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TENSION-TENSION FATIGUE BEHAVIOR OF THE SPACE SHUTTLE STRAIN-ISOLATION-PAD MATERIAL

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SUMMARY

The room temperature fatigue behavior of 0.41-cm (0.16-in) thick strain-isolation-pad (SIP) material was explored in a series of constant- and random-amplitude loading tests. The SIP material is used on the Space Shuttle to isolate the ceramic insulating tiles from the strains and deflections of the aluminum alloy airframe. The tests were conducted to evaluate changes in thickness and tangent modulus that occur when the SIP is cyclically loaded, and to evaluate the feasibility of using linear cumulative damage fatigue models and constant-amplitude loading fatigue data to predict the response of SIP subjected to random-amplitude loading. In all tests, 12.7- by 12.7-cm (5.0- by 5.0-in) SIP specimens were subjected to tension-tension loading in the through-the-thickness direction at a frequency of 10 Hz.

When subjected to cyclic loading, the SIP material exhibited a monotonic increase in thickness and a monotonic increase in tensile tangent moduli. The rate of thickness growth increased with increasing test stress level and decreased with increasing number of cycles endured. Power law equations were found to provide a good representation of the thickness growth rate data. Tensile tangent moduli increased by as much as 80 percent during fatigue tests. Simple cumulative damage fatigue models predicted the mean thickness growth under random-amplitude loading with reasonable accuracy (factor of 2 on life).

INTRODUCTION

The thermal protection system that protects most of the exterior of the Space Shuttle from entry heating consists of rigidized silica fiber insulating tiles that are bonded to Nomex-felt strain isolation pads (SIP) that are, in turn, bonded to the aluminum alloy airframe. The low-stiffness SIP is necessary to prevent airframe strains and local deflections from breaking the low-strain-to-failure tiles. The SIP itself, however, forms part of the structural chain holding the tiles on the airframe and so must sustain numerous static and cyclic loads without failure.

To evaluate the potentially detrimental effects of cyclic loads on the structural integrity of the SIP and tile combination, Rockwell International conducted constant-amplitude loading fatigue tests on 15.2- by 15.2-cm (6.0- by 6.0-in) tiles bonded to 12.7- by 12.7-cm (5.0- by 5.0-in) SIP. Analysis of those test results indicated that the SIP exhibited a progressive increase in elongation (in the thickness direction) when cyclically loaded. The increased elongation could potentially result in tile damage or loss by allowing contact between adjacent tiles or by allowing the tiles to protrude into the airstream, thereby causing increased aerodynamic loads and heating.

The purpose of the current work was to generate further data and information about the response of the SIP material to cyclic loading. Specific objectives of the work were: (1) to fill in gaps in the Rockwell International data base describing the SIP response during early stages of constant-amplitude fatigue tests, (2) to develop simple analytical expressions describing the constant-amplitude data for use in sensitivity studies of SIP life, (3) to generate data on changes in SIP stiffness during constant-amplitude fatigue tests, and (4) to evaluate the feasibility of using constant-amplitude fatigue data with a simple cumulative damage fatigue model to predict the elongation response of SIP when subjected to random-amplitude cyclic loading.

MATERIALS AND SPECIMENS

The SIP material used in the current tests was nominally (0.41 cm (0.16 in)) thick and was received in 0.3-m (1-ft) square sheets that had a silicone rubber layer cured onto one surface. Each sheet had a quality-control identification tag stapled to it. The information written on the tags was the same on all sheets and is reproduced in table I.

The specimen configuration used in the tests is shown in figure 1. The specimen consisted of a 1.27- by 12.7-cm (5.0- by 5.0-in) square of SIP bonded between aluminum alloy plates. The SIP was bonded to the aluminum plates using the same silicone rubber adhesive (RTV-560) and procedures as those used in Space Shuttle bonding operations at the NASA Kennedy Space Center. Bonding and quality-control personnel had received training in the procedures at NASA-Kennedy. The nominal thickness of the adhesive layer was 0.18 mm (0.007 in).

Tensile tests of two small specimens (5.72 by 5.72 cm (2.25 by 2.25 in)) resulted in failures at mid-SIP (about one-half of the SIP remained attached to each of the aluminum plates after failure) at strengths of 309.6 and 314.4 kPa (44.9 and 45.6 psi).

TESTS

All fatigue tests were conducted in a closed-loop, servohydraulic testing machine. Details of the equipment and procedures are given in the appendix. A total of 15 specimens were fatigue tested. Of that number, 11 were subjected to constant-amplitude loading and 4 were subjected to random-amplitude loading. The distribution of the tests among the loading conditions is given in table II.

In all of the tests, the SIP was subjected to uniaxial loading in the through-the-thickness direction. The load on the specimen was cycled between zero and tension loading ($R = 0$ loading) at a cyclic frequency of 10 Hz. All tests were conducted at room temperature. Specimens were subjected to the 69-kPa (10-psi) proof load cycle shown in figure 2 before they were fatigue tested. Periodically during the tests, the load and SIP elongation were recorded during a complete load cycle that was run at 0.1 Hz.

In the random-amplitude tests, the spectrum of $R = 0$ stress cycles given in table III was applied to represent the loading experienced during the ascent portion of a single Shuttle mission. Use of this particular spectrum was rather arbitrary. Other spectra would have served the current purpose of evaluating life prediction methods equally well. The sequence of application of the load cycles from the spectrum was determined by a random draw without replacement procedure.

RESULTS AND DISCUSSION

Constant-Amplitude Tests

General elongation response.- The basic data taken during the fatigue tests consisted of SIP elongations as a function of load level and cycles of loading. A typical plot of the data recorded in a test is given in figure 3. As can be seen in the figure, the response of the SIP to the load cycling was marked by a progressive shift of the load/elongation curves to greater elongations without a noticeable change in the shape of the curves. That is, the principal change that occurred was an increase in the elongation at zero load, or an increase in the SIP thickness.

Measurement of thickness growth.- To characterize the increase in SIP thickness as a function of cycles of loading, the elongation of the SIP was measured at the peak load in the first cycle and in subsequent cycles. The increase in elongation above the first cycle datum level was taken as the measure of thickness growth in all subsequent data analyses. Measurements were taken at the peak load rather than at zero load for the following two reasons:

1. The data were to be compared to the data generated by Rockwell International, and those data were only available in the form of load/elongation X-Y plots that were frequently impossible to read at other points in the cycle (especially true at zero load) due to overlapping of the traces.

2. The elongation measurements at zero load were not reliable because the stiffness of the SIP was so low at zero load that small, within-tolerance changes in the testing machine load-control zero caused significant changes in measured elongation.

Data from the current constant-amplitude tests indicate that, as expected from examination of data plots such as in figure 3, about the same thickness growth would be measured regardless of the stress level at which thickness was measured. Figures 4(a) and 4(b) show the ratio of the thickness growth measured at the peak stress (71.7 kPa (10.4 psi) in this case) to the thickness growth measured at several lower stresses plotted against log cycles and cycles, respectively. As is evident in figure 4(a), the relative differences among the measurements could be large early in the tests when the thickness growth was small, but the differences rapidly diminished as the test progressed and the thickness growth increased. The maximum absolute difference between the growth measured at 13.8 kPa (2 psi) and at the peak stress was 0.2 mm (0.008 in).

Variation of thickness growth with load cycles.- The plot of thickness growth versus cycles that is shown in figure 4(b) is typical of the response of the SIP to cyclic loading. The thickness increased rapidly early in the test and continued to increase at a lower, almost constant rate for the majority of the test duration. If the tests were continued long enough, the rate of thickness growth eventually increased back to its early high levels before the specimen separated into two pieces.

Residual strength after fatigue test.- Most of the fatigue tests were stopped before SIP rupture occurred. Thickness growth ranged from 2.5 to 6.4 mm (0.10 to 0.25 in) when the various tests were stopped. After the fatigue tests, the intact specimens were loaded to determine residual strength. Of the 12 specimens tested, all had a residual strength equal to or greater than 276 kPa (40 psi), which was the testing limit imposed by load cell capacity (see table II).

Comparison of NASA-Langley and Rockwell data.- The thickness growth data from the current tests are plotted with the data from Rockwell International tests in figures 5 and 6. The two data sets agree well except at the low cycle ends of the curves for the 58.3-kPa (8.45-psi) tests. Some of the observed difference at the 58.3-kPa level is attributable to the application of a 69-kPa (10-psi) proof load cycle in the current tests but not in the Rockwell tests.

The difference in elongation behavior in tests with and without a proof cycle was investigated in a pair of tests using SIP from adjacent locations in the SIP sheet. The data plotted in figure 7 show that a difference in behavior was only evident for the first few cycles of the tests. The specimen that had not been proof tested showed a higher growth rate than the specimen that had been proof tested. As a result, proof loaded specimens required more cycles to attain a given growth due to fatigue loading. The proportionate effect of the proof cycle on cycles to attain a given thickness growth decreased as the test progressed. Also, the effect of the proof cycle was probably even smaller at higher fatigue stress levels.

The NASA-Langley and Rockwell data sets were also compared by plotting the data in the form of S-N curves. In the current case, the "N" represents the number of cycles to attain a given thickness growth. The data are plotted together in figure 8 for growths of 0.76, 1.52, and 2.29 mm (0.03, 0.06, and 0.09 in). The two data sets agree well at the 2.29-mm growth level, but there is an apparently widening disagreement between the data sets as the growth level is lowered. The apparent disagreement at the lower growth levels is due largely to inaccurate interpolation of the Rockwell data over large intervals and to the differences caused by the proof cycle. At the 2.29-mm level, the interpolation problem with the Rockwell data did not exist, and the effect of the proof cycle was greatly diminished.

Based on the foregoing comparisons, it appears that the two data sets are consistent, but that the data sets cannot be directly combined at the low growth levels of low stress level tests due to testing differences.

Analytical representation of constant-amplitude test data.- One of the purposes of the current work was to develop an analytical procedure for calculating the thickness growth of the SIP as a function of the cyclic loading. The first step in this procedure was to develop equations representing the SIP response in constant-amplitude loading tests. The approach taken in the current work was to write equations for the rate data and then integrate to obtain thickness growth.

The NASA-Langley rate data in figure 6 have been replotted in figure 9. From the figure, it appeared that the rate data for each stress level could be adequately represented by two straight line segments. The equations for the lines were of the form

$$\log\,(\text{rate}) = C_0 + C_1 \log\,(\text{cycles}) \qquad (1 < \text{cycles} < N_o)$$

$$\log\,(\text{rate}) = C_2 \qquad (\text{cycles} \geqq N_o)$$

where C_0, C_1, C_2, and N_o are constants. The slope, C_1, appeared to be about the same for all of the stress levels, but C_0, C_2, and N_o were functions of stress level. Since N_o is implicitly defined by the other constants, all of the rate data could be represented by two equations by writing equations for C_0 and C_2 in terms of test stress level. The resulting equations for the NASA-Langley data were

$$\log\,(\text{rate}) = (-6.99 + 2.88 \log\,(\text{stress})) - 0.75 \log\,(\text{cycles}) \qquad (1 < \text{cycles} < N_o)$$

$$\log\,(\text{rate}) = -20.25 + 8.00 \log\,(\text{stress}) \qquad (\text{cycles} \geqq N_o)$$

when thickness growth rate was expressed in mm/cycle and stress in kPa. When thickness growth rate was expressed in in/cycle and stress in psi, the corresponding equations were

$$\log\,(\text{rate}) = (-5.98 + 2.88 \log\,(\text{stress})) - 0.75 \log\,(\text{cycles}) \qquad (1 < \text{cycles} < N_o)$$

$$\log\,(\text{rate}) = -14.95 + 8.00 \log\,(\text{stress}) \qquad (\text{cycles} \geqq N_o)$$

Results obtained by integrating the above equations are plotted along with test data in figure 10. Results are plotted in figure 11 in the form of S-N curves. As can be seen in the figures, integration of the rate equations produces a good fit to the test data.

