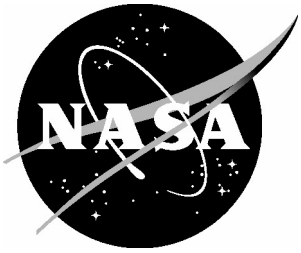
NASA/TM-2005-213907



7075-T6 and 2024-T351 Aluminum Alloy Fatigue Crack Growth Rate Data

Scott C. Forth and Christopher W. Wright
Langley Research Center, Hampton, Virginia

William M. Johnston, Jr.
Lockheed Martin Corporation, Hampton, Virginia

August 2005

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results ... even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

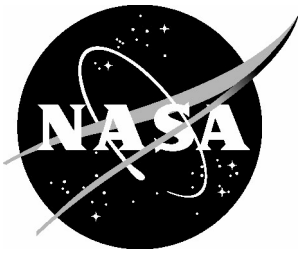
- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA STI Help Desk at (301) 621-0134

- Phone the NASA STI Help Desk at (301) 621-0390

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076-1320

NASA/TM-2005-213907



7075-T6 and 2024-T351 Aluminum Alloy Fatigue Crack Growth Rate Data

Scott C. Forth and Christopher W. Wright
Langley Research Center, Hampton, Virginia

William M. Johnston, Jr.
Lockheed Martin Corporation, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

August 2005

Available from:

NASA Center for AeroSpace Information (CASI)
7121 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161-2171
(703) 605-6000

Abstract

Experimental test procedures for the development of fatigue crack growth rate data has been standardized by the American Society for Testing and Materials. Over the past 30 years several gradual changes have been made to the standard without rigorous assessment of the affect these changes have on the precision or variability of the data generated. Therefore, the ASTM committee on fatigue crack growth has initiated an international round robin test program to assess the precision and variability of test results generated using the standard E647-00. Crack growth rate data presented in this report, in support of the ASTM round-robin, shows excellent precision and repeatability.

Introduction

The experimental test procedure for the development of fatigue crack growth rate data has been standardized by ASTM (American Society for Testing and Materials) in E647-00 "Standard Test Method for Measurement of Fatigue Crack Growth Rates." The laboratory procedure first evolved in the early to mid 1970's as a means to characterize the resistance of materials to cracking under cyclic loading conditions. Over the past 30 years several gradual changes have been made to the standard without rigorous assessment of the affect these changes have on the precision or variability of the data generated. Therefore, the ASTM committee on fatigue crack growth has initiated an international round robin test program to assess the precision and variability of test results generated using the standard E647-00. Test data in support of this ASTM round-robin presented in this report was generated at the National Aeronautics and Space Administration (NASA) Langley Research Center, Materials Characterization Laboratory in Hampton, Virginia USA.

Apparatus and Tests

The experiment section of this report is separated into two sections: laboratory equipment and specimen configuration. Testing was conducted in accordance with ASTM standard E647-00 "Standard Test Method for Measurement of Fatigue Crack Growth Rates."

Laboratory Equipment

All experiments were conducted sequentially in a single servo-hydraulic loading frame of 100kN capacity. The load cell was calibrated using NIST traceable standard to within 2.0% of any displayed reading. The tests were conducted in force control using a digital controller. The digital controller scales the internal load range to the smallest usable range to ensure accurate control. The specimens were installed in hydraulically actuated grips with a grip pressure of 350 bar. Wedge grips were used and equipped with alignment tabs for positive specimen location with serrated jaws for anti-slip control. Strain gauged test bars of similar geometry to the actual test specimens were used to ensure test stand alignment to a total maximum bending strain (front to back + side to side) amplitude of 2.5% at 5 kips and 1.2% at 10 kips.

Visual measurements of the specimen crack length were taken as a straight-line distance normal to the loading axis using a floating optical microscope. The translation stage used to measure crack length was calibrated to 0.03 mm.

Specimen Configuration

Two aluminum alloys were chosen to be included in the round robin: 7075-T6 and 2024-T351. The specimens were machined into middle tension specimens, denoted M(T), prior to delivery to NASA Langley. The standard

configuration for an M(T) specimen is presented in Figure 1. Actual specimen dimensions were measured prior to testing and are reported in Appendix A. The specimen surfaces were machined to a surface finish of 32 RMS or better and the area where crack growth was expected was hand polished to a surface finish better than 16 RMS. The hand-polishing was performed for easier detection of the crack using visual measurements.

Test Conditions

The fatigue crack growth testing was performed under constant amplitude force control. The applied force was introduced using a function generator producing a sine wave. The initial force level was chosen based on the desired crack growth rate range of the round robin (10^{-8} to 10^{-4} meters/cycle). The frequency of the applied loading was chosen to maintain the accuracy of controlling force to within 2%. The cyclic increment chosen to measure crack growth was determined through trial and error to achieve approximately 0.5 mm of growth on each side of the specimen between measurements. The average temperature and humidity during the testing program was 25 ^{o}C and 40 % respectively. Specific information on hold times, test frequency and test times can be found in Appendix A.

Results

The fatigue crack growth rate data generated for each aluminum alloy will be presented separately. The data collected during the test was crack length and cycle count. This data is collected and presented in tabular form in Appendix A. The stress intensity factor range, ΔK, is computed using the applied force, specimen dimensions and crack length defined by ASTM E647-00 as

$$\Delta K = \frac{\Delta P}{B}\sqrt{\frac{\pi\alpha}{2W}}\sec\frac{\pi\alpha}{2}$$

where the applied force range is $\Delta P = P_{max} - P_{min}$, B is the specimen thickness; W is the specimen width; and $\alpha = 2a/W$ where a is the half crack length. The expression is valid for $2a/W < 0.95$ with the implicit assumption that the test material is linear-elastic, isotropic, and homogeneous. The computed stress intensity factor range and fatigue crack growth rate were reduced using the guidelines of ASTM E 647-00 and are presented with the measured crack length and cycle count data in Appendix A.

All crack growth data that does not meet ASTM E 647-00 standards are documented and italicized in Appendix A, but not presented in the main text. One form of data rejection applicable to this program is from inelastic material response where data is rejected if:

$$(W - 2a) \geq 1.25P_{\max}/(B\sigma_{YS})$$

where σ_{YS} is the 0.2% offset yield strength of material at the same temperature of the fatigue crack growth rate test. Two data points were rejected for the remaining ligament criterion. The other criterion for data rejection applicable to this program is crack symmetry where data is rejected if the crack length measurements referenced from the specimen center line differ more than 0.025W. None of the data generated was rejected for asymmetric crack growth.

7075-T6 Aluminum Data

The 7075-T6 material was provided by the Southwest Research Institute machined into specimens. No additional fabrication was performed by NASA Langley. Forty-four middle tension specimens were machined from a single 1.2 meter wide by 2.4 meter long by 3.175 millimeter thick sheet. The specimens were numbered AL-7-x where x = 1-44. The data presented in this report is for specimens AL-7-21, -22 and -23. Location of the specimens within the larger sheet was not provided. The supplied average material properties were σ_{TS} of 593 MPa, σ_{YS} of 524 MPa and elongation of 14%.

The maximum applied force was 19.02, 26.79 and 9.82 kilonewtons for specimens AL-7-21, -22 and -23 respectively. Figure 2 shows the

measured crack length versus cycle count for each test denoted in the legend by specimen number (AL7-x), front (F) or back (B) and left (L) or right (R) measurement. Figure 3 shows the computed fatigue crack growth rate versus stress intensity factor range for each test.

2024-T351 Aluminum Data

The 2024-T351 material was provided by the Southwest Research Institute machined into specimens. No additional fabrication was performed by NASA Langley. Thirty-two middle tension and sixty compact tension specimens were machined from a single 1.2 meter wide by 2.4 meter long by 9.525 millimeter thick sheet. The middle tension specimens were numbered AL-2-x where x = 1-32. The data presented in this report is for specimens AL-2-26, -27 and -28. Location of the specimens within the larger sheet was not provided. The supplied average material properties were σ_{TS} of 496 MPa, σ_{YS} of 386 MPa and elongation of 20%.

The maximum applied force was 57.05, 40.18 and 71.43 kilonewtons for specimens AL-2-26, -27 and -28 respectively. Figure 4 shows the measured crack length versus cycle count for each test denoted in the legend by specimen number (AL2-x), front (F) or back (B) and left (L) or right (R) measurement. Figure 5 shows the computed fatigue crack growth rate versus stress intensity factor range for each test.

Summary

Experimental fatigue crack growth rate data was generated according to the guidelines of ASTM standard E647-00 “Standard Test Method for Measurement of Fatigue Crack Growth Rates.” The testing was conducted in support of an ASTM round-robin on precision and variability. The crack growth rate data presented in this report for 7075-T6 and 2024-T351 aluminum alloys show excellent precision and repeatability.

