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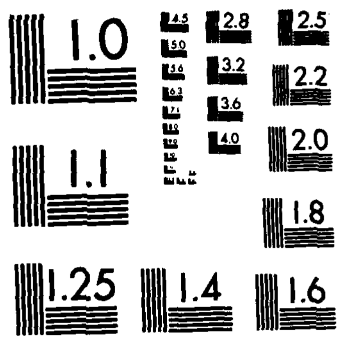

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AFWAL-TR-85-4052

THE MECHANICAL PROPERTY DATA BASE FROM A COOPERATIVE PROGRAM ON FIRST GENERATION PM ALUMINUMS

G.J. PETRAK and MARY ANN MALAS
Materials Engineering Branch
Systems Support Division

August 1985

Final Report for Period June 1982 - August 1984

Approved for public release; distribution unlimited.

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fatigue crack growth	sheet	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Development of a mechanical property data base on first generation P/M structural aluminum alloys is detailed. P/M aluminum alloys tested were 7091 forgings, 7090 forgings, IN9021 forgings, 7091 extrusions, 7090 extrusions, IN9021 extrusions, 7091 plates, 7090 plates, and 7091 sheets. Basic mechanical property data consisted of tension, compression, shear, bearing and fracture toughness. Fatigue data was developed for both smooth and notched specimens.

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Constant amplitude fatigue crack growth rate data were obtained for all materials and spectrum tests were performed on most products. Corrosion characteristics were also obtained. All data developed by the participants are detailed.

PREFACE

This report describes work that was conducted during the period June 1982 to August 1984. The efforts was initiated by the Metals and Ceramics Division of the Materials Laboratory under the leadership of Mr W.M. Griffith who was responsible for organizing and coordinating the cooperative test program. The work herein, which consisted of sorting, compiling, and analyzing mechanical property test data, was performed by the Materials Engineering Branch (AFWAL/MLSE), Systems Support Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories, 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 I
INTRODUCTION

Powder metallurgy processing of materials has been intensively pursued by the aerospace community for about a decade and is motivated by the cost savings and/or improved mechanical properties that can be obtained by this method of producing materials compared to ingot metallurgy technology. High temperature nickel base alloys for gas turbine engines have been routinely produced by P/M (powder metallurgy) methods for a number of years and titanium P/M parts are gaining acceptance. Similarly, aluminum alloy P/M parts are being flown on a limited number of aircraft.

As part of the continued involvement of the Materials Laboratory in the development of P/M technology an effort was initiated in 1981 to develop a database on P/M structural aluminum alloys that were considered to be the first generation products. The effort, which involved many Air Force prime contractors and P/M aluminum supplies, was targeted to have a dual payoff. The first was the development of a broad mechanical property data base which could be used by industry to gain an understanding of the structural applications best suited for these materials. This data base would also shorten the lead time individual companies would need to start designing with the products. The second payoff was that each participating airframer was to use the data base to perform a cost-benefit-analysis to identify those products and classes of alloys that demonstrate greatest potential to increase performance or decrease cost of a system. The analysis was to be used to target specific areas for additional research emphasis.

A kick-off meeting was organized by the Metals and Ceramics Division for the fall of 1981. Mr Walt Griffith of the Materials Laboratory served as facilitator for the meeting and subsequently acted as the focal point for all interaction between government and industry. At the meeting, participants agreed to support the effort by performing mechanical property tests and conducting the cost-benefit-analysis. The tests included basic mechanical properties (tension, compression, etc.) and fatigue related properties (S/N, da/dN). Corrosion testing was left to the individual company as was spectrum fatigue testing. ALCOA volunteered to evaluate the corrosion properties of all materials. A list of participants is shown in Table 1.

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Materials were supplied by ALCOA and Novamet. The resulting mechanical property data from each participant was sent to the Systems Support Division of the Materials Laboratory to be compiled into data bases for each alloy/ product form from which estimates of design allowables were obtained. The complete data base along with the estimated design allowables were supplied to all involved organizations.

This report documents the mechanical property data obtained from the cooperative effort. Comparisons to other materials, and ranking of materials, is generally avoided since each potential application must be based on a comparison to the other particular candidates for a part. The results of the cost-benefit-analysis have not, and will not, be formally documented in the literature inasmuch as it was intended as a planning guide.

Table 1

Participants and P/M Aluminums in the Cooperative Test Program

	Forgings			Extrusions			Plate		Sheet
	7091-T7E78	7090-T7E80	IN-9021	7091-T7E69	7090-T7E71	IN-9021	7091-T7E69	7090-T7E71	7091-T7E69
Boeing	X	X	X		X	X			
McDonnell Douglas, CA	X								
Fairchild				X		X			X
General Dynamics			X				X		
Lockheed, CA				X		X			
Lockheed, GA			X						X
McDonnell Douglas, MO	X								
Northrop						X	X		X
Rockwell	X	X	X		X		X		X
Vought		X	X		X				
AFWAL	X	X		X	X		X	X	
ALCOA	X	X		X	X	X	X	X	X

X Indicates data was obtained by a participant on the form/alloy

SECTION II
MATERIALS AND TESTS

Aluminum P/M materials are classified into three broad categories that reflect the optimized characteristic of the alloy/processing. These categories are high strength, high temperature, and low density. Materials used in this cooperative effort fall into the high strength category which is intended to save structural weight when used instead of current I/M aluminum alloys. Table 2 contains the product forms, alloys and suppliers.

Table 2

Materials Tested in Cooperative Test Program

Form	Source: ALCOA Alloy/Heat treat	Source: Novamet Alloy
Forging	7091-T7E78 7090-T7E80	IN9021
Extrusion	7091-T7E69 7090-T7E71	IN9021
Plate	7091-T7E69 7090-T7E71	
Sheet	7091-T7E69	

Basic mechanical tests along with fatigue, fatigue crack growth, spectrum fatigue and stress corrosion tests were performed by the participants. When available, ASTM standards were used for testing. For other tests a laboratory used its current procedures. Emphasis was on room temperature properties.

SECTION III
PRESENTATION AND ANALYSIS

The intent of the effort was not to compare the materials to other structural aluminums but to present data and give an estimate of design allowables. These allowables were used by industry to perform a cost benefit analysis based on a comparison to their currently used alloys.

Each participant compiled a data package which sometimes contained extensive discussion and in other cases contained only the data itself. As the packages were received, the tensile, compression, bearing, shear, and fracture toughness data were extracted and compiled in tables by alloy, property and orientation. Fatigue, fatigue crack growth, and spectrum fatigue data were prepared in tabular and graphical form. Stress corrosion results were prepared as tabular results and written descriptions.

Several standard approaches were evaluated for determining design allowables for the basic mechanical properties, but ultimately an engineering approach was used. This method was dictated because of the limited number of data points in any particular set and the need to eliminate obvious outlieres. The preferred approach would have been to use the methods of MIL-HDBK-5, but the calculated allowables would have been unrealistically low (MIL-HDBK-5 details procedures for calculating "A" and "B" allowables which have 95 percent confidence that 99 percent and 90 percent, respectively, of the population will equal or exceed the allowable). Once the 99 and 90 percent of population allowables were observed to be impractical a different population was investigated, that being the 75 percent population. Even with this reduced population it was obvious the values were still unrealisticly low for very small data sets. However, for moderate size data sets (9-15 data points) this allowable corresponded closely to the lowest value in the data set which one might expect to be close to a design allowable. Consequently, it was decided that for all groups of data the procedure would be to first calculate a value of an allowable based on the MIL-HDBK-5 procedure except for using 75 percent of the population and then compare this to the lowest value in the set; the higher of the two would be the suggested allowable.

For the fatigue data analysis, a MIL-HDBK-5 equation was used to give a mean trend best fit. Preliminary results found this to be inadequate for fitting data sets that exhibited scatter since it often resulted in curves that turned vertically in the high and low cycle regions. The approach that was used in the case of scattered fatigue data was to define a point to force the curve to pass through. This point was chosen to be at 10^7 cycles and the lowest stress value for which a failure occurred in the data set. Run outs were eliminated.

The analysis of fatigue crack growth data used a mean trend that was developed from a segmented spline fit as used in the Damage Tolerant Design Handbook. From the spline fit, tabular data were derived and presented as suggested design allowables. However, 7091 sheet crack growth data was not evaluated using the spline fit and therefore no tabular data is reported. This is due to the sheet data coming in after the bulk of the data had been fitted and the analysis system was not available.

Spectrum crack growth results were ranked against baseline I/M alloys which are considered state-of-the-art wrought structural materials. FALSTAFF and mini-TWIST spectrums were the spectra most often used in these tests. Stress corrosion results are given in tabular and descriptive form almost exactly as they came from the participants.

SECTION IV
RESULTS AND DISCUSSION

There are nine appendices to this report each containing the results for a specific alloy and product form. Table 3 lists the form, P/M alloy and the appendix for the nine combinations.

Table 3
Contents of Appendices

Form	P/M Alloy	Appendix
Forging	7091-T7E78	A
Forging	7090-T7E80	B
Forging	IN-9021	C
Extrusion	7091-T7E69	D
Extrusion	7090-T7E71	E
Extrusion	IN-9021	F
Plate	7091-T7E69	G
Plate	7090-T7E71	H
Sheet	7091-T7E69	I

Some of these materials had processing histories that could affect the subsequent results. Also, some of the testing was performed using unique conditions. In light of the significance of such information it was included on the front page of the appropriate appendix. The body of each appendix starts with a list of suggested design allowables followed by the basic mechanical properties (tensile, compression, bearing, shear and fracture toughness), fatigue, fatigue crack growth, spectrum fatigue, and stress corrosion properties. All data submitted by the participants are included.

The suggested allowables were no more than what is implied, i.e., suggested. Each participant was encouraged to develop design values based on their own procedure for dealing with a small data base if they felt their allowable calculation would be better. One must keep in mind that the purpose for the suggested values was to use them for a cost-benefit-analysis. They are not based on a data set of sufficient size to be used to design actual hardware. It will be observed by inspection of the data base they are at best an attempt to assess the potential quality of the materials.

Appendix A contains the data for 7091 forgings and is typical of the other appendices. Therefore subsequent discussion will be limited to this section. The tensile data for the longitudinal direction is comprised of seventeen data points, which is one of the larger sets developed in this program. The short transverse shear data set is comprised of five data points, typical of some of the smaller sets. Since, MIL-HDBK-5 requires hundreds of points for calculating an "A" or "B" allowable it is obvious the suggested allowables are not close to meeting the requirements.

The fatigue data is presented graphically and in tabular format, the latter allowing those interested to perform their own analysis and/or add it to another data base. The first figure, 1A, exemplifies a well behaved group of data that was easy to fit. Figure 2A, however, typifies the type of data that prompted the decision to induce the fitted curve to go through a point close to 10^7 cycles and the lowest stress value for which a failure occurred. Doing this is quite risky in that some specimens that failed at relatively low stresses are ignored. Hopefully, the curve does represent the potential for the material and a cost-benefit-analysis would be fairly accurate for future lots of the product. It is clear that *designing* based on the curve would be inappropriate.

Most fatigue data was generated at an R-ratio of 0.1, but there are a few curves for other stress ratios. Considerable work was done on smooth samples with a fair amount of data for a stress concentrations close to or equal to three. No higher stress concentrations were tested.

Constant amplitude fatigue crack growth rate data is also presented in graphical and tabular form. But, there is one big difference in the tabular results in that they are not actual test data but a best fit approximation to the crack growth rate curves. In Figure A5 the disjointed points in the top left graph have a line fitted to them which was the basis for the data in Table A19. This data has an abnormal appearance and consequently the fit is very poor. Similarly, the data in the top right graph has much more scatter than would normally be expected. The fatigue crack growth rate curves in Figure A6 are more typical of P/M aluminums, exhibiting little scatter.

The last two types of data are spectrum fatigue and corrosion. Preceding these are few explanatory paragraphs conveying information that is not necessarily included in the graphical and tabular presentations of these data. Spectrum fatigue tests in Figures A13 and A14 showed the 7091 to be superior to 7050-T76. However, the 7091 forging that was tested by McDonnell Douglas, St Louis MO, compared 7091 with 7050-T73. The 7091 was inferior to the 7050-T73.

Stress corrosion and/or exfoliation tests were performed on each alloy/product form. All P/M aluminum alloys displayed good corrosion resistance.

SECTION V

CONCLUSIONS

Twelve aerospace laboratories participated in developing an extensive data base on first generation P/M structural aluminums. From this base estimates of the mechanical properties that are typical for these materials were obtained. The effort was successful for the intended purpose of assessing the applications suitable for the material. The data itself is not sufficient to develop design allowables for inclusion in MIL-HDBK-5 or for design but can serve as a start toward that end. Some data showed an inordinate amount of scatter and nonhomogenity which may be eliminated by manufacturing controls. Future efforts on similar materials, or second generation materials, should focus on a less broad spectrum of alloys and forms and be targeted toward a more indepth study of each property.

APPENDIX A

7091-T7E78 FORGINGS

NOTICE: Suggested allowables, mean trends, and trend curves in this document were developed to be used in a cost benefit analysis to assess the potential benefit of using the material in a structure. These suggested allowables and trends are not considered accurate for design of actual hardware.

TABLE A1

SUGGESTED ALLOWABLES FOR

7091-T7E78 FORGINGS: 2-1/2 x 6"

F_{tu}, KSI	
L	76.8
LT	75.6
ST	74.2
F_{ty}, KSI	
L	68.4
LT	64.9
ST	61.9
F_{cy}, KSI	
L	69.9
LT	68.8
ST	70.1
F_{su}, KSI	
L	40.1
LT	40.3
ST	38.9
F_{bu}, KSI	
L	
(e/D = 1.5)	119.0
(e/D = 2.0)	154.9
LT	
(e/D = 1.5)	119.5
(e/D = 2.0)	151.2
F_{by}, KSI	
L	
(e/D = 1.5)	106.1
(e/D = 2.0	116.8
LT	
(e/D = 1.5)	103.6
(e/D = 2.0)	117.0
K_{IC}, KSI $\sqrt{IN}$	
LT	26.8
TL	15.9
SL	18.4

NOTE: These values were developed to be used only in a cost-benefit-analysis and are not necessarily accurate for design of hardware.

TABLE A2

7091-T7E78 FORGINGS:
TENSILE

COMPANY	TEST TEMP °F	ORIENTATION	ULT STR KSI	YIELD STR KSI	ELONG %
McDonnell Douglas-CA	RT	Long	77.3	68.7	11.6
			79.6	68.4	12.3
			77.3	69.3	11.5
Rockwell			78.7	71.0	13.7
			77.5	68.6	14.0
			79.1	70.4	13.6
McDonnell Douglas-ST L.			83.0	74.5	12
			83.0	75.0	12
			83.5	74.5	14
ALCOA			77.0	68.8	12.5
			80.2	71.5	13.0*
			77.4	68.5	13.5*
Boeing			78.7	70.1	11.8
			76.8	69.3	14.0
AFWAL			80.3	72.7	14.8
			78.0	70.2	13.6
			79.3	71.9	13.7

* Internal discontinuity

TABLE A3

7091-T7E78 FORGING
TENSILE

COMPANY	TEST TEMP °F	ORIENTATION	ULT STR KSI	YIELD STR KSI	ELONG %
McDonnell Douglas-CA	RT	TRANS	77.4	66.4	6.5
			75.5	64.2	10.9
			76.8	67.3	11.4
Rockwell			77.2	67.1	13.5
			78.1	66.5	13.6
			78.0	67.3	12.3
McDonnell Douglas, ST. L			80.0	70.5	8.0
			81.5	72.0	8.0
			81.0	72.5	11.0
ALCOA			76.2	66.2	10.5
			79.0	68.8	12.5
			77.3	67.3	12.5
Boeing			77.0	69.3	4.7
			76.4	66.6	11.6

TABLE A4

7091-T7E78 FORGING
TENSILE

COMPANY	TEST TEMP	ORIENTATION	ULT STR KSI	YIELD STR KSI	ELONG %
McDonnell Douglas-CA	RT	S.TRANS	76.6	64.1	10.6
			76.8	64.6	8.6
			76.2	64.1	10.0
Rockwell			76.6	62.5	7.5
			76.0	62.6	7.8
			75.9	64.2	7.5
McDonnell Douglas, ST. L			76.5	63.5	10.0
			77.0	64.5	10.0
			80.5	66.6	10.0
ALCOA			73.6	61.8	7.0
			76.3	63.3	9.0
			75.3	62.9	8.0

TABLE A17

FATIGUE RESULTS FOR 7091 FORGINGS: R =-0.4, K_t = 2.6

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
10000	2600000	0
12500	6868000	0
15000	148300	1
20000	76400	1
25000	35800	1
30000	26000	1
40000	8380	1
50000	3400	1

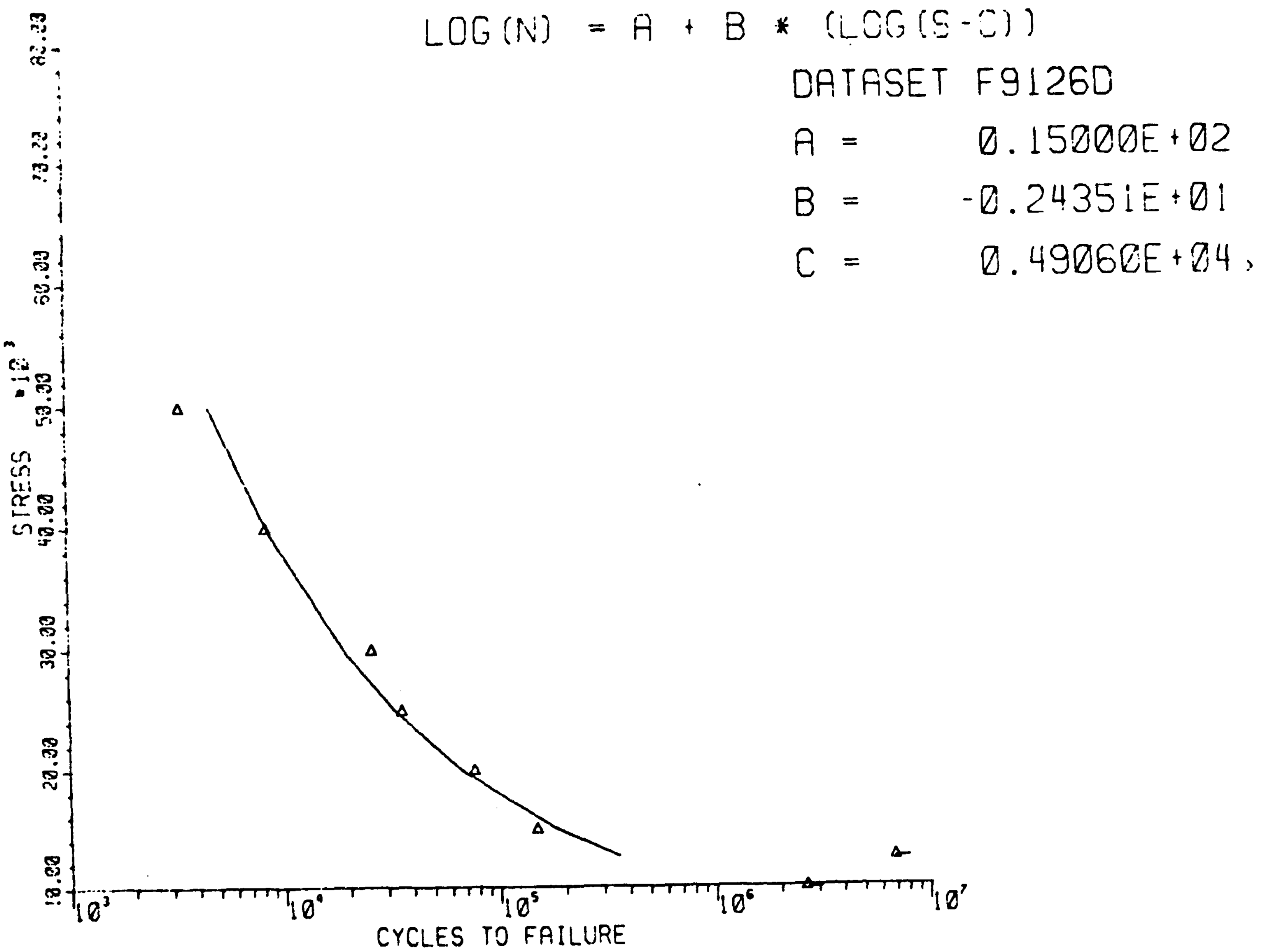


Figure A3. Fatigue Results for 7091 Forgings; R = -0.4, K_t = 2.6

TABLE A16

FATIGUE RESULTS FOR 7091 FORGINGS: R = 0.1, K_t = 1.0

Stress PSI	Cycles	Fail (1) No Fail (0)
38900	10000000	0
42800	78100	1
44700	5000000	1
45000	10690600	0
45000	15534150	0
46700	1600000	1
47000	1796000	1
47000	11803250	0
49000	8797100	1
49000	15541900	0
50600	2400000	1
51000	6352500	0
52500	2100000	1
53000	1659700	0
54500	21950	1
57000	3161700	1
58400	125200	1
63000	360000	1
63000	396100	1
65000	22350	1
65000	29000	1
65000	205200	1
66200	19350	1
67000	310300	1
67000	738000	1
69000	59900	1
74000	7850	1

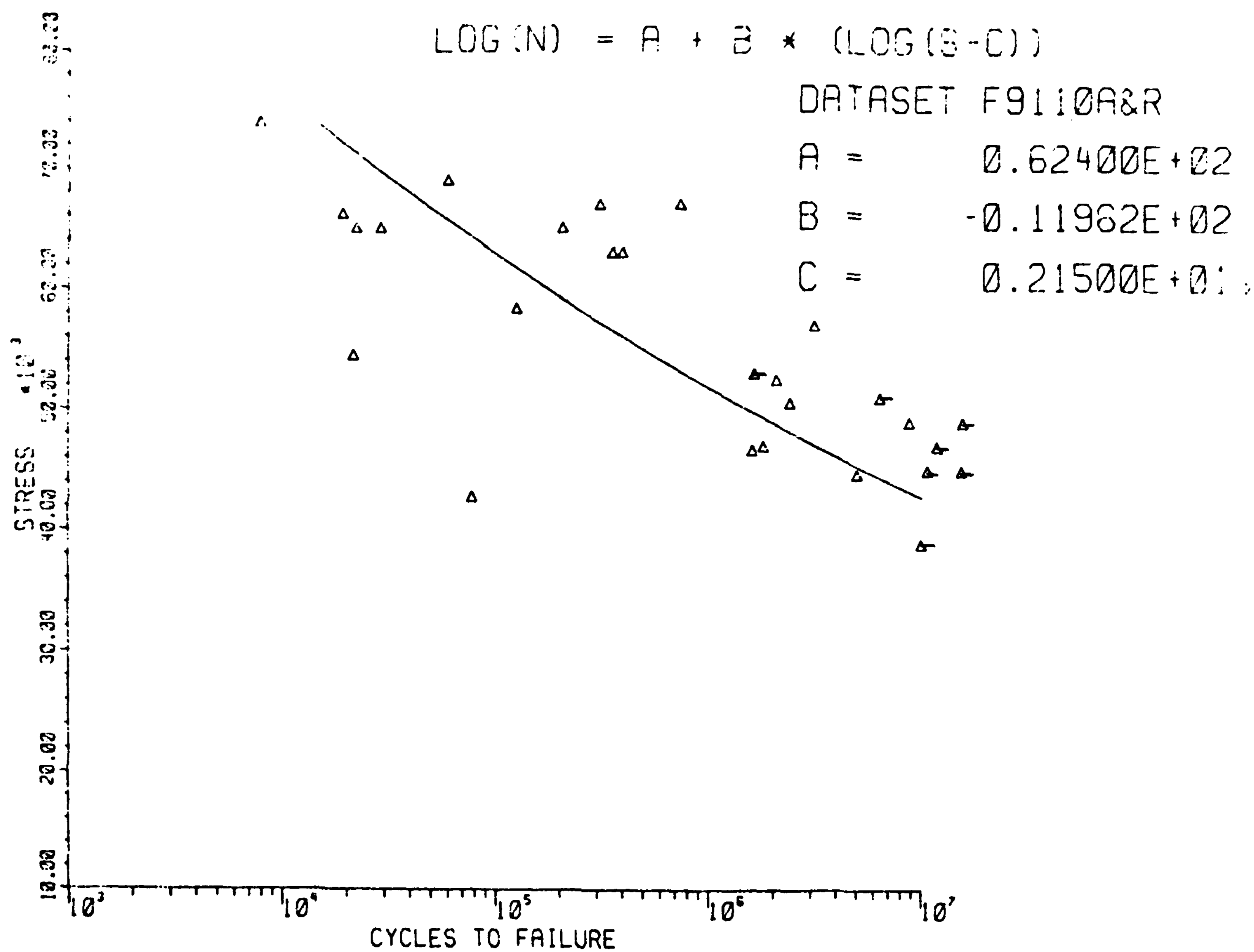


Figure A2. Fatigue Results for 7091 Forgings; R = 0.1, K_t = 1.0

TABLE A15

FATIGUE RESULTS FOR 7091 FORGINGS: R =-1.0, K_t = 1.0

Stress PSI	Cycles	Fail(1) No fail (0)
27500	1018690	1
27500	1341200	1
40000	26919	1
40000	44634	1
40000	46071	1
60000	1876	1
60000	1825	1
60000	2596	1
68000	539	1
72000	297	1

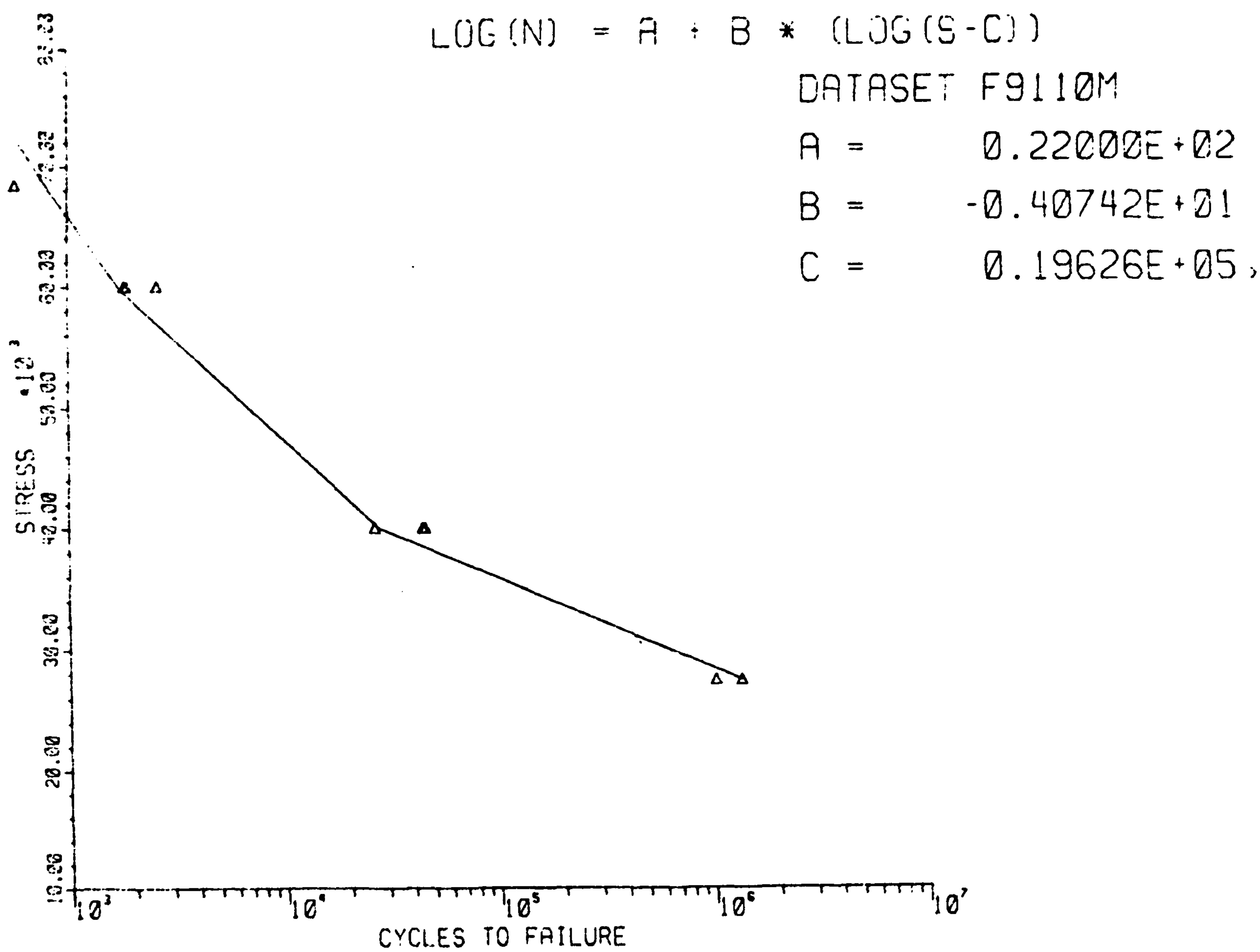


Figure A1. Fatigue Results for 7091 Forgings: R = -1.0, K_t = 1.0

TABLE A14

7091-T7E78 FORGING
FRACTURE TOUGHNESS, K_{IC}

COMPANY	ORIENTATION	K_{IC} KSI $\sqrt{IN}$	K_Q KSI $\sqrt{IN}$	COMMENT
McDonnell	S-L	18.4		Valid
Douglas-CA		22.1		Valid
McDonnell		20.3		Valid
St L.		26.4		Valid
ALCOA		31.5		Valid
		26.2		Valid
			40.8	Invalid specimen not thick enough and fatigue crack too short
Rockwell	T-L		16.5	Invalid Sec 11.2.3 B645
			15.7	Valid
McDonnell		18.6		Valid
St. L		20.2		Valid
ALCOA		22.8		Valid
		19.4		Valid
		23.2		Valid
Boeing		15.9		

TABLE A13

7091-T7E78 FORGING
FRACTURE TOUGHNESS, K_{IC}

COMPANY	ORIENTATION	K_{IC} KSI$\sqrt{IN}$	K_Q KSI$\sqrt{IN}$	COMMENT
McDonnell	L-T		35.7	Failed crack plane angle
Douglas-CA			30.2	" " " "
Rockwell			26.3	Invalid crack deviation from notch plane more 10^o
			24.8	" " "
McDonnell		27.7		Valid
St. L		27.0		Valid
ALCOA		30.2		Valid
		26.8		Valid
		37.3		Valid
Boeing		27.8		

TABLE A12

7091-T7E78 FORGING
BEARING

COMPANY	ORIENTATION	e/D	BEARING ULT KSI	BEARING YIELD KSI
McDonnell Douglas-CA	LONG	2.0	168.4	132.3
			157.2	124.6
Rockwell			164.1	116.9
			158.9	113.4
			163.0	116.8
McDonnell Douglas-St.L.			-	126.0
			175.0	127.0
			171.0	123.0
ALCOA			158.0	128.3
			156.2	126.8
			154.9	122.2
McDonnell Douglas-CA	TRANS	2.0	168.6	133.9
			170.9	132.6
Rockwell			163.2	117.9
			168.7	120.4
			168.2	118.2
McDonnell Douglas-St. L.			162.0	126.0
			158.0	117.0
			160.0	119.0
ALCOA			150.4	125.3
			152.4	125.1
			155.1	122.4

TABLE A11

7091-T7E78 FORGING
BEARING

COMPANY	ORIENTATION	e/D	BEARING ULT KSI	BEARING YIELD KSI
McDonnell Douglas-CA	Long	1.5	134.0	-
			128.9	107.5
ALCOA			119.5	106.7
			124.9	109.3
			119.0	106.1
Boeing			121.6	-
			126.1	
McDonnell Douglas-CA	Trans	1.5	134.9	111.9
			135.4	115.3
Rockwell			126.6	104.4
			125.0	103.6
			126.6	105.0
ALCOA			120.1	104.5
			119.5	105.1
			123.9	107.7
Boeing			120.9	

TABLE A10

7091-T7E78 FORGING
SHEAR

COMPANY	ORIENTATION	SHEAR STRENGTH KSI
McDonnell Douglas-CA	S.TRANS	42.6
		41.9
		41.6
Boeing		39.6
		38.9

TABLE A9

7091-T7E78 FORGING
SHEAR

COMPANY	ORIENTATION	SHEAR STRENGTH KSI
McDonnell Douglas-CA	TRANS	45.6
		45.3
		47.8
Rockwell		50.4
		50.2
		46.6
McDonnell Douglas, ST. L.		40.3
		41.2
		39.3
ALCOA		44.7
		47.4
		45.6

TABLE A6

7091-T7E78 FORGING
COMPRESSION

COMPANY	ORIENTATION	COMP YIELD STR KSI
McDonnell Douglas-CA	TRANS	71.4
		70.0
		69.9
Rockwell		70.3
		70.8
		70.5
McDonnell Douglas, ST. L.		72.5
		73.5
		76.5
ALCOA		69.6
		70.8
		68.8
Boeing		72.1
		71.8

TABLE A5

7091-T7E78 FORGING
COMPRESSION

COMPANY	ORIENTATION	COMPR YIELD STR KSI
McDonnell Douglas-CA	Long	72.2
		73.2
		73.6
Rockwell		74.9
		74.6
		76.4
McDonnell Douglas, ST. L.		79.5
		78.5
		74.5
ALCOA		71.1
		72.6
		70.8
Boeing		68.8
		73.1

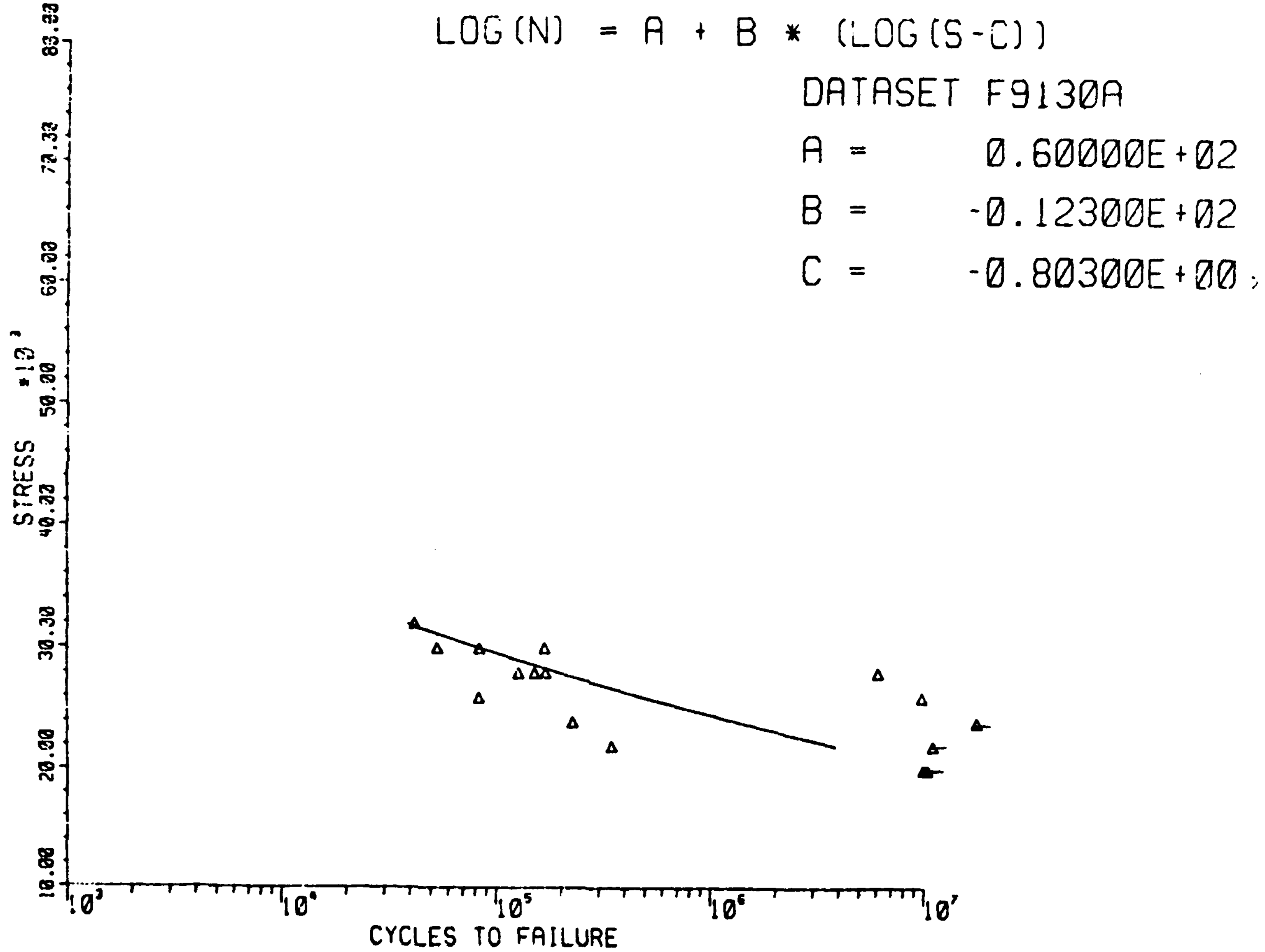


Figure A4. Fatigue Results for 7091 Forgings; R = 0.1, K_t = 3.0

TABLE A18

FATIGUE RESULTS FOR 7091 FORGINGS: $R = 0.1$, $K_t = 3.0$

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
20000	10010000	0
20000	10429400	0
22000	350150	1
22000	11044080	0
24000	229500	1
24000	17860800	0
24000	17850350	0
26000	83900	1
26000	9812200	1
28000	128250	1
28000	151900	1
28000	171800	1
28000	6152500	1
30000	54000	1
30000	83900	1
30000	168300	1
32000	41900	1

CONDITION/HT: T7E78
FORM: 2.50- 2.60"TH FORGING
SPECIMEN TYPE: CT
ORIENTATION: L-T
FREQUENCY: 1.00- 30.00 HZ
ENVIRONMENT: R.T., LAB AIR

YIELD STRENGTH: 68.8- 74.5 KSI
ULT. STRENGTH: 77.8- 83.0 KSI
SPECIMEN THK: 0.251- 1.250"
SPECIMEN WIDTH: 1.965- 4.995"
REFERENCES:

ALUM. ALLOY

7091

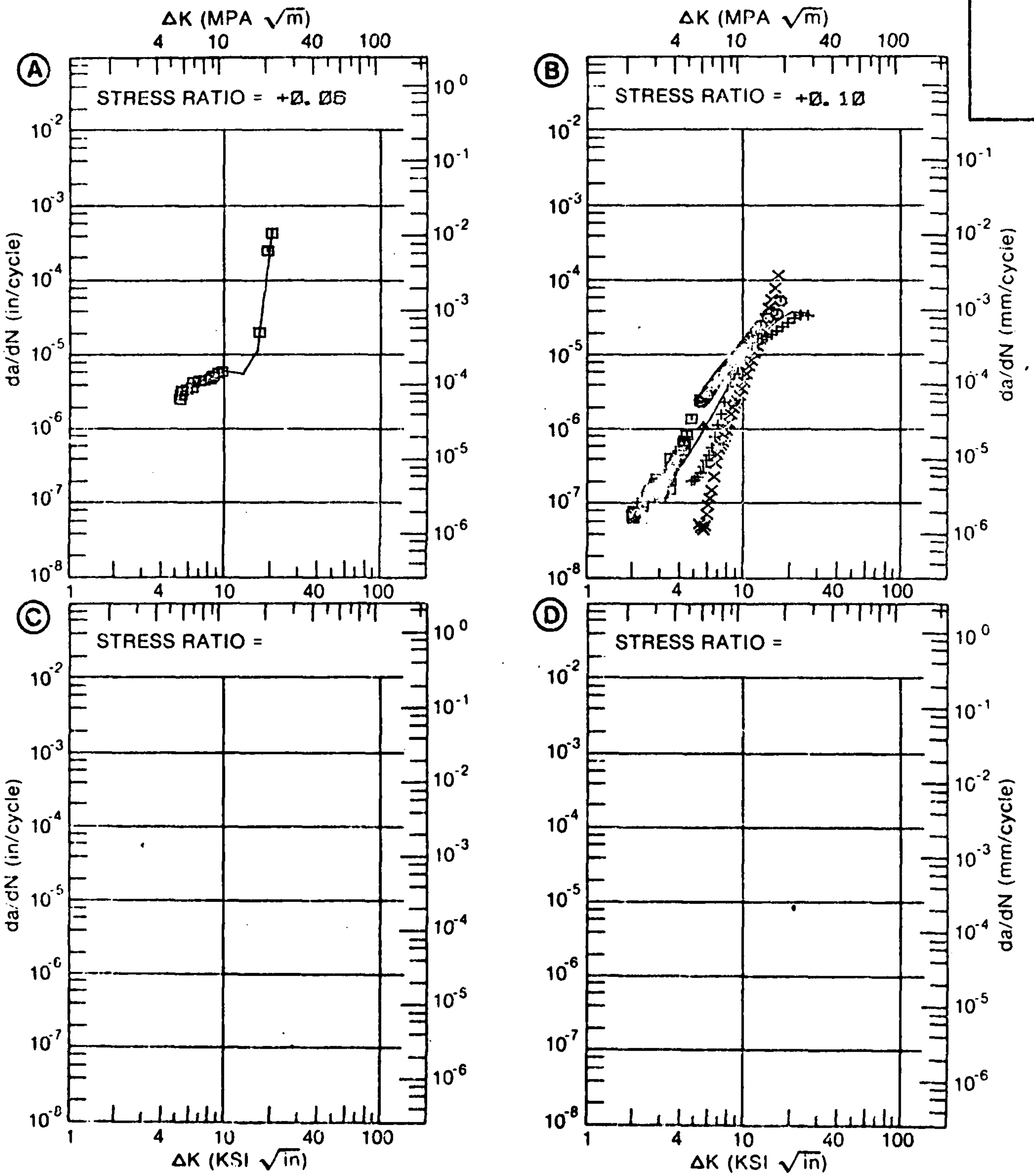


Figure A5. Fatigue Crack Growth Rate Data for 7091 Forgings; Boeing, McDonnell-Douglas-CA, McDonnell Douglas St. L., and Rockwell

TABLE A19

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE A5 INDICATING EFFECT
OF STRESS RATIO

Boeing, McDonnell Douglas-CA, McDonnell Douglas St. L and Rockwell

MATERIAL: ALUMINUM 7091
CONDITION: T7E78
ENVIRONMENT: R.T. LAB AIR

DELTA K KSI*IN**1/2		DA/DN (10**-6 IN./CYCLE) A	B	C	D
		R=+0.06	R=+0.10		
DELTA K A:	5.05	[illegible]			
DELTA K B:	1.90		.103		
LIM C:					
D					
	2.00		.103		
	2.50		.120		
	3.00		.164		
	3.50		.207		
	4.00		.348		
	5.00		.727		
	6.00	3.71	1.40		
	7.00	4.16	2.40		
	8.00	5.12	4.03		
	9.00	5.62	6.12		
	10.00	5.91	8.71		
	12.00	5.53	16.7		
	16.00	21.4	29.0		
	20.00		37.3		
	25.00		54.1		
DELTA K A:	19.[illegible]	[illegible]			
DELTA K B:	25.41		35.5		
[illegible] C:					
D:					

CONDITION/HT: T7E78
FORM: 2.50"TH FORGING
SPECIMEN TYPE: CT
ORIENTATION: L-T
FREQUENCY: 10.00- 25.00 HZ
ENVIRONMENT: R.T., HI HUMIDITY

YIELD STRENGTH: 69.6 KSI
ULT. STRENGTH: 78.2 KSI
SPECIMEN THK: 0.251"
SPECIMEN WIDTH: 1.999"
REFERENCES:

ALUM. ALLOY

7091

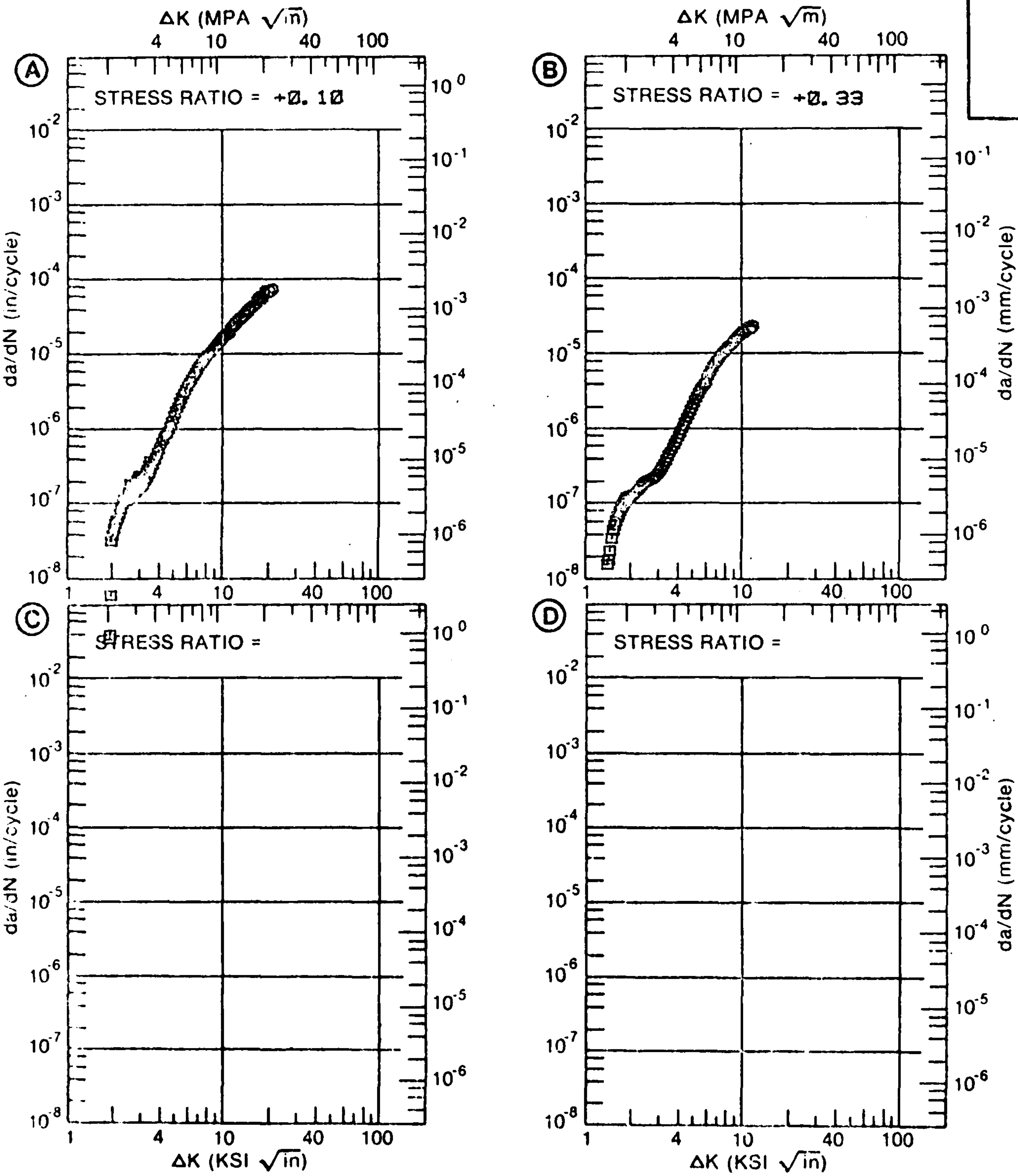


Figure A6. Fatigue Crack Growth Rate Data for 7091 Forgings; ALCOA

TABLE A20

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE A6 INDICATING EFFECT
OF STRESS RATIO

ALCOA

MATERIAL: ALUMINUM 7071
CONDITION: T7E73
ENVIRONMENT: R.T. ,HI HUMIDITY

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN./CYCLE) A	B	C	D
		R=+0.10	R=+0.33		
DELTA K MIN A:	1.04	.0316			
B:	1.35		.0429		
C:					
D:					
	1.60		.0604		
	2.00	.0149	.107		
	2.50	.115	.212		
	3.00	.245	.392		
	3.50	.459	.675		
	4.00	.782	1.09		
	5.00	1.84	2.43		
	6.00	3.56	4.57		
	7.00	6.01	7.56		
	8.00	9.19	11.3		
	9.00	13.0	15.7		
	10.00	17.4	20.5		
	13.00	31.7			
	16.00	43.2			
	20.00	64.6			
DELTA K MAX A:	20.48	66.1			
B:	11.49		27.2		
C:					
D:					

CONDITION/HT: T7E78
FORM: 2.50"TH FORGING
SPECIMEN TYPE: CCP
ORIENTATION: L-T
STRESS RATIO: +0.10
FREQUENCY: 1.00- 20.00 HZ

YIELD STRENGTH: 74.5 KSI
ULT. STRENGTH: 83.0 KSI
SPECIMEN THK: 0.252- 0.256"
SPECIMEN WIDTH: 3.913- 3.919"
REFERENCES:

ALUM. ALLOY

7091

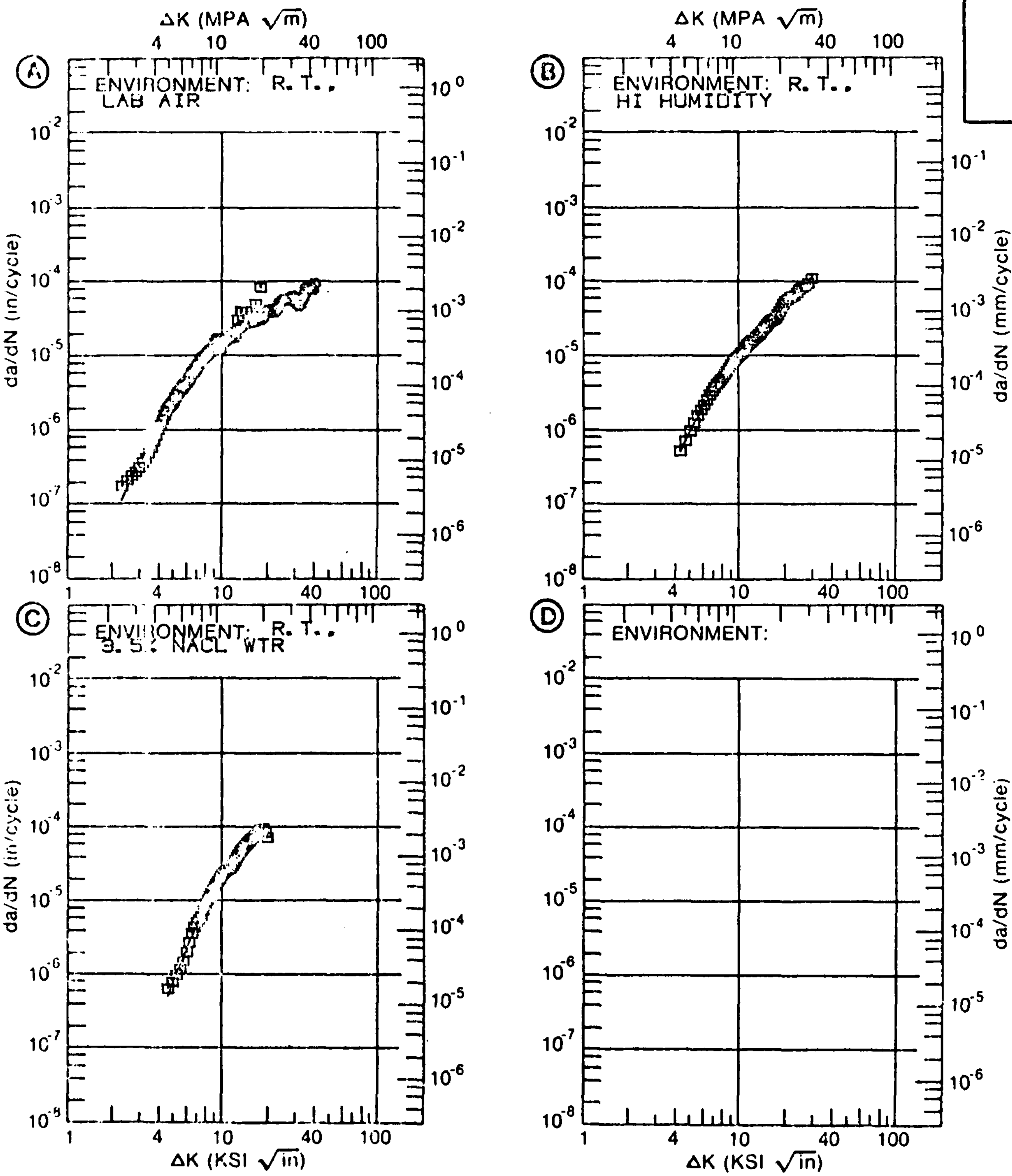


Figure A7 Fatigue Crack Growth Rate Data for 7091 Forgings; McDonnell-Douglas St.L

TABLE A21

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE A7 INDICATING EFFECT
OF ENVIRONMENT

McDonnell-Douglas St.L

MATERIAL: ALUMINUM 7091
CONDITION: T7E78

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN./CYCLE) A	B	C	D
		E= R.T. LAB AIR	E= R.T. HI HUMIDITY	E= R.T. 3.5% NACL WTR	
DELTA K MIN	A: 2.17	.115			
	B: 4.10		.519		
	C: 4.40			.498	
	D:				
	2.50	.211			
	3.00	.458			
	3.50	.836			
	4.00	1.36			
	5.00	2.83	1.20	1.01	
	6.00	4.83	2.35	2.57	
	7.00	7.25	3.89	5.32	
	8.00	9.98	5.79	9.47	
	9.00	12.9	8.00	15.1	
	10.00	[illegible]	10.5	22.0	
	13.00	25.3	19.5	42.6	
	16.00	34.1	30.7	72.9	
	20.00	44.0	49.4		
	25.00	53.6	80.7		
	30.00	60.4			
	35.00	[illegible]			
DELTA K MAX	A 39.03	67.5			
	B: 28.87		113.		
	C: 19.23			91.4	
	D:				

CONDITION/HT: T7E78
FORM: 2.50"TH FORGING
SPECIMEN TYPE: CT
ORIENTATION: T-L
FREQUENCY: 1.00- 5.00 HZ
ENVIRONMENT: R.T., LAB AIR

YIELD STRENGTH: 70.0- 72.0 KSI
ULT. STRENGTH: 78.4- 81.0 KSI
SPECIMEN THK: 0.248- 0.494"
SPECIMEN WIDTH: 1.954- 2.999"
REFERENCES:

ALUM. ALLOY

7091

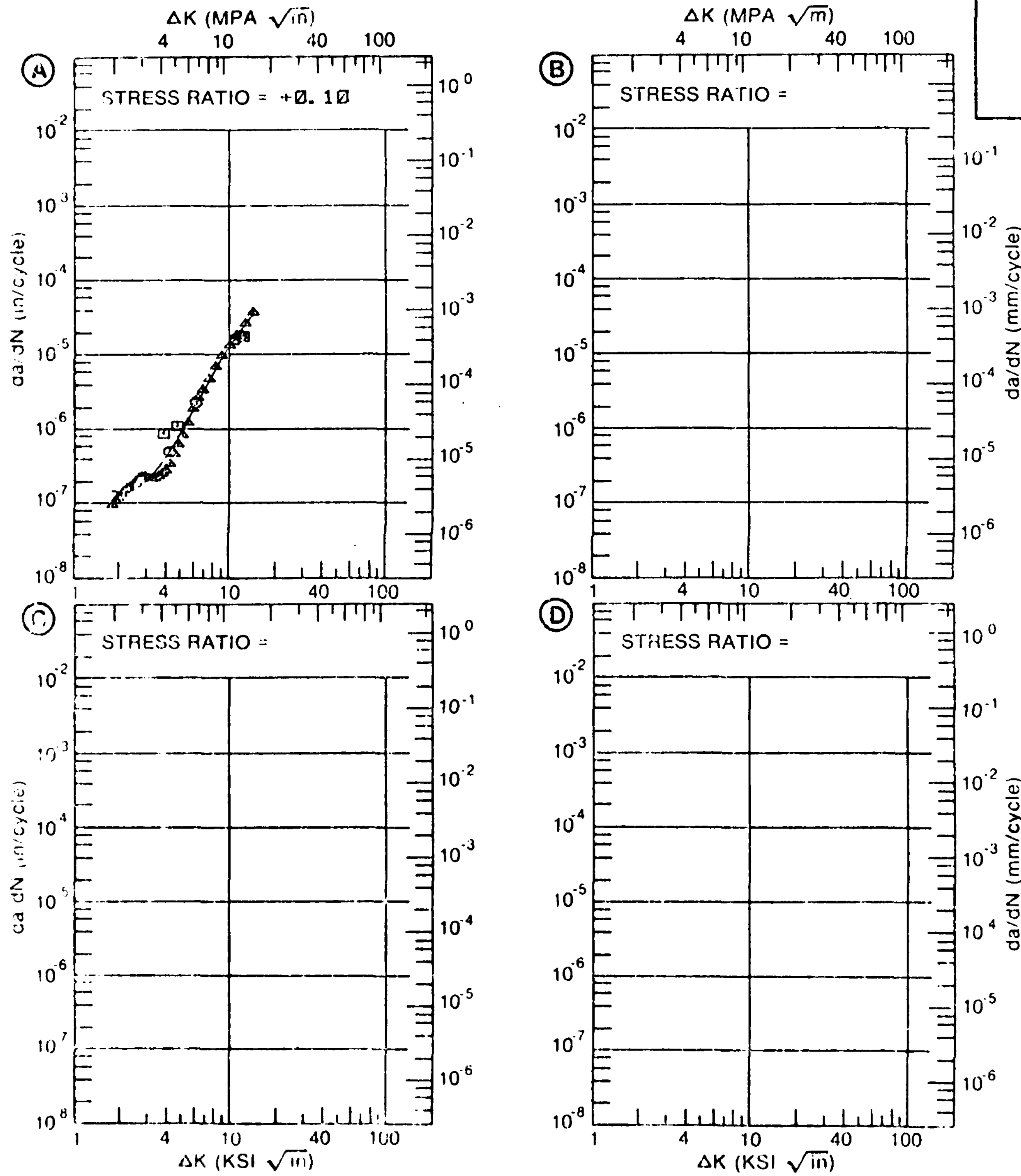


Figure A8. Fatigue Crack Growth Rate Data for 7091 Forgings; McDonnell-Douglas-St.L. and Rockwell

TABLE A22

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS OF
STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE A8 INDICATING EFFECT
OF STRESS RATIO

McDonnell Douglas-St. L and Rockwell

MATERIAL: ALUMINUM 7091
CONDITION: T7E73
ENVIRONMENT: R.T. , LAB AIR

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN./CYCLE) A	B	C	D
		R=+0.10			
DELTA K MIN A:	1.73	.149			
B:					
C:					
D					
	2.00	.156			
	2.50	.198			
	3.00	.218			
	3.50	.321			
	4.00	.431			
	5.00	1.04			
	6.00	2.07			
	7.00	3.75			
	8.00	6.21			
	9.00	9.51			
	10.00	13.6			
	13.00	29.9			
DELTA K MAX A:	13.86	33.6			
B:					
C:					
D:					

CONDITION/HT:	T7E78	YIELD STRENGTH:	67.4 KSI
FORM:	2.50"TH FORGING	ULT. STRENGTH:	77.5 KSI
SPECIMEN TYPE:	CT	SPECIMEN THK:	0.250- 0.251"
ORIENTATION:	T-L	SPECIMEN WIDTH:	1.997- 1.998"
FREQUENCY:	10.00- 25.00 HZ	REFERENCES:	
ENVIRONMENT:	R.T., HI HUMIDITY		

ALUM. ALLOY

7091

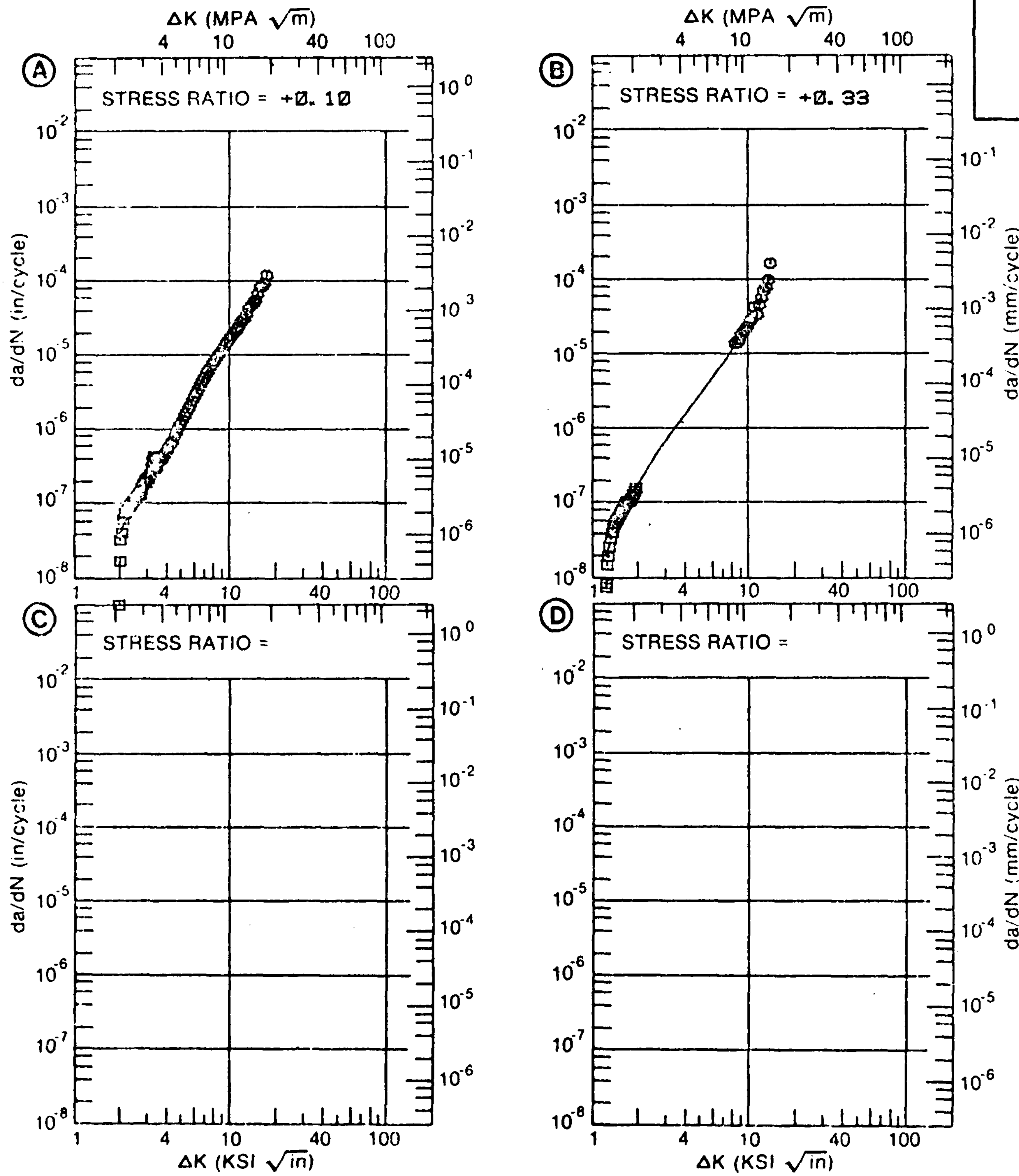


Figure A9. Fatigue Crack Growth Rate Data for 7091 Forgings; ALCOA

TABLE A23

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE A9 INDICATING EFFECT
OF STRESS RATIO

ALCOA

MATERIAL : ALUMINUM 7091
CONDITION: T7E76
ENVIRONMENT: R.T., HI HUMIDITY

DELTA K (KSI*IN**1/2)		:	DA/DN (10**-6 IN./CYCLE) A R=+0.10	B R=+0.33	C	D
DELTA K MIN	A: 1.89	:	.0398			
	B: 1.18	:		.0202		
	C:	:				
	D:	:				
	1.30	:		.0332		
	1.60	:		.0359		
	2.00	:	.0500	.206		
	2.50	:	.120	.440		
	3.00	:	.241	.766		
	3.50	:	.428	1.19		
	4.00	:	.700	1.72		
	5.00	:	1.57	3.17		
	6.00	:	2.98	5.30		
	7.00	:	5.10	8.43		
	8.00	:	8.08	13.0		
	9.00	:	12.1	19.5		
	10.00	:	17.3	28.8		
	13.00	:	43.7	37.3		
	16.00	:	63.1			
DELTA K MAX	A: 17.06	:	106.			
	B: 13.54	:		106.		
	C:	:				
	D:	:				

CONDITION/HT: T7E78
FORM: 2.50"TH FORGING
SPECIMEN TYPE: CT
ORIENTATION: S-L
FREQUENCY: 1.00- 30.00 HZ
ENVIRONMENT: R. T., LAB AIR

YIELD STRENGTH: 65.0 KSI
ULT. STRENGTH: 78.0 KSI
SPECIMEN THK: 0.200- 0.210"
SPECIMEN WIDTH: 1.992- 1.997"
REFERENCES:

ALUM. ALLOY

7091

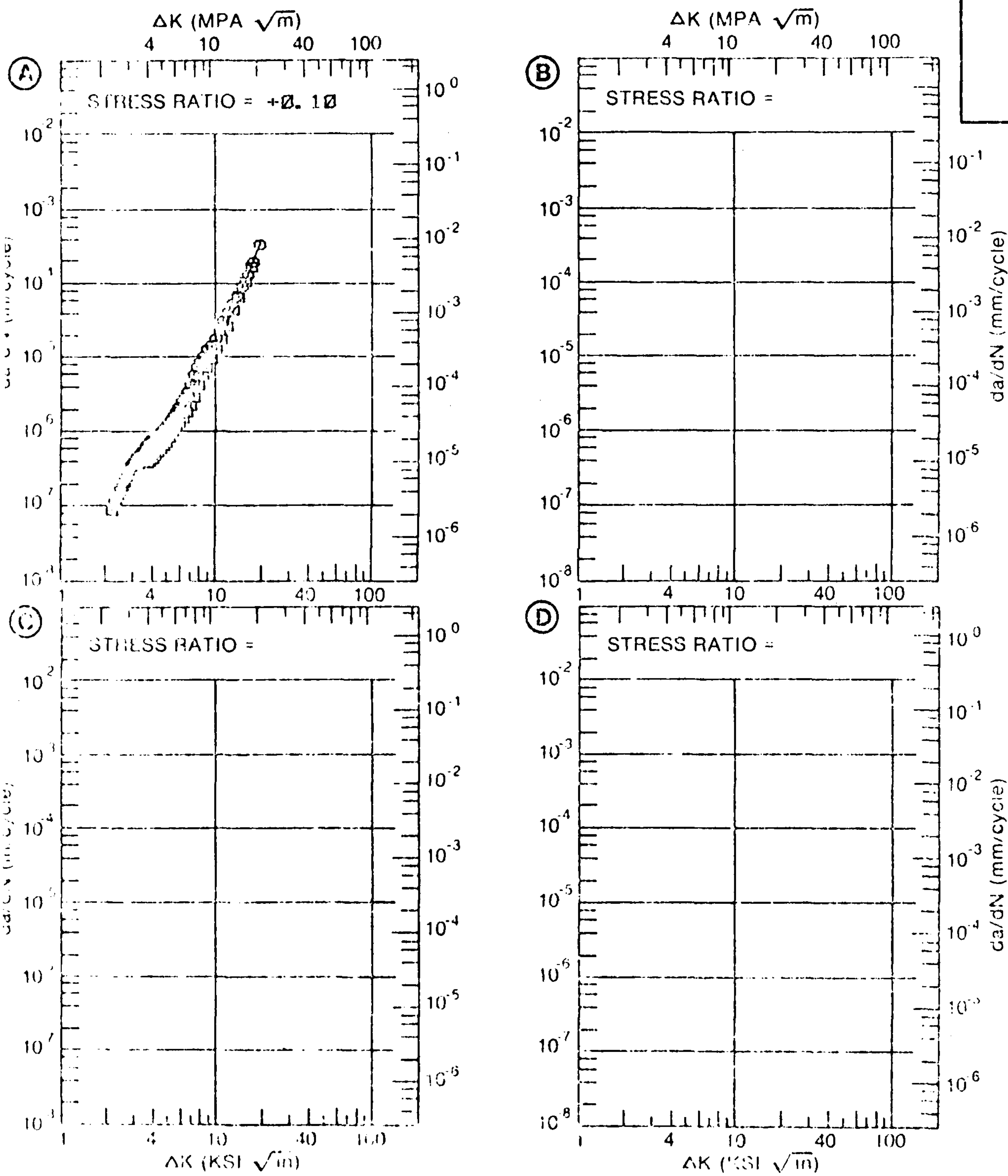


Figure A10. Fatigue Crack Growth Rate Data for 7091 Forgings; McDonnell Douglas-St. L