Variation of tangent modulus with load cycles.- As mentioned previously, visual examination of the basic load versus SIP elongation data charts (see fig. 3) did not reveal a noticeable change in the shape of the curves as the test progressed. To determine whether this assessment was correct, the sampled load/elongation data that were stored on magnetic tape were analyzed to determine the variation in tangent modulus with load cycles. Tangent moduli for the increasing load portion of the cycles were estimated by calculating the slope defined by successive data samples and assuming that the slope was equal to the tangent modulus at the midpoint of the load interval.

Typical variations of tangent modulus with stress level during various cycles in a test are shown in figure 12. Figure 13, a crossplot of the data in figure 12, illustrates the variation of tangent modulus with load cycles at several stress levels. Although not obvious in plots like figure 3, figure 13 shows that the tangent modulus increases by as much as 80 percent above that measured in the first cycle after proof test. Much of the increase in tangent modulus occurs early in the test, as shown in the linear plot in figure 13(b).

Random-Amplitude Tests

To evaluate the capability of simple cumulative damage fatigue models to predict the life/thickness growth behavior of SIP subjected to random-amplitude loading, four specimens were tested to the spectrum of $R = 0$ load cycles given in table III. Test results are plotted in figure 14.

The lives predicted by using the Miner linear cumulative damage model (see ref.) in conjunction with the NASA-Langley S-N data (fig. 8) are plotted in figure 14 along with the random-amplitude test results. The ratio of predicted to experimental mean lives was 1.5 at the 0.76-mm (0.03-in) growth level and was 1.0 at the 2.29-mm (0.09-in) growth level. Although the experimental data are very limited, these results indicate that it is feasible to use the Miner method to predict the thickness growth behavior of SIP subjected to random-amplitude loading.

Another method used to predict the results of the random-amplitude loading was to assume that the thickness growth in any load cycle depends only upon the cycle stress level and the growth level at the start of the cycle, and then to simply integrate the growth rate equations presented earlier for constant-amplitude loading. The assumptions of this method are similar to, but not exactly the same as, those for the Miner method. Lives predicted by this method are plotted in figure 14 along with the test results and the lives predicted by the Miner method. The results obtained with this method were about the same as those by the Miner method.

CONCLUDING REMARKS

The fatigue behavior of 0.41-cm (0.16-in) thick SIP material was explored in a series of constant- and random-amplitude loading tests. In the tests, 12.7- by 12.7-cm (5.0- by 5.0-in) SIP specimens were subjected to tension-tension loading in the through-the-thickness direction at a cyclic frequency of 10 Hz. Analysis of the results of these tests supports the following conclusions and observations:

1. The SIP stress-strain behavior changed continually throughout the course of a fatigue test. During a test, the SIP exhibited a monotonic increase in thickness (permanent elongation) and a monotonic increase in tensile tangent moduli.

2. The thickness growth per cycle was a function of the test stress level and the number of load cycles already endured. The growth rate increased

with increasing stress level and decreased with increasing number of cycles endured.

3. Power law equations fit the constant-amplitude thickness growth rate data very well.

4. After the SIP thickness had grown about 2.5 mm (0.10 in) in the tests, tensile tangent moduli were as much as 80 percent greater than those at the start of fatigue loading.

5. Application of a 69-kPa (10-psi) proof load cycle before fatigue testing at a level below 69 kPa retarded the thickness growth for about the first 10 cycles of the test.

6. The constant-amplitude loading fatigue data generated by NASA-Langley and Rockwell International agreed well except for the early portions of low stress level tests. Some of the disagreement at low stress levels was caused by the inclusion of a 69-kPa (10-psi) proof load cycle in the NASA tests that was not in the Rockwell tests.

7. Based on limited (four tests) random-amplitude testing, it appears that simple cumulative damage fatigue models and constant-amplitude loading fatigue data can be used to predict the thickness growth behavior of SIP subjected to random-amplitude loading with reasonable accuracy. In the current tests, the ratio of predicted to experimental mean lives was 1.5 at the 0.76-mm (0.03-in) thickness growth level and was 1.0 at the 2.29-mm (0.09-in) growth level.

APPENDIX

TEST EQUIPMENT AND PROCEDURES

Specimen Installation

The procedure for installing a specimen in the testing machine was as follows: (1) the top specimen plate was screwed onto the stud in the load cell and secured with a locknut; (2) the extensometers were fastened to the upper specimen plate; (3) the load cell output was zeroed; (4) the grip tang was screwed into the bottom specimen plate and secured with a locknut; (5) the hydraulic actuator was moved up into position using a manual flow control valve and was secured to the grip tang; (6) the machine was put into active load control and held at zero load while the extensometer outputs were zeroed. Care was taken during all steps to avoid applying torque to the specimen.

Load and SIP Elongation Measurements

A 4.45-kN (1000-lb) capacity load cell was used to measure the loads applied to the SIP specimens. The cell output was amplified so that 2.22 kN (500 lb) corresponded to full-scale command in the servocontrol circuits.

Axial elongation of the SIP was measured by using direct-current-differential-transformer (DCDT) extensometers to sense the relative displacement between the top and bottom specimen plates. An extensometer was attached at the center of each of the sides of the specimen. The average of the four extensometer measurements was used as the measure of axial elongation in all data analyses.

Periodically during the fatigue tests, the outputs of the load cell and the extensometers were recorded during a complete load cycle that was run at a frequency of 0.1 Hz. The following recordings were made during each cycle: (1) load and average SIP elongation (average of the four extensometer outputs) were recorded versus time on an oscillograph; (2) load versus individual extensometer outputs were recorded on X-Y-Y recorders; (3) load and average SIP elongation were sampled three times per second and recorded on a digital magnetic tape cassette.

Testing Machine Programming and Control

Test load sequences were programmed using a digital programming unit that included a magnetic tape reader and a command signal generator. Information on loading frequency, load level, number of cycles to be completed before the next instruction, and number of load cycles between SIP elongation recordings was stored on the tape. The command signal generator generated analog signals for the servocontrol loop in accordance with instructions on the tape. Before extensometer readings were to be recorded, the programmer automatically stopped the load cycling and held the load at zero until a manual instruction was input indicating that the recording instrumentation was ready.

A load-error pacing system was used to assure that the load level remained at the correct level while the test machine was unattended. With this system, when the error (difference between command and load feedback) exceeded preset limits (±2 percent of range at peak load), the signal generator was temporarily held at its current value until the error was reduced to within the limits. The action of the pacing system required the input of a frequency command higher than that actually desired. The correct command had to be determined experimentally before the test program began. The pacing system also tended to lower the cyclic frequency during the course of a test as SIP elongation increased, but the frequency seldom went below 9.5 Hz. Infrequent manual inputs to the programmer kept the frequency very near 10 Hz.

REFERENCE

Miner, Milton A.: Cumulative Damage in Fatigue. J. Appl. Mech., vol. 12, no. 3, Sept. 1945, pp. A159-A164.

TABLE I.- INFORMATION ON SIP MATERIAL

IDENTIFICATION TAG

PART NUMBER		
CLASS 3		TYPE 2
CHG.	DATE	INSP.
160	JUL 22 '80	ANM 381
REMARKS:		
SIP D88218		GRADE A
TCK MBO 135-051		PSI 43.1

TABLE II.- SUMMARY OF TESTS

Maximum fatigue stress, kPa (psi)	Specimen number	SIP thickness growth at end of fatigue test, mm (in)	Residual strength, kPa (psi)
Constant-amplitude loading[a]			
103 (15.0)	A4	5.6 (0.22)	>276 (>40)
	B2	>7.6 (>0.30)	b b
	C3	5.1 (0.22)	>276 (>40)
71.7 (10.4)	A2	6.1 (0.24)	>276 (>40)
	B3	3.0 (0.12)	>276 (>40)
	D1	6.4 (0.25)	c c
58.3 (8.45)	A3	2.8 (0.11)	>276 (>40)
	C1	2.8 (0.11)	>276 (>40)
	D2	2.5 (0.10)	c c
	[d]E2	5.1 (0.20)	276 (40)
	E4	3.8 (0.15)	>276 (>40)
Random-amplitude loading[a]			
101 (14.7)	B1	4.1 (0.16)	>276 (>40)
	C2	6.6 (0.26)	>276 (>40)
	D3	2.8 (0.11)	>276 (>40)
	D4	3.0 (0.12)	>276 (>40)

[a]All load cycles were zero-to-tension (R = 0). Cyclic frequency was 10 Hz.

[b]Taken to failure in fatigue test.

[c]No residual strength test.

[d]No proof load cycle was applied in this test.

TABLE III.- STRESS SPECTRUM USED IN RANDOM-AMPLITUDE LOADING TESTS

Maximum stress in cycle, kPa (psi)	Occurrences per mission
43 (6.3)	302
53 (7.7)	266
63 (9.1)	904
72 (10.5)	1074
82 (11.9)	556
92 (13.3)	96
101 (14.7)	4

Note: All load cycles were zero-to-tension ($R = 0$).

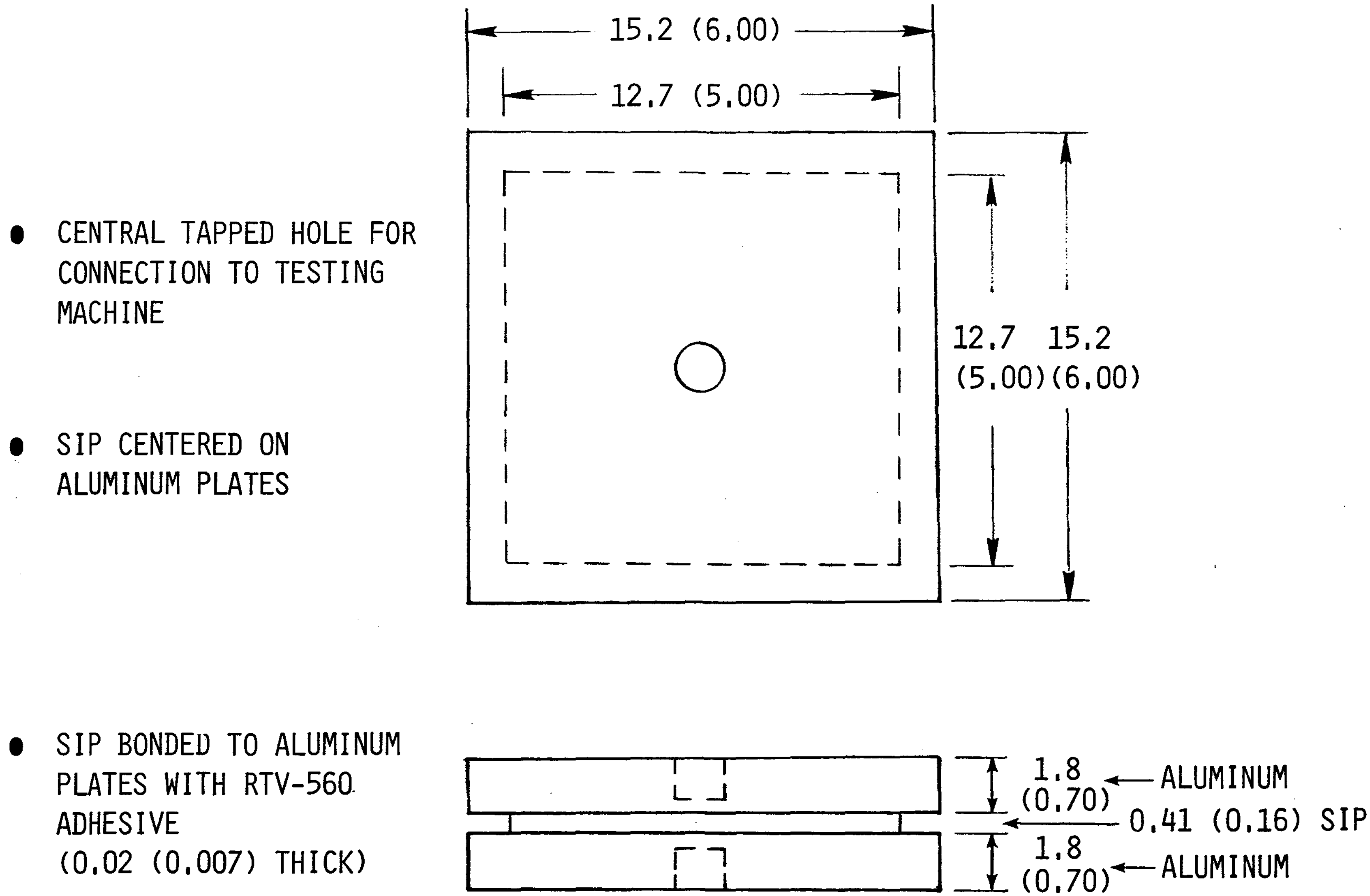


Figure 1.- Specimen configuration. Dimensions in cm (in).