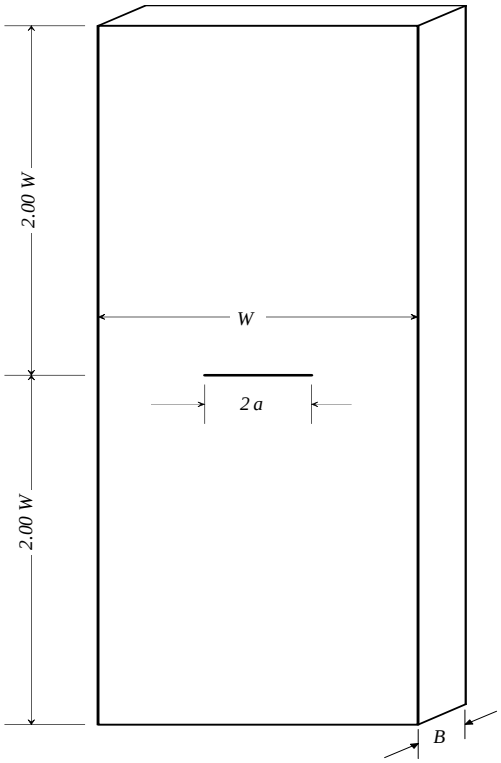


Figure 1. Schematic of a middle through crack specimen, M(T). (W = 76.2 mm, B = 12.7 mm, initial notch width (2a) of 12.7 mm)..

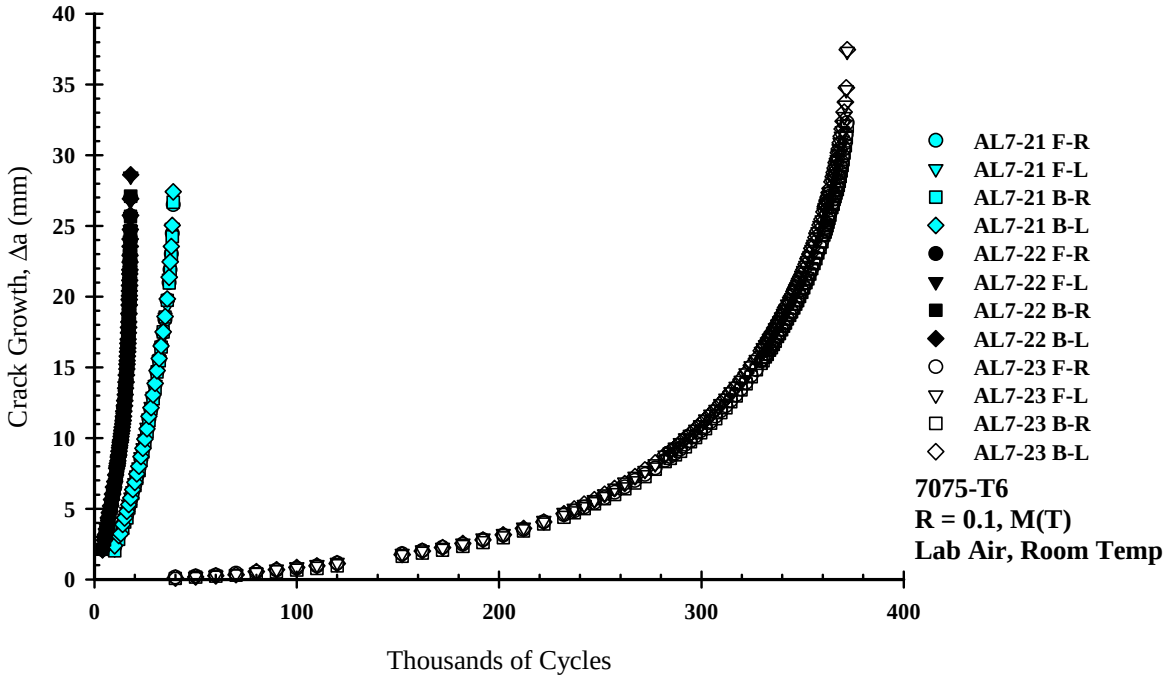


Figure 2. Crack growth versus cycles for 7075-T6 aluminum M(T) specimens (F-front; B-back; R-right; L-left).

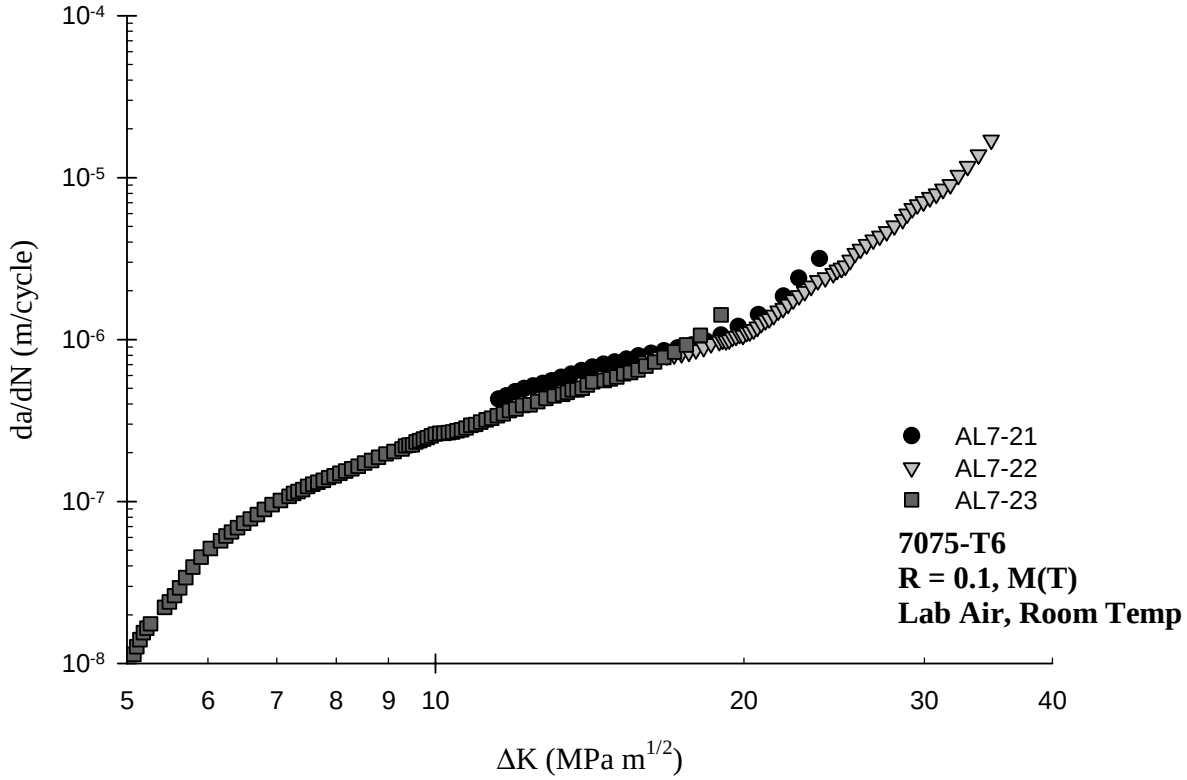


Figure 3. Fatigue crack growth rate versus stress intensity factor range for 7075-T6 aluminum M(T) specimens.

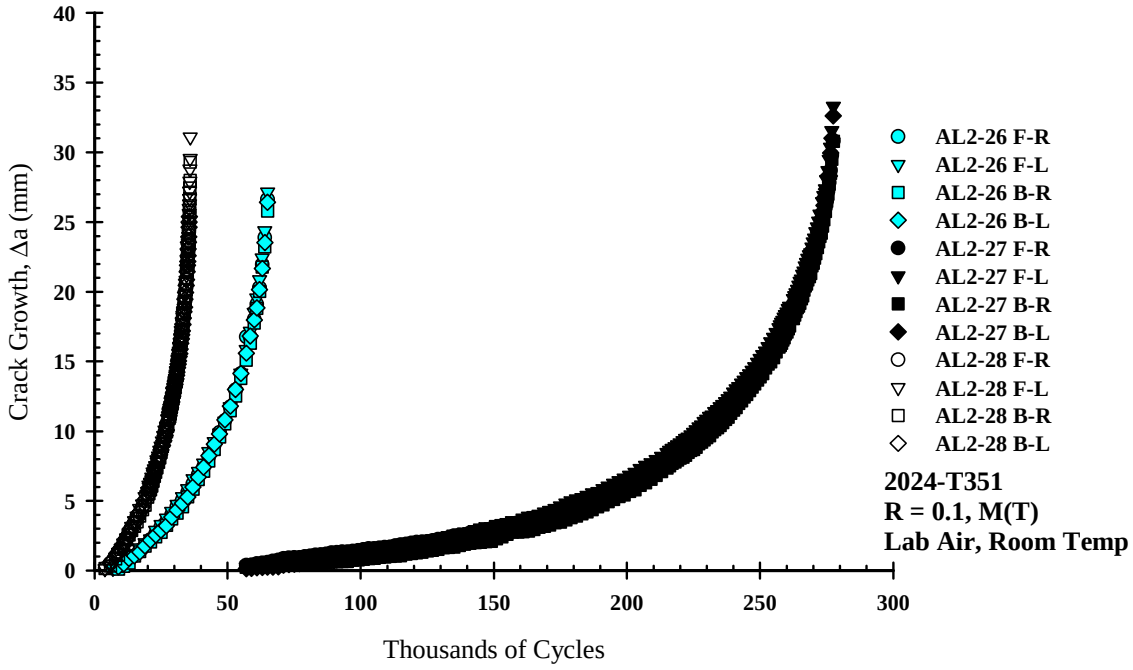


Figure 4: Crack growth versus cycles for 2024-T351 aluminum M(T) specimens (F-front; B-back; R-right; L-left).

