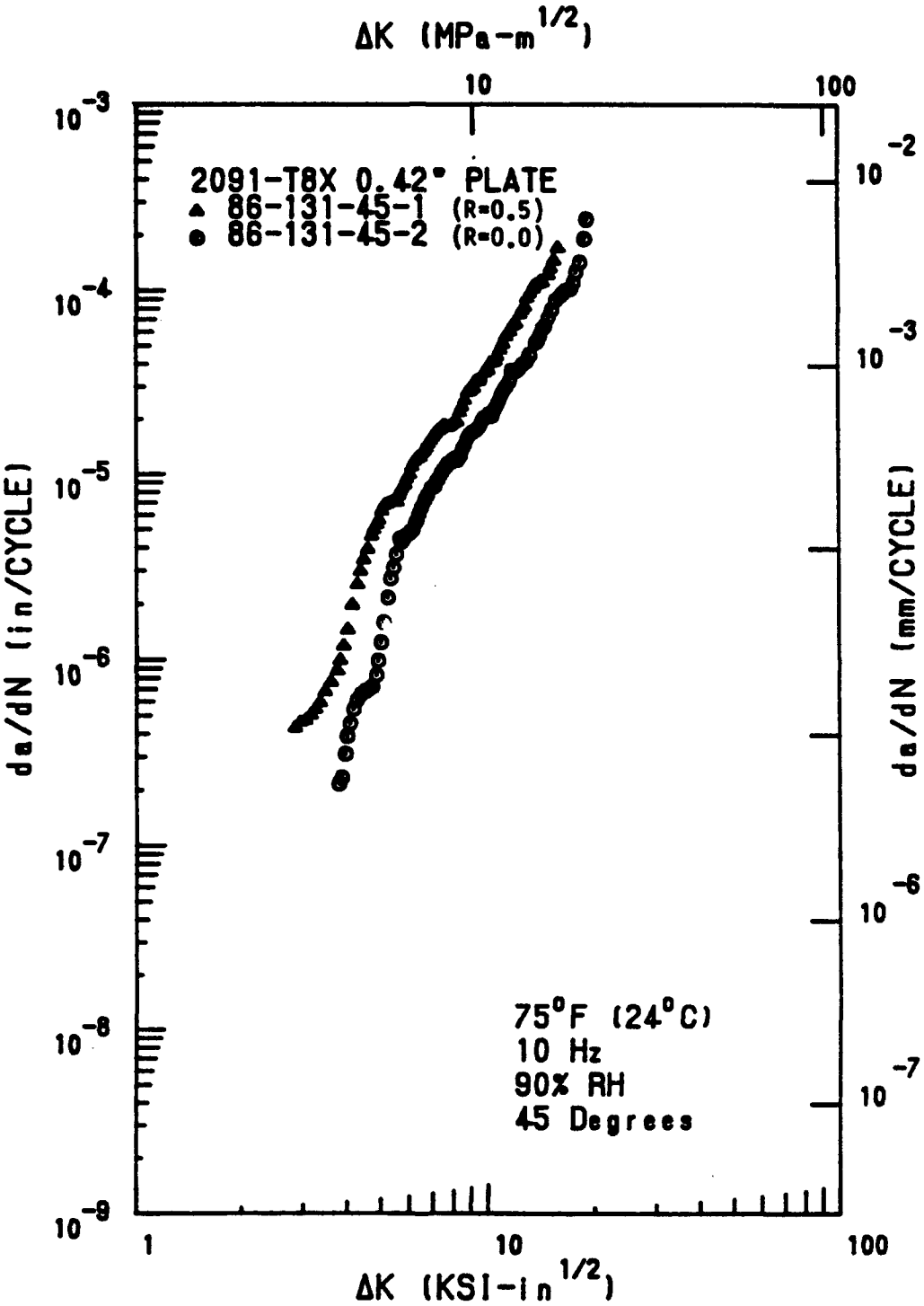
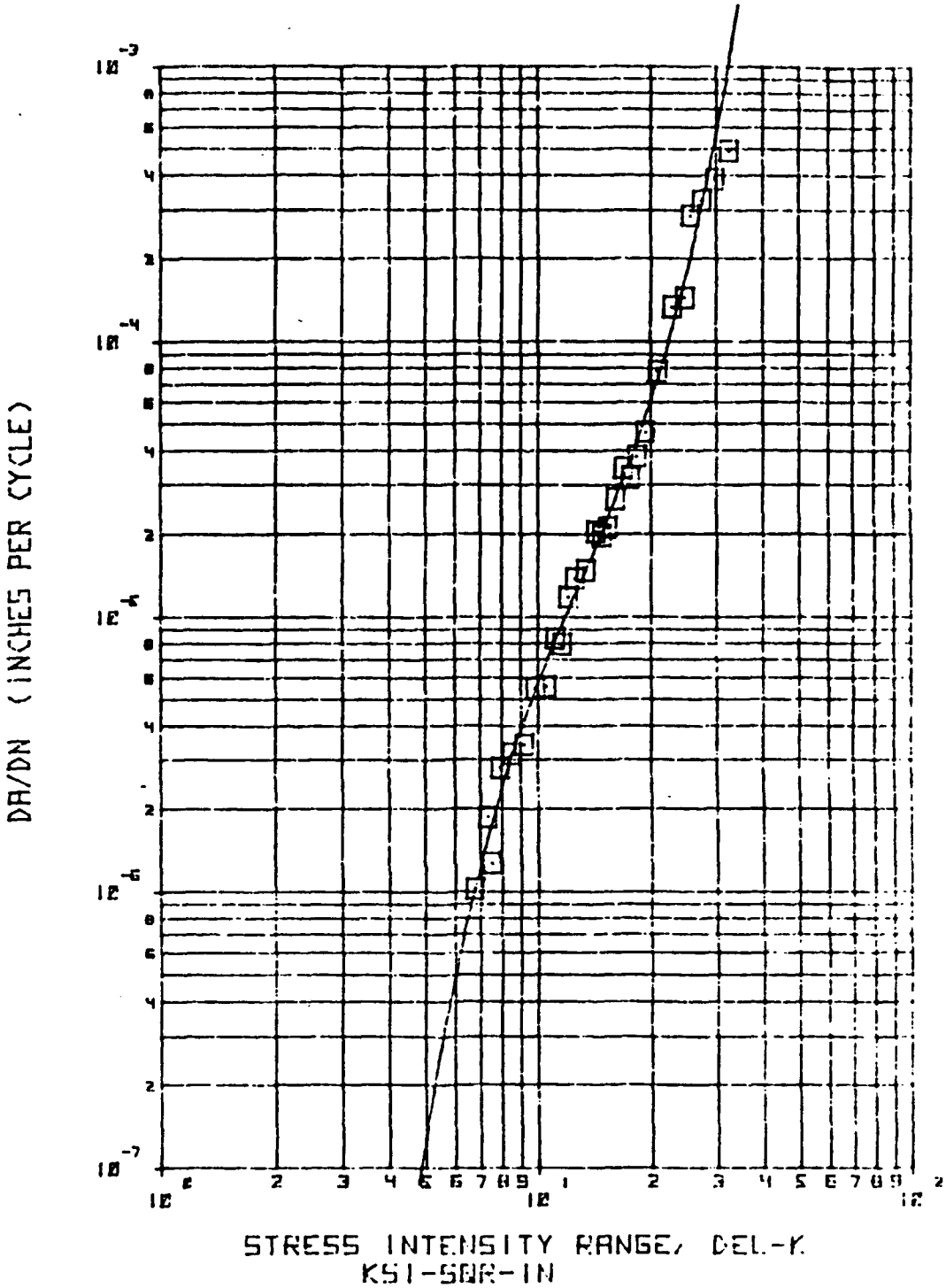
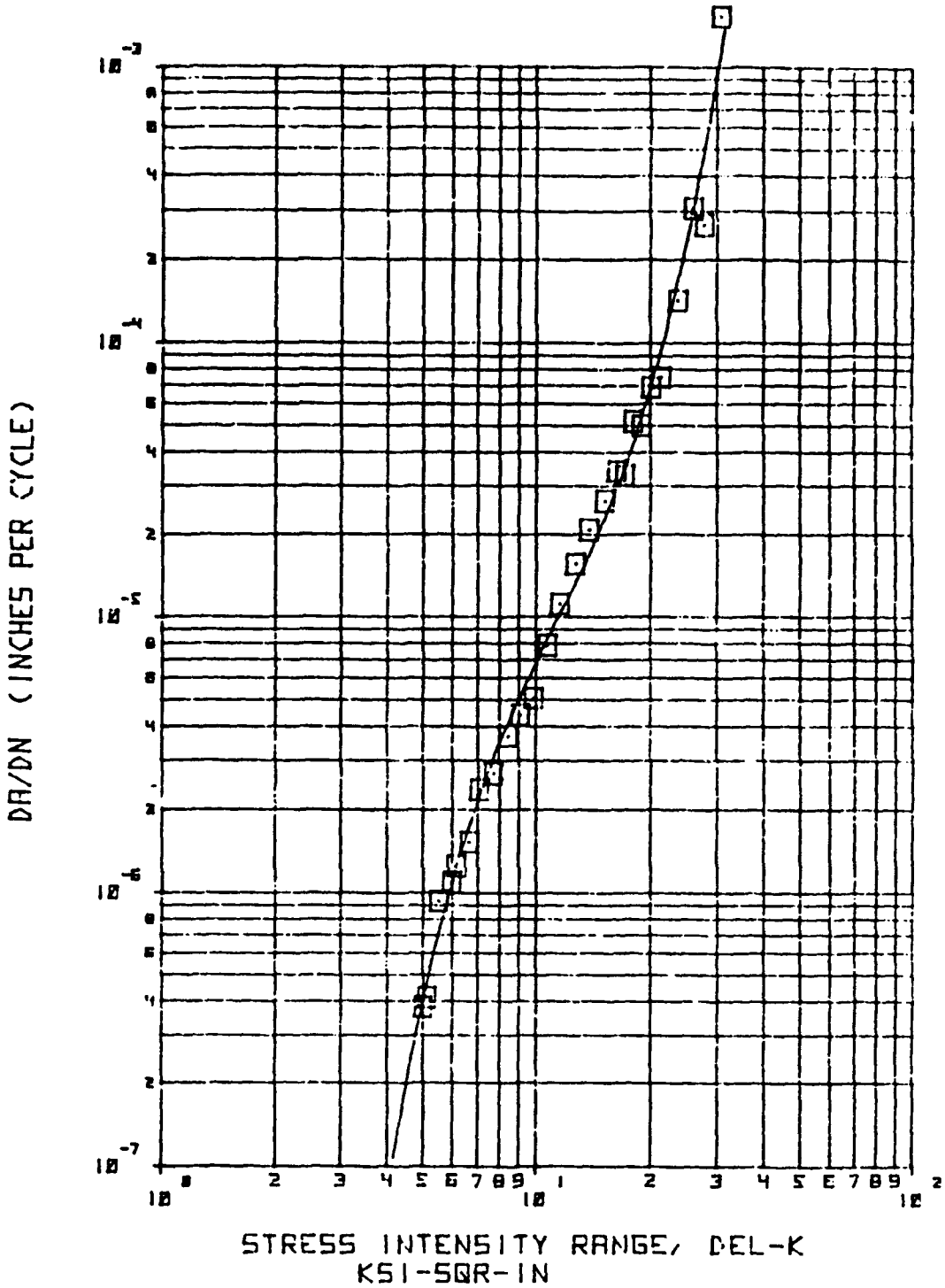


Figure A18 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.42" Plate (45 degrees Orientation). Grumman.



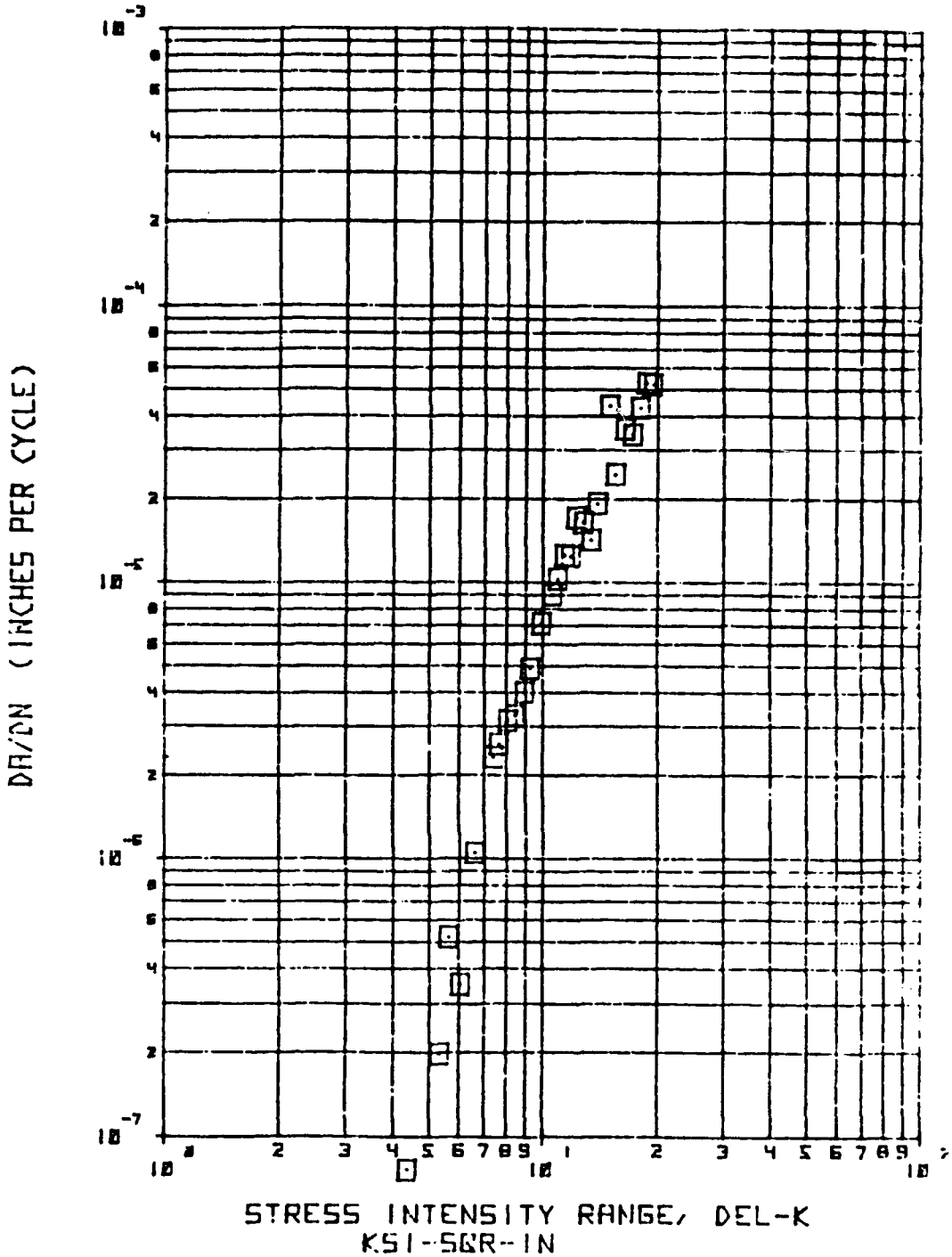
Material:	2091-T851 Plate
Age:	335°F - 16 hrs
Environment:	Lab air, Room temperature
Orientation:	L-T
Stress Ratio:	0.1
Frequency:	5 Hz

Figure A19 Fatigue Crack Growth Rate Data for 2091-T8X 0.42" Plate (L-T orientation). General Dynamics TX.



Material:	2091-T851 Plate
Age:	335°F - 16 hrs
Environment:	Lab air, Room temperature
Orientation:	T-L
Stress Ratio:	0.1
Frequency:	5 Hz

Figure A20 Fatigue Crack Growth Rate Data for 2091-T8X 0.42" Plate (T-L orientation). General Dynamics TX.



Material:	2091-T851 Plate
Age:	335°F - 16 hrs
Environment:	Lab air, Room temperature
Orientation:	T-L
Stress Ratio:	0.1
Frequency:	5 Hz

Figure A21 Fatigue Crack Growth Rate Data for 2091-T8X 0.42" Plate (T-L orientation). General Dynamics TX.

APPENDIX B

PECHINEY 2091-T3 AND 2091-T8X
(0.063" X 79" X 39')

INTRODUCTION

The Pechiney 2091-T3 0.063-inch sheets were received the second quarter of 1986. Three participants heat treated the 2091-T3 to a T8X temper. Grumman Aircraft Systems and Northrop Corporation achieved the T8 condition by aging the 2091 sheet at 275°F for 12 hours (recommended by the producer of this alloy). General Dynamics Fort Worth Division aged the 2091 sheet at 335°F for 32 hours achieving the T81 condition.

TESTING

Basic mechanical properties (tension, compression, bearing, etc.) were tested according to ASTM standards, unless otherwise specified.

Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 standard. The growth rate a-N data that was generated by the participants (Grumman, McDonnell Aircraft Co., and Northrop) were reduced using a seven-point incremental polynomial method. This involves fitting a second-order polynomial (parabola) to sets of seven successive data points. The data are also checked against size requirements per ASTM E647, Section 7.2. General Dynamics, TX performed constant amplitude fatigue crack growth tests using a K-increasing (load increasing) method.

2091-T3 SHEET
(0.063"x79"x79")

TABLE B1

TENSILE RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
BOEING	RT	LONG	57.0	41.3	13.0		
			58.1	41.2	20.0		
			58.0	41.2	22.0		
LTV	RT	LONG	58.8		21.5		
			58.6	39.0	21.0		10.7
			58.2	39.4	19.5		11.0
GENERAL DYNAMICS, CALIF.	RT	LONG	56.7	41.1	20.0		10.7
			55.9	40.3	20.0		10.7
			56.5	41.7	18.5		10.7
NORTHROP			58.5	42.3	16.9		
			58.9	42.1	16.9		
			59.0	42.5	16.9		
MCAIR	RT	LONG	57.5	42.6	19.0		12.0
			57.0	42.4	16.0		12.1
			57.5	42.4	23.0		12.2
MARTIN MARIETTA, LOUISIANA	RT	LONG	56.1	39.4	18.0	27.0	
			57.6	40.8	20.0	21.0	
			59.2	42.5	22.0	25.0	
		AVERAGE	57.7	41.3	19.1	24.3	11.3
	STANDARD DEVIATION		1.0	1.2	2.5	3.1	0.7

TABLE B2

TENSILE RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
BOEING	RT	L TRANS	60.8	41.5	16.0		
			61.4	41.5	17.0		
			60.8	41.6	16.0		
NORTHROP	RT	L TRANS	62.0	41.9	17.0		
			62.7	41.6	16.8		
			62.0	42.0	17.1		
LTV	RT	L TRANS	61.7	40.0	17.0		10.7
			61.6	39.9	18.5		10.6
			61.9	39.3	16.5		11.0
GENERAL DYNAMICS, CALIF.	RT	L TRANS	60.0	41.3	22.0		10.9
			60.2	41.2	21.0		10.9
			59.7	41.4	20.0		10.9
MCAIR	RT	L TRANS	62.0	42.2	17.0		12.0
			60.5	42.7	17.0		12.0
			60.5	41.9	18.0		12.1
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	60.8	41.2	17.0	27.0	
			60.5	40.8	16.0	21.0	
			60.3	40.9	16.0	24.0	
		AVERAGE	61.1	41.3	17.6	24.0	11.2
	STANDARD DEVIATION		0.9	0.9	1.8	3.0	0.6

TABLE B3

COMPRESSION RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
BOEING	RT	LONG	39.4	
			39.6	
			39.9	
LTV	RT	LONG	41.4	10.6
			41.4	10.6
GENERAL DYNAMICS, CALIF.	RT	LONG	38.7	11.7
			38.9	12.0
			39.1	12.0
		AVERAGE	39.8	11.4
		STANDARD DEVIATION	1.0	0.7

TABLE B4

COMPRESSION RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
BOEING	RT	L TRANS	44.6	
			44.7	
			44.5	
LTV	RT	L TRANS	45.9	
			45.2	
			45.3	
GENERAL DYNAMICS, CALIF.	RT	L TRANS	42.7	11.8
			44.3	11.5
		AVERAGE	44.7	11.7
		STANDARD DEVIATION	1.0	0.2

TABLE B5

PUNCH SHEAR RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
BOEING	S TRANS	36.0
		36.5
		36.0
	AVERAGE	36.2
	STANDARD DEVIATION	0.3

TABLE B6

SLOTTED SHEAR RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 39" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
BOEING	LONG	39.8
		39.0
		36.9
LTV	LONG	38.3
		38.6
		37.9
MCAIR	LONG	38.1
		37.9
		38.2
	AVERAGE	38.3
	STANDARD DEVIATION	0.8

TABLE B7

SLOTTED SHEAR RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 39" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
BOEING	T - L	36.8
		40.1
		36.4
LTV	T - L	40.0
		40.5
		40.5
MCAIR	T - L	39.2
		37.9
		39.0
	AVERAGE	38.9
	STANDARD DEVIATION	1.5

TABLE B8

BEARING RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING	LONG	1.5	88.9	61.4
			90.2	63.0
			90.3	63.5
LTV	LONG	1.5	90.4	58.9
			88.5	61.2
			89.3	61.4
GENERAL DYNAMICS, CALIF.	LONG	1.5	88.6	66.6
			88.1	64.0
			90.0	64.0
		AVERAGE	89.4	62.7
		STANDARD DEVIATION	0.9	2.2

TABLE B9

BEARING RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING	L TRANS	1.5	92.9	62.6
			93.1	63.3
			93.1	63.3
LTV	L TRANS	1.5	91.0	60.5
			92.1	59.7
			92.2	61.8
GENERAL DYNAMICS, CALIF.	L TRANS	1.5	90.3	65.7
			88.5	62.3
			87.9	64.0
		AVERAGE	91.2	62.6
		STANDARD DEVIATION	2.0	1.8

TABLE B10

BEARING RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING	LONG	2.0	115.2	75.6
			115.8	76.1
			115.3	76.2
LTV	LONG	2.0	111.6	77.3
			111.0	76.4
			112.5	76.9
GENERAL DYNAMICS, CALIF.	LONG	2.0	115.6	76.8
			114.3	73.2
MCAIR	LONG	2.0		73.5
				73.9
		AVERAGE	113.9	75.6
		STANDARD DEVIATION	1.9	

TABLE B11

BEARING RESULTS FOR PECHINEY

2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING	L TRANS	2.0	118.8	76.5
			115.2	75.4
LTV	L TRANS	2.0	111.1	75.9
			114.1	78.8
			116.0	75.1
GENERAL DYNAMICS, CALIF.	L TRANS	2.0	120.6	76.8
			115.9	81.8
			111.7	80.3
MCAIR	L TRANS	2.0		76.5
				72.7
		AVERAGE	115.4	77.0
		STANDARD DEVIATION	3.2	2.7

TABLE B12

General Dynamics, CA

ASTM E561 R Curve CCT Al-Li B-5-LT-1

W = 3.994 in Fty = 41.10 ksi
B = 0.0644 in Pmax = 7540 lb
a = 1.255 in
a/2 = 0.6275 in

a eff	Loads 5000	7540	10000
0.6	28	43	57
0.6	29	44	58
0.7	30	45	59
0.7	30	46	61
0.7	31	47	62
0.7	32	48	64
0.8	33	49	65
0.8	33	51	67
0.8	34	52	69
0.8	35	53	70
0.9	36	54	72
0.9	37	55	73
0.9	38	57	75
0.9	38	58	77
1.0	39	59	78
1.0	40	60	80
1.0	41	62	82
1.0	42	63	84
1.1	43	65	86
1.1	44	66	88
1.1	45	68	90

Load	a (half)	a plastic	a eff	K
0	0.6275	0.0000	0.6275	0
200	0.7225	0.0002	0.7227	1
600	0.7225	0.0014	0.7239	4
1000	0.7225	0.0038	0.7263	6
1400	0.7225	0.0075	0.7300	9
1800	0.7225	0.0124	0.7349	12
2200	0.7225	0.0186	0.7411	14
2600	0.7225	0.0259	0.7484	17
2800	0.7250	0.0302	0.7552	18
3200	0.7250	0.0395	0.7645	21
3600	0.7250	0.0499	0.7749	24
4000	0.7275	0.0619	0.7894	27
4400	0.7275	0.0750	0.8025	30
4600	0.7275	0.0819	0.8094	32
4800	0.7300	0.0896	0.8196	33
5200	0.7300	0.1052	0.8352	37
5600	0.7300	0.1220	0.8520	40
5800	0.7300	0.1309	0.8609	42
6000	0.7450	0.1440	0.8890	45
6200	0.7450	0.1538	0.8988	46
6400	0.7600	0.1685	0.9285	49
6800	0.7600	0.1902	0.9502	53
7000	0.7700	0.2053	0.9753	56
7200	0.7700	0.2172	0.9872	58
7400	0.7850	0.2359	1.0209	62

$K_c = 61.8 \text{ Ksi} \sqrt{in}$

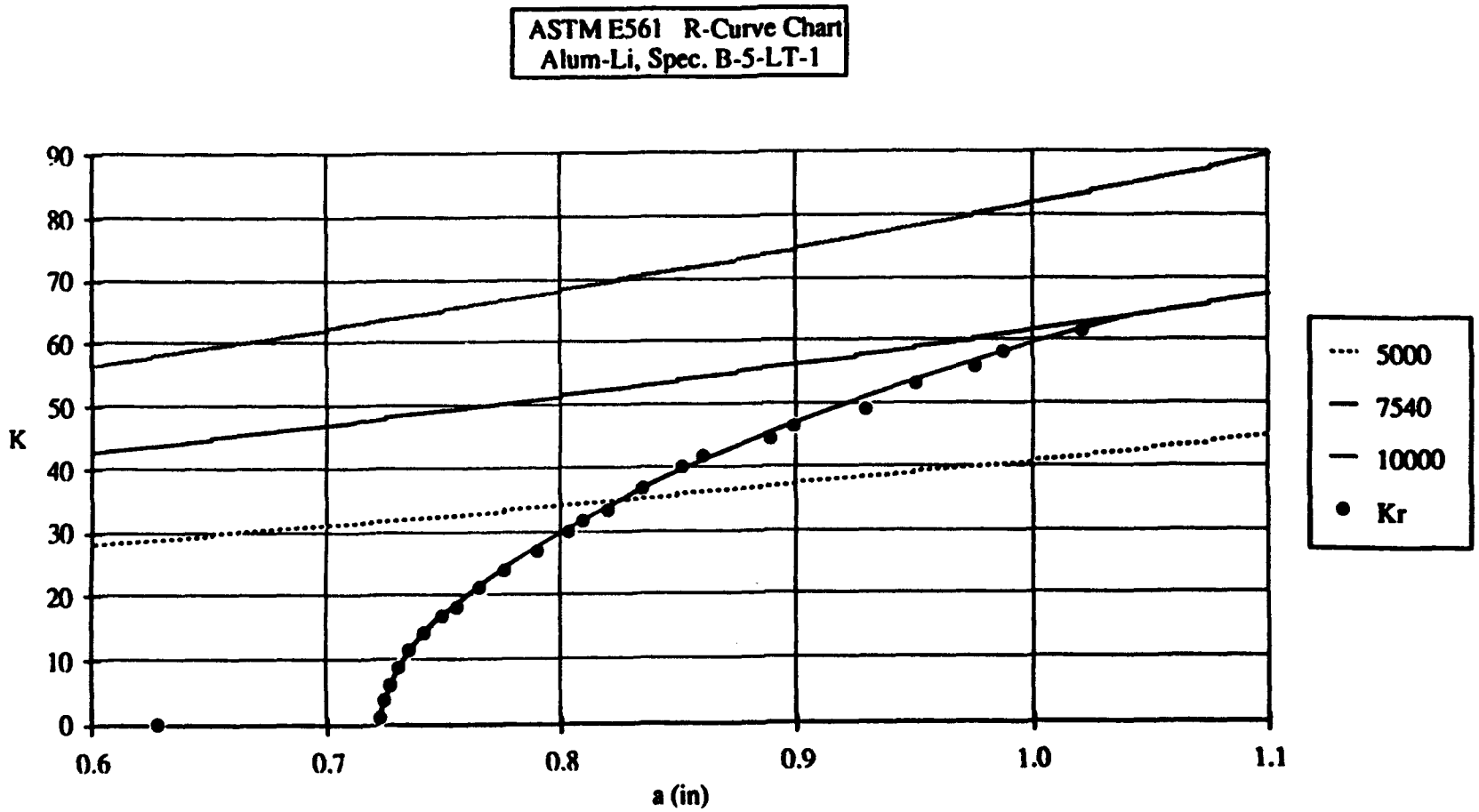


Figure B1 R-Curve Results for 2091-T3 0.063" Sheet (LT) General Dynamics, CA.

TABLE B13

General Dynamics, CA

ASTM E561 R Curve CCT Al-Li B-5-LT-2

W = 3.995 in
B = 0.0647 in
a = 1.255 in
a/2 = 0.6275 in

Fty = 41.10 ksi
Pmax = 7250 lb

a eff	Loads 5000	7250	10000
0.6	28	41	56
0.6	29	42	58
0.7	30	43	59
0.7	30	44	61
0.7	31	45	62
0.7	32	46	64
0.8	33	47	65
0.8	33	48	67
0.8	34	49	68
0.8	35	51	70
0.9	36	52	71
0.9	36	53	73
0.9	37	54	75
0.9	38	55	76
1.0	39	57	78
1.0	40	58	80
1.0	41	59	82
1.0	42	60	83
1.1	43	62	85
1.1	44	63	87
1.1	45	65	89

Load	a (half)	a plastic	a eff	K
0	0.6275	0.0000	0.6275	0
200	0.7250	0.0002	0.7252	1
600	0.7250	0.0014	0.7264	4
1000	0.7250	0.0038	0.7288	6
1400	0.7250	0.0075	0.7325	9
1800	0.7250	0.0124	0.7374	12
2200	0.7250	0.0185	0.7435	14
2600	0.7250	0.0258	0.7508	17
2800	0.7250	0.0299	0.7549	18
3200	0.7250	0.0391	0.7641	21
3600	0.7250	0.0494	0.7744	24
4000	0.7275	0.0613	0.7888	27
4200	0.7275	0.0676	0.7951	29
4400	0.7300	0.0746	0.8046	30
4600	0.7300	0.0815	0.8115	32
4800	0.7300	0.0887	0.8187	33
5200	0.7300	0.1041	0.8341	37
5600	0.7300	0.1208	0.8508	40
5800	0.7300	0.1296	0.8596	42
6000	0.7300	0.1387	0.8687	44
6200	0.7325	0.1488	0.8813	46
6400	0.7325	0.1585	0.8910	47
6800	0.7375	0.1806	0.9181	52
7000	0.7450	0.1941	0.9391	54
7200	0.7550	0.2092	0.9642	57

Kc = 56.9 Ksi $\sqrt{in}$

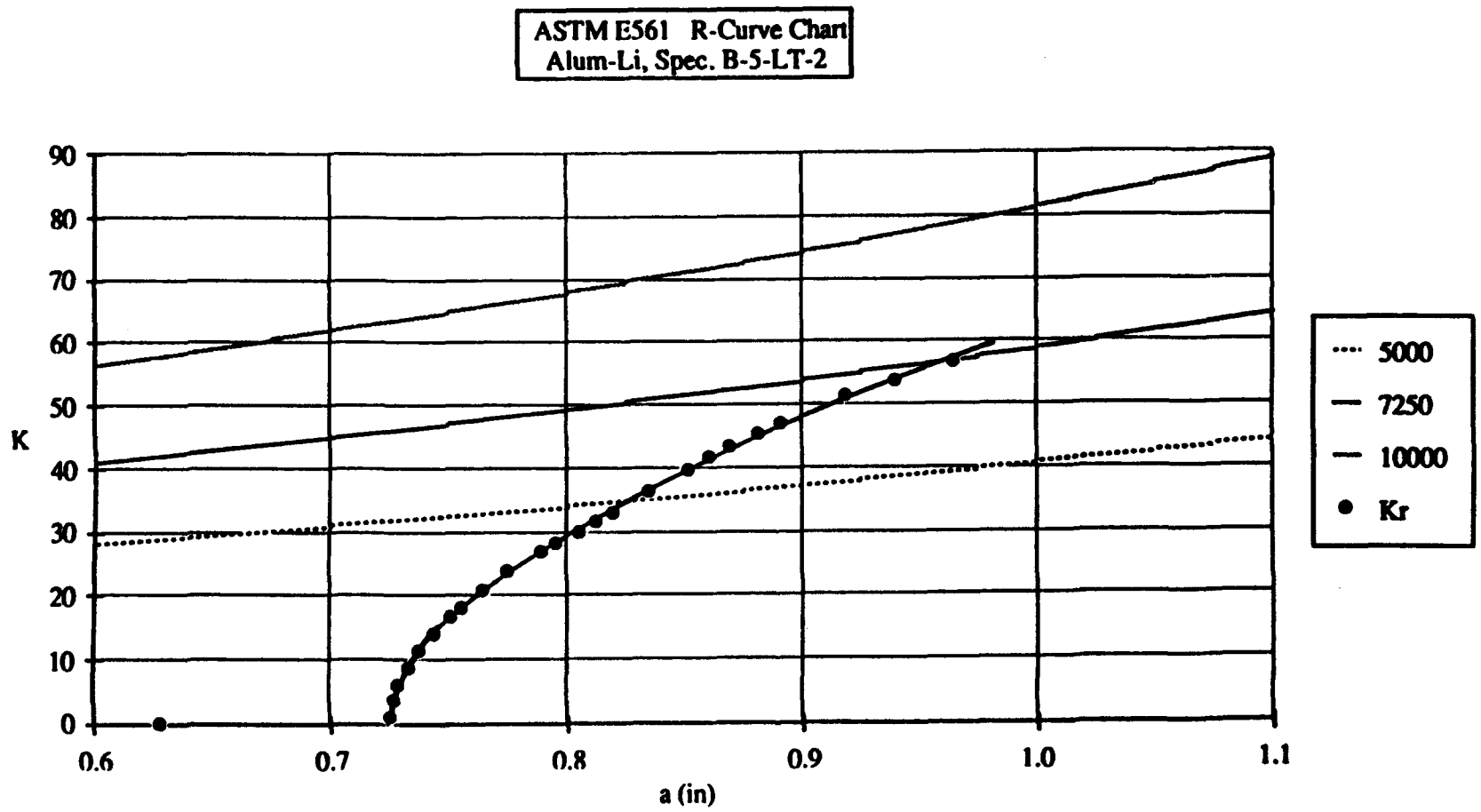


Figure B2 R-Curve Results for 2091-T3 0.063" Sheet (LT). General Dynamics, CA.

TABLE B14

General Dynamics, CA

ASTM E561 R Curve CCT Al-Li B-5-LT-3

W = 3.992 in
B = 0.0642 in
a = 1.2600 in
a/2 = 0.6300 in

Fty = 41.10 ksi
Pmax = 5875 lb

a eff	Loads 4000	5875	8000
0.6	23	33	45
0.6	23	34	47
0.7	24	35	48
0.7	24	36	49
0.7	25	37	50
0.7	26	38	51
0.8	26	39	53
0.8	27	40	54
0.8	28	40	55
0.8	28	41	56
0.9	29	42	58
0.9	29	43	59
0.9	30	44	60
0.9	31	45	62
1.0	31	46	63
1.0	32	47	64
1.0	33	48	66

Load	a (half)	a plastic	a eff	K
0	0.6300	0.0000	0.6300	0
200	0.7275	0.0002	0.7277	1
600	0.7275	0.0014	0.7289	4
1000	0.7275	0.0039	0.7314	6
1400	0.7275	0.0076	0.7351	9
1800	0.7275	0.0126	0.7401	12
2000	0.7275	0.0156	0.7431	13
2200	0.7275	0.0189	0.7464	14
2600	0.7275	0.0264	0.7539	17
3000	0.7275	0.0351	0.7626	20
3400	0.7275	0.0451	0.7726	23
3800	0.7275	0.0563	0.7838	26
4200	0.7275	0.0688	0.7963	29
4400	0.7275	0.0755	0.8030	30
4600	0.7275	0.0825	0.8100	32
4800	0.7275	0.0899	0.8174	34
5000	0.7275	0.0975	0.8250	35
5200	0.7275	0.1055	0.8330	37
5400	0.7275	0.1137	0.8412	39
5600	0.7275	0.1223	0.8498	40
5800	0.7275	0.1312	0.8587	42

~~Kc = 42.1 Ksi√in~~ Specimen failed in doubler region

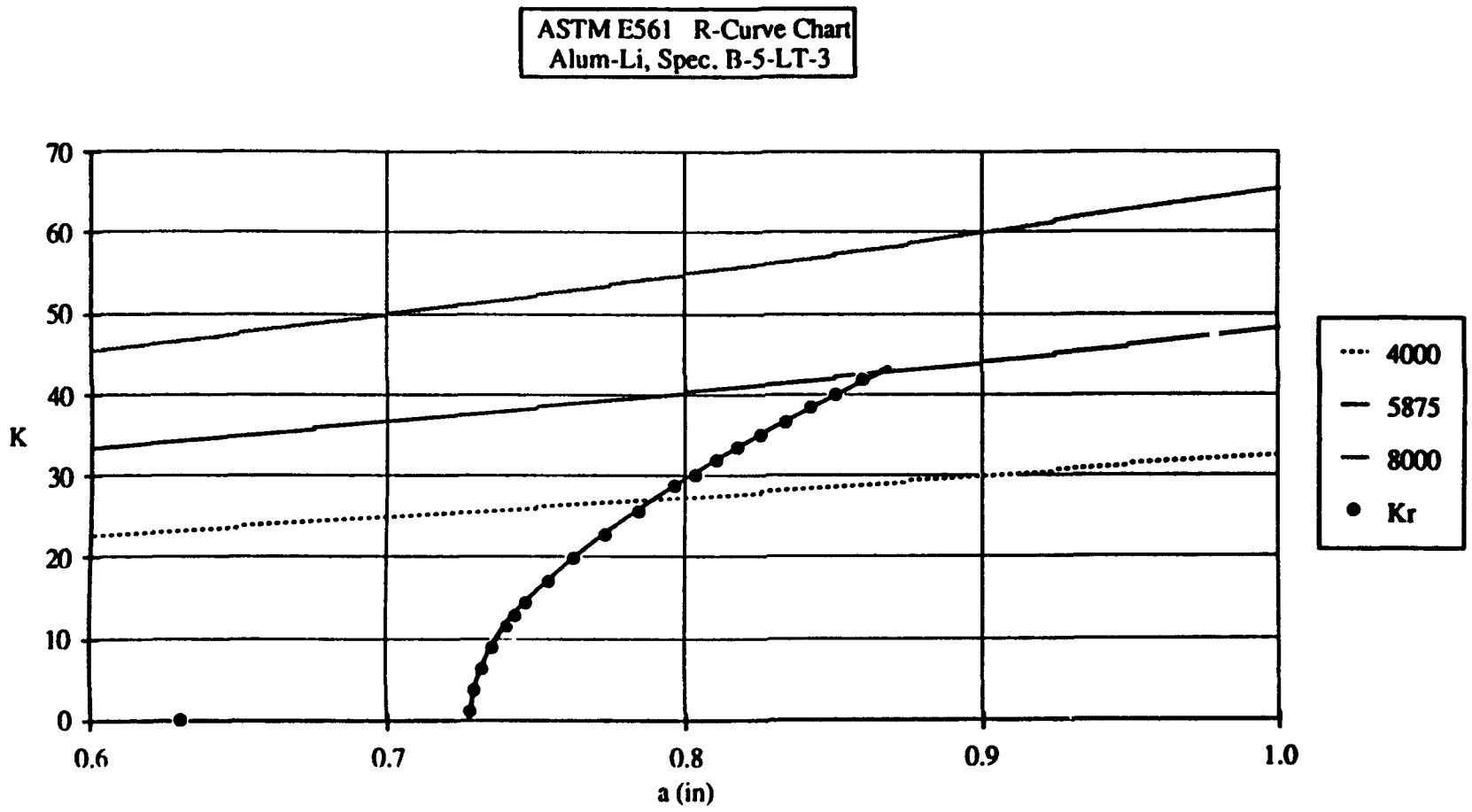


Figure B3 R-Curve Results for 2091-T3 0.063" Sheet (LT). General Dynamics, CA.

TABLE B15

General Dynamics, CA

ASTM E561 R Curve CCT Al-Li B-5-TL-1

W = 3.995 in
B = 0.0649 in
a = 1.25 in
a/2 = 0.625 in

Fty = 41.10 ksi
Pmax = 7290 lb

a eff	Loads 5000	7290	10000
0.6	28	41	56
0.6	29	42	58
0.7	30	43	59
0.7	30	44	60
0.7	31	45	62
0.7	32	46	63
0.8	32	47	65
0.8	33	48	66
0.8	34	50	68
0.8	35	51	70
0.9	36	52	71
0.9	36	53	73
0.9	37	54	74
0.9	38	55	76
1.0	39	57	78
1.0	40	58	80
1.0	41	59	81
1.0	42	61	83
1.1	43	62	85
1.1	44	63	87
1.1	45	65	89

Load	a (half)	a plastic	a eff	K
0	0.6250	0.0000	0.6250	0
200	0.7400	0.0002	0.7402	1
600	0.7400	0.0014	0.7414	4
1000	0.7400	0.0039	0.7439	6
1400	0.7400	0.0076	0.7476	9
1600	0.7425	0.0100	0.7525	10
2000	0.7425	0.0157	0.7582	13
2400	0.7425	0.0226	0.7651	16
2800	0.7425	0.0307	0.7732	19
3200	0.7425	0.0401	0.7826	21
3600	0.7425	0.0508	0.7933	24
4000	0.7425	0.0627	0.8052	27
4400	0.7425	0.0759	0.8184	30
4600	0.7425	0.0829	0.8254	32
4800	0.7450	0.0907	0.8357	34
5000	0.7475	0.0989	0.8464	35
5200	0.7525	0.1079	0.8604	37
5600	0.7525	0.1252	0.8777	41
6000	0.7525	0.1437	0.8962	44
6200	0.7550	0.1542	0.9092	47
6400	0.7575	0.1650	0.9225	49
6600	0.7575	0.1755	0.9330	51
6800	0.7625	0.1881	0.9506	53
7000	0.7625	0.1993	0.9618	55
7200	0.7950	0.2238	1.0188	60

$Kc = 59.6\ Ksi\sqrt{in}$

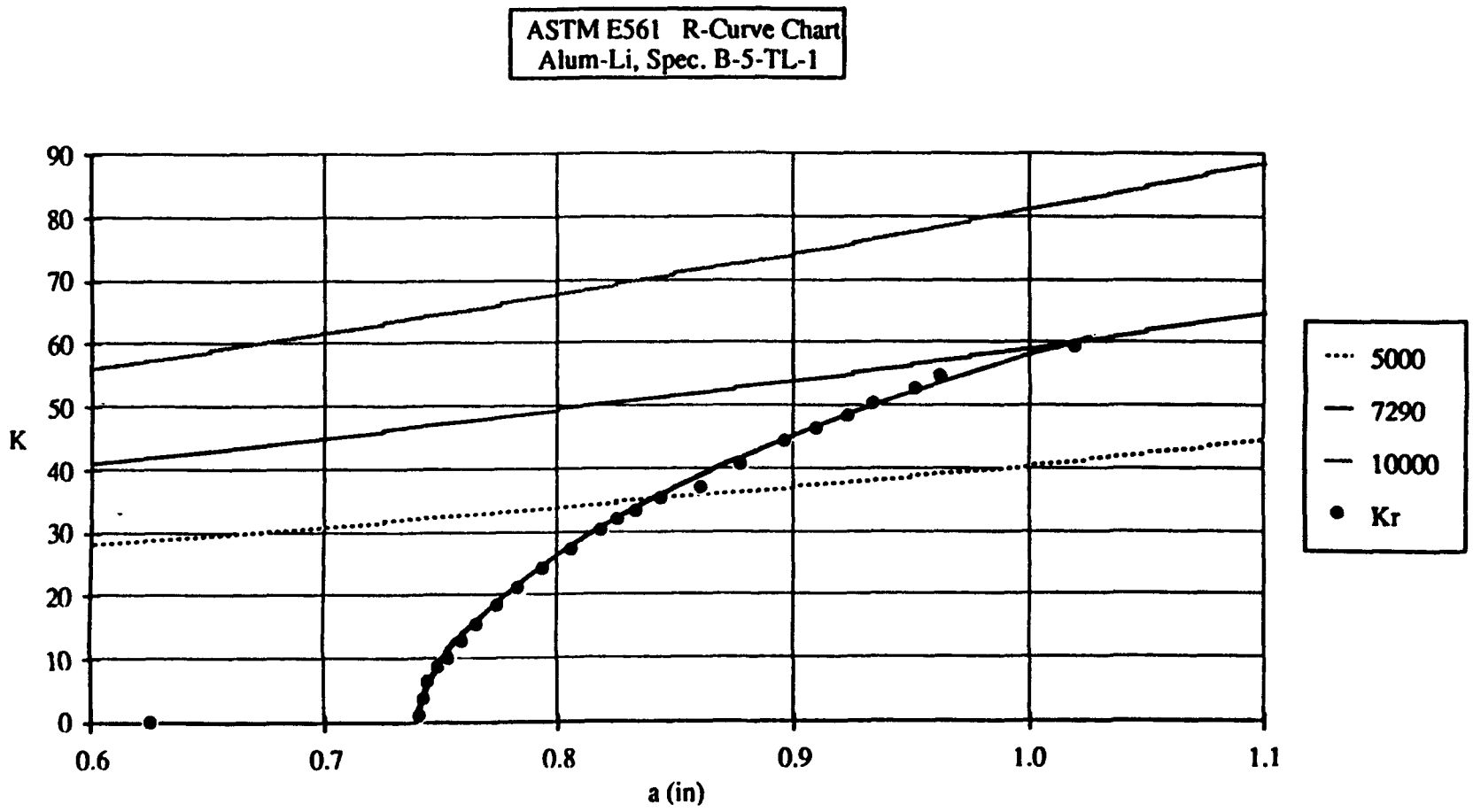


Figure B4 R-Curve Results for 2091-T3 0.063" Sheet (TL). General Dynamics, CA.

TABLE B16

General Dynamics, CA

ASTM E561 R Curve CCT Al-Li B-5-TL-2

W = 3.992 in
B = 0.0646 in
a = 1.2550 in
a/2 = 0.6275 in

Fty = 41.10 ksi
Pmax = 7450 lb

a eff	Loads 5000	7450	10000
0.6	28	42	56
0.6	29	43	58
0.7	30	44	59
0.7	30	45	61
0.7	31	46	62
0.7	32	48	64
0.8	33	49	65
0.8	33	50	67
0.8	34	51	68
0.8	35	52	70
0.9	36	53	72
0.9	37	55	73
0.9	37	56	75
0.9	38	57	77
1.0	39	58	78
1.0	40	60	80
1.0	41	61	82
1.0	42	62	84
1.1	43	64	86
1.1	44	65	88
1.1	45	67	90

Load	a (half)	a plastic	a eff	K
0	0.6275	0.0000	0.6275	0
200	0.7275	0.0002	0.7277	1
400	0.7275	0.0006	0.7281	3
600	0.7325	0.0014	0.7339	4
1000	0.7325	0.0039	0.7364	6
1400	0.7325	0.0076	0.7401	9
1800	0.7325	0.0126	0.7451	12
2200	0.7325	0.0188	0.7513	14
2600	0.7325	0.0263	0.7588	17
3000	0.7325	0.0350	0.7675	20
3400	0.7325	0.0450	0.7775	23
3600	0.7425	0.0513	0.7938	24
3800	0.7425	0.0572	0.7997	26
4000	0.7450	0.0637	0.8087	28
4200	0.7450	0.0702	0.8152	29
4400	0.7525	0.0781	0.8306	31
4600	0.7525	0.0854	0.8379	33
4800	0.7550	0.0934	0.8484	34
5400	0.7550	0.1183	0.8733	39
5600	0.7575	0.1278	0.8853	41
6000	0.7575	0.1467	0.9042	45
6200	0.7600	0.1573	0.9173	47
6400	0.7600	0.1677	0.9277	49
6600	0.7675	0.1808	0.9483	52
6800	0.7725	0.1937	0.9662	54
7000	0.7800	0.2081	0.9881	57
7200	0.7875	0.2232	1.0107	59
7400	0.8025	0.2423	1.0448	63

$K_c = 63.0 \text{ Ksi}\sqrt{in}$

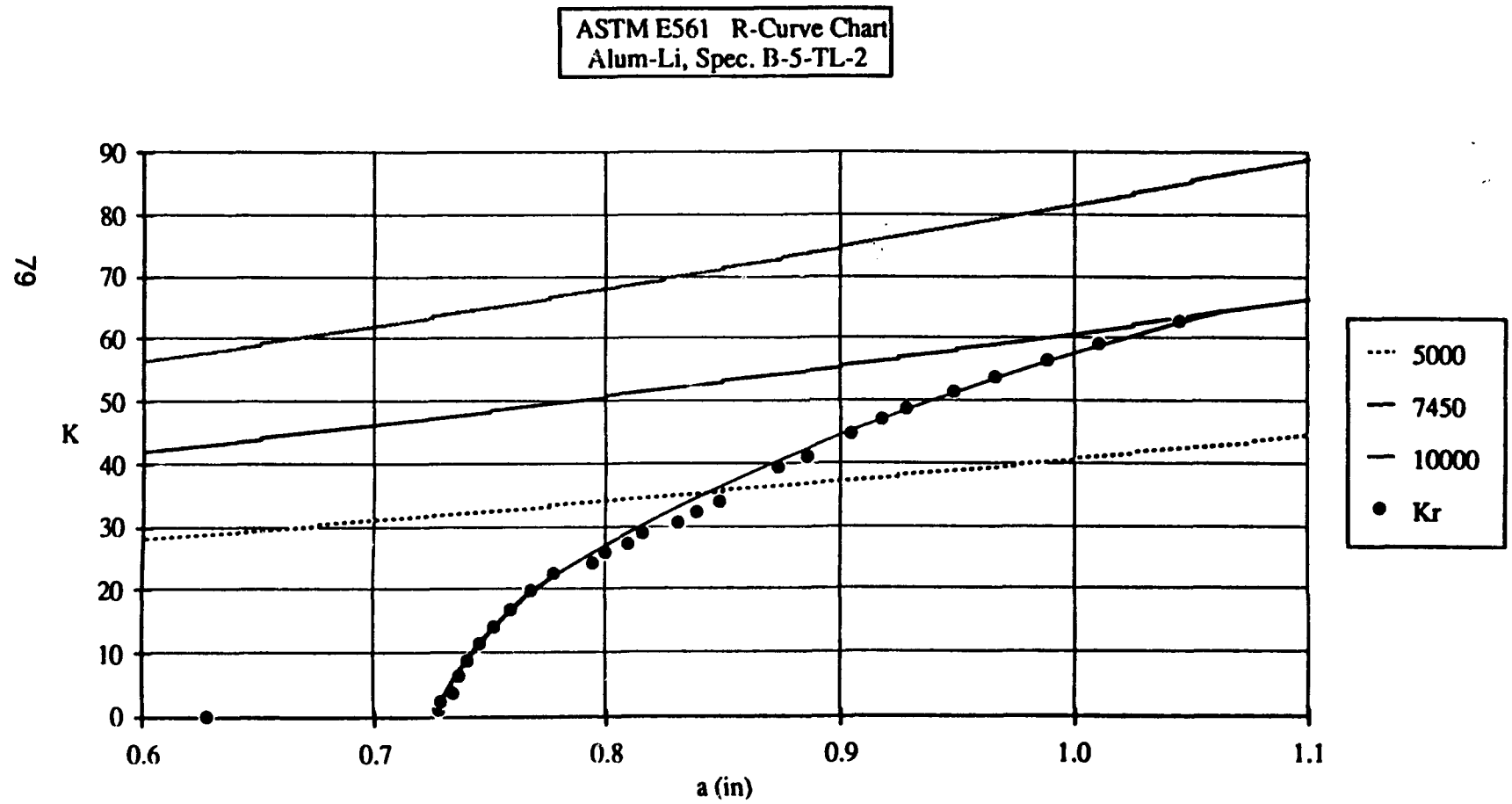


Figure B5 R-Curve Results for 2091-T3 0.063" Sheet (TL). General Dynamics, CA

TABLE B17

General Dynamics, CA

ASTM E561 R Curve CCT Al-Li B-5-TL-3

W = 3.996 in
B = 0.0642 in
a = 1.2500 in
a/2 = 0.6250 in

Fty = 41.10 ksi
Pmax = 7290 lb

a eff	Loads 5000	7290	10000
0.6	28	41	57
0.6	29	42	58
0.7	30	43	60
0.7	31	45	61
0.7	31	46	63
0.7	32	47	64
0.8	33	48	66
0.8	34	49	67
0.8	34	50	69
0.8	35	51	70
0.9	36	52	72
0.9	37	54	74
0.9	38	55	75
0.9	38	56	77
1.0	39	57	79
1.0	40	59	80
1.0	41	60	82
1.0	42	61	84
1.1	43	63	86
1.1	44	64	88
1.1	45	66	90

Load	a (half)	a plastic	a eff	K
0	0.6250	0.0000	0.6250	0
200	0.7250	0.0002	0.7252	1
600	0.7250	0.0014	0.7264	4
1000	0.7250	0.0039	0.7289	6
1400	0.7250	0.0076	0.7326	9
1800	0.7250	0.0125	0.7375	12
2000	0.7250	0.0155	0.7405	13
2400	0.7250	0.0223	0.7473	16
2800	0.7250	0.0304	0.7554	18
3200	0.7250	0.0397	0.7647	21
3600	0.7250	0.0502	0.7752	24
3800	0.7250	0.0559	0.7809	26
4200	0.7250	0.0683	0.7933	29
4600	0.7250	0.0820	0.8070	32
4800	0.7250	0.0892	0.8142	33
5200	0.7250	0.1047	0.8297	37
5600	0.7250	0.1215	0.8465	40
5800	0.7250	0.1303	0.8553	42
6000	0.7250	0.1394	0.8644	44
6400	0.7250	0.1586	0.8836	47
6600	0.7250	0.1687	0.8937	49
6800	0.7250	0.1791	0.9041	51
7000	0.7250	0.1898	0.9148	53
7200	0.7250	0.2008	0.9258	55

$Kc = 55.4\ Ksi\sqrt{in}$

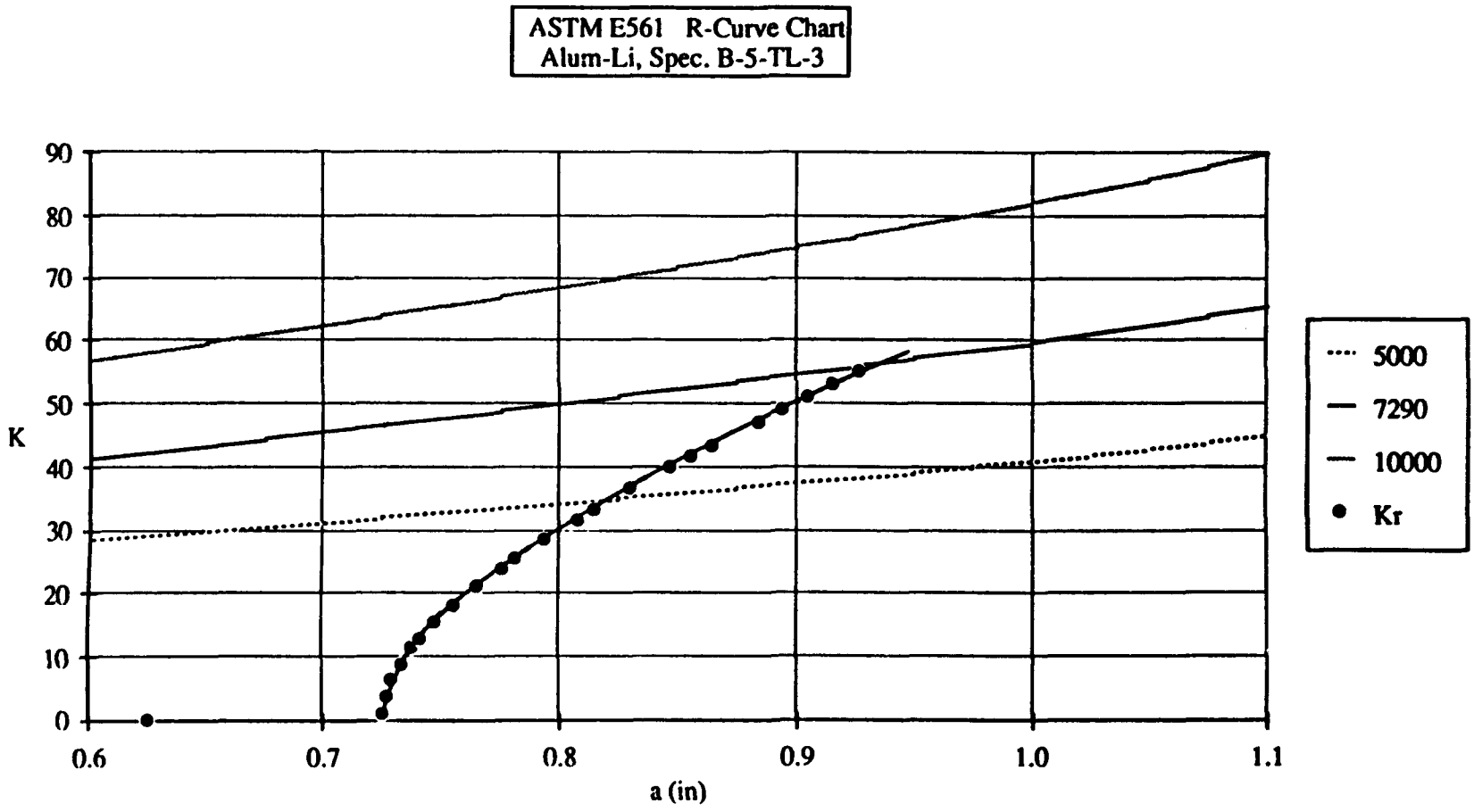


Figure B6 R-Curve Results for 2091-T3 0.063" Sheet (TL). General Dynamics, CA.

TABLE B18

MCAIR

R-CURVE TOUGHNESS DATA FOR PECHINEY 2091
ALUMINUM LITHIUM ALLOY

SPECIMEN IDENTIFICATION	ORIENTATION	SLOT LENGTH 2a, (IN)	PRECRACK LENGTH 2a, (IN)	FINAL CRACK LENGTH 2a, (IN)	LOAD AT FAILURE (LB)	PLANE STRESS FRACTURE TOUGHNESS, Kc, (KSI(IN)^.5)
1	LT-L	1.9915	2.1006	2.2480	10,900	57.0
2		1.9945	2.1000	2.2566	10,980	57.4
AVERAGE		------	------	------	[illegible],940	57.2
3	L-LT	1.9925	2.0993	2.2120	[illegible]940	57.1
4		1.9965	2.1015	2.1815	10,900	55.9
AVERAGE		------	------	------	10,920	56.5

DATA COLLECTED AND REDUCED PER ASTM STANDARD TEST METHOD E561-81.

The four toughness specimens were tested in accordance with ASTM Standard Test Method E561-81. The specimens were precracked to a total crack length, 2a, equal to 35% of the width, as is required per the standard. A stress ratio of 0.1 was used for precracking. The specimens were statically failed using a loading rate of 3000 pound/minute. Cathetometers were used to monitor crack length during static loading to determine the final crack length, at failure, which is required for toughness calculations. Table B18 presents toughness test data. All four specimens had a plane stress toughness value in the range of 56 to 57 ksi(in)^.5. It should be noted that no plastic zone corrections were incorporated into the toughness calculations.

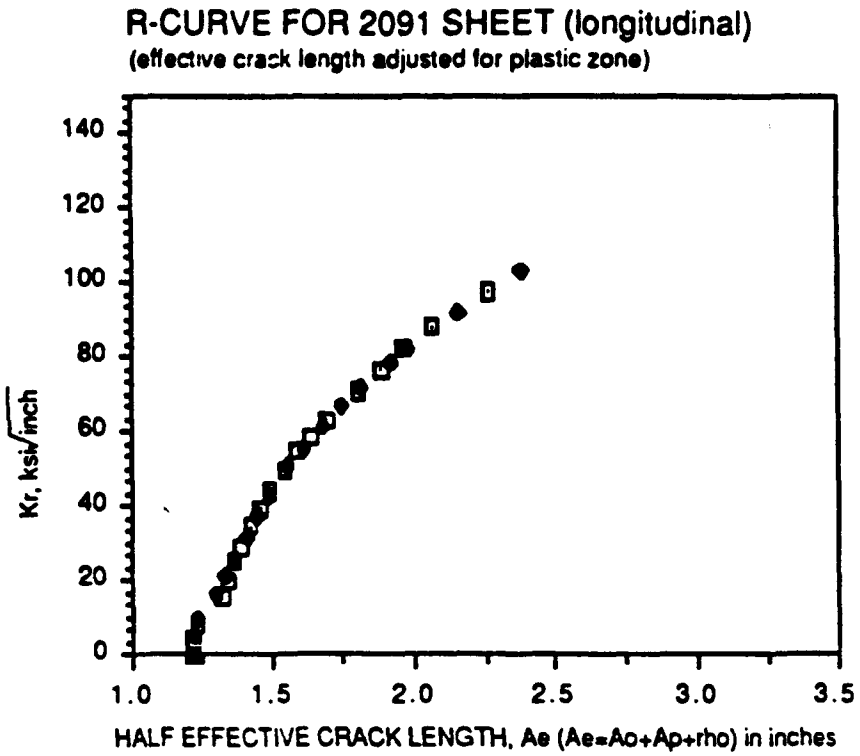


Figure B7 R-Curve Results for 2091-T3 0.063" Sheet (longitudinal) Martin Marietta, LA.

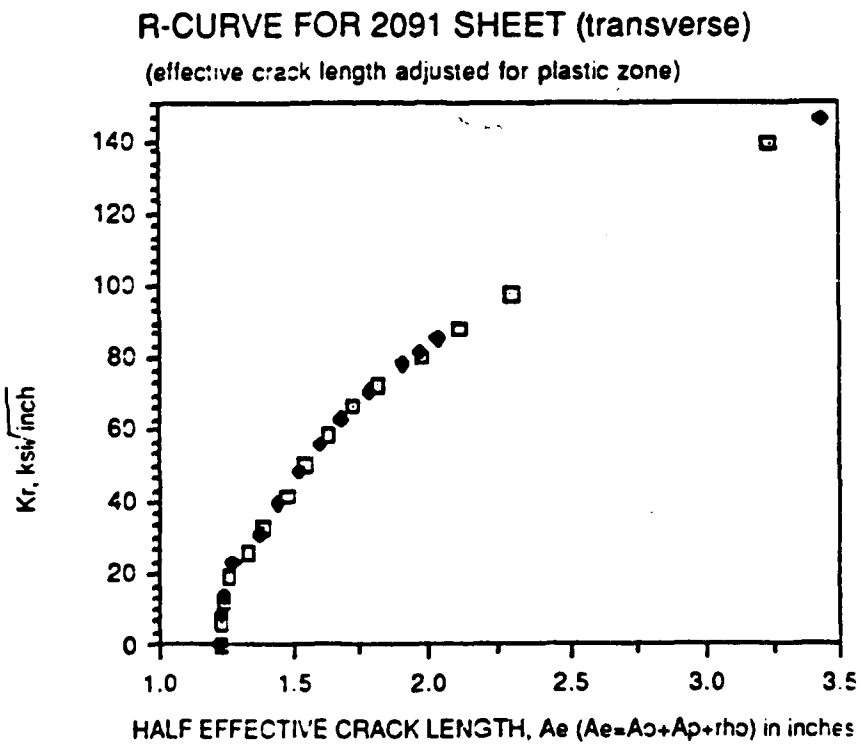


Figure B8 R-Curve Results for 2091-T3 0.063" Sheet (transverse). Martin Marietta

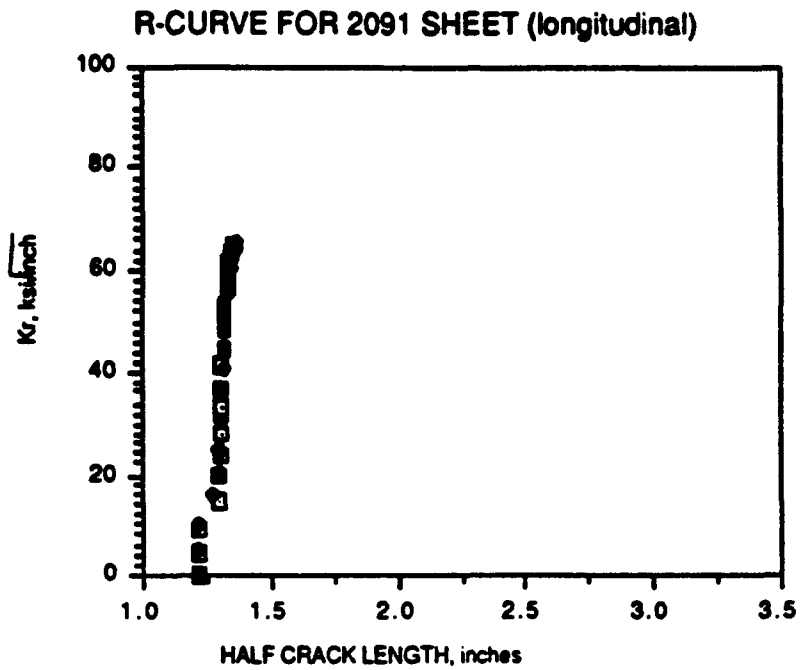


Figure B9 R-Curve Results for 2091-T3 0.063" Sheet (longitudinal). Martin Marietta, LA.

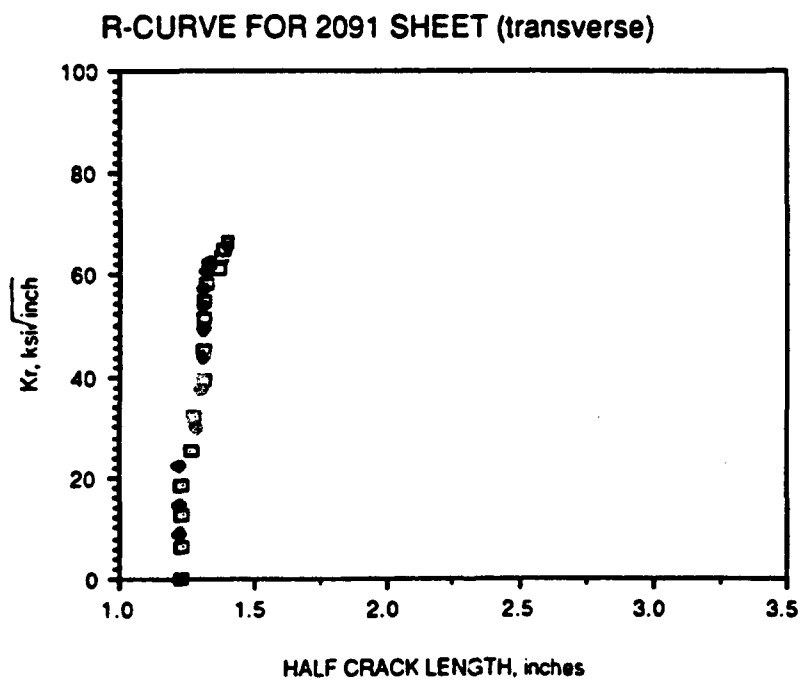


Figure B10 R-Curve Results for 2091-T3 0.063" Sheet (transverse). Martin Marietta, LA.

TABLE B19

Martin Marietta, LA

DATA FOR SPECIMEN NO. 4, 2091

LONGITUDINAL SHEET

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{inch}$	
			Not Adjusted	Adjusted for Plasticity
0.0	1.215	1.215	0.0	0.0
1.17	1.215	1.217	4.81	4.55
2.54	1.220	1.229	10.47	9.86
3.71	1.270	1.294	15.69	15.85
4.79	1.295	1.336	20.51	20.87
5.76	1.300	1.361	24.73	25.35
7.08	1.310	1.406	30.54	31.71
8.21	1.310	1.442	35.42	37.24
9.38	1.315	1.493	40.56	43.31
10.41	1.320	1.560	45.13	50.26
11.28	1.320	1.615	48.90	55.05
12.07	1.325	1.680	52.45	61.05
12.70	1.330	1.756	55.30	66.92
13.29	1.330	1.821	57.90	71.84
13.78	1.340	1.919	60.33	78.02
14.12	1.345	1.986	61.97	82.10
14.51	1.365	2.159	64.30	91.36
14.80	1.370	2.381	65.74	103.09

Thickness = .063 inch
Yield = 40.9 ksi
Specimen Width = 8.00 inch

TABLE B20

Martin Marietta, LA

DATA FOR SPECIMEN NO. 5 2091

LONGITUDINAL SHEET

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{inch}$	
			Not Adjusted	Adjusted for Plasticity
0.0	1.220	1.220	0.0	0.0
1.06	1.220	1.222	4.37	4.12
2.09	1.220	1.226	8.62	8.12
3.48	1.295	1.317	14.90	15.04
4.67	1.300	1.340	20.05	20.36
5.55	1.305	1.362	23.88	24.48
6.53	1.310	1.390	28.17	29.09
7.62	1.310	1.442	32.67	34.33
8.52	1.310	1.453	36.76	38.80
9.54	1.310	1.494	41.16	44.03
10.32	1.315	1.549	44.63	49.59
11.14	1.315	1.599	48.17	54.60
11.74	1.315	1.640	50.77	58.47
12.39	1.320	1.699	53.71	63.08
13.19	1.330	1.809	57.46	70.97
13.71	1.335	1.891	59.77	76.77
14.71	1.335	1.974	61.88	81.95
14.52	1.340	2.076	63.57	87.94
14.79	1.355	2.262	65.22	97.62

Thickness = .063 inch
Yield = 40.9 ksi
Specimen Width = 8.00 inch

TABLE B21

Martin Marietta, LA

DATA FOR SPECIMEN NO. 6 2091

TRANSVERSE SHEET

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0.0	1.215	1.215	0.0	0.0
2.19	1.215	1.222	9.01	8.49
3.50	1.220	1.238	14.43	13.60
5.47	1.220	1.271	22.56	23.05
7.00	1.282	1.373	29.79	30.90
8.75	1.295	1.445	37.47	39.65
10.16	1.300	1.521	43.61	48.23
11.43	1.300	1.605	49.19	56.11
12.43	1.305	1.680	53.49	62.77
13.31	1.305	1.781	57.28	70.74
13.95	1.320	1.906	60.48	78.51
14.21	1.327	1.965	61.83	81.87
14.42	1.330	2.028	62.82	85.66
14.62	1.395	3.433	65.73	146.00

Thickness = .063 inch
Yield = 40.9 ksi
Specimen Width = 8.00 inch

TABLE B22

Martin Marietta, LA

DATA FOR SPECIMEN NO. 7, 2091

TRANSVERSE SHEET

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi $\sqrt{\text{inch}}$	
			Not Adjusted	Adjusted for Plasticity
0.0	1.225	1.225	0.0	0.0
1.52	1.225	1.228	6.28	5.92
3.00	1.225	1.238	12.40	11.66
4.51	1.225	1.259	18.65	18.92
7.00	1.260	1.324	25.20	25.94
7.50	1.275	1.380	31.81	33.16
9.11	1.305	1.470	39.20	41.69
10.51	1.305	1.547	45.23	50.43
11.86	1.305	1.635	51.04	58.91
12.74	1.310	1.729	54.96	66.33
13.40	1.320	1.817	58.09	72.27
13.89	1.360	1.977	61.40	80.55
14.28	1.375	2.107	63.58	87.73
14.56	1.390	2.299	65.30	97.73
14.77	1.400	3.245	66.56	139.00

Thickness = .063 inch
Yield = 40.9 ksi
Specimen Width = 8.00 inch

TABLE B23

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR

PECHINEY 2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
GENERAL DYNAMICS, CALIF.	LONG	21.8	10,000,000 *
		25.0	1,888,000
		27.0	10,140,000 *
		30.0	303,000
		32.0	363,000
		35.0	143,000
		38.0	122,000

(*):INDICATES A RUN-OUT TEST

TABLE B24

FATIGUE RESULTS WITH R=0.1 AND Kt=3.0 FOR

PECHINEY 2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
GENERAL DYNAMICS, CALIF.	LONG	10.0	10,000,000 *
		12.0	319,000
		13.0	10,330,000 *
		13.5	193,000
		14.5	158,000
		16.0	163,000
		20.0	47,000
		25.0	15,000

(*): INDICATES A RUN-OUT TEST

TABLE B25

FATIGUE RESULTS WITH R=0.1 AND Kt=2.8 FOR

PECHINEY 2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
LTV	LONG	15.4	1,000,000 *
		15.4	410,760
		15.5	700,100
		16.5	192,020
		16.5	236,950
		18.5	202,250
		18.7	203,450 #
		19.0	155,800
		22.1	83,190
		22.4	76,450
		22.4	49,000

(*): INDICATES A RUN-OUT TEST
(#): INDICATES SPECIMEN FAILED IN GRIP

TABLE B26

FATIGUE RESULTS WITH R=0.1 AND Kt=2.8 FOR

PECHINEY 2091-T3 SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
LTV	L TRANS	15.5	1,500,000 *
		16.0	369,700
		18.7	94,490
		18.7	138,430
		22.1	84,900
		22.5	52,100

(*): INDICATES A RUN-OUT TEST

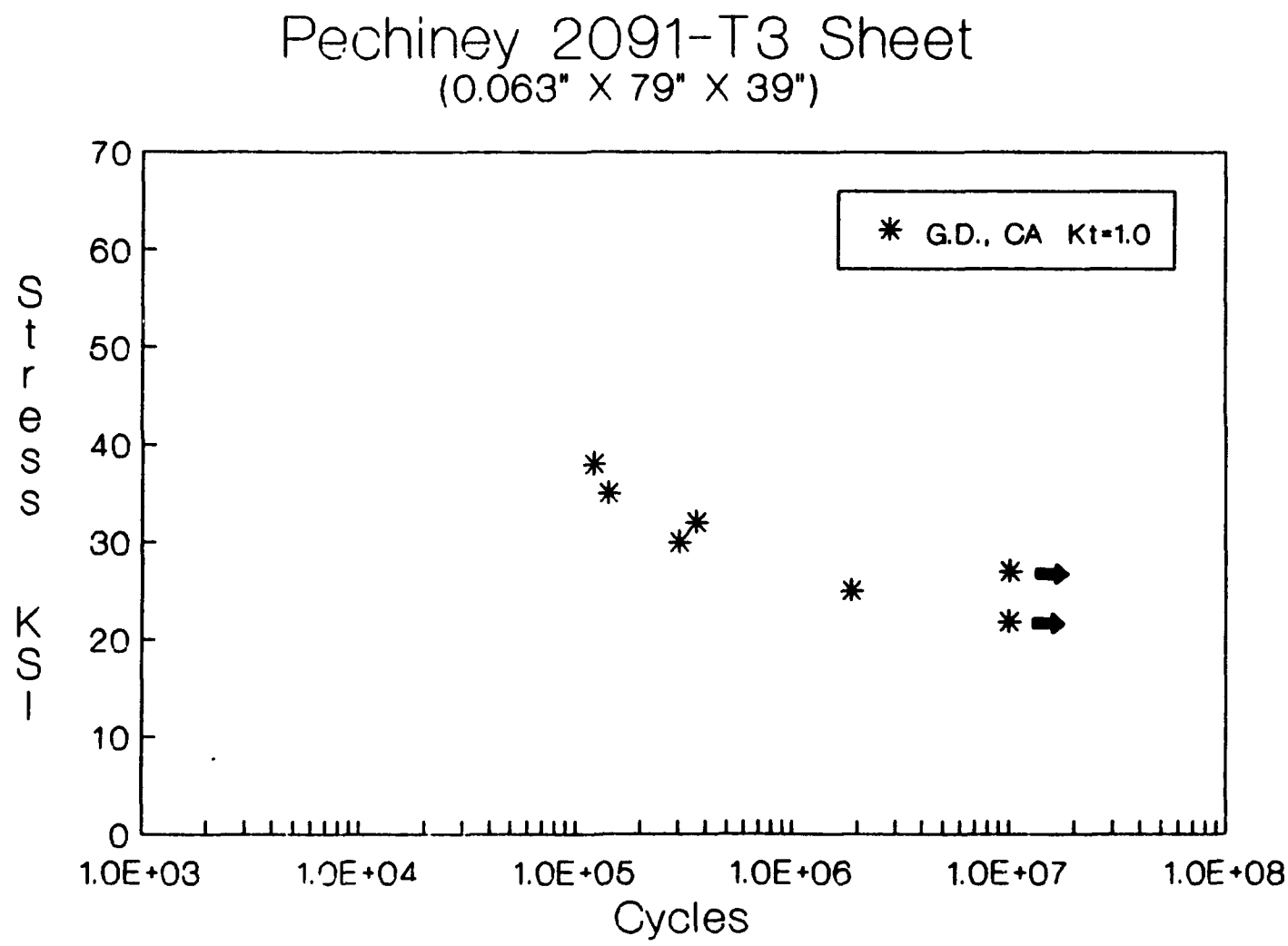


Figure B11 Fatigue Results for 2091-T3 0.063" Sheet (R=0.1, K_t=1.0, and longitudinal). General Dynamics, CA

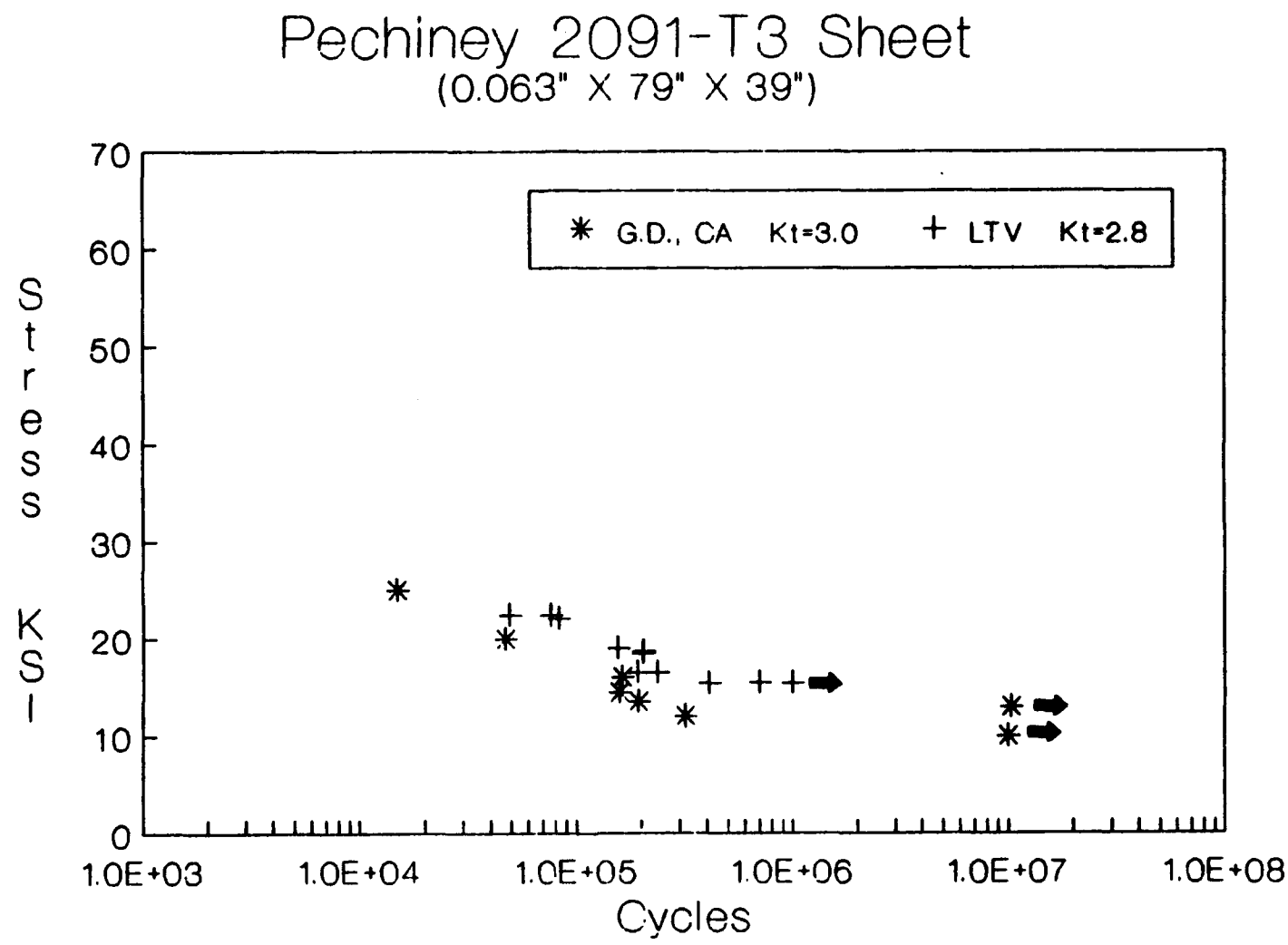


Figure B12 Fatigue Results for 2091-T3 0.063" Sheet (R=0.1, $K_t \geq 2.8$, and Longitudinal). General Dynamics, CA and LTV.

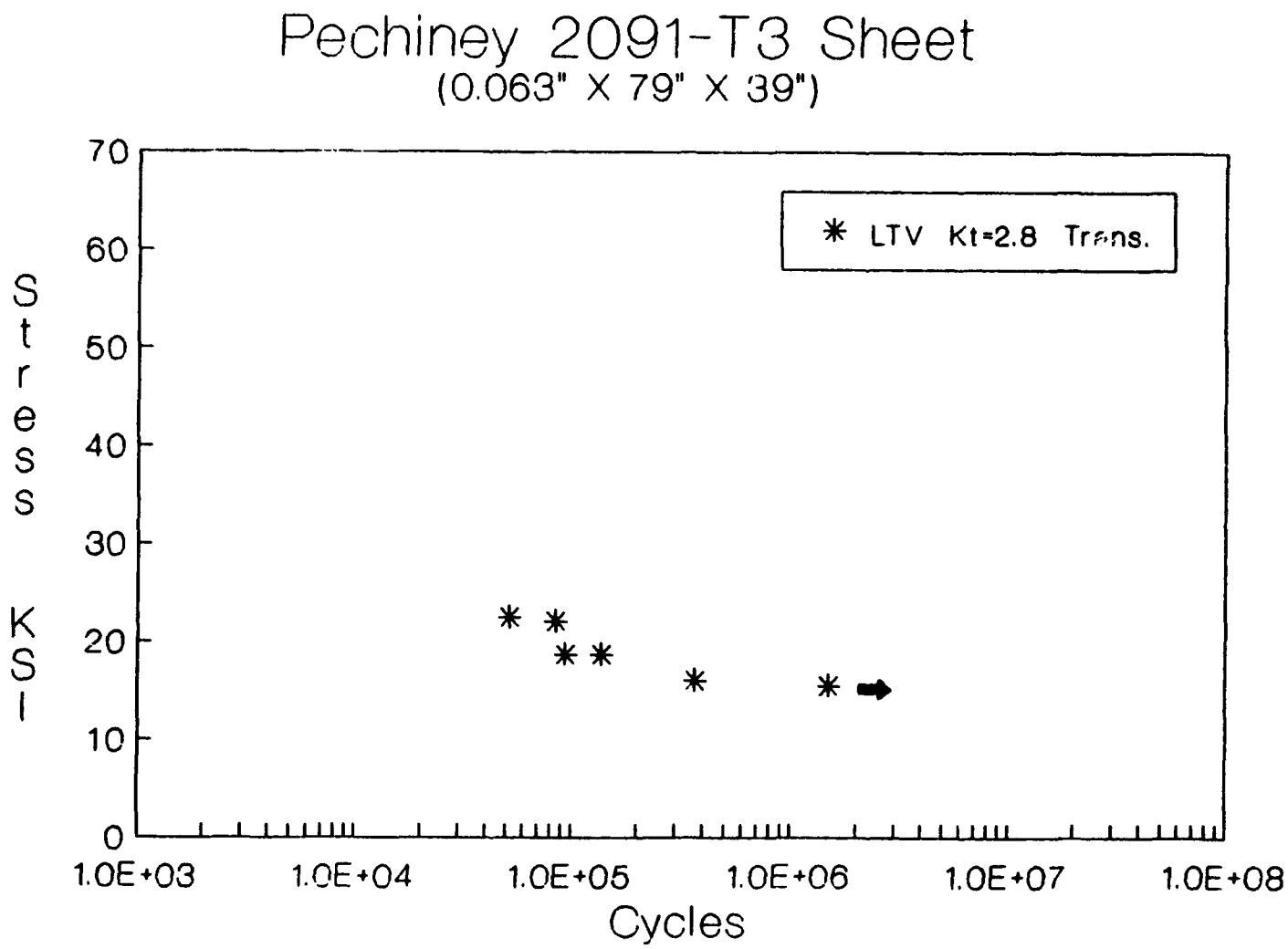


Figure B13 Fatigue Results for 2091-T3 0.063" Sheet (R=0.1, K_t=2.8, and Transverse). LTV.

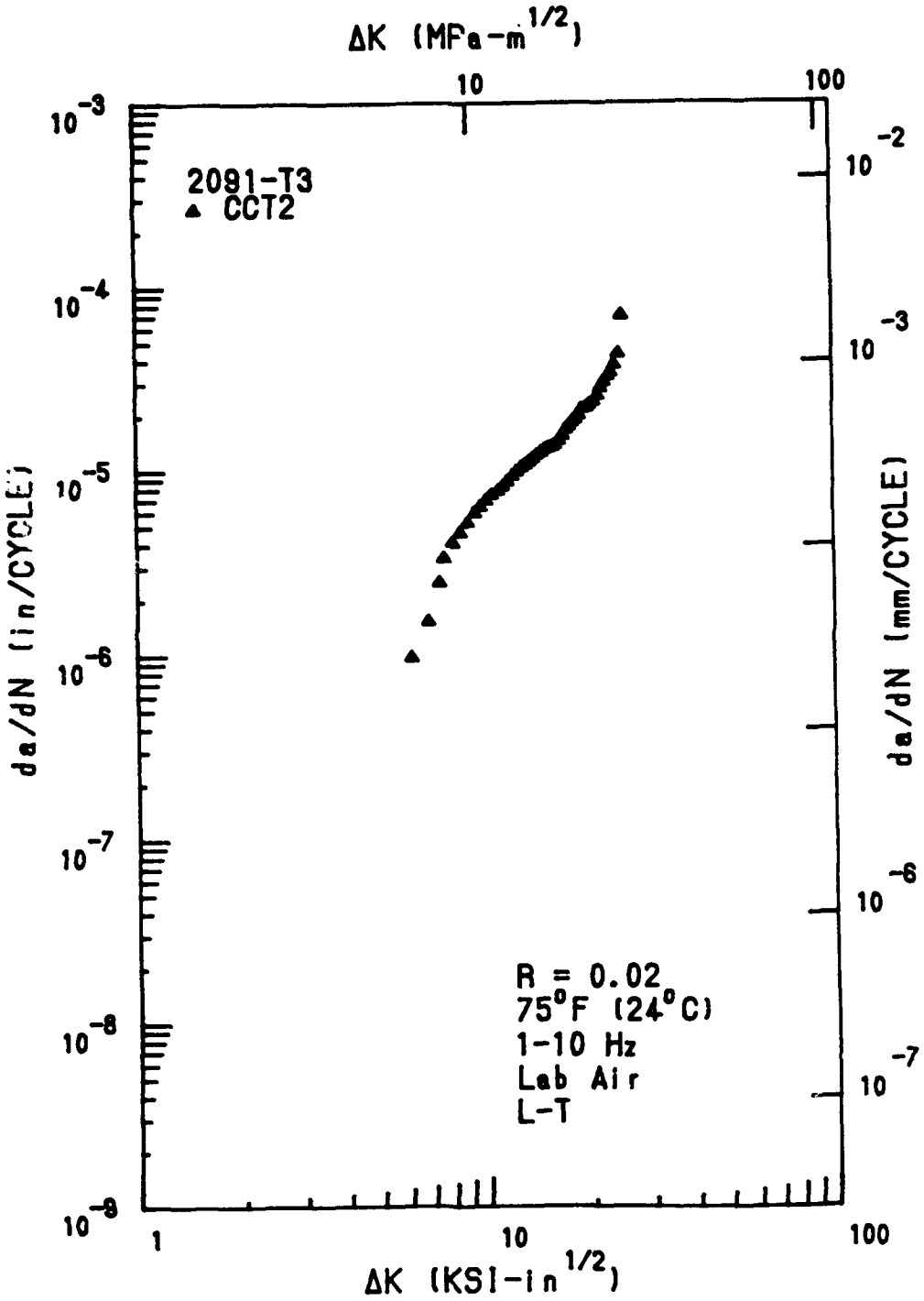


Figure B14 Fatigue Crack Growth Rate Data for Pechiney 2091-T3 0.063" Sheet (L-T Orientation). McDonnel Aircraft LA.

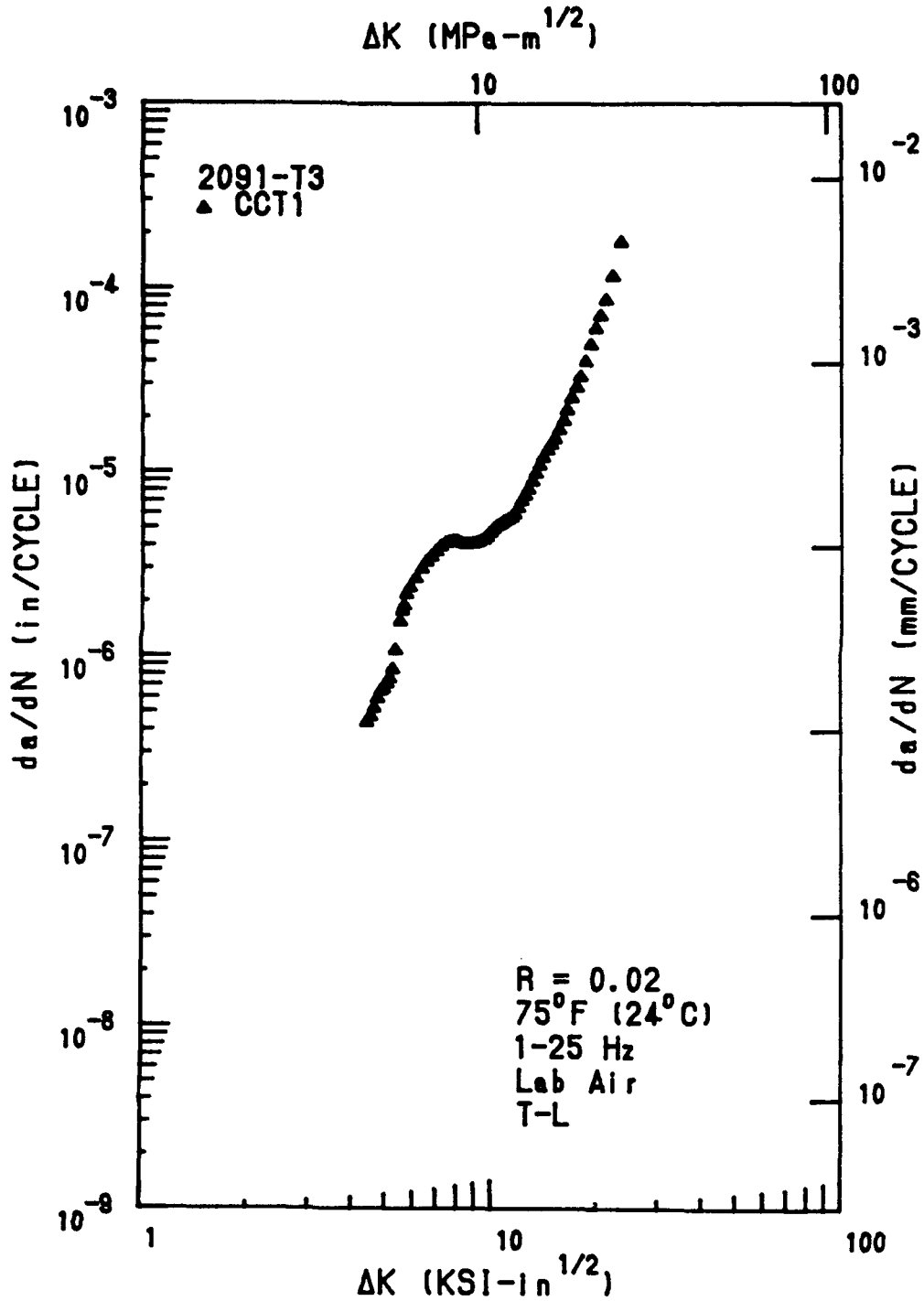


Figure B15 Fatigue Crack Growth Rate Data for Pechiney 2091-T3 0.063" Sheet (T-L Orientation). McDonnell Aircraft LA.

2091-T8X SHEET
(0.063"x79"x79")

TABLE B27

TENSILE RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
NORTHROP	RT	LONG	62.9	47.5	15.6		11.1
			63.0	47.4	16.5		11.1
			63.1	47.7	18.3		10.5
GRUMMAN	RT	LONG	61.8	47.3	15.5		10.9
			61.8	47.7	16.5		11.2
			62.8	47.3	15.5		11.6
GENERAL DYNAMICS, TEXAS	RT	LONG	65.6	49.7	14.1		
			64.7	49.1	14.1		
		AVERAGE	63.2	48.0	15.8		11.1
	STANDARD DEVIATION		1.3	0.9	1.4		0.4

TABLE B28

TENSILE RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
NORTHROP	RT	L TRANS	65.9	47.5	14.3		11.0
			66.0	47.6	13.6		11.4
			66.6	48.0	14.0		11.2
GRUMMAN	RT	L TRANS	64.4	46.3	12.0		11.0
			64.6	46.6	15.0		11.4
			64.8	46.7	14.0		11.5
GENERAL DYNAMICS, TEXAS	RT	L TRANS	67.2	50.2	11.0		
			67.5	50.7	10.4		
		AVERAGE	65.9	48.0	13.0		11.3
	STANDARD DEVIATION		1.2	1.7	1.7		0.2

TABLE B29

COMPRESSION RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
NORTHROP	RT	LONG	46.8	11.6
			46.7	11.5
			46.9	11.5
GRUMMAN	RT	LONG	45.3	11.6
			47.9	11.5
			46.3	11.5
GENERAL DYNAMICS, TEXAS	RT	LONG	48.8	
			49.7	
		AVERAGE	47.3	11.5
	STANDARD DEVIATION		1.4	0.1

TABLE B30

COMPRESSION RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
NORTHROP	RT	L TRANS	53.0	11.5
			52.7	11.5
			53.0	11.3
GRUMMAN	RT	L TRANS	51.3	11.2
			51.3	11.4
			52.3	11.7
GENERAL DYNAMICS, TEXAS	RT	L TRANS	53.1	
			53.7	
		AVERAGE	52.5	11.4
	STANDARD DEVIATION		0.9	0.2

TABLE B31

COMPRESSION RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
GRUMMAN	RT	45	44.6	11.4
			45.5	11.3
			45.2	11.4
		AVERAGE	45.1	11.4
	STANDARD DEVIATION		0.5	0.1

TABLE B32

SLOTTED SHEAR RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	LONG	39.4
		35.5
		39.6
GRUMMAN	LONG	38.2
		40.0
		39.1
GENERAL DYNAMICS, TEXAS	LONG	40.9
		42.0
	AVERAGE	39.3
	STANDARD DEVIATION	1.9

TABLE B33

SLOTTED SHEAR RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	L TRANS	41.8
		41.9
		41.9
GRUMMAN	L TRANS	41.1
		41.7
		40.7
GENERAL DYNAMICS, TEXAS	L TRANS	38.4
	AVERAGE	41.1
	STANDARD DEVIATION	1.3

TABLE B34

BEARING RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	LONG	1.5	94.9	67.6
			94.9	68.3
			94.9	67.2
GRUMMAN	LONG	1.5	91.7	65.5
			91.7	65.4
			91.7	66.2
GENERAL DYNAMICS, TEXAS	LONG	1.5	88.6	75.6
			93.8	78.2
		AVERAGE	92.8	69.3
		STANDARD DEVIATION	2.3	4.9

TABLE B35

BEARING RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	L TRANS	1.5	96.3	67.6
			96.3	67.1
			96.2	68.0
GRUMMAN	L TRANS	1.5	91.9	65.0
			92.4	66.7
			93.1	66.5
GENERAL DYNAMICS, TEXAS	L TRANS	1.5	92.9	78.8
			92.3	78.5
		AVERAGE	93.9	69.8
		STANDARD DEVIATION	2.0	5.5

TABLE B36

BEARING RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	LONG	2.0	117.2	80.0
			118.6	79.8
			117.1	81.5
GRUMMAN	LONG	2.0	116.4	79.2
			116.4	78.7
			116.4	78.6
GENERAL DYNAMICS, TEXAS	LONG	2.0	106.0	88.1
			117.0	92.2
		AVERAGE	115.6	82.3
		STANDARD DEVIATION	4.0	5.1

TABLE B37

BEARING RESULTS FOR PECHINEY

2091-T8X SHEET (0.063" X 79" X 39")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	L TRANS	2.0	120.4	81.6
			120.1	84.0
			118.6	82.0
GRUMMAN	L TRANS	2.0	121.8	83.2
			120.0	81.8
			117.6	80.8
GENERAL DYNAMICS, TEXAS	L TRANS	2.0	114.0	95.8
			105.0	93.6
		AVERAGE	117.2	85.4
		STANDARD DEVIATION	5.5	5.9

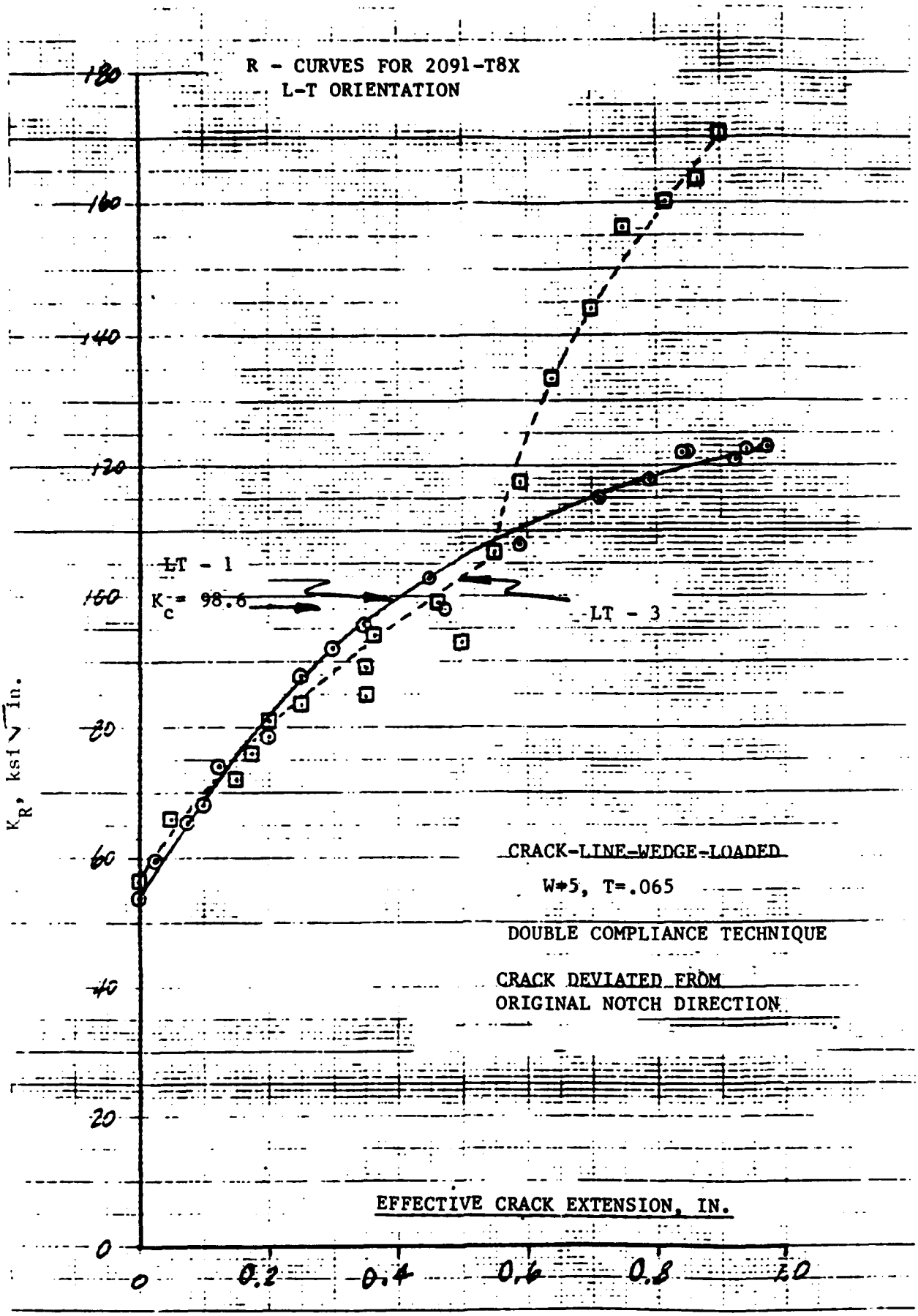


Figure B16 R-Curve Results for 2091-T8X 0.063" Sheet (L-T). Grumman.

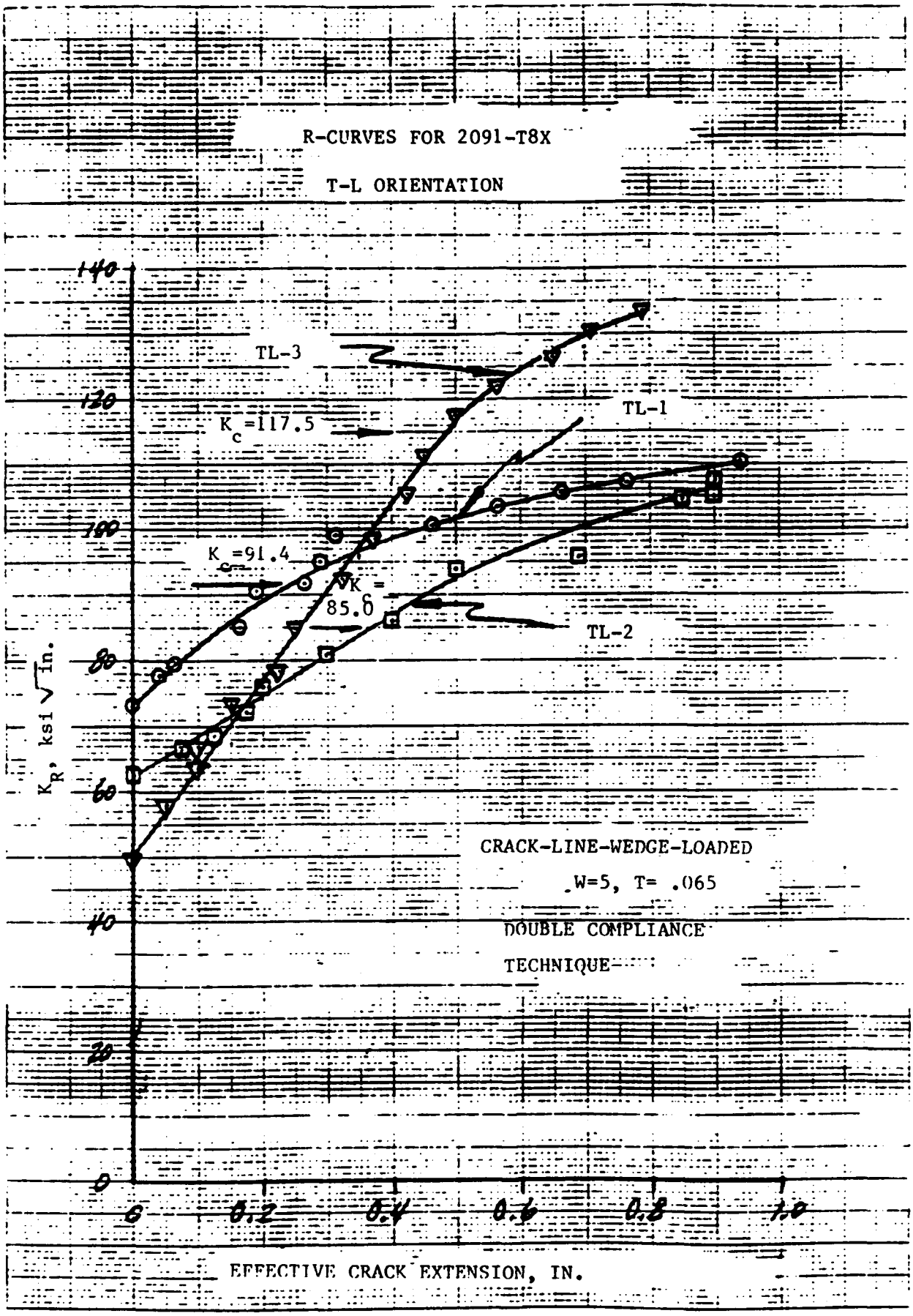


Figure B17 R-Curve Results for 2091-T8X 0.063" Sheet (T-L). Grumman.

TABLE B38

General Dynamics, Texas

Pechiney 2091-T81 Sheet
(0.063" X 79" X 39")
Average Results of R-Curve Tests

	K_{R25}, ksi-in $^{1/2}$
L-T	91.2
T-L	81.4

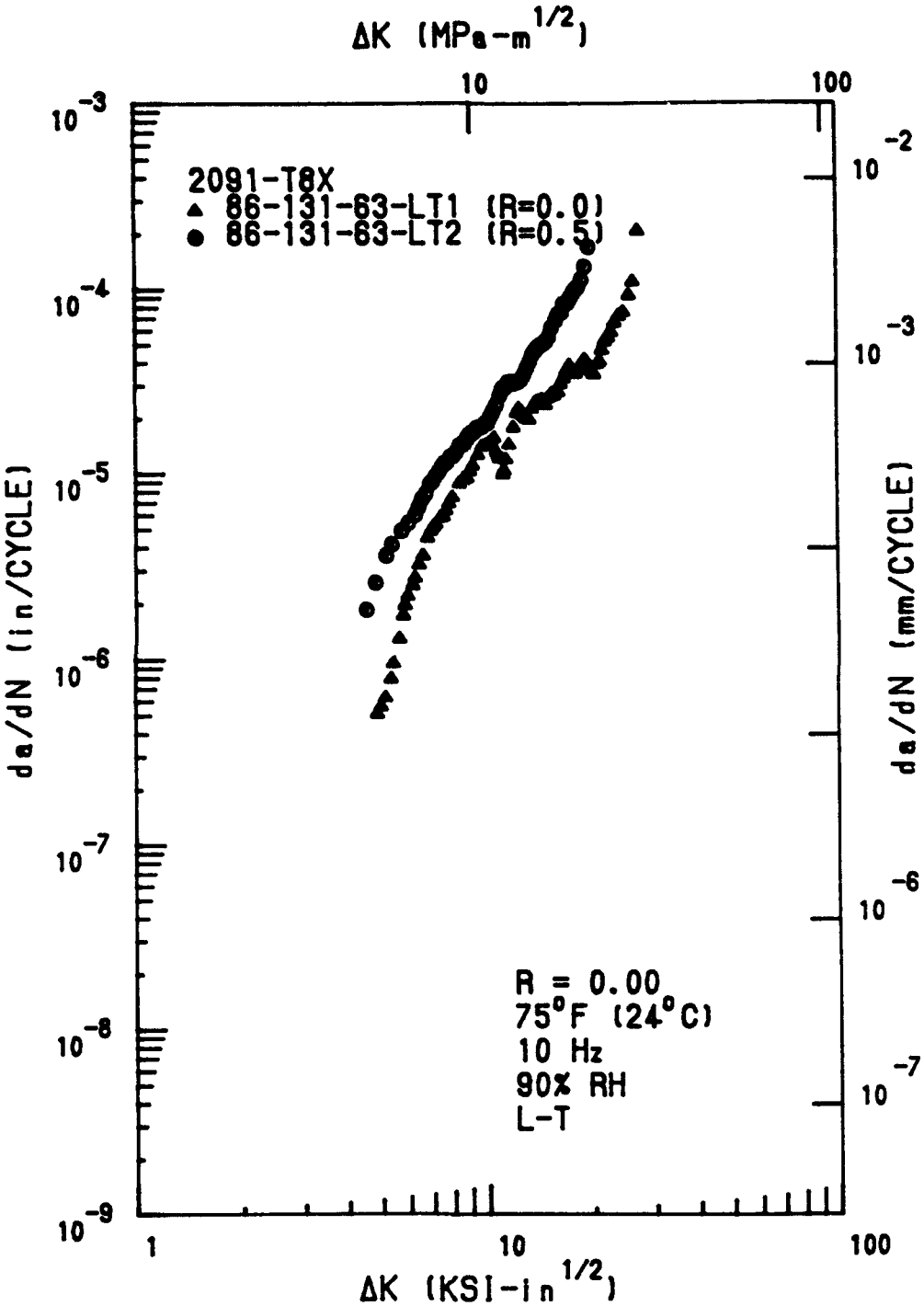


Figure B18 Fatigue Crack Growth Rate Data for Pechiney 2091-T3X 0.063" Sheet (L-T Orientation). Grumman.

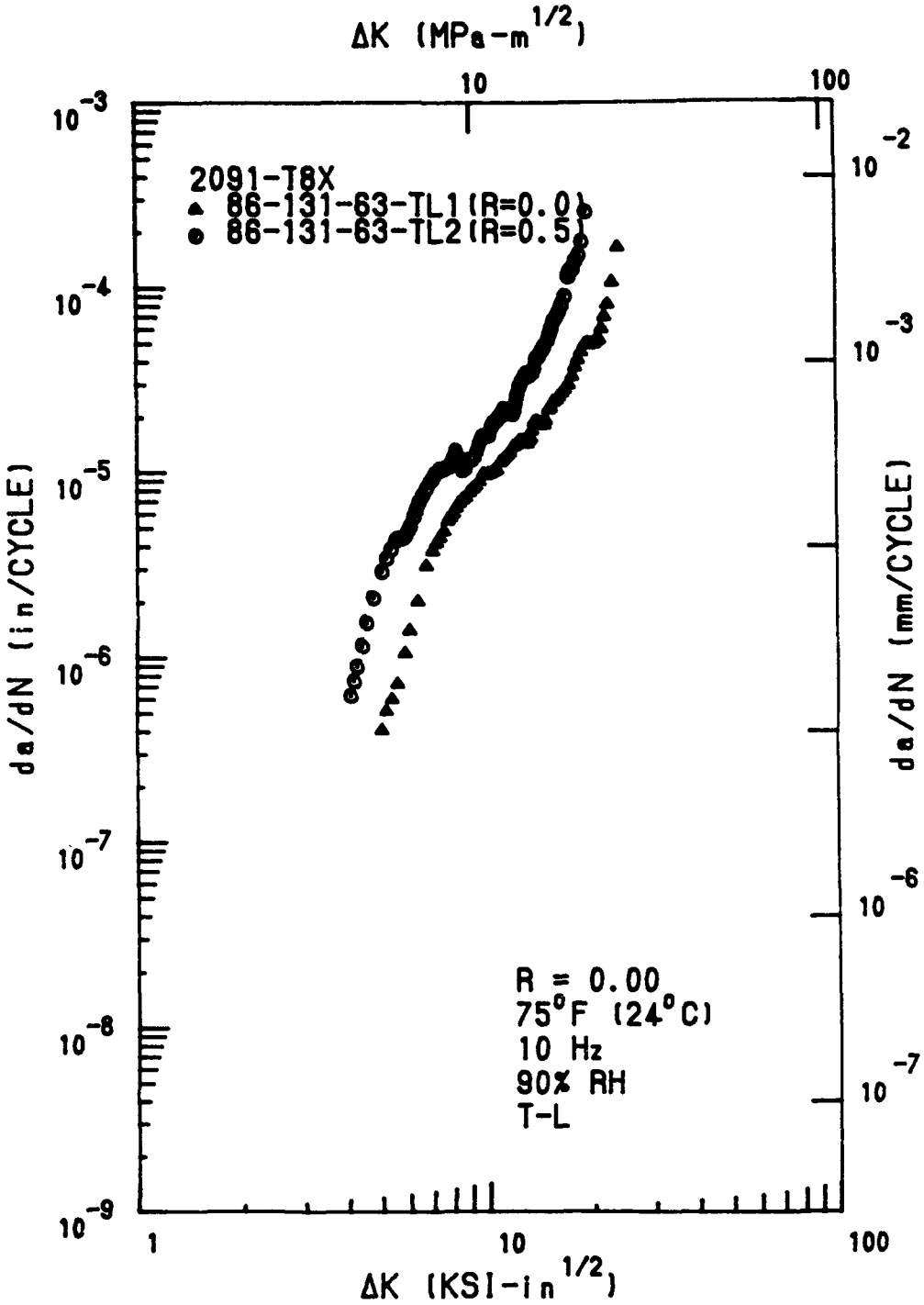


Figure B19 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.063" Sheet (T-L Orientation). Grumman.

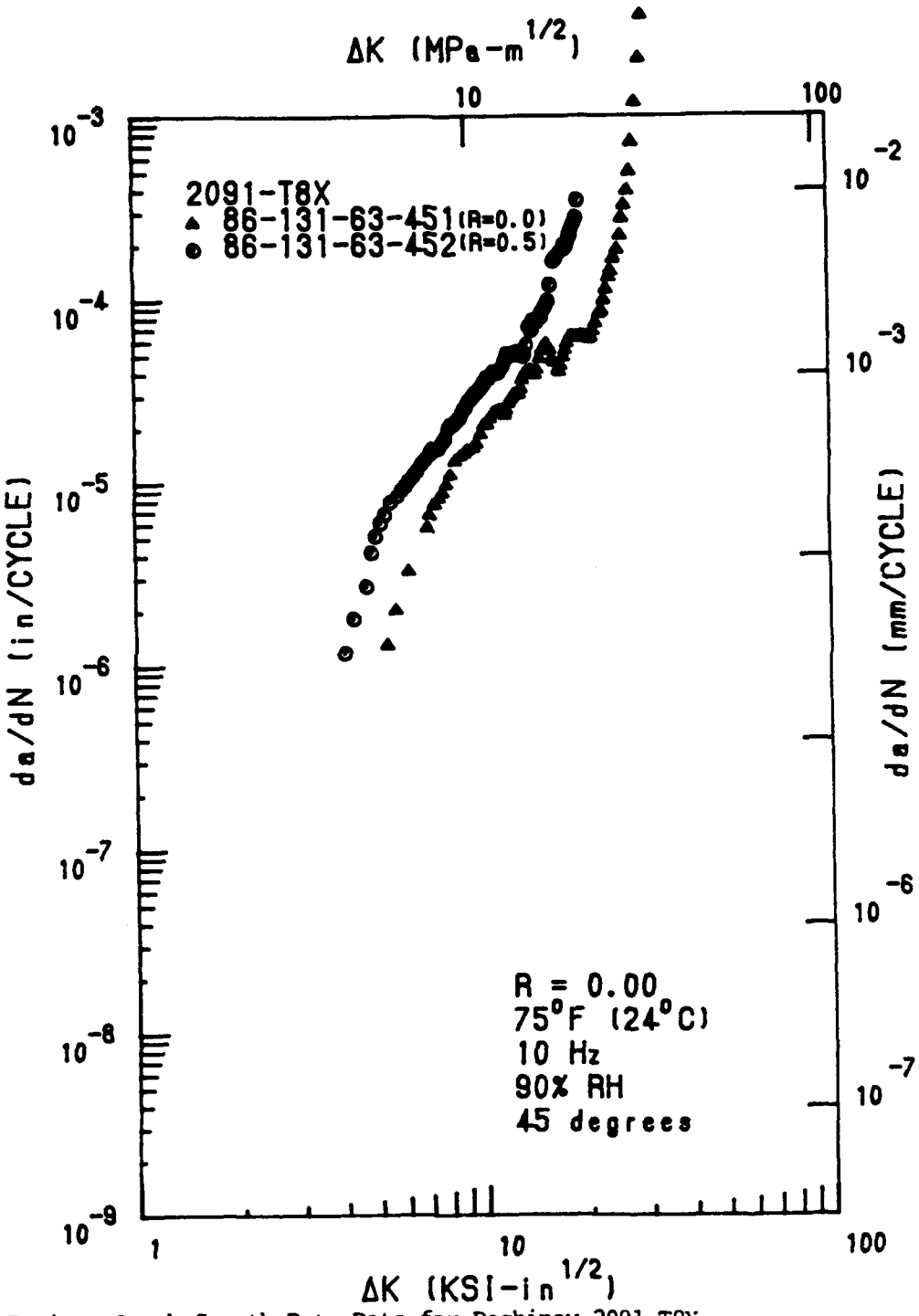


Figure B20 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.063" Sheet (45° Orientation). Grumman.