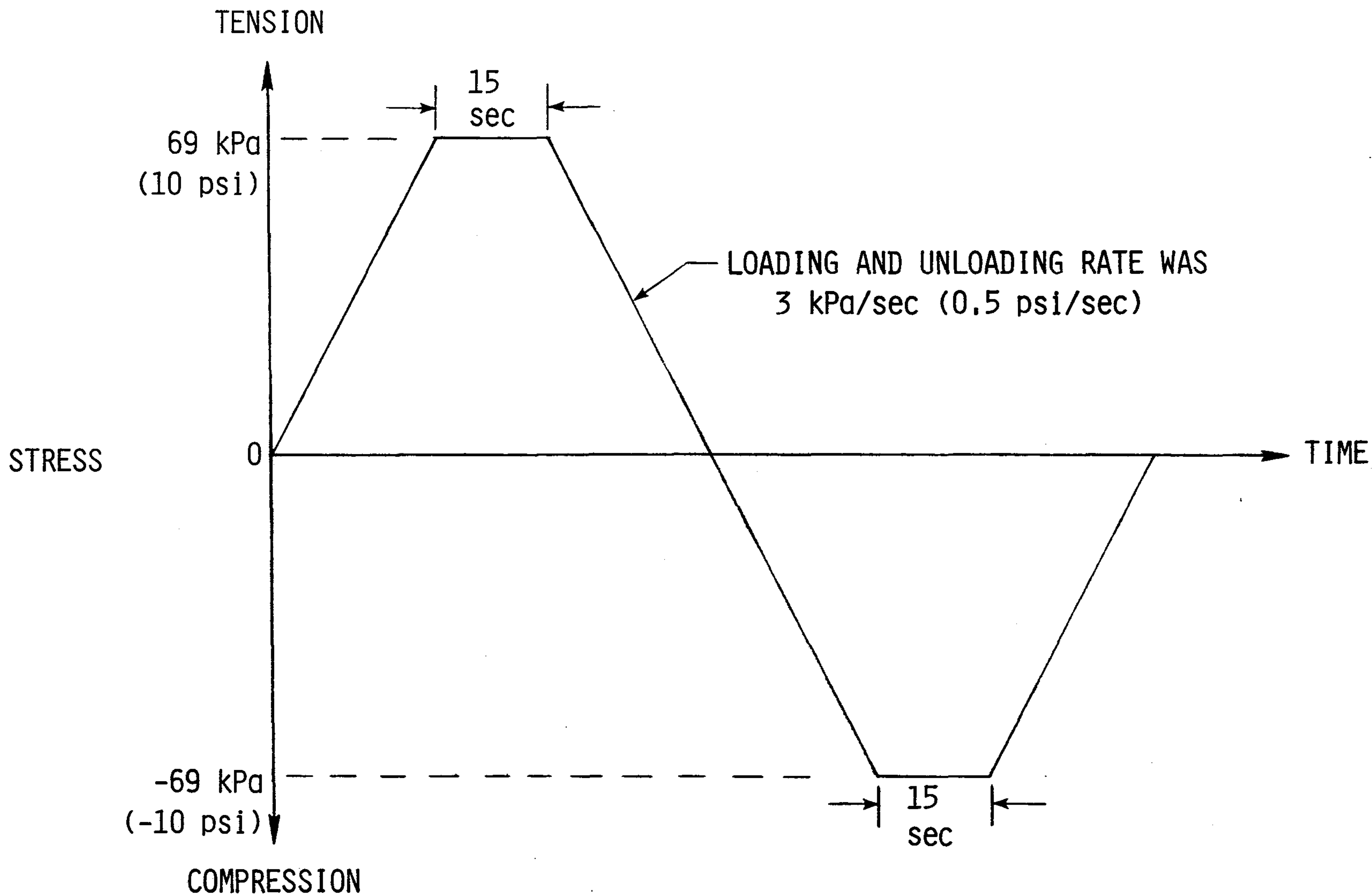


Figure 2.- Proof load cycle.

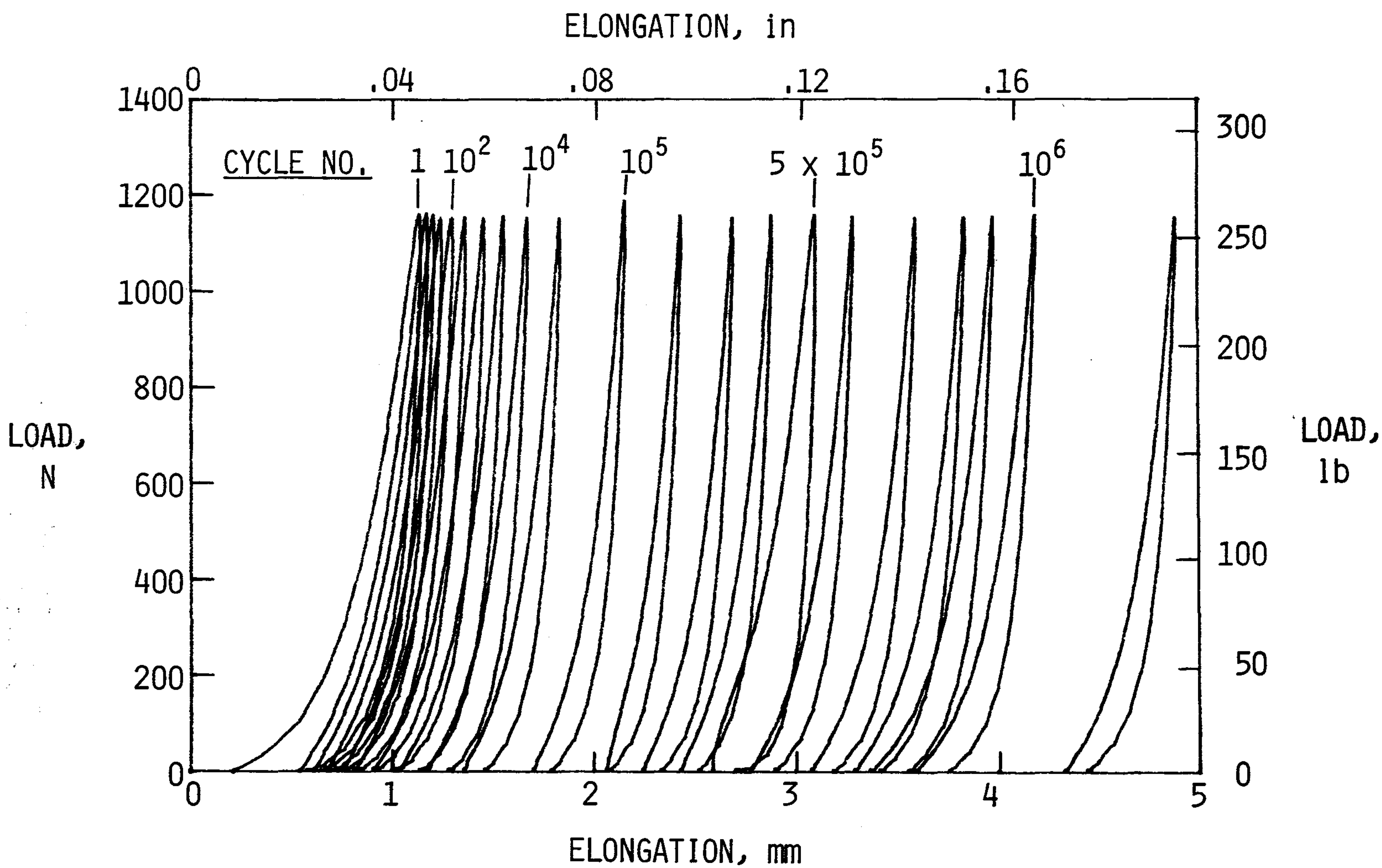


Figure 3.- Typical plot of the load/elongation data recorded in the fatigue tests.

(a) Variation with the logarithm of load cycles.

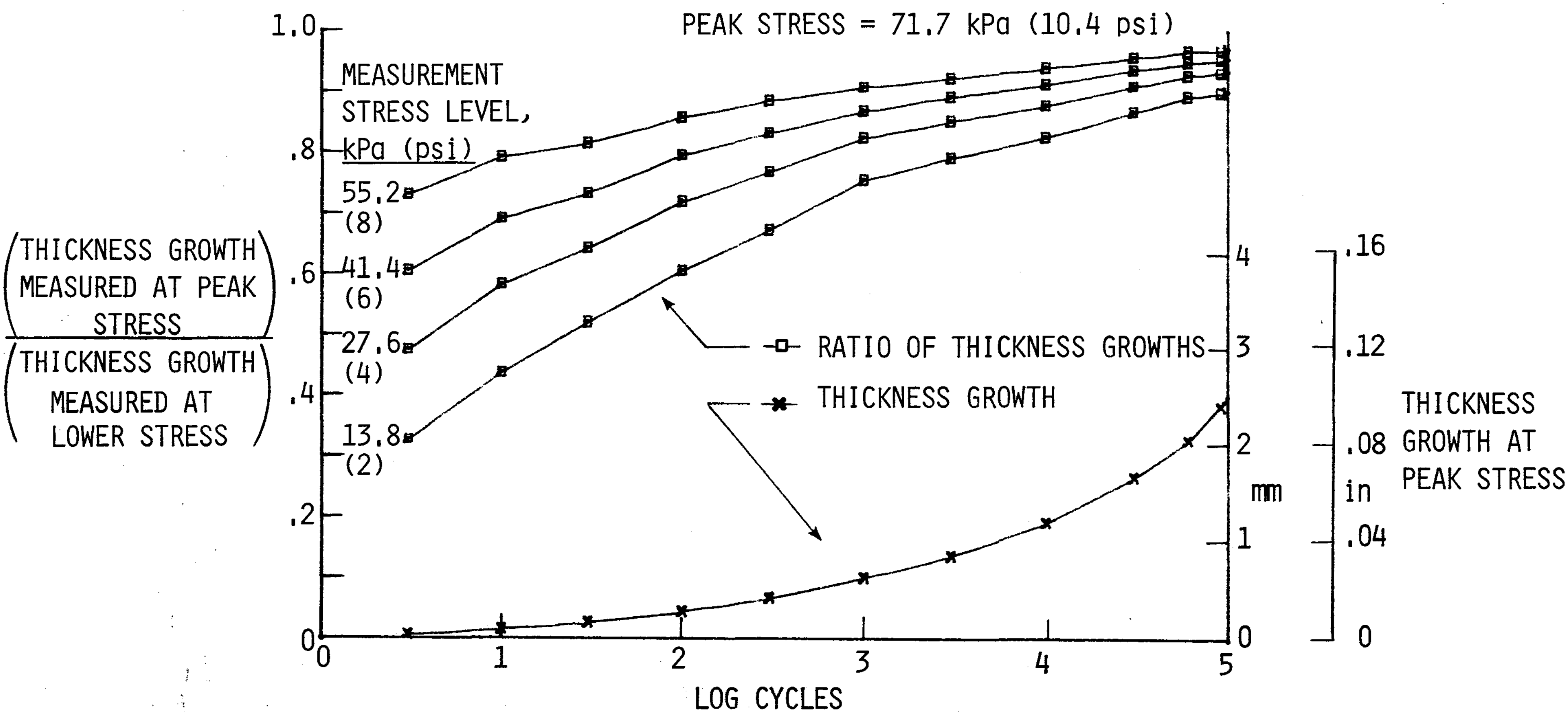


Figure 4.- Effect of the measurement stress level on the SIP thickness growth measured during fatigue tests.