TABLE A24

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS OF
STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE A10 INDICATING EFFECT
OF STRESS RATIO

McDonnell Douglas-St.L

MATERIAL: ALUMINUM 7091
CONDITION: T7E70
ENVIRONMENT: R.T ,LAB AIR

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN./CYCLE) A	B	C	D
		R=+0.10			
DELTA K MIN A:	2.09	.130			
B:					
C:					
D:					
	2.50	.200			
	3.00	.316			
	3.50	.475			
	4.00	.687			
	5.00	1.33			
	6.00	2.38			
	7.00	4.04			
	8.00	6.58			
	9.00	10.4			
	10.00	15.9			
	13.00	50.7			
	16.00	140.			
DELTA K MAX A:	18.97	348.			
B:					
C:					
D:					

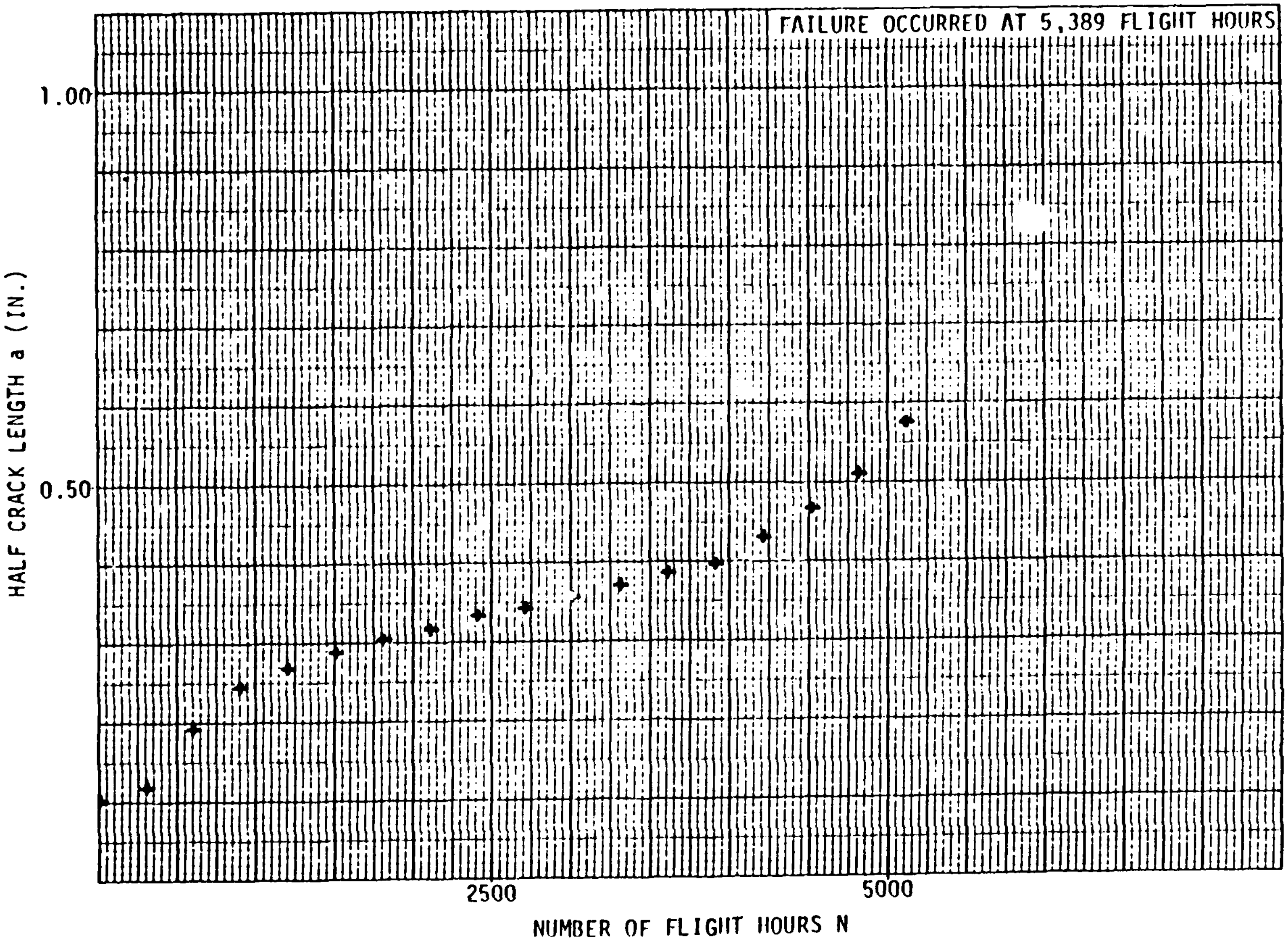


FIGURE A22. a VS N PLOT FOR AN X7091-T7E78 ALUMINUM ALLOY HAND FORGING SUBJECTED TO THE TSTROOT SPECTRUM USING A 100% TLS OF 45 KSI (SPECIMEN 10L-SF6-FWR)

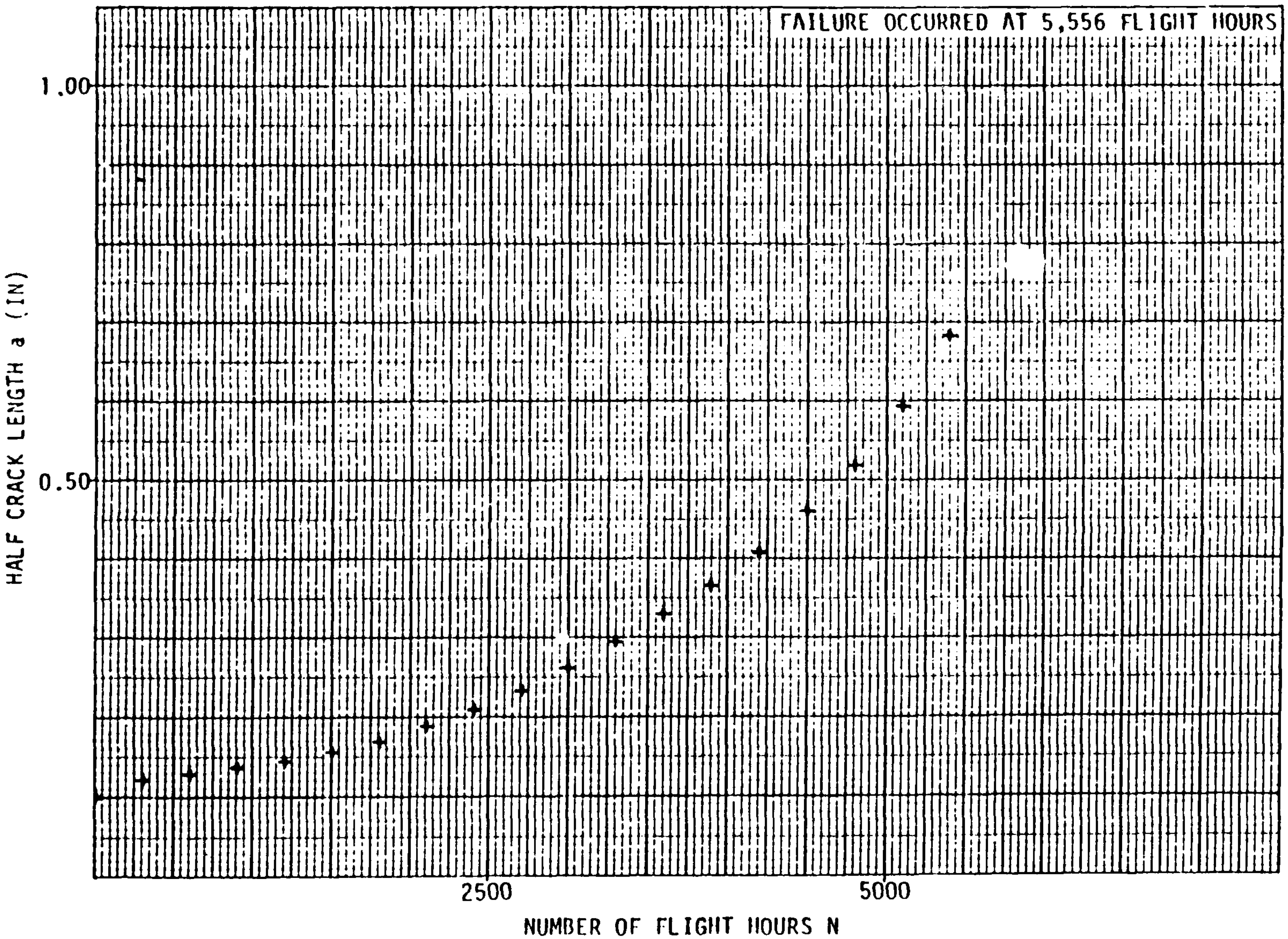


FIGURE A21. a VS N PLOT FOR AN X7091-T7E78 ALUMINUM ALLOY HAND FORGING SUBJECTED TO THE TSTROOT SPECTRUM USING A 100% TLS OF 30 KSI (SPECIMEN 10L-SF5-FWR)

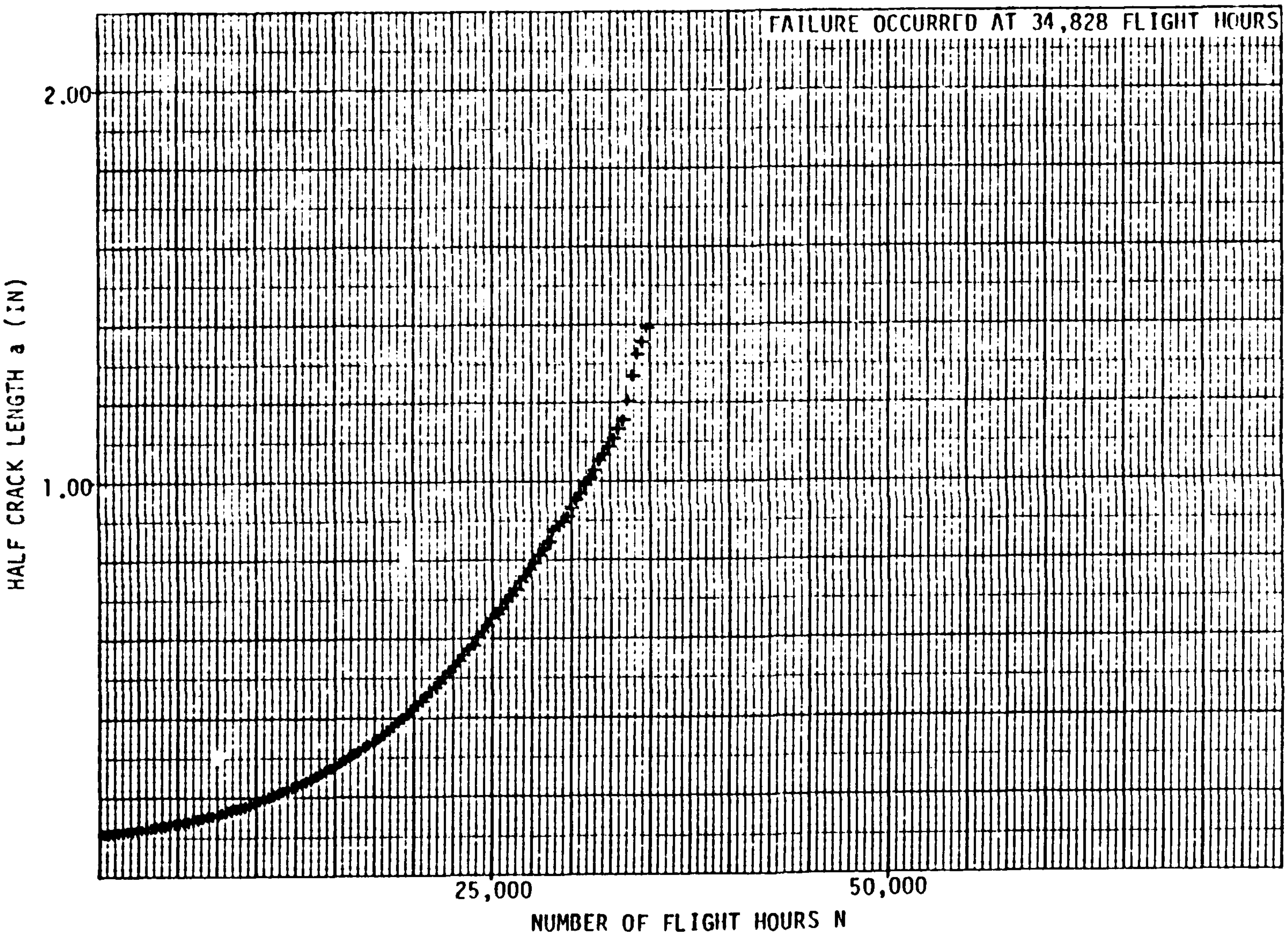


FIGURE A20. a VS N PLOT FOR AN X7091-T7E78 ALUMINUM ALLOY HAND FORGING SUBJECTED TO THE TSTROOT SPECTRUM USING A 100% TLS OF 15 KSI (SPECIMEN 10L-SF4-FWR)

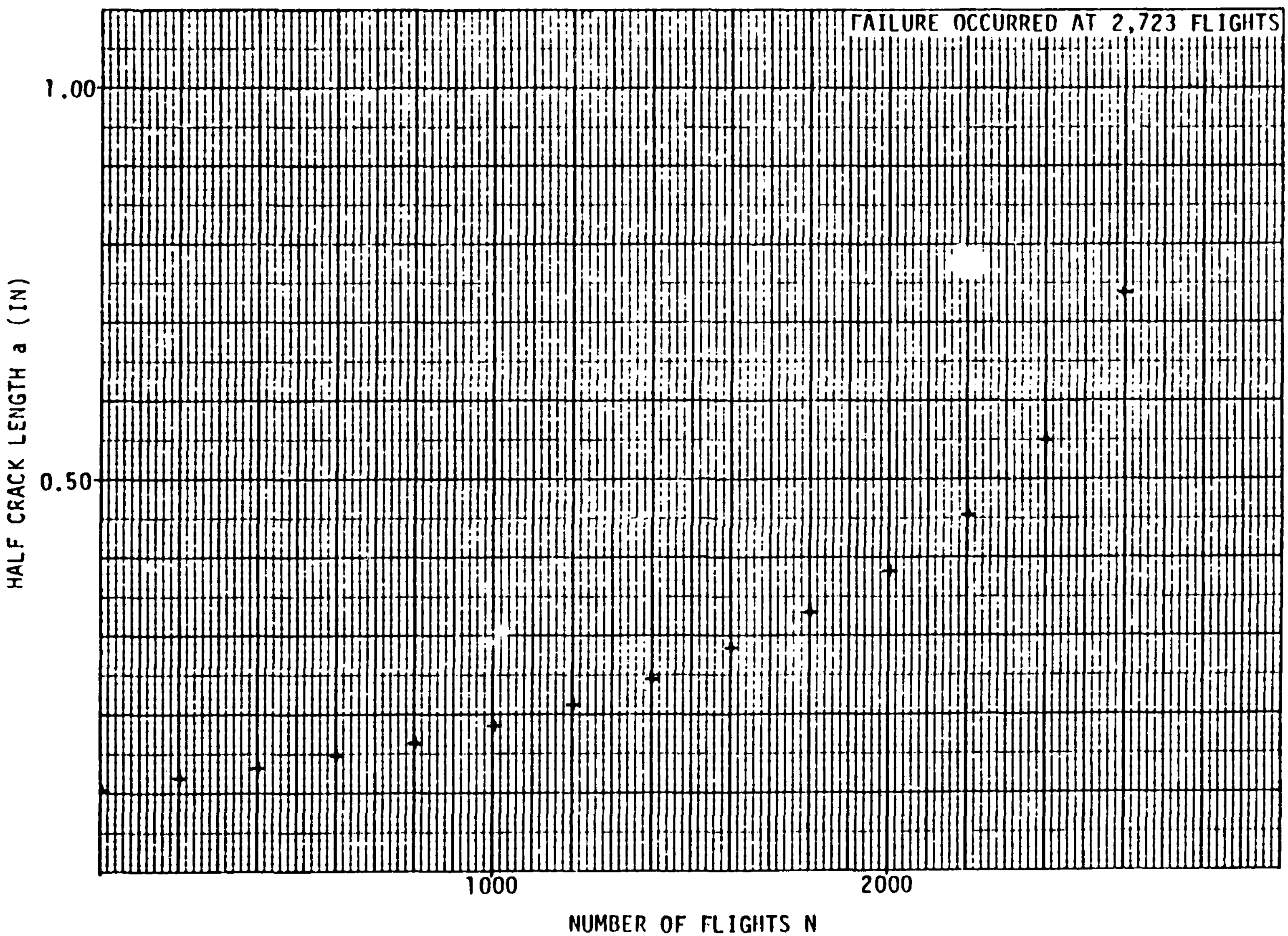


FIGURE A19. a VS N PLOT FOR A 7050-T73651 ALUMINUM ALLOY PLATE SUBJECTED TO THE FALSTAFF SPECTRUM USING A 100% TLS OF 30 KSI (SPECIMEN 10L-7050-FAL)

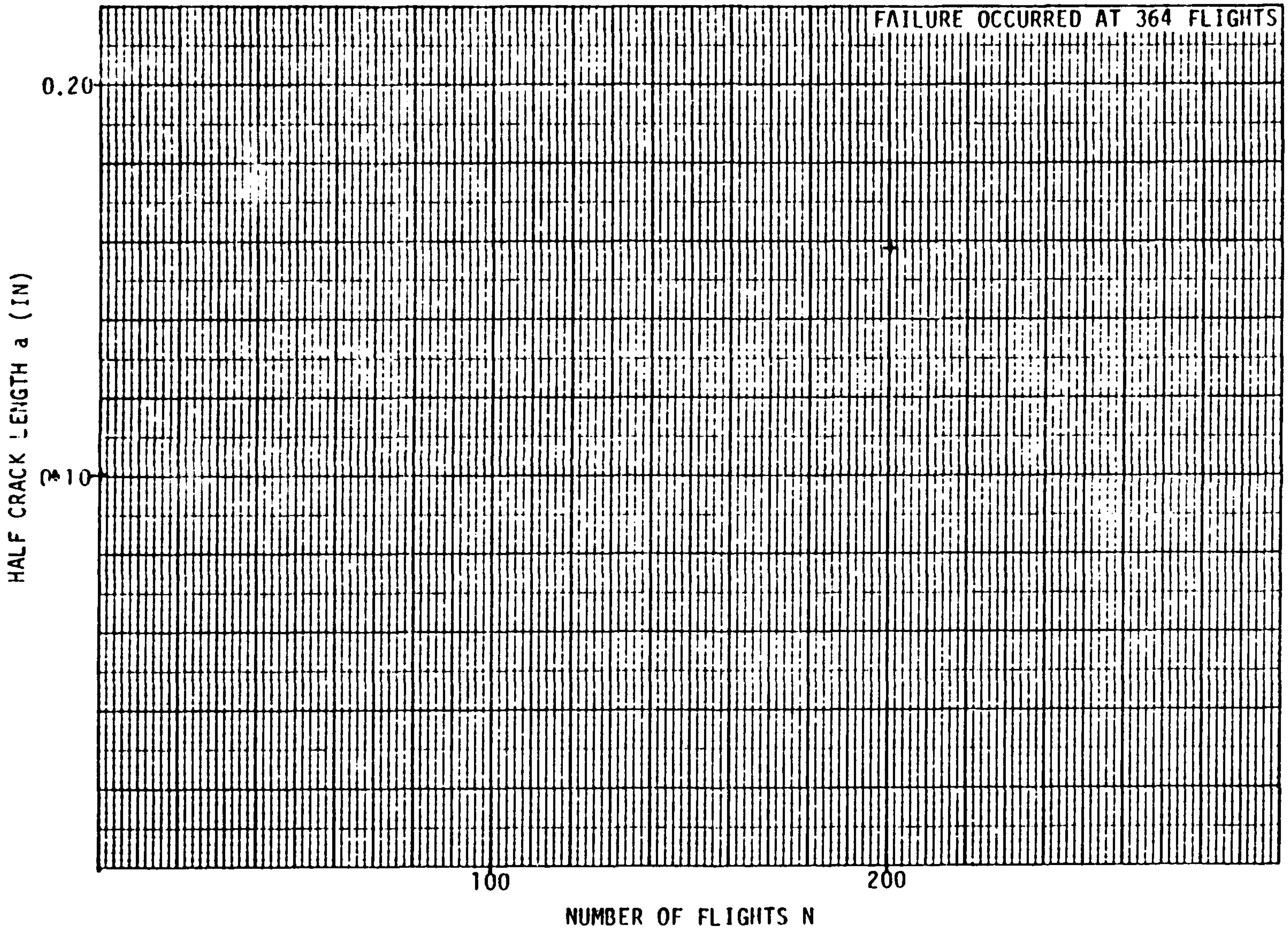


FIGURE A18. a VS N PLOT FOR AN X7091-T7E78 ALUMINUM ALLOY HAND FORGING SUBJECTED TO THE FALSTAFF SPECTRUM USING A 100% TLS OF 45 KSI (SPECIMEN 10L-SF3-FAL)

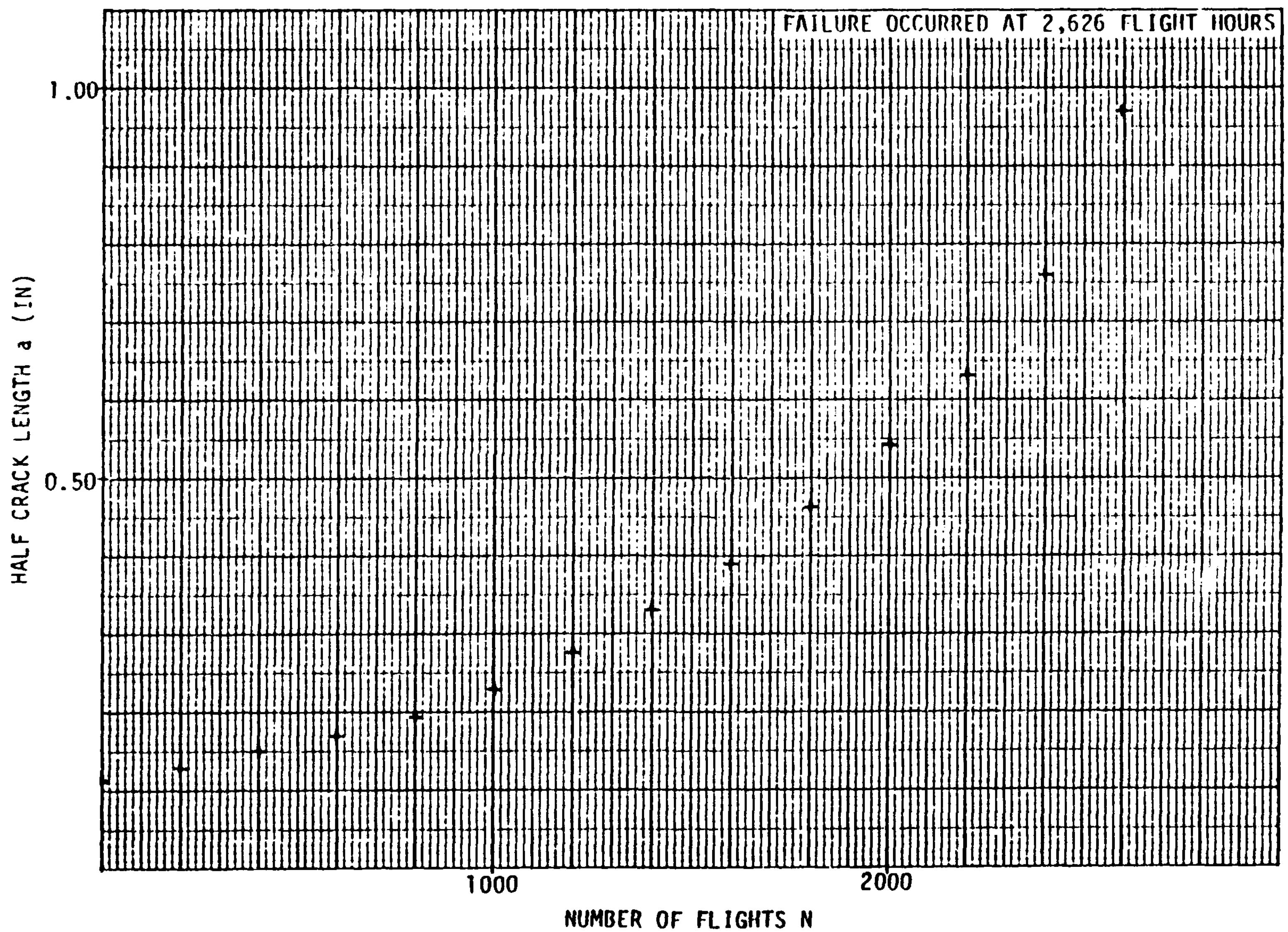


FIGURE A17. a VS N PLOT FOR AN X7091-T7E78 ALUMINUM ALLOY HAND FORGING SUBJECTED TO THE FALSTAFF SPECTRUM USING A 100% TLS OF 30 KSI (SPECIMEN 10L-SF2-FAL)

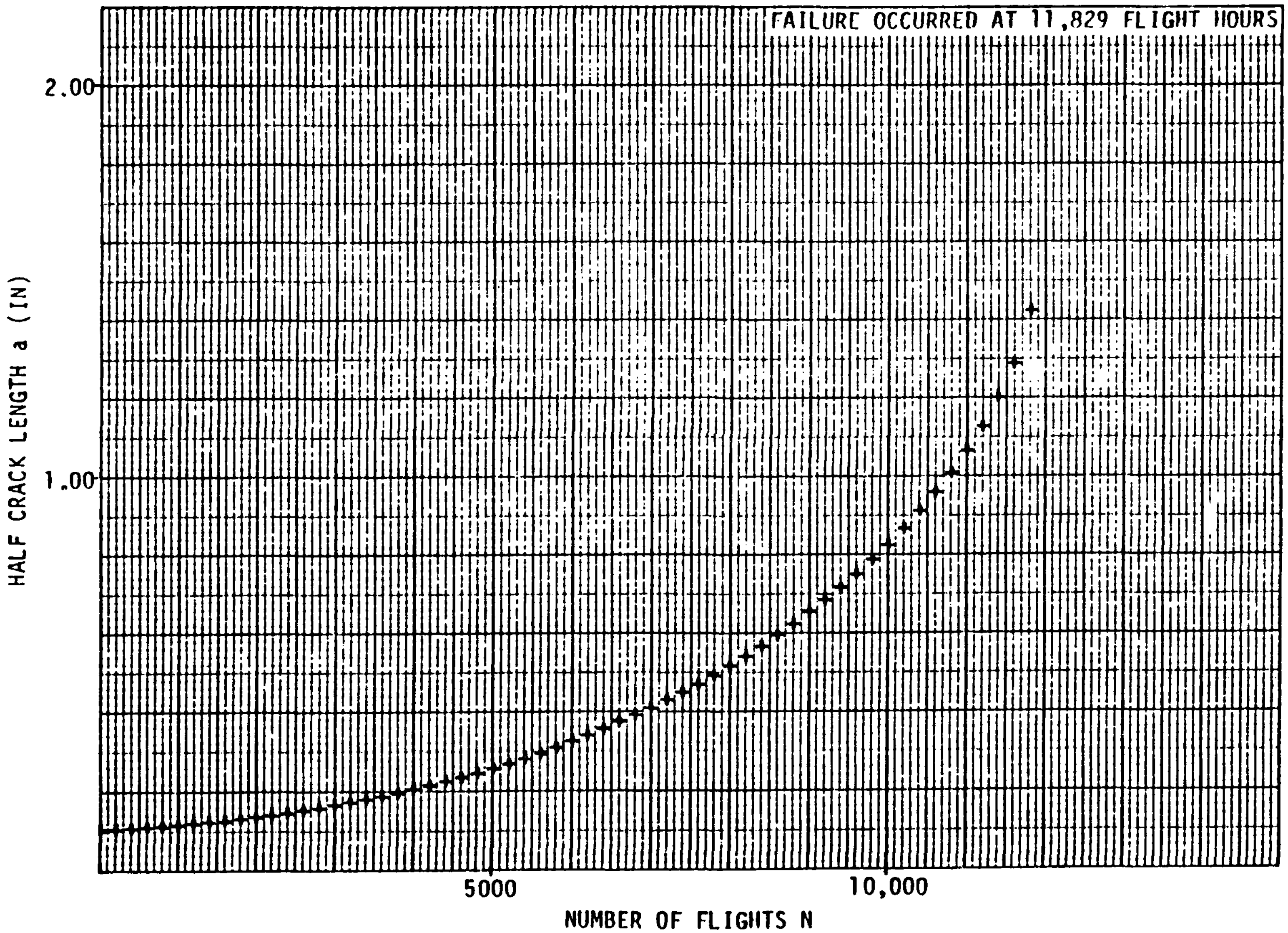


FIGURE A16 - a VS N PLOT FOR AN X7091-T7E78 ALUMINUM ALLOY HAND FORGING SUBJECTED TO THE FALSTAFF SPECTRUM USING A 100% TLS OF 15 KSI (SPECIMEN 10L-SF1-FAL)

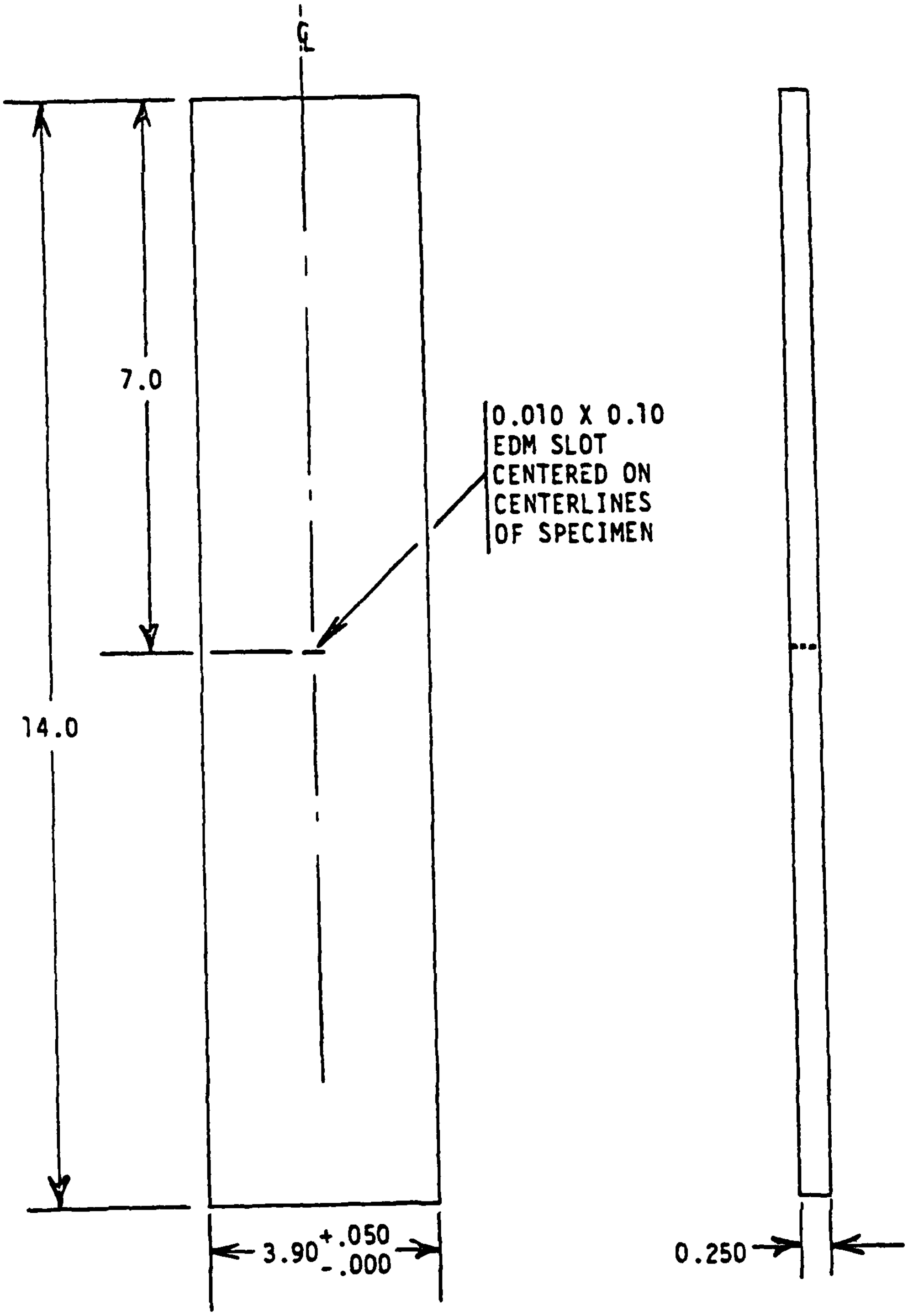


Figure A15. Specimen used by McDonnell-Douglas to Generate Data in Figures A16 thru A23.

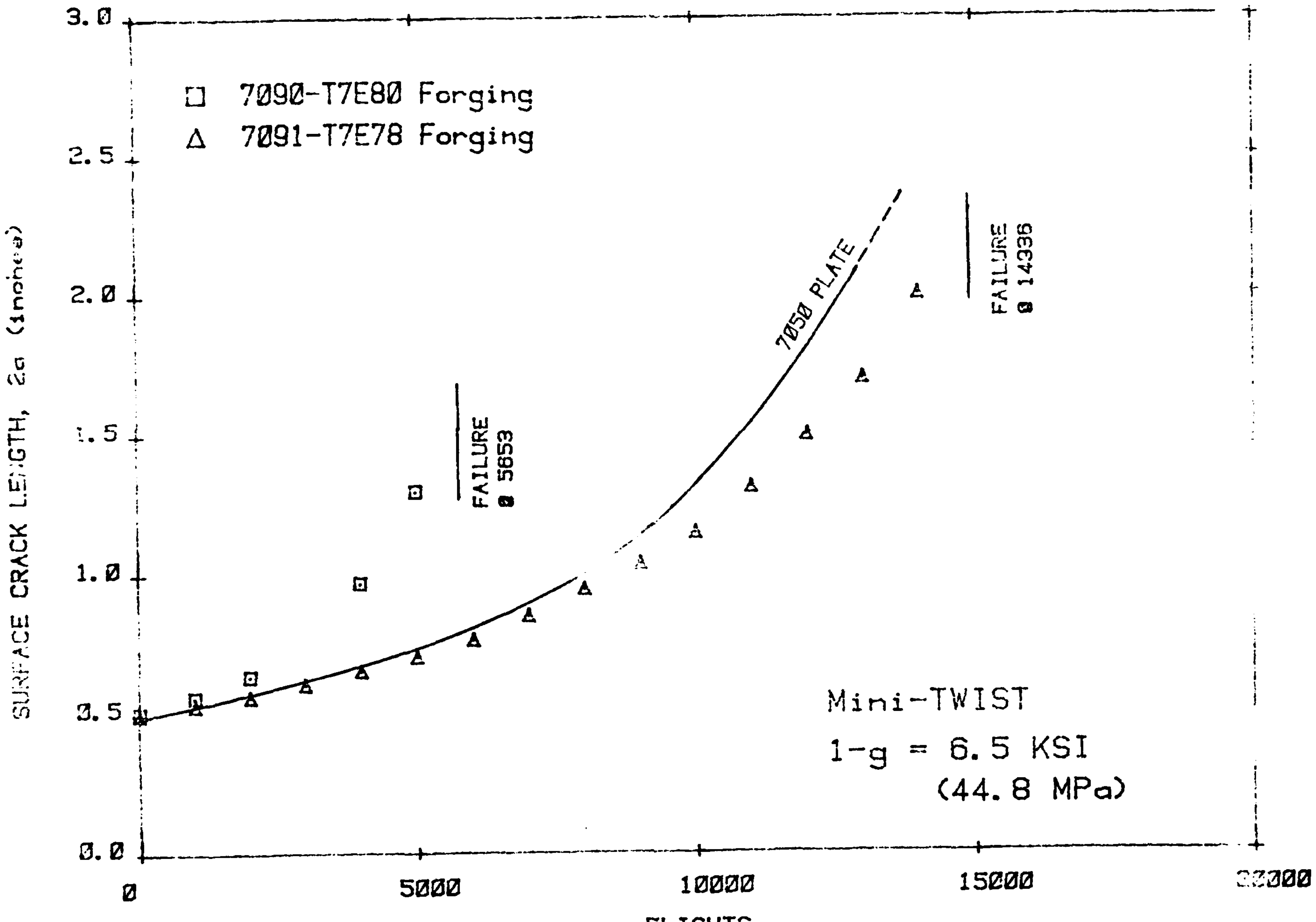


Figure A14. Crack Length Versus Flights Record for 7091 Forging Under Mini-TWIST Loading.

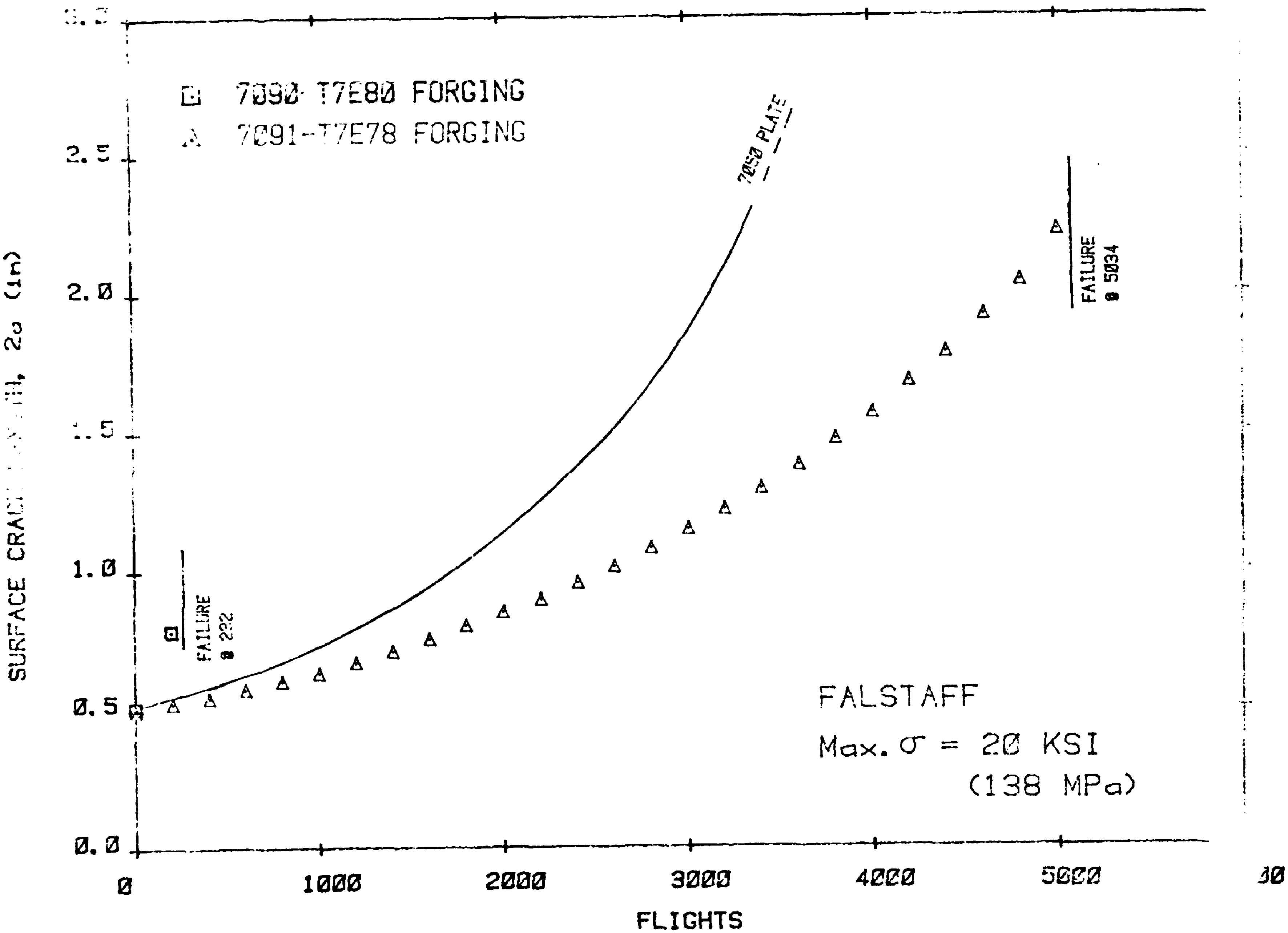


Figure A13. Crack Length Versus Flights Record for 7091 Forging Under FALSTAFF Loading.

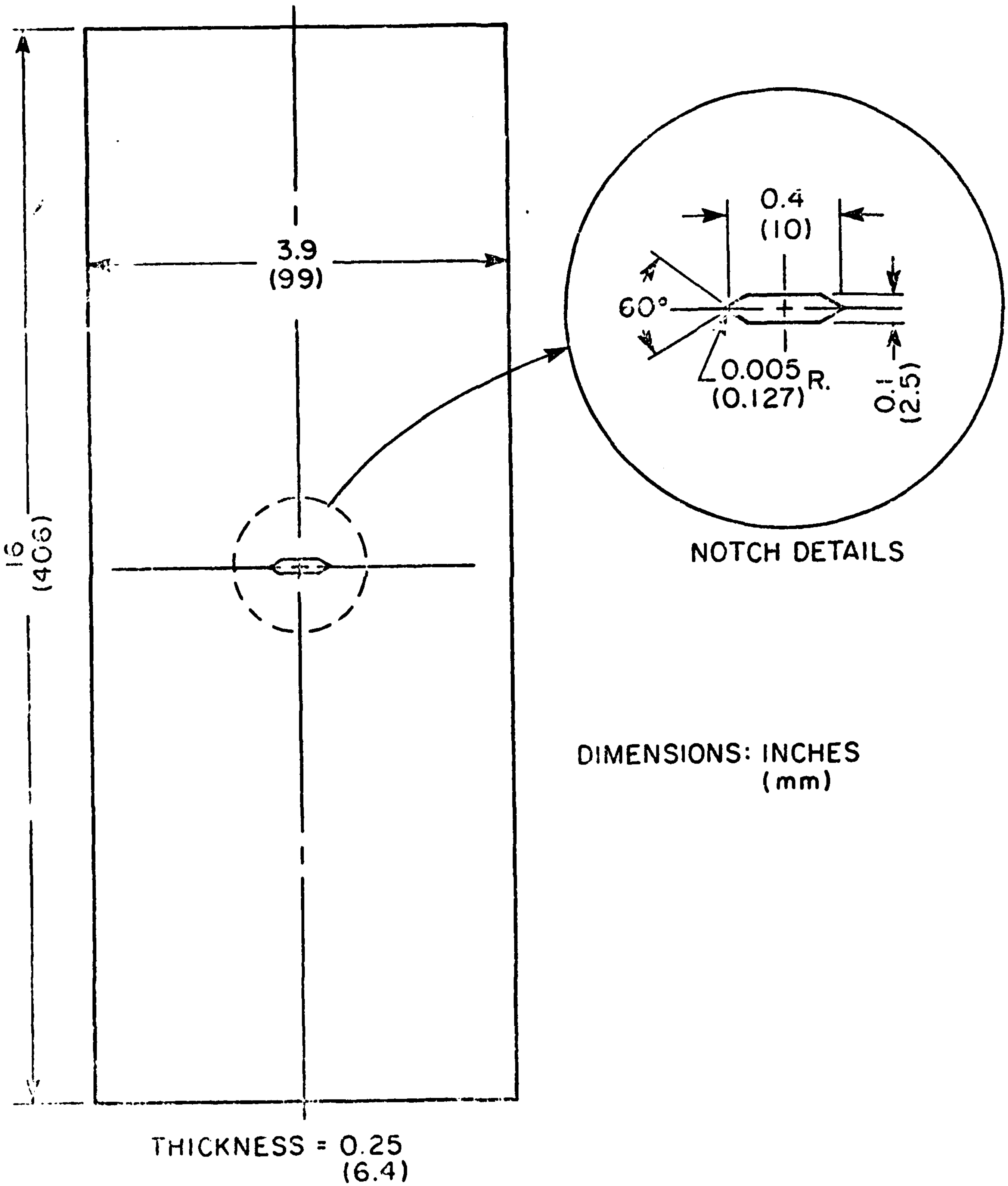


Figure A12. Specimen used to Generate Data in Figures A13 and A14.

SPECTRUM FATIGUE CRACK GROWTH

Two different investigations, using four different spectra, evaluated 7091 forgings. Although both investigations employed the FALSTAFF spectrum, one was a modified (truncated) version. The study conducted at the Materials Laboratory used the standard FALSTAFF and (Standard) mini-TWIST. Results were compared to similar results for 7050-T76 plates. The FALSTAFF tests showed the 7091 forgings to have a slightly longer life while the mini-TWIST results showed a significantly longer life for the 7091. These are shown in the attached figures which include a specimen drawing.

McDonnell, St Louis, used a FALSTAFF and a fighter wing root spectrum called TSTROOT. Tests of 7091 were performed at three stress levels for each spectrum while companion tests on 7050-T73651 plate were performed at one stress level for each spectrum. Comparing flights to failure for the one stress the 7050 plate has a slightly better life using the FALSTAFF spectrum and a significantly better life for the TSTROOT spectrum. Some of the data was normalized in terms of crack growth per flight and maximum stress intensity during the spectrum and are shown in the attached two figures. Here the different responses to the two spectra are not so apparent, but it does appear that the first pass through the TSTROOT spectrum by the 7091 displayed an overly fast growth rate which may have affected the total flights to failure. All of the data from these tests are attached.

CORROSION

Three companies, ALCOA, Boeing and McDonnell-Douglas, St Louis, tested the material in the short transverse direction for stress corrosion cracking. The lowest reported failure occurred at 40 KSI.

TABLE A25

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE A11 INDICATING EFFECT OF STRESS RATIO

ALCOA

MATERIAL: ALUMINUM 7091
CONDITION: T7E78
ENVIRONMENT: R.T. ,HI HUMIDITY

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN./CYCLE) A R=+0.10	B R=+0.33	C	D
DELTA K MIN A:	1.74	.0251			
DELTA K MIN B:	1.07		.0381		
DELTA K MIN C:					
DELTA K MIN D:					
	1.30		.0807		
	1.60		.159		
	2.00	.0520	.298		
	2.50	.152	.516		
	3.00	.328	.786		
	3.50	.590	1.11		
	4.00	.947	1.52		
	5.00	1.98	2.63		
	6.00	3.49	4.59		
	7.00	5.59	7.01		
	8.00	8.42	11.1		
	9.00	12.2	17.5		
	10.00	17.0	27.4		
	13.00	41.9	100.		
	16.00	93.0			
DELTA K MAX A:	18.95	142.			
DELTA K MAX B:	14.40		131.		
DELTA K MAX C:					
DELTA K MAX D:					

CONDITION/HT: T7E78
FORM: 2.50"TH FORGING
SPECIMEN TYPE: CT
ORIENTATION: S-L
FREQUENCY: 10.00- 25.00 HZ
ENVIRONMENT: R.T., HI HUMIDITY

YIELD STRENGTH: 62.7 KSI
ULT. STRENGTH: 75.1 KSI
SPECIMEN THK: 0.251"
SPECIMEN WIDTH: 1.998- 1.999"
REFERENCES:

ALUM. ALLOY

7091

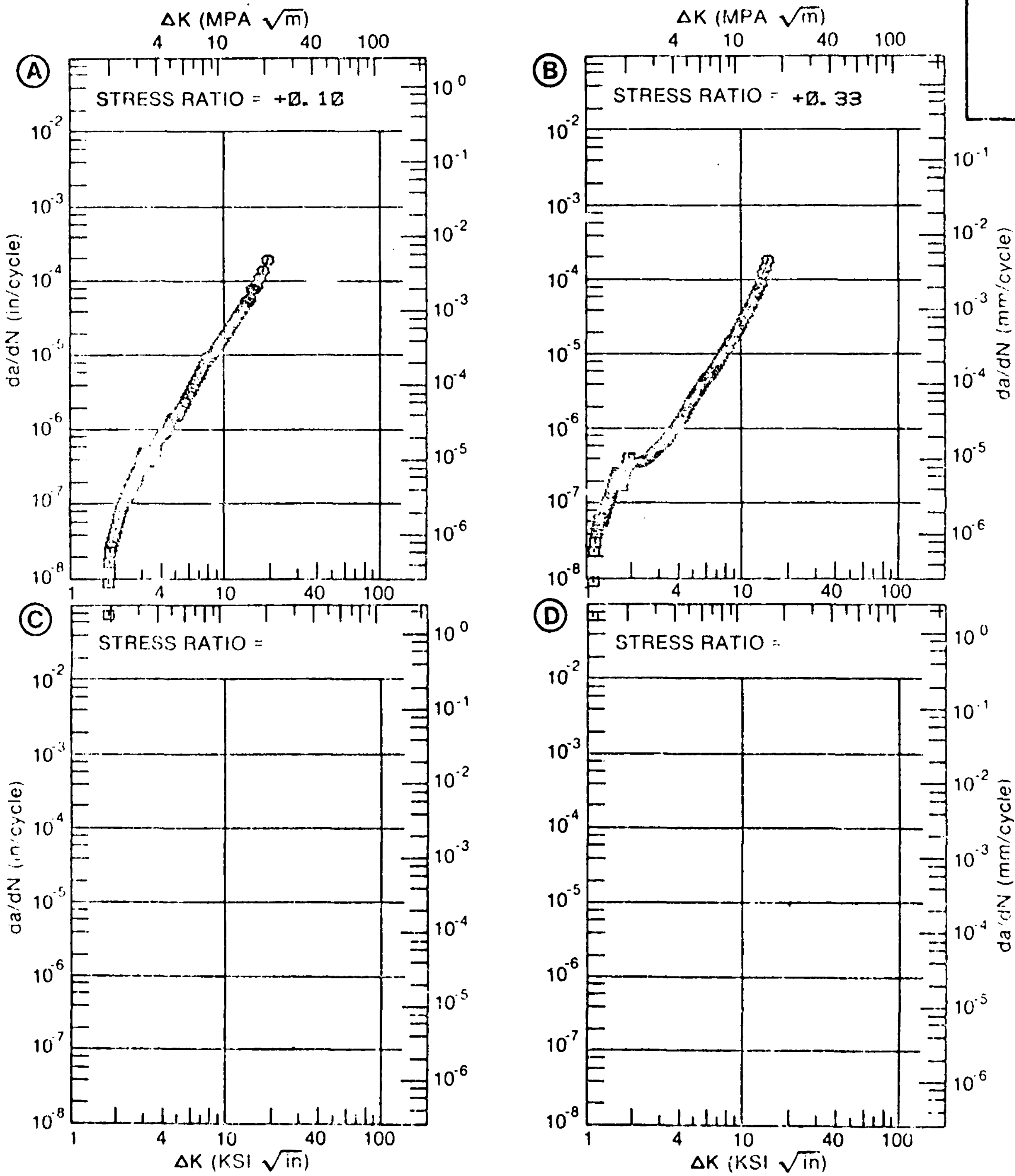


Figure A11 Fatigue Crack Growth Rate Data for 7091 Forgings; ALCOA

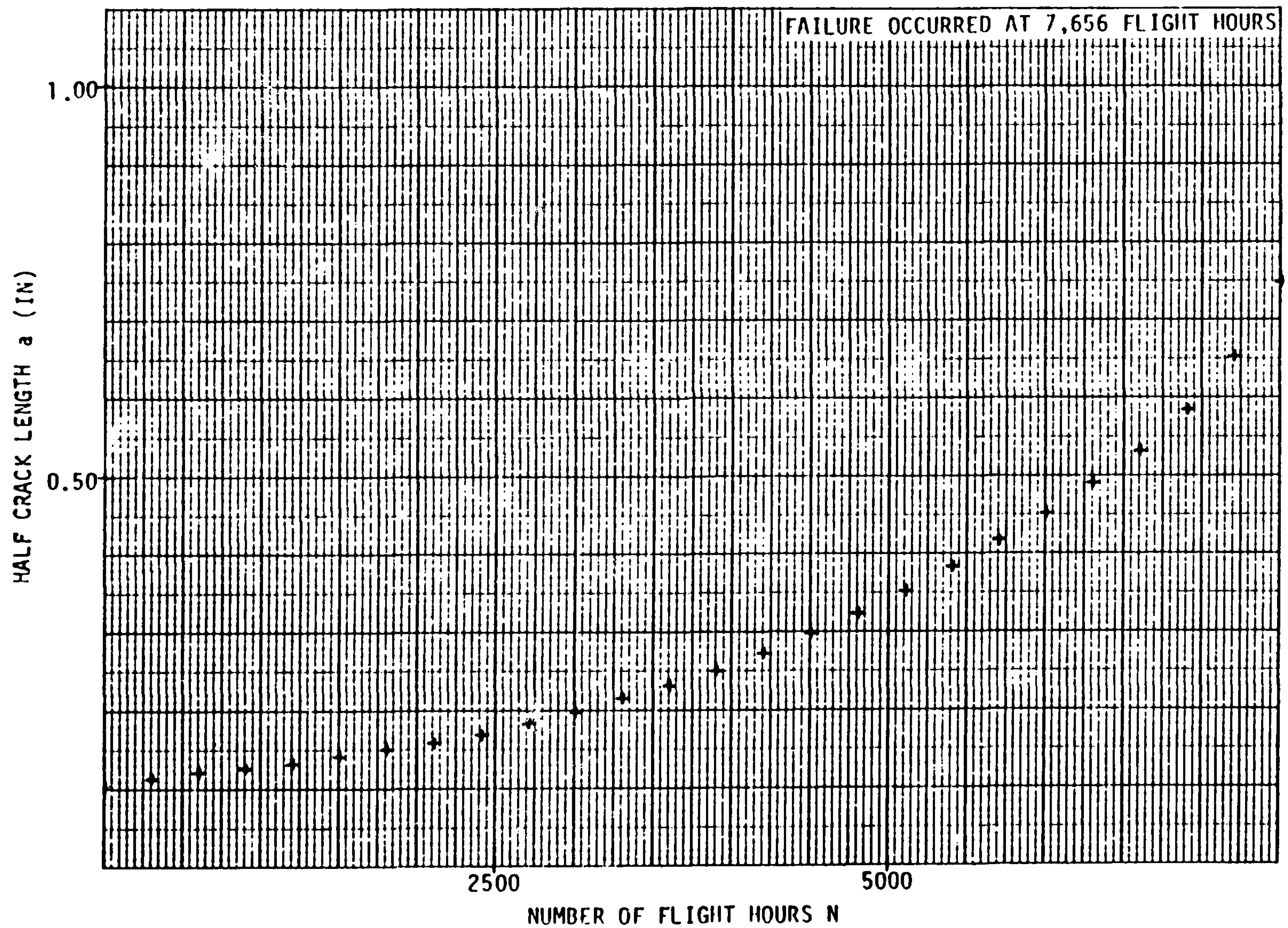


FIGURE A23. a VS N PLOT FOR A 7050-T73651 ALUMINUM ALLOY PLATE SUBJECTED TO THE TSTROOT SPECTRUM USING A 100% TLS OF 30 KSI (SPECIMEN 10L-7050-FWR)

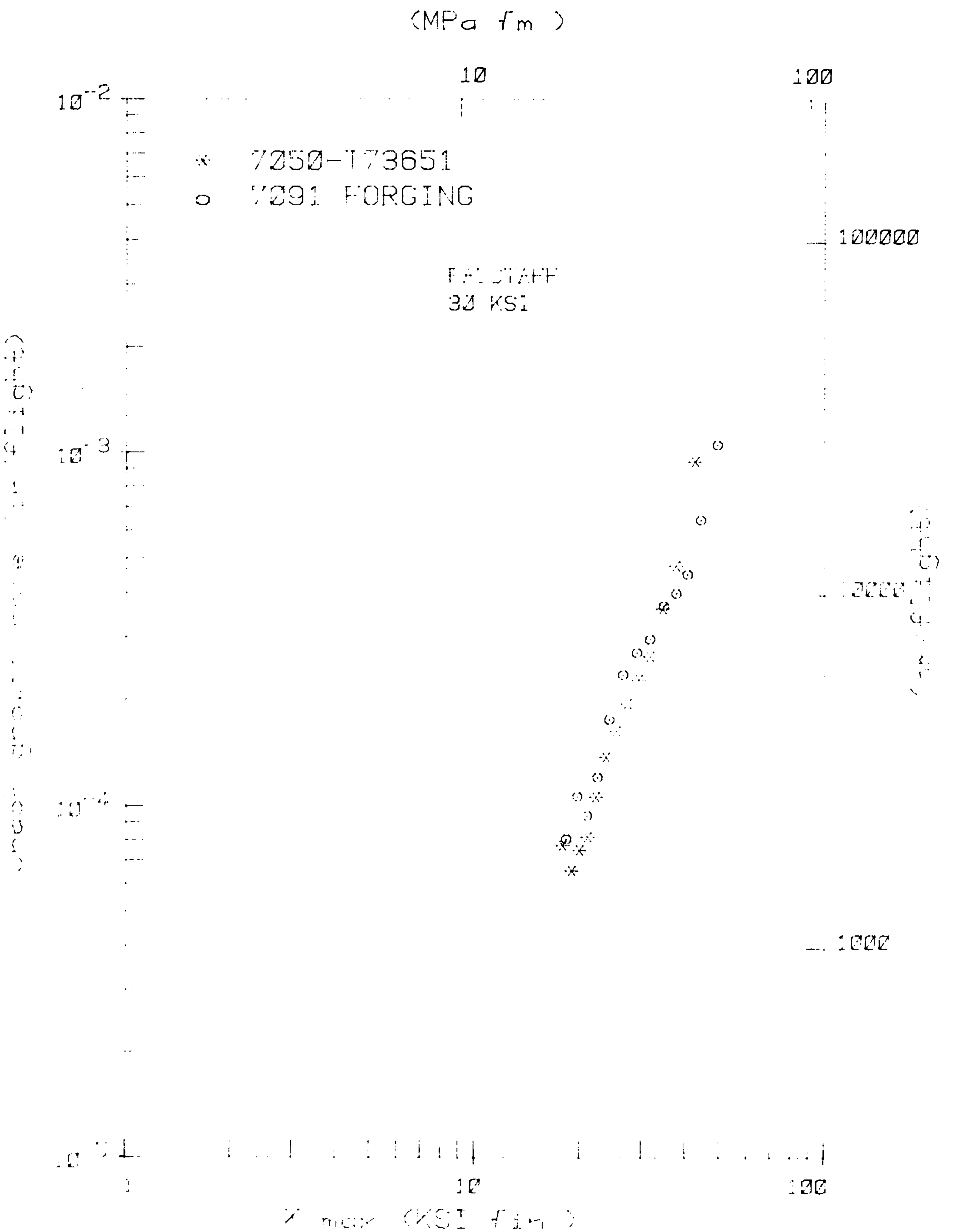


Figure A24. Spectrum Data from McDonnell-Douglas Reduced in Term of Crack Growth Rate.

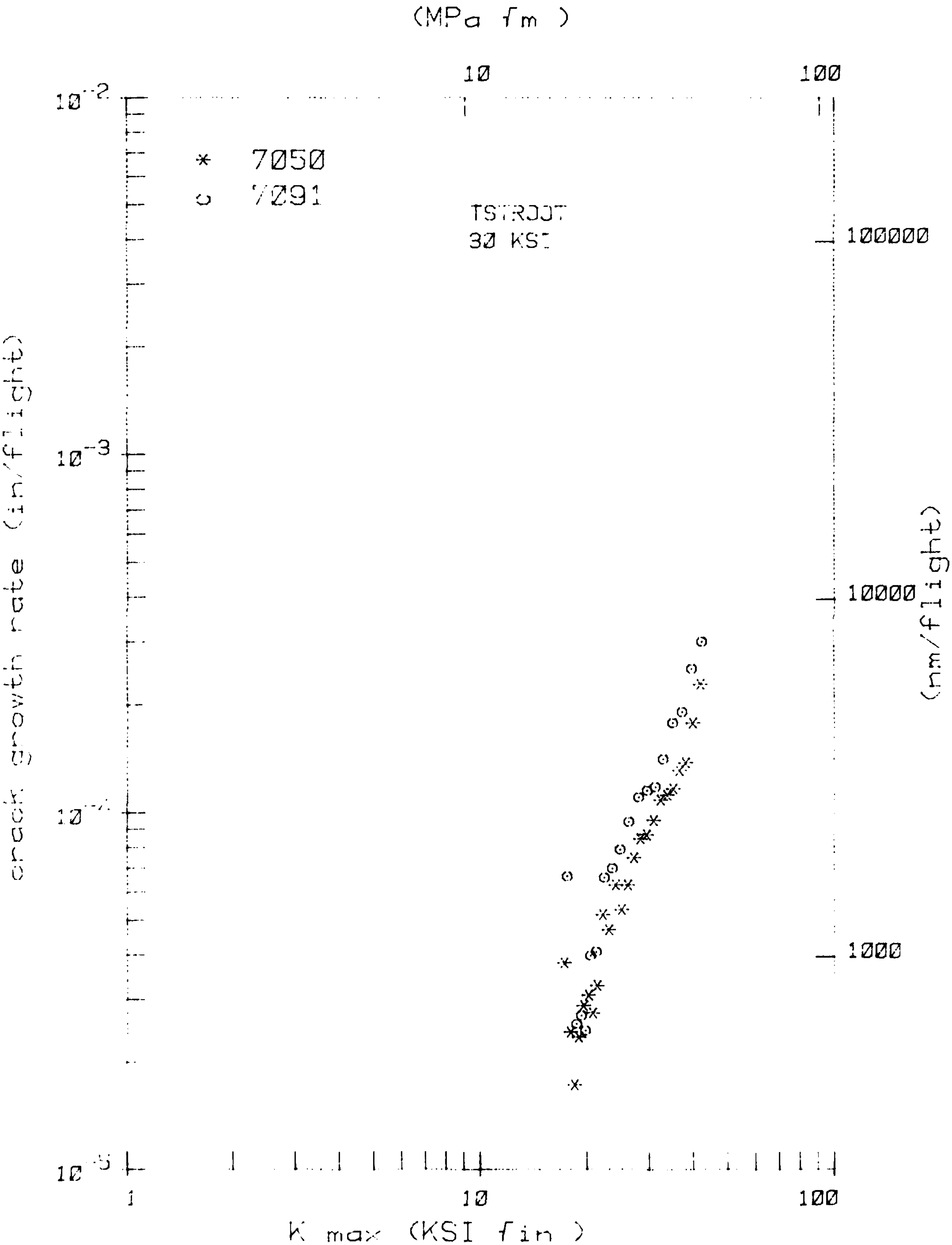


Figure A25. Specimen Data From McDonnell-Douglas Reduced in Term of Crack Growth Rate.

CORROSION RESULTS FROM ALCOA

Table A26 lists the results of a 30-day exposure to 3-½% sodium chloride by alternate immersion of triplicate short-transverse 3.1 mm (1/8") diameter by 51 mm (2") long tensile bars removed from 7091-T7E78 alloy hand forgings. The tensile bars were stressed to two stress levels- 172 MPa (25ksi) and 310 MPa (45ksi). No failures were encountered in any case with the stressed tensile specimens.

TABLE A26

Corrosion Results From ALCOA

PERFORMANCE OF SHORT TRANSVERSE 3.1 mm (1/8") DIAMETER SMOOTH TENSILE BARS WHICH WERE REMOVED FROM 7090 AND 7091 HAND FORGINGS (1), STRESSED AND EXPOSED 30 DAYS TO 3-1/2% SODIUM CHLORIDE BY ALTERNATE IMMERSION (2)

S. No.	Alloy	Temper	Stress Level (ksi/MPa)	No. Failures/No. Specimens Tested
513910-2-16	7090	T7E80	25/172	0/3
513910-2-16	7090	T7E80	45/310	0/3
513910-7-11	7090	T7E80	25/172	0/3
513910-7-11	7090	T7E80	45/310	0/3
513825-10-18	7091	T7E78	25/172	0/3
513825-10-18	7091	T7E78	45/310	0/3
513825-26-13	7091	T7E78	25/172	0/3
513825-26-13	7091	T7378	45/310	0/3

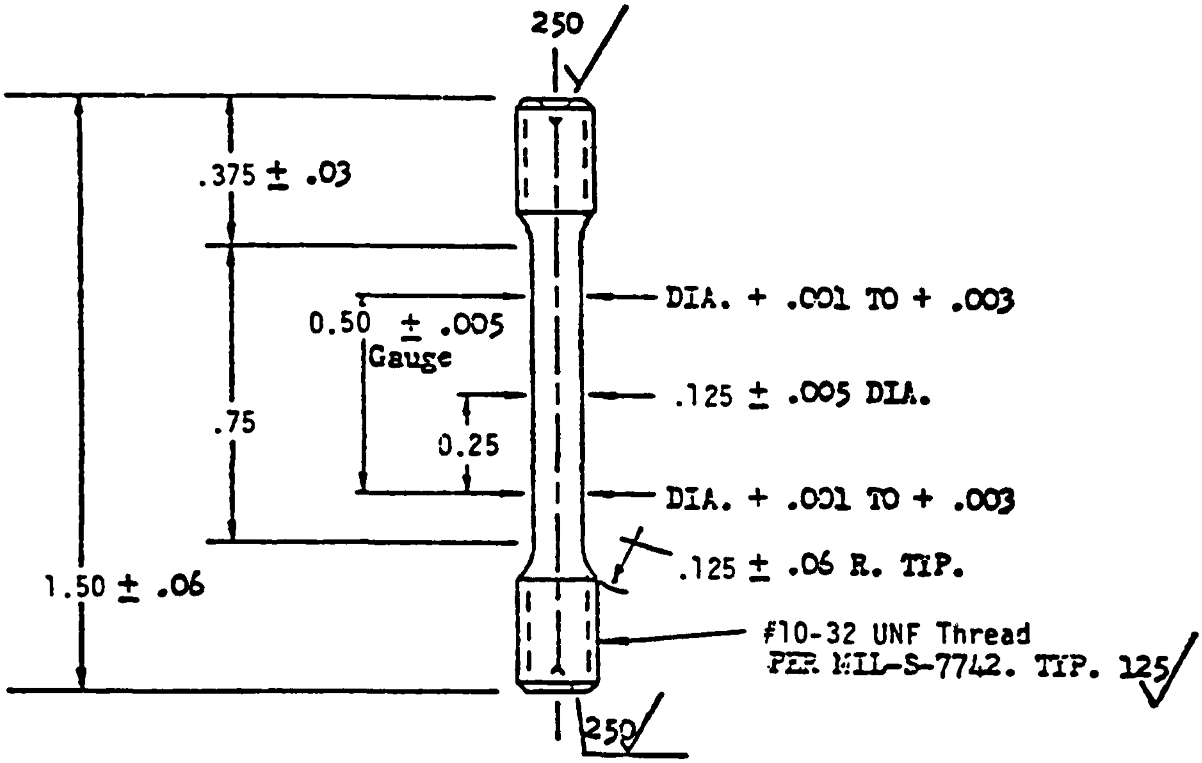
NOTES: (1) Hand forgings were 63 mm x 152 mm x 610 mm (2-1/2" x 6" x 24") in size and were produced in Cleveland from 50 kg (110 lb) billets sawed in half.

