NASA Contractor Report 201668

Overload and Underload Effects on the Fatigue Crack Growth Behavior of the 2024-T3 Aluminum Alloy

David S. Dawicke
Analytical Services & Materials, Inc., Hampton, Virginia

Contract NAS1-96014

March 1997

National Aeronautics and
Space Administration
Langley Research Center
Hampton, Virginia 23681-0001

Overload and Underload Effects on the Fatigue Crack Growth Behavior of the 2024-T3 Aluminum Alloy

D. S. Dawicke
Analytical Services & Materials, Inc.

ABSTRACT

Fatigue crack growth tests were conducted on 0.09 inch thick, 3.0 inch wide middle-crack tension specimens cut from sheets of 2024-T3 aluminum alloy. The tests were conducted using a load sequence that consisted of a single block of 2,500 cycles of constant amplitude loading followed by an overload/underload combination. The largest fatigue crack growth life occurred for the tests with the overload stress equal to 2 times the constant amplitude stress and the underload stress equal to the constant amplitude minimum stress. For the tests with compressive underloads, the fatigue crack growth life decreased with increasing compressive underload stress.

KEYWORDS

Fatigue crack growth, retardation, overload, underload

INTRODUCTION

An experimental program was conducted to evaluate the effects of periodic overloads and underloads on the fatigue crack growth behavior of 2024-T3 aluminum alloy. Middle crack tension (M(T)) specimens were fatigue cycled, until failure, with a load sequence that consisted of blocks of 2,500 constant amplitude cycles followed by an overload/underload combination. The objective of this study was to develop a database that could be used to evaluate the ability of fatigue crack growth analysis codes to predict load sequence effects.

EXPERIMENTAL PROCEDURE

Fatigue crack growth tests were conducted on 3 inch wide middle crack tension (M(T)) specimens cut from sheets of 0.09 inch thick 2024-T3 aluminum alloy. The specimens had an initial notch that was 0.6 inches long ($2a_N$) and 0.125 inches wide (N_h), as shown in Figure 1. The specimens were fatigue precracked, to a crack length of $2a_i$ = 1.000±0.002 inches, under constant amplitude loading with a maximum stress of S_{max} = 10 ksi and a stress ratio of ($R = S_{min}/S_{max}$) of 0.02. After the fatigue precracking, the specimens were cycled to failure using a load sequence that consisted of a single repeated block. The block began with 2,500 constant amplitude cycles with a maximum stress of S_{max} = 10 ksi and a stress ratio of R = 0.02. The constant amplitude loading was followed by a single spike overload at a stress of S_{ol} that ranged from 1.125 to $3.4S_{max}$. The overload was followed by a single spike underload at a stress of S_{ul} that ranged from 0 to $-3S_{max}$. This load sequence is illustrated in Figure 2. In each test, the number of cycles to failure was measured.

RESULTS AND DISCUSSION

A total of 41 fatigue tests were conducted. For 24 of the tests, the minimum stress (S_{min}) was 0.2 ksi. Thus, the load sequence consisted of a single spike overload that repeated every 2,500 cycles. The number of cycles to failure was recorded for each test and is plotted in Figure 3 against the ratio of overload stress to constant amplitude stress (S_{ol}/S_{max}). The tests with constant amplitude loading (S_{ol}/S_{max} = 1.0) had an average fatigue life of about 30,700 cycles. The addition of a 12.5% (S_{ol}/S_{max} = 1.125) overload every 2,500 cycles increased the average fatigue life to about 52,800 cycles, an increase of about 70%. This increase in fatigue life was a result of a reduction of the effective stress-intensity factor range due to the increased crack opening load following the spike overload. The fatigue life continued to increase with increasing overload stress up to S_{ol}/S_{max} = 2.0, where the corresponding fatigue life was about 2,090,000 cycles. Further increases in the overload ratio resulted in a drop in the number of cycles to failure as a result of damage accumulation during the spike overload cycles. At an overload stress of S_{ol}/S_{max} = 3.4, the test failed during the application of the first spike overload.

The single spike overload was followed by a compressive underload in the remaining 17 tests. The application of the underload following the overload resulted in a shorter fatigue life than in the tests with just the spike overload, as shown in Figure 4. During the underload the crack surfaces yielded in compression, reducing the tensile plastic deformation due to the overload, thus decreasing the subsequent crack opening stress (and increasing the effective stress-intensity factor).