(b) Variation with load cycles.

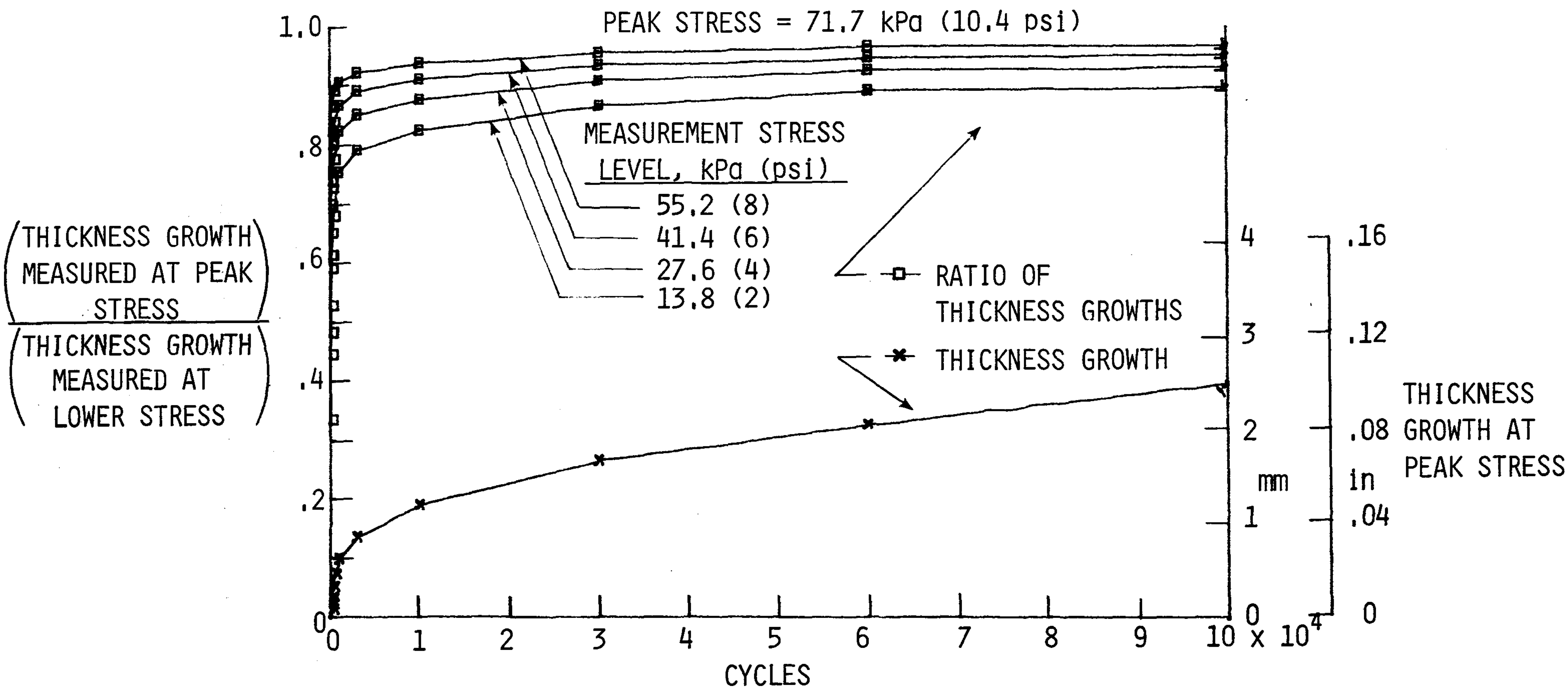


Figure 4.- Concluded.

(a) Peak stress = 103 kPa (15.0 psi).

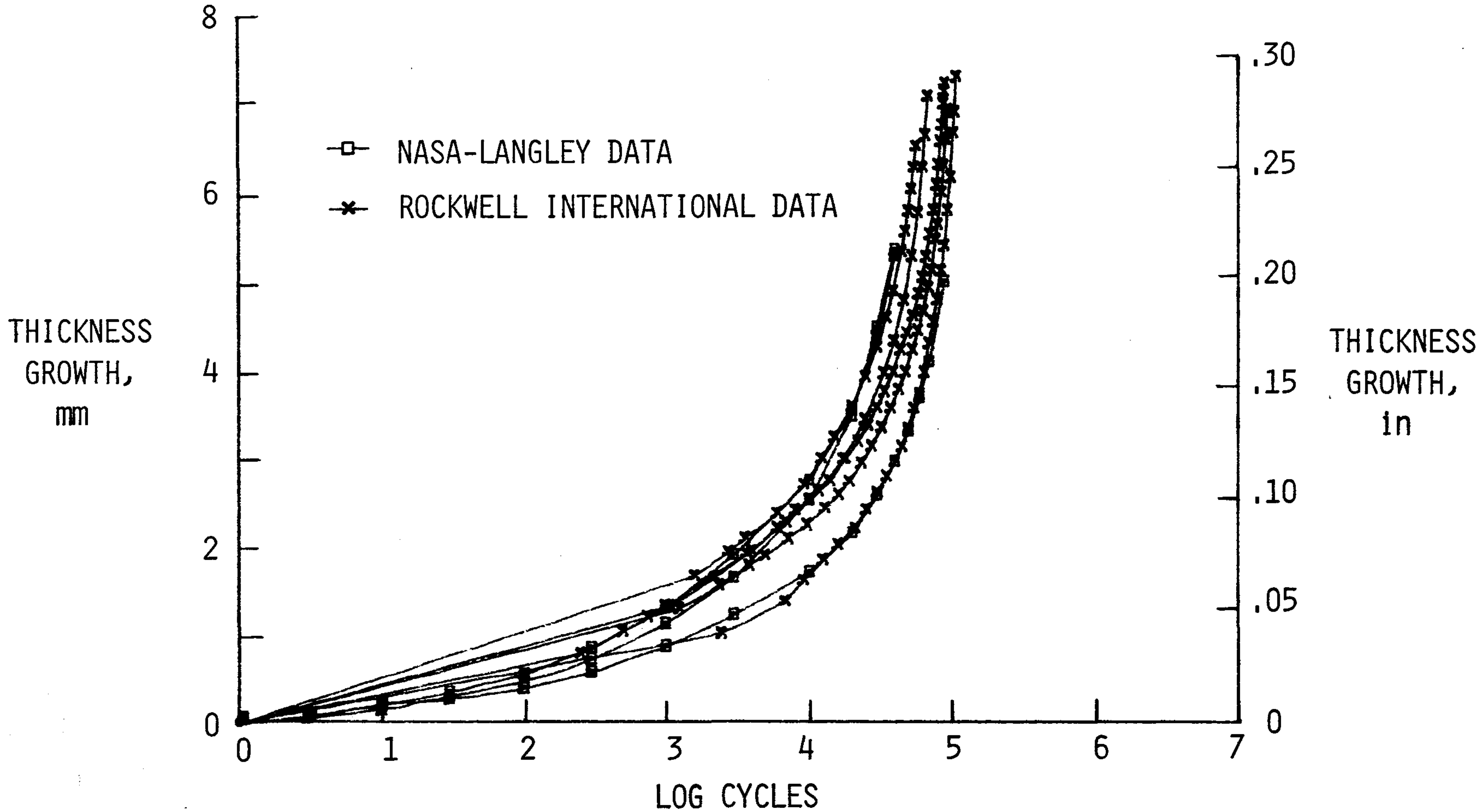


Figure 5.- SIP thickness-growth data generated by NASA-Langley and Rockwell International in constant-amplitude loading fatigue tests.

(b) Peak stress = 71.7 kPa (10.4 psi).

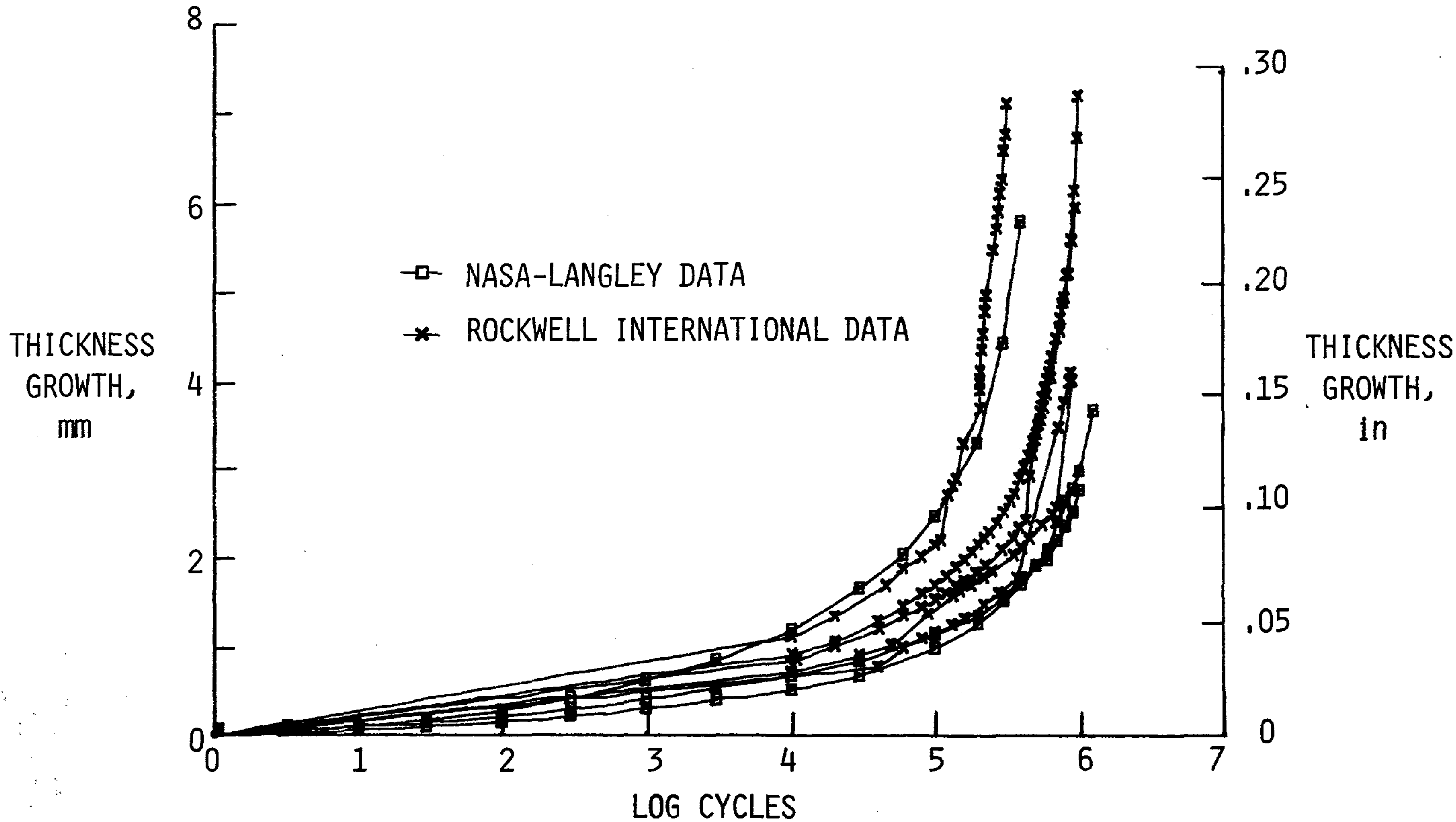


Figure 5.- Continued.