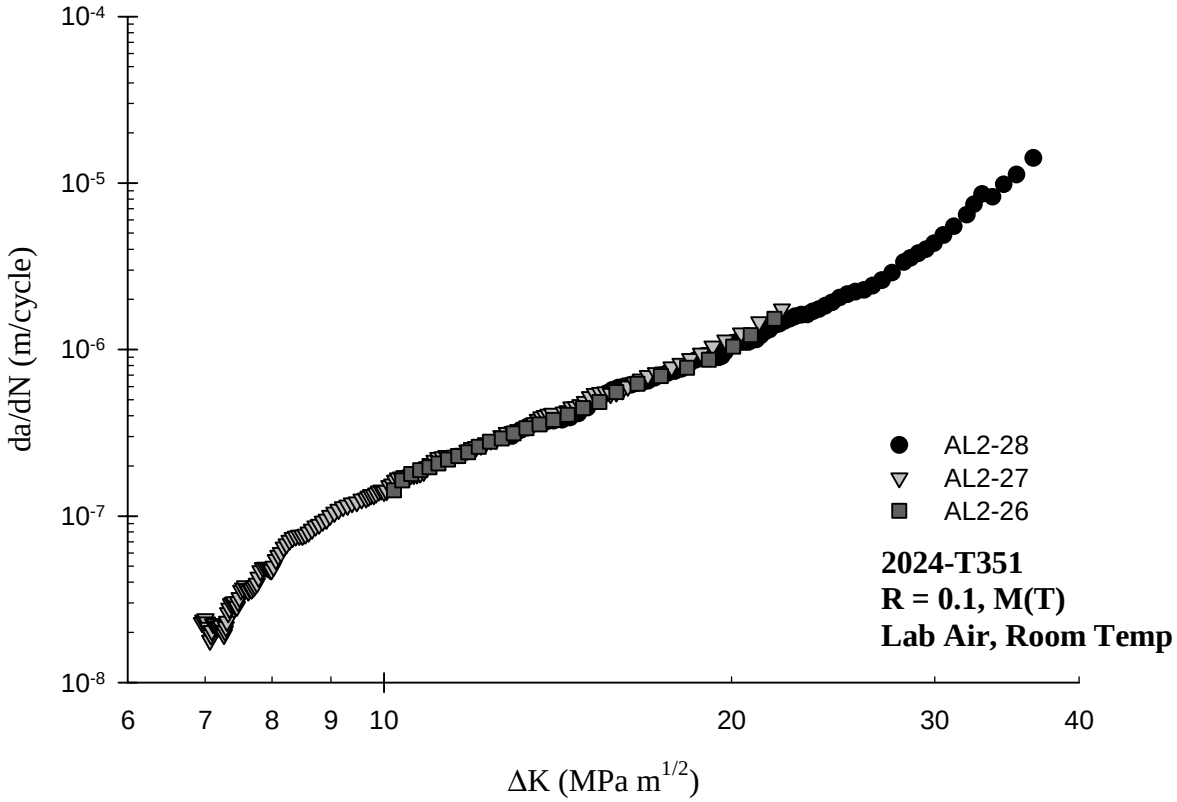


Figure 5: Fatigue crack growth rate versus stress intensity factor range for 2024-T351 aluminum M(T) specimens.

APPENDIX A

The measured test data and the computed fatigue crack growth rate and stress intensity factor range for 7075-T6 and 2024-T351 aluminum alloys are listed in Tables A1 through A3 and A4 through A6 of this appendix respectively in the order of the specimen number.

Table A1. Fatigue crack growth rate data for specimen AL-7-21 of 7075-T6 Al.

Specimen: AL-7-21	Frequency: 5 Hz	R = 0.1	B = 3.18 mm		W = 102.03 mm		
P_{max} = 19.02 N	P_{min} = 1.902 N	Initial notch length (2a): 20.28 mm					
Time & Date		Δa front		Δa back		da/dN	ΔK
hours : minutes (date/note)	Total Cycles	left (mm)	right (mm)	left (mm)	right (mm)	(meter/cycle)	(MPa $m^{1/2}$)
12:15 pm (1/7/2005)	10,000	2.29	2.16	2.03	2.39		
1:00	12,000	3.05	3.00	2.84	3.10		
1:15	13,000	3.33	3.43	3.51	3.23		
1:21	14,000	3.86	3.76	3.63	3.89	4.29×10^{-7}	11.52
1:27	15,000	4.27	4.32	4.06	4.34	4.49×10^{-7}	11.73
1:35	16,000	4.60	4.80	4.34	4.80	4.75×10^{-7}	11.96
1:42	17,000	5.13	5.31	5.05	5.28	4.97×10^{-7}	12.20
1:50	18,000	5.64	5.82	5.54	5.77	5.17×10^{-7}	12.46
1:57	19,000	6.20	6.27	6.07	6.35	5.37×10^{-7}	12.73
2:05	20,000	6.71	6.83	6.63	6.86	5.56×10^{-7}	12.99
2:10	21,000	7.26	7.37	7.16	7.47	5.83×10^{-7}	13.27
2:17	22,000	7.87	7.95	7.70	8.00	6.11×10^{-7}	13.57
2:24	23,000	8.48	8.66	8.41	8.69	6.43×10^{-7}	13.89
2:30	24,000	9.22	9.30	9.02	9.27	6.77×10^{-7}	14.23
2:37	25,000	9.91	9.93	9.75	9.93	7.05×10^{-7}	14.59
2:45	26,000	10.59	10.74	10.44	10.64	7.29×10^{-7}	14.96
2:52	27,000	11.35	11.40	11.23	11.53	7.57×10^{-7}	15.37
3:00	28,000	12.01	12.22	12.07	12.14	7.94×10^{-7}	15.78
3:07	29,000	12.90	12.95	12.78	13.06	8.23×10^{-7}	16.24
3:15	30,000	13.77	13.79	13.54	13.87	8.51×10^{-7}	16.72
3:21	31,000	14.68	14.61	14.68	14.76	8.86×10^{-7}	17.24
3:28	32,000	15.54	15.52	15.47	15.62	9.26×10^{-7}	17.78
3:35	33,000	16.48	16.36	16.43	16.51	9.78×10^{-7}	18.37
3:44	34,000	17.45	17.27	17.50	17.50	1.06×10^{-6}	19.01
3:50	35,000	18.36	18.54	18.57	18.59	1.20×10^{-6}	19.76
3:57 (unclamped)	36,000	19.76	19.41	19.74	19.84	1.43×10^{-6}	20.67
9:05 am (1/10/2005)	37,000	20.98	21.29	20.96	21.36	1.85×10^{-6}	21.87
9:12	37,500	21.89	22.30	21.74	22.45	2.40×10^{-6}	22.62
9:18	38,000	23.01	23.27	22.86	23.55	3.16×10^{-6}	23.71
9:21	38,500	24.46	24.89	24.23	25.04		
9:27	39,000	26.49	27.18	26.67	27.41		
9:33	39,250	29.34	28.07	28.32	29.39		

Table A2. Fatigue crack growth rate data for specimen AL-7-22 of 7075-T6 Al.