CONCLUDING REMARKS

Fatigue crack growth tests were conducted on 0.09 inch thick, 3.0 inch wide middle-crack tension specimens cut from sheets of 2024-T3 aluminum alloy. The tests were conducted using a load sequence that consisted of 2,500 cycles of constant amplitude loading followed by an overload/underload combination. For the tests with the underload stress equal to $S_{ul}/S_{max} = 0.02$, the fatigue crack growth life increased for overloads in the range of $1.0 \leq S_{ol}/S_{max} \leq 2.0$. At an overload of $S_{ol}/S_{max} = 2.0$, the fatigue life was more than 60 times greater than the constant amplitude fatigue life. For overloads greater than $S_{ol}/S_{max} = 2.0$, the fatigue crack growth life decreased with increasing overload stress. For the tests with compressive underloads, the fatigue life decreased with increasing compressive underload stress.

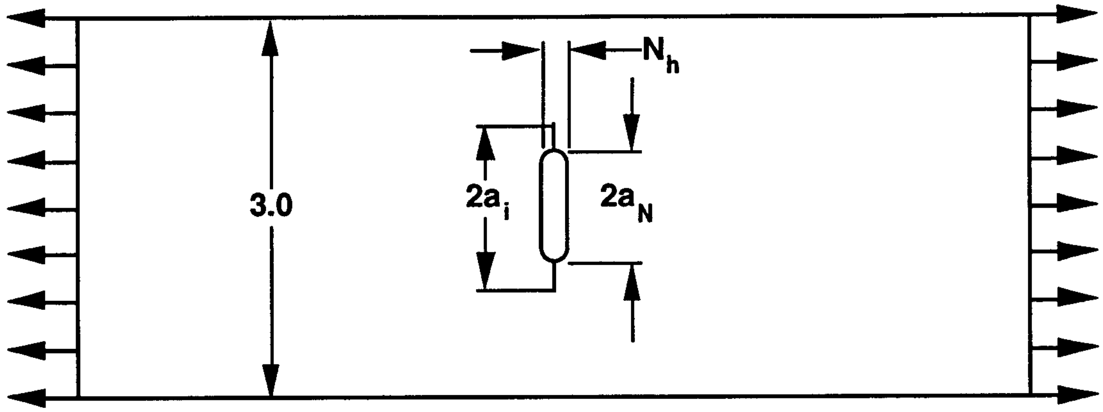

Figure 1 Middle-crack tension specimen with crack starting from notch.

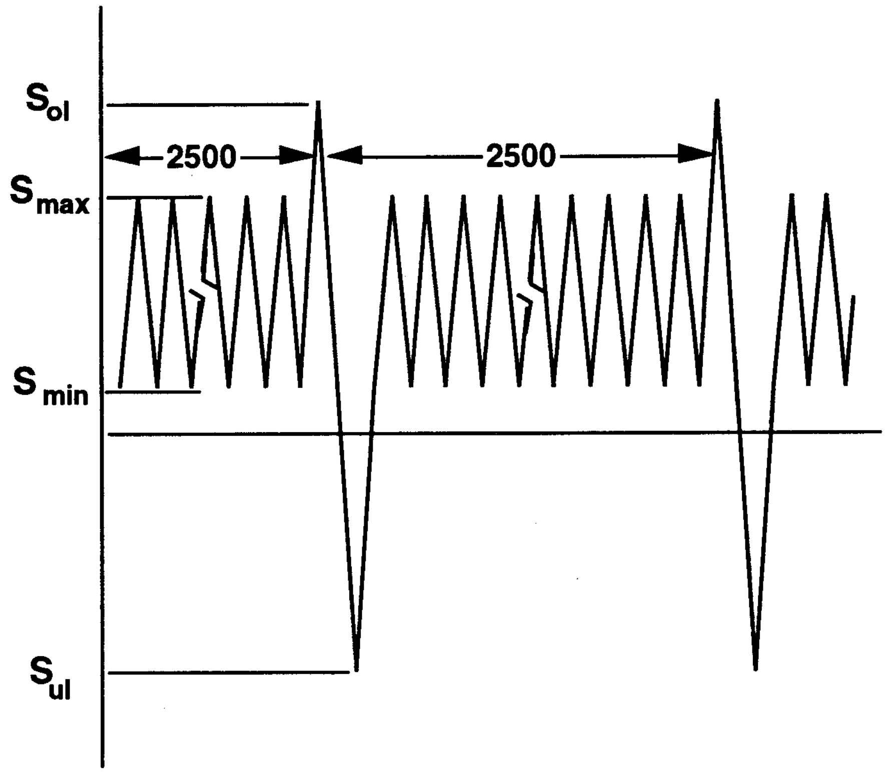

Figure 2 Schematic of overload/underload spectra.