(c) Peak stress = 58.3 kPa (8.45 psi).

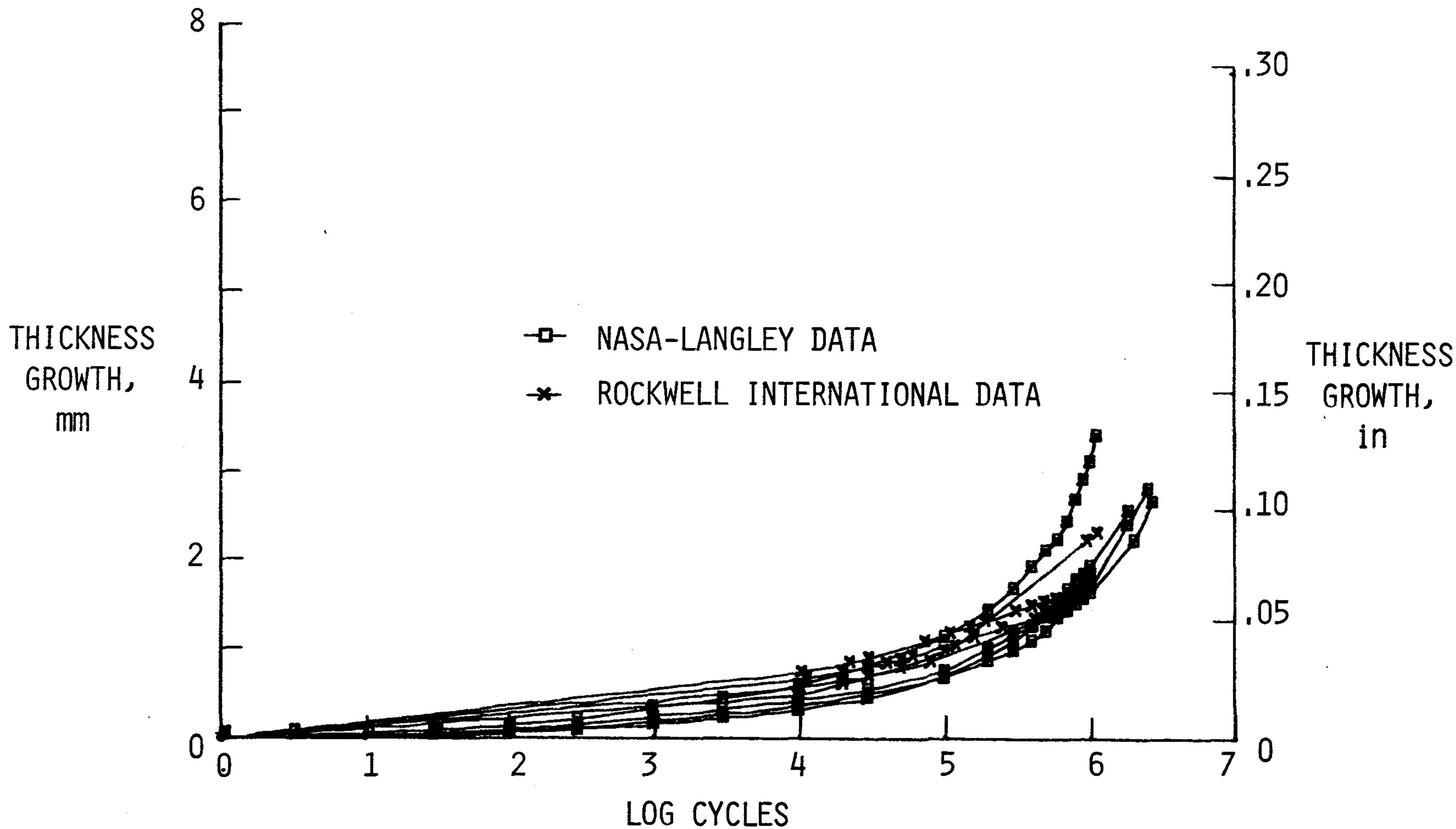


Figure 5.- Concluded.

(a) Peak stress = 103 kPa (15.0 psi).

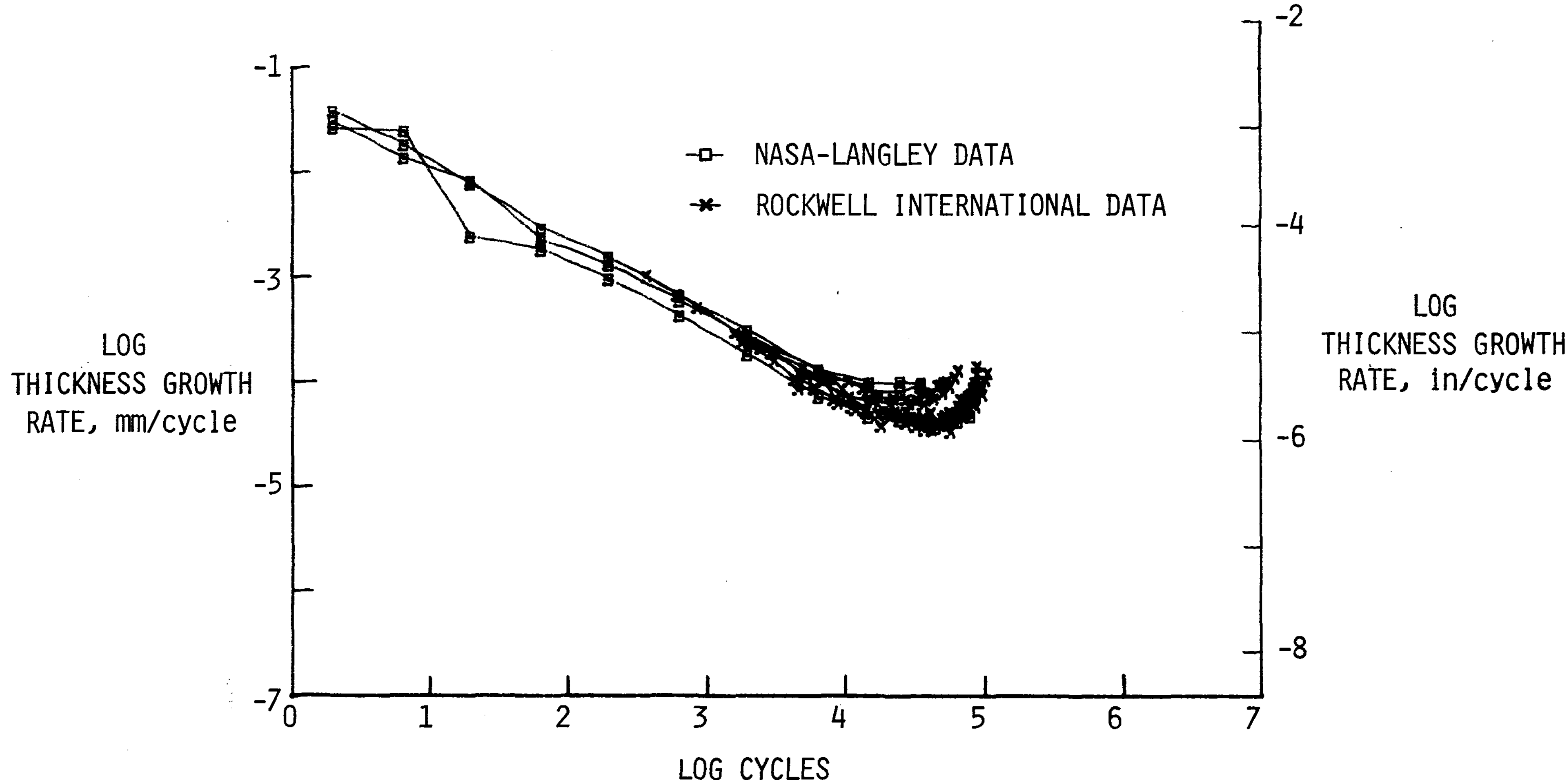


Figure 6.- SIP thickness-growth-rate data generated by NASA-Langley and Rockwell International in constant-amplitude loading fatigue tests.

(b) Peak stress = 71.7 kPa (10.4 psi).

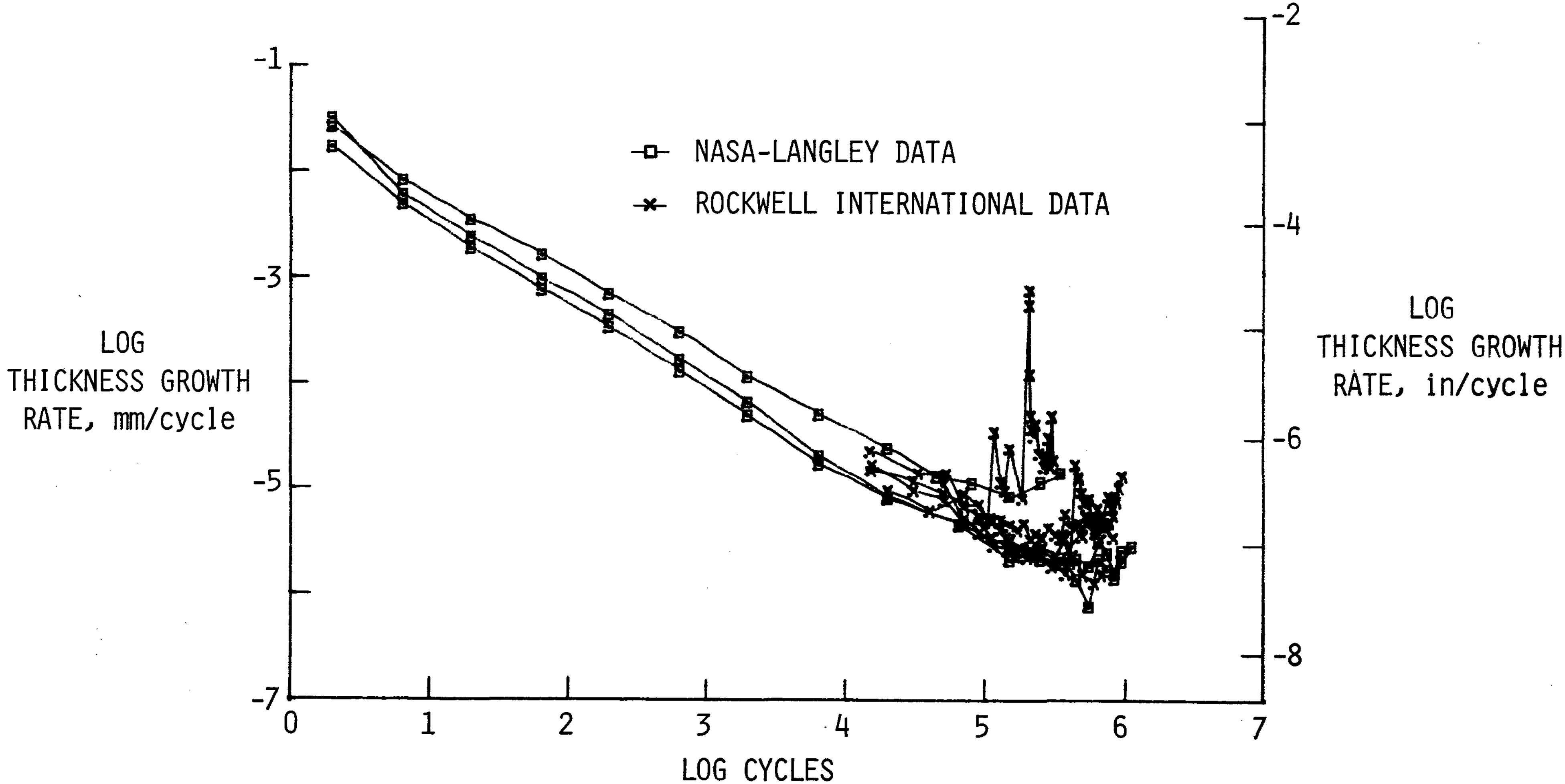


Figure 6.- Continued.