(2) 3-1/2% sodium chloride alternate immersion tests was conducted in accordance with ASTM G44-75.

TABLE A27 **Durability Properties of Aluminum P/M Products**
Results From BOEING.

Material	Direction	Notch Fatigue, cycles (23 ksi, R=0.06, ν=25 Hz)	Fastener Fatigue, cycles (20 ksi, R = -1.0 ν = 30 Hz)	Stress Corrosion Cracking, ksi (90-day threshold)	Exfoliation (MASTMAASIS)
Hand Forgings:					
<u>Alcoa</u>					
7075-T7352	L	-	115,000/124,000/221,000	-	Small amt of exfoliation and pitting
	LT	-		-	
7050-T73652	L	-		-	
	LT	-		-	
X7090-T7E80	L	-		-	Very slight amt of exfoliation and no pitting
	LT	-		-	
X7091-T7E78	L	53,100/38,100/43,500	416,000/256,000	-	Small amt of exfoliation and very slight pitting
	LT	53,400/46,300/29,800		>60	
	ST	-		>10	
<u>Novamet</u>					
7075-T7352	L	-	117,000/98,000	-	Very slight amt of exfoliation and moderate pitting
	LT	-		-	
IN9021-T352	L	30,000/18,800/1,000,000+	265,000/533,000	-	Very slight amt of exfoliation and moderate pitting
	LT	208,000/1,000,000+/33,000		>60	
Extrusions:					
<u>Alcoa</u>					
X7090-T7E71	L	-		-	Very slight amt of exfoliation and no pitting
	LT	-		>60	
<u>Novamet</u>					
IN9021-T6X[a]	L	27,300/19,300/17,600		-	Small amt of exfoliation and pitting
	LT	-		>50	
IN9021-T6Y[b]	L	12,500/155,000/27,000		-	
	LT			>50	

(a) T6X: solution treated, quenched, stretched 4%, artifically aged
(b) T6Y: solution treated, quenched, artifically aged



NOTES:

1. ALL REQUIRED HEAT TREATMENT SHALL BE PERFORMED PRIOR TO FINISH MACHINING.
2. DO NOT GRIND.
3. SPECIMEN SHALL BE CONCENTRIC WITH THREADS WITHIN .005 FIR.
4. CENTER OF GAUGE MUST BE SMALLER THAN ENDS WITHIN THE SPECIFIED TOLERANCE. TAPER MUST BE GRADUAL.
5. SURFACE ROUGHNESS PER MIL-STD-10. 63/ RHR EXCEPT AS NOTED.
6. SPECIMEN SHALL BE FREE OF NICKS, DENTS, SCRATCHES AND MACHINING MISMATCH.

TOLERANCES: ± .010 UNLESS OTHERWISE SPECIFIED.

Figure A26. Subsize Tensile Specimen Configuration used by McDonnell-Douglas.

TABLE A28

CORROSION TEST RESULTS FROM McDONNELL-DOUGLAS

SPECIMEN	STRESS LEVEL (KSI)	TIME TO FAILURE (HOURS)
2S-SCC-1	30	NF
2S-SCC-2	30	NF
2S-SCC-3	40	NF
2S-SCC-4	40	33 to 80*
2S-SCC-5	50	33 to 80*
2S-SCC-6	50	33 to 80*

* Specimens failed during a weekend.

TABLE A29

Results From McDonnell-Douglas

STRESS CORROSION DATA FOR 7091-T7E78

2 1/2 INCH THICK HAND FORGING

Specimen Dwg. No. ZC007394-1 ST Grain Direction

ASTM G44 & D1141, Substitute Ocean Water

SPECIMEN CODE	SUSTAINED STRESS (KSI)	EXPOSURE (DAYS)	RESULTS
SC1 Anodized	50	92	No Failure (NF)
SC2 Anodized	50	71	Failure
SC3	50	92	NF *
SC4	50	92	NF *

* Significant surface corrosion on unanodized specimens.

APPENDIX B

7090-T7E80 FORGINGS

NOTICE: Suggested allowables, mean trends, and trend curves in this document were developed to be used in a cost benefit analysis to assess the potential benefit of using the material in a structure. These suggested allowables and trends are not considered accurate for design of actual hardware.

TABLE B1

SUGGESTED ALLOWABLES FOR

7090-T7E80 FORGINGS: 2-1/2" x 6"

F_{tu}, KSI		
	L	78.6
	LT	77.2
	ST	74.8
F_{ty}, KSI		
	L	70.1
	LT	67.1
	ST	63.5
F_{cy}, KSI		
	L	70.3
	LT	73.3
	ST	73.6
F_{su}, KSI		
	L	46.9
	LT	47.1
F_{bu}, KSI		
	L	
	(e/D = 1.5)	123.5
	(e/D = 2.0)	146.9
	LT	
	(e/D = 1.5)	128.2
	(e/D = 2.0)	147.5)
F_{by}, KSI		
	L	
	(e/D = 1.5)	111.0
	(e/D = 2.0)	112.5
	LT	
	(e/D = 1.5)	111.5
	(e/D = 2.0)	115.6
K_{IC}, KSI $\sqrt{IN}$		
	LT	14.6
	TL	16.6
	SL	18.1

NOTE: These values were developed to be used only in a cost-benefit-analysis and are not necessarily accurate for design of hardware.

TABLE B2
7090 FORGING:
TENSILE

COMPANY	TEST TEMP °F	ORIENTATION	ULT STR KSI	YIELD STR KSI	ELONG %
ROCKWELL	RT	LONG	82.6	74.5	11.9
			81.0	72.5	12.2
			78.7	70.8	11.2
VOUGHT	RT		80.0	75.3	-
			80.0	73.3	7.6
			83.7	77.6	5.3
ALCOA	RT		80.9	71.9	11.5
			78.6	70.8	10.0*
			81.2	72.0	12.5*
BOEING	RT		80.7	72.3	11.8
			78.6	69.9	11.5
AFWAL	RT		86.4	78.2	12.0
			82.9	73.9	11.6
			84.0	75.9	12.9
VOUGHT	500°		74.7	66.3	10.2
			75.3	67.2	10.0
			69.7	66.3	8.8

* Internal discontinuity

TABLE B3

7090 FORGING
TENSILE

COMPANY	TEST TEMP °F	ORIENTATION	ULT STR KSI	YIELD STR KSI	ELONG %
ROCKWELL	RT	TRANS	79.6	70.1	10.4
			79.8	70.1	12.2
			79.8	71.0	11.6
VOUGHT			79.0	69.8	7.6
			83.3	75.9	6.6
			75.9	66.4	8.8
ALCOA			81.8	71.4	8.5
			81.0	71.3	8.0
			79.9	69.7	10.5*
BOEING			79.6	69.5	8.5
			79.4	69.3	8.9
ALCOA	RT	SHORT TRANS	78.1	64.9	5.0
			77.6	66.5	5.0
			77.7	66.8	2.0
ROCKWELL			76.7	65.5	2.8
			74.8	64.7	2.2
			75.3	63.5	3.6

* Internal discontinuity

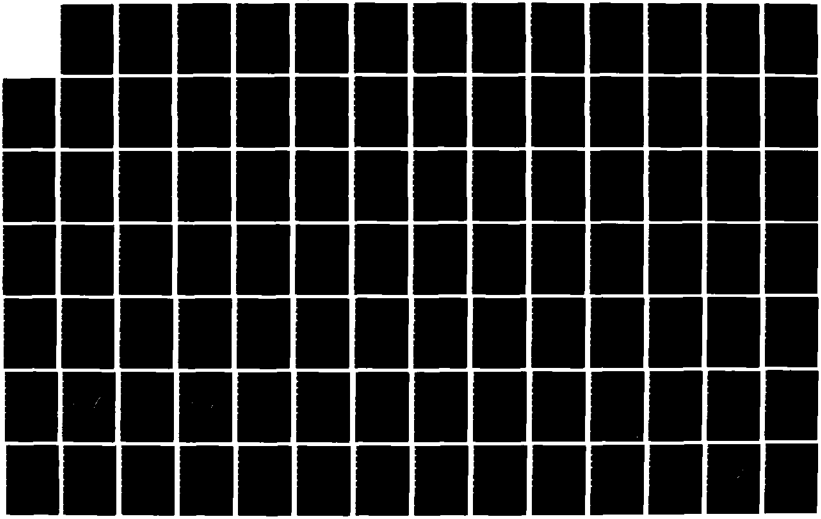
TABLE B4

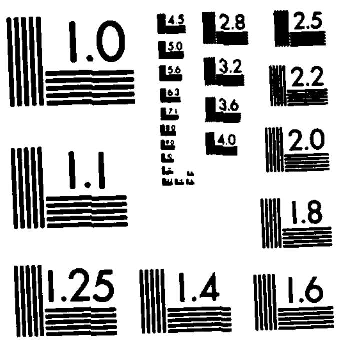
7090 FORGING
COMPRESSION

COMPANY	ORIENTATION	COMP YIELD STR KSI
ROCKWELL	LONG	72.5
		73.0
		75.1
VOUGHT		80.6
		85.4
		83.6
ALCOA		73.9
		73.2
		70.3
BOEING		73.3
		74.4
VOUGHT		73.1 Tested at 410^{o}F

AD-A159 779 THE MECHANICAL PROPERTY DATA BASE FROM A COOPERATIVE PROGRAM ON FIRST GEN. (U) AIR FORCE WRIGHT AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH G J PETRAK ET AL. AUG 85 2/4

UNCLASSIFIED AFWAL-TR-85-4052 F/G 11/6 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE B5

7090 FORGING
COMPRESSION

COMPANY	ORIENTATION	COMP YIELD STR (KSI)
ROCKWELL	TRANS	76.9
		73.3
		74.4
VOUGHT		83.1
		86.9
		85.4
ALCOA		73.4
		74.1
		73.5
ALCOA	SHORT TRANS	73.6
		75.9
		75.7

TABLE B6

7090 FORGING
SHEAR

COMPANY	ORIENTATION	SHEAR STR KSI
ROCKWELL	LONG	49.7
		49.5
		50.2
VOUGHT		54.1
		48.8
		48.6
		50.5
ALCOA		47.3
		46.9
		46.9

TABLE B7

7090 FORGING
SHEAR

COMPANY	ORIENTATION	SHEAR STR KSI
ROCKWELL	TRANS	-
		48.4
		48.0
ALCOA		48.2
		47.1
		47.6

TABLE B8

7090 FORGING
BEARING

COMPANY	ORIENTATION	e/D	BEARING ULT STR KSI	BEARING YIELD STR KSI	
ALCOA	LONG	1.5	129.8	117.6	
			127.1	111.0	
			123.5	112.7	
ALCOA		2.0	147.8	125.9	
			147.7	127.5	
			160.5	132.2	
VOUGHT			154.7	126.6	
			152.4	120.5	
			146.9	112.5	
			98.4	-	500^{0}F
			104.7	-	500^{0}F
			68.8	-	500^{0}F

TABLE B9

7090 FORGING
BEARING

COMPANY	ORIENTATION	e/D	BEARING ULT STR KSI	BEARING YIELD STR KSI
ALCOA	TRANS	1.5	130.3	117.6
			128.2	111.5
			129.3	117.2
ALCOA	TRANS	2.0	162.5	132.6
			160.0	132.7
			162.7	137.4
VOUGHT			148.4	120.3
			159.4	121.9
			153.1	115.6
			147.5	126.9

TABLE B10

7090 FORGING
FRACTURE TOUGHNESS, K_{IC}

COMPANY	ORIENTATION	K_{IC} (KSI $\sqrt{IN}$)	K_Q (KSI $\sqrt{IN}$)	COMMENT
VOUGHT	L-T	15.8		valid
			17.8	invalid
ALCOA	L-T	20.4		valid
		21.4		valid
		21.4		valid
BOEING	L-T	14.6		
VOUGHT	T-L	19.0		valid
		21.2		valid
ALCOA	T-L		13.5	invalid Kf greater than $0.6K_Q$ for last step
		16.6		valid
			16.0	invalid Kf greater than $0.6K_Q$ for last step
ALCOA	S-L		18.6	invalid Kf greater than $0.6\ K_Q$ for last step
	S-L	18.1		valid
	S-L	19.8		valid

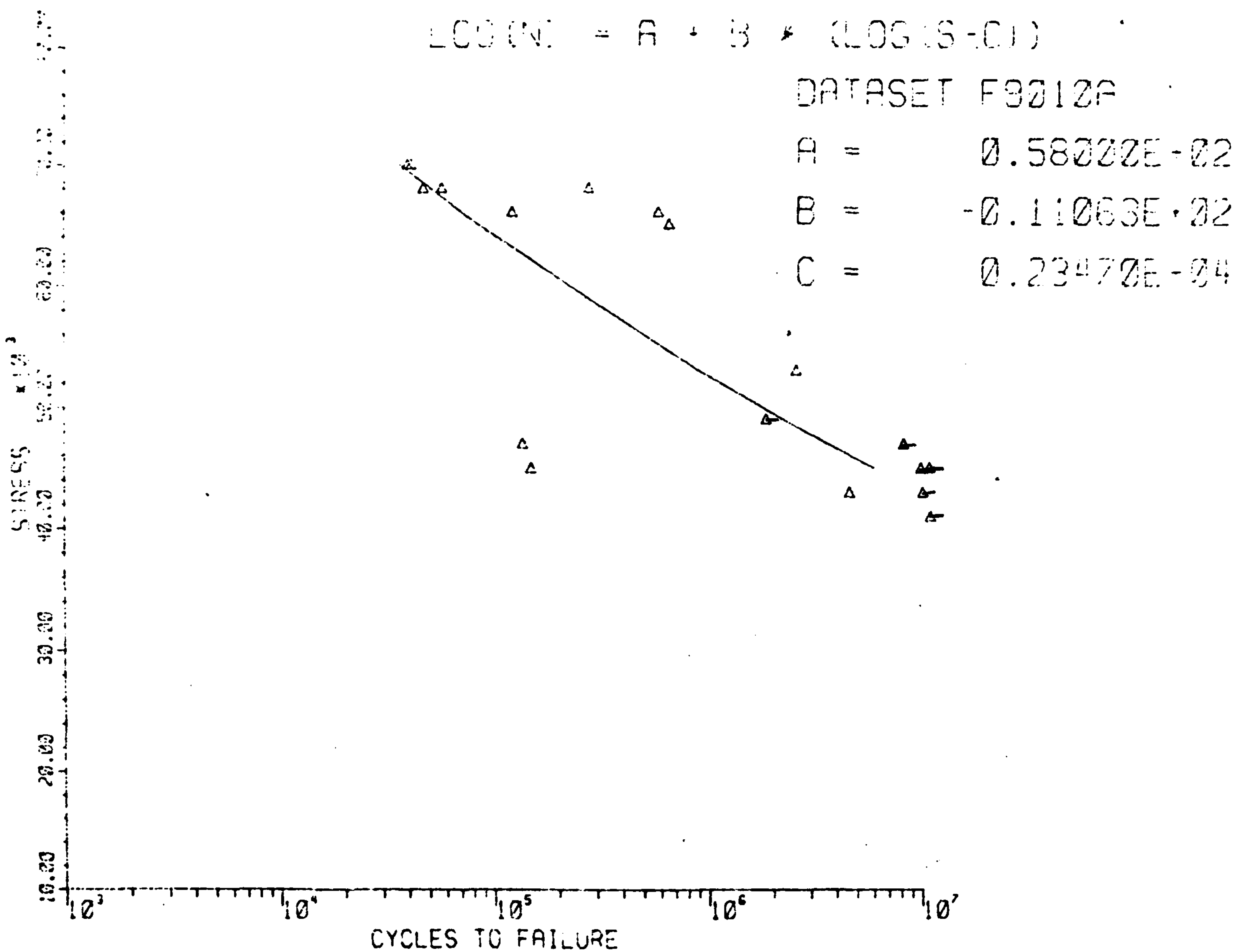


Figure B1. Fatigue Results for 7090 Forgings; R = 0.1, K_t = 1.0

TABLE B11

FATIGUE RESULTS FOR 7090 FORGINGS: R = 0.1, K_t = 1.0

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
41000	11075150	0
43000	4639200	1
43000	10250500	0
45000	151300	1
45000	10090100	0
45000	10928000	0
47000	138400	1
47000	8339900	0
49000	1876400	0
53000	2621000	1
65000	677500	1
66000	125200	1
66000	602400	1
68000	47600	1
68000	58500	1
68000	281400	1
70000	40150	1
70000	42200	1

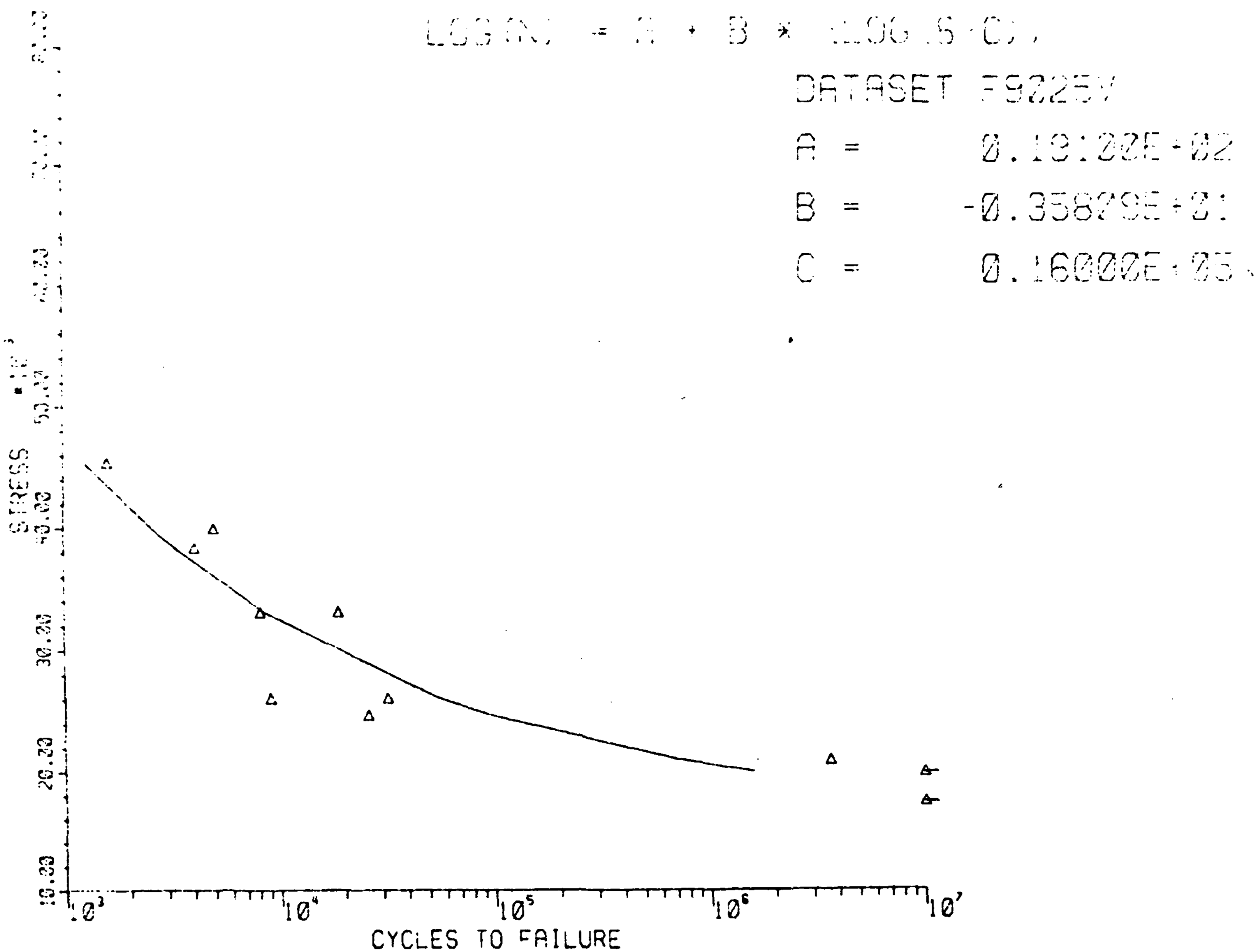


Figure B2. Fatigue Results for 7090 Forgings; R = 0.1, K_t = 2.5

TABLE B12

FATIGUE RESULTS FOR 7090 FORGINGS: R = 0.1, K_t = 2.5

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
17500	10000000	0
20000	10000000	0
21000	3633690	1
24800	26090	1
26200	9180	1
26200	32330	1
33200	19100	1
33200	8190	1
38400	4100	1
40000	5070	1
45400	1600	1

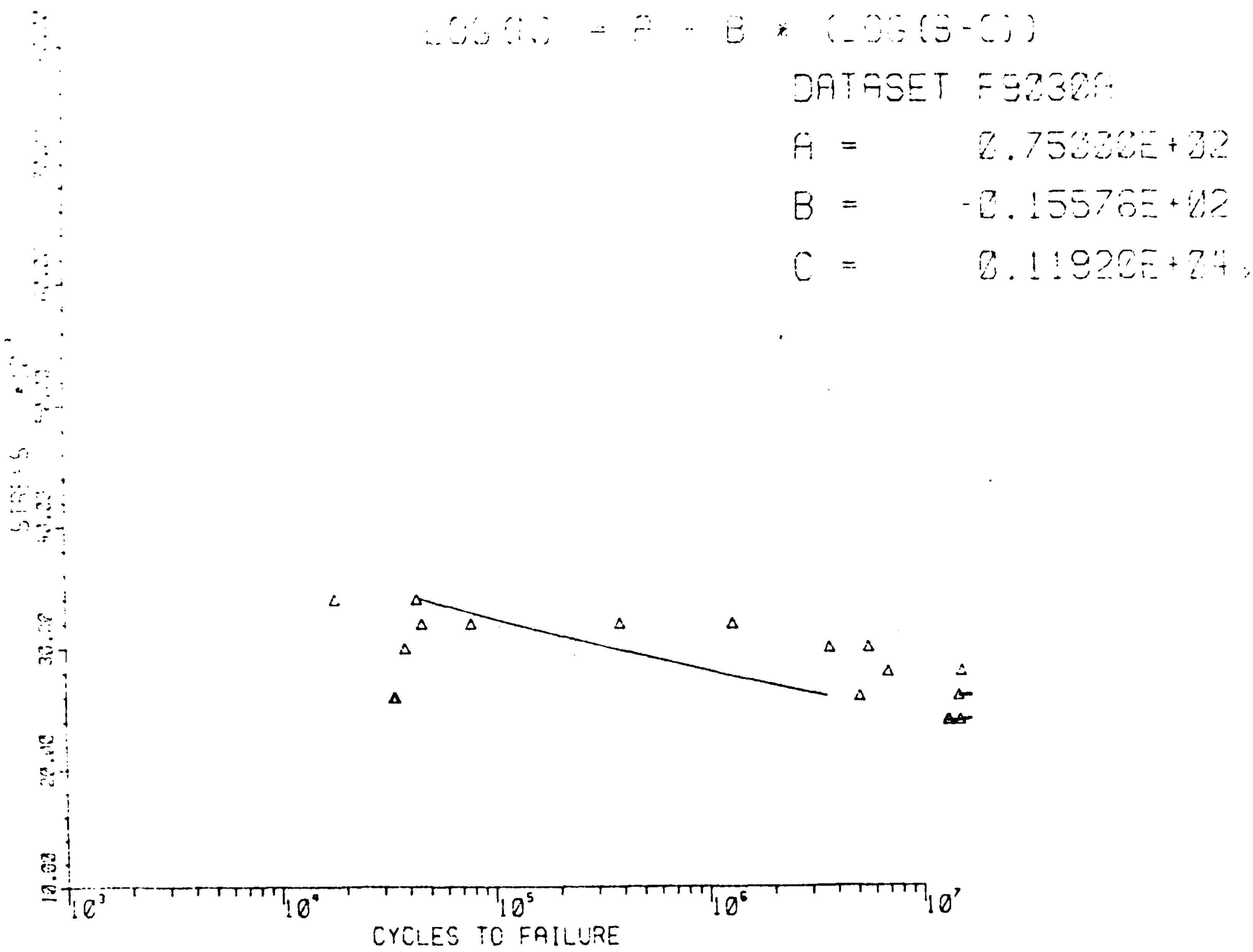


Figure B3. Fatigue Results for 7090 Forgings; $R = 0.1$, $K_t = 3.0$

TABLE B13

FATIGUE RESULTS FOR 7090 FORGINGS: R = 0.1, K_t = 3.0

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
24000	13158550	0
24000	13404300	0
24000	14995800	0
26000	34450	1
26000	34700	1
26000	5101550	1
26000	14775500	0
28000	6952500	1
28000	15306100	1
30000	39000	1
30000	3684600	1
30000	5615300	1
32000	46400	1
32000	78500	1
32000	389200	1
32000	1307300	1
34000	18200	1
34000	44300	1

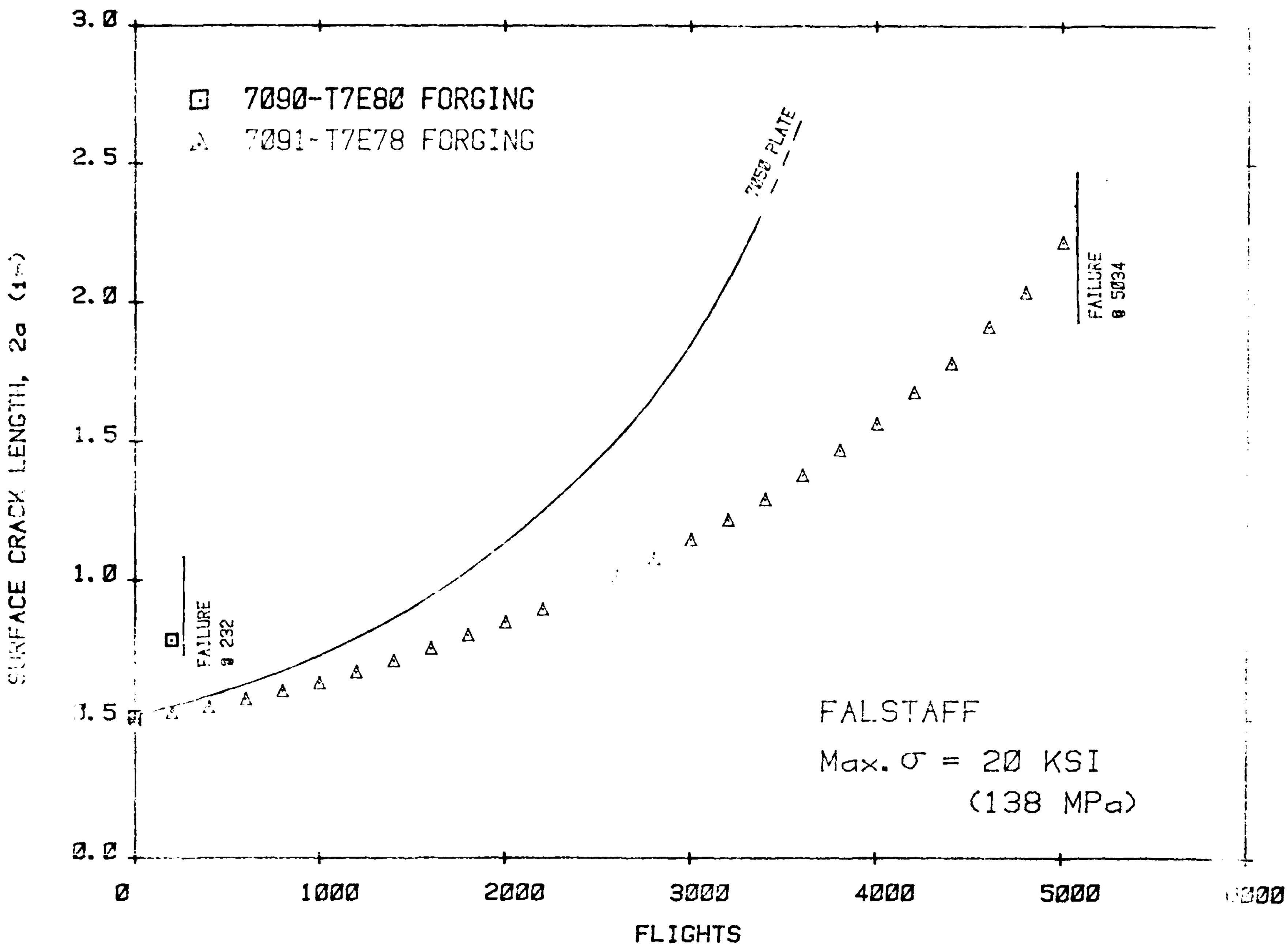


Figure B9. Crack Length Versus Flights for 7090 Forging Under FALSTAFF Loading.

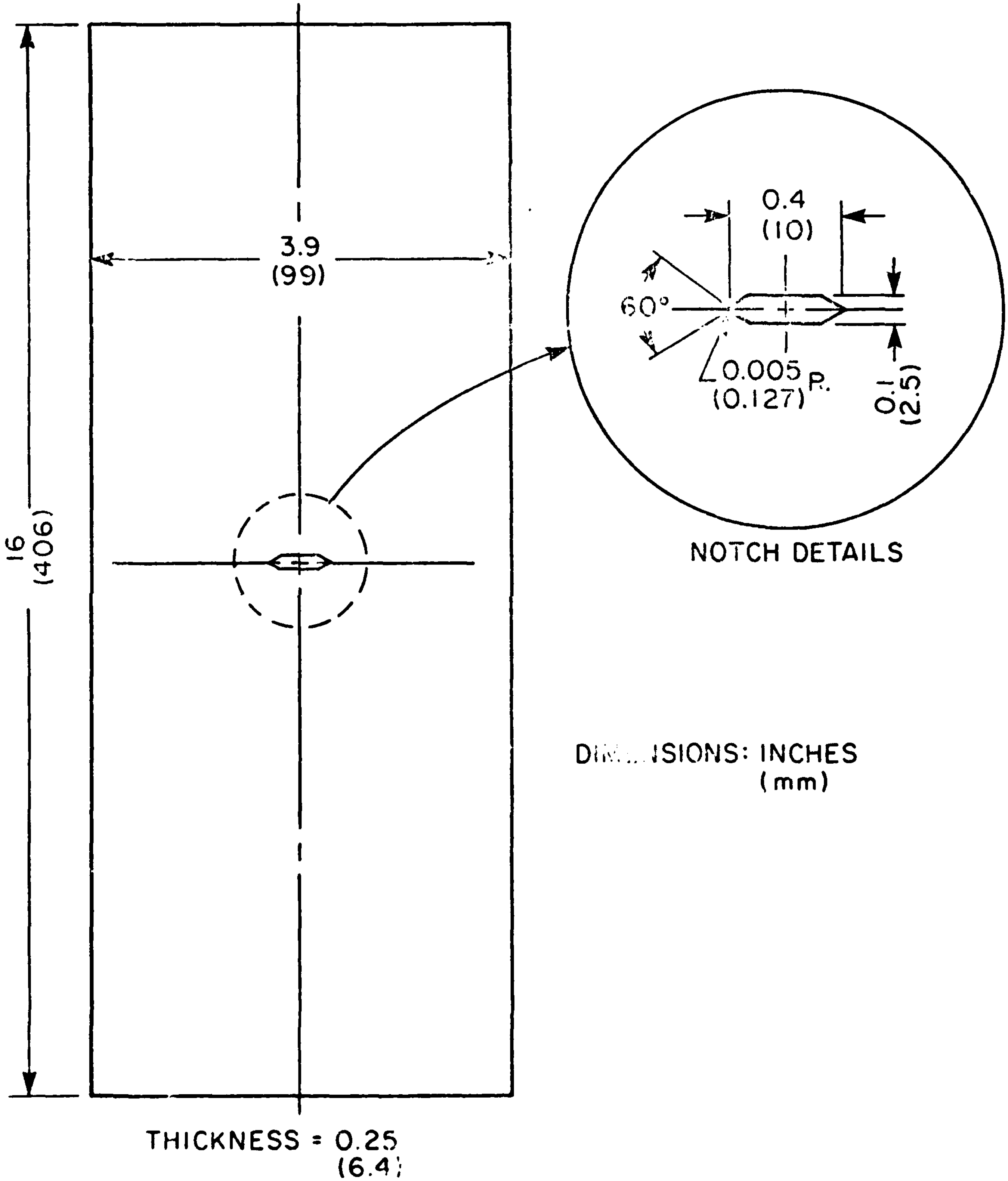


Figure B8. Specimen Used to Generate Data in Figures B9 and B10.

TABLE B19 Durability Properties of Aluminum P/M Products

Corrosion Results From BOEING

Material	Direction	Notch Fatigue, cycles (23 ksi, R=0.06, ν=25 Hz)	Fastener Fatigue, cycles (20 ksi, R = -1.0 ν = 30 Hz)	Stress Corrosion Cracking, ksi (90-day threshold)	Exfoliation (MASTMAASIS)
Hand Forgings:					
Alcoa					
7075-T7352	L	-	115,000/124,000/221,000	-	Small amt of exfoliation and pitting
	LT	-		-	
7050-T73652	L	-		-	
	LT	-		-	
X7090-T7E80	L	-		-	Very slight amt of exfoliation and no pitting
	LT	-		-	
X7091-T7E78	L	53,100/38,100/43,500	416,000/256,000	-	Small amt of exfoliation and very slight pitting
	LT	53,400/46,300/29,800		>60	
	ST	-		>10	
Novamet					
7075-T7352	L	-	117,000/98,000	-	Very slight amt of exfoliation and moderate pitting
	LT	-		-	
IN9021-T352	L	30,000/18,800/1,000,000+	265,000/533,000	-	Very slight amt of exfoliation and moderate pitting
	LT	208,000/1,000,000+/33,000		>60	
Extrusions:					
Alcoa					
X7090-T7E71	L	-		-	Very slight amt of exfoliation and no pitting
	LT	-		>60	
Novamet					
IN9021-T6X[a]	L	27,300/19,300/17,600		-	Small amt of exfoliation and pitting
	LT	-		>50	
IN9021-T6Y[b]	L	12,500/155,000/27,000		-	
	LT			>50	

(a) T6X: solution treated, quenched, stretched 4%, artifically aged

(b) T6Y: solution treated, quenched, artifically aged

TABLE B18
Corrosion Results From ALCOA

PERFORMANCE OF SHORT TRANSVERSE 3.1 mm (1/8") DIAMETER SMOOTH TENSILE BARS WHICH WERE REMOVED FROM 7090 AND 7091 HAND FORGINGS (1), STRESSED AND EXPOSED 30 DAYS TO 3-1/2% SODIUM CHLORIDE BY ALTERNATE IMMERSION (2)

S. No.	Alloy	Temper	Stress Level (ksi/MPa)	No. Failures/No. Specimens Tested
513910-2-16	7090	T7E80	25/172	0/3
513910-2-16	7090	T7E80	45/310	0/3
513910-7-11	7090	T7E80	25/172	0/3
513910-7-11	7090	T7E80	45/310	0/3
513825-10-18	7091	T7E78	25/172	0/3
513825-10-18	7091	T7E78	45/310	0/3
513825-26-13	7091	T7E78	25/172	0/3
513825-26-13	7091	T7378	45/310	0/3

NOTES: (1) Hand forgings were 63 mm x 152 mm x 610 mm (2-1/2" x 6" x 24") in size and were produced in Cleveland from 50 kg (110 lb) billets sawed in half.

(2) 3-1/2% sodium chloride alternate immersion tests was conducted in accordance with ASTM G44-75.

CORROSION RESULTS FROM ALCOA

Table B18 lists the results of a 30-day exposure to 3-1/2% sodium chloride by alternate immersion of triplicate short-transverse 3.1 mm (1/8") diameter by 51 mm (2") long tensile bars removed from 7090-T7E80 alloy hand forgings. The tensile bars were stressed to two stress levels - 172 MPa (25 ksi) and 310 MPa (45 ksi). No failures were encountered in any case with the stressed tensile specimens.

CORROSION

Corrosion characteristics of 7090 forgings were evaluated by ALCOA and Boeing. ALCOA's results from the stress corrosion tests are summarized in the attached write up and table and Boeing's exfoliation test results are shown in the attached table on durability properties. This material appears to be corrosion resistant.

SPECTRUM

Spectrum fatigue crack growth of 7090 forgings was investigated by AFWAL. Results relative to I/M 7050 plate using both the standard FALSTAFF and Mini-TWIST spectra are shown in the attached figures. 7090 forgings are inferior to the 7050 plate and also to 7091 forgings.

TABLE B17

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE B7 INDICATING EFFECT OF STRESS RATIO

ALCOA

MATERIAL: ALUMINUM 7090
CONDITION: T7E80
ENVIRONMENT: R.T. ,HI HUMIDITY

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN./CYCLE) A R=+0.10	B R=+0.33	C	D
DELTA K MIN A:	1.17	.02			
DELTA K MIN B:	1.14		.02		
DELTA K MIN C:	4				
DELTA K MIN D:					
	1.30	.0470	.0484		
	1.60	.106	.103		
	2.00	.225	.214		
	2.50	.435	.420		
	3.00	.715	.715		
	3.50	1.07	1.13		
	4.00	1.53	1.69		
	5.00	2.82	3.49		
	6.00	4.86	6.75		
	7.00	8.06	12.5		
	8.00	13.1	22.7		
	9.00	20.9	40.2		
	10.00	32.9	69.9		
	13.00	123.			
DELTA K MAX A:	13.97	185.			
DELTA K MAX B:	11.05		123.		
DELTA K MAX C:					
DELTA K MAX D:					

CONDITION/HT: T7E80	
FORM: 2.50"TH FORGING	YIELD STRENGTH: 66.1 KSI
SPECIMEN TYPE: CT	ULT. STRENGTH: 77.8 KSI
ORIENTATION: S-L	SPECIMEN THK: 0.251"
FREQUENCY: 25.00 HZ	SPECIMEN WIDTH: 1.997- 1.999"
ENVIRONMENT: R.T., HI HUMIDITY	REFERENCES:

ALUM. ALLOY

7090

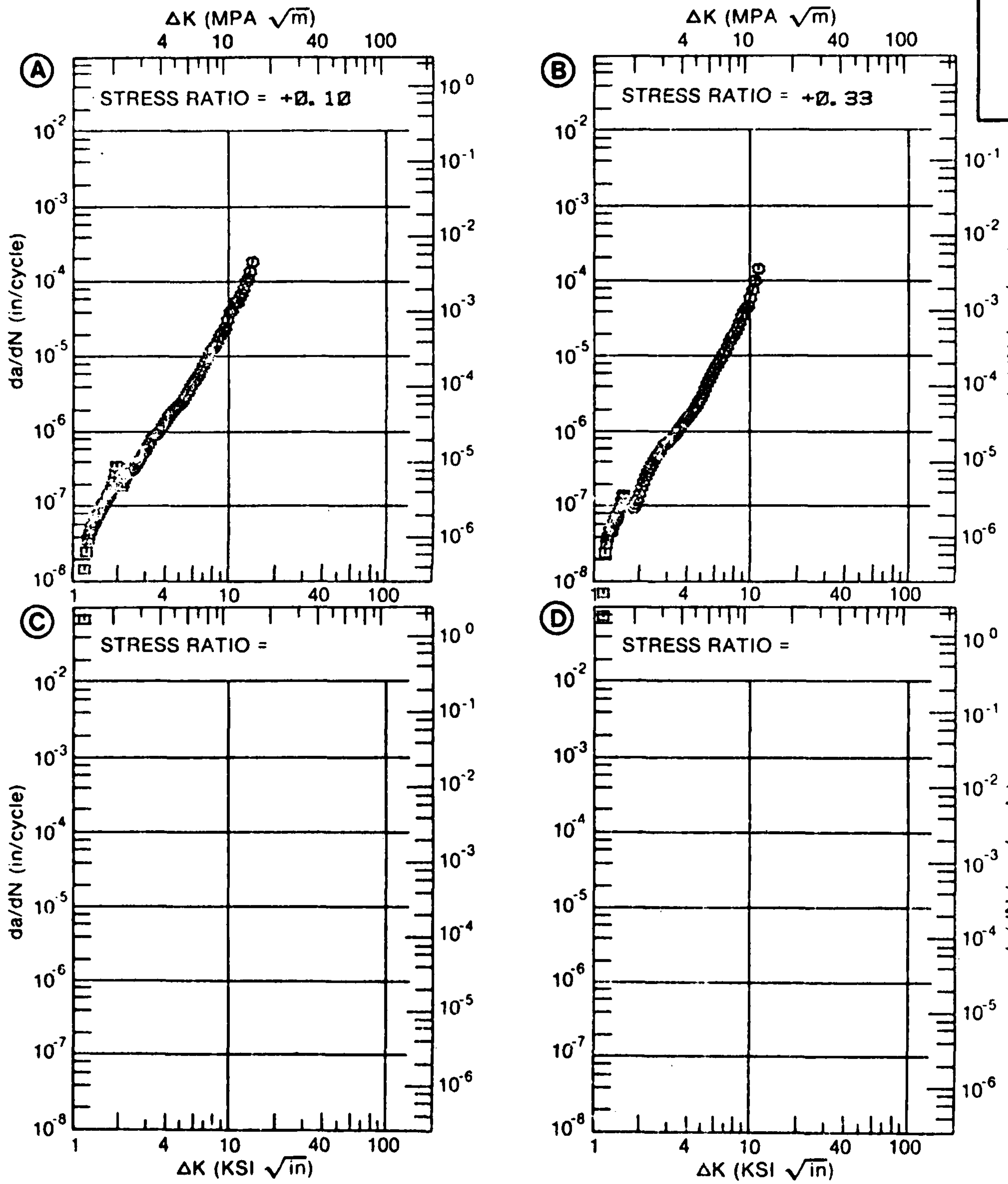


Figure B7. Fatigue Crack Growth Rate Data for 7090 Forgings; ALCOA

TABLE B16

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE B6 INDICATING EFFECT
OF STRESS RATIO

ALCOA

MATERIAL: ALUMINUM 7090
CONDITION: T7E80
ENVIRONMENT: R.T. ,HI HUMIDITY

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN./CYCLE) A	B	C	D
		R=+0.10	R=+0.33		
DELTA K MIN	A: 1.65	.00			
	B: 1.10		.00		
	C: 60				
	D:				
	1.30		.0547		
	1.60		.105		
	2.00	.104	.197		
	2.50	.228	.360		
	3.00	.412	.595		
	3.50	.668	.932		
	4.00	1.02	1.42		
	5.00	2.09	3.10		
	6.00	3.94	6.55		
	7.00	7.07	13.5		
	8.00	12.3	27.3		
	9.00	20.9	54.4		
	10.00	35.0			
DELTA K MAX	A: 12.47	118.			
	B: 9.28		65.9		
	C:				
	D:				

CONDITION/HT: T7E80
FORM: 2.50"TH FORGING
SPECIMEN TYPE: CT
ORIENTATION: T-L
FREQUENCY: 10.00- 25.00 HZ
ENVIRONMENT: R.T., HI HUMIDITY

YIELD STRENGTH: 70.8 KSI
ULT. STRENGTH: 80.9 KSI
SPECIMEN THK: 0.251"
SPECIMEN WIDTH: 1.999"
REFERENCES:

ALUM. ALLOY

7090

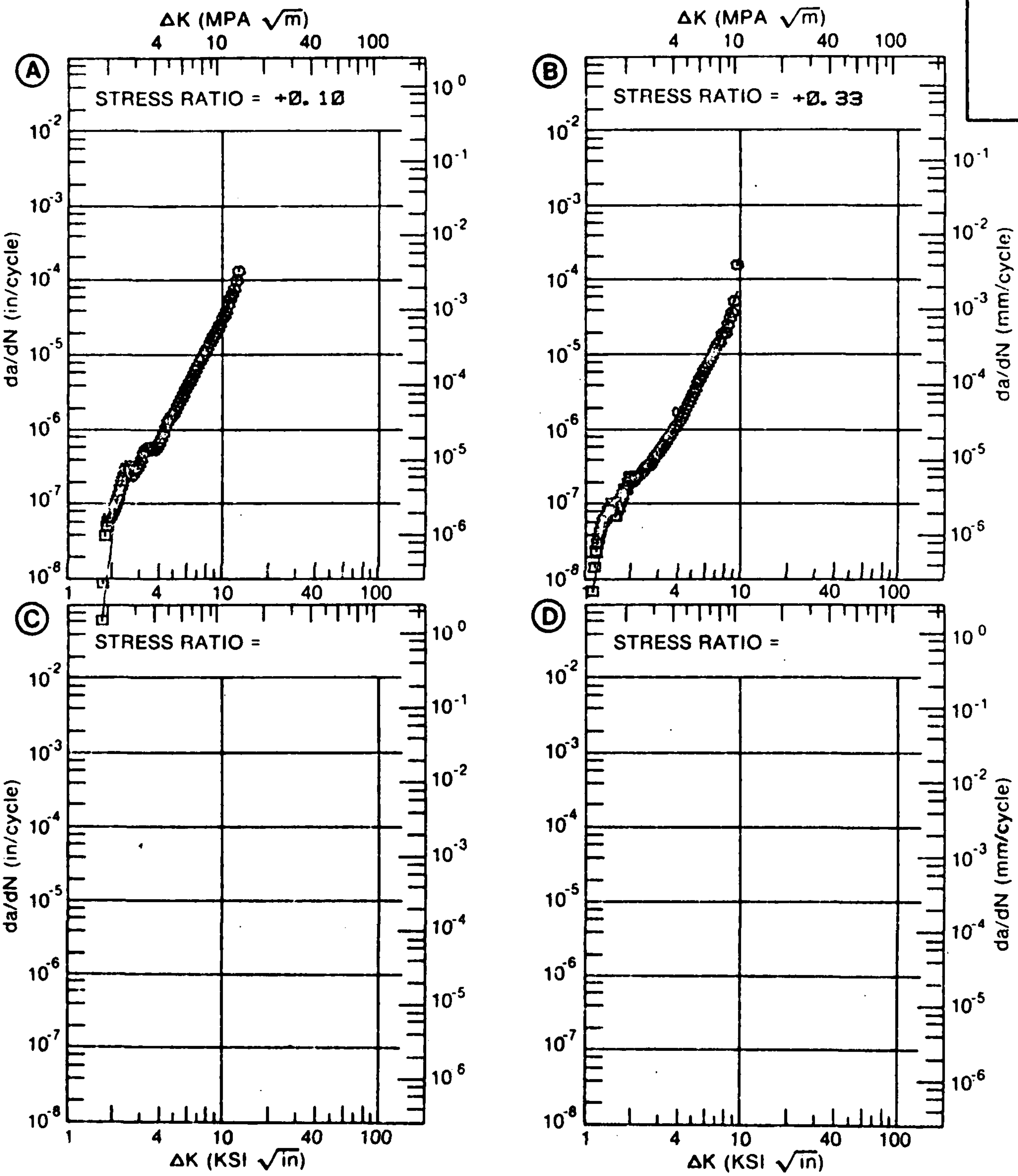


Figure B6. Fatigue Crack Growth Rate Data for 7090 Forgings; ALCOA

TABLE B15

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE B5 INDICATING EFFECT
OF STRESS RATIO

ALCOA

MATERIAL: ALUMINUM 7090
CONDITION: T7E80
ENVIRONMENT: R.T. ,HI HUMIDITY

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN./CYCLE) A	B	C	D
		R=+0.10	R=+0.33		
DELTA K MIN	A: 1.62	.01			
	B: 1.20		.00		
	C: 70				
	D:				
	1.30		.0424		
	1.60		.0875		
	2.00	.0684	.134		
	2.50	.172	.242		
	3.00	.361	.430		
	3.50	.664	.731		
	4.00	1.11	1.18		
	5.00	2.50	2.65		
	6.00	4.61	5.05		
	7.00	7.41	8.41		
	8.00	10.8	12.6		
	9.00	14.5	17.3		
	10.00	19.5	22.2		
	13.00	29.6			
DELTA K MAX	A: 14.34	33.6			
	B: 11.39		28.5		
	C:				
	D:				

CONDITION/HT: T7E80
FORM: 2.50"TH FORGING
SPECIMEN TYPE: CT
ORIENTATION: L-T
FREQUENCY: 25.00 HZ
ENVIRONMENT: R.T., HI HUMIDITY

YIELD STRENGTH: 71.6 KSI
ULT. STRENGTH: 80.2 KSI
SPECIMEN THK: 0.251"
SPECIMEN WIDTH: 1.939"
REFERENCES:

ALUM. ALLOY

7090

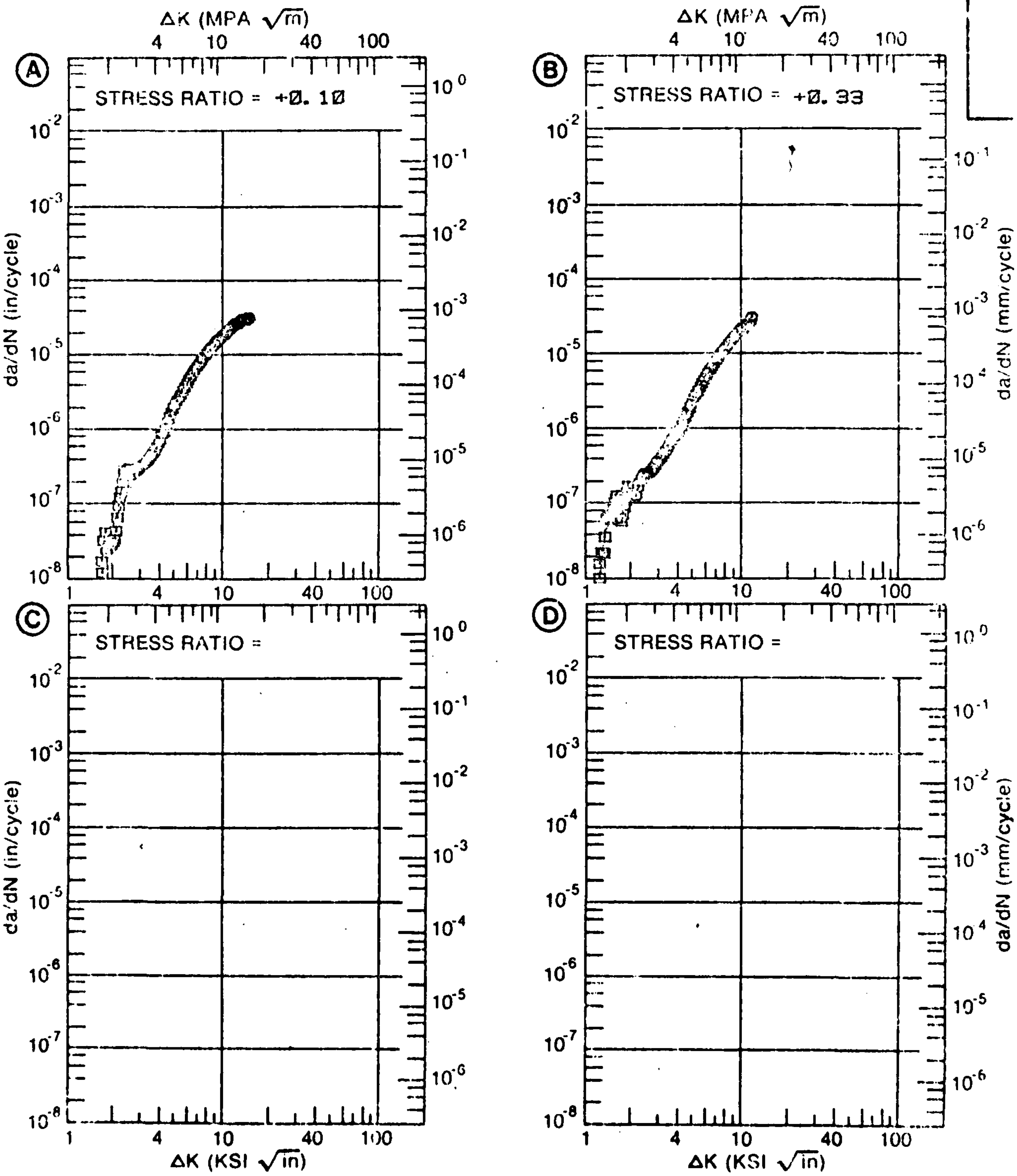


Figure B5. Fatigue Crack Growth Rate Data for 7090 Forgings; ALCOA

TABLE B14

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE B4 INDICATING EFFECT
OF STRESS RATIO

BOEING

MATERIAL: ALUMINUM 7090
CONDITION: T7E80
ENVIRONMENT: R.T. , LAB AIR

DELTA K (KSI*IN**1/2)			DA/DN (10**-6 IN./CYCLE) A	B	C	D
			R=+0.06			
DELTA K MIN	A:	4.49	1.43			
	B:					
	C:					
	D:					
		5.00	3.23			
		6.00	7.33			
		7.00	9.98			
		8.00	11.2			
		9.00	12.1			
		10.00	13.4			
		13.00	29.2			
		16.00	136.			
DELTA K MAX	A:	17.26	320.			
	B:					
	C:					
	D:					

CONDITION/HT: T7E80
FORM: 2.60"TH FORGING
SPECIMEN TYPE: CT
ORIENTATION: L-T
FREQUENCY: 30.00 HZ
ENVIRONMENT: R.T., LAB AIR

YIELD STRENGTH: 71.1 KSI
ULT. STRENGTH: 79.6 KSI
SPECIMEN THK:
SPECIMEN WIDTH:
REFERENCES:

ALUM. ALLOY

7090

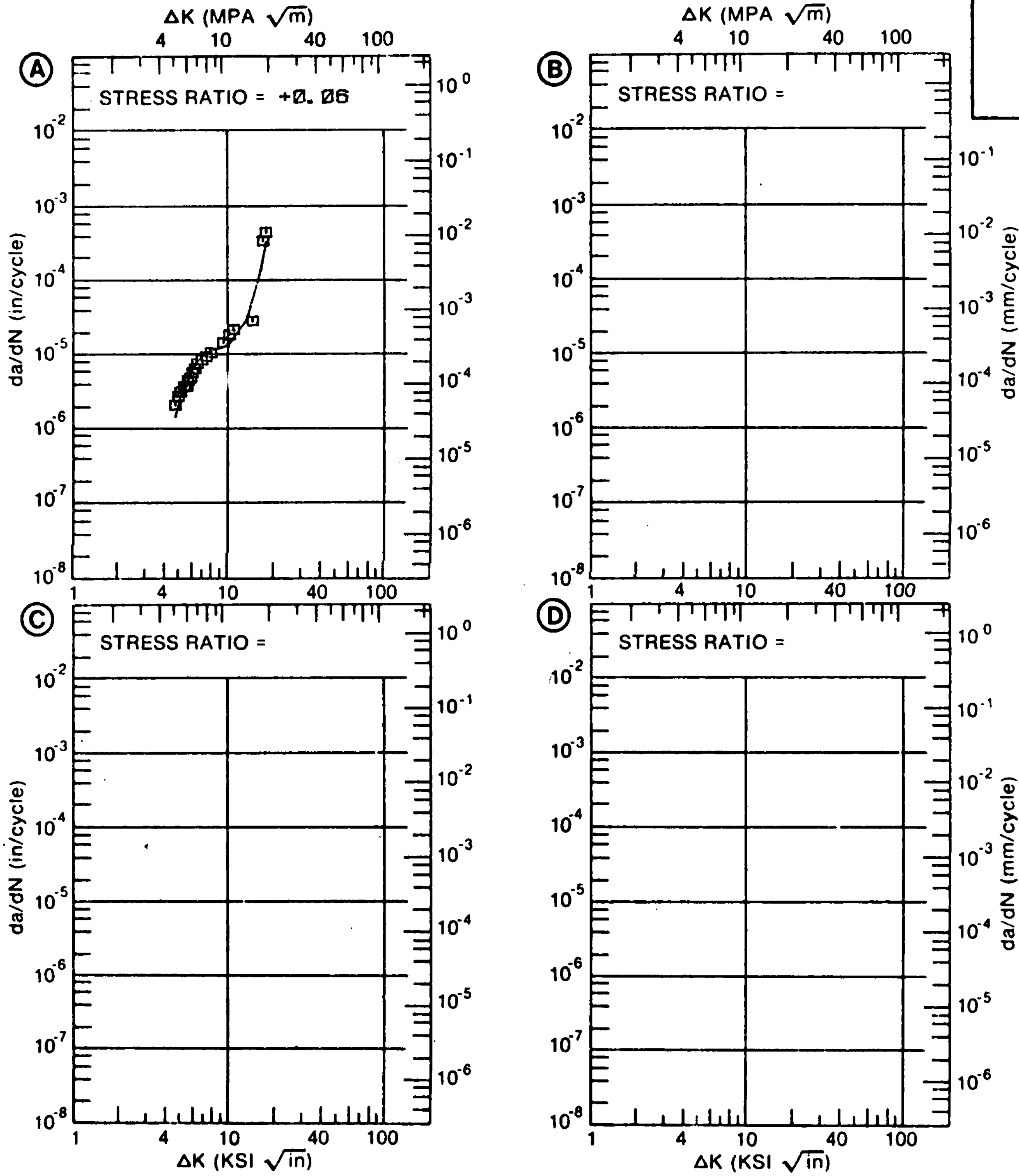


Figure B4. Fatigue Crack Growth Rate Data for 7090 Forgings; Boeing

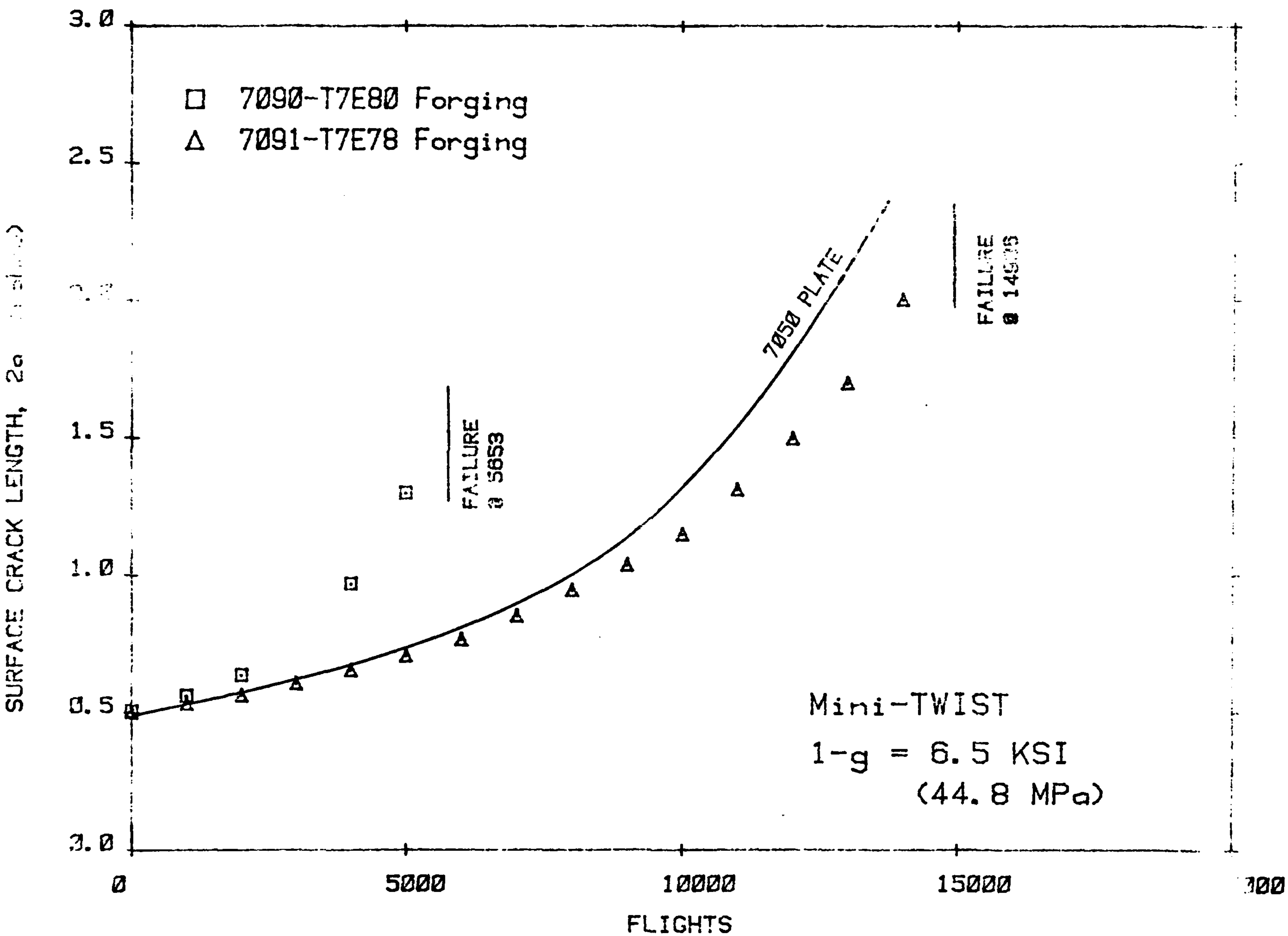


Figure B10. Crack Length Versus Flights for 7090 Forging Under Mini-TWIST Loading.

APPENDIX C

IN9021-T352 FORGINGS

Comment: The fatigue crack growth rate data from Boeing for the L-T orientation was developed at two frequencies. The data at the lower part of the curve was developed at a frequency of 30 Hz while the four points at the higher part of the curve was from the same specimen tested at 3 Hz.

NOTICE: Suggested allowables, mean trends, and trend curves in this document were developed to be used in a cost benefit analysis to assess the potential benefit of using the material in a structure. These suggested allowables and trends are not considered accurate for design of actual hardware.

TABLE C1

SUGGESTED ALLOWABLES FOR
IN 9021 FORGINGS: .75" x 5"

F_{tu}, KSI	
L	80.3
LT	83.2
F_{ty}, KSI	
L	70.5
LT	72.1
F_{cy}, KSI	
L	65.4
LT	73.3
F_{su}, KSI	
L	41.5
LT	40.9
F_{bu}, KSI	
L	
(e/D=1.5)	120.5
e/D=2.0)	140.6
LT	
(e/D=1.5)	119.9
(e/D=2.0)	140.6
F_{by}, KSI	
L	
(e/D=1.5)	104.0
(e/D=2.0)	118.0
LT	
(e/D=1.5)	-
(e/D=2.0)	121.1
K_{IC}, KSI $\sqrt{IN}$	
LT	17.8
TL	20.1

NOTE: These values were developed to be used only in a cost-benefit-analysis and are not necessarily accurate for design of hardware.