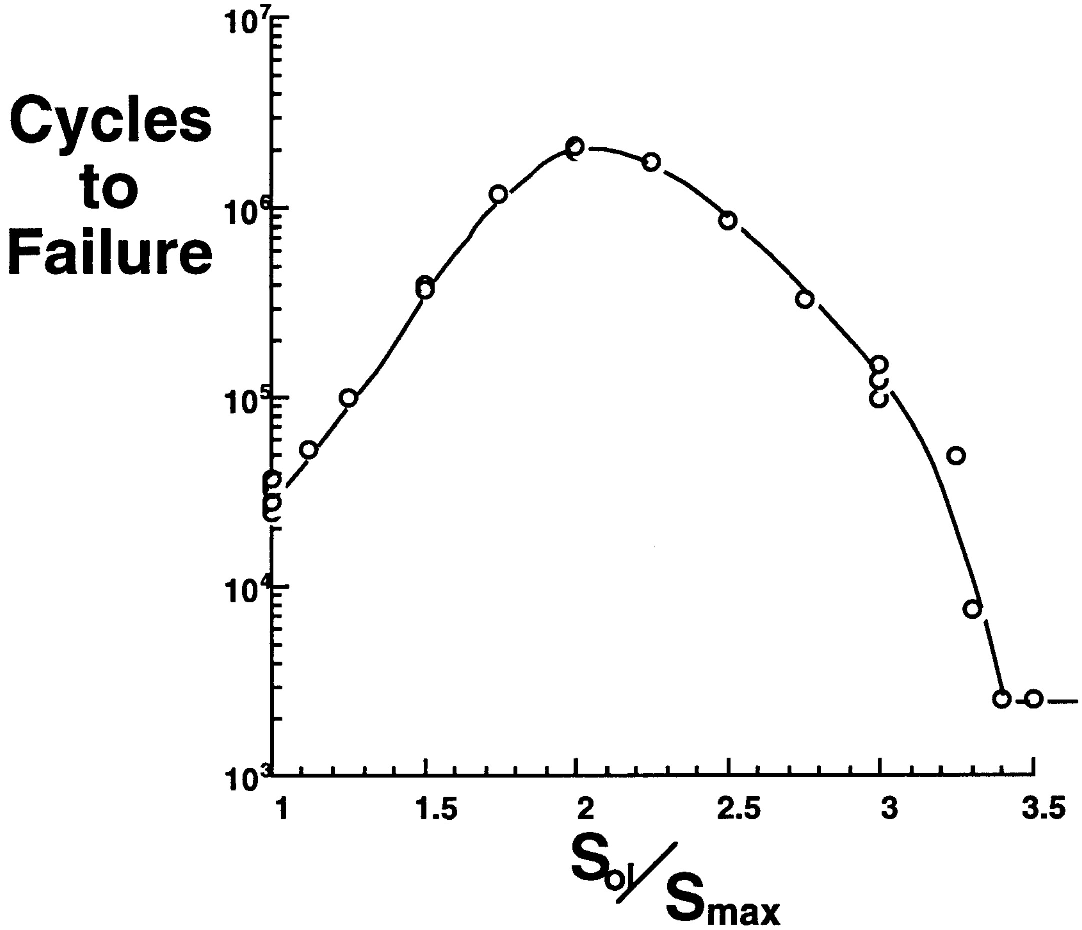

Figure 3 Fatigue test results for the tests conducted with repeated spike overloads (S_{ul} = 0.2 ksi).