(c) Peak stress = 58.3 kPa (8.45 psi).

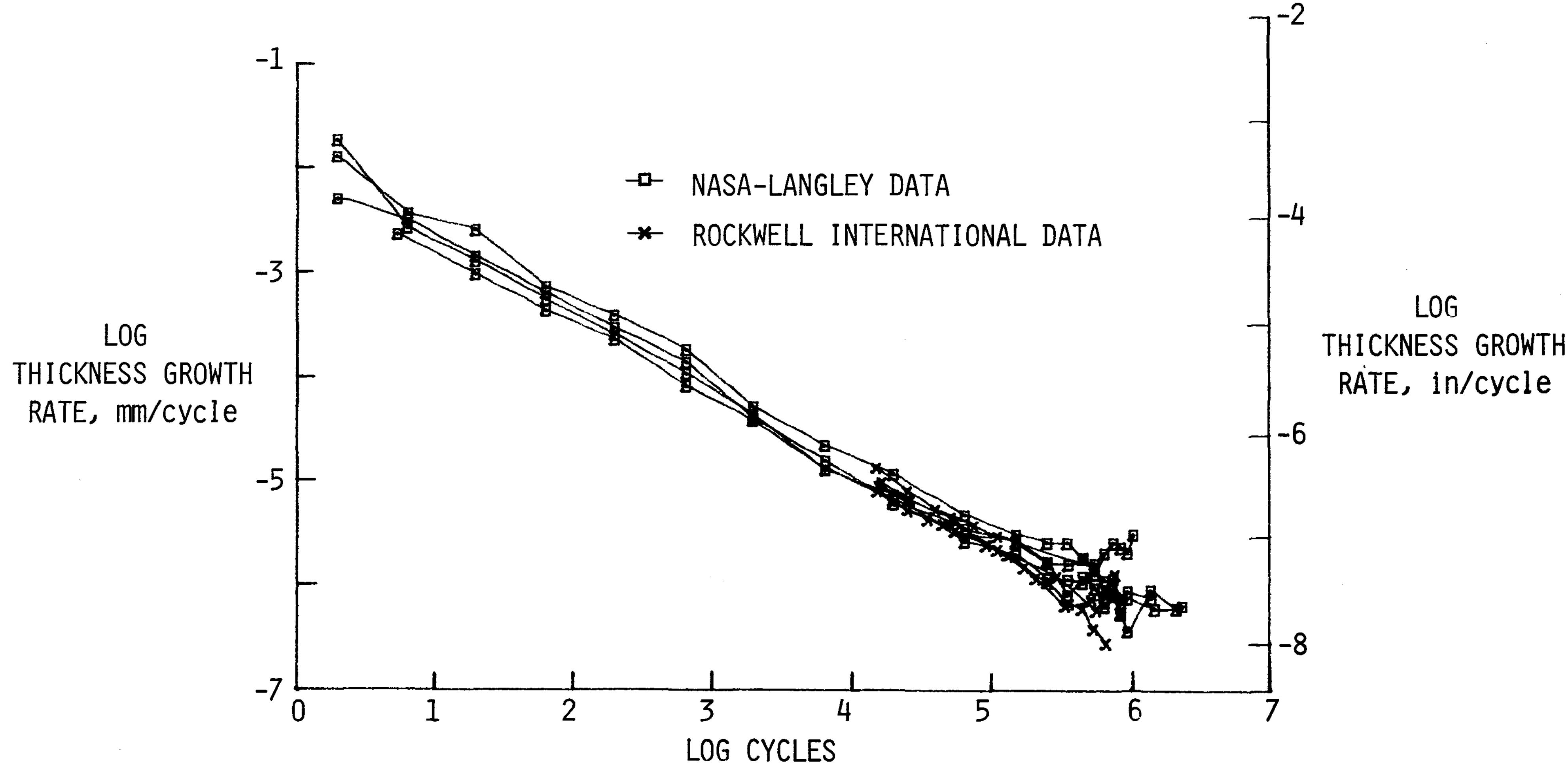


Figure 6.- Concluded.

(a) Thickness-growth data.

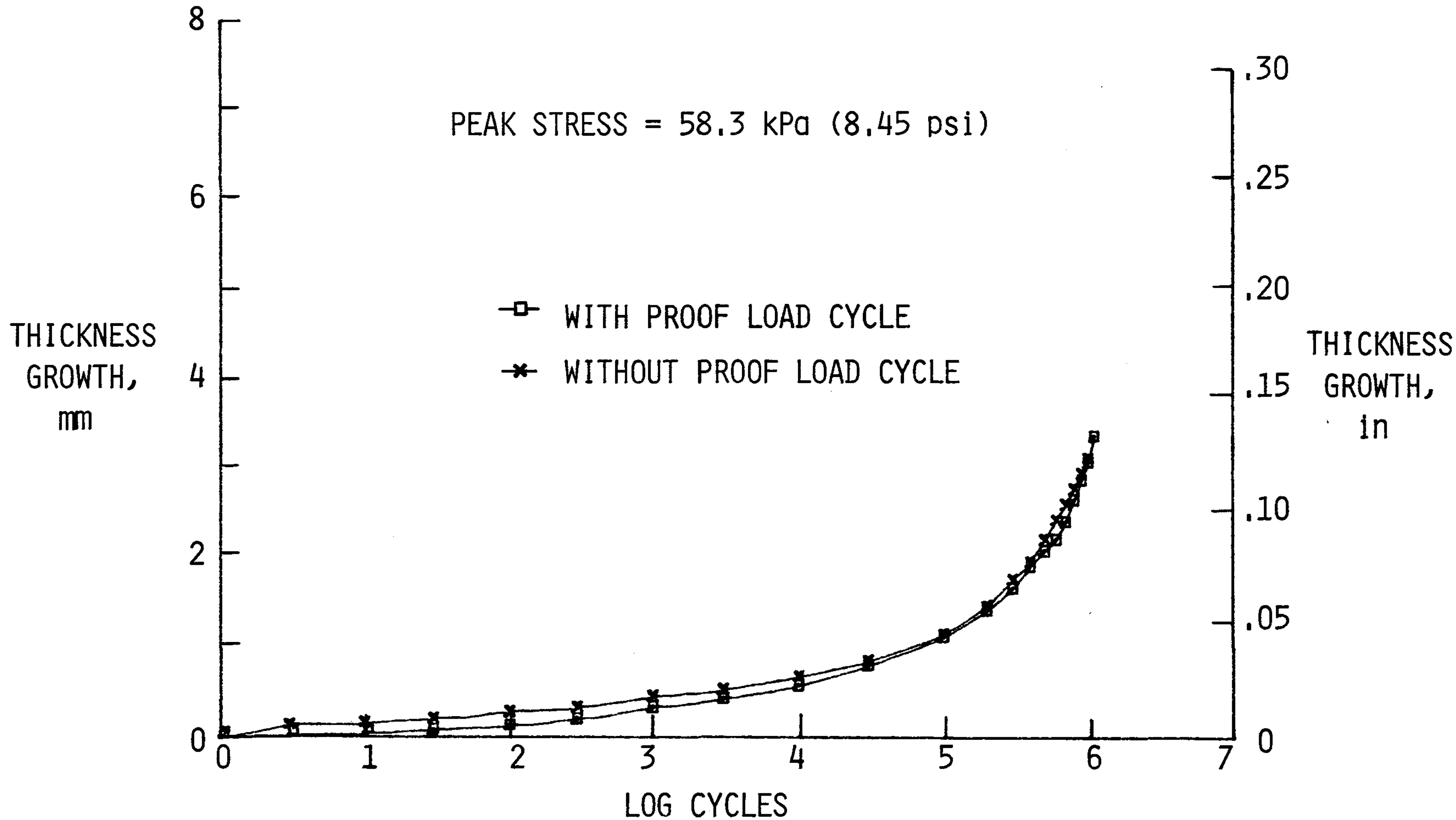


Figure 7.- Effect of a 69 kPa (10 psi) proof load cycle on the thickness-growth behavior of the SIP.

(b) Thickness-growth-rate data.

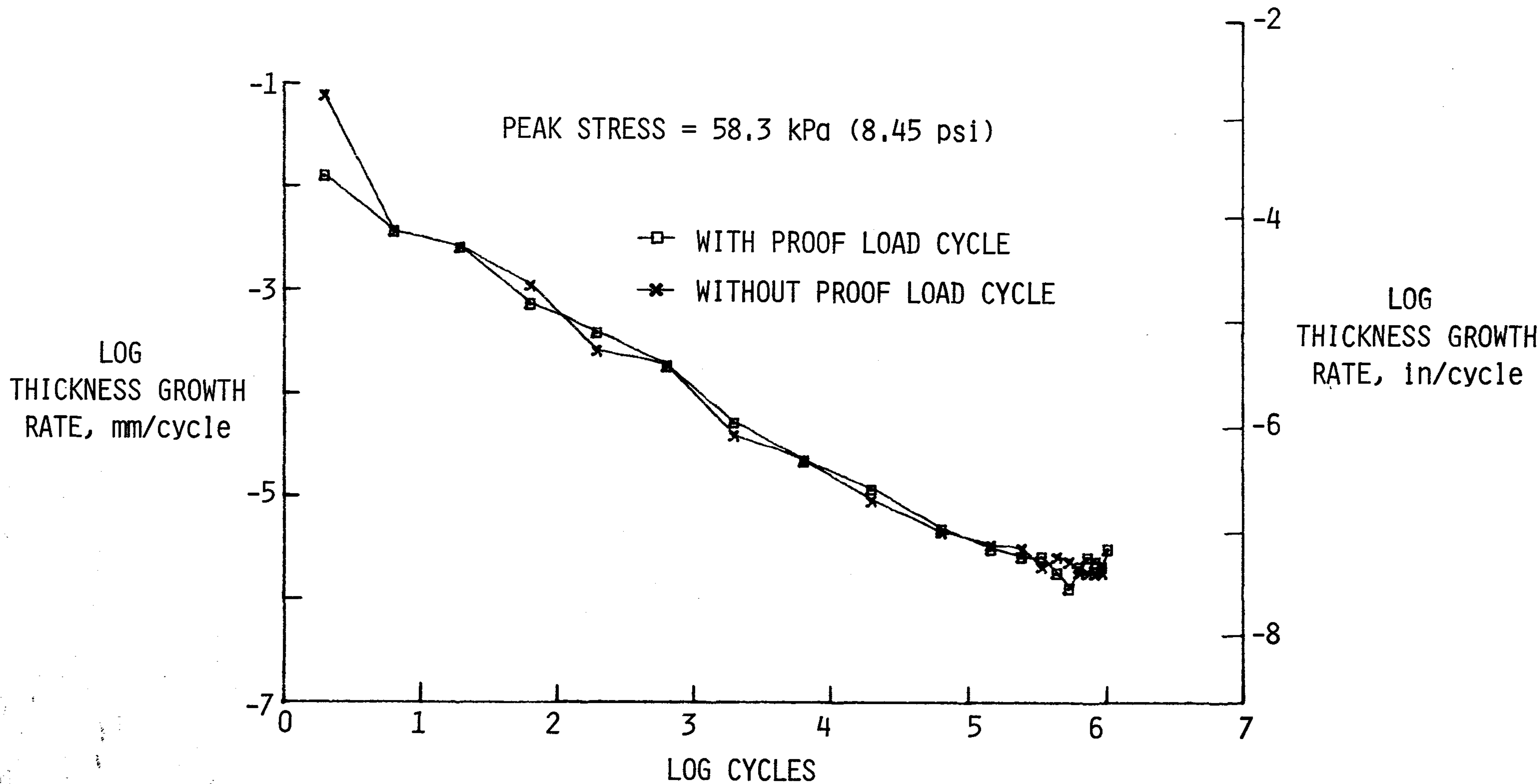


Figure 7.- Concluded.