TABLE C2

IN-9021 FORGING .75" x 5"

TENSILE

COMPANY	TEST TEMP (°F)	ORIENTATION	ULT STR (KSI)	YIELD STR (KSI)	ELONG (%)	RA (%)
Vought	RT	Long	80.7	70.0	12.2	
			82.7	73.2	12.3	
			82.1	73.2	9.5	
General Dynamics			87.3	74.4	9.5	
			84.4	70.2	11.0	
			89.8	77.3	9.0	
Lockheed GA			89.0	79.0	13.0	
			89.0	77.5	10.5	
			89.6	76.7	11.0	
Rockwell			87.6	73.5	12.4	
			86.3	76.0	12.4	
			83.9	73.6	12.1	
Boeing			78.6	71.2	8.8	
			81.7	73.4	10.5	
Vought	500		77.7	68.7	14.6	
			82.4	72.5	12.9	
			76.7	68.7	16.6	

TABLE C3

IN-9021 FORGING

TENSILE

COMPANY	TEST TEMP (°F)	ORIENTATION	ULT STR (KSI)	YIELD STR (KSI)	ELONG (%)
Vought	RT	Trans	84.0	74.6	12.4
			85.4	74.6	12.8
			83.4	74.6	13.6
General Dynamics			85.9	73.6	12.0
			86.0	72.5	9.0
			84.8	72.1	11.5
Lockheed-GA			87.4	78.1	10.5
			87.3	79.4	11.0
			87.3	78.5	12.0
Rockwell			86.0	72.3	12.1
			84.7	74.8	12.3
			84.7	74.4	12.3
Boeing			82.5	72.3	11.0
			83.5	72.1	9.2

TABLE C4

IN-9021 FORGING

COMPRESSION

COMPANY	ORIENTATION	COMPR YIELD STR (KSI)
Vought	Long	74.1
		75.3
		68.6
		74.1
Lockheed-GA		74.4
		72.5
		71.4
Boeing		64.8
		67.0
Vought	Trans	77.0
		75.7
		76.1
Lockheed-GA		81.1
		78.3
		79.7
Boeing		73.3
		73.8

TABLE C5

IN-9021 FORGING

SHEAR

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
Vought	Long	52.8
		53.0
		52.8
		52.8
Lockheed-GA		46.8*
		47.9*
		48.9*
Boeing		41.4
		42.8
Lockheed-GA	Trans	48.7*
		48.0*
		47.3*
Boeing		40.9
		41.5

* double shear

TABLE C6

IN-9021 FORGING

BEARING

COMPANY	ORIENTATION	e/D	BEARING ULT (KSI)	BEARING YIELD (KSI)
Lockheed-GA	Long	1.5	124.0	107.0
			122.0	104.0
			123.0	104.0
Boeing	Long	1.5	121.6	-
			120.5	-
Boeing	Trans	1.5	119.9	-
Lockheed-GA	Long	2.0	156.0	127.0
			158.0	129.0
			154.0	139.0
Vought	Long	2.0	142.2	125.0
			140.6	125.0
			142.2	118.0
			142.2	118.0
			106.0	NA 500°F
			132.8	NA 500°F
Vought	Trans	2.0	146.9	125.0
			140.6	125.0
			154.7	121.1

TABLE C7

IN-9021 FORGING

FRACTURE TOUGHNESS, K_{IC}

COMPANY	ORIENTATION	K_{IC} (KSI $\sqrt{IN}$)	K_Q (KSI $\sqrt{IN}$)	COMMENT
Rockwell	L-T		43.0	insufficient size
			42.1	insufficient size
Vought			15.1	invalid
			31.7	invalid
			30.6	invalid
General Dynamics		29.8		valid
		19.4		valid
Boeing		17.8		
		26.5		
Lockheed-GA			39.3	insufficient size, etc.
			40.5	insufficient size, etc.
			39.5	insufficient size, etc.
ALCOA		25.6		valid
		25.2		valid
Rockwell	T-L		43.4	insufficient size
			41.2	insufficient size
Vought			31.7	invalid
		31.5		valid
General Dynamics		21.5		valid
		23.6		valid
Boeing		20.1		
Lockheed-GA			39.4	insufficient size, etc.
			42.8	insufficient size, etc.
			39.7	insufficient size, etc.
ALCOA		30.3		valid
		31.0		valid

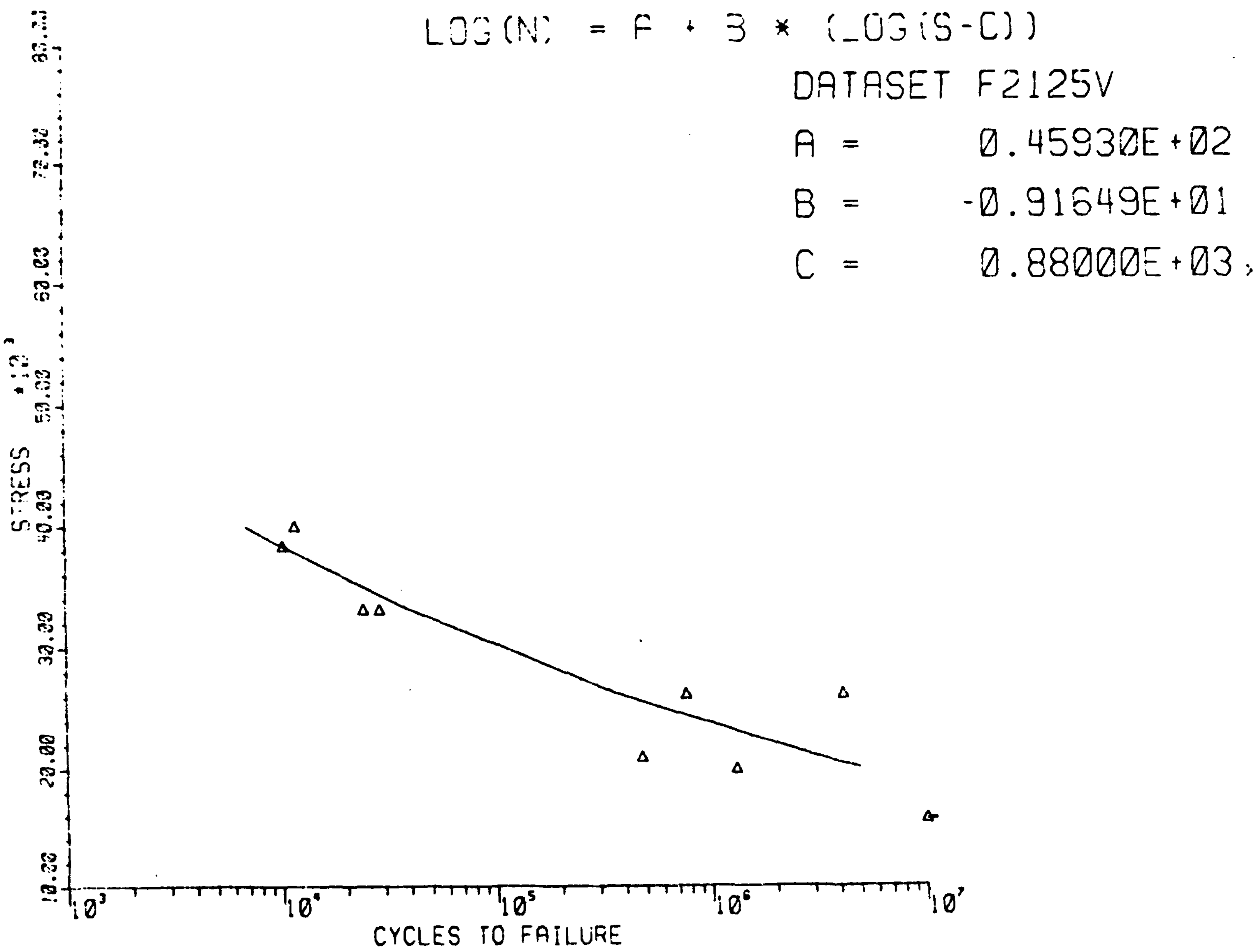


Figure C1. Fatigue Results for IN-9021 Forgings; R = 0.1, K_t = 2.5

TABLE C8

FATIGUE RESULTS FOR IN-9021 FORGINGS: $R = 0.1$, $K_t = 2.5$

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
15700	10000000	0
20000	1300000	1
21000	476590	1
26200	765000	1
26200	4123310	1
33200	24700	1
33200	29370	1
38400	10430	1
40000	11840	1

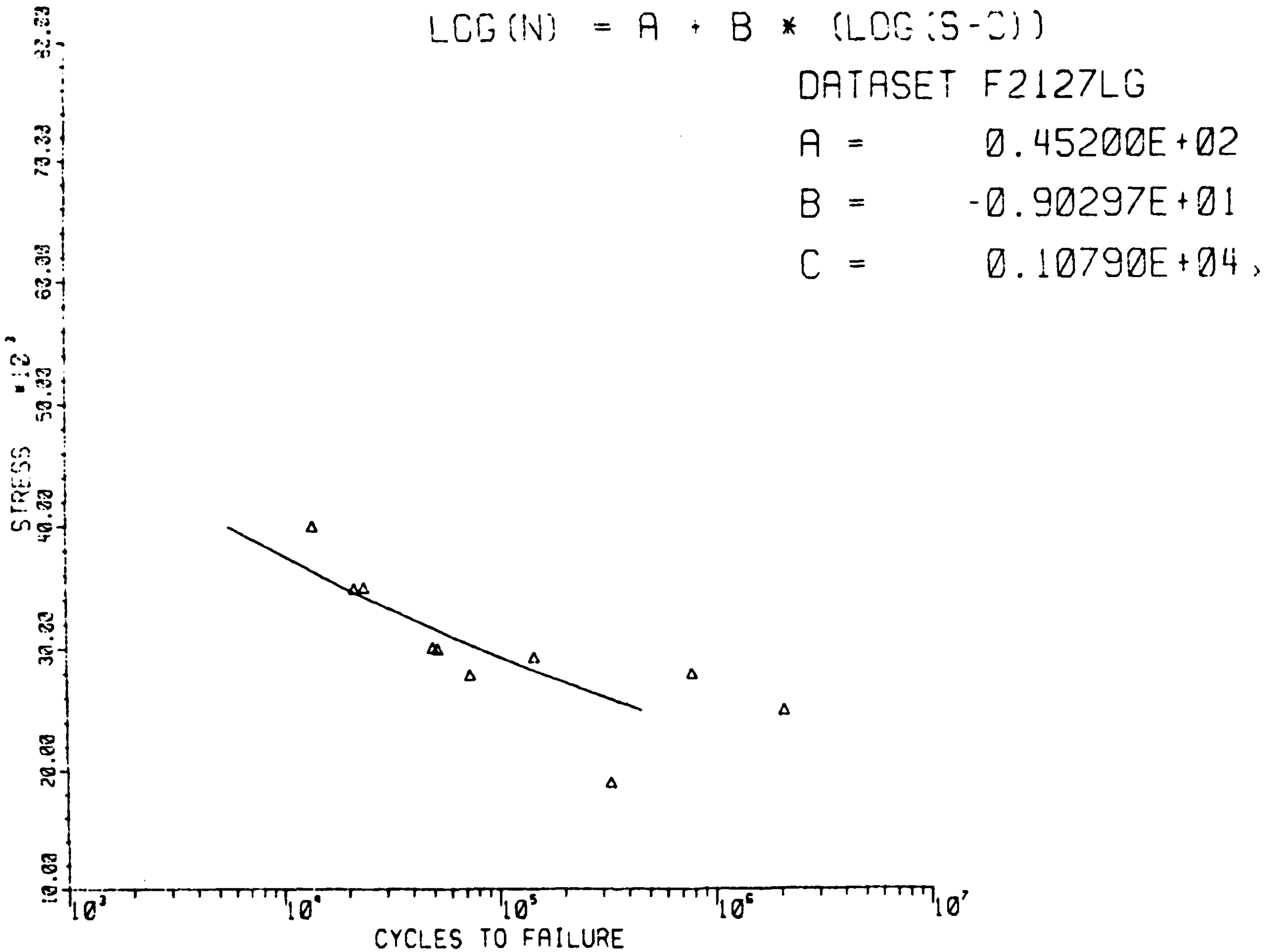


Figure C2. Fatigue Results for IN-9021 Forgings; R = 0.1, K_t = 2.7

TABLE C9

FATIGUE RESULTS FOR IN-9021 FORGING: $R = 0.1$, $K_t = 2.7$

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
19000	333000	1
25000	2083500	1
27900	75200	1
28000	787100	1
29300	147700	1
30000	53400	1
30100	50300	1
34900	22000	1
35000	24400	1
40000	14000	1

CONDITION/HT: T352
FORM: 0.90"TH FORGING
SPECIMEN TYPE: CT
ORIENTATION: L-T
FREQUENCY: 30.00 HZ
ENVIRONMENT: R. T., LAB AIR

YIELD STRENGTH: 72.3 KSI
ULT. STRENGTH: 80.2 KSI
SPECIMEN THK:
SPECIMEN WIDTH:
REFERENCES:

ALUM. ALLOY

IN9021

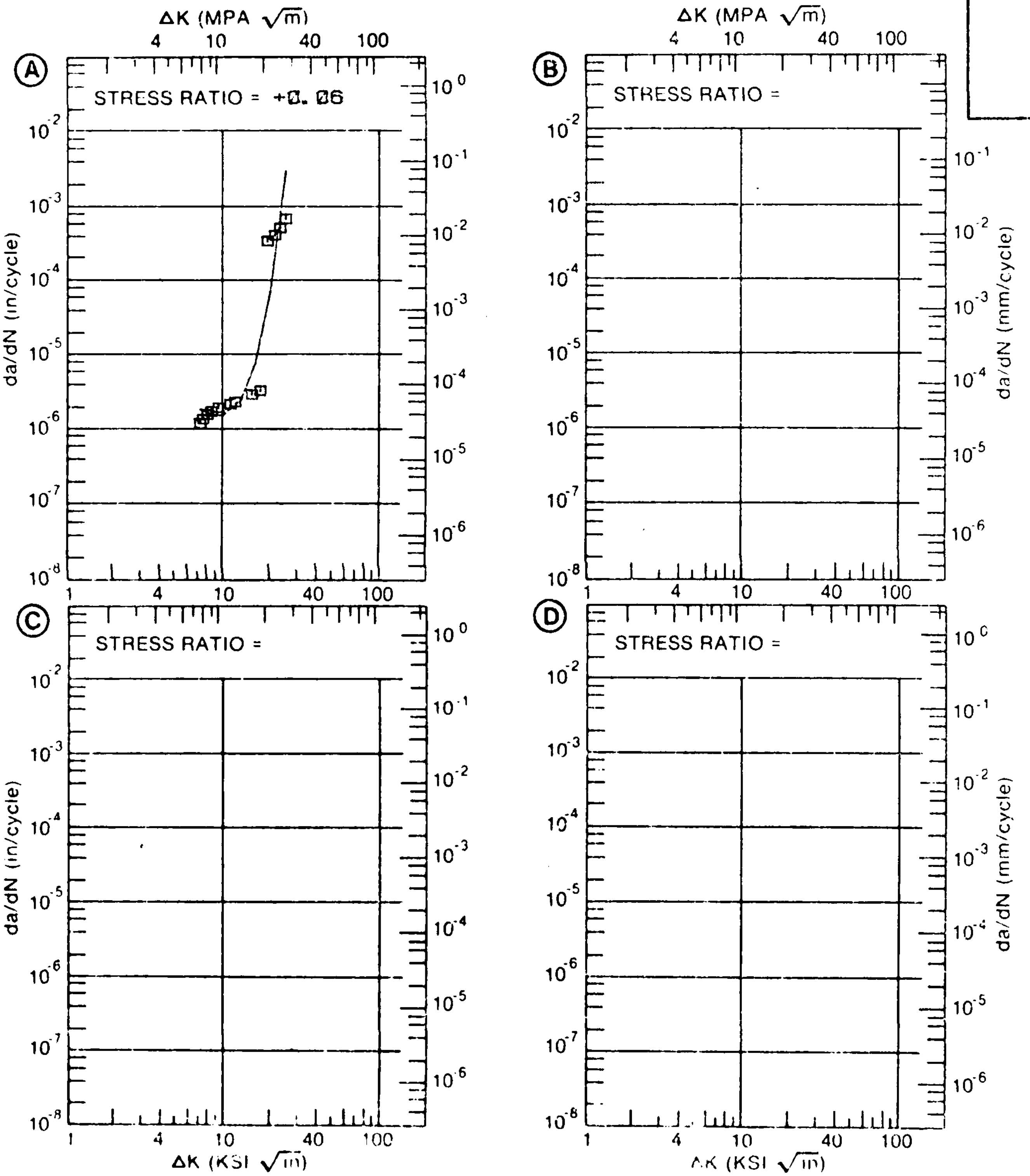


Figure C3. Fatigue Crack Growth Rate Data for IN-9021 Forgings; Boeing

TABLE D1

SUGGESTED ALLOWABLES FOR
7091-T7E69 Extrusions; 1½" x 4½"

F_{tu}, KSI	
L	82.7
LT	76.5
ST	76.9
F_{ty}, KSI	
L	74.1
LT	66.7
ST	63.7
F_{cy}, KSI	
L	73.4
LT	69.6
F_{su}, KSI	
L	45.8
LT	43.8
F_{bru}, KSI	
L	
(e/D=1.5)	120.0
(e/D=2.0)	147.6
LT	
(e/D=1.5)	107.4
(e/D=2.0)	139.3
F_{by}, KSI	
L	
(e/D=1.5)	99.6
(e/D=2.0)	112.7
LT	
(e/D=1.5)	94.1
(e/D=2.0)	111.2
K_{IC}, KSI$\sqrt{IN}$	
LT	35.8
TL	26.6
SL	25.7

NOTE: These values were developed to be used only in a cost-benefit-analysis and are not necessarily accurate for design of hardware.

APPENDIX D

7091-T7E69 EXTRUSIONS

NOTICE: Suggested allowables, mean trends, and trend curves in this document were developed to be used in a cost benefit analysis to assess the potential benefit of using the material in a structure. These suggested allowables and trends are not considered accurate for design of actual hardware.

MATERIAL 7475-T7351 SPECIMEN(S) 8210 A+B

SPECTRUM 400 HR STRESS 42 Ksi NET

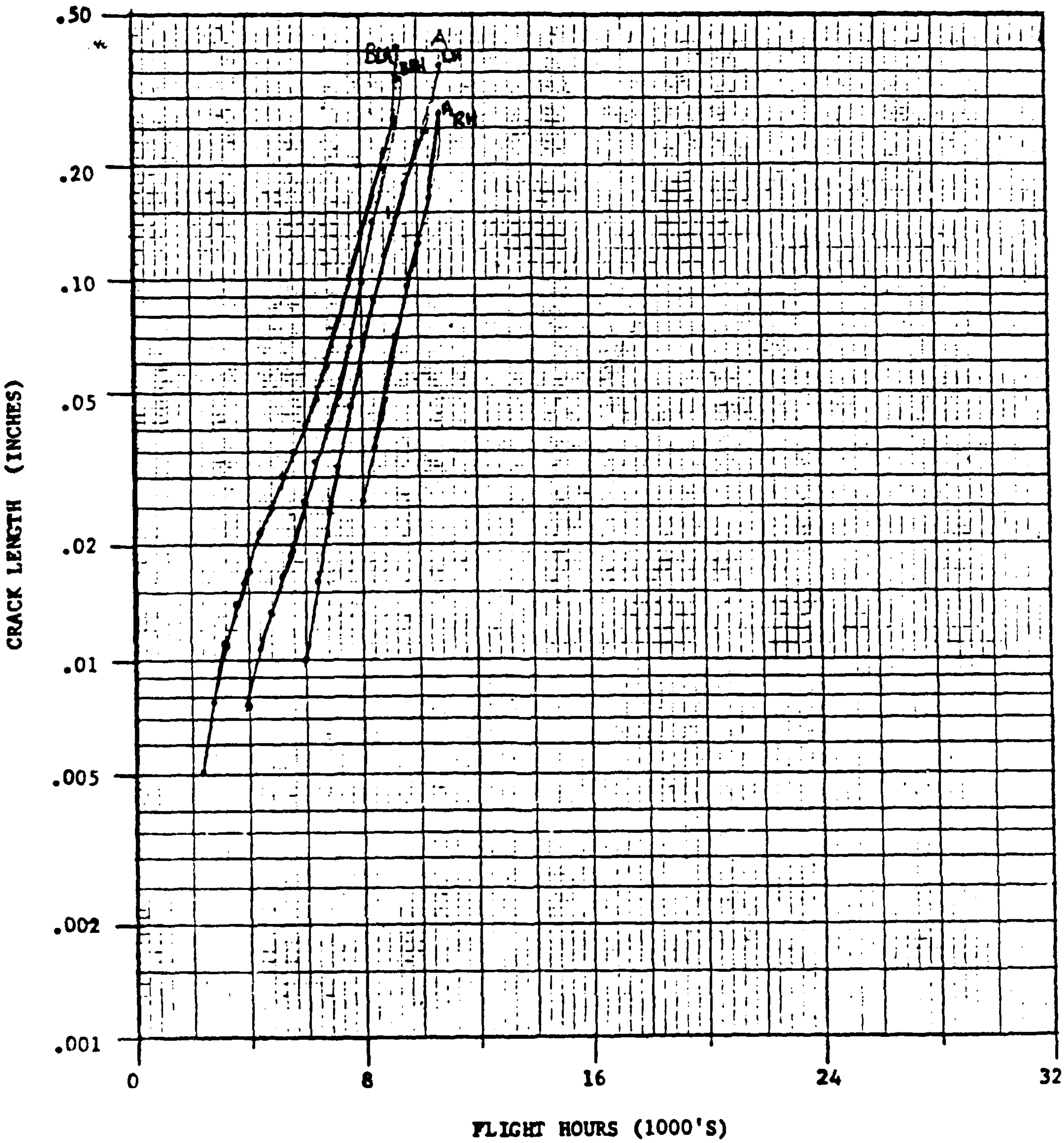


Figure C8. Crack Length Versus Flights for 7475-T7351 Generated by General Dynamics.

MATERIAL IN9021 SPECIMEN(S) No Flaw · Lab Air

SPECTRUM 400 HR. STRESS 42 KSI · NET

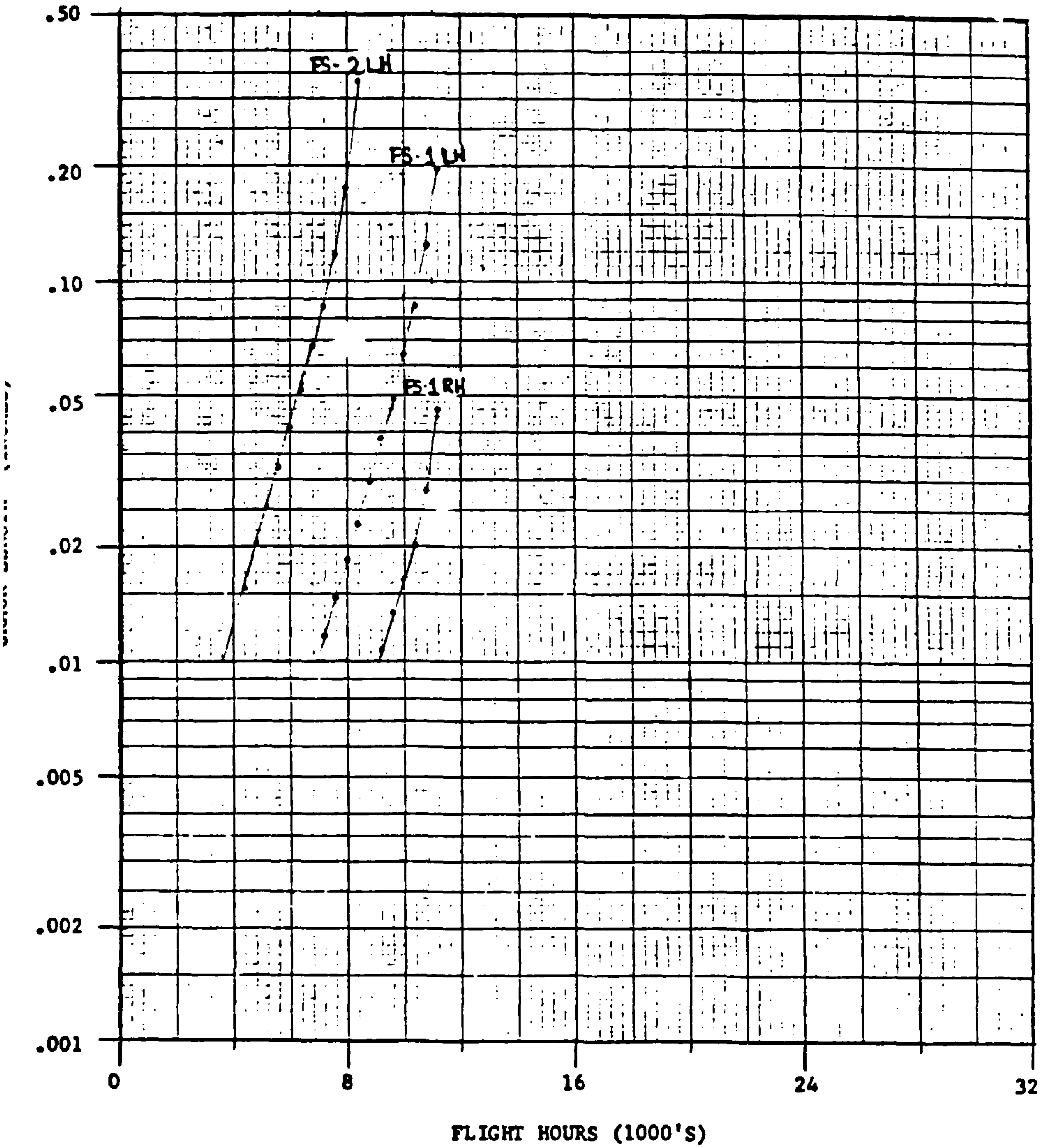


Figure C7. Crack Length Versus Flights for IN9021 Generated by General Dynamics.

TABLE C14 **Durability Properties of Aluminum P/M Products**
Results From BOEING.

Material	Direction	Notch Fatigue, cycles (23 ksi, R=0.06, ν=25 Hz)	Fastener Fatigue, cycles (20 ksi, R = -1.0 ν = 30 Hz)	Stress Corrosion Cracking, ksi (90-day threshold)	Exfoliation (MASTMAASIS)
Hand Forgings:					
Alcoa					
7075-T7352	L	-	115,000/124,000/221,000	-	Small amt of exfoliation and pitting
	LT	-		-	
7050-T73652	L	-		-	
	LT	-		-	
X7090-T7E80	L	-		-	Very slight amt of exfoliation and no pitting
	LT	-		-	
X7091-T7E78	L	53,100/38,100/43,500	416,000/256,000	-	Small amt of exfoliation and very slight pitting
	LT	53,400/46,300/29,800		>60	
	ST	-		>10	
Novamet					
7075-T7352	L	-	117,000/98,000	-	Very slight amt of exfoliation and moderate pitting
	LT	-		-	
IN9021-T352	L	30,000/18,800/1,000,000+	265,000/533,000	-	Very slight amt of exfoliation and moderate pitting
	LT	208,000/1,000,000+/33,000		>60	
Extrusions:					
Alcoa					
X7090-T7E71	L	-		-	Very slight amt of exfoliation and no pitting
	LT	-		>60	
Novamet					
IN9021-T6X[a]	L	27,300/19,300/17,600		-	Small amt of exfoliation and pitting
	LT	-		>50	
IN9021-T6Y[b]	L	12,500/155,000/27,000		-	
	LT			>50	

(a) T6X: solution treated, quenched, stretched 4%, artifically aged
(b) T6Y: solution treated, quenched, artifically aged

STRESS CORROSION
IN9021-T4 FORGING
Results From Lockheed GA.

Three specimens were exposed to alternate immersion (10 minutes wet/50 minutes dry) for 30 days in 3½% salt water. The specimens were stressed to 59 ksi. All specimens were intact after 30 days. 720 hrs.

Corrosion

Lockheed-GA and Boeing evaluated the IN-9021 forgings for corrosion. Lockheed tested 3 samples in an alternating 3.5% salt water (10 minutes wet/50 minutes dry) for 30 days. All specimens were stressed at 59 KSI. At the end of 30 days there were no failures.

Boeing studied both stress corrosion cracking and exfoliation and reported a 90-day threshold in excess of 60 KSI for stress corrosion cracking. Exfoliation was termed very slight with moderate pitting.

Spectrum

General Dynamics performed spectrum fatigue on specimens that were not precracked but had centered hole in the test section. The spectrum was equivalent to 400 hours on the lower wing root of a fighter aircraft. Crack growth was observed post-test on the fracture face. However, because of the nonsymmmetric cracking it was not practical to reduce the data in terms of a stress intensity factor. Total flight hours to failure appear to be the most practical way to index the data. Besides the tests run at a maximum net section stress of 42 KSI on IN-9021 there were duplicate tests performed on 7475-T7351. Flight hours to failure which included initiation and propagation, were between 8,000 and 12,000 flight hours for the IN-9021 while the 7475 had similar lives. It appears the materials are equivalent.

TABLE C13

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE C6 INDICATING EFFECT
OF STRESS RATIO

BOEING

MATERIAL: ALUMINUM IN9021
CONDIT'ON: T352
ENVIRONMENT: R.T. ,LAB AIR

DELTA K (KSI*IN**1/2)			DA/DN (10**-6 IN./CYCLE) A	B	C	D
			R=+0.06			
	A:	9.11	1.76			
DELTA K MIN	B:					
	C:					
	D:					
		10.00	2.47			
		13.00	7.75			
		16.00	18.2			
		20.00	31.7			
	A:	20.88	33.0			
DELTA K MAX	B:					
	C:					
	D:					

CONDITION/HT: T352
FORM: 0.90"TH FORGING
SPECIMEN TYPE: CT
ORIENTATION: T-L
FREQUENCY: 30.00 HZ
ENVIRONMENT: R.T., LAB AIR

YIELD STRENGTH: 72.2 KSI
ULT. STRENGTH: 83.0 KSI
SPECIMEN THK:
SPECIMEN WIDTH:
REFERENCES:

ALUM. ALLOY

IN9021

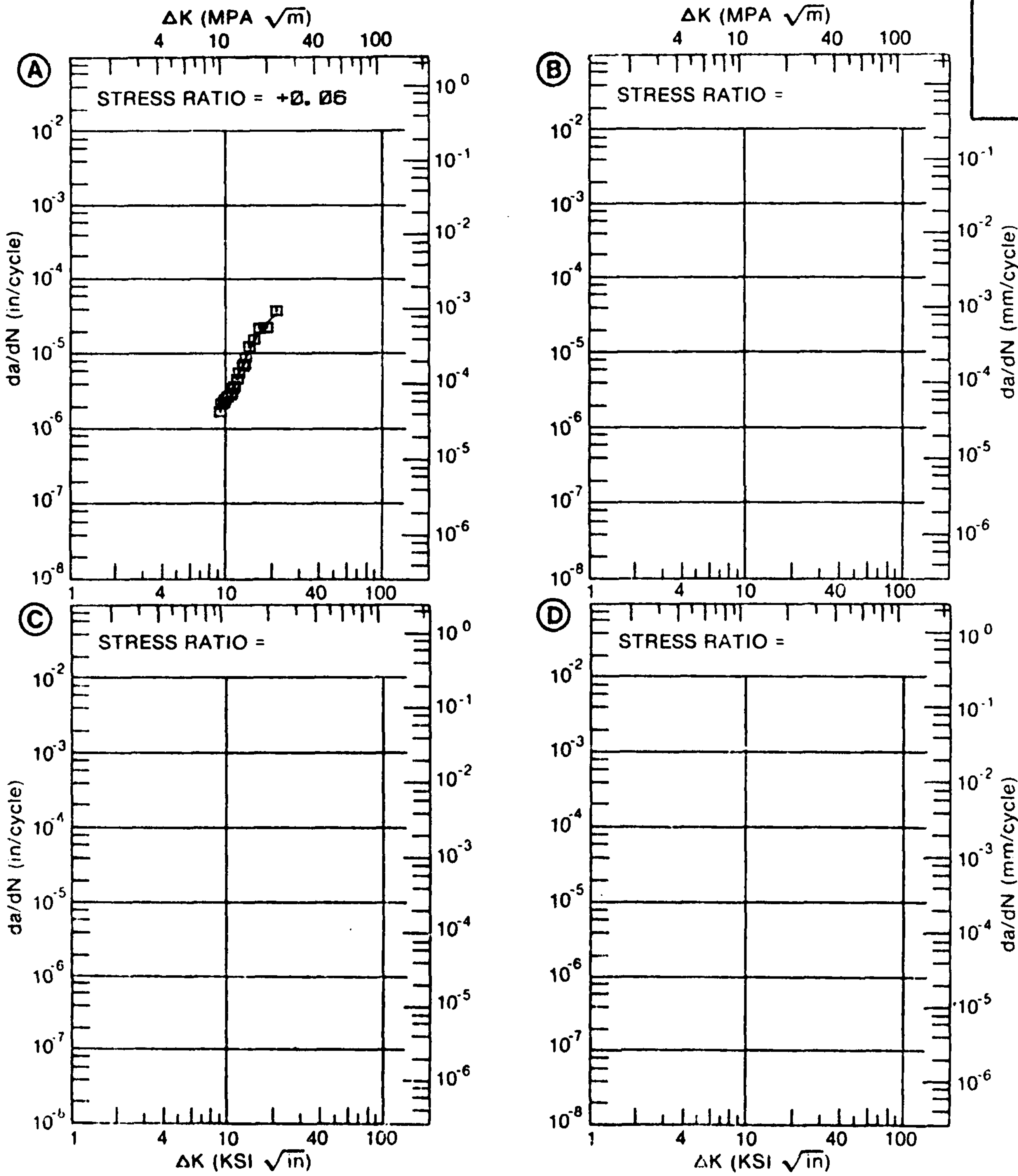


Figure C6. Fatigue Crack Growth Rate Data for IN-9021 Forgings; Boeing

TABLE C12

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE C5 INDICATING EFFECT
OF STRESS RATIO

GENERAL DYNAMICS

MATERIAL: ALUMINUM IN9021
CONDITION:
ENVIRONMENT: R. T. , HI HUMIDITY

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN. /CYCLE) A	B	C	D
		R=+0. 10			
DELTA K MIN A:	4. 53	. 12			
DELTA K MIN B:					
DELTA K MIN C:					
DELTA K MIN D:					
	5. 00	. 153			
	6. 00	. 316			
	7. 00	. 773			
	8. 00	1. 92			
	9. 00	4. 51			
	10. 00	9. 82			
	13. 00	59. 2			
	16. 00	171.			
	20. 00	288.			
DELTA K MAX A:	22. 38	270.			
DELTA K MAX B:					
DELTA K MAX C:					
DELTA K MAX D:					

CONDITION/HT:
FORM: Ø.75"TH FORGING
SPECIMEN TYPE: WOL
ORIENTATION: L-T
FREQUENCY: 9.ØØ HZ
ENVIRONMENT: R.T., HI HUMIDITY

YIELD STRENGTH: 74.Ø KSI
ULT. STRENGTH: 87.2 KSI
SPECIMEN THK: Ø.398"
SPECIMEN WIDTH: 2.553"
REFERENCES:

ALUM. ALLOY

IN9Ø21

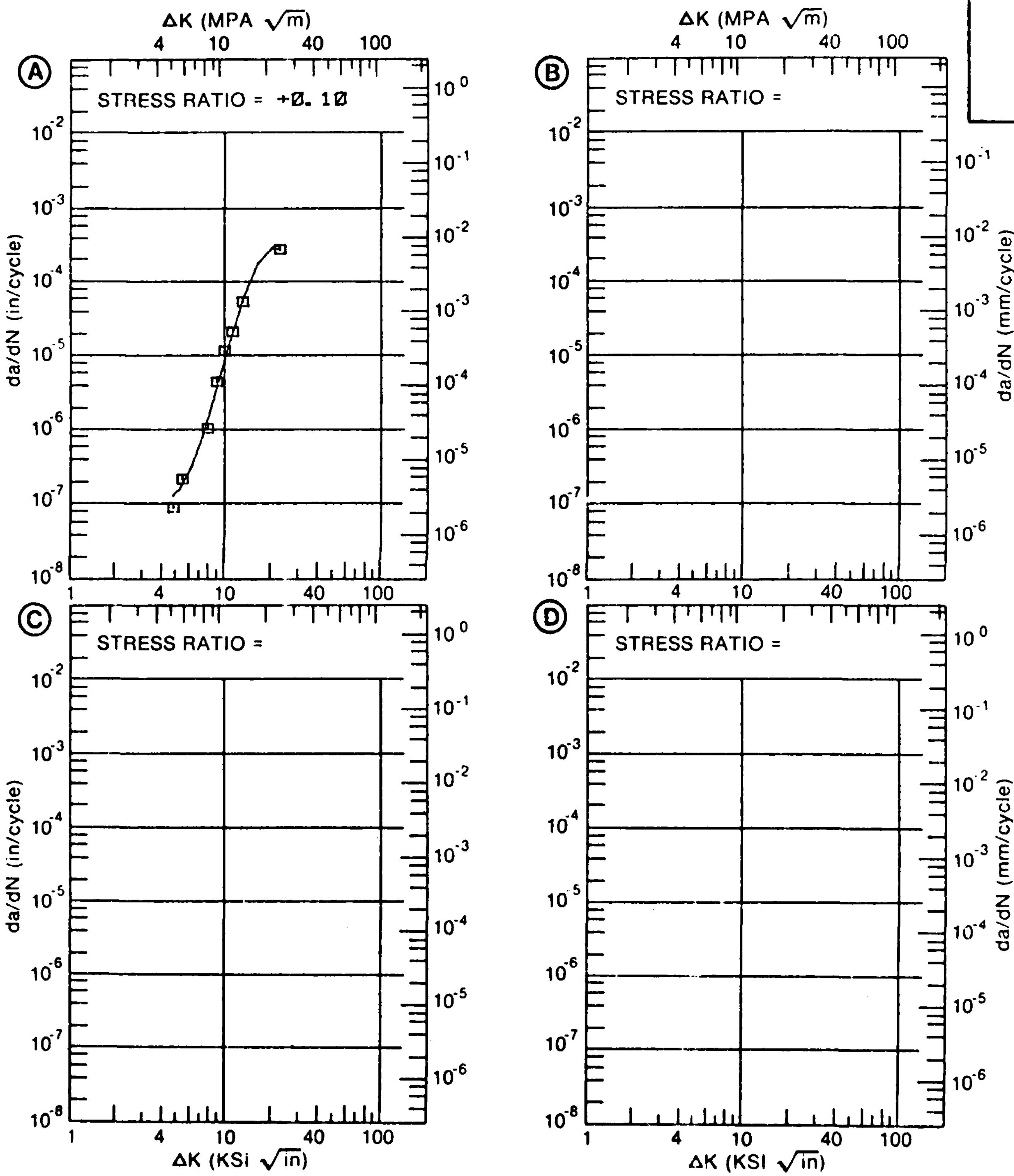


Figure C5. Fatigue Crack Growth Rate Data for IN-9021 Forgings; General Dynamics

TABLE C11

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE C4 INDICATING EFFECT OF STRESS RATIO

LOCKHEED-GA

MATERIAL: ALUMINUM IN7021
CONDITION:
ENVIRONMENT: R.T. ,HI HUMIDITY

DELTA K (KSI*IN**1/2)			DA/DN (10**-6 IN./CYCLE) A	B	C	D
			R=+0.10	R=+0.50		
DELTA K MIN	A:	5.68	.04			
	B:	1.64		.08		
	C:	2				
	D:					
		2.00		.151		
		2.50		.270		
		3.00		.445		
		3.50		.721		
		4.00		1.17		
		5.00		3.16		
		6.00	.0744	7.90		
		7.00	.303	17.3		
		8.00	.905	34.9		
		9.00	1.89	66.8		
		10.00	3.14	123.		
		13.00	7.65			
DELTA K MAX	A:	14.62	10.9			
	B:	10.85		178.		
	C:					
	D:					

ALUM. ALLOY

IN9021

CONDITION/HT:
FORM: 0.75"TH FORGING
SPECIMEN TYPE: CCP
ORIENTATION: L-T
FREQUENCY: 20.00 HZ
ENVIRONMENT: R.T., HI HUMIDITY

YIELD STRENGTH: 77.7 KSI
ULT. STRENGTH: 89.2 KSI
SPECIMEN THK: 0.248-- 0.254"
SPECIMEN WIDTH: 3.999-- 4.009"
REFERENCES:

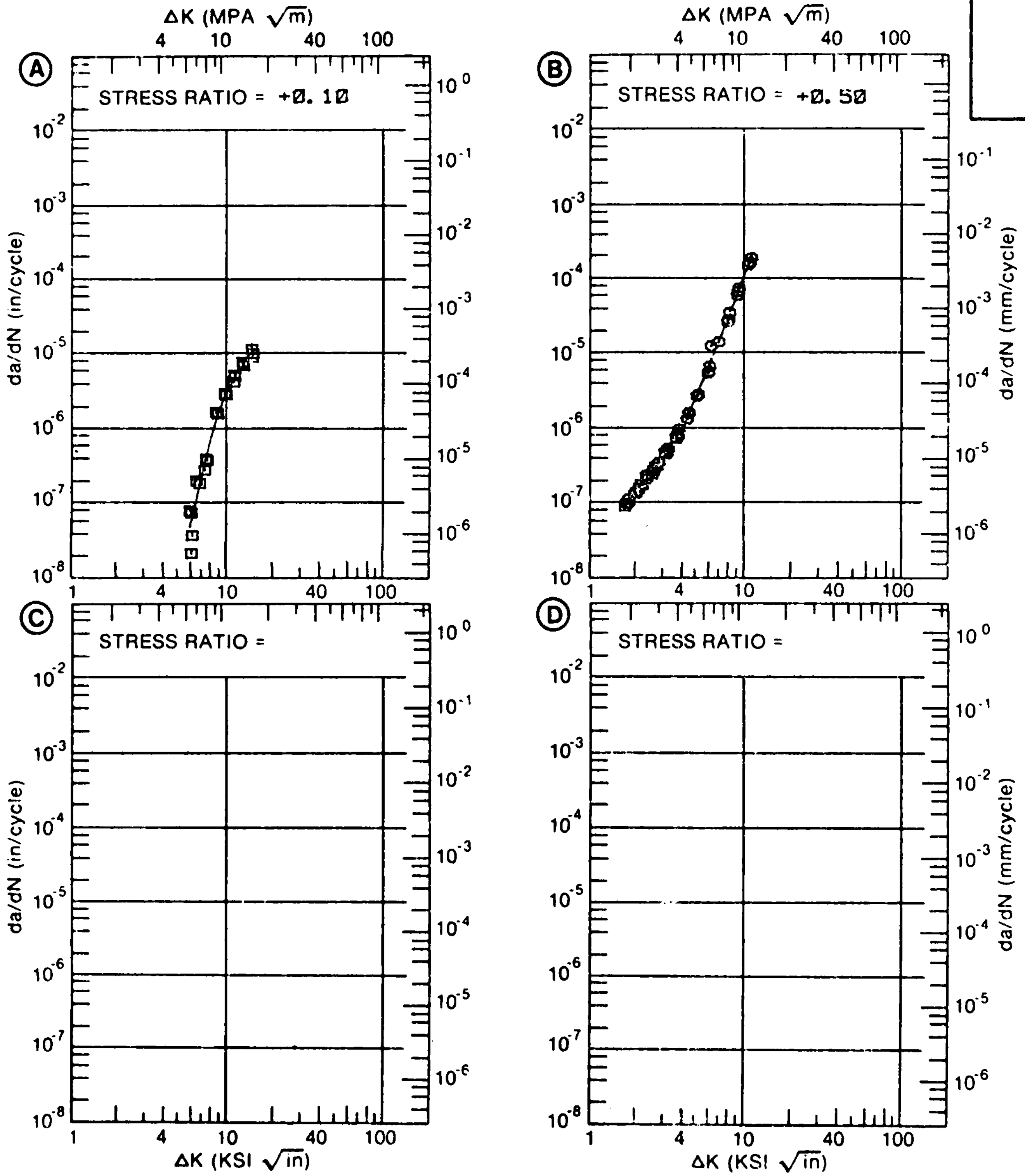


Figure C4. Fatigue Crack Growth Rate Data for IN-9021 Forgings; Lockheed-GA

TABLE C10

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE C3 INDICATING EFFECT
OF STRESS RATIO

BOEING

MATERIAL: ALUMINUM IN9021
CONDITION: T352
ENVIRONMENT: R.T. ,LAB AIR

DELTA K (KSI*IN**1/2)			DA/DN (10**-6 IN./CYCLE) A	B	C	D
			R=+0.06			
DELTA K MIN	A:	7.10	1.77			
	B:					
	C:					
	D:					
		8.00	1.59			
		9.00	1.48			
		10.00	1.48			
		13.00	2.40			
		16.00	7.35			
		20.00	68.5			
		25.00	2480.			
DELTA K MAX	A:	25.20	2902.			
	B:					
	C:					
	D:					

TABLE D2

7091-T7E69 EXTRUSION: 1½" x 4½"

TENSILE

COMPANY	TEST TEMP (°F)	ORIENTATION	ULT STR, KSI	YIELD STR, KSI	ELONG, %
ALCOA	RT	LONG	84.8	75.9	9.5
			82.8	74.1	9.5
			84.2	75.7	10.0
ALCOA			86.6	79.7	11.5
			87.1	80.2	11.0
AFWAL			84.9	77.0	11.3
			83.6	74.9	11.7
			84.7	77.0	11.3
FAIRCHILD			86.1	75.4	9.1
			84.3	76.4	
			86.1	80.3	8.3
			84.7	77.5	8.1
			90.7	85.1	10.4

TABLE D3

7091-T7E69 EXTRUSION: 1½" x 4½"

TENSILE

COMPANY	TEST TEMP (°F)	ORIENTATION	ULT STR, KSI	YIELD STR, KSI	ELONG, %
ALCOA	RT	TRANS	79.1	69.9	10.7(h)
			76.5	66.7	10.0
			79.1	70.0	9.3
ALCOA			81.0	72.5	9.3
			80.9	72.8	12.1
FAIRCHILD			82.0	73.0	13.3
			78.0	67.3	19.3
			80.8	72.2	12.8

h) fragmented fracture

TABLE D4

7091-T7E69 EXTRUSION

TENSILE

COMPANY	ORIENT	ULT STR KSI	YIELD STR KSI	ELONG %
ALCOA	S TRANS	79.1	68.4	9.4(h)
		76.9	63.7	10.9
		78.9	66.2	10.9
ALCOA		81.3	69.6	9.4
		81.1	69.2	9.4
		81.1	69.4	10.9
		81.3	70.2	9.4

(h) fragmented fracture

TABLE D5

7091-T7E69 EXTRUSION

COMPRESSION

COMPANY	ORIENTATION	COMP .2% YIELD STR (KSI)
ALCOA	LONG	75.4
		74.7
		75.7
ALCOA		81.2
		81.7
FAIRCHILD		73.9
		57.2 *
		73.6
		73.4
		50.0 *

* Eliminated from analysis

TABLE D6

7091-T7E69 EXTRUSION

COMPRESSION

COMPANY	ORIENTATION	COMP YS, KSI
ALCOA	TRANS	74.1
		72.0
		74.1
ALCOA		78.5
		78.6
FAIRCHILD		69.6
		77.3
		79.1
		72.2
		70.5

TABLE D7

7091-T7E69 EXTRUSION

SHEAR

COMPANY	ORIENTATION	SHEAR STR, (KSI)
ALCOA	LONG	46.1
		45.8
		46.1
ALCOA		48.1
		47.6
FAIRCHILD		50.8
		49.1
		49.1
		49.1
		47.0
		48.4

TABLE D8

7091-T7E69 EXTRUSION

SHEAR

COMPANY	ORIENTATION	SHEAR STR, (KSI)
ALCOA	TRANS	45.0
		43.8
		44.8
ALCOA		46.2
		45.1
FAIRCHILD		46.1
		44.5
		46.7

TABLE D9

7091-T7E69 EXTRUSION

BEARING

COMPANY	ORIENT	e/D	ULT BEARING STR(KSI)	YIELD BEARING STR(KSI)
ALCOA	LONG	1.5	120.0	99.2
			121.2	102.4
			124.5	104.4
ALCOA			127.2	107.1
			128.3	104.3
FAIRCHILD			126.2	105.7
			123.4	103.6
			127.9	108.2
			130.8	108.6
			121.0	100.3

TABLE D10

7091-T7E69 EXTRUSION

BEARING

COMPANY	ORIENT	e/D	ULT B. STR, (KSI)	YIELD B. STR, (KSI)
ALCOA	LONG	2.0	154.6	119.7
			154.6	121.4
			156.8	125.0
ALCOA			163.2	118.2
			162.6	124.2
FAIRCHILD			160.1	121.4
			142.1	108.8
			155.4	117.8
			158.8	118.7
			160.4	124.2

TABLE D11

7091-T7E69 EXTRUSIONS

BEARING

COMPANY	ORIENTATION	e/D	ULT. B. STR, (KSI)	YIELD B. STR, (KSI)
FAIRCHILD	TRANS	1.5	109.3	97.7
			107.4	97.1
			108.7	94.1
		2.0	139.3	111.5
			141.4	111.2
			142.6	119.4
			144.3	117.8
			143.3	113.9

TABLE D12

7091-T7E69 EXTRUSION

FRACTURE TOUGHNESS

COMPANY	ORIENT	KIC (KSI√IN)	KQ (KSI√IN)	COMMENT
ALCOA	L-T	42.3		VALID
		48.1		VALID
		35.8		VALID
ALCOA		45.8		
		43.1		
		50.4		
		52.9		
ALCOA	T-L	28.3		VALID
		32.3		VALID
		26.6		VALID
ALCOA		31.4		
		32.4		
		30.7		
		32.2		
ALCOA	S-L	27.3		VALID
			29.8	INVALID Specimen not thick enough
		25.7		VALID
ALCOA		26.9		
		27.3		

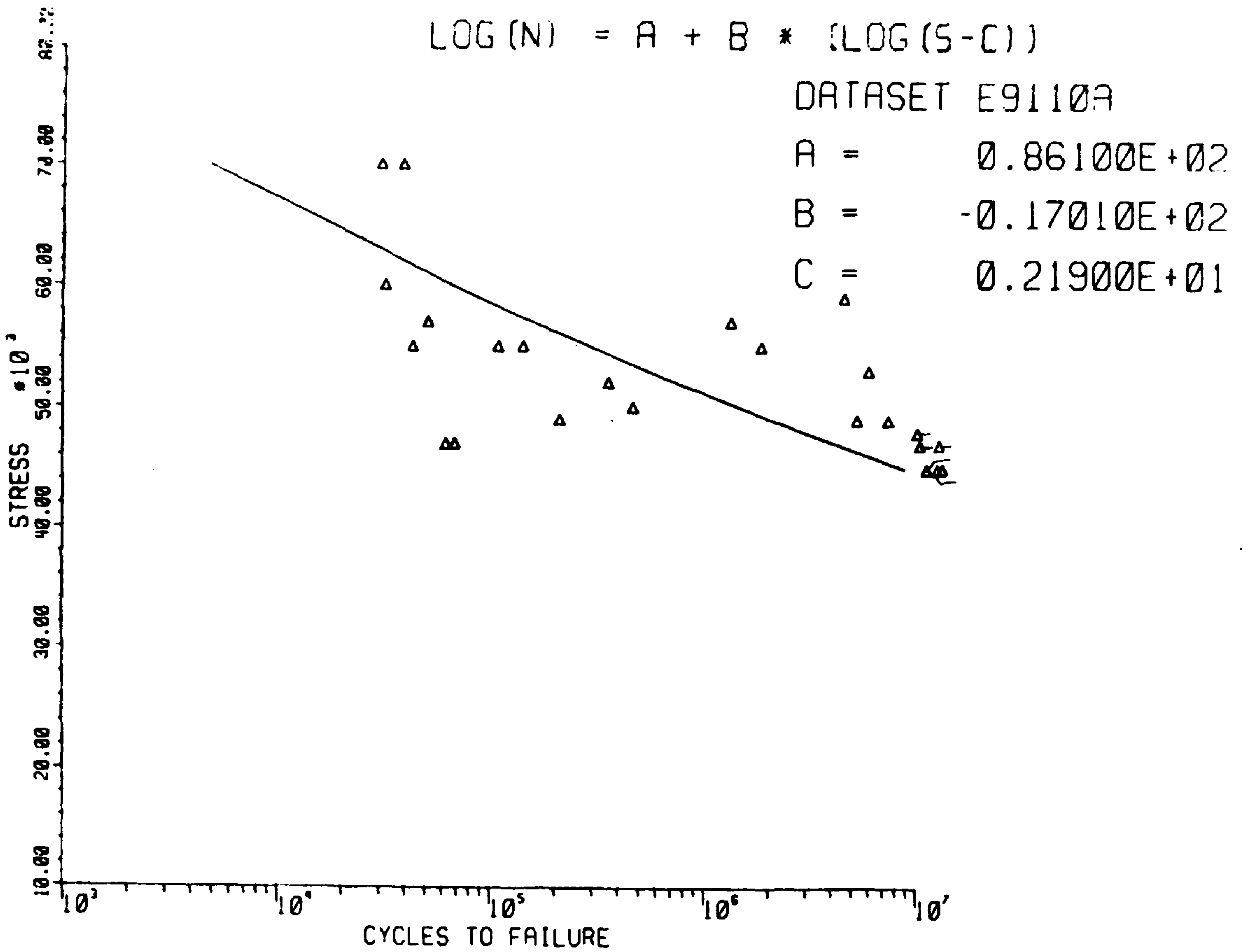


Figure D1. Fatigue Results for 7091 Extrusions; R=0.1, K_t=1.0

TABLE D13

FATIGUE RESULTS FOR 7091 EXTRUSIONS; R=0.1,K_t=1.0

Stress PSI	Cycles	Fail(1) No Fail(0)
45000	11267800	0
45000	12659400	0
45000	13354000	1
47000	63100	1
47000	69500	1
47000	10402500	0
47000	12771800	0
48000	10163100	0
49000	215400	1
49000	5243700	1
49000	7431700	1
50000	474900	1
52000	363300	1
53000	5959200	1
55000	110550	1
55000	1848300	1
55000	44400	1
55000	144600	1
57000	51800	1
57000	1335200	1
59000	4605400	1
60000	32600	1
70000	39200	1
70000	31200	1

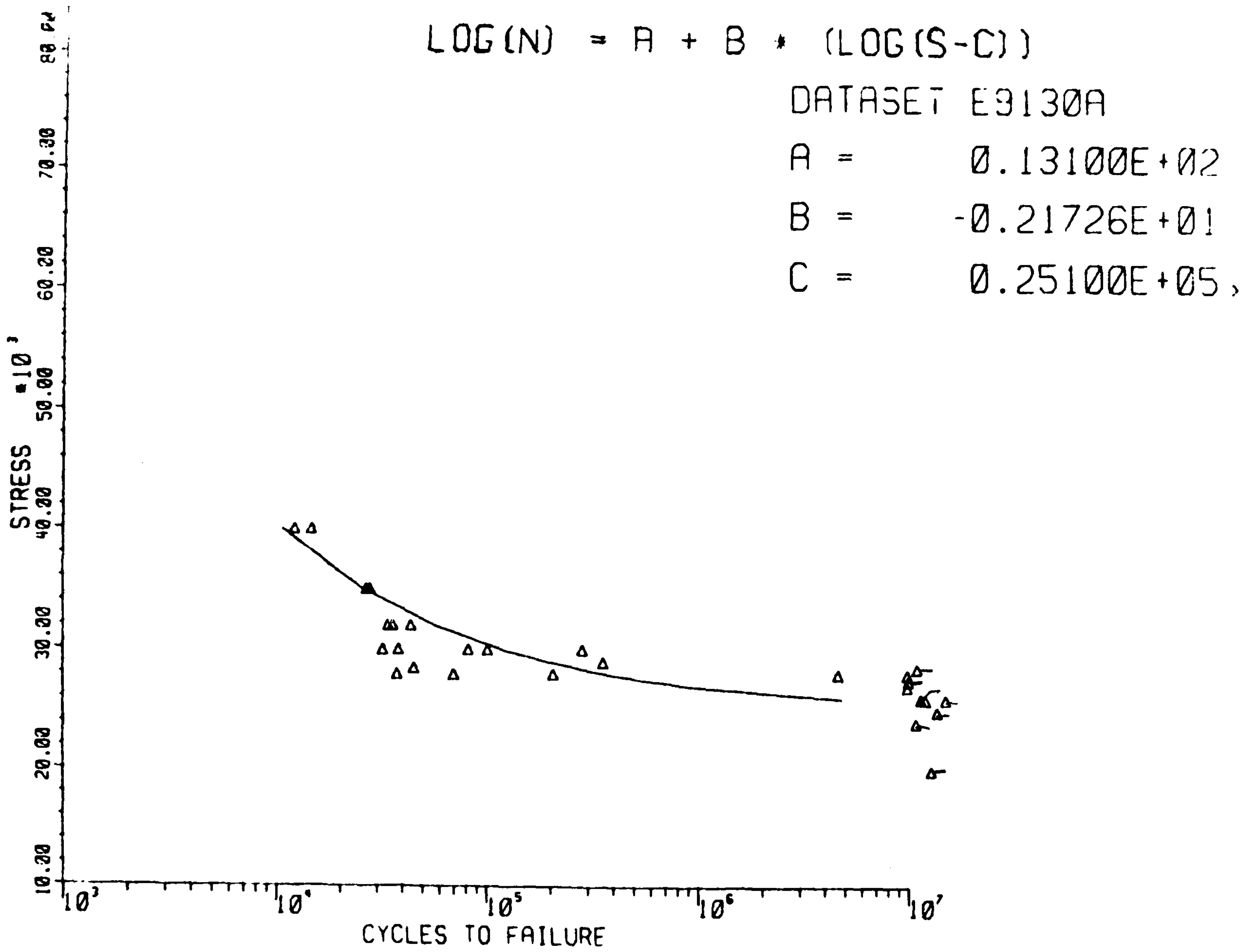


Figure D2.- Fatigue Results for 7091 Extrusions: R=0.1,K_t=3.0

TABLE E2

7090 EXTRUSION; 1½" x 4½"

TENSILE

COMPANY	TEST TEMP	ORIENT	ULT STR, (KSI)	YIELD STR, (KSI)	ELONG (%)
ROCKWELL	RT	LONG	87.2	81.3	8.5
			88.2	82.3	9.4
			90.1	84.2	10.1
VOUGHT			91.5	85.4	9.9
			90.1	85.4	8.9
			86.0	81.3	-
ALCOA			91.8	85.3	9.5
			86.8	80.0	9.5
			90.3	83.7	9.5
BOEING			90.6	84.1	9.1
			89.2	84.5	9.5
ALCOA			92.5	87.8	10.0
			89.1	82.8	10.0
			93.8	88.8	7.5
			92.1	86.4	10.0
AFWAL			93.9	88.7	8.5
			91.6	85.4	9.5
			93.7	88.7	10.6

TABLE E1

SUGGESTED ALLOWABLES FOR

7090-T7E71 Extrusions

1½" x 4½"

F_{tu}, KSI

L	87.5
LT	83.1
S	82.3

F_{ty}, KSI

L	81.5
LT	75.1
S	70.0

F_{cy},, KSI

L	80.4
LT	80.3

F_{su}, KSI

L	48.0
LT	46.5

F_{bru},KSI

L	
(e/D=1.5)	126.0
(e/D=2.0)	157.7
LT	
(e/D=1.5)	126.2
(e/D=2.0)	172.8

F_{bry}, KSI

L	
(e/D-1.5)	106.1
(e/D=2.0)	119.5
LT	
(e/D=1.5)	104.9
(e/D=2.0)	125.9

K_{IC},KSI$\sqrt{IN}$

L-T	19.3
T-L	13.5
S-L	10.3

NOTE: These values were developed to be used only in a cost-benefit-analysis and are not necessarily accurate for design of hardware.

APPENDIX E

7090-T7E71 EXTRUSIONS

NOTICE: Suggested allowables, mean trends, and trend curves in this document were developed to be used in a cost benefit analysis to assess the potential benefit of using the material in a structure. These suggested allowables and trends are not considered accurate for design of actual hardware.

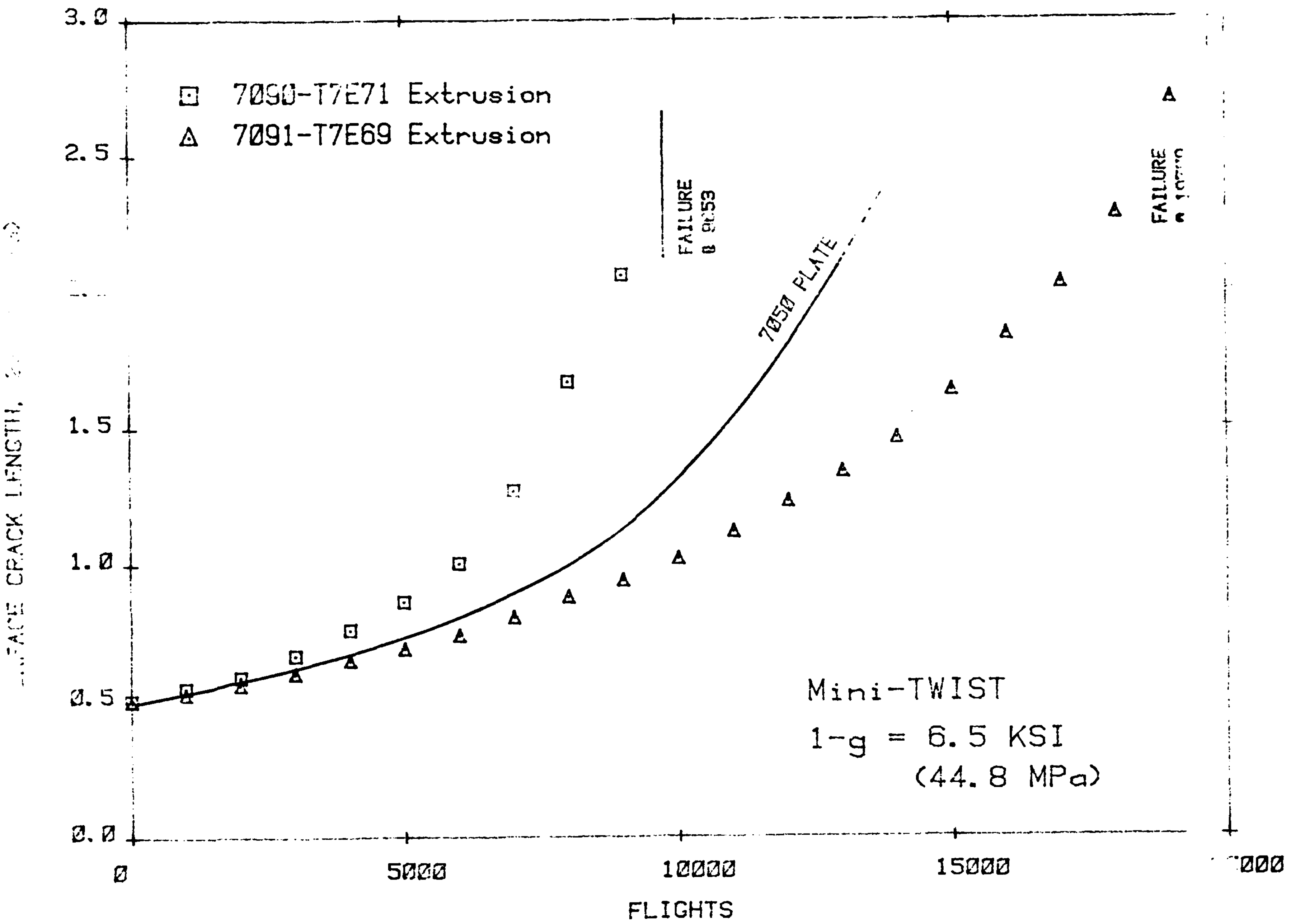


Figure D7. Crack Length Versus Flights for 7091 Extrusion Under Mini-TWIST Loading.

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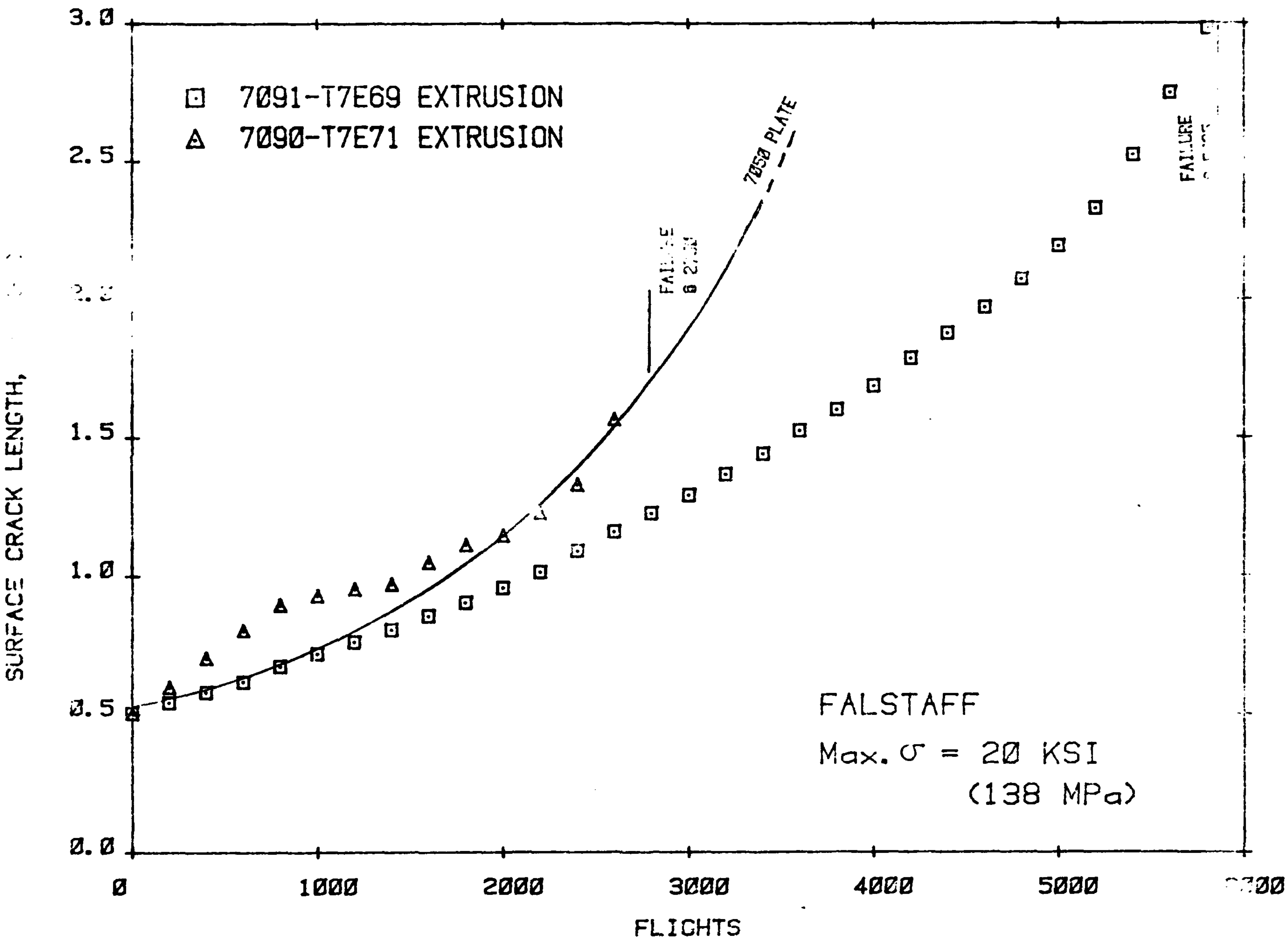

Figure D6. Crack Length Versus Flights for 7091 Extrusion Under FALSTAFF Loading.

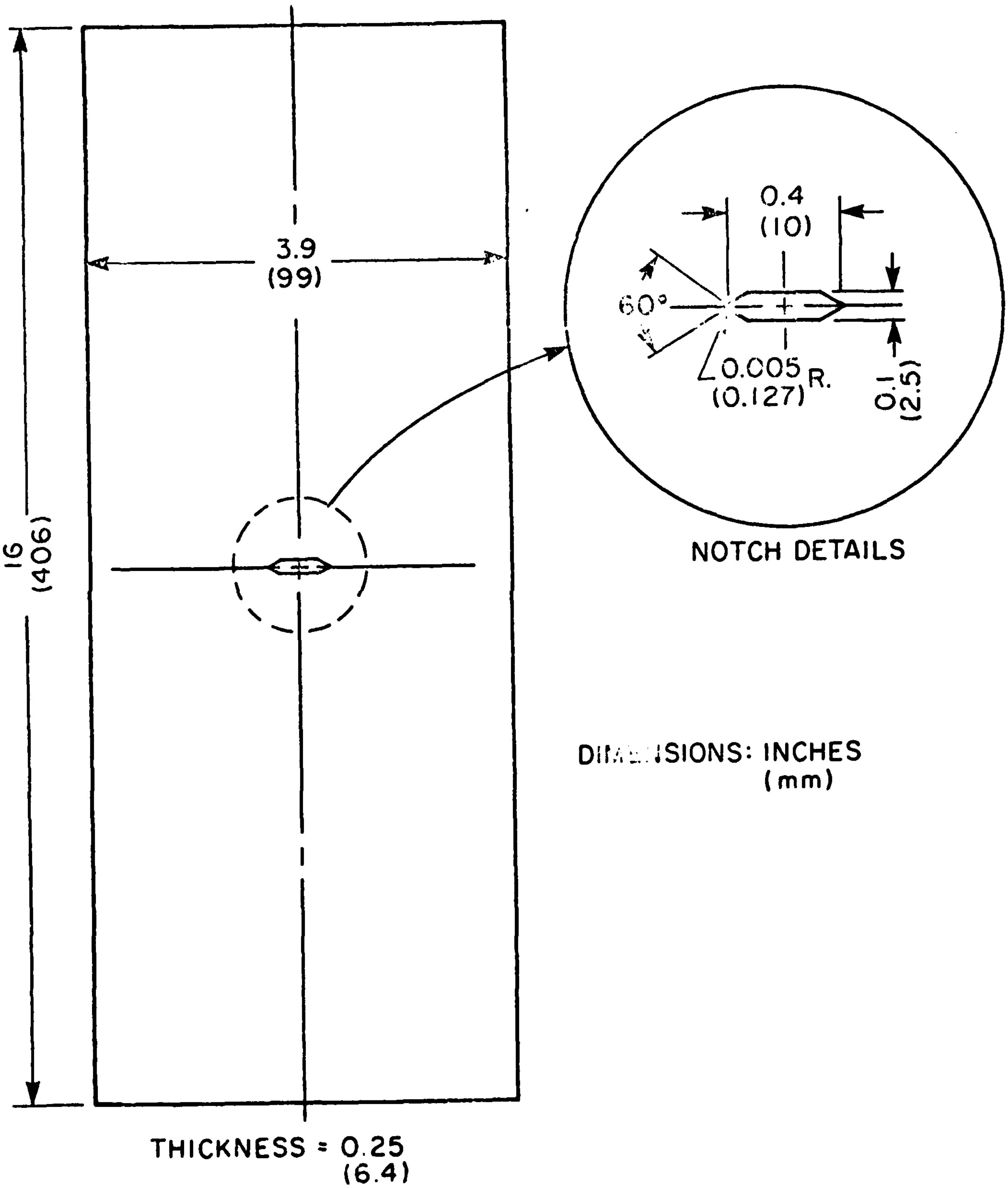

Figure D5. Specimen Used to Generate Data in Figures D6 and D7.