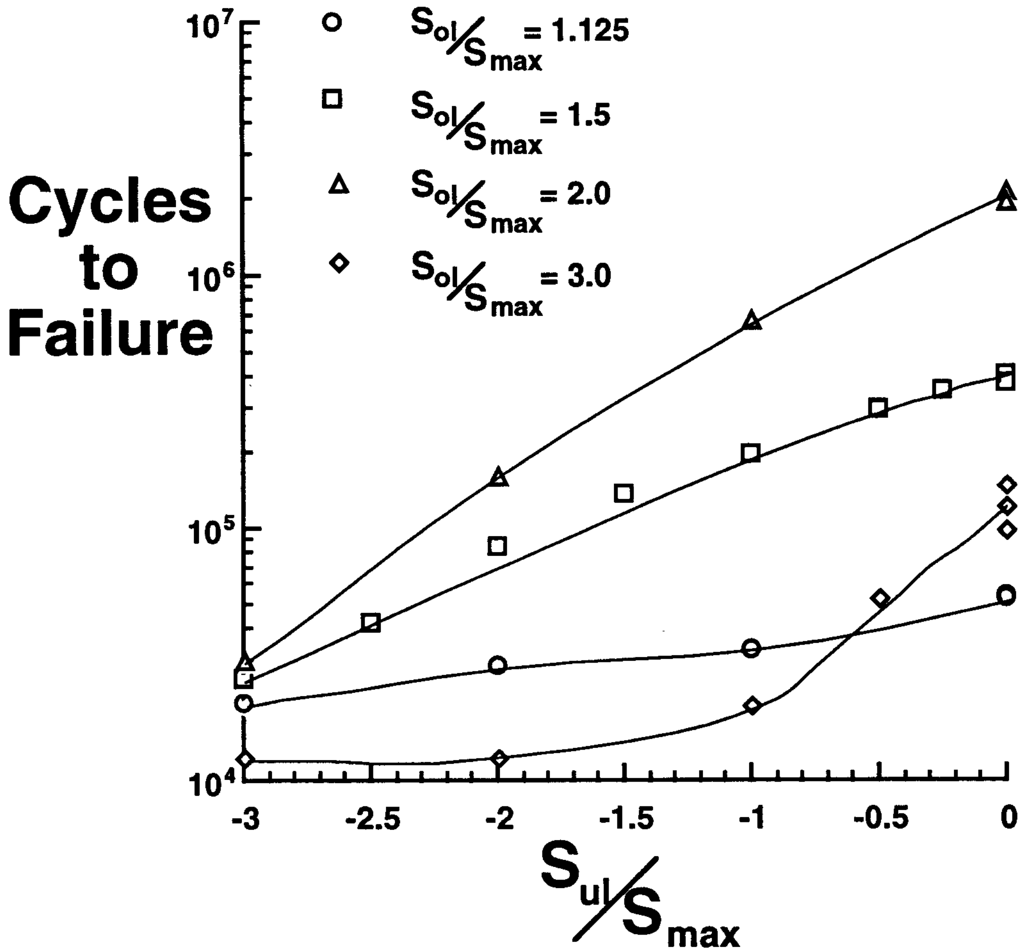

Figure 4 Fatigue test results for the tests conducted with repeated spike overloads followed by spike underloads.

APPENDIX

Table 1
Cycles to Failure for the Single Spike Overload Sequence (S_{ul}/S_{max} = 0.02)

S_{ol}/S_{max}	Cycles to Failure
1.0	26,764
1.0	24,417
1.0	34,628
1.0	32,936
1.0	37,484
1.0	28,088
1.125	53,608
1.125	52,073
1.25	101,023
1.5	397,659
1.5	373,005
1.75	1,168,164
2.0	1,930,938
2.0	2,088,070
2.25	1,750,202
2.5	865,438
2.75	330,132
3.0	97,359
3.0	120,048
3.0	147,559
3.25	47,519
3.3	7,503
3.4	2,501
3.5	2,501

Table 2
Cycles to Failure for the Single Spike Overload/Underload Sequence

S_{ol}/S_{max}	S_{ul}/S_{max}	Cycles to Failure
1.125	0.0	53,608
1.125	0.0	52,073
1.125	-1.0	33,192
1.125	-2.0	29,083
1.125	-3.0	20,472
1.5	0.0	397,659
1.5	0.0	373,005
1.5	-0.25	345,098
1.5	-0.5	294,052
1.5	-1.0	195,075
1.5	-1.5	135,177
1.5	-2.0	85,529
1.5	-2.5	42,042
1.5	-3.0	25,753
2.0	0.0	2,088,070
2.0	0.0	1,930,938
2.0	-1.0	660,264
2.0	-2.0	160,064
2.0	-3.0	30,012
3.0	0.0	120,048
3.0	0.0	97,359
3.0	0.0	147,559
3.0	-0.5	52,521
3.0	-1.0	20,008
3.0	-2.0	12,505
3.0	-3.0	12,505

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1997	Contractor Report

4. TITLE AND SUBTITLE
Overload and Underload Effects on the Fatigue Crack Growth Behavior of the 2024-T3 Aluminum Alloy

5. FUNDING NUMBERS
C NAS1-96014
WU 538-02-10-01

6. AUTHOR(S)
David S. Dawicke

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Lockheed Martin Engineering & Sciences
Langley Program Office
Langley Research Center, Mail Stop 371
Hampton, VA 23681-0001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
NASA CR-201668

11. SUPPLEMENTARY NOTES
This report was prepared for Langley under contract NAS1-96014, Task DM01, by Analytical Services & Materials, Inc., Hampton, VA, under subcontract to Lockheed Martin Engineering & Sciences Company, Hampton, VA.
Langley Technical Monitor: James C. Newman, Jr.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified - Unlimited

Subject Category 26

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Fatigue crack growth tests were conducted on 0.09 inch thick, 3.0 inch wide middle-crack tension specimens cut from sheets of 2024-T3 aluminum alloy. The tests were conducted using a load sequence that consisted of a single block of 2,500 cycles of constant amplitude loading followed by an overload/underload combination. The largest fatigue crack growth life occurred for the tests with the overload stress equal to 2 times the constant amplitude stress and the underload stress equal to the constant amplitude minimum stress. For the tests with compressive underloads, the fatigue crack growth life decreased with increasing compressive underload stress.

14. SUBJECT TERMS
Fatigue crack growth, retardation, overload, underload

15. NUMBER OF PAGES
10

16. PRICE CODE
A02

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102