(a) Thickness growth = 0.76 mm (0.030 in).

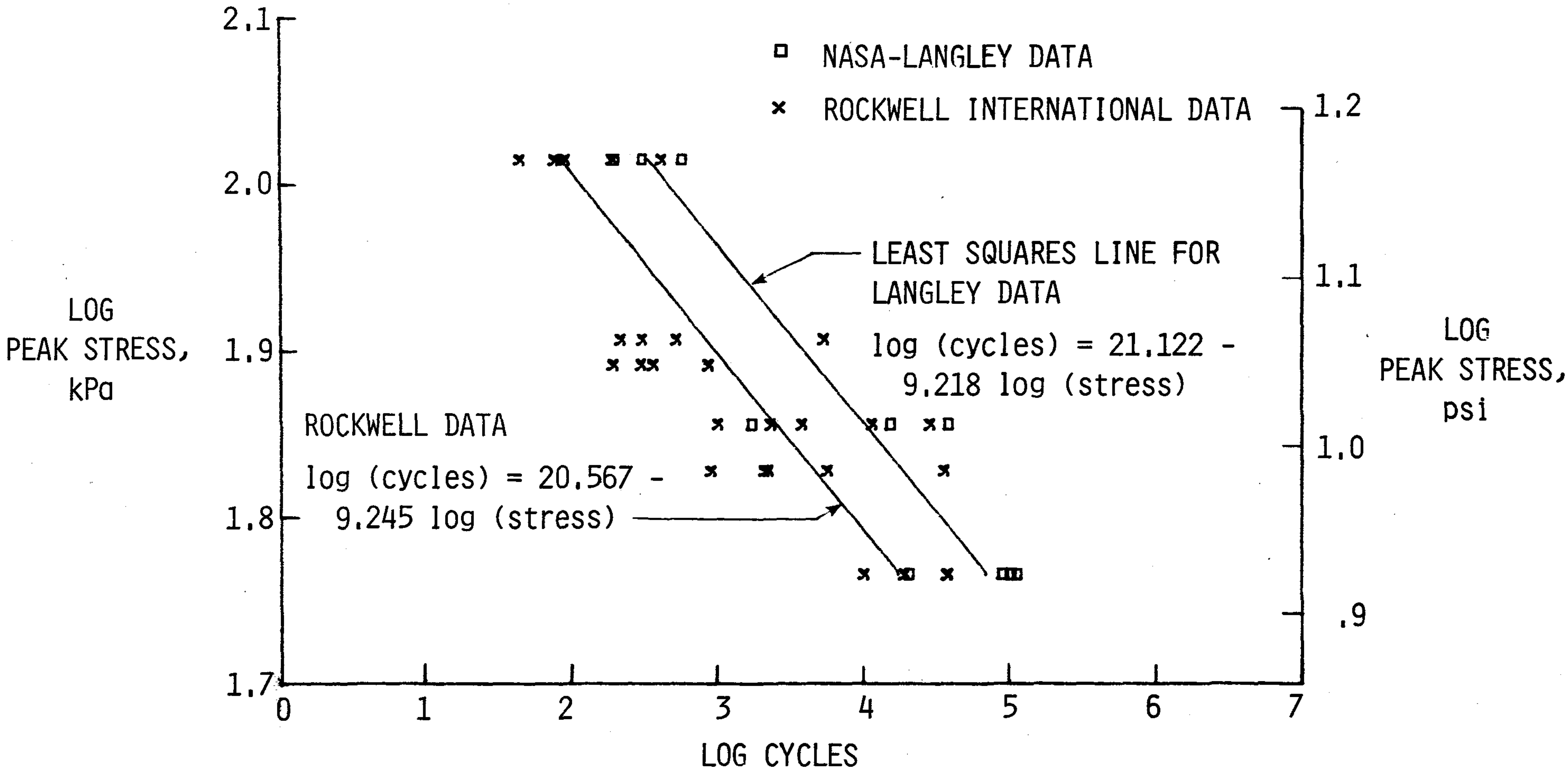


Figure 8.- S-N curve representation of the NASA-Langley and Rockwell International thickness-growth fatigue data.

(b) Thickness growth = 1.52 mm (0.060 in).

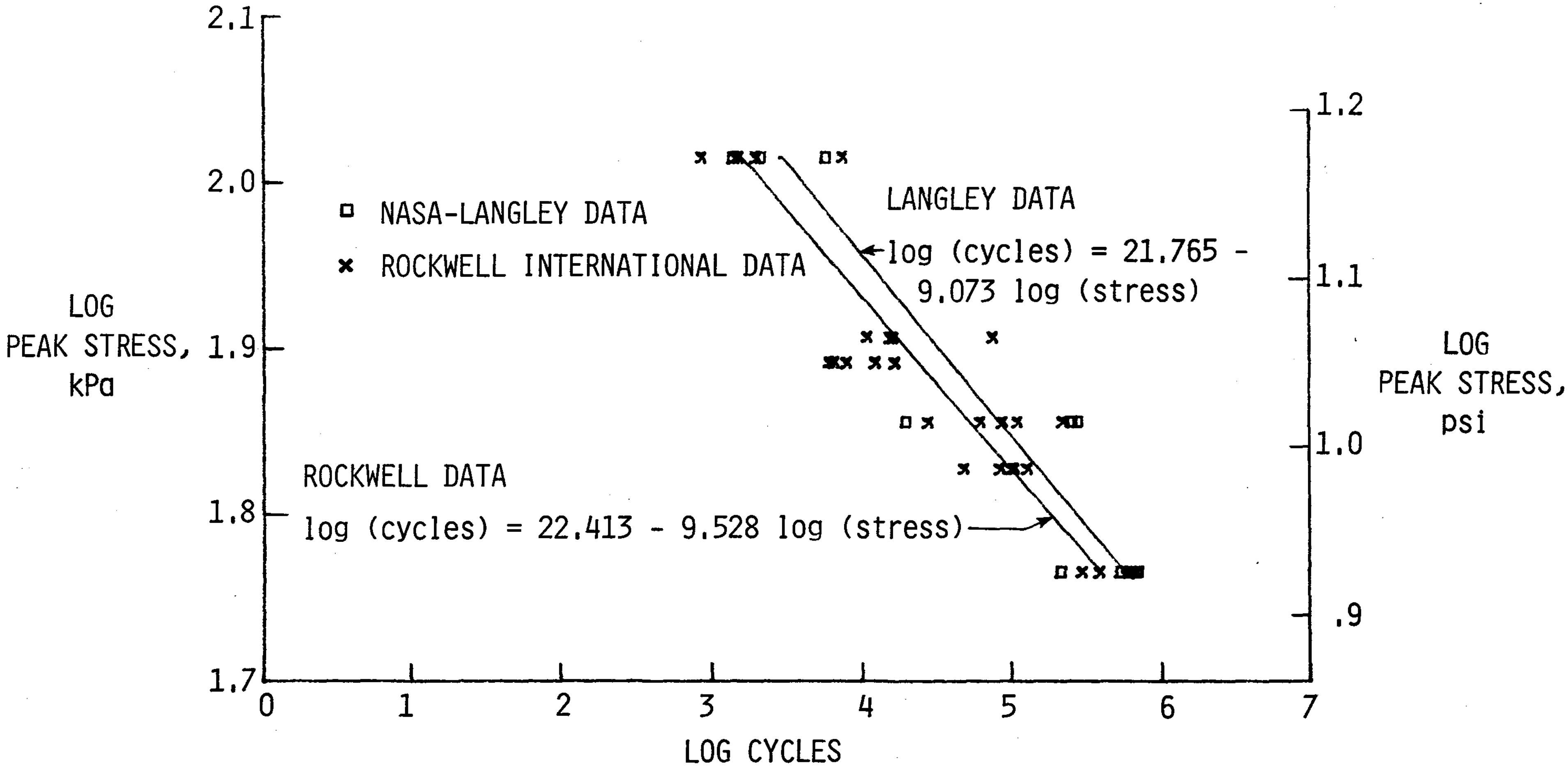


Figure 8.- Continued.

(c) Thickness growth = 2.29 mm (0.090 in).

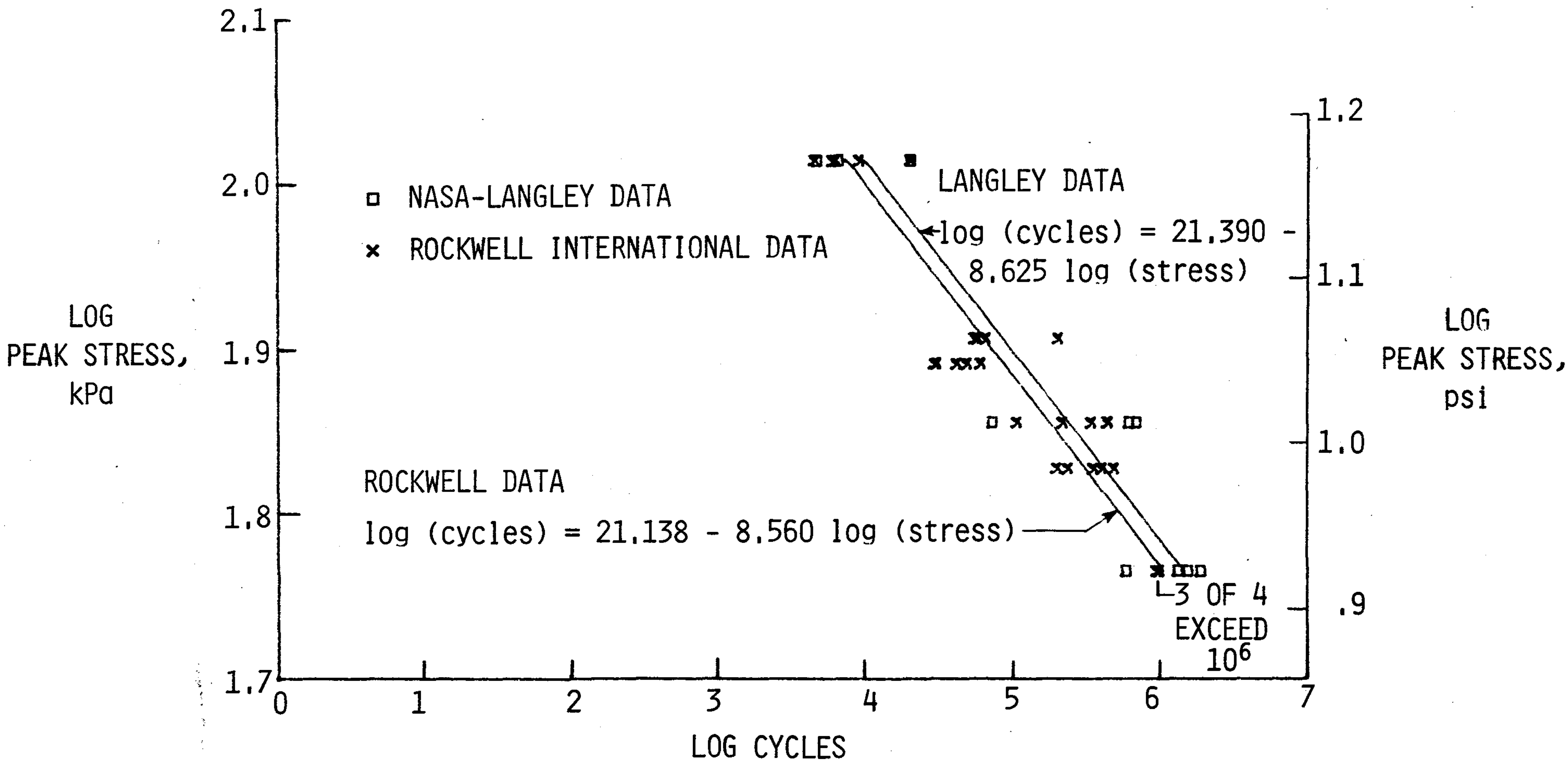


Figure 8.- Concluded.