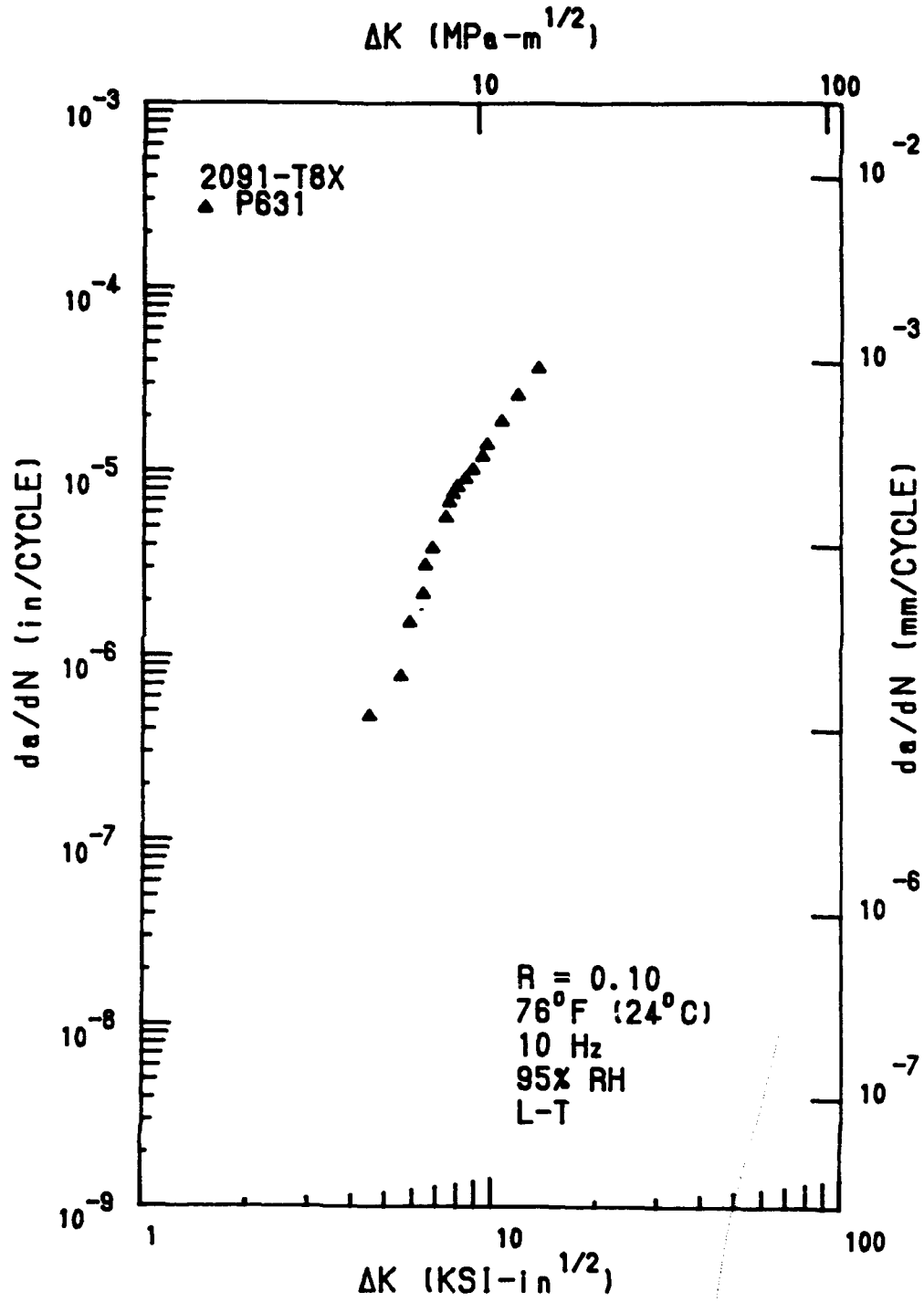


Figure B21 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.063" Sheet (L-T Orientation). Northrop.

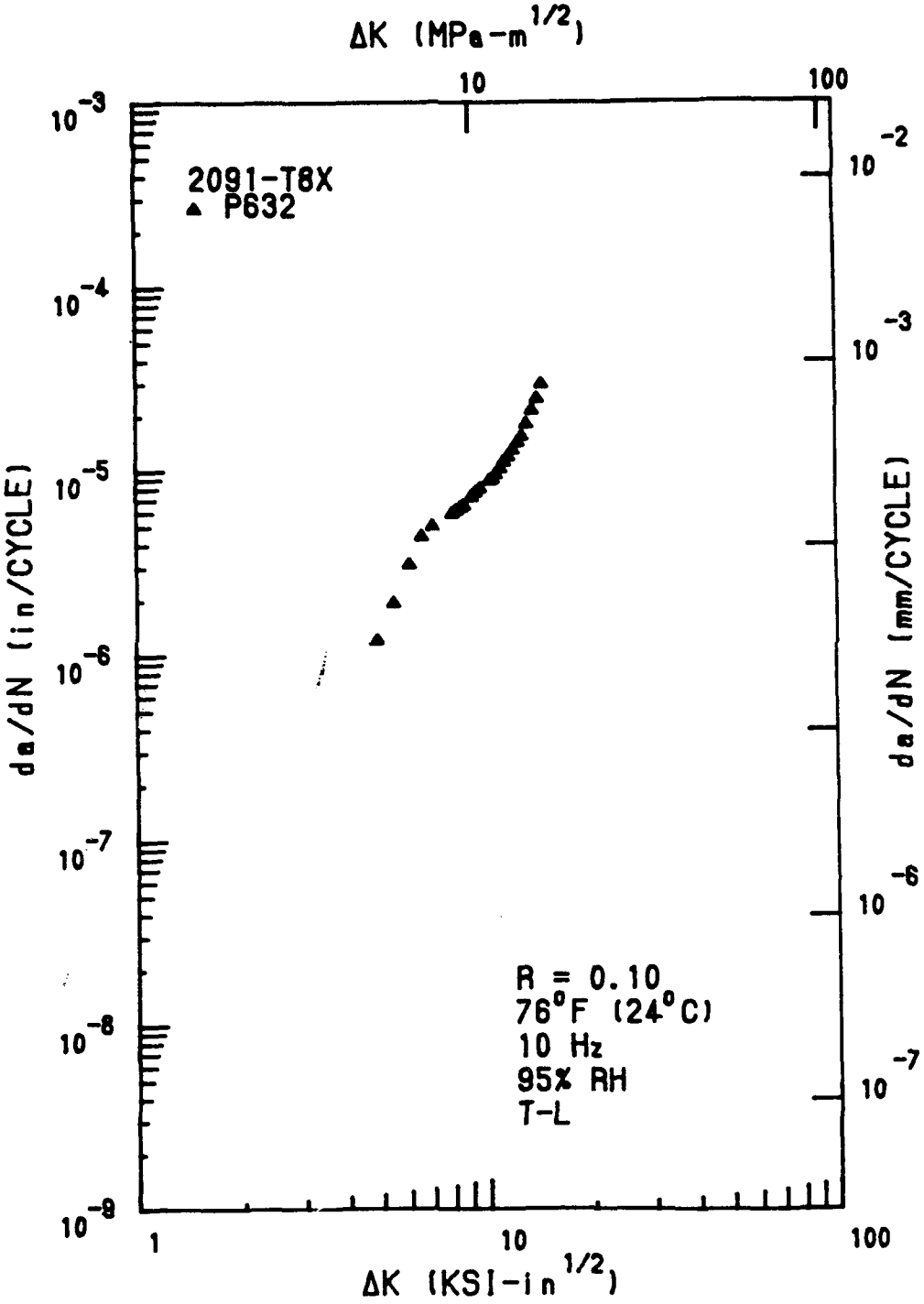
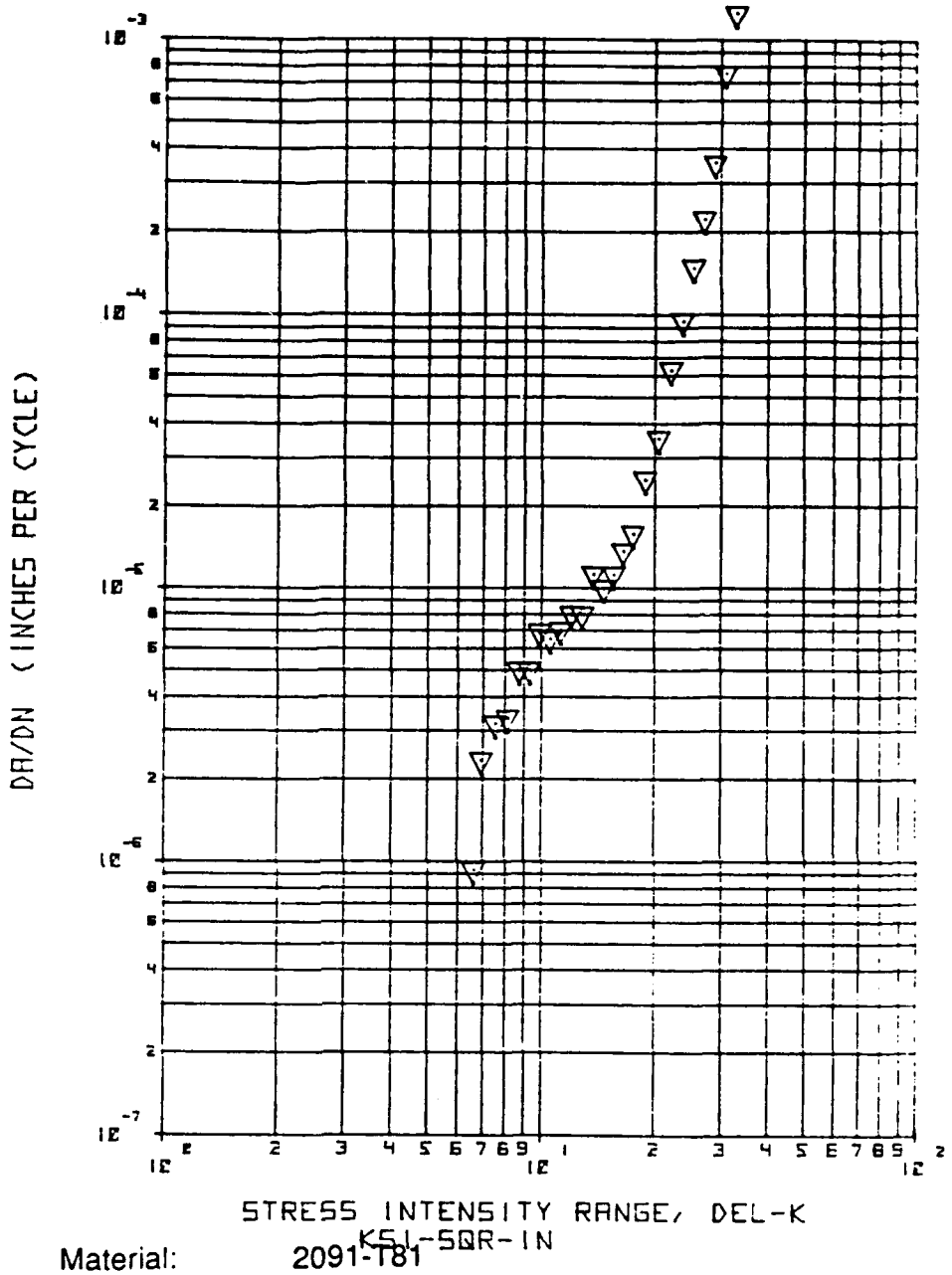
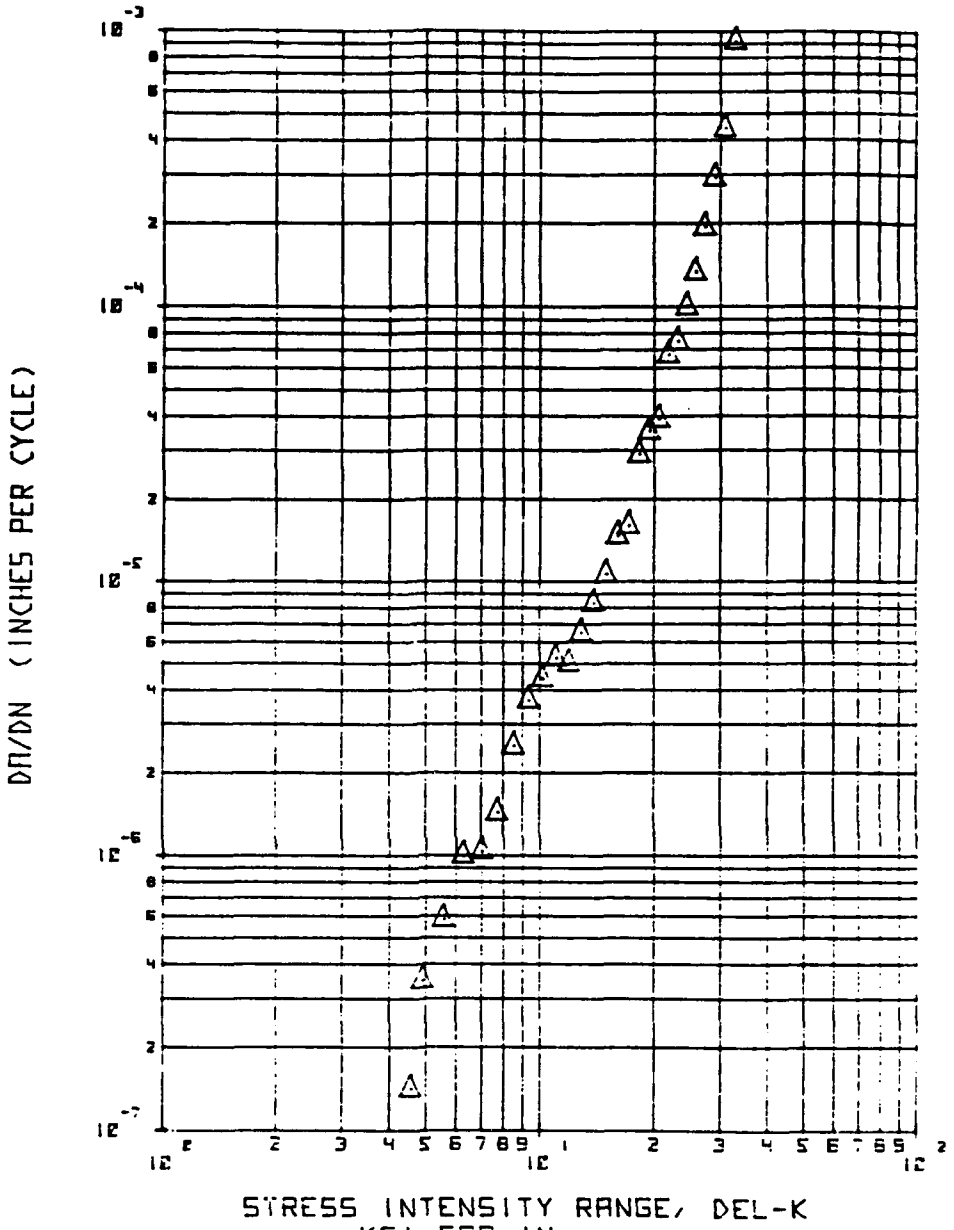


Figure B22 Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.063" Sheet (T-L Orientation). Northrop.



Material:	2091-T81
Age:	335°F - 32 hrs
Environment:	Lab air, Room temperature
Orientation:	L-T
Stress Ratio:	0.1
Frequency:	5 Hz

Figure B23 K-increasing Constant Amplitude Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.063" Sheet (L-T Orientation). General Dynamics, TX.



Material:	2091-T81 Sheet
Age:	335°F - 32 hrs
Environment:	Lab air, Room temperature
Orientation:	T-L
Stress Ratio:	0.1
Frequency:	5 Hz

Figure B24 K-increasing Constant Amplitude Fatigue Crack Growth Rate Data for Pechiney 2091-T8X 0.063" Sheet (T-L). General Dynamics, TX.

APPENDIX C

PECHINEY

2091-T6 PRECISION FORGING

INTRODUCTION

The Pechiney 2091-T6 precision forgings were received the third quarter of 1986. Five participants tested this material; Boeing Commercial Airplane Company, General Dynamics Fort Worth Division, Lockheed Aeronautical Systems Company, Martin Marietta Manned Space Systems and Northrop Corporation. Forging Dimensions are shown in Figure C1.

TESTING

Basic mechanical properties (tension, compression, bearing, etc.) were tested according to ASTM standards, unless otherwise specified.

Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 Standard. The growth rate a-N data that was generated by the participant, Northrop Corporation, was reduced using a seven-point incremental polynomial (parabola) to sets of seven successive data points. The data are also checked against size requirements per ASTM E647, Section 7.2.

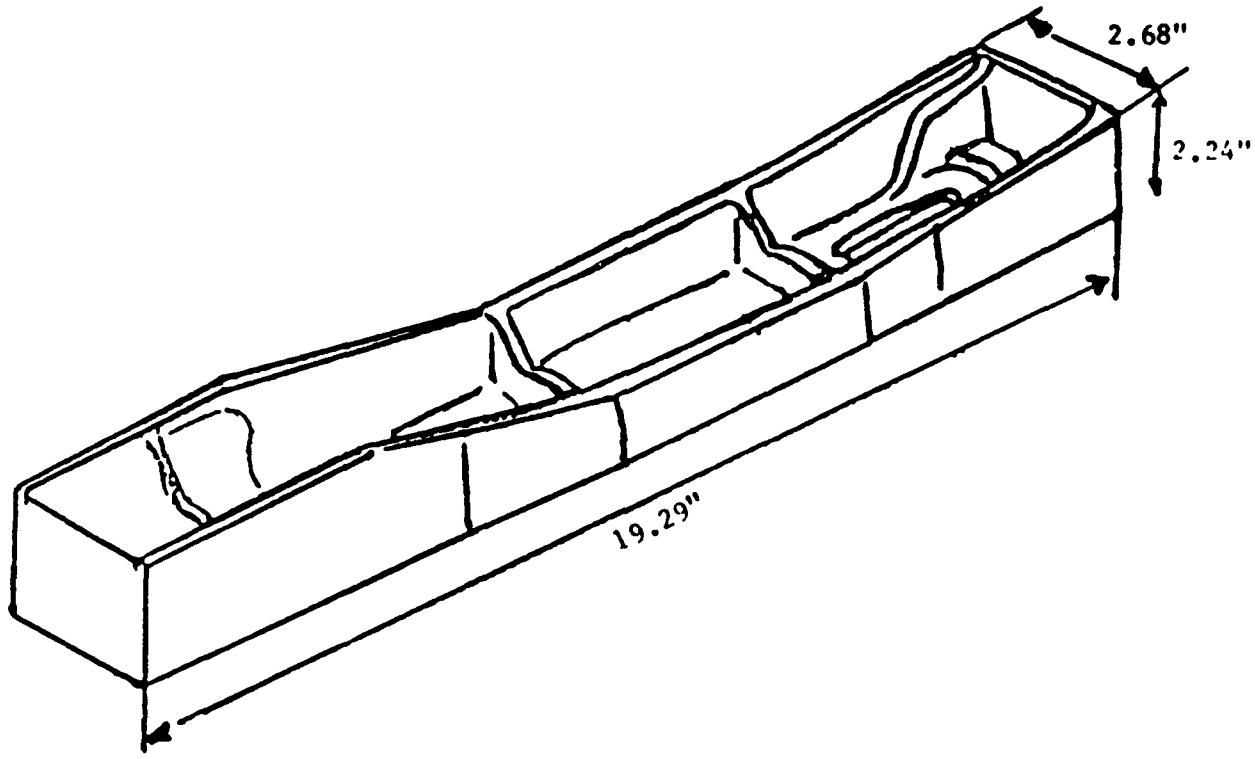


Figure C1 2091-T6 Precision Die Forging Dimensions.

TABLE C1

TENSILE RESULTS AT t/2 LOCATION FOR

PECHINEY 2091-T6 FORGINGS

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)	COMMENT
BOEING	RT	LONG	73.6	65.3	4.0			
			77.9	66.5	5.0			
			82.2	72.3	8.0			
NORTHROP	RT	LONG	81.3	69.4	10.0	9.0	11.2	(1),(2)
			82.8	72.1	9.0	7.5	11.4	(2)
			83.1	73.0	8.0	6.4	11.4	(2)
			85.9	76.7	8.0	7.5	11.1	(2)
			80.2	69.8	8.0	7.1	11.5	(2)
			85.0	75.5	8.0	7.4	11.3	(2)
			81.7	72.7	5.0	4.5	11.2	(3)
			81.6	71.8	7.0	5.7	11.3	(3)
			67.1	58.4	3.0	2.0	11.2	(4)
			68.0	56.6	4.0	3.3	11.2	(4)
GENERAL DYNAMICS, TEXAS	RT	LONG	84.4	73.5	6.7			
			84.0	73.0	6.8			
LOCKHEED, GEORGIA	RT	LONG	83.9	72.7	9.0		12.8	
			80.1	68.4	8.0		12.5	
			80.9	68.9	9.0		11.5	
			83.9	72.4	8.0		11.1	
			83.7	72.7	9.0		11.8	
MARTIN MARIETTA, LOUISIANA	RT	LONG	74.6	68.4	2.0	6.0	11.4	
			81.3	68.7	5.0	10.0	11.8	
			77.9	63.2	5.0	10.0	11.8	
		AVERAGE	80.2	69.7	6.8	6.6	11.5	
	STANDARD DEVIATION		5.0	5.0	2.2	2.4	0.5	

(1): INDICATES THAT THE SPECIMEN FAILED OUTSIDE THE GAGE MARKS
(2): SPECIMEN REMOVED FROM THE FORGING BASE
(3): SPECIMEN REMOVED FROM THE FORGING SIDE WALL
(4): SPECIMEN REMOVED FROM THE FORGING END WALL

TABLE C2

TENSILE RESULTS AT t/2 LOCATION FOR

PECHINEY 2091-T6 FORGINGS

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)	COMMENT
NORTHROP	RT	L TRANS	66.4				11.2	(1),(2)
			78.6	70.9	5.0		11.4	(2)
			63.8				11.3	(1),(2)
			75.0	68.3	3.0		11.2	(1),(2)
			60.6		1.0		11.2	(1),(2)
			71.5	66.0	2.0		10.8	(1),(2)
			69.2	63.2	2.0		11.3	(4)
			66.1	58.7	2.0		11.1	(4)
		AVERAGE	68.9	65.4	2.5		11.2	
	STANDARD DEVIATION		5.9	4.7	1.4		0.2	

(1): INDICATES THAT THE SPECIMEN FAILED OUTSIDE THE GAGE MARKS
(2): SPECIMEN REMOVED FROM THE FORGING BASE
(3): SPECIMEN REMOVED FROM THE FORGING SIDE WALL
(4): SPECIMEN REMOVED FROM THE FORGING END WALL

TABLE C3

TENSILE RESULTS AT t/2 LOCATION FOR

PECHINEY 2091-T6 FORGINGS

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)	COMMENT
LOCKHEED, GEORGIA	RT	S TRANS	68.7		6.0			
			72.2		6.0			
			66.6		6.0			
			70.9		6.0			
			72.1		6.0			
		AVERAGE	70.1		6.0			
	STANDARD DEVIATION		2.4		0.0			

TABLE C4

COMPRESSION RESULTS AT t/2 LOCATION FOR

PECHINEY 2091-T6 FORGINGS

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
BOEING	RT	LONG	68.6	
			72.4	
			70.4	
NORTHROP	RT	LONG	67.3	11.7
			73.8	11.6
			75.4	11.8
LOCKHEED, GEORGIA	RT	LONG	67.0	
			62.0	
			64.7	
			62.7	
			65.6	
GENERAL DYNAMICS, TEXAS	RT	LONG	57.7	
MARTIN MARIETTA, LOUISIANA	RT	LONG	73.4	12.2
			64.3	12.1
		AVERAGE	67.5	11.9
		STANDARD DEVIATION	5.1	0.3

NOTE: NORTHROP SPECIMENS TAKEN FROM FORGING SIDE WALL.

TABLE C5

COMPRESSION RESULTS AT t/2 LOCATION FOR

PECHINEY 2091-T6 FORGINGS

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	61.7	12.0
			60.2	12.0
		AVERAGE	61.0	12.0
		STANDARD DEVIATION	1.1	0.0

TABLE C6

AMSLER DOUBLE SHEAR RESULTS FOR

PECHINEY 2091-T6 FORGINGS

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	L-S	38.6
		39.5
		38.9
LOCKHEED, GEORGIA	L-S	38.7
		40.4
		39.8
	AVERAGE	39.3
	STANDARD DEVIATION	0.7

NOTE: NORTHROP SPECIMENS TAKEN FROM FORGING SIDE WALL.

TABLE C7

AMSLER DOUBLE SHEAR RESULTS FOR

PECHINEY 2091-T6 FORGINGS

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	T-S	38.0
		37.1
		35.8
LOCKHEED, GEORGIA	T-S	39.0
		42.4
		38.3
	AVERAGE	38.4
	STANDARD DEVIATION	2.2

NOTE: NORTHROP SPECIMENS TAKEN FROM FORGING SIDE WALL.

TABLE C8

SLOTTED SHEAR RESULTS FOR PECHINEY

2091-T6 FORGINGS

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
BOEING	LONG	43.3
		44.9
		43.1
	AVERAGE	43.8
	STANDARD DEVIATION	1.0

TABLE C9

BEARING RESULTS FOR PECHINEY

2091-T6 FORGINGS

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING	LONG	1.5	73.9	65.6
			82.7	65.9
			85.5	72.3
NORTHROP	LONG	1.5	103.8	87.7
			95.0	81.8
			99.8	82.2
LOCKHEED, GEORGIA	LONG	1.5	95.3	84.7
			99.0	85.7
			102.2	86.3
		AVERAGE	93.0	79.1
		STANDARD DEVIATION	10.1	8.8

NOTE: NORTHROP SPECIMENS REMOVED FROM FORGING SIDE WALL.

TABLE C10

BEARING RESULTS FOR PECHINEY

2091-T6 FORGINGS

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING	LONG	2.0	142.3	105.3
			144.9	112.9
			142.0	105.7
NORTHROP	LONG	2.0	134.8	104.3
			139.6	105.1
			136.4	105.0
GENERAL DYNAMICS, TEXAS	LONG	2.0	129.0	116.0
LOCKHEED, GEORGIA	LONG	2.0	129.2	108.8
			128.1	105.1
			132.8	109.2
		AVERAGE	135.9	107.7
		STANDARD DEVIATION	6.1	4.0

NOTE: NORTHROP SPECIMENS REMOVED FROM FORGING SIDE WALL.

TABLE C11

BEARING RESULTS FOR PECHINEY

2091-T6 FORGINGS

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
GENERAL DYNAMICS, TEXAS	L TRANS	2.0	128.0	87.2
		AVERAGE	128.0	87.2
	STANDARD DEVIATION			

TABLE C12

FRACTURE TOUGHNESS RESULTS FOR

PECHINEY 2091-T6 FORGINGS

COMPANY	ORIENTATION	KIC (KSI IN^0.5)	Kq (KSI IN^0.5)	COMMENT
NORTHROP	L-T		29.1	(1),(3),(4)
			22.2	(2),(3),(4)
MARTIN MARIETTA, LOUISIANA	L-T		25.8	(4),(5)
			27.6	(4),(5)
	AVERAGE		26.2	
	STANDARD DEVIATION		3.0	

(1): W=1.0
(2): W=0.8
(3): SPECIMEN REMOVED FROM FORGING BASE
(4): INVALID
(5): VIOLATES SPECIMEN THICKNESS REQUIREMENTS

TABLE C13

FRACTURE TOUGHNESS RESULTS FOR

PECHINEY 2091-T6 FORGINGS

COMPANY	ORIENTATION	KIC (KSI IN^0.5)	Kq (KSI IN^0.5)	COMMENT
NORTHROP	T-L		24.1	(1),(3),(4)
			27.4	(2),(3),(4)
GENERAL DYNAMICS, TEXAS	T-L		25.9	(5)
			20.4	(5)
MARTIN MARIETTA, LOUISIANA	T-L		22.0	(4),(7)
			25.3	(4),(7)
	AVERAGE		24.2	
	STANDARD DEVIATION		2.6	

(1): W=1.0
(2): W=0.8
(3): SPECIMEN REMOVED FROM FORGING BASE
(4): INVALID
(5): INVALID DUE TO - INSUFFICIENT THICKNESS, Pmax/Pq > 1.10, AND MINIMUM SURFACE CRACK LENGTH < 90%
(6): INVALID DUE TO - Pmax/Pq > 1.10, MINIMUM SURFACE CRACK LENGTH < 90%, AND CRACK CURVATURE > 5%
(7): VIOLATED SPECIMEN THICKNESS REQUIREMENTS

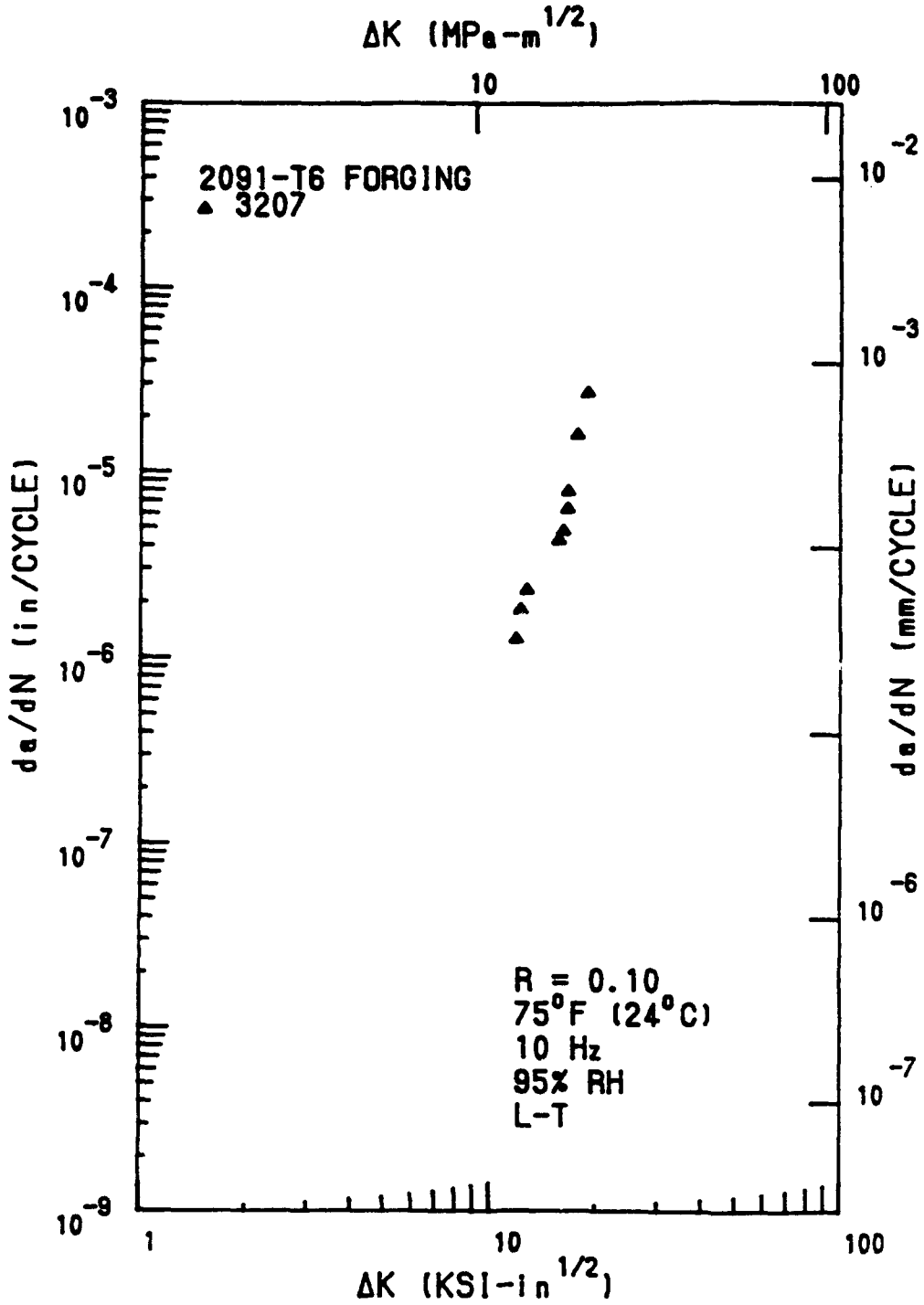


Figure C2 Fatigue Crack Growth Rate Data for Pechiney 2091-T6 Forging (L-T Orientation). Northrop.

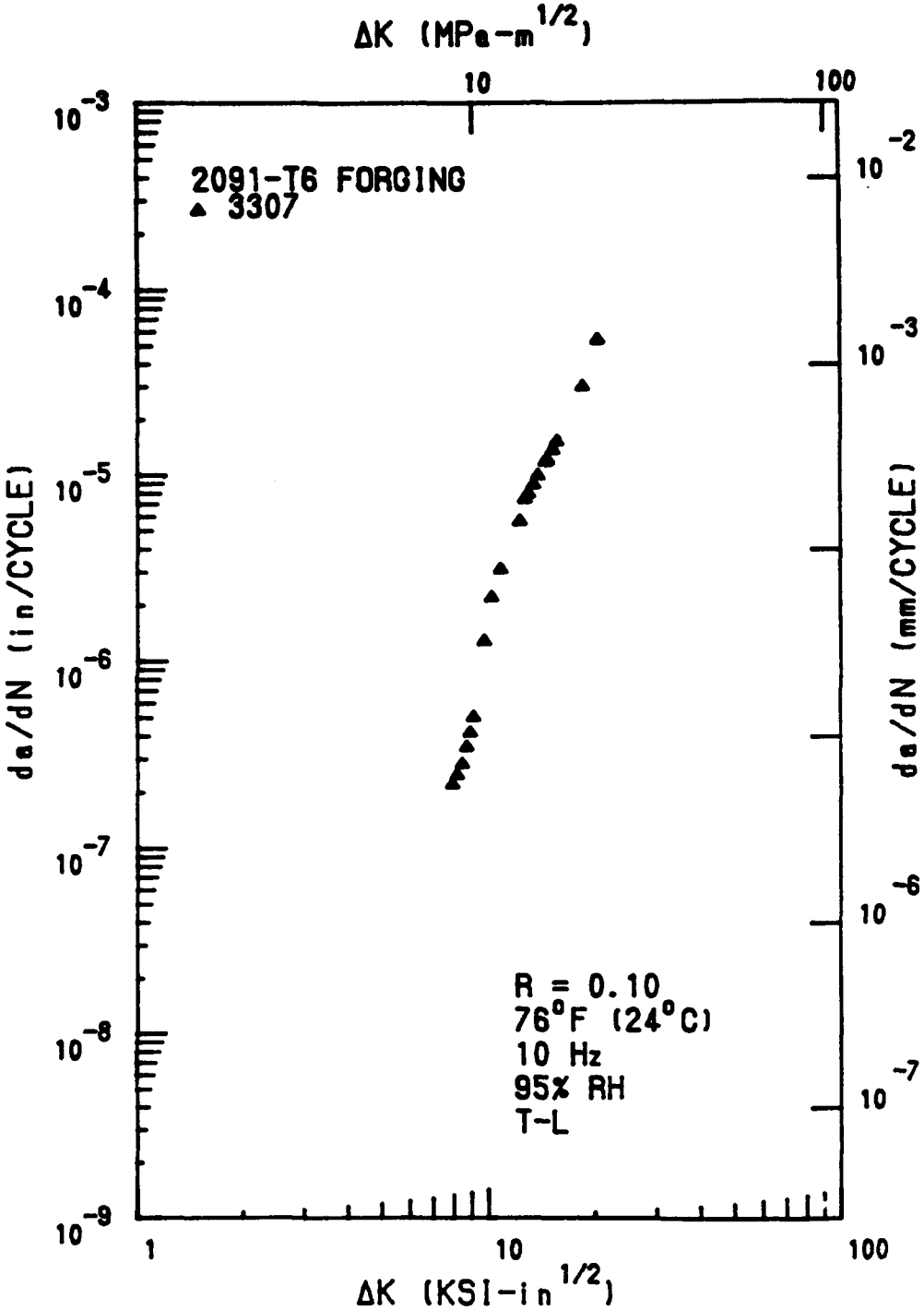


Figure C3 Fatigue Crack Growth Rate Data for Pechiney 2091-T6 Forging (T-L Orientation). Northrop.

APPENDIX D

PECHINEY

8090-T651 T-EXTRUSION

INTRODUCTION

The Pechiney 8090-T651 T-Extrusions were received the fourth quarter of 1986. Dimensions of the T-Extrusion are 0.19" x 2.5" x 3.0" x 79". Four participants tested this material; Boeing Commercial Airplane Company WA, General Dynamics Fort Worth Division, LTV Aircraft Products Group TX, and the Navy (Naval Air Development Center).

TESTING

Basic mechanical properties (tension, compression, bearing, etc.) were tested according to ASTM standards, unless otherwise specified.

TABLE D1

TENSILE RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
BOEING	RT	LONG	77.4	66.9	8.0		
			77.5	67.0	8.0		
			77.4	67.0	8.0		
GENERAL DYNAMICS, TEXAS	RT	LONG	81.0	71.5	5.9		
			77.1	68.3	2.9		
			80.3	70.5	5.7		
			80.7	70.9	4.9		
NADC	RT	LONG	76.0	66.9	3.0		10.4
			81.2	72.4	3.0		11.5
			80.7	71.3	3.0		10.0
			82.2	72.4	3.0		9.5
LTV	RT	LONG	78.5	68.9	6.1		11.6
			77.4	68.5	7.2		11.6
			78.5	69.2	6.9		11.6
		AVERAGE	79.0	69.4	5.4		10.9
	STANDARD DEVIATION		2.0	2.1	2.1		0.9

TABLE D2

TENSILE RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GENERAL DYNAMICS, TEXAS	RT	L TRANS	78.4	69.5	4.4		
			78.2	69.6	4.5		
		AVERAGE	78.3	69.6	4.5		
	STANDARD DEVIATION		0.1	0.1	0.1		

TABLE D3

COMPRESSION RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
BOEING	RT	LONG	68.0	
			67.1	
			67.7	
		AVERAGE	67.6	
		STANDARD DEVIATION	0.5	

TABLE D4

SLOTTED SHEAR RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
BOEING	LONG	42.5
		42.5
		42.5
	AVERAGE	42.5
	STANDARD DEVIATION	0.0

TABLE D5

SLOTTED SHEAR RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
GENERAL DYNAMICS, TEXAS	L TRANS	41.7
		41.2
	AVERAGE	41.5
	STANDARD DEVIATION	0.4

TABLE D6

IOSIPESCU SHEAR RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
LTV	LONG	41.4
		40.6
		42.5
	AVERAGE	41.5
	STANDARD DEVIATION	1.0

TABLE D7

IOSIPESCU SHEAR RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
LTV	L TRANS	39.5
		40.4
		39.3
	AVERAGE	39.7
	STANDARD DEVIATION	0.6

TABLE D8

BEARING RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5 X 3" X 79")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING	LONG	1.5	103.4	90.2
			106.5	94.6 *
			107.6	95.5 *
GENERAL DYNAMICS, TEXAS	LONG	1.5	106.0	94.3
			104.0	91.2
LTV	LONG	1.5	105.5	97.4
			107.0	96.2
			106.2	93.3
		AVERAGE	105.8	94.1
		STANDARD DEVIATION	1.4	2.4

(*): INDICATES SHEAR TEAR OUT FAILURE

TABLE D9

BEARING RESULTS FOR PECHINEY

8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
BOEING	LONG	2.0	131.8	105.1 *
			138.6	113.1 *
			135.2	111.4 *
GENERAL DYNAMICS, TEXAS	LONG	2.0	116.0	106.0
			135.0	107.0
LTV	LONG	2.0	135.6	116.4
			136.0	
			133.6	111.2
		AVERAGE	132.7	110.0
		STANDARD DEVIATION	7.0	4.1

(*): INDICATES SHEAR-TENSION FAILURE

TABLE D10

FATIGUE RESULTS WITH R=0.1 AND Kt=2.8 FOR

PECHINEY 8090-T651 T-EXTRUSION (0.19" X 2.5" X 3" X 79")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
LTV	LONG	22.0	54,800
		22.0	58,700
		21.2	83,700
		19.6	213,900
		19.5	78,800
		19.5	176,700
		17.3	219,100
		16.5	212,300
		16.0	300,200
		15.0	341,600
		14.9	1,000,000 *

(*): INDICATES A RUN-OUT TEST

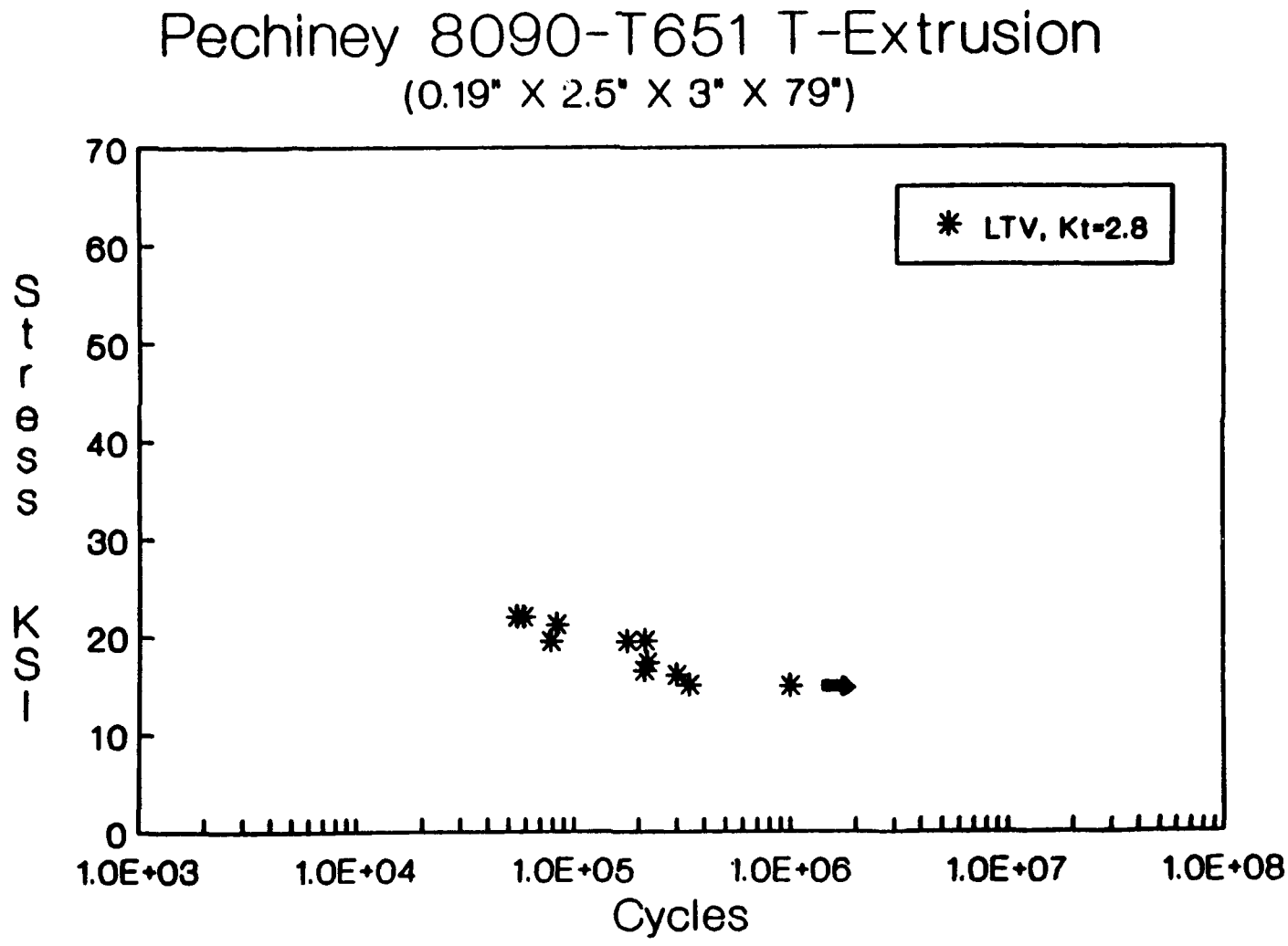


Figure D1 Fatigue Results for 8090-T651 T-Extrusion (R=0.1, Kt=2.8). LTV.

APPENDIX E

ALCAN 8090-T651 AND 8090-T8 EXTRUSION (1.0" X 4.0")

INTRODUCTION

The Alcan 8090-T651 1-inch x 4-inch extrusions were received the first quarter of 1986. One participant heat treated the 8090-T651 to a T8 temper. Grumman-T8 condition was achieved by heating the material to 238°F for 24 hours. The other participants tested the material in the as-received condition (-T651).

TESTING

Basic mechanical properties (tension, compression, bearing, etc.) were tested according to ASTM standards, unless otherwise specified.

Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 standard. The growth rate a-N data that were generated by the participants (Northrop, Grumman, and Air Force) were reduced using a seven-point incremental polynomial method. This involves fitting a second-order polynomial (parabola) to sets of seven successive data points. The data are also checked against size requirements per ASTM E647, Section 7.2. NASA-Langley performed constant amplitude fatigue crack growth tests using K-increasing (load increasing) and K-decreasing (load decreasing) methods.

Spectrum tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE E1

TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	LONG	72.7	62.9	5.3	13.0	
			76.1	64.2	5.3	6.0	
			77.0	65.2	6.1	9.9	
			76.6	65.2	5.3	9.9	
			74.2	62.2	5.7	8.5	
			76.8	64.9	5.6	7.0	
MARTIN MARIETTA	RT	LONG	81.0	76.8	4.9		11.3
			73.1	63.5	6.2		11.3
			81.1	77.2	7.9		11.2
NORTHROP	RT	LONG	73.7	65.6	4.0	19.6	11.8
			76.4	68.5	6.0	20.8	11.6
			79.9	76.5	4.0	19.4	11.7
			76.6	71.1	7.0		12.0
			73.1	64.8	7.0		12.5
			73.9	65.5	7.0		12.5
NASA LANGLEY	RT	LONG	77.1	67.9	5.0		11.4
			75.8	66.6	10.0		11.3
			76.4	67.5	9.0		11.4
			77.0	68.0	7.5		11.4
		AVERAGE	76.2	67.6	6.3	12.7	11.6
	STANDARD DEVIATION		2.5	4.6	1.6	5.8	0.4

TABLE E2

TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN MARIETTA	-423	LONG	103.9		22.0		13.1
			102.9	52.7	8.0		12.9
			99.8	62.0	16.0		12.3
			123.6		14.0		14.4
			107.0	71.3	20.0		13.4
	-320	LONG	89.4	64.4	12.0		14.9
			89.4	68.6	11.0		13.5
			89.1	64.5			13.5
	+200	LONG	68.3	65.6	16.0		11.0
			69.6	63.9	14.0		11.2
			69.3	66.0	18.0		12.4
	+350	LONG	55.3	55.2	36.0		10.5
			55.6	55.5	26.0		10.5
			55.7	55.6	30.0		10.7

TABLE E3

TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	L TRANS	67.4	54.7	7.8	16.0	
			68.2	54.0	0.0	15.9	
			69.6	55.0	8.6	21.8	
NORTHROP	RT	L TRANS	68.6	58.4	7.0	19.6	11.8
			68.3	58.1	7.0	20.8	11.6
			68.2	58.0	7.0	19.4	11.7
			68.0	58.0	8.0		12.3
			67.8	57.2	8.0		12.5
			68.2	58.2	9.0		12.2
MARTIN MARIETTA	RT	L TRANS	67.9	56.1	8.0		11.1
			68.2	56.8	9.5		11.1
			68.5	56.5	9.5		11.5
NASA LANGLEY	RT	L TRANS	70.5	57.8	10.0		11.4
			70.1	57.7	11.0		11.4
			70.8	58.3	10.0		11.4
			70.7	57.8	10.0		11.4
		AVERAGE	68.8	57.0	8.2	18.9	11.6
	STANDARD DEVIATION		1.1	1.4	2.5	2.5	0.4

TABLE E4

TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN MARIETTA	-423	L TRANS	86.9	62.6	8.0		12.5
			81.8	72.0			12.5
			87.9	62.5	9.0		13.1
	-320	L TRANS	78.9	60.6	5.0		13.6
			79.3	60.2	8.0		13.5
			77.3	60.1			13.2
	+200	L TRANS	63.5	56.1	12.3		9.0
			63.6	56.5	13.3		10.6
			63.6	56.7	12.5		10.8
	+350	L TRANS	50.7	50.6	22.0		10.4
			51.4	51.2	18.0		10.0
			58.5	56.3	18.0		10.0

TABLE E5

TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	S TRANS	69.4	55.9	8.0	7.8	11.1
			68.0	52.4	4.0	3.1	11.3
			66.5	51.6	4.0	3.1	11.2
		AVERAGE	68.0	53.3	5.3	4.7	11.2
	STANDARD DEVIATION		1.5	2.3	2.3	2.7	0.1

TABLE E6

TENSILE RESULTS AT t/10 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	LONG	77.9	69.0	6.0		12.0
			75.7	66.8	5.0		12.2
			74.1	65.1	5.0		11.9
		AVERAGE	75.9	67.0	5.3		12.0
	STANDARD DEVIATION		1.9	2.0	0.6		0.2

TABLE E7

TENSILE RESULTS AT t/10 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	L TRANS	72.4	63.4	9.0		12.4
			72.2	63.1	9.0		12.2
			72.3	63.0	9.0		12.2
		AVERAGE	72.3	63.2	9.0		12.3
	STANDARD DEVIATION		0.1	0.2	0.0		0.1

TABLE E8

TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4") AFTER 100 HRS AT 350F

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	LONG	78.0	72.1	7.0	14.5	11.6
			73.6	66.8	7.0	12.3	12.5
			72.3	65.0	7.0	10.9	11.8
		AVERAGE	74.6	68.0	7.0	12.6	12.0
	STANDARD DEVIATION		3.0	3.7	0.0	1.8	0.5
	RT	L TRANS	68.1	60.4	6.0	13.8	11.5
			68.2	60.4	6.0	13.8	12.3
			68.1	60.5	6.0	13.8	12.9
		AVERAGE	68.1	60.4	6.0	13.8	12.2
	STANDARD DEVIATION		0.1	0.1	0.0	0.0	0.7
	RT	S TRANS	67.2	56.9	4.0	6.2	11.3
			64.8	55.8	2.0	2.5	10.8
			67.1	55.2	2.0	4.7	10.8
		AVERAGE	66.4	56.0	2.7	4.5	11.0
	STANDARD DEVIATION		1.4	0.9	1.2	1.9	0.3

TABLE E9

NOTCH TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	NTS (KSI)	NTS/TYS
NORTHROP	RT	LONG	82.7	1.2
			78.1	1.1
			85.0	1.2
		AVERAGE	81.9	1.2
	STANDARD DEVIATION		3.5	0.1
	RT	L TRANS	60.5	1.0
			54.1	0.9
			50.3	0.9
		AVERAGE	55.0	0.9
	STANDARD DEVIATION		5.2	0.0

TABLE E10

COMPRESSION RESULTS FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
AIR FORCE	RT	LONG	69.1	
			69.4	
			69.0	
NORTHROP	RT	LONG	74.6	12.0
			71.9	12.0
			71.8	11.9
NASA LANGLEY	RT	LONG	67.4	11.7
			66.9	11.7
			66.9	11.7
		AVERAGE	69.7	11.8
		STANDARD DEVIATION	2.6	0.2

TABLE E11

COMPRESSION RESULTS FOR ALCAN

8090-T651 EXTRUSION (1" x 4")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
AIR FORCE	RT	L TRANS	65.5	
			64.5	
			65.2	
NORTHROP	RT	L TRANS	64.9	12.1
			65.3	11.9
			62.5	12.3
NASA LANGLEY	RT	L TRANS	63.2	11.8
			63.1	11.5
			63.9	11.8
			63.4	11.8
		AVERAGE	64.2	11.9
		STANDARD DEVIATION	1.1	0.3

TABLE E12

RIVET SHEAR RESULTS FOR ALCAN

8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	L - S	36.9
		37.4
		37.1
	AVERAGE	37.1
	STANDARD DEVIATION	0.3

TABLE E13

RIVET SHEAR RESULTS FOR ALCAN

8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	T - S	34.5
		34.6
		36.6
	AVERAGE	35.2
	STANDARD DEVIATION	1.2

TABLE E14

AMSLER DOUBLE SHEAR RESULTS FOR

ALCAN 8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
AIR FORCE	L - S	36.5
		34.6
		34.7
NASA - LANGLEY	L - S	36.7
		36.7
		36.4
		37.0
	AVERAGE	36.1
	STANDARD DEVIATION	1.0

TABLE E15

AMSLER DOUBLE SHEAR RESULTS FOR

ALCAN 8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
AIR FORCE	T - S	36.5
		36.6
		34.6
NASA - LANGLEY	T - S	35.4
		35.1
		35.0
		34.8
	AVERAGE	35.4
	STANDARD DEVIATION	0.8

TABLE E16

BEARING RESULTS FOR ALCAN

8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
AIR FORCE	LONG	1.5	94.2	74.3
			100.6	82.7
			100.4	79.3
NORTHROP	LONG	1.5	101.0	84.4
			99.4	77.7
			100.0	81.5
NASA LANGLEY	LONG	1.5	104.5	86.1
			103.2	85.5
			101.9	82.4
			103.5	84.3
		AVERAGE	100.9	81.8
		STANDARD DEVIATION	2.9	3.7

TABLE E17

BEARING RESULTS FOR ALCAN

8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
AIR FORCE	L TRANS	1.5	88.3	79.4
			80.0	71.8
			87.4	78.2
NORTHROP	L TRANS	1.5	87.7	79.5
			88.3	80.1
			86.3	78.9
		AVERAGE	86.3	78.0
		STANDARD DEVIATION	3.2	3.1

TABLE E18

BEARING RESULTS FOR ALCAN

8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
AIR FORCE	LONG	2.0	123.0	
			126.0	
			116.7	87.0
NORTHROP	LONG	2.0	126.0	98.3
			125.0	94.8
			128.0	97.1
NASA LANGLEY	LONG	2.0	131.4	100.0
			131.0	97.4
			127.0	98.1
			132.4	97.4
		AVERAGE	126.7	96.3
		STANDARD DEVIATION	4.6	4.0

TABLE E19

BEARING RESULTS FOR ALCAN

8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
AIR FORCE	L TRANS	2.0	116.0	98.0
			115.1	90.3
			104.7	86.6
NORTHROP	L TRANS	2.0	116.0	98.3
			115.0	98.3
		AVERAGE	113.4	94.3
		STANDARD DEVIATION	4.9	5.5

TABLE E20

FRACTURE TOUGHNESS RESULTS FOR

ALCAN 8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
AIR FORCE	L - T		25.2	INVALID(1)
		25.8		VALID
			27.8	INVALID(1,2)
NORTHROP	L - T	26.2		(3)
		28.3		(3)
		28.4		(3)
NASA LANGLEY	L - T		25.3	INVALID(1,2)
			28.1	INVALID(1,2)
			27.4	INVALID(1,2)
			28.9	INVALID(1,2)
	AVERAGE	27.2	27.1	
	STANDARD DEVIATION	1.4	1.5	

(1): Pmax/Pq was greater than 1.10

(2): The difference between the two surface crack length measurements exceed 10% of the average crack length.

(3): Fractured parallel to load line

TABLE E21

FRACTURE TOUGHNESS RESULTS FOR

ALCAN 8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
AIR FORCE	T - L	16.1		VALID
		16.3		VALID
		15.9		VALID
NORTHROP	T - L	15.1		VALID
		14.9		VALID
		15.3		VALID
NASA LANGLEY	T - L		5.4	INVALID(1,2)
			6.8	INVALID(1,3)
			17.1	INVALID(1)
			17.9	INVALID(1)
	AVERAGE	15.6	11.8	
	STANDARD DEVIATION	0.6		

(1): Kmax > 0.6 Kq
(2): Pmax / Pq = 3.6
(3): Pmax / Pq = 2.6

TABLE E22

STRESS CORROSION CRACKING RESULTS FOR

ALCAN 8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	STRESS APPLIED (KSI in^0.5)	% OF T-L KIC (KSI in^0.5)	COMMENT
AIR FORCE	T-L	12.0	75.0	DID NOT FAIL
		14.0	87.0	DID NOT FAIL

NOTE: TESTING DISCONTINUED AFTER SPECIMEN WAS LOADED TO 87% OF T-L KIC AND DID NOT FAIL AFTER 2000 HRS.

TABLE E23

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR

ALCAN 8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
NORTHROP	LONG	80.0	98
		70.0	18,793
		60.0	28,082
		50.0	57,511
		45.0	362,662
		42.5	642,818
		40.0	4,000,000 *
		37.5	5,000,000 *
NASA - LANGLEY	LONG	60.0	29,100
		50.0	43,000
		45.0	55,600
		40.0	549,000
		38.0	2,472,100
		36.0	10,557,700 *
		36.0	139,300
		36.0	317,600
		30.0	12,900,000 *

(*): INDICATES RUN-OUT TEST

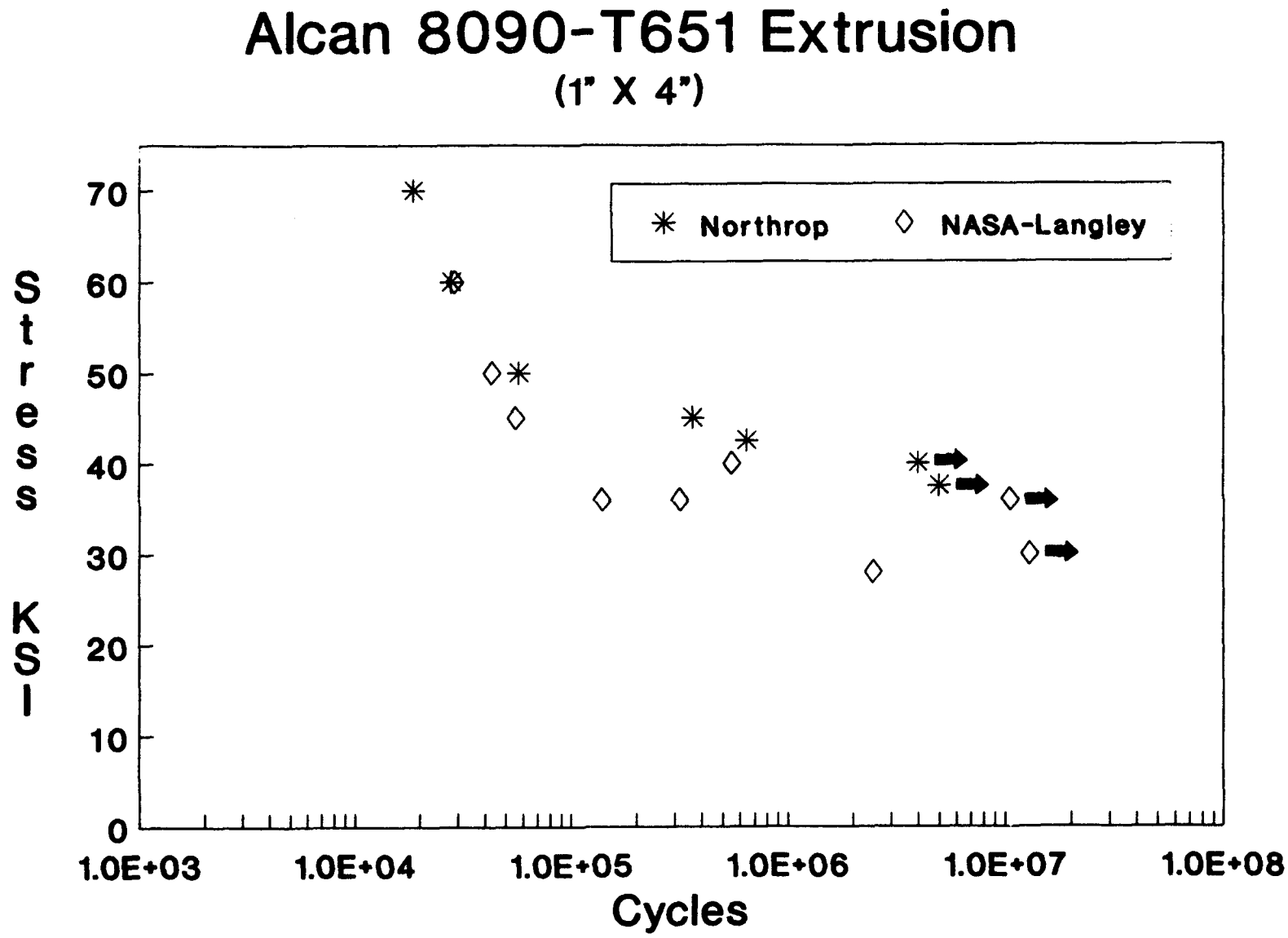


Figure E1. Fatigue Results for 8090-T651 1" x 4" Extrusion (R=0.1, K_t=1.0, Longitudinal).

TABLE E24

FATIGUE RESULTS WITH R=0.1 AND Kt=3.0 FOR

ALCAN 8090-T651 EXTRUSION (1" X 4")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
NORTHROP	LONG	55.0	4,413
		50.0	6,373
		40.0	13,431
		35.0	35,620
		30.0	115,117
		27.5	210,968
		27.5	150,596
		25.0	5,000,000 *
NASA - LANGLEY	LONG	35.0	20,400
		30.0	47,600
		25.0	462,400
		23.0	1,785,300
		22.0	1,169,200
		22.0	725,500
		22.0	12,300,000 *
		21.0	10,908,100 *
		20.0	10,045,000 *

(*): INDICATES RUN-OUT TEST

NOTE: NASA-LANGLEY SPECIMENS HAD A Ktg=3.01 AND A Ktn=2.88

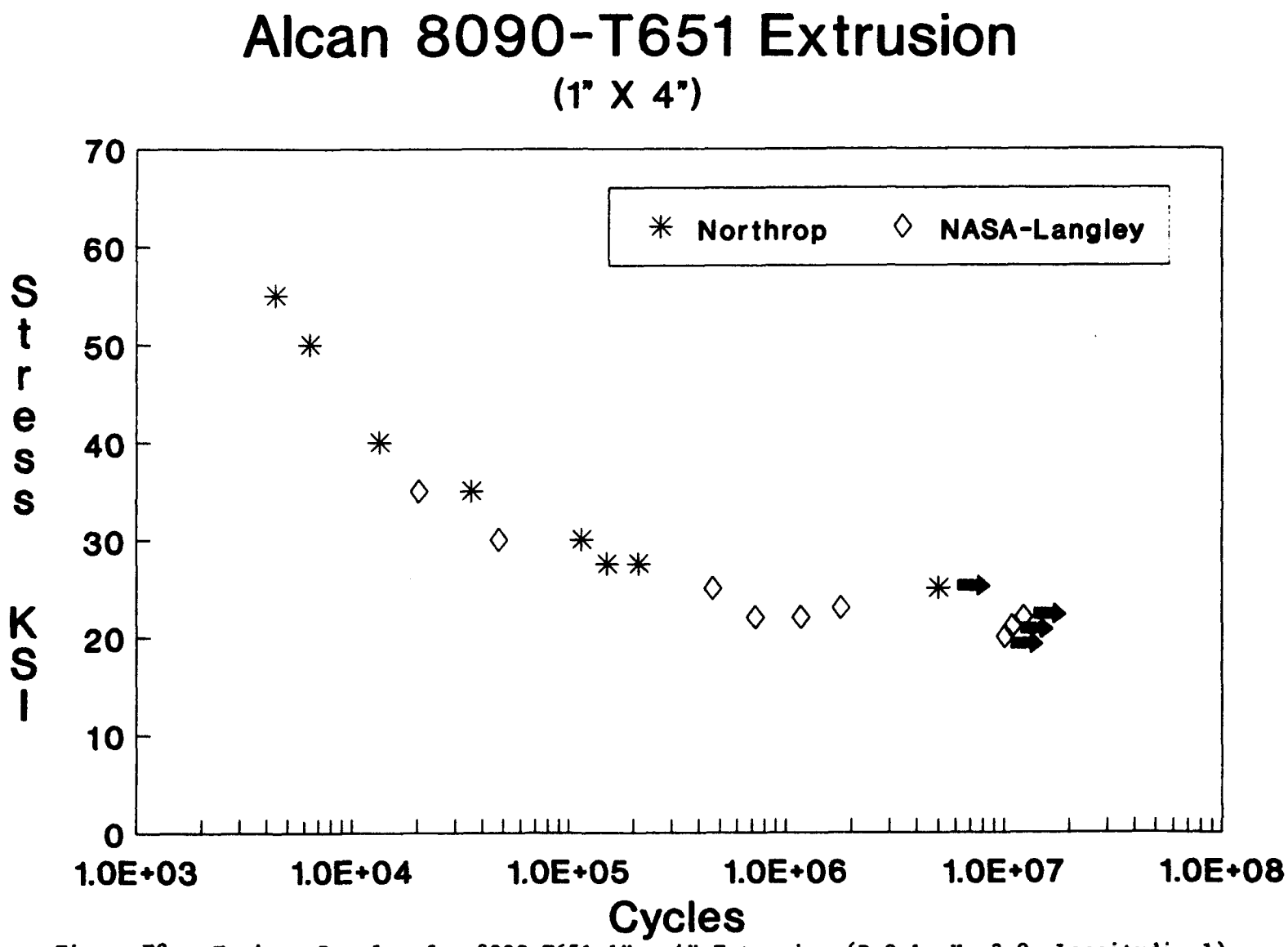


Figure E2. Fatigue Results for 8090-T651 1" x 4" Extrusion (R=0.1, K_t=3.0, Longitudinal).

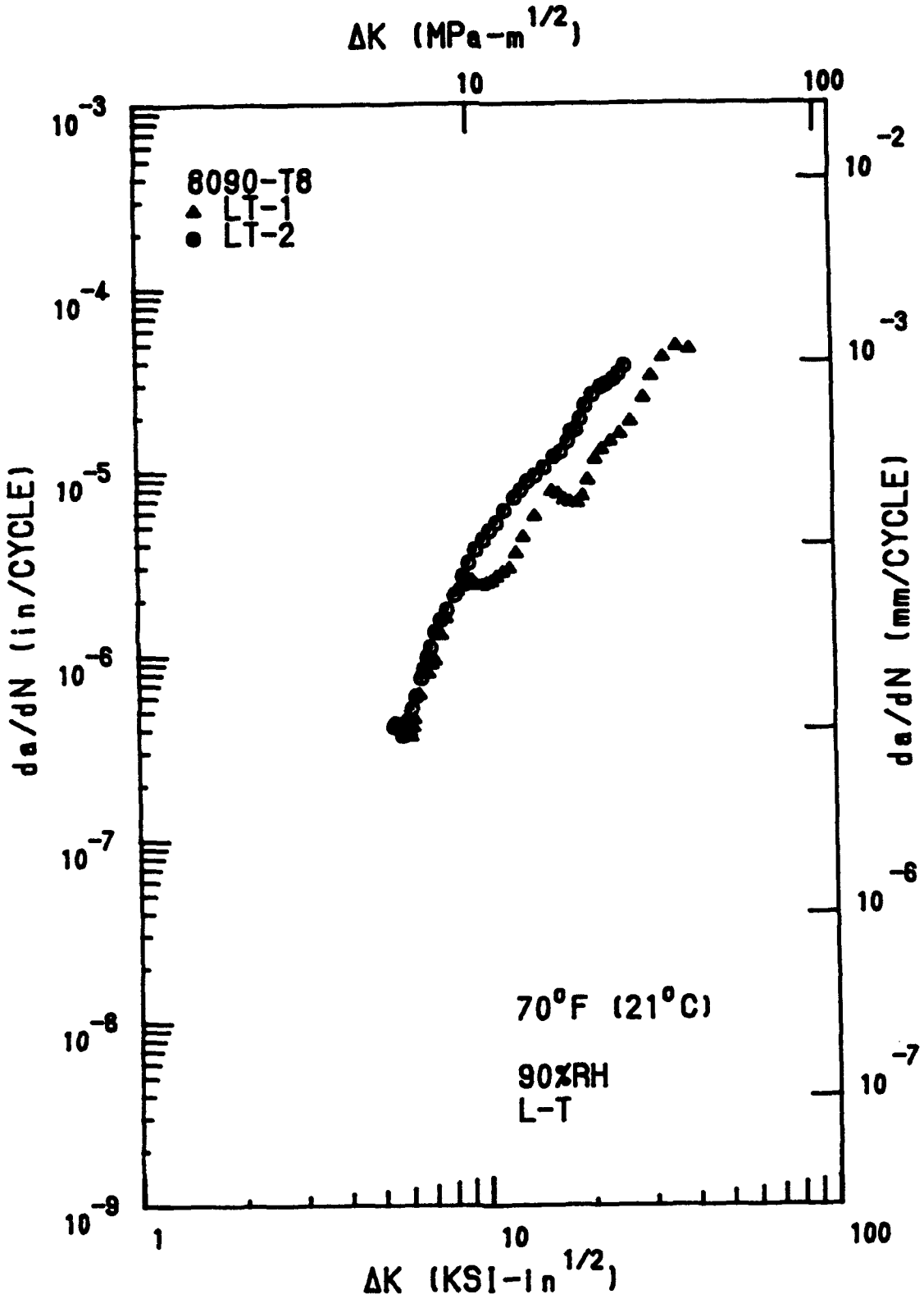


Figure E3. Fatigue Crack Growth Rate Data for Alcan 8090-T8 1" x 4" Extrusion (L-T Orientation). Grumman.

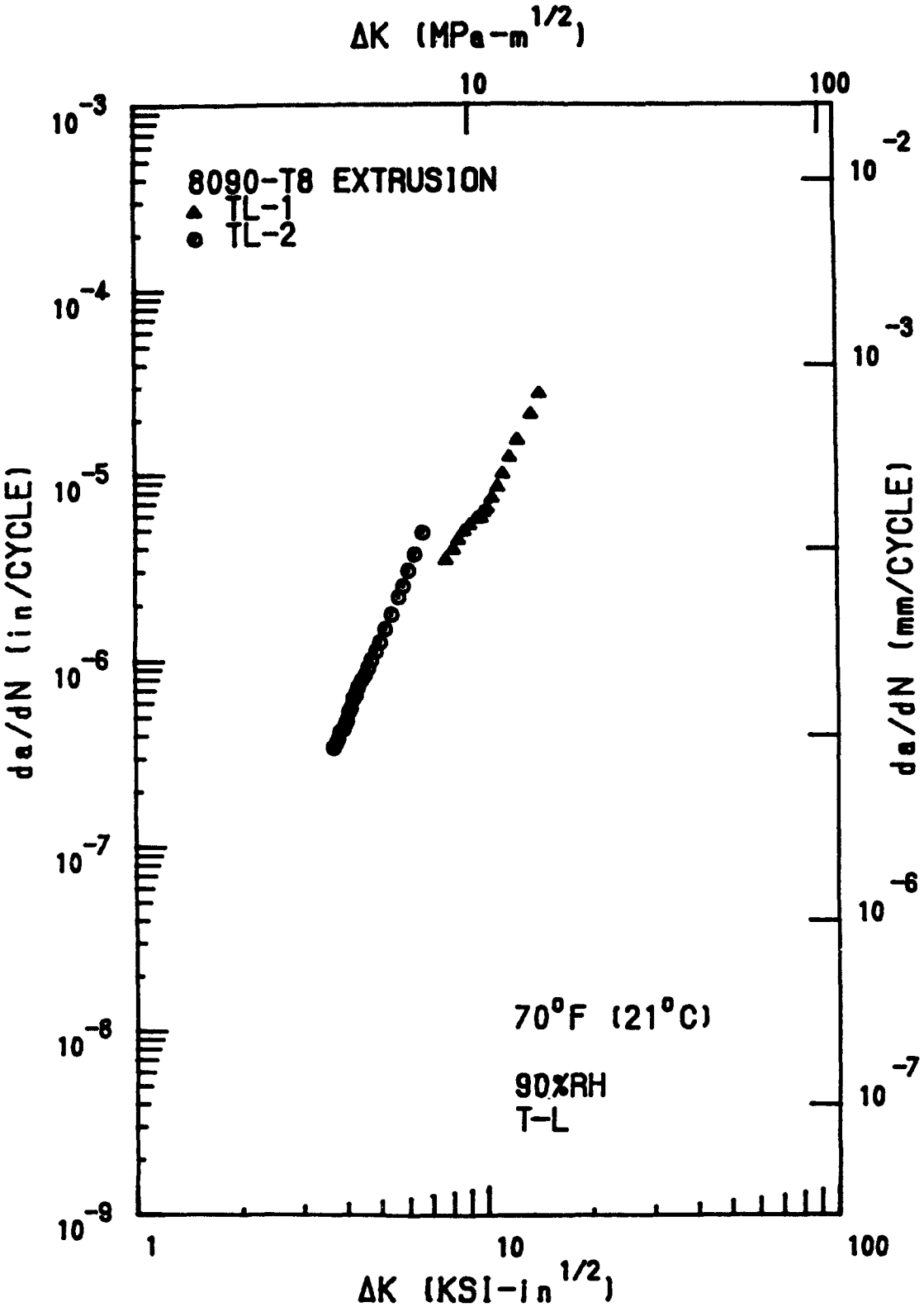


Figure E4 . Fatigue Crack Growth Rate Data for Alcan 8090-T8 1" x 4" Extrusion (T-L Orientation). Grumman.

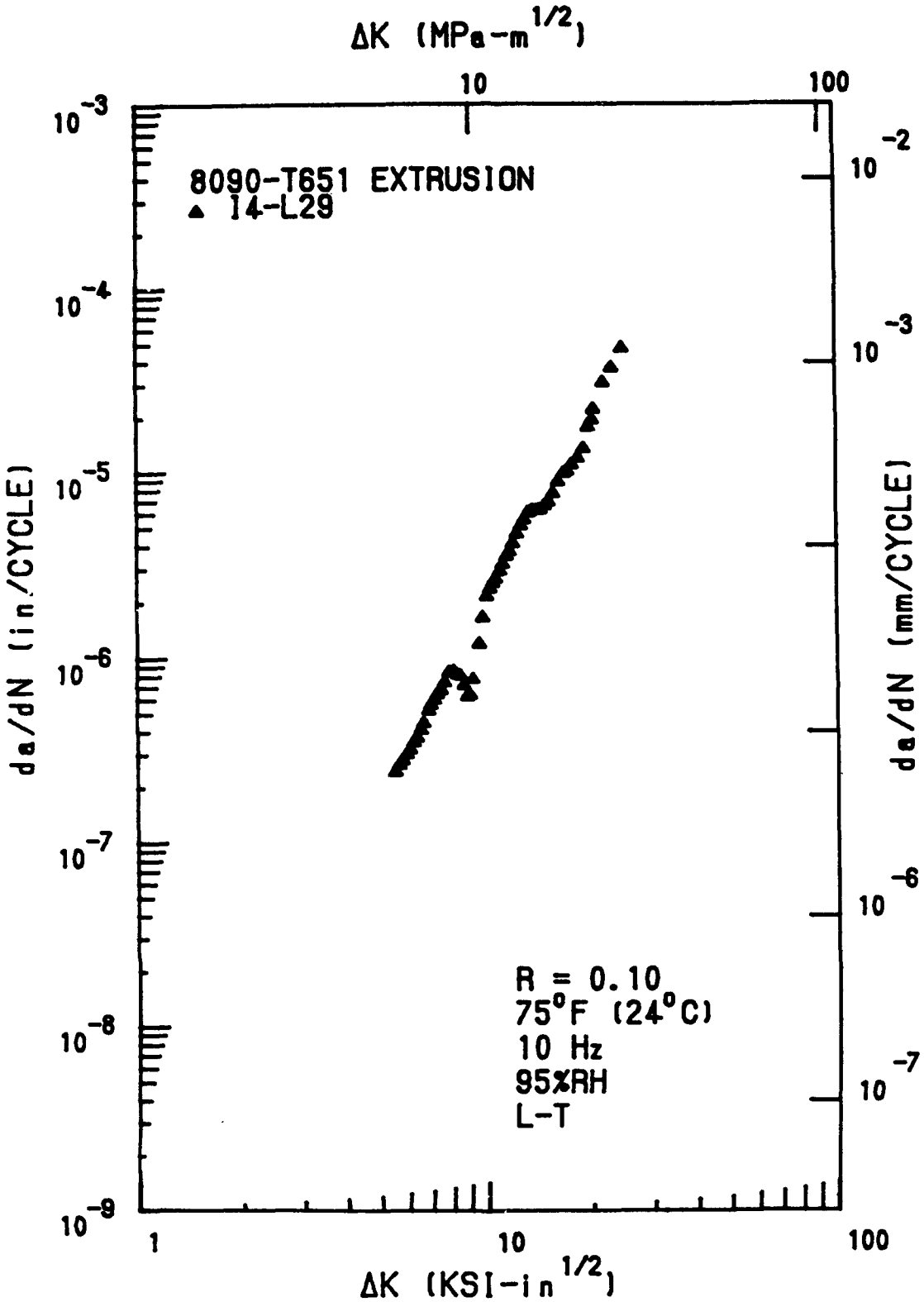


Figure E5. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Orientation). Northrop.

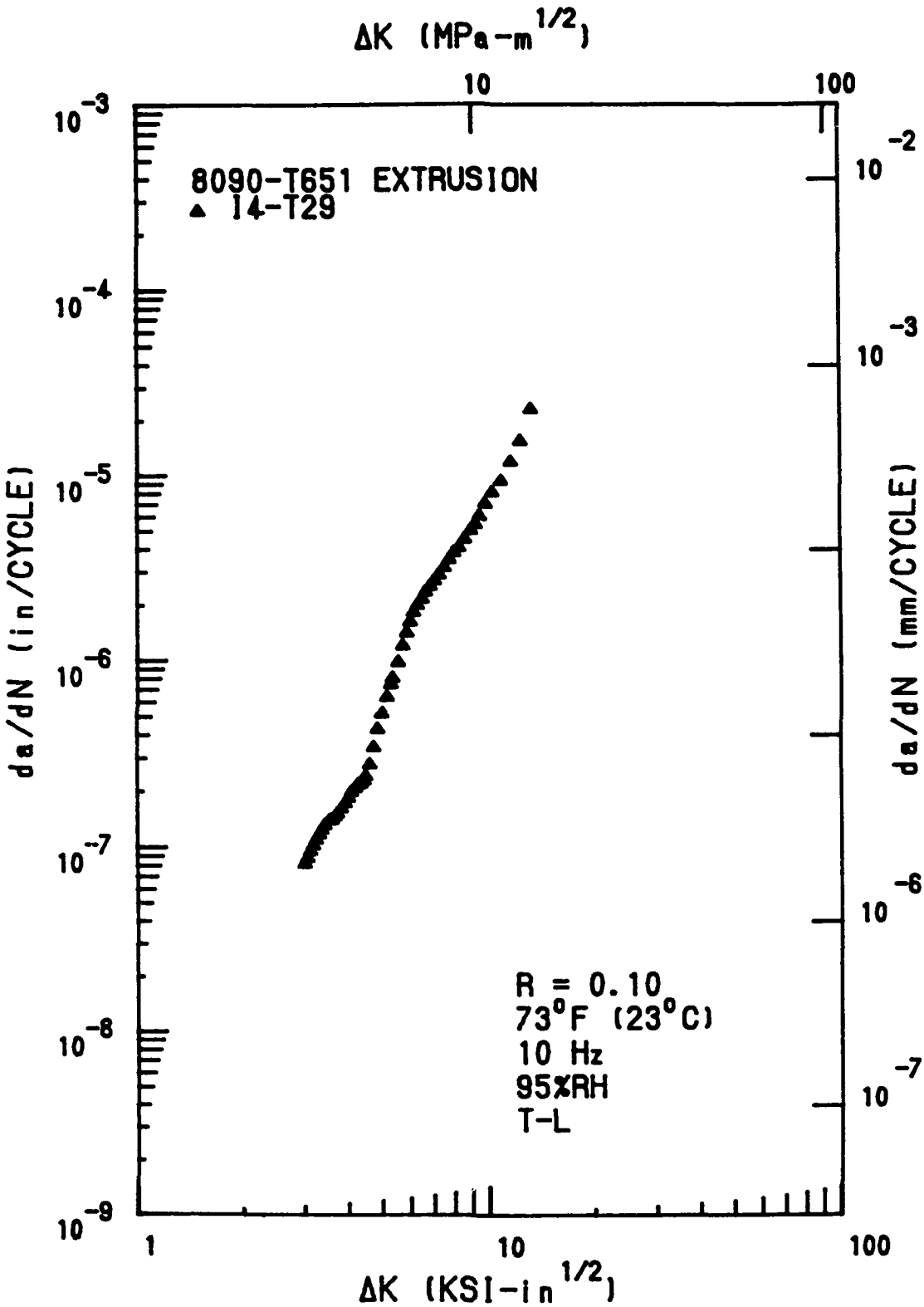


Figure E6. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L orientation). Northrop.

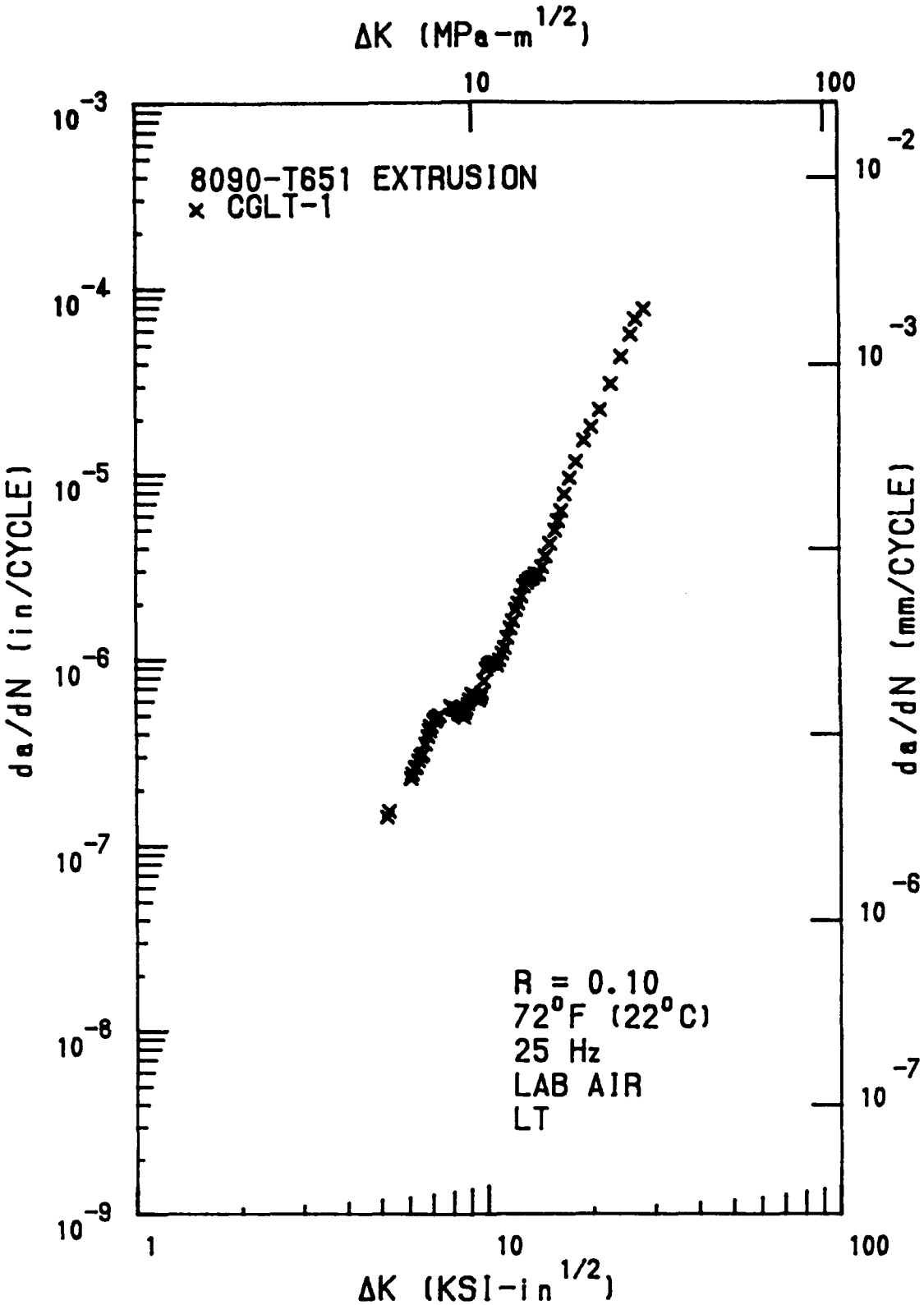


Figure E7. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Orientation). U.S. Air Force.

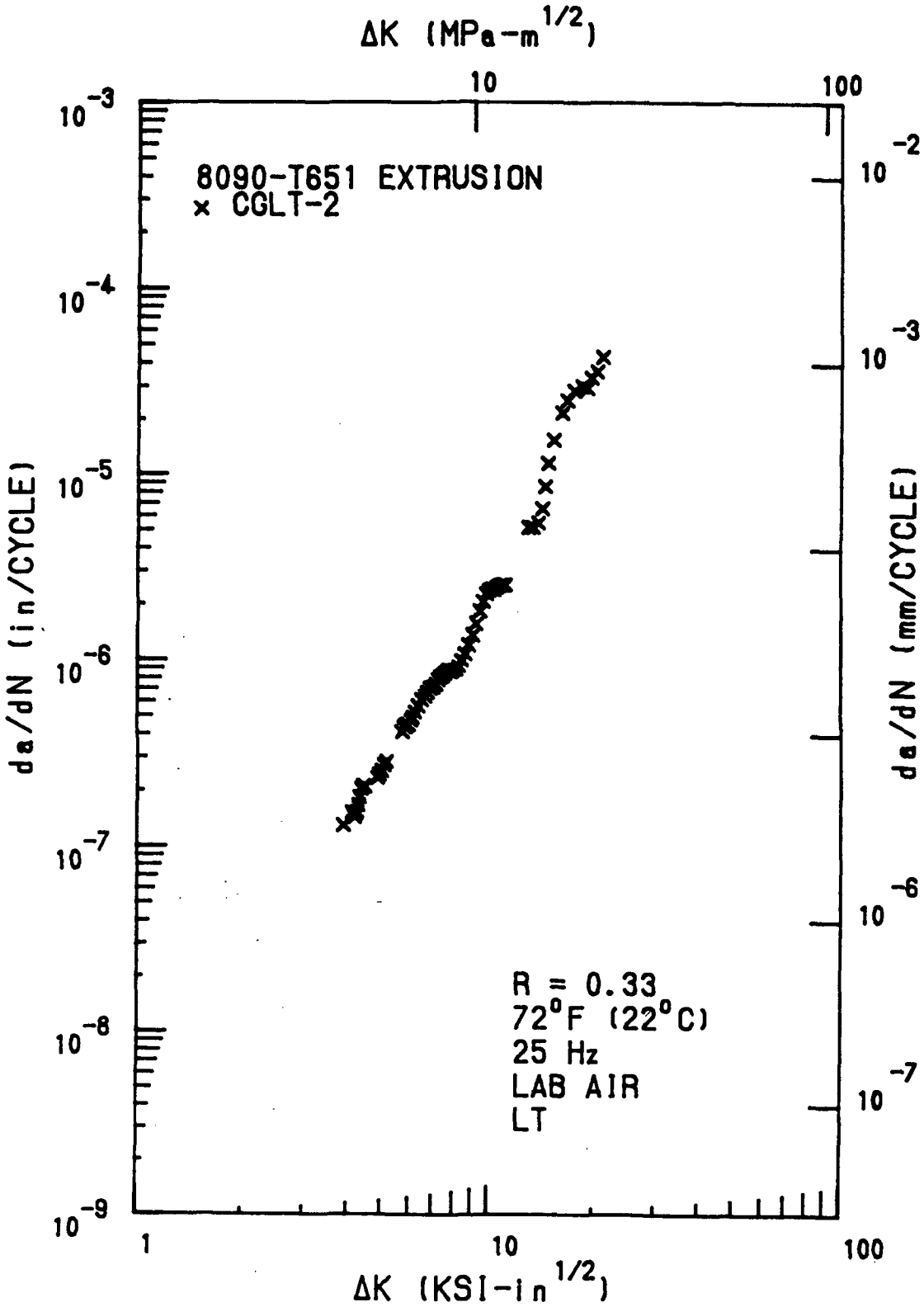


Figure E8. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Extrusion). U.S. Air Force.

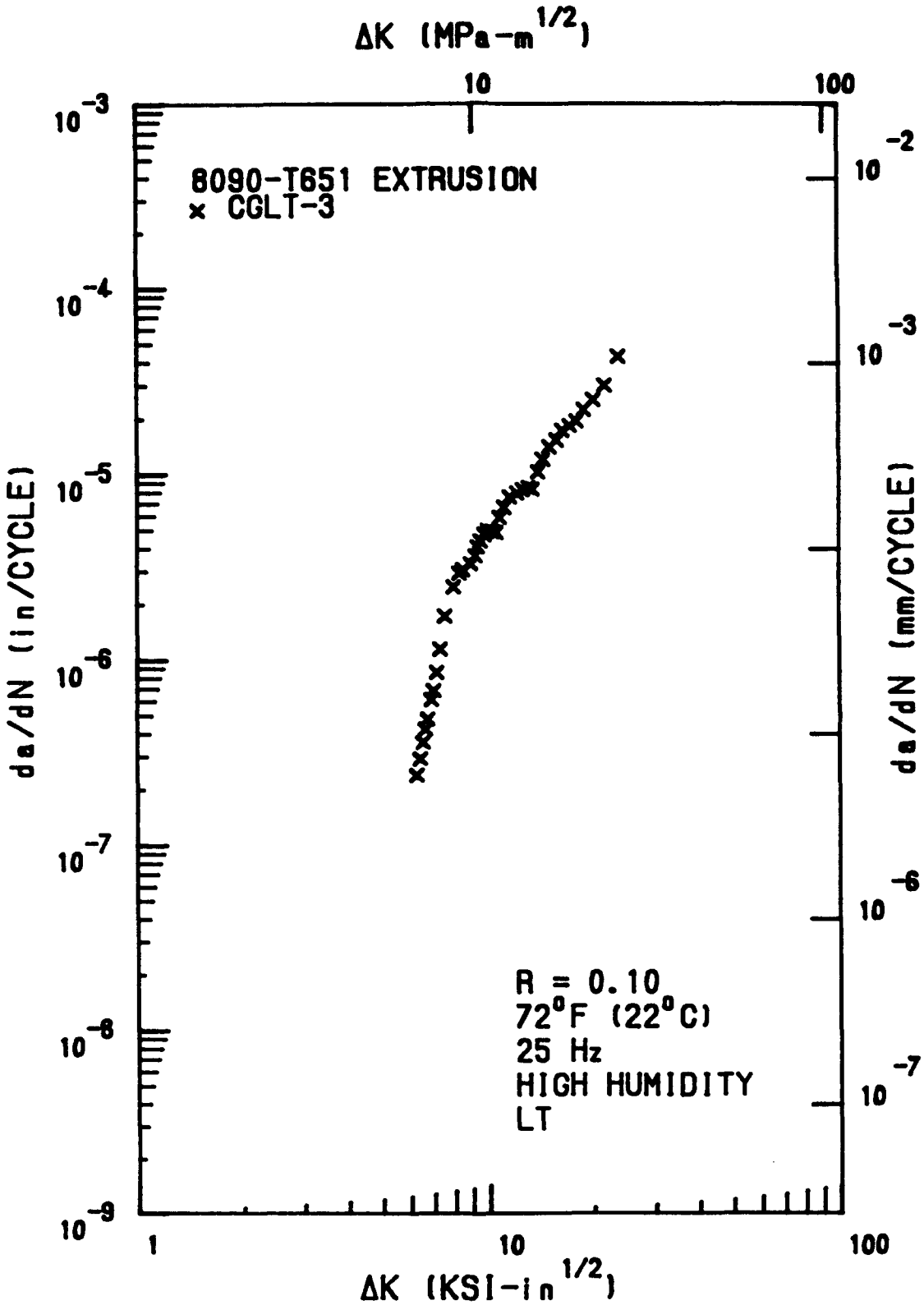


Figure E9. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Orientation). U.S. Air Force.

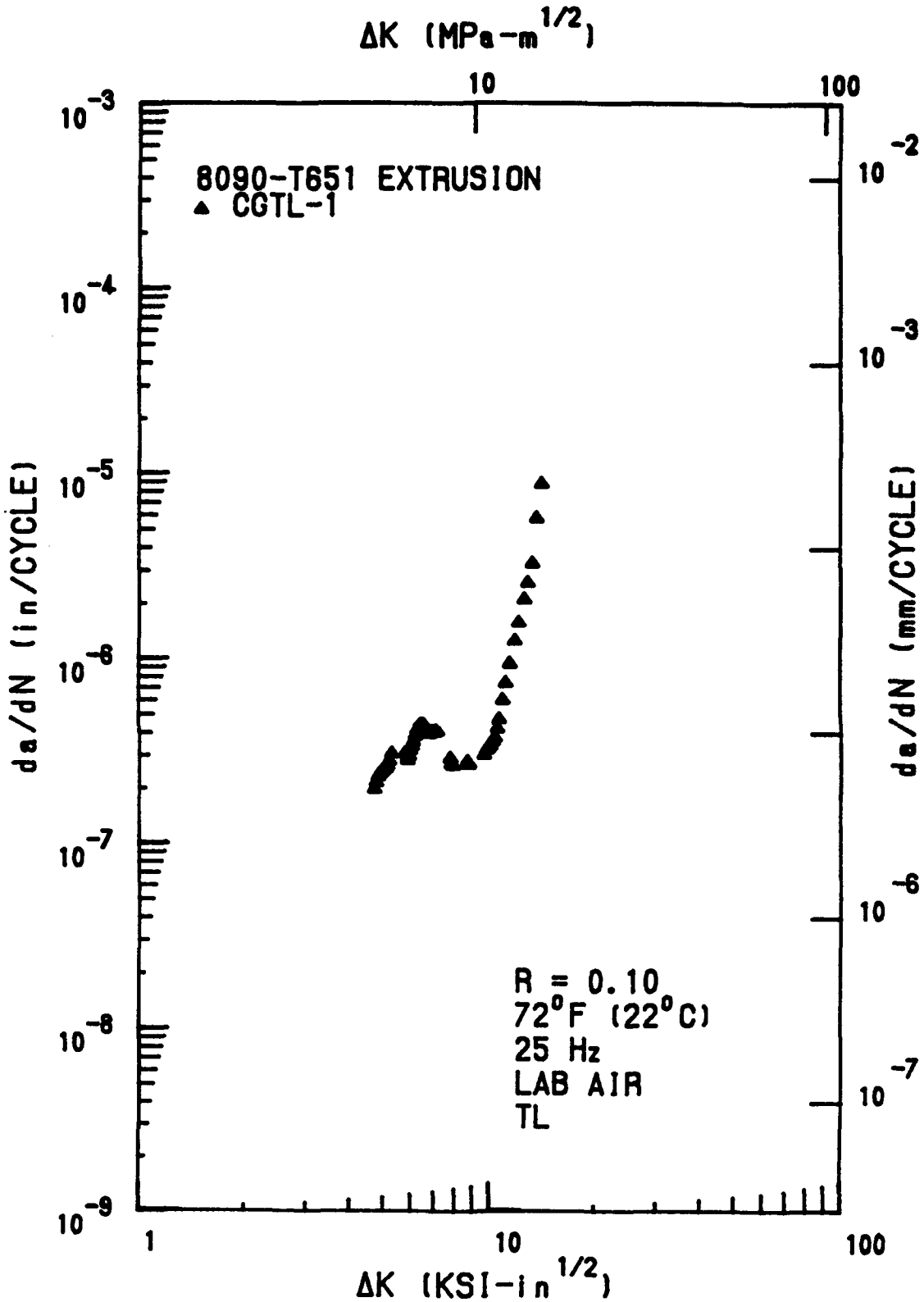


Figure E10. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). U.S. Air Force.

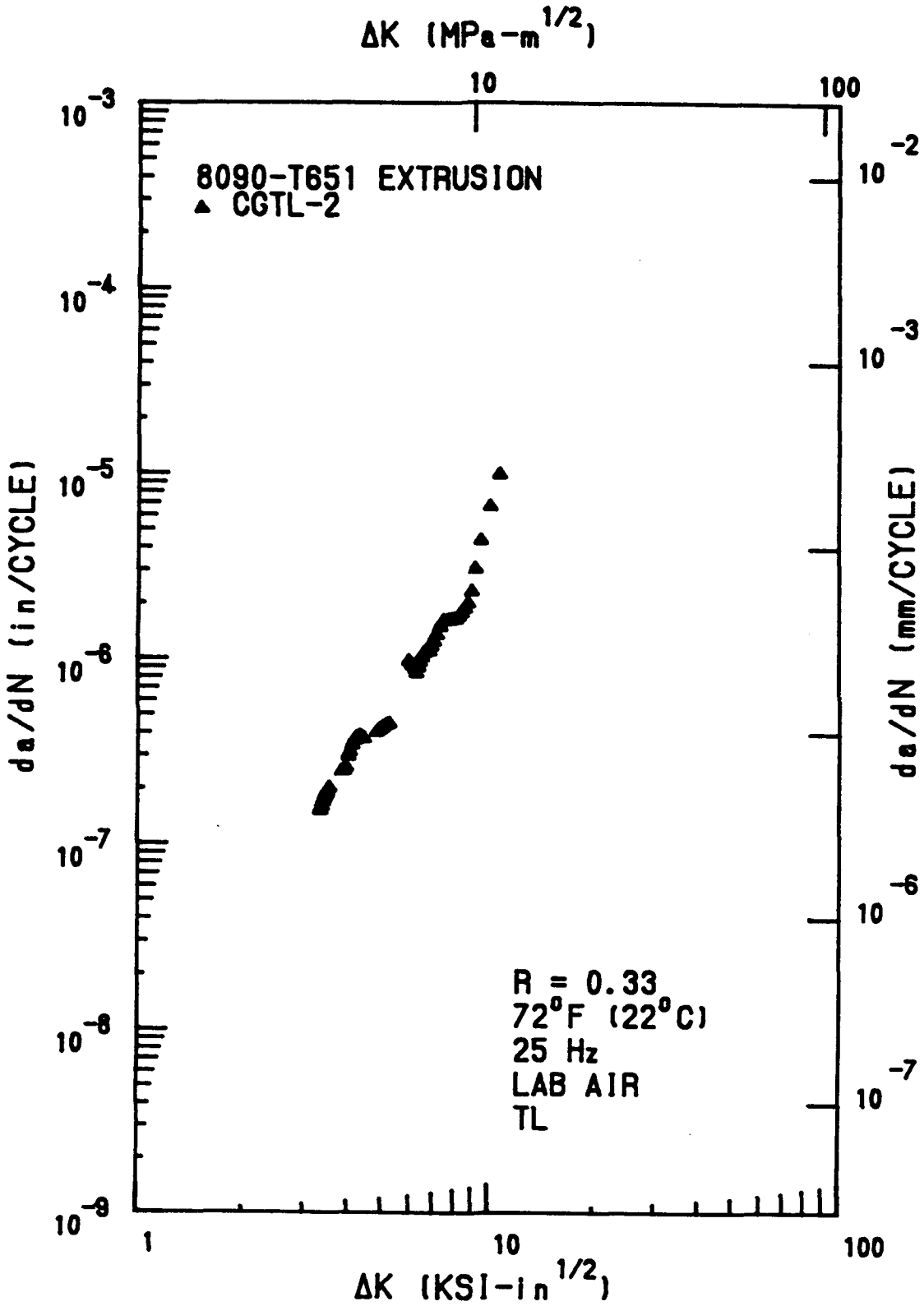


Figure E11. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). U.S. Air Force.

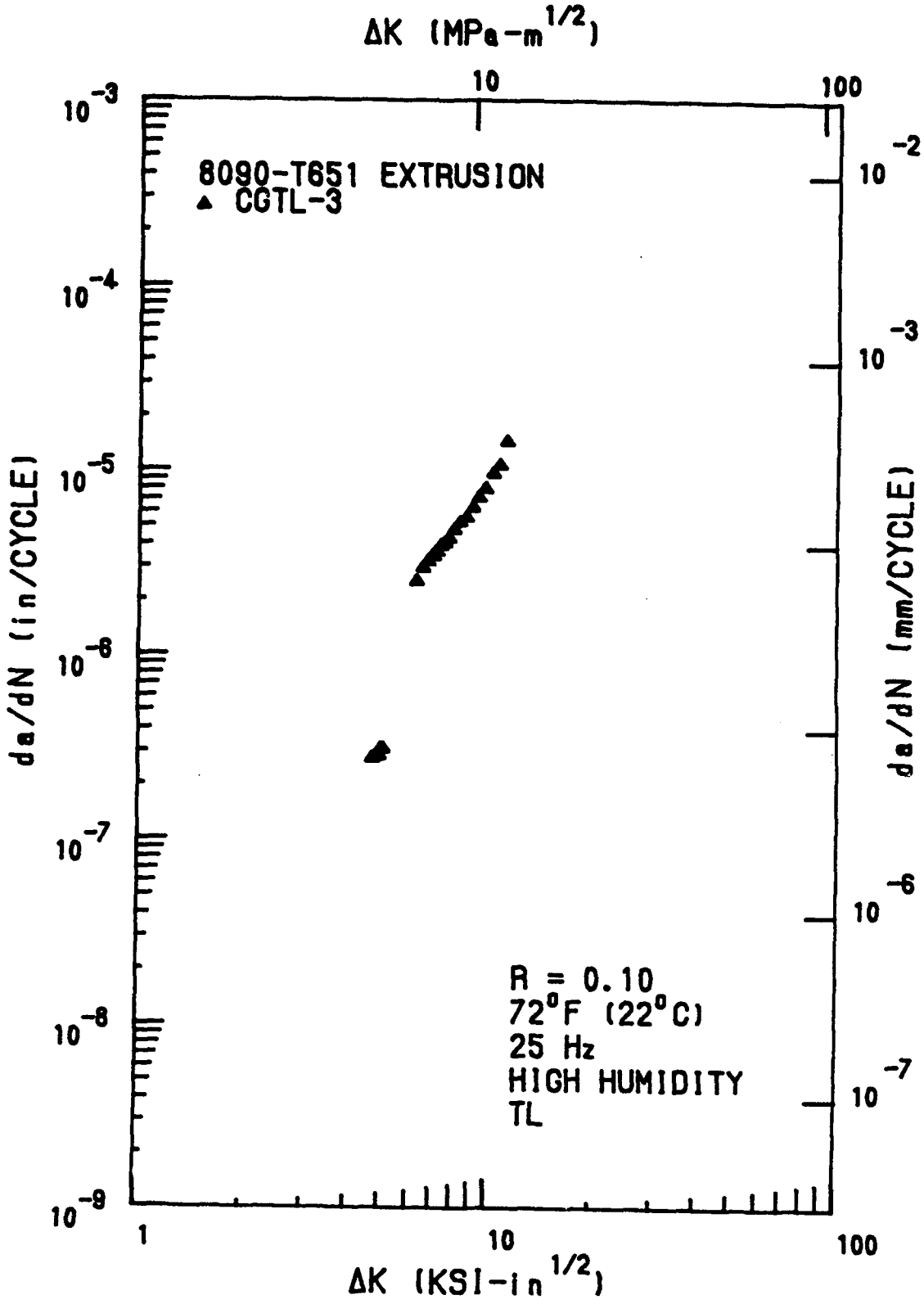


Figure E12. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). U.S. Air Force.

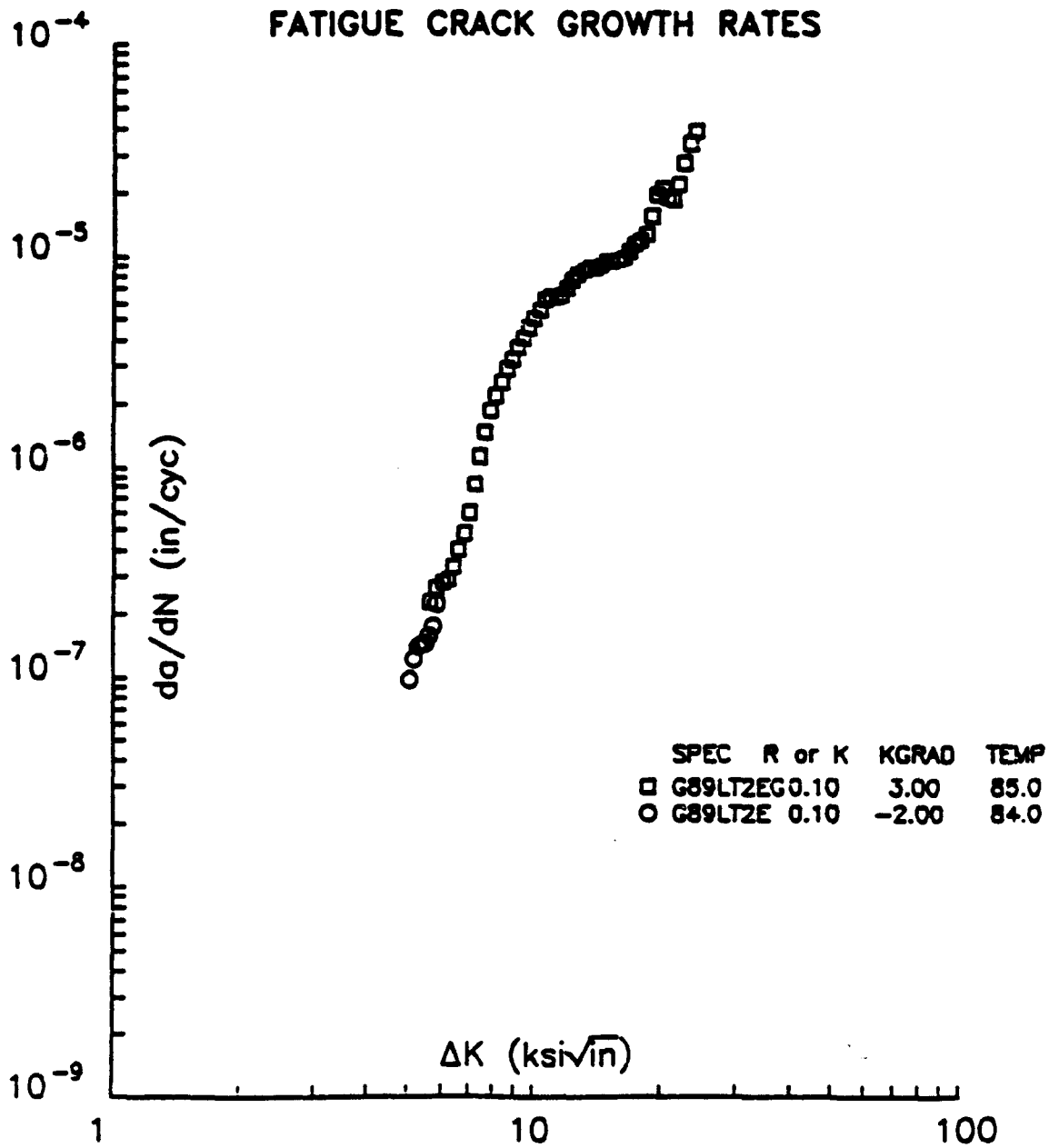


Figure E13. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Orientation). NASA-Langley.

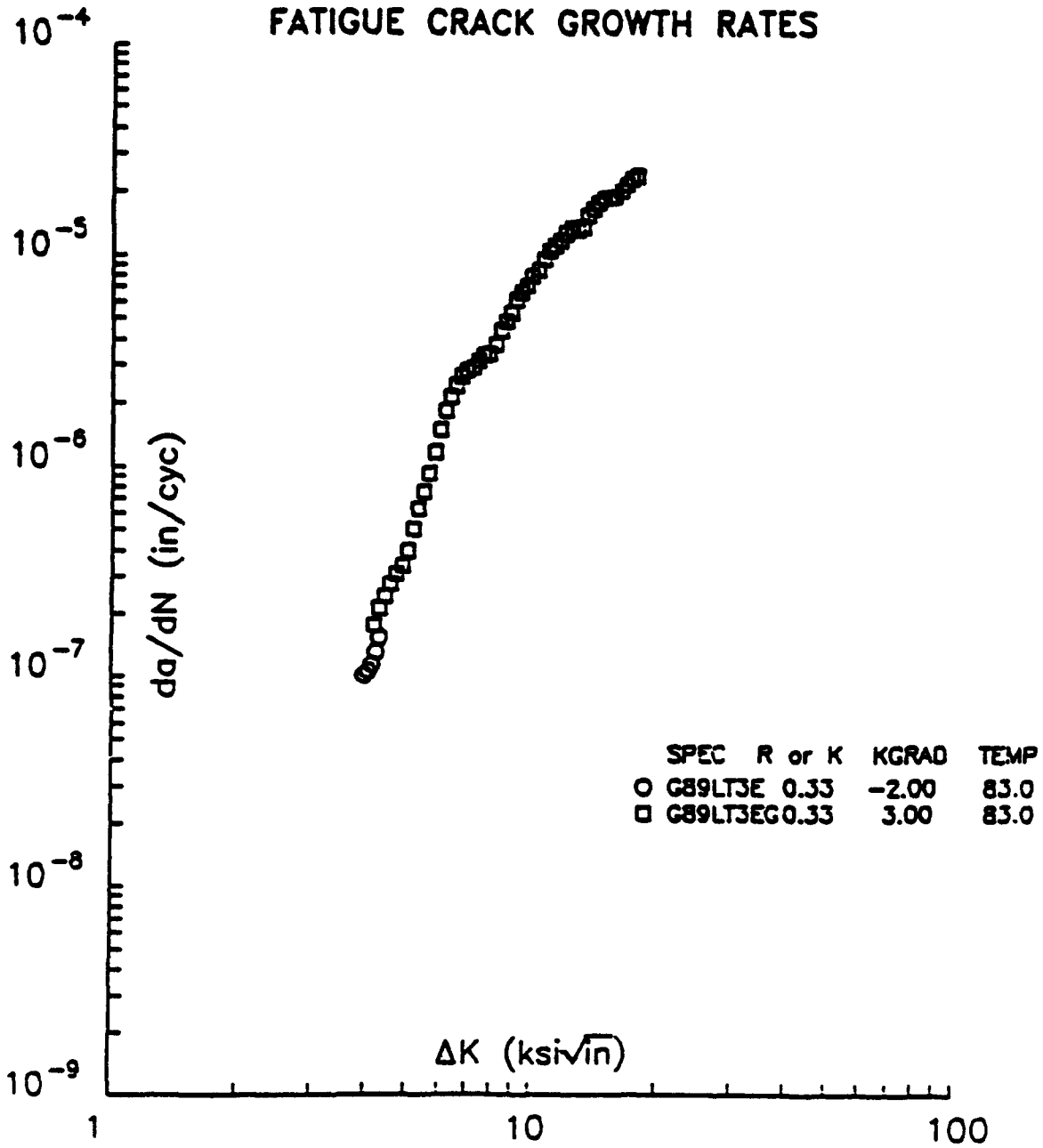


Figure E14. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (L-T Orientation). NASA-Langley.

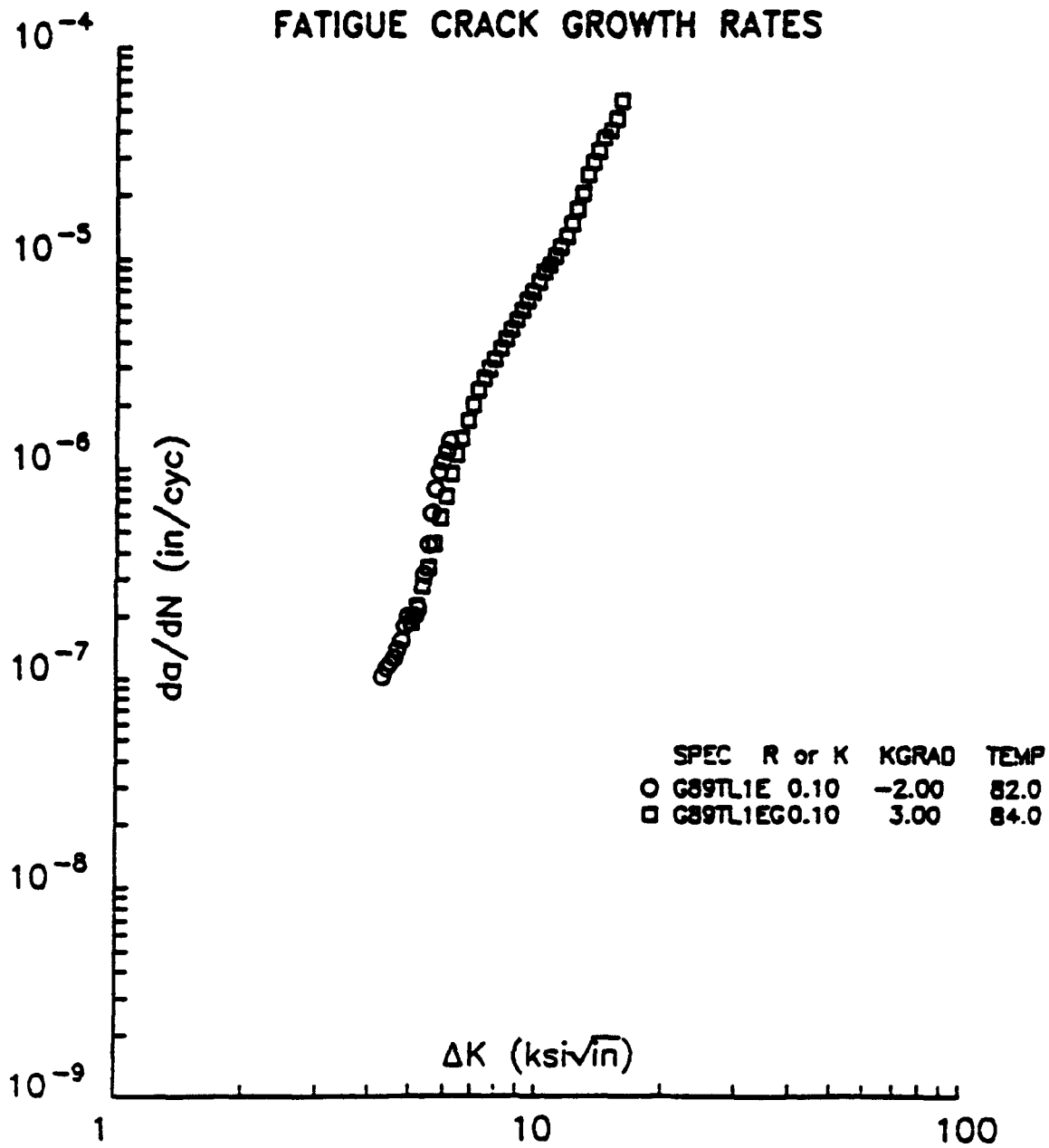


Figure E15. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). NASA-Langley.

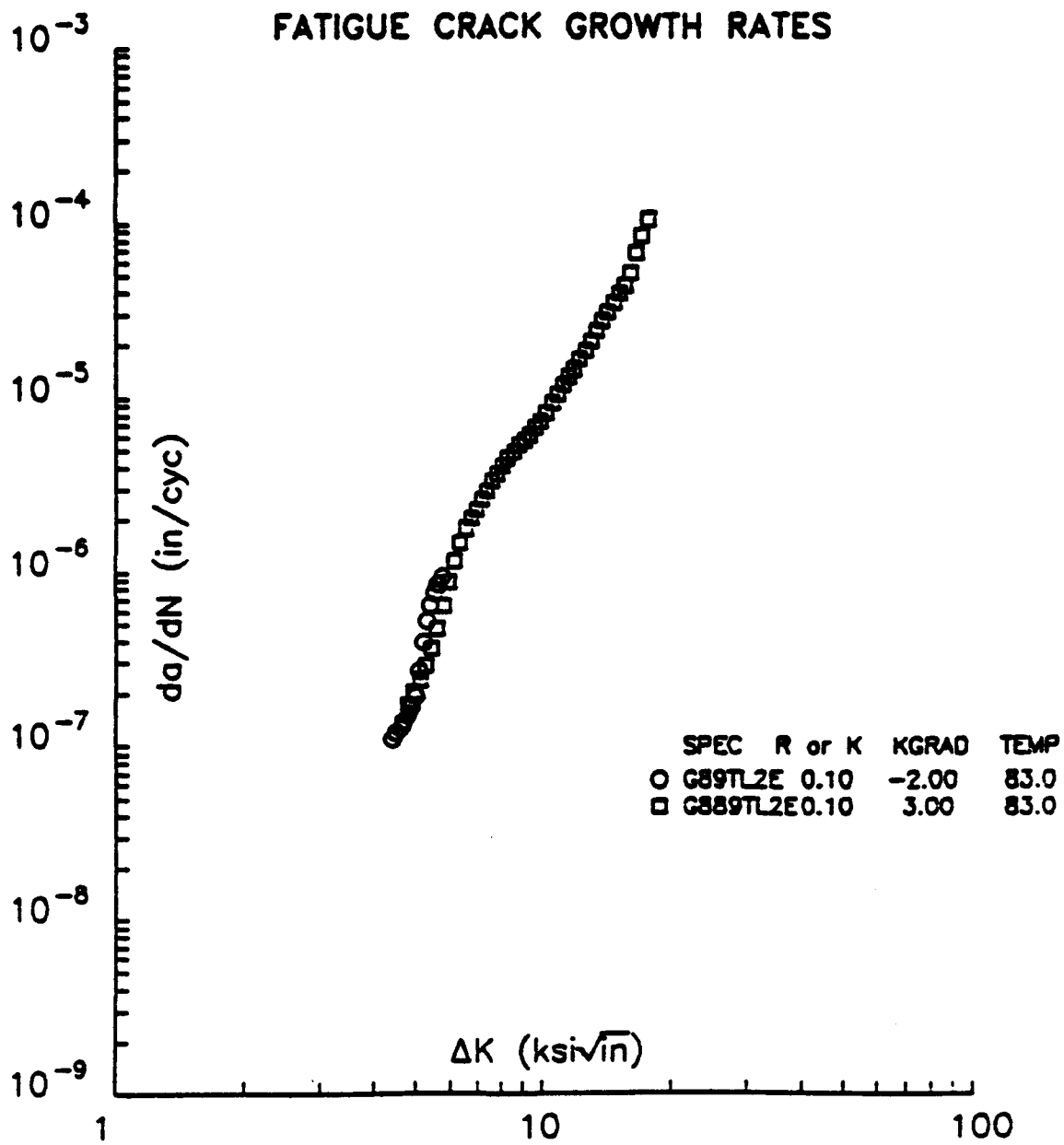


Figure E16. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). NASA-Langley.