Specimen: AL-7-22	Frequency: 5 Hz	R = 0.1	B = 3.18 mm		W = 102.03 mm		
P_{max} = 26.79 N	P_{min} = 2.679 N	Initial notch length (2a): 20.28 mm					
Time & Date		Δa front		Δa back		da/dN	ΔK
hours : minutes (date/note)	Total Cycles	left (mm)	right (mm)	left (mm)	right (mm)	(meter/cycle)	(MPa $m^{1/2}$)
10:19am (02/03/05)	4,000	2.11	2.11	2.13	2.11		
10:28	5,000	2.84	2.79	2.79	2.77		
10:34	5,500	3.12	2.90	3.10	3.15		
10:45	6,000	3.43	3.48	3.51	3.56	$7.36x10^{-7}$	16.01
10:49	6,500	3.78	3.91	3.96	3.91	$7.58x10^{-7}$	16.28
10:56	7,000	4.14	4.19	4.29	4.34	$7.83x10^{-7}$	16.55
11:01	7,500	4.57	4.55	4.70	4.72	$7.94x10^{-7}$	16.82
11:05	8,000	4.90	4.88	5.18	5.21	$8.05x10^{-7}$	17.10
11:10	8,500	5.28	5.31	5.54	5.64	$8.22x10^{-7}$	17.39
11:15	9,000	5.77	5.79	5.99	6.05	$8.38x10^{-7}$	17.67
11:19	9,500	6.15	6.10	6.32	6.53	$8.66x10^{-7}$	17.96
11:23	10,000	6.50	6.65	6.73	6.91	$8.96x10^{-7}$	18.27
11:27	10,500	7.01	7.09	7.16	7.39	$9.44x10^{-7}$	18.58
12:46 pm	11,000	7.54	7.62	7.65	7.87	$9.76x10^{-7}$	18.93
12:52	11,200	7.70	7.85	7.80	8.03	$9.96x10^{-7}$	19.07
12:57	11,400	7.92	8.10	8.00	8.20	$9.82x10^{-7}$	19.21
12:59	11,600	8.10	8.23	8.23	8.38	$9.98x10^{-7}$	19.35
1:02	11,800	8.31	8.43	8.48	8.66	$1.03x10^{-6}$	19.50
1:07	12,000	8.51	8.61	8.61	8.79	$1.05x10^{-6}$	19.64
1:12	12,200	8.74	8.86	8.81	9.07	$1.08x10^{-6}$	19.80
1:15	12,400	8.99	9.04	9.04	9.32	$1.06x10^{-6}$	19.96
1:20	12,600	9.22	9.32	9.22	9.47	$1.11x10^{-6}$	20.12
1:23	12,800	9.45	9.53	9.45	9.70	$1.12x10^{-6}$	20.27
1:27	13,000	9.65	9.65	9.68	9.86	$1.15x10^{-6}$	20.44
1:30	13,200	9.91	10.01	9.96	10.11	$1.19x10^{-6}$	20.61
1:33	13,400	10.08	10.31	10.21	10.31	$1.26x10^{-6}$	20.79
1:36	13,600	10.36	10.49	10.54	10.52	$1.31x10^{-6}$	20.99
1:40	13,800	10.52	10.85	10.80	10.77	$1.35x10^{-6}$	21.18
1:45	14,000	10.95	11.15	11.05	11.00	$1.41x10^{-6}$	21.39
1:48	14,200	11.20	11.48	11.28	11.23	$1.50x10^{-6}$	21.60
1:51	14,400	11.51	11.86	11.56	11.53	$1.56x10^{-6}$	21.84
1:54	14,600	11.81	12.09	11.89	11.89	$1.66x10^{-6}$	22.08
1:57	14,800	12.14	12.42	12.34	12.27	$1.76x10^{-6}$	22.35
2:01	15,000	12.57	12.55	12.60	12.65	$1.87x10^{-6}$	22.63
2:05	15,200	12.90	13.06	13.11	13.08	$1.99x10^{-6}$	22.94
2:09	15,400	13.21	13.46	13.46	13.51	$2.14x10^{-6}$	23.26
2:12	15,600	13.72	13.87	13.89	13.94	$2.32x10^{-6}$	23.62
2:16	15,800	14.12	14.38	14.30	14.45	$2.41x10^{-6}$	24.02
2:19	16,000	14.68	14.99	14.88	14.88	$2.56x10^{-6}$	24.44
2:22	16,100	14.96	15.24	15.11	15.21	$2.69x10^{-6}$	24.67
2:29	16,200	15.06	15.44	15.27	15.47	$2.76x10^{-6}$	24.90
2:32	16,300	15.37	15.77	15.67	15.77	$2.85x10^{-6}$	25.14
2:35	16,400	15.82	16.05	15.85	16.10	$3.09x10^{-6}$	25.39
2:39	16,500	16.10	16.26	16.21	16.36	$3.40x10^{-6}$	25.68

2:42	16,600	16.43	16.61	16.54	16.69	3.62×10^{-6}	25.99
2:47	16,700	16.79	17.20	16.94	16.99	3.86×10^{-6}	26.35
2:50	16,800	17.20	17.55	17.37	17.45	4.12×10^{-6}	26.74
2:53	16,900	17.65	17.98	17.81	17.83	4.36×10^{-6}	27.14
2:56	17,000	18.06	18.42	18.24	18.21	4.64×10^{-6}	27.56
2:59	17,100	18.44	18.85	18.67	18.80	5.04×10^{-6}	28.04
3:03	17,200	18.97	19.38	19.10	19.41	5.53×10^{-6}	28.57
3:07	17,250	19.30	19.66	19.38	19.79	5.96×10^{-6}	28.87
3:10	17,300	19.58	19.94	19.66	20.07	6.43×10^{-6}	29.20
3:13	17,350	19.81	20.32	19.89	20.40	6.80×10^{-6}	29.55
3:16 (unclamped)	17,400	20.24	20.70	20.27	20.78	7.12×10^{-6}	29.95
8:02 am (02/03/05)	17,450	20.60	21.03	20.75	21.16	7.54×10^{-6}	30.37
8:05	17,500	20.98	21.46	21.03	21.59	7.91×10^{-6}	30.82
8:09	17,550	21.36	21.84	21.36	21.89	8.48×10^{-6}	31.28
8:11	17,600	21.72	22.28	21.87	22.43	9.06×10^{-6}	31.80
8:15	17,650	22.15	22.76	22.23	22.91	1.03×10^{-5}	32.38
8:19	17,700	22.61	23.29	22.86	23.55	1.18×10^{-5}	33.07
8:24	17,750	23.22	23.98	23.29	24.08	1.38×10^{-5}	33.87
8:27	17,800	23.95	24.74	24.00	24.74	1.70×10^{-5}	34.86
8:31	17,850	24.69	25.65	24.69	25.76		
8:35	17,900	25.70	26.77	25.68	26.92		
8:39	17,950	27.00	28.52	27.10	28.63		

Table A3. Fatigue crack growth rate data for specimen AL-7-23 of 7075-T6 Al.

Specimen: AL-7-23	Frequency: 10 Hz	R = 0.1	B = 3.18 mm		W = 101.91 mm		
P_{max} = 9.82 N	P_{min} = 0.982 N	Initial notch length (2a): 20.34 mm					
Time & Date		Δa front		Δa back		da/dN	ΔK
hours : minutes (date/note)	Total Cycles	left (mm)	right (mm)	left (mm)	right (mm)	(meter/cycle)	(MPa $m^{1/2}$)
8:15am (01/28/05)	40,000	0.15		0.08	0.10		
8:38	50,000	0.23	0.20	0.15	0.18		
9:00	60,000	0.30	0.30	0.23	0.25		
9:24	70,000	0.43	0.38	0.30	0.33	$1.14x10^{-8}$	5.08
9:44	80,000	0.51	0.51	0.41	0.56	$1.27x10^{-8}$	5.11
10:04	90,000	0.66	0.71	0.53	0.69	$1.41x10^{-8}$	5.15
10:25	100,000	0.79	0.89	0.66	0.84	$1.55x10^{-8}$	5.19
10:57	110,000	0.94	1.04	0.79	0.97	$1.65x10^{-8}$	5.23
11:21	120,000	1.14	1.19	0.97	1.12	$1.76x10^{-8}$	5.27
1:16 pm	152,138	1.80	1.83	1.63	1.75	$2.22x10^{-8}$	5.44
1:52	162,138	2.03	2.08	1.85	2.01	$2.40x10^{-8}$	5.50
2:31	172,138	2.26	2.26	2.06	2.26	$2.62x10^{-8}$	5.56
3:06	182,138	2.49	2.57	2.34	2.54	$2.94x10^{-8}$	5.63
3:45	192,138	2.79	2.92	2.62	2.79	$3.39x10^{-8}$	5.71
4:21	202,138	3.12	3.23	2.95	3.15	$3.94x10^{-8}$	5.80
8:17 am (01/31/05)	212,138	3.53	3.68	3.43	3.61	$4.53x10^{-8}$	5.91
8:54	222,138	4.06	4.17	3.91	4.06	$5.13x10^{-8}$	6.03
9:33	232,138	4.57	4.72	4.39	4.65	$5.72x10^{-8}$	6.17
9:52	237,138	4.83	5.03	4.70	4.98	$6.12x10^{-8}$	6.24
10:13	242,138	5.11	5.28	5.00	5.33	$6.49x10^{-8}$	6.32
10:32	247,138	5.44	5.64	5.36	5.64	$6.89x10^{-8}$	6.41
11:05	252,138	5.77	6.05	5.72	6.02	$7.36x10^{-8}$	6.50
11:31	257,138	6.15	6.45	5.99	6.43	$7.83x10^{-8}$	6.60
11:50	262,138	6.53	6.88	6.40	6.78	$8.31x10^{-8}$	6.70
2:46 pm	267,138	6.99	7.29	6.83	7.26	$8.94x10^{-8}$	6.81
3:09	272,138	7.42	7.70	7.26	7.75	$9.57x10^{-8}$	6.93
3:28	277,138	7.87	8.18	7.80	8.23	$1.02\ x10^{-7}$	7.06
3:47	282,138	8.41	8.79	8.33	8.81	$1.08x10^{-7}$	7.20
3:57	284,638	8.69	9.02	8.56	9.07	$1.12x10^{-7}$	7.27
4:10	287,138	8.92	9.35	8.81	9.32	$1.15x10^{-7}$	7.35
4:20	289,638	9.22	9.65	9.07	9.65	$1.19x10^{-7}$	7.42
8:18 am (02/01/05)	292,138	9.55	10.01	9.37	9.98	$1.24x10^{-7}$	7.50
8:32	294,638	9.80	10.26	9.73	10.29	$1.28x10^{-7}$	7.59
8:46	297,138	10.13	10.62	10.03	10.62	$1.32x10^{-7}$	7.68
8:57	299,638	10.49	10.92	10.36	11.00	$1.35x10^{-7}$	7.77
9:09	302,138	10.80	11.33	10.67	11.30	$1.41x10^{-7}$	7.87
9:21	304,638	11.15	11.68	11.05	11.66	$1.44x10^{-7}$	7.97
9:34	307,138	11.53	12.01	11.38	12.07	$1.49x10^{-7}$	8.07
9:48	309,638	11.91	12.42	11.79	12.45	$1.54x10^{-7}$	8.18
10:04	312,138	12.27	12.80	12.14	12.83	$1.59x10^{-7}$	8.29
10:16	314,638	12.65	13.26	12.57	13.26	$1.65x10^{-7}$	8.41
10:31	317,138	13.03	13.64	12.98	13.69	$1.73x10^{-7}$	8.53
10:44	319,638	13.46	14.07	13.41	14.15	$1.80x10^{-7}$	8.66
11:03	322,138	13.92	14.61	13.82	14.61	$1.88x10^{-7}$	8.80