TABLE D18

Corrosion Results From ALCOA

PIT DEPTH MEASUREMENTS (1) OBTAINED FROM 114 mm (4-1/2") WIDE BY 152 mm (6") LONG PANELS OF 7090-T7E71 AND 7091-T7E69 ALLOY EXTRUSIONS (2) EXPOSED 14 DAYS TO MASTMAASIS TEST

		Pit Depth - Mean[3] and Range								
		Near Surface			T/10 Plane (4)			T/2 Plane		
S. No.	Alloy	Mean mm	Range - mm Min.	Max.	Mean mm	Range - mm Min.	Max.	Mean mm	Range - mm Min.	Max.
513907-4A	7090-T7E71	0.43	0.31	0.58	0.28	0.05	0.69	0.13	0.05	0.23
-4B	7090-T7E71	0.13	0.05	0.18	0.13	0.08	0.23	0.10	0.05	0.13
513995-5A	7091-T7E69	0.33	0.20	0.71	0.28	0.10	0.48	0.18	0.05	0.31
-5B	7091-T7E69	0.15	0.13	0.25	0.13	0.08	0.25	0.10	0.05	0.28

NOTES:

(1) Pit depth measurements obtained with Starrett Pit Depth Gauge No. 643.

(2) Extrusions were 38 mm (1-1/2") thick by 114 mm (4-1/2") wide in cross-section.

(3) Mean pit depth was obtained from 10 measurements from each panel.

(4) The T/10 plane was that plane at 1/10 the distance from the "bottom surface" of the extrusion as opposed to the "top surface" of the extrusion which provided the near surface plane sample.

TABLE D17

Corrosion Results From ALCOA

PERFORMANCE OF SHORT TRANSVERSE 3.1 mm (1/8") DIAMETER SMOOTH TENSILE BARS WHICH WERE REMOVED FROM X7090 AND X7091 ALLOY EXTRUSIONS (1), STRESSED AND EXPOSED 30 DAYS TO 3-1/2% SODIUM CHLORIDE BY ALTERNATE IMMERSION (2)

S. - No.	Alloy	Temper	Stress Level (ksi/MPa)	No. Failures/ No. of Specimens Tested
513907-4	X7090	T7E71	25/172	0/3
513907-4	X7090	T7E71	45/310	0/3
513995-5	X7091	T7E69	25/172	0/3
513995-5	X7091	T7E69	45/310	0/3

Notes: (1) Extrusions were 38 mm (1-1/2") thick by 114 mm (4-1/2") wide in cross section.

(2) The 3-1/2% sodium chloride - alternate immersion test was conducted in accordance with ASTM G44-75.

STRESS CORROSION

ALCOA reported there was no exfoliation corrosion in 7091 extrusions using an accelerated corrosion test. Tabular stress corrosion results are presented in Tables D17 and D18.

SPECTRUM FATIGUE CRACK GROWTH

Figures D5 to D7 are, respectively: 1) a specimen drawing, 2) results of spectrum fatigue crack growth tests using Mini-TWIST spectrum, and 3) the results of spectrum fatigue tests using the FALSTAFF spectrum. These data, developed by AFWAL, are shown along with similar data for 7050-T76 plate. In general, 7091 out performs 7050.

TABLE D16

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE D4 INDICATING EFFECT
OF STRESS RATIO

Alcoa

MATERIAL: ALUMINUM 7091
CONDITION: T7E69
ENVIRONMENT: R.T , HI HUMIDITY

DELTA K (KSI*IN**1/2)			DA/DN (10**-6 IN./CYCLE) A	B	C	D
			R=+0.10	R=+0.33		
	A:	1.66	.0451			
DELTA K	B:	1.31		.0252		
MIN	C:					
	D:					
		1.60		.0702		
		2.00	.0787	.133		
		2.50	.140	.235		
		3.00	.308	.400		
		3.50	.549	.653		
		4.00	.895	1.02		
		5.00	1.95	2.20		
		6.00	3.58	4.13		
		7.00	5.83	7.00		
		8.00	8.72	10.9		
		9.00	12.2	15.8		
		10.00	16.4	21.7		
		13.00	32.0	43.9		
		16.00	51.4	68.3		
		20.00	80.4			
	A:	21.38	90.7			
DELTA K	B:	16.97		75.7		
MAX	C:					
	D:					

CONDITION/HT: T7E69
FORM: 1.50"TH EXTRUSION
SPECIMEN TYPE: CT
ORIENTATION: T-L
FREQUENCY: 25.00 HZ
ENVIRONMENT: R.T., HI HUMIDITY

YIELD STRENGTH: 68.9 KSI
ULT. STRENGTH: 78.2 KSI
SPECIMEN THK: 0.245- 0.252"
SPECIMEN WIDTH: 1.998- 2.008"
REFERENCES:

ALUM. ALLOY

7091

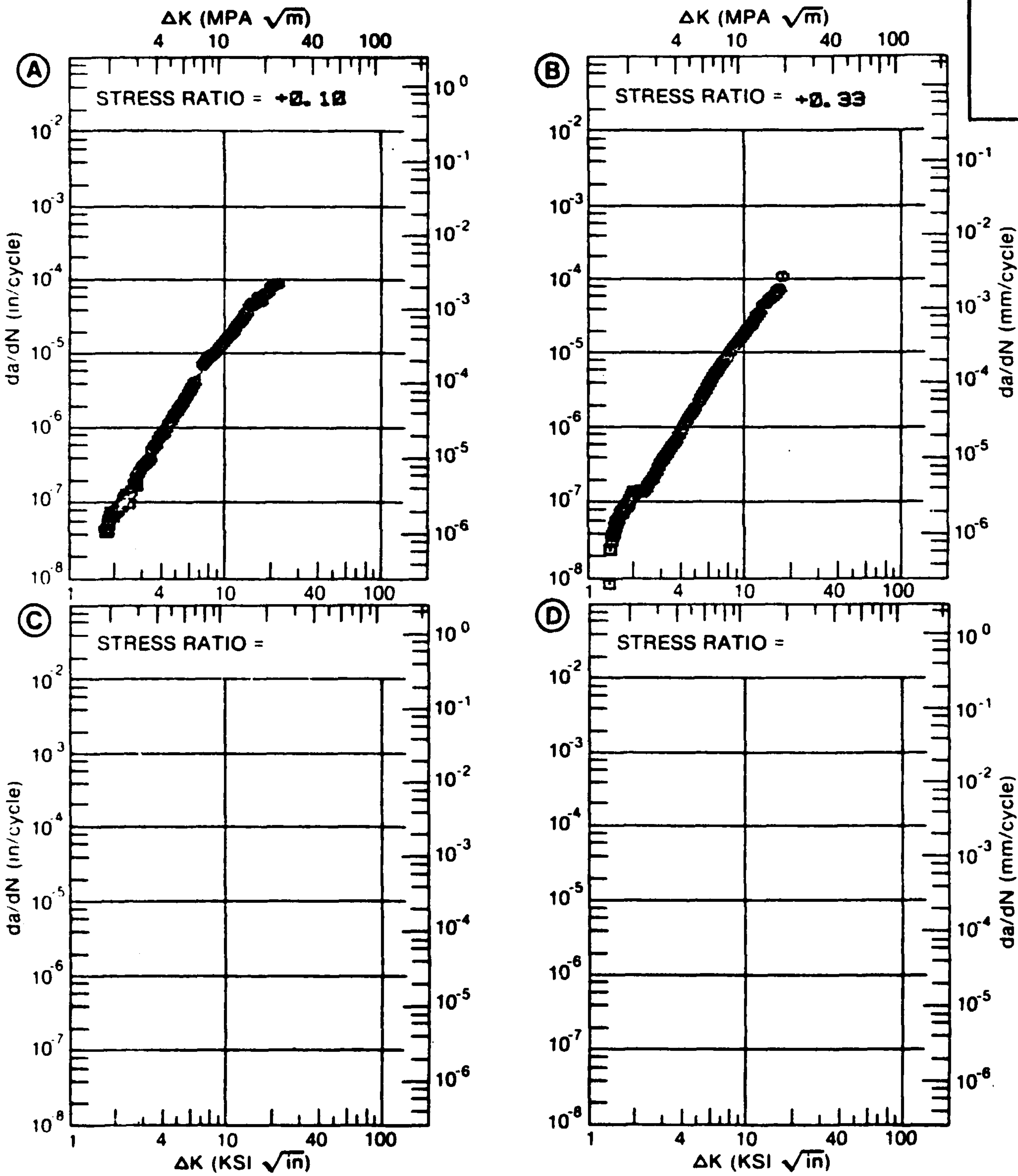

Figure D4. Fatigue Crack Growth Rate Data for 7091 Extrusions; ALCOA.

TABLE D15

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE D3 INDICATING EFFECT
OF STRESS RATIO

Alcoa

MATERIAL: ALUMINUM 7091
CONDITION: T7E69
ENVIRONMENT: R.T., HI HUMIDITY

DELTA K (KSI*IN**1/2)			DA/DN (10**-6 IN./CYCLE) A R=+0.10	B R=+0.33	C R=+0.80
	A:	1.57	.0144		
DELTA K	B:	1.15		.0281	
MIN	C:	1.00			.00857
	D:				
		1.30		.0327	.0382
		1.60	.0174	.0485	.0878
		2.00	.0759	.0866	.179
		2.50	.142	.175	.353
		3.00	.216	.331	.674
		3.50	.350	.581	1.33
		4.00	.573	.955	2.76
		5.00	1.43	2.17	13.8
		6.00	3.04	4.10	
		7.00	5.51	6.74	
		8.00	8.64	9.94	
		9.00	12.0	13.5	
		10.00	14.9	17.0	
		13.00		25.4	
	A:	11.96	18.0		
DELTA K	B:	14.48		27.5	
MAX	C:	5.04			14.8
	D:				

CONDITION/HT: T7E69	
FORM: 1.5Ø"TH EXTRUSION	YIELD STRENGTH: 75.2 KSI
SPECIMEN TYPE: CT	ULT. STRENGTH: 83.9 KSI
ORIENTATION: L-T	SPECIMEN THK: Ø.249- Ø.252"
FREQUENCY: 1Ø.ØØ- 25.ØØ HZ	SPECIMEN WIDTH: 2.ØØ3- 2.545"
ENVIRONMENT: R.T., HI HUMIDITY	REFERENCES:

ALUM. ALLOY

7Ø91

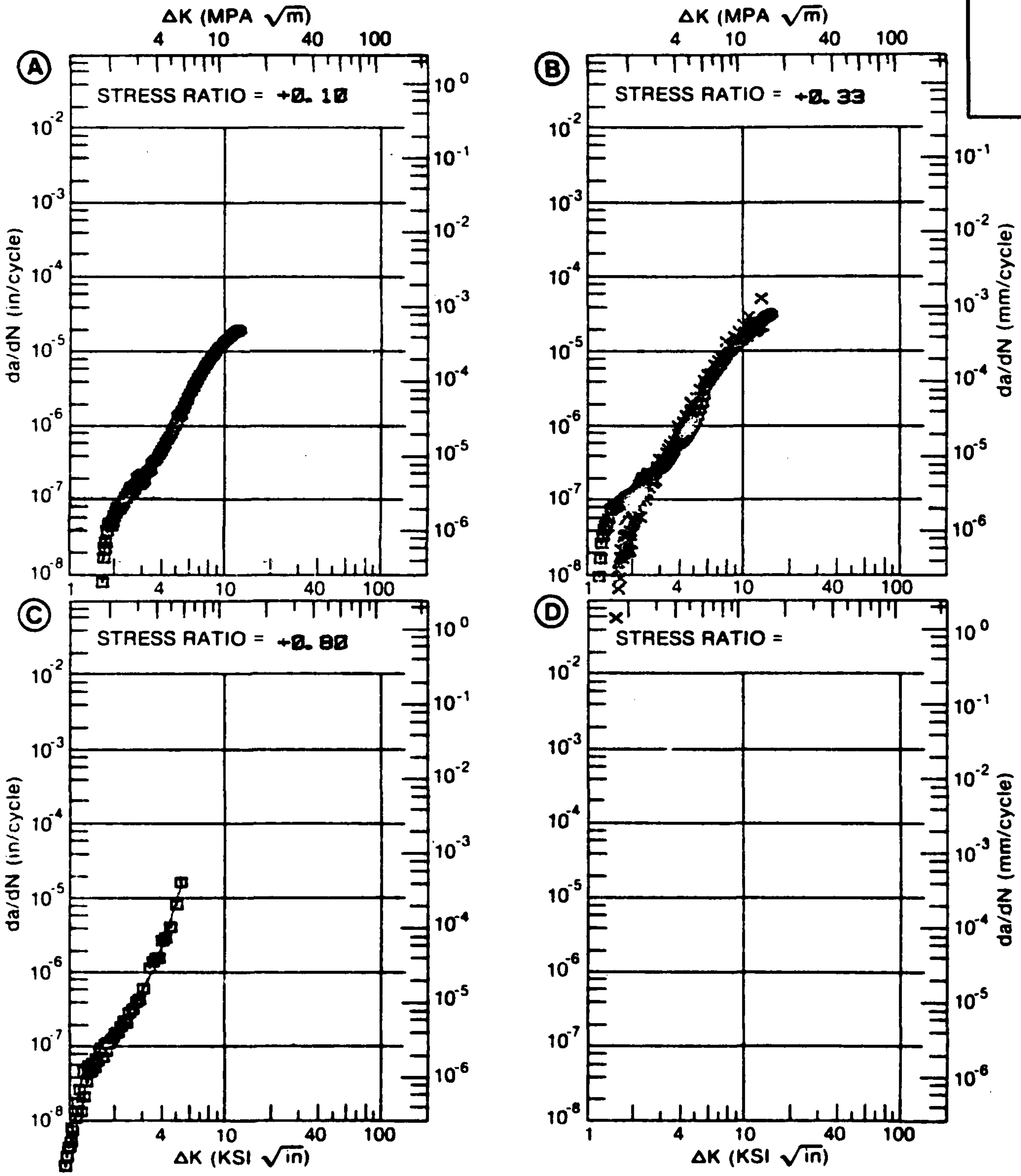

Figure D3. Fatigue Crack Growth Rate Data for 7091 Extrusions; ALCOA.

TABLE D14

FATIGUE RESULTS FOR 7091 EXTRUSIONS; R=0.1,K_t=3.0

Stress PSI	Cycles	Fail(1) No Fail(0)
20000	12797300	0
24000	10888100	0
25000	13718700	0
26000	11354900	0
26000	11980200	1
26000	15038200	0
27000	9845600	1
27500	10031500	0
28000	38200	1
28000	70800	1
28000	208800	1
28000	4627100	1
28000	9904600	1
28500	46300	1
28500	11031350	0
29000	359700	1
30000	32600	1
30000	83300	1
30000	287300	1
30000	39000	1
30000	103000	1
32000	34500	1
32000	36400	1
32000	44300	1
35000	28250	1
35000	27300	1
40000	12400	1
40000	14800	1

TABLE E3

7090 EXTRUSION

TENSILE

COMPANY	TEST TEMP OF	ORIENT	ULT STR, (KSI)	YIELD STR, (KSI)	ELONG (%)
ROCKWELL CA	RT	TRANS	86.0	79.3	10.9
			85.7	77.5	9.6
			86.0	78.7	10.3
ALCOA			86.4	78.6	7.9(h)
			81.8	74.0	7.9(i)
			85.7	77.9	7.9(i)
BOEING			85.8	78.4	12.0
			85.6	77.6	5.7
ALCOA			86.9	78.9	12.0
			89.4	82.4	8.6
ALCOA	RT	SHORT TRANSVERSE	86.5	71.8	7.8
			82.6	70.0	10.9
			85.3	73.5	7.8
			86,2	75.9	4.7
			87.2	75.6	6.3
			88.5	77.1	6.3
			82.3	76.4	1.6*

(h) Fragmented fracture
(i) failed outside middle half of gage length
* eliminated from analysis

TABLE E4

7090 EXTRUSION

COMPRESSION

COMPANY	ORIENTATION	COMP YIELD STR (KSI)
ROCKWELL CA	LONG	83.9
		85.2
		82.5
ALCOA		84.9
		79.9
		83.3
BOEING		84.7
		85.9
ALCOA		86.7
		89.8
ROCKWELL	TRANS	85.0
		86.1
		85.6
ALCOA		84.5
		80.3
		82.6
ALCOA		84.9
		89.3

TABLE E5

7090 EXTRUSION

SHEAR

COMPANY	ORIENTATION	SHEAR STR (KSI)
ROCKWELL	LONG	48.3 50.3 51.1
ALCOA		50.4 48.0 49.4
ALCOA		50.8 52.4
ROCKWELL	TRANS	54.3 50.4 49.9
ALCOA		49.2 46.5 48.3
ALCOA		48.7 49.9

TABLE E6

7090 EXTRUSION

BEARING

COMPANY	ORIENT	e/D	BEARING ULT(KSI)	BEARING YIELD (KSI)
ALCOA	LONG	1.5	131.6	113.4
			126.0	106.1
			130.5	110.7
ALCOA			135.5	118.4
			136.8	121.6
ROCKWELL CA	TRANS		127.0	105.9
			128.4	108.3
			126.2	104.9

TABLE E7

7090 EXTRUSION

BEARING

COMPANY	ORIENT	e/D	BEARING ULT(KSI)	BEARING YIELD(KSI)
ROCKWELL	LONG	2.0	160.8	119.6
			158.9	119.5
			164.8	122.8
ALCOA			170.7	134.8
			157.7	122.6
			166.0	130.6
ALCOA			163.1	133.3
			162.7	128.8
			169.5	139.2
			167.9	132.5
ROCKWELL	TRANS	2.0	173.4	126.0
			172.8	125.9
			174.3	127.3

TABLE E8

7090 EXTRUSION

FRACTURE TOUGHNESS (K_{IC})

COMPANY	ORIENTATION	K_{IC} KSI$\sqrt{IN}$	K_Q KSI$\sqrt{IN}$	Comments
ROCKWELL	L-T		30.2	Crack deviation from notch
			29.8	Crack deviation from notch
ALCOA		22.2		VALID
		28.1		VALID
		25.1		VALID
ALCOA		22.0		
		19.3		
VOUGHT			16.4	INVALID
			18.9	INVALID
BOEING		19.6		VALID
ROCKWELL		19.5		VALID
		19.8		VALID
ALCOA			14.9	INVALID
		19.4		VALID
		17.6		VALID
ALCOA		16.0		
		13.5		
ALCOA	S-L		14.0	INVALID
		19.2		VALID
			16.1	INVALID
ALCOA		12.3		
		10.3		

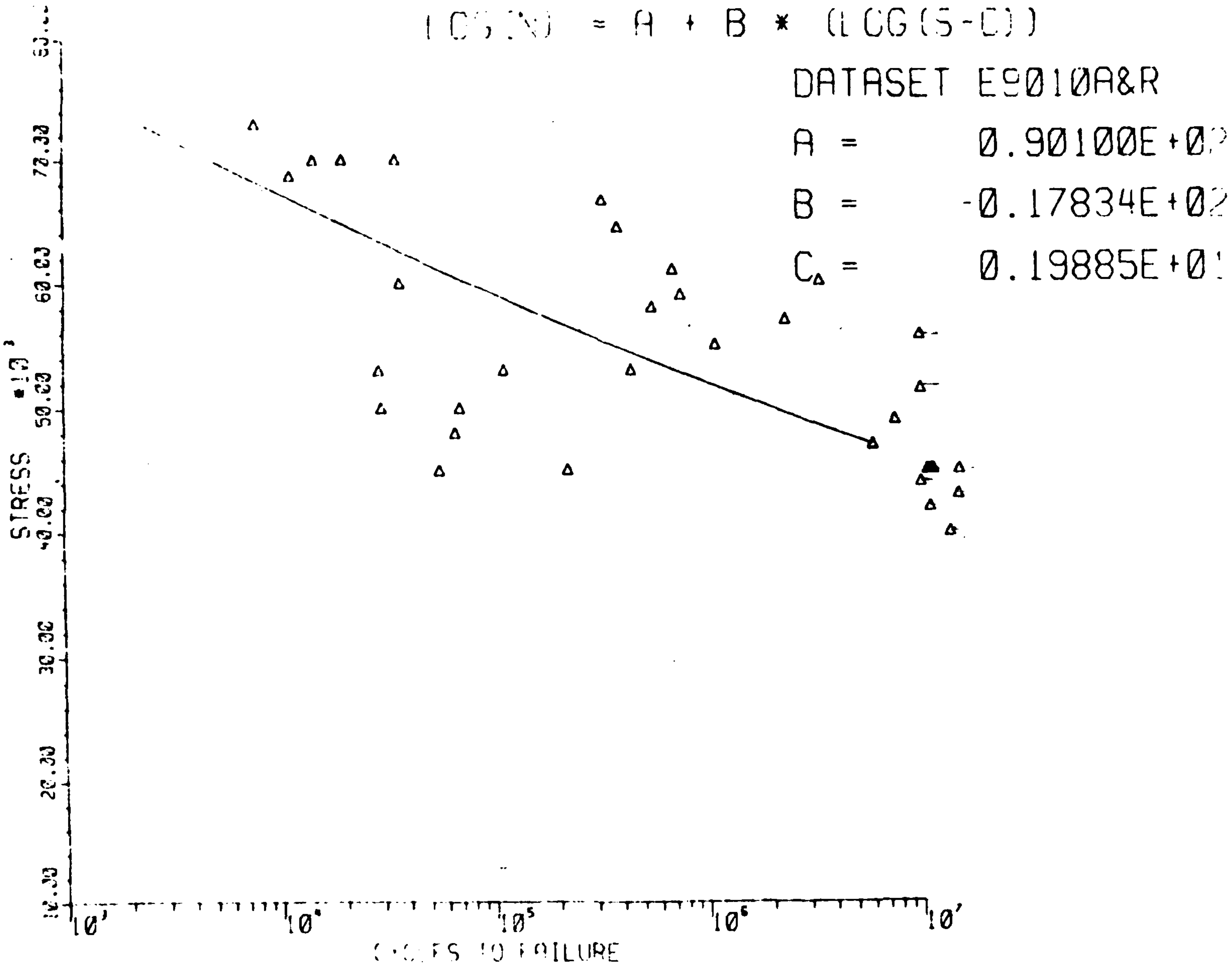

Figure E1. Fatigue Results for 7090 Extrusions; R=0.1, K_t=1.0

TABLE E9

FATIGUE RESULTS FOR 7090 EXTRUSIONS; R=0.1, k_t=1.0

Stress PSI	Cycles	Fail (1) No Fail (0)
40000	13750300	0
42000	11003500	0
43000	14893000	0
44000	10052600	0
45000	55300	1
45000	10718500	0
45000	11117000	0
45000	15044400	0
45000	11336300	0
45000	225500	1
47000	6006500	1
48000	66950	1
49000	7578700	1
50000	30600	1
50000	70800	1
51500	10000000	0
53000	29300	1
53000	114100	1
53000	447000	1
55000	1105800	1
55800	10000000	0
57000	2359600	1
57980	560800	1
59000	762200	1
60000	37300	1
60130	3400000	1
61000	697700	1
64400	387830	1
66570	330940	1
68700	11431	1
70000	20200	1
70000	36000	1
70000	14600	1
73000	7780	1

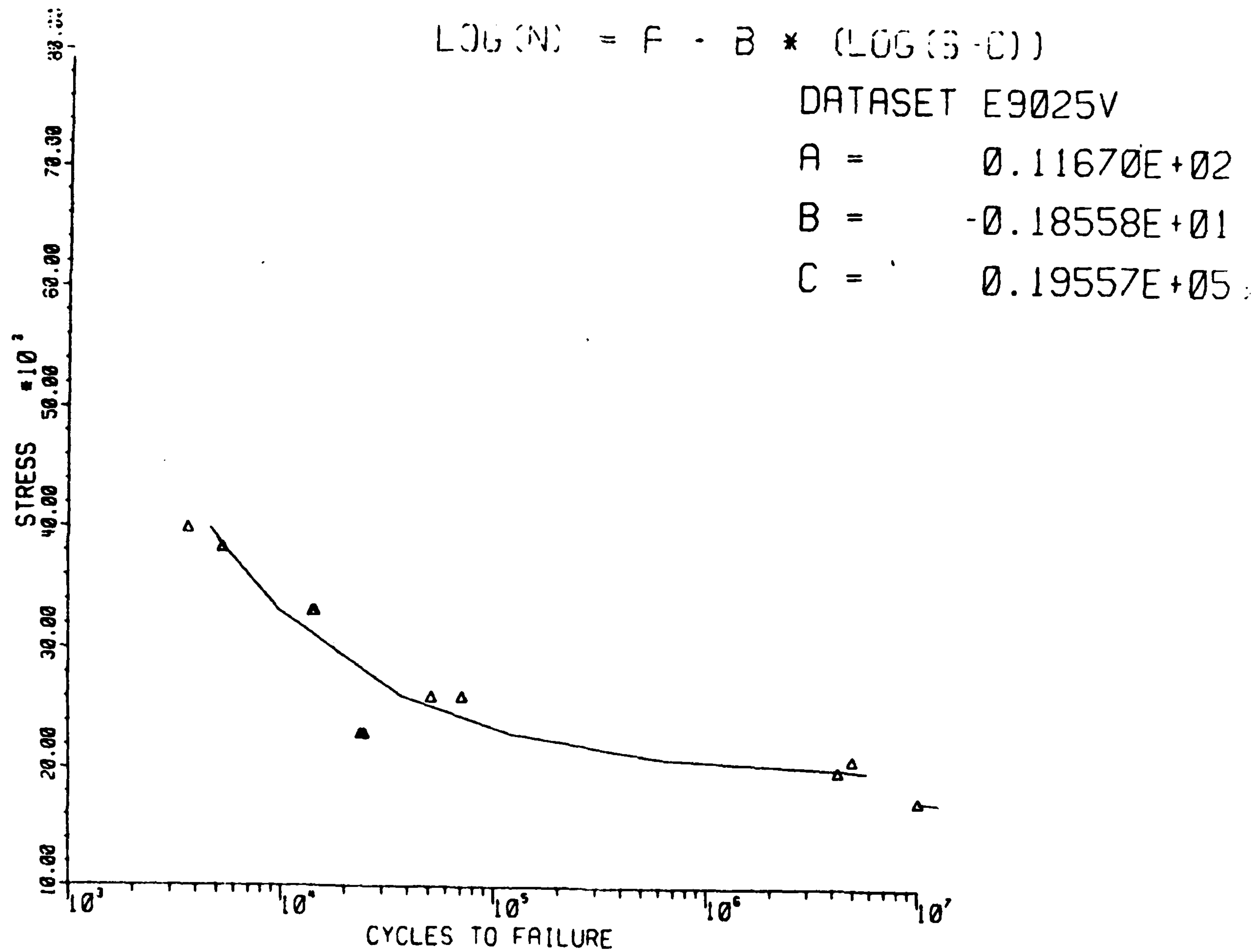

Figure E2. Fatigue Results for 7090 Extrusions; R=0.1, K_t=2.5

TABLE E10

FATIGUE RESULTS FOR 7090 EXTRUSIONS; R=0.1, K_t=2.5

Stress PSI	Cycles	Fail(1) No Fail(0)
17500	10000000	0
17500	10000000	0
20000	4200125	1
21000	4900120	1
23100	25000	1
23100	24000	1
26200	72400	1
26200	51500	1
33200	14700	1
33200	14280	1
38400	5400	1
40000	3690	1

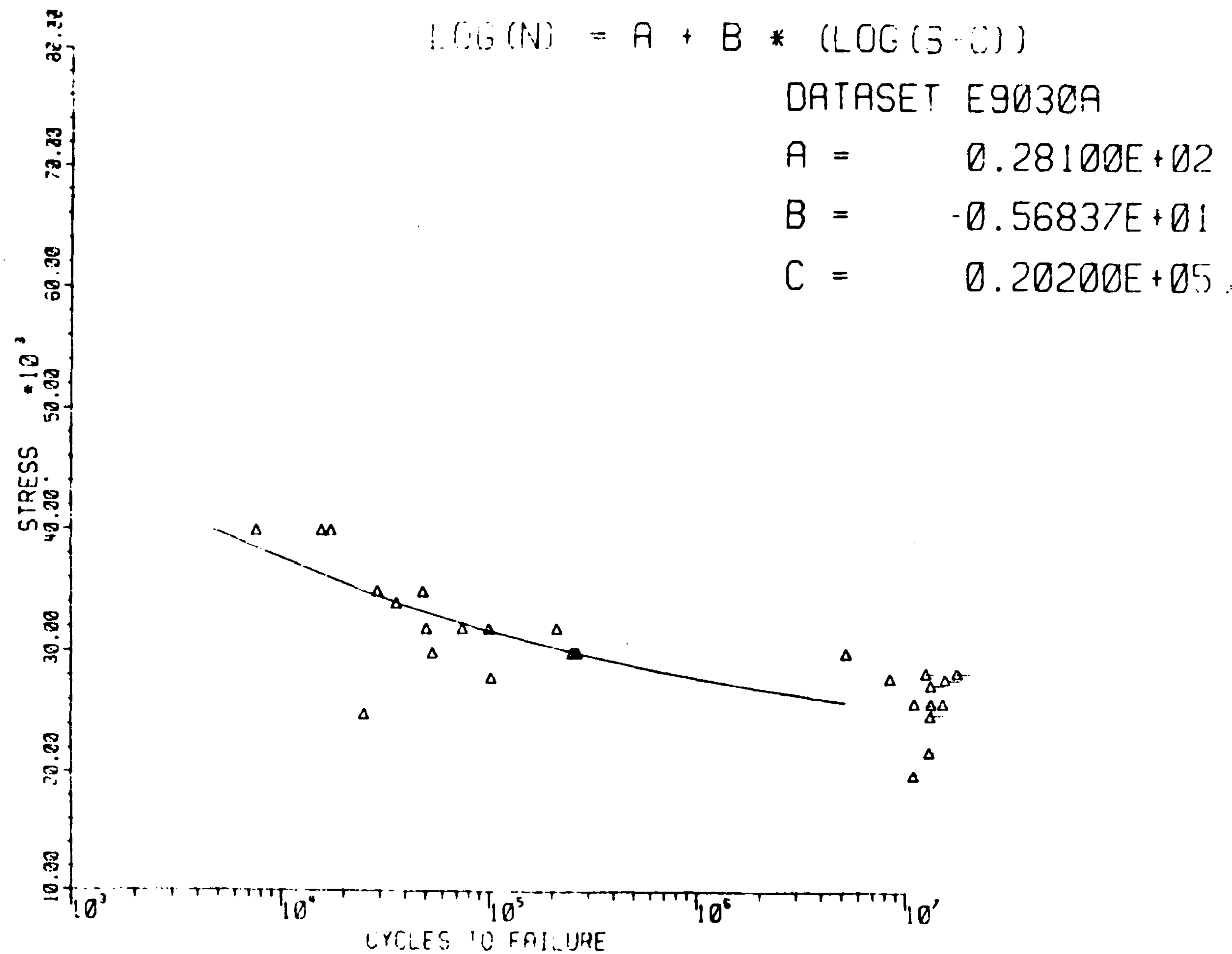

Figure E3. Fatigue Results for 7090 Extrusions; R=0.1, K_t=3.0

TABLE E11

FATIGUE RESULTS FOR 7090 EXTRUSIONS; R=0.1, K_t=3.0

Stress PSI	Cycles	Fail(1) No Fail(0)
20000	11021400	0
22000	13071100	0
25000	25500	1
25000	13183700	0
26000	10927000	0
26000	13228650	0
26000	14996800	0
27500	13173700	0
28000	102000	1
28000	8473200	1
28000	15412150	0
28500	17619400	0
28500	12543100	0
30000	262800	1
30000	263200	1
30000	5194100	1
30000	251900	1
30000	54200	1
32000	50700	1
32000	75300	1
32000	100000	1
32000	211400	1
34000	36100	1
35000	48800	1
35000	29500	1
40000	15850	1
40000	17700	1
40000	7700	1

CONDITION/HT: T7E71		ALUM. ALLOY
FORM: 1.50"TH EXTRUSION	YIELD STRENGTH: 82.6- 83.0 KSI	
SPECIMEN TYPE: CT	ULT. STRENGTH: 88.5- 89.6 KSI	
ORIENTATION: L-T	SPECIMEN THK: 0.245- 0.497"	
FREQUENCY: 20.00- 75.00 HZ	SPECIMEN WIDTH: 1.967- 2.500"	7090
ENVIRONMENT: R.T., HI HUMIDITY	REFERENCES:	

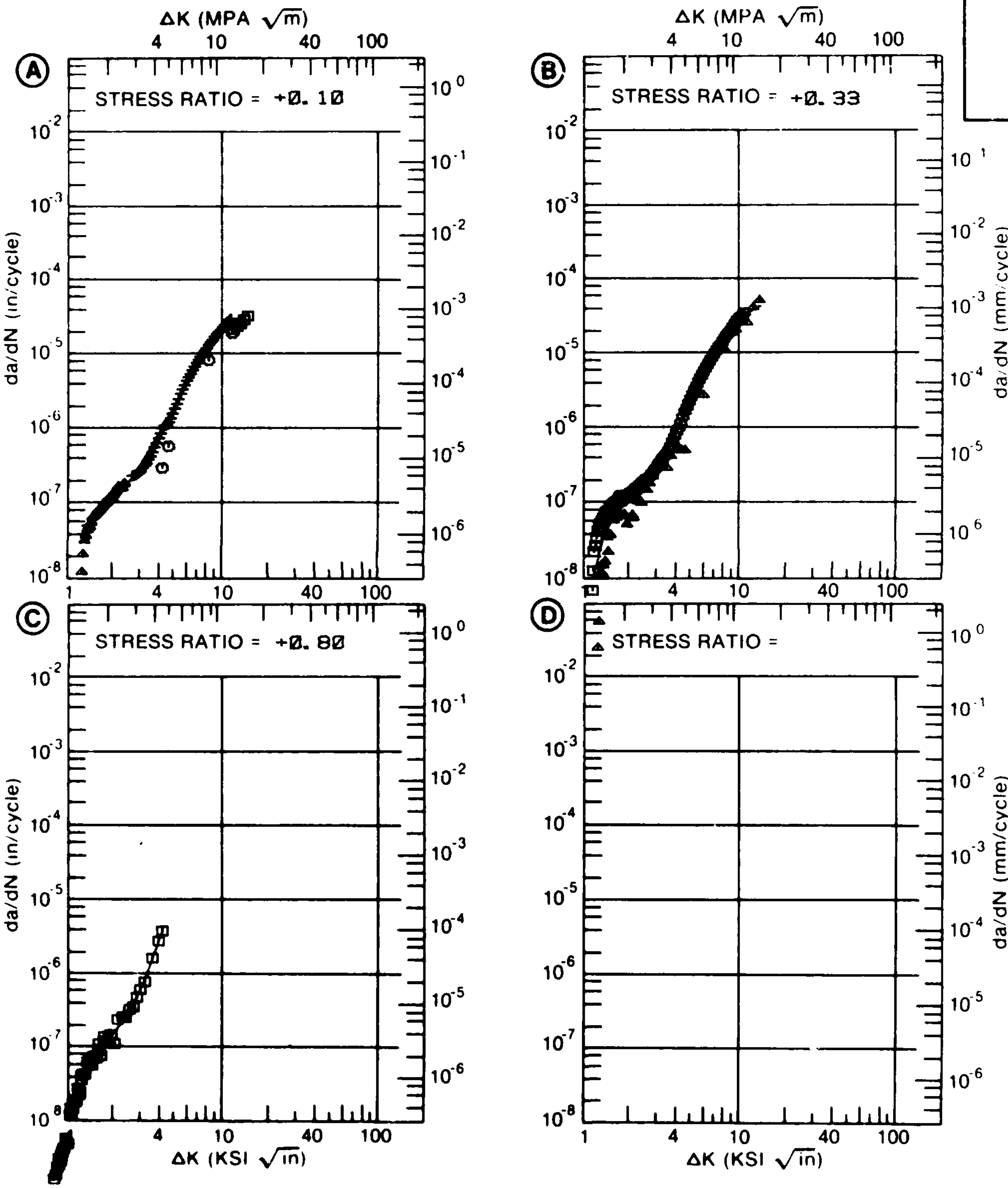

Figure F4. Fatigue Crack Growth Rate Data for 7090 Extrusions; Alcoa & Rockwell

TABLE E12

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE E4 INDICATING EFFECT
OF STRESS RATIO

Alcoa and Rockwell

MATERIAL: ALUMINUM 7090
CONDITION: T7E71
ENVIRONMENT: R.T., HI HUMIDITY

DELTA K (KSI*IN**1/2)			DA/DN (10**-6 IN./CYCLE) A R=+0.10	B R=+0.33	C R=+0.80	D
DELTA K MIN	A:	1.20	.0482			
	B:	1.11		.00953		
	C:	1.00			.0109	
	D:					
		1.30	.0507	.0365	.0504	
		1.60	.0661	.0774	.0983	
		2.00	.106	.106	.170	
		2.50	.199	.176	.337	
		3.00	.359	.316	.743	
		3.50	.616	.560	1.81	
		4.00	.998	.984		
		5.00	2.25	2.56		
		6.00	4.29	5.51		
		7.00	7.15	10.1		
		8.00	10.7	16.0		
		9.00	14.8	22.6		
		10.00	19.1	29.2		
		12.00	30.3	41.0		
DELTA K MAX	A:	14.33	39.4			
	B:	13.17		41.1		
	C:	3.94			[illegible]	
	D:					

AD-A159 779 THE MECHANICAL PROPERTY DATA BASE FROM A COOPERATIVE PROGRAM ON FIRST GEN. (U) AIR FORCE WRIGHT AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH G J PETRAK ET AL. AUG 85 3/4

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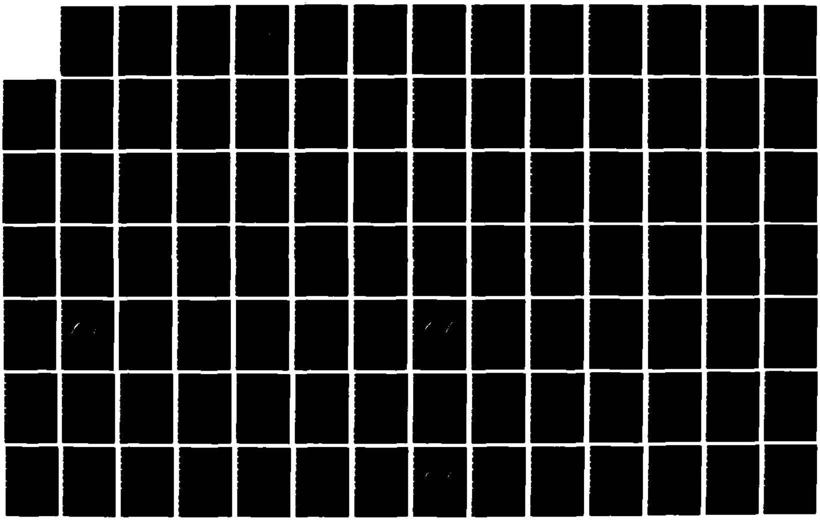

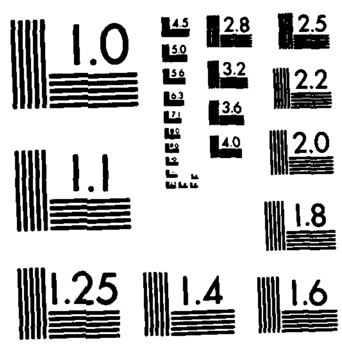

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

CONDITION/HT: T7E71
FORM: 1.50"TH EXTRUSION
SPECIMEN TYPE: CT
ORIENTATION: L-T
FREQUENCY: 10.00- 30.00 HZ
ENVIRONMENT: R.T., LAB AIR

YIELD STRENGTH: 84.3 KSI
ULT. STRENGTH: 89.9 KSI
SPECIMEN THK:
SPECIMEN WIDTH:
REFERENCES:

ALUM. ALLOY

7090

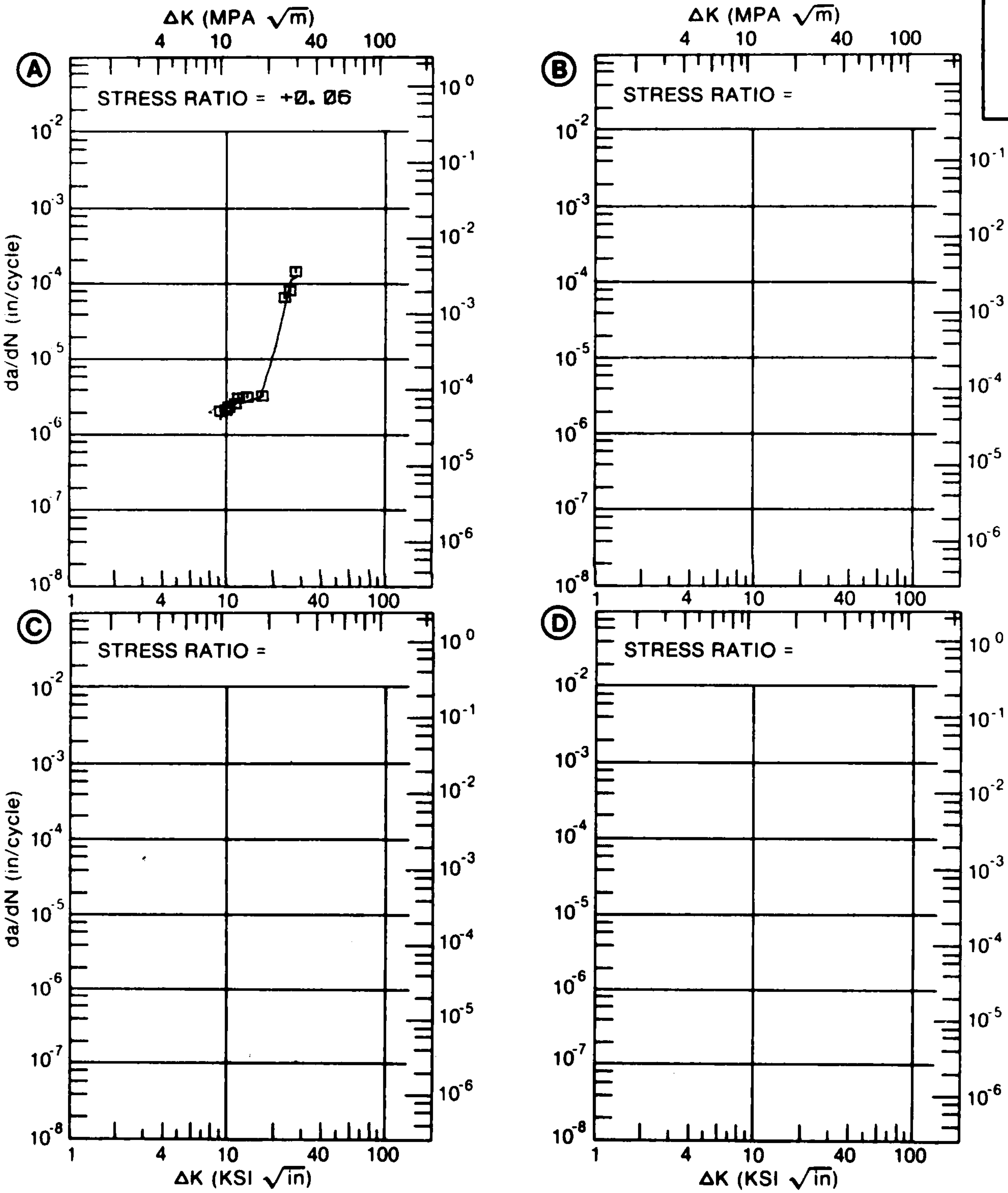

Figure E5. Fatigue Crack Growth Rate Data for 7090 Extrusions: Boeing

TABLE E13

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE E5 INDICATING EFFECT OF STRESS RATIO

Boeing

MATERIAL: ALUMINUM 7090
CONDITION: T7E71
ENVIRONMENT: R. T. , LAB AIR

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN./CYCLE) A	B	C	D
		R=+0.06			
DELTA K MIN	A: 8.25	1.56			
	B:				
	C:				
	D:				
	9.00	1.67			
	10.00	2.54			
	13.00	2.66			
	16.00	3.08			
	20.00	14.5			
	25.00	111.			
DELTA K MAX	A: 26.80	122.			
	B:				
	C:				
	D:				

CONDITION/HT: T7E71	
FORM: 1.50"TH EXTRUSION	YIELD STRENGTH: 76.8- 78.5 KSI
SPECIMEN TYPE: CT	ULT. STRENGTH: 84.6- 85.9 KSI
ORIENTATION: T-L	SPECIMEN THK: 0.245- 0.498"
FREQUENCY: 10.00- 25.00 HZ	SPECIMEN WIDTH: 1.968- 2.002"
ENVIRONMENT: R.T., HI HUMIDITY	REFERENCES:

ALUM. ALLOY

7090

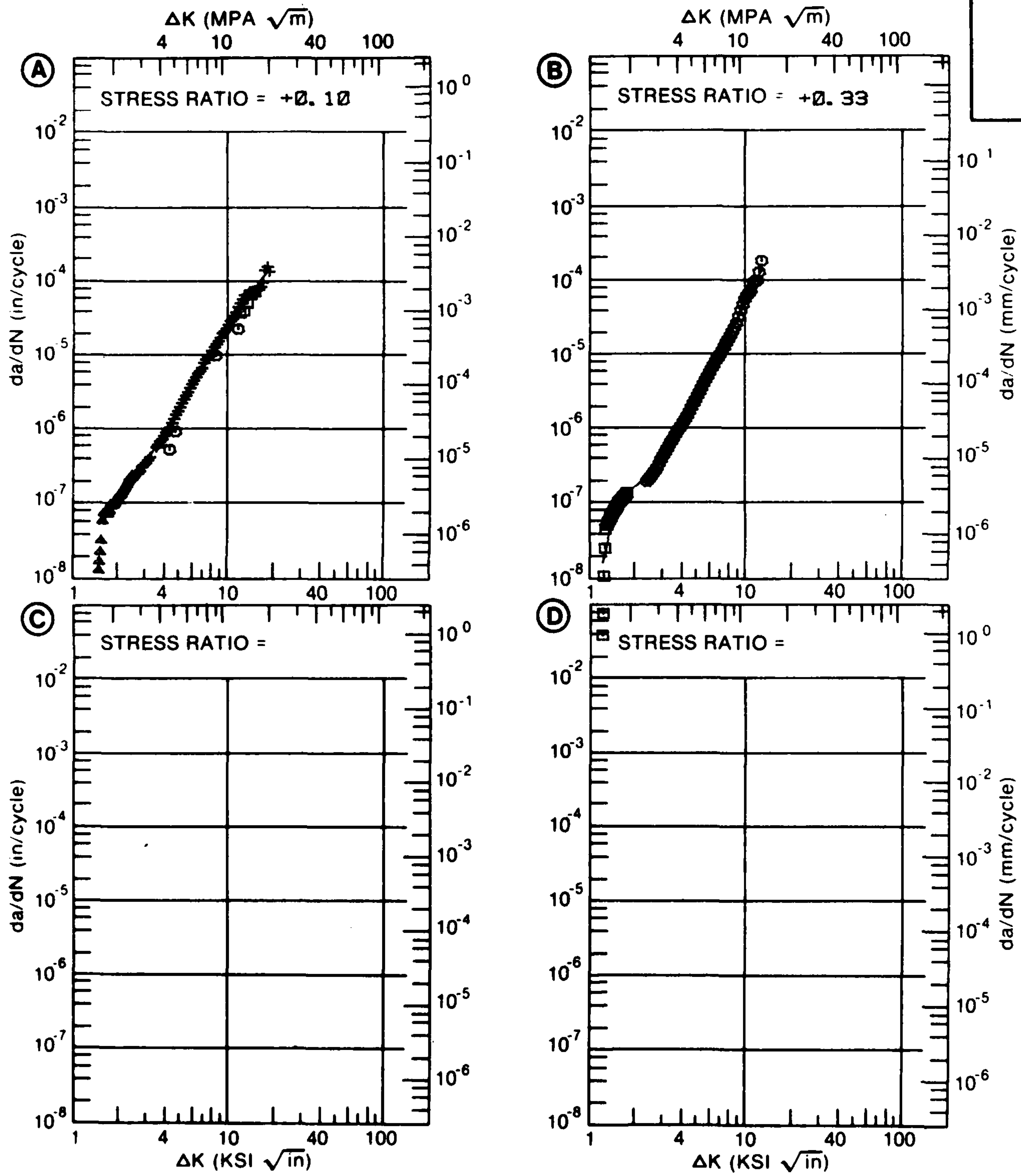

Figure E6. Fatigue Crack Growth Rate Data for 7090 Extrusions: Alcoa & Rockwell

TABLE E14

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE E6 INDICATING EFFECT OF STRESS RATIO

Alcoa and Rockwell

MATERIAL: ALUMINUM 7090
CONDITION: T7E71
ENVIRONMENT: R.T., HI HUMIDITY

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN/CYCLE) A	B	C	D
		R=+0.10	R=+0.33		
DELTA K MIN	A: 1.43	.0522			
	B: 1.17		.0160		
	C:				
	D:				
	1.30		.0448		
	1.60	[illegible]	.124		
	2.00	.120	.180		
	2.50	.230	.275		
	3.00	.408	.452		
	3.50	.679	.752		
	4.00	1.07	1.23		
	5.00	2.32	3.03		
	6.00	4.40	6.63		
	7.00	7.55	13.9		
	8.00	12.0	23.4		
	9.00	17.8	38.8		
	10.00	25.2	60.3		
	13.00	57.4			
	16.00	104			
DELTA K MAX	A: [illegible]	[illegible]			
	B: 12.32		136		
	C:				
	D:				

STRESS CORROSION

ALCOA reported there was no exfoliation corrosion in 7090 extrusions using an accelerated corrosion test. Boeing reported the stress corrosion cracking threshold for 90 days exposure was greater than 60 KSI and that there was a very slight amount of exfoliation but no pitting. Tabular stress corrosion results from ALCOA are shown in Tables E15 and E16.

SPECTRUM FATIGUE CRACK GROWTH

Figures E7 to E9 are, respectively: 1) a specimen drawing, 2) results of spectrum fatigue crack growth tests using the Mini-TWIST spectrum, and 3) the results of spectrum fatigue tests using the FALSTAFF spectrum. These data, developed by AFWAL, are shown along with similar data for 7050-T76 plate. The 7090 is inferior to 7050.

TABLE E15

Corrosion Results From ALCOA

PERFORMANCE OF SHORT TRANSVERSE 3.1 mm (1/8") DIAMETER SMOOTH TENSILE BARS WHICH WERE REMOVED FROM X7090 AND X7091 ALLOY EXTRUSIONS (1), STRESSED AND EXPOSED 30 DAYS TO 3-1/2% SODIUM CHLORIDE BY ALTERNATE IMMERSION (2)

S. - No.	Alloy	Temper	Stress Level (ksi/MPa)	No. Failures/ No. of Specimens Tested
513907-4	X7090	T7E71	25/172	0/3
513907-4	X7090	T7E71	45/310	0/3
513995-5	X7091	T7E69	25/172	0/3
513995-5	X7091	T7E69	45/310	0/3

Notes: (1) Extrusions were 38 mm (1-1/2") thick by 114 mm (4-1/2") wide in cross section.

(2) The 3-1/2% sodium chloride - alternate immersion test was conducted in accordance with ASTM G44-75.

TABLE E16

Corrosion Results From ALCOA

PIT DEPTH MEASUREMENTS (1) OBTAINED FROM 114 mm (4-1/2") WIDE BY 152 mm (6") LONG PANELS OF 7090-T7E71 AND 7091-T7E69 ALLOY EXTRUSIONS (2) EXPOSED 14 DAYS TO MASTMAASIS TEST

		Pit Depth - Mean(3) and Range								
		Near Surface			T/10 Plane (4)			T/2 Plane		
		Mean	Range - mm		Mean	Range - mm		Mean	Range - mm	
S. No.	Alloy	mm	Min.	Max.	mm	Min.	Max.	mm	Min.	Max.
513907-4A	7090-T7E71	0.43	0.31	0.58	0.28	0.05	0.69	0.13	0.05	0.23
-4B	7090-T7E71	0.13	0.05	0.18	0.13	0.08	0.23	0.10	0.05	0.13
513995-5A	7091-T7E69	0.33	0.20	0.71	0.28	0.10	0.48	0.18	0.05	0.31
-5B	7091-T7E69	0.15	0.13	0.25	0.13	0.08	0.25	0.10	0.05	0.28

NOTES:

(1) Pit depth measurements obtained with Starrett Pit Depth Gauge No. 643.

(2) Extrusions were 38 mm (1-1/2") thick by 114 mm (4-1/2") wide in cross-section.

(3) Mean pit depth was obtained from 10 measurements from each panel.

(4) The T/10 plane was that plane at 1/10 the distance from the "bottom surface" of the extrusion as opposed to the "top surface" of the extrusion which provided the near surface plane sample.

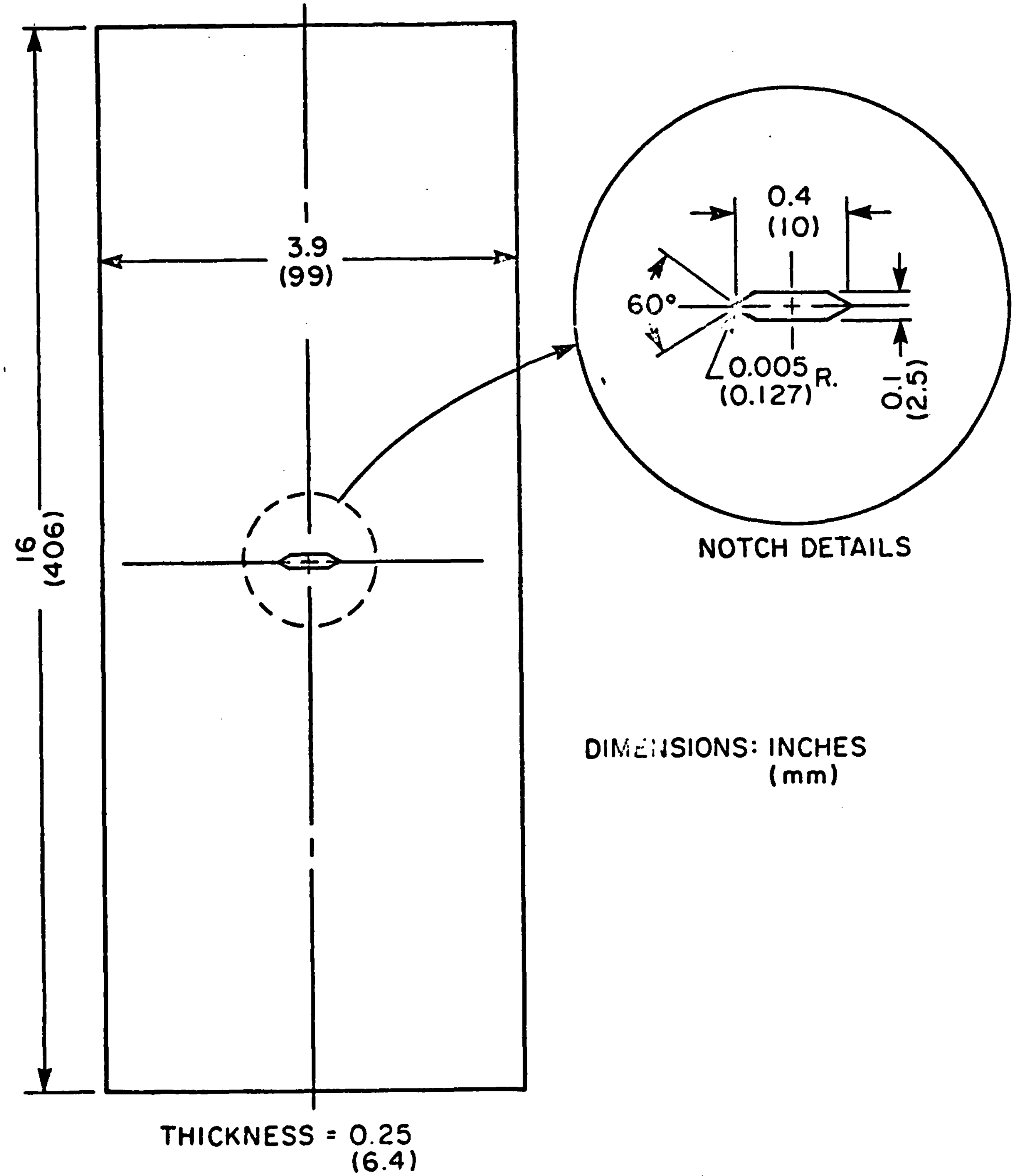

Figure E7. Specimen Used to Generate Data in Figures E8 and E9.

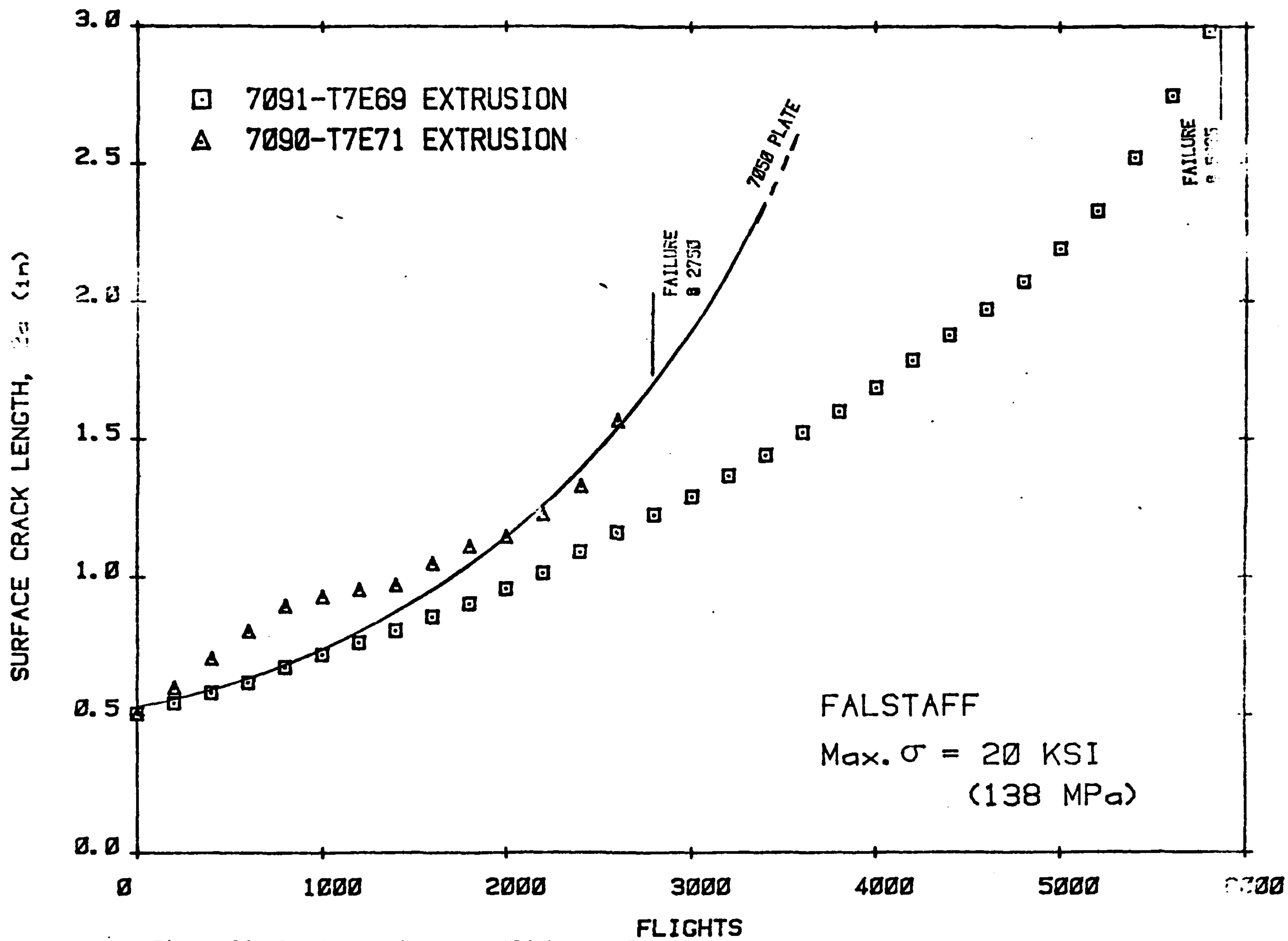

Figure E8. Crack Length Versus Flights of 7090 Extrusion Under FALSTAFF Loading.

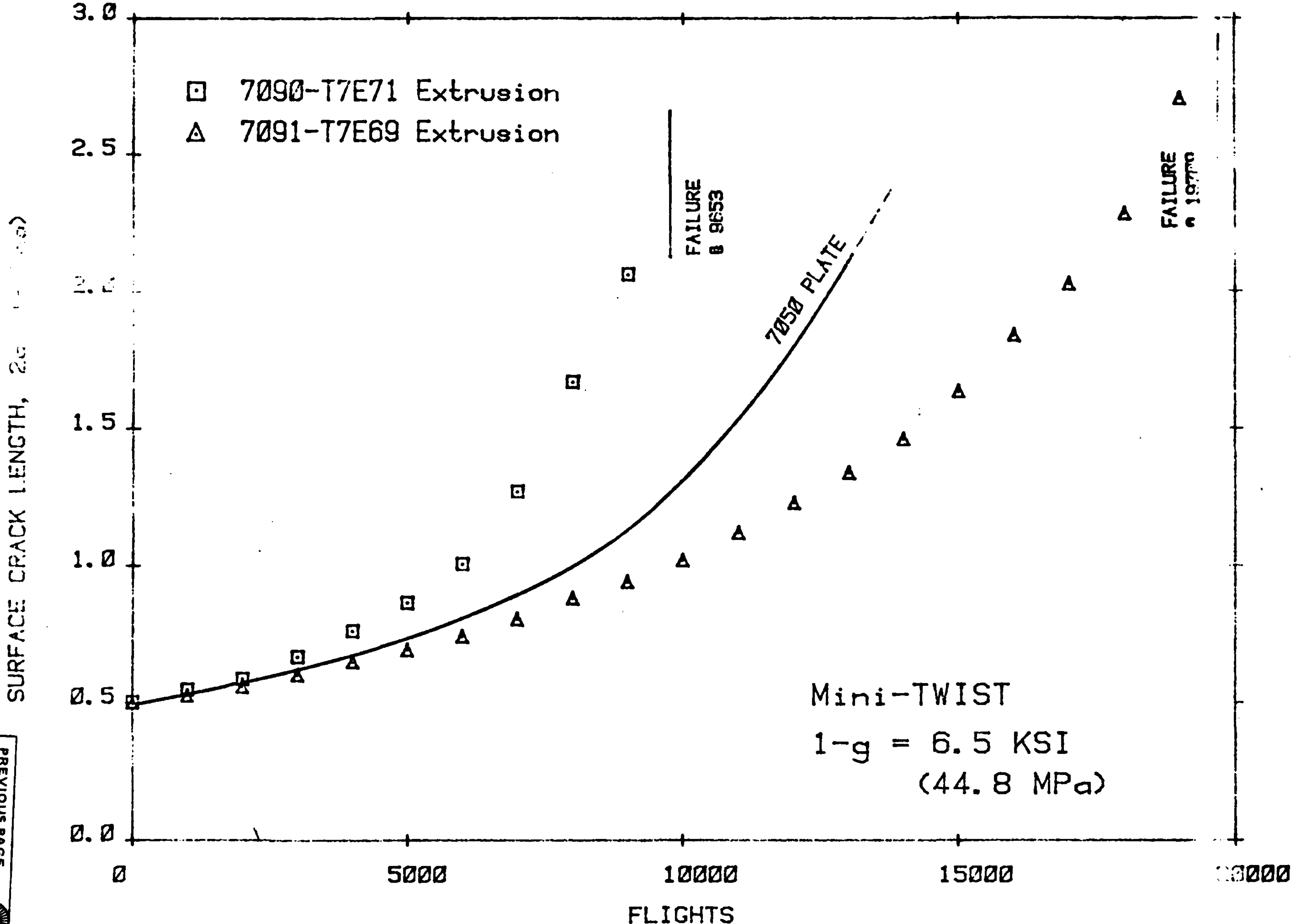

Figure E9. Crack Length Versus Flights of 7090 Extrusion Under Mini-TWIST Loading.

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APPENDIX F

IN9021 EXTRUSIONS

Comment: Extruded IN-9021 was supplied by Novamet. However, the samples were shipped by the processor before a final heat treatment was applied to the extrusions. This was caused by the fact that Novamet had not yet determined what they considered the best aging temperature. Information on final aging time and temperature was supplied to the participants and they were asked to process the extrusions. It is assumed that unless stated otherwise the participants followed the recommended schedule.

This data base on IN-9021 consists of test results from ALCOA, Boeing, Lockheed-California, Fairchild and Northrop. It is assumed that four of the companies processed the extrusions according to the information provided by Novamet, that being 24 hours at 275°. The exception is Boeing; extrusion processing is as indicated in the tables and this data was not included in the calculation of allowables.

> NOTICE: Suggested allowables, mean trends, and trend curves in this document were developed to be used in a cost benefit analysis to assess the potential benefit of using the material in a structure. These suggested allowables and trends are not considered accurate for design of actual hardware.

TABLE F1
SUGGESTED ALLOWABLES FOR
IN-9021 Extrusions; 5/8" x 2-1/2"

F_{tu}, KSI		
	L	88.3
	LT	86.2
F_{ty}, KSI		
	L	83.1
	LT	74.2
F_{cy}, KSI		
	L	60.1
	LT	78.3
F_{su}, KSI		
	L	47.2
	LT	47.4
F_{bru}, KSI		
	L	
	(e/D=1.5)	118.2
	(e/D=2.0)	145.2
	LT	
	(e/D=1.5)	114.2
	(e/D=2.0)	149.3
F_{by}, KSI		
	L	
	(e/D=1.5)	99.2
	(e/D=2.0)	117.8
	LT	
	(e/D=1.5)	99.6
	(e/D=2.0)	120.9
K_{IC}, KSI$\sqrt{IN}$		
	LT	25.2
	TL	28.0

NOTE: These values were developed to be used only in a cost-benefit-analysis and are not necessarily accurate for design of hardware.