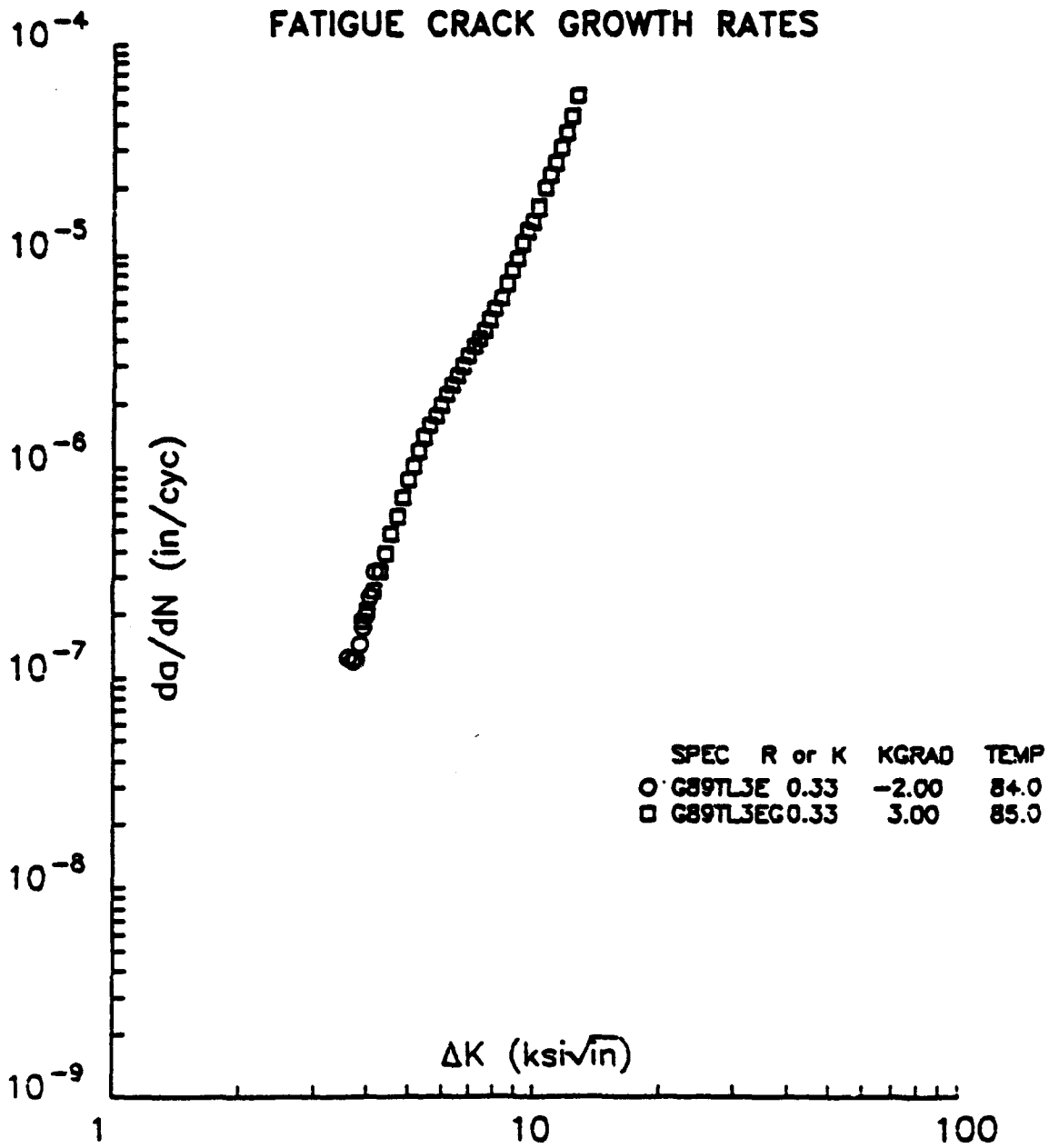


Figure E17. Fatigue Crack Growth Rate Data for Alcan 8090-T651 1" x 4" Extrusion (T-L Orientation). NASA-Langley.

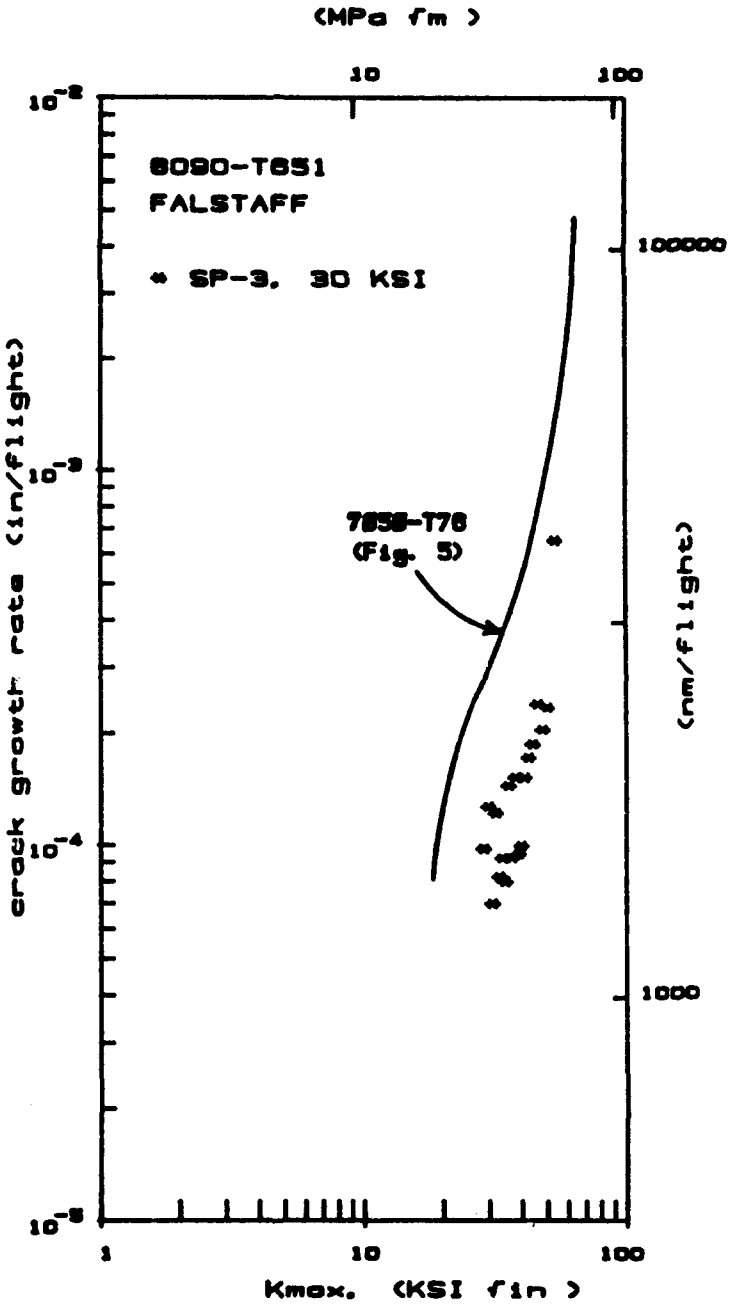


Figure E18 FALSTAFF Spectrum Results for 8090-T651 Extrusion. Reduced in Terms of Growth Rate and Maximum Spectrum Stress Intensity.

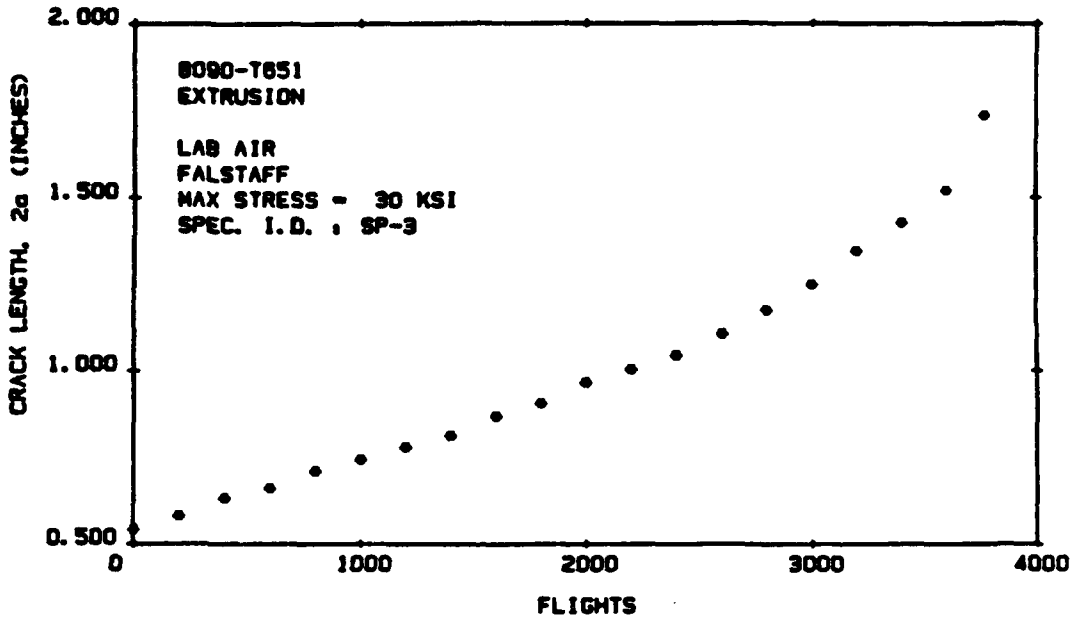


Figure E19 Crack Length Versus Flights for 8090-T651 Extrusion Under FALSTAFF Loading, Max Stress=30 KSI.

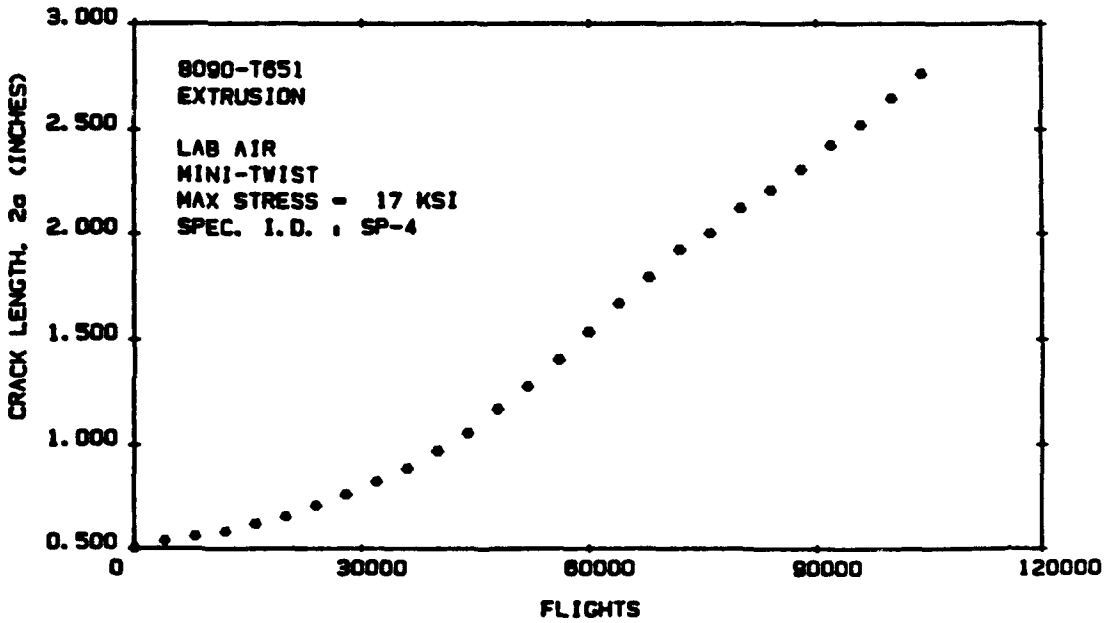


Figure E20 Crack Length Versus Flights for 8090-T651 Extrusion Under Mini-TWIST Loading, Max Stress=17 KSI.

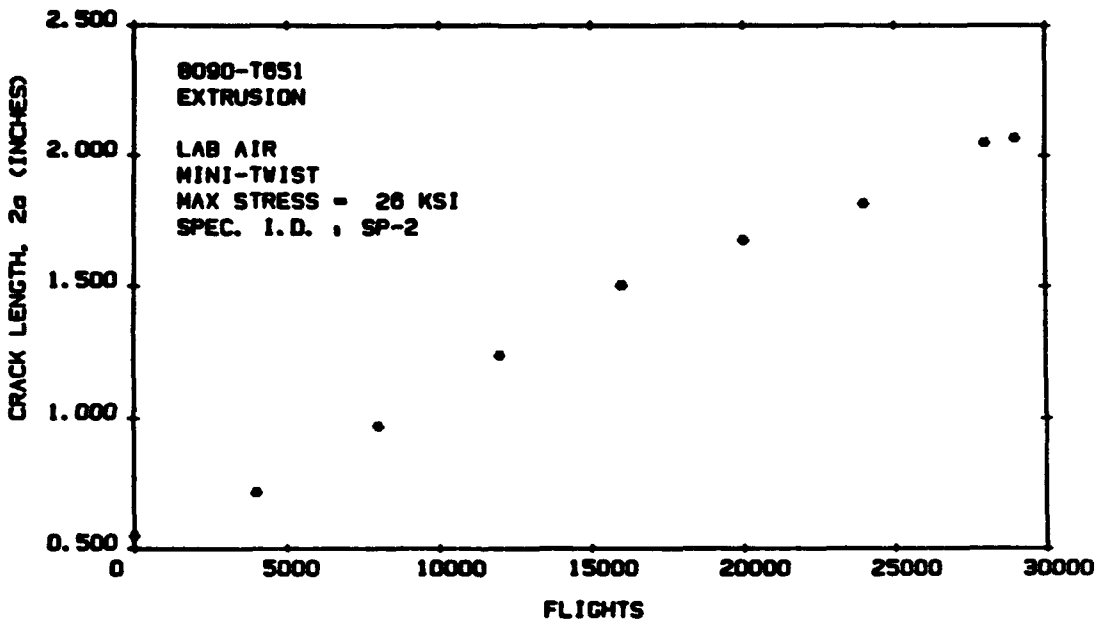


Figure E21 Crack Length Versus Flights for 8090-T651 Extrusion Under Mini-TWIST Loading, Max Stress=26 KSI.

TABLE E25

TENSILE RESULTS AT t/2 LOCATION FOR ALCAN

8090-T8 [338F FOR 24 HRS] EXTRUSION (1" x 4")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GRUMMAN	RT	LONG	80.9	78.0	3.5	4.8	12.3
			80.1	77.5	4.0	5.9	11.6
			80.9	76.8	4.0	7.5	11.2
		AVERAGE	80.6	77.4	3.8	6.1	11.7
	STANDARD DEVIATION		0.5	0.6	0.3	1.4	0.6
GRUMMAN	RT	45	67.9	57.3	10.0	32.8	10.1
			67.6	57.6	10.0	30.4	11.4
			67.1	56.2	10.0	31.2	11.2
		AVERAGE	67.5	57.0	10.0	31.5	10.9
	STANDARD DEVIATION		0.4	0.7	0.0	1.2	0.7
GRUMMAN	RT	L TRANS	71.9	64.0	7.5	13.4	11.8
			70.8	62.7	7.0	18.9	11.3
			70.5	61.6	7.0	19.4	11.1
		AVERAGE	71.1	62.8	7.2	17.2	11.4
	STANDARD DEVIATION		0.7	1.2	0.3	3.3	0.4

TABLE E26

COMPRESSION RESULTS FOR ALCAN

8090-T8 [338F FOR 24 HRS] EXTRUSION (1" x 4")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
GRUMMAN	RT	LONG	78.4	12.1
			77.7	12.1
			68.6	12.0
		AVERAGE	74.9	12.1
		STANDARD DEVIATION	5.5	0.1
GRUMMAN	RT	45	60.3	11.8
			60.3	11.8
			60.1	11.7
		AVERAGE	60.2	11.8
		STANDARD DEVIATION	0.1	0.1
GRUMMAN	RT	L TRANS	67.9	11.9
			67.4	12.1
			67.4	12.1
		AVERAGE	67.6	12.0
		STANDARD DEVIATION	0.3	0.1

TABLE E27

FRACTURE TOUGHNESS RESULTS FOR ALCAN

8090-T8 (338F FOR 24 HRS) EXTRUSION (1" x 4")

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
GRUMMAN	L - T		33.3	INVALID(1),(2)
			27.6	INVALID(2),(3)
	AVERAGE		30.5	
	STANDARD DEVIATION		4.0	
GRUMMAN	T - L	14.6		VALID
	AVERAGE	14.6		
	STANDARD DEVIATION	0.0		

(1) 1.08 greater than B

(2) Angle of fracture greater than 5 degrees

(3) Pmax/Pq greater than 1.10

APPENDIX F

8090-T8771 1.75 INCH THICK PLATE

INTRODUCTION

The Alcan aluminum-lithium alloy 8090-T8771 1.75 inch plates were received May 1991. The 8090 was tested in the as received condition by Martin Marietta and the Air Force.

TESTING

Mechanical properties (tension, compression, bearing shear and fracture toughness), fatigue and constant amplitude fatigue crack growth tests were performed according to ASTM standards, unless otherwise specified. Spectrum fatigue crack growth tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE F1

TENSILE RESULTS AT t/2 LOCATION FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	LONG	79.1	71.0	5.0	3.9	
MARIETTA			79.1	71.2	5.0	9.6	
			79.3		5.0	3.5	
AIR FORCE	RT	LONG	76.7	65.7	8.1	9.2	
			80.2	72.6	5.5	5.2	
			76.7	66.0	7.9	11.6	
		AVERAGE	78.5	69.3	6.1	7.2	
	STANDARD DEVIATION		1.5	3.2	1.5	3.4	

TABLE F2

TENSILE RESULTS AT t/2 LOCATION FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	45	72.3	54.7	11.5	17.6	
			72.4	58.0	8.9	14.5	
			72.5	55.5	9.8	15.4	
		AVERAGE	72.4	56.1	10.0	15.8	
	STANDARD DEVIATION		0.1	1.7	1.3	1.6	

TABLE F3

TENSILE RESULTS AT t/2 LOCATION FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN MARIETTA	RT	L TRANS	78.2	66.9	6.0	8.1	
			78.1	66.8	6.0	8.9	
			78.5	67.1	6.0	8.5	
AIR FORCE	RT	L TRANS	73.3	56.9	10.4	10.3	
			79.5	68.4	6.5	9.7	
			73.8	57.3	10.5	11.2	
		AVERAGE	76.9	63.9	7.6	9.4	
	STANDARD DEVIATION		2.7	5.3	2.2	1.2	

TABLE F4

TENSILE RESULTS AT t/2 LOCATION FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	S TRANS	75.6	61.4	1.7	2.4	
			75.0	61.0	3.5	2.4	
			75.8	62.0	5.4	5.1	
		AVERAGE	75.4	61.5	3.5	3.3	
	STANDARD DEVIATION		0.4	0.5	1.8	1.6	

TABLE F5

COMPRESSION RESULTS AT t/2 LOCATION FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MARTIN MARIETTA	RT	LONG	70.3	12.1
			67.0	12.1
			68.1	12.1
AIR FORCE	RT	LONG	62.5	11.8
			63.9	12.0
			60.5	10.1
		AVERAGE	65.4	11.7
		STANDARD DEVIATION	3.7	0.8

TABLE F6

COMPRESSION RESULTS AT t/2 LOCATION FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MARTIN MARIETTA	RT	L TRANS	72.6	12.2
			73.6	12.0
			73.1	12.1
AIR FORCE	RT	L TRANS	62.5	11.8
			70.9	12.0
			67.5	11.9
		AVERAGE	70.0	12.0
		STANDARD DEVIATION	4.3	0.1

TABLE F7

COMPRESSION RESULTS AT t/2 LOCATION FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MARTIN MARIETTA	RT	S TRANS	69.6	12.1
			68.8	12.0
			68.5	12.0
		AVERAGE	69.0	12.0
		STANDARD DEVIATION	0.6	0.1

TABLE F8

AMSLER DOUBLE SHEAR RESULTS AT t/2 LOCATION FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
AIR FORCE	T-L	41.1
		41.8
		43.4
		44.4
		43.6
		41.4
	AVERAGE	42.6
	STANDARD DEVIATION	1.4

TABLE F9

BEARING RESULTS AT t/2 LOCATION FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
AIR FORCE	LONG	1.5	112.1	90.6
			112.8	91.5
			106.9	83.7
		AVERAGE	110.6	88.6
		STANDARD DEVIATION	3.2	4.3

TABLE F10

BEARING RESULTS AT t/2 LOCATION FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
AIR FORCE	L TRANS	1.5	109.9	89.6
			112.7	90.6
			105.7	87.3
		AVERAGE	109.4	89.2
		STANDARD DEVIATION	3.5	1.7

TABLE F11

FRACTURE TOUGHNESS RESULTS FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MARTIN MARIETTA	L-T		29.9	(1)
			27.9	(1)
			28.3	(1)
AIR FORCE	L-T		24.7	(2)
			23.7	(2)
		27.0		
	AVERAGE	27.0	26.9	
	STANDARD DEVIATION	0.0	2.6	

(1): INVALID DUE TO a/W < 0.45
(2): INVALID DUE TO Pmax/Pq > 1.1

TABLE F12

FRACTURE TOUGHNESS RESULTS FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MARTIN MARIETTA	S-L		11.1	(1)
			11.0	(1)
AIR FORCE	S-L		12.1	(1)
			12.8	(1)
			9.9	(1),(2)
	AVERAGE		11.8	
	STANDARD DEVIATION		0.9	

(1): INVALID DUE TO Kfat/Kq > 0.6
(2): INVALID DUE TO a,B < 2.5(Kq/YS)^2

TABLE F13

FRACTURE TOUGHNESS RESULTS FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MARTIN MARIETTA	T-L		21.0	(1)
			20.1	(1)
AIR FORCE	T-L	25.0		
		24.3		
		22.7		
	AVERAGE	24.0	20.6	
	STANDARD DEVIATION	1.2	0.6	

(1): INVALID DUE TO Kfat/Kq > 0.6

TABLE F14

FRACTURE TOUGHNESS RESULTS FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MARTIN MARIETTA	S-T		13.1	(1)
	AVERAGE		13.1	
	STANDARD DEVIATION		0.0	

(1): INVALID DUE TO Kfat/Kq > 0.6

TABLE F15

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
AIR FORCE	LONG	73.5	5,016
		69.0	15,020
		66.0	16,366
		60.0	36,998
		57.0	93,383
		50.8	280,000
		48.0	95,642
		43.5	2,946,918
		37.5	17,000,000 *
		29.0	10,000,000 *

(*): RUN OUT

TABLE F16

FATIGUE RESULTS WITH R=0.1 AND Kt=3.0 FOR
ALCAN 8090-T8771 PLATE (1.75" THICK)

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
AIR FORCE	LONG	50.0	3,822
		40.0	7,994
		30.0	32,103
		28.0	39,796
		26.0	74,224
		24.0	64,517
		22.0	135,951
		21.0	648,867
		20.5	103,502
		20.0	10,000,000 *

(*): RUN OUT

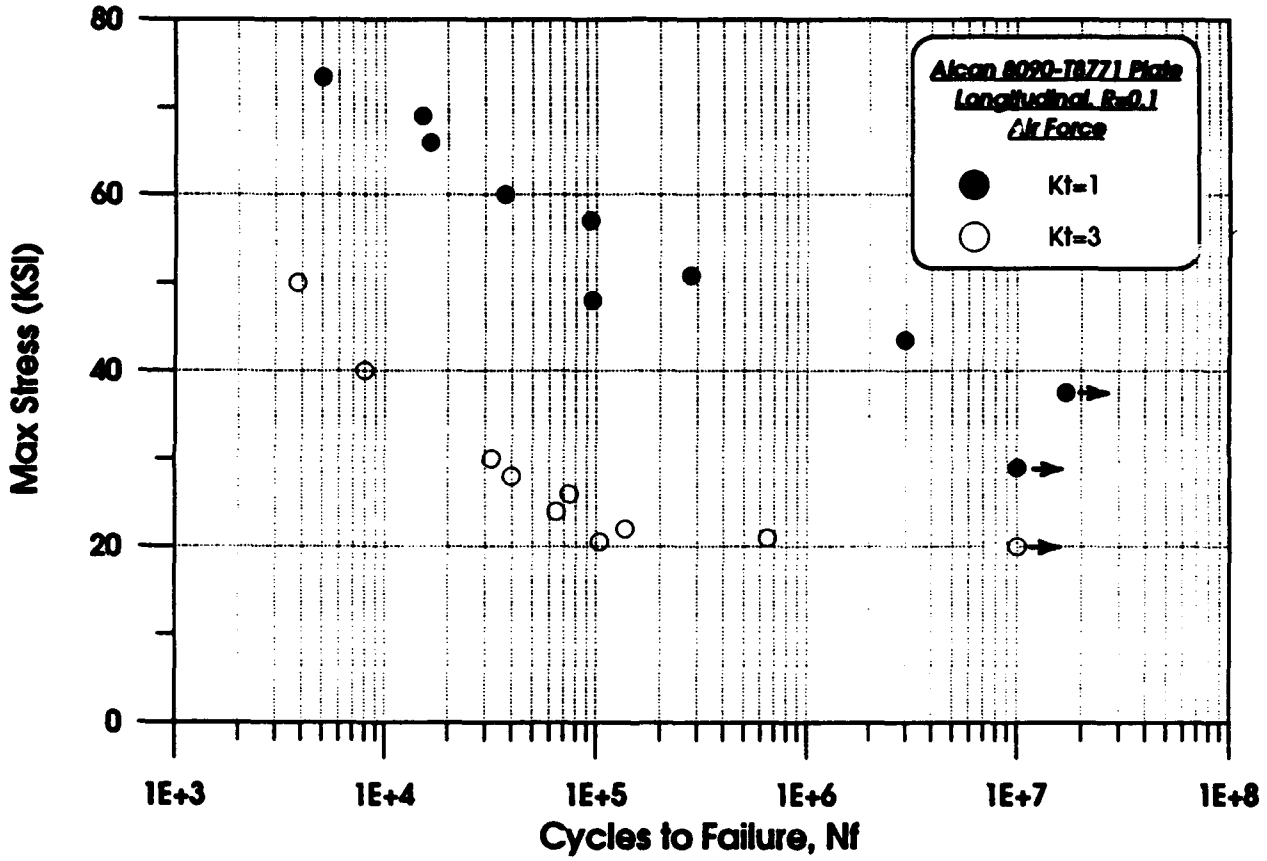


FIGURE F1. Fatigue Results for 8090-T8771 Plate (Longitudinal Orientation). Air Force.

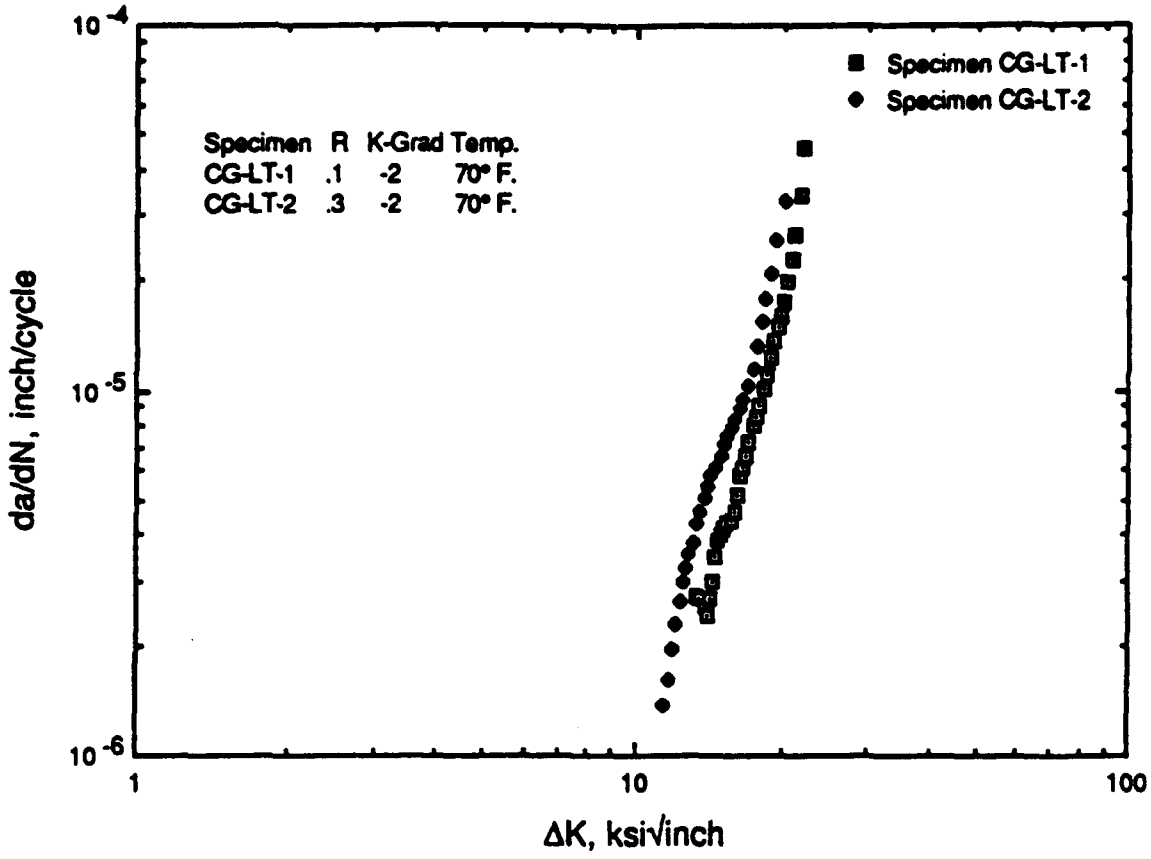


FIGURE F2. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation). Martin Marietta.

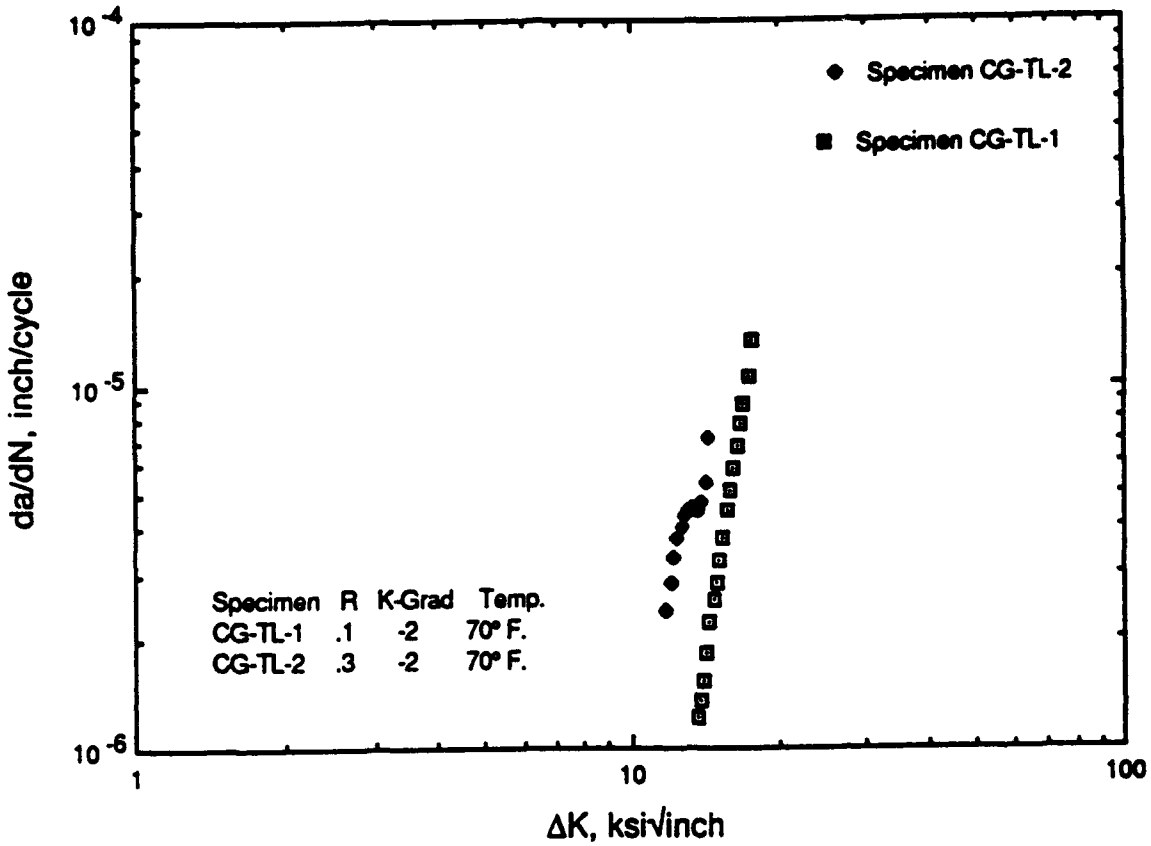


FIGURE F3. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (T-L Orientation). Martin Marietta.

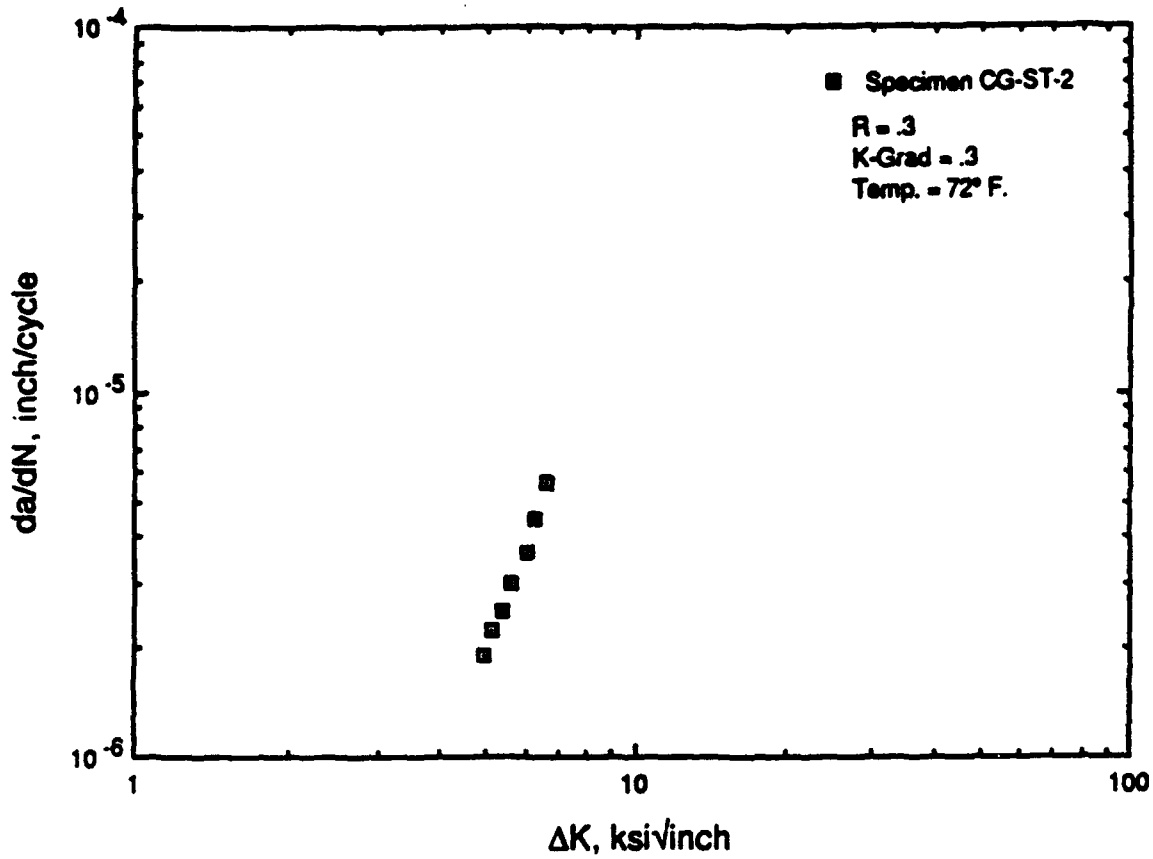


FIGURE F4. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (S-T Orientation). Martin Marietta.

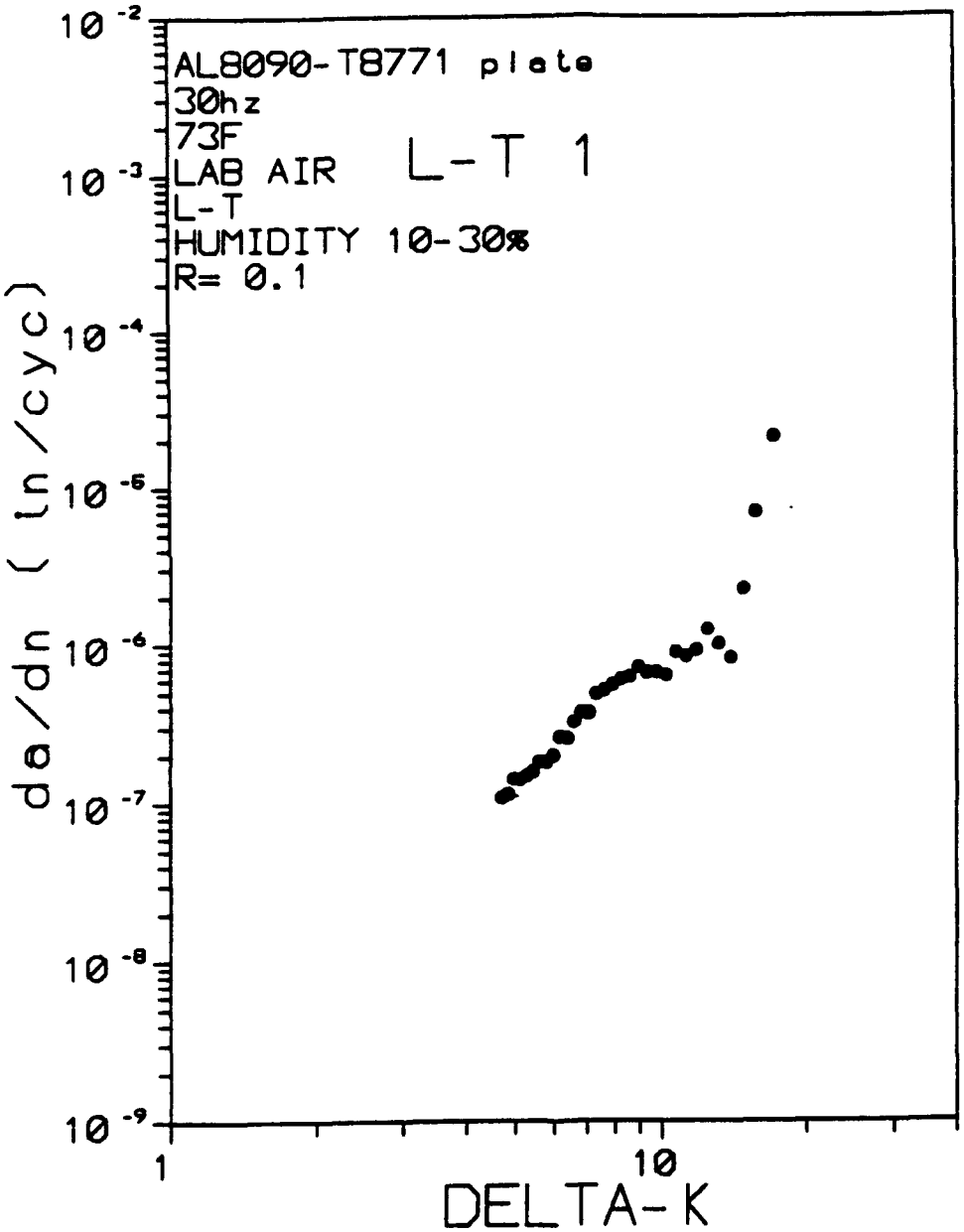


FIGURE F5. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation and R=0.1).
Air Force.

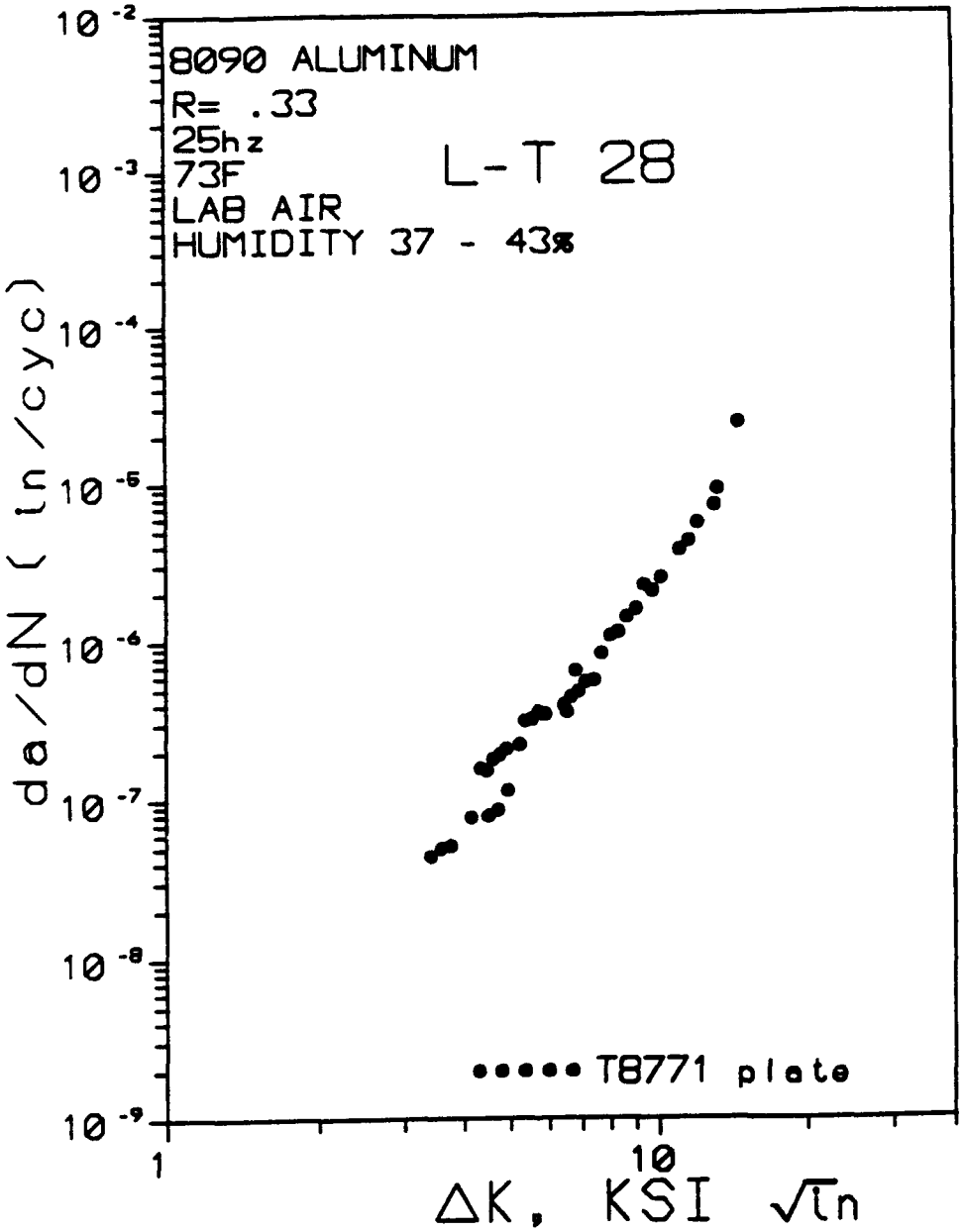


FIGURE F6. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation and R=0.33).
Air Force.

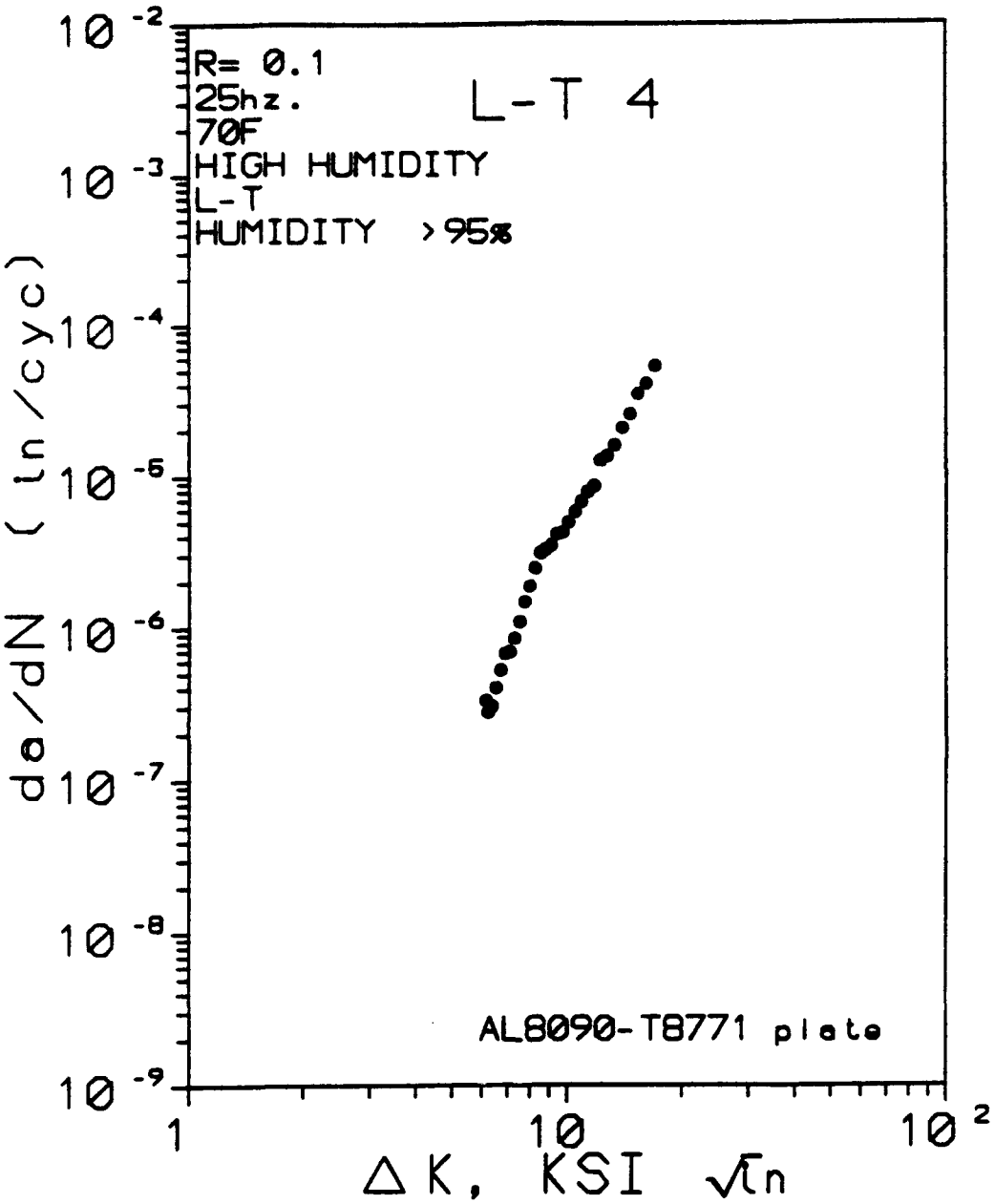


FIGURE F7. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation and R=0.1 and High Humidity).
Air Force.

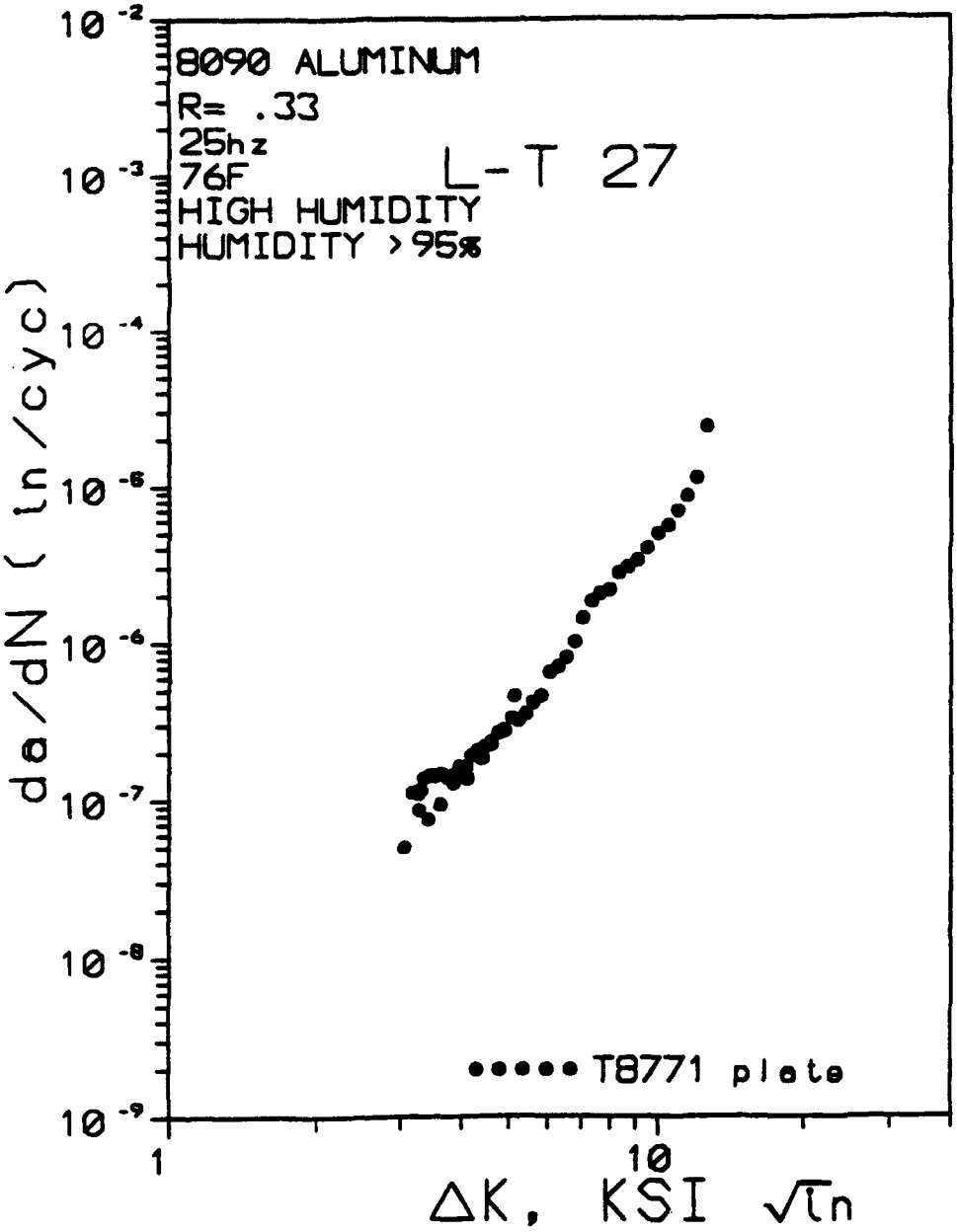


FIGURE F8. Fatigue Crack Growth Rate Data for 8090-T8771 Plate (L-T Orientation and R=0.33 and High Humidity).
Air Force.

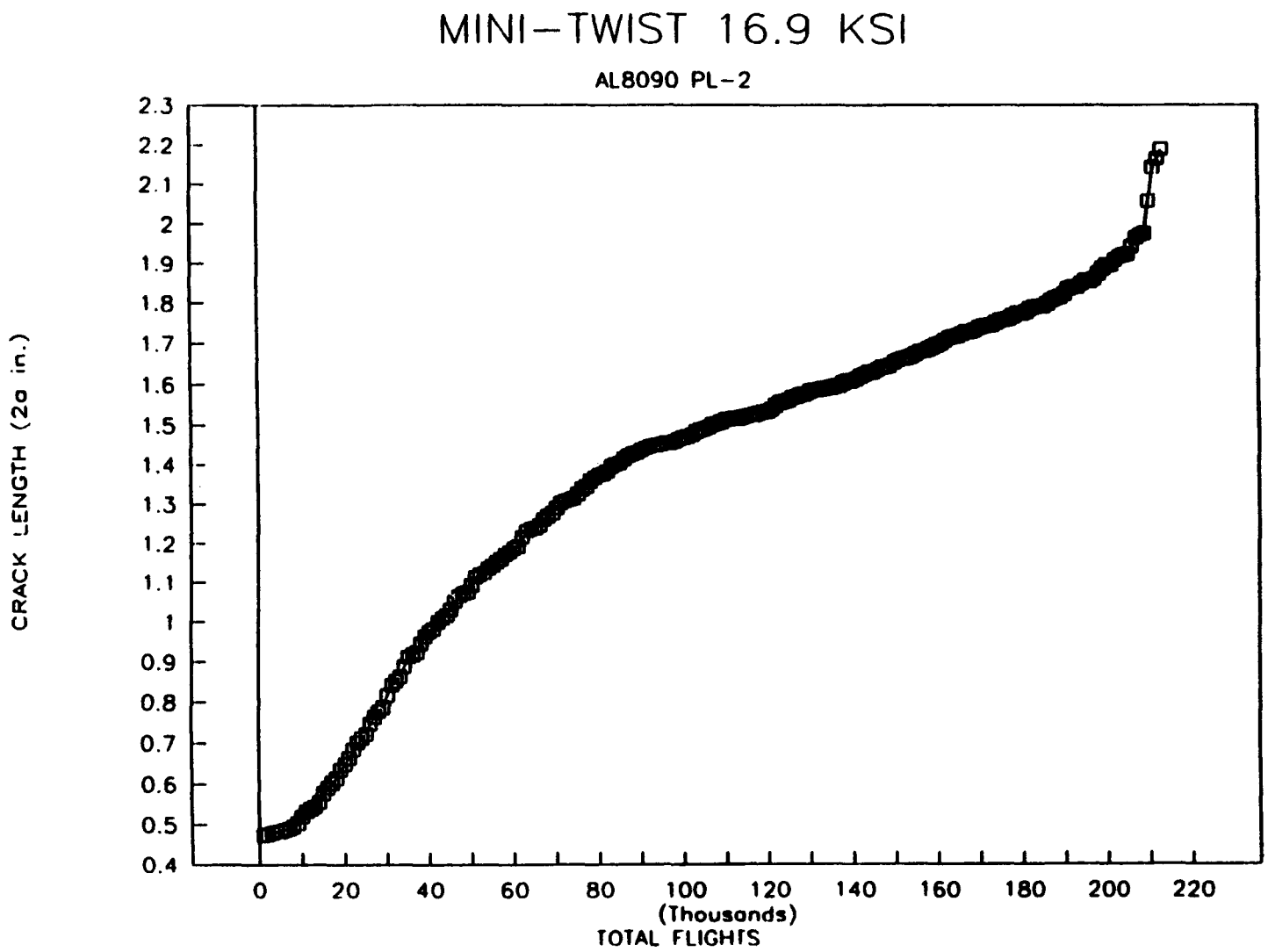


FIGURE F9. Mini-TWIST Spectrum Crack Length vs Flights Data for 8090-T8771 Plate (L-T Orientation, Room Temperature, Lab Air and Maximum Stress = 16.9 Ksi). Air Force.

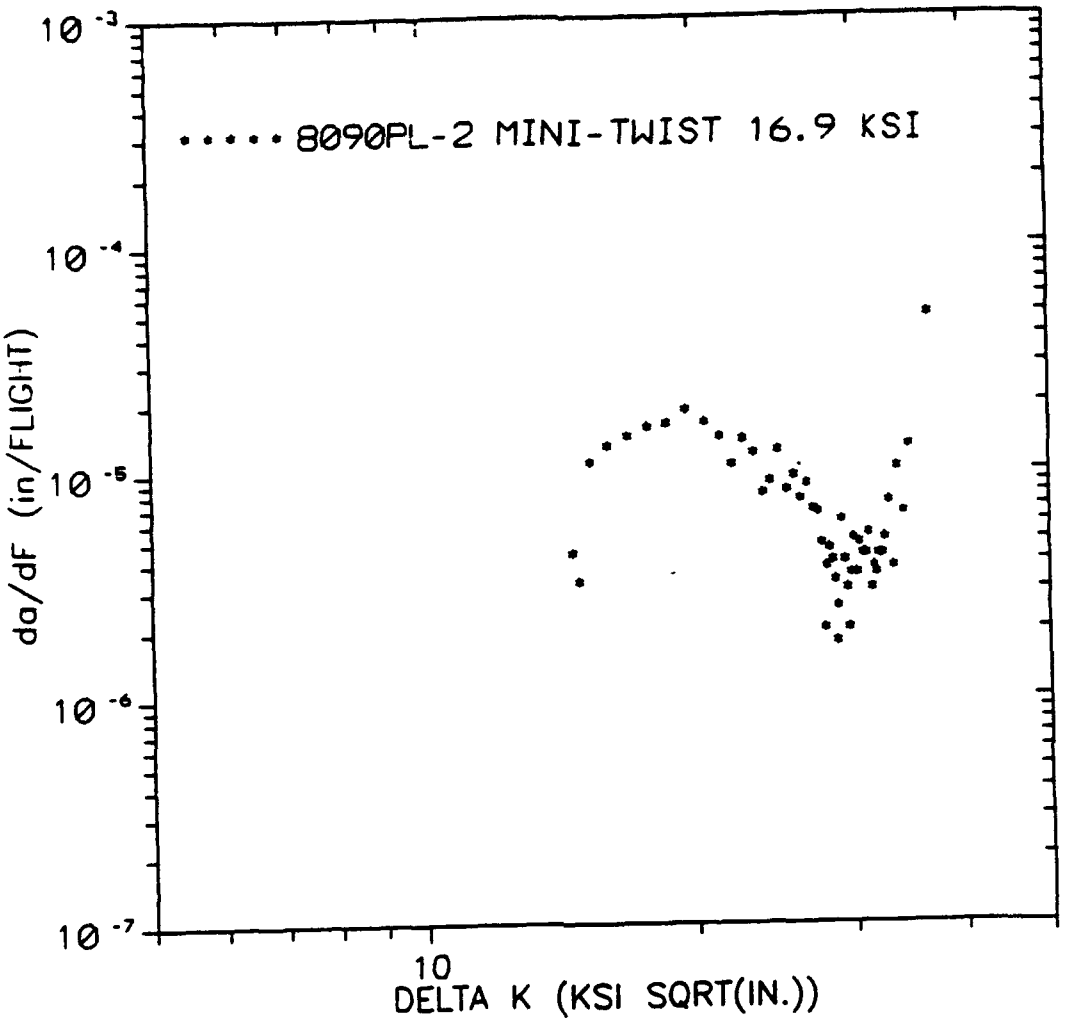


FIGURE F10. Mini-TWIST Spectrum Crack Growth Rate vs Delta K Data for 8090-T8771 Plate (L-T Orientation, Room Temperature, Lab Air and Maximum Stress = 16.9 KSU).
Air Force.

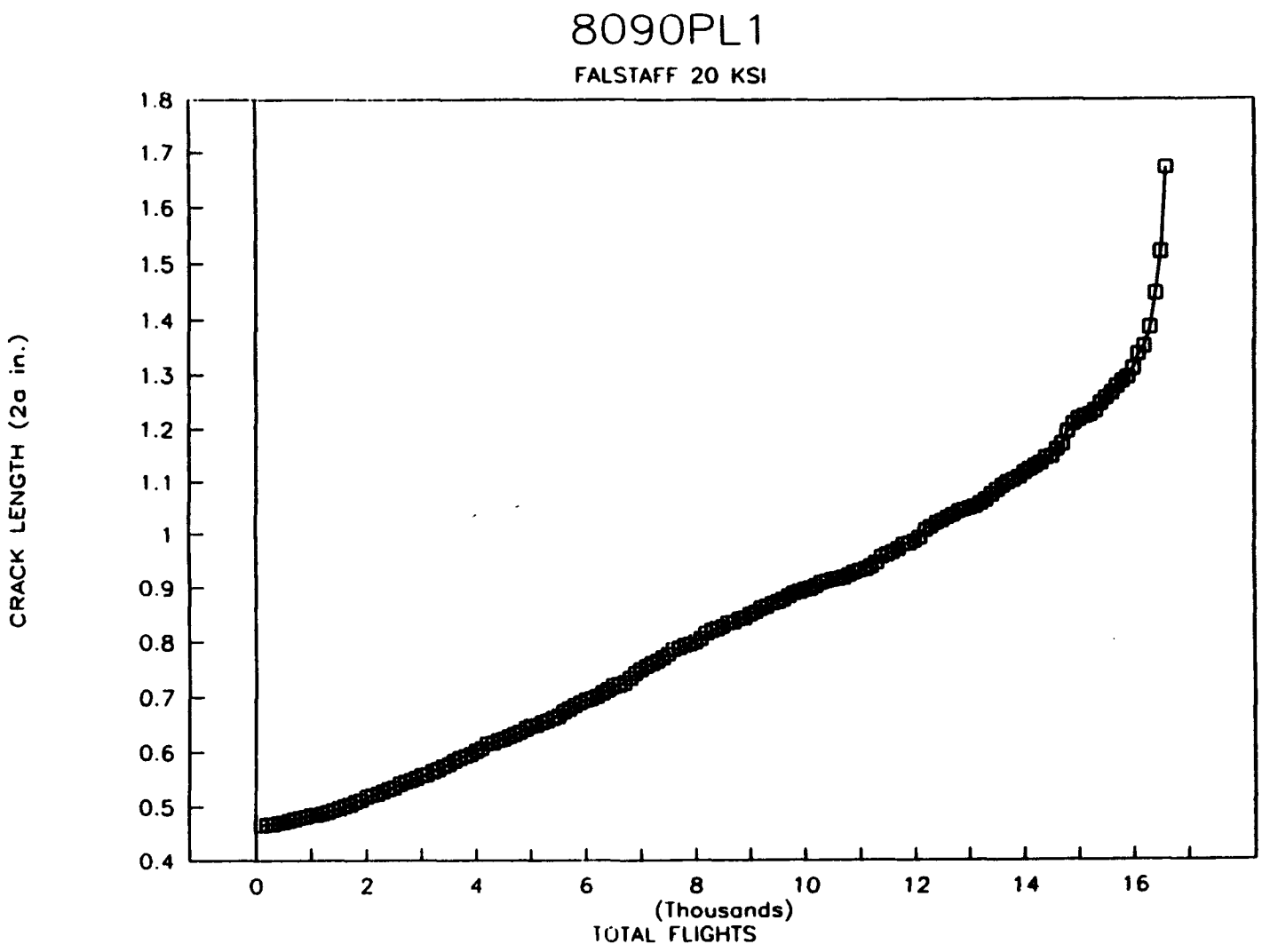


FIGURE F11. FALSTAFF Spectrum Crack Length vs Total Flights Data for 8090-T8771 Plate (L-T Orientation, Room Temperature, Lab Air and Maximum Stress = 20 Ksi). Air Force.

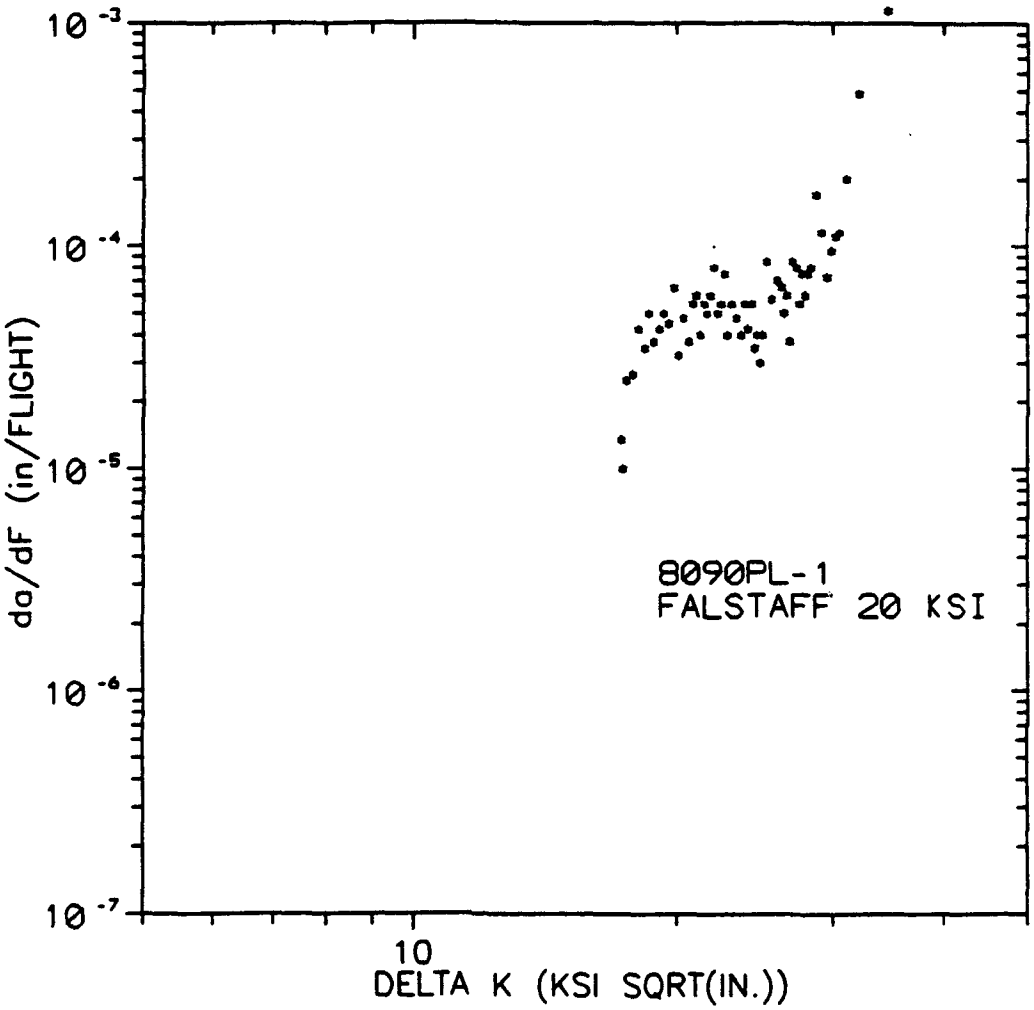


FIGURE F12. FALSTAFF Spectrum Crack Growth Rate vs Delta K Data for 8090-T8771 Plate (L-T Orientation, Room Temperature, Lab Air and Maximum Stress = 20 Ksi).
Air Force.

APPENDIX G

IN905XL PRECISION FORGING

INTRODUCTION

The IN905XL Forgings were produced in a pilot plant under developmental conditions in 1986. Significant variability in properties can be expected under such conditions.

The IN905XL forgings were received the first quarter of 1987 and all the participants except General Dynamics TX tested the material in the as-received condition. General Dynamics TX exposed the forging to a two-step solution treatment and aging. Figure G1 shows the geometry of the IN905XL jack fitting precision forging.

TESTING

Basic mechanical properties (tension, compression, bearing, etc) were tested according to ASTM standards, unless otherwise specified.

Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 standard. Northrop Corporation and General Dynamics performed constant amplitude fatigue crack growth test using K controlled methods. McDonnell Aircraft Company (MCAIR) used a WOL specimen geometry.

A mini-TWIST (moderately intense fatigue environment) spectrum test was performed by the Air Force.

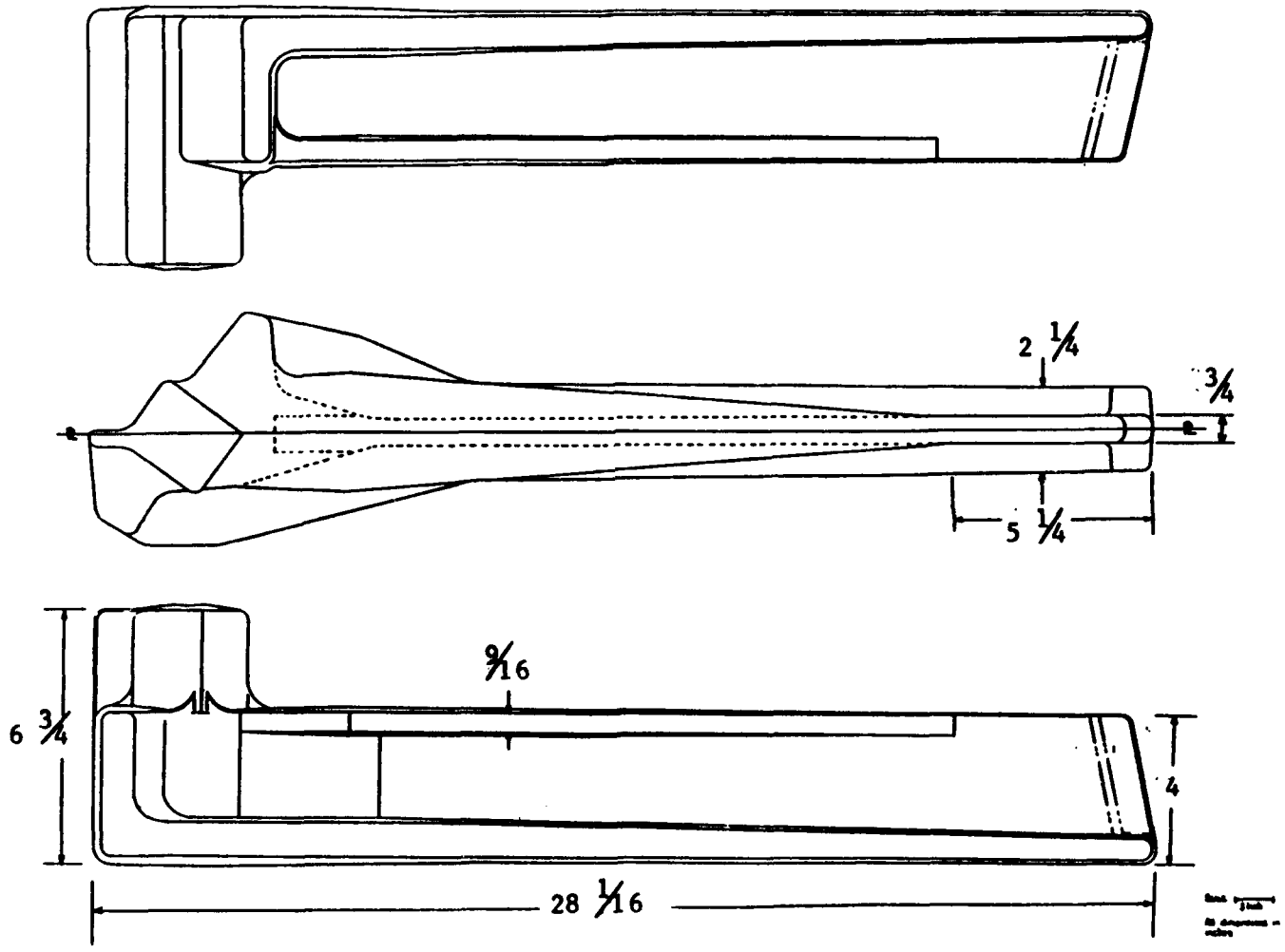


Figure G1 IN905XL Jack Fitting Precision Forging

TABLE G1

TENSILE RESULTS FOR

IN905XL FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	COMMENT
AIR FORCE	RT	LONG	66.6	52.0	11.5	23.0		(1)
			65.9	50.6	11.9	21.0		(1)
			66.1	52.0	11.8	25.0		(1)
			64.3	51.6	13.6	27.6		(2)
			63.7	48.7	10.4	12.4		(2)
			62.7	49.5	11.0	19.4		(2)
			67.7	56.0	13.0	30.3		(1)
			68.0	56.1	13.0	25.3		(1)
			68.3	57.7	13.0	28.0		(1)
MCAIR	RT	LONG	75.0	65.0	9.0	18.2	11.6	(1)
			75.5	64.5	8.0	15.6	11.9	(1)
			74.5	62.0	9.0	20.3	12.4	(1)
LTV	RT	LONG	68.0	51.5	13.0	21.6	10.8	(1)
			67.9	54.8	12.0	17.4	10.8	(1)
			64.7	50.2	11.0	9.2	10.8	(1)
NORTHROP	RT	LONG	67.4	55.4	10.0		11.6	(1)
				55.7			12.1	(1)
			67.0	55.3	12.0		12.2	(1)
			64.3	53.9	12.0		11.5	(2)
			65.0	53.3	11.0		11.9	(2)
			64.7	51.7	12.0		11.3	(2)
MARTIN MARIETTA	RT	LONG	75.1	62.2	12.0	13.9	11.4	
			75.9	63.8	10.0	14.7	11.4	
			78.1	64.9	10.0	13.2	11.6	
SIKORSKY	RT	LONG	67.5	57.7	7.5		12.4	(1)
			67.8	55.9	14.0		12.2	(1)
			68.0	55.3	13.0		12.6	(1)
			67.8	54.7	13.0		12.1	(1)
			68.9	57.0	13.0		12.7	(1)
			68.5	56.1	14.0		12.0	(1)
NASA LANGLEY	RT	LONG	67.0	57.3	7.0		11.5	
			67.9	57.8	9.0		11.4	
			67.6	58.1	7.0		11.5	
		AVERAGE	68.4	56.0	11.2	19.8	11.7	
		STANDARD DEVIATION	3.9	4.5	2.0	6.0	0.5	

(1): THIN SECTION (WEB/FLANGE SECTION)
(2): THICK SECTION (END SECTION)

TABLE G2

TENSILE RESULTS FOR

IN905XL FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	COMMENT
AIR FORCE	RT	L TRANS	66.9	54.1	9.3	16.8		(1)
			67.2	53.9	7.0	11.7		(1)
			67.8	54.7	8.0	15.8		(1)
			64.9	51.2	13.3	19.9		(2)
			64.4	50.4	11.1	19.0		(2)
			64.4	49.7	9.3	13.5		(2)
			64.8	50.9	9.0	18.3		(1)
			64.1	50.1	11.0	12.3		(1)
			63.5	49.5	8.0	17.6		(1)
MCAIR	RT	L TRANS	74.5	66.0	8.0	15.1	12.4	(1)
			74.5	61.5	9.0	18.5	12.6	(1)
			74.5	64.5	8.0	16.3	11.5	(1)
LTV	RT	L TRANS	66.8	55.2	10.0	19.2	11.2	(1)
			67.0	54.7	10.0	18.6	11.5	(1)
			67.4	55.2	12.0	17.7	11.2	(1)
NORTHROP	RT	L TRANS	66.3	54.9	10.0		11.6	(1)
			65.8	54.3	11.0		11.5	(1)
			66.6	54.9	12.5		11.6	(1)
			64.8	51.4	6.0		11.9	(2)
			65.0	52.5	8.0		11.7	(2)
			65.3	52.9	8.0		11.9	(2)
MARTIN MARIETTA	RT	L TRANS	69.5	54.9	4.0	1.6	11.3	
			69.8	54.8	3.0	1.6	11.1	
			69.3	54.6	4.0	3.2	11.0	
SIKORSKY	RT	L TRANS	68.1	56.7	14.0		12.7	(1)
			67.9	56.8	10.0		11.8	(1)
			69.0	57.8	13.0		13.5	(1)
			68.7	58.1	9.0		11.1	(1)
NASA LANGLEY	RT	L TRANS	67.9	58.1	8.0		11.5	
			67.8	58.4	8.0		11.4	
			68.0	58.4	8.0		11.5	
		AVERAGE	67.5	55.2	9.0	14.3	11.7	
	STANDARD DEVIATION		2.9	4.0	2.6	6.1	0.6	

(1): THIN SECTION (WEB/FLANGE SECTION)
(2): THICK SECTION (END SECTION)

TABLE G3

TENSILE RESULTS FOR

IN905XL FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	COMMENT
LTV	RT	S TRANS	64.7	50.8	8.0	7.7	11.2	(2)
			67.3	54.8	12.0	28.4	10.9	(2)
			63.2	50.8	8.0	10.3	11.2	(2)
NORTHROP	RT	S TRANS	64.1	52.6	6.5		11.4	(1)
			64.3	52.2	8.0		12.1	(1)
			64.7	51.5	8.0		11.9	(1)
MARTIN MARIETTA	RT	S TRANS	74.1	61.2	6.0	4.8	11.6	
			75.5	62.0	6.0	4.0	11.3	
			72.6	60.8	4.0	4.8	11.2	
SIKORSKY	RT	S TRANS	67.7	54.8	9.0		11.6	(1)
			65.3	50.8	5.0		12.8	(1)
NASA LANGLEY	RT	S TRANS	63.9	53.3	5.0		11.2	
			63.1	53.7	5.0		11.4	
			63.8	53.6	5.0		11.3	
		AVERAGE	66.7	54.5	6.8	10.0	11.5	
	STANDARD DEVIATION		4.2	4.0	2.1	9.3	0.5	

(1): THIN SECTION (WEB/FLANGE SECTION)
(2): THICK SECTION (END SECTION)

TABLE G4

TENSILE RESULTS FOR

IN905XL FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	COMMENT
GENERAL DYNAMICS	RT	LONG	69.7	57.6				*
			67.1	59.2	9.7			*
		AVERAGE	68.4	58.4	9.7			
	STANDARD DEVIATION		1.8	1.1				

(*): THIN SECTION
NOTE: HEAT TREATED WITH THE FOLLOWING SCHEDULE:
STEP 1 - 850F FOR 2 HRS
STEP 2 - 665F FOR 2 HRS
STEP 3 - WARM WATER QUENCH
STEP 4 - 230F FOR 24 HRS

TABLE G5

TENSILE RESULTS FOR

IN905XL FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	COMMENT
GENERAL DYNAMICS	RT	L TRANS	71.2	58.7	8.6			*
			67.9	56.6	9.7			*
		AVERAGE	69.6	57.7	9.2			
	STANDARD DEVIATION		2.3	1.5	0.8			

(*): THIN SECTION
NOTE: HEAT TREATED WITH THE FOLLOWING SCHEDULE:
STEP 1 - 850F FOR 2 HRS
STEP 2 - 665F FOR 2 HRS
STEP 3 - WARM WATER QUENCH
STEP 4 - 230F FOR 24 HRS

TABLE G6

COMPRESSION RESULTS FOR

IN905XL FORGING

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCAIR	RT	LONG	65.9	11.9
			65.9	10.4
			65.6	11.8
LTV	RT	LONG	59.1	11.9
			53.3	12.1
			60.5	12.0
NORTHROP	RT	LONG	56.6	11.7
			57.1	12.2
			57.4	12.0
MARTIN MARIETTA	RT	LONG	70.3	12.4
			70.9	12.3
			71.0	12.3
SIKORSKY	RT	LONG	57.9	13.2
			56.6	11.2
NASA LANGLEY	RT	LONG	60.7	11.7
			61.4	11.7
			61.6	11.7
		AVERAGE	61.9	11.9
		STANDARD DEVIATION	5.5	0.6

NOTE: NORTHROP SPECIMENS TAKEN FROM WEB/FLANGE SECTION.

TABLE G7

COMPRESSION RESULTS FOR

IN905XL FORGING

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCAIR	RT	L TRANS	64.2	12.1
			62.5	12.4
			62.0	12.7
LTV	RT	L TRANS	57.3	11.5
			58.9	12.3
			56.5	12.2
NORTHROP	RT	L TRANS	56.2	11.9
			56.0	11.8
			56.0	11.9
MARTIN MARIETTA	RT	L TRANS	67.2	12.3
			67.2	12.2
			67.3	12.3
SIKORSKY	RT	L TRANS	56.2	12.5
			55.5	11.8
			55.4	12.4
NASA LANGLEY	RT	L TRANS	59.3	11.7
			59.2	11.6
			59.2	11.7
		AVERAGE	59.8	12.1
		STANDARD DEVIATION	4.3	0.3

NOTE: NORTHROP SPECIMENS TAKEN FROM WEB/FLANGE SECTION.

TABLE G8

COMPRESSION RESULTS FOR

IN905XL FORGING

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
LTV	RT	S TRANS	54.1	11.5
			59.3	12.0
			53.7	11.8
NORTHROP	RT	S TRANS	50.8	11.9
			51.1	11.9
			50.1	11.8
MARTIN MARIETTA	RT	S TRANS	57.1	12.2
			57.1	12.1
			56.5	12.0
NASA LANGLEY	RT	S TRANS	56.5	11.6
		AVERAGE	54.6	11.9
		STANDARD DEVIATION	3.2	0.2

NOTE: NORTHROP SPECIMENS TAKEN FROM WEB/FLANGE SECTION.

TABLE G9

COMPRESSION RESULTS FOR

IN905XL FORGING

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
GENERAL DYNAMICS (*)	RT	LONG	58.0	11.4

(*): HEAT TREATED TO THE FOLLOWING SCHEDULE:
STEP 1 - 850F FOR 2 HRS
STEP 2 - 665F FOR 2 HRS
STEP 3 - WARM WATER QUENCH
STEP 4 - 230F FOR 24 HRS

TABLE G10

COMPRESSION RESULTS FOR

IN905XL FORGING

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
GENERAL DYNAMICS (*)	RT	L TRANS	59.3	11.7
			55.9	11.7
		AVERAGE	57.6	11.7
		STANDARD DEVIATION	2.4	0.0

(*): HEAT TREATED TO THE FOLLOWING SCHEDULE:
STEP 1 - 850F FOR 2 HRS
STEP 2 - 665F FOR 2 HRS
STEP 3 - WARM WATER QUENCH
STEP 4 - 230F FOR 24 HRS

TABLE G11

IOSIPESCU SHEAR RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
LTV	LONG	41.8
		41.7
	AVERAGE	41.8
	STANDARD DEVIATION	0.1

TABLE G12

IOSIPESCU SHEAR RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
LTV	L TRANS	40.4
		41.4
		41.7
		41.1
	AVERAGE	41.2
	STANDARD DEVIATION	0

TABLE G13

AMSLER DOUBLE SHEAR RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
GENERAL DYNAMICS (*)	L - S	37.7
		37.9
	AVERAGE	37.8
	STANDARD DEVIATION	0.1

(*): HEAT TREATED TO THE FOLLOWING SCHEDULE:
STEP 1 - 850F FOR 2 HRS
STEP 2 - 665F FOR 2 HRS
STEP 3 - WARM WATER QUENCH
STEP 4 - 230F FOR 24 HRS

TABLE G14

AMSLER DOUBLE SHEAR RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	L - S	39.6
		39.3
		39.3
NASA-LANGLEY	L - S	41.0
		40.9
		40.7
	AVERAGE	40.1
	STANDARD DEVIATION	0.8

TABLE G15

AMSLER DOUBLE SHEAR RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NASA-LANGLEY	T - S	40.9
		41.0
		40.7
	AVERAGE	40.9
	STANDARD DEVIATION	0.2

TABLE G16

SLOTTED SHEAR RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
MCAIR	LONG	44.5
		41.5
		38.0
	AVERAGE	41.3
	STANDARD DEVIATION	3.3

TABLE G17

BEARING RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	LONG	1.5	97.0	82.5
			95.9	83.7
NORTHROP	LONG	1.5	102.0	83.9
			89.4	77.7
			100.8	82.3
NASA-LANGLEY	LONG	1.5	88.4	79.3
			92.6	78.7
		AVERAGE	97.0	82.0
	STANDARD DEVIATION		5.0	2.5

NOTE: NORTHROP SPECIMENS TAKEN FROM WEB/FLANGE SECTION.

TABLE G18

BEARING RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	L TRANS	1.5	118.0	91.5
			115.0	97.9
NORTHROP	L TRANS	1.5	85.3	77.3
			98.1	82.3
			86.7	77.2
		AVERAGE	100.6	85.2
	STANDARD DEVIATION		15.4	9.2

NOTE: NORTHROP SPECIMENS TAKEN FROM WEB/FLANGE SECTION.

TABLE G19

BEARING RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCAIR	LONG	2.0	125.0	104.0
			125.0	107.0
			124.0	102.0
LTV	LONG	2.0	118.0	91.5
			115.0	97.9
NORTHROP	LONG	2.0	125.1	96.5
			125.9	95.7
			125.9	93.7
		AVERAGE	123.0	98.5
	STANDARD DEVIATION		4.1	5.3

TABLE G20

BEARING RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
GENERAL DYNAMICS (*)	LONG	2.0	111.0	93.4
			113.3	92.9
		AVERAGE	112.2	93.2
	STANDARD DEVIATION		1.6	0.4

(*): HEAT TREATED TO THE FOLLOWING SCHEDULE:
STEP 1 - 850F FOR 2 HRS
STEP 2 - 665F FOR 2 HRS
STEP 3 - WARM WATER QUENCH
STEP 4 - 230F FOR 24 HRS

TABLE G21

BEARING RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCAIR	L TRANS	2.0	105.0	101.0
			123.0	103.0
			122.0	103.0
LTV	L TRANS	2.0	117.2	100.5
			124.7	97.3
NORTHROP	L TRANS	2.0	117.5	89.0
			124.2	92.2
			115.7	89.0
		AVERAGE	118.7	96.9
	STANDARD DEVIATION		6.5	6.0

TABLE G22

BEARING RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
GENERAL DYNAMICS (*)	L TRANS	2.0	108.4	89.3
			107.9	90.4
		AVERAGE	108.2	89.9
	STANDARD DEVIATION		0.4	0.8

(*): HEAT TREATED TO THE FOLLOWING SCHEDULE:
STEP 1 - 850F FOR 2 HRS
STEP 2 - 665F FOR 2 HRS
STEP 3 - WARM WATER QUENCH
STEP 4 - 230F FOR 24 HRS

TABLE G23

FRACTURE TOUGHNESS RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MCAIR	L-T	18.8		VALID
		24.9		VALID
NORTHROP	L-T		37.9	(1)
			38.3	(1)
MARTIN MARIETTA	L-T		27.7	(2)
	AVERAGE	21.9	34.6	
	STANDARD DEVIATION	4.3	6.0	

(1): INVALID DUE TO Pmax/Pq > 1.10
(2): INVALID DUE TO PRE-CRACK GROWTH > 0.55W

NOTE: NORTHROP SPECIMENS TAKEN FROM END SECTION.

TABLE G24

FRACTURE TOUGHNESS RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MCAIR	T-L	23.5		VALID
		21.0		VALID
LTV	T-L		33.9	(1)
			35.4	(1)
			31.5	(1)
			33.4	(1)
NORTHROP	T-L		34.4	(1)
			33.4	(1)
MARTIN MARIETTA	T-L		22.8	(2)
			21.7	(2)
	AVERAGE	22.3	30.8	
	STANDARD DEVIATION	1.7	5.4	

(1): INVALID DUE TO Pmax/Pq > 1.10
(2): INVALID DUE TO PRE-CRACK GROWTH > 0.55W

NOTE: NORTHROP SPECIMENS TAKEN FROM END SECTION.

TABLE G25

FRACTURE TOUGHNESS RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
LTV	T-S		34.1	(1)
			33.3	(1)
	AVERAGE		33.7	
	STANDARD DEVIATION		0.6	

(1): INVALID DUE TO Pmax/Pq > 1.10

TABLE G26

FRACTURE TOUGHNESS RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MCAIR	S-T	17.8		VALID
		19.3		VALID
MARTIN MARIETTA	S-T	15.6		
		16.3		
			15.0	(1)
	AVERAGE	17.2	15.0	
	STANDARD DEVIATION	1.6		

(1): INVALID DUE TO PRE-CRACK GROWTH > 0.55W

TABLE G27

FRACTURE TOUGHNESS RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MARTIN MARIETTA	S-L	19.5		VALID
			19.1	(1)
			23.8	(2)
	AVERAGE	19.5	21.5	
	STANDARD DEVIATION		3.3	

(1): INVALID DUE TO ASSYMETRIC CRACK GROWTH
(2): INVALID DUE TO PRE-CRACK GROWTH > 0.55W

TABLE G28

FRACTURE TOUGHNESS RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
GENERAL DYNAMICS	L-T		32.4	(1),(2)
			35.1	(1),(2)
	AVERAGE		33.8	
	STANDARD DEVIATION		1.9	

(1): SPECIMEN THICKNESS LESS THAN REQUIRED FOR VALIDITY
(2): HEAT TREATED TO THE FOLLOWING SCHEDULE:
STEP 1 - 850F FOR 2 HRS
STEP 2 - 665F FOR 2 HRS
STEP 3 - WARM WATER QUENCH
STEP 4 - 230F FOR 24 HRS

TABLE G29

FRACTURE TOUGHNESS RESULTS FOR

IN905XL FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
GENERAL DYNAMICS	T-L		29.8	(1),(2)
			30.7	(1),(2)
	AVERAGE		30.3	
	STANDARD DEVIATION		0.6	

(1): SPECIMEN THICKNESS LESS THAN REQUIRED FOR VALIDITY
(2): HEAT TREATED TO THE FOLLOWING SCHEDULE:
STEP 1 - 850F FOR 2 HRS
STEP 2 - 665F FOR 2 HRS
STEP 3 - WARM WATER QUENCH

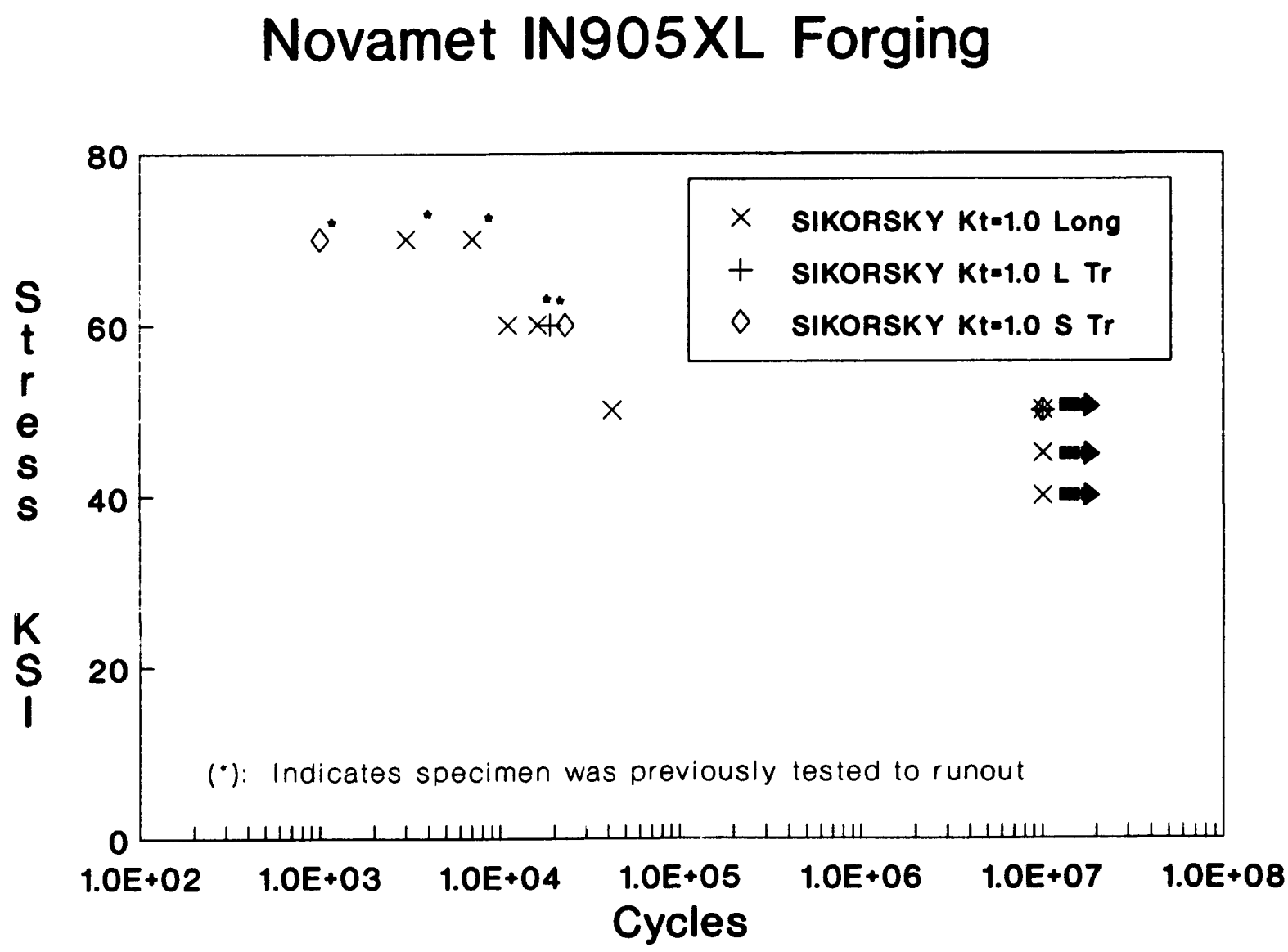


Figure G2 Fatigue Results for IN905XL Forging (R=0.1, Kt=1.0). Sikorsky.

TABLE G30

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR

IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SIKORSKY	LONG	70.0	3,000 #
		70.0	7,000 !
		60.0	16,000 &
		60.0	11,000
		50.0	42,000
		50.0	10,000,000 *
		45.0	10,000,000 *
		40.0	10,000,000 *

(*): INDICATES A RUNOUT TEST
(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 40 KSI
(!): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 50 KSI
(&): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 45 KSI

TABLE G31

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR

IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SIKORSKY	L TRANS	60.0	19,000 #
		50.0	10,000,000 *

(*): INDICATES A RUNOUT TEST
(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 50 KSI

TABLE G32

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR

IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SIKORSKY	S TRANS	70.0	1,000 #
		60.0	23,000
		50.0	10,000,000 *

(*): INDICATES A RUNOUT TEST
(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 50 KSI

Novamet IN905XL Forging

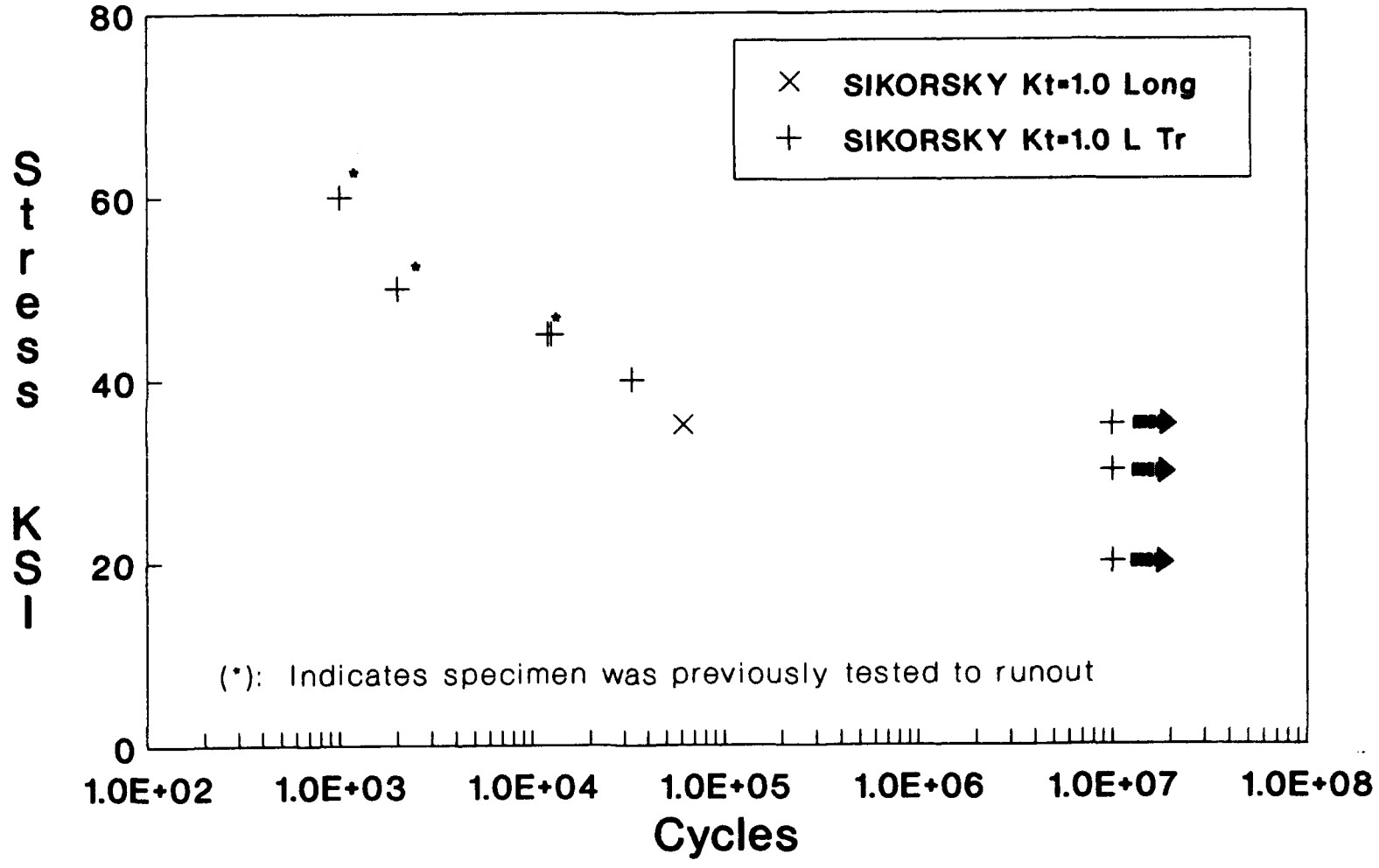


Figure C3 Fatigue Results for IN905XL Forging (R=-1.0, Kt=1.0). Sikorsky.

TABLE G33

FATIGUE RESULTS WITH R=-1.0 AND Kt=1.0 FOR

IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SIKORSKY	LONG	35.0	61,200

TABLE G34

FATIGUE RESULTS WITH R=-1.0 AND Kt=1.0 FOR

IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SIKORSKY	L TRANS	60.0	1,000 #
		50.0	2,000 !
		45.0	12,500
		45.0	12,000 &
		40.0	32,500
		35.0	10,000,000 *
		30.0	10,000,000 *
		20.0	10,000,000 *

(*): INDICATES A RUNOUT TEST
(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 30 KSI
(!): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 20 KSI
(&): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 35 KSI

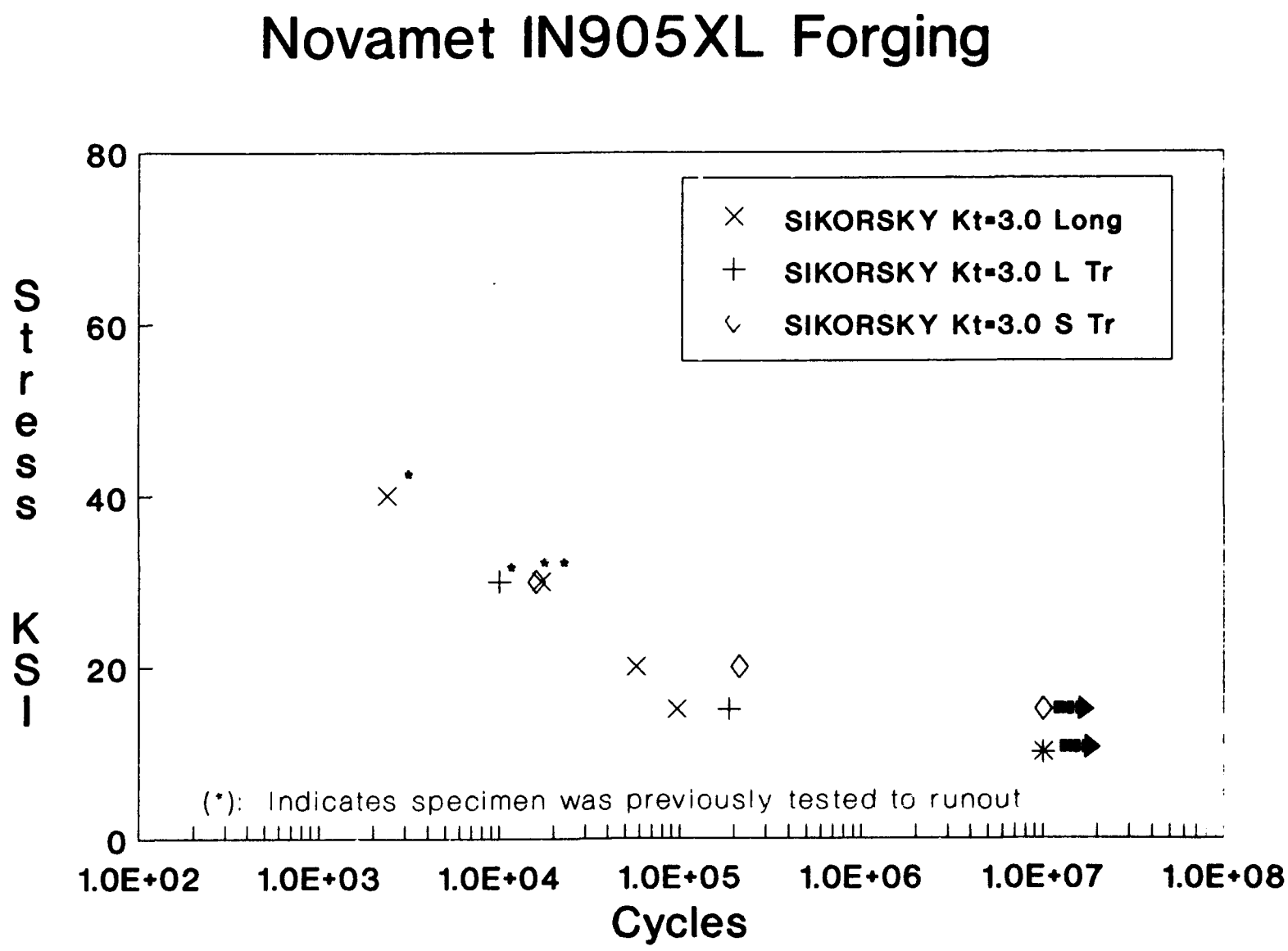


Figure C4 Fatigue Results for IN905XL Forging (R=0.1, Kt=3.0). Sikorsky.

TABLE G35

FATIGUE RESULTS WITH R=0.1 AND Kt=3.07 FOR

IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SIKORSKY	LONG	40.0	2,400 #
		30.0	17,000 #
		20.0	57,000
		15.0	96,000
		10.0	10,000,000 *
		10.0	10,000,000 *

(*): INDICATES A RUNOUT TEST
(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 10 KSI

TABLE G36

FATIGUE RESULTS WITH R=0.1 AND Kt=3.07 FOR

IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SIKORSKY	L TRANS	30.0	10,000 #
		15.0	187,400
		10.0	10,000,000 *

(*): INDICATES A RUNOUT TEST
(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 10 KSI

TABLE G37

FATIGUE RESULTS WITH R=0.1 AND Kt=3.07 FOR

IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SIKORSKY	S TRANS	30.0	16,000 #
		20.0	213,400
		15.0	10,000,000 *

(*): INDICATES A RUNOUT TEST
(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 15 KSI

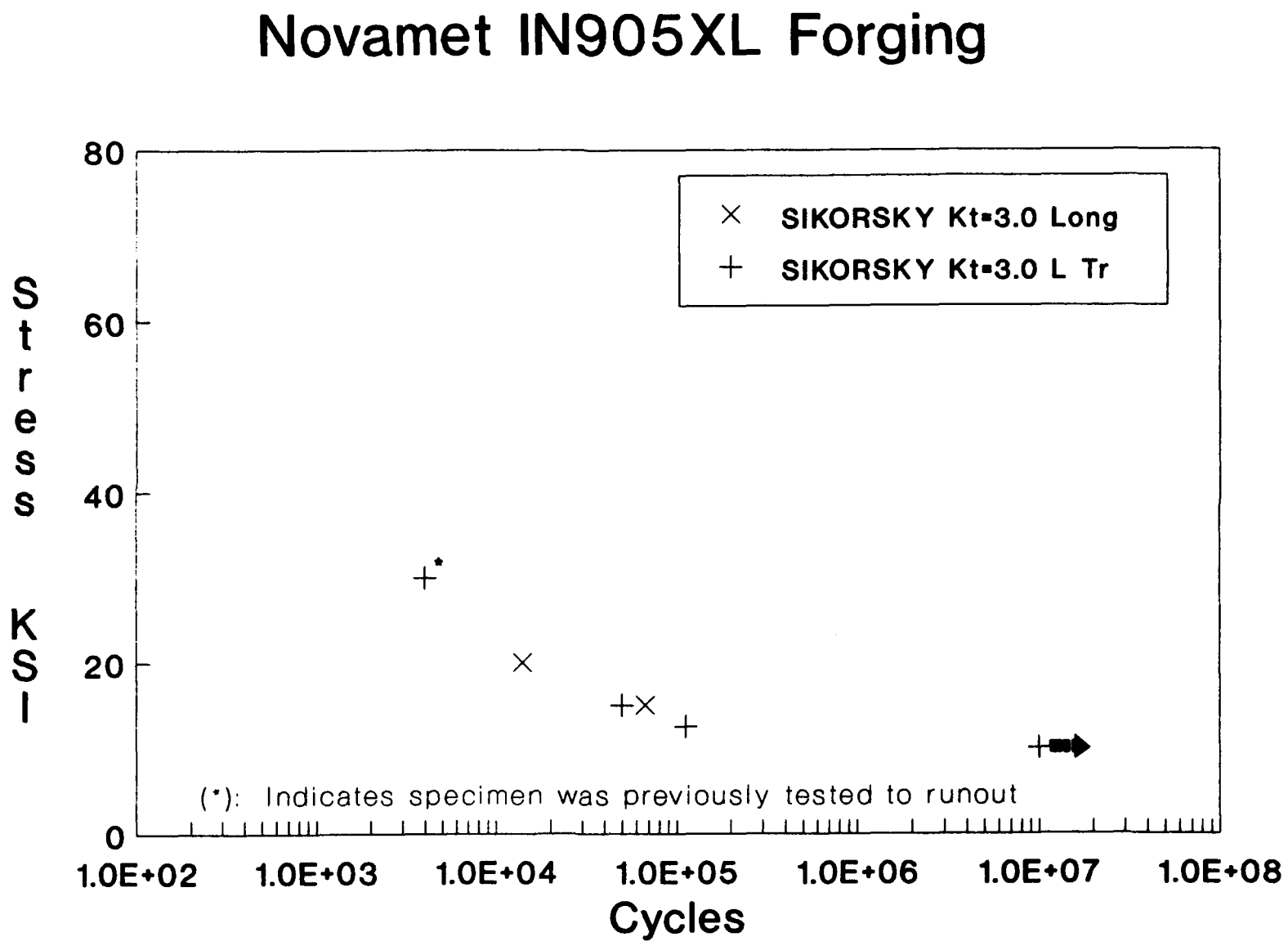


Figure G5 Fatigue Results for IN905XL Forging (R=-1.0, Kt=3.0). Sikorsky.

TABLE G38

FATIGUE RESULTS WITH R=-1.0 AND Kt=3.07 FOR

IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SIKORSKY	LONG	20.0	14,000
		15.0	67,000

(*): INDICATES A RUNOUT TEST
(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 15 KSI

TABLE G39

FATIGUE RESULTS WITH R=-1.0 AND Kt=3.07 FOR

IN905XL FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SIKORSKY	L TRANS	30.0	4,000 #
		15.0	50,000
		12.5	112,400
		10.0	10,000,000 *

(*): INDICATES A RUNOUT TEST
(#): INDICATES THAT SPECIMEN WAS PREVIOUSLY TESTED TO RUNOUT @ 10 KSI

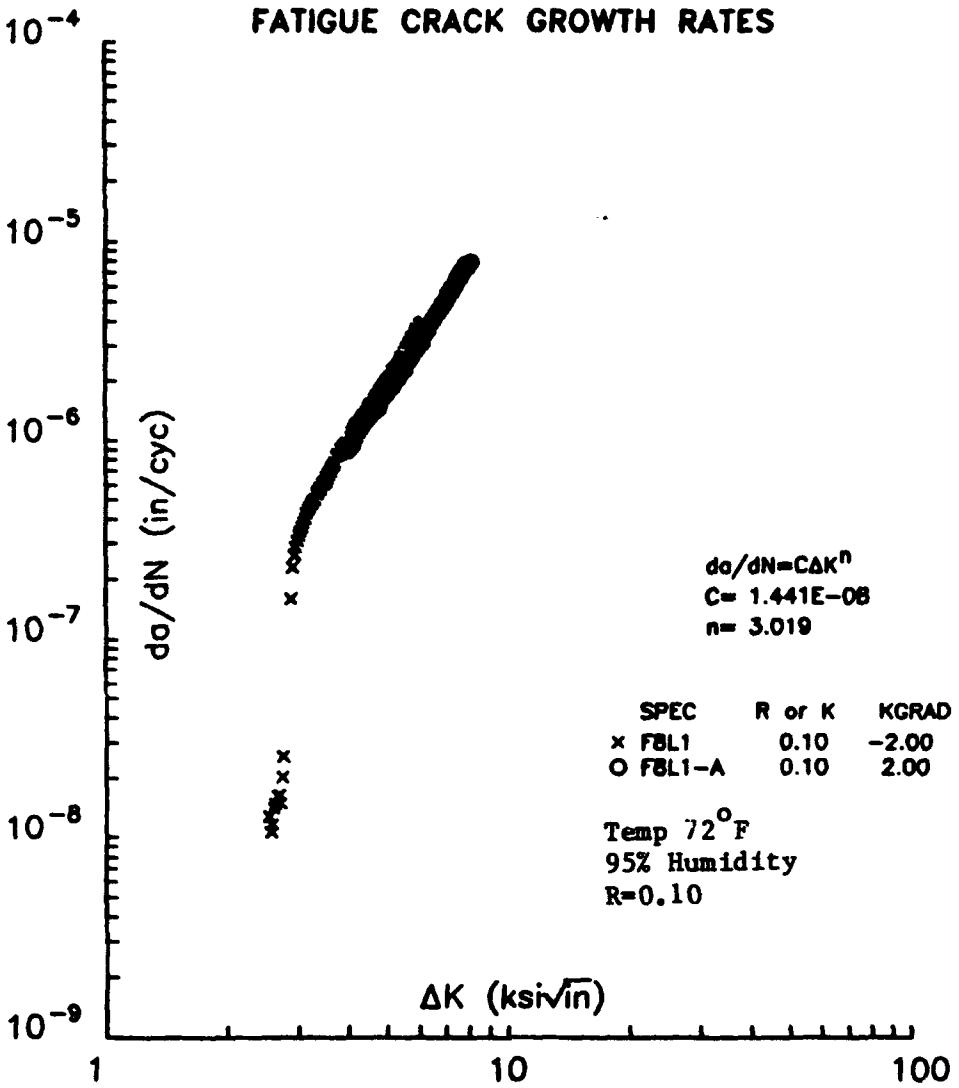


Figure G6 Fatigue Crack Growth Rate Data for IN905XL Forging (L-T Orientation, KGRAD -2.00 and 2.00). Northrop.

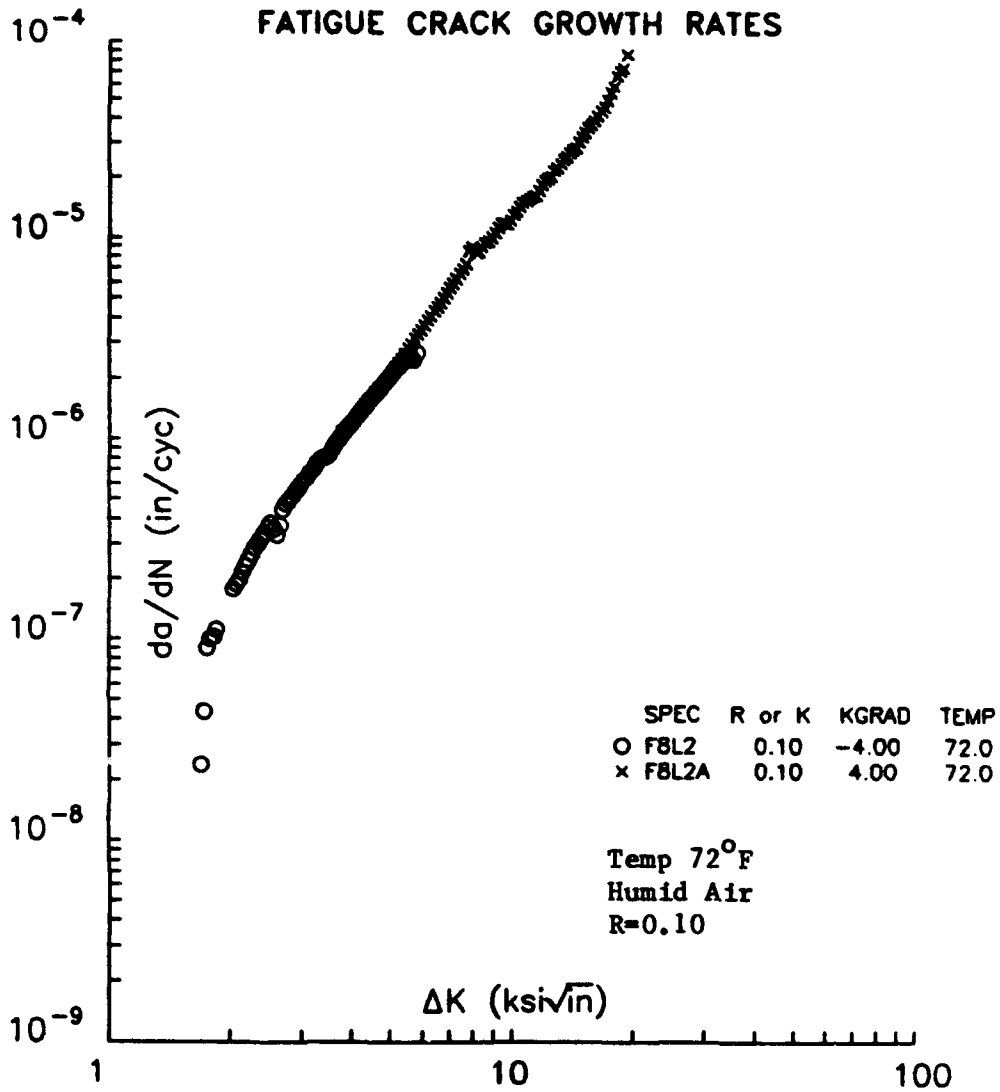


Figure G7 Fatigue Crack Growth Rate Data for IN905XL Forging (L-T Orientation, KGARAD -4.00 and 4.00). Northrop.

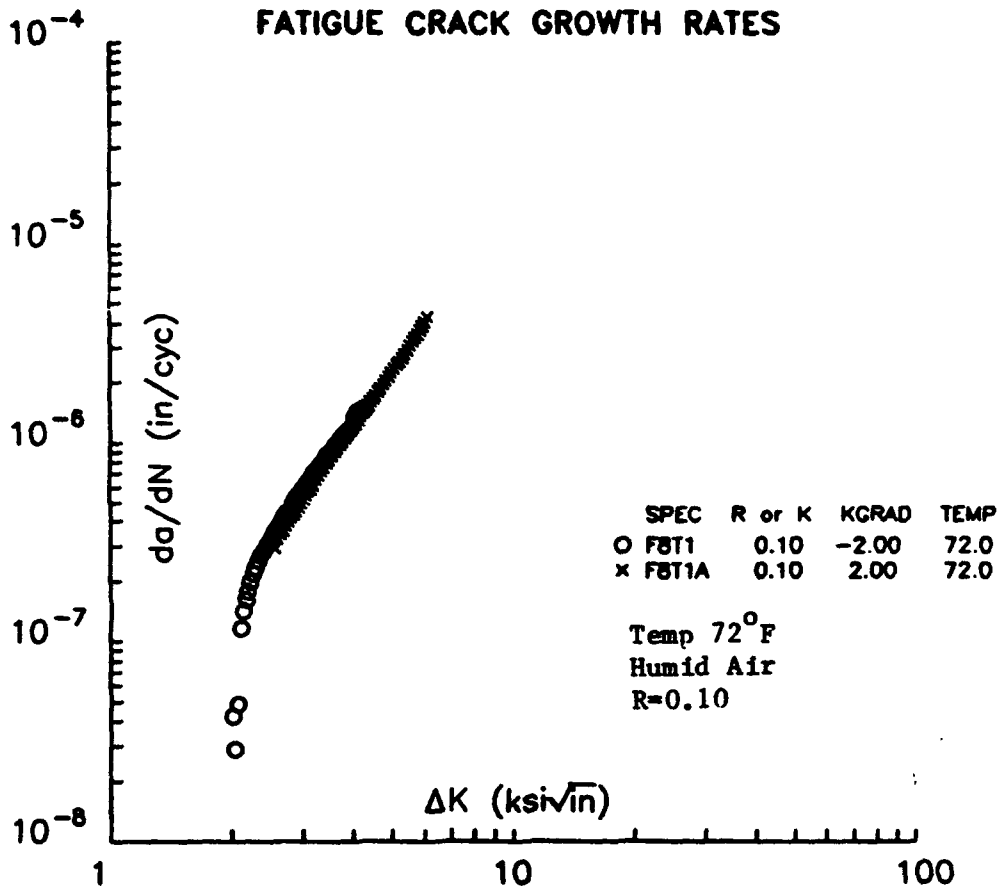


Figure G8 Fatigue Crack Growth Rate Data for IN905XL Forging (T-L Orientation, KGRAD -2.00 and 2.00). Northrop.

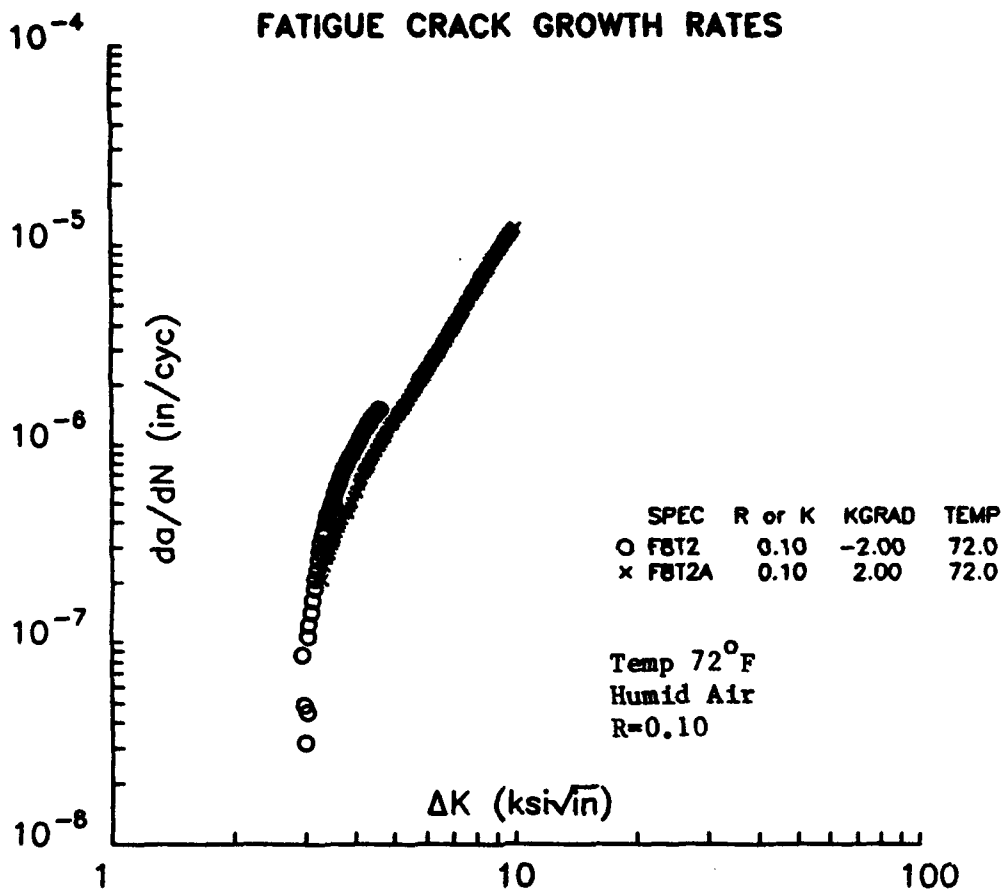


Figure G9 Fatigue Crack Growth Rate Data for IN905XL Forging (T-L Orientation, KGRAD -4.00 and 4.00). Northrop.