11:15	324,638	14.40	15.09	14.33	15.14	1.97×10^{-7}	8.95
11:31	327,138	14.83	15.54	14.83	15.60	2.04×10^{-7}	9.11
12:57 pm	329,638	15.44	16.10	15.29	16.18	2.11×10^{-7}	9.28
1:03	330,638	15.60	16.38	15.47	16.38	2.20×10^{-7}	9.35
1:09	331,638	15.75	16.59	15.75	16.59	2.23×10^{-7}	9.42
1:15	332,638	15.98	16.79	15.93	16.87	2.24×10^{-7}	9.50
1:24	333,638	16.23	17.04	16.21	17.12	2.34×10^{-7}	9.57
1:30	334,638	16.46	17.22	16.38	17.37	2.38×10^{-7}	9.65
1:36	335,638	16.69	17.50	16.61	17.58	2.43×10^{-7}	9.74
1:44	336,638	16.94	17.78	16.84	17.83	2.48×10^{-7}	9.82
1:51	337,638	17.15	18.03	17.17	18.08	2.55×10^{-7}	9.91
1:57	338,638	17.40	18.29	17.37	18.34	2.61×10^{-7}	10.00
2:02	339,638	17.68	18.57	17.65	18.62	2.64×10^{-7}	10.10
7:49 am (02/02/05)	340,638	17.93	18.80	17.91	18.87	2.64×10^{-7}	10.19
7:54	341,638	18.19	19.10	18.14	19.23	2.67×10^{-7}	10.29
8:02	342,638	18.44	19.46	18.42	19.43	2.69×10^{-7}	10.39
8:08	343,638	18.72	19.66	18.67	19.69	2.74×10^{-7}	10.50
8:15	344,638	18.92	19.91	18.92	20.04	2.78×10^{-7}	10.60
8:21	345,638	19.20	20.24	19.20	20.35	2.84×10^{-7}	10.71
8:27	346,638	19.51	20.55	19.46	20.65	2.96×10^{-7}	10.83
8:34	347,638	19.76	20.88	19.71	20.96	2.99×10^{-7}	10.95
8:39	348,638	20.04	21.16	20.02	21.26	3.09×10^{-7}	11.07
8:45	349,638	20.47	21.49	20.32	21.56	3.20×10^{-7}	11.21
8:51	350,638	20.68	21.84	20.62	21.89	3.27×10^{-7}	11.35
8:59	351,638	20.98	22.20	20.98	22.28	3.39×10^{-7}	11.49
9:05	352,638	21.31	22.53	21.26	22.68	3.48×10^{-7}	11.65
9:11	353,638	21.67	22.91	21.59	23.01	3.64×10^{-7}	11.81
9:23	354,638	21.97	23.32	21.97	23.42	3.73×10^{-7}	11.98
9:30	355,638	22.35	23.70	22.35	23.77	3.93×10^{-7}	12.17
9:36	356,638	22.76	24.21	22.68	24.18	3.96×10^{-7}	12.37
9:42	357,638	23.11	24.56	23.09	24.64	4.14×10^{-7}	12.59
9:48	358,638	23.52	25.02	23.47	25.07	4.33×10^{-7}	12.82
9:54	359,638	23.93	25.43	23.88	25.48	4.48×10^{-7}	13.06
10:01	360,638	24.41	25.93	24.36	25.98	4.61×10^{-7}	13.31
10:05	361,138	24.64	26.29	24.56	26.37	4.73×10^{-7}	13.45
10:10	361,638	24.89	26.54	24.79	26.49	4.90×10^{-7}	13.59
10:14	362,138	25.12	26.64	25.02	26.72	4.91×10^{-7}	13.75
10:20	362,638	25.40	26.87	25.25	27.03	5.02×10^{-7}	13.91
10:30	363,138	25.65	27.15	25.53	27.36	5.26×10^{-7}	14.07
10:36	363,638	25.86	27.43	25.76	27.64	5.49×10^{-7}	14.24
10:41	364,621	26.37	28.02	26.29	28.12	5.60×10^{-7}	14.62
10:47	365,121	26.64	28.35	26.52	28.47	5.73×10^{-7}	14.82
10:51	365,621	26.90	28.68	26.87	28.78	5.89×10^{-7}	15.03
10:56	366,121	27.18	29.01	27.08	29.11	6.14×10^{-7}	15.26
11:00	366,621	27.51	29.34	27.33	29.46	6.26×10^{-7}	15.51
11:05	367,121	27.81	29.69	27.56	29.74	6.51×10^{-7}	15.77
11:09	367,621	28.12	30.07	27.86	30.18	6.88×10^{-7}	16.05
11:14	368,121	28.45	30.45	28.17	30.45	7.26×10^{-7}	16.37
11:18	368,621	28.78	30.91	28.50	30.89	7.76×10^{-7}	16.71
11:23	369,121	29.11	31.34	28.88	31.34	8.37×10^{-7}	17.11

11:27	369,621	29.49	31.72	29.26	31.85	9.28×10^{-7}	17.57
11:33	370,121	29.92	32.18	29.67	32.41	1.06×10^{-6}	18.14
11:37	370,621	30.43	32.72	30.15	33.05	1.42×10^{-6}	19.00
11:42	371,121	30.86	33.53	30.68	33.76		
12:56 pm	371,621	31.45	34.62	31.27	34.77		
1:07	372,121	32.28	37.34	32.05	37.47		

Table A4. Fatigue crack growth rate data for specimen AL-2-26 of 2024-T351 Al.

Specimen: AL-2-26	Frequency: 5 Hz	R = 0.1	B = 9.53 mm		W = 100.35 mm		
P_{max} = 57.04 N	P_{min} = 5.704 N	Initial notch length (2a): 20.28 mm					
Time & Date		Δa front		Δa back		da/dN	ΔK
hours : minutes (date/note)	Total Cycles	left (mm)	right (mm)	left (mm)	right (mm)	(meter/cycle)	(MPa $m^{1/2}$)
2:30 pm (01/13/05)	7,000	0.15	0.15				
3:20	9,000	0.25	0.41	0.10	0.28		
3:40	11,000	0.46	0.61	0.30	0.48		
3:50	13,000	0.74	0.94	0.53	0.86	$1.43x10^{-7}$	10.20
8:20 am (01/14/05)	15,000	1.05	1.18	1.03	1.05	$1.63x10^{-7}$	10.37
8:30	17,000	1.44	1.63	1.36	1.33	$1.79x10^{-7}$	10.56
8:45	19,000	1.79	1.98	1.75	1.78	$1.89x10^{-7}$	10.75
9:00	21,000	2.21	2.26	2.06	2.18	$1.96x10^{-7}$	10.95
9:10	23,000	2.64	2.87	2.41	2.54	$2.07x10^{-7}$	11.15
9:20	25,000	3.12	3.30	2.74	2.90	$2.18x10^{-7}$	11.36
9:35	27,000	3.48	3.76	3.25	3.20	$2.30x10^{-7}$	11.60
9:45	29,000	4.01	4.24	3.71	3.84	$2.42x10^{-7}$	11.83
10:00	31,000	4.57	4.75	4.11	4.34	$2.61x10^{-7}$	12.08
10:10	33,000	5.05	5.28	4.57	4.83	$2.79x10^{-7}$	12.36
10:20	35,000	5.61	5.87	5.28	5.28	$2.92x10^{-7}$	12.65
10:30	37,000	6.22	6.58	5.84	5.99	$3.13x10^{-7}$	12.95
10:40	39,000	6.88	7.11	6.53	6.71	$3.36x10^{-7}$	13.29
10:50	41,000	7.44	7.70	7.14	7.42	$3.55x10^{-7}$	13.64
11:10	43,000	8.18	8.53	7.87	8.23	$3.78x10^{-7}$	14.02
11:15	45,000	8.99	9.25	8.69	9.07	$4.06x10^{-7}$	14.43
12:00	47,000	9.91	9.86	9.58	9.80	$4.44x10^{-7}$	14.87
1:00	49,000	10.74	10.72	10.52	10.82	$4.84x10^{-7}$	15.36
1:10	51,000	11.73	11.73	11.46	11.79	$5.56x10^{-7}$	15.90
1:15	53,000	12.95	12.83	12.52	13.00	$6.22x10^{-7}$	16.58
1:28	55,000	14.12	14.15	13.79	14.15	$6.94x10^{-7}$	17.38
1:35	57,000	16.76	15.85	15.09	15.60	$7.75x10^{-7}$	18.31
1:45	58,500	16.76	17.15	16.31	16.81	$8.69x10^{-7}$	19.12
1:55	60,000	18.03	18.52	17.75	17.98	$1.04x10^{-6}$	20.07
2:05	61,000	19.10	19.53	18.82	18.85	$1.22x10^{-6}$	20.79
2:10	62,000	20.29	20.85	20.02	20.14	$1.52x10^{-6}$	21.79
2:18	63,000	21.95	22.40	21.77	21.67		
2:25	64,000	23.88	24.36	23.22	23.52		
2:30	65,000	26.62	27.15	25.78	26.42		