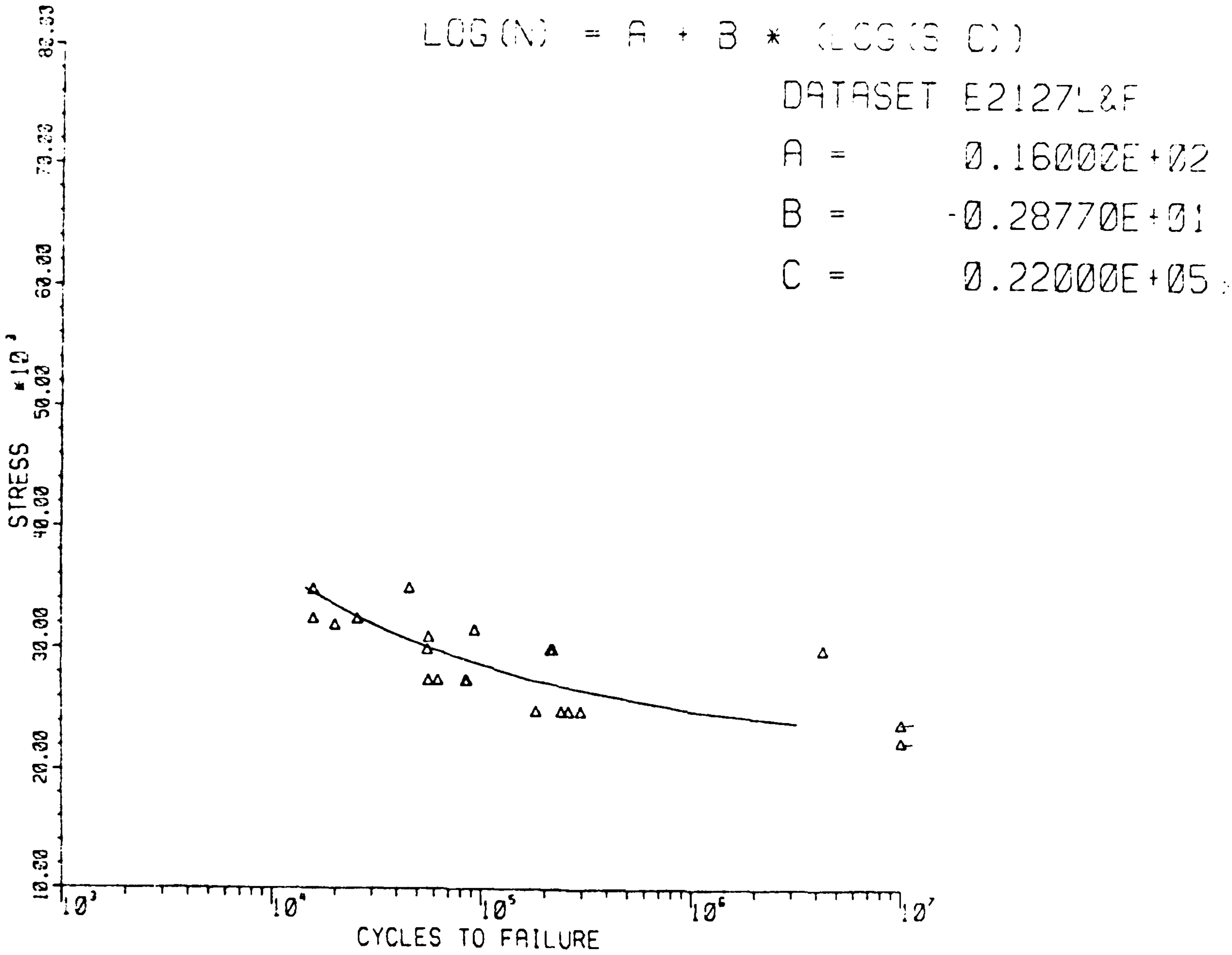

Figure F2. Fatigue Results for IN9021 Extrusions; R = 0.1, K_t = 2.7

TABLE F13

FATIGUE RESULTS FOR IN9021 EXTRUSIONS: $R = 0.1$, $K_t = 1.0$

Stress PSI	Cycles	Fail(1) No Fail(0)
35000	17126700	0
35000	247000	0
35000	324000	1
37000	6322950	1
37000	9473150	0
37000	19445900	0
39000	106700	1
39000	4726300	1
39000	93000	1
39000	99000	1
41000	158550	1
42000	98000	1
42000	140000	1
43000	1755650	1
43000	48900	1
43000	102100	1
45000	116000	1
45000	109000	1
45000	127000	1
55000	32000	1

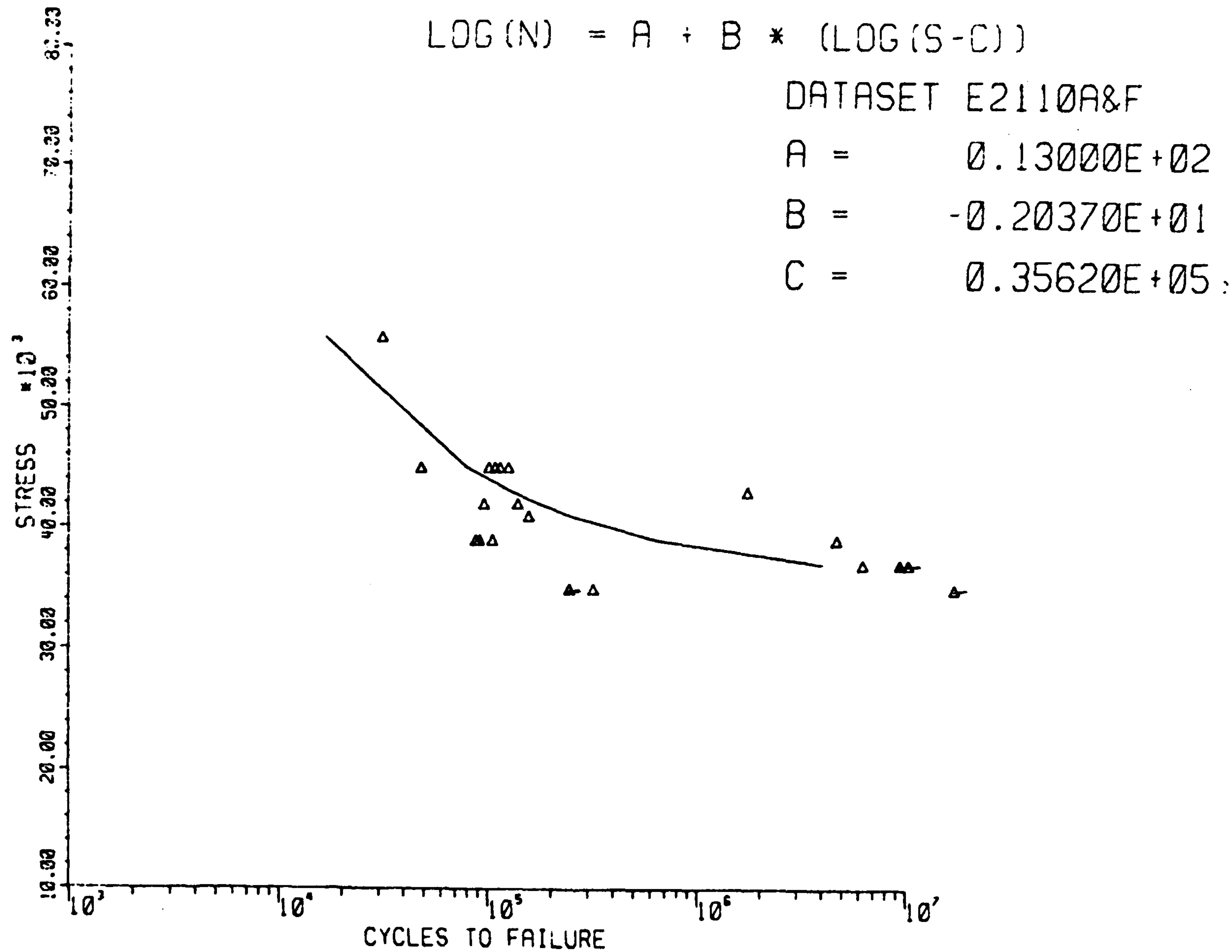

Figure F1. Fatigue Results for IN9021 Extrusions; $R = 0.1$, $K_t = 1.0$

TABLE F12

IN-9021 EXTRUSION

FRACTURE TOUGHNESS

COMPANY	ORIENTATION	KIC (KSI$\sqrt{IN}$)	KQ (KSI$\sqrt{IN}$)	COMMENT
NORTHROP	L-T	28.0		valid
			27.5	invalid
ALCOA		25.6 25.2		
LOCKHEED CA		30.0 25.9		valid valid
BOEING (x)		25.4		valid
BOEING (y)		41.5		valid
NORTHROP	T-L	28.0		valid
			32.0	invalid
ALCOA		30.3 31.0		
BOEING (x)		28.5		valid

(x) T6X solution treated, quenched, stretched 4%, artificially aged

(y) T6Y solution treated, quenched artificially aged

TABLE F11

IN-9021 EXTRUSION

BEARING

COMPANY	ORIENTATION	e/D	ULT B STR KSI	YIELD B STR KSI
LOCKHEED CA	TRANS	2.0	161	153
			164	152
			169	165
FAIRCHILD			152.2	123.7
			151.1	120.9
			149.4	123.6
			149.3	124.2

TABLE F10

IN-9021 EXTRUSION

BEARING

COMPANY	ORIENTATION	e/D	ULT B STR KSI	YIELD B STR KSI
LOCKHEED	TRAN	1.5	133	127
CA			128	
			130	127
FAIRCHILD			117.1	104.1
			114.2	99.6
			115.6	100.6
			120.7	108.2

TABLE F9

IN-9021 EXTRUSION

BEARING

COMPANY	ORIENT	e/D	ULT B STR KSI	YIELD B STR KSI
LOCKHEED CA	LONG	2.0	164	139
			162	126
			162	143
FAIRCHILD			147.4	122.4
			148.5	121.5
			150.6	123.4
			145.2	119.5
			149.0	117.8

TABLE F8

IN-9021 EXTRUSION

BEARING

COMPANY	ORIENTATION	e/D	ULT B STR KSI	YIELD B STR KSI
LOCKHEED CA	LONG	1.5	134	
			134	111
			127	109
BOEING (x)			128.2	
BOEING (y)			123.8	
FAIRCHILD			118.2	103.2
			118.9	99.2
			121.5	105.7
			120.9	103.5
			120.3	105.4

(x) Solution treated, quenched, stretched 4%, artifically aged

(y) Solution treated, quenched artificially aged

TABLE F7

IN-9021 EXTRUSION

SHEAR

COMPANY	ORIENTATION	ULT SHEAR STR
LOCKHEED CA	TRANS	48.0*
		47.7*
		47.4*
BOEING (x)		44.6
		43.8
FAIRCHILD		48.2
		49.7
		53.6

* Double Shear Tests

(x) Solution treated, quenched, stretched 4%, artificially aged

TABLE F6

IN-9021 EXTRUSION

SHEAR

COMPANY	ORIENTATION	ULT SHEAR STR
LOCKHEED CA	LONG	49.1*
		49.0*
		48.5*
BOEING		43.8
		44.6
FAIRCHILD		48.4
		47.7
		47.2
		48.4
		48.6
		49.9

* Double Shear Tests

(x) Solution treated, quenched, stretched 4%, artificially aged

TABLE F5

IN-9021 EXTRUSION

COMPRESSION

COMPANY	ORIENTATION	COMP YIELD STR (KSI)	
LOCKHEED	TRANS	83.2	ROUND
		84.6	ROUND
		78.3	ROUND
BOEING (x)		83.1	
		84.5	

(x) Solution treated, quenched, stretched 4%, artificially aged

TABLE F4

IN-9021 EXTRUSION

COMPRESSION

COMPANY	ORIENTATION	COMP YIELD STR KSI	
LOCKHEED CA	LONG	75.9	FLAT
		76.3	FLAT
		74.4	FLAT
BOEING (x)		77.0	
		77.7	
BOEING (y)		84.7	
		84.5	
FAIRCHILD		60.6	
		65.1	
		63.8	
		60.9	
		60.6	
		60.1	

(x) Solution treated, quenched, stretched 4%, artificially aged

(y) Solution treated, quenched, artificially aged

TABLE F3

IN-9021 EXTRUSION: 5/8" x 2-1/2"

TENSILE

COMPANY	ORIENTATION	ULT STR, KSI	YIELD STR, KSI	ELONG %
LOCKHEED CA	TRA''S	76.6*	63.8*	5*
		75.2*	62.2*	8*
		87.2	74.2	10
NORTHROP		87.4	77.0	10.0
		86.8	76.4	10.0
		87.6	80.2	9.0
ALCOA		86.2	74.8	11.0
		87.3	74.9	8.0(d)
		86.9	74.9	11.0

* Failed @ surface flaw or in radius. Eliminated from analysis

(d) Failure outside of middle half of gage length

TABLE F2

IN-9021 EXTRUSIONS: 5/8" x 2-1/2"

TENSILE

COMPANY	ORIENTATION	ULT STR, KSI	YIELD STR, KSI	ELONG, %
LOCKHEED CA	LONG	91.4	83.6	10
		91.7	84.7	10
		91.8	84.6	10
NORTHROP		90.5	86.9	7.0
		89.6	85.4	8.0
		90.3	86.9	7.0
ALCOA		89.9	84.5	9.3 (b)
		88.3	83.3	9.3 (b,c)
		89.0	83.8	7.9
BOEING		93.3	87.0	6.1 (x)
		92.5	86.6	8.8
		91.7	86.0	5.5
BOEING		84.3	84.3	11.0 (y)
		82.0	82.0	11.1
		83.5	83.5	5.5
FAIRCHILD		90.5	90.0	8.4
		90.2	87.1	9.1
		89.1	87.3	9.2
		89.2	83.1	8.4
		90.1	85.7	8.0
		89.1	85.9	8.3
		89.5	85.2	9.3
		90.0	86.3	8.6
		86.8	82.6	7.5

(x) T6X: solution treated, quenched, stretched 4%, artificially aged

(y) T6Y: solution treated, quenched, artificially aged

(b) Internal discontinuity

(c) Fragmented fracture

TABLE F14

FATIGUE RESULTS FOR IN9021 EXTRUSIONS: R = 0.1, K_t = 2.7

Stress PSI	Cycles	Fail(1) No Fail(0)
22500	10000000	0
24000	10000000	0
25000	298863	1
25000	184176	1
25000	261000	1
25000	241000	1
27500	63111	1
27500	56438	1
27500	86000	1
27500	85000	1
30000	55872	1
30000	220000	1
30000	215000	1
30000	4260000	1
31000	57000	1
31600	94000	1
32000	20278	1
32500	16111	1
32500	26000	1
34900	16024	1
35000	46000	1

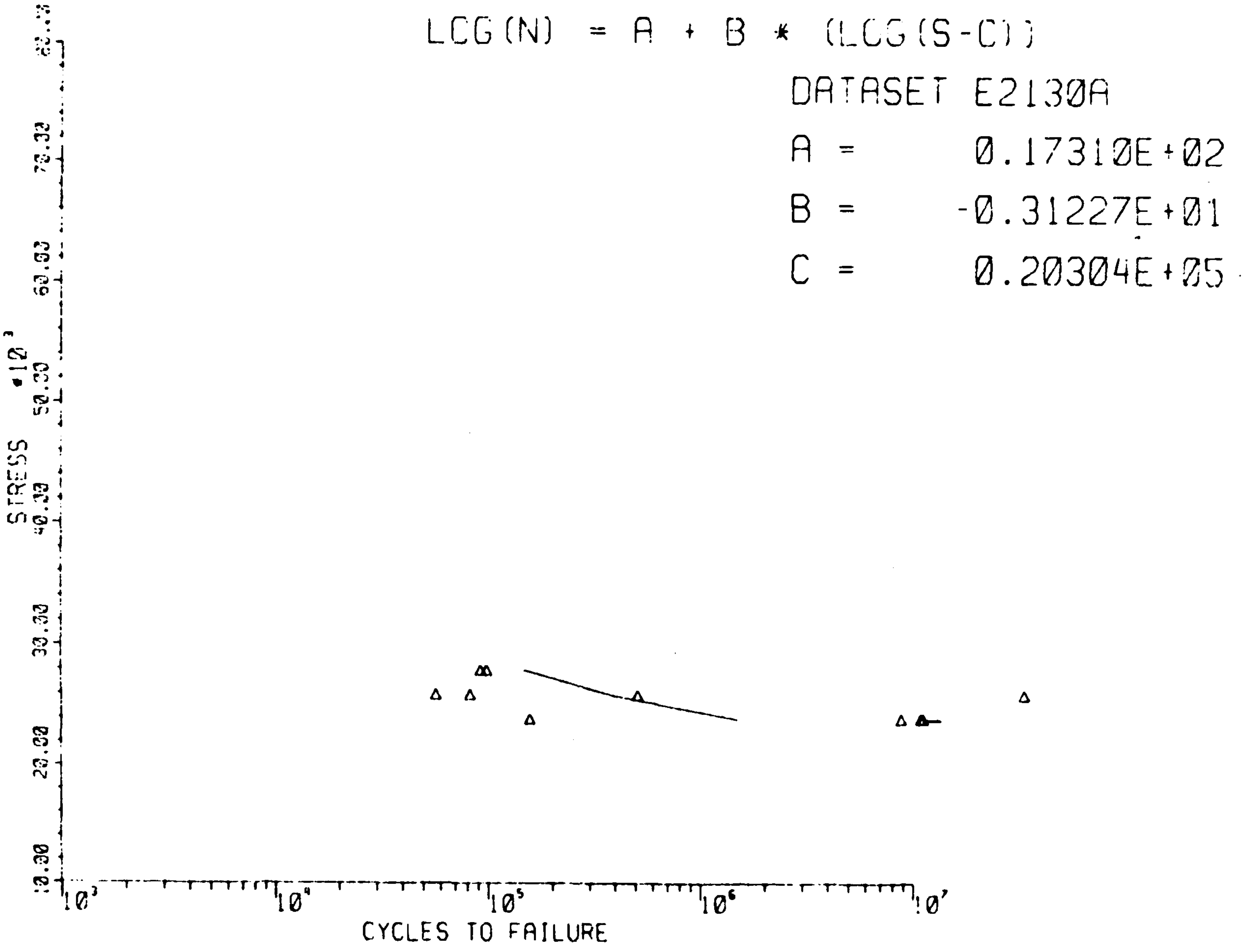

Figure F3.Fatigue Results for IN-9021 Extrusions; R = 0.1, K_t = 3.0

TABLE F15

FATIGUE DATA FOR IN-9021 EXTRUSIONS: R=0.1, K_t=3.0

Stress PSI	Cycles	Fail (1) No Fail (0)
24000	159100	1
24000	8752650	1
24000	10805550	0
24000	11060900	0
26000	57500	1
26000	83000	1
26000	510200	1
26000	32990400	1
28000	94250	1
28000	99900	1

CONDITION/HT:	YIELD STRENGTH: 83.9 - 86.4 KSI
FORM: 0.50- 0.63"TH EXTRUSION	ULT. STRENGTH: 89.1- 91.0 KSI
SPECIMEN TYPE: CT	SPECIMEN THK: 0.123- 0.500"
ORIENTATION: L-T	SPECIMEN WIDTH: 1.497- 2.200"
FREQUENCY: 5.00- 25.00 HZ	REFERENCES:
ENVIRONMENT: R.T., HI HUMIDITY	

ALUM. ALLOY

IN9021

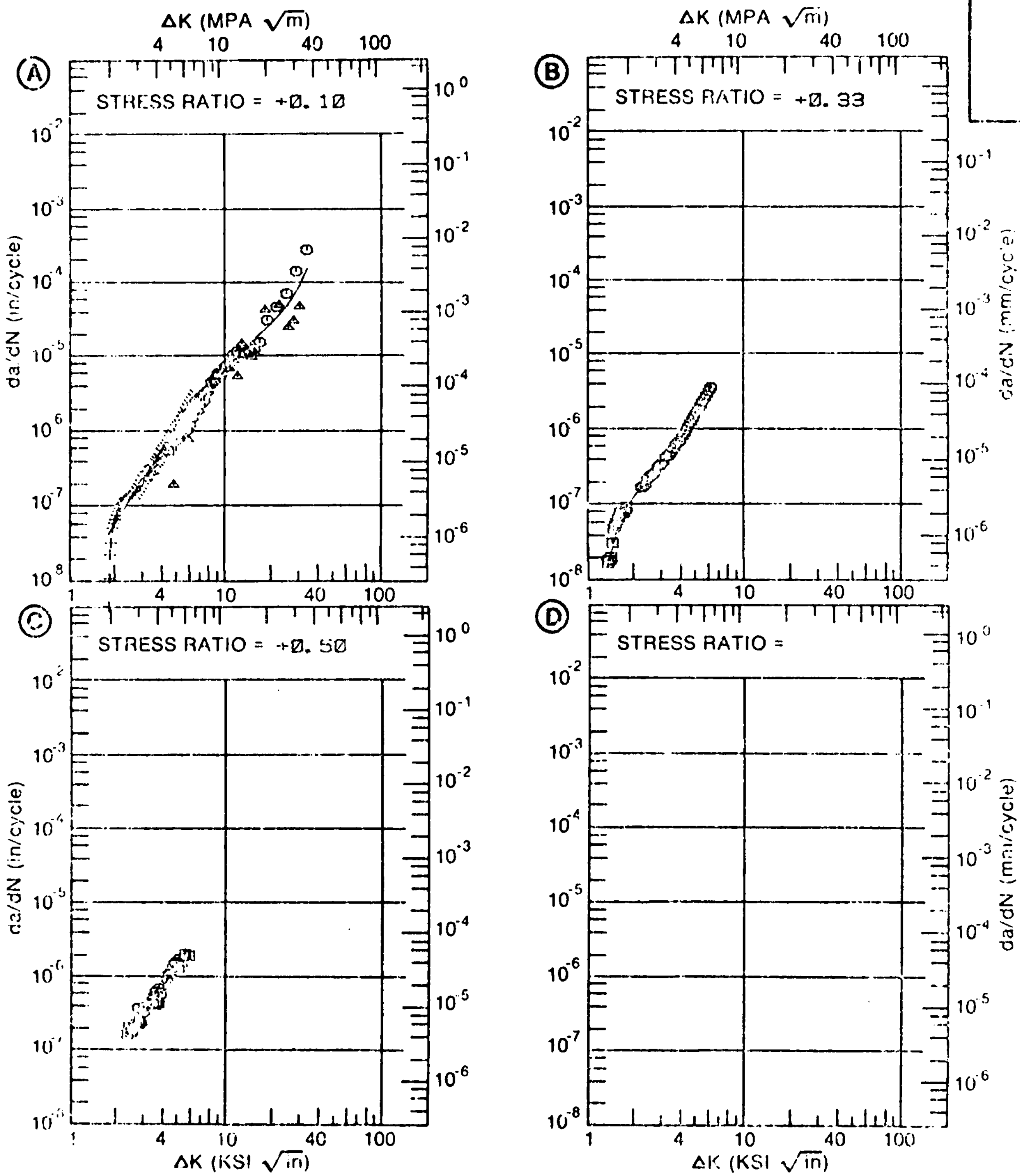

Figure F4.Fatigue Crack Growth Rate Data for IN9021 Extrusions; Alcoa, Lockheed-CA, Northrop

TABLE F16

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE F4 INDICATING EFFECT
OF STRESS RATIO

ALCOA, Lockheed-CA, and Northrop

MATERIAL: ALUMINUM IN9021
CONDITION:
ENVIRONMENT: R. T. , HI HUMIDITY

	DELTA K (KSI*IN**1/2)	DA/DN (10**-6 IN./CYCLE) A	B	C	D
		R=+0.10	R=+0.30	R=+0.50	
DELTA K MIN A:	1.76	.0420			
B:	1.30		.0144		
C:	2.30			.161	
D:					
	1.00		.0716		
	2.00	.0646	.137		
	2.50	.134	.230	.200	
	3.00	.230	.365	.321	
	3.50	.331	.560	.499	
	4.00	.567	.837	.770	
	5.00	1.08	1.76	1.64	
	6.00	1.77	3.51		
	7.00	2.66			
	8.00	3.74			
	9.00	5.01			
	10.00	5.44			
	13.00	11.7			
	16.00	13.2			
	20.00	23.4			
	25.00	42.1			
	30.00	[illegible]			
DELTA K MAX A:	23.44	[illegible]			
B:	6.01		3.53		
C:	5.72			1.82	
D:					

CONDITION/HT:			
FORM:	0.60"TH EXTRUSION	YIELD STRENGTH:	88.5 KSI
SPECIMEN TYPE:	CTH	ULT. STRENGTH:	92.5 KSI
ORIENTATION:	L-T	SPECIMEN THK:	0.000"
FREQUENCY:	25.00 HZ	SPECIMEN WIDTH:	0.000"
ENVIRONMENT:	R.T., LAB AIR	REFERENCES:	

ALUM. ALLOY

IN9021

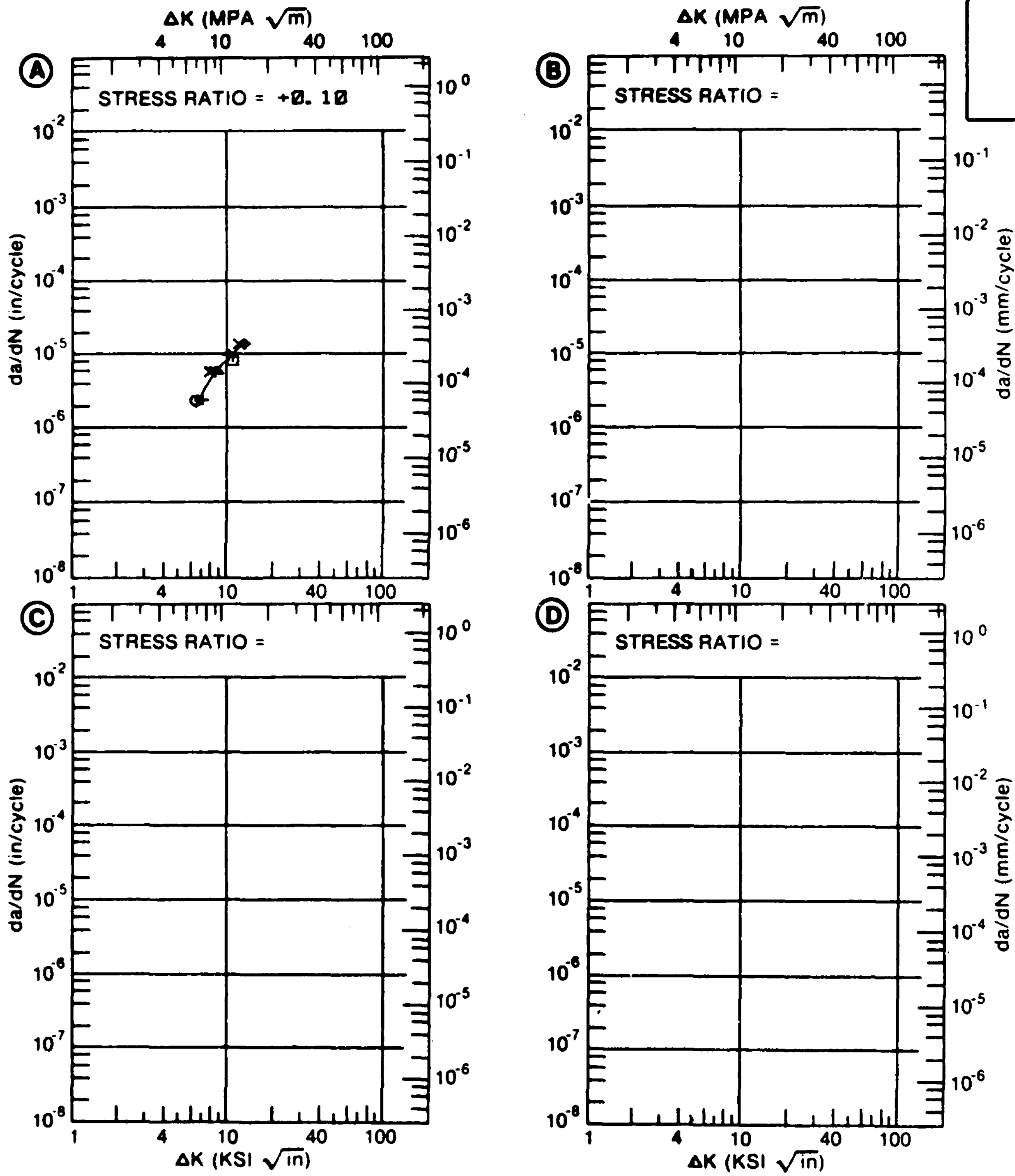

Figure F5. Fatigue Crack Growth Rate Data for IN9021 Extrusions; Boeing

TABLE F17

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE F5 INDICATING EFFECT OF STRESS RATIO

Boeing

MATERIAL: ALUMINUM IN9021
CONDITION:
ENVIRONMENT: R.T. ,LAB AIR

DELTA K (KSI*IN**1/2)			DA/DN (10**-6 IN./CYCLE)			
			A	B	C	D
			R=+0.10			
	A:	6.20	1.87			
DELTA K	B:					
MIN	C:					
	D:					
		7.00	3.21			
		8.00	4.99			
		9.00	6.73			
		10.00	8.46			
	A:	12.64	14.2			
DELTA K	B:					
MAX	C:					
	D:					

CONDITION/HT.
FORM: 0.50-- 0.63"TH EXTRUSION
SPECIMEN TYPE: CT
ORIENTATION: T-L
FREQUENCY: 5.00-- 25.00 HZ
ENVIRONMENT: R.T., HI HUMIDITY

YIELD STRENGTH: 74.9- 77.9 KSI
ULT. STRENGTH: 86.8- 87.3 KSI
SPECIMEN THK: 0.124-- 0.251"
SPECIMEN WIDTH: 1.999- 2.007"
REFERENCES:

ALUM. ALLOY

IN9021

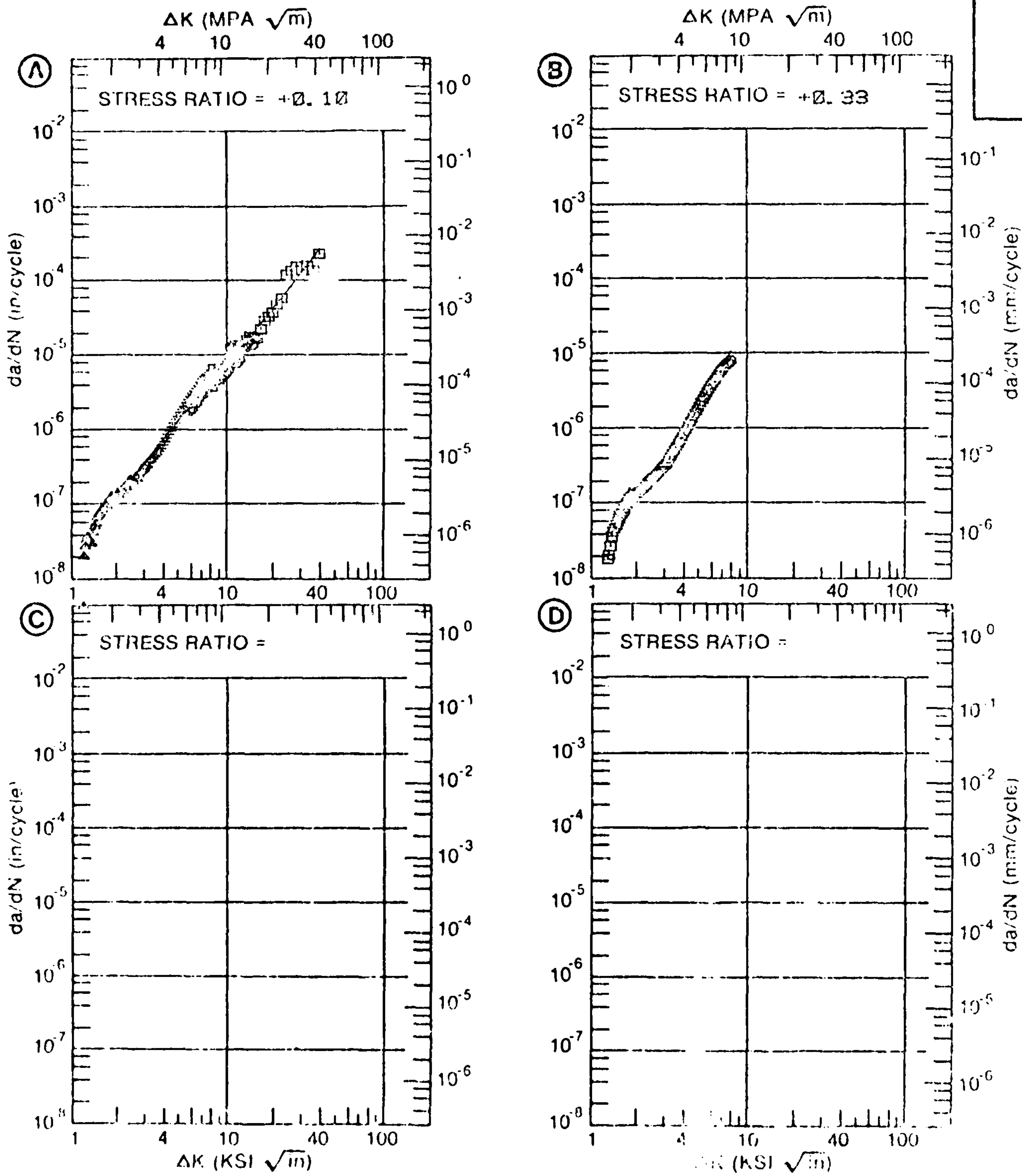

Figure F6. Fatigue Crack Growth Rate Data for IN9021 Extrusions; ALCOA and Northrop

TABLE F18

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE F6 INDICATING EFFECT
OF STRESS RATIO

ALCOA and Northrop

MATERIAL: ALUMINUM IN9021
CONDITION:
ENVIRONMENT: R. T. , HI HUMIDITY

DELTA K (KSI*IN**1/2)			DA/DN (10**-6 IN./CYCLE) A R=+0.10	B R=+0.33	C
DELTA K MIN	A:	1.17	.0286		
	B:	1.25		.0320	
	C:				
	D:				
		1.30	.0392	.0365	
		1.60	.0718	.0705	
		2.00	.134	.134	
		2.50	.245	.247	
		3.00	.396	.406	
		3.50	.597	.626	
		4.00	.826	.929	
		5.00	1.44	1.90	
		6.00	2.26	3.68	
		7.00	3.30	6.88	
		8.00	4.58		
		9.00	6.10		
		10.00	7.90		
		13.00	15.1		
		16.00	20.3		
		20.00	41.5		
		25.00	79.5		
		30.00	129.		
		35.00	197.		
DELTA K MAX	A:	38.68	[illegible]		
	B:	7.65		10.2	
	C:				
	D:				

CORROSION

Corrosion related properties of IN-9021 were reported by two companies. ALCOA reported on the exfoliation resistance while Boeing reported on both stress corrosion cracking and exfoliation. Their findings are detailed in the following write-ups and table.

SPECTRUM

Spectrum fatigue of joint specimens was reported by Lockheed-CA while Northrop studied spectrum crack growth characteristics. Lockheed found IN-9021 to be equivalent to 7075-T6 sheet in the joint tests. The spectrum fatigue test results from Northrop are complicated by the fact that the IN-9021 specimens were not as wide as the other specimens tested. The IN-9021 samples were 2.4 inch wide while all other specimens were 4 inch wide. It is estimated that for the tension dominated spectrum this would result in a decrease of 25 percent in life.

STRESS CORROSION RESULTS FROM ALCOA

IN-9021 Extrusion

The SCC resistance of the Novamet produced IN-9021 was not determined. Because of the small size of the extruded shape, short-transverse specimens of a satisfactory size and type could not be obtained.

The exfoliation resistance of the IN-9021 extrusion was determined by exposing a duplicate set of three machined panels to the MASTMAASIS test. The panel specimens of each set were removed from the extrusion in such a way that the machined surface of one panel was from the "near surface" of the extrusion while that of the second and third panels was from the T/10 and T/2 planes of the extrusion, respectively. Though exposed in the same test chamber, one set of panels was tested at a different time than the other. A visual examination after 3 days, 7 days, and finally 2 weeks of exposure revealed that the performance of both sets of panels was similar. In no case was there any evidence of exfoliation corrosion. Randomly scattered pitting was observed on the "near surface," T/10 and T/2 machined planes of both sets of panels. Upon completion of the two-week exposure, the panels revealed that the pits ranged in size from minute (pinpoint size) to as large as 4.8 mm (3/16") in diameter. There was a preponderance of the large size pits on the "near surface" and T/2 plane panels. A survey of the pit depth with a Scarrett Pit Depth Gauge of several of the larger pits indicated that the depths ranged from 0.15 mm (0.006") to 1.14 mm (0.045"), with the T/2 plane panels containing more pits near the deep end of the range than the "near surface" or T/10 plane panels.

Corrosion Results From BOEING.

Material	Direction	Notch Fatigue, cycles (23 ksi, R=0.06, ν=25 Hz)	Fastener Fatigue, cycles (20 ksi, R = -1.0 ν = 30 Hz)	Stress Corrosion Cracking, ksi (90-day threshold)	Exfoliation (MASTMAASIS)
Hand Forgings:					
Alcoa					
7075-T7352	L	-	115,000/124,000/221,000	-	Small amt of exfoliation and pitting
	LT	-		-	
7050-T73652	L	-		-	
	LT	-		-	
X7090-T7E80	L	-		-	Very slight amt of exfoliation and no pitting
	LT	-		-	
X7091-T7E78	L	53,100/38,100/43,500	416,000/256,000	-	Small amt of exfoliation and very slight pitting
	LT	53,400/46,300/29,800		>60	
	ST	-		>10	
Novamet					
7075-T7352	L	-	117,000/98,000	-	Very slight amt of exfoliation and moderate pitting
	LT	-		-	
IN9021-T352	L	30,000/18,800/1,000,000+	265,000/533,000	-	Very slight amt of exfoliation and moderate pitting
	LT	208,000/1,000,000+/33,000		>60	
Extrusions:					
Alcoa					
X7090-T7E71	L	-		-	Very slight amt of exfoliation and no pitting
	LT	-		>60	
Novamet					
IN9021-T6X[a]	L	27,300/19,300/17,600		-	Small amt of exfoliation and pitting
	LT	-		>50	
IN9021-T6Y[b]	L	12,500/155,000/27,000		-	
	LT			>50	

(a) T6X: solution treated, quenched, stretched 4%, artifically aged
(b) T6Y: solution treated, quenched, artifically aged

TABLE F20

Results from Lockheed-CA

SPECTRUM FATIGUE OF RIVETED JOINTS

Flight-by-flight spectrum fatigue tests were conducted on a 1½-inch-wide single-lap riveted joints. Figure F7 shows the joint geometry. The Minitwist spectrum (Modification "A") was used for loading all joint specimens, at a 1-g flight (mean) stress of 10.0 ksi. The flights to specimen failure are noted in the following table.

Joint Material	Specimen Number	Flights to Failure	Geometric Mean
X7091-T7E69 Plate	B2 B3	19,941 29,203	24,100
X7091-T7E69 Extrusion	C2 C3	80,011 17,507	37,400
IN9021 Extrusion	D2 D3	17,321 96,055	40,800
7075-T6 Sheet	F1 F3	50,788 29,991	39,000

A comparison of the geometric mean of flights to failure shows an equivalent performance for the X7091-T7E69 and IN9021 Extrusion and 7075-T6 Sheet, while the X7091-T7E69 Plate has a shorter fatigue life. Significant scatter was exhibited by both extrusion materials.

Based on visual examination, inclusions were noted in the fracture surfaces of the IN9021 material. The specimens were consequently sent to the Calac Materials Laboratory for investigation. The laboratory confirmed the inclusions. Analyses performed by use of a scanning electron microscope and energy dispersive x-ray analysis (EDAX) showed the inclusions had high concentrations of copper, chromium, and iron in comparison to the base metal.

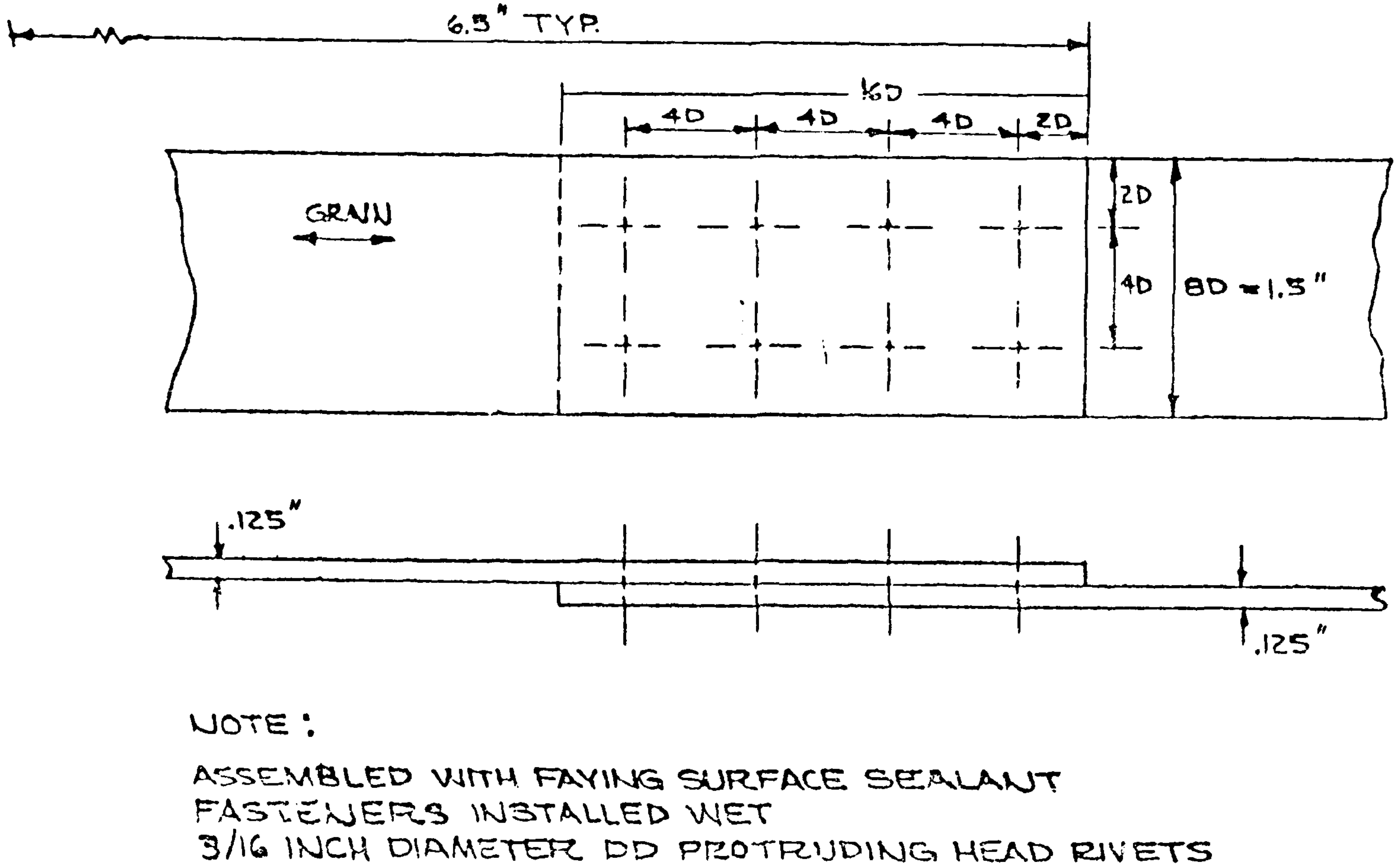

Figure F7. Riveted Joint Specimen Used by Lockheed-CA to Generate Data in Table F20.

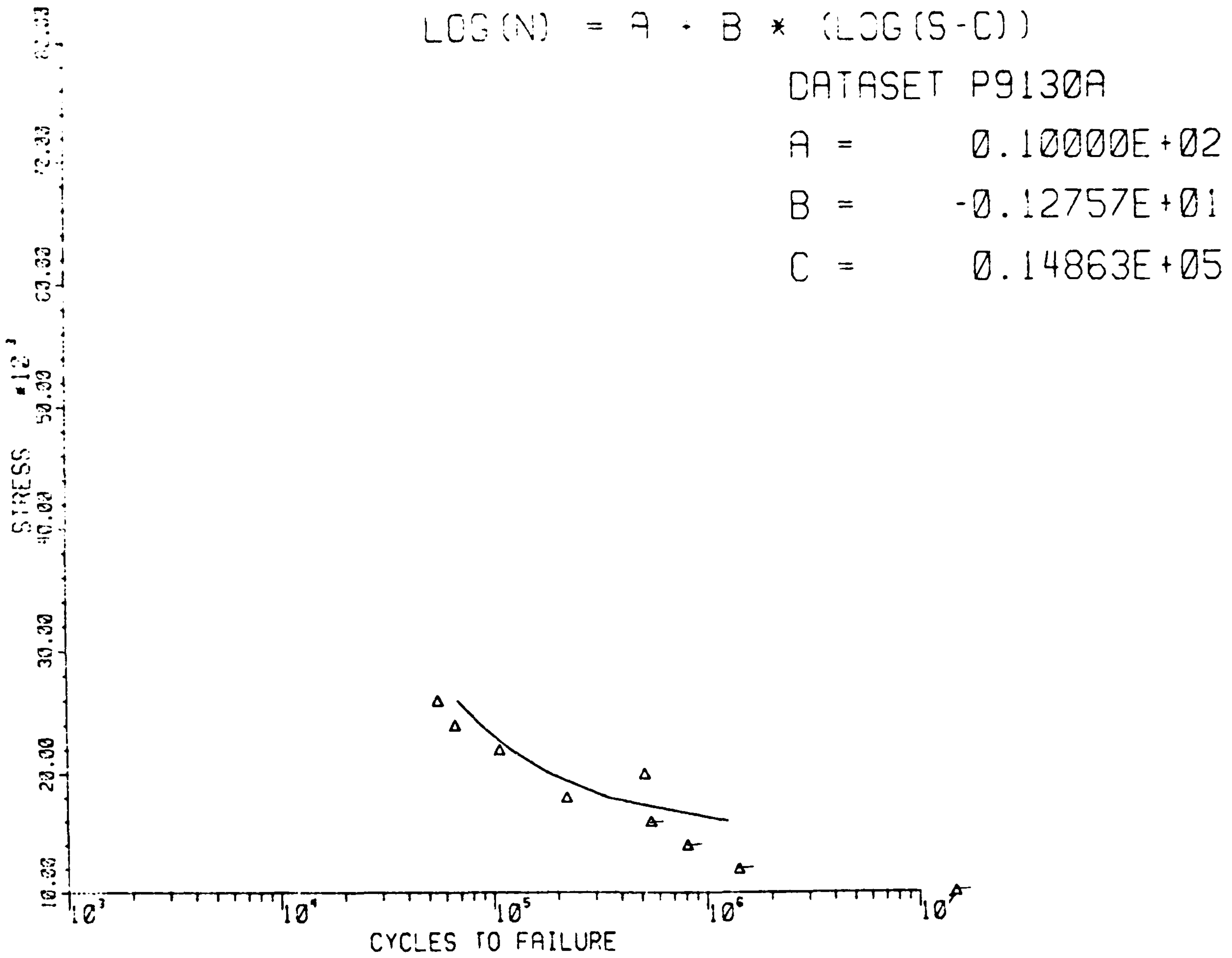

Figure G2.Fatigue Results for 7091 Plates; R=0.1, K_t=3.0

TABLE G9

FATIGUE RESULTS FOR 7091 PLATES: R=0.1, K_t=1.0

STRESS PSI	CYCLES	FAIL(1) NO FAIL(0)
41000	14967000	0
41000	12926100	0
43000	2091300	1
43000	839000	0
43000	485300	0
45000	692500	0
49000	177300	1
51000	204000	1
51000	94500	1
51000	44300	1
53000	292000	1
53000	72600	1
55000	112200	1
55000	44600	1
57000	57500	1

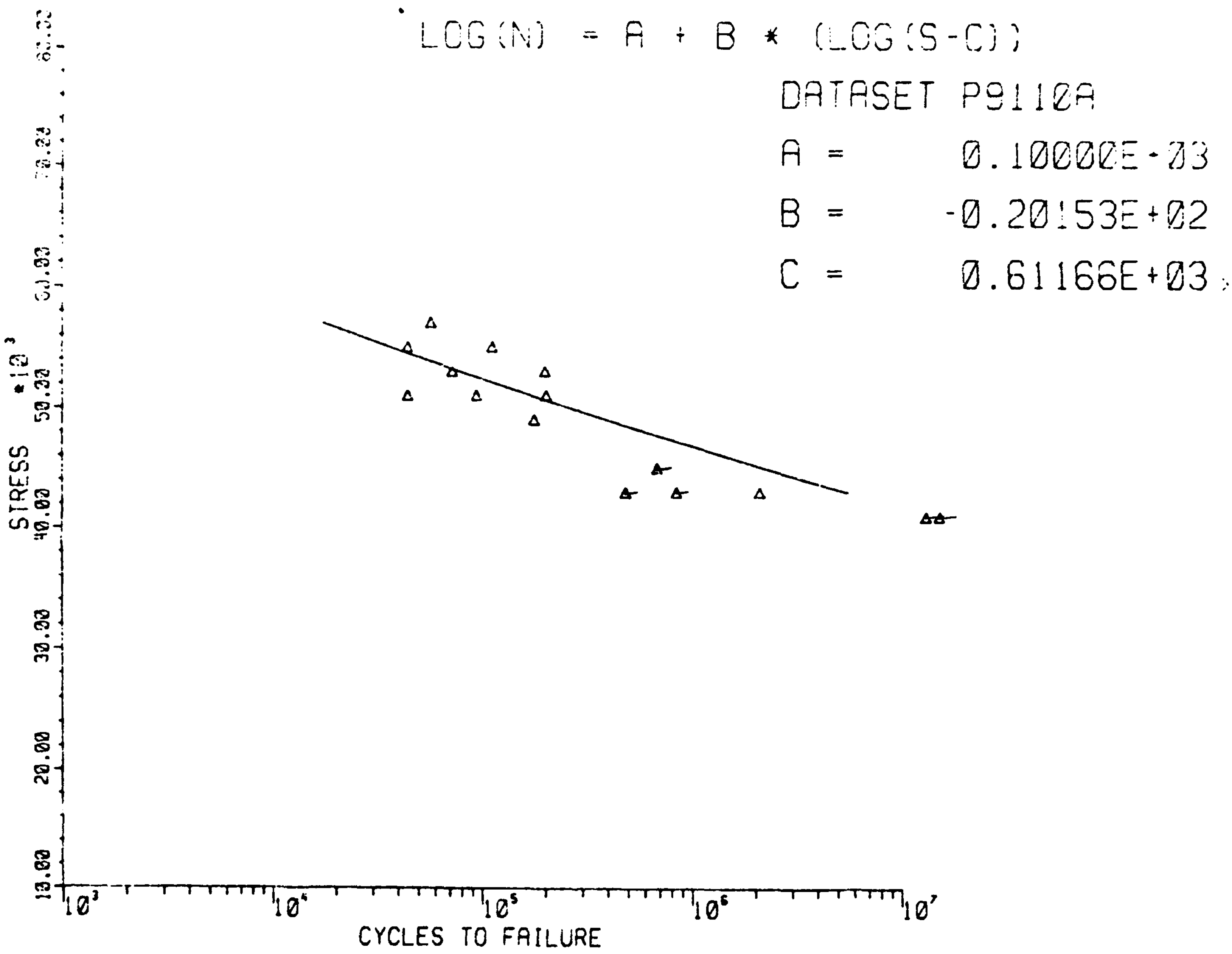

Figure G1. Fatigue Results for 7091 Plates, R=0.1, K_t=1.0

TABLE G8

7091-T7E69 PLATES

FRACTURE TOUGHNESS, K_{IC}

COMPANY	ORIENTATION	KC (KSI vIV)	KQ (KSI vIN)	COMMENT
GENERAL DYNAMICS	L-T		51.1	Insufficient thickness
			52.0	" "
ALCOA		141.1		invalid
		<140.0		invalid Grip-end failure
GENERAL DYNAMICS	T-L		36.2	Insufficient thickness and PMAX/PQ exceeds 1.1
			35.3	" "

TABLE G7

7091-T7E69 PLATES

BEARING

COMPANY	ORIENTATION	e/D	BEARING ULT STR (KSI)	BEARING YLD STR (KSI)
ALCOA	LONG	1.5	126.7	110.9
			127.8	108.5
			124.4	106.7
ALCOA		2.0	163.7	122.0
			160.0	123.0
			154.7	119.8
ALCOA	TRAN	1.5	132.2	112.9
			130.3	110.9
			132.8	114.0
ALCOA		2.0	166.7	130.2
			163.7	127.9
			163.3	128.5

TABLE G6

7091-T7E69 PLATES

SHEAR

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
ROCKWELL	LONG	52.8
		50.0
		53.5
ALCOA		52.0
		48.5
		50.5
ROCKWELL	TRANS	49.2
		52.4
		50.6
ALCOA		49.9
		48.7
		49.6

TABLE G5

7091-T7E69 PLATES

COMPRESSION

COMPANY	ORIENTATION	COMP YIELD STR (KSI)
ROCKWELL	TRANS	85.8
		85.5
		86.4
ALCOA		85.0
		82.6
		83.4

TABLE G4

7091-T7E69 PLATES

COMPRESSION

COMPANY	ORIENTATION	COMP YIELD STR (KSI)
ROCKWELL	LONG	78.9
		80.9
		81.9
ALCOA		77.8
		74.1
		75.4

TABLE G3

7091-T7E69 PLATES
TENSILE

COMPANY	TEST TEMP (^{o}F)	ORIENTATION	ULT STR (KSI)	YIELD STR (KSI)	ELONG (%)	
ROCKWELL	RT	TRANS	86.3	80.0	9.9	
			87.0	81.4	10.0	
			87.3	82.0	11.1	
GENERAL DYNAMICS			85.1	78.3	8.0	
			84.8	78.2	7.0	
			85.2	78.8	7.0	
ALCOA			86.5	79.6	10.0	
			83.5	76.8	9.0	
			85.2	77.7	11.0	
NORTHROP			82.1	75.6	5.0	Flat
			81.0	73.2	8.0	"
			81.3	76.6	7.0	"
			84.6	77.2	9.0	"
			79.5	73.6	6.0	"
			81.4	74.4	7.0	"
			83.0	76.9	10.0	"
			81.8	76.9	9.0	"
			81.1	75.7	6.0	"
			78.6	72.6	5.0	"
			80.0	72.8	5.0	"
			74.5	68.3	5.0	"
			87.4	81.8	8.0	Round(a)*
			87.0	81.4	8.0	"
			81.7	75.1	7.0	Round(b)*
			81.9	75.5	10.0	"

(a) 18% Recrystallized grain structure in cross sectional area

(b) 25% Recrystallized grain structure in cross sectional area

* Eliminated from analysis

TABLE G2

7091-T7E69 PLATES: 1/4(.4)"x16"

TENSILE

COMPANY	TEST TEMP (°F)	ORIENTATION	ULT STR (KSI)	YIELD STR (KSI)	ELONG (%)	
ROCKWELL	RT	LONG	84.4	78.5	11.2	
			84.6	78.5	11.0	
			82.6	77.3	8.3	
GENERAL DYNAMICS			83.6	76.8	10.0	
			82.7	76.3	7.0	
			82.3	75.5	9.0	
AFWAL			82.7	75.9	11.0	
			82.9	76.3	11.0	
			82.4	76.2	11.2	
ALCOA			78.8	74.5	13.0	
			77.3	71.7	11.0	
			78.5	72.8	12.0	
NORTHROP			79.2	74.4	10.0	Flat
			79.5	74.2	9.0	"
			77.6	72.6	10.0	"
			82.1	75.5	9.0	"
			79.8	76.1	6.0	"
			81.3	74.2	10.0	"
			79.7	75.0	9.0	"
			78.4	74.1	10.0	"
			77.7	73.4	9.0	"
			82.1	74.4	10.0	"
			84.4	77.7	10.0	"
			81.9	74.8	7.0	"
			85.4	79.5	9.0	Round(a)*
			84.7	79.1	9.0	"
			83.2	75.5	8.0	Round(b)*
			82.5	76.1	9.0	"

(a) 18% Recrystallized grain structure in cross sectional area

(b) 25% Recrystallized grain structure in cross sectional area

* Eliminated from analysis

TABLE 31

SUGGESTED ALLOWABLES FOR 7091-T7E69 PLATES; 1/4(.4)"x16"

F_{tu},KSI	
L	78.5
LT	79.1
F_{ty},KSI	
L	73.3
LT	72.7
F_{cy},KSI	
L	74.1
LT	82.6
F_{su},KSI	
L	48.5
LT	48.7
F_{bu},KSI $\sqrt{IN}$	
L	
(e/D=1.5)	124.4
(e/D=2.0)	154.7
LT	
(e/D=1.5)	130.3
(e/D=2.0)	163.3
F_{by},KSI $\sqrt{IN}$	
L	
(e/D=1.5)	106.7
(e/D=2.0)	119.8
LT	
(e/D=1.5)	110.9
(e/D=2.0)	127.9

NOTE: These values were developed to be used only in a cost-benefit-analysis and are not necessarily accurate for design of hardware.

APPENDIX G

7091-T7E69 PLATES

NOTICE: Suggested allowables, mean trends, and trend curves in this document were developed to be used in a cost benefit analysis to assess the potential benefit of using the material in a structure. These suggested allowables and trends are not considered accurate for design of actual hardware.

TABLE F22

Results From NORTHROP

Ranking of Aluminum Alloys & Tempers Under Spectrum Loading with 21 ksi Peak Stress Based on Simulated Flight hours for Crack Growth from 6 mm to Failure

Tension Dominated Spectrum (F-18/C2, Lower Wing Root Load)

Material*	Hours to Failure**
2024-T351	22,100
7475-T651	19,000
7091-T7E69 Plate	18,600
2020-T651	18,[illegible]00
2324-T39	17,[illegible]00
7091-T7E69 Extrusion	15,300
7475-T7351	15,000
7050-T7451	14,900
7150-T6E189	13,000
7075-T7351	12,900
2124-T851	11,200
7075-T651	10,800
IN9021-T851 Extrusion	9,100
2024-T851	8,500

Tension-Compression Spectrum (F-18/E3, Horizontal Tail Hinge Moment Load)

Material*	Hours to Failure**
7091-T7E69 Plate	15,800
2024-T351	15,400
7091-T7E69 Extrusion	15,300
7475-T651	14,900
2324-T39	14,400
7475-T7351	13,400
7050-T7451	13,200
2020-T651	13,100
7150-T6E189	11,300
7075-T7351	10,700
2124-T851	9,100
7075-T651	8,900
2024-T851	7,100
IN9021-T851 Extrusion	3,400

*All material is plate except where noted. Round Robin materials are underlined. Remaining materials are from Contracts N00019-80-C-0427, N00019-81-C-0550, and N00019-82-C-0425 and Northrop IR&D. Round Robin specimens differed as noted in the text.

**All data is the average of two tests except F-18/C2 data reported for IN9021-T851 which was from one test. Multiple test data were logarithmically averaged. All data is rounded to the nearest 100 hours.

TABLE F21

Results From NORTHROP

Spectrum Fatigue Data for 7091-T7E69 Plate and IN9021-T851 Extrusion Relative to Data for 7075-T7351, 7075-T651 and 2324-T39

SIMULATED FLIGHT HOURS FOR CRACK GROWTH FROM 6 mm TO FAILURE

Spectrum		Tension Dominated Spectrum (F-18/C2, Lower Wing Root Load)			Tension-Compression Spectrum (F-18/E3, Horizontal Tail Hinge Moment)	
Peak Stress		21 ksi	15 ksi		21 ksi	15 ksi
Material						
7091-T7E69 Plate	Specimen			Specimen		
	P-1E-2	19,668	-	P-1E-1	14,882	-
	P3	17,635	-	P4	16,867	-
Log Averaged		18,624			15,843	
IN9021-T851 Extrusion	Specimen			Specimen		
	6C-16	9,145	-	6A-12	3,282	-
	6C-18	-	22,640	6B-14	3,611	-
				6D-17	-	33,297
				Log Averaged	3,443	
7075-T7351 Plate*		12,900	-		10,700	-
7075-T651 Plate*		10,800	27,300		8,900	25,300
2324-T39 Plate*		17,800	53,700		14,400	42,900

*Data from the final report "Investigation of Fatigue Crack-Growth Resistance of Aluminum Alloys Under Spectrum Loading," Contract N00019-81-C-0550. Specimens differed from those used for the Round Robin as noted in the text.