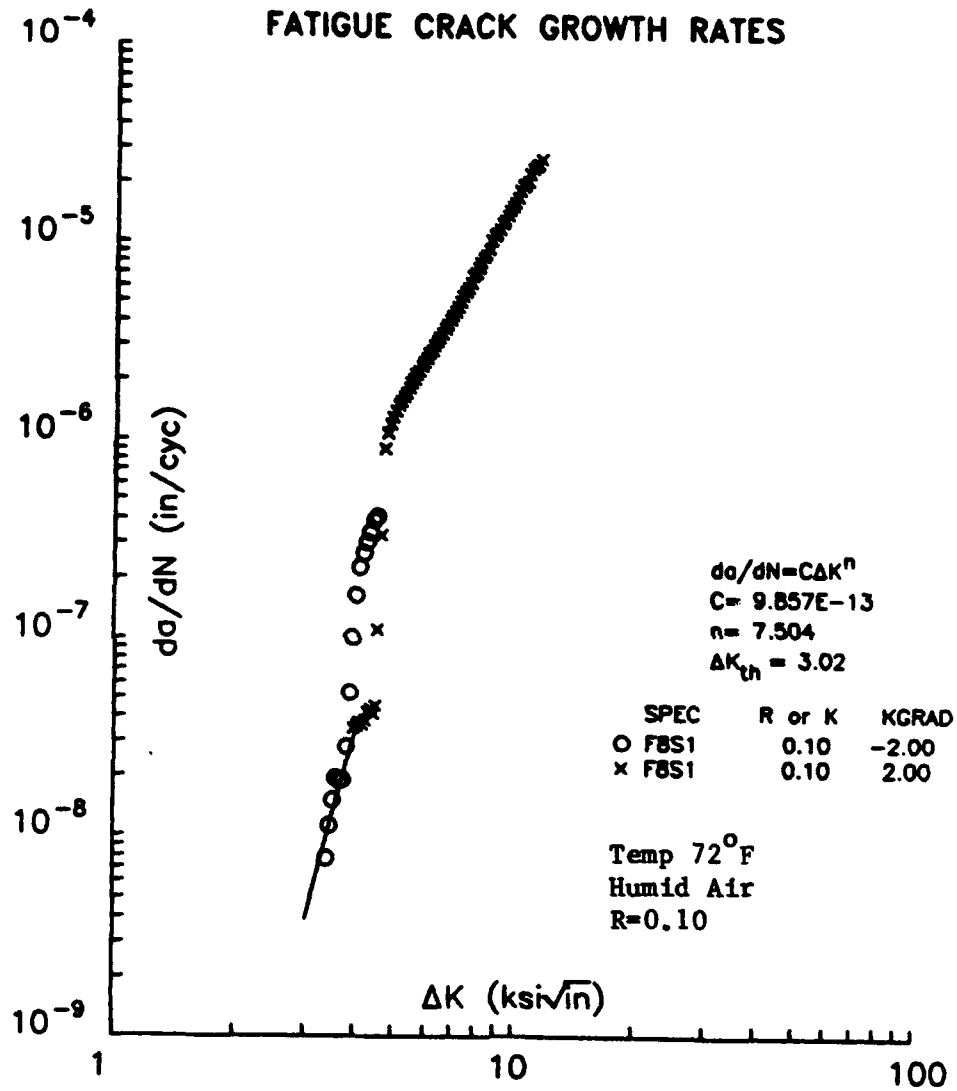


Figure G10 Fatigue Crack Growth Rate Data for IN905XL Forging (S-L Orientation, KGRAD -2.00 and 2.00). Northrop.

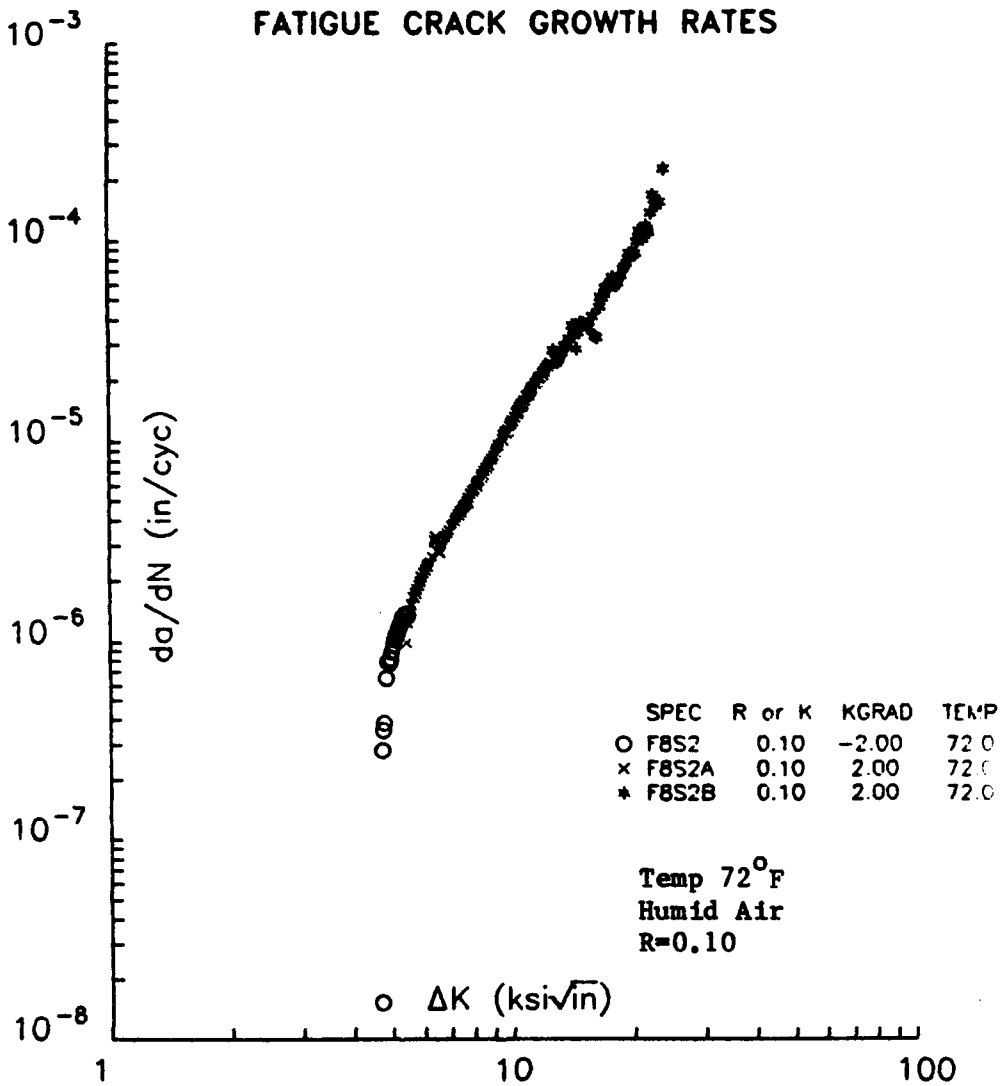


Figure C11 Fatigue Crack Growth Rate Data for IN905XL Forging (S-L Orientation, KGRAD -2.00, 2.00 and 2.00). Northrop.

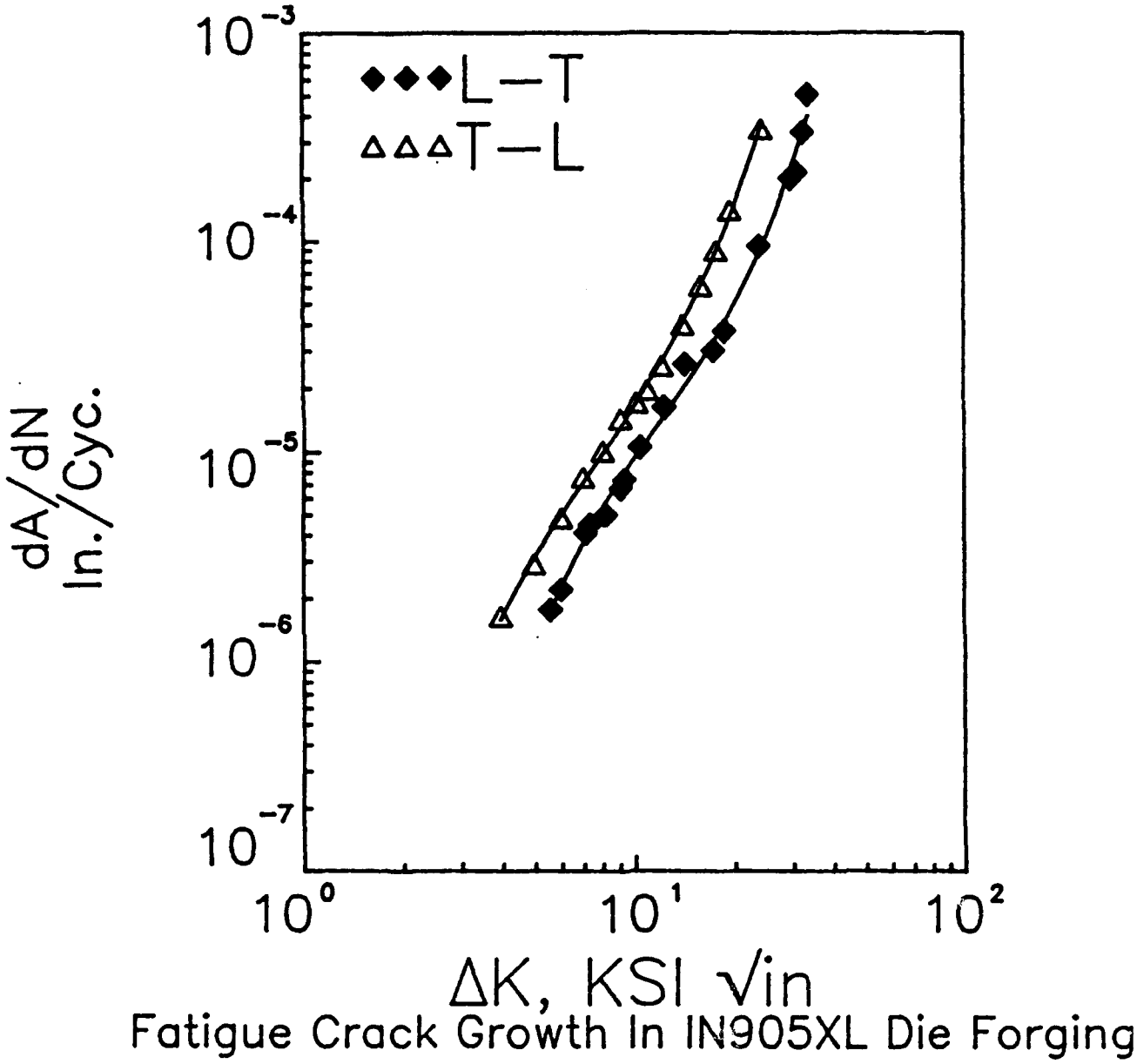


Figure G12 Fatigue Crack Growth Rate Data for Solutiontreated and aged IN905XL Forging (L-T and T-L Orientation, R=0.1, Lab Air and a third order regression fit to each data set). General Dynamics TX.

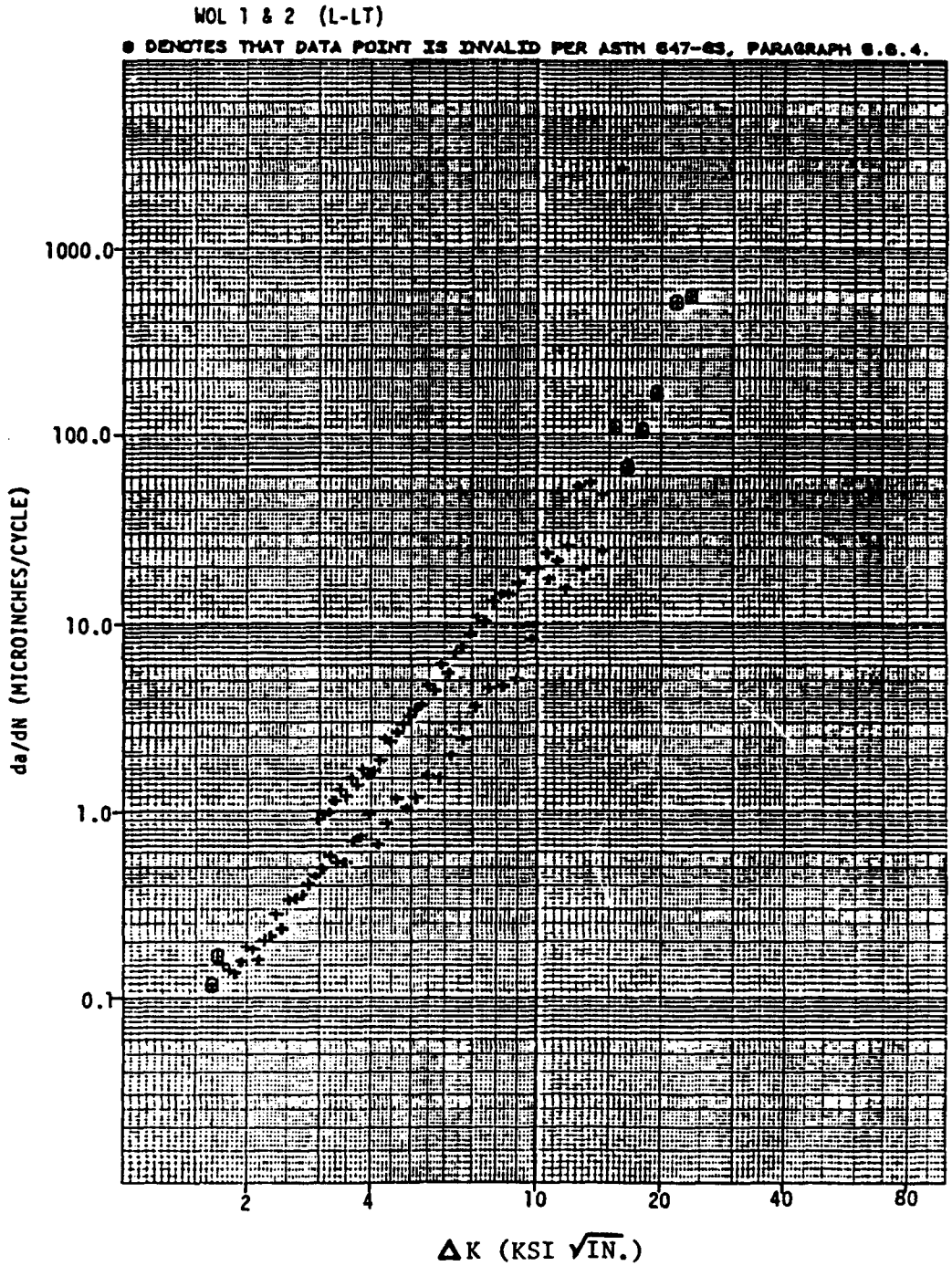


Figure G13 Fatigue Crack Growth Rate Data for IN905XL Forging (WOL Specimen, L-T Orientation, R=0.02, Lab Air). McDonnell Aircraft Mo.

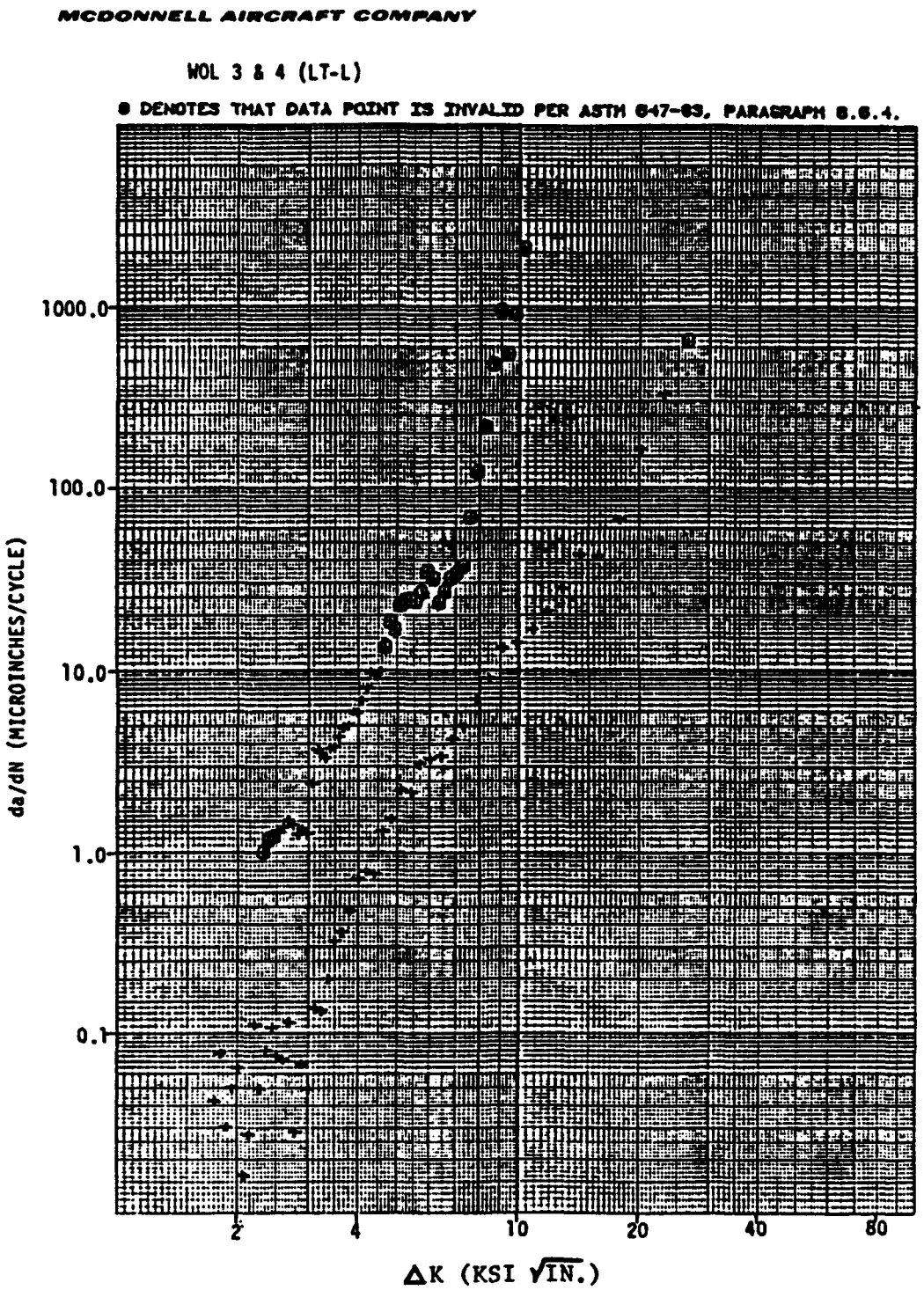


Figure G14 Fatigue Crack Growth Rate Data for IN905XL Forging (WOL Specimen, T-L Orientation, R=0.02 and Lab Air). McDonnell Aircraft Mo.

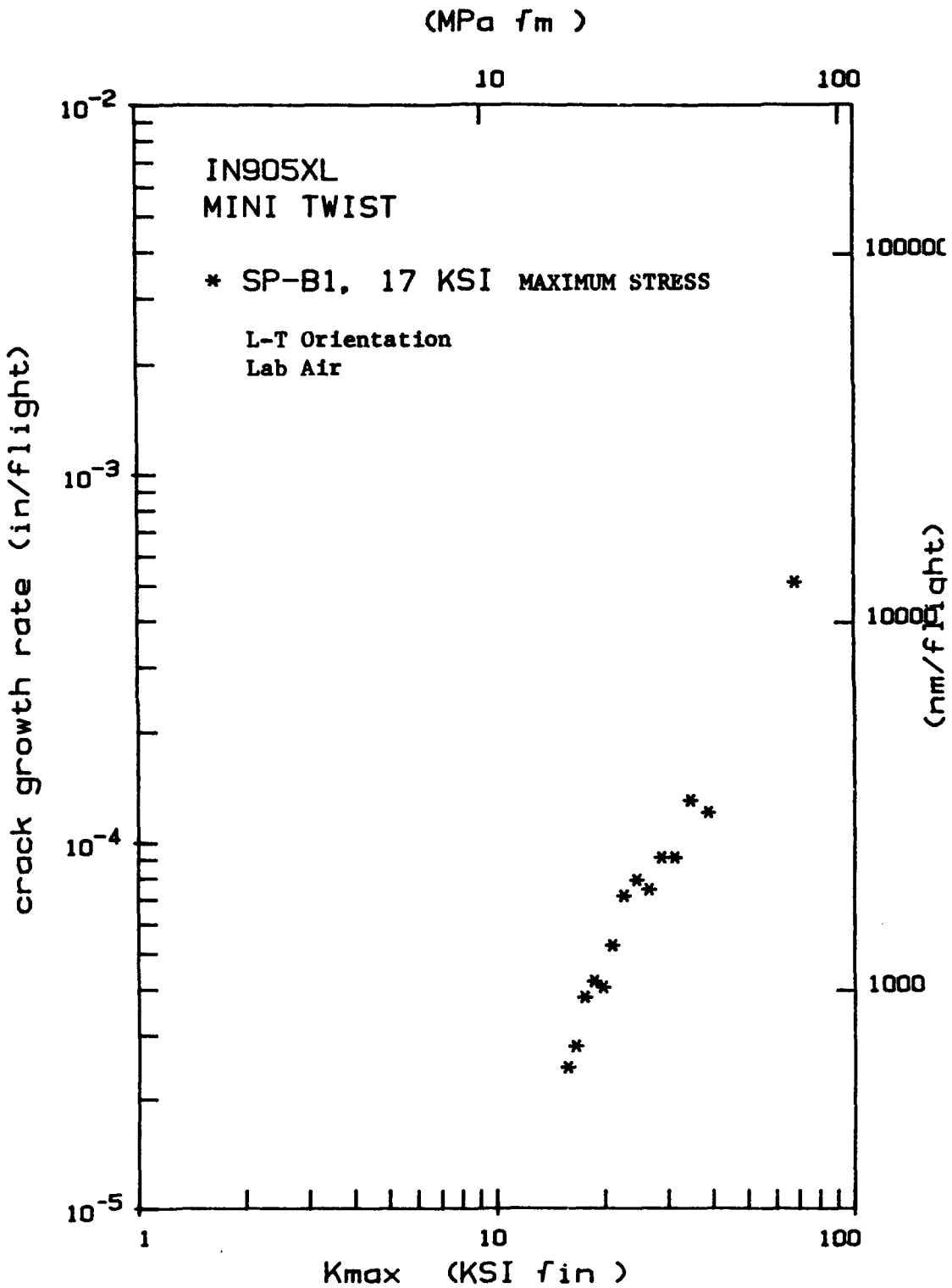


Figure G15 Mini-TWIST Spectrum Fatigue Crack Growth Rata Data. Air Force.

APPENDIX H

AL905XL PRECISION FORGING

INTRODUCTION

The IN905XL and AL905XL are the same alloy but they were produced in different years and production plants. In 1989, Inco Alloys International constructed a production facility to make the AL905XL and other mechanically alloyed aluminum alloys. Production practices through all stages of alloy manufacture were changed to yield greatly improved reproducibility.

The AL905XL forgings were received the second quarter of 1989. All the participants tested the material in the as received condition. Figure H1 shows the geometry of the AL905XL back-up fitting precision forging.

TESTING

Basic mechanical properties (tension, compression, bearing, etc.) were tested according to ASTM standards, unless otherwise specified.

Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 standard. The growth rate a-N data that were generated by the participants (Northrop, McDonnell Aircraft Company and the Air Force) were reduced using a seven-point incremental polynomial method. This involves fitting a second-order polynomial (parabola) to sets of seven successive data points. The data are also checked against size requirements per ASTM E647, Section 7.2. Northrop also performed two constant amplitude fatigue crack growth tests using a K-decreasing method.

Spectrum fatigue crack growth tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

Stress Corrosion tests were performed by Wyman Gordon and the results are shown in tabular form.

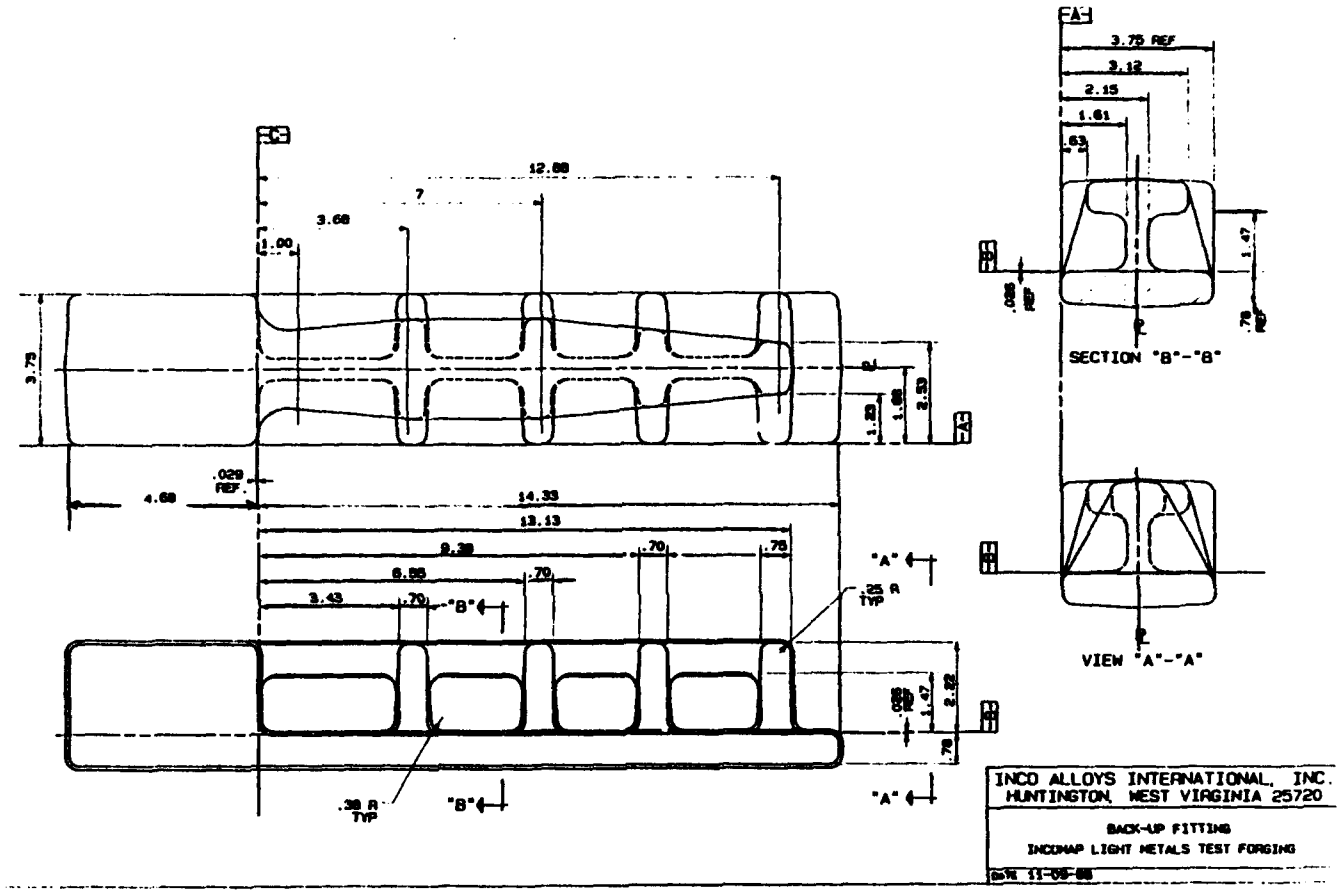


Figure H1 AL905XL Back-up Fitting Precision Forging.

TABLE H1

TENSILE RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	LONG	79.0	70.9		24.0	
			77.3	67.8		16.7	
			76.9	71.7	9.9	22.6	
LTV	RT	LONG	74.7	66.7	12.0		13.4
			74.5	67.5	7.7		13.2
			75.0	67.7	11.6		13.1
MCAIR	RT	LONG	75.0	66.0	11.0	22.1	11.3
			75.5	66.5	11.0	20.0	11.9
			75.0	65.5	11.0	17.8	10.6
WYMAN-GORDON	RT	LONG	75.2	67.8	9.0		
			73.6	62.8	12.0		
			73.2	64.2	11.0		
NASA-LANGLEY	RT	LONG	76.7	67.7	9.0		11.3
			76.1	67.9	9.0		11.3
			77.1	68.7	8.8		11.3
MCDONNELL DOUGLAS HELICOPTER	RT	LONG	73.5	65.7	13.0		
			72.5	64.1	13.0		
			73.3	62.1	12.0		
MARTIN MARIETTA	RT	LONG	75.3	64.3	12.0	18.3	11.6
			75.3	65.0	12.0	23.2	12.0
			72.9	61.2	12.0	24.1	11.6
NORTHROP	RT	LONG	76.1	66.8	10.2	27.8	12.1
			76.0	66.9	7.8	18.9	11.8
			76.1	67.1	8.6	18.3	11.7
		AVERAGE	75.2	66.4	10.6	21.1	11.9
	STANDARD DEVIATION		1.6	2.5	1.6	3.3	0.8

TABLE H2

TENSILE RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	L TRANS	72.0	60.4	8.7	20.8	
			72.5	62.4	8.7	16.6	
			71.1	58.1	8.3	16.7	
LTV	RT	L TRANS	71.8	61.2	8.0		13.1
			72.2	61.3	8.8		12.8
			71.4	58.9	8.4		12.9
MCAIR	RT	L TRANS	72.5	60.0	9.0	13.6	11.2
			72.5	60.0	9.0	16.5	11.2
			73.0	60.0	7.0	13.8	10.5
WYMAN-GORDON	RT	L TRANS	72.0	60.8	8.0		
			72.2	57.2	8.0		
			72.3	60.1	8.0		
NASA-LANGLEY	RT	L TRANS	73.5	60.5	7.5		11.2
			73.5	60.5	7.1		11.2
			73.1	59.2	8.8		11.2
MCDONNELL	RT	L TRANS	68.0	57.0	7.0		
DOUGLAS			67.3	53.7	7.0		
HELICOPTER			71.3	62.6	12.0		
MARTIN	RT	L TRANS	72.4	58.7	11.0	17.6	
MARIETTA			71.8	60.2	11.0	13.9	
			71.7	56.8	12.0	16.1	
NORTHROP	RT	L TRANS	72.9	58.5	8.6	18.3	11.5
			73.9	60.4	6.2	14.4	11.2
			74.4	61.3	9.4	14.4	11.7
		AVERAGE	72.1	59.6	8.6	16.1	11.6
	STANDARD DEVIATION		1.6	2.0	1.5	2.2	0.8

TABLE H3

TENSILE RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	S TRANS	72.6	58.6	6.4	12.3	
			72.5	59.4	5.3	13.8	
			72.4	59.5	3.9	7.8	
LTV	RT	S TRANS	69.1	56.4	3.1		13.3
			71.2	58.4	5.3		13.9
			69.4	56.0	3.1		14.3
MCAIR	RT	S TRANS	70.5	61.5	5.0	7.9	13.4
			71.5	58.5	7.0	12.4	10.8
			71.5	59.0	8.0	14.8	10.9
WYMAN-GORDON	RT	S TRANS	69.6	54.4	6.0		
			70.0	56.0	8.0		
			70.6	56.1	7.0		
NASA-LANGLEY	RT	S TRANS	70.4	56.3	4.9		11.2
			70.6	55.7	4.8		11.2
			70.8	55.3	4.8		11.1
MCDONNELL DOUGLAS HELICOPTER	RT	S TRANS	67.7	54.5	11.0		
			68.0	54.0	10.0		
			68.7	55.6	10.0		
MARTIN MARIETTA	RT	S TRANS	68.3	57.1	4.0	7.0	11.7
			70.2	54.7	5.0	5.5	11.5
			68.4	54.9	5.0	4.0	11.5
NORTHROP	RT	S TRANS	72.4	59.4	7.8	17.8	11.2
			71.1	57.6	7.8	9.7	11.5
			71.5	57.9	7.8	16.5	11.3
		AVERAGE	70.4	57.0	6.3	10.8	11.9
	STANDARD DEVIATION		1.5	2.0	2.2	4.5	1.2

TABLE H4

COMPRESSION RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
LTV	RT	LONG	72.5	11.8
			73.9	11.7
			73.3	12.2
MCAIR	RT	LONG	64.0	9.9
			66.0	10.3
			56.5	9.4
WYMAN-GORDON	RT	LONG	64.4	
			70.0	
			70.6	
NASA-LANGLEY	RT	LONG	70.5	11.5
			70.3	11.5
MARTIN MARIETTA	RT	LONG	70.4	
			72.0	
			70.4	
NORTHROP	RT	LONG	70.9	11.8
			70.4	11.7
			67.1	11.8
		AVERAGE	69.0	11.2
		STANDARD DEVIATION	4.3	0.9

TABLE H5

COMPRESSION RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
NASA-LANGLEY	RT	L TRANS	56.4	11.5
			55.3	11.4
			55.9	11.5
		AVERAGE	55.9	11.5
		STANDARD DEVIATION	0.6	0.1

TABLE H6

COMPRESSION RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
LTV	RT	S TRANS	58.5	11.8
			58.8	11.6
			60.5	12.2
MCAIR	RT	S TRANS	54.0	10.4
			53.5	9.6
			64.0	10.4
WYMAN-GORDON	RT	S TRANS	60.6	
			63.1	
			61.5	
MARTIN MARIETTA	RT	S TRANS	57.1	
			58.2	
			57.1	
NORTHROP	RT	S TRANS	56.9	11.7
			57.8	11.8
			58.1	11.8
		AVERAGE	58.6	11.3
		STANDARD DEVIATION	2.9	0.9

TABLE H7

AMSLER DOUBLE SHEAR RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
LTV	L - S	32.8
		33.1
		36.5
NASA-LANGLEY	L - S	42.3
		41.1
		41.6
MCDONNELL DOUGLAS HELICOPTER	L - S	41.4
		41.5
		41.7
NORTHROP	L - S	39.1
		41.2
		41.9
	AVERAGE	39.5

TABLE H8

PIN SHEAR RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
MCAIR	L - S	42.2
		40.6
		42.0
WYMAN-GORDON	L - S	40.4
		50.0
		40.2
	AVERAGE	42.6
	STANDARD DEVIATION	3.7

TABLE H9

BEARING RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	LONG	1.5	100.7	88.7
			96.0	91.4
MCAIR	LONG	1.5	101.4	
			100.2	
WYMAN-GORDON	LONG	1.5	103.1	
			99.2	
NORTHROP	LONG	1.5	101.6	91.3
			98.5	89.1
		AVERAGE	100.1	90.1
	STANDARD DEVIATION		2.2	1.4

TABLE H10

BEARING RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	LONG	2.0	125.2	101.2
			122.3	100.5
MCAIR	LONG	2.0	129.8	127.8
			133.2	129.4
WYMAN-GORDON	LONG	2.0	127.6	
			122.5	
NORTHROP	LONG	2.0	134.9	107.1
			133.1	106.6
		AVERAGE	128.6	112.1
	STANDARD DEVIATION		5.0	13.1

TABLE H11

FRACTURE TOUGHNESS RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
AIR FORCE	L-T	27.1		VALID
		23.6		VALID
LTV	L-T	28.9		VALID
		27.7		VALID
MCAIR	L-T		27.1	INVALID(1)
		29.9		VALID
WYMAN-GORDON	L-T	29.5		VALID
		28.9		VALID
MCDONNELL DOUGLAS HELICOPTER	L-T		31.1	INVALID(2)
			29.9	INVALID(2)
MARTIN MARIETTA	L-T	31.2		VALID
		30.8		VALID
NORTHROP	L-T	29.1		VALID
			29.9	INVALID(2)
	AVERAGE	28.7	29.5	
	STANDARD DEVIATION	2.2	1.7	

(1): DIFF. BETWEEN SURFACE CRACK LENGTHS > 10% OF AVERAGE CRACK LENGTH
(2): Pmax/Pq EXCEEDED 1.10

TABLE H12

FRACTURE TOUGHNESS RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
AIR FORCE	T-L	22.3		VALID
		21.3		VALID
LTV	T-L	19.0		VALID
		19.1		VALID
MCAIR	T-L	25.7		VALID
		24.0		VALID
WYMAN-GORDON	T-L	22.2		VALID
		20.4		VALID
MCDONNELL DOUGLAS HELICOPTER	T-L		28.2	INVALID(1)
			29.0	INVALID(1)
MARTIN MARIETTA	T-L	23.1		VALID
NORTHROP	T-L	24.1		VALID
		25.4		VALID
	AVERAGE	22.4	28.6	
	STANDARD DEVIATION	2.3	0.6	

(1): Pmax/Pq EXCEEDED 1.10

TABLE H13

FRACTURE TOUGHNESS RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
AIR FORCE	S-L	21.2		VALID
LTV	S-L	20.5		VALID
		20.6		VALID
MCAIR	S-L		24.9	INVALID(1)
WYMAN-GORDON	S-L	21.8		VALID
		20.9		VALID
MARTIN	S-L	22.9		VALID
MARIETTA			23.6	INVALID(2)
	AVERAGE	21.3	24.3	
	STANDARD DEVIATION	0.9	0.9	

(1): DIFF. BETWEEN SURFACE CRACK LENGTHS > 10% OF AVERAGE CRACK LENGTH
(2): PRECRACK LENGTH TOO LONG, a/W=0.6

TABLE H14

FRACTURE TOUGHNESS RESULTS FOR

INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
AIR FORCE	S-T	26.1		VALID
		22.3		VALID
LTV	S-T		21.1	INVALID(1)
		24.6		VALID
MCAIR	S-T		27.2	INVALID(2)
			25.2	INVALID(2)
WYMAN-GORDON	S-T	22.6		VALID
		22.9		VALID
MCDONNELL DOUGLAS HELICOPTER	S-T		29.5	INVALID(3)
		26.2		VALID
MARTIN MARIETTA	S-T	24.2		VALID
		24.2		VALID
NORTHROP	S-T	26.2		VALID
		24.1		VALID
	AVERAGE	24.3	25.8	
	STANDARD DEVIATION	1.5	3.6	

(1): CRACK SYMMETRY OUTSIDE LIMITS
(2): DIFF. BETWEEN SURFACE CRACK LENGTHS > 10% OF AVERAGE CRACK LENGTH
(3): W,B > 2.5(Kq/YS)**2

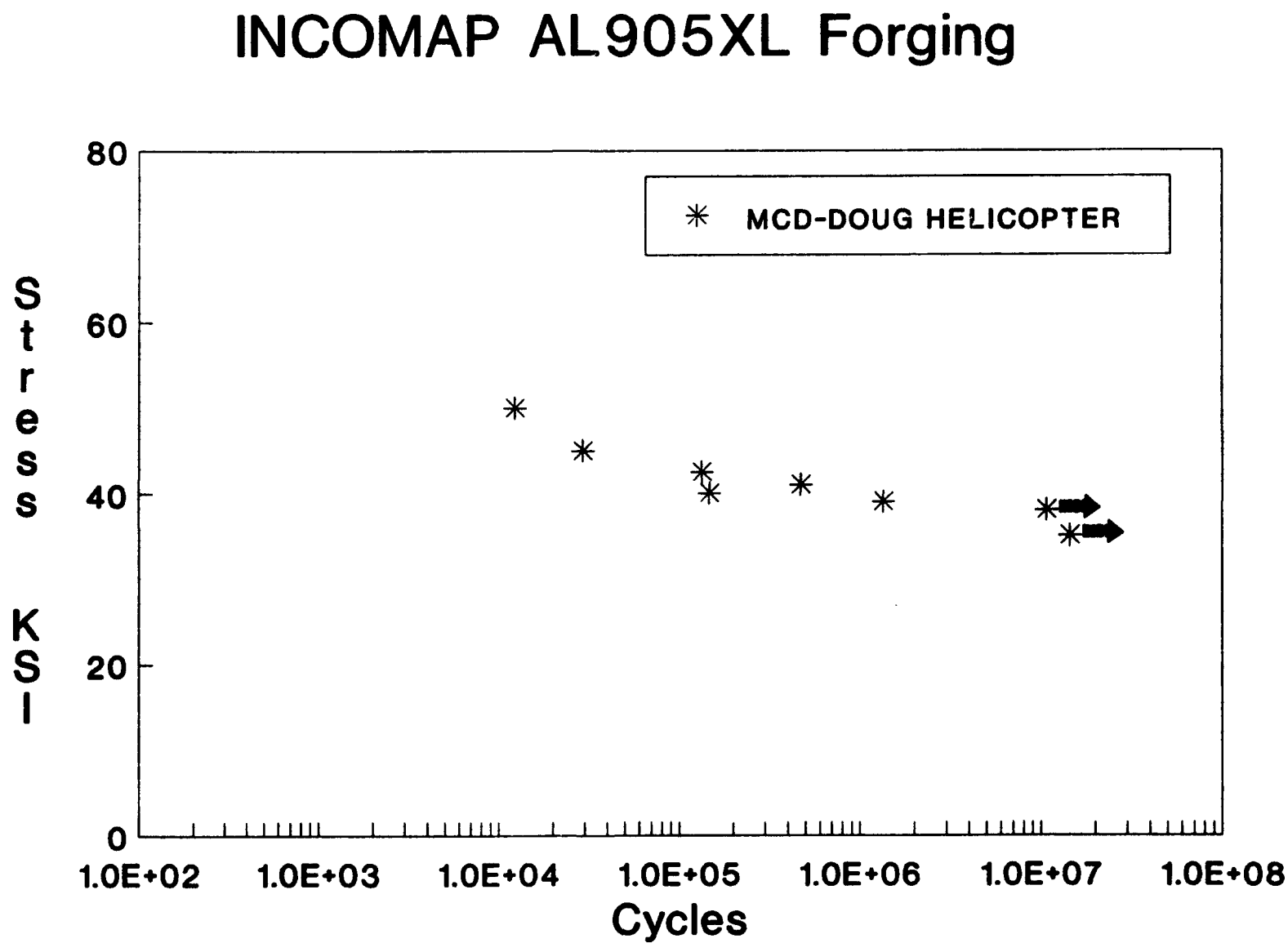


Figure H2 Fatigue Results for AL905XL Forging (Longitudinal Orientation, R=0.1, Kt=1.0). McDonnell Douglas Helicopter.

TABLE H15

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR

INCOMAP AL905XL DIE FORGING

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
MCDONNELL	LONG	50.0	12,300
DOUGLAS		45.0	29,200
HELICOPTER		42.5	133,200
		41.0	467,400
		40.0	146,500
		39.0	1,346,200
		38.0	10,685,100 *
		35.0	14,455,400 *

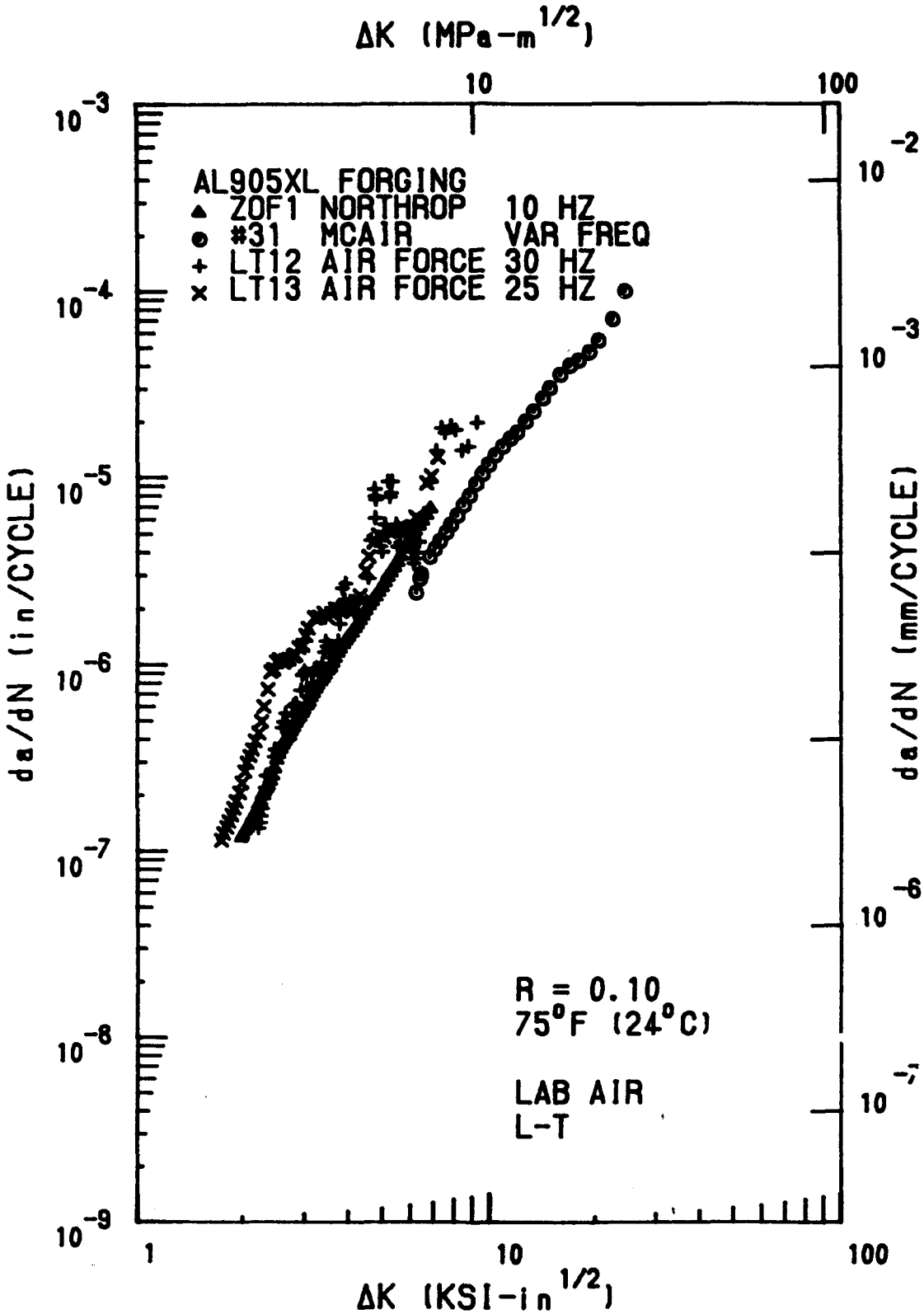


Figure H3 Fatigue Crack Growth Rate Data for AL905XL Forging (L-T Orientation). Northrop, MCAIR, and Air Force.

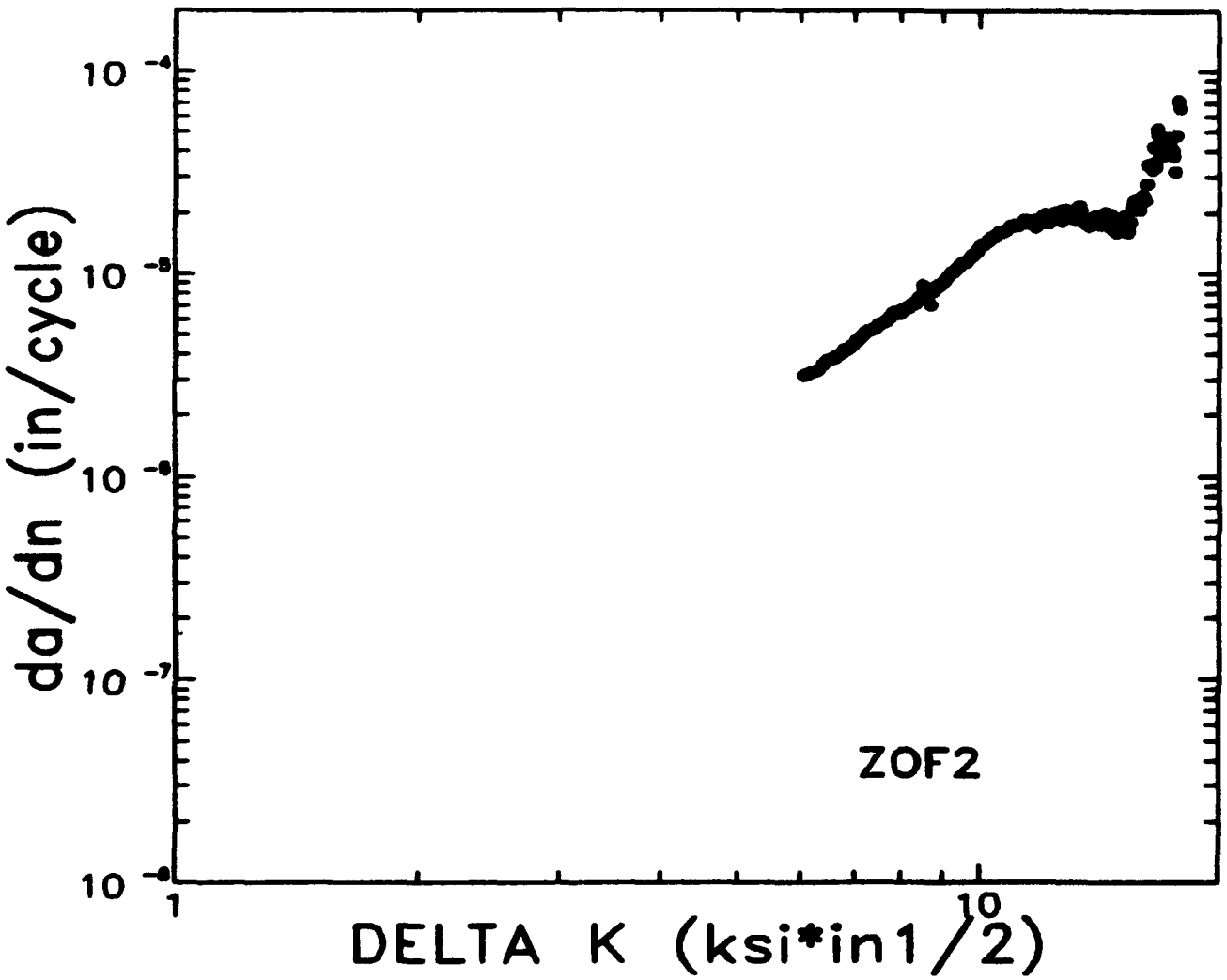


Figure H4 Fatigue Crack Growth Rate Data for AL905XL Forging (K-decreasing method, L-T Orientation, R=0.1, Lab Air, Room Temperature). Northrop.

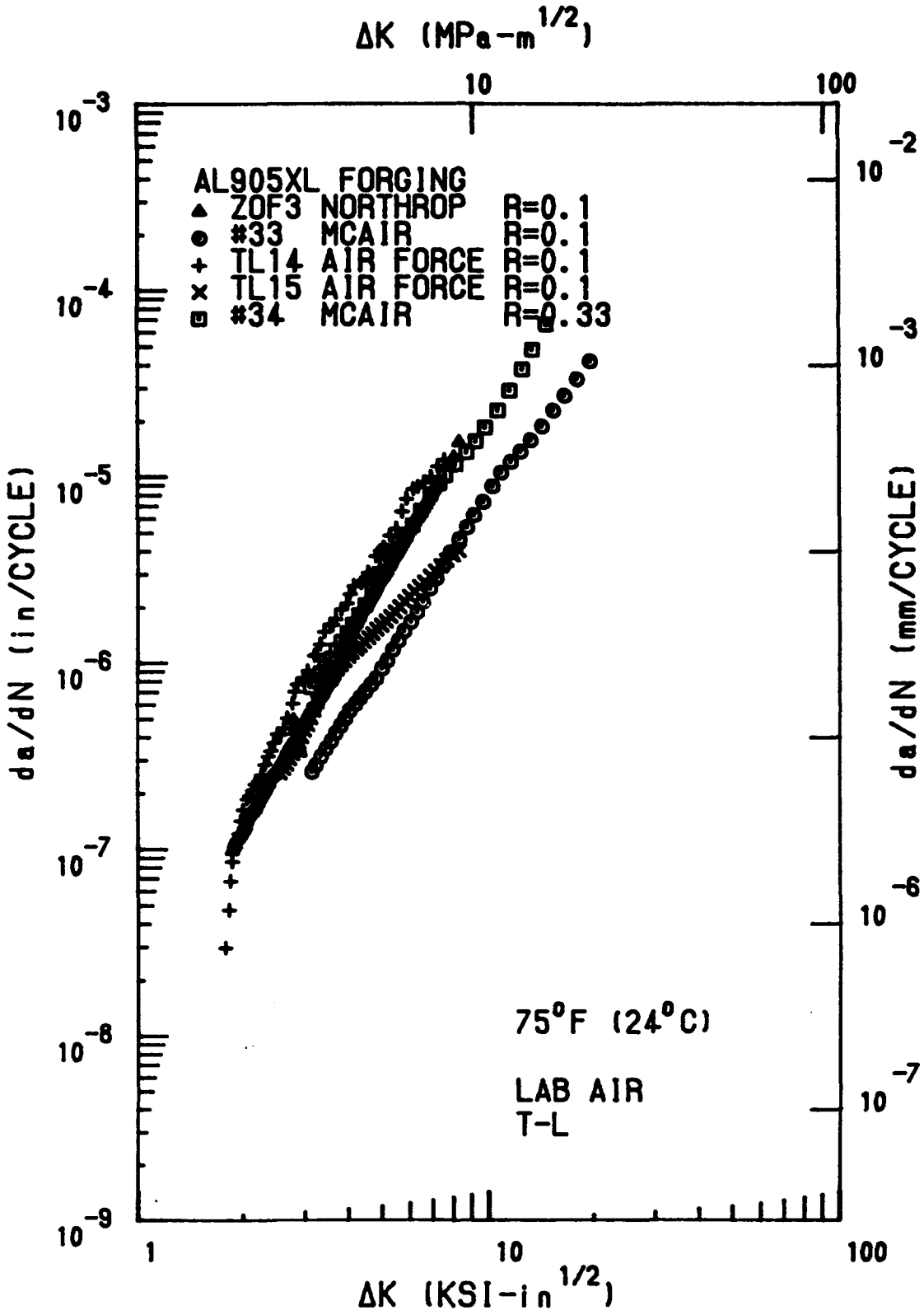


Figure H5 Fatigue Crack Growth Rate Data for AL905XL Forging (T-L Orientation). Northrop 10Hz, MCAIR Var Hz and Air Force 30 Hz.

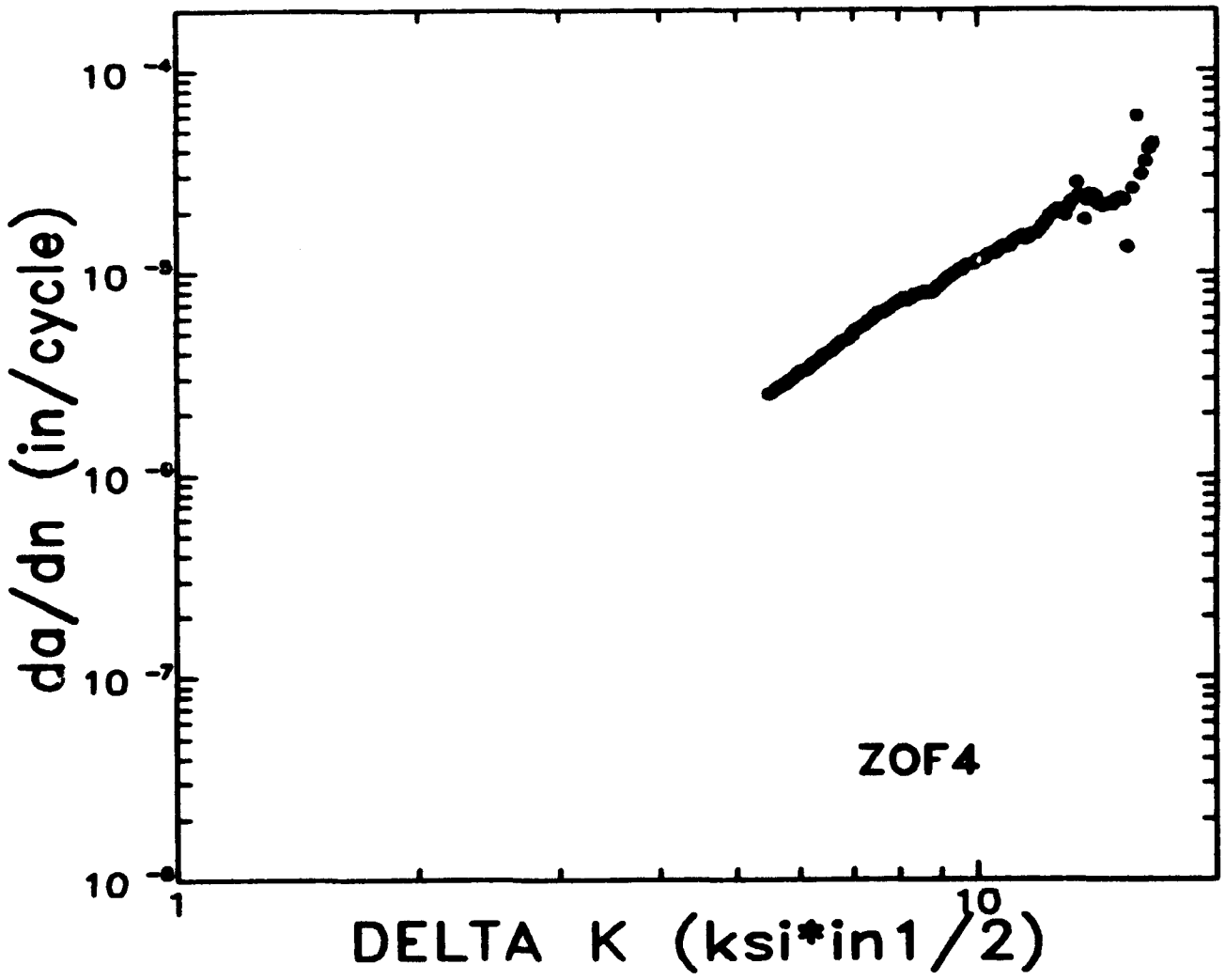


Figure H6 Fatigue Crack Growth Rate Data for AL905XL Forging (K-decreasing method, T-L Orientation, R=0.1 Lab Air, Room Temperature). Northrop.

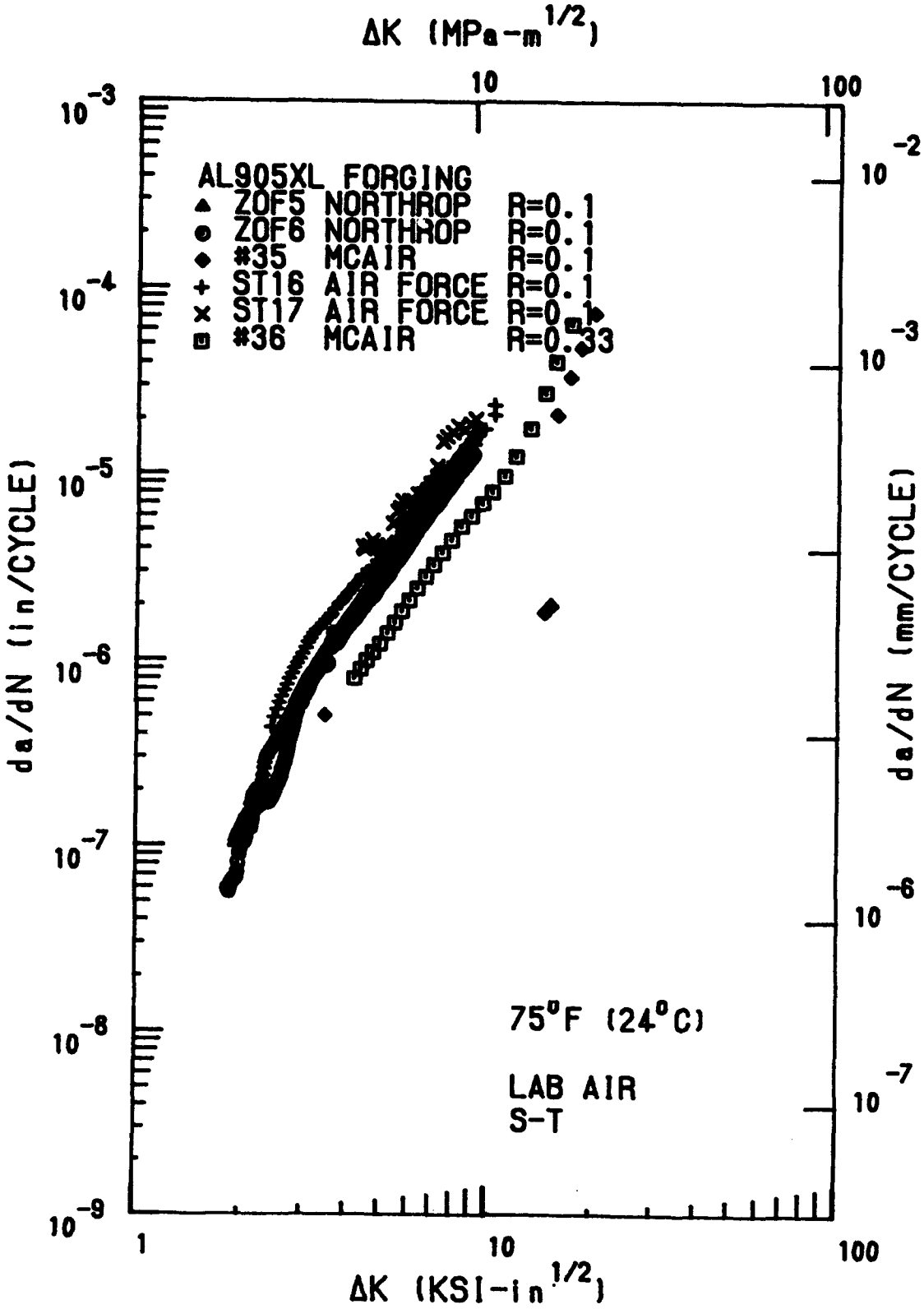


Figure H7 Fatigue Crack Growth Rate Data for AL905XL Forging (S-T Orientation). Nortrhop 10 Hz, MCAIR Var Hz and Air Force #ST16 25Hz, #ST17 30Hz.

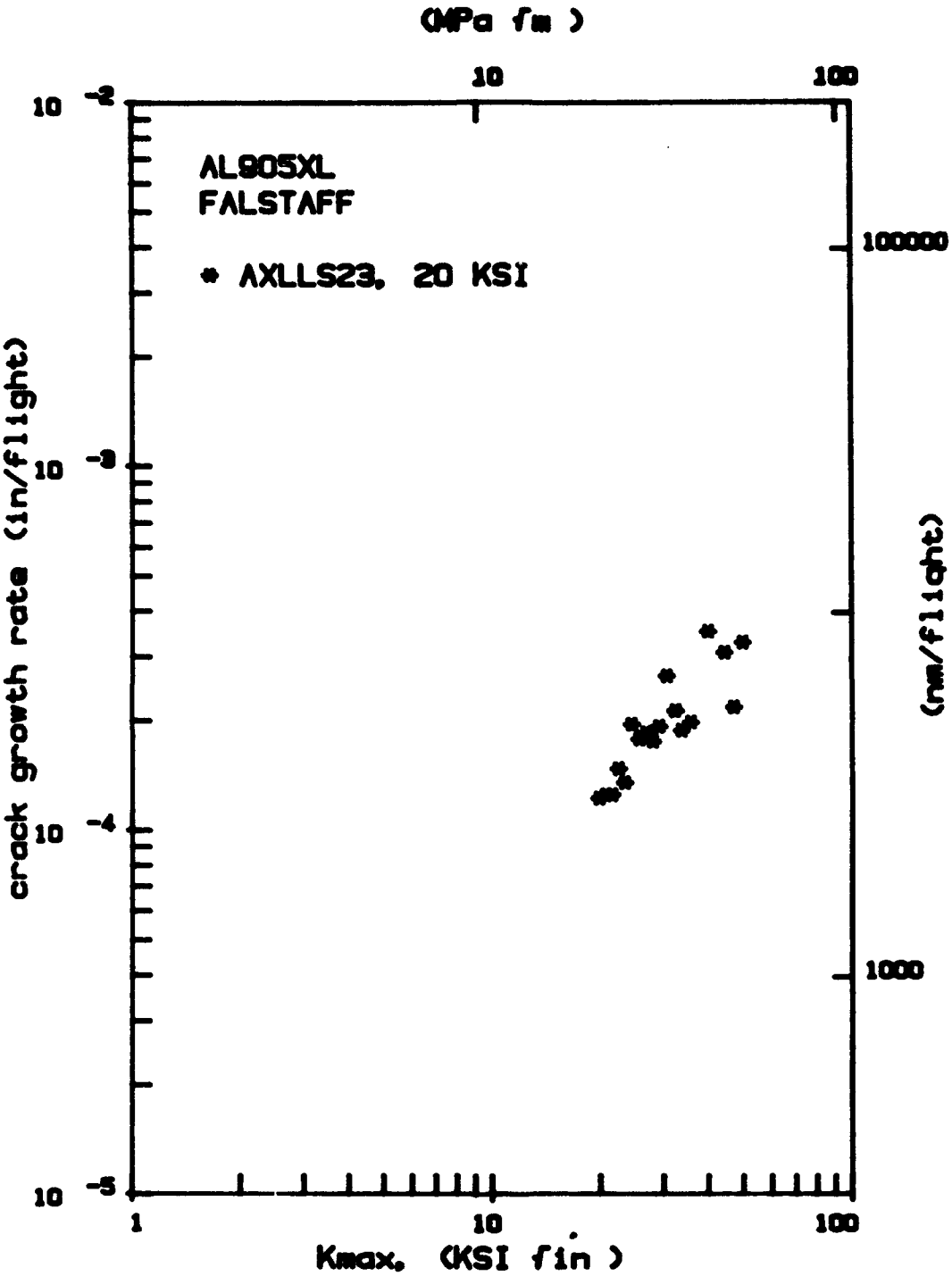


Figure H8 FALSTAFF Spectrum Fatigue Crack Growth Rate Data for AL905XL Forging (L-S Orientation, Maximum Stress = 20 KSI, Lab Air and Room Temperature). Air Force.

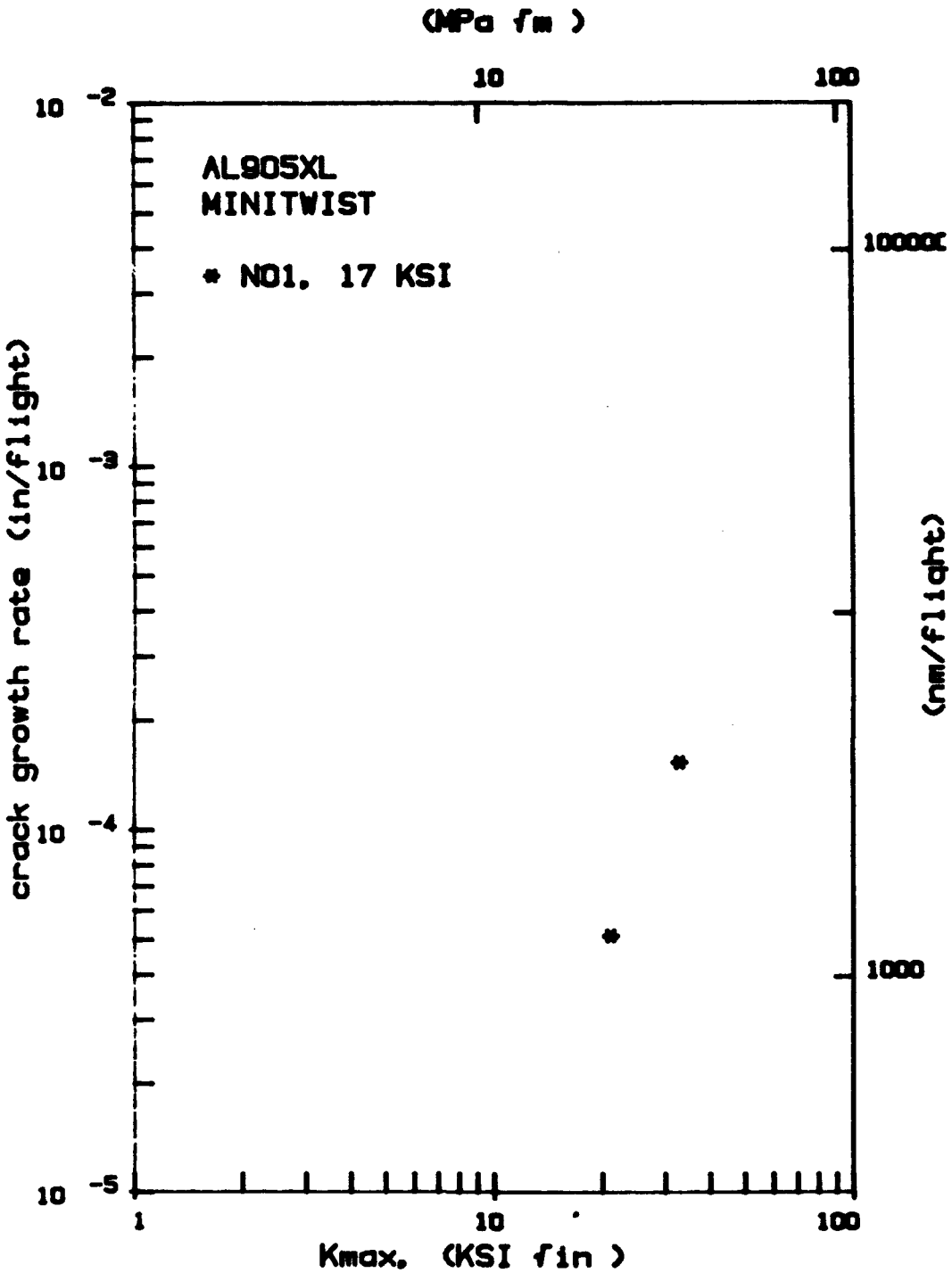


Figure H9 Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for AL905XL Forging (L-S Orientation, Maximum Stress = 16.9 KSI, Lab Air and Room Temperature). Air Force.

TABLE H16

STRESS CORROSION PROPERTIES FOR AL905XL FORGING WYMAN GORDON

ASTM G47
Specimen Size: .125" dia. x 1.80" long
Tested at Dirats Laboratories

S/N	Orientation	Location	Applied Load (ksi)	No. of Days** to Failure
31	S	rail	30	Passed
32	S	rail	30	Passed
33	S	rib	30	Passed
34	S	rail	40	Passed
35	S	rail	40	Passed
36	S	rib	40	Passed
39***	S	rail	50	Passed
40	S	rail	55	Passed

** Minimum 30 days by alternate immersion in 3.5% NaCl.

*** Specimens actually ran 50 days and then was terminated.

APPENDIX I

WELDALITE 049™ RX815 PLATE (2095-T8)
(0.5" X 24" X 48")

INTRODUCTION

The Reynold's 2095-T8 0.5-inch plates were received the first quarter of 1991. The 2095 was received in the T8 condition.

TESTING

Basic mechanical properties (tension, compression, bearing, etc) were tested according to ASTM standards, unless otherwise specified. General Dynamics generated hardness and conductivity data. Constant amplitude fatigue crack growth tests were conducted according to ASTM E647 standard. Northrop Corporation performed constant amplitude fatigue crack growth test using K controlled methods. A T-38 LIF (lead-in-fighter) spectrum test was performed by Northrop Corporation. The spectrum specimen was not precracked but contained a countersunk hole to simulate a crack initiating from a fastener hole. The Army evaluated the ballistic performance of the material. The Army and Northrop Corporation have corrosion tests in progress.

TABLE I1

TENSILE RESULTS AT t/2 LOCATION FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL DOUGLAS, MO	RT	LONG	89.7	85.7	12.0	23.7	10.9
			88.4	84.3	12.0	19.7	10.8
			86.8	81.1	12.0	26.4	11.4
SUNDSTRAND	RT	LONG	89.4	83.4	13.1	19.2	
			89.4	81.2	12.8	20.1	
			89.9	83.7	13.0	19.3	
ARMY-MTL	RT	LONG	88.6	81.9	12.9		10.8
			88.2	81.3	11.7		10.9
			87.7	80.4	12.9		10.4
GENERAL DYNAMICS	RT	LONG	88.1	82.5	10.7	17.1	11.0
			89.2	84.9	11.0	21.3	11.0
			89.1	84.6	10.0	17.6	11.2
NASA-LANGLEY	RT	LONG	88.0	81.2	12.3		11.2
			84.9	75.6	9.6		11.3
			85.0	77.2	9.6		11.3
NORTHROP	RT	LONG	89.7	83.6	13.9		11.5
			88.1	80.6	13.0		11.1
			89.0	81.8	13.6		11.0
AIR FORCE(*)	RT	LONG	89.4	83.1	7.4	27.0	
MCDONNELL DOUGLAS, CA	RT	LONG	84.0	77.9	12.0		
			82.5	76.0	13.0		
			82.7	77.1	10.0		
		AVERAGE	87.6	81.3	11.7	21.1	11.1
	STANDARD DEVIATION		2.3	2.9	1.6	3.5	0.3

(*): TEST SECTION DIAMETER = 0.16"

TABLE I2

TENSILE RESULTS AT t/2 LOCATION FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL DOUGLAS, MO	RT	L TRANS	87.0	80.8	11.0	23.8	11.1
			87.0	81.1	11.0	26.8	10.8
			86.8	80.8	11.0	28.4	10.9
SUNDSTRAND	RT	L TRANS	86.3	79.0	12.0	25.1	
			85.8	78.3	12.7	25.7	
			86.2	79.2	13.4	27.3	
ARMY-MTL	RT	L TRANS	84.7	75.4	14.1		10.8
			85.6	76.8	13.6		10.2
			84.9	75.7	15.0		10.7
GENERAL DYNAMICS	RT	L TRANS	84.0	75.6	11.4	21.9	11.0
			86.1	79.1	11.0	22.1	10.7
			83.8	75.4	11.0	29.7	10.8
NASA-LANGLEY	RT	L TRANS	84.8	76.4		13.1	11.3
			87.2	80.1		9.1	11.1
			87.3	80.3		14.5	11.2
NORTHROP	RT	L TRANS	85.7	75.9	14.7		11.6
			87.0	78.5	14.6		11.6
			85.2	75.3	15.5		11.1
AIR FORCE(*)	RT	L TRANS	88.9	82.4	8.8	31.0	
MCDONNELL DOUGLAS, CA	RT	L TRANS	81.2	71.7	14.5		
			80.5	71.0	14.5		
			81.8	73.0	14.0		
		AVERAGE	85.4	77.4	12.8	23.0	11.0
	STANDARD DEVIATION		2.1	3.1	1.9	6.8	0.4

(*): TEST SECTION DIAMETER = 0.16"

TABLE I3

TENSILE RESULTS AT t/2 LOCATION FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL DOUGLAS	RT	45	77.0	70.6	14.0	36.6	11.4
			77.2	70.1	16.0	39.1	10.9
			76.3	69.2	17.0	39.3	10.8
AIR FORCE(*)	RT	45	75.5	69.0	8.9	41.7	9.9
		AVERAGE	76.5	69.7	14.0	39.2	10.8
	STANDARD DEVIATION		0.8	0.8	3.6	2.1	0.6

(*): TEST SECTION DIAMETER = 0.16"

TABLE I4

TENSILE RESULTS AT t/2 LOCATION FOR REYNOLDS
2095-T8 PLATE (0.5" X [illegible]" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	-321(*)	LONG	108.0	97.5		22.0	12.0
		L TRANS	104.0	93.8	9.6	26.0	11.7
	-150	45	95.4	89.9	12.6	25.0	11.0
	-100(*)	LONG	92.3	86.2	8.8	27.0	11.0
		45	78.7	71.5	11.4	21.6	11.5
		L TRANS	91.9	85.0	8.0	26.0	
	-40	45	90.2	83.1	12.3	25.3	10.1
	0	45	89.2	82.2	11.1	22.6	10.0
	150	45	87.5	82.9	11.4	29.2	11.4
			88.7	84.8	11.9	27.7	11.4
	200	45	78.9	78.1	16.4	47.3	10.7
			79.7	78.6	17.2	47.8	11.5

(*): TEST SECTION DIAMETER = 0.16"

TABLE I5

TENSILE RESULTS AT t/2 LOCATION FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")
(1000 HR EXPOSURE @ 350F)

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	45	70.4	58.3	8.1	22.9	11.2
			70.1	58.0	8.2	23.8	11.3
		AVERAGE	70.3	58.1	8.2	23.3	11.2
	STANDARD DEVIATION		0.2	0.2	0.1	0.6	0.1

TABLE I6

COMPRESSION RESULTS AT t/2 LOCATION FOR REYNOLDS 2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCDONNELL DOUGLAS, MO	RT	LONG	73.8	11.1
			75.3	10.9
			76.1	11.1
SUNDSTRAND	RT	LONG	73.1	12.0
			73.3	11.8
			73.8	11.7
GENERAL DYNAMICS	RT	LONG	77.0	11.3
			79.0	11.6
			80.0	11.4
NASA-LANGLEY	RT	LONG	62.3	11.4
NORTHROP	RT	LONG	70.9	12.2
			72.2	12.1
			76.7	11.9
MCDONNELL DOUGLAS, CA	RT	LONG	68.1	11.0
			69.1	11.5
			69.6	11.7
		AVERAGE	73.1	11.6
		STANDARD DEVIATION	4.5	0.4

TABLE I7

COMPRESSION RESULTS AT t/2 LOCATION FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCDONNELL DOUGLAS, MO	RT	L TRANS	79.5	11.8
			78.5	11.8
			79.1	11.6
SUNDSTRAND	RT	L TRANS	79.4	11.6
			79.0	11.5
			77.6	12.7
GENERAL DYNAMICS	RT	L TRANS	79.2	11.4
			80.6	11.6
			80.4	12.0
NASA-LANGLEY	RT	L TRANS	75.1	11.4
			77.0	11.5
			76.0	11.4
NORTHROP	RT	L TRANS	79.4	11.9
			75.9	12.1
			73.5	12.2
MCDONNELL DOUGLAS, CA	RT	L TRANS	72.9	14.0
			72.3	13.5
			73.2	13.8
		AVERAGE	77.1	12.1
		STANDARD DEVIATION	2.8	0.8

TABLE I8

COMPRESSION RESULTS AT t/2 LOCATION FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCDONNELL DOUGLAS	RT	45	70.5	11.1
			70.3	11.0
			72.2	10.9
		AVERAGE	71.0	11.0
		STANDARD DEVIATION	1.0	0.1

TABLE I9

COMPRESSION RESULTS AT t/2 LOCATION FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE ULT STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
ARMY-MTL	RT	LONG	111.2	
			107.2	
			110.7	
		AVERAGE	109.7	
		STANDARD DEVIATION	2.2	
ARMY-MTL	RT	L TRANS	115.4	
			119.0	
			114.7	
		AVERAGE	116.4	
		STANDARD DEVIATION	2.3	

TABLE I10

PIN SHEAR RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
ARMY-MTL	LONG	49.5
		48.8
		49.7
NORTHROP	LONG	45.7
		46.6
		46.0
	AVERAGE	47.7
	STANDARD DEVIATION	1.8

TABLE I11

RIVET SHEAR RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
ARMY-MTL	L TRANS	49.0
		48.5
		47.7
	AVERAGE	48.4
	STANDARD DEVIATION	0.7

TABLE I12

TORSIONAL SHEAR RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
SUNDSTRAND	LONG	47.1
		46.4
		45.1
	AVERAGE	46.2
	STANDARD DEVIATION	1.0
SUNDSTRAND	L TRANS	45.4
		45.1
		46.8
	AVERAGE	45.8
	STANDARD DEVIATION	0.9

TABLE I13

AMSLER DOUBLE SHEAR RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NASA-LANGLEY	L-S	44.4
		46.3
		47.7
	AVERAGE	46.1
	STANDARD DEVIATION	1.7
NASA-LANGLEY	T-S	47.5
		45.6
		45.0
	AVERAGE	46.0
	STANDARD DEVIATION	1.3

TABLE I14

BEARING RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL DOUGLAS, MO	LONG	1.5	128.0	106.0
			119.0	100.0
			122.0	103.0
NASA-LANGLEY	LONG	1.5	123.1	99.2
			119.4	98.4
			120.6	100.3
MCDONNELL DOUGLAS, CA	LONG	1.5	120.2	102.1
			121.1	101.9
			121.1	101.5
		AVERAGE	121.6	101.4
		STANDARD DEVIATION	2.7	2.3

TABLE I15

BEARING RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL DOUGLAS, MO	45	1.5	128.0	106.0
			131.0	110.0
			135.0	111.0
		AVERAGE	131.3	109.0
		STANDARD DEVIATION	3.5	2.6

TABLE I16

BEARING RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL DOUGLAS, MO	L TRANS	1.5	125.0	106.0
			129.0	105.0
			131.0	107.0
NASA-LANGLEY	L TRANS	1.5	122.2	98.4
			124.2	101.6
			124.7	99.4
MCDONNELL DOUGLAS, CA	L TRANS	1.5	121.7	100.4
			121.7	98.3
			120.5	97.3
		AVERAGE	124.4	101.5
		STANDARD DEVIATION	3.5	3.6

TABLE I17

BEARING RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL DOUGLAS, MO	LONG	2.0	164.0	128.0
			159.0	131.0
			158.0	130.0
NASA-LANGLEY	LONG	2.0		114.5
			148.0	111.0
			146.7	112.3
NORTHROP	LONG	2.0	156.4	116.5
			154.3	114.3
			153.6	113.7
MCDONNELL DOUGLAS, CA	LONG	2.0	157.5	119.6
			156.5	124.1
			157.4	120.2
		AVERAGE	155.6	119.6
		STANDARD DEVIATION	4.9	7.1

TABLE I18

BEARING RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL DOUGLAS, MO	45	2.0	172.0	141.0
			166.0	136.0
			169.0	138.0
		AVERAGE	169.0	138.3
		STANDARD DEVIATION	3.0	2.5

TABLE I19

BEARING RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL DOUGLAS, MO	L TRANS	2.0	163.0	132.0
			160.0	137.0
			166.0	137.0
NASA-LANGLEY	L TRANS	2.0		116.4
			154.5	116.6
			154.5	116.1
NORTHROP	L TRANS	2.0	158.7	121.1
			160.4	120.6
			160.2	128.5
MCDONNELL DOUGLAS, CA	L TRANS	2.0	155.4	122.1
			158.9	124.6
			156.8	122.9
		AVERAGE	158.9	124.6
		STANDARD DEVIATION	3.6	7.5

TABLE I20

FRACTURE TOUGHNESS RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MCDONNELL DOUGLAS	L-T		26.3	(1)
			22.8	(2)
SUNDSTRAND	L-T	30.2		
		30.0		
ARMY-MTL	L-T	26.8		
			37.3	(2),(3)
			33.3	(2)
			36.4	(2),(3)
			33.7	(2)
GENERAL DYNAMICS	L-T		33.5	(2)
			30.7	(2)
			30.1	(2)
NASA-LANGLEY	L-T	27.0		
			25.3	(2)
NORTHROP	L-T		37.7	(3)
			40.4	(3)
			43.3	(3)
	AVERAGE	28.5	33.1	
	STANDARD DEVIATION	1.8	6.0	

(1): INVALID DUE TO SURFACE CRACK LENGTH MEASUREMENTS EXCEEDED 10% OF AVERAGE CRACK LENGTH

(2): INVALID DUE TO Pmax/Pq > 1.10

(3): INVALID DUE TO a & B > 2.5(Kq/YS)**2

TABLE I21

FRACTURE TOUGHNESS RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MCDONNELL DOUGLAS	T-L		25.8	(1)
		29.6		
SUNDSTRAND	T-L	29.1		
		29.0		
ARMY-MTL	T-L		40.2	(2),(3)
			35.6	(2)
			35.0	(2),(3)
			35.9	(2),(3)
			36.9	(2),(3)
			35.5	(3)
GENERAL DYNAMICS	T-L	31.4		
			29.4	(2)
			29.2	(2)
NASA-LANGLEY	T-L	24.4		
NORTHROP	T-L		38.7	(3)
			38.3	(3)
			37.9	(3)
	AVERAGE	28.7	34.9	
	STANDARD DEVIATION	2.6	4.4	

(1): INVALID DUE TO SURFACE CRACK LENGTH MEASUREMENTS EXCEEDED 10% OF AVERAGE CRACK LENGTH

(2): INVALID DUE TO Pmax/Pq > 1.10

(3): INVALID DUE TO a & B > 2.5(Kq/YS)**2

TABLE I22

FRACTURE TOUGHNESS RESULTS FOR REYNOLDS
2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MCDONNELL	45		25.4	(1)
DOUGLAS		23.6		

(1): INVALID DUE TO SURFACE CRACK LENGTH MEASUREMENTS EXCEEDED 10% OF AVERAGE CRACK LENGTH

TABLE I23

Hardness & Conductivity Results for 2095-T8
0.5 Inch Plate. General Dynamics, CA

Alloy/Product Form	Hardness (R_B Scale)	Conductivity (% IACS)
Weldalite 2095-T8 0.50 Inch Plate	See Figure	22 (a) 17 (b)
(a) as received mill surface (b) machined surface		

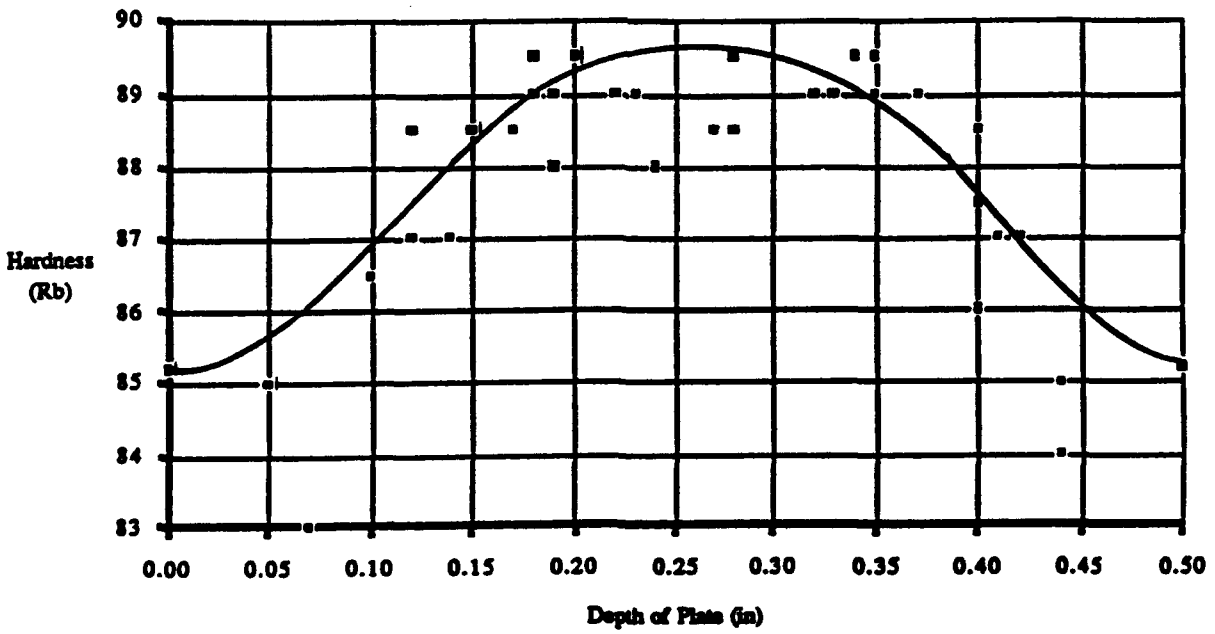
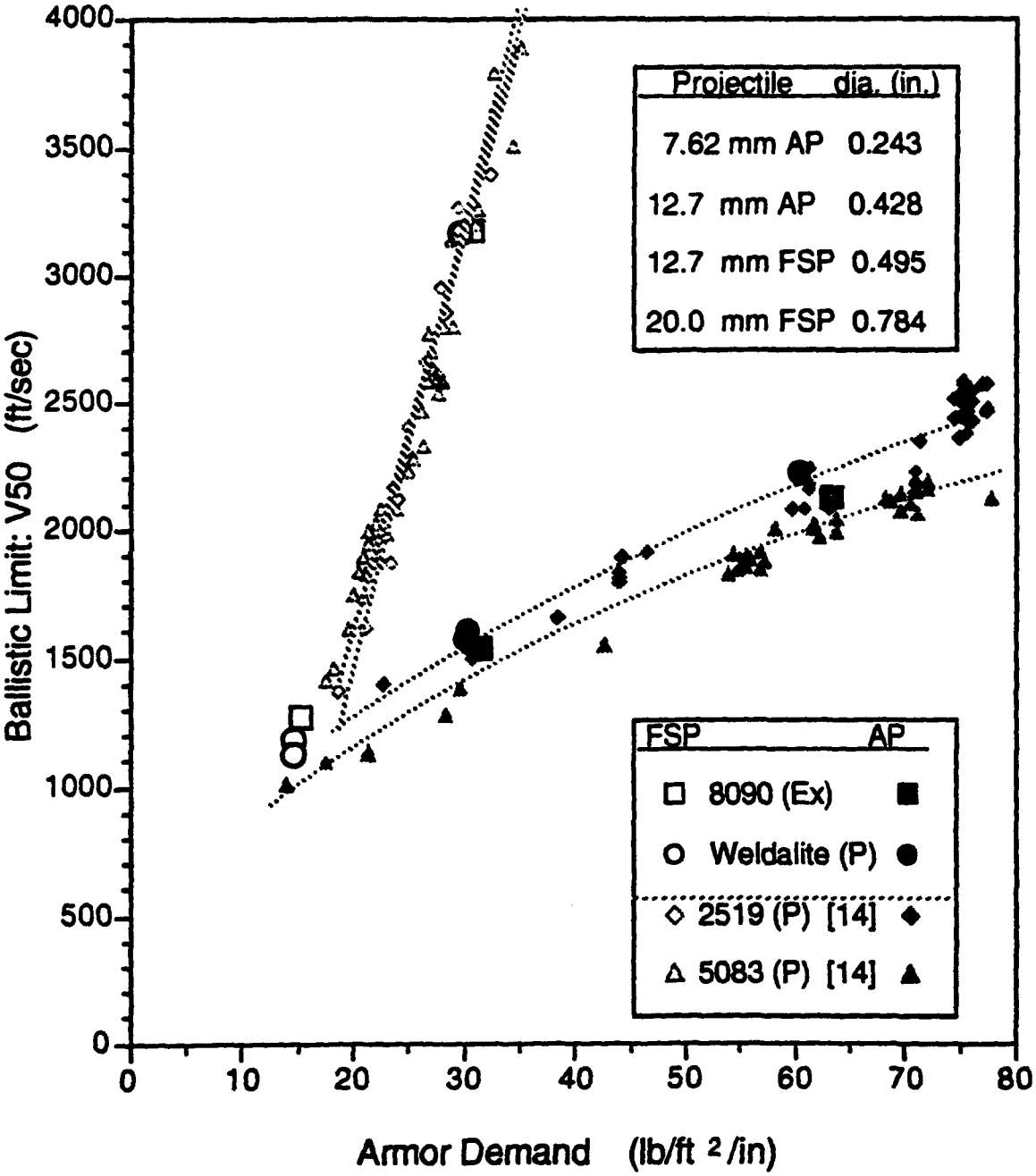


Figure I1. Hardness profile through 2095-T8
0.5 Inch Plate. General Dynamics, CA.



Both 8090 extrusions (Ex) and Weldalite plates (P) provided enhanced ballistic performance over 2519 and 5083 Al alloys. The V_{50} ballistic limits against AP and FSP projectiles at 0° obliquity are plotted versus Armor demand. The Armor demand is defined as the (density x thickness) / projectile diameter. The ballistic data for different caliber projectiles superimpose on single curves for either AP or FSP projectiles when plotted against armor demand. This technique allows designers to evaluate ballistic performance as a function of projectile type rather than for individual munitions. The AP and FSP projectile diameters are included as inserts in the plot. Ballistic data for 2519 and 5083 are included as the high and low ends of aluminum alloys currently being considered for structural armor applications The lower set of 8090 and Weldalite data points for both AP and FSP projectiles represent 0.5 inch ballistic targets. The second series of data points for each projectile type represent stacked plates to provide 1.0 inch thickness. The ballistic limits of both AL-Li alloys are attributed to the witness plate being perforated by spalling rather than by the projectile exiting the target.

Figure I2. Ballistic limit (V_{50}) verses Armor Demand at 0° obliquity against Armor Piercing (AP) and Fragment Simulating Projectiles (FSP). Army.

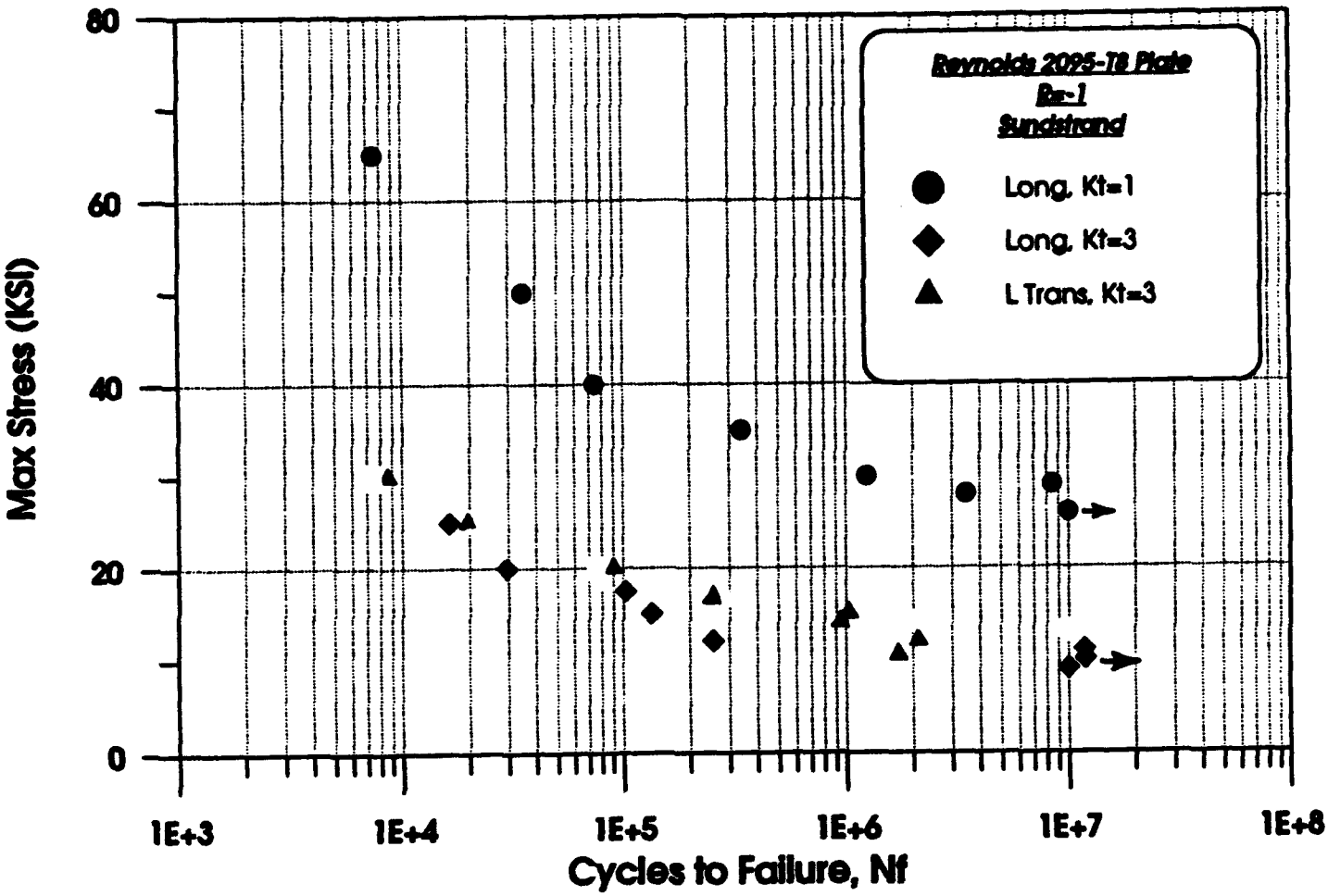


Figure I3. Fatigue Results for 2095-T8 0.5 Inch Plate (R =-1, Kt =1.0 and Kt =3.0) and 2095-T6 (R =-1 and Kt =3)

TABLE I24

FATIGUE RESULTS WITH R=-1.0 AND Kt=1.0 FOR
REYNOLDS 2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SUNDSTRAND	LONG	65.0	7,500
		50.0	34,950
		40.0	73,820
		35.0	338,910
		30.0	1,240,950
		29.0	8,461,080
		28.0	3,489,830
		26.0	10,000,000 *

(*): RUN OUT

TABLE I25

FATIGUE RESULTS WITH R=-1.0 AND Kt=3.0 FOR
REYNOLDS 2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SUNDSTRAND	LONG	25.0	16,300
		20.0	29,460
		17.5	102,580
		15.0	133,920
		12.0	253,810
		11.0	11,796,000 *
		10.0	11,913,000 *
		9.0	10,000,000 *

(*): RUN OUT

TABLE I26

FATIGUE RESULTS WITH R=-1.0 AND Kt=3.0 FOR
REYNOLDS 2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
SUNDSTRAND	L TRANS	30.0	8,620
		25.0	19,690
		20.0	90,000
		17.0	254,530
		15.0	1,024,210
		14.0	943,790
		12.0	2,110,280
		10.5	1,715,500

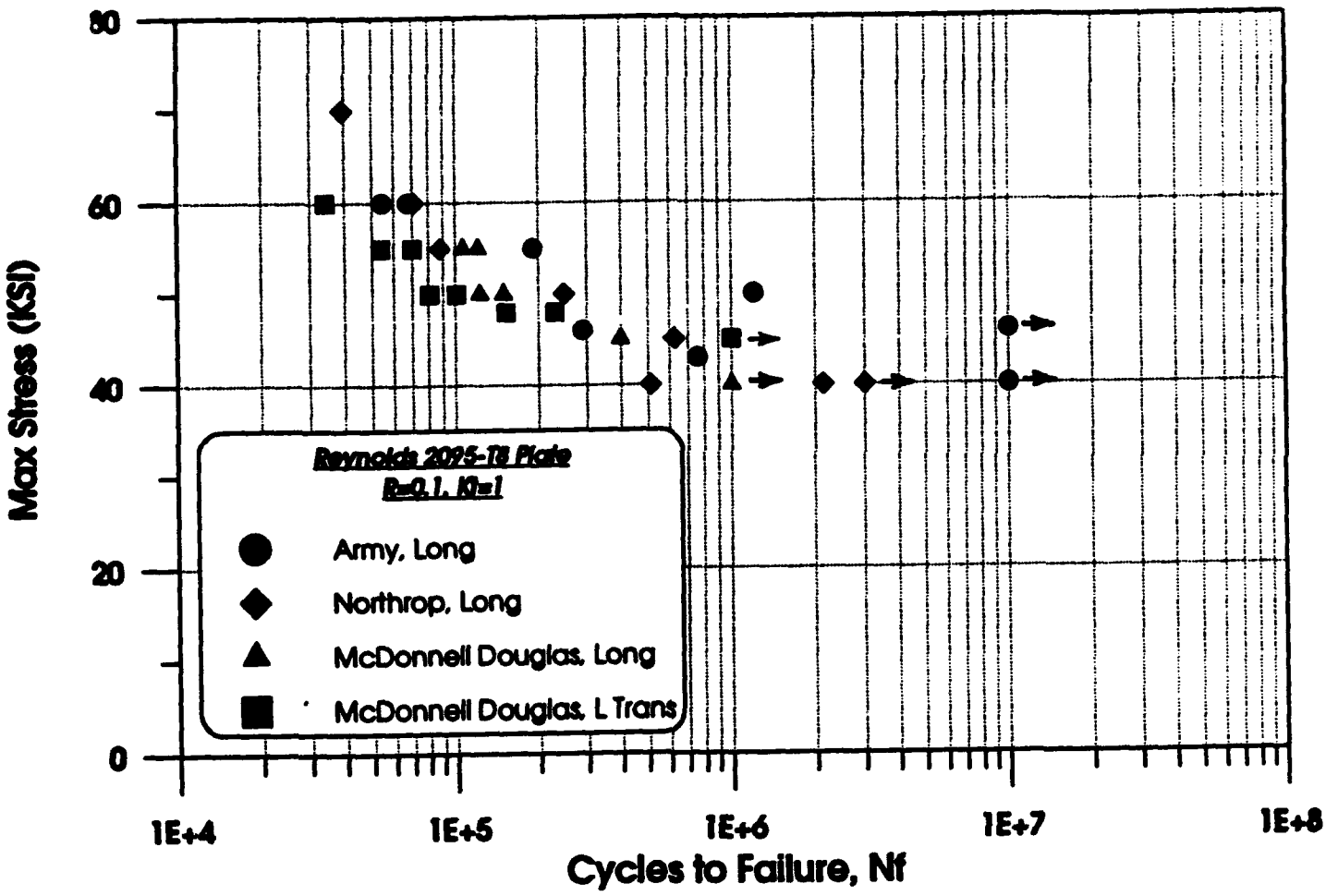


Figure I4. Fatigue Results for 2095-T8 0.5 Inch Plate (R =0.1 and Kt =1.0)

TABLE I27

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR
REYNOLDS 2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
ARMY-MTL	LONG	60.0	54,220
		60.0	67,580
		55.0	191,520
		50.0	1,205,760
		46.0	290,042
		46.0	10,026,880 *
		43.0	754,000
		40.0	10,010,000 *
NORTHROP	LONG	70.0	39,420
		60.0	70,550
		55.0	87,944
		50.0	247,950
		45.0	623,760
		40.0	511,870
		40.0	3,000,000 *
		40.0	2,135,840
MCDONNELL DOUGLAS, CA	LONG	55.0	106,010
		55.0	120,950
		50.0	149,620
		50.0	122,970
		45.0	398,910
		45.0	398,300
		40.0	1,000,000 *
		40.0	1,000,000 *
MCDONNELL DOUGLAS, CA	L TRANS	60.0	34,170
		55.0	53,870
		55.0	69,800
		50.0	101,060
		50.0	80,470
		48.0	153,080
		48.0	229,570
		45.0	1,000,000 *
		45.0	1,000,000 *

(*): RUN-OUT

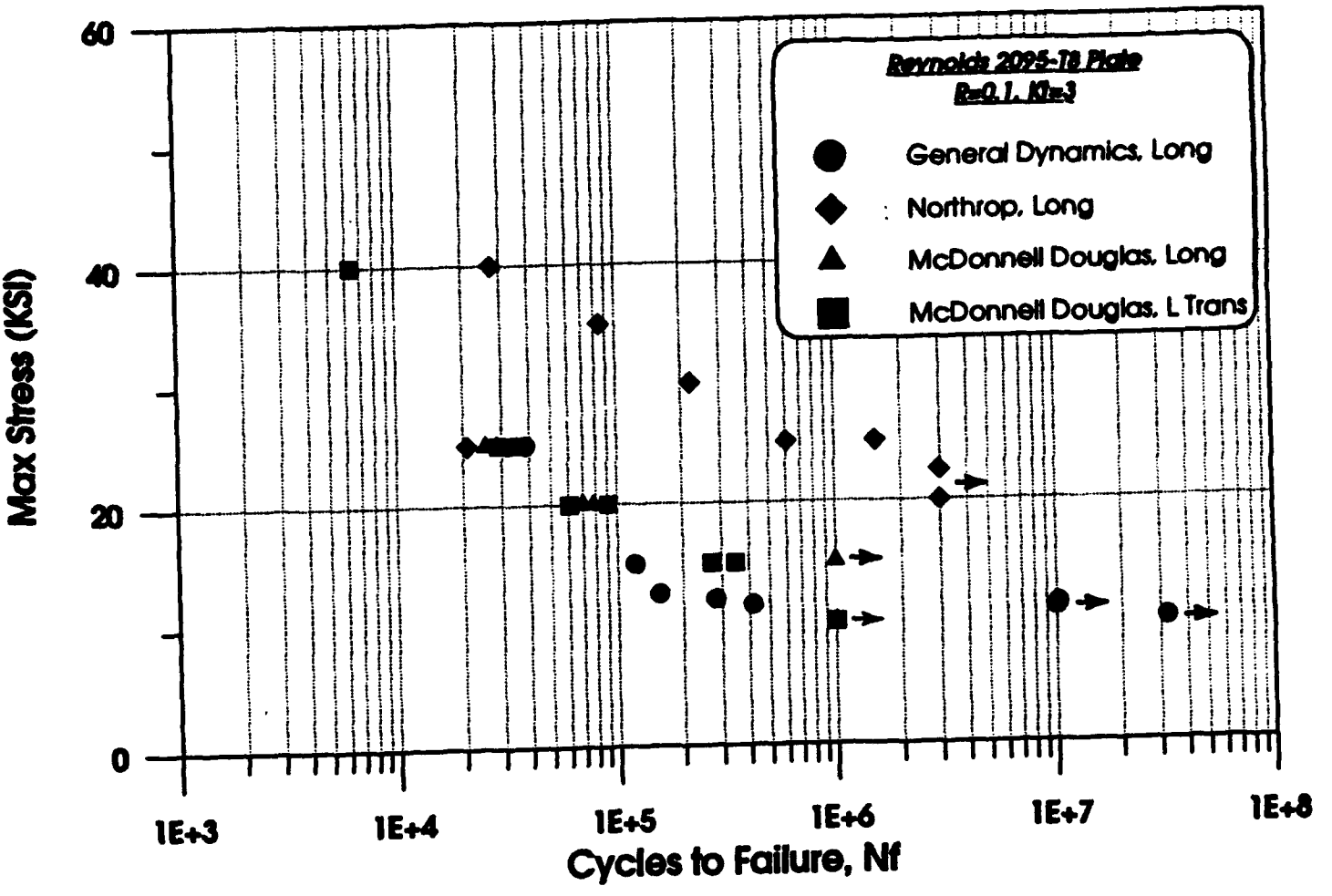


Figure I5. Fatigue Results for 2095-T8 0.5 Inch Plate (R = 0.1 and Kt = 3)

TABLE I28

FATIGUE RESULTS WITH R=0.1 AND Kt=3.0 FOR
REYNOLDS 2095-T8 PLATE (0.5" X 24" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
GENERAL DYNAMICS	LONG	25.0	38,200
		15.0	120,600
		12.5	155,500
		12.0	281,900
		11.5	417,100
		11.3	10,240,300 *
		11.0	10,000,000 *
		10.0	32,313,000 *
NORTHROP	LONG	40.0	27,530
		35.0	84,820
		30.0	220,840
		25.0	20,830
		25.0	605,470
		25.0	1,535,480
		22.5	3,000,000 *
		20.0	3,000,000 *
MCDONNELL DOUGLAS, CA	LONG	25.0	28,540
		25.0	25,320
		20.0	78,410
		20.0	69,950
		15.0	1,000,000 *
		15.0	1,000,000 *
		10.0	1,000,000 *
		10.0	1,000,000 *
MCDONNELL DOUGLAS, CA	L TRANS	40.0	6,331
		25.0	28,860
		25.0	32,940
		20.0	60,520
		20.0	91,030
		15.0	348,180
		15.0	271,490
		10.0	1,000,000 *
		10.0	1,000,000 *

(*): RUN-OUT

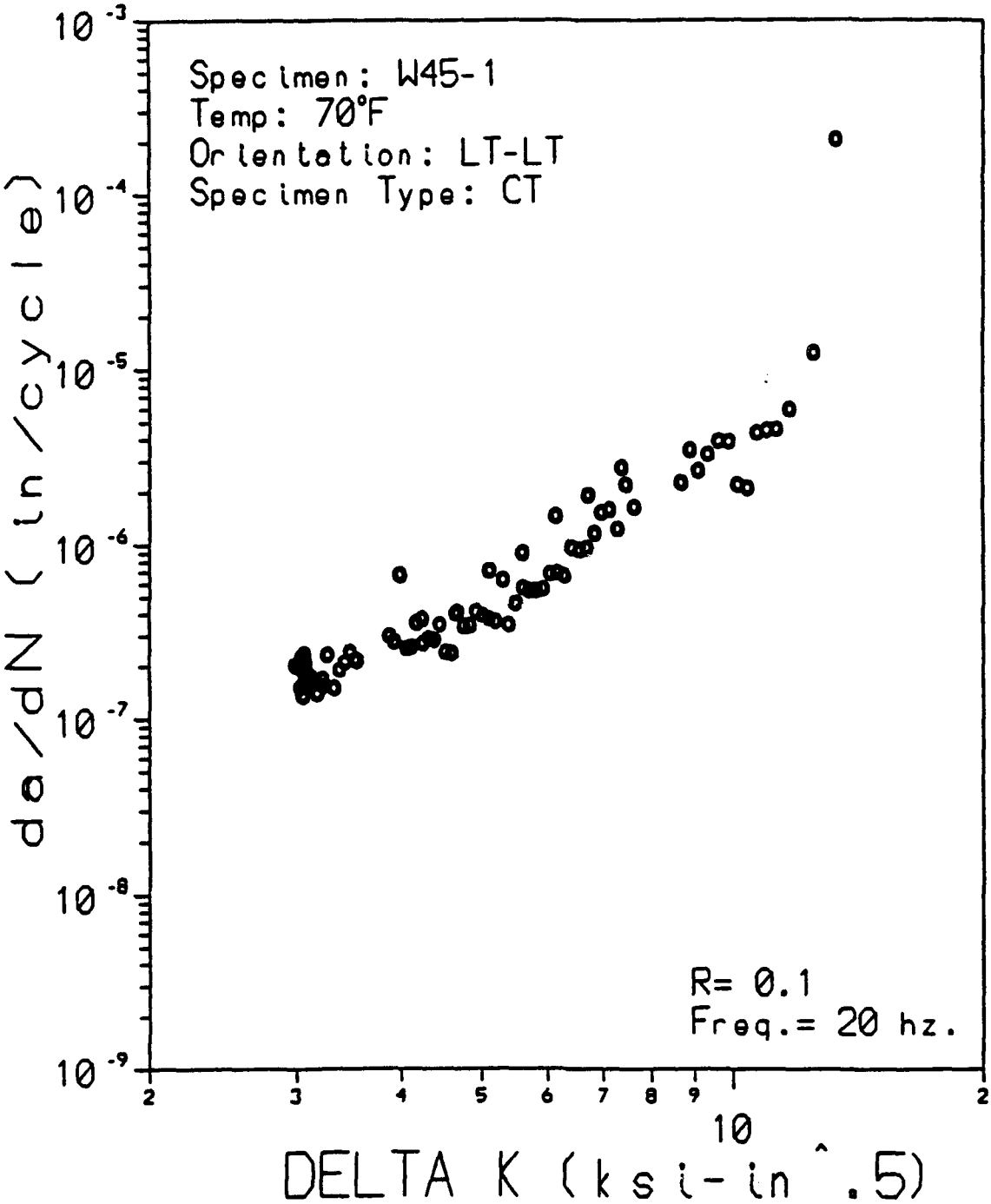


Figure I6. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Plate (LT-LT orientation, Specimen W45-1). Air Force.

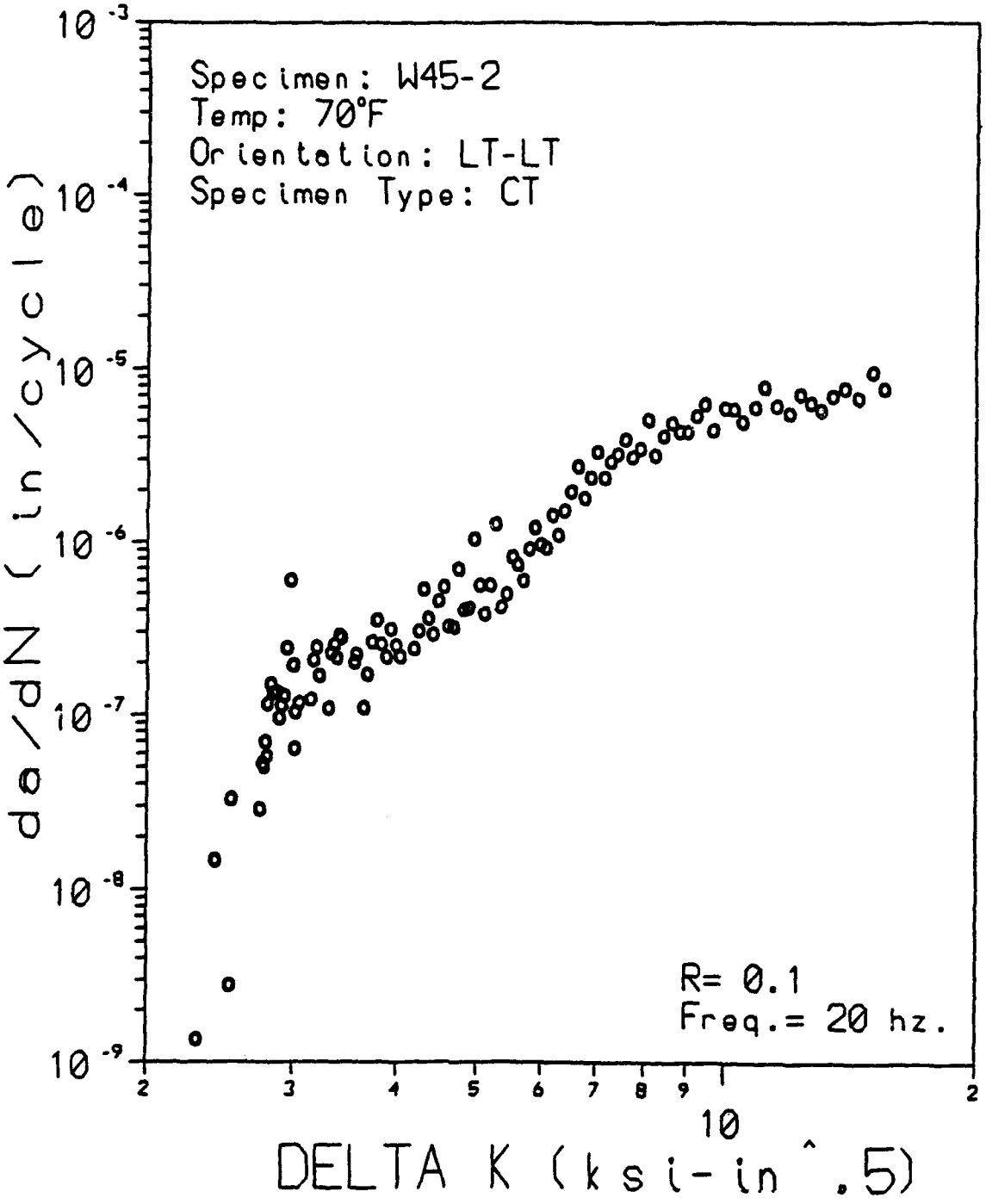


Figure I7. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Plate (LT-LT orientation, Specimen W45-2). Air Force.

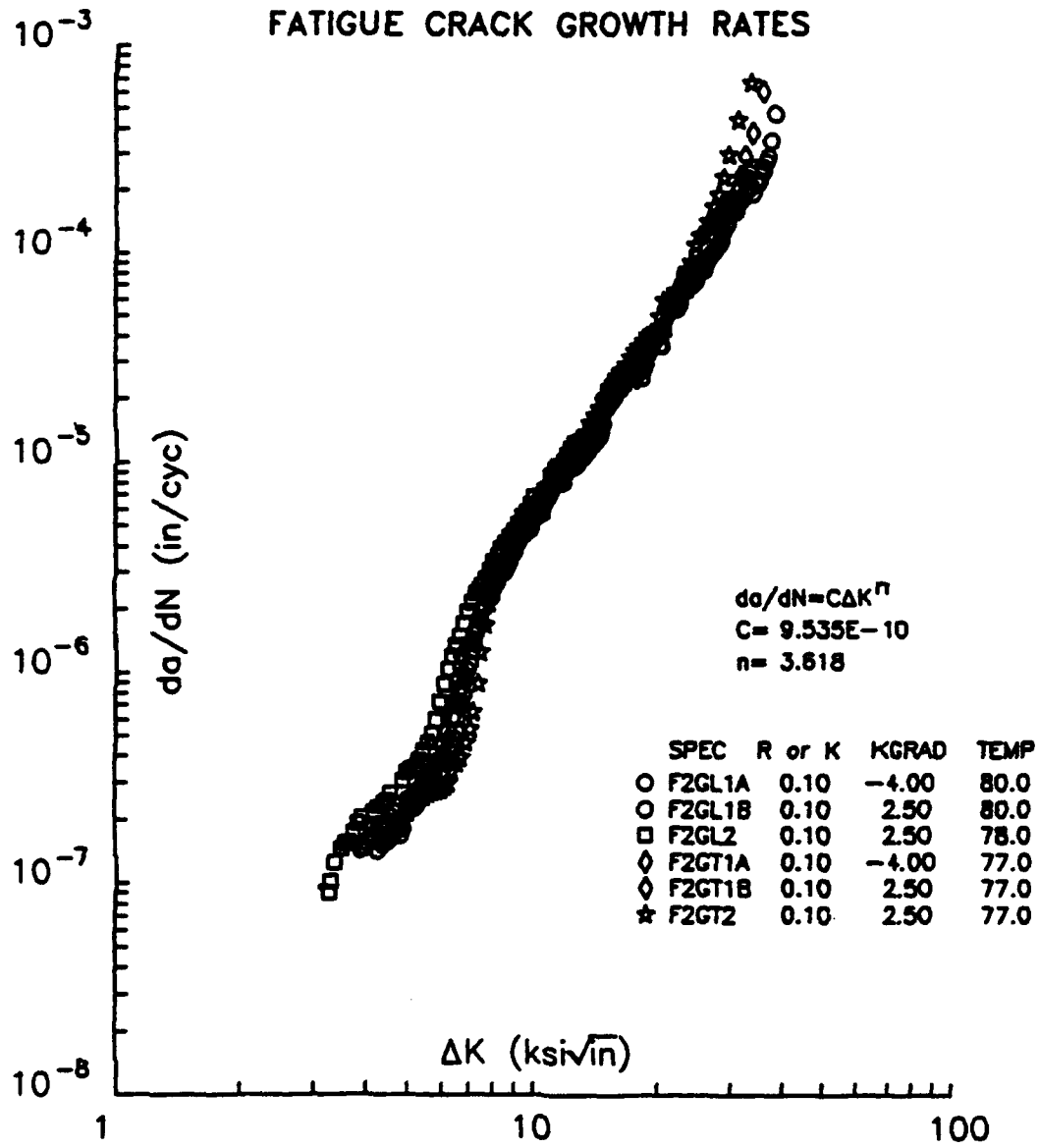


Figure I8. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Thick Plate (L-T and T-L orientations). Northrop.