Table A5. Fatigue crack growth rate data for specimen AL-2-27 of 2024-T351 Al.

Specimen: AL-2-27	Frequency: 5 Hz	R = 0.1	B = 9.66 mm		W = 100.38 mm	
P_{max} = 40.17 N	P_{min} = 4.017 N	Initial notch length (2a): 20.29 mm				
Time & Date		Δa front		Δa back	da/dN	ΔK
hours : minutes (date/note)	Total Cycles	left (mm)	right (mm)	left (mm)	right (mm)	(meter/cycle)	(MPa $m^{1/2}$)
3:10 pm (01/19/05)	57,000	0.38	0.23	0.23	0.13		
3:25	59,000	0.41	0.33	0.25	0.15		
3:40	61,000	0.48	0.43	0.28	0.20		
3:50	63,000	0.53	0.51	0.30	0.23	$2.29x10^{-8}$	6.95
4:05	65,000	0.58	0.53	0.36	0.25	$2.37x10^{-8}$	6.96
4:15	67,000	0.69	0.61	0.36	0.25	$2.35x10^{-8}$	6.98
10:18 am (01/20/05)	69,000	0.76	0.66	0.36	0.28	$2.40x10^{-8}$	7.00
10:30	71,000	0.86	0.74	0.38	0.38	$2.30x10^{-8}$	7.02
10:44	73,000	0.91	0.74	0.43	0.43	$2.14x10^{-8}$	7.04
10:55	75,000	0.94	0.84	0.46	0.46	$1.97x10^{-8}$	7.05
11:13	77,000	0.94	0.86	0.46	0.51	$1.79x10^{-8}$	7.06
11:23	79,000	1.02	0.91	0.46	0.53	$1.93x10^{-8}$	7.07
11:34	81,000	1.04	0.94	0.48	0.61	$2.04x10^{-8}$	7.09
11:44	83,000	1.12	0.99	0.51	0.64	$2.25x10^{-8}$	7.10
11:55	85,000	1.14	1.07	0.56	0.71	$2.25x10^{-8}$	7.12
12:05 pm	87,000	1.19	1.14	0.58	0.71	$2.26x10^{-8}$	7.14
12:20	89,000	1.27	1.19	0.64	0.74	$2.15x10^{-8}$	7.16
12:32	91,000	1.30	1.24	0.64	0.79	$2.13x10^{-8}$	7.17
12:45	93,000	1.35	1.35	0.66	0.81	$2.19x10^{-8}$	7.18
12:57	95,000	1.35	1.47	0.66	0.81	$2.14x10^{-8}$	7.20
1:15	97,000	1.40	1.47	0.74	0.91	$2.20x10^{-8}$	7.22
1:26	99,000	1.45	1.52	0.76	0.97	$2.05x10^{-8}$	7.23
1:37	101,000	1.50	1.55	0.81	0.97	$2.00x10^{-8}$	7.25
2:05	103,000	1.57	1.57	0.86	1.02	$1.94x10^{-8}$	7.26
2:20	105,000	1.57	1.57	0.89	1.07	$2.03x10^{-8}$	7.27
2:33	107,000	1.63	1.65	0.94	1.07	$2.15x10^{-8}$	7.29
2:48	109,000	1.68	1.70	0.97	1.14	$2.32x10^{-8}$	7.30
3:00	111,000	1.70	1.75	1.02	1.22	$2.62x10^{-8}$	7.32
3:11	113,000	1.78	1.78	1.04	1.27	$2.79x10^{-8}$	7.34
3:22	115,000	1.85	1.85	1.07	1.35	$2.97x10^{-8}$	7.36
3:38	117,000	1.91	1.93	1.17	1.37	$3.03x10^{-8}$	7.39
3:53	119,000	1.96	2.01	1.22	1.45	$3.04x10^{-8}$	7.41
4:05	121,000	2.03	2.16	1.27	1.45	$2.88x10^{-8}$	7.43
4:16	123,000	2.06	2.18	1.32	1.52	$2.86x10^{-8}$	7.45
10:45 am (01/21/05)	125,000	2.08	2.21	1.40	1.63	$3.05x10^{-8}$	7.47
10:56	127,000	2.16	2.24	1.45	1.65	$3.23x10^{-8}$	7.49
11:10	129,000	2.24	2.29	1.52	1.75	$3.58x10^{-8}$	7.51
11:21	131,000	2.29	2.41	1.65	1.83	$3.69x10^{-8}$	7.54
11:30	133,000	2.36	2.49	1.68	1.91	$3.79x10^{-8}$	7.57
11:42	135,000	2.49	2.62	1.70	1.98	$3.65x10^{-8}$	7.60
11:54	137,000	2.54	2.62	1.80	2.03	$3.54x10^{-8}$	7.62
12:10 pm	139,000	2.57	2.74	1.91	2.11	$3.65x10^{-8}$	7.65
12:21	141,000	2.69	2.77	1.96	2.16	$3.64x10^{-8}$	7.67
12:32	143,000	2.72	2.92	2.01	2.24	$3.72x10^{-8}$	7.70

12:42	145,000	2.84	3.05	2.03	2.31	3.82×10^{-8}	7.73
12:52	147,000	2.87	3.12	2.08	2.41	3.95×10^{-8}	7.75
1:02	149,000	3.00	3.12	2.11	2.54	4.27×10^{-8}	7.78
1:17	151,000	3.02	3.30	2.29	2.57	4.67×10^{-8}	7.81
1:30	153,000	3.10	3.35	2.41	2.62	4.89×10^{-8}	7.85
1:39	155,000	3.23	3.43	2.62	2.74	4.92×10^{-8}	7.89
1:50	157,000	3.30	3.56	2.77	2.84	4.88×10^{-8}	7.92
2:07	159,000	3.43	3.58	2.77	2.95	4.77×10^{-8}	7.95
2:22	161,000	3.48	3.76	2.79	3.05	4.74×10^{-8}	7.98
2:38	163,000	3.63	3.89	2.84	3.15	4.98×10^{-8}	8.02
2:50	165,000	3.71	3.94	2.95	3.25	5.45×10^{-8}	8.05
3:02	167,000	3.84	4.04	3.10	3.40	5.78×10^{-8}	8.09
3:15	169,000	3.94	4.19	3.18	3.53	6.03×10^{-8}	8.14
3:27	171,000	4.09	4.32	3.28	3.66	6.51×10^{-8}	8.18
3:36	173,000	4.19	4.45	3.43	3.78	6.78×10^{-8}	8.23
3:55	175,000	4.29	4.62	3.48	3.96	7.13×10^{-8}	8.28
8:45 am (01/24/05)	177,000	4.47	4.83	3.63	4.11	7.39×10^{-8}	8.33
9:00	179,000	4.60	5.00	3.78	4.24	7.55×10^{-8}	8.38
9:15	181,000	4.78	5.13	3.91	4.42	7.64×10^{-8}	8.44
9:30	183,000	5.00	5.23	4.06	4.55	7.64×10^{-8}	8.49
9:40	185,000	5.13	5.38	4.22	4.70	7.77×10^{-8}	8.54
9:50	187,000	5.23	5.56	4.37	4.90	7.99×10^{-8}	8.60
10:00	189,000	5.38	5.66	4.57	5.11	8.30×10^{-8}	8.65
10:15	191,000	5.54	5.87	4.72	5.23	8.70×10^{-8}	8.71
10:25	193,000	5.72	6.05	4.95	5.38	8.89×10^{-8}	8.78
10:34	195,000	5.87	6.25	5.11	5.61	9.28×10^{-8}	8.84
10:43	197,000	6.07	6.45	5.31	5.79	9.54×10^{-8}	8.91
10:53	199,000	6.22	6.63	5.44	5.99	1.00×10^{-7}	8.97
11:02	201,000	6.43	6.83	5.69	6.25	1.05×10^{-7}	9.05
11:11	203,000	6.73	7.04	5.79	6.38	1.09×10^{-7}	9.12
11:21	205,000	6.91	7.32	6.12	6.65	1.14×10^{-7}	9.21
12:44 pm	207,000	7.11	7.54	6.30	6.91	1.16×10^{-7}	9.29
12:55	209,000	7.34	7.72	6.55	7.16	1.20×10^{-7}	9.37
1:05	211,000	7.57	7.95	6.83	7.39	1.21×10^{-7}	9.46
2:45	213,000	7.82	8.18	7.09	7.62	1.26×10^{-7}	9.55
2:59	215,000	8.05	8.46	7.37	7.90	1.28×10^{-7}	9.64
3:03	216,000	8.18	8.61	7.52	8.03	1.31×10^{-7}	9.69
3:11	217,000	8.33	8.76	7.70	8.10	1.34×10^{-7}	9.74
3:17	218,000	8.41	8.86	7.80	8.20	1.34×10^{-7}	9.79
3:27	219,000	8.56	9.02	7.92	8.43	1.37×10^{-7}	9.84
3:36	220,000	8.66	9.14	8.08	8.61	1.41×10^{-7}	9.89
3:42	221,000	8.81	9.32	8.13	8.74	1.43×10^{-7}	9.94
3:49	222,000	8.97	9.47	8.28	8.92	1.40×10^{-7}	9.99
3:55	223,000	9.09	9.58	8.48	9.07	1.42×10^{-7}	10.04
4:03	224,000	9.25	9.73	8.61	9.12	1.52×10^{-7}	10.10
4:09	225,000	9.40	9.91	8.69	9.30	1.55×10^{-7}	10.16
4:14	226,000	9.53	10.08	8.84	9.47	1.64×10^{-7}	10.22
7:42 am (01/25/05)	227,000	9.70	10.29	9.09	9.70	1.68×10^{-7}	10.27
7:49	228,000	9.86	10.44	9.22	9.80	1.71×10^{-7}	10.34
7:54	229,000	10.01	10.69	9.37	10.01	1.74×10^{-7}	10.40