TABLE G10

FATIGUE RESULTS FOR 7091 PLATES: R=0.1, K_t=3.0

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
10000	14815400	0
12000	1415300	0
14000	814600	0
16000	552200	0
18000	224500	1
20000	514700	1
22000	108700	1
24000	67100	1
26000	56300	1

CONDITION/HT: T7E69
FORM: 0.40"TH PLATE
SPECIMEN TYPE: CT
ORIENTATION: L-T
FREQUENCY: 2.00- 25.00 HZ
ENVIRONMENT: R.T., HI HUMIDITY

YIELD STRENGTH: 73.0- 79.3 KSI
ULT. STRENGTH: 78.2- 85.1 KSI
SPECIMEN THK: 0.124- 0.252"
SPECIMEN WIDTH: 1.999- 2.004"
REFERENCES:

ALUM. ALLOY

7091

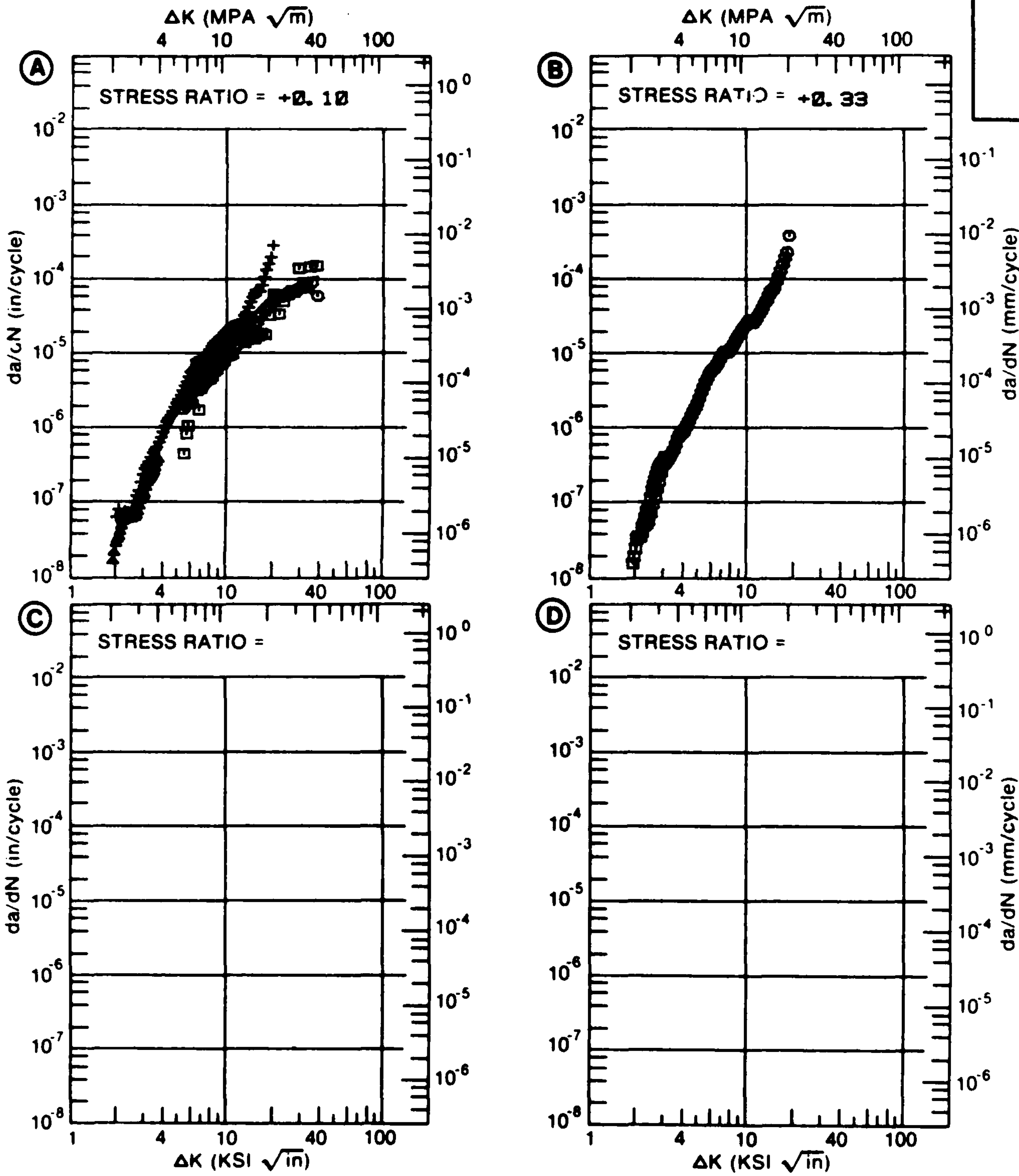

Figure G3. Fatigue Crack Growth Rate Data for 7091 Plates; ALCOA and Northrop

TABLE G11

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE G3 INDICATING EFFECT
OF STRESS RATIO

ALCOA and Northrop

MATERIAL: ALUMINUM 7091
CONDITION: T7E69
ENVIRONMENT: R.T. ,HI HUMIDITY

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN./CYCLE) A	B	C	D
		R=+0.10	R=+0.33		
DELTA K MIN	A: 1.84	.021			
	B: 1.83		.017		
	C: 1				
	D:				
	2.00	.0335	.0324		
	2.50	.104	.133		
	3.00	.245	.351		
	3.50	.481	.721		
	4.00	.834	1.26		
	5.00	1.95	2.86		
	6.00	3.64	5.20		
	7.00	5.92	8.34		
	8.00	8.73	12.4		
	9.00	12.0	17.6		
	10.00	15.7	24.3		
	13.00	28.1	56.7		
	16.00	41.5	121.		
	20.00	58.7			
	25.00	77.4			
	30.00	92.1			
	35.00	103.			
DELTA K MAX	A: 37.67	108.			
	B: 18.22		208.		
	C:				
	D:				

CONDITION/HT: T7E69	
FORM: 0.40"TH PLATE	YIELD STRENGTH: 76.2 KSI
SPECIMEN TYPE: WOL	ULT. STRENGTH: 82.9 KSI
ORIENTATION: L-T	SPECIMEN THK: 0.386- 0.391"
STRESS RATIO: +0.10	SPECIMEN WIDTH: 2.560- 2.597"
FREQUENCY: 1.00- 9.00 HZ	REFERENCES:

ALUM. ALLOY

7091

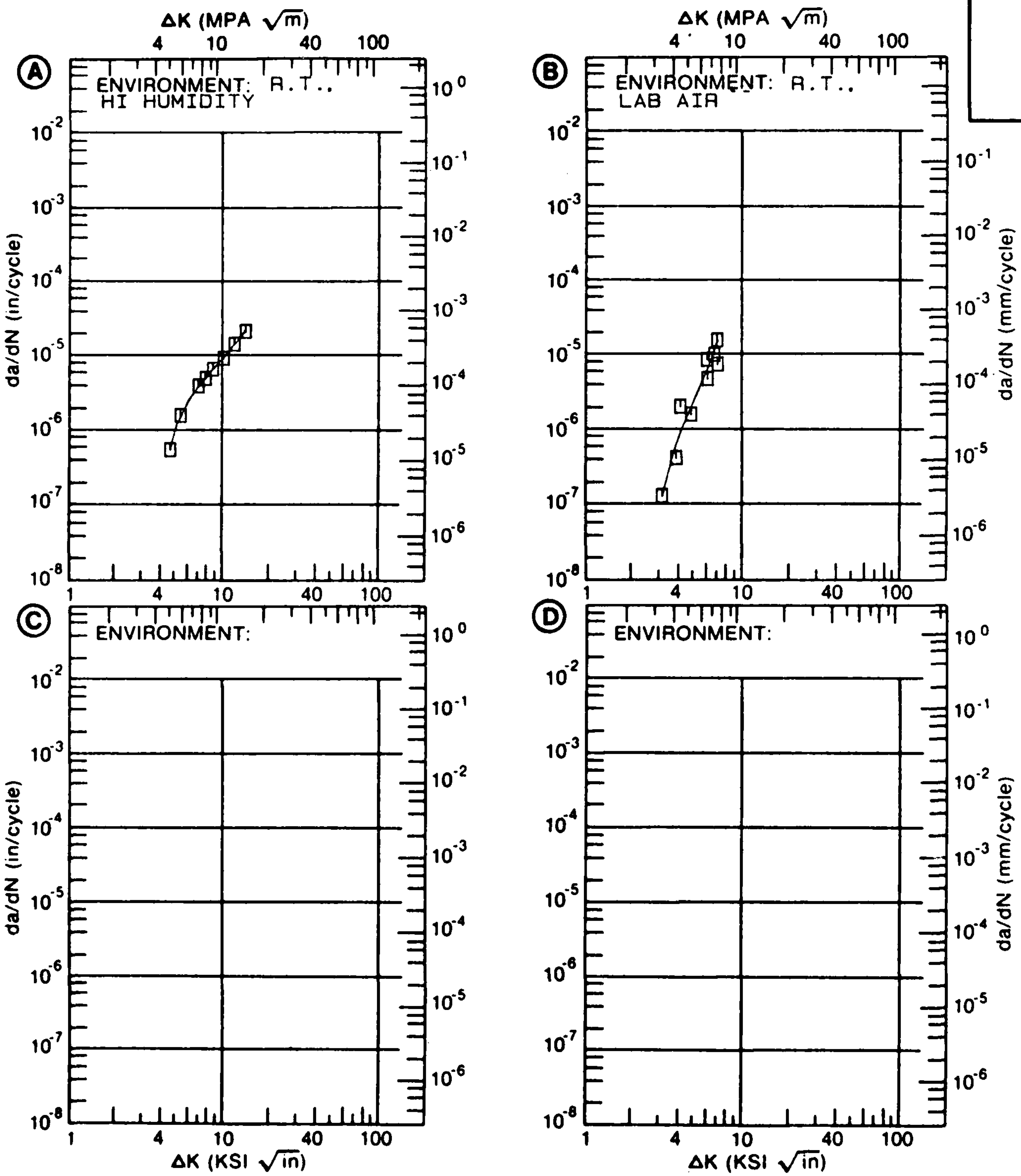

Figure G4.Fatigue Crack Growth Rate Data for 7091 Plates; General Dynamics

TABLE G12

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE G4 INDICATING EFFECT
OF ENVIRONMENT

GENERAL DYNAMICS

MATERIAL: ALUMINUM 7091
CONDITION: T7E69

DELTA K (KSI*IN**1/2)			DA/DN (10**-6 IN./CYCLE) A E= R.T. HI HUMIDITY	B E= R.T. LAB AIR	C	D
DELTA K MIN	A:	4.52	.545			
	B:	3.03		.129		
	C:					
	D:					
		3.50		.409		
		4.00		.929		
		5.00	1.16	2.75		
		6.00	2.51	6.67		
		7.00	3.93			
		8.00	5.50			
		9.00	7.23			
		10.00	9.20			
		13.00	17.7			
DELTA K MAX	A:	13.94	21.6			
	B:	6.90		15.4		
	C:					
	D:					

CONDITION/HT: T7E69
FORM: 0.40"TH PLATE
SPECIMEN TYPE: WOL
ORIENTATION: L-T
STRESS RATIO: +0.30
FREQUENCY: 1.00 HZ

YIELD STRENGTH: 76.2 KSI
ULT. STRENGTH: 82.9 KSI
SPECIMEN THK: 0.390"
SPECIMEN WIDTH: 2.549"
REFERENCES:

ALUM. ALLOY

7091

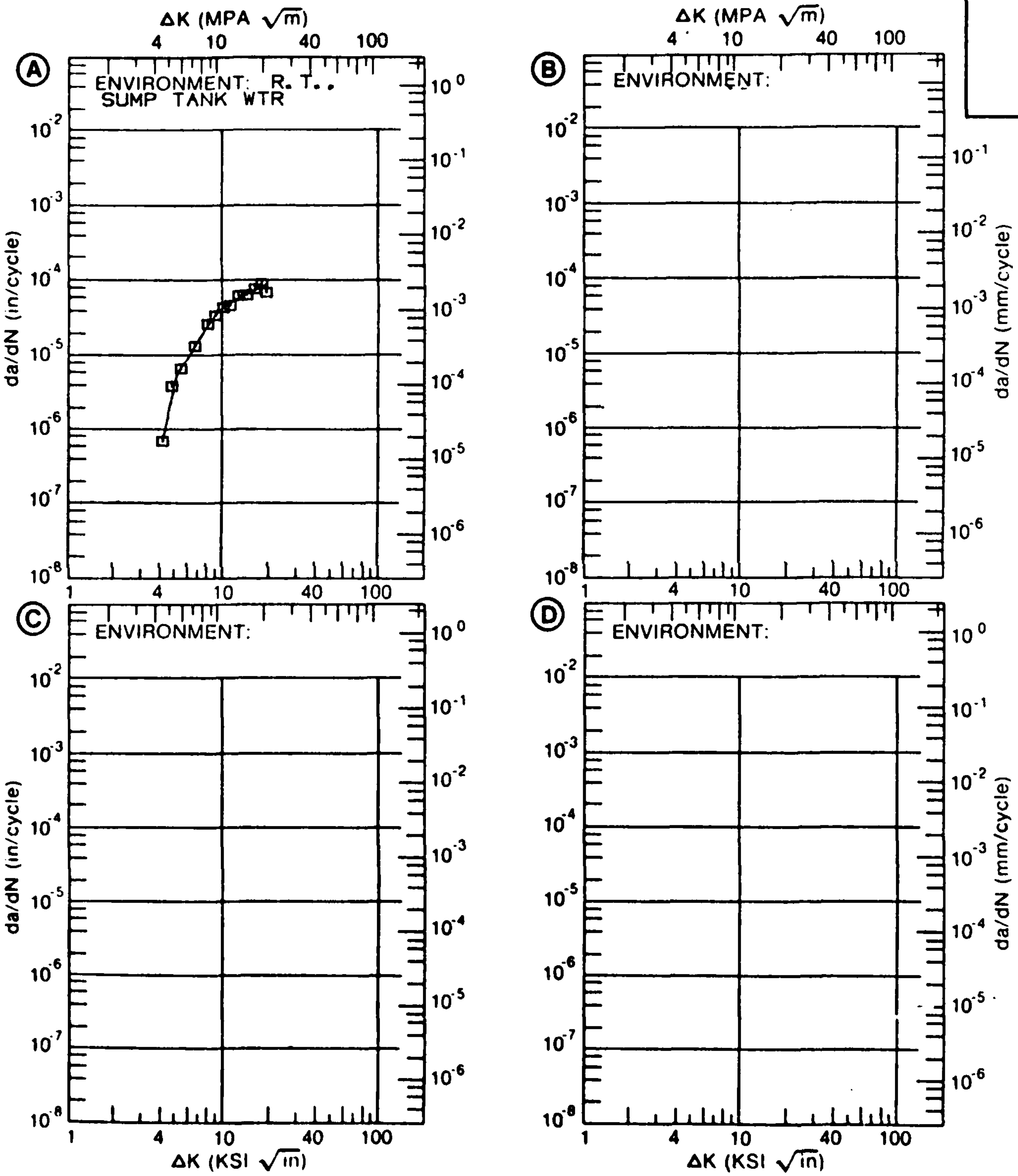

Figure G5.Fatigue Crack Growth Rate Data for 7091 Plates; General Dynamics

TABLE G13

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE G5 INDICATING EFFECT OF ENVIRONMENT

GENERAL DYNAMICS

MATERIAL: ALUMINUM 7091
CONDITION: T7E69

DELTA K (KSI*IN**1/2)			DA/DN (10**-6 IN./CYCLE) A	B	C	D
			E= R.T. SUMP TANK WTR			
	A:	4.01	.694			
DELTA K MIN	B:					
	C:					
	D:					
		5.00	5.62			
		6.00	9.81			
		7.00	16.9			
		8.00	26.3			
		9.00	35.5			
		10.00	43.6			
		13.00	61.3			
		16.00	73.7			
	A:	18.85	86.0			
DELTA K MAX	B:					
	C:					
	D:					

CONDITION/HT: T7E69
FORM: 0.40"TH PLATE
SPECIMEN TYPE: CT
ORIENTATION: T-L
FREQUENCY: 2.00- 25.00 HZ
ENVIRONMENT: R.T., HI HUMIDITY

YIELD STRENGTH: 76.5- 81.6 KSI
ULT. STRENGTH: 82.0- 87.2 KSI
SPECIMEN THK: 0.124- 0.251"
SPECIMEN WIDTH: 1.998- 2.005"
REFERENCES:

ALUM. ALLOY

7091

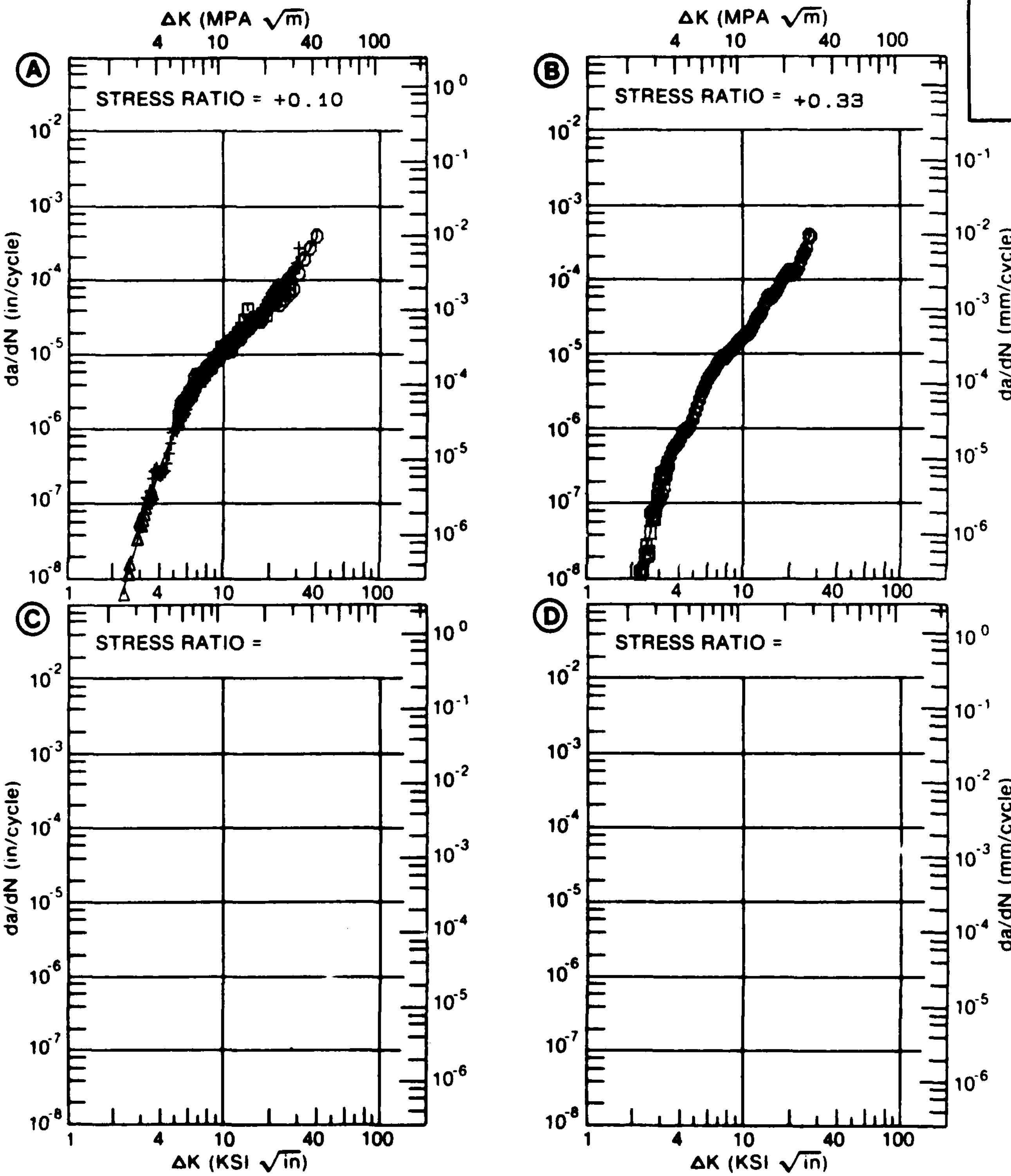

Figure G6. Fatigue Crack Growth Rate Data for 7091 Plate; ALCOA and Northrop

TABLE G14

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE G6 INDICATING EFFECT

OF STRESS RATIO

ALCOA and NORTHROP

MATERIAL: ALUMINUM 7091
CONDITION: T7E69
ENVIRONMENT: R.T. ,HI HUMIDITY

DELTA K (KSI*IN**1/2)			DA/DN (10**-6 IN./CYCLE) A	B	C	D
			R=+0.10	R=+0.33		
DELTA K MIN	A:	2.30	.007			
	B:	2.19		.010		
	C:	?				
	D:					
		2.50	.0153	.0418		
		3.00	.0594	.185		
		3.50	.167	.474		
		4.00	.373	.911		
		5.00	1.19	2.25		
		6.00	2.59	4.25		
		7.00	4.45	6.90		
		8.00	6.64	10.2		
		9.00	9.04	14.3		
		10.00	11.6	19.2		
		13.00	20.3	40.2		
		16.00	31.1	71.3		
		20.00	51.1	125.		
		25.00	90.2	274.		
		30.00	153.			
		35.00	254.			
DELTA K MAX	A:	39.51	394.			
	B:	26.72		450.		
	C:					
	D:					

Spectrum Fatigue

Spectrum fatigue crack growth of 7091 plate was performed by three participants. Northrop used two different spectra and found that relative to other structural aluminum alloys the 7091 had good characteristics. There was one qualification of the results; the 7091 plate specimens were 0.15 inch thick while all other samples were 0.25 inch thick. This may have caused a slight increase in the life of the 7091 specimens.

General Dynamics performed tests on flawed and unflawed samples. Each sample had a hole in the center and for the flawed configuration an elox notch was put in the hole. Comparative data was only available for the unflawed configuration at a maximum spectrum stress of 42 KSI for 7475-T7351. For these conditions the 7091 plate had a longer life.

AFWAL performed tests using the FALSTAFF and Mini-TWIST spectra along with comparative data on 7050-T76 plate. Irrespective of the spectrum the 7091 had better lives and crack growth resistance than the 7050 plate.

7091 plate does appear to be resistant to spectrum fatigue compared to other structural aluminum alloys.

Stress Corrosion

Exfoliation testing results from ALCOA showed the 7091 plate having good resistance to exfoliation when compared to the 7050-T6 plate.

TABLE G15

Spectrum Fatigue Data for 7091-T7E69 Plate and IN9021-T851 Extrusion Relative to Data for 7075-T7351, 7075-T651 and 2324-T39

Results From Northrop

SIMULATED FLIGHT HOURS FOR CRACK GROWTH FROM 6 mm TO FAILURE

Spectrum		Tension Dominated Spectrum (F-18/C2, Lower Wing Root Load)			Tension-Compression Spectrum (F-18/E3, Horizontal Tail Hinge Moment)	
Peak Stress		21 ksi	15 ksi		21 ksi	15 ksi
Material						
7091-T7E69 Plate	Specimen			Specimen		
	P-1E-2	19,668	-	P-1E-1	14,882	-
	P3	17,635	-	P4	16,867	-
Log Averaged		18,624			15,843	
IN9021-T851 Extrusion	Specimen			Specimen		
	6C-16	9,145	-	6A-12	3,282	-
	6C-18	-	22,640	6B-14	3,611	-
				6D-17	-	33,297
				Log Averaged	3,443	
7075-T7351 Plate*		12,900	-		10,700	-
7075-T651 Plate*		10,800	27,300		8,900	25,300
2324-T39 Plate*		17,800	53,700		14,400	42,900

*Data from the final report "Investigation of Fatigue Crack-Growth Resistance of Aluminum Alloys Under Spectrum Loading," Contract N00019-81-C-0550. Specimens differed from those used for the Round Robin as noted in the text.

TABLE G16

Ranking of Aluminum Alloys & Tempers Under Spectrum Loading with 21 ksi Peak Stress Based on Simulated Flight hours for Crack Growth from 6 mm to Failure

Results From Northrop

Tension Dominated Spectrum (F-18/C2, Lower Wing Root Load)		Tension-Compression Spectrum (F-18/E3, Horizontal Tail Hinge Moment Load)	
Material*	**Hours to Failure****	**Material***	**Hours to Failure****
2024-T351	22,100	7091-T7E69 Plate	15,800
7475-T651	19,000	2024-T351	15,400
7091-T7E69 Plate	18,600	7091-T7E69 Extrusion	15,300
2020-T651	18,500	7475-T651	14,900
2324-T39	17,800	2324-T39	14,400
7091-T7E69 Extrusion	15,300	7475-T7351	13,400
7475-T7351	15,000	7050-T7451	13,200
7050-T7451	14,900	2020-T651	13,100
7150-T6E189	13,000	7150-T6E189	11,300
7075-T7351	12,900	7075-T7351	10,700
2124-T851	11,200	2124-T851	9,100
7075-T651	10,800	7075-T651	8,900
IN9021-T851 Extrusion	9,100	2024-T851	7,100
2024-T851	8,500	IN9021-T851 Extrusion	3,400

*All material is plate except where noted. Round Robin materials are underlined. Remaining materials are from Contracts N00019-80-C-0427, N00019-81-C-0550, and N00019-82-C-0425 and Northrop IR&D. Round Robin specimens differed as noted in the text.

**All data is the average of two tests except F-18/C2 data reported for IN9021-T851 which was from one test. Multiple test data were logarithmically averaged. All data is rounded to the nearest 100 hours.

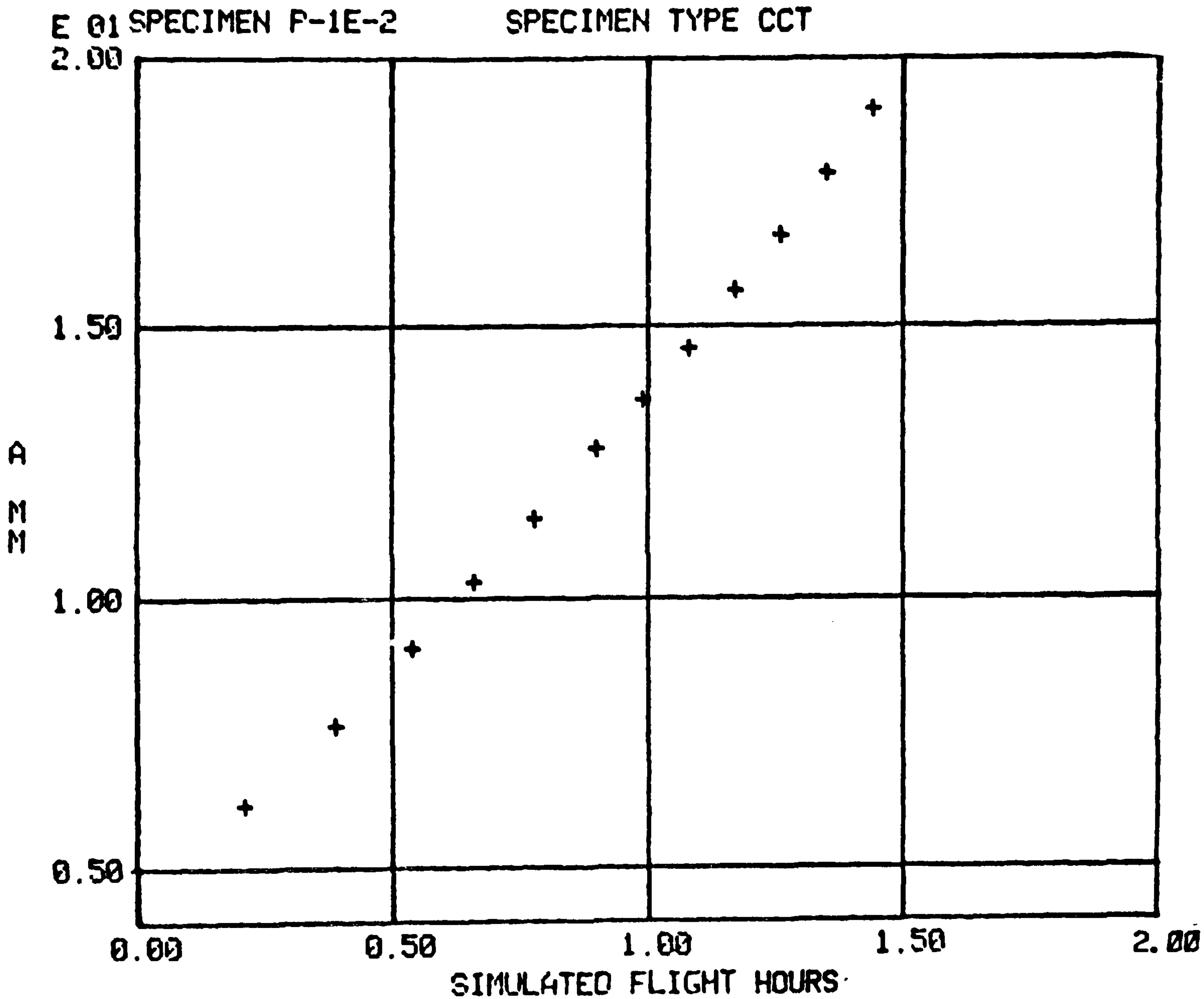

Figure G7. Crack Length Versus Flight Hours for 7091 Plate Generated by Northrop.

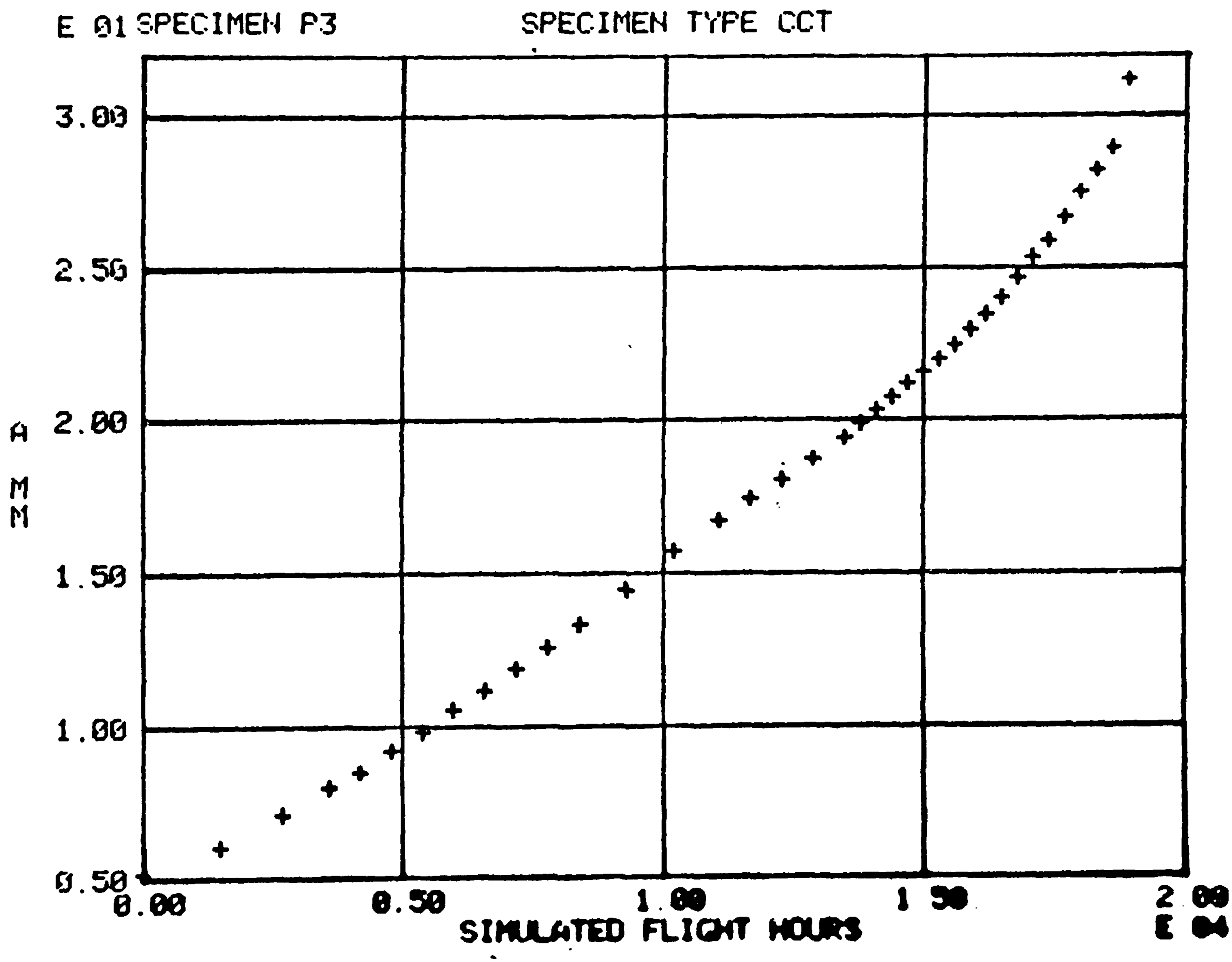

Figure G8. Crack Length Versus Flight Hours for 7091 Plate Generated by Northrop.

TABLE H3

7090-T7E71 PLATES
COMPRESSION

COMPANY	ORIENTATION	COMP YIELD STR (KSI)
AFWAL	LONG.	86.9
		89.1
		86.7
AFWAL	TRANS	94.5
		95.8
		92.8

TABLE H2

7090-T7E71 PLATES: 1/4(.4)" x 16"
TENSILE

COMPANY	TEST TEMP (°F)	ORIENTATION	ULT STR (KSI)	YIELD STR (KSI)	ELONG (%)
AFWAL	RT	LONG	87.8	82.5	10.0
			87.5	82.6	8.5
			87.2	82.7	9.3
ALCOA			86.4	82.0	9.0
			86.9	82.8	10.0
			85.6	79.8	10.0
AFWAL		TRANS	89.8	85.3	11.5
			89.2	85.0	12.0
			89.5	85.1	13.0
ALCOA			87.8	82.6	6.0
			92.0	87.1	7.0
			86.3	80.7	8.0

TABLE H1
SUGGESTED ALLOWABLES FOR
7090-T7E71 PLATES: 1/4(.4)" x 16"

F_{tu}, KSI		
	L	85.6
	LT	86.3
F_{ty}, KSI		
	L	79.8
	LT	80.7
F_{cy}, KSI		
	L	86.7
	LT	92.8
F_{su}, KSI		
	L	48.6
	LT	47.0
F_{bu}, KSI		
	L	
	(e/D=1.5)	127.9
	(e/D=2.0)	166.2
	LT	
	(e/D=1.5)	132.3
	(e/D=2.0)	176.7
F_{by}, KSI		
	L	
	(e/D=1.5)	108.0
	(e/D=2.0)	123.4
	LT	
	(e/D=1.5)	113.5
	(e/D=2.0)	132.8
K_{IC}, KSI $\sqrt{IN}$		
	LT	23.5

NOTE: These values were developed to be used only in a cost-benefit-analysis and are not necessarily accurate for design of hardware.

APPENDIX H
7090-T7E71 PLATES

Comment: The material was originally scheduled to be supplied as 0.25-inch-thick plates. Because the processing parameters required to produce the plates were not obtainable on the available equipment, the plates were 0.4 inch thick, with recrystalized surfaces on both sides. Participants were requested to remove an equal amount of material from both sides when making specimens, i.e., use the mid-thickness, one quarter inch, for testing.

NOTICE: Suggested allowables, mean trends, and trend curves in this document were developed to be used in a cost benefit analysis to assess the potential benefit of using the material in a structure. These suggested allowables and trends are not considered accurate for design of actual hardware.

TABLE G18

RESULTS OF EXFOLIATION RATINGS AND METALLOGRAPHIC EXAMINATION ON SPECIMENS 7090-T7E71 AND 7091-T7E69 P/M SHEET AND PLATE AFTER EXPOSURE IN THE MASTMAASIS TEST

Results From ALCOA

S. No.	Alloy	Thickness (mm)	Thickness (in)	Surface Tested	Exfoliation Rating 1 Wk	Exfoliation Rating 2 Wks	Metallographic Exam. Type Of Attack	Metallographic Exam. Max. Depth Of Attack (mm)	Metallographic Exam. Max. Depth Of Attack (in)
514024-4A-1M	7090-T7E71	10.54	.415	T/10	P	P	P (1)	.142	.0056
514024-4A-2M	7090-T7E71	10.54	.415	T/10	P	P	---	---	---
514024-4A-1M	7090-T7E71	10.54	.415	T/2	P	P	P (2)	.124	.0049
514024-4A-2M	7090-T7E71	10.54	.415	T/2	P	P	---	---	---
514024-4B-1M	7090-T7E71	1.57	.062	T/10	P	P	P (2)	.086	.0052
514024-4B-2M	7090-T7E71	1.57	.062	T/10	P	P	---	---	---
514037-1A-1M	7091-T7E69	10.34	.407	T/10	P	P	P&I	.345	.0136
514037-1A-2M	7091-T7E69	10.34	.407	T/10	P	P	---	---	---
514037-1A-1M	7091-T7E69	10.34	.407	T/2	P	P	P (3)	.391	.0154
514037-1A-2M	7091-T7E69	10.34	.407	T/2	P	P	---	---	---
514037-1B-1M	7091-T7E69	1.57	.062	T/10	P	P	I&P	.238	.0094
514037-1B-2M	7091-T7E69	1.57	.062	T/10	P	P	---	---	---
475332-2-1-B-1M	7075-T6	19.1	.750	T/10	EA	EC	---	---	---
475332-2-1-B-2E	7075-T6	19.1	.750	T/2	EA	EC	---	---	---

NOTES: (1) Lamellar
(2) Scroungy
(3) Tends toward Lamellar

TABLE G17

WEIGHT LOSS DETERMINATION, EXFOLIATION RATINGS AND METALLOGRAPHIC EXAMINATION ON SPECIMENS OF 7090-T7E71 AND 7091-T7E69 P/M SHEET AND PLATE AFTER EXPOSURE IN THE EXCO TEST

Results From ALCOA

S. No.	Alloy	Thickness (mm)	Thickness (in)	Surface Tested	Wt. Loss (Mg/cm)	EXCO Rating 24 Hrs	EXCO Rating 48 Hrs	Metallographic Exam. Type Of Attack	Metallographic Exam. Max. Depth Of Attack (mm)	Metallographic Exam. Max. Depth Of Attack (in)
514024-4A-1E	7090-T7E71	10.54	.415	T/10	28.3	EB	EB	P (1)	.353	.0139
514024-4A-2E	7090-T7E71	10.54	.415	T/10	29.0	EB	EB	---	---	---
514024-4A-1E	7090-T7E71	10.54	.415	T/2	27.5	EB	EB	P (2)	.338	.0133
514024-4A-2E	7090-T7E71	10.54	.415	T/2	27.6	EB	EB	---	---	---
514024-4B-1E	7090-T7E71	1.57	.062	T/10	31.1	EB	EB	P (3)	.132	.0052
514024-4B-2E	7090-T7E71	1.57	.062	T/10	31.6	EB	EB	---	---	---
514037-1A-1E	7091-T7E69	10.34	.407	T/10	17.7	EB	EB	P&I (3)	.223	.0088
514037-1A-2E	7091-T7E69	10.34	.407	T/10	19.6	EB	EB	---	---	---
514037-1A-1E	7091-T7E69	10.34	.407	T/2	32.8	EC	EC	P (1)	.320	.0126
514037-1A-2E	7091-T7E69	10.34	.407	T/2	36.3	EC	EC	---	---	---
514037-1B-1E	7091-T7E69	1.57	.062	T/10	28.5	EB	EB	I&P	.259	.0102
514037-1B-2E	7091-T7E69	1.57	.062	T/10	31.3	EB	EB	---	---	---
475332-2-1-B-1E	7075-T6	19.1	.750	T/10	66.2	EB	ED	---	---	---
475332-2-1-B-2E	7075-T6	19.1	.750	T/2	91.0	EB	EC	---	---	---

NOTES: (1) Lamellar - Tends to exfoliate

(2) Tends toward Lamellar

(3) Scroungy

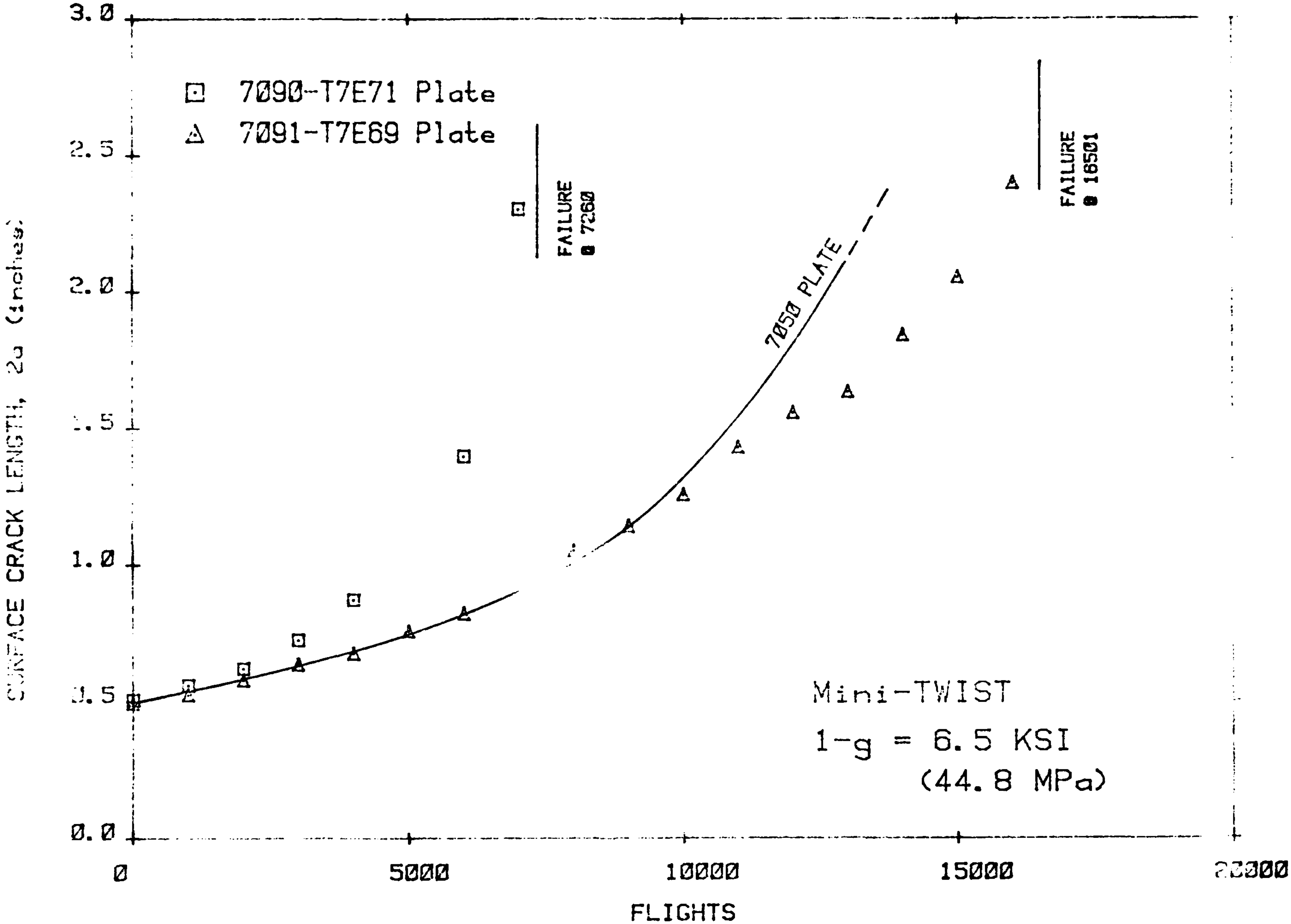

Figure G16. Crack Length Versus Flights for 7091 Plate Under Mini-TWIST Loading.

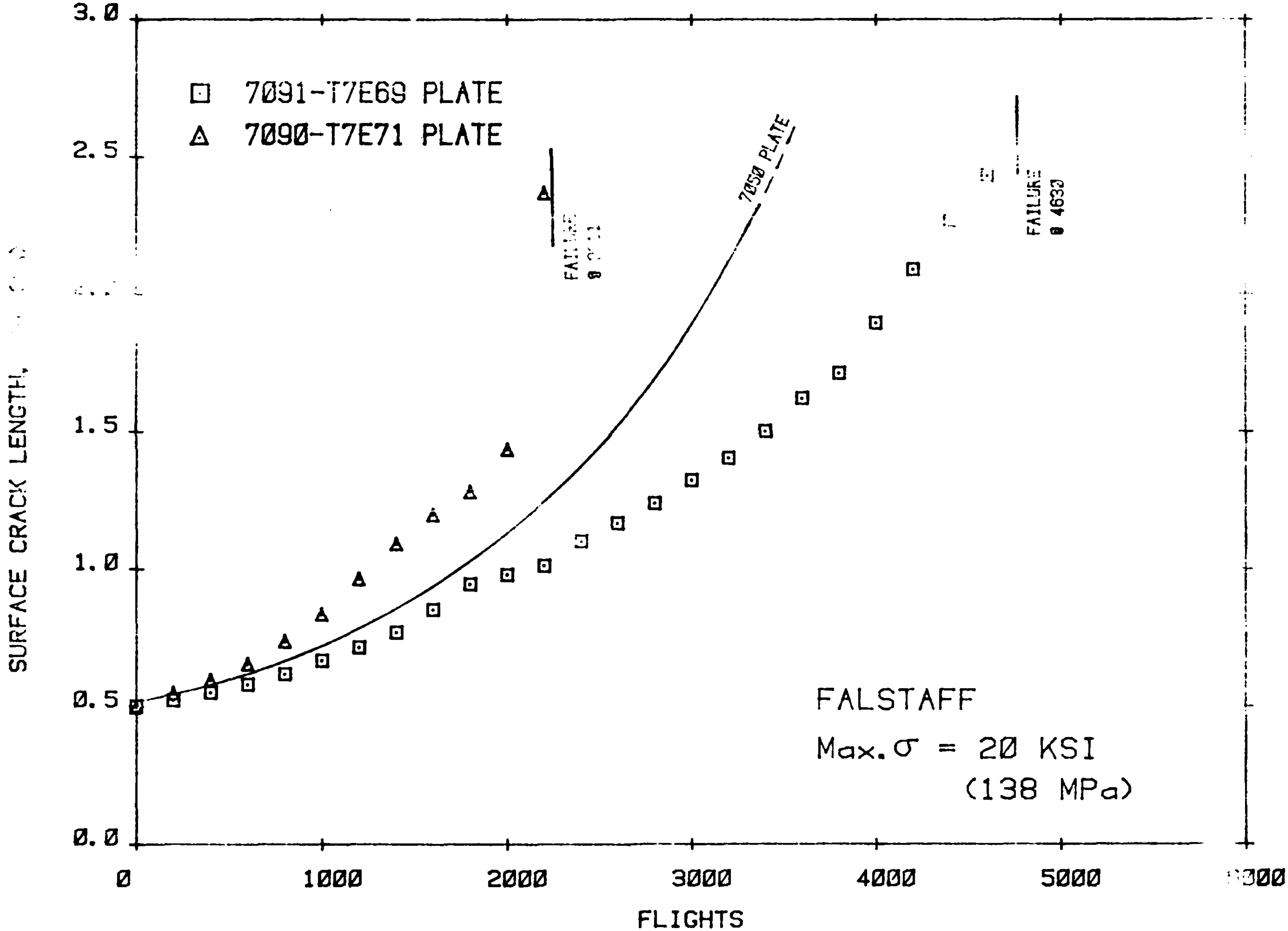

Figure G15. Crack Length Versus Flights for 7091 Plate Under FALSTAFF Loading.

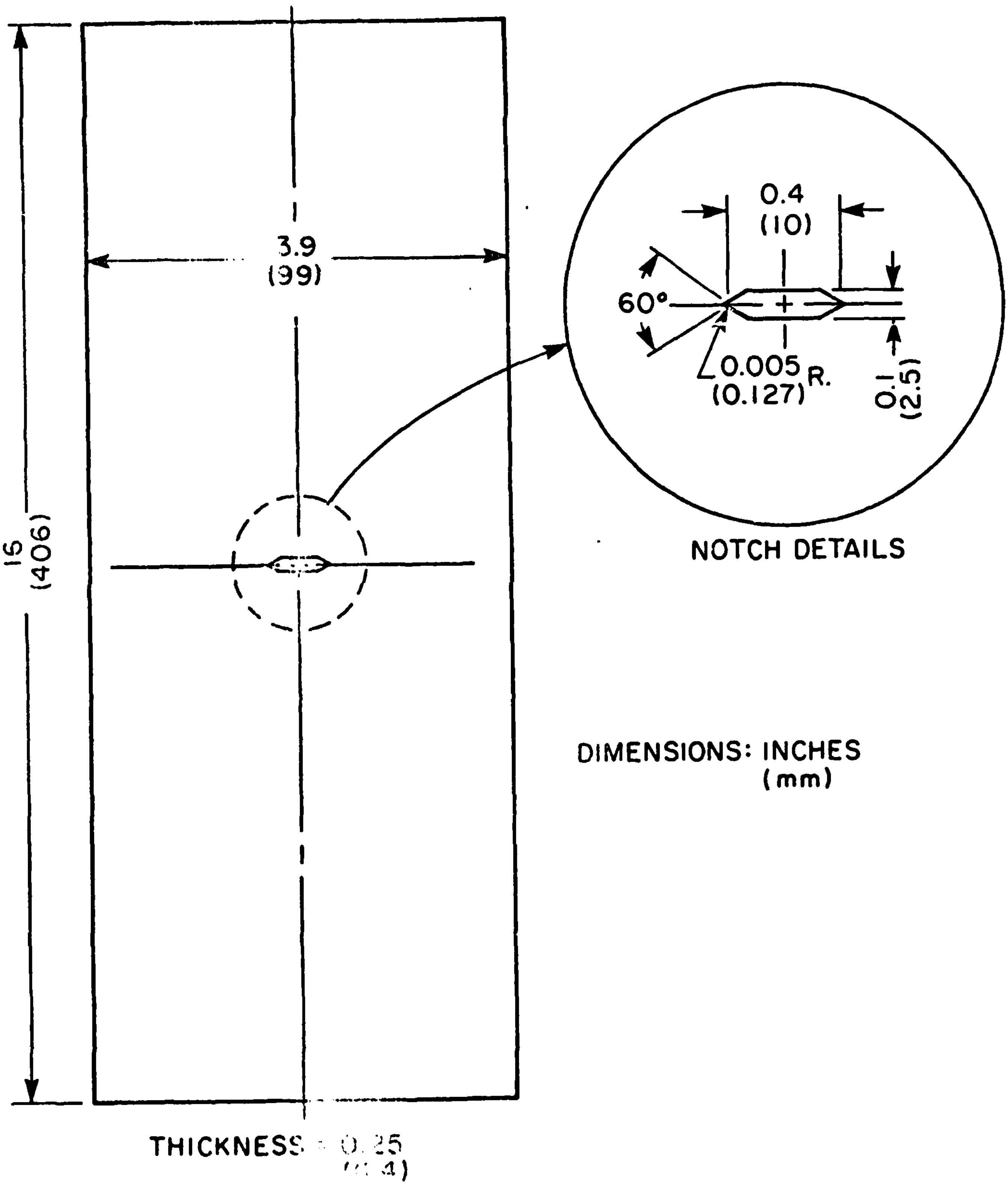

Figure G14. Specimen Used to Generate Data in Figures G15 and G16.

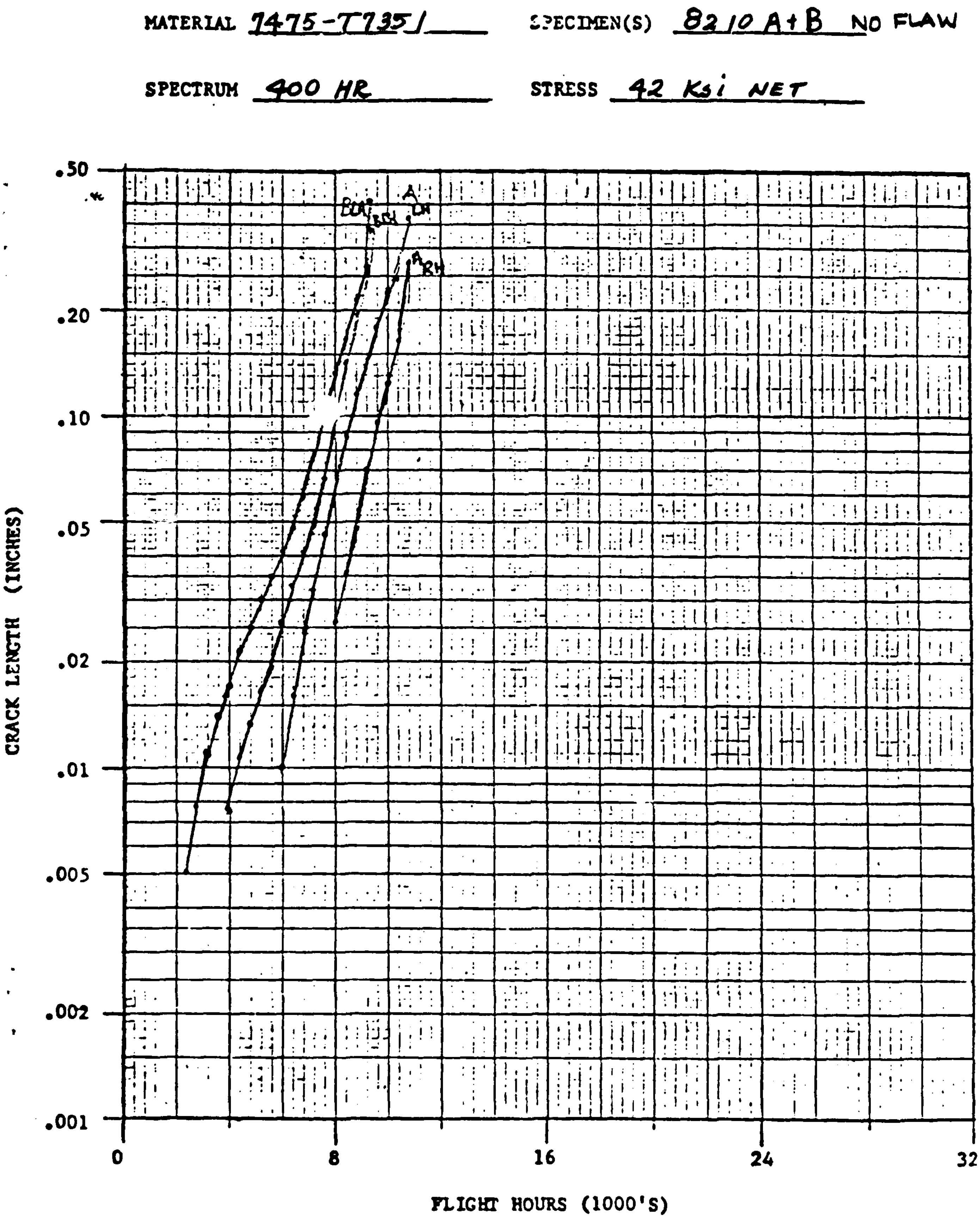

Figure G13. Crack Length Versus Flight Hours for 7475-T7351 Generated by General Dynamics.

MATERIAL 7091-T7E69 SPECIMEN(S) Flawed-Lab Air

SPECTRUM 400 HR STRESS 39 ksi & 42 ksi NET

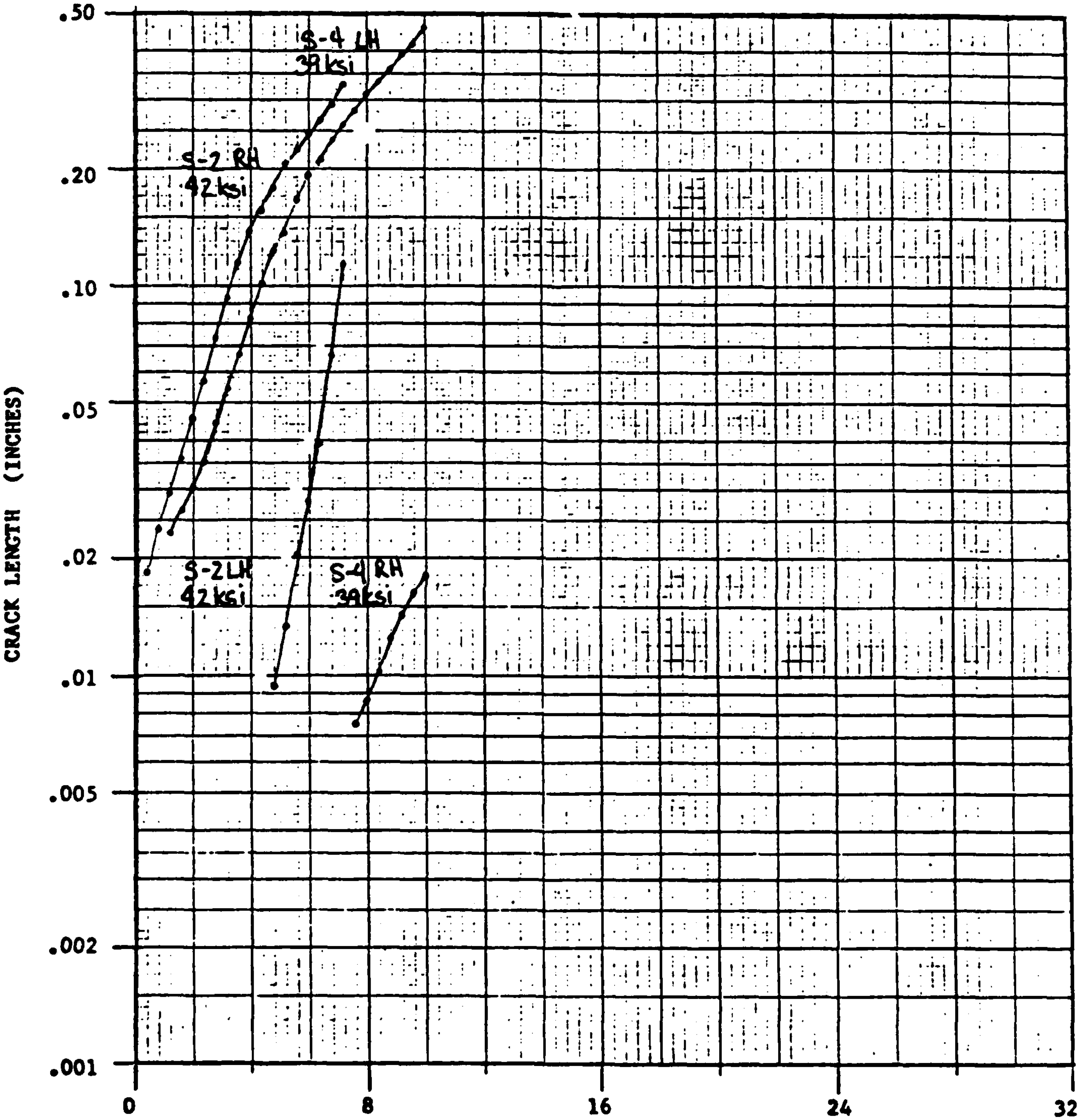

Figure G12. Crack Length Versus Flight Hours for 7091 Plate Generated by General Dynamics.

MATERIAL 7091-T7E69 SPECIMEN(S) NoFlaw-LabAir

SPECTRUM 400 HR STRESS 39 ksi & 42 ksi NET

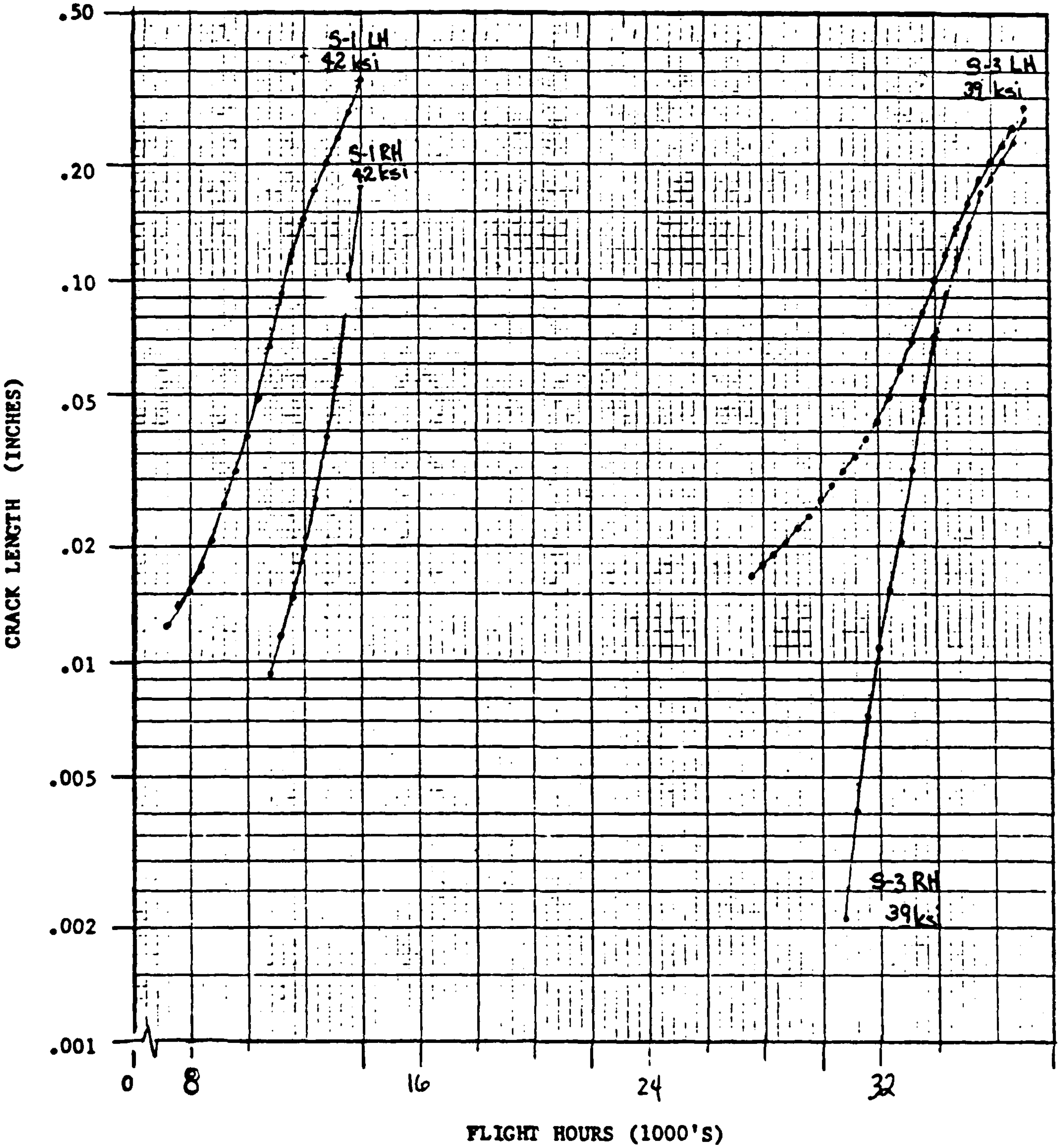

Figure G11. Crack Length Versus Flight Hours for 7091 Plate Generated by General Dynamics.

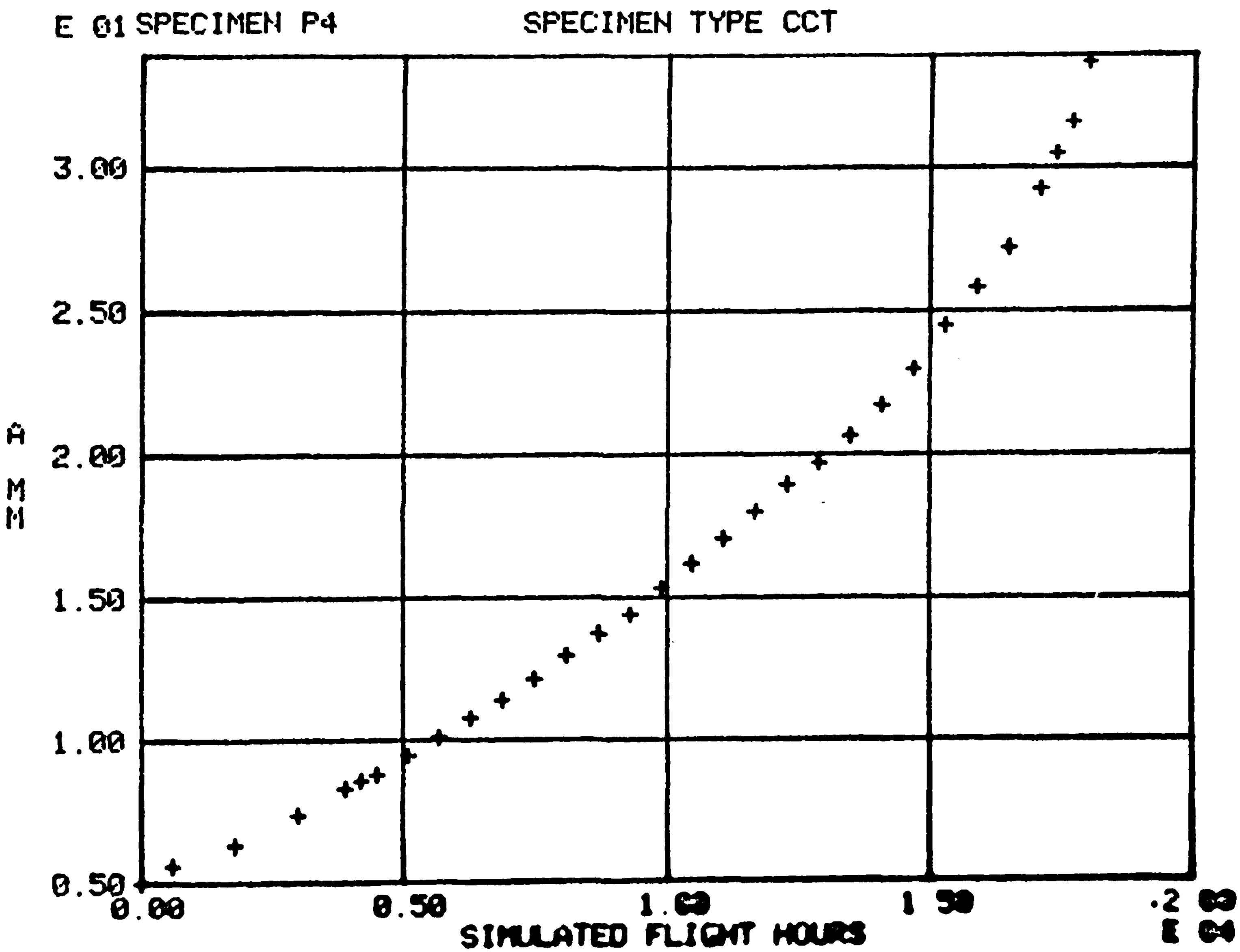

Figure G10. Crack Length Versus Flight Hours for 7091 Plate Generated by Northrop.

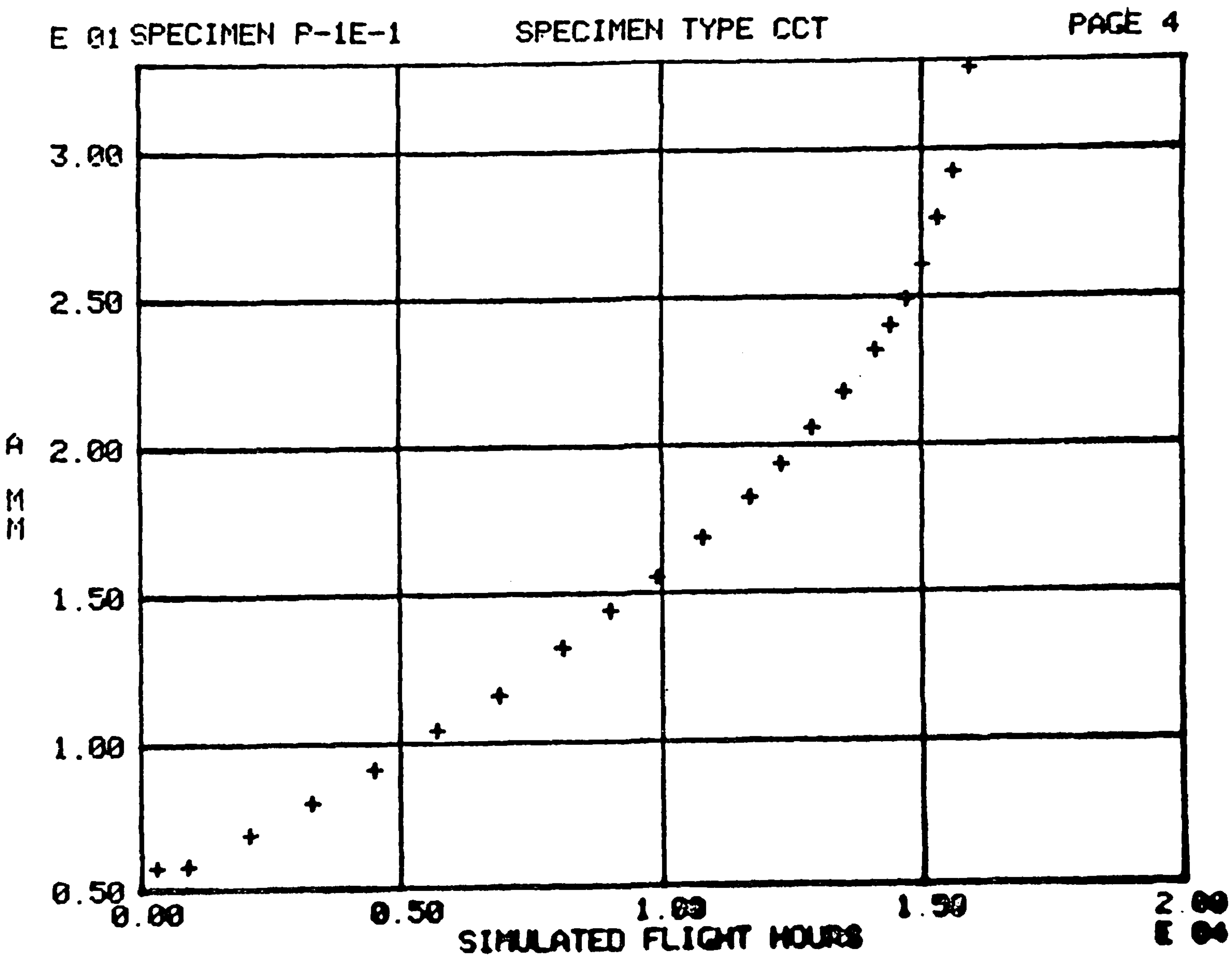

Figure G9. Crack Length Versus Flight Hours for 7091 Plate Generated by Northrop.

TABLE H4

7090-T7E71 PLATES
SHEAR

COMPANY	ORIENTATION	SHEAR STRENGTH (KSI)
AFWAL	LONG	49.2
		48.6
		48.9
	TRANS	47.2
		47.0
		49.2

TABLE H5

7090-T7E71 PLATES
BEARING

COMPANY	ORIENTATION	e/D	BEARING ULT (KSI)	BEARING YIELD (KSI)
AFWAL	LONG	2.0	172.9	128.1
			172.4	123.4
			166.2	132.0
	TRANS		181.2	132.8
			181.5	138.4
			176.7	134.9
	LONG	1.5	131.7	110.6
			127.9	110.3
			129.5	108.0
	TRANS		132.3	115.0
			136.4	117.6
			134.4	113.5

TABLE H6

7090-T7E71 PLATES

FRACTURE TOUGHNESS, K_{IC}, K_C

COMPANY	ORIENTATION	K_{IC} (KSI $\sqrt{IN}$)	K_C (KSI $\sqrt{IN}$)	COMMENT
AFWAL	L-T	24.3		valid
		23.5		valid
		26.1		valid
ALCOA			58.2 *	
			58.9 *	

* 16 inch wide CCT panels evaluated per ASTM standard B646-78.