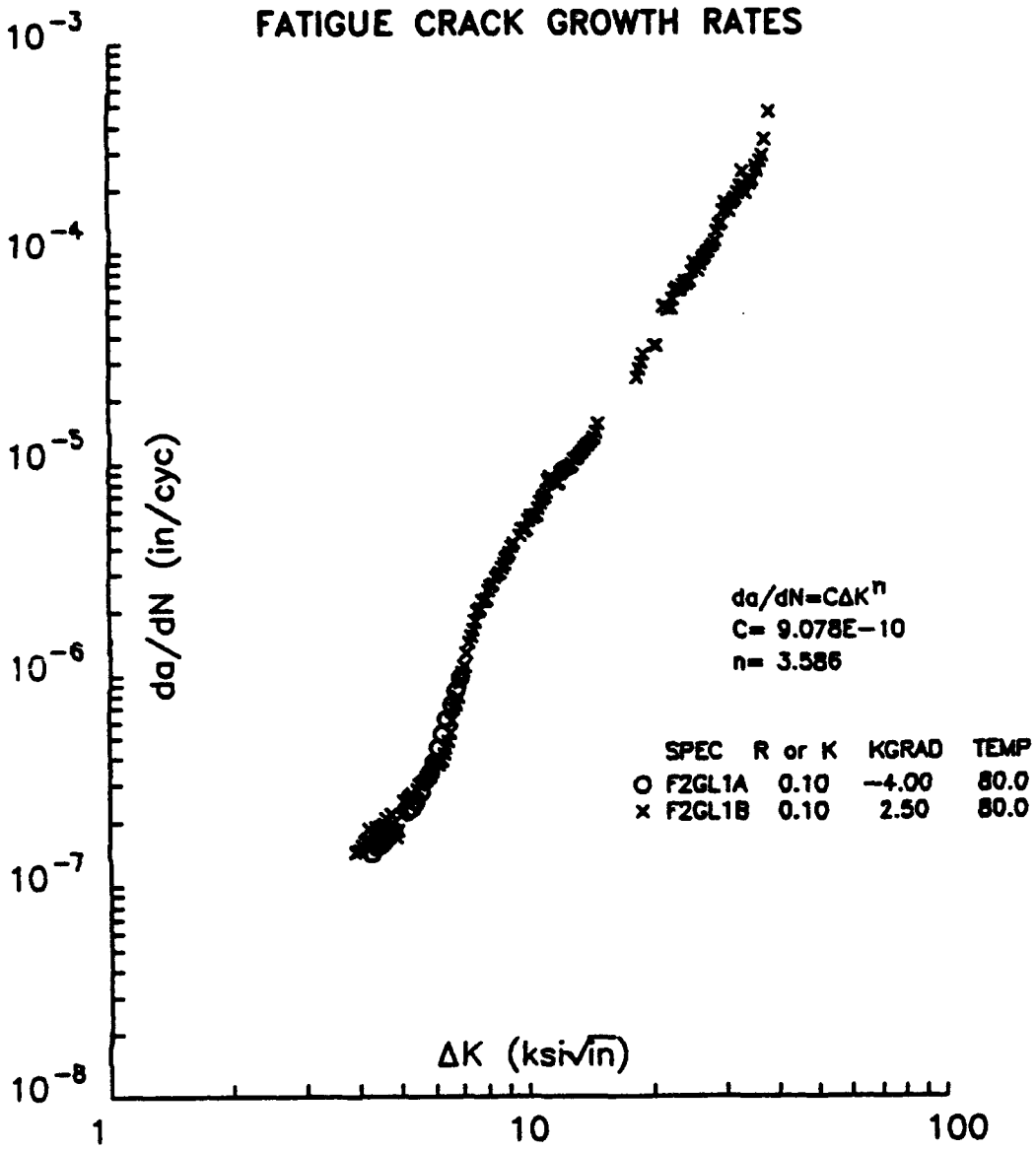


Figure I9. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Thick Plate (L-T orientation, KGRAD - 4.00 and 2.50). Northrop.

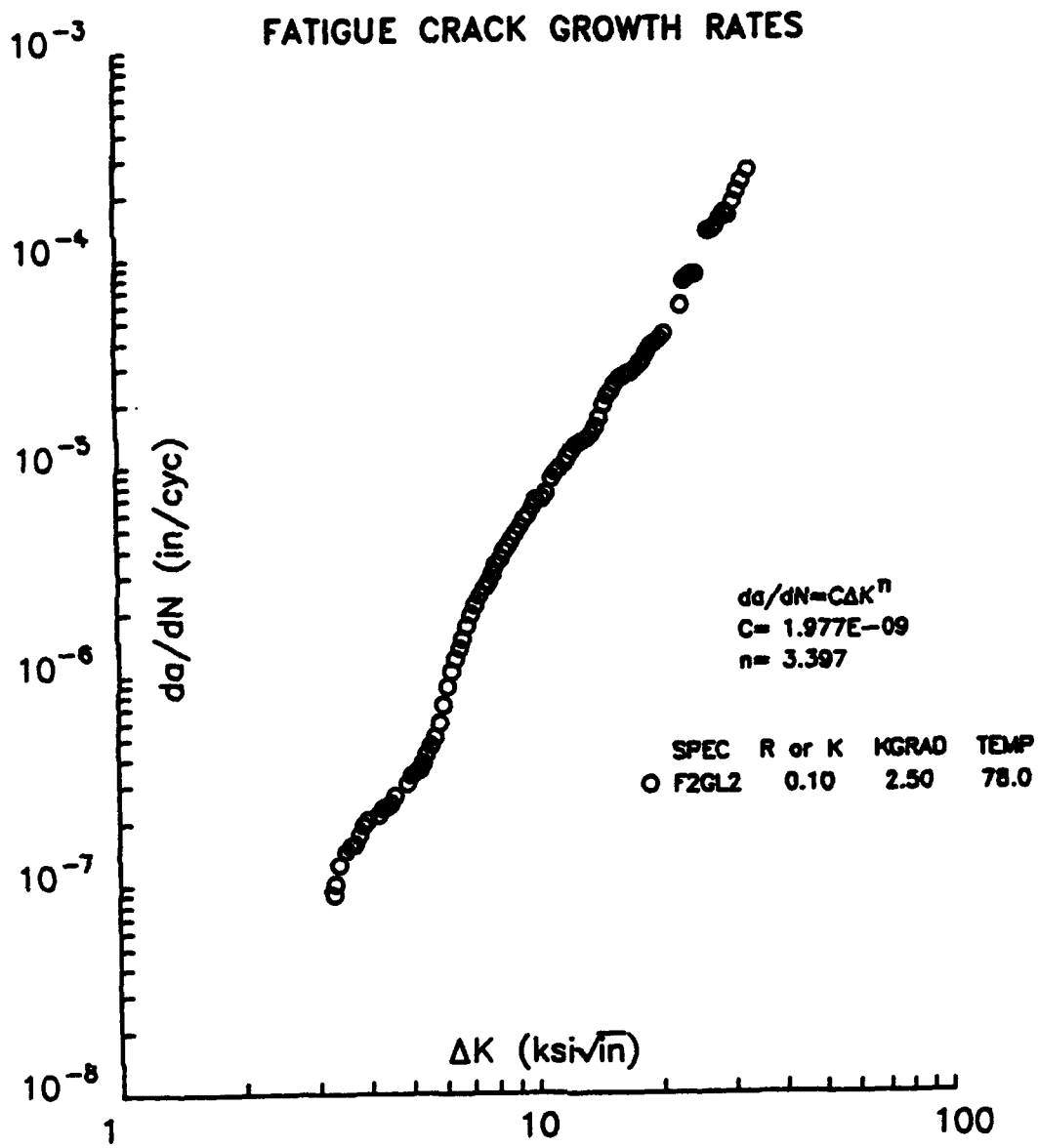


Figure I10. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Thick Plate (L-T orientation, KGRAD 2.50). Northrop.

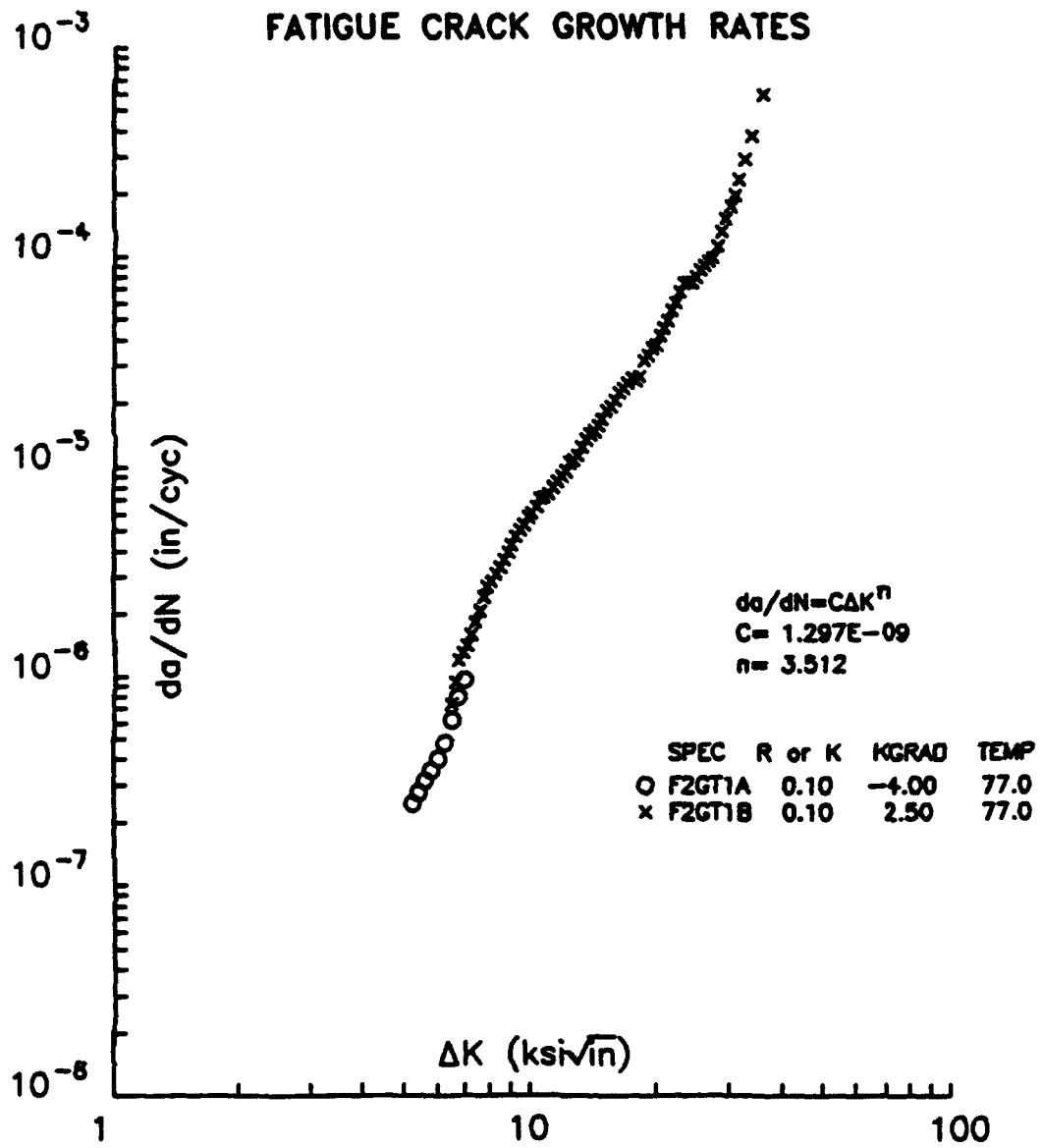


Figure I11. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Thick Plate (T-L orientation, KGRAD - 4.00 and 2.50). Northrop.

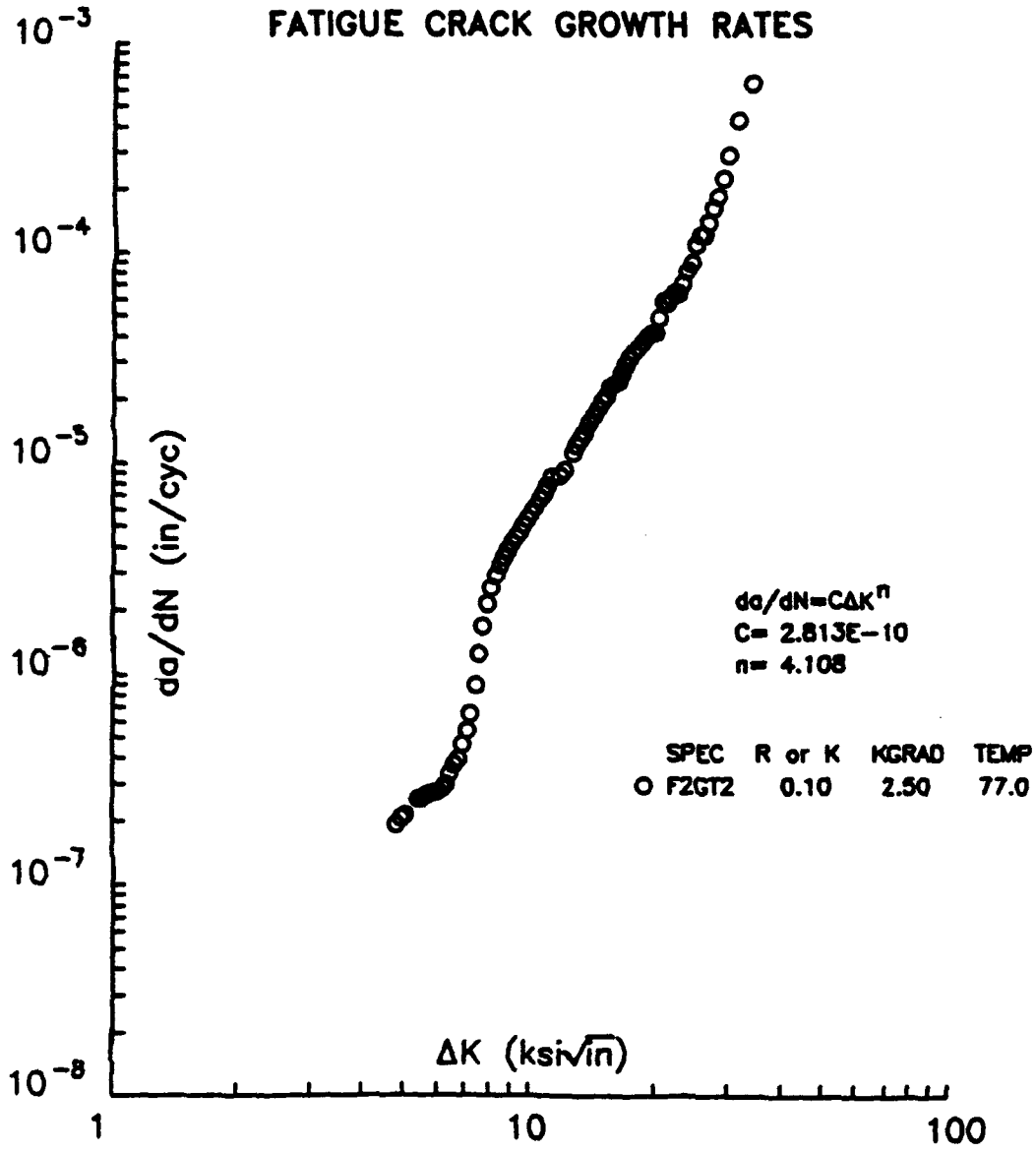
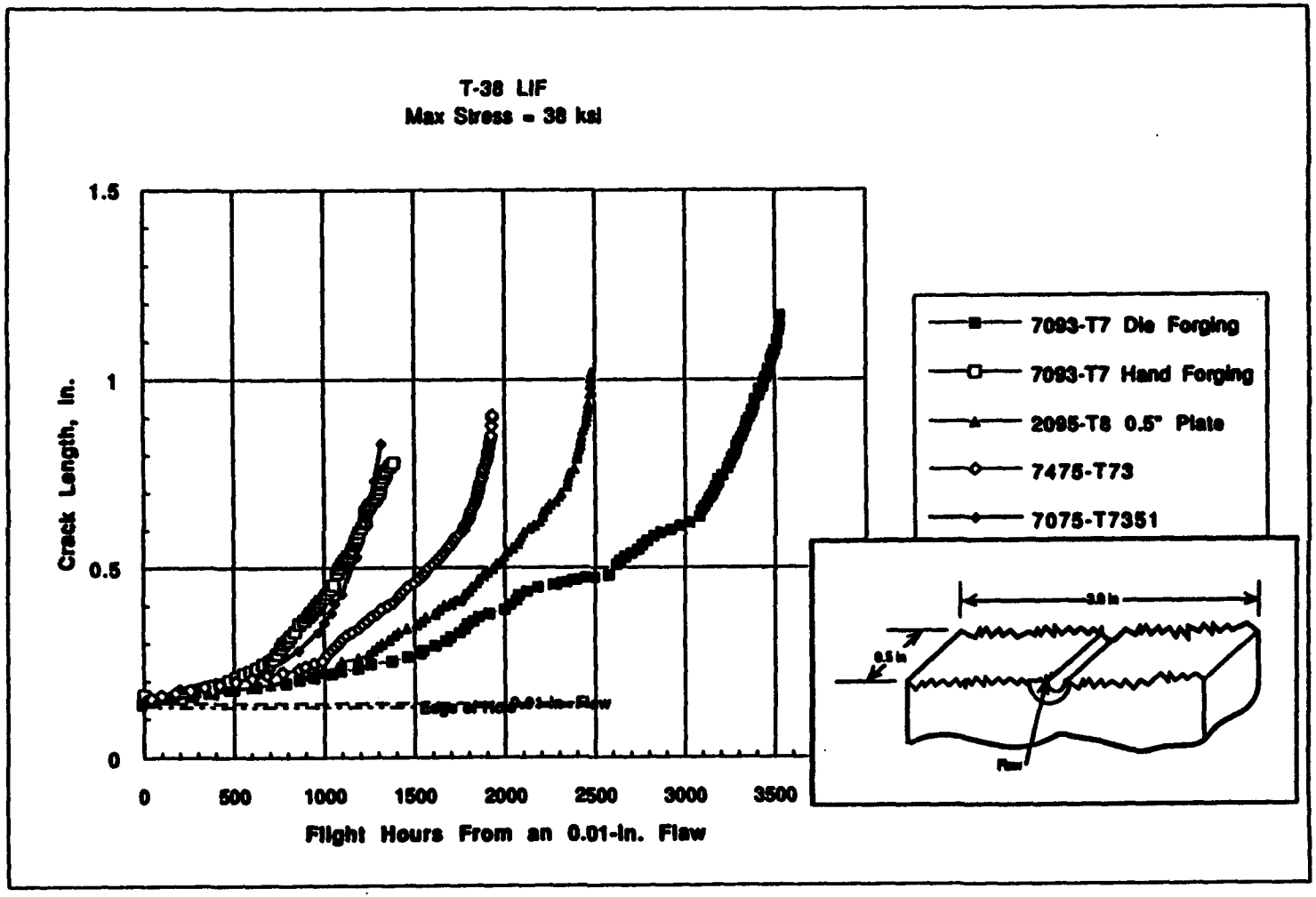
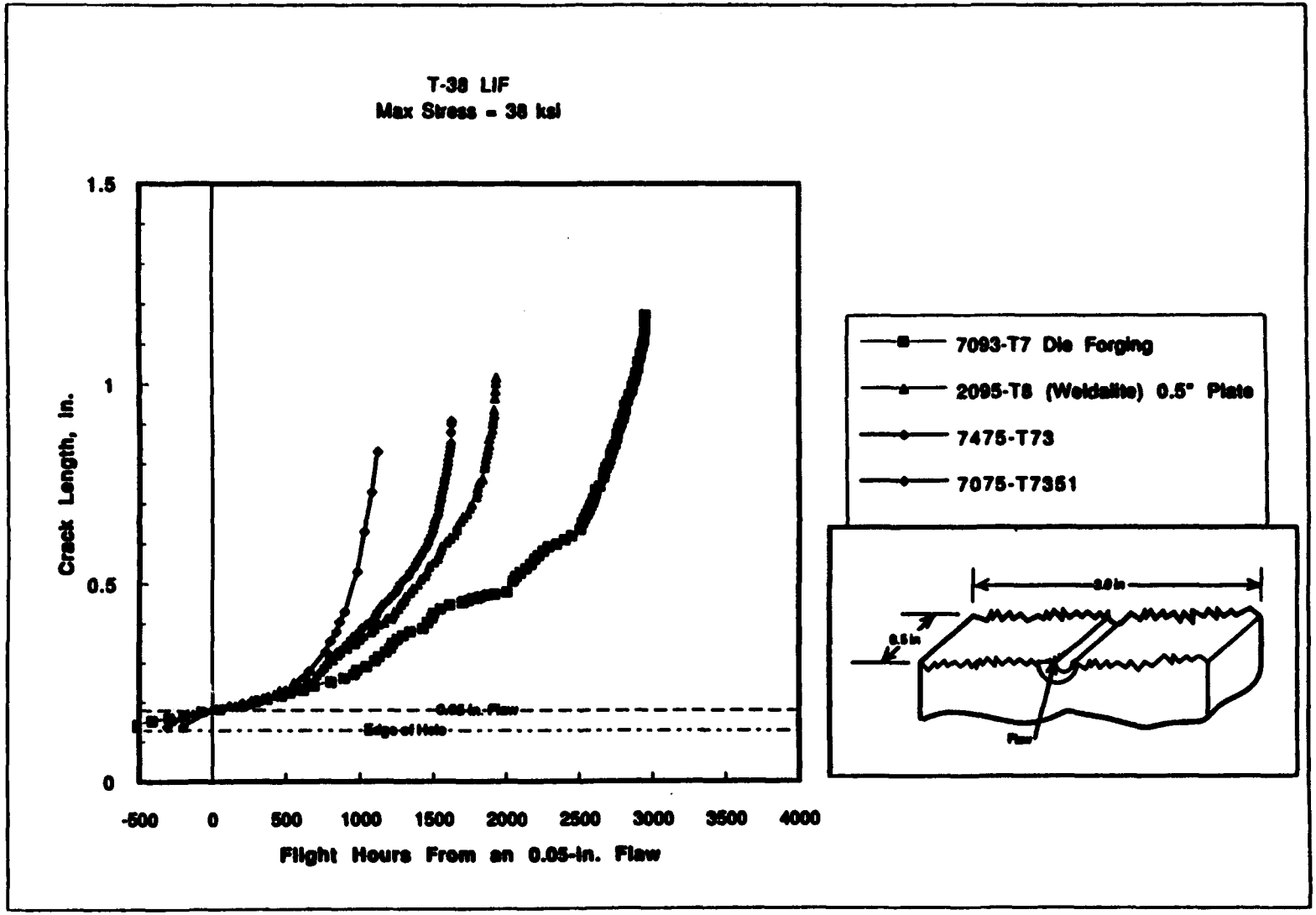


Figure I12. Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Thick Plate (T-L orientation, KGRAD 2.50). Northrop.



T-38 LIF a v. N 0.01" 4/24/92

Figure I13. T38 LIF Spectrum Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Plate (Max Stress = 38 Ksi, Flaw = 0.01 inch). Northop.



T-38 LIF a v. N 0.05" 5/8/92

Figure I14. T38 LIF Spectrum Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Plate (Max Stress = 38 Ksi, Flaw = 0.05 inch). Northop.

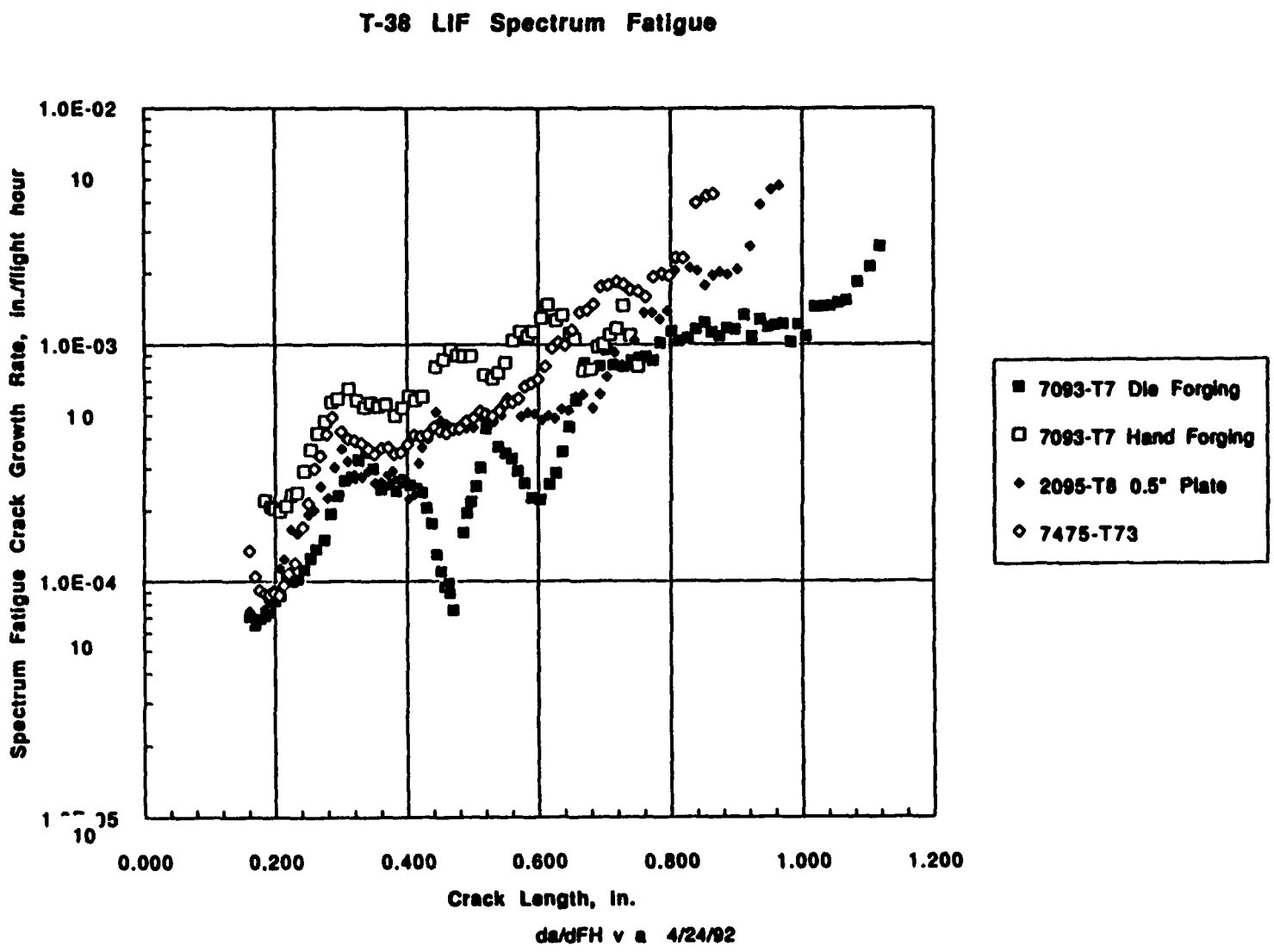


Figure I15. T38 LIF Spectrum Fatigue Crack Growth Rate Data for 2095-T8 0.5 Inch Plate (Max Stress = 38 Ksi). Northop.

APPENDIX J

2091-T3 AND 2091-T8
0.063 INCH SHEET

INTRODUCTION

The Alcoa aluminum-lithium alloy 2091-T3 0.063 inch sheets were received October 1988. The 2091-T3 0.063 inch sheet was tested as received by the Air Force and Martin Marietta. However, Northrop and McDonnell Aircraft Company heat treated the alloy to a T8 condition.

TESTING

Mechanical properties, (tension, compression, bearing, shear, and fracture toughness) fatigue and constant amplitude fatigue crack growth tests were tested according to ASTM standards, unless otherwise specified.

Spectrum tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderatley intense fatigue environment) spectrums.

TABLE J1

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	LONG	62.5	48.1	19.0	23.0	10.8
MARIETTA,			61.1	47.0	19.5	23.0	10.6
LOUISIANA			61.7	47.5	21.0	23.0	10.1
AIR FORCE	RT	LONG	60.8	47.6	22.4	24.8	
			60.7	47.6	25.1	23.1	
			60.4	47.5	22.9	23.1	
		AVERAGE	61.2	47.6	21.7	23.3	10.5
	STANDARD DEVIATION		0.8	0.4	1.0	0.3	0.4

TABLE J2

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	45	60.6	40.4	23.4	27.3	
			60.6	40.4	22.9	25.3	
			60.8	41.1	21.8	26.4	
		AVERAGE	60.7	40.6	22.7	26.3	
	STANDARD DEVIATION		0.1	0.4	0.8	1.0	

TABLE J3

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	60	62.4	41.9	23.6	24.5	
			60.5	39.7	20.4	25.1	
			60.5		22.1	26.2	
		AVERAGE	61.1	40.8	22.0	25.3	
	STANDARD DEVIATION		1.1	1.6	1.6	0.9	

TABLE J4

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	L TRANS	65.0	43.2	11.0	19.0	10.4
MARIETTA,			65.8	44.5	19.0	19.0	10.9
LOUISIANA			65.5	42.7	17.0	19.0	8.9
AIR FORCE	RT	L TRANS	63.9	42.7	17.1	20.7	
			63.5	42.1	17.9	21.4	
			64.2	43.7	19.0	21.2	
		AVERAGE	64.7	43.2	16.8	20.1	10.1
	STANDARD DEVIATION		0.9	0.9	3.0	1.2	1.0

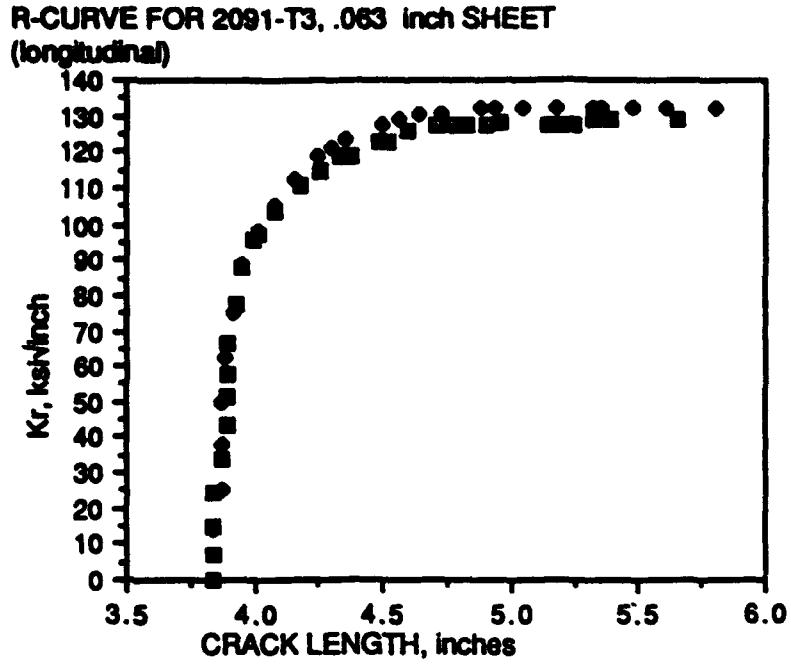


Figure J1. R-Curve Results for 2091-T3 0.063 inch Sheet (L-T Orientation). Martin Marietta.

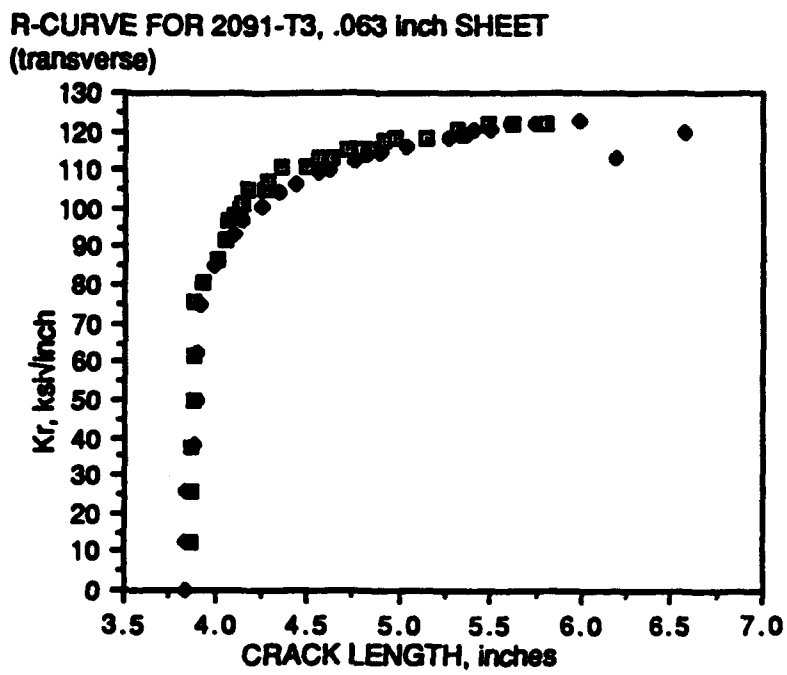


Figure J2. R-Curve Results for 2091-T3 0.063 inch Sheet (T-L Orientation). Martin Marietta.

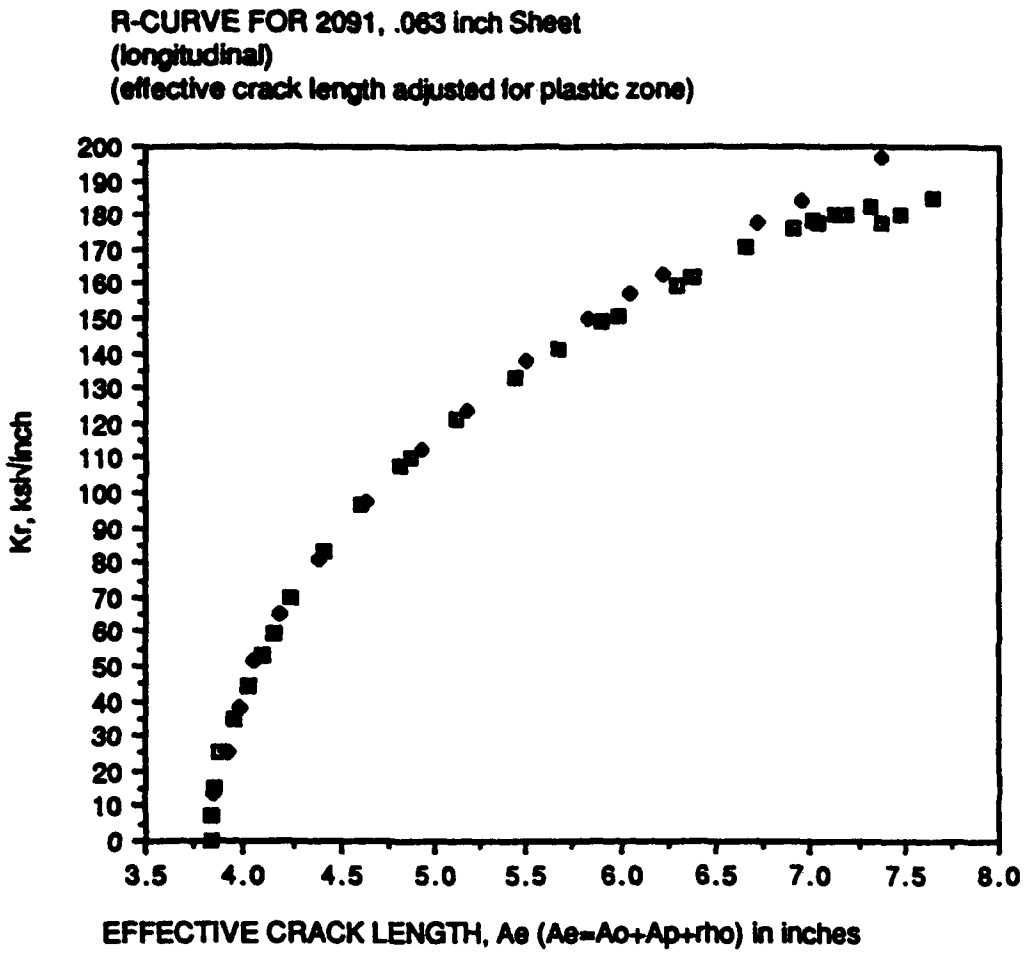


Figure J3. R-Curve Results for 2091-T3 0.063 Inch Sheet, with Effective Crack Length Adjusted for Plastic Zone (L-T Orientation). Martin Marietta.

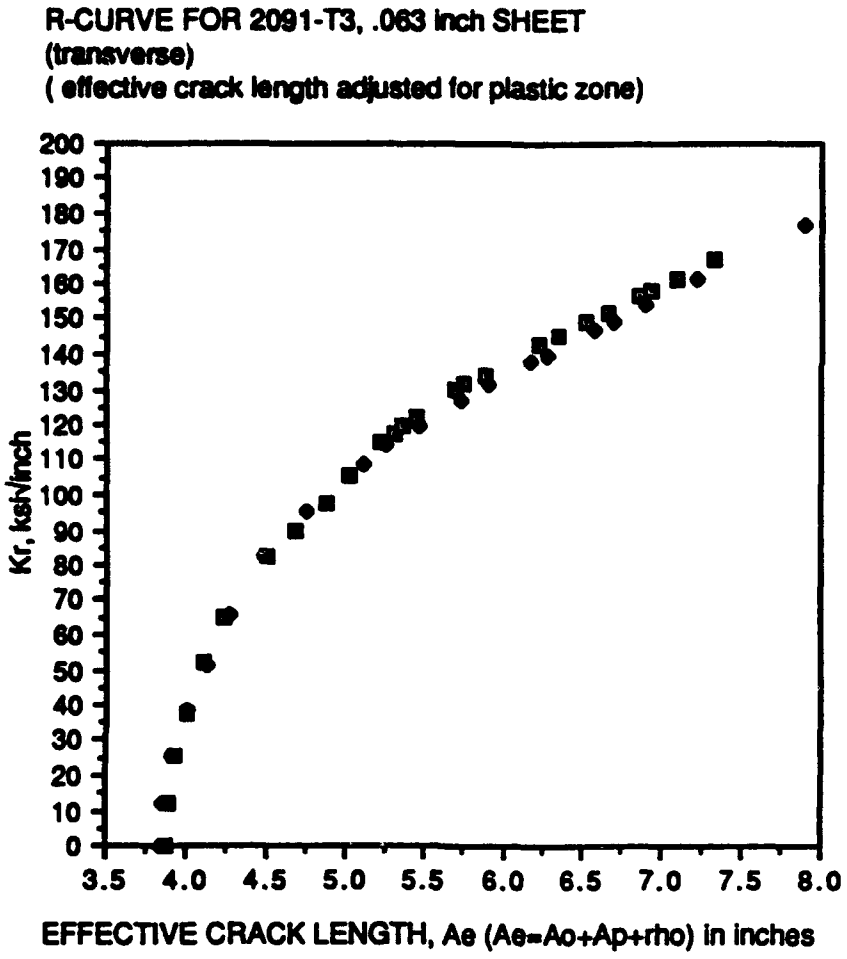


Figure J4. R-Curve Results for 2091-T3 0.063 Inch Sheet, with Effective Crack Length Adjusted for Plastic Zone. (T-L Orientation). Martin Marietta.

TABLE J5

R-Curve Data Associated with Figures J1 and J3

DATA FOR SPECIMEN NO. 1

2091-T3 LONGITUDINAL SHEET

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi √inch	
			Not Adjusted	Adjusted for Plasticity
0	3.835	3.835	0.0	0.0
3.0	3.835	3.838	7.4	6.9
6.1	3.835	3.851	15.0	15.1
10.1	3.835	3.879	24.9	25.1
13.8	3.870	3.955	34.2	34.6
17.4	3.890	4.027	43.3	44.1
20.8	3.895	4.095	51.8	53.2
23.1	3.900	4.150	57.5	59.5
26.7	3.900	4.241	66.5	69.6
30.9	3.925	4.416	77.3	83.5
34.9	3.950	4.613	87.7	97.0
37.7	3.995	4.813	95.5	107.7
38.3	4.015	4.873	97.3	110.3
40.4	4.080	5.118	103.7	121.3
42.5	4.180	5.437	110.9	133.5
43.4	4.255	5.667	114.6	141.5
44.3	4.330	5.902	118.4	149.3
44.3	4.375	5.985	118.4	151.1
44.7	4.490	6.293	122.4	159.9
44.8	4.515	6.362	122.4	161.8
44.8	4.525	6.384	122.4	162.3
45.2	4.600	6.661	125.9	170.9
44.9	4.710	6.908	127.2	176.5
44.7	4.765	7.013	127.2	178.5
44.3	4.810	7.034	127.2	177.5
44.3	4.830	7.120	127.2	180.2
43.8	4.900	7.186	127.2	180.0
43.6	4.960	7.320	128.3	182.9
42.1	5.140	7.376	127.3	178.0
41.8	5.190	7.473	127.3	179.9
41.7	5.240	7.646	127.3	184.7
41.4	5.325		128.7	
40.9	5.385		128.7	
39.2	5.650		128.7	
35.6	6.040		123.2	

Thickness = .063 inches
Yield Strength = 47.5 ksi
Specimen Width = 23.88 inches

TABLE J6

R-Curve Data Associated with Figures J1 and J3

DATA FOR SPECIMEN NO. 2

2091-T3 LONGITUDINAL SHEET

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi √inch	
			Not Adjusted	Adjusted for Plasticity
0	3.835	3.835	0.0	0.0
5.7	3.835	3.847	14.1	13.2
10.2	3.875	3.921	25.3	25.5
15.2	3.875	3.978	37.8	38.3
20.1	3.875	4.060	49.9	51.2
25.2	3.885	4.185	62.7	65.2
30.1	3.920	4.382	75.3	80.9
35.1	3.955	4.630	88.3	97.8
38.7	4.020	4.921	98.4	113.0
41.0	4.085	5.172	105.4	124.1
43.3	4.160	5.501	112.7	137.9
44.9	4.245	5.825	118.4	149.7
45.5	4.305	6.042	121.1	156.9
46.0	4.355	6.225	123.4	162.8
46.5	4.495	6.723	127.5	177.7
46.5	4.560	6.951	128.8	184.1
46.5	4.635	7.376	130.3	197.1
46.0	4.730		130.3	
45.3	4.885		131.9	
44.9	4.940		131.9	
44.2	5.045		131.9	
43.4	5.175		131.9	
42.3	5.325		131.9	
42.5	5.350		131.9	
41.6	5.470		131.9	
40.4	5.610		131.9	
39.3	5.800		131.9	

Thickness = .063 inches
Yield Strength = 47.5 ksi
Specimen Width = 23.87 inches

TABLE J7

R-Curve Data Associated with Figures J2 and J4

DATA FOR SPECIMEN NO. 3

2091-T3 TRANSVERSE SHEET

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi √inch	
			Not Adjusted	Adjusted for Plasticity
0	3.875	3.875	0.0	0.0
5.1	3.875	3.887	12.7	11.8
10.3	3.875	3.931	25.6	25.8
15.0	3.880	4.001	37.3	37.9
20.2	3.880	4.105	50.2	51.8
24.8	3.880	4.230	61.6	64.5
30.1	3.925	4.494	75.4	82.3
31.9	4.000	4.673	80.9	89.5
34.0	4.055	4.861	87.0	97.9
35.8	4.070	5.015	91.8	106.0
37.7	4.105	5.214	97.2	114.8
38.1	4.135	5.293	98.7	117.4
38.6	4.145	5.354	100.2	119.9
39.0	4.175	5.439	101.7	122.6
39.8	4.260	5.684	105.2	130.1
39.9	4.290	5.748	105.2	131.7
40.0	4.360	5.883	107.4	134.6
40.4	4.500	6.226	110.9	143.2
40.4	4.555	6.338	110.9	145.6
40.4	4.640	6.519	113.3	149.5
40.2	4.710	6.660	113.3	152.3
40.2	4.790	6.856	115.4	156.7
40.1	4.830	6.934	115.4	158.2
39.8	4.910	7.099	115.4	161.3
39.8	4.975	7.318	117.5	167.4
39.2	5.140		118.6	
38.5	5.315		118.6	
37.7	5.485		120.1	
37.5	5.625		122.0	
36.5	5.810		122.0	

Thickness = .063 inches
Yield Strength = 43.5 ksi
Specimen Width = 23.87 inches

TABLE J8

R-CURVE DATA ASSOCIATED WITH FIGURES J2 AND J4

DATA FOR SPECIMEN NO. 4

2091-T3 TRANSVERSE SHEET

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi √inch	
			Not Adjusted	Adjusted for Plasticity
0.0	3.845	3.845	0.0	0.0
5.1	3.845	3.857	12.6	11.8
10.4	3.845	3.901	25.7	25.9
15.3	3.880	4.006	38.0	38.7
20.0	3.895	4.116	49.8	51.3
25.1	3.895	4.256	62.5	65.5
30.1	3.915	4.481	75.2	82.1
33.7	3.985	4.751	85.2	95.5
36.2	4.105	5.092	93.3	108.4
37.4	4.145	5.246	97.0	114.4
38.1	4.245	5.459	100.4	120.1
38.8	4.350	5.717	104.0	127.5
39.2	4.430	5.900	106.4	132.2
39.4	4.565	6.170	109.2	138.1
39.4	4.625	6.282	110.2	140.4
39.4	4.755	6.571	112.4	146.9
39.4	4.815	6.701	113.5	149.8
39.3	4.900	6.905	114.6	154.4
39.1	5.030	7.226	116.3	161.6
38.3	5.260	7.896	117.9	177.0
38.3	5.320		119.0	
38.3	5.350		119.0	
38.2	5.400		120.1	
37.7	5.495		120.1	
37.6	5.605		121.9	
36.9	5.735		121.9	
35.8	5.990		122.9	
31.9	6.185		112.8	
31.9	6.575		119.7	

Thickness = .063 inches
Yield Strength = 43.5 ksi
Specimen Width = 23.88 inches

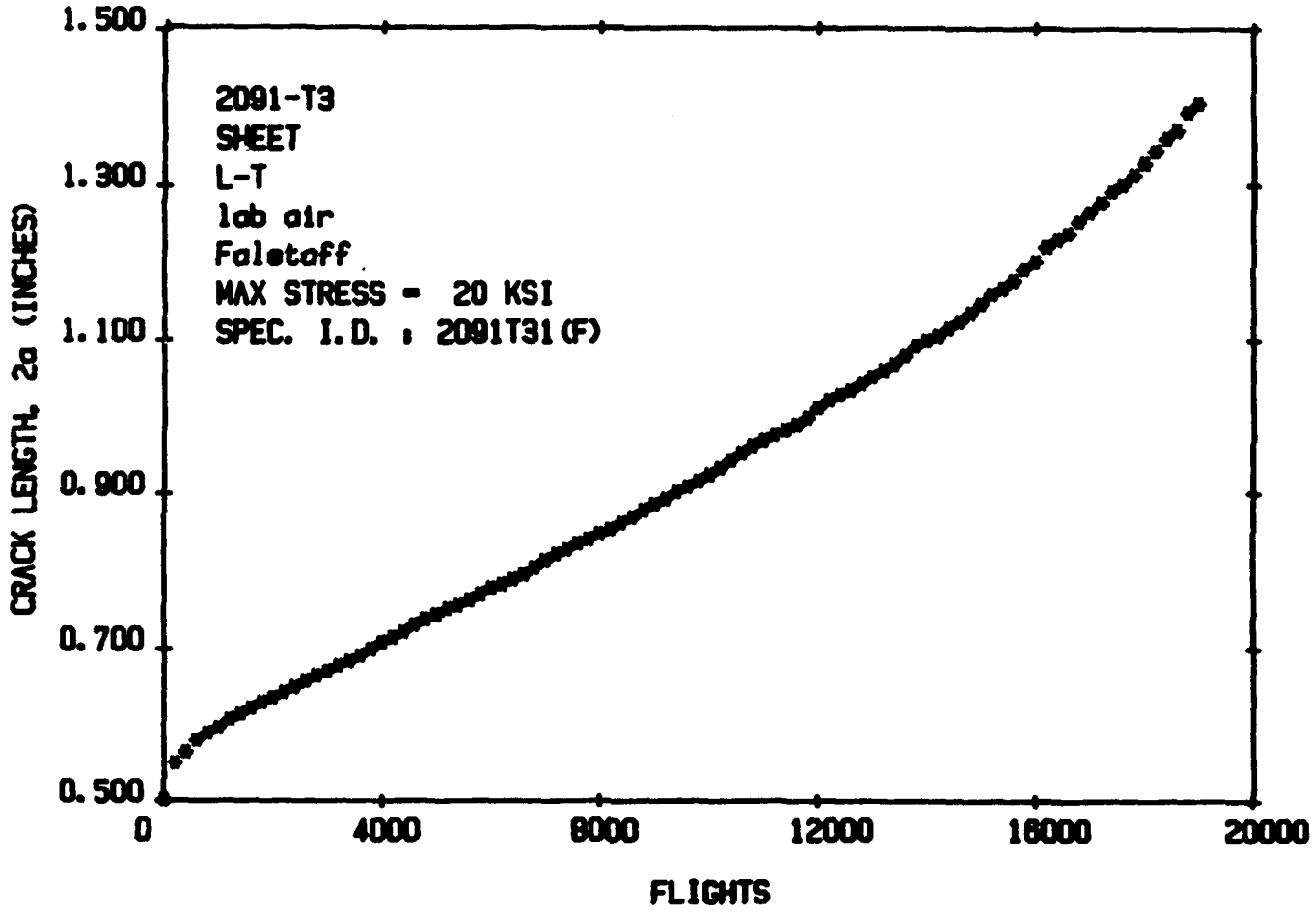


FIGURE J5. FALSTAFF SPECTRUM
CRACK LENGTH VS FLIGHTS DATA FOR 2091-T3
0.063 INCH SHEET,
AIR FORCE.

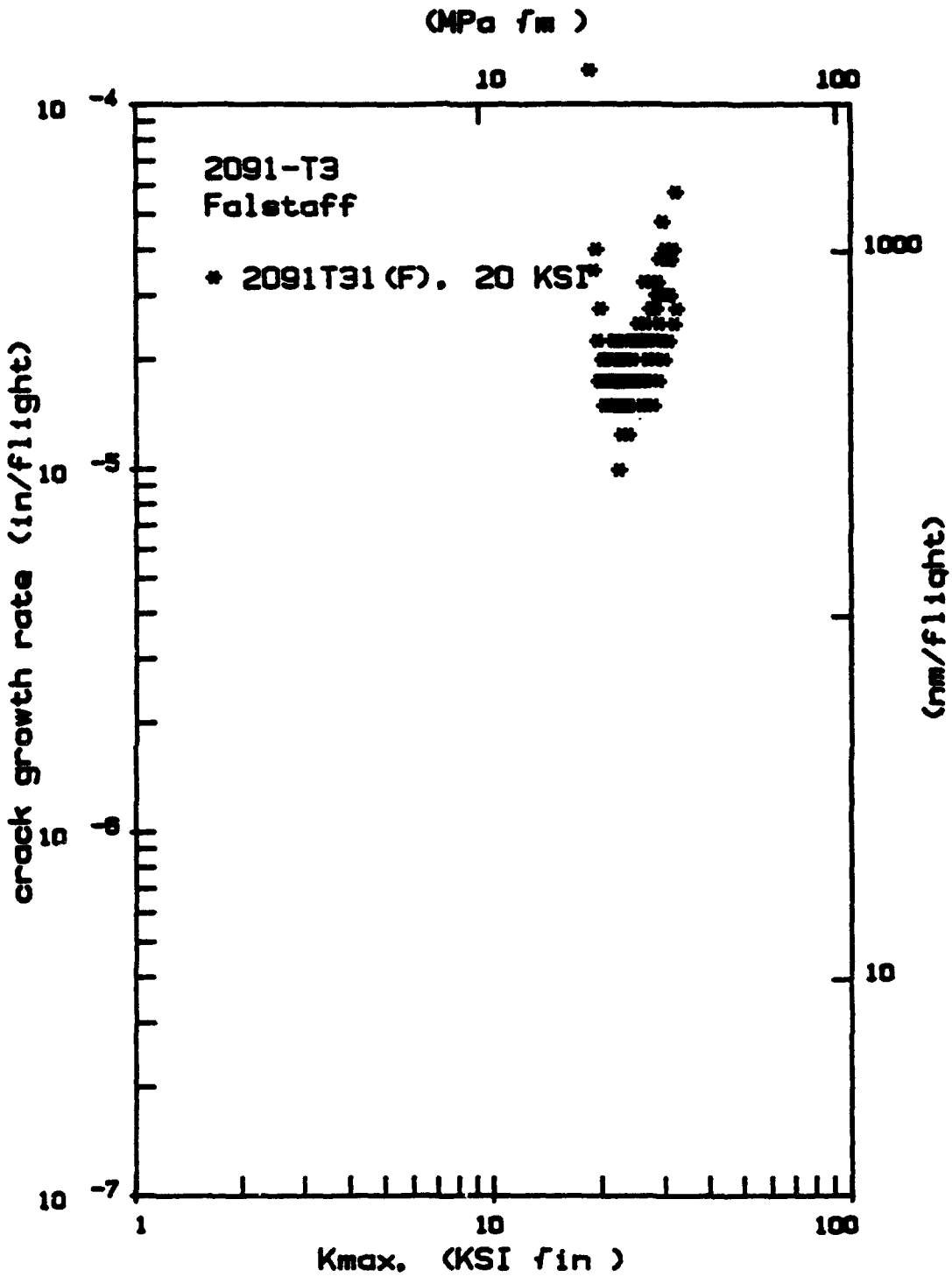


Figure J6. FALSTAFF Spectrum Crack Growth Rate vs Kmax Data for 2091-T3 0.063 Inch Sheet, Air Force

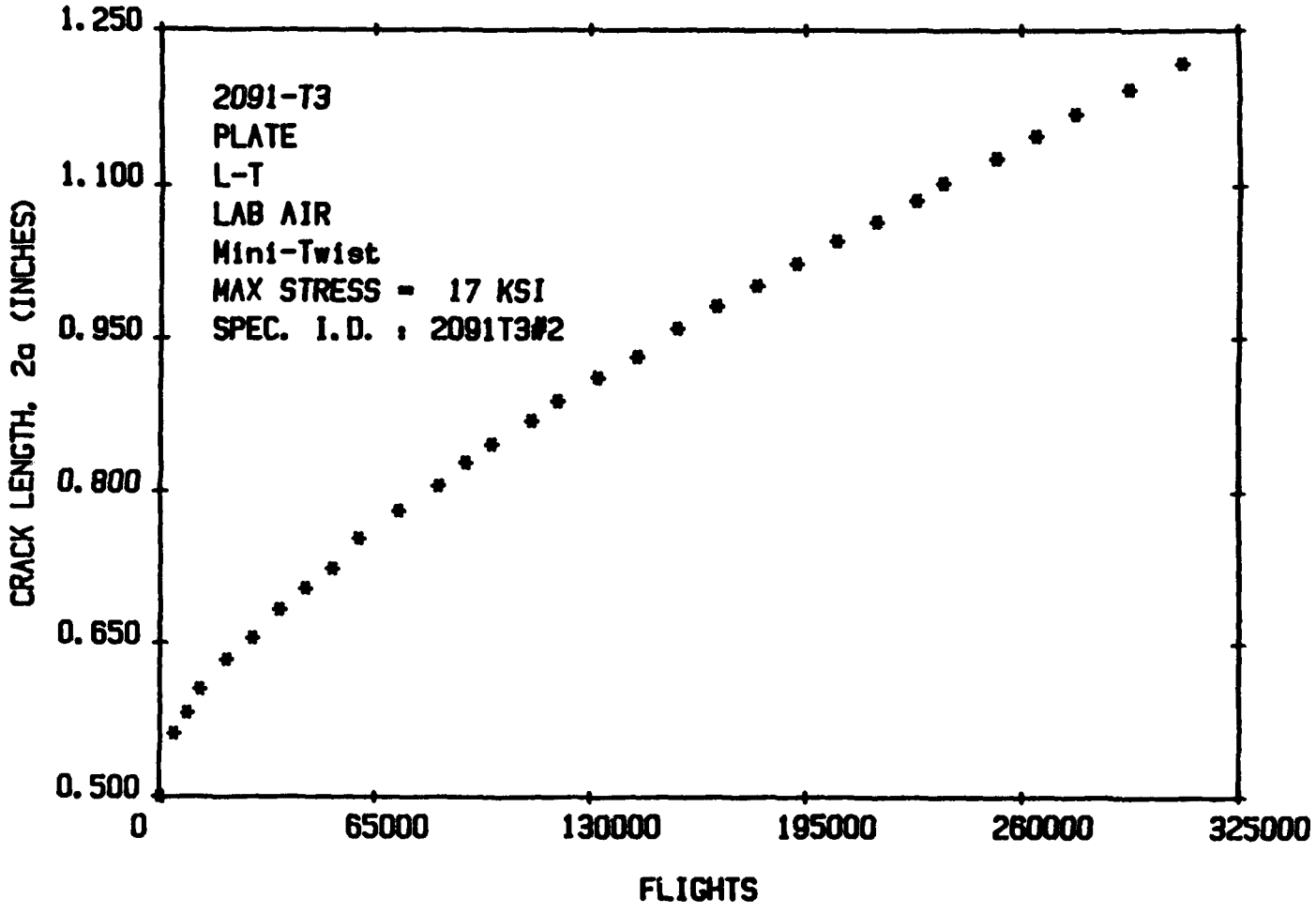


Figure J7. Mini-TWIST Spectrum Crack Length vs Flights Data for for 2091-T3 0.063 Inch Sheet.
Air Force

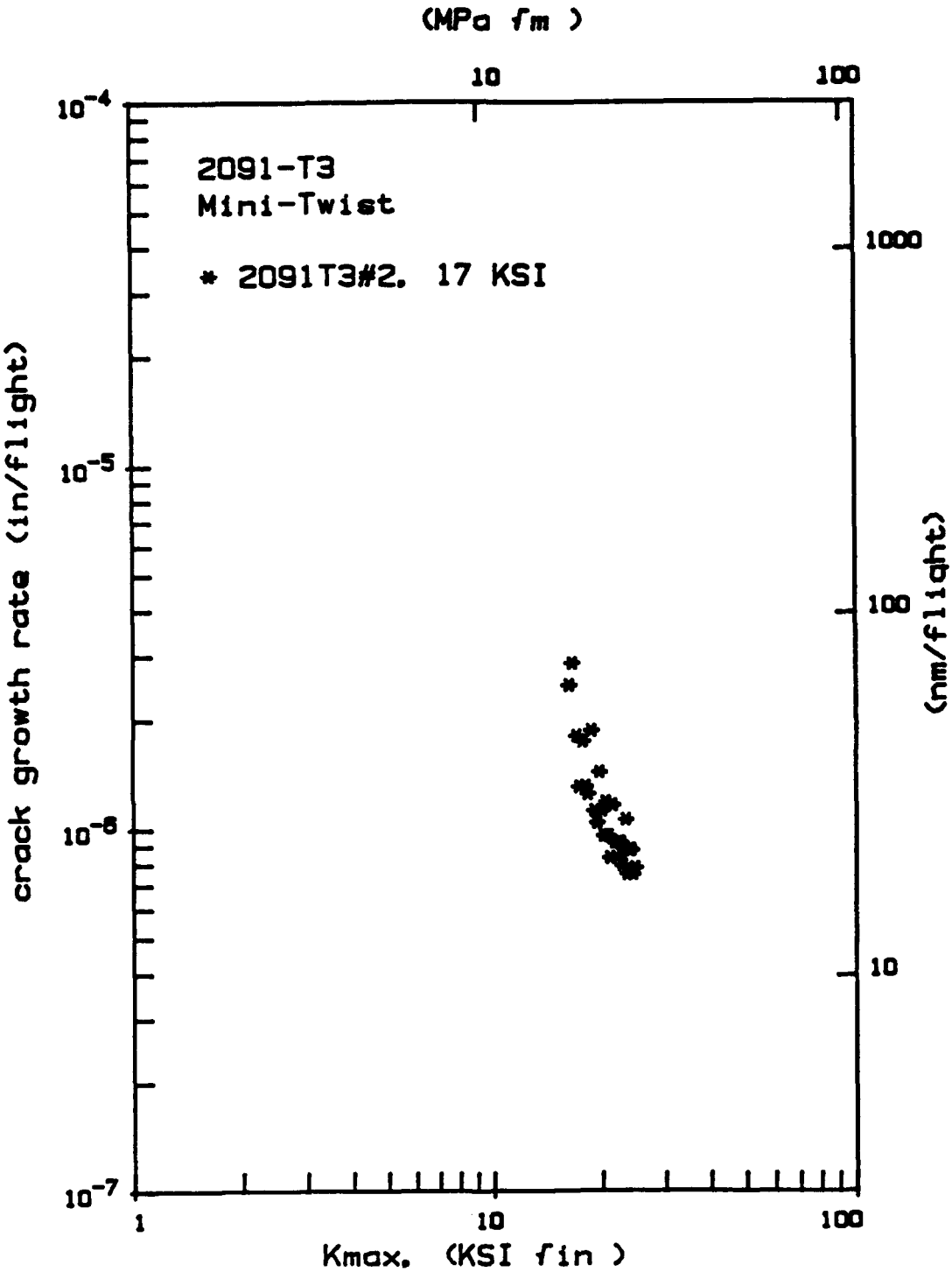


Figure J8. Mini-TWIST Spectrum Crack Growth Rate vs Kmax Data for 2091-T3 0.063 Inch Sheet, Air Force

TABLE J9

TENSILE RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCAIR	RT	LONG	62.5	50.0	22.0		5.5
			62.5	49.4	21.0		5.4
			61.5	49.2	20.0		5.9
NORTHROP	RT	LONG	65.2	53.2	21.9		11.2
			64.9	52.9	19.0		11.2
			64.9	53.1	21.9		11.2
			64.7	52.9	21.9		11.3
		AVERAGE	63.7	51.5	21.1		8.8
	STANDARD DEVIATION		1.5	1.9	0.6		3.0

TABLE J10

TENSILE RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCAIR	RT	45 DEG	62.0	38.0	24.0		6.0
			62.0	38.5	25.0		5.9
			62.5	38.0	22.0		6.7
NORTHROP	RT	45 DEG	64.3	43.9	16.9		11.0
			63.4	43.8	14.1		11.0
			64.1	43.9	17.2		11.2
			63.8	43.1	16.7		11.0
		AVERAGE	63.2	41.3	19.4		9.0
	STANDARD DEVIATION		1.0	3.0	4.2		2.6

TABLE J11

TENSILE RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCAIR	RT	L TRANS	64.5	40.9	18.0		5.6
			65.0	43.6	16.0		5.9
			66.0	42.3	21.0		5.5
NORTHROP	RT	L TRANS	67.9	47.7	20.8		11.3
			68.2	47.4	18.2		11.3
			67.5	47.7	16.9		11.2
			68.3	47.2	18.7		11.1
		AVERAGE	65.2	42.3	18.3		5.7
	STANDARD DEVIATION		0.8	1.4	2.5		0.2

TABLE J12

COMPRESSION RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCAIR	RT	LONG		12.5
				11.5
NORTHROP	RT	LONG	41.7	11.5
			42.2	11.2
			41.7	12.1
		AVERAGE	41.9	11.8
		STANDARD DEVIATION	0.3	0.5

TABLE J13

COMPRESSION RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCAIR	RT	45 DEG		12.1
				12.2
				11.7
		AVERAGE		12.0
		STANDARD DEVIATION		0.3

TABLE J14

COMPRESSION RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCAIR	RT	L TRANS		12.6
				12.6
				12.5
NORTHROP	RT	L TRANS	48.4	12.1
			48.8	11.9
			48.9	12.0
		AVERAGE	48.7	12.3
		STANDARD DEVIATION	0.3	0.3

TABLE J15

SLOTTED SHEAR RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
MCAIR	LONG	44.8
		46.8
NORTHROP	LONG	43.9
		43.8
		43.7
	AVERAGE	44.6
	STANDARD DEVIATION	1.3

TABLE J16

SLOTTED SHEAR RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	L TRANS	44.7
		45.0
		44.6
	AVERAGE	44.8
	STANDARD DEVIATION	0.2

TABLE J17

BEARING RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCAIR	LONG	1.5	96.1	
			98.9	83.5
			99.2	83.9
NORTHROP	LONG	1.5	101.6	71.1
			100.7	69.7
			101.7	72.2
		AVERAGE	99.7	76.1
	STANDARD DEVIATION		2.1	7.0

TABLE J18

BEARING RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCAIR	L TRANS	1.5	98.2	85.7
			97.4	84.0
			97.5	85.1
NORTHROP	L TRANS	1.5	104.4	76.9
			103.7	73.9
			104.0	75.4
		AVERAGE	100.9	80.2
	STANDARD DEVIATION		3.5	5.3

TABLE J19

BEARING RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCAIR	LONG	2.0	128.6	107.0
			130.3	108.4
			127.1	107.0
NORTHROP	LONG	2.0	127.3	72.8
			129.9	76.0
			130.2	74.7
		AVERAGE	128.9	91.0
	STANDARD DEVIATION		1.5	18.1

TABLE J20

BEARING RESULTS FOR ALCOA

2091-T8 SHEET (0.063" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCAIR	L TRANS	2.0	131.2	110.7
			130.6	109.5
			128.3	107.0
NORTHROP	L TRANS	2.0	130.4	85.2
			129.7	85.0
			129.0	88.2
		AVERAGE	129.9	97.6
	STANDARD DEVIATION		1.1	12.7

TABLE J21

R-CURVE FRACTURE TOUGHNESS
RESULTS FOR 2091-T8X SHEET
(0.063" X 48" X 48")
Northrop

Specimen ID	Orientation	Kc
VIRLI	L-T	130.0

TABLE J22

R-CURVE FRACTURE TOUGHNESS RESULTS

For 2091-T8 Sheet (0.063" x 48" x 48")

MCDONNELL AIRCRAFT CO

SPECIMEN IDENTIFICATION: LT1
MATERIAL DESCRIPTION: 2091 AL-LI SHEET
SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)
SPECIMEN ORIENTATION: L-T
YIELD STRENGTH: 49.5 KSI
SPECIMEN THICKNESS: 0.063 IN
SPECIMEN WIDTH: 3.999 IN

SPECIMEN IS INVALID PER ASTM E561-86, PARA. 7.5

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi √in)	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi √in)
800	1.485	42,884	1.629	47,141
975	1.500	52,765	1.753	62,495
1,025	1.507	55,716	1.810	68,349
1,100	1.516	60,171	1.935	80,342
1,150	1.523	63,194	***	***
1,175	1.529	64,829	***	***
1,200	1.534	66,420	***	***
1,225	1.545	68,270	***	***
1,250	1.555	70,121	***	***
1,275	FAILURE	---	---	---

*** Indicates that the equation for Kr (Corrected) did not converge to a solution.

TABLE J23

R-CURVE FRACTURE TOUGHNESS RESULTS

For 2091-T8 Sheet (0.063" x 48" x 48")

MCDONNELL AIRCRAFT CO

SPECIMEN IDENTIFICATION: LT2
MATERIAL DESCRIPTION: 2091 AL-LI SHEET
SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)
SPECIMEN ORIENTATION: L-T
YIELD STRENGTH: 49.5 KSI
SPECIMEN THICKNESS: 0.064 IN
SPECIMEN WIDTH: 4.002 IN

SPECIMEN IS INVALID PER ASTM E561-86, PARA. 7.5

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi √in)	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi √in)
975	1.501	51,927	1.743	60,983
1,000	1.515	53,727	1.783	64,343
1,050	1.523	56,711	1.847	70,665
1,110	1.526	60,073	1.943	80,115
1,160	1.530	62,951	***	***
1,190	1.534	64,769	***	***
1,220	1.540	66,640	***	***
1,235	1.543	67,574	***	***
1,270	1.549	69,785	***	***
1,285	1.570	71,568	***	***
1,305	1.576	72,983	***	***
1,315	1.585	73,989	***	***
1,325	1.592	74,876	***	***
1,335	1.598	75,731	***	***
1,340	1.605	76,397	***	***
1,345	FAILURE	---	---	---

*** Indicates that the equation for Kr (Corrected) did not converge to a solution.

TABLE J24

R-CURVE FRACTURE TOUGHNESS RESULTS

For 2091-T8 Sheet (0.063" x 48" x 48")

MCDONNELL AIRCRAFT CO

SPECIMEN IDENTIFICATION: TL1
MATERIAL DESCRIPTION: 2091 AL-LI SHEET
SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)
SPECIMEN ORIENTATION: T-L
YIELD STRENGTH: 42.3 KSI
SPECIMEN THICKNESS: 0.064 IN
SPECIMEN WIDTH: 3.998 IN

SPECIMEN IS INVALID PER ASTM E561-86. PARA. 7.5

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi √in)	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi √in)
800	1.495	42,504	1.708	48,955
825	1.499	43,946	1.734	51,378
1,025	1.503	54,749	***	***
1,050	1.509	56,296	***	***
1,085	1.513	58,335	***	***
1,095	1.518	59,045	***	***
1,135	1.524	61,462	***	***
1,165	1.535	63,532	***	***
1,175	1.544	64,468	***	***
1,190	1.544	65,291	***	***
1,215	1.549	66,881	***	***
1,230	1.557	68,045	***	***
1,240	1.562	68,819	***	***
1,250	1.583	70,357	***	***
1,270	1.587	71,638	***	***
1,280	1.594	72,565	***	***
1,290	1.612	73,989	***	***
1,295	1.616	74,493	***	***
1,305	FAILURE	---	---	---

*** Indicates that the equation for Kr (Corrected) did not converge to a solution.

TABLE J25

R-CURVE FRACTURE TOUGHNESS RESULTS

For 2091-T8 Sheet (0.063" x 48" x 48")

MCDONNELL AIRCRAFT CO

SPECIMEN IDENTIFICATION: TLZ
MATERIAL DESCRIPTION: 2091 AL-LI SHEET
SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)
SPECIMEN ORIENTATION: T-L
YIELD STRENGTH: 42.3 KSI
SPECIMEN THICKNESS: 0.061 IN
SPECIMEN WIDTH: 3.999 IN

SPECIMEN IS INVALID PER ASTM E561-86, PARA. 7.5

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi √in)	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi √in)
950	1.507	53,350	2.062	79,002
975	1.511	54,882	***	***
1,075	1.517	60,775	***	***
1,120	1.522	63,517	***	***
1,130	1.526	64,248	***	***
1,180	1.531	67,305	***	***
1,240	1.541	71,181	***	***
1,255	1.544	72,179	***	***
1,265	1.550	73,059	***	***
1,280	1.569	74,867	***	***
1,285	1.576	75,466	***	***
1,295	FAILURE	---	---	---

*** Indicates that the equation for Kr (Corrected) did not converge to a solution.

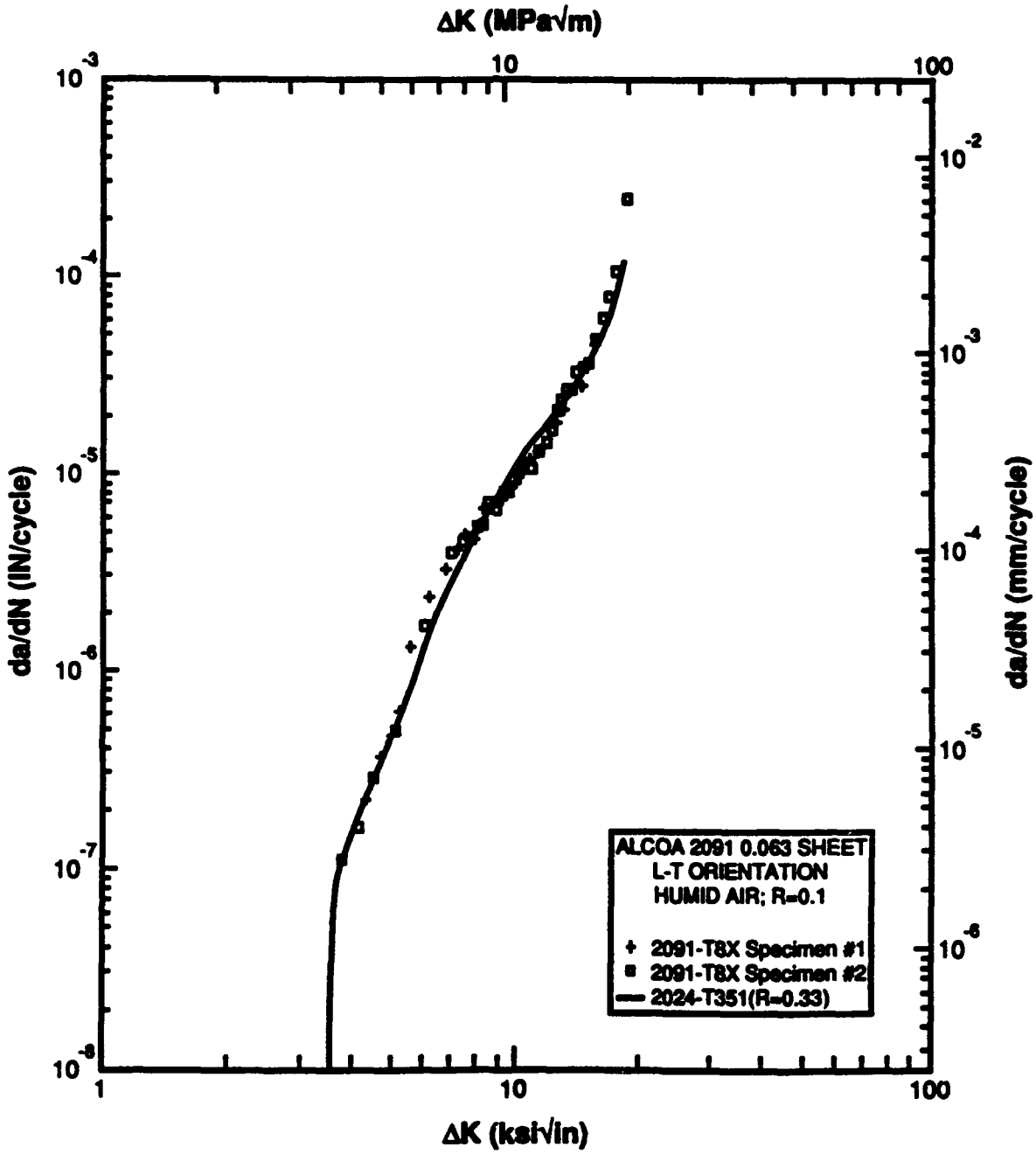


FIGURE J9. FATIGUE CRACK GROWTH RATE DATA for 2091-T8X 0.063 Inch Sheet Relative to 2024-T351 (L-T Orientation). Northrop.

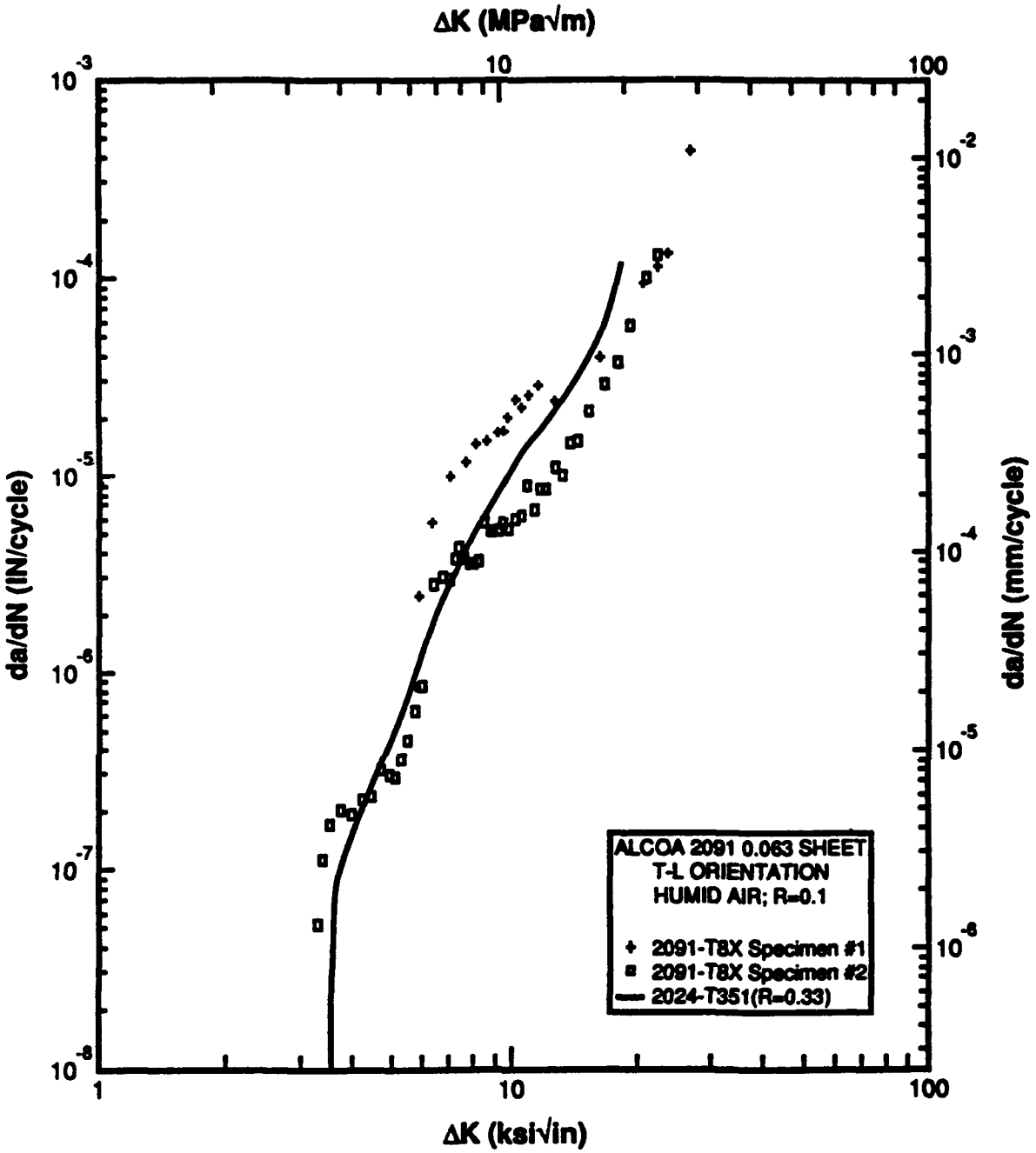


FIGURE J10. FATIGUE CRACK GROWTH RATE DATA for 2091-T8X 0.063 Inch Sheet Relative to 2024-T351 (T-L Orientation). Northrop.

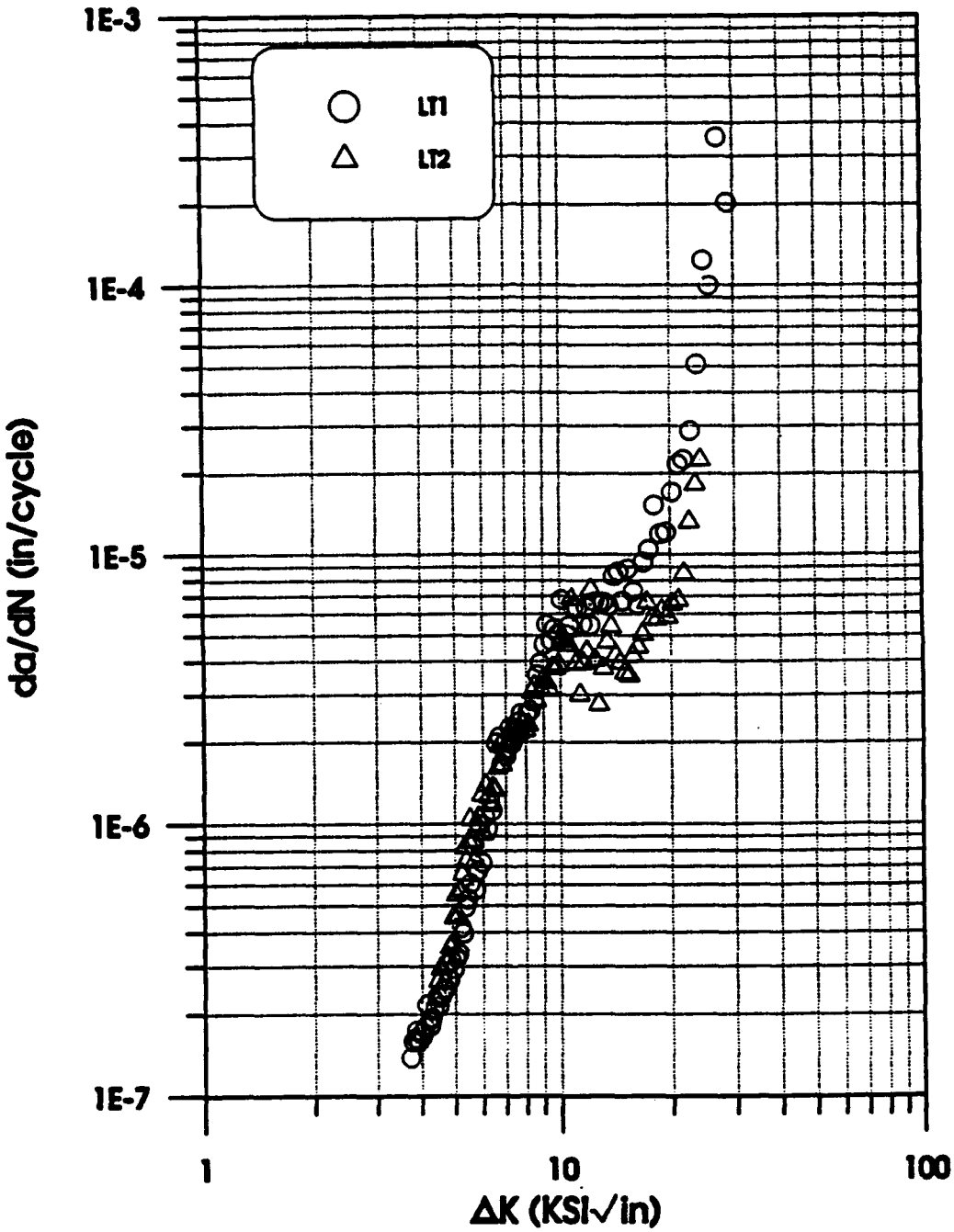


Figure J11 Figure Crack Growth Rate Data for 2091-T8 0.063 Inch Sheet. (L-T Orientation, R=0.33, Lab Air and 75°F). McDonnell Aircraft Company.

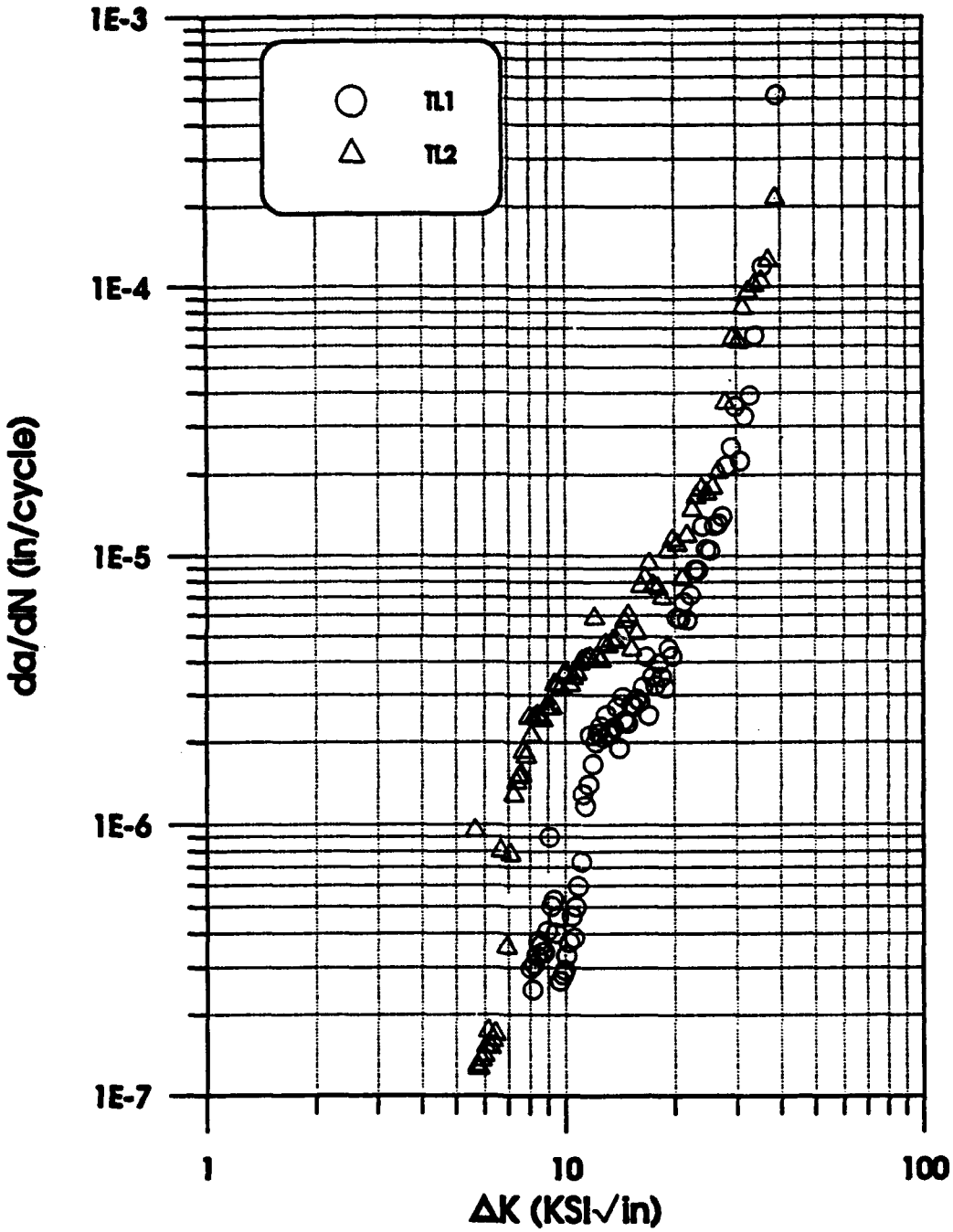


Figure J12 Fatigue Crack Growth Rate Data for 2091-T8 0.063 Inch Sheet (T-L Orientation, Lab Air, 75°F, and TLI R=0.02 and TL2 R=0.10). McDonnell Aircraft Company

APPENDIX K

2091-T3 AND 2091-T8
0.144 INCH SHEET

INTRODUCTION

The Alcoa aluminum-lithium alloy 2091-T3 0.144 inch sheets were received March 1988. The 2091-T3 0.144 inch sheets were tested as received by the Air Force, Martin Marietta and McDonnell Douglas Astronautics. However, General Dynamics aged their material at 16 and 32 hours at 335°F and Northrop heat treated their material to a T8X temper.

TESTING

Mechanical properties, (tension, compression, bearing, shear, and fracture toughness) fatigue and constant amplitude fatigue crack growth tests were tested according to ASTM standards, unless otherwise specified.

Spectrum tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE K1

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL	RT	LONG	59.4	49.0	20.0		11.4
DOUGLAS			60.1	49.2	20.0		11.6
ASTRO., CA			59.9	49.5	20.0		11.5
			59.9	49.6	20.0		11.5
			58.9	49.5	22.0		11.5
MARTIN							
MARIETTA, LA	RT	LONG	60.6	50.0	17.0	12.7	11.4
			59.9	49.6	17.0	15.5	11.1
			59.9	49.6	17.0	19.7	11.4
AIR FORCE	RT	LONG	61.4	51.1	14.3	14.7	
			61.4	50.9	17.9	20.5	
			61.4	51.3	17.2	19.7	
		AVERAGE	60.3	49.9	18.4	17.1	11.4
	STANDARD DEVIATION		0.8	0.8	2.2	3.2	0.1

TABLE K2

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	30	62.4	45.0	20.0	25.6	
			62.1	44.0	19.1	25.4	
			62.2	43.2	18.9	25.5	
		AVERAGE	62.2	44.1	19.3	25.5	
	STANDARD DEVIATION		0.2	0.9	0.6	0.1	

TABLE K3

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	45	61.4	42.0	23.3	28.3	
			61.6	42.7	24.4	28.2	
			61.5	42.7	23.9	29.3	
		AVERAGE	61.5	42.5	23.9	28.6	
	STANDARD DEVIATION		0.1	0.4	0.6	0.6	

TABLE K4

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	60	61.2	40.9	24.0	29.0	
			61.0	43.3	21.5	27.8	
			60.3	41.5	22.8	31.1	
		AVERAGE	60.8	41.9	22.8	29.3	
	STANDARD DEVIATION		0.5	1.2	1.3	1.7	

TABLE K5

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL	RT	L TRANS	64.3				12.0
DOUGLAS			65.3	46.6	14.0		11.6
ASTRO., CA			65.2	46.6	14.0		11.6
			64.3	46.4	12.5		11.5
			64.6	46.7	12.5		11.6
MARTIN	RT	L TRANS	64.7	46.2	12.0	12.7	11.1
MARIETTA, LA			65.1	45.8	13.0	11.3	11.4
			64.7	45.6	13.0	11.3	11.3
AIR FORCE	RT	L TRANS	66.0	47.3	16.4	16.2	
			66.4	47.4	17.5	17.3	
			66.0	47.5	15.7	18.8	
		AVERAGE	65.1	46.6	14.1	14.6	11.5
	STANDARD	DEVIATION	0.7	0.6	1.9	3.3	0.3

TABLE K6

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%	E (MSI)
MCDONNELL	-320 F	LONG	75.3	57.6	16.0		12.4
DOUGLAS			76.2	58.1	16.5		12.5
ASTRO., CA			75.1	57.4	17.0		12.5
			75.0	58.0	17.0		12.5
		AVERAGE	75.4	57.8	16.6		12.5
	STANDARD	DEVIATION	0.5	0.3	0.5		0.1

TABLE K7

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MCDONNELL	-320 F	L TRANS	81.6	53.9	16.5		12.7
DOUGLAS			82.2	54.2	14.5		12.7
ASTRO., CA			81.5	55.1	14.5		12.7
			80.6	55.1	13.0		12.5
		AVERAGE	81.5	54.6	14.6		12.7
	STANDARD	DEVIATION	0.7	0.6	1.4		0.1

TABLE K8

COMPRESSION RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCDONNELL	RT	LONG	41.1	11.5
DOUGLAS				11.5
ASTRO., CA			40.7	11.4
		AVERAGE	40.9	11.5
		STANDARD DEVIATION	0.3	0.1

TABLE K9

COMPRESSION RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCDONNELL	RT	L TRANS	49.0	11.3
DOUGLAS			48.6	11.5
ASTRO., CA			49.8	11.5
		AVERAGE	49.1	11.4
		STANDARD DEVIATION	0.6	0.1

TABLE K10

COMPRESSION RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCDONNELL	-320 F	LONG	46.8	12.7
DOUGLAS				12.5
ASTRO., CA			46.4	12.4
		AVERAGE	46.6	12.5
		STANDARD DEVIATION	0.3	0.2

TABLE K11

COMPRESSION RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MCDONNELL	-320 F	L TRANS	56.8	12.8
DOUGLAS			55.1	12.8
ASTRO., CA			58.8	12.5
		AVERAGE	56.9	12.7
		STANDARD DEVIATION	1.9	0.2

TABLE K12

BEARING RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL	LONG	1.5	95.6	
DOUGLAS			95.9	75.3
ASTRO., CA			95.3	75.8
			95.2	74.3
			95.1	72.9
		AVERAGE	95.4	74.6
		STANDARD DEVIATION	0.3	1.3

TABLE K13

BEARING RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL	L TRANS	1.5	98.1	75.3
DOUGLAS			98.2	74.2
ASTRO., CA			98.5	78.6
			96.5	74.6
			98.1	
		AVERAGE	97.9	75.7
		STANDARD DEVIATION	0.8	2.0

TABLE K14

BEARING RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL DOUGLAS ASTRO., CA	LONG	2.0	119.0	86.2
			119.0	
			120.0	86.6
			120.0	
			120.0	85.3
		AVERAGE	119.6	86.0
		STANDARD DEVIATION	0.5	0.7

TABLE K15

BEARING RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL DOUGLAS ASTRO., CA	L TRANS	2.0	122.0	89.2
			122.0	90.7
			122.0	
			123.0	88.7
			121.0	87.9
		AVERAGE	122.0	89.1
		STANDARD DEVIATION	0.7	1.2

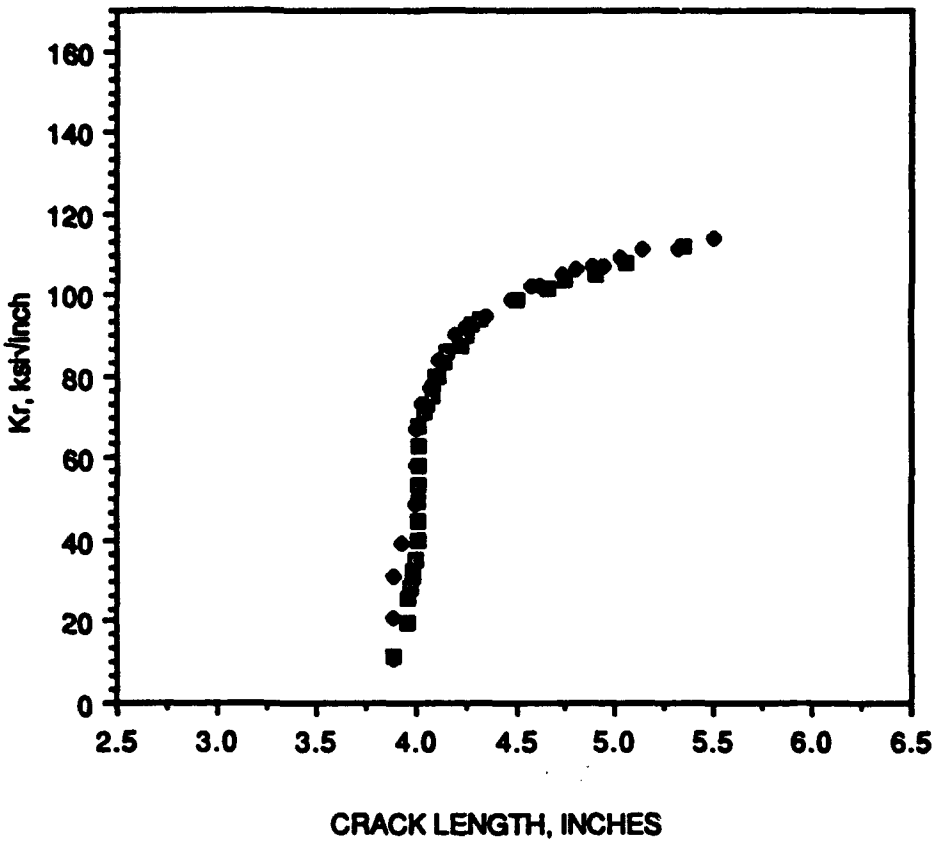


Figure K1. R-Curve Results for 2091-T3
0.144 Inch Sheet (L-T Orientation).
Martin Marietta

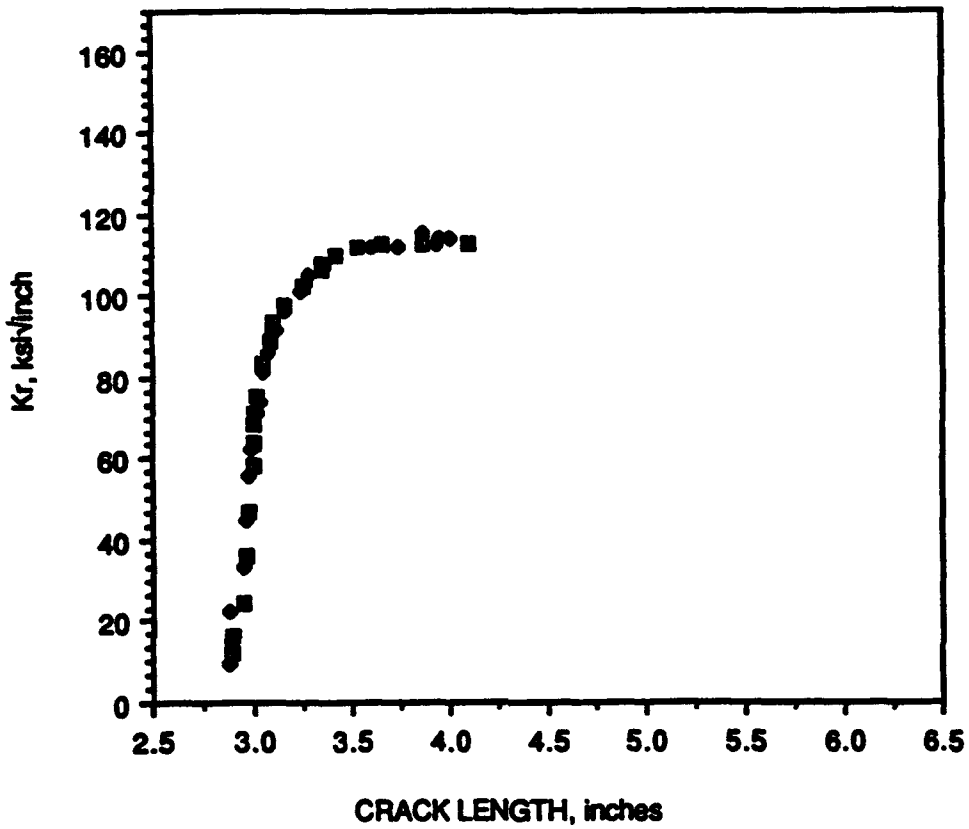


Figure K2. R-Curve Results for 2091-T3 0.144 Inch Sheet (T-L Orientation). Martin Marietta.

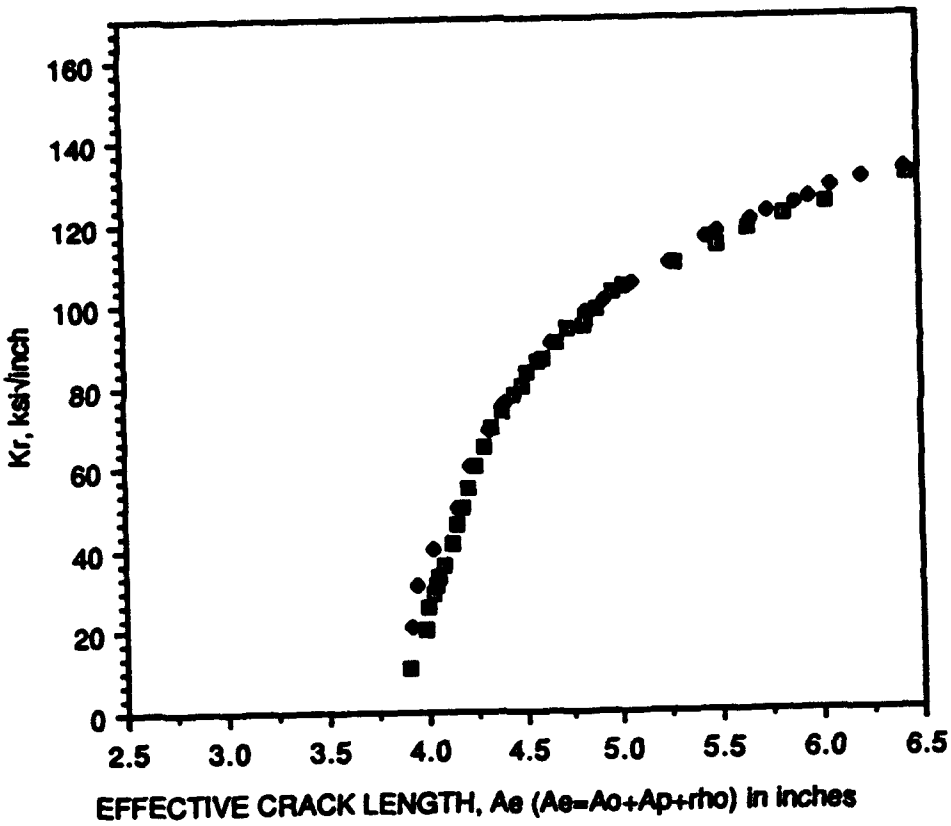


Figure K3. R-Curve Results for 2091-T3
0.144 Inch Sheet with Effective Crack Length
Adjusted for Plastic Zone (L-T Orientation)
Martin Marietta.

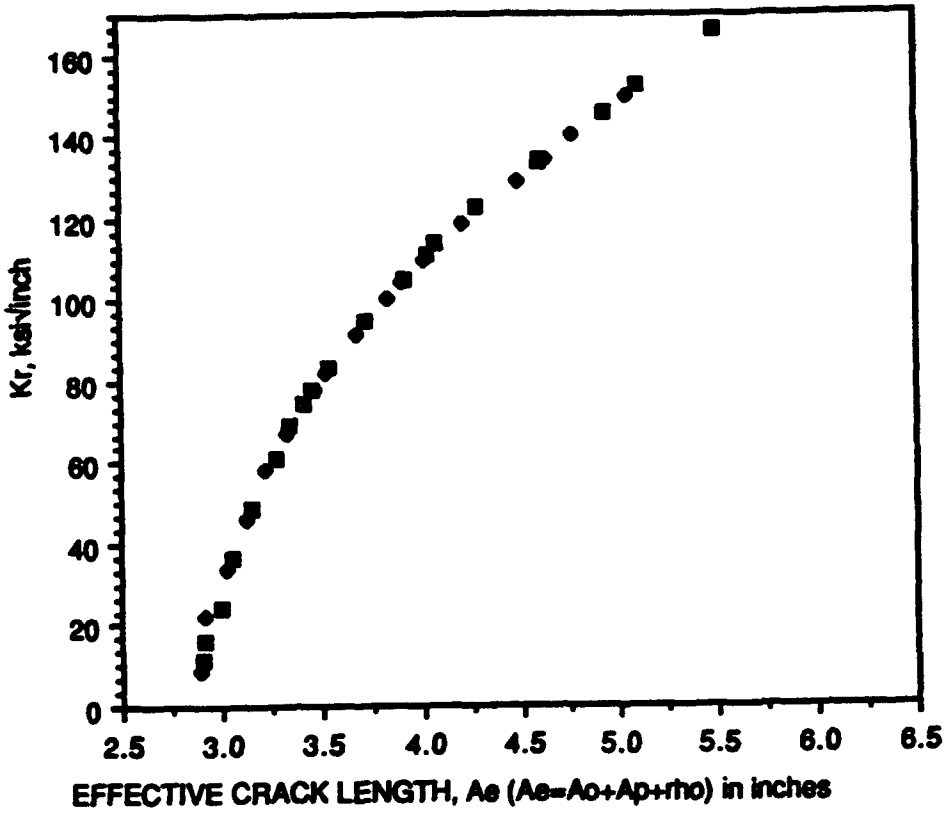


Figure K4. R-Curve Results for 2091-T3
0.144 Inch Sheet with Effective Crack Length
Adjusted for Plastic Zone (T-L Orientation)
Martin Marietta.

TABLE K16

R-CURVE DATA ASSOCIATED WITH

FIGURES K1 AND K3 (SPECIMEN 3)

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi √inch	
			Not adjusted	Adjusted for Plasticity
10	3.895	3.902	11	11
18	3.960	3.985	20	20
24	3.960	4.004	26	26
26	3.975	4.029	29	29
28	3.990	4.053	31	31
29	3.990	4.059	32	33
32	4.000	4.083	36	36
36	4.020	4.126	40	41
40	4.020	4.154	45	46
44	4.020	4.183	49	50
48	4.020	4.213	53	55
52	4.020	4.251	58	60
57	4.020	4.295	63	65
61	4.020	4.340	68	70
64	4.045	4.402	71	74
65	4.060	4.451	73	78
67	4.085	4.497	75	80
69	4.085	4.525	77	83
71	4.105	4.581	80	86
71	4.115	4.601	80	87
74	4.140	4.668	84	91
74	4.140	4.677	84	91
76	4.165	4.732	86	94
76	4.225	4.812	88	95
76	4.225	4.823	88	96
78	4.255	4.886	90	99
80	4.290	4.967	93	103
81	4.325	5.027	94	104
82	4.500	5.284	99	110
82	4.655	5.495	102	114
83	4.750	5.649	104	118
82	4.900	5.837	105	121
82	5.045	6.042	108	124
81	5.345	6.447	112	131

Thickness = .144 inch
Yield = 49.7 ksi
Specimen Width = 23.83 inch

TABLE K17

R-CURVE DATA ASSOCIATED WITH

FIGURES K1 AND K3 (SPECIMEN 4)

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi √inch	
			Not adjusted	Adjusted for Plasticity
10	3.895	3.902	11	11
19	3.895	3.924	21	21
28	3.895	3.956	31	31
36	3.930	4.032	39	40
44	4.000	4.163	49	50
52	4.000	4.231	58	60
60	4.010	4.319	67	69
65	4.040	4.416	73	76
69	4.080	4.523	77	83
74	4.110	4.641	84	91
78	4.200	4.823	90	98
79	4.260	4.921	92	101
80	4.350	5.058	95	105
82	4.480	5.262	99	110
84	4.575	5.440	102	116
84	4.615	5.492	102	117
84	4.735	5.663	105	120
84	4.800	5.754	106	122
84	4.890	5.883	107	124
84	4.945	5.956	107	125
84	5.025	6.072	109	128
84	5.135	6.223	111	130
82	5.320	6.435	111	132
81	5.490	6.661	114	135
79	5.730	6.962	115	138
74.5	6.265	7.660	117	144
74.5	6.440	7.932	118	152

Thickness = .144 inch
Yield = 49.7 ksi
Specimen Width = 23.81 inch

TABLE K18

R-CURVE DATA ASSOCIATED WITH

FIGURES K2 AND K4 (SPECIMEN 1)

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi √inch	
			Not adjusted	Adjusted for Plasticity
10	2.895	2.905	12	12
13	2.895	2.915	16	16
19	2.950	2.995	24	25
28	2.960	3.061	36	36
37	2.980	3.158	47	49
46	2.995	3.279	58	61
50	2.995	3.354	64	69
54	3.000	3.422	69	75
56	3.005	3.461	71	78
59	3.020	3.547	75	83
65	3.045	3.728	83	95
69	3.085	3.920	89	105
71	3.100	4.032	92	111
72	3.100	4.077	94	114
75	3.150	4.282	98	122
76	3.250	4.598	102	133
77	3.250	4.608	102	134
78	3.345	4.943	106	145
79	3.355	5.104	108	152
79	3.420	5.500	110	166
79	3.525		112	
77	3.655		113	
75	3.865		113	
71	4.100		113	

Thickness = .144 inch
Yield = 45.9 ksi
Specimen Width = 18.03 inch

TABLE K19

R-CURVE DATA ASSOCIATED WITH

FIGURES K2 AND K4 (SPECIMEN 2)

Load, kips	Half Crack Length (c) inch	Half Crack Length, (c + rho) inch	Corresponding Fracture Toughness, ksi √inch	
			Not adjusted	Adjusted for Plasticity
8	2.880	2.886	10	9
18	2.880	2.918	22	22
26	2.950	3.036	33	34
36	2.950	3.122	45	46
44	2.975	3.231	56	58
49	2.990	3.331	63	67
56	3.020	3.477	71	78
58	3.025	3.530	74	82
63	3.050	3.687	81	92
67	3.075	3.837	86	100
68	3.080	3.901	88	104
70	3.115	4.025	92	110
73	3.150	4.214	96	119
75	3.240	4.499	101	129
76	3.260	4.627	103	134
78	3.275	4.766	105	140
78	3.365	5.054	107	149
79	3.425		110	
79	3.425		110	
78	3.540		112	
78	3.605		112	
76	3.735		112	
75	3.865		115	
73	3.940		113	
74	3.955		114	
73	4.000		114	

Thickness = .144 inch
Yield = 45.9 ksi
Specimen Width = 18.01 inch

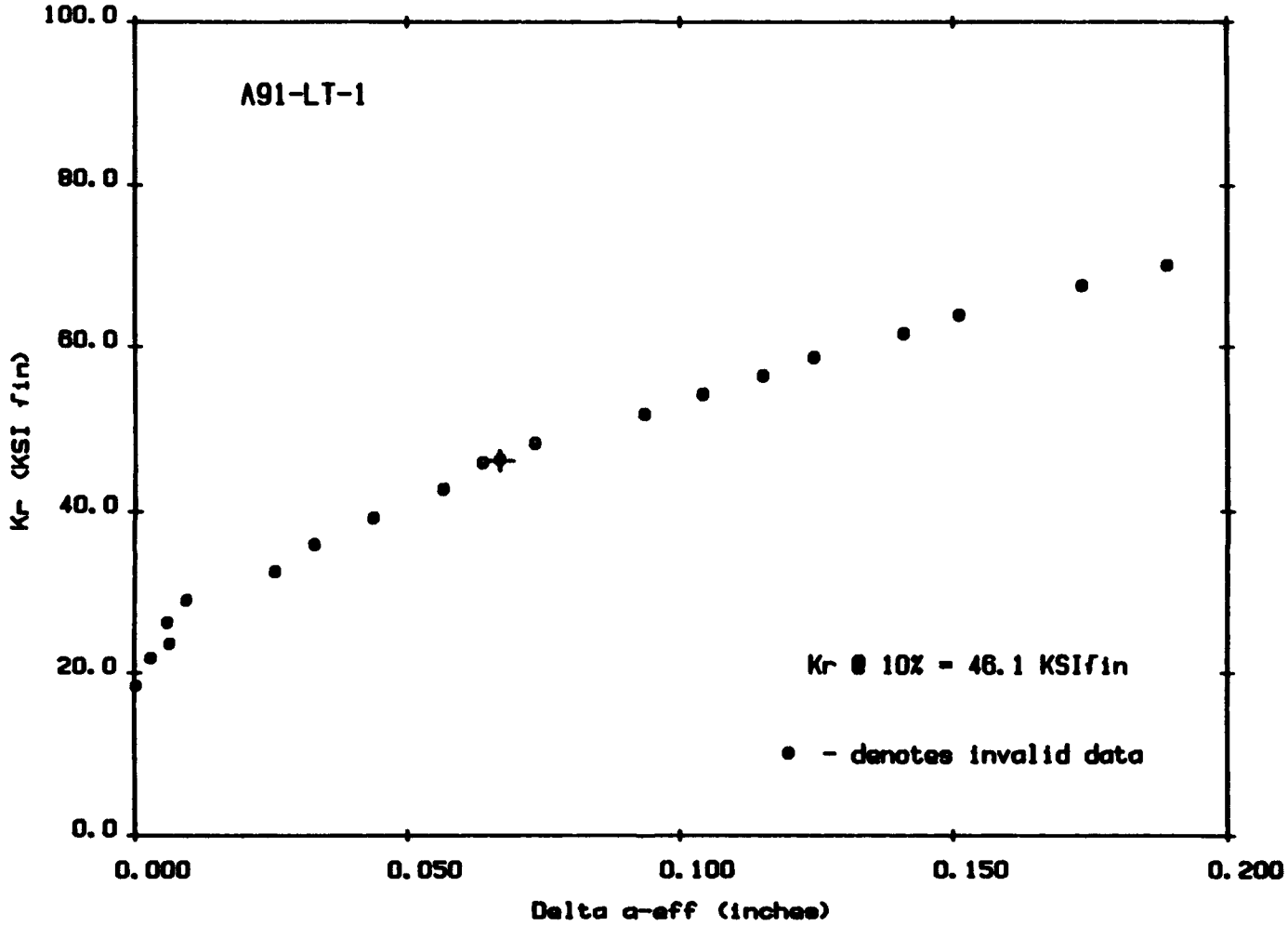


FIGURE K5. R-CURVE RESULTS FOR 2091-T3 0.144 INCH SHEET (L-T ORIENTATION). AIR FORCE.

TABLE K20

R-CURVE DATA ASSOCIATED WITH

FIGURE K5 (L-T ORIENTATION)

A91-LT-1 Oct 7, 1988
W = 2.509 inches
B = 0.143 inches
E = 12.760 MSI
YS = 51.000 KSI
Initial a (physical) = 1.046 inches
Initial a (compliance) = 1.044 inches

POINT	2V	P (LBF)	EB2V/P	a-eff/W	Kr	a-eff	delta a	
1	***	initial compliance crack length ***				1.0436		
1	0.0116	542	42.57	0.4160	18.22	1.0438	0.0003	
2	0.0140	645	42.74	0.4171	21.74	1.0465	0.0030	
3	0.0153	696	42.95	0.4185	23.57	1.0500	0.0064	
4	0.0172	775	42.92	0.4183	26.22	1.0495	0.0060	
5	0.0191	854	43.14	0.4197	29.01	1.0530	0.0095	
6	0.0218	942	44.17	0.4262	32.57	1.0694	0.0258	
7	0.0241	1029	44.64	0.4291	35.87	1.0767	0.0331	
8	0.0265	1109	45.34	0.4334	39.10	1.0874	0.0438	
9	0.0292	1192	46.21	0.4385	42.61	1.1002	0.0566	
10	0.0315	1271	46.70	0.4413	45.79	1.1074	0.0638	
11	0.0333	1321	47.37	0.4452	48.13	1.1170	0.0734	
12	0.0360	1384	48.82	0.4532	51.57	1.1371	0.0935	
13	0.0380	1434	49.62	0.4575	54.08	1.1479	0.1043	invalid
14	0.0398	1475	50.46	0.4619	56.34	1.1589	0.1153	invalid
15	0.0416	1518	51.19	0.4656	58.59	1.1683	0.1247	invalid
16	0.0440	1564	52.51	0.4722	61.52	1.1847	0.1411	invalid
17	0.0459	1603	53.35	0.4762	63.81	1.1949	0.1513	invalid
18	0.0490	1651	55.26	0.4851	67.47	1.2172	0.1736	invalid
19	0.0512	1682	56.64	0.4913	70.04	1.2326	0.1890	invalid
20	0.0565	1738	60.36	0.5068	75.90	1.2717	0.2281	invalid
21	0.0597	1762	62.84	0.5165	79.32	1.2959	0.2523	invalid
22	0.0660	1792	68.12	0.5353	85.79	1.3430	0.2994	invalid
The following value is the 10% SECANT value								
23	0.0318	1275	46.92	0.4426	46.10	1.1105	0.0670	

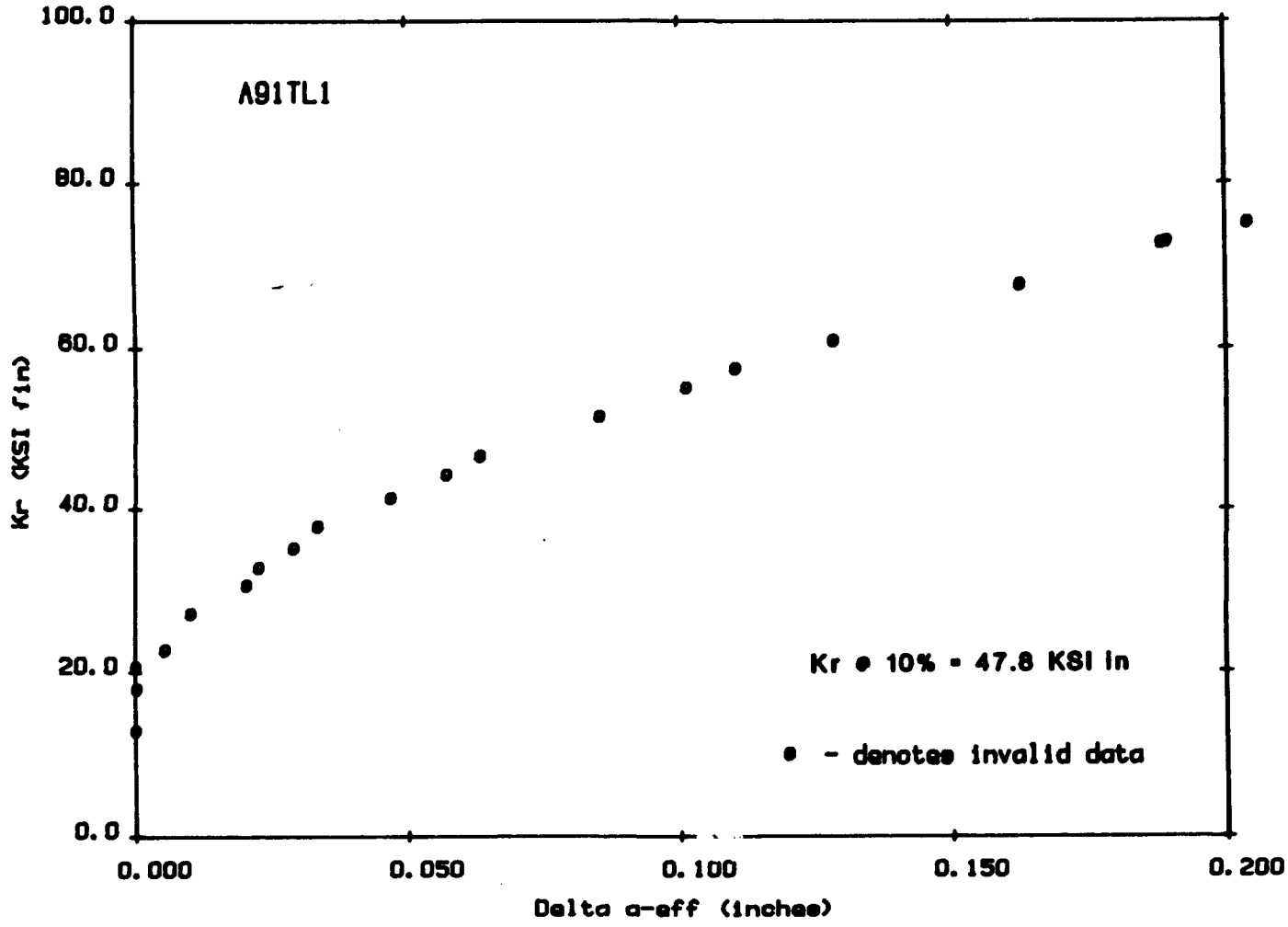


FIGURE K6. R-CURVE RESULTS FOR 2091-T3
0.144 INCH SHEET (T-L Orientation).
AIR FORCE.