8:03	230,100	10.19	10.85	9.53	10.11	1.73×10^{-7}	10.47
8:09	231,118	10.39	11.05	9.68	10.31	1.76×10^{-7}	10.54
8:16	232,000	10.57	11.15	9.96	10.54	1.77×10^{-7}	10.60
8:23	233,000	10.72	11.40	10.11	10.64	1.78×10^{-7}	10.67
8:30	234,000	10.95	11.53	10.26	10.77	1.81×10^{-7}	10.74
8:38	235,000	11.13	11.73	10.41	11.05	1.86×10^{-7}	10.81
8:44	236,000	11.25	11.89	10.62	11.20	1.97×10^{-7}	10.89
8:50	237,000	11.48	12.12	10.85	11.43	2.06×10^{-7}	10.97
8:57	238,000	11.66	12.32	11.00	11.68	2.16×10^{-7}	11.05
9:02	239,000	11.94	12.50	11.28	11.89	2.24×10^{-7}	11.13
9:08	240,000	12.12	12.80	11.51	12.04	2.27×10^{-7}	11.22
9:20	241,000	12.34	13.03	11.68	12.40	2.30×10^{-7}	11.31
9:28	242,000	12.60	13.18	11.99	12.57	2.29×10^{-7}	11.41
9:34	243,000	12.80	13.44	12.17	12.85	2.31×10^{-7}	11.50
9:41	244,000	13.03	13.64	12.45	13.06	2.35×10^{-7}	11.60
9:47	245,000	13.26	13.89	12.62	13.28	2.37×10^{-7}	11.69
9:54	246,000	13.54	14.10	12.90	13.54	2.48×10^{-7}	11.80
10:06	247,000	13.82	14.35	13.16	13.82	2.57×10^{-7}	11.90
10:30	248,000	14.02	14.61	13.39	13.97	2.60×10^{-7}	12.01
10:36	249,000	14.33	14.94	13.67	14.35	2.66×10^{-7}	12.12
10:42	250,000	14.58	15.21	13.89	14.63	2.75×10^{-7}	12.24
10:50	251,000	14.76	15.49	14.12	14.86	2.85×10^{-7}	12.36
10:56	252,000	15.09	15.75	14.53	15.14	2.88×10^{-7}	12.49
11:02	253,000	15.37	16.05	14.81	15.52	3.03×10^{-7}	12.62
11:09	254,000	15.72	16.41	14.96	15.82	3.17×10^{-7}	12.76
11:16	255,000	16.05	16.71	15.27	16.08	3.21×10^{-7}	12.91
11:26	256,000	16.31	17.07	15.70	16.51	3.29×10^{-7}	13.06
1:15 pm	257,056	16.69	17.40	16.03	16.87	3.41×10^{-7}	13.23
1:23	257,556	16.76	17.63	16.15	17.04	3.46×10^{-7}	13.31
1:35	258,056	16.97	17.81	16.31	17.25	3.51×10^{-7}	13.40
1:55	258,556	17.17	17.93	16.54	17.48	3.62×10^{-7}	13.48
1:59	259,056	17.30	18.16	16.69	17.58	3.81×10^{-7}	13.58
2:05	259,556	17.50	18.36	16.97	17.75	3.94×10^{-7}	13.67
2:11	260,056	17.65	18.54	17.12	17.96	4.01×10^{-7}	13.77
2:16	260,556	17.86	18.80	17.35	18.24	4.09×10^{-7}	13.87
2:21	261,056	18.14	18.95	17.55	18.44	4.12×10^{-7}	13.98
2:32	262,500	18.72	19.51	18.06	19.05	4.20×10^{-7}	14.30
2:38	263,000	18.92	19.71	18.34	19.30	4.28×10^{-7}	14.41
2:42	263,500	19.15	19.91	18.59	19.46	4.51×10^{-7}	14.52
2:47	264,000	19.33	20.17	18.85	19.74	4.54×10^{-7}	14.65
2:51	264,500	19.46	20.47	18.97	20.02	4.64×10^{-7}	14.78
3:02	265,000	19.71	20.75	19.18	20.24	4.87×10^{-7}	14.92
3:07	265,500	19.94	20.90	19.51	20.45	5.20×10^{-7}	15.06
3:12	266,000	20.24	21.23	19.71	20.70	5.42×10^{-7}	15.21
3:16	266,500	20.47	21.46	20.12	20.98	5.51×10^{-7}	15.37
3:22	267,000	20.80	21.84	20.42	21.31	5.56×10^{-7}	15.54
3:27	267,500	21.06	22.10	20.55	21.59	5.42×10^{-7}	15.70
3:33	268,000	21.23	22.38	20.85	21.87	5.54×10^{-7}	15.88
3:36	268,500	21.56	22.63	21.08	22.17	5.72×10^{-7}	16.07
3:43	269,000	21.89	22.78	21.31	22.43	6.01×10^{-7}	16.26

3:47	269,500	22.20	23.19	21.87	22.71	6.33×10^{-7}	16.46
3:52	270,000	22.50	23.57	22.05	23.11	6.64×10^{-7}	16.68
3:56	270,500	22.83	23.85	22.40	23.32	6.95×10^{-7}	16.92
4:00	271,000	23.16	24.31	22.73	23.70	7.24×10^{-7}	17.18
4:05	271,500	23.55	24.64	23.16	24.03	7.29×10^{-7}	17.43
4:10	272,000	24.00	25.04	23.57	24.28	7.85×10^{-7}	17.73
7:53 am (01/26/05)	272,500	24.41	25.55	23.98	24.77	8.23×10^{-7}	18.05
8:06	273,000	24.74	25.46	24.21	25.25	8.77×10^{-7}	18.40
8:10	273,500	25.17	26.47	24.71	25.76	9.50×10^{-7}	18.80
8:23	274,000	25.60	26.90	25.17	26.19	1.05×10^{-6}	19.25
8:30	274,500	26.01	27.38	25.76	26.82	1.14×10^{-6}	19.73
8:36	275,000	26.49	28.04	26.49	27.36	1.26×10^{-6}	20.37
8:43	275,500	27.18	28.68	27.00	28.27	1.46×10^{-6}	21.11
8:50	276,000	27.84	29.49	27.71	28.30	1.75×10^{-6}	22.10
8:56	276,500	28.70	30.35	28.50	29.95	2.29×10^{-6}	
9:04	277,000	29.79	31.55	29.49	31.01		
9:15	277,500	30.81	33.30	30.78	32.61		

Table A6. Fatigue crack growth rate data for specimen AL-2-28 of 2024-T351 Al.