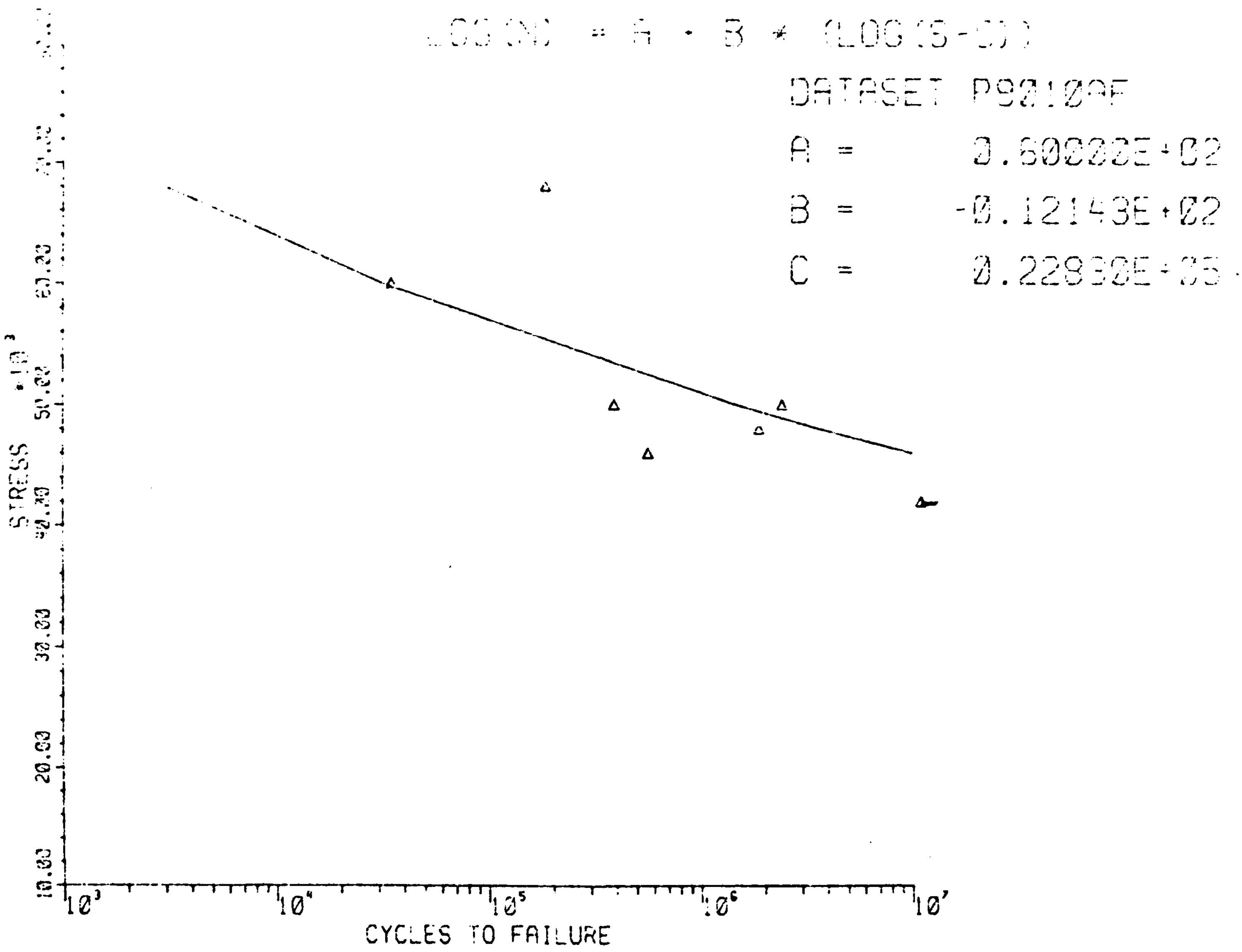

Figure H1. Fatigue Results for 7090 Plates; R = 0.1, K_t = 1.0

TABLE H7

FATIGUE DATA FOR 7090 PLATES: $R = 0.1$, $K_t = 1.0$

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
42000	11000000	0
46000	571300	1
48000	1890000	1
50000	393200	1
50000	2420500	1
60000	35500	1
68000	185400	1

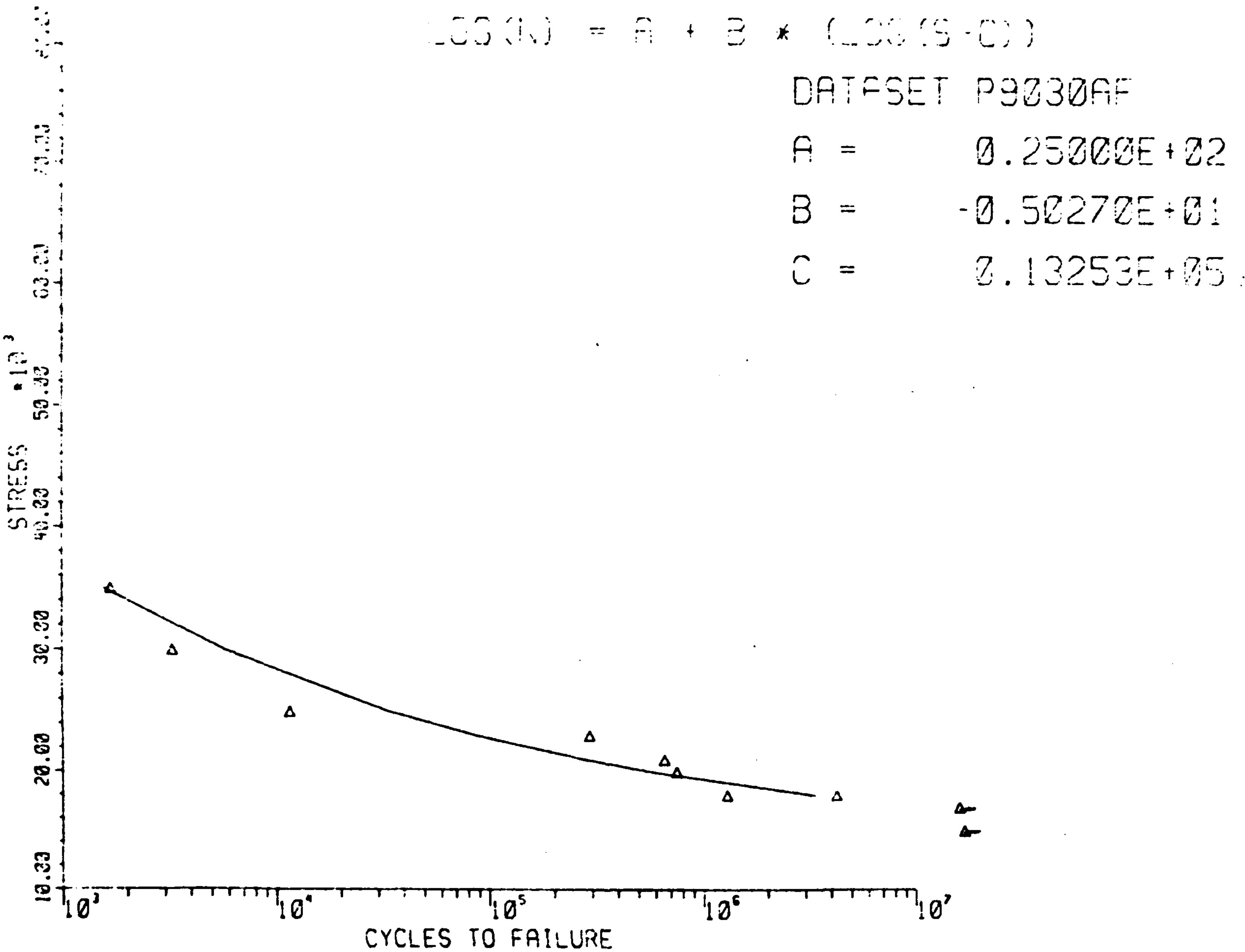

Figure H2. Fatigue Results for 7090 Plates; R = 0.1, K_t = 3.0

TABLE H8

FATIGUE DATA FOR 7090 PLATES: R = 0.1, K_t = 3.0

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
15000	17000000	0
17000	16000000	0
18000	1280400	1
18000	4172300	1
20000	749100	1
21000	657700	1
23000	293400	1
25000	11700	1
30000	3300	1
35000	1700	1

CONDITION/HT: T7E71
FORM: Ø.4Ø"TH PLATE
SPECIMEN TYPE: CT
ORIENTATION: L-T
STRESS RATIO: +Ø.1Ø
FREQUENCY: 25.ØØ HZ

YIELD STRENGTH: 82.6 KSI
ULT. STRENGTH: 87.5 KSI
SPECIMEN THK: Ø.25Ø- Ø.251"
SPECIMEN WIDTH: 1.5Ø1- 1.5Ø3"
REFERENCES:

ALUM. ALLOY

7Ø9Ø

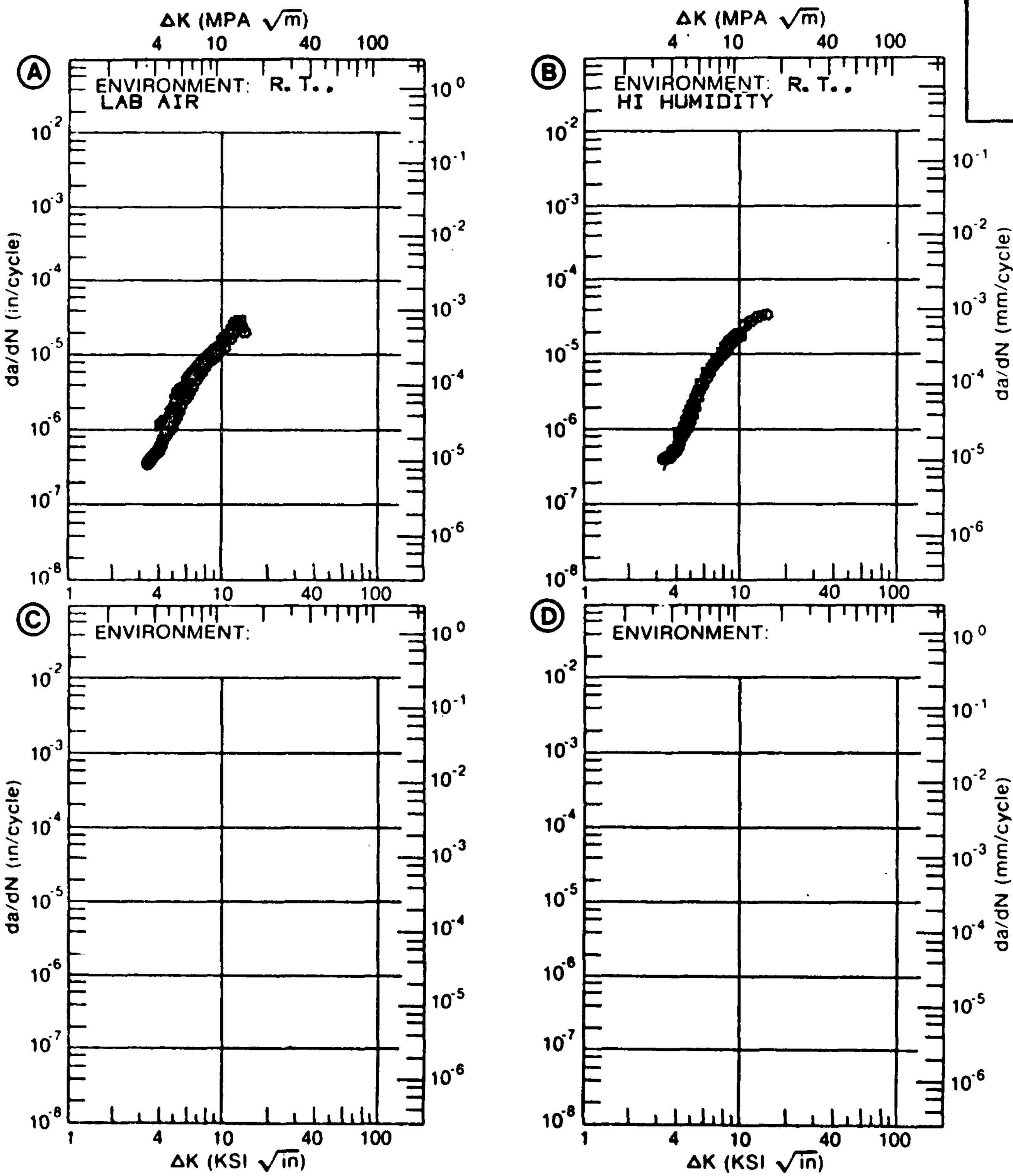

Figure H3. Fatigue Crack Growth Rate Data for 7090 Plates; AFWAL

TABLE H9

FATIGUE CRACK GROWTH RATES AT DEFINED LEVELS
OF STRESS INTENSITY FACTOR

DATA ASSOCIATED WITH FIGURE H3 INDICATING EFFECT
OF ENVIRONMENT

AFWAL

MATERIAL: ALUMINUM 7090
CONDITION: T7E71

DELTA K (KSI*IN**1/2)		DA/DN (10**-6 IN./CYCLE) A	B	C	D
		E= R.T. LAB AIR	E= R.T. HI HUMIDITY		
DELTA K MIN A:	3.28	.290			
DELTA K MIN B:	3.24		.291		
DELTA K MIN C:					
DELTA K MIN D:					
	3.50	.420	.412		
	4.00	.805	.752		
	5.00	2.05	2.01		
	6.00	3.89	4.25		
	7.00	6.20	7.55		
	8.00	8.85	11.7		
	9.00	11.7	16.3		
	10.00	14.7	20.9		
	13.00	24.2	30.6		
DELTA K MAX A:	13.88	27.1			
DELTA K MAX B:	14.66		31.9		
DELTA K MAX C:					
DELTA K MAX D:					

SPECTRUM

Spectrum fatigue crack growth of 7090 plates was evaluated by AFWAL. Both the standard FALSTAFF and Mini-TWIST spectra were used. 7090 plates are inferior to the baseline 7050 plates and also to 7091 plates as shown in Figures H5 and H6.

STRESS CORROSION

ALCOA reported the 7090-T7E71 plates has good resistance to exfoliation when compared to 7075-T6 plate. Tabular results are in Table H10 and H11.

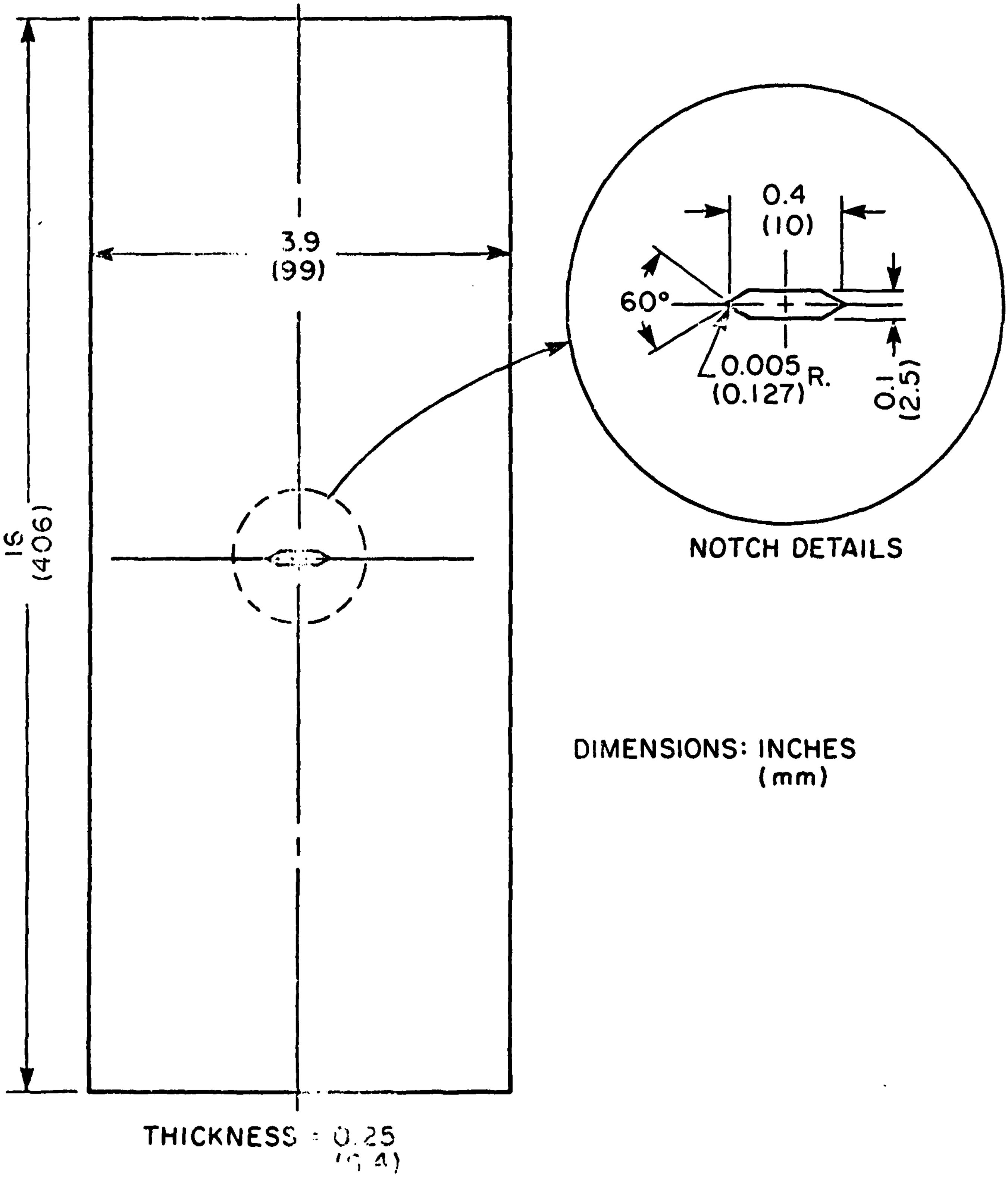

Figure H4. Specimen Used to Generate Data in Figures H5 and H6.

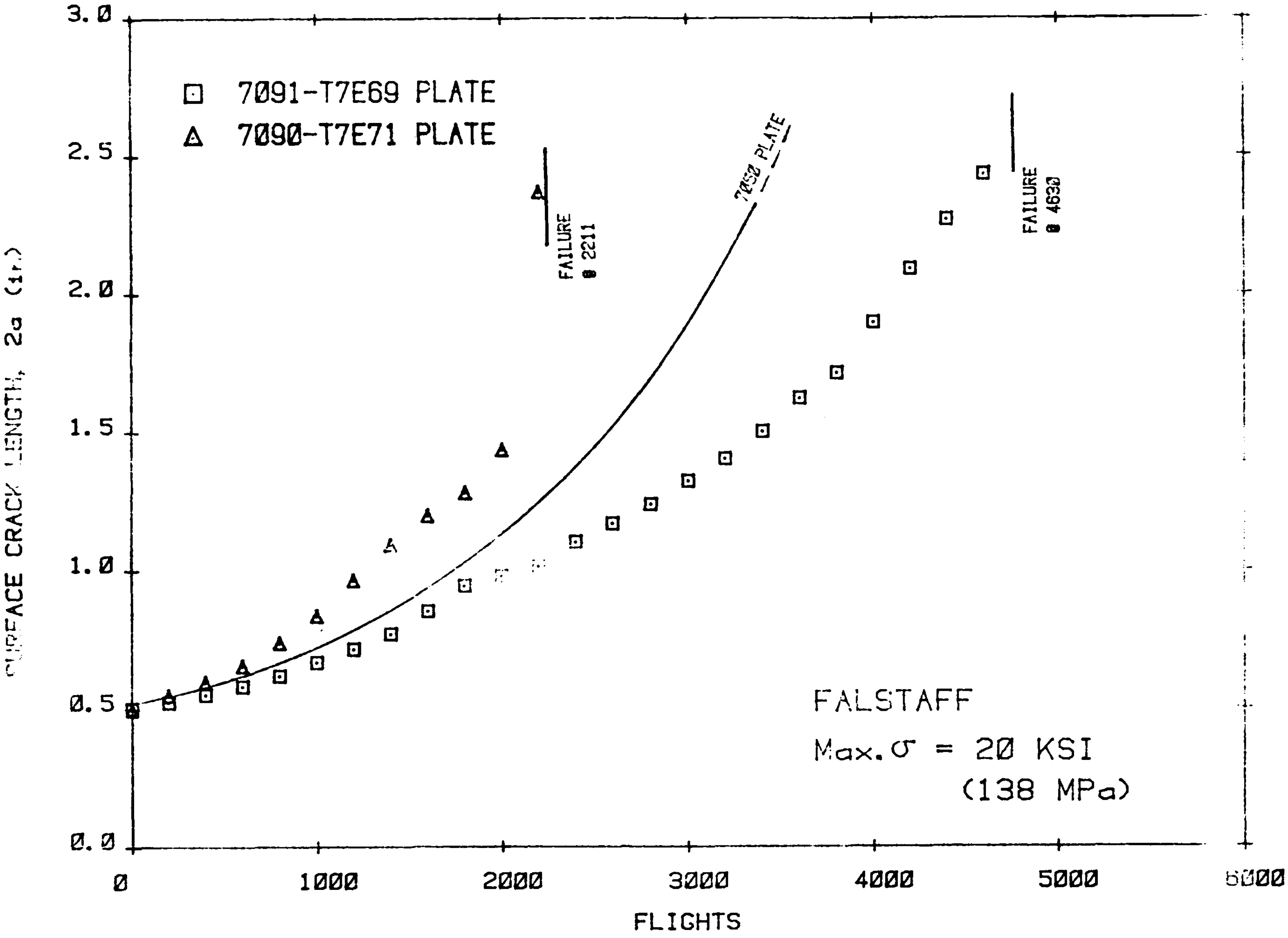

Figure H5. Crack Length Versus Flights for 7090 Plate Under FALSTAFF Loading.

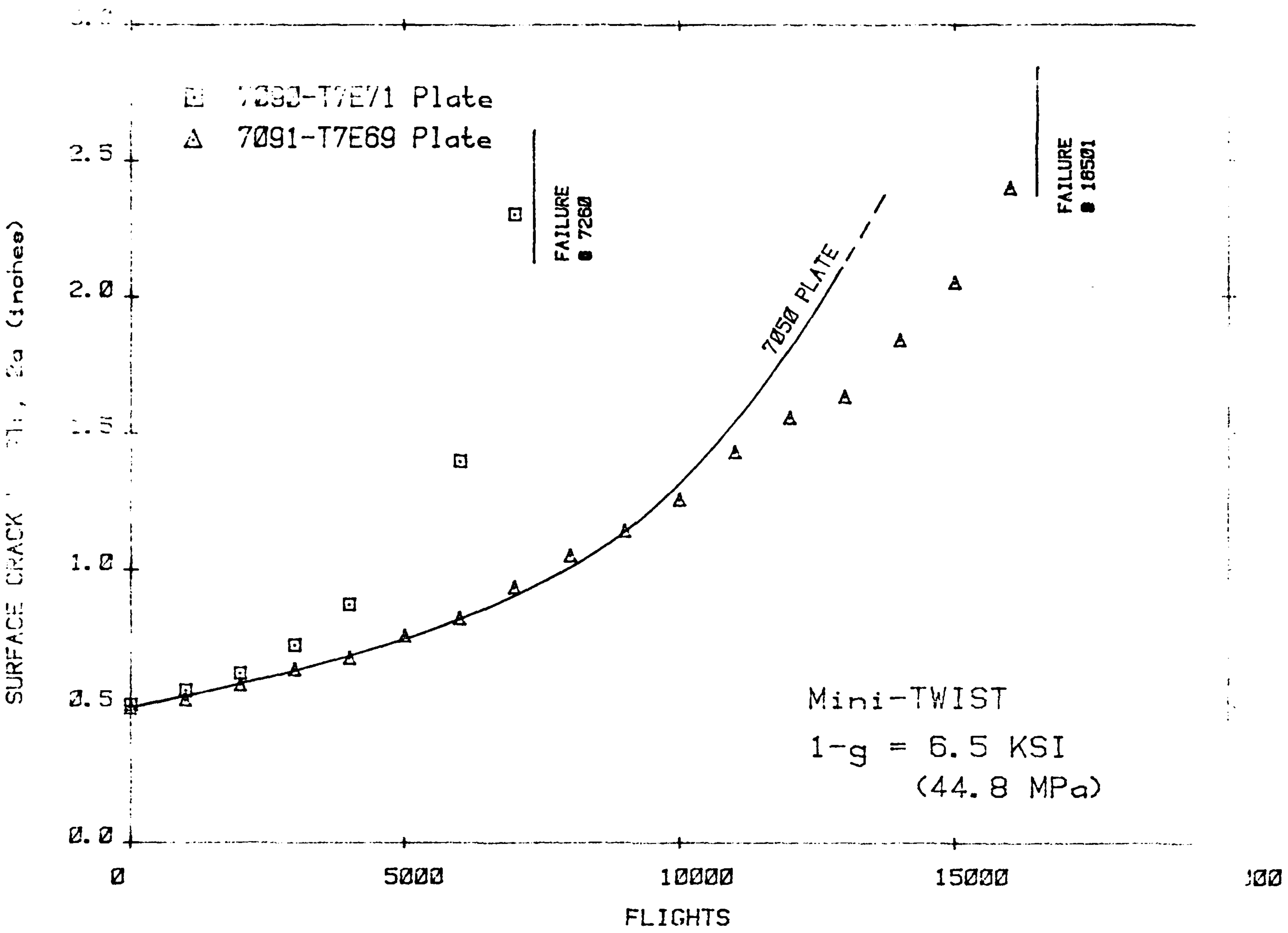

Figure H6. Crack Length Versus Flights for 7090 Plate Under Mini-TWIST Loading.

TABLE H10

WEIGHT LOSS DETERMINATION, EXFOLIATION RATINGS AND METALLOGRAPHIC EXAMINATION ON SPECIMENS OF 7090-T7E71 AND 7091-T7E69 P/M SHEET AND PLATE AFTER EXPOSURE IN THE EXCO TEST

Corrosion Results From ALCOA

S. No.	Alloy	Thickness (mm)	Thickness (in)	Surface Tested	Wt. Loss (Mg/cm)	EXCO Rating 24 Hrs	EXCO Rating 48 Hrs	Metallographic Exam. Type Of Attack	Metallographic Exam. Max. Depth Of Attack (mm)	Metallographic Exam. Max. Depth Of Attack (in)
514024-4A-1E	7090-T7E71	10.54	.415	T/10	28.3	EB	EB	P (1)	.353	.0139
514024-4A-2E	7090-T7E71	10.54	.415	T/10	29.0	EB	EB	---	---	---
514024-4A-1E	7090-T7E71	10.54	.415	T/2	27.5	EB	EB	P (2)	.338	.0133
514024-4A-2E	7090-T7E71	10.54	.415	T/2	27.6	EB	EB	---	---	---
514024-4B-1E	7090-T7E71	1.57	.062	T/10	31.1	EB	EB	P (3)	.132	.0052
514024-4B-2E	7090-T7E71	1.57	.062	T/10	31.6	EB	EB	---	---	---
514037-1A-1E	7091-T7E69	10.34	.407	T/10	17.7	EB	EB	P&I (3)	.223	.0088
514037-1A-2E	7091-T7E69	10.34	.407	T/10	19.6	EB	EB	---	---	---
514037-1A-1E	7091-T7E69	10.34	.407	T/2	32.8	EC	EC	P (1)	.320	.0126
514037-1A-2E	7091-T7E69	10.34	.407	T/2	36.3	EC	EC	---	---	---
514037-1B-1E	7091-T7E69	1.57	.062	T/10	28.5	EB	EB	I&P	.259	.0102
514037-1B-2E	7091-T7E69	1.57	.062	T/10	31.3	EB	EB	---	---	---
475332-2-1-B-1E	7075-T6	19.1	.750	T/10	66.2	EB	ED	---	---	---
475332-2-1-B-2E	7075-T6	19.1	.750	T/2	91.0	EB	EC	---	---	---

NOTES: (1) Lamellar - Tends to exfoliate

(2) Tends toward Lamellar

(3) Scroungy

AD-A159 779 THE MECHANICAL PROPERTY DATA BASE FROM A COOPERATIVE PROGRAM ON FIRST GEN..(U) AIR FORCE WRIGHT AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH G J PETRAK ET AL. AUG 85 4/4

UNCLASSIFIED AFWAL-TR-85-4052 F/G 11/6 NL

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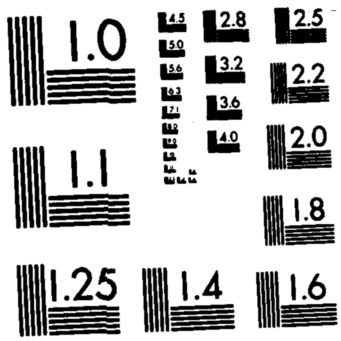

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE H11

RESULTS OF EXFOLIATION RATINGS AND METALLOGRAPHIC EXAMINATION ON SPECIMENS 7090-T7E71 AND 7091-T7E69 P/M SHEET AND PLATE AFTER EXPOSURE IN THE MASTMAASIS TEST

Corrosion Results From ALCOA

S. No.	Alloy	Thickness (mm)	Thickness (in)	Surface Tested	Exfoliation Rating 1 Wk	Exfoliation Rating 2 Wks	Metallographic Exam. Type Of Attack	Max. Depth Of Attack (mm)	Max. Depth Of Attack (in)
514024-4A-1M	7090-T7E71	10.54	.415	T/10	P	P	P (1)	.142	.0056
514024-4A-2M	7090-T7E71	10.54	.415	T/10	P	P	---	---	---
514024-4A-1M	7090-T7E71	10.54	.415	T/2	P	P	P (2)	.124	.0049
514024-4A-2M	7090-T7E71	10.54	.415	T/2	P	P	---	---	---
514024-4B-1M	7090-T7E71	1.57	.062	T/10	P	P	P (2)	.086	.0052
514024-4B-2M	7090-T7E71	1.57	.062	T/10	P	P	---	---	---
514037-1A-1M	7091-T7E69	10.34	.407	T/10	P	P	P&I	.345	.0136
514037-1A-2M	7091-T7E69	10.34	.407	T/10	P	P	---	---	---
514037-1A-1M	7091-T7E69	10.34	.407	T/2	P	P	P (3)	.391	.0154
514037-1A-2M	7091-T7E69	10.34	.407	T/2	P	P	---	---	---
514037-1B-1M	7091-T7E69	1.57	.062	T/10	P	P	I&P	.238	.0094
514037-1B-2M	7091-T7E69	1.57	.062	T/10	P	P	---	---	---
475332-2-1-B-1M	7075-T6	19.1	.750	T/10	EA	EC	---	---	---
475332-2-1-B-2E	7075-T6	19.1	.750	T/2	EA	EC	---	---	---

NOTES: (1) Lamellar

(2) Scroungy

(3) Tends toward Lamellar

APPENDIX I

7091-T7E69 SHEET

NOTICE: Suggested allowables, mean trends, and trend curves in this document were developed to be used in a cost benefit analysis to assess the potential benefit of using the material in a structure. These suggested allowables and trends are not considered accurate for design of actual hardware.

TABLE I1

SUGGESTED ALLOWABLES FOR
7091-T7E69 SHEET: 0.063" x 16"

F_{tu}, KSI		
	L	77.4
	LT	79.0
F_{ty}, KSI		
	L	72.6
	LT	69.3
F_{cy}, KSI		
	L	74.9
	LT	77.1
F_{su}, KSI		
	L	48.0
	LT	48.4
F_{bu}, KSI		
	L	
	(e/D=1.5)	133.3
	(e/D=2.0)	166.3
	LT	
	(e/D=1.5)	133.0
	(e/D=2.0)	167.0
F_{by}, KSI		
	L	
	(e/D=1.5)	108.6
	(e/D=2.0)	120.3
	LT	
	(e/D=1.5)	107.9
	(e/D=2.0)	128.0
K_C, KSI $\sqrt{IN}$		
	L	75.4

NOTE: These values were developed to be used only in a cost-benefit-analysis and are not necessarily accurate for design of hardware.

TABLE I2

7091-T7E69 SHEET
TENSILE : 0.063" x 16"

COMPANY	TEST TEMP (°F)	ORIENTATION	ULT STR (KSI)	YIELD STR (KSI)	ELONG (%)
ROCKWELL	RT	LONG	79.7	74.9	12.3
			79.7	74.5	10.7
			79.3	74.2	10.8
LOCKHEED-GA			78.2	73.2	10.0
			78.0	72.6	10.0
			77.4	72.7	9.5
NORTHROP			80.4	75.3	10.0
			80.4	75.2	10.0
			80.5	75.2	11.0
FAIRCHILD			78.7	73.3	12.1
			78.2	73.2	14.1
ALCOA			83.7	78.0	10.0
			82.0	75.6	10.0
			84.4	78.2	10.0

TABLE I3

7091-T7E69 SHEET
TENSILE

COMPANY	TEST TEMP(^{O}F)	ORIENTATION	ULT STR (KSI)	YIELD STR (KSI)	ELONG (%)
ROCKWELL	RT	TRANS	80.9	72.6	12.4
			80.5	71.9	12.3
			80.8	72.1	12.5
LOCKHEED-GA			80.2	72.8	10.5
			80.6	72.1	10.5
			80.0	71.9	11.0
NORTHROP			82.0	74.0	11.0
			81.9	73.9	12.0
			81.9	73.8	12.0
FAIRCHILD			79.6	67.0	13.3
			79.5	71.1	15.0
			79.0	69.6	12.0
			78.9	70.1	12.5
ALCOA			82.1	75.2	10.0
			80.5	73.5	10.0
			84.4	78.2	10.0

TABLE I4

7091-T7E69 SHEET
COMPRESSION

COMPANY	ORIENTATION	COMP YIELD STR (KSI)
ROCKWELL	LONG	75.7
		75.1
		74.9
LOCKHEED-GA		76.6
		76.4
		76.3
		77.0
ALCOA		81.0
		77.6
		81.5

TABLE I5

7091-T7E69 SHEET
COMPRESSION

COMPANY	ORIENTATION	COMP YIELD STR (KSI)
ROCKWELL	TRANS	77.4
		77.1
		79.0
ALCOA		81.4
		79.1
		83.7

TABLE I6

7091-T7E69 SHEET
SHEAR

COMPANY	ORIENTATION	SHEAR STR (KSI)
ROCKWELL	LONG	51.4
		48.9
		50.5
FAIRCHILD		53.7
		53.0
		52.8
		53.9
ALCOA		49.2
		48.0
		50.3
ROCKWELL	TRANS	48.4
		50.0
		50.6
FAIRCHILD		53.3
		53.1

TABLE I7

7091-T7E69 SHEET
BEARING

COMPANY	ORIENTATION	e/D	ULT B.STR (KSI)	YIELD B.STR (KSI)
ALCOA	LONG	1.5	135.2	111.7
			133.3	108.6
			133.8	109.9
		2.0	168.3	130.8
			166.3	120.3
			170.1	123.6
ALCOA	TRAN	1.5	133.0	113.7
			134.0	107.9
			135.9	113.6
		2.0	168.3	133.3
			167.0	128.3
			167.7	128.0

TABLE I8

7091-T7E69 SHEET

FRACTURE TOUGHNESS

COMPANY	ORIENT	K_C (KSI $\sqrt{IN}$)
LOCKHEED-GA		87.4[(a)] 82.5
ALCOA	LONG	75.4[(b)] 78.7

(a) 6" wide CCT panel
(b) 16" wide CCTpanel

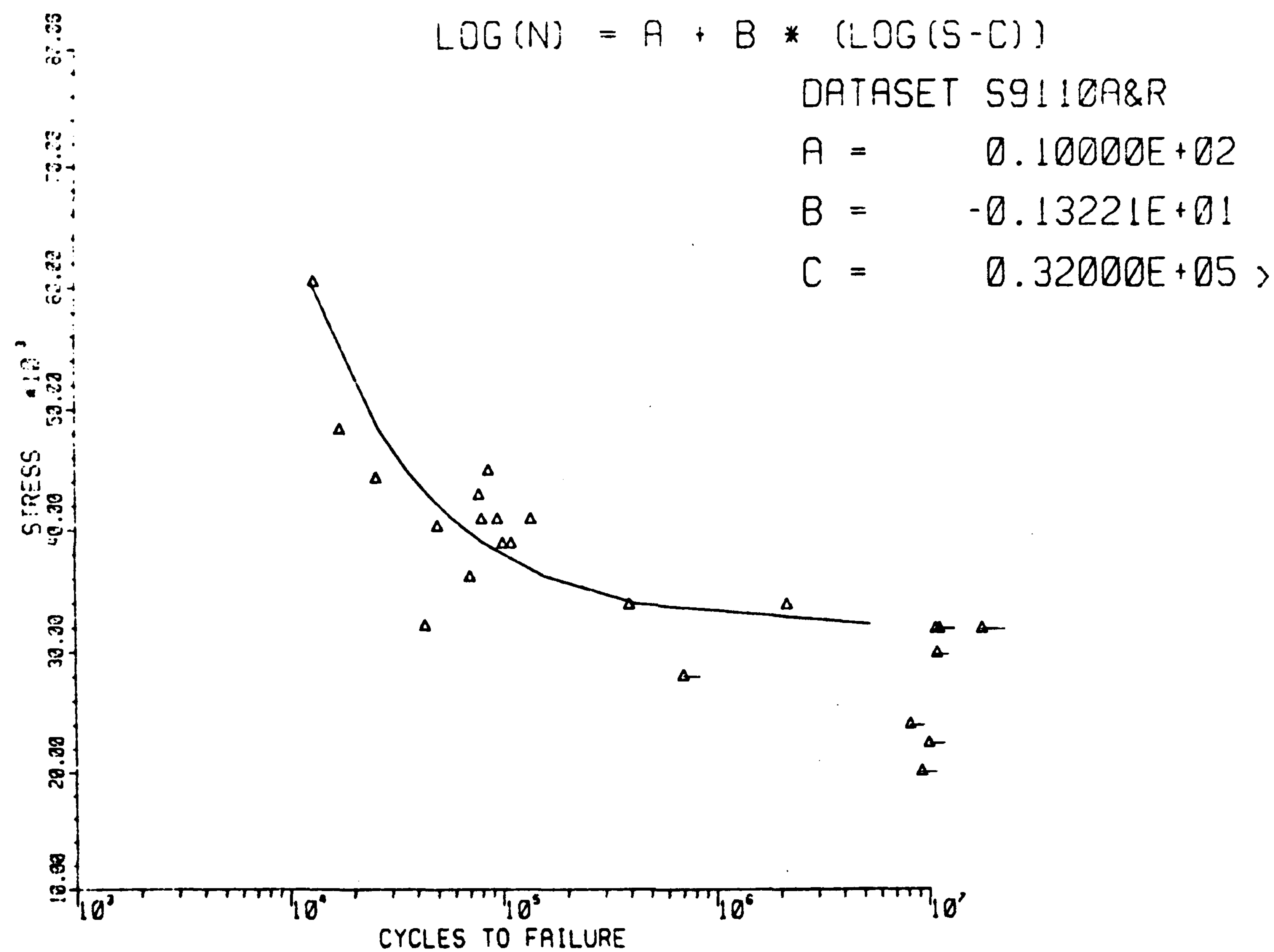

Figure I1. Fatigue Results for 7091 Sheets; R = 0.1, K_t = 1.0

TABLE I9

FATIGUE RESULTS FOR 7091 SHEETS: R = 0.1, K_t = 1.0

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
20200	9200000	0
22600	10000000	0
24200	8200000	0
28200	710000	0
30000	10941100	0
32000	17739400	0
32000	11287500	0
32000	10878300	1
32300	44350	1
34000	2181000	1
34000	400100	1
36300	72000	1
39000	111600	1
39000	100900	1
40400	50168	1
41000	137500	1
41000	95900	1
41000	80600	1
43000	79200	1
44400	26276	1
45000	86000	1
48400	17649	1
60500	13435	1

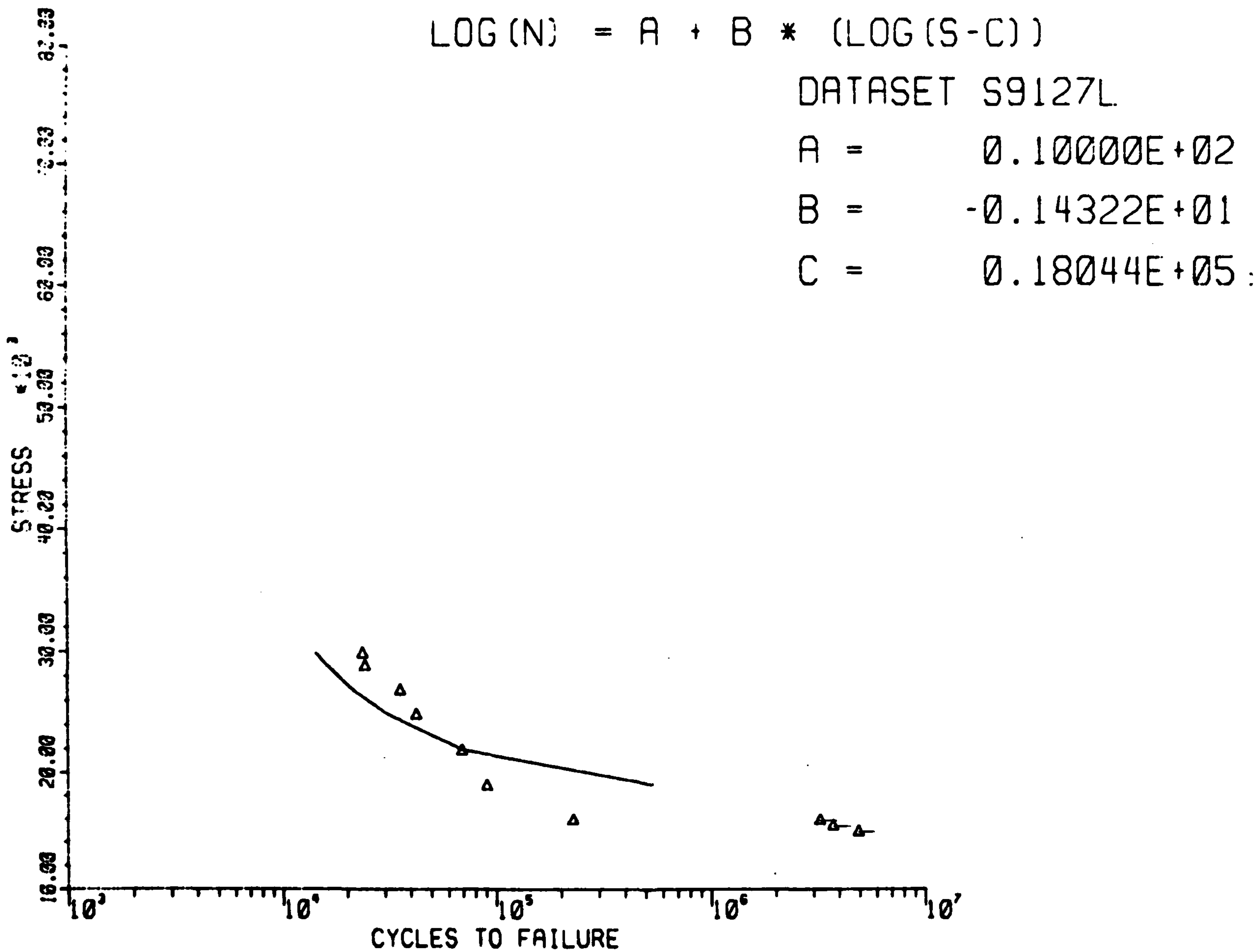

Figure I2. Fatigue Results for 7091 Sheets; R = 0.1, K_t = 2.7

TABLE I10

FATIGUE RESULTS FOR 7091 SHEETS: R = 0.1, K_t = 2.7

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
15000	4887900	0
15500	3745900	0
16000	3232000	0
16000	230580	1
19000	91190	1
22000	70100	1
25000	42950	1
27000	36380	1
29000	24770	1
30000	24000	1

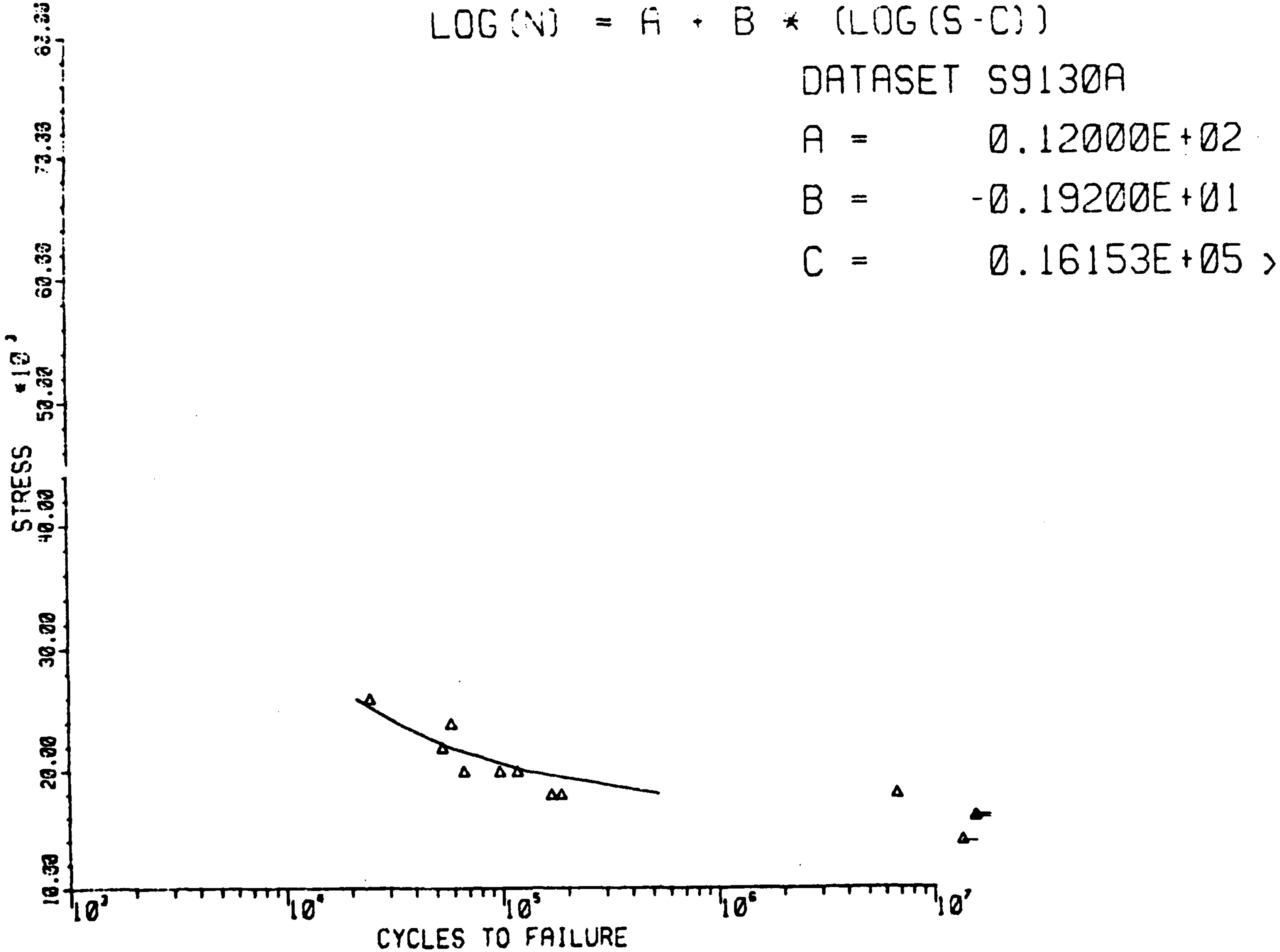

Figure I3. Fatigue Results for 7091 Sheets; R = 0.1, K_t = 3.0

TABLE I11

FATIGUE RESULTS FOR 7091 SHEETS: R = 0.1, K_t = 3.0

STRESS PSI	CYCLES	FAIL (1) NO FAIL (0)
14000	13553100	0
16000	15731900	0
16000	15447700	0
18000	6738400	1
18000	187300	1
18000	169800	1
20000	118100	1
20000	98800	1
20000	67600	1
22000	54100	1
24000	59000	1
26000	24700	1

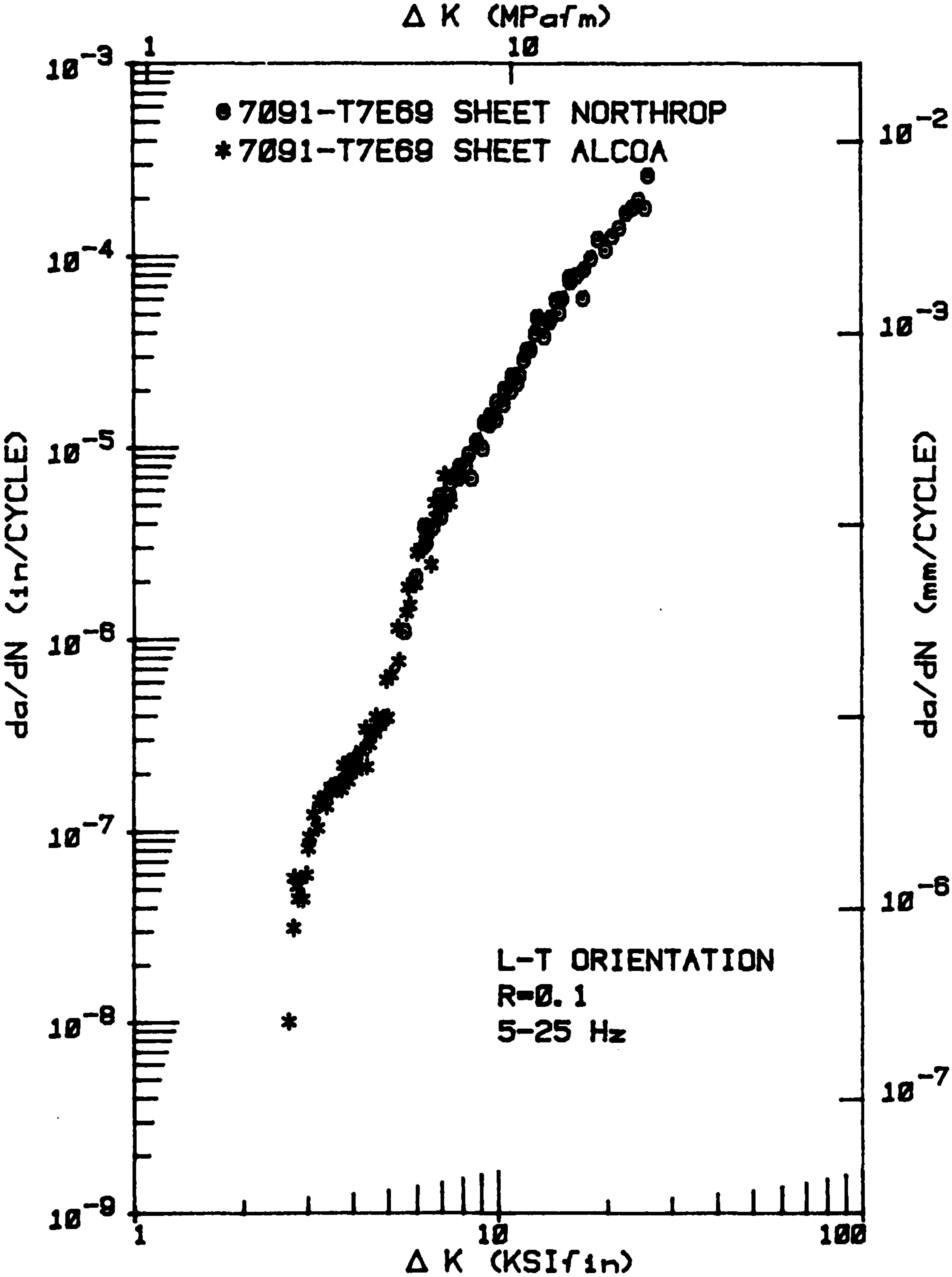

Figure I4. Fatigue Crack Growth Rate Data for 7091 Sheet, L-T Orientation.

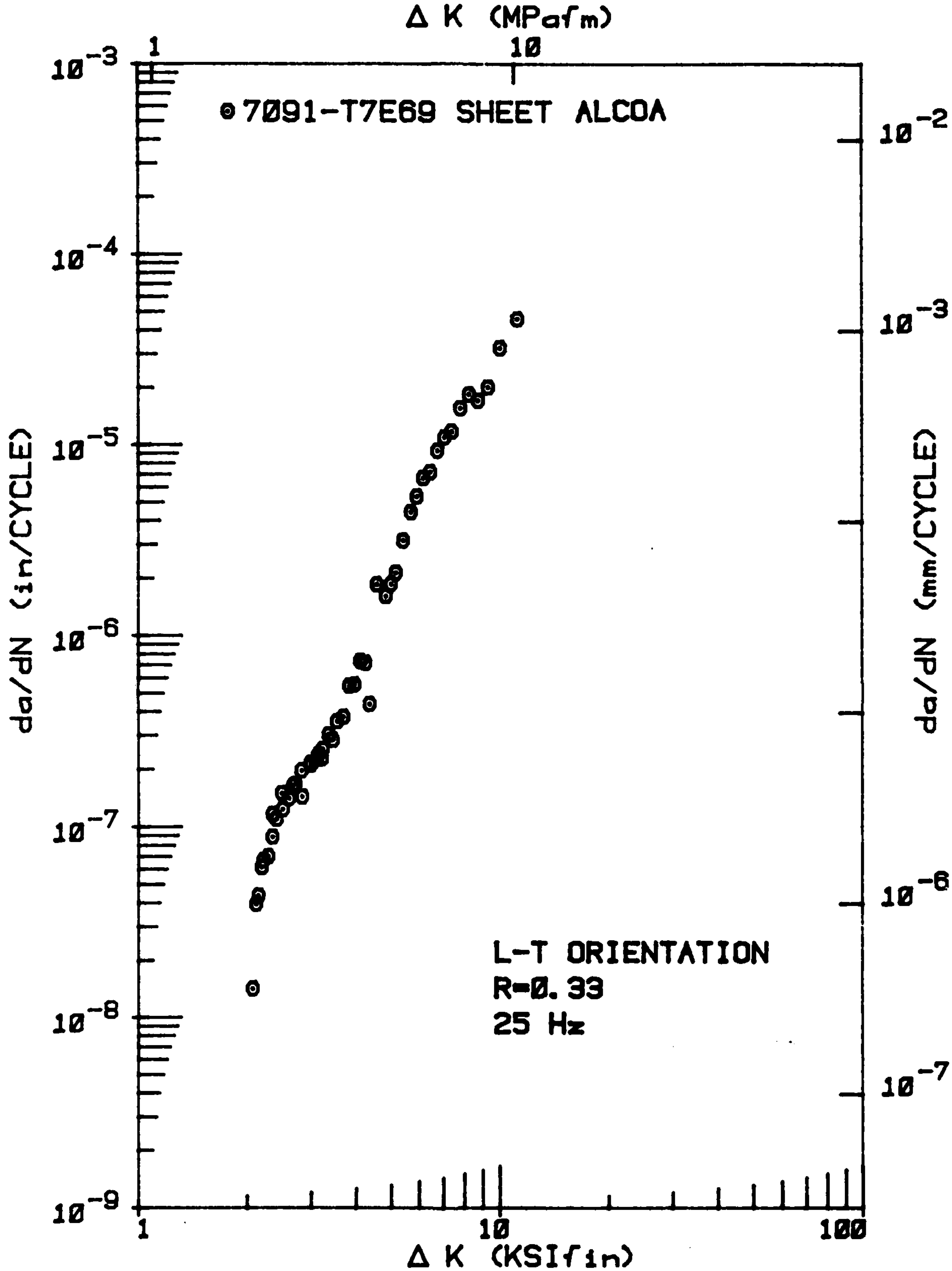

Figure I5. Fatigue Crack Growth Rate Date for 7091 Sheet, L-T Orientation.

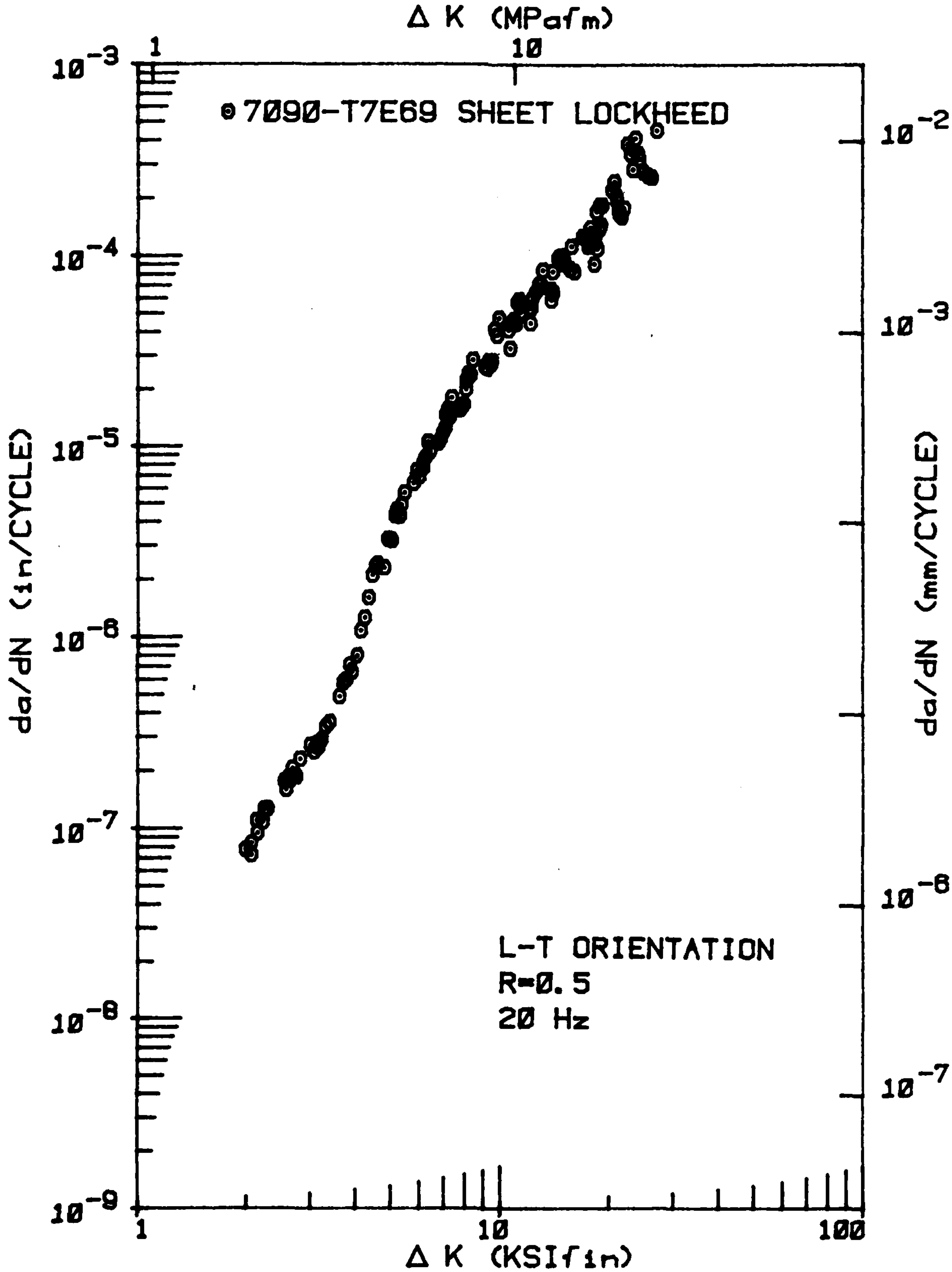

Figure I6. Fatigue Crack Growth Rate Date for 7091 Sheet, L-T Orientation.

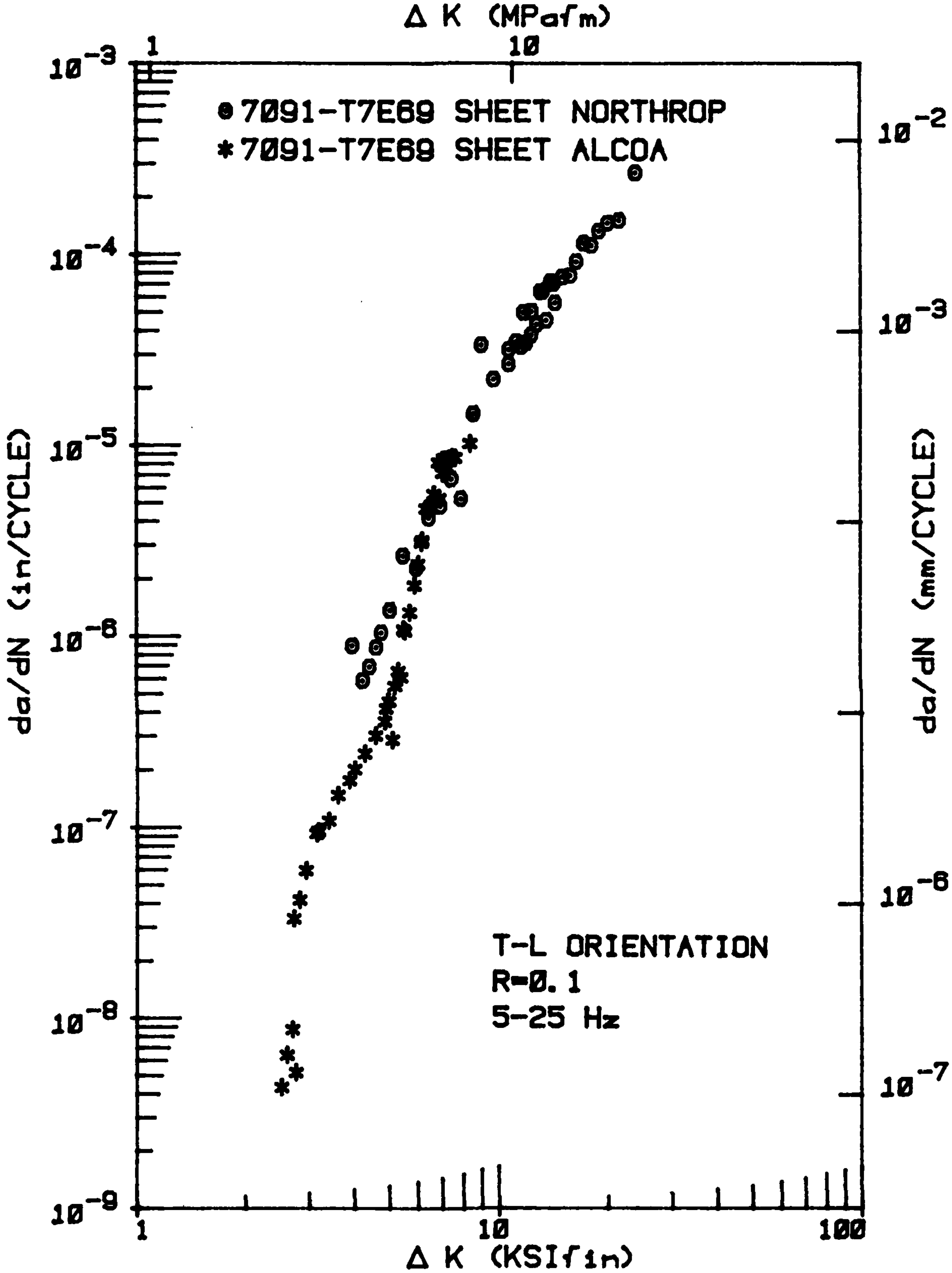

Figure I7. Fatigue Crack Growth Rate Data for 7091 Sheet, T-L Orientation.

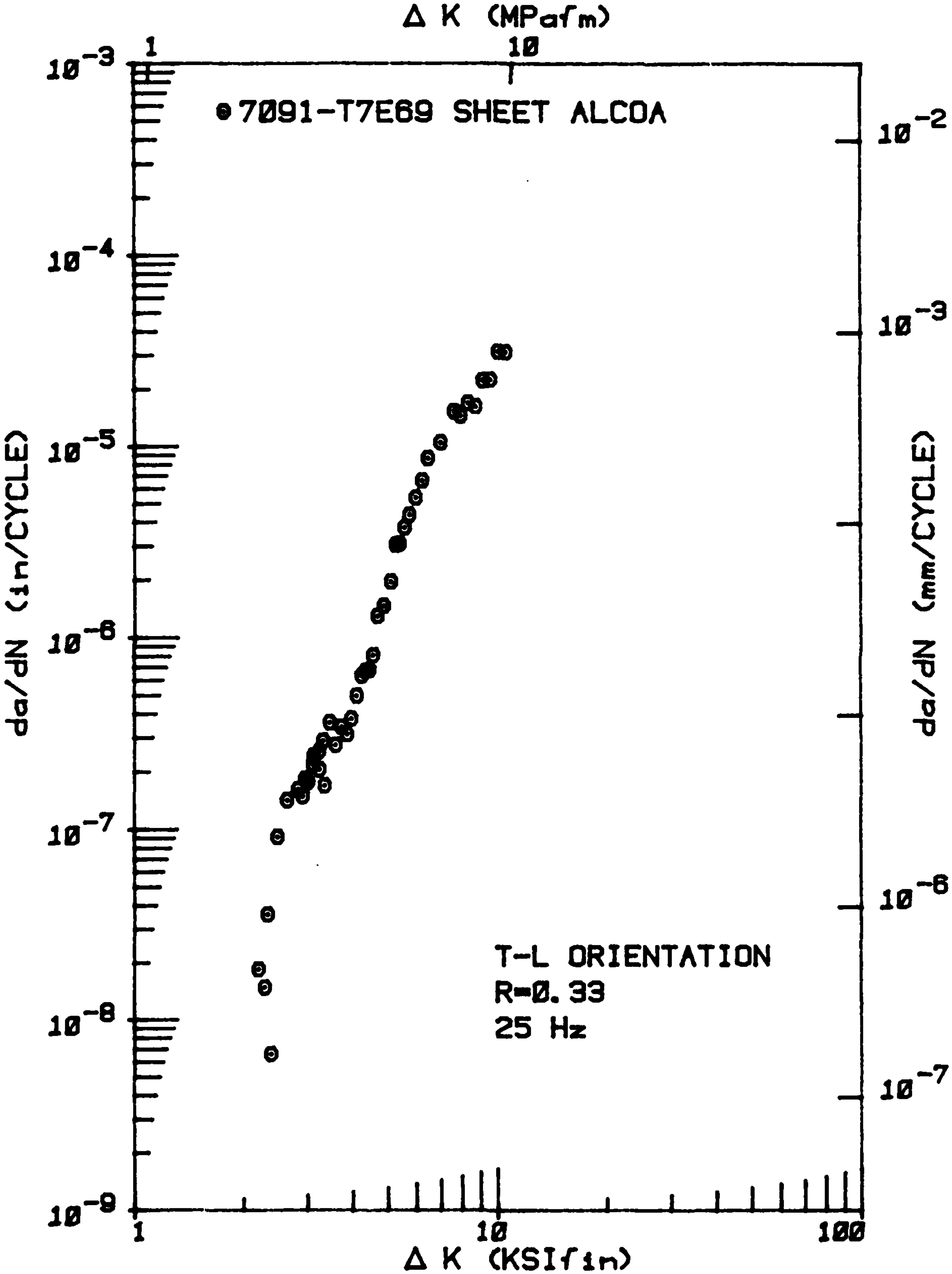

Figure I8. Fatigue Crack Growth Rate Date for 7091 Sheet, T-L Orientation.

STRESS CORROSION

ALCOA reported the 7091-T7E69 sheet has good resistance to exfoliation when compared to the 7075-T6 plate. Tabular results are in Table I12 and I13 .

TABLE I12

WEIGHT LOSS DETERMINATION, EXFOLIATION RATINGS AND METALLOGRAPHIC EXAMINATION ON SPECIMENS OF 7090-T7E71 AND 7091-T7E69 P/M SHEET AND PLATE AFTER EXPOSURE IN THE EXCO TEST

Results From ALCOA

S. No.	Alloy	Thickness		Surface Tested	Wt. Loss	EXCO Rating		Metallographic Exam.		
								Type	Max. Depth	
						24 Hrs	48 Hrs	Of Attack	Of Attack	
		(mm)	(in)		(Mg/cm)				(mm)	(in)
514024-4A-1E	7090-T7E71	10.54	.415	T/10	28.3	Eb	EB	P (1)	.353	.0139
514024-4A-2E	7090-T7E71	10.54	.415	T/10	29.0	EB	EB	---	---	---
514024-4A-1E	7090-T7E71	10.54	.415	T/2	27.5	EB	EB	P (2)	.338	.0133
514024-4A-2E	7090-T7E71	10.54	.415	T/2	27.6	EB	EB	---	---	---
514024-4B-1E	7090-T7E71	1.57	.062	T/10	31.1	EB	EB	P (3)	.132	.0052
514024-4B-2E	7090-T7E71	1.57	.062	T/10	31.6	EB	EB	---	---	---
514037-1A-1E	7091-T7E69	10.34	.407	T/10	17.7	EB	EB	P&I (3)	.223	.0088
514037-1A-2E	7091-T7E69	10.34	.407	T/10	19.6	EB	EB	---	---	---
514037-1A-1E	7091-T7E69	10.34	.407	T/2	32.8	EC	EC	P (1)	.320	.0126
514037-1A-2E	7091-T7E69	10.34	.407	T/2	36.3	EC	EC	---	---	---
514037-1B-1E	7091-T7E69	1.57	.062	T/10	28.5	EB	EB	I&P	.259	.0102
514037-1B-2E	7091-T7E69	1.57	.062	T/10	31.3	EB	EB	---	---	---
475332-2-1-B-1E	7075-T6	19.1	.750	T/10	66.2	EB	ED	---	---	---
475332-2-1-B-2E	7075-T6	19.1	.750	T/2	91.0	EB	EC	---	---	---

NOTES: (1) Lamellar - Tends to exfoliate
(2) Tends toward Lamellar
(3) Scroungy

TABLE 113

RESULTS OF EXFOLIATION RATINGS AND METALLOGRAPHIC EXAMINATION ON SPECIMENS 7090-T7E71 AND 7091-T7E69 P/M SHEET AND PLATE AFTER EXPOSURE IN THE MASTMAASIS TEST

Results From ALCOA

S. No.	Alloy	Thickness (mm)	Thickness (in)	Surface Tested	Exfoliation Rating 1 Wk	Exfoliation Rating 2 Wks	Metallographic Exam. Type Of Attack	Max. Depth Of Attack (mm)	Max. Depth Of Attack (in)
514024-4A-1M	7090-T7E71	10.54	.415	T/10	P	P	P (1)	.142	.0056
514024-4A-2M	7090-T7E71	10.54	.415	T/10	P	P	---	---	---
514024-4A-1M	7090-T7E71	10.54	.415	T/2	P	P	P (2)	.124	.0049
514024-4A-2M	7090-T7E71	10.54	.415	T/2	P	P	---	---	---
514024-4B-1M	7090-T7E71	1.57	.062	T/10	P	P	P (2)	.086	.0052
514024-4B-2M	7090-T7E71	1.57	.062	T/10	P	P	---	---	---
514037-1A-1M	7091-T7E69	10.34	.407	T/10	P	P	P&I	.345	.0136
514037-1A-2M	7091-T7E69	10.34	.407	T/10	P	P	---	---	---
514037-1A-1M	7091-T7E69	10.34	.407	T/2	P	P	P (3)	.391	.0154
514037-1A-2M	7091-T7E69	10.34	.407	T/2	P	P	---	---	---
514037-1B-1M	7091-T7E69	1.57	.062	T/10	P	P	I&P	.238	.0094
514037-1B-2M	7091-T7E69	1.57	.062	T/10	P	P	---	---	---
475332-2-1-B-1M	7075-T6	19.1	.750	T/10	EA	EC	---	---	---
475332-2-1-B-2E	7075-T6	19.1	.750	T/2	EA	EC	---	---	---

NOTES: *(1) Lamellar*

(2) Scroungy

(3) Tends toward Lamellar

U.S. GPO 559-065

END

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