TABLE K21

R-CURVE DATA ASSOCIATED WITH

FIGURE K6 (T-L ORIENTATION)

A91TL1 Oct 6, 1988
W = 2.504 inches
B = 0.143 inches
E = 12.520 MSI
YS = 55.000 KSI
Initial a (physical) = 1.048 inches
Initial a (compliance) = 1.046 inches

POINT	2V	P (LBF)	EB2V/P	a-eff/W	Kr	a-eff	delta a	
1	***	initial compliance crack length ***				1.0456		
1	0.0080	381	42.68	0.4167	12.82	1.0433	-0.0023	
2	0.0116	528	42.84	0.4177	17.82	1.0459	0.0002	
3	0.0135	608	42.81	0.4175	20.48	1.0453	-0.0003	
4	0.0150	665	43.16	0.4198	22.56	1.0511	0.0054	
5	0.0182	792	43.45	0.4217	26.99	1.0558	0.0101	
6	0.0207	882	44.11	0.4258	30.41	1.0661	0.0205	
7	0.0222	943	44.25	0.4267	32.58	1.0684	0.0227	
8	0.0240	1005	44.67	0.4293	34.97	1.0747	0.0291	
9	0.0260	1076	44.96	0.4311	37.64	1.0792	0.0335	
10	0.0287	1161	45.84	0.4364	41.21	1.0925	0.0468	
11	0.0309	1230	46.54	0.4404	44.14	1.1026	0.0570	
12	0.0327	1286	46.97	0.4429	46.47	1.1089	0.0632	
13	0.0366	1388	48.54	0.4517	51.40	1.1308	0.0851	
14	0.0395	1460	49.73	0.4581	55.05	1.1468	0.1012	
15	0.0414	1507	50.43	0.4617	57.41	1.1559	0.1103	invalid
16	0.0442	1564	51.85	0.4689	60.86	1.1739	0.1283	invalid
17	0.0499	1669	54.71	0.4826	67.59	1.2082	0.1626	invalid
18	0.0544	1740	57.11	0.4933	72.76	1.2350	0.1894	invalid
19	0.0565	1762	58.49	0.4992	75.02	1.2498	0.2041	invalid
20	0.0607	1797	61.56	0.5116	79.53	1.2808	0.2351	invalid
21	0.0643	1781	66.18	0.5286	83.23	1.3234	0.2778	invalid
22	0.0704	1745	73.25	0.5516	88.15	1.3810	0.3353	invalid
23	0.0754	1738	78.78	0.5674	92.78	1.4205	0.3749	invalid
The following value is the 25% SECANT value								
24	0.0543	1738	57.02	0.4929	72.58	1.2340	0.1884	invalid
The following value is the 10% SECANT value								
	0.0339	1314	47.48	0.4458	47.82	1.1161	0705	

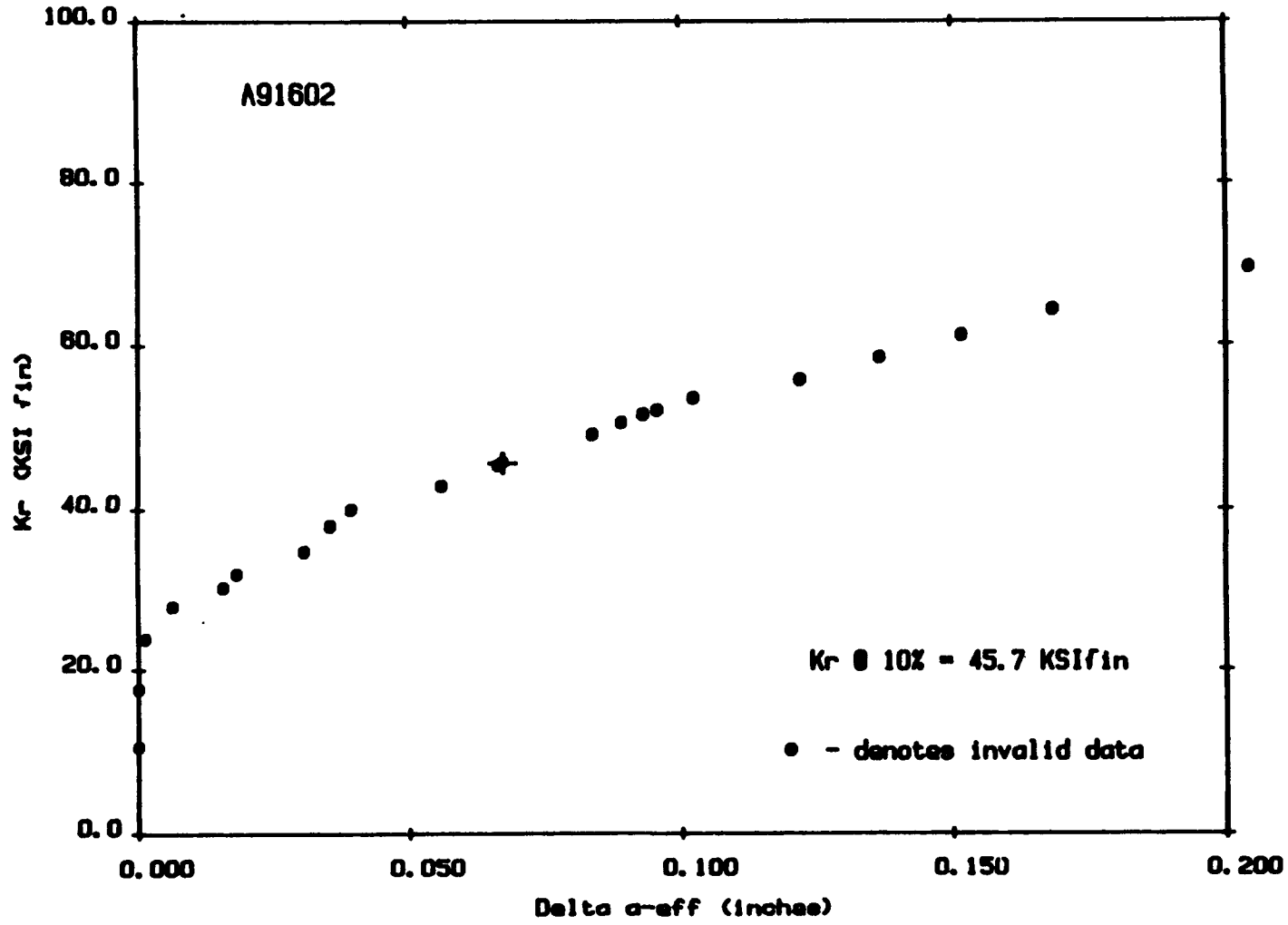


FIGURE K7. R-CURVE RESULTS for 2091-T3 0.144 Inch Sheet (60° Orientation, Specimen 1). Air Force.

TABLE K22

R-CURVE DATA ASSOCIATED WITH

FIGURE K7 (60° ORIENTATION, SPECIMEN 1)

A91602 Oct 7, 1988
W = 2.506 inches
B = 0.143 inches
E = 12.450 MSI
YS = 50.000 KSI
Initial a (physical) = 1.109 inches
Initial a (compliance) = 1.106 inches

POINT	2V	P (LBF)	EB2V/P	a-eff/W	Kr	a-eff	delta a	
1	***	initial compliance crack length ***				1.1065		
1	0.0063	292	46.08	0.4378	10.39	1.0968	-0.0097	
2	0.0115	489	46.35	0.4393	17.49	1.1007	-0.0058	
3	0.0161	656	46.83	0.4421	23.66	1.1077	0.0012	
4	0.0190	764	47.19	0.4442	27.70	1.1129	0.0064	
5	0.0209	821	47.86	0.4479	30.10	1.1222	0.0157	
6	0.0222	866	48.04	0.4489	31.82	1.1247	0.0183	
7	0.0244	930	48.95	0.4539	34.68	1.1372	0.0307	
8	0.0268	1011	49.31	0.4558	37.87	1.1420	0.0355	
9	0.0283	1060	49.59	0.4573	39.89	1.1458	0.0393	
10	0.0307	1116	50.86	0.4639	42.82	1.1623	0.0558	
11	0.0327	1168	51.69	0.4681	45.34	1.1728	0.0663	
12	0.0357	1238	53.10	0.4750	49.03	1.1902	0.0837	
13	0.0377	1284	53.89	0.4788	51.45	1.1996	0.0931	invalid
14	0.0369	1266	53.55	0.4772	50.47	1.1955	0.0890	
15	0.0381	1293	54.11	0.4798	51.93	1.2021	0.0956	invalid
16	0.0394	1321	54.67	0.4824	53.48	1.2087	0.1022	invalid
17	0.0414	1343	56.42	0.4903	55.69	1.2284	0.1219	invalid
18	0.0437	1384	57.76	0.4961	58.41	1.2430	0.1365	invalid
19	0.0461	1422	59.20	0.5021	61.10	1.2580	0.1516	invalid
20	0.0488	1463	60.86	0.5088	64.21	1.2749	0.1684	invalid
21	0.0536	1508	64.64	0.5231	69.27	1.3106	0.2042	invalid
22	0.0605	1530	71.77	0.5471	76.10	1.3706	0.2642	invalid
23	0.0680	1515	81.30	0.5741	82.92	1.4384	0.3319	invalid
The following value is the 10% SECANT value								
24	0.0330	1175	51.76	0.4684	45.67	1.1737	0.0672	

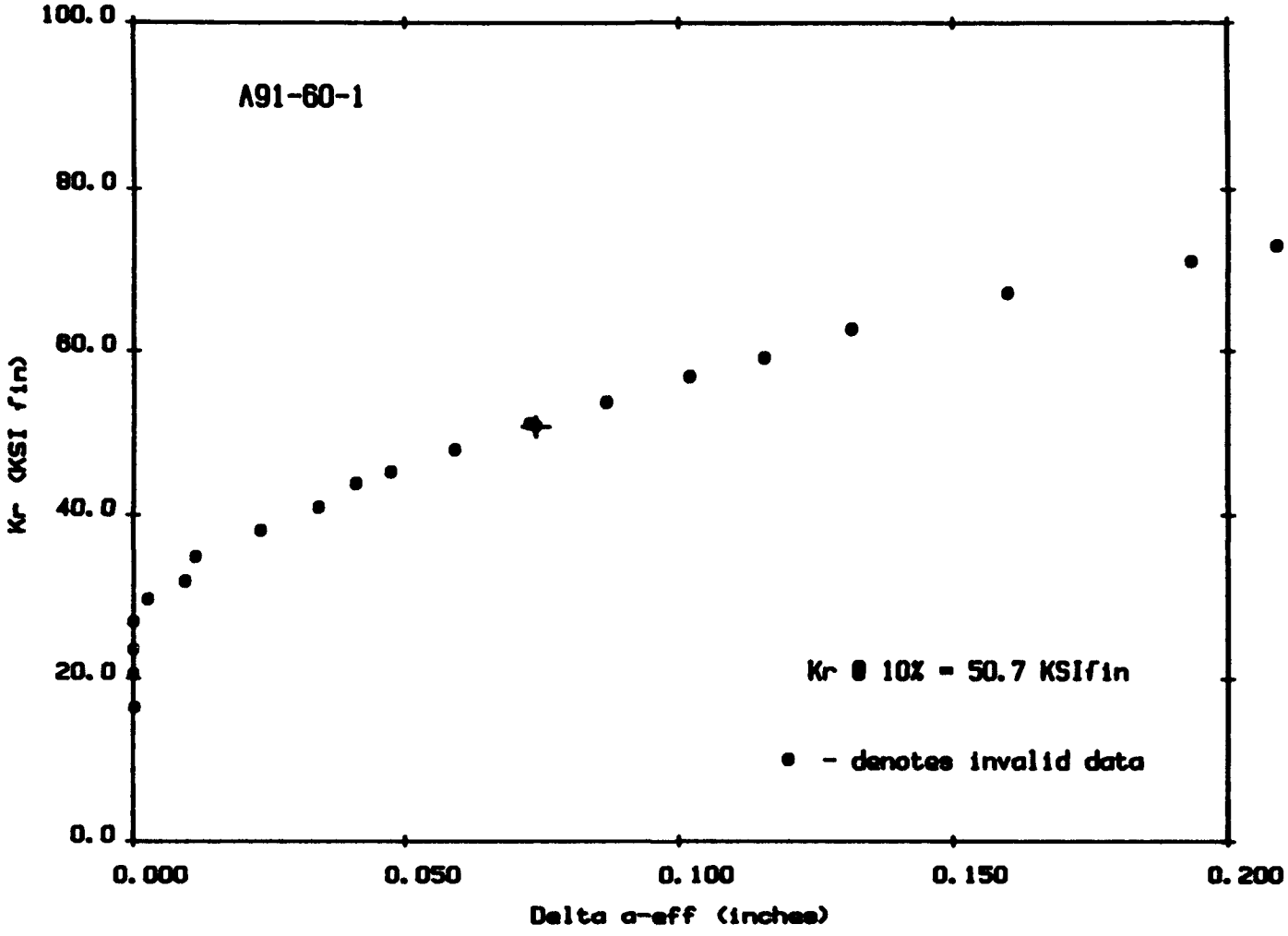


FIGURE K8. R-CURVE RESULTS FOR 2091-T3 0.144 INCH SHEET (60° ORIENTATION, SPECIMEN 2). AIR FORCE

TABLE K23

R-CURVE DATA ASSOCIATED WITH FIGURE K8
(60° ORIENTATION, SPECIMEN 2)

A91-60-1 Oct 7, 1988
W = 2.508 inches
B = 0.143 inches
E = 11.980 MSI
YS = 50.000 KSI
Initial a (physical) = 1.036 inches
Initial a (compliance) = 1.034 inches

POINT	2V	P (LBF)	EB2V/P	a-eff/W	K	a-eff	delta a	
1	***	initial compliance crack length ***				1.0343		
1	0.0106	493	42.05	0.4125	16.32	1.0346	0.0002	
2	0.0136	622	41.66	0.4099	20.46	1.0280	-0.0063	
3	0.0159	709	42.03	0.4124	23.49	1.0342	-0.0001	
4	0.0184	815	41.84	0.4112	26.92	1.0311	-0.0032	
5	0.0205	893	42.19	0.4135	29.67	1.0369	0.0026	
6	0.0222	952	42.60	0.4162	31.86	1.0438	0.0095	
7	0.0244	1038	42.72	0.4170	34.80	1.0457	0.0114	
8	0.0269	1119	43.48	0.4218	38.03	1.0579	0.0236	
9	0.0291	1189	44.15	0.4261	40.85	1.0685	0.0342	
10	0.0313	1263	44.59	0.4288	43.73	1.0753	0.0410	
11	0.0325	1294	45.00	0.4313	45.13	1.0816	0.0473	
12	0.0346	1354	45.77	0.4359	47.80	1.0933	0.0590	
13	0.0372	1421	46.71	0.4414	50.96	1.1070	0.0727	
14	0.0394	1472	47.69	0.4470	53.60	1.1210	0.0867	invalid
15	0.0421	1533	48.80	0.4531	56.77	1.1362	0.1019	invalid
16	0.0441	1570	49.82	0.4585	59.09	1.1499	0.1156	invalid
17	0.0471	1636	51.05	0.4649	62.66	1.1658	0.1315	invalid
18	0.0512	1696	53.35	0.4762	67.17	1.1943	0.1600	invalid
19	0.0550	1725	56.24	0.4895	71.07	1.2276	0.1933	invalid
20	0.0569	1740	57.68	0.4957	73.03	1.2432	0.2089	invalid
21	0.0771	1765	76.54	0.5612	91.85	1.4074	0.3731	invalid
The following value is the 10% SECANT value								
22	0.0370	1411	46.79	0.4419	50.66	1.1081	0.0738	

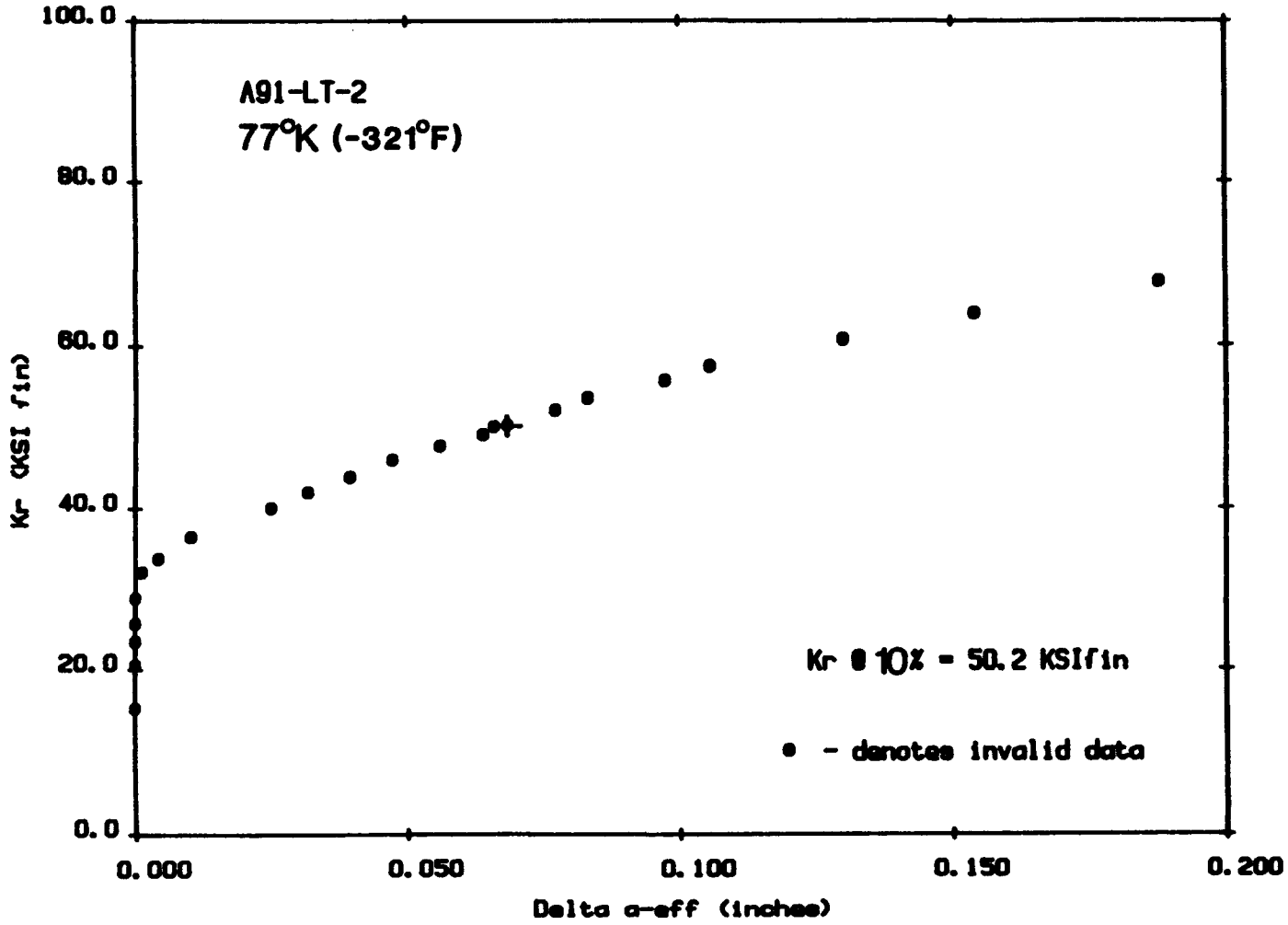


FIGURE K9. R-CURVE RESULTS FOR 2091-T3 0.144 INCH SHEET (L-T ORIENTATION, -321°F). AIR FORCE.

TABLE K24

R-CURVE DATA ASSOCIATED WITH FIGURE K9
(L-T ORIENTATION, -321°F)

A91-LT-2 7 Oct, 1988
W = 2.501 inches
B = 0.144 inches
E = 13.690 MSI
YS = 51.000 KSI
Initial a (physical) = 1.031 inches
Initial a (compliance) = 1.029 inches

POINT	2V	P (LBF)	EB2V/P	a-eff/W	Kr	a-eff	delta a	
1	***	initial compliance crack length ***				1.0287		
~~1~~	~~0.0074~~	~~387~~	~~48.35~~	~~0.4146~~	~~12.09~~	~~1.0266~~	~~-0.0021~~	
2	0.0088	460	41.75	0.4105	15.15	1.0266	-0.0021	
3	0.0121	624	41.34	0.4078	20.38	1.0197	-0.0089	
4	0.0140	708	41.69	0.4102	23.27	1.0257	-0.0030	
5	0.0154	778	41.47	0.4087	25.49	1.0219	-0.0067	
6	0.0175	872	41.62	0.4097	28.64	1.0244	-0.0043	
7	0.0196	965	41.94	0.4118	31.89	1.0299	0.0012	
8	0.0207	1014	42.12	0.4130	33.59	1.0328	0.0042	
9	0.0225	1089	42.49	0.4154	36.32	1.0389	0.0102	
10	0.0250	1178	43.40	0.4214	39.91	1.0537	0.0251	
11	0.0264	1228	43.83	0.4241	41.91	1.0604	0.0318	
12	0.0277	1272	44.33	0.4272	43.81	1.0682	0.0396	
13	0.0292	1323	44.84	0.4303	45.93	1.0761	0.0474	
14	0.0304	1359	45.41	0.4338	47.65	1.0848	0.0561	
15	0.0314	1387	45.94	0.4369	49.05	1.0925	0.0639	
16	0.0321	1412	46.07	0.4377	50.04	1.0945	0.0659	
17	0.0335	1449	46.85	0.4422	52.01	1.1058	0.0771	
18	0.0346	1481	47.27	0.4446	53.50	1.1117	0.0831	invalid
19	0.0362	1515	48.29	0.4503	55.61	1.1260	0.0973	invalid
20	0.0375	1550	48.89	0.4536	57.43	1.1342	0.1056	invalid
21	0.0402	1594	50.76	0.4634	60.74	1.1587	0.1301	invalid
22	0.0427	1630	52.67	0.4729	63.84	1.1826	0.1540	invalid
23	0.0459	1660	55.56	0.4865	67.66	1.2164	0.1878	invalid
24	0.0491	1678	58.69	0.5000	71.29	1.2504	0.2217	invalid
25	0.0548	1678	65.36	0.5257	77.31	1.3146	0.2859	invalid
26	0.0564	1651	68.39	0.5362	78.74	1.3408	0.3121	invalid
The following value is the 10% SECANT value								
27	0.0322	1412	46.24	0.4387	50.17	1.0970	0.0683	

TABLE K25

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR

ALCOA 2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
MCDONNELL DOUGLAS ASTRO., CA	LONG	50.2	65,600 +
		45.2	209,000 +
		42.0	67,000
		40.0	353,000 +
		38.1	670,000 +
		35.9	84,400 @
		35.7	45,700 #
		33.1	120,000 @
		30.9	340,000
		29.1	1,000,000 *

(*): INDICATES A RUN-OUT TEST
(#): INDICATES FAILURE AT PIN HOLE
(@): INDICATES FAILURE AT RADIUS
(+): INDICATES SPECIMENS WERE RECONFIGURED AND HAD SURFACE COATING REMOVED

TABLE K26

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR

ALCOA 2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
MCDONNELL DOUGLAS ASTRO., CA	L TRANS	49.9	42,300 +
		45.0	87,700 #+
		45.0	39,900
		39.8	293,000 +
		35.0	1,000,000 *+
		34.9	385,000 !
		33.0	203,000 !
		33.0	621,000 !
		30.9	1,530,000 *!

(*): INDICATES A RUN-OUT TEST
(#): INDICATES FAILURE AT PIN HOLE
(!): INDICATES THE SPECIMENS WERE ONLY RECONFIGURED
(+): INDICATES SPECIMENS WERE RECONFIGURED AND HAD SURFACE COATING REMOVED

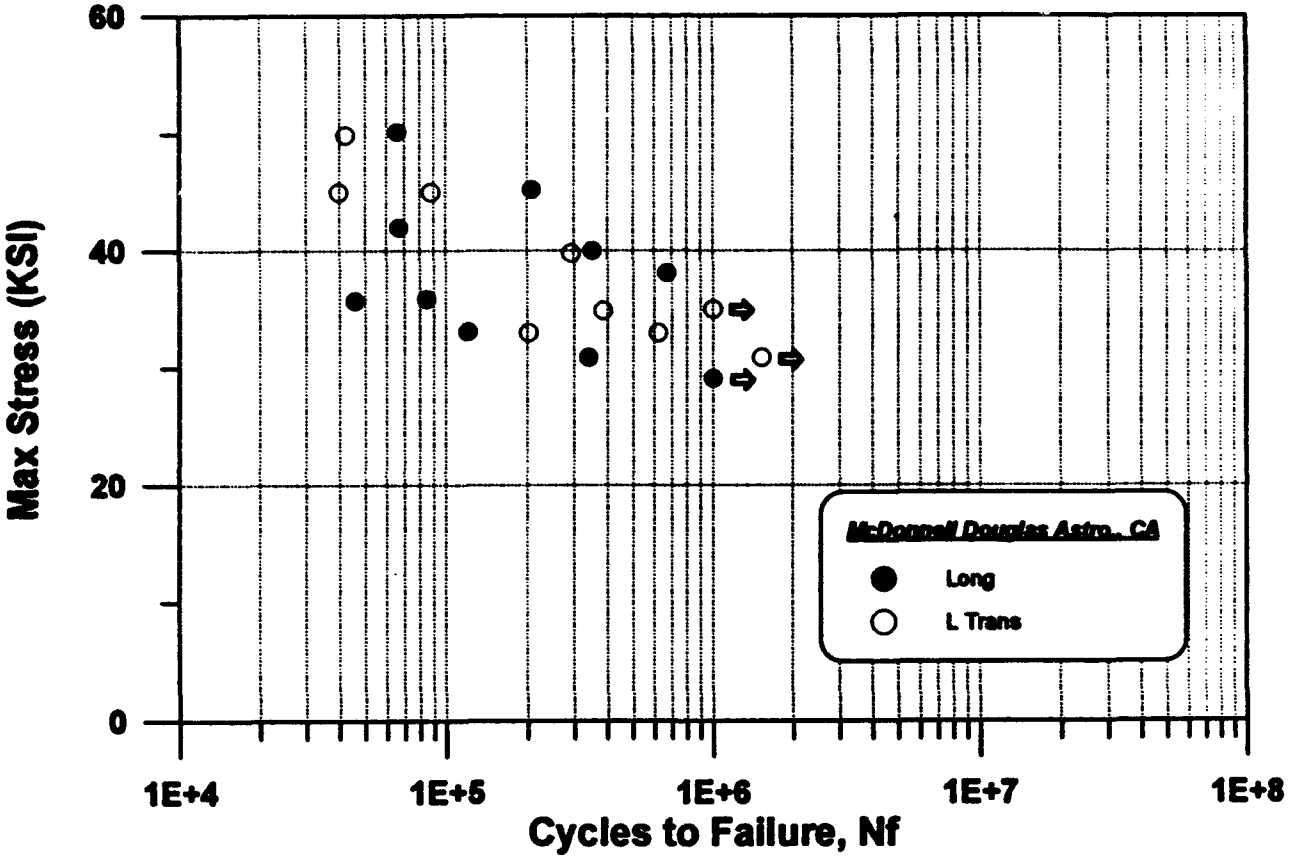


FIGURE K10. FATIGUE RESULTS FOR 2091-T3
0.144 INCH SHEET (R=1.0, Kt =1.0).
MCDONNELL DOUGLAS ASTRONAUTICS

TABLE K27

FATIGUE RESULTS WITH R=0.1 AND Kt=3.0 FOR

ALCOA 2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
MCDONNELL DOUGLAS ASTRO., CA	LONG	24.9	16,100
		21.9	32,200
		19.9	109,000
		18.0	112,000
		18.0	71,250
		15.0	294,000
		14.9	1,000,000 *
		14.0	1,000,000 *
		13.0	1,000,000 *

(*): INDICATES A RUN-OUT TEST

TABLE K28

FATIGUE RESULTS WITH R=0.1 AND Kt=3.0 FOR

ALCOA 2091-T3 SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
MCDONNELL DOUGLAS ASTRO., CA	L TRANS	29.9	10,800
		28.1	11,200
		26.8	23,700
		25.1	34,900
		22.1	58,700
		19.9	87,400
		18.0	135,000
		16.0	247,000
		14.9	1,000,000

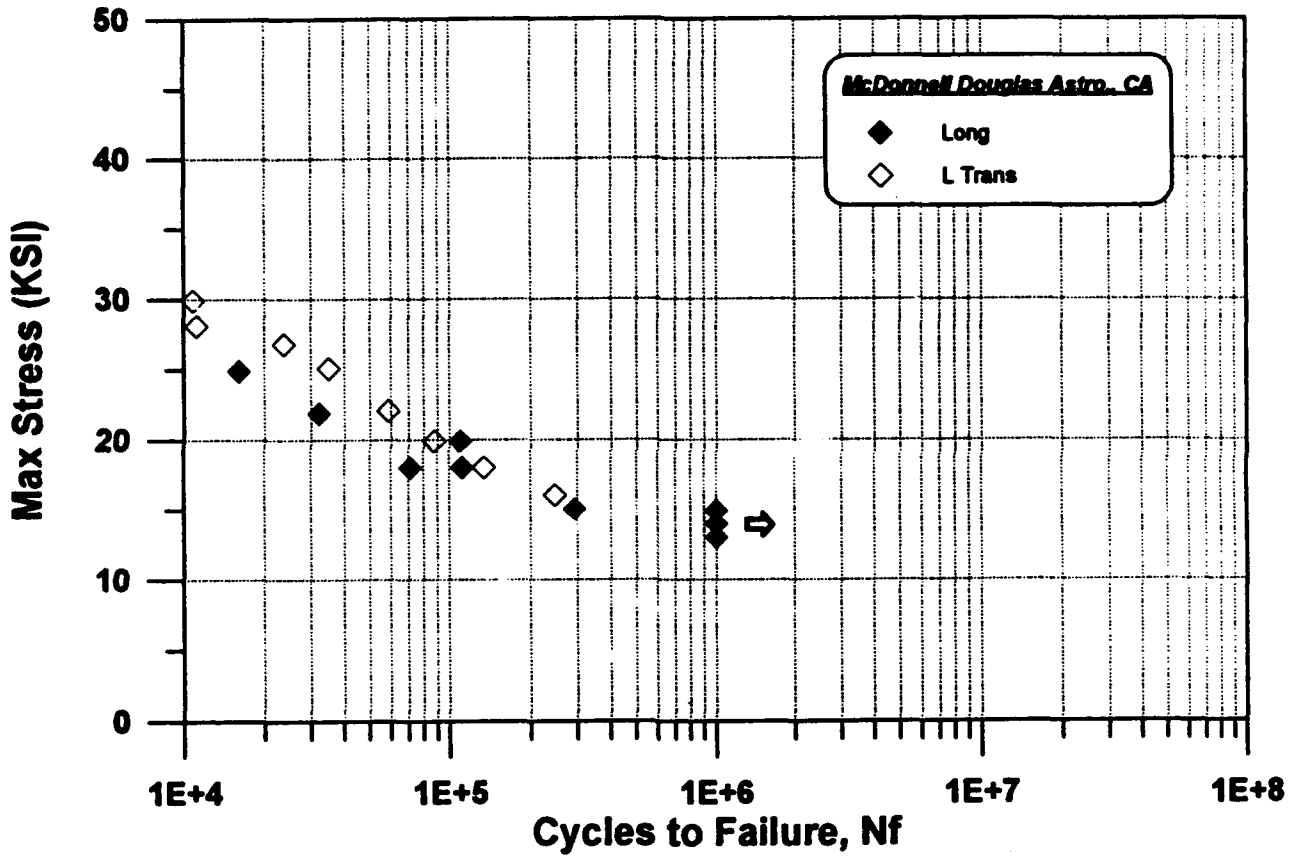


FIGURE K11. FATIGUE RESULTS FOR 2091-T3
0.144 INCH SHEET (R=1.0, Kt=3.0).
MCDONNELL DOUGLAS ASTRONAUTICS

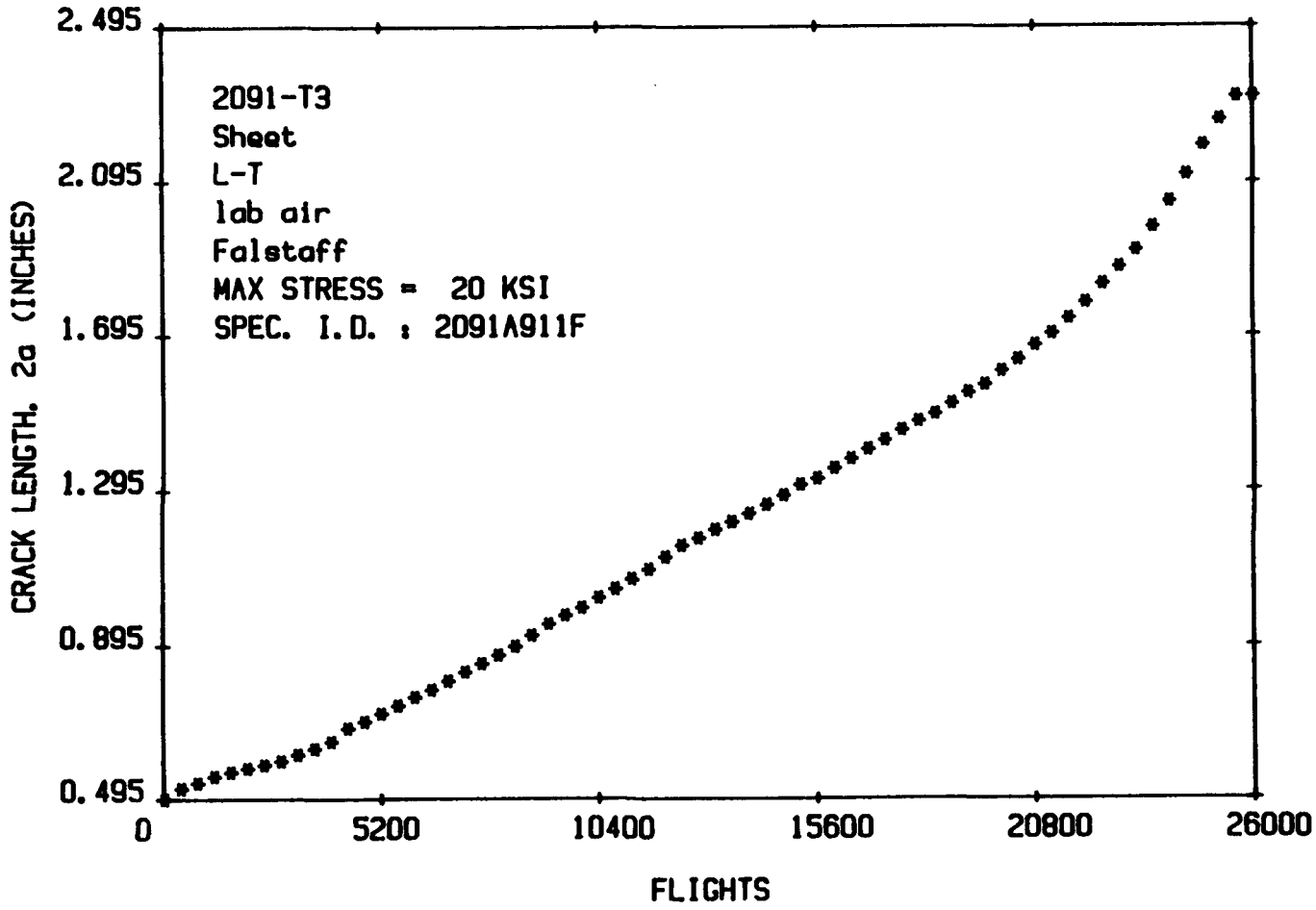


FIGURE K12. FALSTAFF SPECTRUM FATIGUE CRACK LENGTH VS FLIGHTS DATA FOR 2091-T3 0.144 INCH SHEET, AIR FORCE.

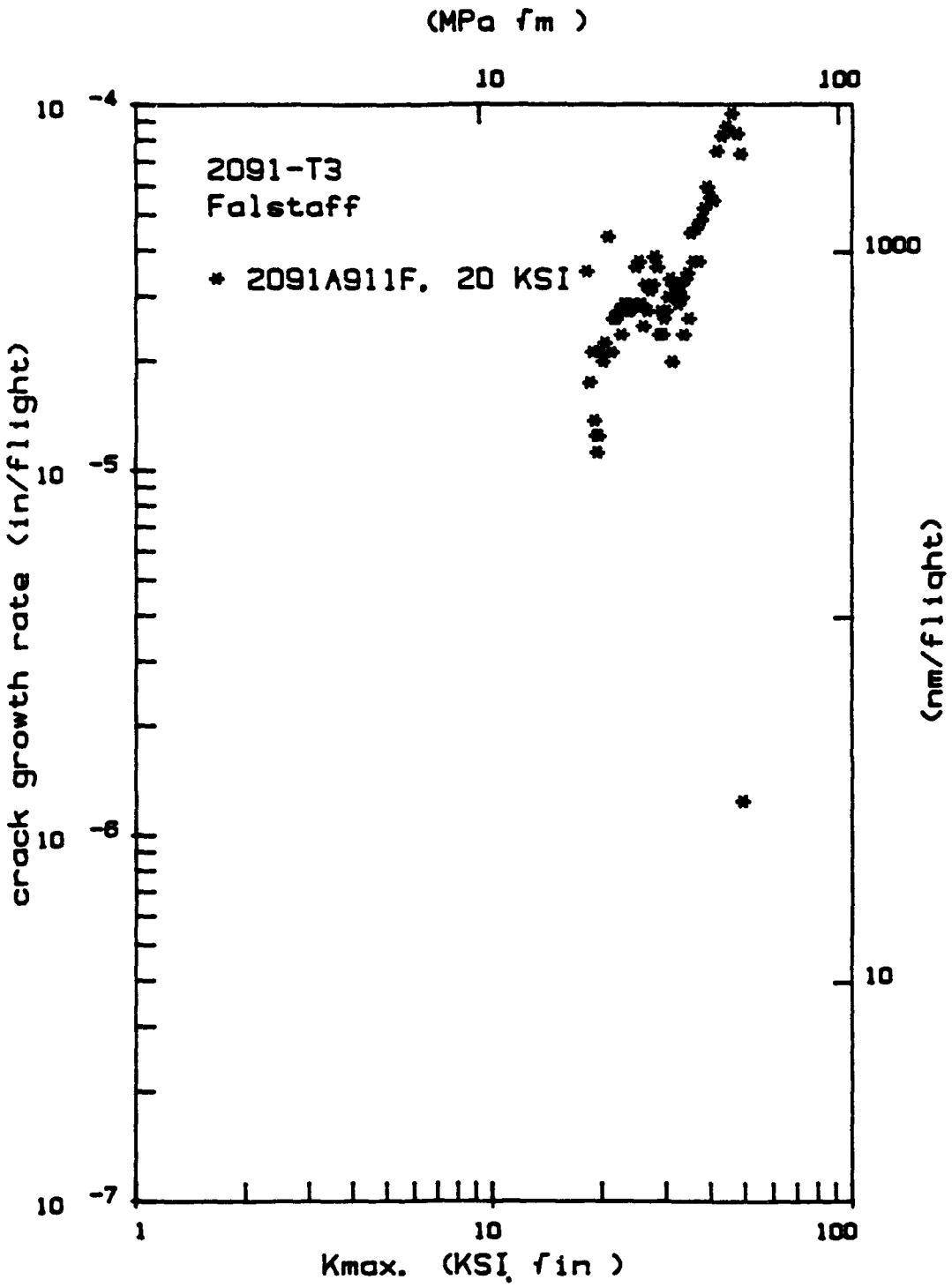


FIGURE K13. FALSTAFF SPECTRUM FATIGUE CRACK GROWTH RATE VS KMAX DATA FOR 2091-T3 0.144 INCH SHEET. AIR FORCE.

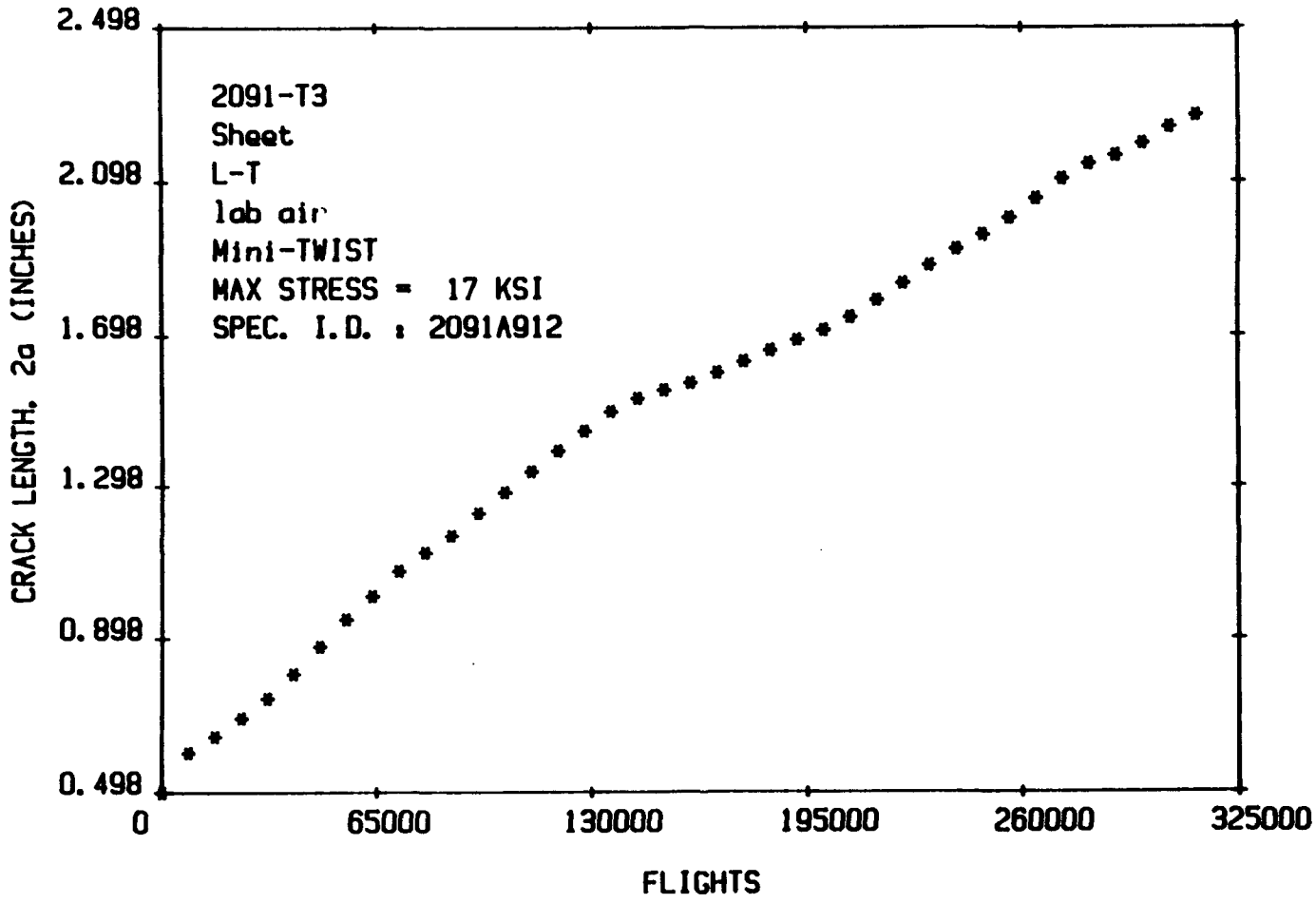


FIGURE K14. MINI-TWIST SPECTRUM FATIGUE CRACK LENGTH VS FLIGHTS DATA FOR 2091-T3 0.144 INCH SHEET(SPECIMEN #2091A912)

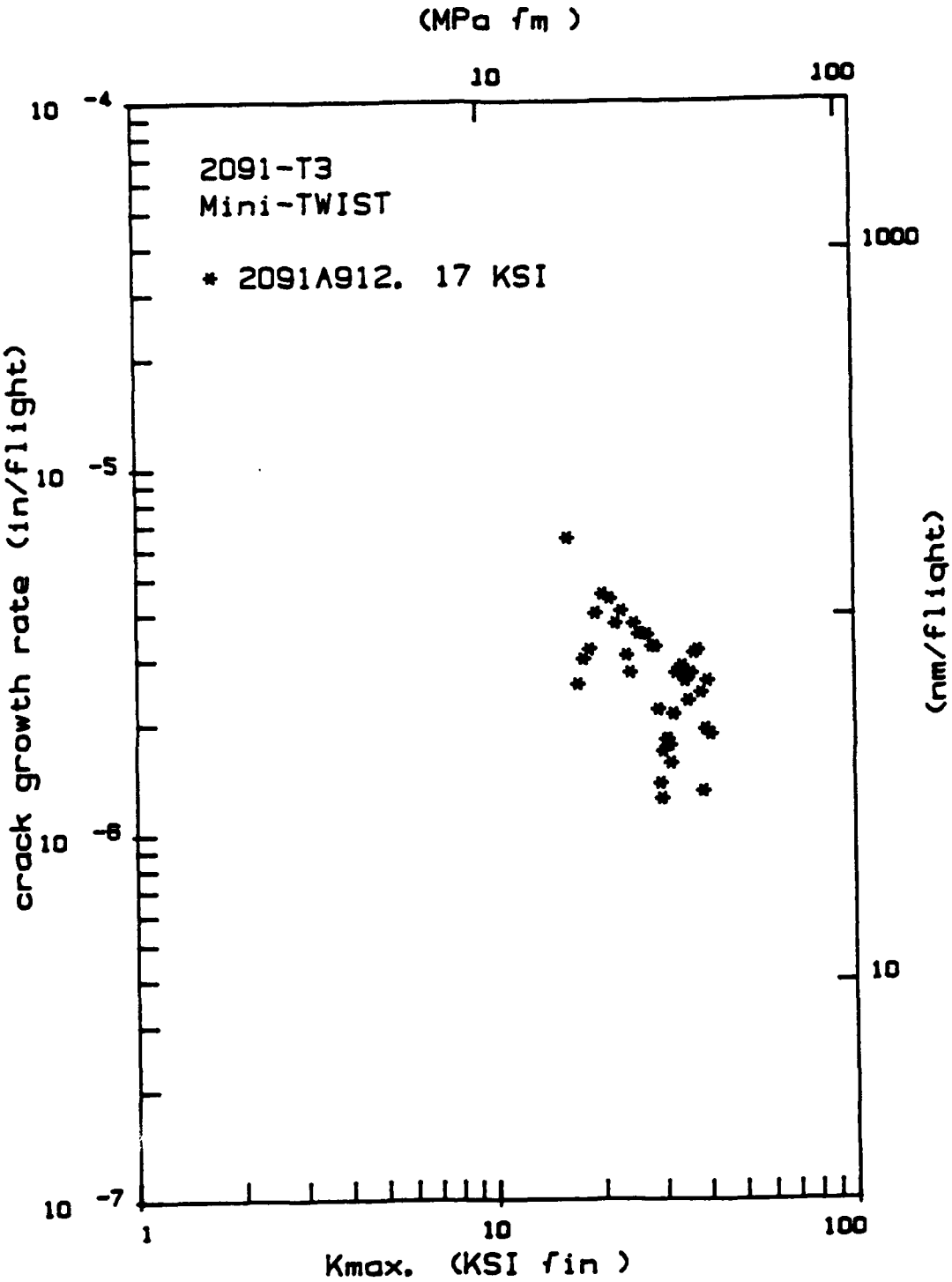


FIGURE K15. MINI-TWIST SPECTRUM CRACK GROWTH RATE VS KMAX DATA FOR 2091-T3 0.144 INCH SHEET (Specimen #2091A912). AIR FORCE.

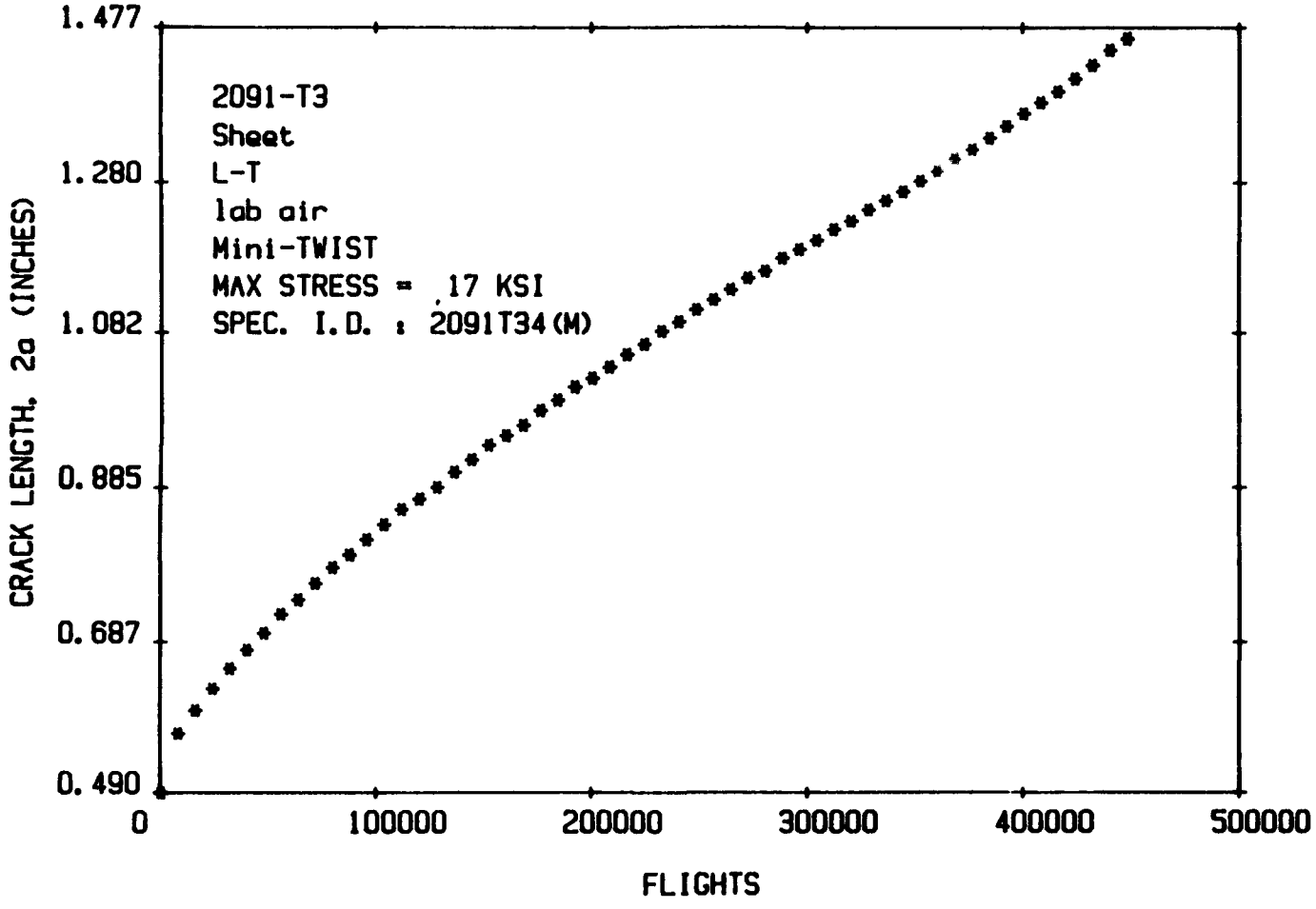


FIGURE K16. MINI-TWIST SPECTRUM FATIGUE CRACK LENGTH VS FLIGHTS DATA FOR 2091-T3 0.144 INCH SHEET(SPECIMEN #2091T34M). AIR FORCE.

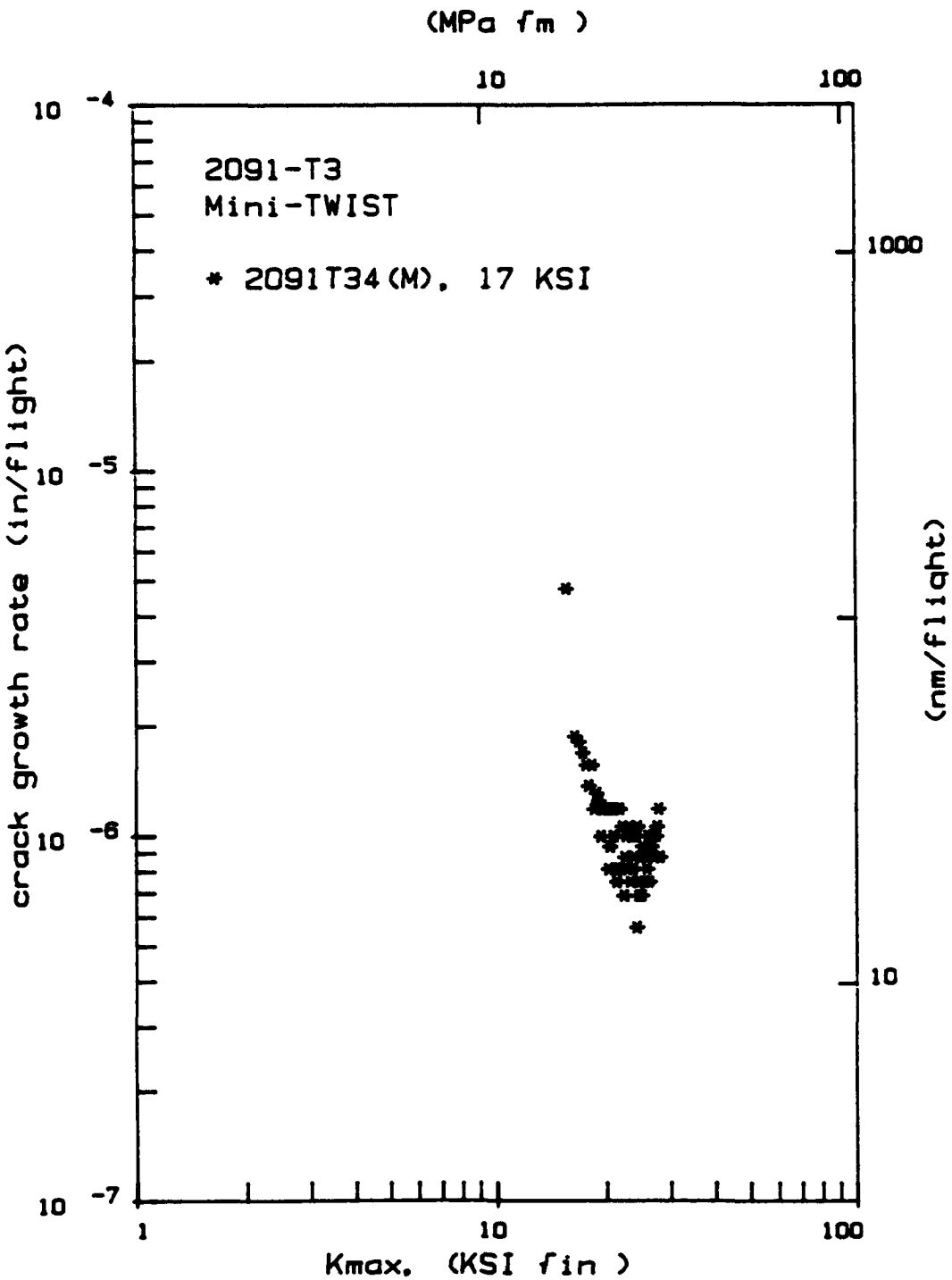


FIGURE K17. MINI-TWIST SPECTRUM CRACK GROWTH RATE VS KMAX DATA FOR 2091-T3 0.144 INCH SHEET (SPECIMEN #2091T34M). AIR FORCE.

TABLE K29

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 16 HOURS AT 335 F

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GENERAL DYNAMICS, TEXAS	RT	LONG	67.3	56.1	14.2		
			67.1	56.3	14.3		
		AVERAGE	67.2	56.2	14.3		
	STANDARD DEVIATION		0.1	0.1	0.1		

TABLE K30

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 16 HOURS AT 335 F

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GENERAL DYNAMICS, TEXAS	RT	45	65.3	46.7	19.2		
			65.6	47.4	19.8		
		AVERAGE	65.5	47.1	19.5		
	STANDARD DEVIATION		0.2	0.5	0.4		

TABLE K31

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 16 HOURS AT 335 F

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GENERAL DYNAMICS, TEXAS	RT	L TRANS	70.7	51.3	12.8		
			70.9	52.8	11.1		
		AVERAGE	70.8	52.1	12.0		
	STANDARD DEVIATION		0.1	1.1	1.2		

TABLE K32

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 32 HOURS AT 335 F

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GENERAL DYNAMICS, TEXAS	RT	LONG	69.6	58.8			
			69.9	59.4	15.3		
		AVERAGE	69.8	59.1	15.3		
	STANDARD DEVIATION		0.2	0.4			

TABLE K33

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 32 HOURS AT 335 F

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GENERAL DYNAMICS, TEXAS	RT	45	68.8	51.9	17.9		
			68.1	51.1	18.5		
		AVERAGE	68.5	51.5	18.2		
	STANDARD DEVIATION		0.5	0.6	0.4		

TABLE K34

TENSILE RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 32 HOURS AT 335 F

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
GENERAL DYNAMICS, TEXAS	RT	L TRANS	73.9	57.0	15.6		
			74.5	54.5	14.3		
		AVERAGE	74.2	55.8	15.0		
	STANDARD DEVIATION		0.4	1.8	0.9		

TABLE K35

KAHN TEAR TEST RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 16 HOURS AT 335 F

COMPANY	ORIENTATION	TEAR STRENGTH (KSI)
GENERAL DYNAMICS, TEXAS	L-T	81.4 78.8
	AVERAGE	80.1
	STANDARD DEVIATION	1.9

TABLE K36

KAHN TEAR TEST RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 16 HOURS AT 335 F

COMPANY	ORIENTATION	TEAR STRENGTH (KSI)
GENERAL DYNAMICS, TEXAS	45-45	74.6
	AVERAGE	74.6
	STANDARD DEVIATION	

TABLE K37

KAHN TEAR TEST RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 16 HOURS AT 335 F

COMPANY	ORIENTATION	TEAR STRENGTH (KSI)
GENERAL DYNAMICS, TEXAS	T-L	78.2
		77.3
	AVERAGE	77.7
	STANDARD DEVIATION	0.6

TABLE K38

KAHN TEAR TEST RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 32 HOURS AT 335 F

COMPANY	ORIENTATION	TEAR STRENGTH (KSI)
GENERAL DYNAMICS, TEXAS	L-T	76.4
		74.6
	AVERAGE	75.5
	STANDARD DEVIATION	1.3

TABLE K39

KAHN TEAR TEST RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 32 HOURS AT 335 F

COMPANY	ORIENTATION	TEAR STRENGTH (KSI)
GENERAL DYNAMICS, TEXAS	45-45	73.7 74.1
	AVERAGE	73.9
	STANDARD DEVIATION	0.2

TABLE K40

KAHN TEAR TEST RESULTS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 32 HOURS AT 335 F

COMPANY	ORIENTATION	TEAR STRENGTH (KSI)
GENERAL DYNAMICS, TEXAS	T-L	74.7
	AVERAGE	74.7
	STANDARD DEVIATION	

TABLE 41

TEAR-YIELD STRENGTH RATIOS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 16 HOURS AT 335 F

COMPANY	TENSILE-TEAR ORIENTATION	TEAR-YIELD STRENGTH RATIO
GENERAL DYNAMICS, TEXAS	L/L-T	1.42
	LT/T-L	1.48
	45/45-45	1.58
	L/T-L	1.38

TABLE 42

TEAR-YIELD STRENGTH RATIOS FOR ALCOA

2091-T3 SHEET (0.144" X 48" X 48")

AGED 32 HOURS AT 335 F

COMPANY	TENSILE-TEAR ORIENTATION	TEAR-YIELD STRENGTH RATIO
GENERAL DYNAMICS, TEXAS	L/L-T	1.27
	LT/T-L	1.34
	45/45-45	1.44
	L/T-L	1.26

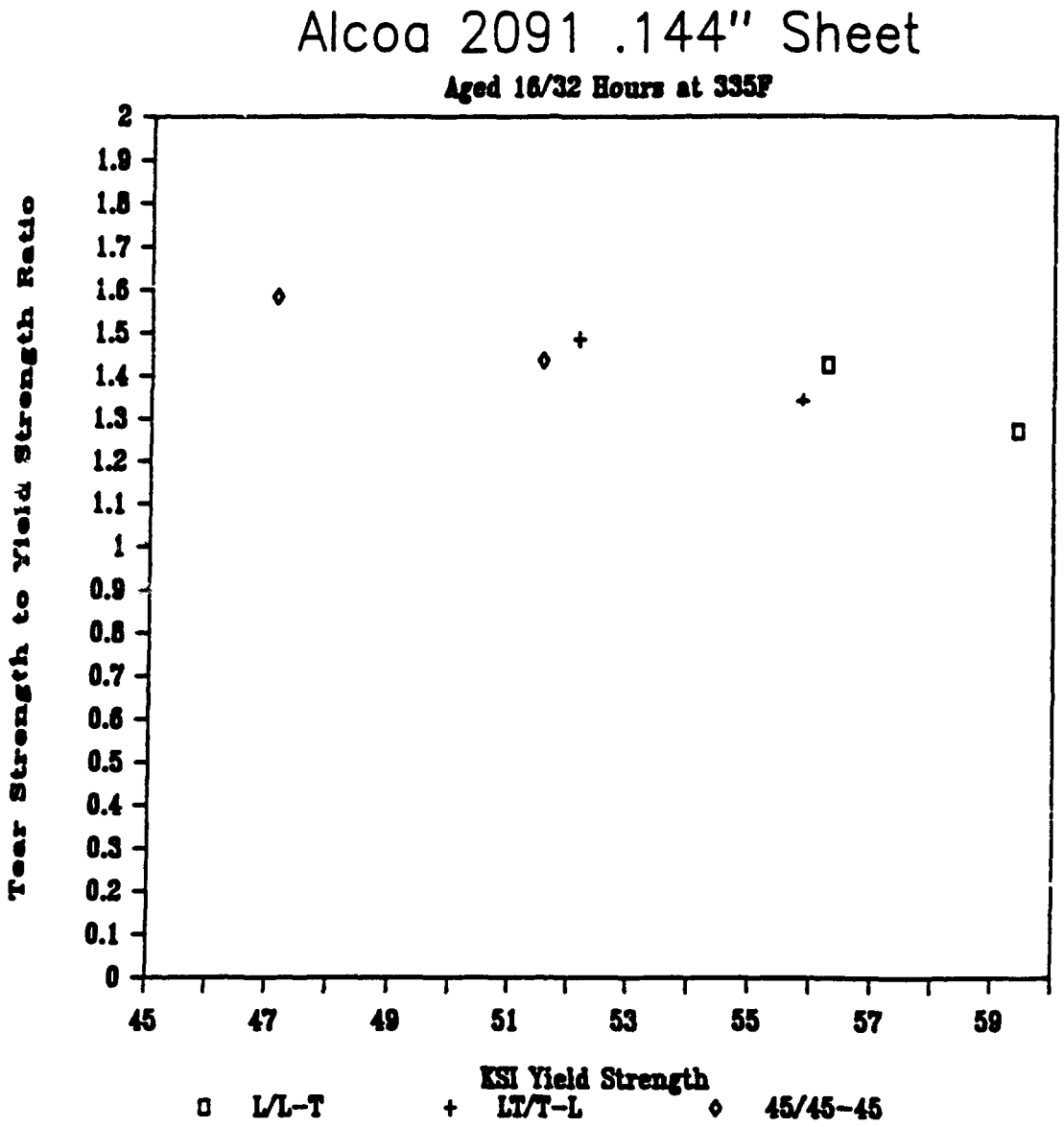


FIGURE K18. TEAR STRENGTH to YIELD STRENGTH RATIO VS YIELD STRENGTH DATA for 2091-T3 Aged 16/32 Hours at 335°F. General Dynamics.

TABLE K43

TENSILE RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	LONG	63.4	53.5	15.6		10.8
			63.2	53.3	16.7		10.2
			63.7	53.7	14.7		10.5
			63.2	53.6	12.6		10.8
		AVERAGE	63.4	53.5	14.9		10.6
	STANDARD DEVIATION		0.2	0.2	1.7		0.3

TABLE K44

TENSILE RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	45		44.3			10.4
			63.3	44.1	19.8		10.5
			62.4	43.5	17.8		11.8
			62.8	44.9	19.2		11.9
		AVERAGE	62.8	44.2	18.9		11.2
	STANDARD DEVIATION		0.5	0.6	1.0		0.8

TABLE K45

TENSILE RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
NORTHROP	RT	L TRANS	67.5	48.7	12.1		10.6
			68.2	49.2	12.7		11.2
			67.8	48.8	13.1		11.3
		AVERAGE	67.8	48.9	12.6		11.0
	STANDARD DEVIATION		0.4	0.3	0.5		0.4

TABLE K46

COMPRESSION RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
NORTHROP	RT	LONG	42.7	12.0
			42.5	11.5
			42.9	11.7
		AVERAGE	42.7	11.7
		STANDARD DEVIATION	0.3	0.2

TABLE K47

COMPRESSION RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
NORTHROP	RT	L TRANS	51.5	11.5
			51.4	11.3
			51.3	11.3
		AVERAGE	51.4	11.4
		STANDARD DEVIATION	0.1	0.1

TABLE K48

SLOTTED SHEAR RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	LONG	40.6
		40.5
		40.5
	AVERAGE	40.5
	STANDARD DEVIATION	0.1

TABLE K49

SLOTTED SHEAR RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
NORTHROP	L TRANS	43.0
		43.0
		43.2
	AVERAGE	43.1
	STANDARD DEVIATION	0.1

TABLE K50

BEARING RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	LONG	1.5	96.8	76.3
			92.9	73.6
		AVERAGE	94.9	75.0
		STANDARD DEVIATION	2.8	1.9

TABLE K51

BEARING RESULTS FOR ALCOA

2091-T8X SHEET (0.063" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	L TRANS	1.5	100.8	76.1
			99.3	75.1
			97.0	74.0
		AVERAGE	99.0	75.1
		STANDARD DEVIATION	1.9	1.1

TABLE K52

BEARING RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	LONG	2.0	120.7	89.8
			122.4	89.1
			123.9	91.8
		AVERAGE	122.3	90.2
		STANDARD DEVIATION	1.6	1.4

TABLE K53

BEARING RESULTS FOR ALCOA

2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
NORTHROP	L TRANS	2.0	125.6	91.9
			126.9	91.0
			126.1	94.6
		AVERAGE	126.2	92.5
		STANDARD DEVIATION	0.7	1.9

TABLE K54

R-CURVE FRACTURE TOUGHNESS RESULTS FOR

ALCOA 2091-T8X SHEET (0.144" X 48" X 48")

COMPANY	SPECIMEN I.D.	ORIENTATION	Kc (KSI SQRT-IN)
NORTHROP	T6RL1	L-T	135.0

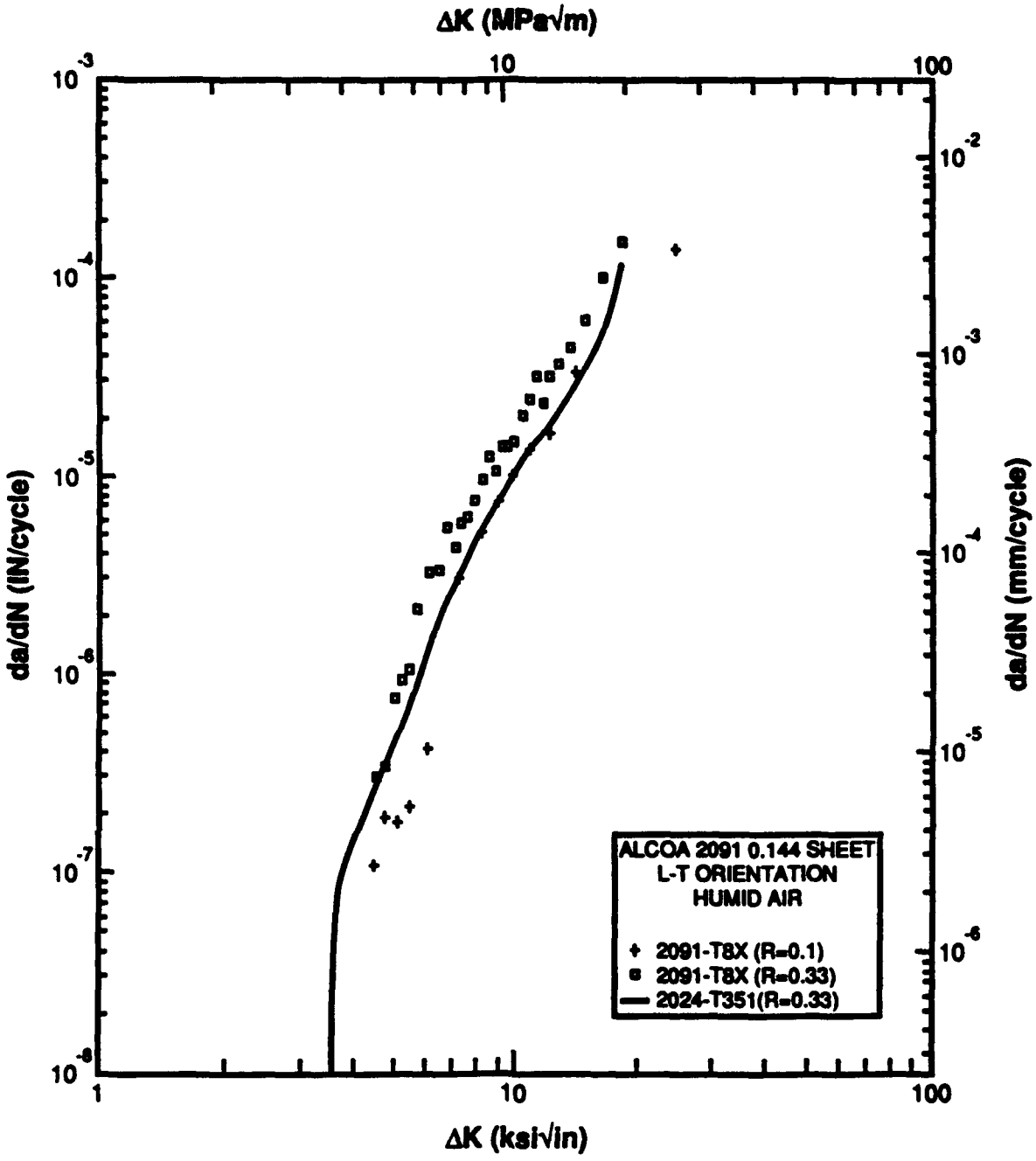


FIGURE K19. FATIGUE CRACK GROWTH RATES FOR 2091-T8X 0.144 INCH SHEET RELATIVE TO 2024-T351 (L-T ORIENTATION). NORTHROP.

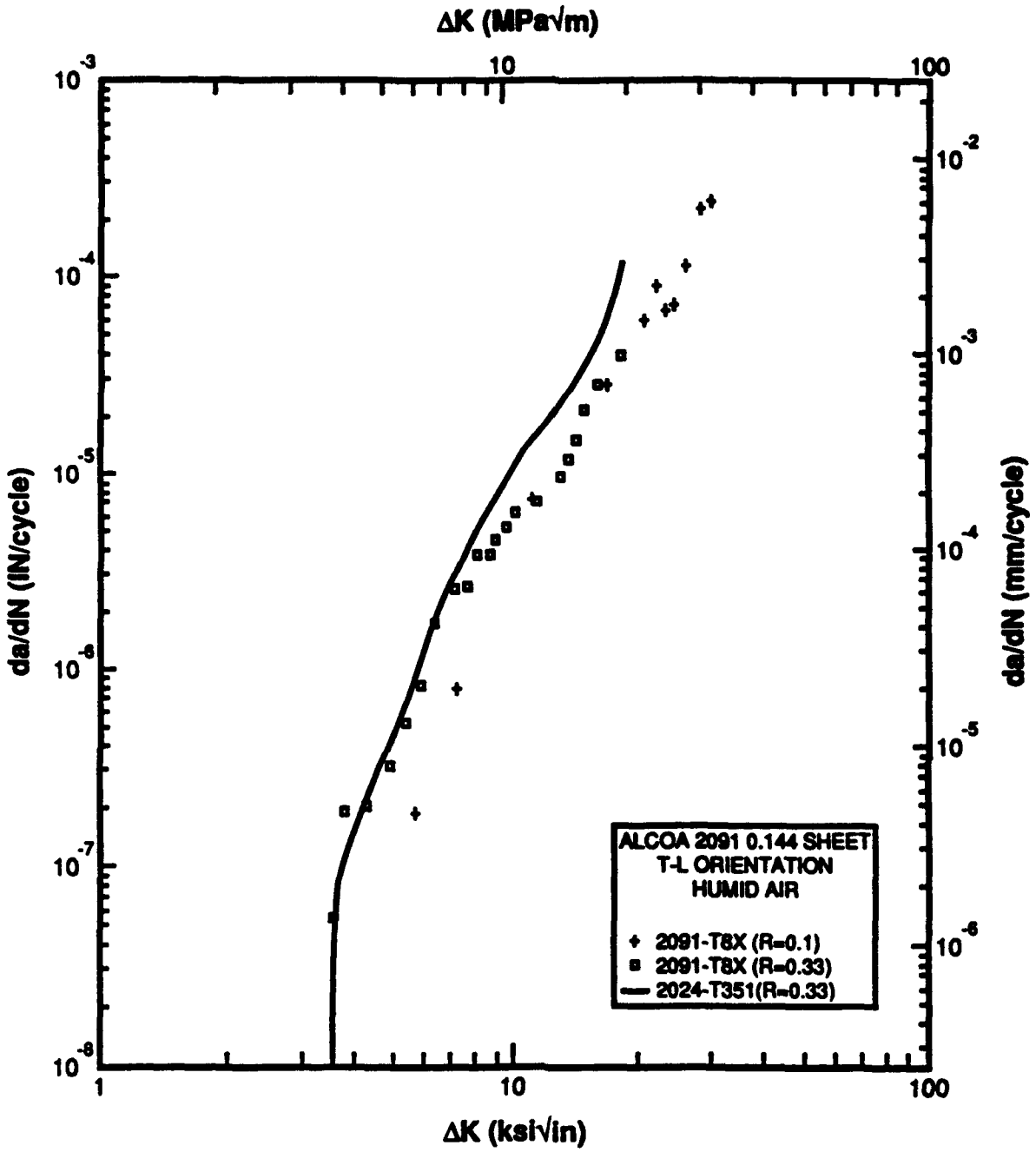


FIGURE K20. FATIGUE CRACK GROWTH RATES FOR 2091-T8X 0.144 INCH SHEET RELATIVE TO 2024-T351 (T-L ORIENTATION). NORTHROP.

APPENDIX L

2091-T8 0.5 INCH PLATE

INTRODUCTION

The Alcoa aluminum-lithium alloy 2091-T8 0.5 inch plates were received March 1988. The 2091-T8 0.5 inch plates were tested in the as received condition.

TESTING

Mechanical properties, (tension, compression, and fracture toughness) were tested according to ASTM standards, unless otherwise specified.

Over load fatigue crack growth tests were not performed according to ASTM standards,

TABLE L1

TENSILE RESULTS FOR ALCOA

2091-T8 PLATE (0.5" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	LONG	74.8	62.1	11.0	11.4	
MARIETTA,			74.2	61.4	11.0	10.8	
LOUISIANA			75.2	62.3	10.0	11.4	
AIR FORCE	RT	LONG	76.2	64.0	8.9	16.2	
			75.6	63.4	9.4	17.0	
			75.3	62.8	8.6	15.1	
		AVERAGE	75.2	62.7	9.8	13.7	
	STANDARD DEVIATION		0.7	0.9	0.4	1.1	

TABLE L2

TENSILE RESULTS FOR ALCOA

2091-T8 PLATE (0.5" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	30	71.6	52.9	11.6	16.2	
			71.6	53.2	11.7	18.4	
		AVERAGE	71.6	53.1	11.7	17.3	
	STANDARD DEVIATION		0.0	0.2	0.1	1.5	

TABLE L3

TENSILE RESULTS FOR ALCOA

2091-T8 PLATE (0.5" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
AIR FORCE	RT	45	64.0	46.6	19.4	32.9	
			63.6	45.9	19.1	35.5	
			63.6	45.9	19.6	33.6	
		AVERAGE	63.7	46.1	19.4	34.0	
	STANDARD DEVIATION		0.2	0.4	0.3	1.3	

TABLE L4

TENSILE RESULTS FOR ALCOA

2091-T8 PLATE (0.5" X 48" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	72.9	55.0	14.0	18.8	
			72.2	54.1	14.0	18.8	
			73.5	55.0	14.0	14.2	
AIR FORCE	RT	L TRANS	73.6	55.6	12.1	24.9	
			73.8	55.7	11.5	24.5	
			73.8	55.4	13.0	22.7	
		AVERAGE	73.3	55.1	13.1	20.7	
	STANDARD DEVIATION		0.6	0.6	1.1	4.1	

TABLE L5

COMPRESSION RESULTS FOR ALCOA

2091-T8 PLATE (0.5" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MARTIN MARIETTA, LOUISIANA	RT	LONG	52.2	11.8
			51.4	11.8
			52.4	11.8
		AVERAGE	52.0	11.8
		STANDARD DEVIATION	0.5	0.0

TABLE L6

COMPRESSION RESULTS FOR ALCOA

2091-T8 PLATE (0.5" X 48" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	57.9	11.9
			58.8	11.9
		AVERAGE	58.4	11.9
		STANDARD DEVIATION	0.6	0.0

TABLE L7

FRACTURE TOUGHNESS RESULTS FOR ALCOA

2091-T8 PLATE (0.5" X 48" X 48")

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MARTIN	L - T		33.8	INVALID(1)
MARIETTA,			31.1	INVALID(1)
LOUISIANA			37.4	INVALID(1)
	AVERAGE		34.1	
	STANDARD DEVIATION		3.2	

(1): SPECIMEN SIZE TOO SMALL

TABLE L8

FRACTURE TOUGHNESS RESULTS FOR ALCOA

2091-T8 PLATE (0.5" X 48" X 48")

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MARTIN	T - L		34.0	INVALID(1)
MARIETTA,			37.8	INVALID(1)
LOUISIANA			37.4	INVALID(1)
	AVERAGE		36.4	
	STANDARD DEVIATION		2.1	

(1): SPECIMEN SIZE TOO SMALL

TABLE L9

POST-OVERLOAD FATIGUE TEST RESULTS for 2091-T8

0.5 INCH PLATE and 2091-T83 0.144 INCH PLATE

R=0.05 LAB AIR delta-K=6.0 ksi(in)^.5 ONE OVERLOAD CYCLE APPLIED

% O.L.	a/W	Pol/Pmax	da/dN @ O.L. (u-in/cyc)	DELAY CYCLES (x10^-3)
		PLATE SPECIMEN THICKNESS = 0.250"		
80	0.369	0.402	0.184	171.7
80	0.463	0.456	0.199	146.7
80	0.559	0.449	0.414	93.4
80	0.600	0.386	0.399	85.8
		PLATE SPECIMEN THICKNESS = 0.140"		
80	0.401	0.845	0.097	arrest
80	0.447	0.803	0.095	arrest
60	0.407	0.535	0.135	137.6
60	0.415	0.840	0.076	arrest
60	0.484	0.584	0.057	891.0
60	0.502	0.847	0.149	126.7
60	0.541	0.800	0.140	72.8
60	0.654	0.623	0.120	59.0
60	0.696	0.574	0.107	71.5
		SHEET SPECIMEN THICKNESS = 0.140"		
60	0.264	0.516	1.227	13.2
60	0.276	0.511	0.896	31.6
60	0.314	0.505	2.435	17.4
60	0.315	0.501	1.381	19.7
60	0.349	0.483	1.133	30.3
60	0.368	0.45	2.495	13.8
60	0.400	0.413	2.331	22.0
60	0.447	0.446	1.624	14.3
60	0.516	0.379	3.143	11.6
60	0.574	0.344	3.527	10.3

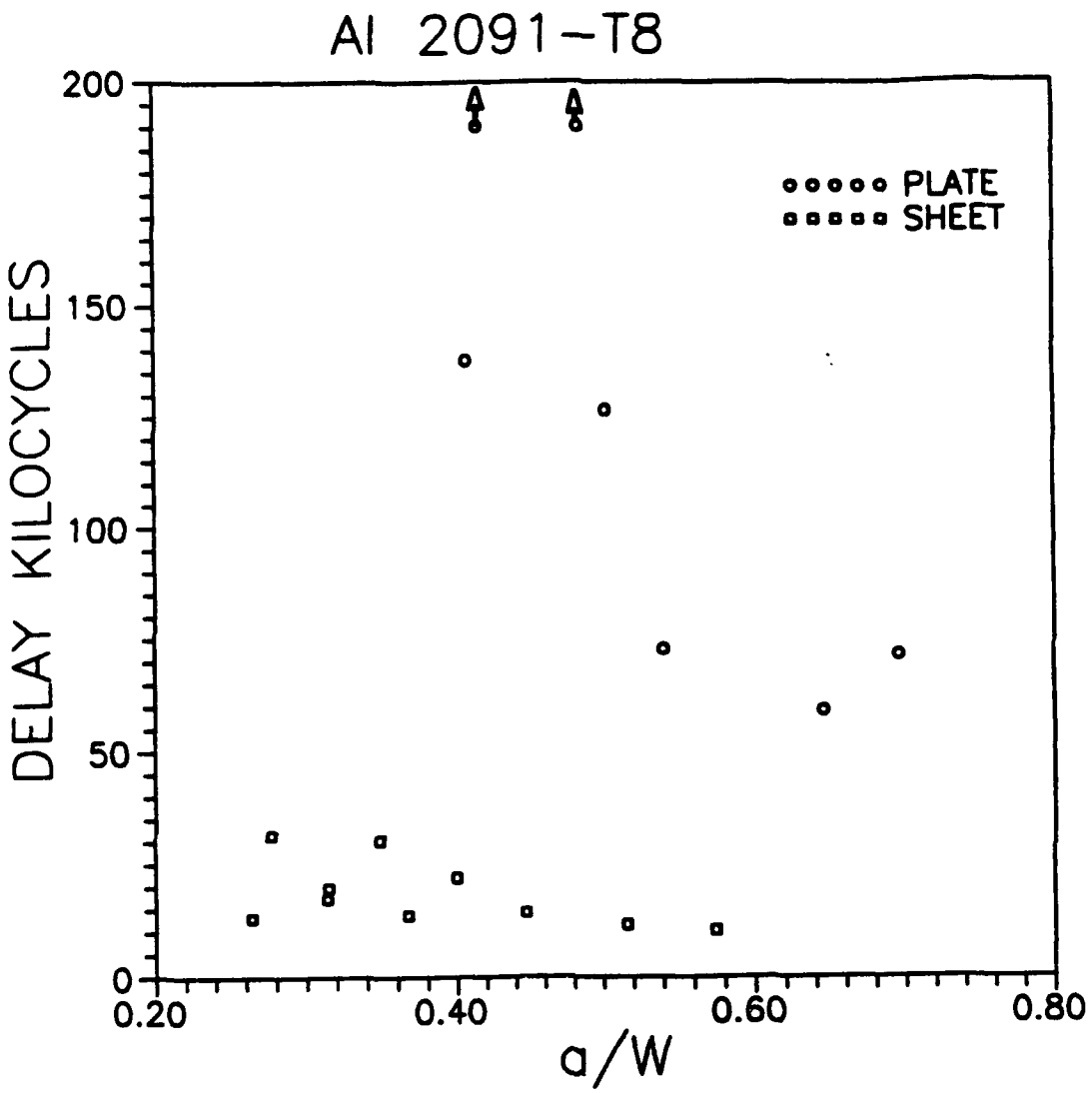


FIGURE L1. A Comparison of Delay Cycles Due to Fatigue Crack Growth Retardation for a 60 Percent Overload Cycle at a Stress Intensity of 6 KSI√in in 2091-T81 Plate Versus 2091-T83 Sheet. Thickness of the Compact Tension Specimens Used for Plate and Sheet was 0.144 Inch. Air Force.

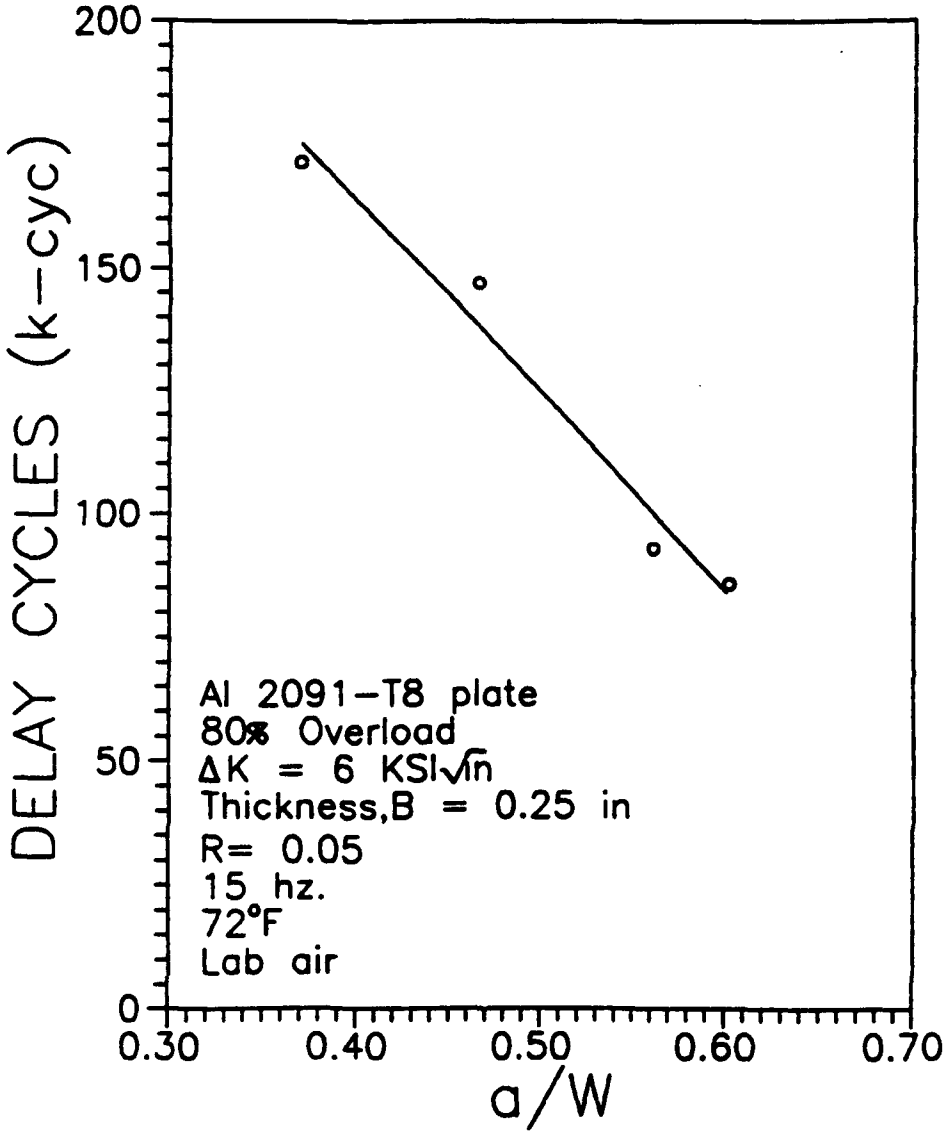


FIGURE L2. Delay Cycles Due to Fatigue Crack Growth Retardation for an 80 Percent Overload Cycle at a Stress Intensity Range of 6 KSI√in, in 2091-T81 Plate, with a Specimen Thickness of 0.250 Inch. Air Force.

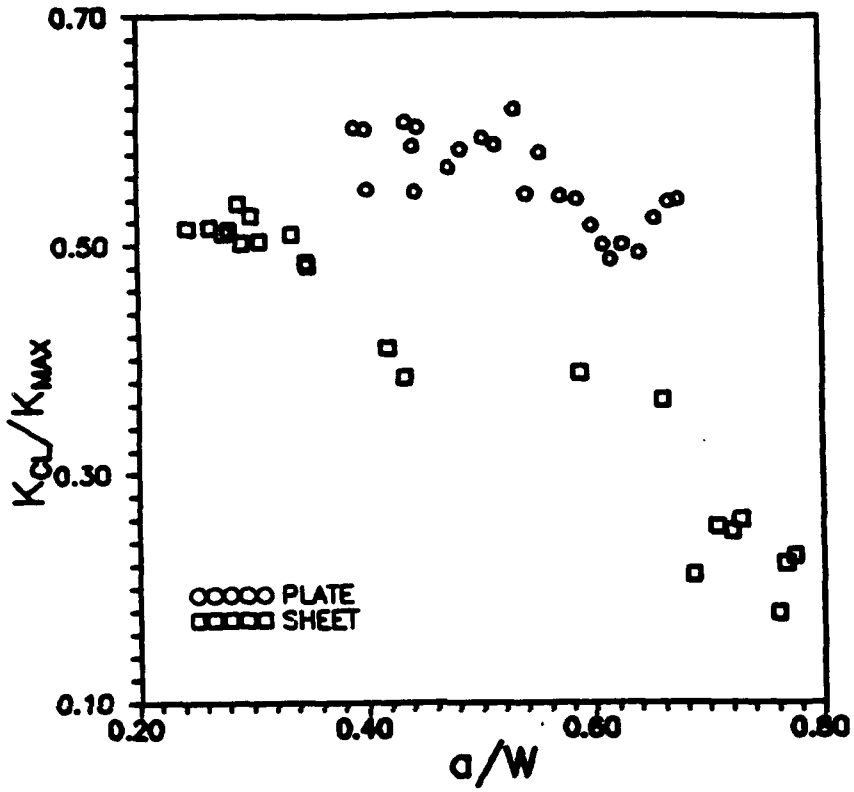


FIGURE L3. A Comparison of the Crack Closure Level Prior to the Application of a 60 Percent Overload Cycle. Note the Larger Level of Crack Closure in the Plate as Compared to Sheet Which Correlates with the Overload Delay Cycles. Air Force.

TABLE L10

POST-OVERLOAD RECOVERY EXTENSION

IN 2091 PLATE AND SHEET

delta-K= 6.0 ksi(in) ^ .5 — One Overload Cycle Applied
15 hz. Lab Air R=.05 — Crack Tip Plastic Zone=0.004 (in)

a/W	da/dN @ O.L. (u-in/cyc)	Accelerate into Plastic Zone?	Post O.L. Recovery delta-A (in)
	PLATE (.250 in. thick) 80 PERCENT OVERLOAD		
0.369	0.184	Yes	0.020
0.463	0.199	Yes	0.025
0.559	0.414	Yes	0.025
0.600	0.399	Yes	0.015
	PLATE (.144 in. thick) 80 PERCENT OVERLOAD		
0.401	0.097	Yes	arrest
0.447	0.095	No	arrest
	PLATE (.144 in. thick) 60 PERCENT OVERLOAD		
0.407	0.135	No	0.015
0.415	0.078	No	arrest
0.484	0.057	No	0.024
0.502	0.149	No	0.016
0.541	0.140	No	0.015
0.654	0.120	No	0.009
0.696	0.107	Yes	0.016
	SHEET (.144 in. thick) 60 PERCENT OVERLOAD		
0.246	1.227	Yes	0.016
0.276	0.696	Yes	0.015
0.314	2.435	Yes	0.042
0.315	1.361	Yes	0.020
0.349	1.133	No	0.020
0.368	2.495	Yes	0.026
0.400	3.331	Yes	0.025
0.447	1.624	Yes	0.016
0.516	1.143	No	0.020
0.574	3.527	Yes	0.026

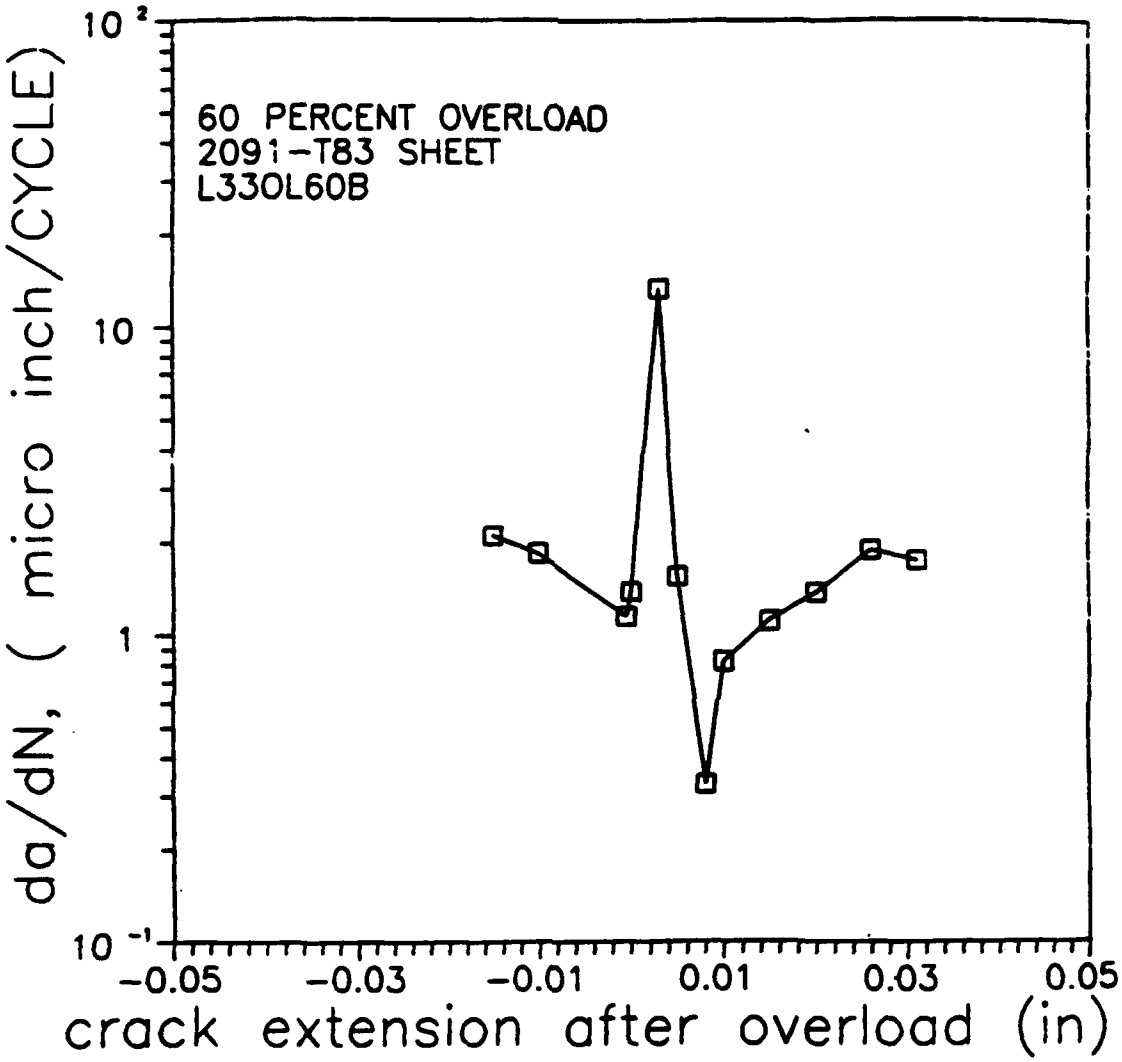


FIGURE L4. Crack Velocity Post-Overload Crack Extension for Alloy 2091-T83 Sheet. Air Force.

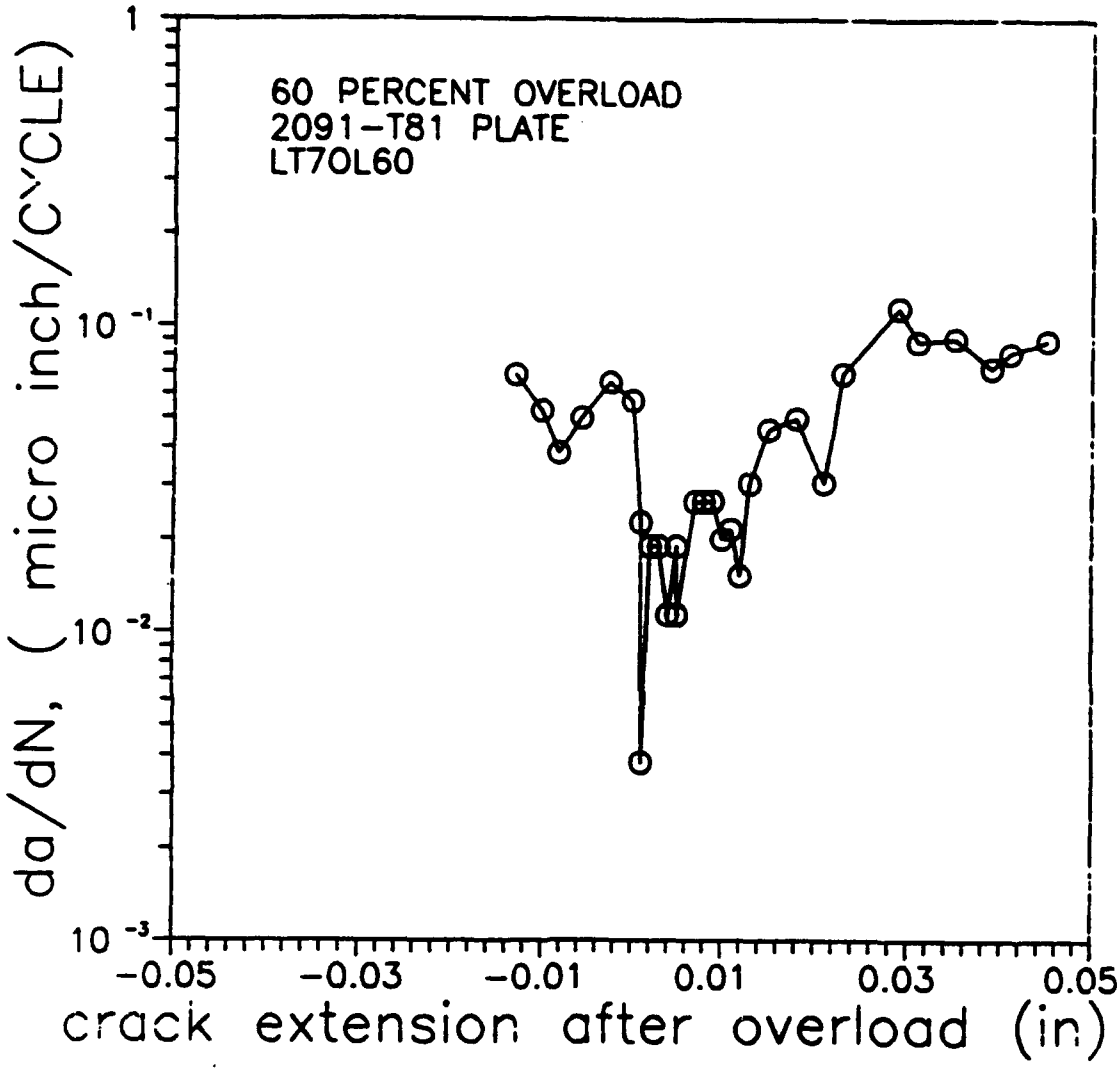


FIGURE L5. Crack Velocity Versus Post-Overload Crack Extension for Alloy 2091-T81 Plate 0.144 Inch Thick Specimen. Air Force.

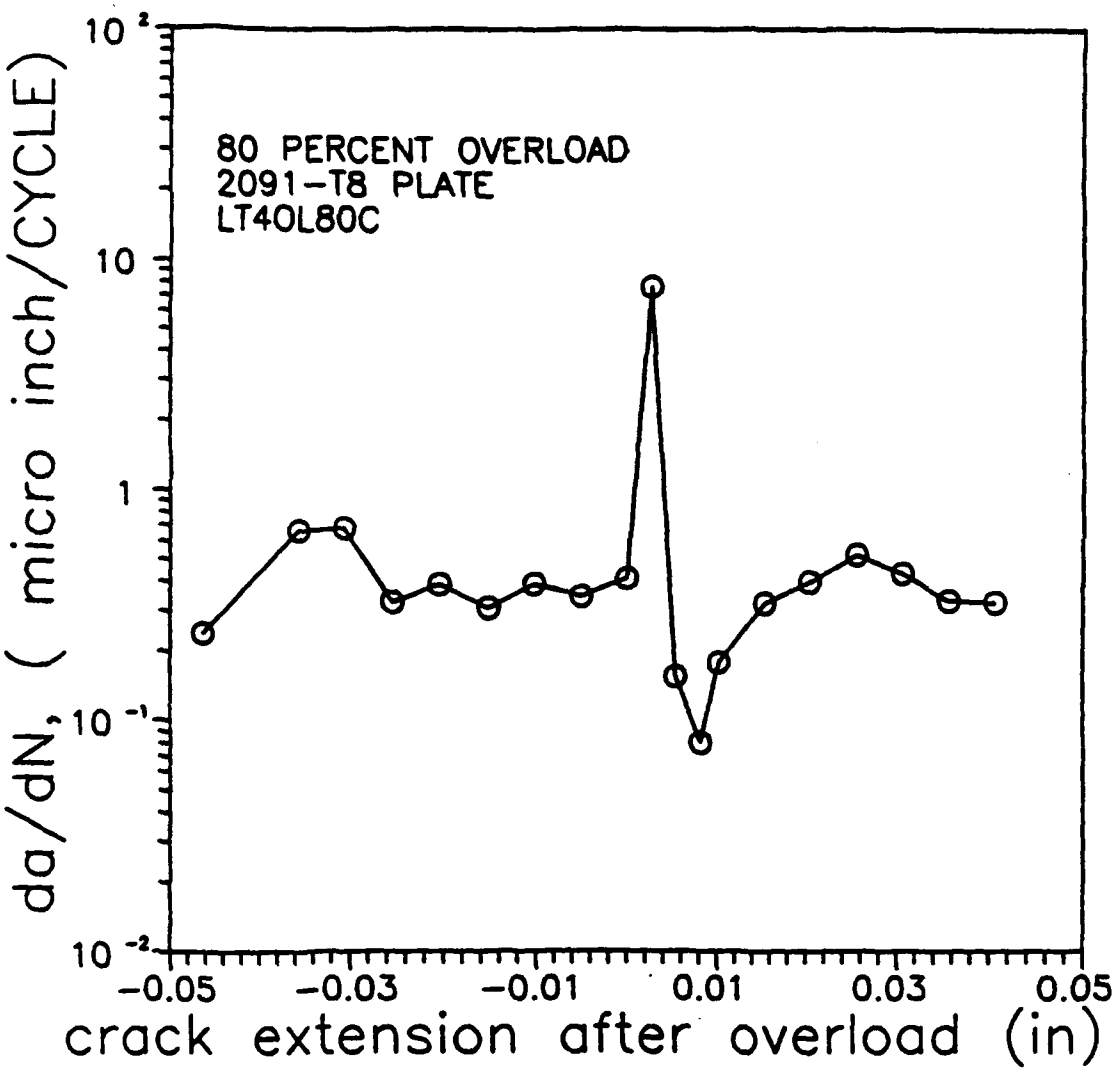


FIGURE L6. Crack Velocity Versus Post-Overload Crack Extension for Alloy 2091-T81 Plate 0.250 Inch Thick Specimen. Air Force.

APPENDIX M

8090-T8 Hat Extrusion and 8090-T8771 L-Extrusion

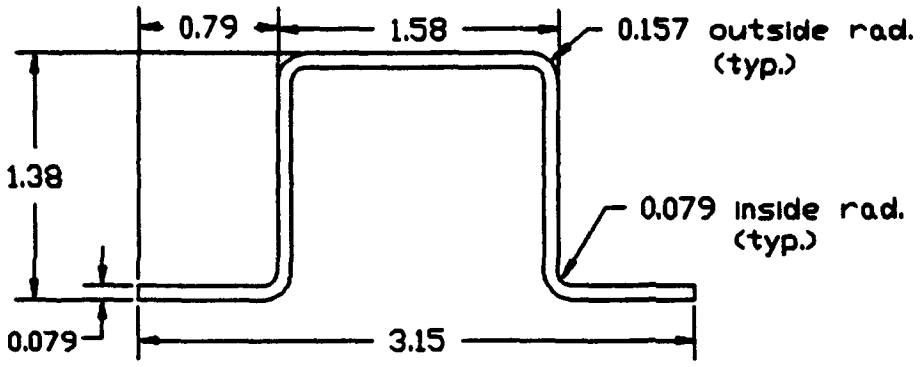
INTRODUCTION

The Alcoa 8090-T8 hat extrusions and 8090-T8 L-extrusions were received September 1991. The dimensions of the 8090-T8 hat and L-Extrusions are shown in Figure M1 and Figure M2 respectively. The L-extrusion had to be cut to achieve the T8 condition, therefore making a thin and a thick piece. The L-extrusion was received in two pieces (0.60" x 4.00" x length and 1.55" x 1.55" x length).

TESTING

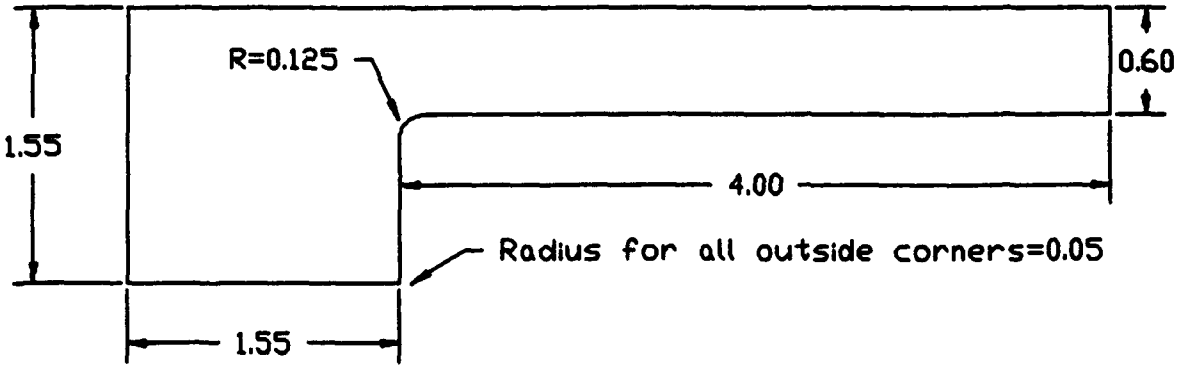
Mechanical properties, (tension, compression, bearing, shear, and fracture toughness) fatigue and constant amplitude fatigue crack growth tests were tested according to ASTM standards, unless otherwise specified.

Spectrum tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.



ALL DIMENSIONS ARE IN INCHES

FIGURE M1. 8090-T8 HAT EXTRUSION GEOMETRY.



ALL DIMENSIONS ARE IN INCHES

FIGURE M2. 8090-T8 L-EXTRUSION GEOMETRY.

TABLE M1

TENSILE RESULTS AT t/2 LOCATION FOR

ALCOA 8090-T8 HAT EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	COMMENT
ARMY-MTL	RT	LONG	62.5	55.4	4.1	3.9	TOP
			62.8	56.0	5.5	5.7	TOP
			63.3	55.6	5.1	5.5	TOP
			63.5	56.7	4.3	5.9	TOP
			62.8	55.9	4.7	5.3	TOP
			62.9	56.3	3.8	4.5	TOP
		AVERAGE	62.9	56.0	4.6	5.1	
	STANDARD DEVIATION		0.4	0.4	0.6	0.8	

TABLE M2

TENSILE RESULTS AT t/2 LOCATION FOR

ALCOA 8090-T8 HAT EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	COMMENT
ARMY-MTL	RT	LONG	64.1	56.6	4.5	4.1	BOTTOM
			63.4	57.1	3.3	3.6	BOTTOM
			64.3	54.7	5.0	5.3	BOTTOM
			63.5	56.3	5.7	5.9	BOTTOM
			63.1	55.9	3.5	4.2	BOTTOM
			61.9	55.4	4.2	6.5	BOTTOM
		AVERAGE	63.4	56.0	4.4	4.9	
	STANDARD DEVIATION		0.9	0.9	0.9	1.1	

TABLE M3

TENSILE RESULTS AT t/2 LOCATION FOR

ALCOA 8090-T8 HAT EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	COMMENT
ARMY-MTL	RT	LONG	64.0	55.7	5.6	5.8	SIDE
			64.3	56.9	4.1	4.2	SIDE
			64.1	57.0	4.8	5.7	SIDE
			64.7	57.4	4.5	4.1	SIDE
			65.2	57.8	5.5	3.7	SIDE
			64.5	57.3	5.5	4.6	SIDE
		AVERAGE	64.5	57.0	5.0	4.7	
	STANDARD DEVIATION		0.4	0.7	0.6	0.9	

TABLE M4

BEARING RESULTS FOR ALCOA

8090-T8 HAT EXTRUSION

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)	COMMENT
ARMY-MTL	LONG	1.5	85.9	74.2	TOP
			87.5	73.4	TOP
			85.6	75.2	TOP
		AVERAGE	86.3	74.3	
	STANDARD DEVIATION		1.0	0.9	

TABLE M5

BEARING RESULTS FOR ALCOA

8090-T8 HAT EXTRUSION

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)	COMMENT
ARMY-MTL	LONG	1.5	91.7	81.6	SIDE
			95.4	80.9	SIDE
			93.2	80.1	SIDE
		AVERAGE	93.4	80.9	
	STANDARD DEVIATION		1.9	0.7	

TABLE M6

BEARING RESULTS FOR ALCOA

8090-T8 HAT EXTRUSION

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)	COMMENT
ARMY-MTL	LONG	2.0	98.9	78.6	TOP
			104.0	82.5	TOP
			106.2	81.5	TOP
		AVERAGE	103.0	80.9	
	STANDARD DEVIATION		3.7	2.0	

TABLE M7

BEARING RESULTS FOR ALCOA

8090-T8 HAT EXTRUSION

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)	COMMENT
ARMY-MTL	LONG	2.0	116.3	89.0	SIDE
			111.6	89.0	SIDE
			112.9	89.9	SIDE
		AVERAGE	113.6	89.3	
	STANDARD DEVIATION		2.4	0.5	

TABLE M8

TENSILE RESULTS AT t/2 LOCATION FOR
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	
ARMY-MTL	RT	LONG	76.0	69.6	2.8		10.9	
			68.8	57.5	3.2		11.0	
			70.8	58.0	4.7		11.3	
			69.8	58.0	5.2		11.1	
			69.4	59.0	3.4		10.8	
			69.4	58.0	4.1		11.3	
MARTIN MARIETTA, LA	RT	LONG	72.1	64.9	5.0	4.9		(1)
			70.3	60.1	6.0	6.3		(1)
			70.4	59.6	5.0	3.3		(1)
			79.5	76.8	5.0	4.1		(2)
			79.5	76.3	3.0	3.9		(2)
			78.9	76.8	5.0	4.1		(2)
		AVERAGE	73.0	64.8	4.6	4.4	11.1	
	STANDARD DEVIATION		4.4	8.4	0.9	1.0	0.2	

(1): THICK SECTION
(2): THIN SECTION

TABLE M9

TENSILE RESULTS AT t/2 LOCATION FOR
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)	
ARMY-MTL	RT	L TRANS	68.2	52.8	6.3		11.0	
			68.4	53.8	5.0		10.8	
			68.6	53.0	6.5		10.6	
			68.0	52.5	6.5		10.3	
			67.5	54.0	4.1		11.0	
			68.5	53.5	5.9		10.8	
MARTIN	RT	L TRANS	69.9	55.1	8.0	11.0		(1)
MARIETTA, LA			69.6	55.4	7.0	8.0		(1)
			70.0	55.2	8.5	9.0		(1)
		AVERAGE	68.7	53.9	6.4	9.3	10.8	
	STANDARD DEVIATION		0.9	1.1	1.4	1.5	0.3	

(1): THIN SECTION

TABLE M10

TENSILE RESULTS AT t/2 LOCATION FOR
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
ARMY-MTL	RT	S TRANS	66.5	51.0	6.0		9.9
			58.3	43.0	8.0		9.6
			67.0	52.0	8.0		9.8
		AVERAGE	63.9	48.7	7.3		9.8
	STANDARD DEVIATION		4.9	4.9	1.2		0.2

TABLE M11

COMPRESSION RESULTS AT t/2 LOCATION FOR
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)	
ARMY-MTL	RT	LONG	65.3	10.6	
			54.6	10.4	
			53.8	11.1	
			61.7	9.9	
			52.8	11.9	
			53.9	10.8	
MARTIN MARIETTA, LA	RT	LONG	49.8	11.5	(1)
			43.4		(1)
			50.0	11.9	(1)
			54.1	11.9	(2)
			47.9	11.8	(2)
			47.7	11.8	(2)
		AVERAGE	52.9	11.2	
		STANDARD DEVIATION	6.0	0.7	

(1): THICK SECTION
(2): THIN SECTION

TABLE M12

COMPRESSION RESULTS AT t/2 LOCATION FOR
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
ARMY-MTL	RT	L TRANS	58.2	9.5
			59.9	11.9
			58.8	13.4
			55.7	11.8
			58.1	11.3
			64.7	8.9
MARTIN MARIETTA, LA	RT	L TRANS	52.0	11.9 (1)
			49.8	11.7 (1)
			49.8	11.8 (1)
		AVERAGE	56.3	11.4
		STANDARD DEVIATION	5.0	1.4

(1): THICK SECTION

TABLE M13

COMPRESSION RESULTS AT t/2 LOCATION FOR
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (KSI)
ARMY-MTL	RT	S TRANS	51.5	10.1
			52.0	11.2
			52.0	11.5
MARTIN MARIETTA, LA	RT	S TRANS	50.1	11.7 (1)
			50.2	11.8 (1)
			50.1	11.4 (1)
		AVERAGE	51.0	11.3
		STANDARD DEVIATION	0.9	0.6

(1): THICK SECTION

TABLE M14

RIVET SHEAR RESULTS FOR ALCOA
8090-T8771 "L" EXTRUSION

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
ARMY-MTL	LONG	40.7
		41.4
		45.0
		39.6
		41.4
		39.9
	AVERAGE	41.3
	STANDARD DEVIATION	2.3

TABLE M15

RIVET SHEAR RESULTS FOR ALCOA
8090-T8771 "L" EXTRUSION

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
ARMY-MTL	L TRANS	38.3
		37.5
		35.5
		38.7
		38.0
		36.8
	AVERAGE	37.5
	STANDARD DEVIATION	1.4

TABLE M16

FRACTURE TOUGHNESS RESULTS FOR
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
ARMY-MTL	L-T		31.9	(1)
			32.9	(1)
			30.2	(1)
			29.0	(1)
MARTIN	L-T		33.1	(1)
MARIETTA, LA			38.5	(1)
		36.3		
	AVERAGE	36.3	32.6	
	STANDARD DEVIATION		3.3	

(1): INVALID DUE TO B < 2.5(KQ/Fty)^2

TABLE M17

FRACTURE TOUGHNESS RESULTS FOR
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
ARMY-MTL	T-L		29.8	(1),(2)
			28.9	(1),(2)
			30.8	(1),(2)
			30.2	(1),(2)
			30.9	(1),(2)
MARTIN MARIETTA, LA	T-L	20.2		
		19.7		
		18.0		
	AVERAGE	19.3	30.1	
	STANDARD DEVIATION	1.2	0.8	

(1): INVALID DUE TO Pmax/Pq > 1.10

(2): INVALID DUE TO B < 2.5(KQ/Fty)^2

TABLE M18

FRACTURE TOUGHNESS RESULTS FOR
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
ARMY-MTL	S-L	22.6		
		22.6		
		22.7		
		22.4		
		22.3		
		21.5		
	AVERAGE	22.4		
	STANDARD DEVIATION	0.4		

TABLE M19

FRACTURE TOUGHNESS RESULTS FOR
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MARTIN	S-T		19.2	(1)
MARIETTA, LA			21.7	(1)
		20.9		
	AVERAGE	20.9	20.5	
	STANDARD DEVIATION		1.8	

(1): INVALID DUE TO Pmax/Pq > 1.10

TABLE M20

FATIGUE RESULTS WITH R=0.1 AND Kt=1.0 FOR
ALCOA 8090-T8771 "L" EXTRUSION

COMPANY	ORIENTATION	STRESS (KSI)	CYCLES
ARMY-MTL	LONG	47.5	30,000
		39.3	164,000
		30.1	1,411,000
		28.0	3,639,000
		27.8	171,000
		27.5	11,787,000 *
		26.2	10,382,000 *

(*): RUN OUT

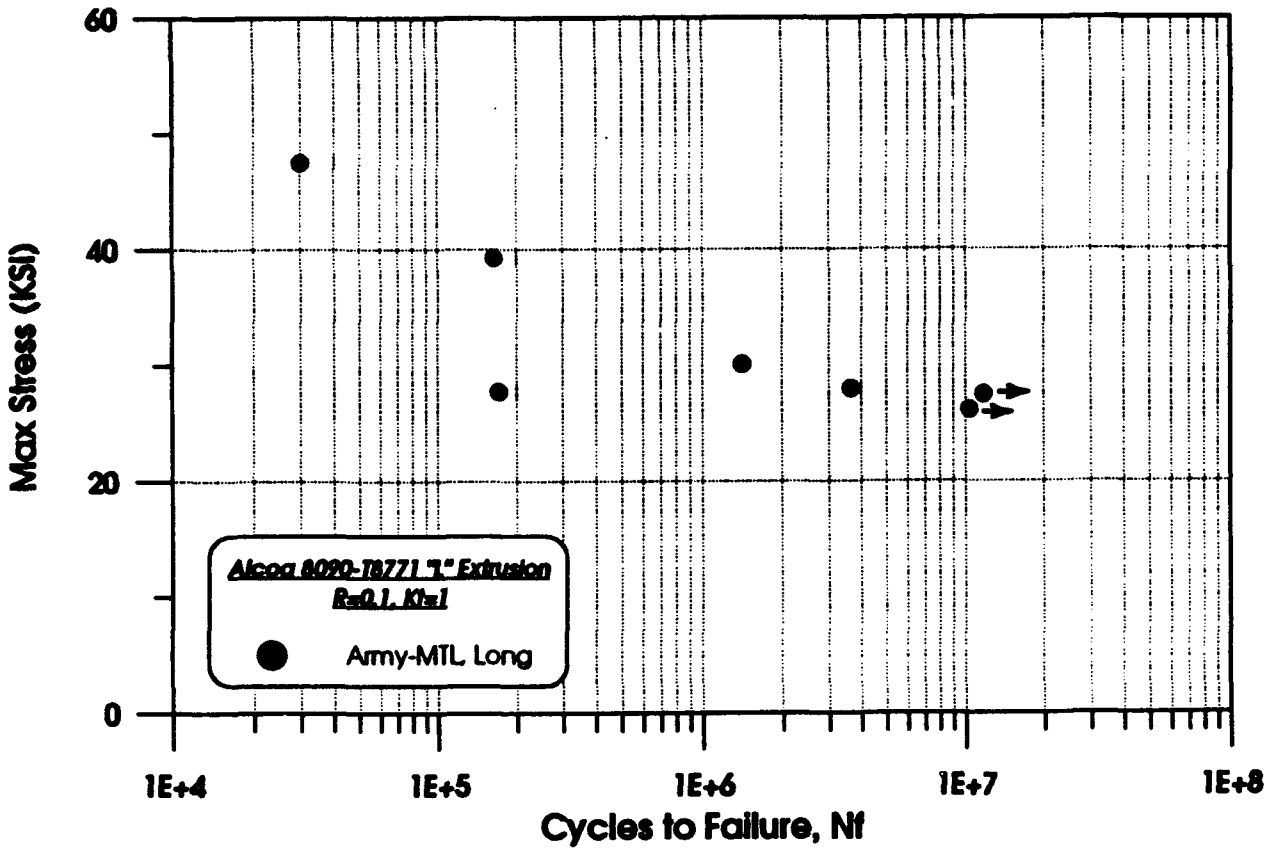


FIGURE M3. FATIGUE RESULTS FOR 8090-T8 771 L-EXTRUSION (R=0.1 AND Kt=1.0). Army.