Specimen: AL-2-28	Frequency: 5 Hz	R = 0.1	B = 9.65 mm		W = 100.41 mm		
P_{max} = 71.41 N	P_{min} = 7.141 N	Initial notch length (2a): 20.29 mm					
Time & Date		Δa front		Δa back		da/dN	ΔK
hours : minutes (date/note)	Total Cycles	left (mm)	right (mm)	left (mm)	right (mm)	(meter/cycle)	(MPa $m^{1/2}$)
9:27 am (02/07/05)	4,000	0.15	0.13	0.15			
9:37	6,000	0.53	0.43	0.33	0.56		
9:46	8,000	1.04	0.97	0.84	1.07		
9:52	9,000	1.35	1.30	1.12	1.30	$3.01x10^{-7}$	12.91
9:59	10,000	1.57	1.57	1.52	1.57	$3.26x10^{-7}$	13.12
10:05	11,000	2.03	1.96	1.80	1.88	$3.45x10^{-7}$	13.33
10:11	12,000	2.34	2.34	2.21	2.26	$3.59x10^{-7}$	13.57
10:17	13,000	2.79	2.69	2.57	2.57	$3.66x10^{-7}$	13.80
10:24	14,000	3.12	3.15	2.87	2.97	$3.72x10^{-7}$	14.03
10:31	15,000	3.43	3.56	3.18	3.40	$3.78x10^{-7}$	14.26
10:38	16,000	3.89	3.89	3.51	3.71	$3.90x10^{-7}$	14.50
10:44	17,000	4.14	4.45	3.91	4.19	$4.11x10^{-7}$	14.74
10:52	18,000	4.52	4.78	4.37	4.57	$4.46x10^{-7}$	15.00
10:58	19,000	4.98	5.28	4.70	5.08	$4.89x10^{-7}$	15.29
11:04	20,000	5.46	5.66	5.26	5.69	$5.45x10^{-7}$	15.60
11:09	20,500	5.72	6.12	5.51	5.94	$5.71x10^{-7}$	15.78
11:13	21,000	6.05	6.32	5.79	6.25	$5.89x10^{-7}$	15.97
11:18	21,500	6.32	6.71	6.07	6.53	$6.00x10^{-7}$	16.16
12:30 pm	22,000	6.65	7.06	6.40	6.78	$6.11x10^{-7}$	16.35
12:34	22,500	6.88	7.29	6.76	7.16	$6.23x10^{-7}$	16.55
12:37	23,000	7.24	7.52	7.06	7.42	$6.31x10^{-7}$	16.75
12:41	23,500	7.62	7.92	7.39	7.72	$6.49x10^{-7}$	16.95
12:45	24,000	7.90	8.20	7.77	8.03	$6.75x10^{-7}$	17.16
12:49	24,500	8.20	8.61	8.10	8.31	$6.98x10^{-7}$	17.38
12:53	25,000	8.64	8.92	8.48	8.66	$7.21x10^{-7}$	17.61
12:56	25,500	9.04	9.30	8.89	8.97	$7.38x10^{-7}$	17.86
1:00	26,000	9.37	9.68	9.27	9.32	$7.64x10^{-7}$	18.10
1:05	26,500	9.91	10.06	9.63	9.70	$8.06x10^{-7}$	18.35
1:09	27,000	10.31	10.29	9.96	10.08	$8.61x10^{-7}$	18.62
1:13	27,500	10.64	10.87	10.36	10.62	$9.14x10^{-7}$	18.92
1:17	28,000	11.15	11.35	10.92	11.13	$9.39x10^{-7}$	19.24
1:20	28,200	11.46	11.46	11.07	11.35	$9.03x10^{-7}$	19.38
1:23	28,400	11.56	11.61	11.23	11.53	$8.95x10^{-7}$	19.51
1:26	28,600	11.73	11.71	11.46	11.68	$9.11x10^{-7}$	19.62
1:29	28,800	11.86	11.86	11.71	11.91	$9.65x10^{-7}$	19.74
1:32	29,000	11.96	12.09	11.94	12.09	$1.03x10^{-6}$	19.89
1:34	29,200	12.24	12.29	12.14	12.37	$1.09x10^{-6}$	20.04
1:37	29,400	12.50	12.57	12.37	12.52	$1.11x10^{-6}$	20.21
1:41	29,600	12.67	12.78	12.57	12.75	$1.11x10^{-6}$	20.37
1:44	29,800	12.83	13.13	12.78	13.08	$1.11x10^{-6}$	20.53
1:50	30,000	13.00	13.34	13.03	13.18	$1.10x10^{-6}$	20.69
1:55	30,200	13.21	13.59	13.23	13.36	$1.14x10^{-6}$	20.85
1:58	30,400	13.59	13.79	13.46	13.59	$1.15x10^{-6}$	21.02
2:02	30,600	13.84	14.07	13.59	13.74	$1.21x10^{-6}$	21.19

2:05	30,800	14.15	14.33	13.87	14.00	1.27×10^{-6}	21.38
2:09	31,000	14.30	14.53	14.17	14.22	1.32×10^{-6}	21.57
2:11	31,200	14.53	14.88	14.43	14.55	1.39×10^{-6}	21.78
2:14	31,400	14.88	15.16	14.73	14.81	1.43×10^{-6}	22.00
2:17	31,600	15.11	15.54	14.99	15.04	1.48×10^{-6}	22.24
2:20	31,800	15.49	15.75	15.34	15.37	1.53×10^{-6}	22.47
2:23	32,000	15.82	16.08	15.60	15.57	1.58×10^{-6}	22.72
2:26	32,200	16.23	16.36	15.93	15.88	1.61×10^{-6}	22.99
2:29	32,400	16.56	16.71	16.21	16.31	1.62×10^{-6}	23.26
2:31	32,600	16.87	17.20	16.48	16.61	1.69×10^{-6}	23.53
2:35	32,800	17.20	17.40	16.81	16.92	1.74×10^{-6}	23.82
2:38	33,000	17.58	17.70	17.15	17.20	1.82×10^{-6}	24.12
2:41	33,200	17.96	18.16	17.58	17.65	1.91×10^{-6}	24.45
2:44	33,400	18.26	18.49	18.01	18.11	2.05×10^{-6}	24.81
2:50	33,600	18.69	18.82	18.49	18.57	2.14×10^{-6}	25.20
2:53	33,800	19.15	19.25	18.87	18.90	2.21×10^{-6}	25.61
2:57	34,000	19.61	19.76	19.33	19.46	2.27×10^{-6}	26.06
3:00	34,200	20.09	20.24	19.69	19.94	2.41×10^{-6}	26.51
3:03	34,400	20.57	20.80	20.14	20.45	2.60×10^{-6}	27.00
3:07	34,600	20.93	21.21	20.62	20.88	2.88×10^{-6}	27.55
3:15	34,800	21.59	21.89	21.39	21.44	3.34×10^{-6}	28.20
3:19	34,900	21.87	22.23	21.72	21.89	3.54×10^{-6}	28.58
3:22	35,000	22.20	22.73	22.05	22.17	3.77×10^{-6}	29.03
3:27	35,100	22.68	23.14	22.35	22.58	3.99×10^{-6}	29.48
3:33	35,200	23.01	23.50	22.68	23.06	4.33×10^{-6}	29.96
3:36	35,300	23.29	23.95	23.22	23.55	4.85×10^{-6}	30.52
3:39	35,400	23.62	24.61	23.70	23.95	5.47×10^{-6}	31.17
3:44	35,500	24.38	25.12	24.28	24.64	6.44×10^{-6}	31.98
3:48 (unclamped)	35,550		25.60	24.56	24.99	7.44×10^{-6}	32.44
8:12 am (02/08/05)	35,600		25.96	24.92	25.37	8.58×10^{-6}	32.96
8:40	35,650		26.29	25.35		8.25×10^{-6}	33.66
9:04	35,700		26.70	25.68		9.81×10^{-6}	34.42
9:24	35,750		27.20	26.04		1.12×10^{-5}	35.31
9:32	35,800		27.91	26.67		1.41×10^{-5}	36.53
9:49	35,850		28.78	27.43			
9:56	35,900		*29.57*	*27.99*			
10:03	35,950		*31.09*	*29.29*			

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01- 08 - 2005	Technical Memorandum	

4. TITLE AND SUBTITLE

7075-T6 and 2024-T351 Aluminum Alloy Fatigue Crack Growth Rate Data

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Forth, Scott C.; Wright, Christopher W.; and Johnston, William M., Jr.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

23-064-30-24

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER

L-19163

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)

NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

NASA/TM-2005-213907

12. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 26
Availability: NASA CASI (301) 621-0390

13. SUPPLEMENTARY NOTES

Langley Research Center: Forth and Wright; Lockheed Martin Corporation: Johnston
An electronic version can be found at http://ntrs.nasa.gov

14. ABSTRACT

Experimental test procedures for the development of fatigue crack growth rate data has been standardized by the American Society for Testing and Materials. Over the past 30 years several gradual changes have been made to the standard without rigorous assessment of the affect these changes have on the precision or variability of the data generated. Therefore, the ASTM committee on fatigue crack growth has initiated an international round robin test program to assess the precision and variability of test results generated using the standard E647-00. Crack growth rate data presented in this report, in support of the ASTM roundrobin, shows excellent precision and repeatability.

15. SUBJECT TERMS

2024-T351; 7075-T6; Alloy; Aluminum; Crack; Fatigue; Growth; Data; Rate

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	24	(301) 621-0390