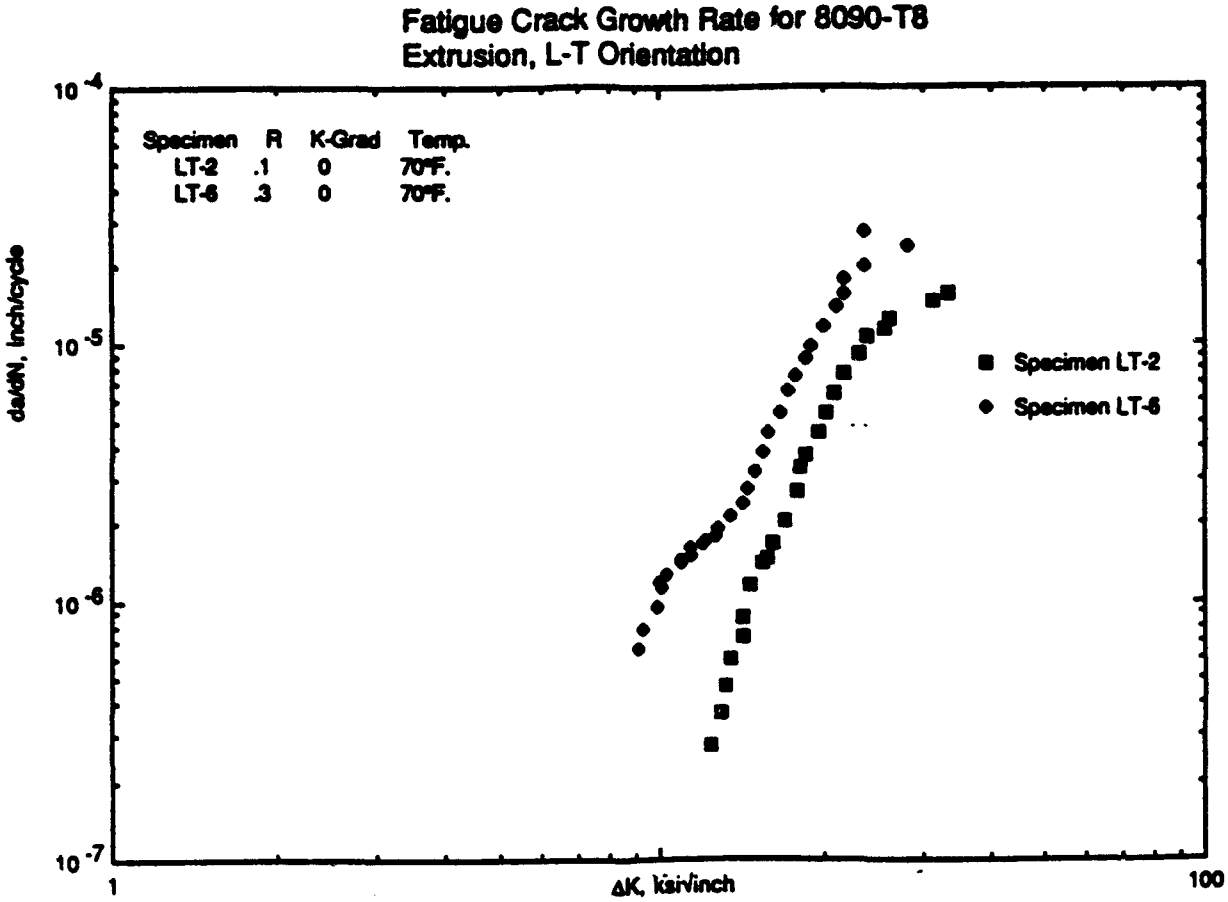


FIGURE M4. FATIGUE CRACK GROWTH RATES for 8090-T8771 L-Extrusion (L-T Orientation). Martin Marietta.

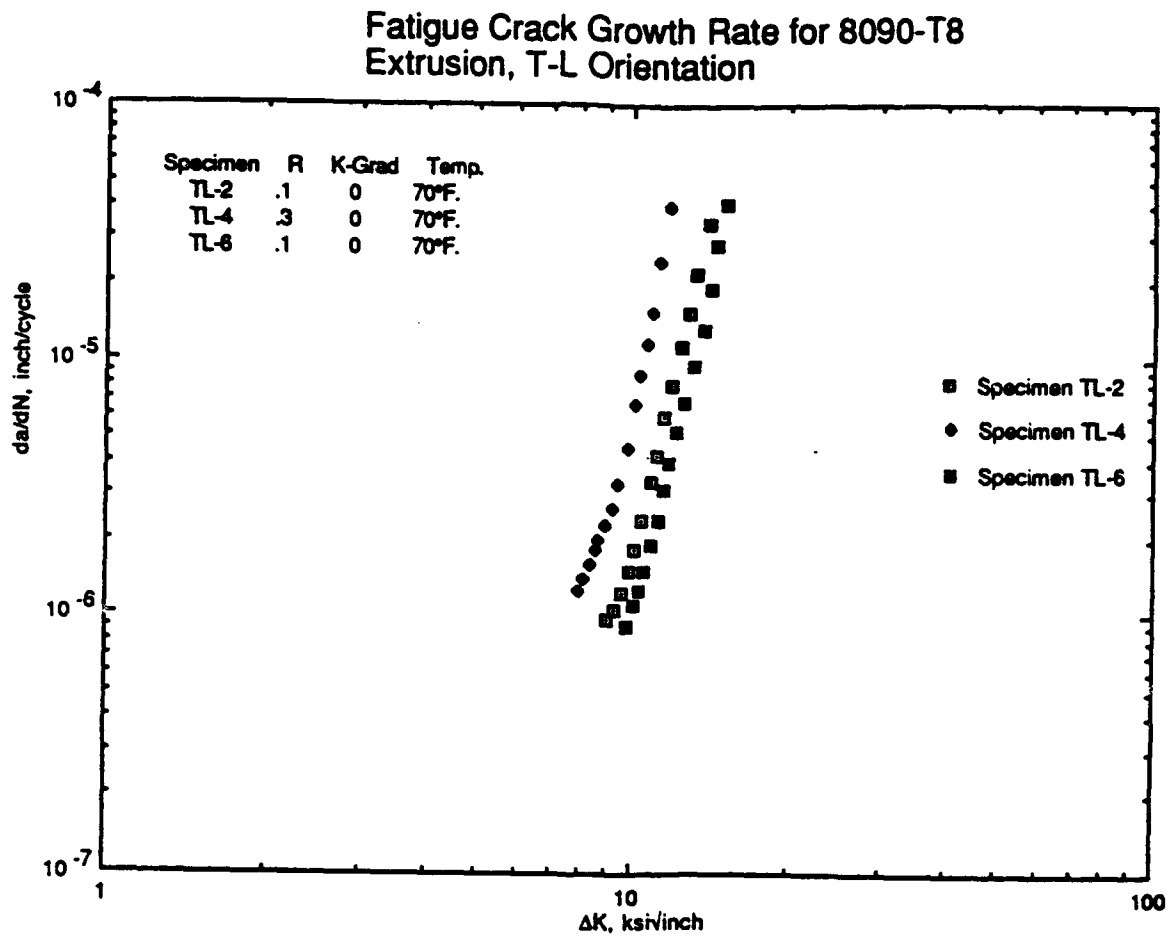


FIGURE M5. FATIGUE CRACK GROWTH RATES for 8090-T8771 L-EXTRUSION (T-L Orientation). MARTIN MARIETTA.

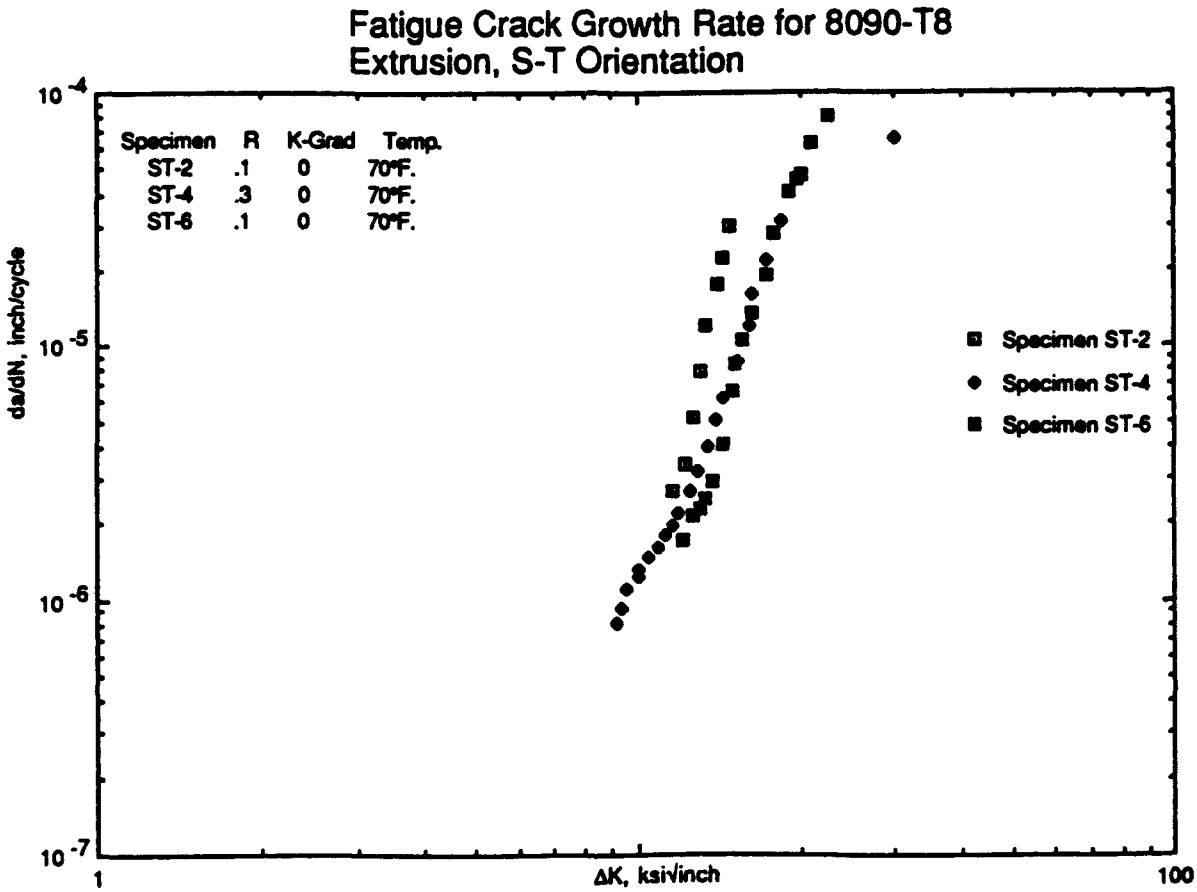


FIGURE M6. FATIGUE CRACK GROWTH RATES for 8090-T8771 L-EXTRUSION (S-T Orientation). MARTIN MARIETTA.

APPENDIX N

7064-T74511 EXTRUSION
1"X4"X48"

INTRODUCTION

The Kaiser P/M aluminum alloy 7064-T74511 1"x4"x48" extrusions were received in December 1986. The 7064 extrusions were tested by LTV, Martin Marietta and the Air Force.

TESTING

Mechanical properties (tension, compression, shear, bearing and fracture toughness), fatigue, and constant amplitude fatigue crack growth tests were generated according to ASTM standards, unless otherwise specified.

Spectrum fatigue crack growth rate tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE N1

TENSILE RESULTS AT t/2 LOCATION FOR

KAISER 7064-T74511 EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
LTV	RT	LONG	85.8	79.4	12.2	21.6	10.0
			87.5	81.7	12.3	19.3	9.7
			87.7	82.2	14.3	22.3	10.3
AIR FORCE	RT	LONG	82.2	75.8	10.5	18.0	
			80.7	73.9	11.3	24.3	
			81.2	74.7	12.0	25.6	
MARTIN MARIETTA, LOUISIANA	RT	LONG	91.6	86.5	18.0	27.5	9.8
			90.5	85.3	20.0	30.6	9.4
			90.2	85.0	19.0	31.0	9.7
		AVERAGE	86.4	80.5	14.4	24.5	9.8
	STANDARD DEVIATION		4.2	4.8	3.6	4.6	0.3

TABLE N2

TENSILE RESULTS AT t/2 LOCATION FOR

KAISER 7064-T74511 EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
LTV	RT	L TRANS	83.0	76.6	9.0	11.8	9.2
			85.3	79.6	8.5	19.1	10.4
			85.5	80.2	11.0	22.7	10.4
AIR FORCE	RT	L TRANS	79.2	72.8	10.0	21.6	
			78.3	72.0	10.7	25.6	
			79.1	72.6	11.3	27.8	
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	88.8	82.7	8.0	7.8	10.7
			89.2	83.2	9.0	2.0	10.1
			88.0	82.7	10.0	16.1	9.7
		AVERAGE	84.0	78.0	9.7	17.2	10.1
	STANDARD DEVIATION		4.3	4.6	1.2	8.6	0.5

TABLE N3

COMPRESSION RESULTS AT t/2 LOCATION FOR

KAISER 7064-T74511 EXTRUSION

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
LTV	RT	LONG	97.4	14.8
			79.8	10.3
			83.0	11.8
AIR FORCE	RT	LONG	83.3	
			81.6	
			82.5	
MARTIN MARIETTA, LOUISIANA	RT	LONG	87.1	11.1
			86.0	11.1
			86.9	11.1
		AVERAGE	85.3	11.7
		STANDARD DEVIATION	5.2	1.6

TABLE N4

COMPRESSION RESULTS AT t/2 LOCATION FOR

KAISER 7064-T74511 EXTRUSION

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
LTV	RT	L TRANS	82.7	10.8
			82.9	11.8
			82.8	11.2
AIR FORCE	RT	L TRANS	83.3	
			81.8	
			84.1	
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	87.3	11.4
			86.1	11.3
			86.6	11.9
		AVERAGE	84.2	11.4
		STANDARD DEVIATION	2.0	0.4

TABLE N5

IOSIPESCU SHEAR RESULTS FOR

KAISER 7064-T74511 EXTRUSION

COMPANY	ORIENTATION	ULTIMATE STRENGTH (KSI)
LTV	LONG	49.7
		51.0
		50.9
	AVERAGE	50.5
	STANDARD DEVIATION	0.7

TABLE N6

IOSIPESCU SHEAR RESULTS FOR

KAISER 7064-T74511 EXTRUSION

COMPANY	ORIENTATION	ULTIMATE STRENGTH (KSI)
LTV	L TRANS	50.4
		49.8
		50.2
	AVERAGE	50.1
	STANDARD DEVIATION	0.3

TABLE N7

BEARING RESULTS FOR KAISER

7064-T74511 EXTRUSION

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	LONG	1.5	124.5	93.9
			134.4	111.9
			129.8	108.2
		AVERAGE	129.6	104.7
		STANDARD DEVIATION	5.0	9.5

TABLE N8

BEARING RESULTS FOR KAISER

7064-T74511 EXTRUSION

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	LONG	2.0	159.5	122.7
			169.5	122.2
			160.8	117.0
AIR FORCE	LONG	2.0	163.5	139.5
			166.7	125.3
			162.3	120.0
		AVERAGE	163.7	124.5
	STANDARD DEVIATION		3.8	7.9

TABLE N9

BEARING RESULTS FOR KAISER

7064-T74511 EXTRUSION

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
AIR FORCE	L TRANS	2.0	164.2	123.8
			159.3	114.7
			163.5	115.6
		AVERAGE	162.3	118.0
	STANDARD DEVIATION		2.7	5.0

TABLE N10

FRACTURE TOUGHNESS RESULTS FOR

KAISER 7064-T74511 EXTRUSION

COMPANY	ORIENTATION	KIC (KSI IN^0.5)	Kq (KSI IN^0.5)	COMMENT
LTV	L-T		32.6	(1)
			33.5	(1)
			29.6	(1)
AIR FORCE	L-T		29.5	(2)
			27.9	(2)
			28.8	(2)
MARTIN	L-T	24.2		VALID
MARIETTA,			26.3	(3)
LOUISIANA			25.2	(3)
	AVERAGE	24.2	29.2	
	STANDARD DEVIATION		2.8	

(1): INVALID DUE TO TEST SPECIMEN FRACTURE SURFACE VIOLATED KIC REQUIREMENTS

(2): INVALID DUE TO SURFACE CRACK LENGTH/AVERAGE CRACK LENGTH > 1.1

(3): INVALID DUE TO CRACK SIZE DID NOT EXCEED PLASTIC ZONE SIZE

TABLE N11

FRACTURE TOUGHNESS RESULTS FOR

KAISER 7064-T74511 EXTRUSION

COMPANY	ORIENTATION	KIC (KSI IN^0.5)	Kq (KSI IN^0.5)	COMMENT
LTV	T-L	24.6		VALID
		25.0		VALID
		25.2		VALID
AIR FORCE	T-L	23.5		VALID
		24.1		VALID
		23.8		VALID
MARTIN	T-L		10.2	(1)
MARIETTA,		17.1		
LOUISIANA		17.1		
	AVERAGE	22.6	10.2	
	STANDARD DEVIATION	3.4		

(1): INVALID DUE TO PRECRACKING LOADS WERE TOO HIGH

TABLE N12

FATIGUE RESULTS WITH Kt=1.0 AND R=0.1 FOR

KAISER 7064-T74511 EXTRUSION

COMPANY	ORIENTATION	LIMIT STRESS (KSI)	CYCLES TO FAILURE
LTV	LONG	65.6	13,900
		65.0	1,800
		56.6	23,400
		47.9	49,900
		47.9	75,700
		47.8	318,100 #
		45.0	6,500
		43.5	2,000,000 *
		39.4	38,500
		39.1	93,100 #
		37.0	193,900
		35.0	113,000
		30.0	800,000 *
		25.2	2,300,000 *

(*): INDICATES A RUN OUT TEST
(#): INDICATES SPECIMEN FAILED IN THE THREADS

TABLE N13

FATIGUE RESULTS WITH Kt=3.0 AND R=0.1 FOR

KAISER 7064-T74511 EXTRUSION

COMPANY	ORIENTATION	LIMIT STRESS (KSI)	CYCLES TO FAILURE
LTV	LONG	43.5	5,100
		34.8	10,800
		32.6	19,700
		31.3	23,500
		30.5	66,200
		28.3	39,300
		26.1	56,700
		26.1	40,400
		24.4	72,000
		23.9	3,000,000 *
		23.5	1,998,100
		21.8	2,000,000 *
		21.7	3,000,000 *
		20.0	2,000,000 *
		17.4	3,000,000 *

(*): INDICATES A RUN-OUT TEST

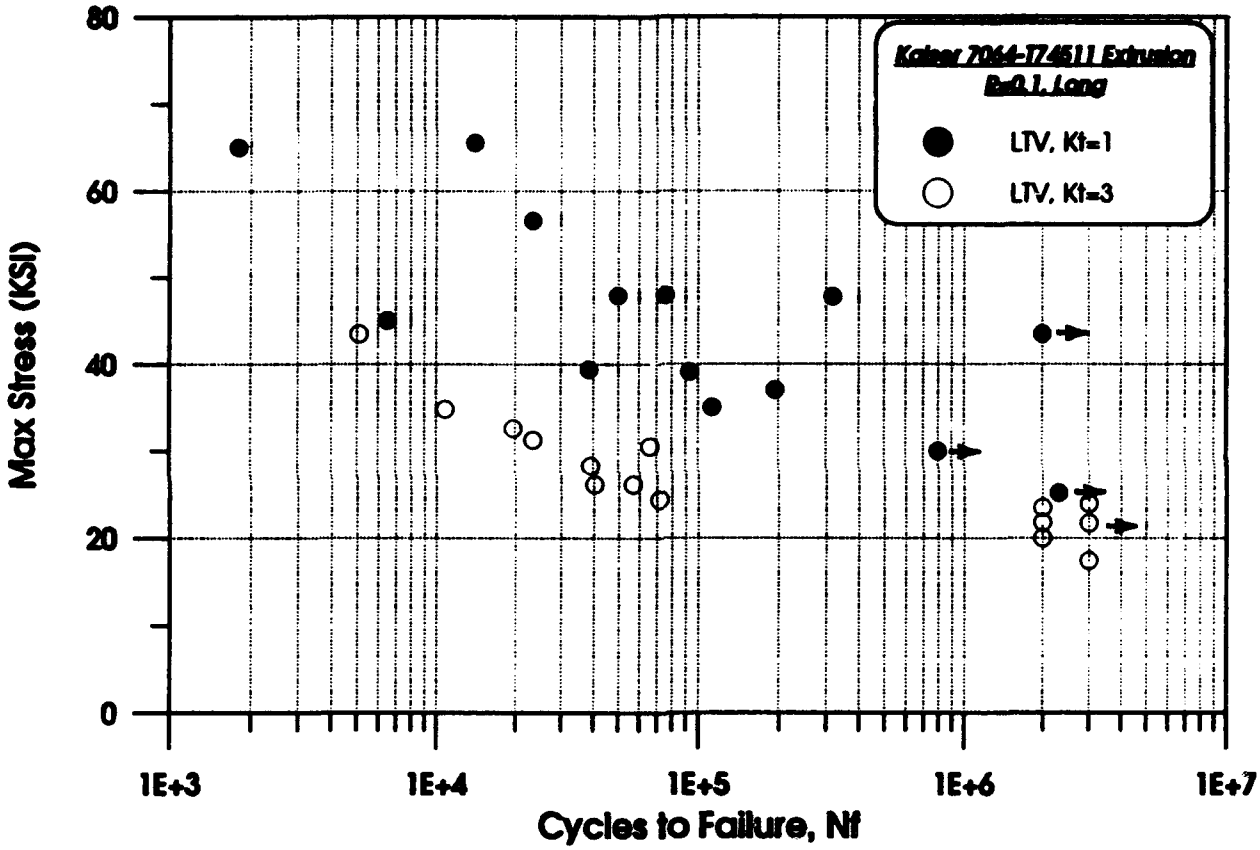


FIGURE N1. FATIGUE RESULTS FOR 7064-T74511 EXTRUSION (LONGITUDINAL ORIENTATION). LTV.

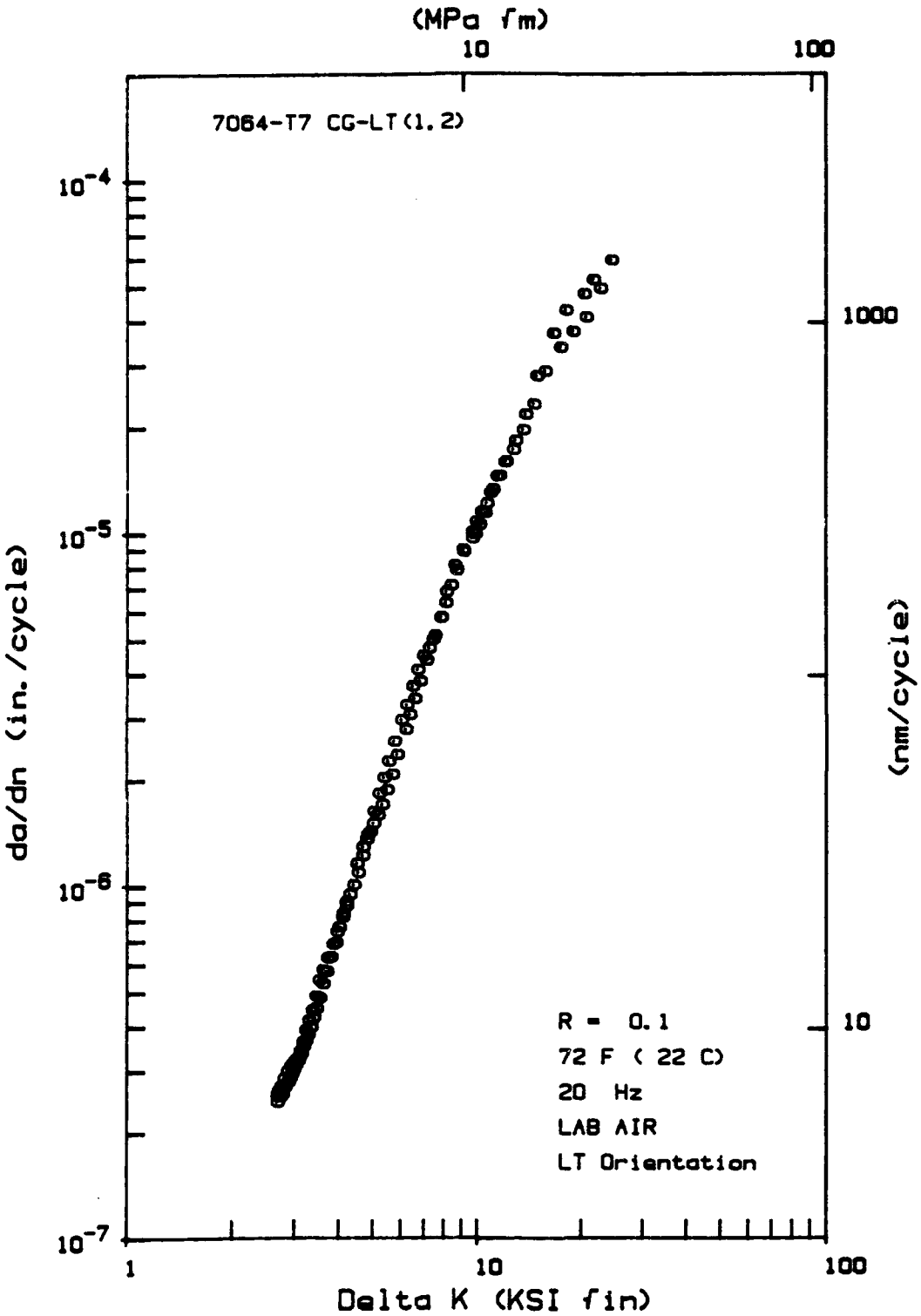


FIGURE N2. FATIGUE CRACK GROWTH RATE DATA for Two 7064-T74511 Extrusion Specimens. (L-T ORIENTATION). AIR FORCE.

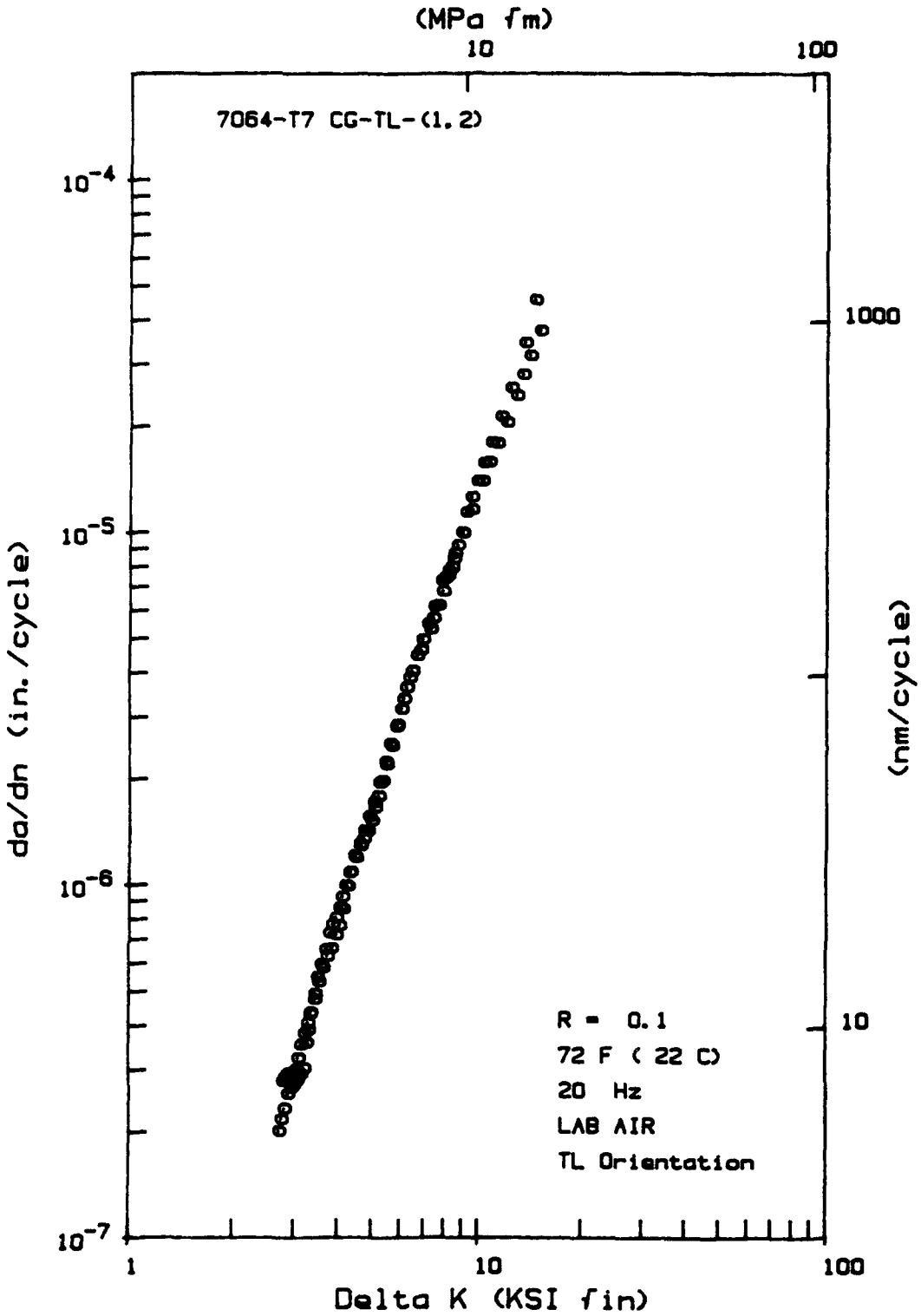


FIGURE N3. FATIGUE CRACK GROWTH RATE DATA for Two 7064-T74511 Extrusion Specimens. (T-L ORIENTATION). AIR FORCE.

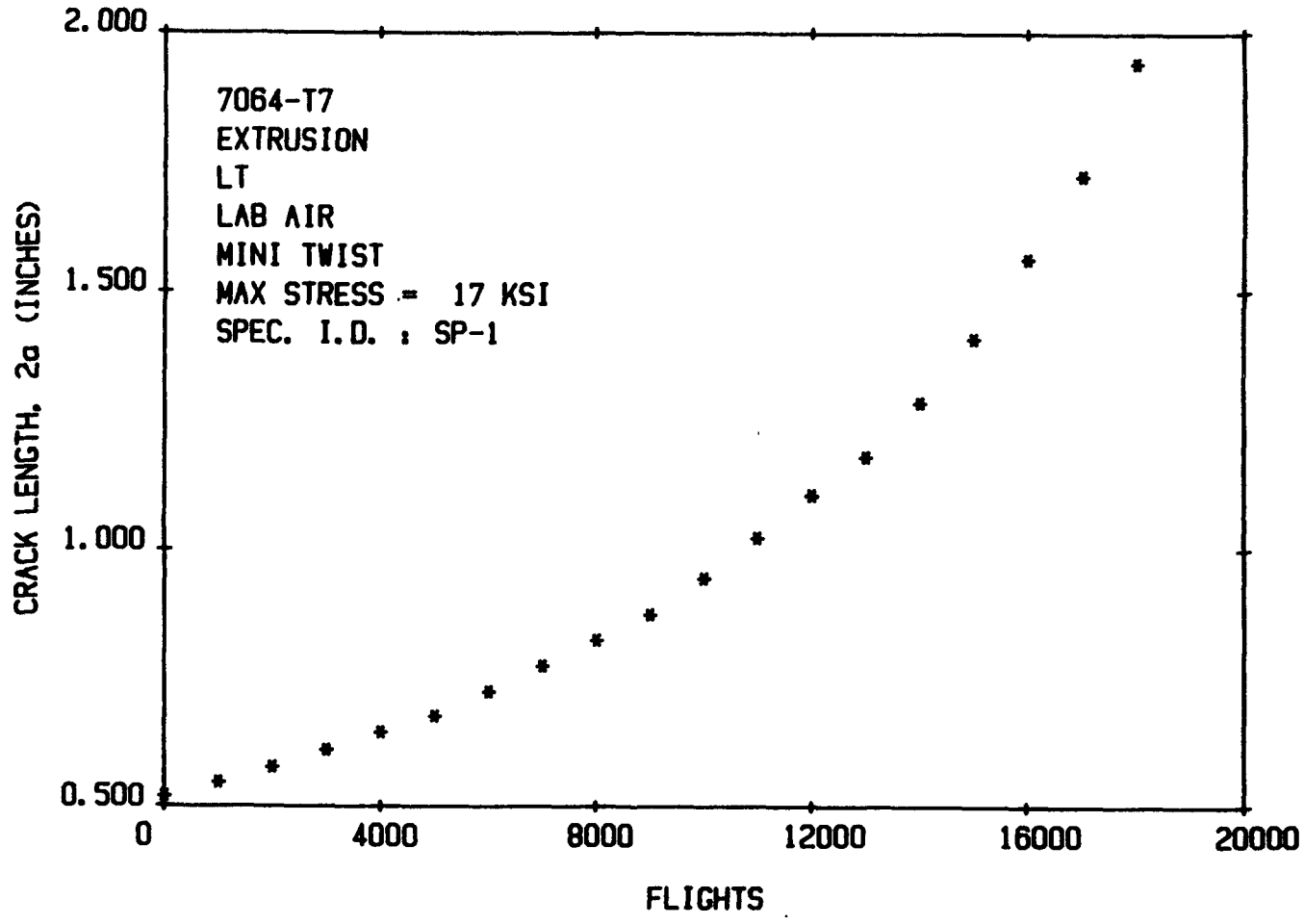


FIGURE N4. Mini-TWIST Spectrum Fatigue Crack Length vs Flights Data for 7064-T74511 Extrusion. Air Force.

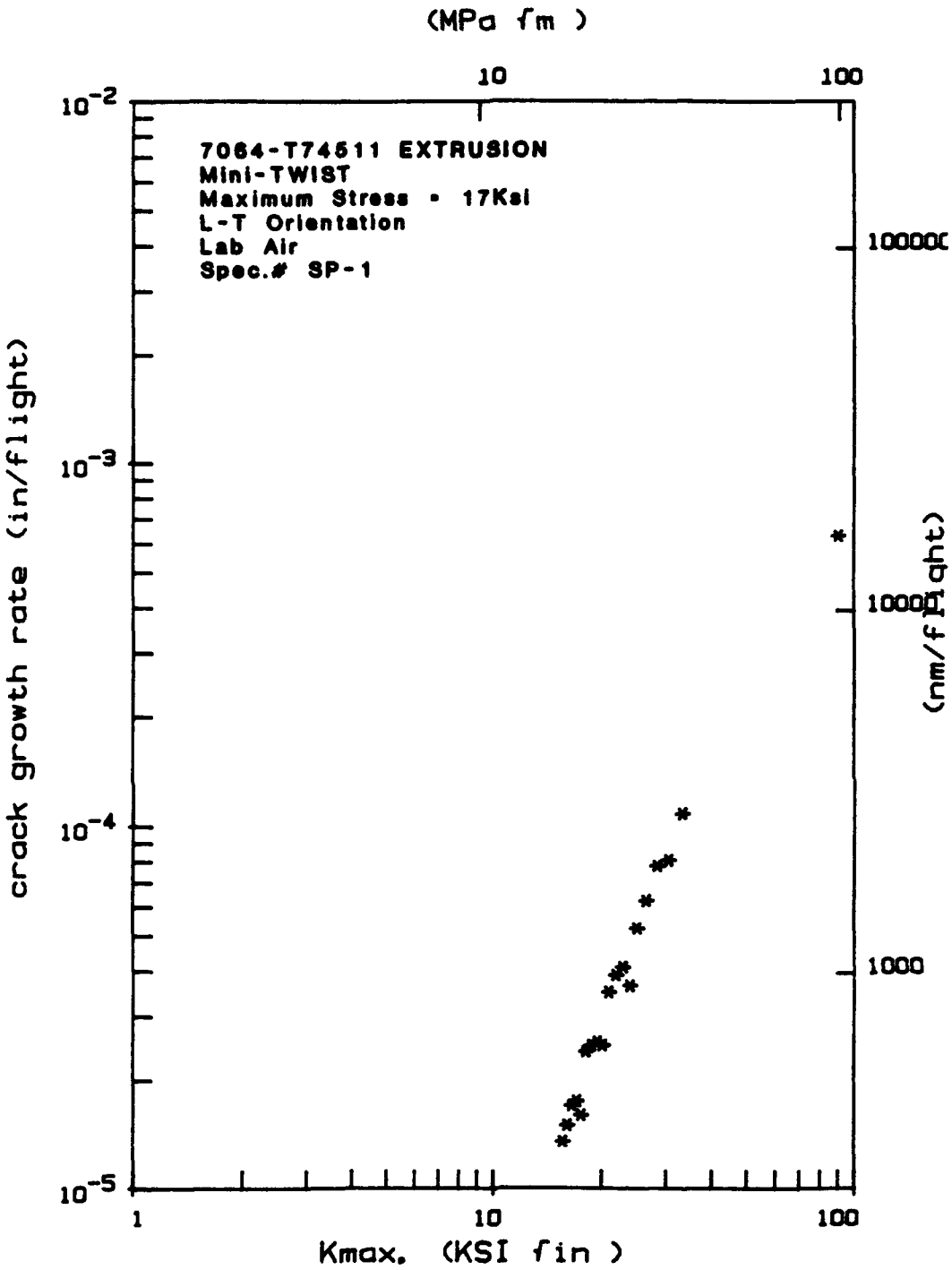


FIGURE N5. Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for 7064-T74511 Extrusion. Air Force.

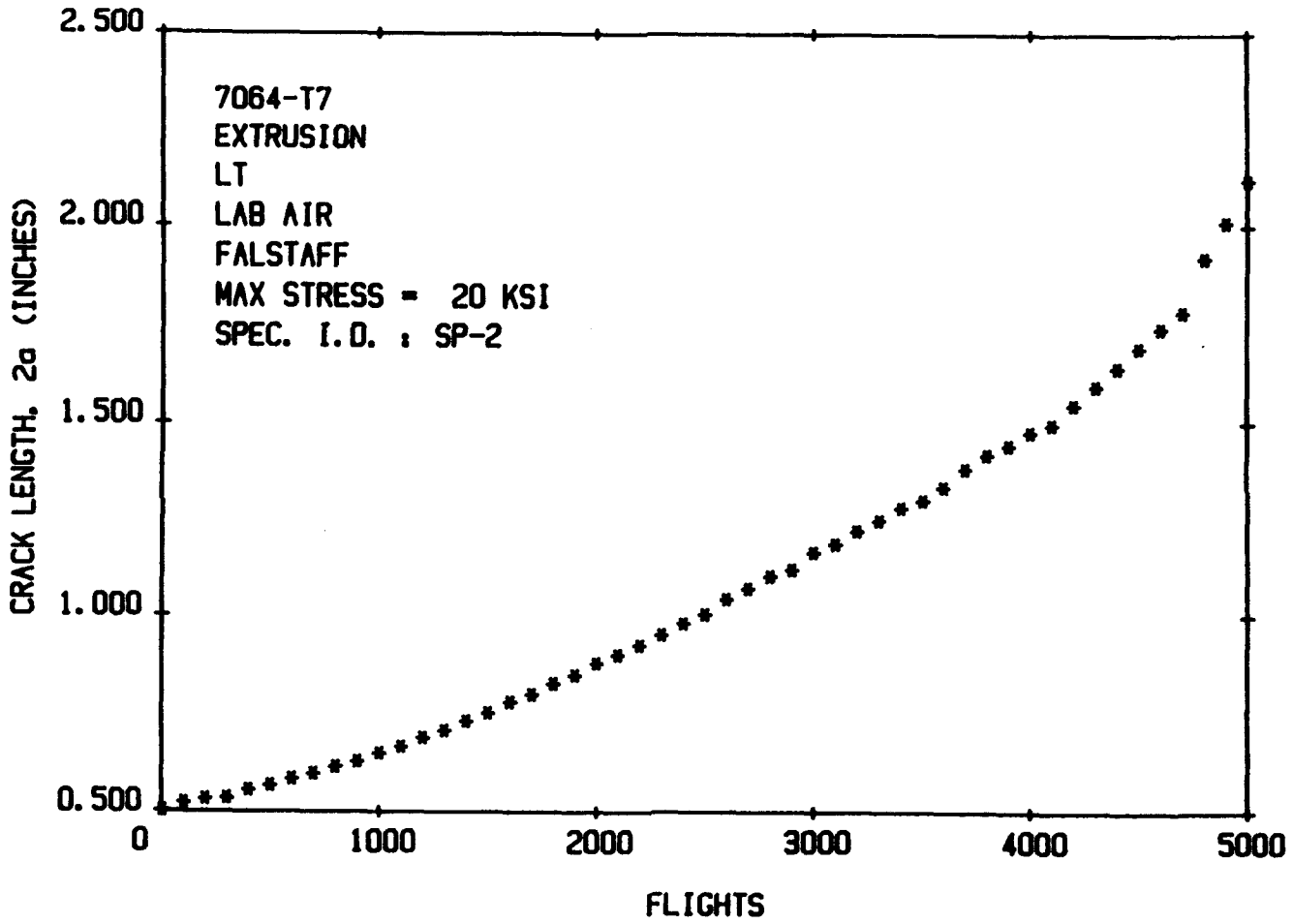


FIGURE N6. FALSTAFF Spectrum Fatigue Crack Length vs Flights Data for 7064-T74511 Extrusion. Air Force.

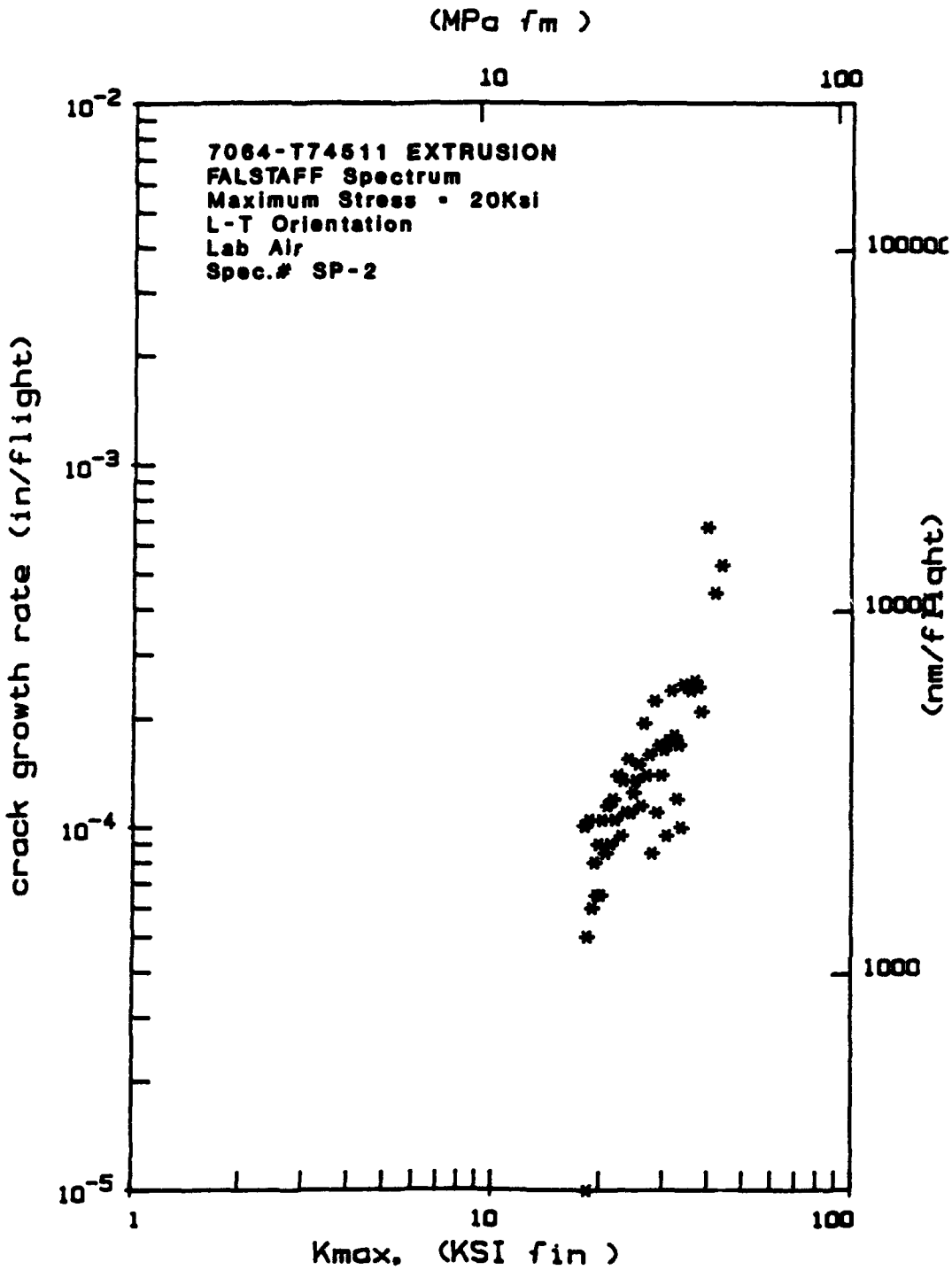


FIGURE N7. FALSTAFF Spectrum Fatigue Crack Growth Rate Data for 7064-T74511 Extrusion. Air Force.

APPENDIX O

7064-T74 HAND FORGING
1.6"X4"X18"

INTRODUCTION

The Kaiser P/M aluminum alloy 7064-T74 1.6"x4"x18" forgings were received in December 1986. Forged 7064 was tested by Lockheed, LTV, Martin Marietta, McDonnell Aircraft Company, and the Air Force.

TESTING

Mechanical properties (tension, compression, shear, bearing and fracture toughness), fatigue, and constant amplitude fatigue crack growth tests were generated according to ASTM standards, unless otherwise specified.

Spectrum fatigue crack growth rate tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE 01

TENSILE RESULTS AT t/2 LOCATION FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
MCAIR, ST. LOUIS	RT	LONG	80.0	74.0	13.0		
			80.0	73.0	14.0		
			81.5	75.0	11.0		
			80.5	74.0	13.0		
LOCKHEED, GEORGIA	RT	LONG	77.2	69.7			9.9
			81.9	75.0			11.2
			81.0	75.2			10.5
			84.9	79.0			10.6
			81.5	74.7			10.2
			81.1	74.1			10.1
			80.0	74.0			10.1
			84.1	78.4			9.9
			80.6	73.6			10.3
			80.5	74.3			10.1
MARTIN MARIETTA, LOUISIANA	RT	LONG	79.5	71.4	5.0	41.6	10.1
			79.4	70.9	12.0	44.0	10.2
			78.6	70.6	14.0	37.9	10.1
LTV	RT	LONG	80.6	74.3	13.3	32.4	9.4
			79.1	72.6	13.7	29.8	9.5
			78.7	71.7	15.4	38.9	9.5
			82.0	75.9	10.6	31.0	9.7
		AVERAGE	80.6	73.9	12.3	36.5	10.1
	STANDARD DEVIATION		1.8	2.3	2.8	5.5	0.4

TABLE 02

TENSILE RESULTS AT t/2 LOCATION FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
MCAIR, ST. LOUIS	RT	L TRANS	80.0	72.0	8.0		
			80.0	72.5	9.0		
			80.5	73.0	8.0		
			80.0	72.5	8.0		
LOCKHEED, GEORGIA	RT	L TRANS	83.0	77.1			10.8
			80.2	73.3			9.6
			80.5	73.7			9.9
			78.9	72.9			10.0
			79.9	73.0			10.7
			79.9	72.5			9.7
			78.6	71.8			10.6
			79.8	71.3			10.6
			78.0	71.4			10.2
			78.9	70.6			10.4
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	78.5	70.0	6.0	6.1	10.0
			79.2	71.3	8.0	10.2	10.0
			77.5	69.1	13.0	32.7	10.0
LTV	RT	L TRANS	77.8	70.9	8.0	15.3	9.5
			78.1	70.6	10.0	19.3	9.7
			77.8	68.8	8.0	11.7	10.0
			77.2	68.7	7.0	9.7	10.3
		AVERAGE	79.3	71.8	8.5	15.0	10.1
	STANDARD DEVIATION		1.3	1.9	1.8	8.9	0.4

TABLE O3

TENSILE RESULTS AT t/2 LOCATION FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	MODULUS (MSI)
MCAIR, ST. LOUIS	RT	S TRANS	82.5	77.0	10.0		
			83.0	76.5	6.0		
			81.5	75.0	6.0		
			82.0	76.0	7.0		
		AVERAGE	82.3	76.1	7.3		
	STANDARD DEVIATION		0.6	0.9	1.9		

TABLE 04

COMPRESSION RESULTS AT t/2 LOCATION FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCAIR, ST. LOUIS	RT	LONG	75.5	11.2
			77.5	11.5
			75.0	10.8
LOCKHEED, GEORGIA	RT	LONG	76.6	10.6
			78.0	
			83.4	10.4
			79.9	10.6
			83.5	
			78.5	
			78.1	10.5
MARTIN MARIETTA, LOUISIANA	RT	LONG	76.4	11.0
			77.2	11.0
			75.3	10.9
LTV	RT	LONG	80.4	11.5
			77.7	11.4
			76.4	12.5
			79.6	11.8
		AVERAGE	78.2	11.1
		STANDARD DEVIATION	2.5	0.6

TABLE 05

COMPRESSION RESULTS AT t/2 LOCATION FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCAIR, ST. LOUIS	RT	L TRANS	75.0	11.2
			76.5	11.8
			76.0	11.9
LOCKHEED, GEORGIA	RT	L TRANS	72.9	
			80.5	
			75.3	11.2
			78.3	11.3
			77.7	11.1
			73.8	9.8
			72.0	9.7
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	76.4	11.2
			76.1	11.1
			76.1	11.1
LTV	RT	L TRANS	77.9	11.1
			76.8	12.0
			78.7	11.8
			74.9	11.7
		AVERAGE	76.2	11.2
		STANDARD DEVIATION	2.1	0.7

TABLE 06

SLOTTED SHEAR RESULTS FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	ULTIMATE STRENGTH (KSI)
MCAIR, ST. LOUIS	LONG	53.5
		47.5
		46.5
	AVERAGE	49.2
	STANDARD DEVIATION	3.8

TABLE 07

AMSLER DOUBLE SHEAR RESULTS FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	ULTIMATE STRENGTH (KSI)
LOCKHEED, GEORGIA	L-T	50.0
		51.8
		50.4
	AVERAGE	50.7
	STANDARD DEVIATION	0.9

TABLE 08

IOSIPESCU SHEAR RESULTS FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	ULTIMATE STRENGTH (KSI)
LTV	LONG	50.5
		52.5
		48.0
		48.9
		51.5
		51.3
		51.7
		50.4
	AVERAGE	50.6
	STANDARD DEVIATION	1.5

TABLE 09

IOSIPESCU SHEAR RESULTS FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	ULTIMATE STRENGTH (KSI)
LTV	L TRANS	50.2
		51.3
		51.2
		52.7
		49.5
		53.7
		51.8
	AVERAGE	51.5
	STANDARD DEVIATION	1.4

TABLE O10

BEARING RESULTS FOR KAISER

7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LOCKHEED, GEORGIA	LONG	1.5	137.0	116.0
			115.0	105.0
			139.0	114.0
LTV	LONG	1.5	132.8	112.4
			132.4	112.1
			137.7	115.9
		AVERAGE	132.3	112.6
	STANDARD DEVIATION		8.9	4.1

TABLE O11

BEARING RESULTS FOR KAISER

7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	L TRANS	1.5	134.3	116.6
			135.2	114.7
			139.1	116.5
			138.5	117.1
		AVERAGE	136.8	116.2
	STANDARD DEVIATION		2.4	1.1

TABLE 012

BEARING RESULTS FOR KAISER

7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCAIR, ST. LOUIS	LONG	2.0	148.0	
			149.0	117.0
			143.0	112.0
LOCKHEED, GEORGIA	LONG	2.0	168.0	135.0
			169.0	123.0
			170.0	126.0
LTV	LONG	2.0	165.1	131.9
			170.6	143.1
			176.1	137.5
		AVERAGE	162.1	128.2
		STANDARD DEVIATION	12.0	10.6

TABLE 013

BEARING RESULTS FOR KAISER

7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCAIR, ST. LOUIS	L TRANS	2.0	149.0	119.0
			149.0	116.0
			151.0	119.0
LTV	L TRANS	2.0	173.0	135.9
			172.1	134.6
			171.8	135.0
			168.1	142.8
		AVERAGE	162.0	128.9
		STANDARD DEVIATION	11.7	10.6

TABLE 014

FRACTURE TOUGHNESS RESULTS FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	KIC (KSI IN^0.5)	Kq (KSI IN^0.5)	COMMENT
MCAIR, ST. LOUIS	L-T	24.1		VALID
		27.5		VALID
LOCKHEED, GEORGIA	L-T	26.0		VALID
		29.0		VALID
MARTIN MARIETTA, LOUISIANA	L-T		27.2	(1)
			23.6	(1)
LTV	L-T		24.1	(2)(3)
			26.4	(2)(3)
			29.4	(2)
	AVERAGE	26.7	26.1	
	STANDARD DEVIATION	2.1	...	

(1): INVALID DUE TO a/W=0.552 > 0.55
(2): INVALID DUE TO TEST SPECIMEN FRACTURE SURFACE VIOLATED KIC REQUIREMENTS
(3): INVALID DUE TO Kmax PRECRACK > 0.6 Kq

TABLE 015

FRACTURE TOUGHNESS RESULTS FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	KIC (KSI IN^0.5)	Kq (KSI IN^0.5)	COMMENT
MCAIR, ST. LOUIS	T-L	17.8		VALID
		17.0		VALID
MARTIN MARIETTA, LOUISIANA	T-L		18.7	(1)
LTV	T-L		30.2	
			21.1	(3)
		27.9		VALID
	AVERAGE	20.9	23.3	
	STANDARD DEVIATION	6.1	6.1	

(1): INVALID DUE TO a/W=0.552 > 0.55
(2): INVALID DUE TO TEST SPECIMEN FRACTURE SURFACE VIOLATED KIC REQUIREMENTS
(3): INVALID DUE TO Kmax PRECRACK > 0.6 Kq

TABLE O16

FRACTURE TOUGHNESS RESULTS FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	KIC (KSI IN^0.5)	Kq (KSI IN^0.5)	COMMENT
MCAIR,	S-T		20.3	(1),(2)
ST. LOUIS		19.9		VALID
MARTIN	S-T		15.8	(1)
MARIETTA,			14.3	(1)
LOUISIANA				
	AVERAGE	19.9	16.8	
	STANDARD DEVIATION	0.0	3.1	

(1): INVALID DUE TO SURFACE TRACE/AVERAGE CRACK ERROR VALUE > VALID REQ
(2): AVERAGE CRACK/W VALUE LESS THAN VALID REQUIREMENT

TABLE 017

FRACTURE TOUGHNESS RESULTS FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	KIC (KSI IN^0.5)	Kq (KSI IN^0.5)	COMMENT
MARTIN MARIETTA, LOUISIANA	S-L		19.3	(1)
		16.7		
		15.0		
	AVERAGE	15.9	19.3	
	STANDARD DEVIATION	1.2	0.0	

(1): INVALID DUE TO a/W=0.552 > 0.55

TABLE 018

FATIGUE RESULTS WITH Kt=1.0 AND R=-1.0 FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	LIMIT STRESS (KSI)	CYCLES TO FAILURE
MCAIR, ST. LOUIS	LONG	60.0	2,270
		55.0	5,140
		50.0	10,750
		45.0	18,150
		40.0	86,100
		35.0	206,670
		30.0	2,560,000 *
		25.0	1,000,000 *

(*): INDICATES A RUN OUT TEST

TABLE 019

FATIGUE RESULTS WITH Kt=1.0 AND R=0.1 FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	LIMIT STRESS (KSI)	CYCLES TO FAILURE
LTV	LONG	50.0	11,600
		46.1	15,100
		44.9	17,400
		44.0	12,100
		43.0	28,200
		42.9	18,800
		41.7	28,000
		40.9	28,300
		40.1	10,700
		39.7	7,400
		36.9	24,700
		36.0	285,600
		35.2	18,000
		34.4	318,700
		33.2	3,000,000 *

(*): INDICATES A RUN-OUT TEST

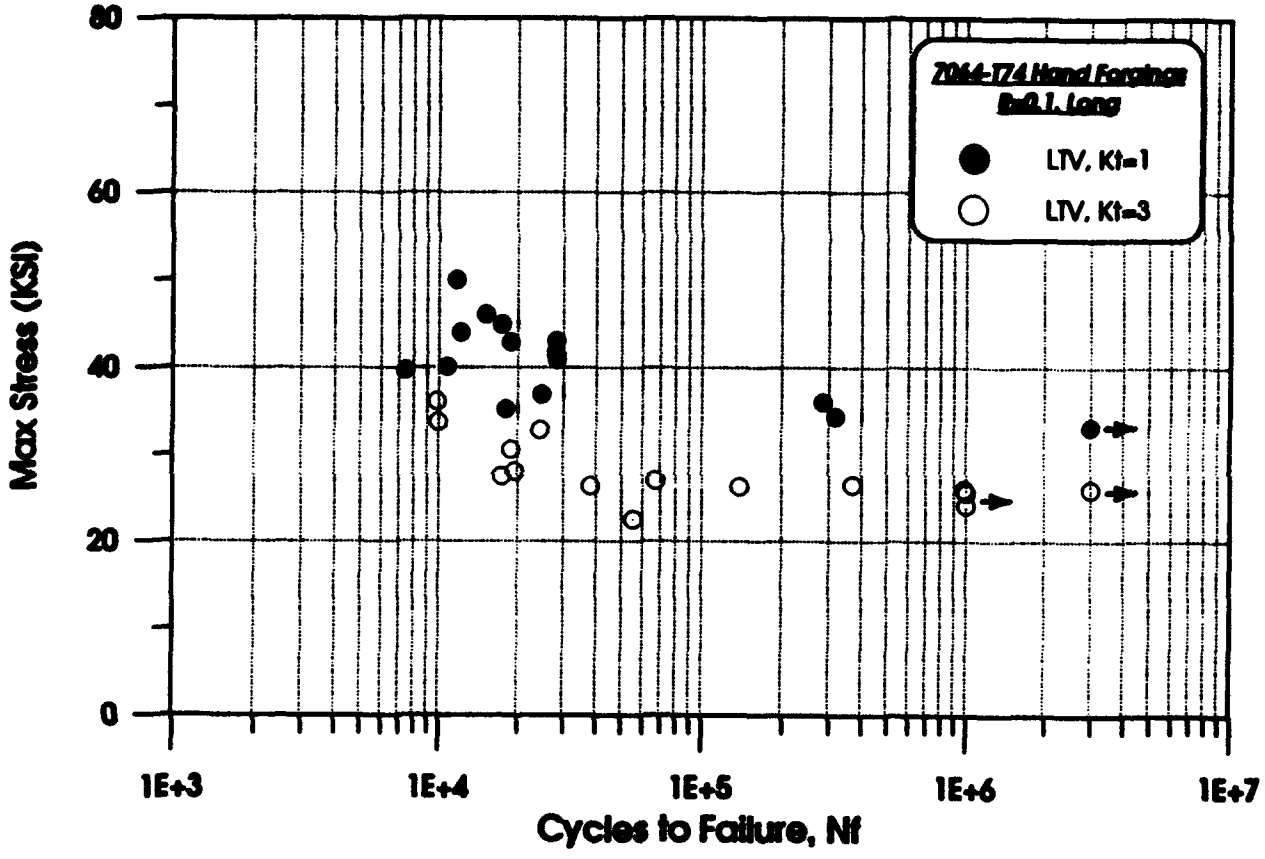


FIGURE O1. FATIGUE DATA for 7064-T74 Hand Forgings (Longitudinal Orientation R=0.1, Kt=1 and Kt=3). LTV.

TABLE 020

FATIGUE RESULTS WITH Kt=3.0 AND R=0.1 FOR

KAISER 7064-T74 HAND FORGINGS

COMPANY	ORIENTATION	LIMIT STRESS (KSI)	CYCLES TO FAILURE
LTV	LONG	36.1	9,800
		33.7	9,900
		32.8	24,500
		30.5	18,900
		28.0	19,600
		27.5	17,400
		27.0	67,100
		26.5	368,300
		26.4	38,100
		26.3	138,700
		26.0	983,800
		26.0	3,000,000 *
		25.6	1,000,000 *
		24.1	1,000,000 *
		22.5	55,500

(*): INDICATES A RUN-OUT TEST

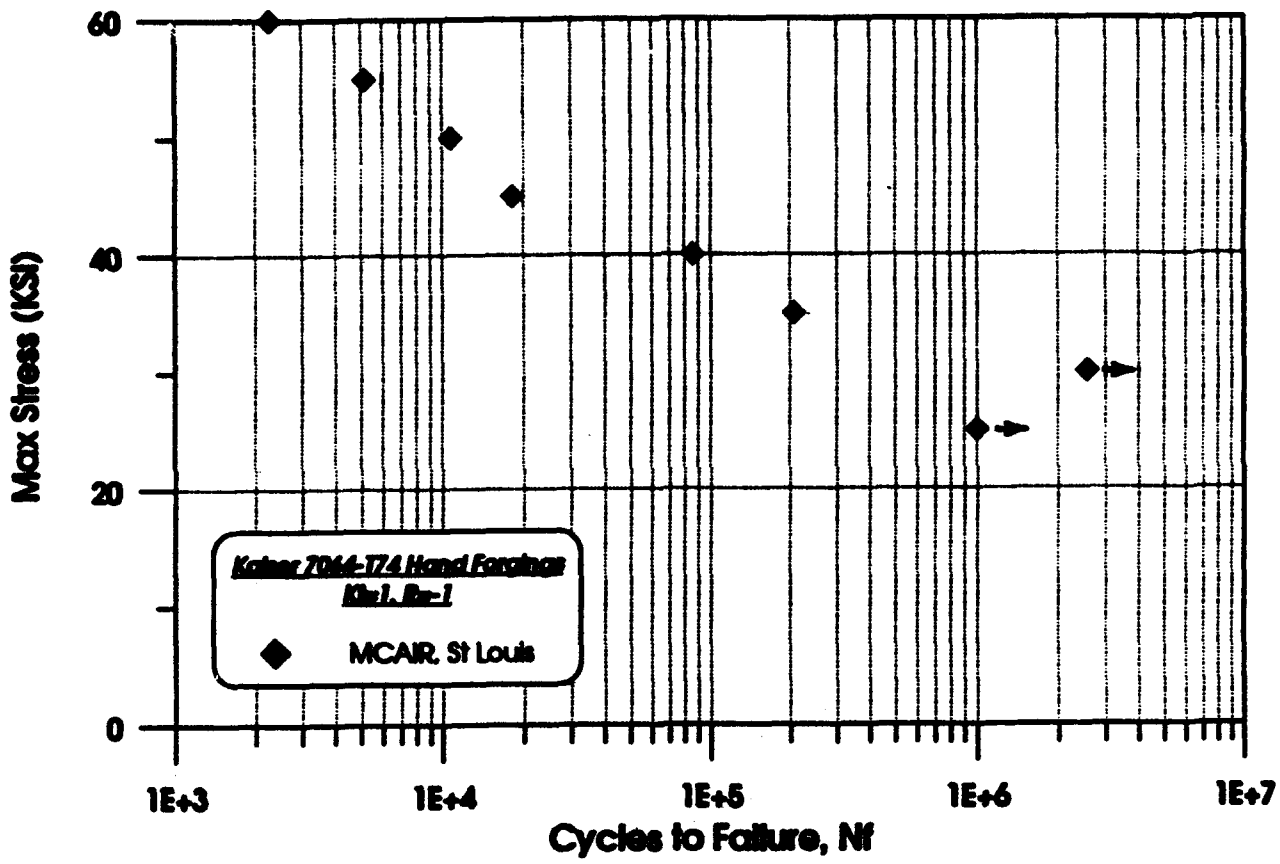
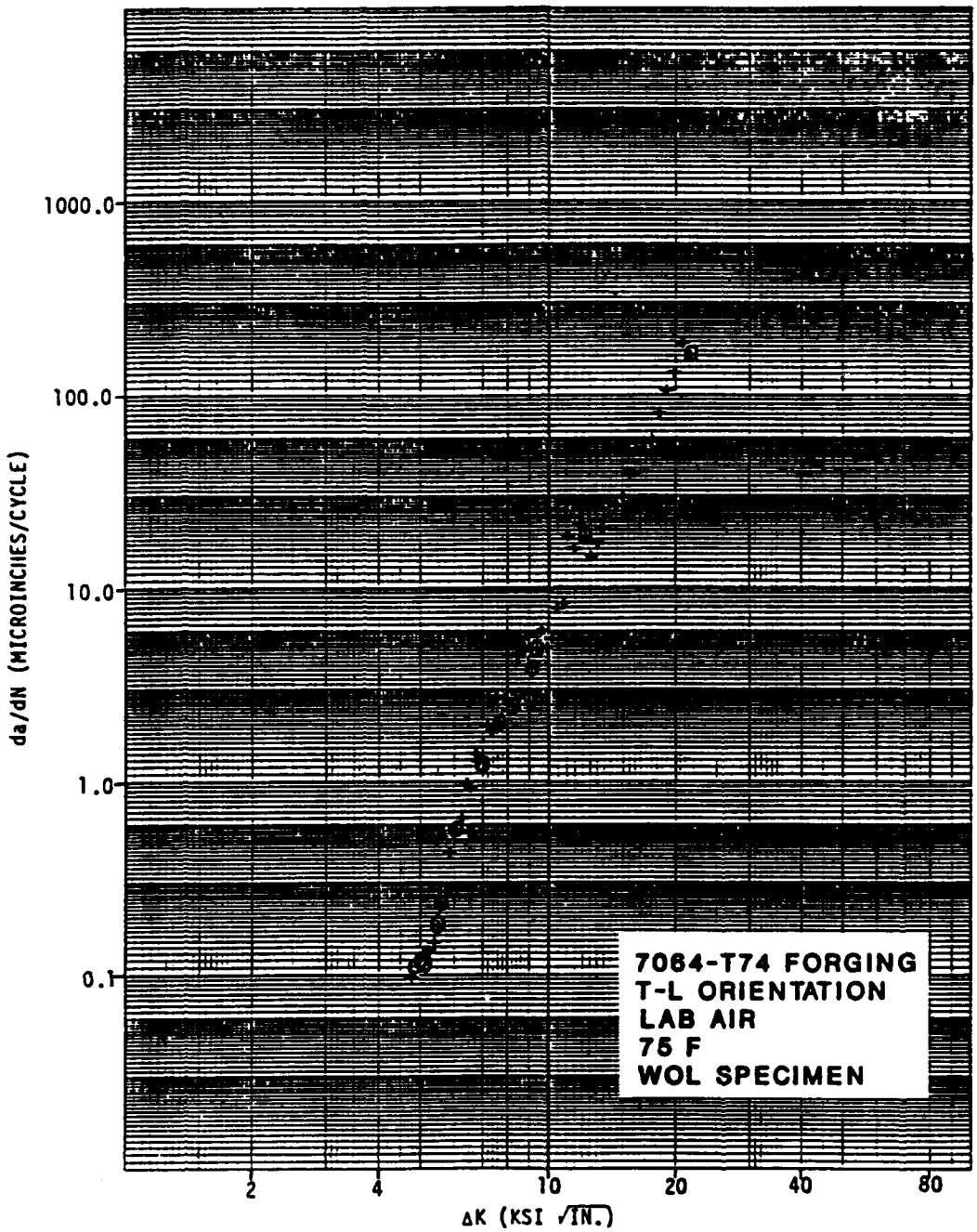


FIGURE O2. FATIGUE DATA FOR 7064-T74 HAND FORGINGS (Longitudinal Orientation, R=-1.0, and Kt=1). McDonnell Aircraft Company.



● DENOTES THAT DATA POINT IS INVALID PER ASTM 647-83, PARAGRAPH 8.6.4.

FIGURE O3. FATIGUE CRACK GROWTH RATE DATA for 7064-T74 Forging (T-L Orientation, WOL Type Specimen). McDonnell Aircraft Company.

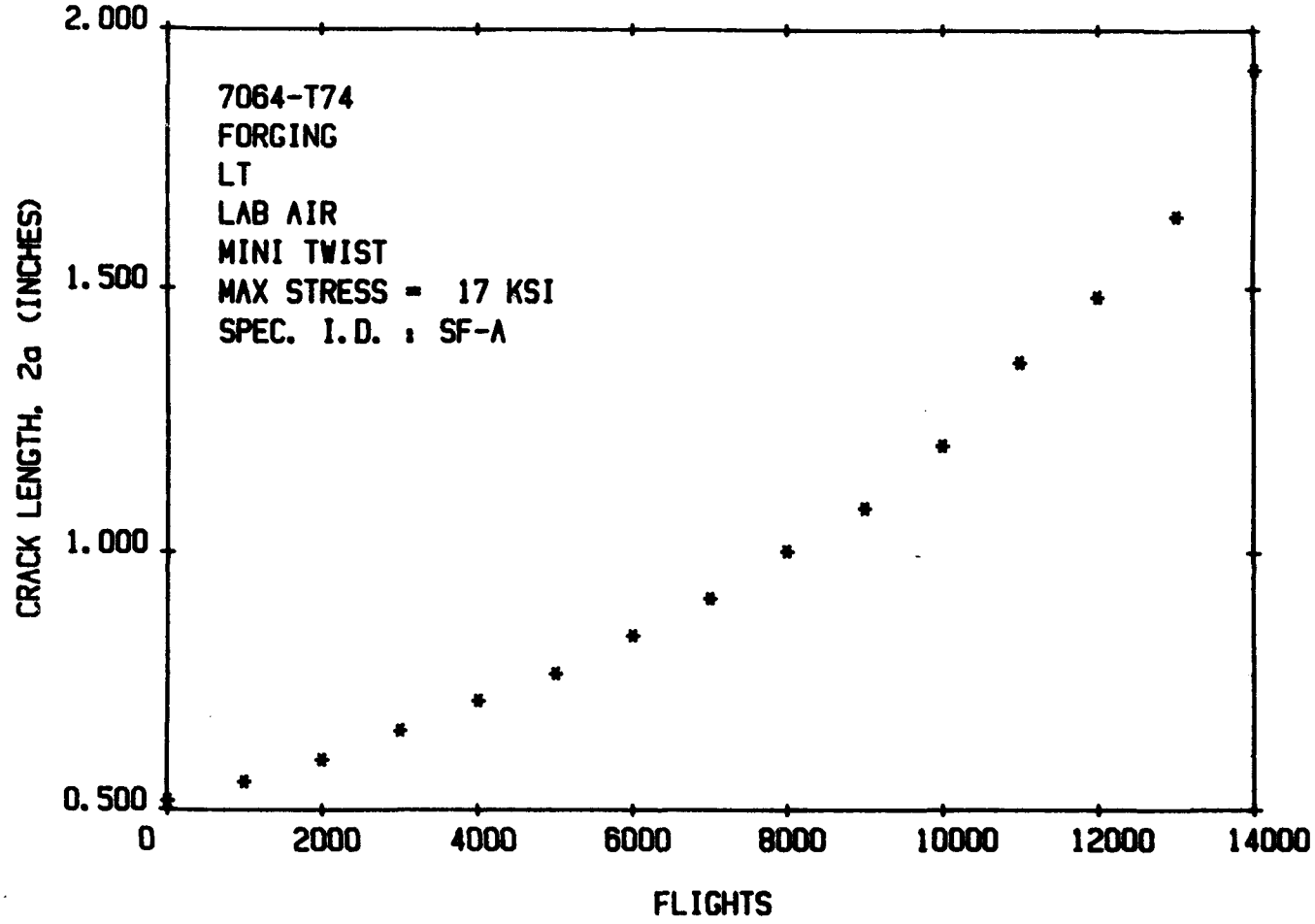


FIGURE O4. Mini-TWIST Spectrum Fatigue Crack Length vs Flights Data for 7064-T74 Forging. Air Force.

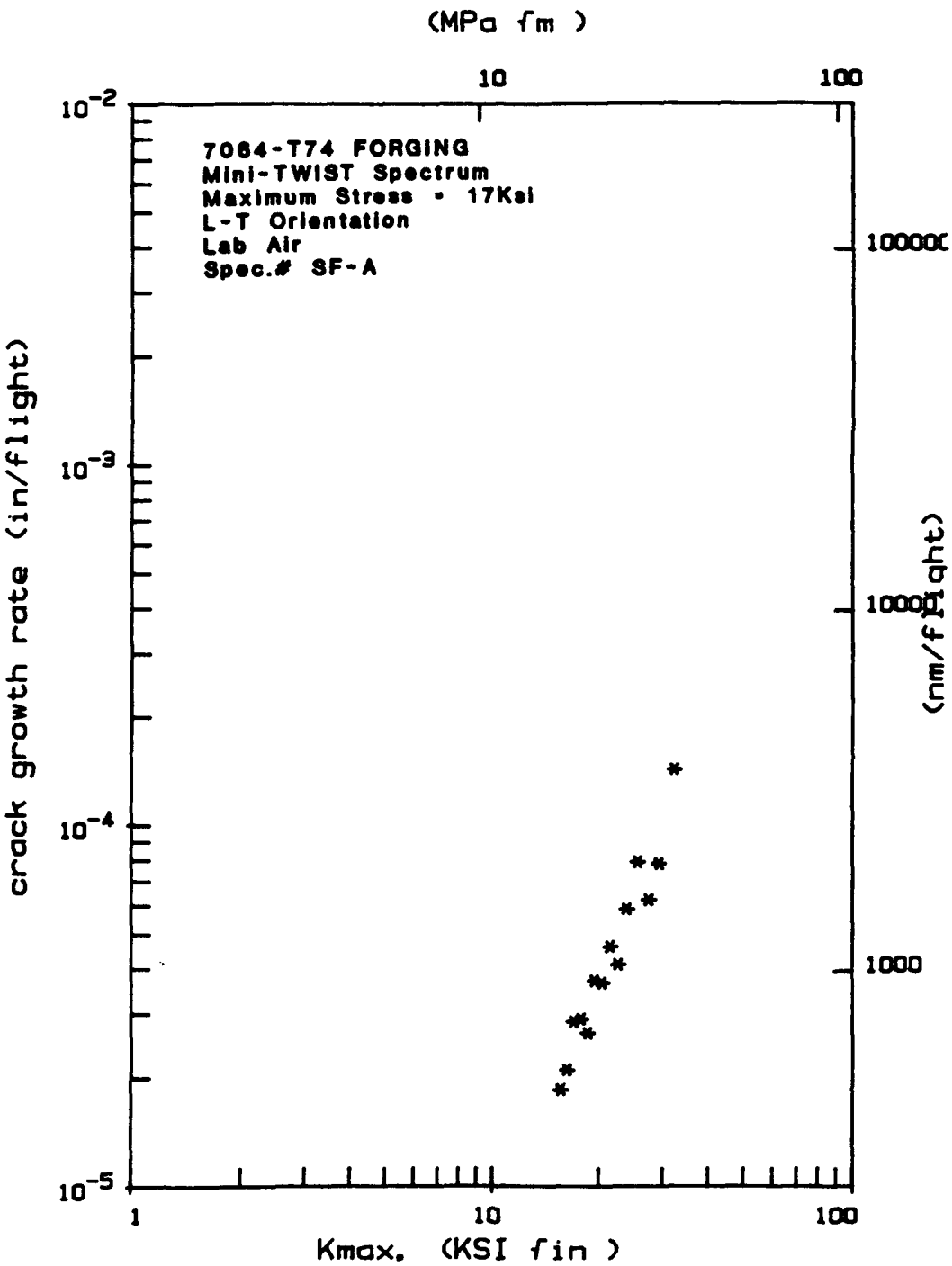


FIGURE O5. Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for 7064-T74 Forging.
Air Force.

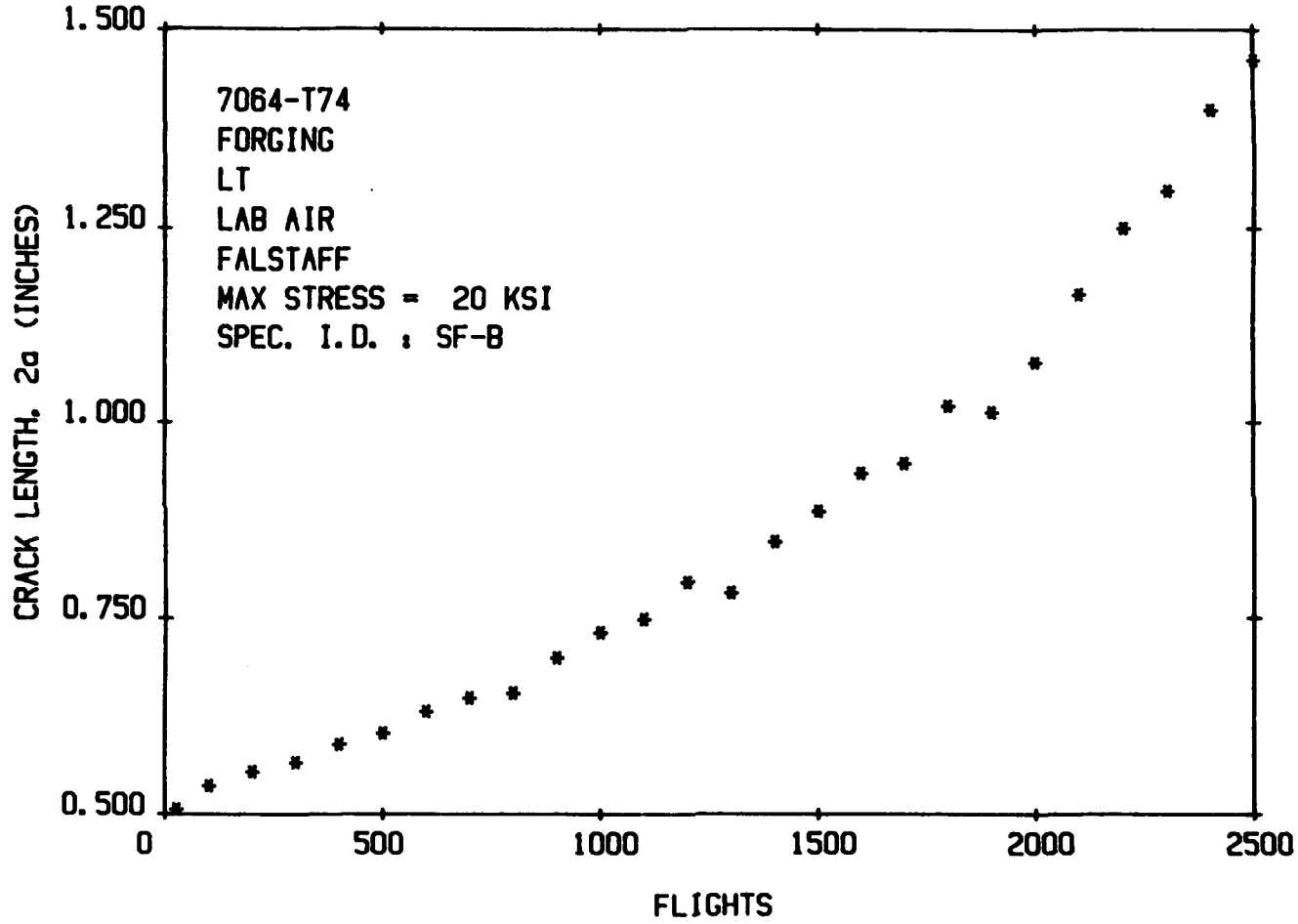


FIGURE O6. FALSTAFF Spectrum Fatigue Crack Length vs Flights Data for 7064-T74 Forging. Air Force.

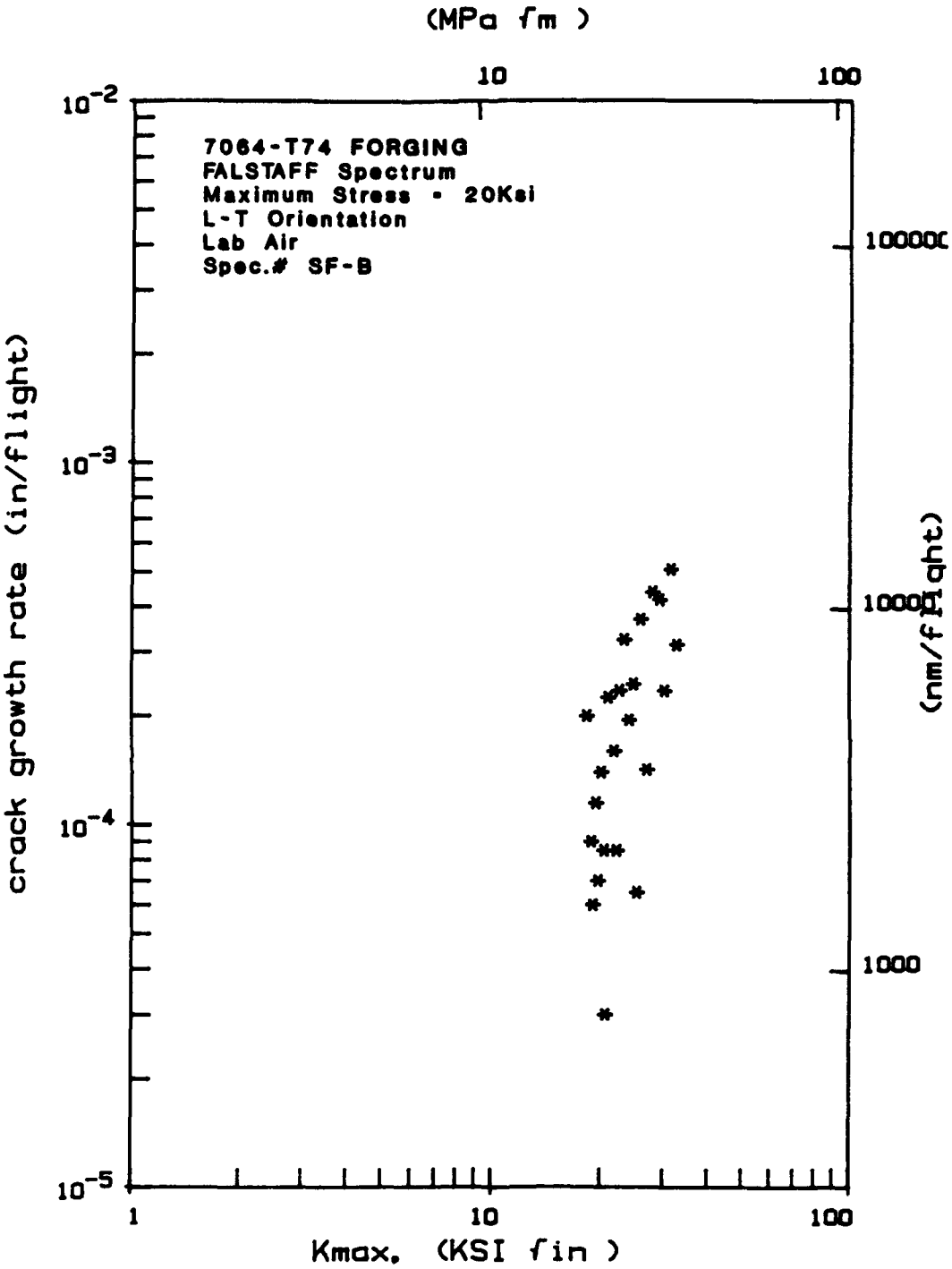


FIGURE O7. FALSTAFF Spectrum Fatigue Crack Growth Rate Data for 7064-T74 Forging.
Air Force.

APPENDIX P

CW67 SHEET
0.063"X16"X48"

INTRODUCTION

The Alcoa P/M aluminum alloy CW67 0.063 inch sheets were received April 1989. CW67 sheets were tested by Martin Marietta and McDonnell Aircraft Company.

TESTING

Mechanical properties (tension, compression, shear, bearing and fracture toughness), and constant amplitude fatigue crack growth tests were generated according to ASTM standards, unless otherwise specified.

TABLE P1

TENSILE RESULTS FOR ALCOA

CW67 SHEET (0.063" X 16" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	LONG	81.5	77.5	8.0	10.0	9.8
MARIETTA,			81.9	78.7	7.0	10.0	9.7
LOUISIANA			82.9	79.5		6.7	9.8
MCDONNELL	RT	LONG	80.0	77.0	6.0		10.0
DOUGLAS			80.0	77.5	8.0		10.4
			81.0	78.5	6.0		10.0
		AVERAGE	81.2	78.1	7.0	8.9	10.0
	STANDARD	DEVIATION	1.1	0.9	1.0	1.9	0.3

TABLE P2

TENSILE RESULTS FOR ALCOA

CW67 SHEET (0.063" X 16" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	L TRANS	83.5	80.8		6.7	9.9
MARIETTA,			83.9	82.0	3.0	3.3	10.0
LOUISIANA			83.7	80.5	2.0	6.7	10.1
MCDONNELL	RT	L TRANS	87.5	83.0	4.0		10.3
DOUGLAS			86.5	82.0	5.0		10.3
			86.5	82.0	5.0		10.4
		AVERAGE	85.3	81.7	3.8	5.6	10.2
	STANDARD	DEVIATION	1.8	0.9	1.3	2.0	0.2

TABLE P3

COMPRESSION RESULTS FOR ALCOA

CW67 SHEET (0.063" X 16" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCDONNELL DOUGLAS	RT	LONG		11.2
				11.5
			72.0	10.3
		AVERAGE	72.0	11.0
		STANDARD DEVIATION	0.0	0.6

TABLE P4

COMPRESSION RESULTS FOR ALCOA

CW67 SHEET (0.063" X 16" X 48")

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCDONNELL DOUGLAS	RT	L TRANS		10.3
				10.8
				11.2
		AVERAGE		10.8
		STANDARD DEVIATION		0.5

TABLE P5

SLOTTED SHEAR RESULTS FOR ALCOA

CW67 SHEET (0.063" X 16" X 48")

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
MCDONNELL DOUGLAS	LONG	31.0
		30.0
		29.3
	AVERAGE	30.1
	STANDARD DEVIATION	0.9

TABLE P6

BEARING RESULTS FOR ALCOA

CW67 SHEET (0.063" X 16" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL DOUGLAS	LONG	1.5	117.1	101.3
			124.3	107.7
			125.5	111.1
		AVERAGE	122.3	106.7
	STANDARD DEVIATION		4.5	5.0

TABLE P7

BEARING RESULTS FOR ALCOA

CW67 SHEET (0.063" X 16" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL DOUGLAS	L TRANS	1.5	127.1	112.0
			126.1	108.9
			126.6	112.9
		AVERAGE	126.6	111.3
	STANDARD DEVIATION		0.5	2.1

TABLE P8

BEARING RESULTS FOR ALCOA

CW67 SHEET (0.063" X 16" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL DOUGLAS	LONG	2.0	169.4	148.8
			162.0	116.3
			163.5	139.5
		AVERAGE	165.0	134.9
	STANDARD DEVIATION		3.9	16.7

TABLE P9

BEARING RESULTS FOR ALCOA

CW67 SHEET (0.063" X 16" X 48")

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
MCDONNELL DOUGLAS	L TRANS	2.0	166.1	146.4
			168.5	146.6
			166.2	146.4
		AVERAGE	166.9	146.5
	STANDARD DEVIATION		1.4	0.1

TABLE P10

R-CURVE DATA FOR CW67 0.063 SHEET
(SPECIMEN 32)
McDonnell Aircraft Company

SPECIMEN IDENTIFICATION: 32
MATERIAL DESCRIPTION: CW67 HIGH STRENGTH ALUMINUM SHEET
SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)
SPECIMEN ORIENTATION: L-T
YIELD STRENGTH: 77.7 KSI
SPECIMEN THICKNESS: 0.071 IN
SPECIMEN WIDTH: 3.999 IN

SPECIMEN IS INVALID PER ASTM E561-86, PARA. 7.5

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi √in)	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi √in)
1,025	1.519	49,842	1.591	52,248
1,050	1.523	51,181	1.599	53,808
1,250	1.533	61,348	1.649	66,212
1,325	1.592	67,582	1.739	74,594
1,375	1.610	70,986	1.777	79,483
1,400	1.613	72,406	1.788	81,590
1,425	1.638	74,930	1.831	85,575
1,450	1.638	76,245	1.840	87,675
1,475	1.642	77,762	1.856	90,199
1,500	1.660	80,039	1.894	94,283
1,525	1.662	81,493	1.910	96,969
1,550	1.663	82,874	1.924	99,627
1,600	1.667	85,818	1.963	105,834
1,650	1.678	89,128	2.022	114,190
1,700	1.684	92,202	2.092	124,368
1,725	1.706	94,972	***	***
1,750	FAILURE	---	---	---

*** Indicates that the equation for Kr (Corrected) did not converge to a solution.

TABLE P11

R-CURVE DATA FOR CW67 0.063 SHEET
(SPECIMEN 33)
McDonnell Aircraft Company

SPECIMEN IDENTIFICATION: 33
MATERIAL DESCRIPTION: CW67 HIGH STRENGTH ALUMINUM SHEET
SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)
SPECIMEN ORIENTATION: L-T
YIELD STRENGTH: 77.7 KSI
SPECIMEN THICKNESS: 0.071 IN
SPECIMEN WIDTH: 4.002 IN

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi √in)	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi √in)
920	1.509	44,397	1.565	46,045
940	1.533	46,088	1.594	47,956
1,000	1.545	49,395	1.615	51,743
1,020	1.548	50,476	1.622	52,997
1,060	1.565	53,059	1.648	56,048
1,100	1.569	55,188	1.659	58,602
1,140	1.573	57,349	1.672	61,243
1,180	FAILURE	---	---	---

TABLE P12

R-CURVE DATA FOR CW67 0.063 SHEET
(SPECIMEN 34)
McDonnell Aircraft Company

SPECIMEN IDENTIFICATION: 34
MATERIAL DESCRIPTION: CW67 HIGH STRENGTH ALUMINUM SHEET
SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)
SPECIMEN ORIENTATION: T-L
YIELD STRENGTH: 82.3 KSI
SPECIMEN THICKNESS: 0.071 IN
SPECIMEN WIDTH: 4.002 IN

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi √in)	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi √in)
820	1.514	39,692	1.553	40,712
840	1.514	40,660	1.555	41,761
860	1.516	41,677	1.559	42,867
880	1.519	42,754	1.565	44,046
900	1.519	43,726	1.567	45,113
920	1.524	44,843	1.575	46,348
940	1.524	45,818	1.577	47,430
960	1.525	46,811	1.580	48,537
1,000	1.525	48,762	1.585	50,730
1,020	1.526	49,786	1.590	51,892
1,040	1.526	50,762	1.593	53,005
1,060	1.526	51,738	1.595	54,125
1,080	1.529	52,786	1.601	55,336
1,120	1.529	54,741	1.607	57,616
1,140	1.532	55,832	1.613	58,902
1,160	1.534	56,893	1.619	60,164
1,180	1.534	57,874	1.622	61,338
1,180	1.534	57,874	1.622	61,338
1,200	1.534	58,854	1.626	62,520
1,220	1.541	60,117	1.638	64,063
1,260	1.544	62,210	1.648	66,648
1,280	1.546	63,272	1.654	67,979
1,300	1.546	64,260	1.659	69,228
1,320	1.548	65,321	1.665	70,584
1,340	1.562	66,926	1.686	72,682
1,380	1.562	68,923	1.695	75,318
1,400	1.571	70,341	1.711	77,245
1,420	1.575	71,552	1.722	78,913
1,440	1.578	72,679	1.730	80,485
1,460	1.578	73,689	1.735	81,907
1,468	FAILURE	---	---	---

TABLE P13

R-CURVE DATA FOR CW67 0.063 SHEET
(SPECIMEN 35)
McDonnell Aircraft Company

SPECIMEN IDENTIFICATION: 35
MATERIAL DESCRIPTION: CW67 HIGH STRENGTH ALUMINUM SHEET
SPECIMEN TYPE: C(T) (COMPACT SPECIMEN)
SPECIMEN ORIENTATION: T-L
YIELD STRENGTH: 82.3 KSI
SPECIMEN THICKNESS: 0.071 IN
SPECIMEN WIDTH: 4.001 IN

APPLIED LOAD (lbs)	PHYSICAL CRACK LENGTH (in)	Kr (UNCORRECTED) (psi √in)	EFFECTIVE CRACK LENGTH (in)	Kr (CORRECTED) (psi √in)
800	1.501	38,420	1.537	39,340
860	1.505	41,420	1.548	42,585
880	1.505	42,383	1.550	43,636
900	1.505	43,346	1.552	44,692
920	1.505	44,310	1.555	45,753
940	1.507	45,320	1.559	46,871
960	1.507	46,284	1.561	47,943
980	1.507	47,248	1.563	49,021
1,000	1.509	48,260	1.568	50,158
1,020	1.509	49,225	1.570	51,248
1,040	1.514	50,363	1.579	52,544
1,060	1.517	51,449	1.585	53,788
1,080	1.517	52,419	1.588	54,906
1,100	1.521	53,526	1.595	56,191
1,120	1.521	54,499	1.598	57,328
1,140	1.521	55,472	1.602	58,471
1,160	1.521	56,445	1.605	59,623
1,180	1.523	57,482	1.610	60,860
1,200	1.523	58,456	1.613	62,031
1,220	1.523	59,430	1.617	63,210
1,240	1.523	60,405	1.620	64,398
1,260	1.643	66,427	1.765	72,199
1,280	1.643	67,482	1.770	73,588
1,300	1.643	68,536	1.775	74,994
1,320	1.650	69,917	1.789	76,881
1,340	1.665	71,679	1.813	79,365
1,360	1.665	72,749	1.818	80,873
1,380	1.671	74,137	1.832	82,893
1,388	FAILURE	---	---	---

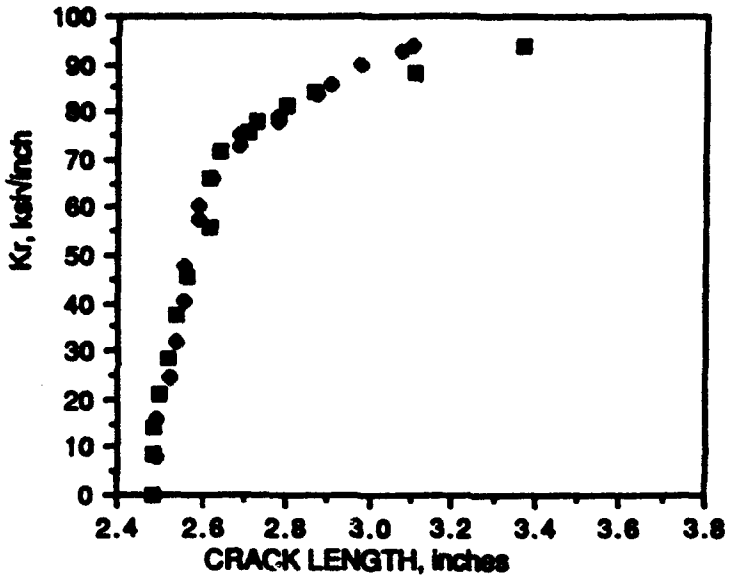


FIGURE P1. R-CURVE DATA for CW67 0.063 Inch Sheet (L-T Orientation).
Martin Marietta.

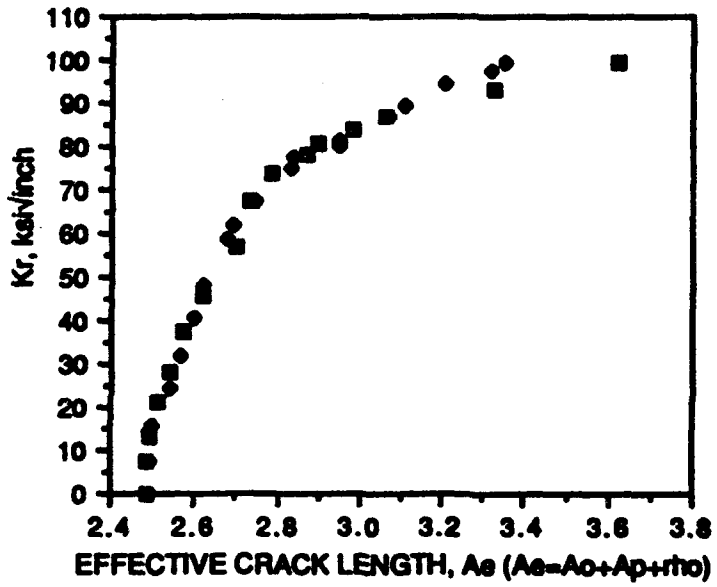


FIGURE P2. R-CURVE EFFECTIVE CRACK LENGTH ADJUSTED for PLASTIC ZONE
(L-T Orientation).
Martin Marietta.

TABLE P14

R-CURVE DATA ASSOCIATED WITH FIGURES P1 AND P2
(SPECIMEN 1)

Load, kips	Half Crack Length (a) inch	Half Crack Length, (a + rho) inch	Corresponding Fracture Toughness, ksi √inch	
			Not Adjusted	Adjusted for Plasticity
0	2.485	2.485	0.0	0.0
2.50	2.485	2.487	8.3	7.8
4.25	2.485	2.490	14.1	13.2
6.40	2.500	2.512	21.3	21.4
8.45	2.520	2.541	28.3	28.4
11.10	2.535	2.571	37.3	37.6
13.35	2.565	2.619	45.2	45.8
16.30	2.615	2.698	55.9	56.9
19.25	2.615	2.733	66.1	67.7
20.75	2.645	2.785	71.8	73.8
21.50	2.710	2.866	75.6	77.9
22.15	2.710	2.893	78.1	80.7
22.60	2.800	2.982	81.2	84.0
23.00	2.865	3.060	83.9	87.0
22.85	3.105	3.327	88.3	92.9
22.90	3.365	3.620	94.0	99.5

Thickness = .058 inches
Yield Strength = 78.6 ksi
Specimen Width = 15.50 inches

TABLE P15

R-CURVE DATA ASSOCIATED WITH FIGURES P1 and P2
(SPECIMEN 2)

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi √inch	
			Not Adjusted	Adjusted for Plasticity
0	2.490	2.490	0.0	0.0
2.8	2.490	2.492	8.2	7.7
5.4	2.490	2.496	15.8	15.8
8.2	2.525	2.540	24.2	24.3
10.8	2.535	2.562	31.9	32.1
13.5	2.555	2.597	40.1	40.5
16.0	2.555	2.615	47.5	48.1
19.3	2.590	2.680	57.4	58.9
20.2	2.590	2.688	60.5	61.8
21.8	2.625	2.742	65.9	67.5
23.7	2.685	2.829	72.7	74.9
24.4	2.685	2.839	74.9	77.2
24.7	2.780	2.945	77.6	80.1
25.1	2.780	2.951	78.9	81.5
26.1	2.870	3.065	83.8	86.9
26.5	2.905	3.109	85.8	89.1
27.2	2.975	3.205	89.6	94.4
27.4	3.075	3.321	92.4	97.7
27.6	3.100	3.353	93.6	99.1

Thickness = 0.066 inches
Yield Strength = 78.6 ksi
Specimen Width = 15.50 inches

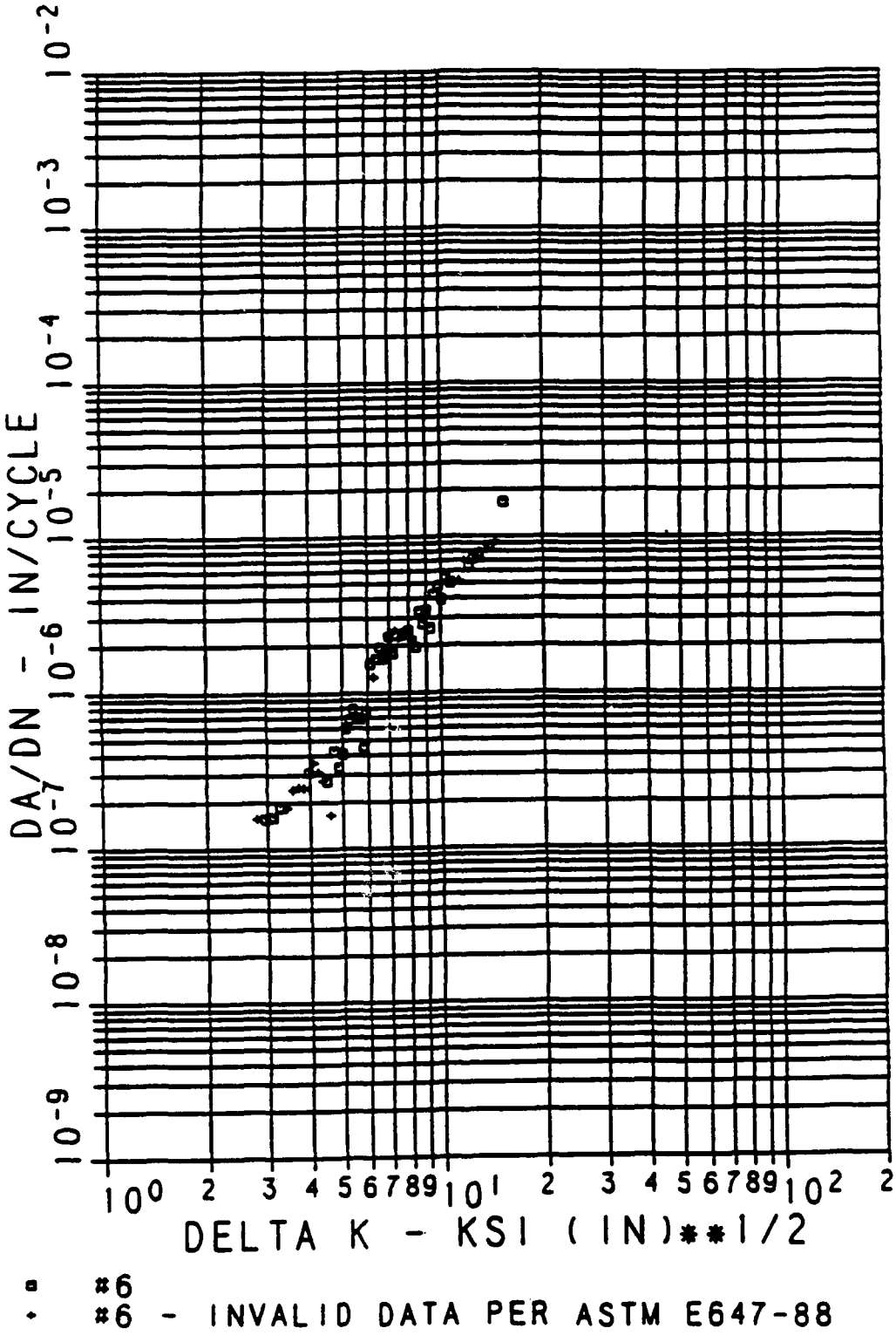


FIGURE P3. FATIGUE CRACK GROWTH RATE DATA for CW67 0.063 Sheet (L-T Orientation, R=0.1, Lab Air, Room Temperature and Specimen #6) McDonnell Aircraft Company.

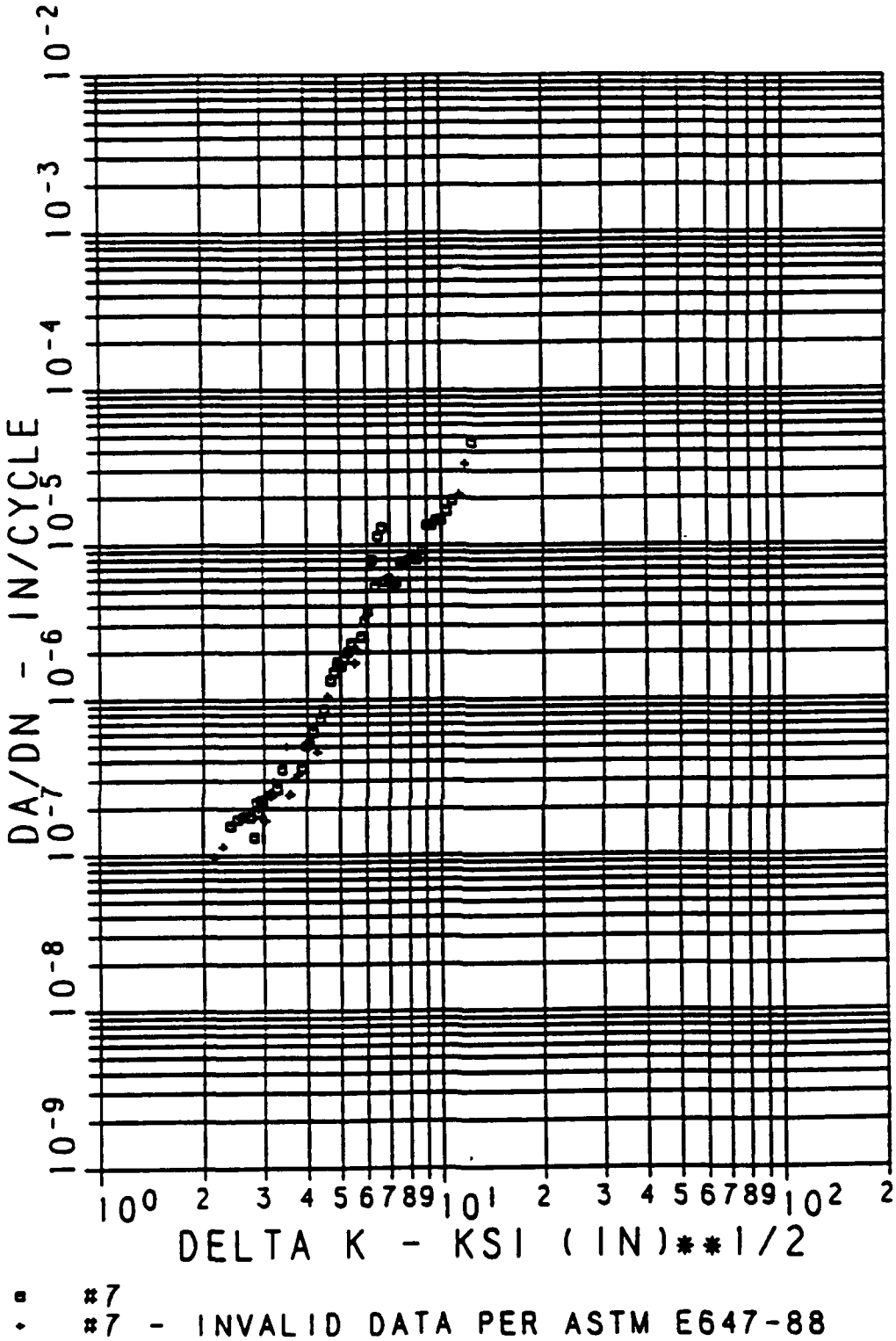
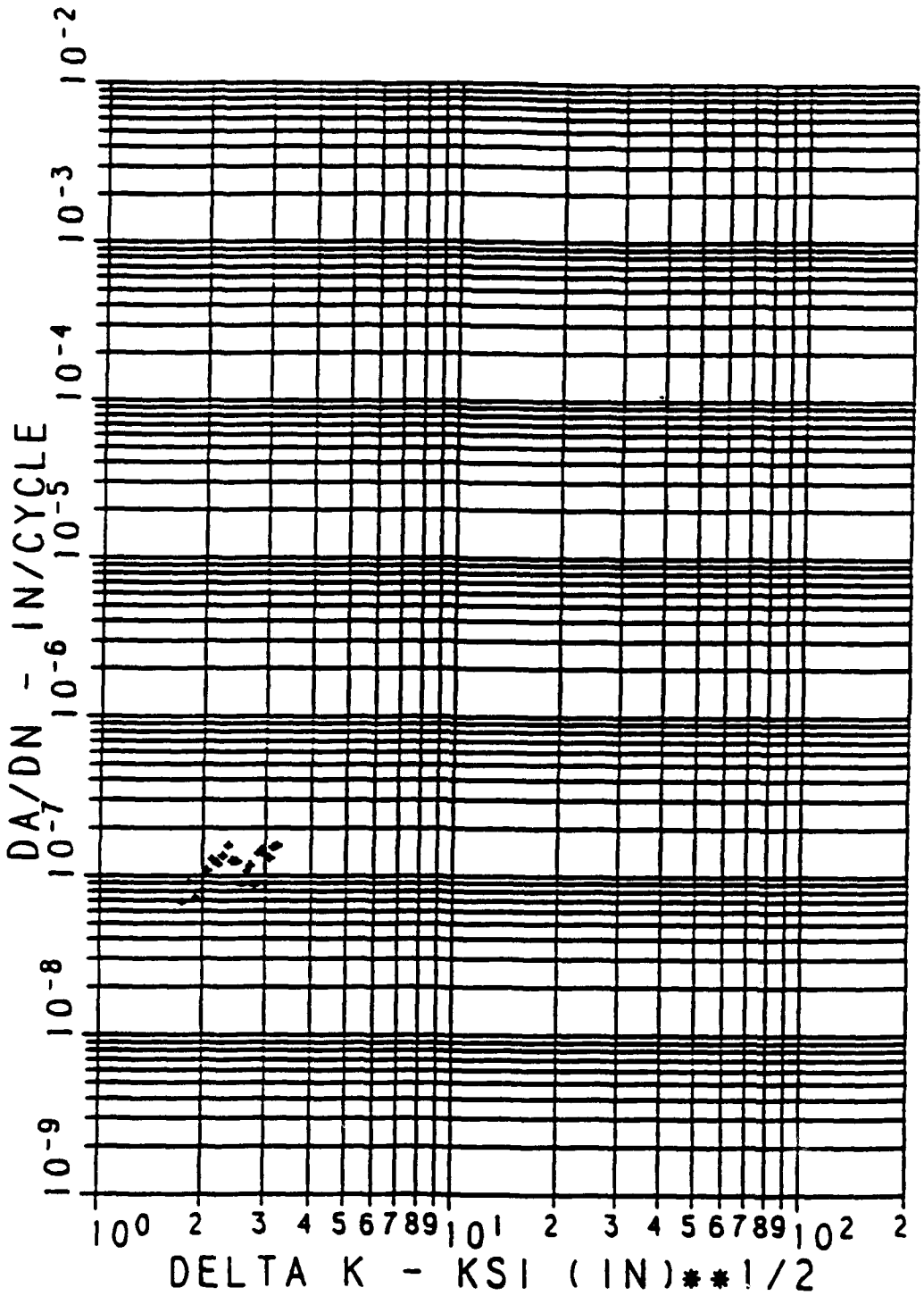


FIGURE P4. FATIGUE CRACK GROWTH RATE DATA for CW67 0.063 Sheet (L-T Orientation, R=0.33, Lab Air, Room Temperature and Specimen #7). McDonnell Aircraft Company.



▪ #4
• #4 - INVALID DATA PER ASTM E647-88

FIGURE P5. FATIGUE CRACK GROWTH RATE DATA for CW67 0.063 Sheet (T-L Orientation, R=0.1, Lab Air, Room Temperature and Specimen #4). McDonnell Aircraft Company.

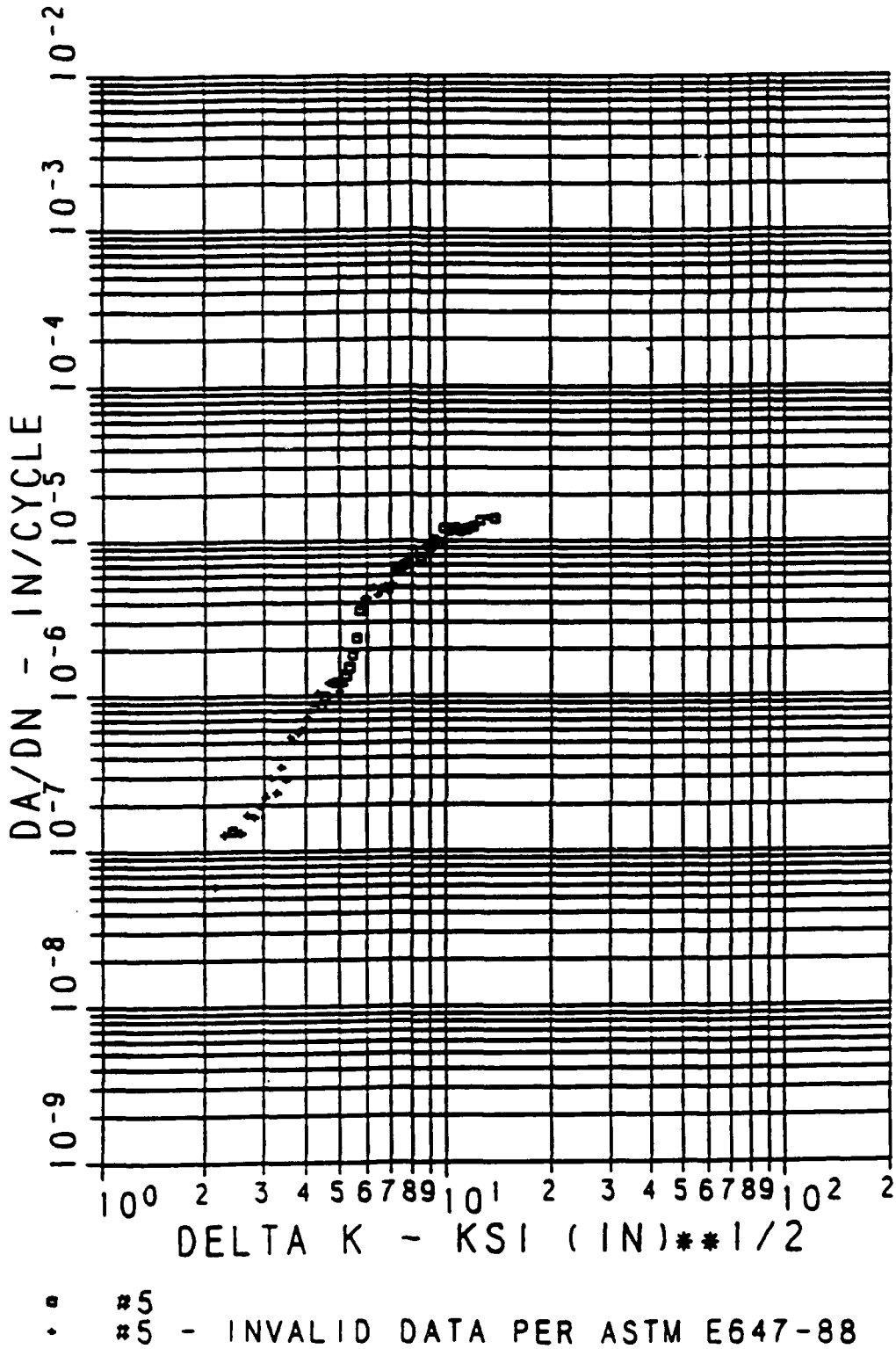


FIGURE P6. FATIGUE CRACK GROWTH RATE DATA for CW67 0.063" Sheet (T-L Orientation, R=0.33, Lab Air, Room Temperature and Specimen #5). McDonnell Aircraft Company.

APPENDIX Q

CW67 PLATE
0.4"X16"X48"

INTRODUCTION

The Alcoa P/M aluminum alloy CW67 0.4 inch plates were received April 1989. Only Martin Marietta tested the CW67 plate.

TESTING

Tensile and toughness tests were generated according to ASTM standards, unless otherwise specified.

TABLE Q1

TENSILE RESULTS FOR ALCOA

CW67 PLATE (0.4" X 16" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN MARIETTA, LOUISIANA	RT	LONG	81.8	79.1	11.0	18.1	9.8
			81.1	77.2	13.0	23.1	9.8
			82.0	78.4	12.5	24.7	9.9
		AVERAGE	81.6	78.2	12.2	22.0	9.8
	STANDARD DEVIATION		0.5	1.0	1.0	3.4	0.1

TABLE Q2

TENSILE RESULTS FOR ALCOA

CW67 PLATE (0.4" X 16" X 48")

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	88.8	84.6	6.0	5.6	9.9
			87.8	83.8	6.0	6.1	10.3
			86.9	83.6	6.5	6.6	10.1
		AVERAGE	87.8	84.0	6.2	6.1	10.1
	STANDARD DEVIATION		1.0	0.5	0.3	0.5	0.2

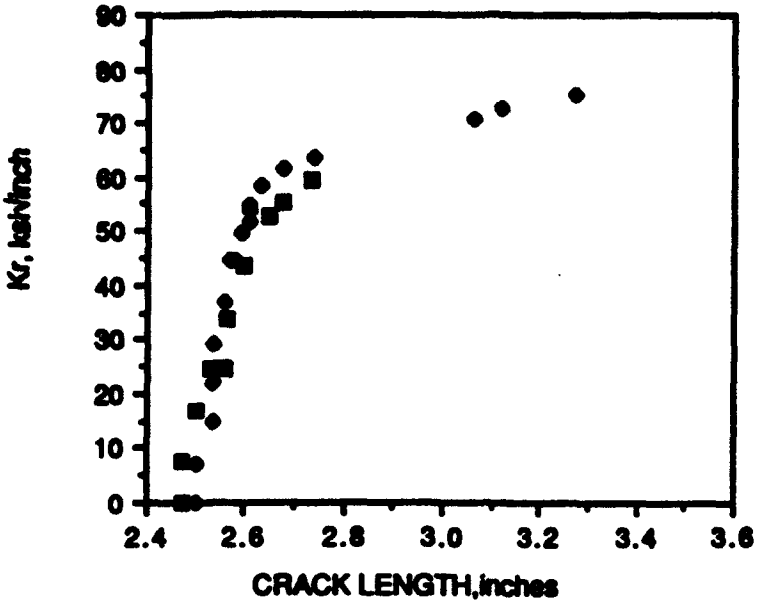


FIGURE Q1. R-CURVE DATA for CW67 0.4 INCH PLATE (L-T ORIENTATION).
Martin Marietta.

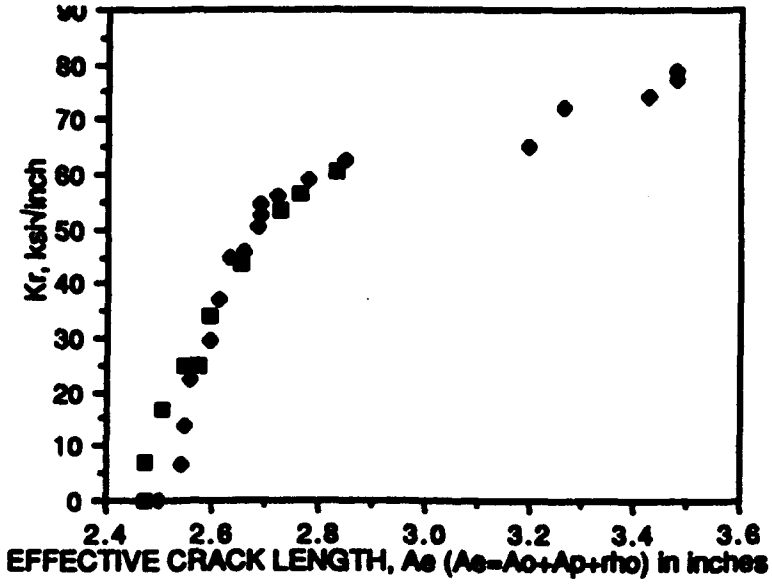


FIGURE Q2. R-CURVE EFFECTIVE CRACK LENGTH ADJUSTED for Plastic Zone Data for CW67 0.4 Inch Plate (L-T Orientation).
Martin Marietta.

TABLE Q3

R-CURVE DATA ASSOCIATED WITH FIGURES Q1 AND Q2
(SPECIMEN 1)

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi √inch	
			Not Adjusted	Adjusted for Plasticity
0	2.475	2.475	0.0	0.0
16.1	2.475	2.476	7.8	7.3
34.3	2.500	2.507	16.8	16.8
50.2	2.503	2.546	24.7	24.8
50.2	2.506	2.576	24.7	25.0
68.5	2.507	2.596	34.0	34.3
86.6	2.600	2.650	43.4	43.9
103.4	2.650	2.724	52.5	53.3
108.0	2.680	2.762	55.2	56.2
114.8	2.735	2.831	59.2	60.7

Thickness = 0.396 inches
Yield Strength = 78.2 ksi
Specimen Width = 15.49 inches

TABLE Q4

R-CURVE DATA ASSOCIATED WITH FIGURES Q1 and Q2
(SPECIMEN 2)

Load, kips	Half Crack Length (a), inch	Half Crack Length (a + rho), inch	Corresponding Fracture Toughness, ksi √inch	
			Not Adjusted	Adjusted for Plasticity
0	2.500	2.501	0.0	0.0
15.0	2.500	2.540	7.3	6.8
29.9	2.535	2.548	14.6	13.6
45.5	2.535	2.558	22.2	22.3
60.1	2.535	2.596	29.3	29.5
75.2	2.560	2.609	36.9	37.2
90.3	2.570	2.634	44.4	44.8
91.5	2.580	2.656	44.4	45.7
100.6	2.590	2.682	49.8	50.5
104.3	2.610	2.688	51.8	52.6
108.1	2.610	2.691	53.7	54.6
110.5	2.610	2.721	54.9	55.9
116.3	2.630	2.777	58.1	59.2
121.1	2.675	2.850	61.2	62.4
123.8	2.740	3.196	63.6	65.0
127.1	3.060	3.264	70.5	72.2
129.0	3.120	3.425	72.5	74.4
129.0	3.270	3.481	75.1	77.1
129.8	3.320	3.481	76.5	78.6

Thickness = 0.396 inches
Yield Strength = 78.2 ksi
Specimen Width = 15.50 inches

APPENDIX R

CW67 EXTRUSION
1.5"X4.5"X36"

INTRODUCTION

The Alcoa P/M aluminum alloy 1.5"x4.5"x36" extrusions were received August 1987. LTV, McDonnell Aircraft Company and the Air Force tested the CW67 extrusion material.

TESTING

Mechanical properties (tension, compression, shear, bearing, and fracture toughness), and constant amplitude fatigue crack growth tests were generated according to ASTM standards, unless otherwise specified.

Spectrum fatigue crack growth rate tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE R1

TENSILE RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
LTV	RT	LONG	86.4	81.3	10.5		10.2
			85.9	81.3	11.4		10.0
			85.9	81.3	12.3		9.9
			85.5	78.6	12.3		9.4
			86.1	80.4	11.7		9.5
AIR FORCE	RT	LONG	89.1	84.9	10.0	28.0	
			86.2	81.5	9.5	27.0	
			85.5	80.6	15.2	28.7	
MCAIR	RT	LONG	86.0	81.5	10.0	35.0	14.3
			83.0	79.0	14.0	38.0	13.4
			82.5	77.5	12.0	36.0	13.7
		AVERAGE	85.6	80.7	11.7	32.1	11.3
	STANDARD DEVIATION		1.7	1.9	1.7	4.7	2.1

TABLE R2

TENSILE RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
LTV	RT	L TRANS	80.9	75.0	10.0		10.0
			81.0	75.0	12.0		11.1
			81.6	71.0	11.2		12.9
			80.9	72.3	9.1		11.0
			80.9		10.9		12.9
AIR FORCE	RT	L TRANS	82.5	77.4	10.0	26.0	
			83.1	78.2	10.7	35.0	
			82.3	76.7	8.4	20.4	
MCAIR	RT	L TRANS	81.5	76.5	12.0	32.0	14.0
			81.0	72.0	10.0	27.0	14.0
			81.5	76.0	15.0	35.0	13.6
		AVERAGE	81.6	75.0	10.8	29.2	12.4
	STANDARD DEVIATION		0.8	2.5	1.8	5.8	1.5

TABLE R3

COMPRESSION RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCAIR	RT	LONG	78.5	10.8
			80.0	10.9
			79.5	11.0
		AVERAGE	79.3	10.9
		STANDARD DEVIATION	0.8	0.1

TABLE R4

COMPRESSION RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MCAIR	RT	L TRANS	80.0	11.2
			74.0	10.8
			79.0	10.8
		AVERAGE	77.7	10.9
		STANDARD DEVIATION	3.2	0.2

TABLE R5

IOSIPESCU SHEAR RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
LTV	LONG	49.8
		50.0
		49.9
		48.1
		48.7
		50.7
	AVERAGE	49.5
	STANDARD DEVIATION	1.0

TABLE R6

IOSIPESCU SHEAR RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
LTV	L TRANS	51.5
		51.2
		51.5
		48.9
		48.6
		51.0
	AVERAGE	50.5
	STANDARD DEVIATION	1.3

TABLE R7

AMSLER DOUBLE SHEAR RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
MCAIR	L - S	52.1
		48.3
		48.5
	AVERAGE	49.6
	STANDARD DEVIATION	2.1

TABLE R8

BEARING RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	LONG	1.5	124.0	103.0
			123.0	104.0
			126.0	106.0
MCAIR	LONG	1.5	126.9	112.1
			122.9	107.2
		AVERAGE	124.6	106.5
	STANDARD DEVIATION		1.8	3.6

TABLE R9

BEARING RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	L TRANS	1.5	122.0	109.0
			123.0	108.0
			129.0	112.0
MCAIR	L TRANS	1.5	123.7	107.4
			121.7	105.7
		AVERAGE	123.9	108.4
	STANDARD DEVIATION		3.0	2.3

TABLE R10

BEARING RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	LONG	2.0	158.0	118.0
			155.0	126.0
			156.0	121.0
MCAIR	LONG	2.0	174.2	144.4
			171.0	139.0
		AVERAGE	162.8	129.7
	STANDARD DEVIATION		9.0	11.5

TABLE R11

BEARING RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	ORIENTATION	e/D	BEARING ULT. STR. (KSI)	BEARING YIELD STR. (KSI)
LTV	L TRANS	2.0	153.0	122.0
			162.0	129.0
			156.0	124.0
MCAIR	L TRANS	2.0	170.7	141.3
			171.1	140.5
		AVERAGE	162.6	131.4
	STANDARD DEVIATION		8.3	9.1

TABLE R12

FRACTURE TOUGHNESS RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
LTV	L-T	24.1		VALID
		22.4		VALID
		21.7		VALID
AIR FORCE	L-T	45.3		VALID
		46.9		VALID
		44.1		VALID
MCAIR	L-T	29.4		VALID
		29.0		VALID
	AVERAGE	32.9		
	STANDARD DEVIATION	10.8		

TABLE R13

FRACTURE TOUGHNESS RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
LTV	T-L		38.5	(1)
			36.1	(1)
			42.2	(1)
AIR FORCE	T-L	26.7		VALID
		27.2		VALID
MCAIR	T-L	18.5		VALID
		18.8		VALID
	AVERAGE	22.8	38.9	
	STANDARD DEVIATION	4.8	3.1	

(1): INVALID DUE TO UNSYMMETRIC CRACK FRONT CURVATURE

TABLE R14

FRACTURE TOUGHNESS RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MCAIR	S-T	20.5		VALID
		21.2		VALID
	AVERAGE	20.9		
	STANDARD DEVIATION	0.5		

TABLE R15

FRACTURE TOUGHNESS RESULTS FOR

ALCOA CW67 EXTRUSION

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MCAIR	S-L	33.0		VALID
	AVERAGE	33.0		
	STANDARD DEVIATION	0.0		

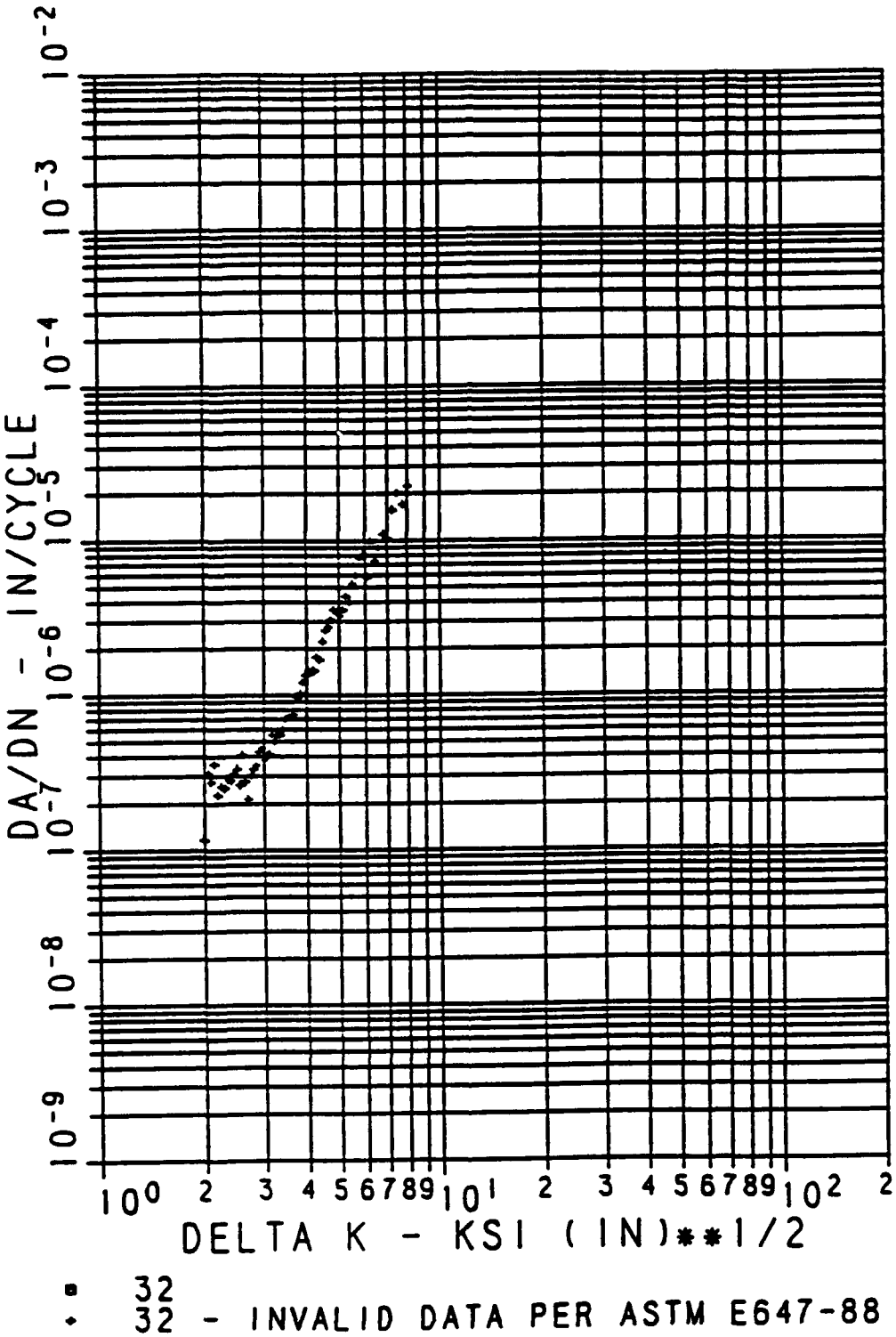


FIGURE R1. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion (L-T Orientation, R=0.1, Lab Air and Room Temperature). McDonnell Aircraft Company.

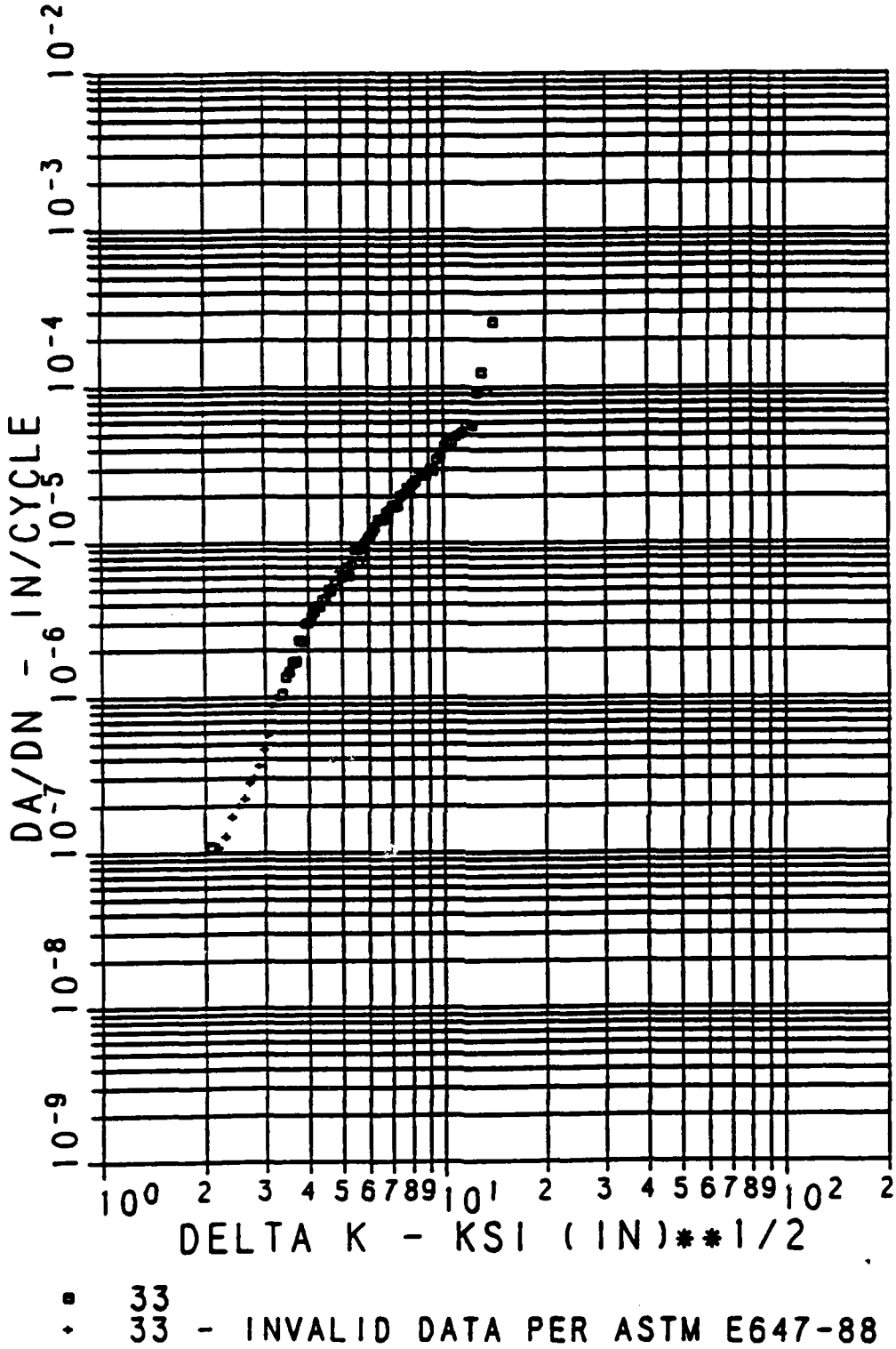
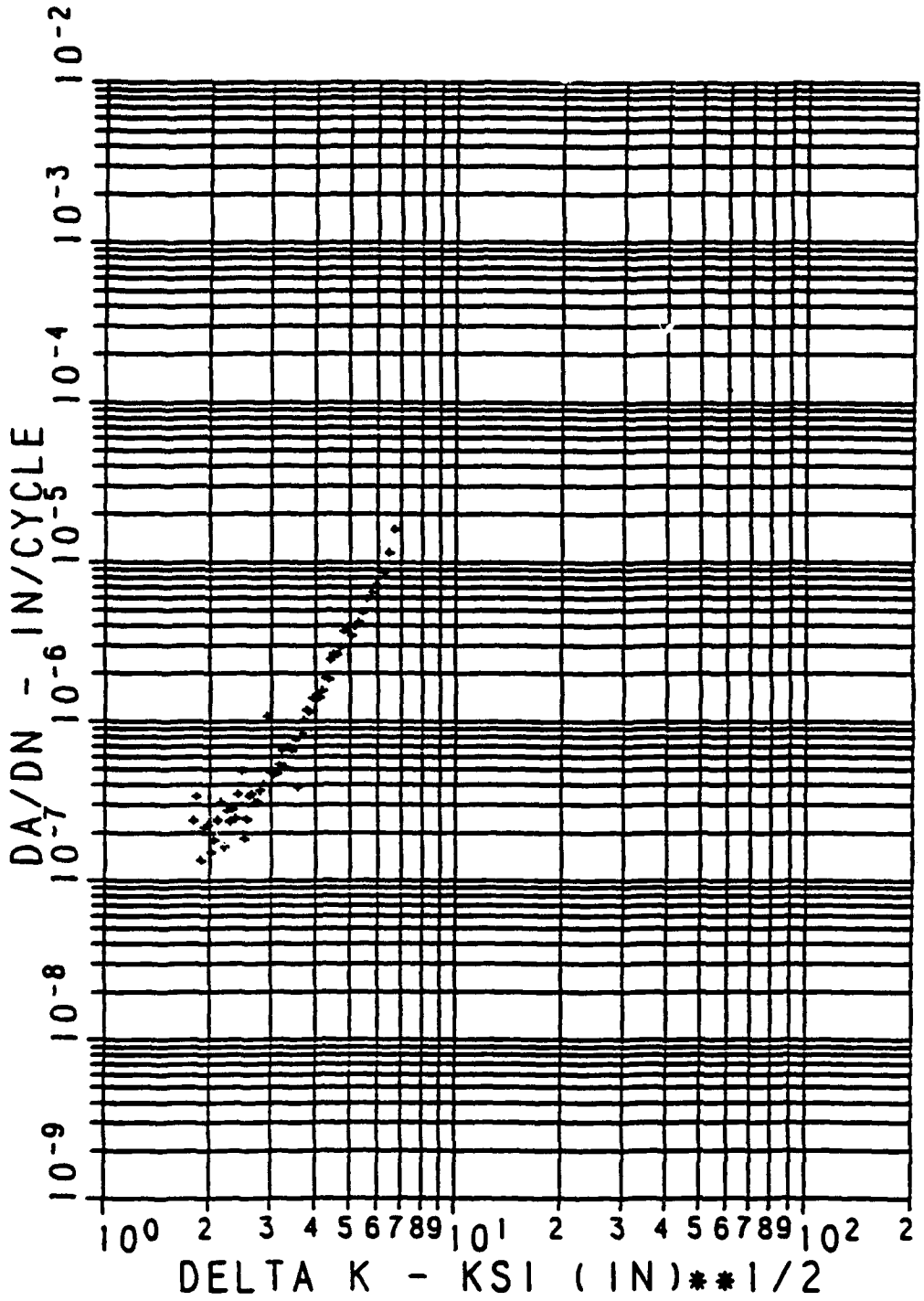


FIGURE R2. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion (L-T Orientation, R=0.33, Lab Air and Room Temperature). McDonnell Aircraft Company.



■ 34
◆ 34 - INVALID DATA PER ASTM E647-88

FIGURE R3. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion (T-L Orientation, R=0.1, Lab Air and Room Temperature). McDonnell Aircraft Company.

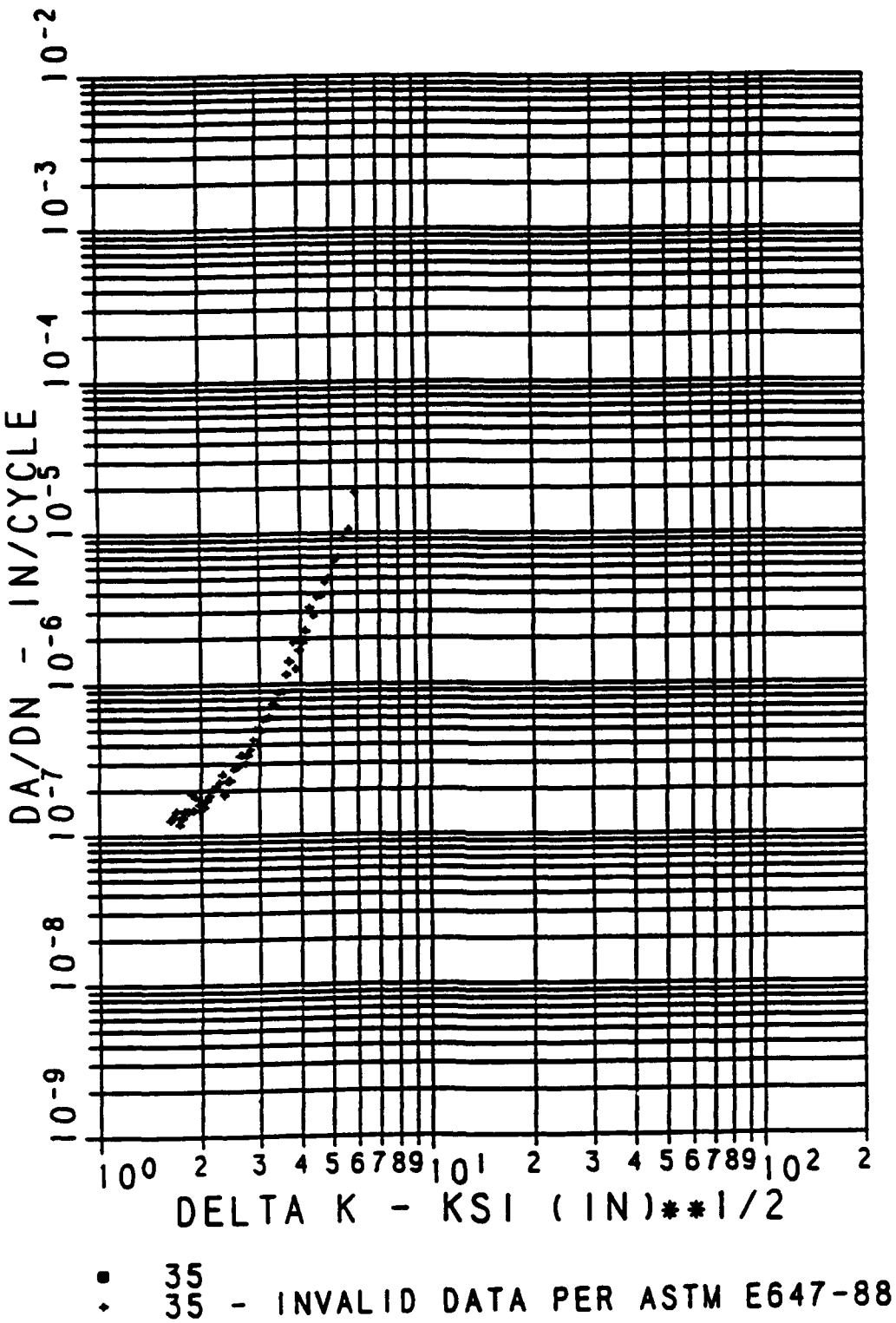


FIGURE R4. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion (T-L Orientation, R=0.33, Lab Air and Room Temperature). McDonnell Aircraft Company.

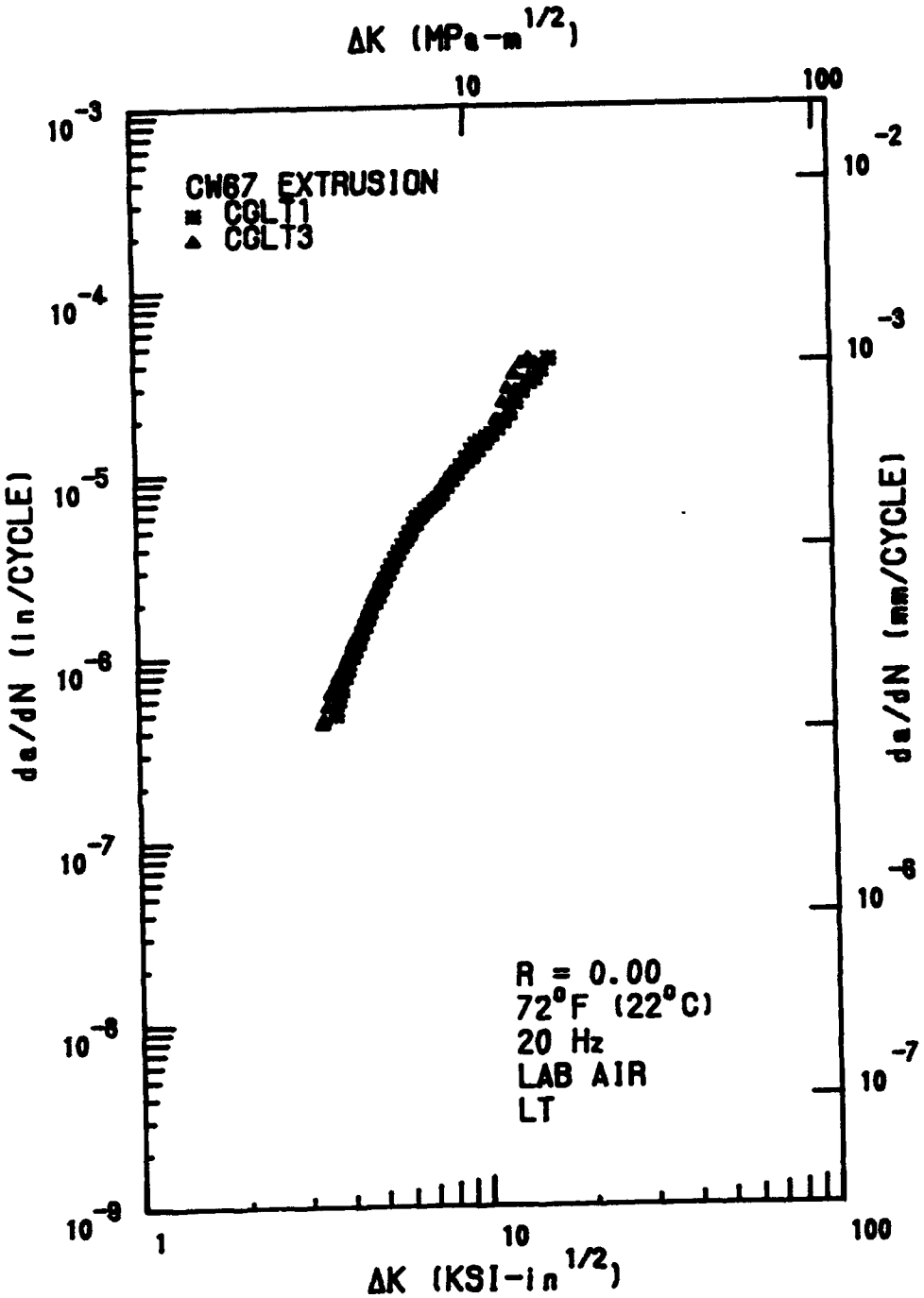


FIGURE R5. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion (L-T Orientation).
Air Force.

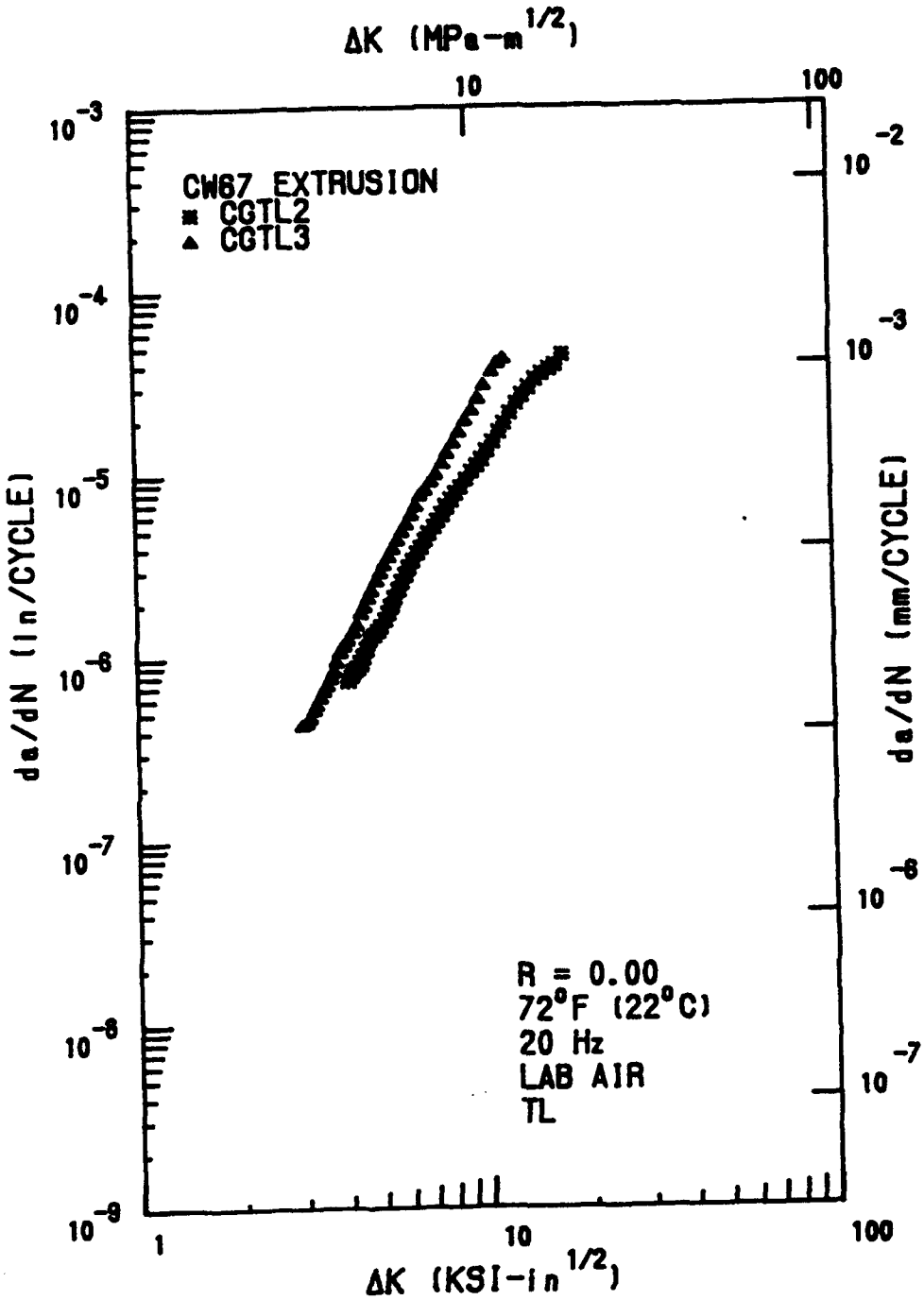


FIGURE R6. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion (T-L Orientation).
Air Force.

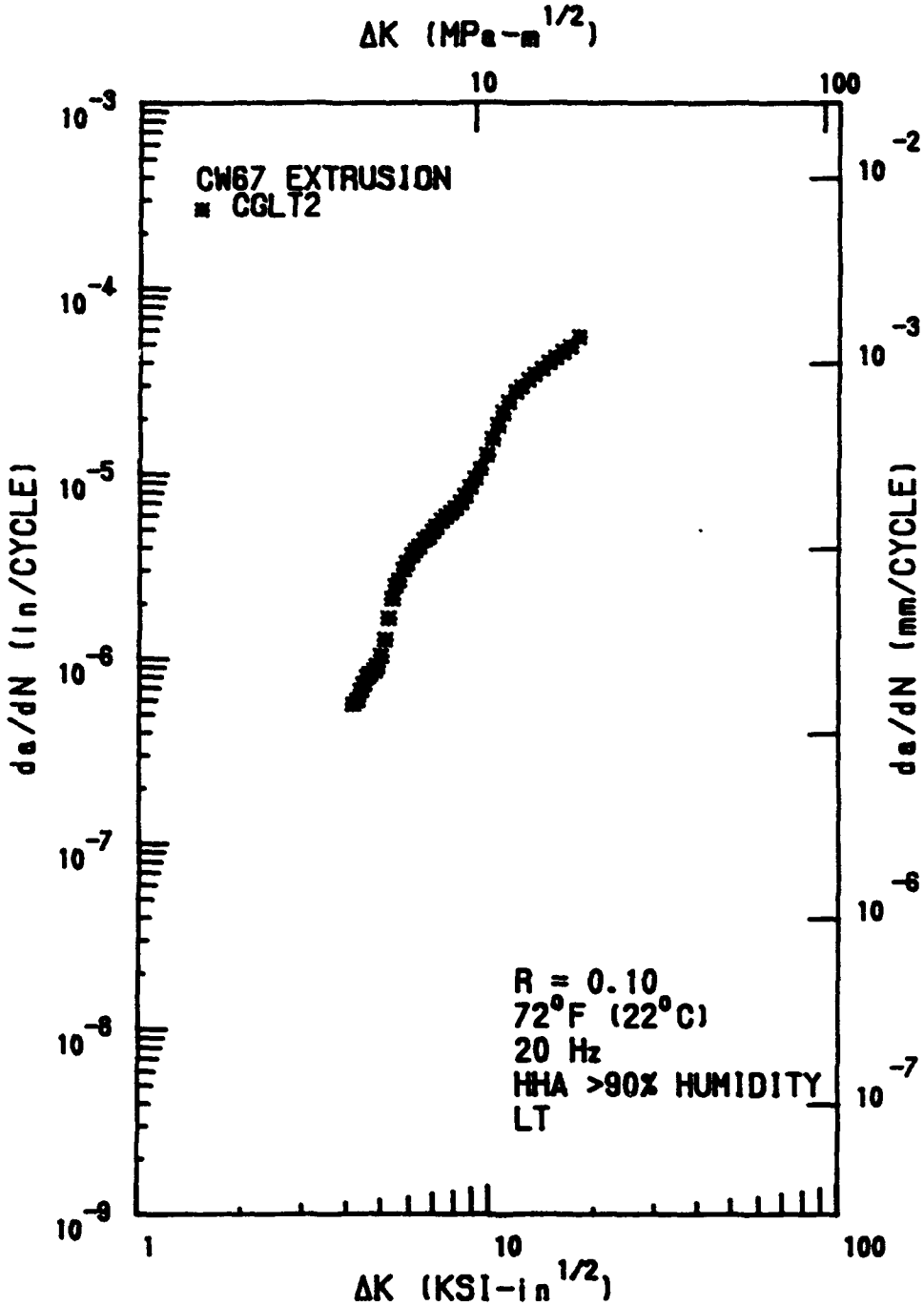


FIGURE R7. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion (L-T Orientation and High Humidity). Air Force.

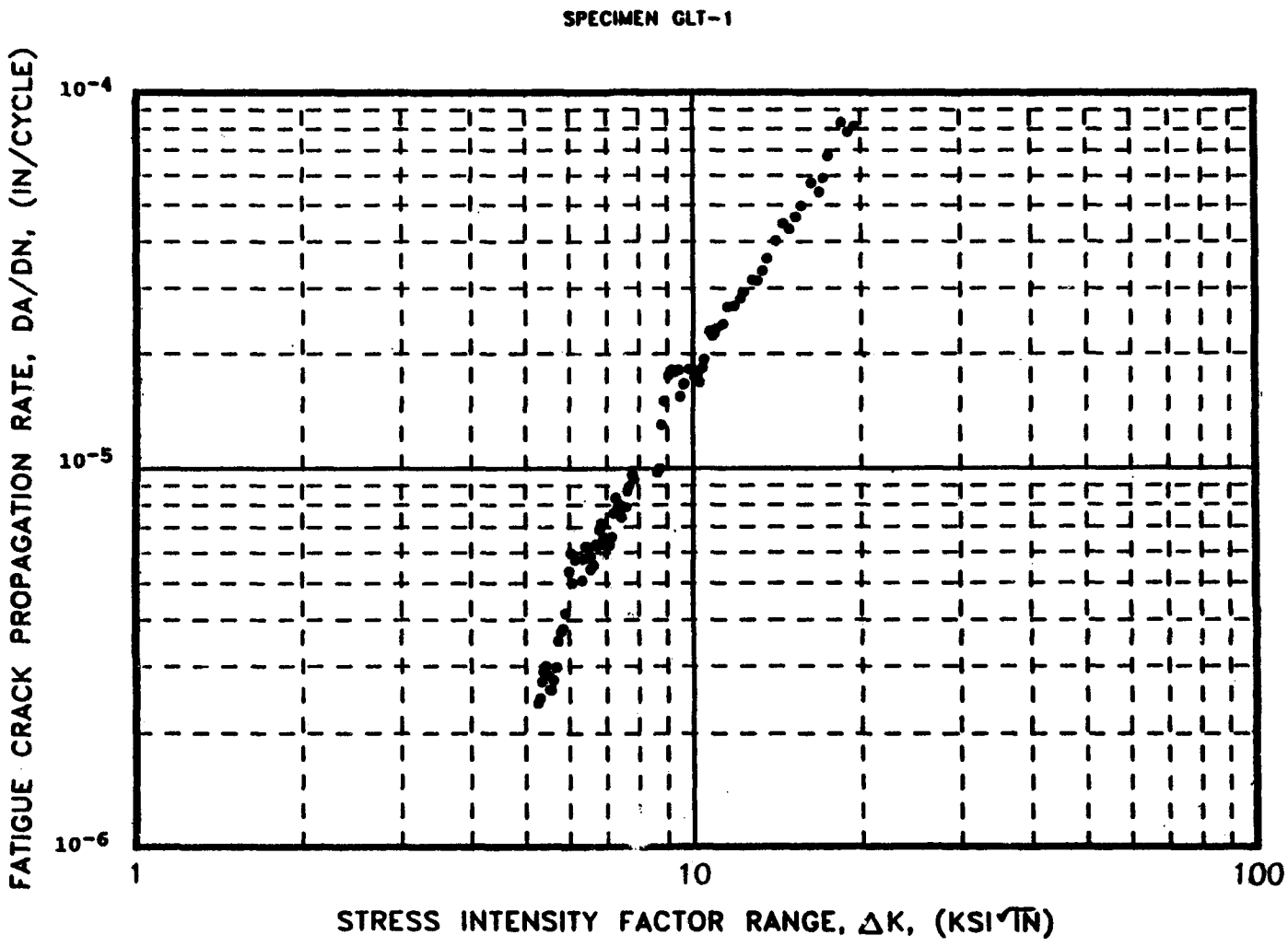


FIGURE R8. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion. (L-T Orientation, Specimen GLT-1). LTV.

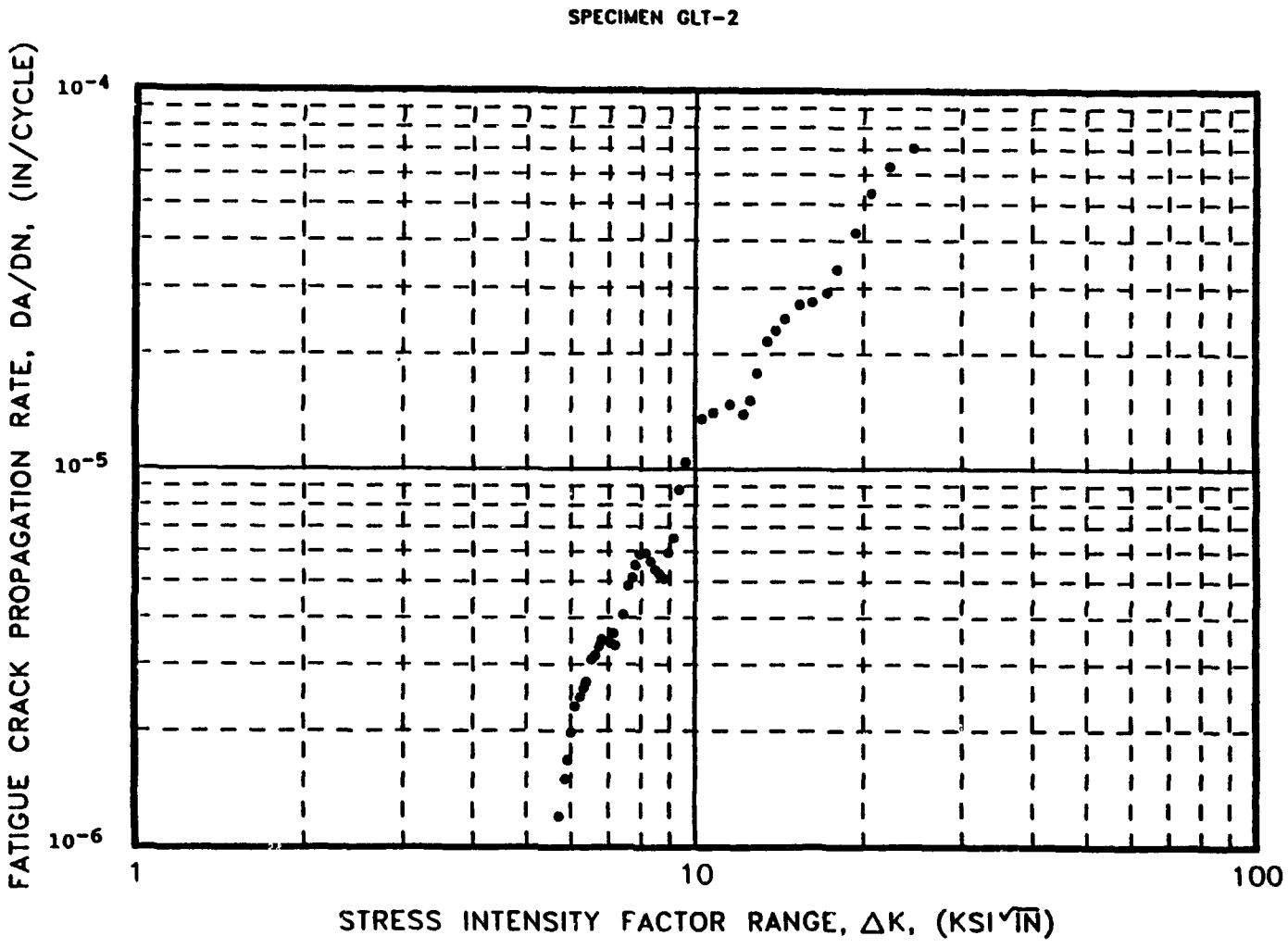


FIGURE R9. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion. (L-T Orientation, Specimen GLT-2). LTV.

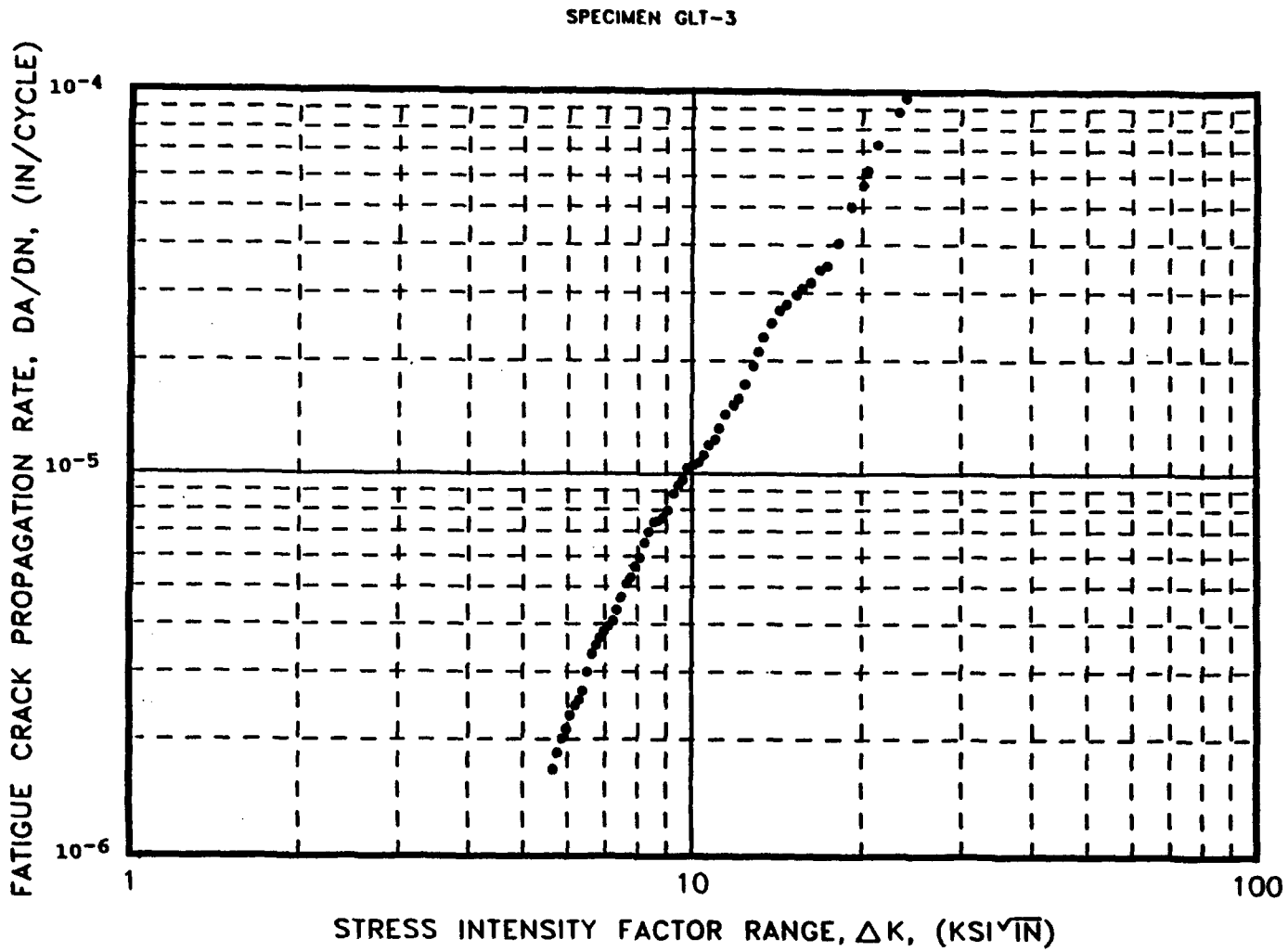


FIGURE R10. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrution. (L-T Orientation, Specimen GLT-3). LTV.

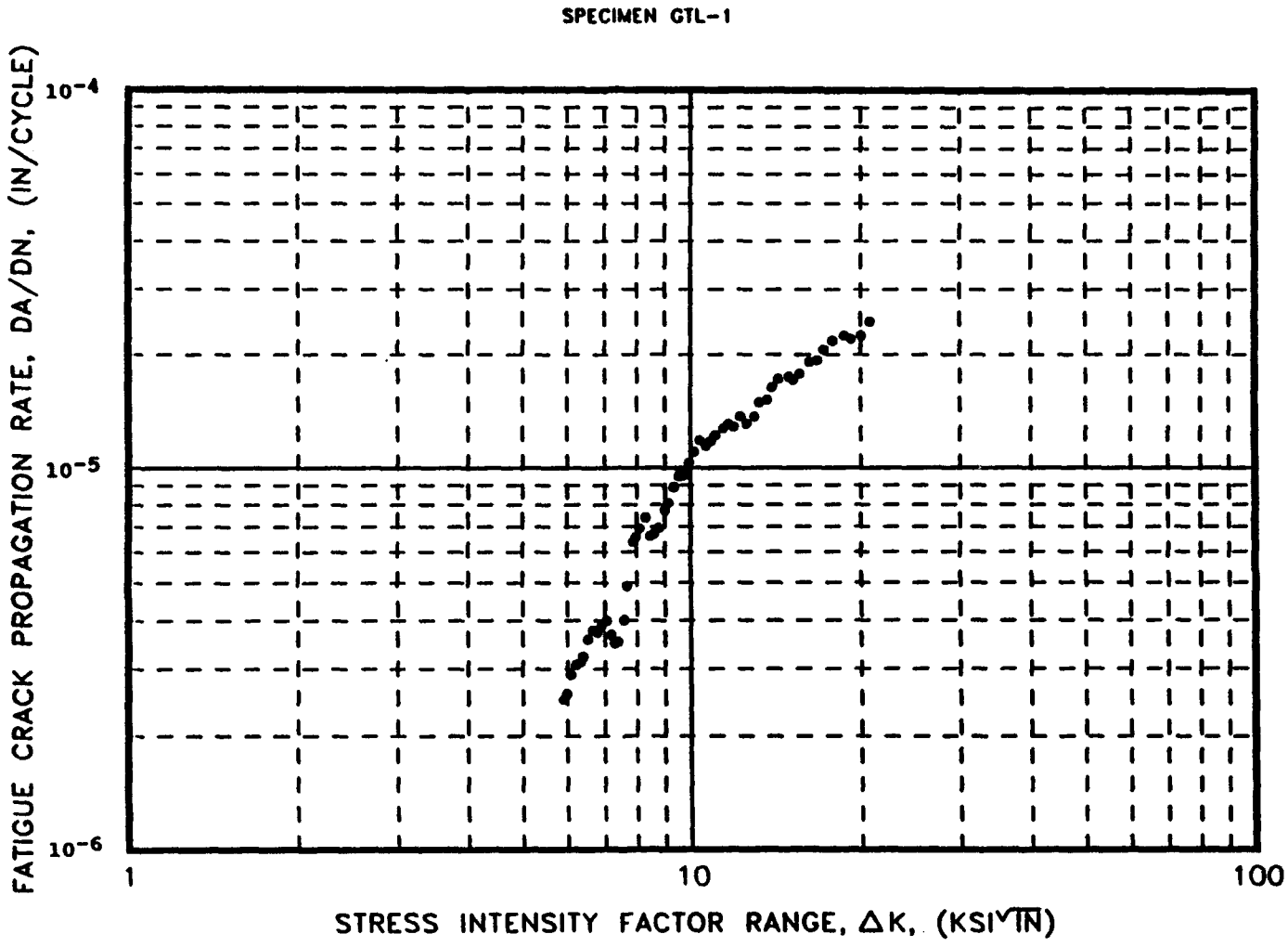


FIGURE R11. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion. (T-L Orientation, Specimen GLT-1). LTV.

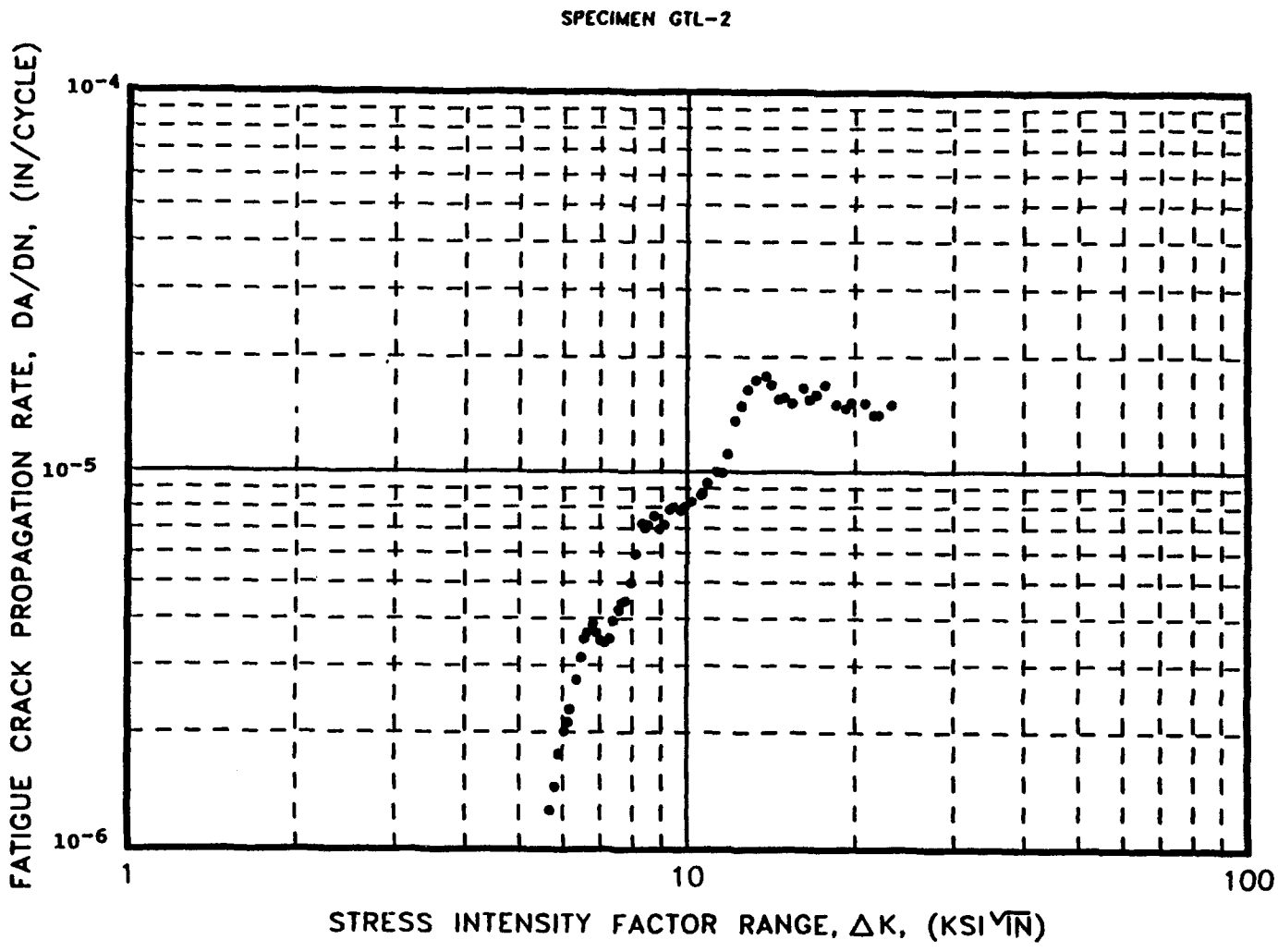


FIGURE R12. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion. (T-L Orientation, Specimen GLT-2). LTV.

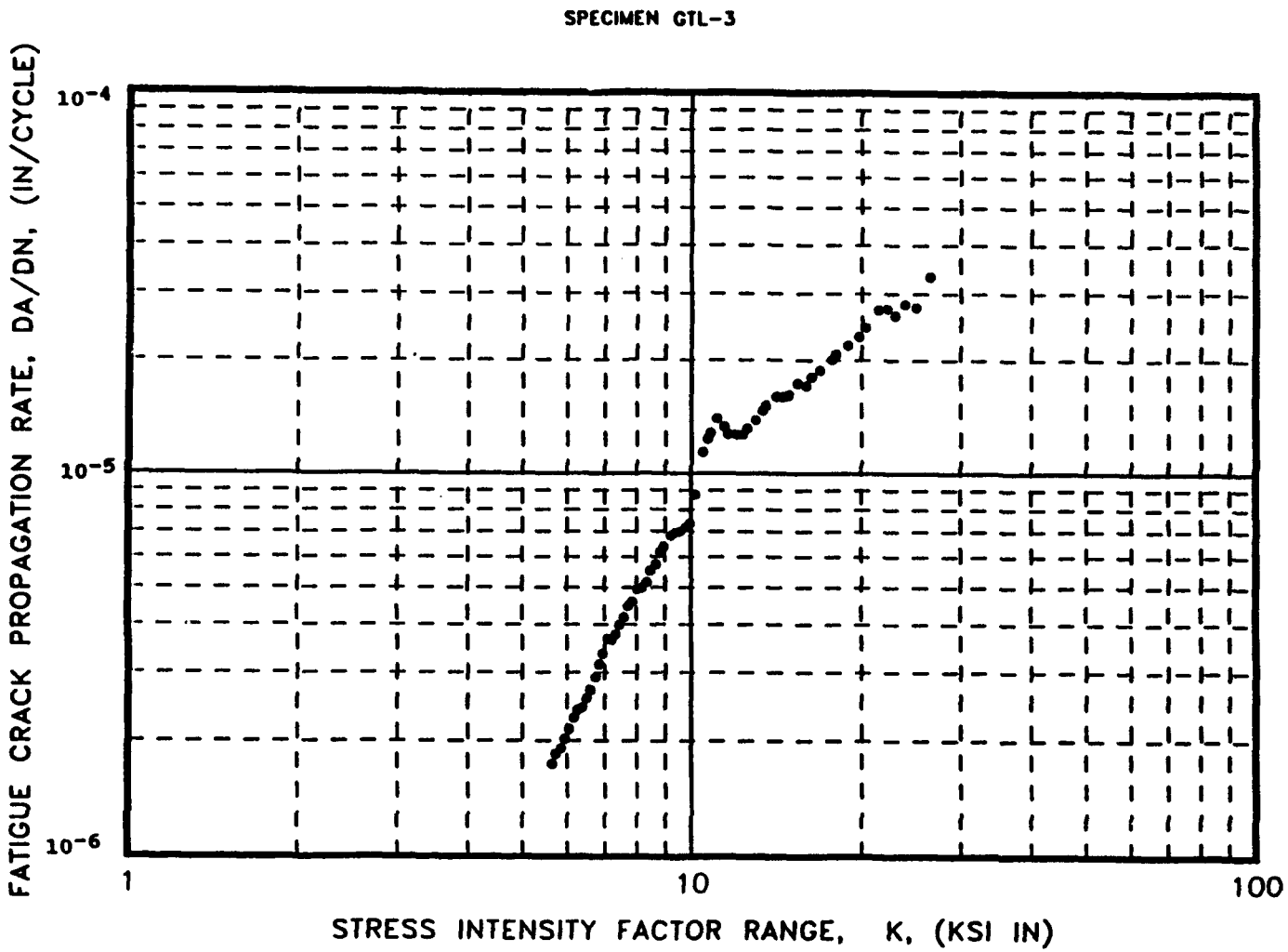


FIGURE R13. FATIGUE CRACK GROWTH RATE DATA for CW67 Extrusion. (T-L Orientation, Specimen GLT-3). LTV.

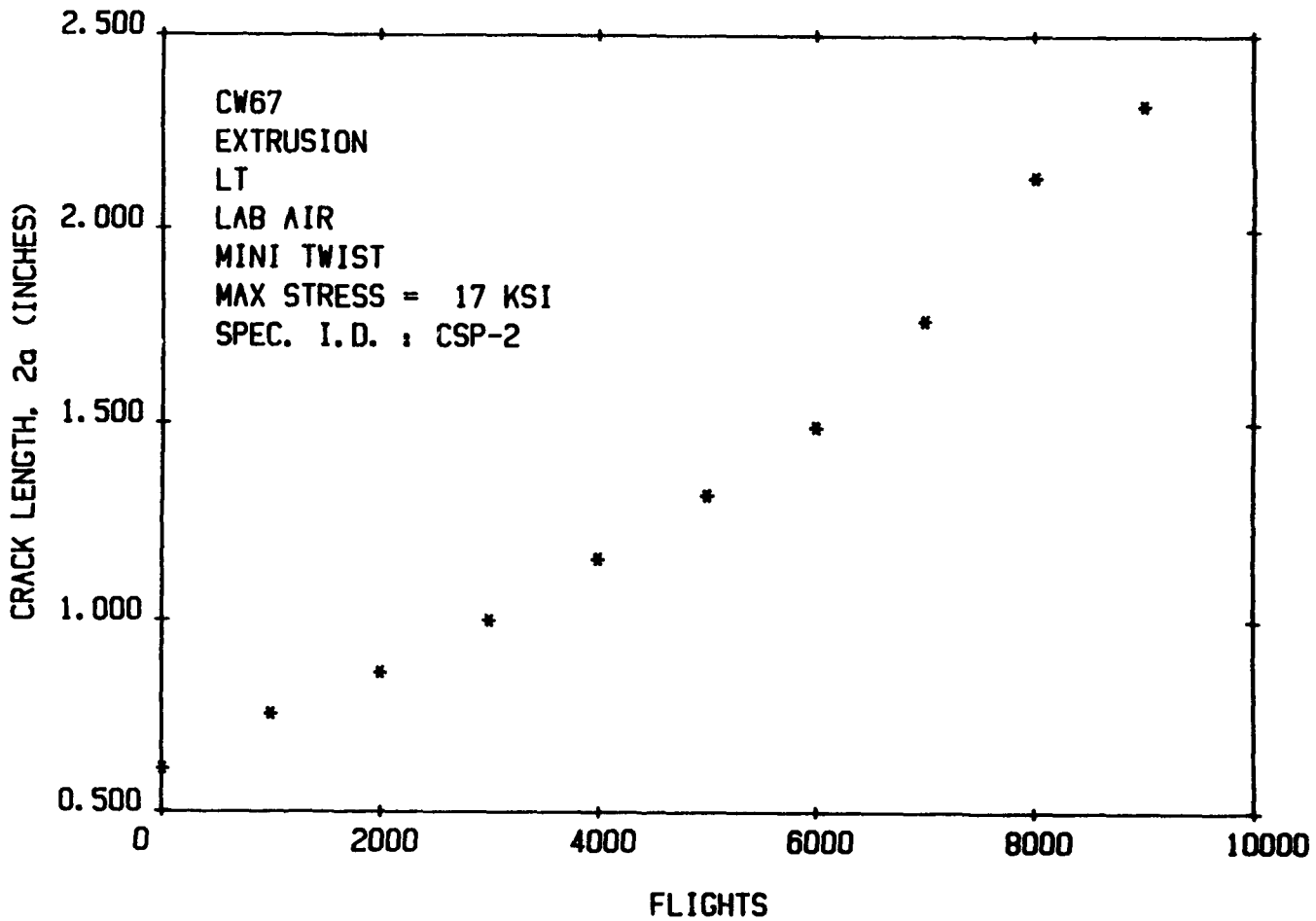


FIGURE R14. Mini-TWIST Spectrum Fatigue Cracklength vs Flights Data for CW67 Extrusion. Air Force.

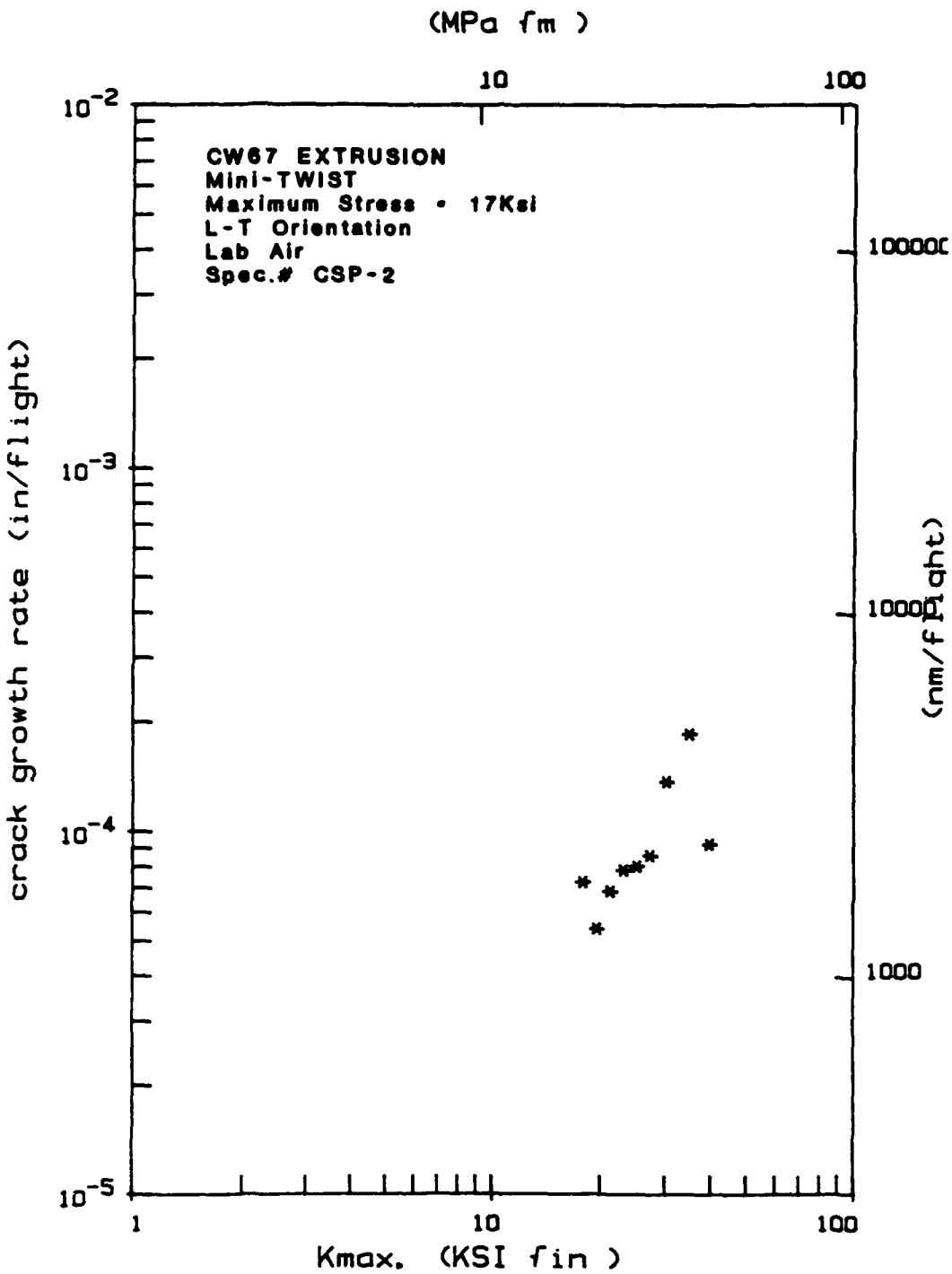


FIGURE R15. Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for CW67 Extrusion.
Air Force.

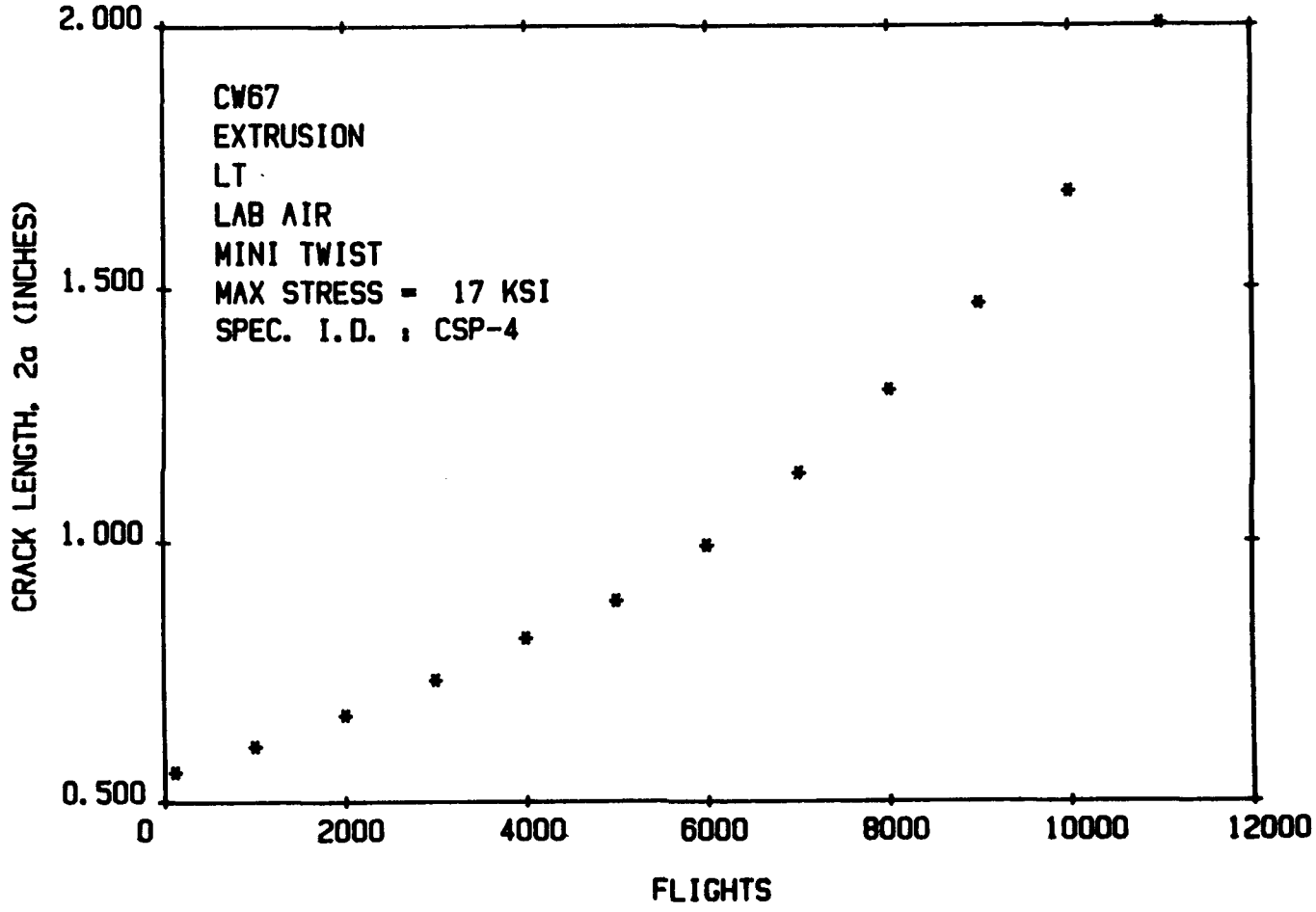


FIGURE R16. Mini-TWIST Spectrum Fatigue Crack Length vs Flights Data for CW67 Extrusion. Air Force.

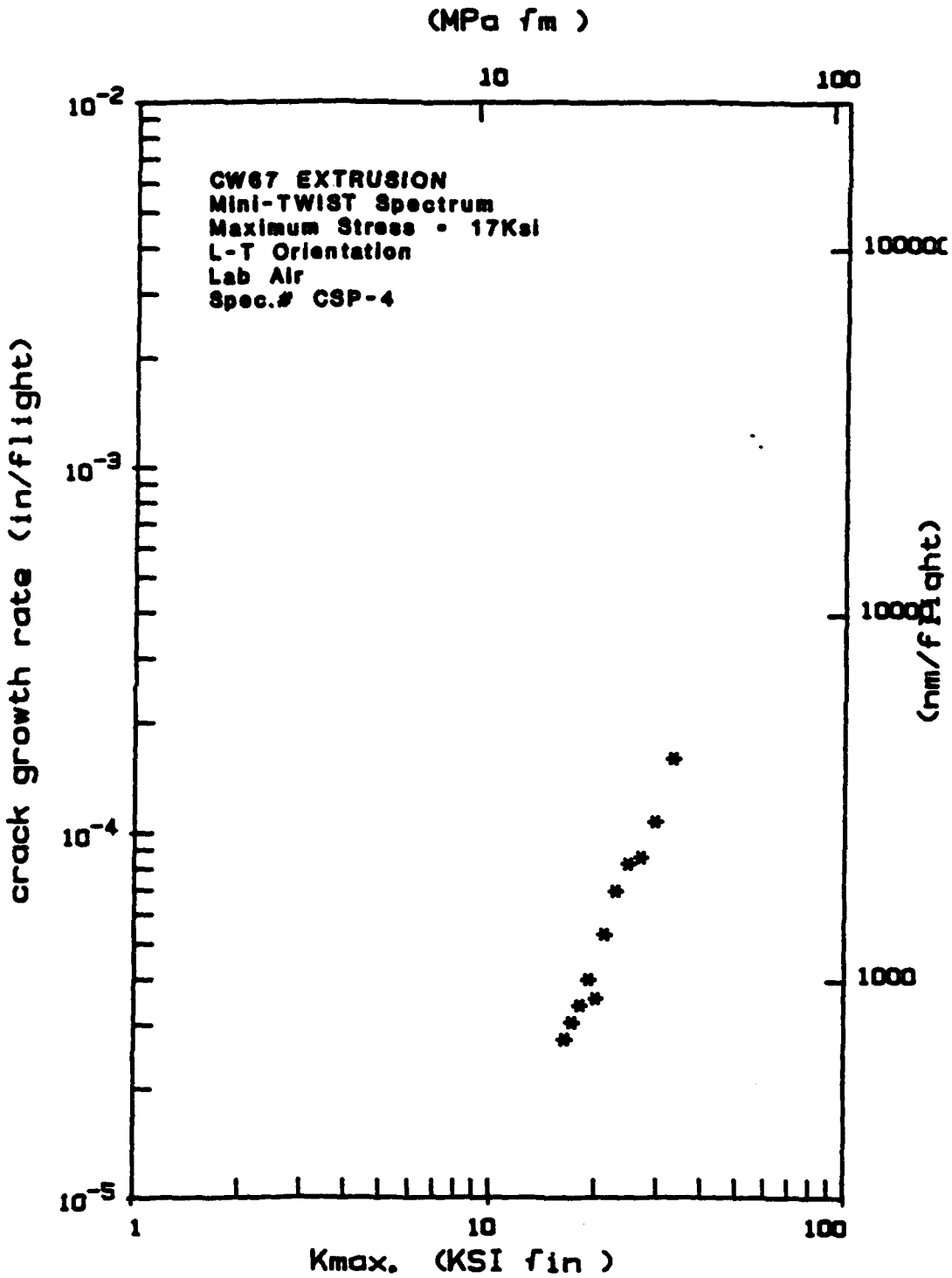


FIGURE R17. Mini-TWIST Spectrum Fatigue Crack Growth Rate Data for CW67 Extrusion.
Air Force.

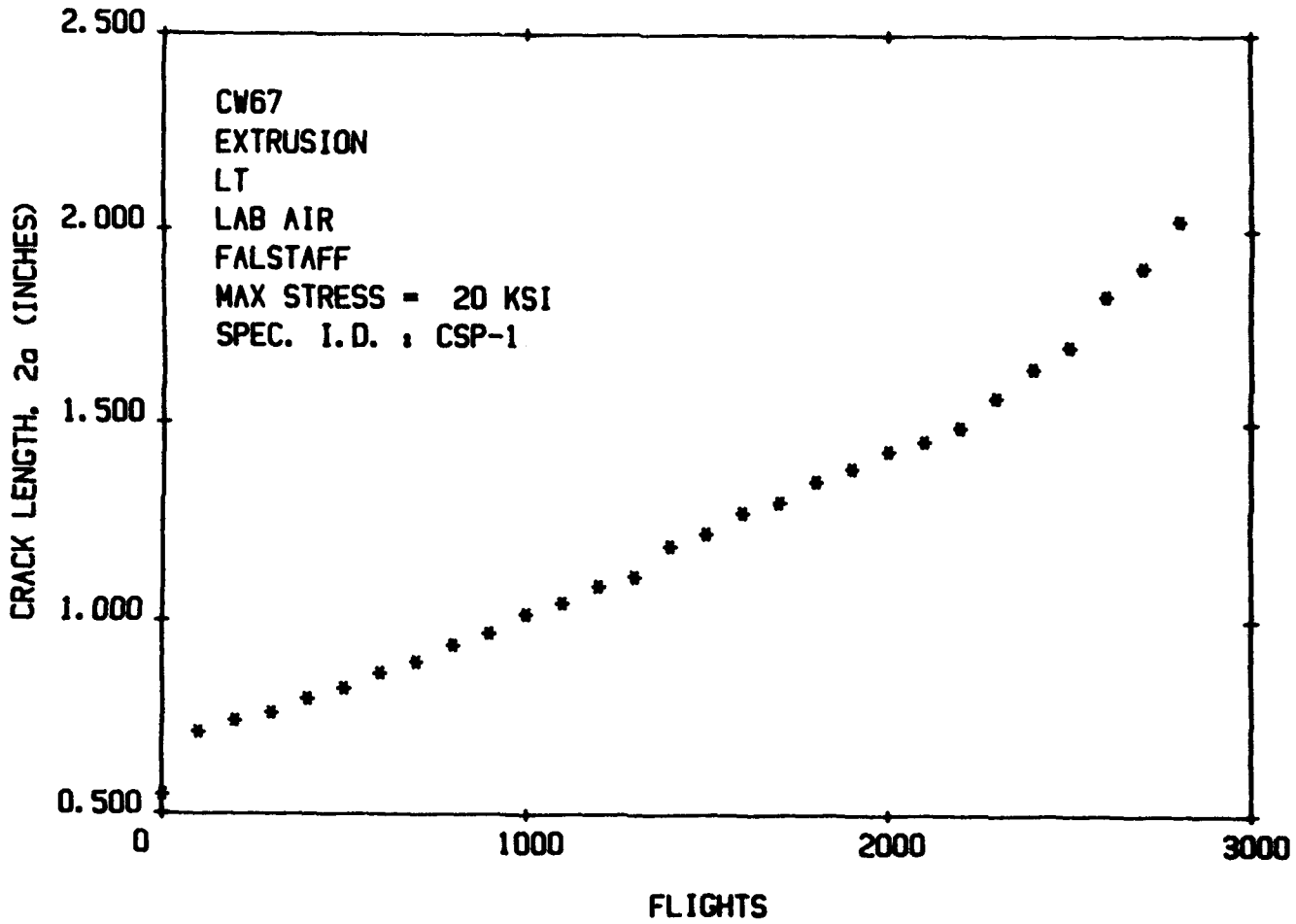


FIGURE R18. FALSTAFF Spectrum Fatigue Crack Length vs Flights. Air Force.

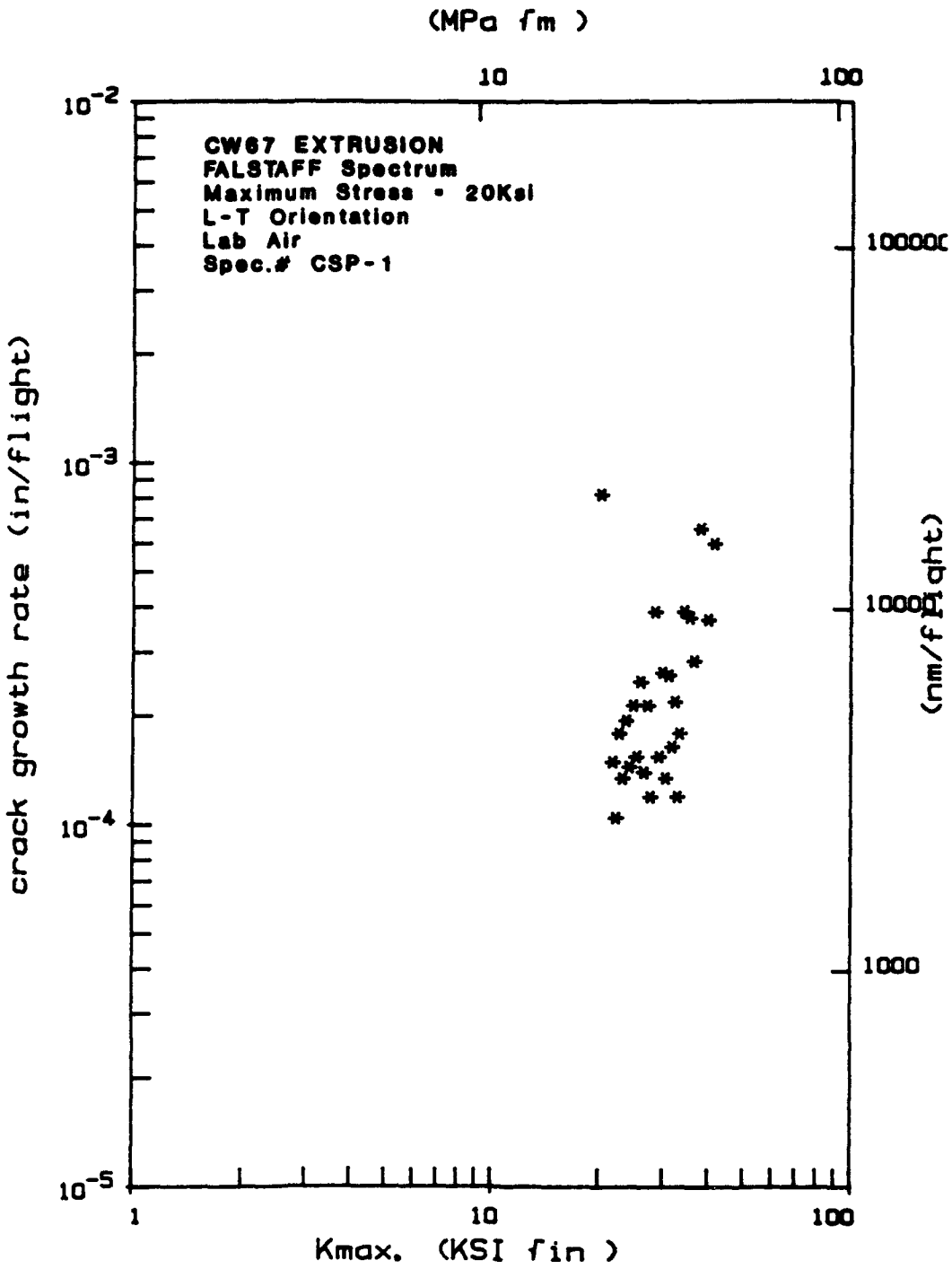


FIGURE R19. FALSTAFF Spectrum Fatigue Crack Growth Rate Data for CW67 Extrusion.
Air Force.

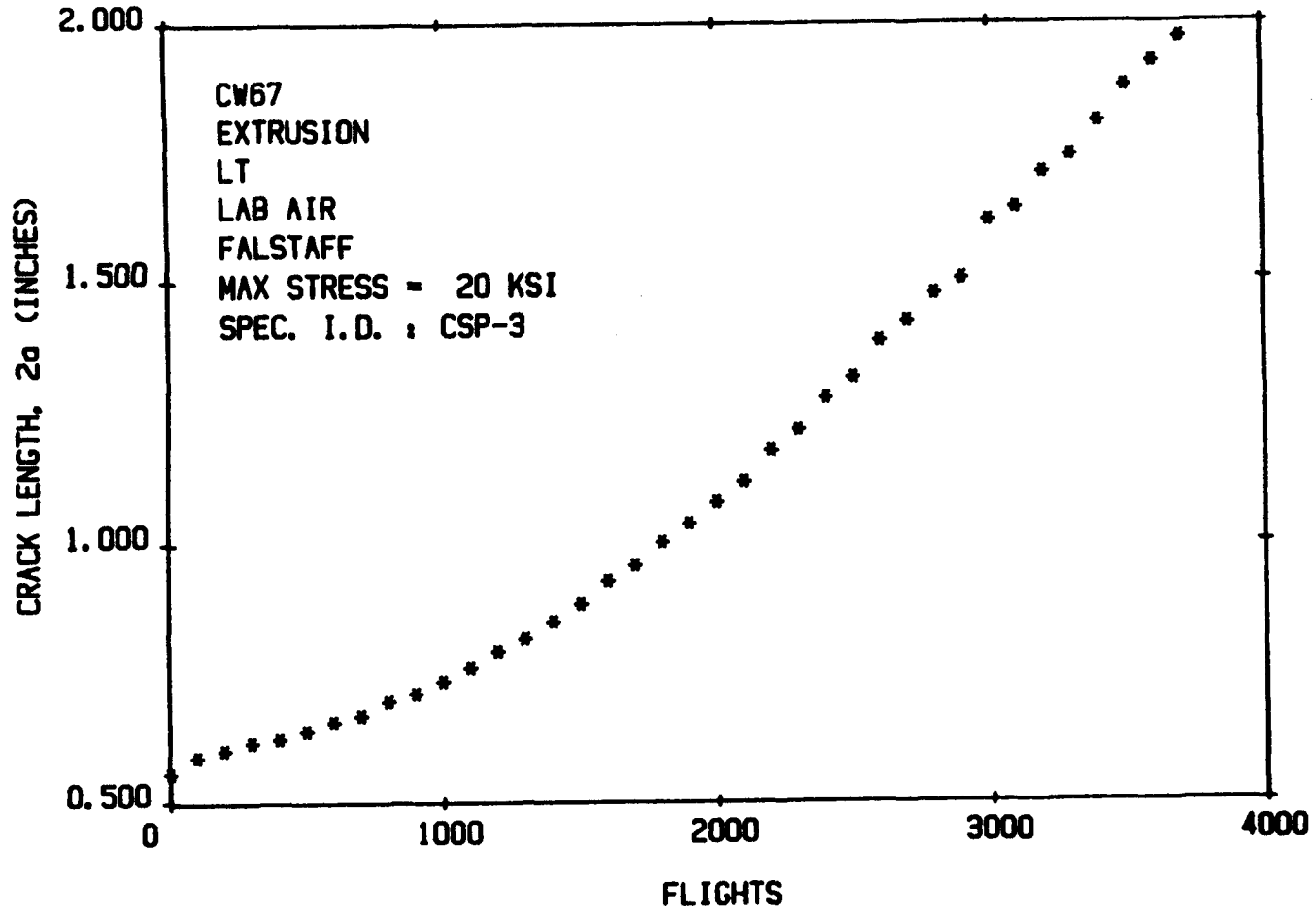


FIGURE R20. FALSTAFF Spectrum Fatigue Crack Length vs Flights. Air Force.

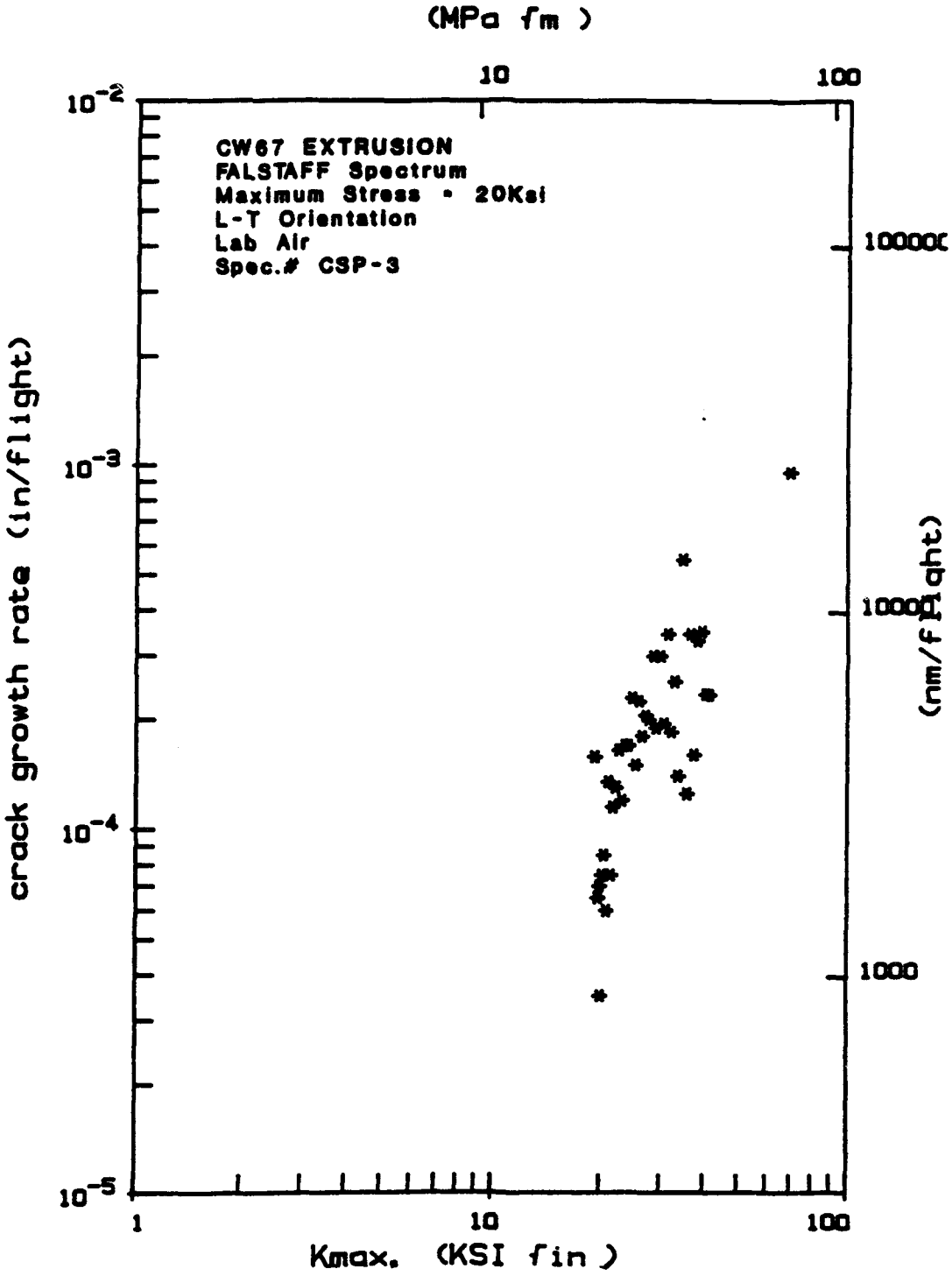


FIGURE R21. FALSTAFF Spectrum Fatigue Crack Growth Rate Data for CW67 Extrusion.
Air Force.

APPENDIX S

CW67 HAND FORGING
2.5"X6"X18"

INTRODUCTION

The Alcoa P/M aluminum alloy CW67 2.5"X6"X18" hand forgings were received October 1988. Martin Marietta and the Air Force tested the CW67 forging.

TESTING

Mechanical properties (tension, compression, shear, bearing and fracture toughness), and constant amplitude fatigue crack growth tests were generated according to ASTM standards, unless otherwise specified.

Spectrum fatigue crack growth rate tests were performed by the Air Force using FALSTAFF (a severe fatigue environment) and Mini-TWIST (a moderately intense fatigue environment) spectrums.

TABLE S1

TENSILE RESULTS FOR

ALCOA CW67 FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN MARIETTA, LOUISIANA	RT	LONG	87.2	84.0	13.0	29.6	
			83.1	75.9	15.0	39.7	
			85.0	82.5	14.0	27.6	
AIR FORCE	RT	LONG	88.0	83.6	13.0	39.7	
			82.2	78.6	13.8	47.9	
			85.4	80.7	12.7	34.5	
			84.6	80.1	12.1	46.9	
		AVERAGE	85.1	80.8	13.4	38.0	
	STANDARD DEVIATION		2.1	2.9	1.0	7.9	

TABLE S2

TENSILE RESULTS FOR

ALCOA CW67 FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	79.1	73.4	12.0	17.6	
			78.8	73.0	14.0	25.5	
			79.4	74.0	17.0	42.5	
AIR FORCE	RT	L TRANS	82.4	77.2	13.9	40.1	
			83.0	77.0	10.2	25.3	
			83.2	77.2	13.5	38.9	
			82.3	75.4	13.0	32.6	
		AVERAGE	81.2	75.3	13.4	31.8	
	STANDARD DEVIATION		2.0	1.9	2.1	9.3	

TABLE S3

TENSILE RESULTS FOR

ALCOA CW67 FORGING

COMPANY	TEST TEMP (DEGREES F)	ORIENT-ATION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONG (%)	RA (%)	E (MSI)
MARTIN	RT	S TRANS	78.7	72.4	12.0	32.7	
MARIETTA,			77.9	71.5	11.0	32.7	
LOUISIANA			77.5	70.8	14.0	36.0	
AIR FORCE	RT	S TRANS	85.7	79.3	6.8	18.1	
			43.8	43.8	9.1	23.1	
		AVERAGE	72.7	67.6	10.6	28.5	
	STANDARD DEVIATION		16.5	13.7	2.7	7.6	

TABLE S4

COMPRESSION RESULTS FOR

ALCOA CW67 FORGING

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MARTIN MARIETTA, LOUISIANA	RT	LONG	82.9	10.6
			81.9	10.6
			81.4	10.6
AIR FORCE	RT	LONG	81.0	
			79.4	
			77.3	
			76.4	
		AVERAGE	80.0	10.6
		STANDARD DEVIATION	2.4	0.0

TABLE S5

COMPRESSION RESULTS FOR

ALCOA CW67 FORGING

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MARTIN MARIETTA, LOUISIANA	RT	L TRANS	78.6	10.8
			78.8	11.0
			79.6	11.0
AIR FORCE	RT	L TRANS	81.6	
			82.5	
			81.5	
			80.0	
		AVERAGE	80.4	10.9
		STANDARD DEVIATION	1.5	0.1

TABLE S6

COMPRESSION RESULTS FOR

ALCOA CW67 FORGING

COMPANY	TEST TEMPERATURE (DEGREES F)	ORIENTATION	COMPRESSIVE YIELD STRENGTH (KSI)	COMPRESSIVE MODULUS (MSI)
MARTIN	RT	S TRANS	80.1	10.7
MARIETTA,			82.1	10.8
LOUISIANA			80.2	10.8
		AVERAGE	80.8	10.8
		STANDARD DEVIATION	1.1	0.1

TABLE S7

PIN SHEAR RESULTS FOR

ALCOA CW67 FORGING

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
AIR FORCE	LONG	50.0
		50.1
		50.2
		49.8
	AVERAGE	50.0
	STANDARD DEVIATION	0.2

TABLE S8

PIN SHEAR RESULTS FOR

ALCOA CW67 FORGING

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
AIR FORCE	L TRANS	49.2
		49.8
		49.5
		49.7
	AVERAGE	49.5
	STANDARD DEVIATION	0.3

TABLE S9

BEARING RESULTS FOR

ALCOA CW67 FORGING

COMPANY	ORIENTATION	e/D	BEARING ULT. STRENGTH (KSI)	BEARING YIELD STRENGTH (KSI)
AIR FORCE	LONG	1.5	137.9	122.3
			137.3	118.8
			131.2	118.9
		AVERAGE	135.5	120.0
	STANDARD DEVIATION		3.7	2.0
	L TRANS	1.5	136.0	123.0
			137.4	130.5
			132.4	128.2
		AVERAGE	135.2	127.2
	STANDARD DEVIATION		2.6	3.8
	LONG	2.0	165.5	118.0
			164.9	77.8
			162.7	104.1
		AVERAGE	164.3	100.0
	STANDARD DEVIATION		1.5	20.5
	L TRANS	2.0	166.4	103.1
			168.1	117.5
			162.1	99.9
		AVERAGE	165.5	106.8
	STANDARD DEVIATION		3.1	9.4

TABLE S10

FRACTURE TOUGHNESS RESULTS FOR

ALCOA CW67 FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MARTIN MARIETTA, LOUISIANA	L - T	44.8		VALID
			35.9	INVALID(1)
AIR FORCE	L - T		28.8	INVALID(2)
			34.4	INVALID(2)
	AVERAGE	44.8	33.0	
	STANDARD DEVIATION	0.0	3.8	

(1): a/W > 0.55
(2): EXCESSIVE CRACK FRONT CURVATURE

TABLE S11

FRACTURE TOUGHNESS RESULTS FOR

ALCOA CW67 FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MARTIN MARIETTA, LOUISIANA	L - S		46.7	INVALID(1)
			52.5	INVALID(1)
		38.6		VALID
	AVERAGE	38.6	49.6	
	STANDARD DEVIATION	0.0	4.1	

(1): a/W > 0.55

TABLE S12

FRACTURE TOUGHNESS RESULTS FOR

ALCOA CW67 FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MARTIN MARIETTA, LOUISIANA	T - L	25.0		VALID
		21.6		VALID
AIR FORCE	T - L		21.0	INVALID(1)
			18.6	INVALID(1)
			22.5	INVALID(1)
	AVERAGE	23.3	20.7	
	STANDARD DEVIATION	2.4	2.0	

(1): EXCESSIVE CRACK FRONT CURVATURE

TABLE S13

FRACTURE TOUGHNESS RESULTS FOR

ALCOA CW67 FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
MARTIN MARIETTA, LOUISIANA	T - S	21.3		VALID
			23.5	INVALID(1)
	AVERAGE	21.3	23.5	
	STANDARD DEVIATION	0.0	0.0	

(1): a/W > 0.55

TABLE S14

FRACTURE TOUGHNESS RESULTS FOR

ALCOA CW67 FORGING

COMPANY	ORIENTATION	KIC (KSI in^0.5)	Kq (KSI in^0.5)	COMMENT
AIR FORCE	S - T		20.9	INVALID(1)
			25.3	INVALID(1)
			23.6	INVALID(1)
	AVERAGE		23.3	
	STANDARD DEVIATION		2.2	

(1): EXCESSIVE CRACK FRONT CURVATURE

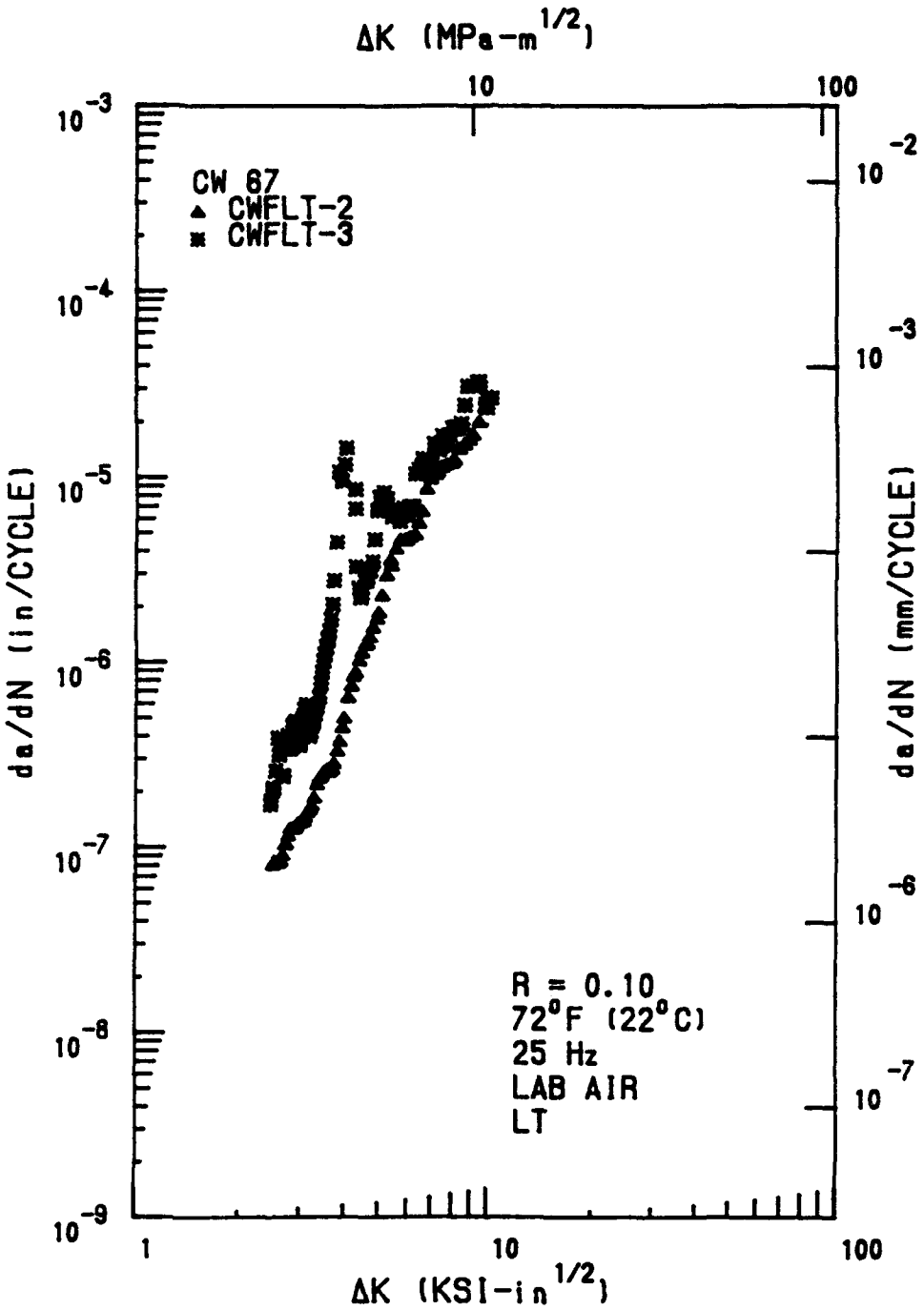


FIGURE S1. Fatigue Crack Growth Rate Data for CW67 Forging (L-T Orientation). Air Force.

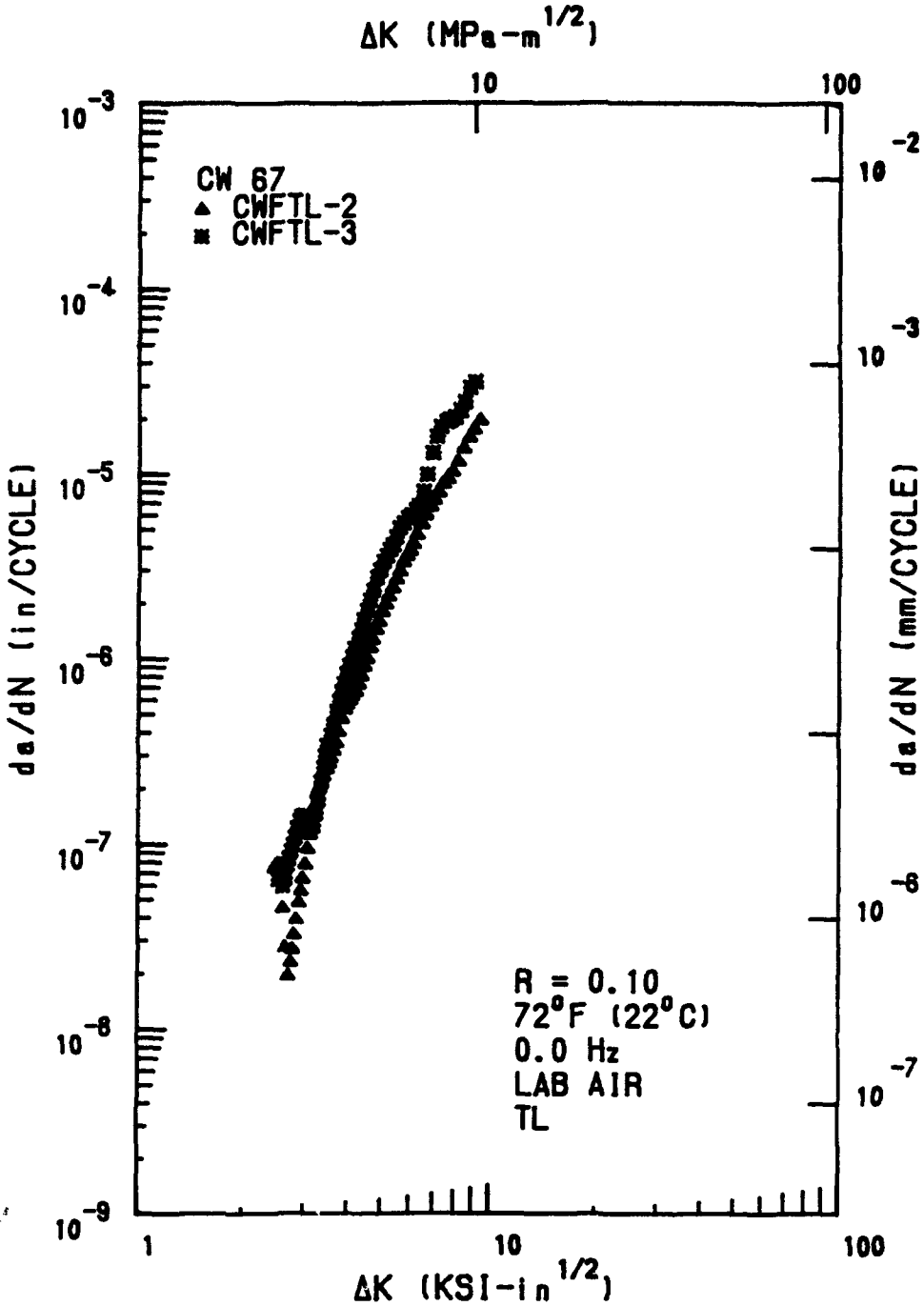


FIGURE S2. Fatigue Crack Growth Rate Data for CW67 Forging (T-L Orientation). Air Force.

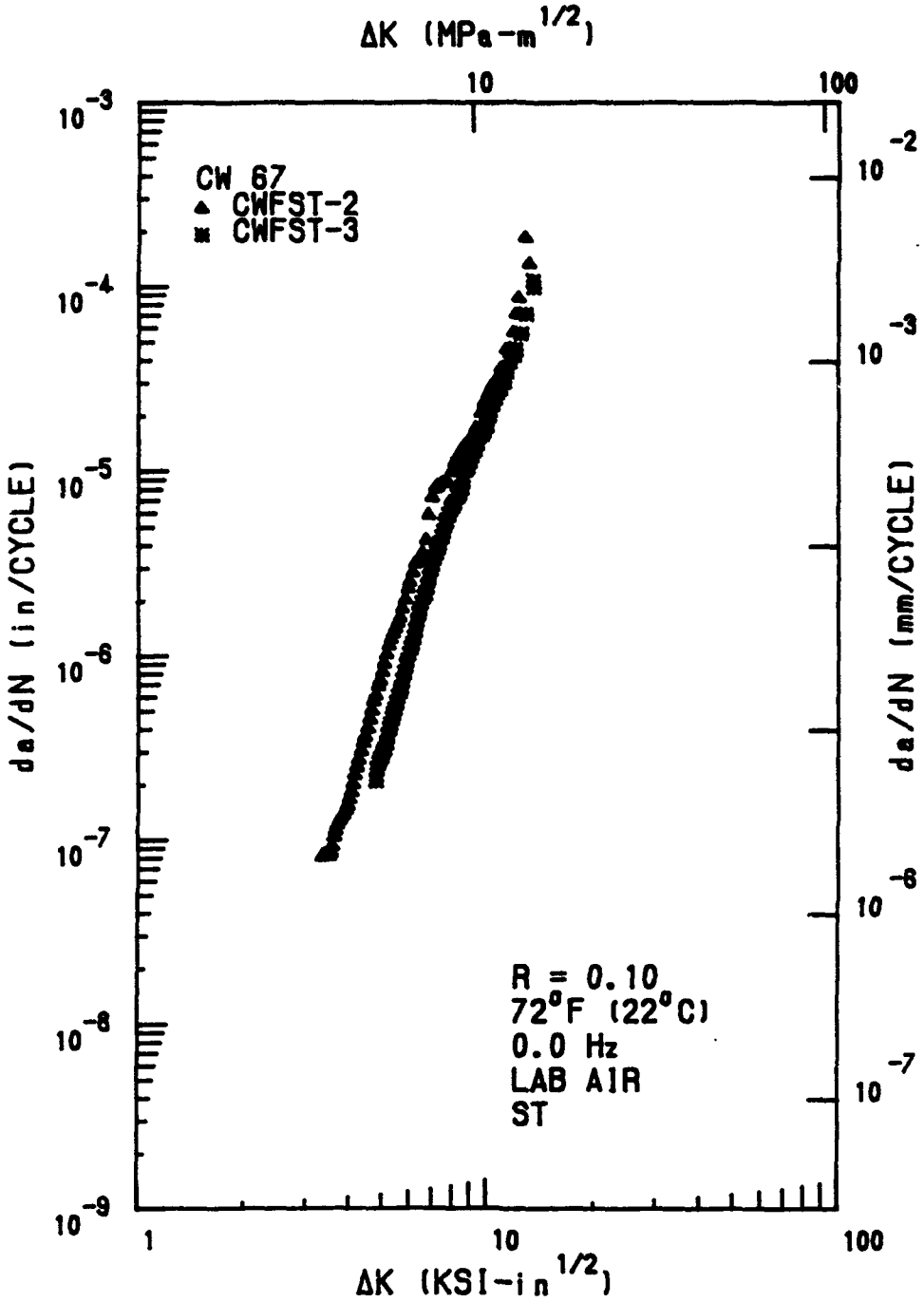


FIGURE S3. Fatigue Crack Growth Rate Data for CW67 Forging (S-T Orientation). Air Force.

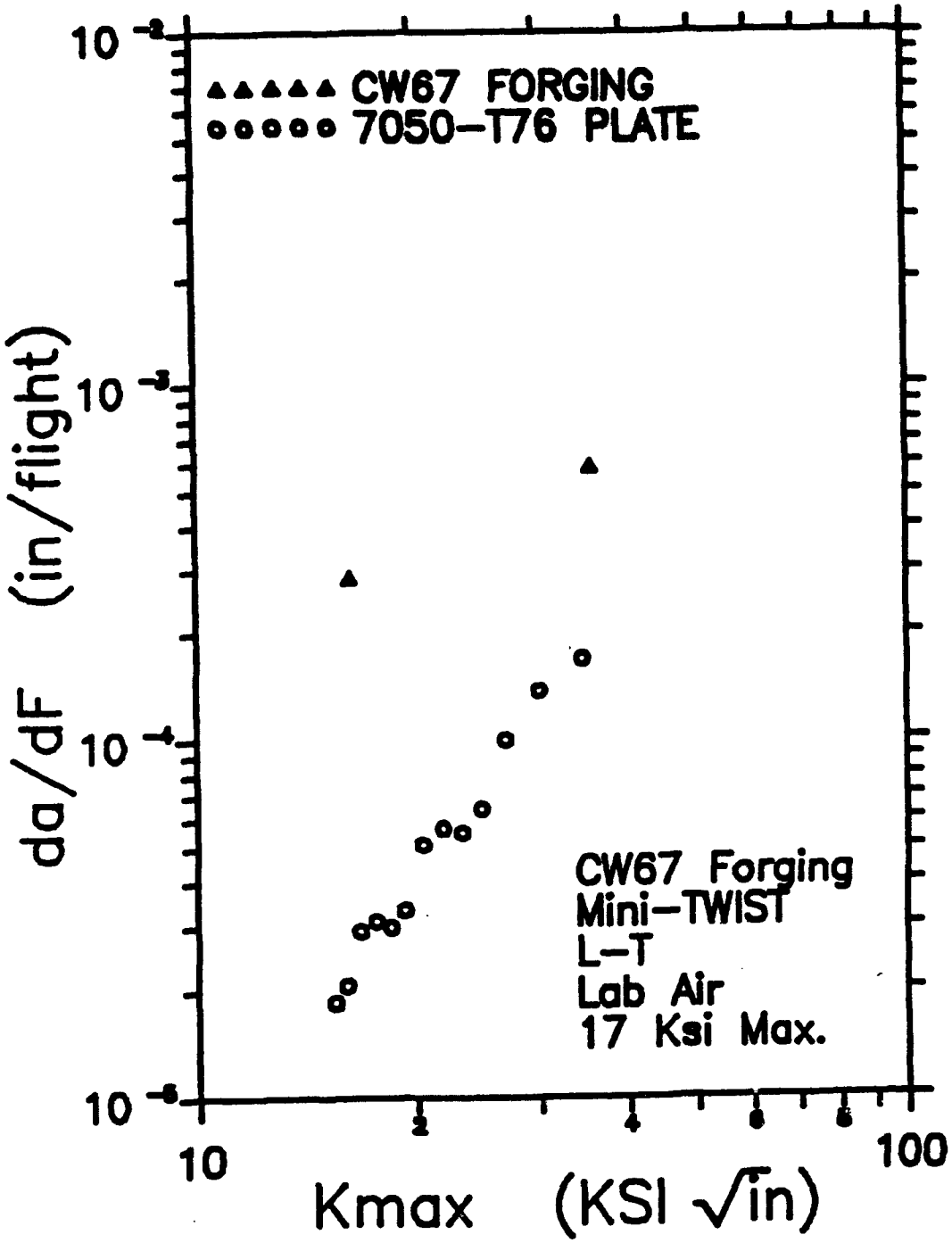


FIGURE S4. Comparison of CW67 Forging and 7050 Plate Mini-TWIST Spectrum Fatigue Crack Growth Rate Data (L-T Orientation). Air Force.

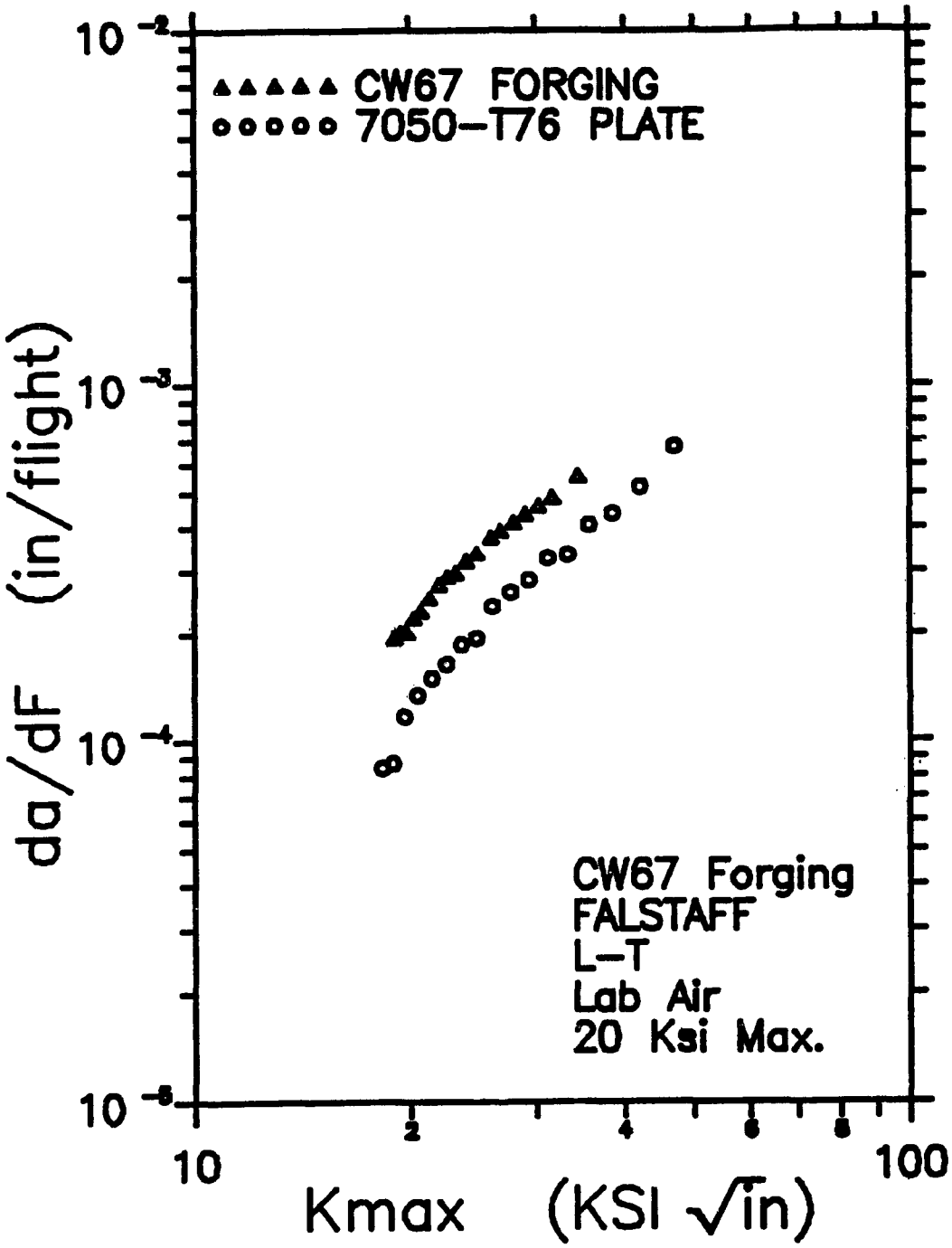


FIGURE S5. Comparison of CW67 Forging and 7050 Plate FALSTAFF Spectrum Fatigue Crack Growth Rate Data (L-T Orientation).
Air Force.

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END