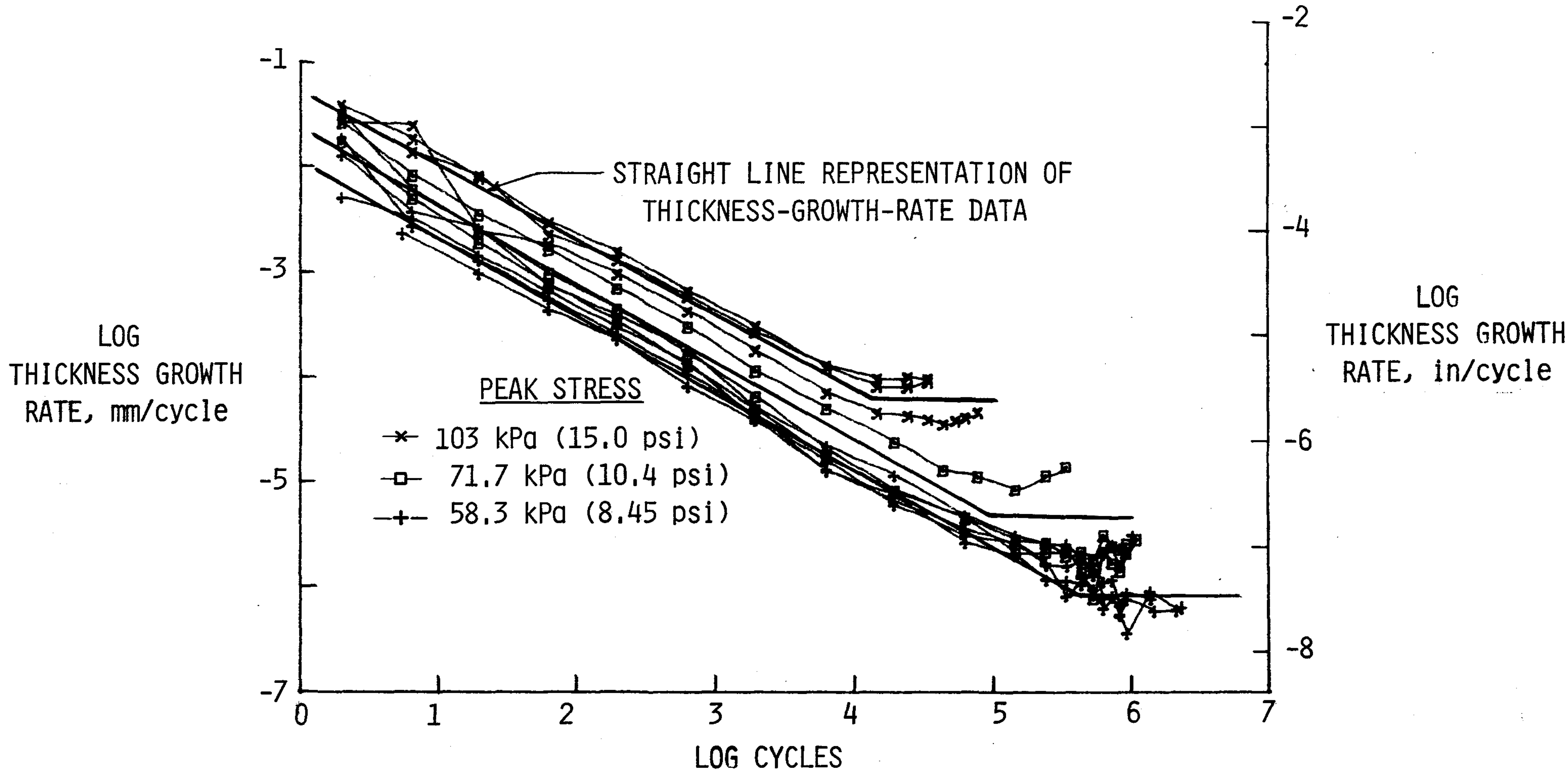


Figure 9.- Representation of the NASA-Langley thickness-growth-rate data for each test stress level by two straight line segments.

(a) Peak stress = 103 kPa (15.0 psi).

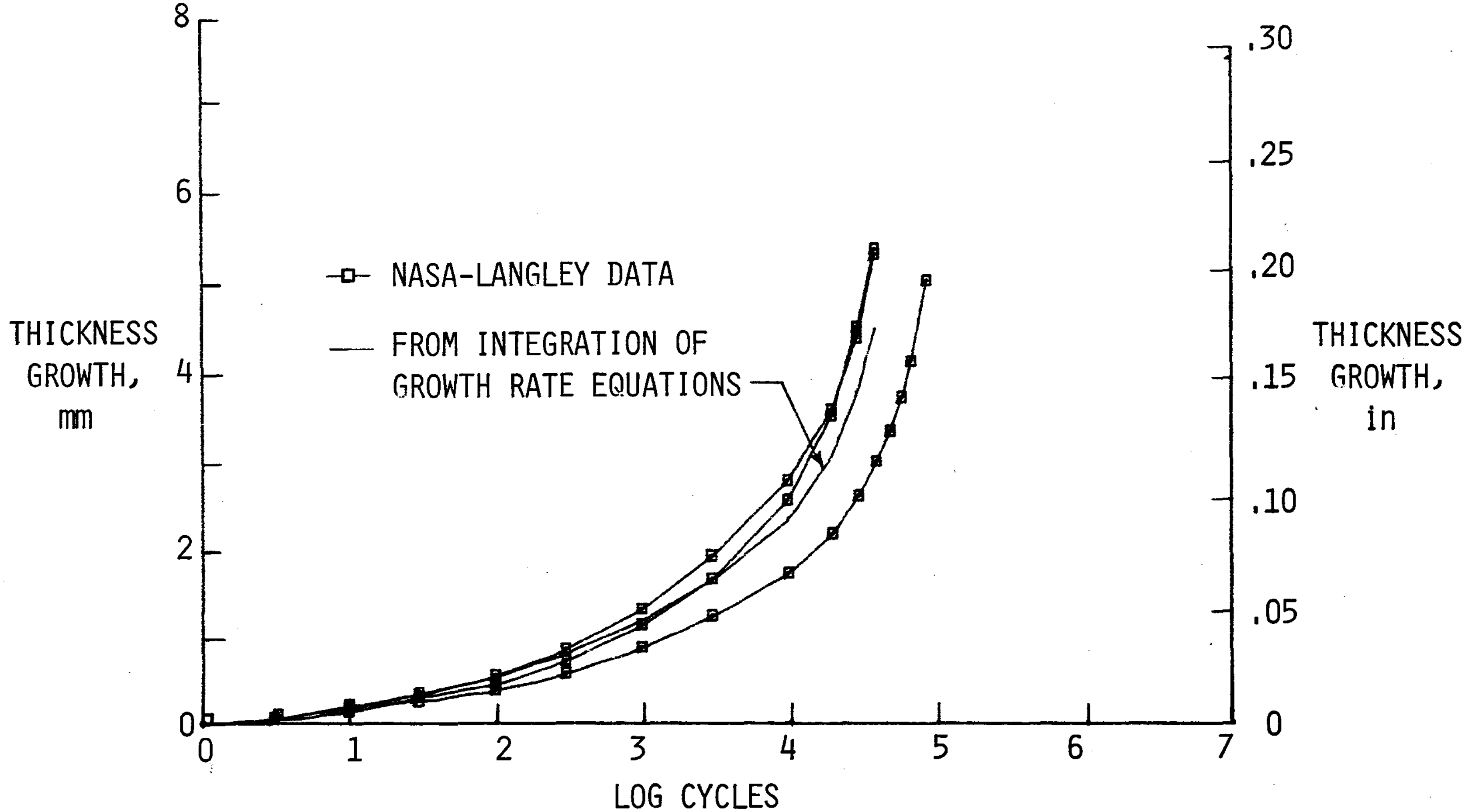


Figure 10.- Comparison of the thickness-growth data to the thickness growth calculated by integrating the thickness-growth-rate equations.

(b) Peak stress = 71.7 kPa (10.4 psi).

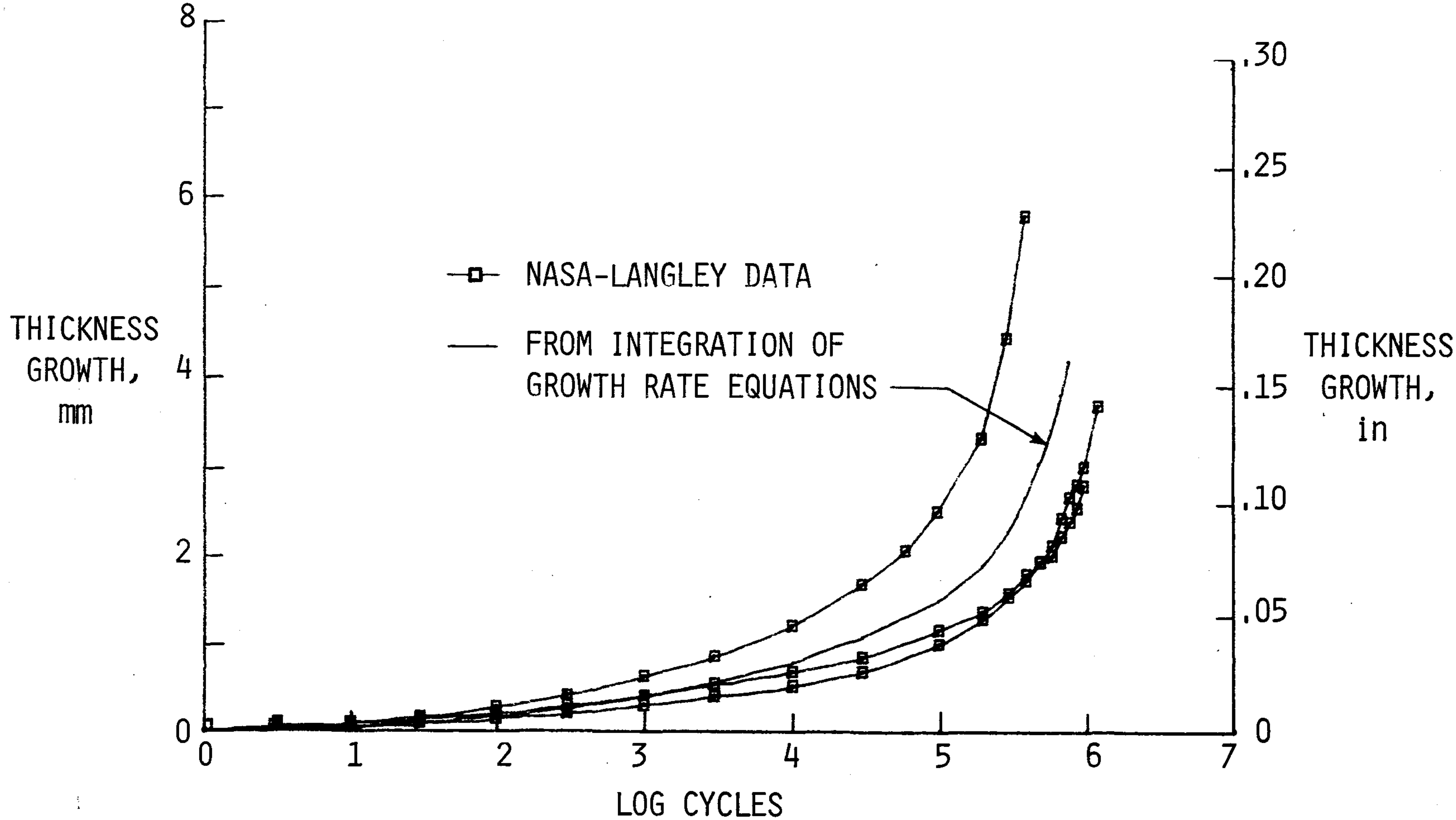


Figure 10.- Continued.

(c) Peak stress = 58.3 kPa (8.45 psi).

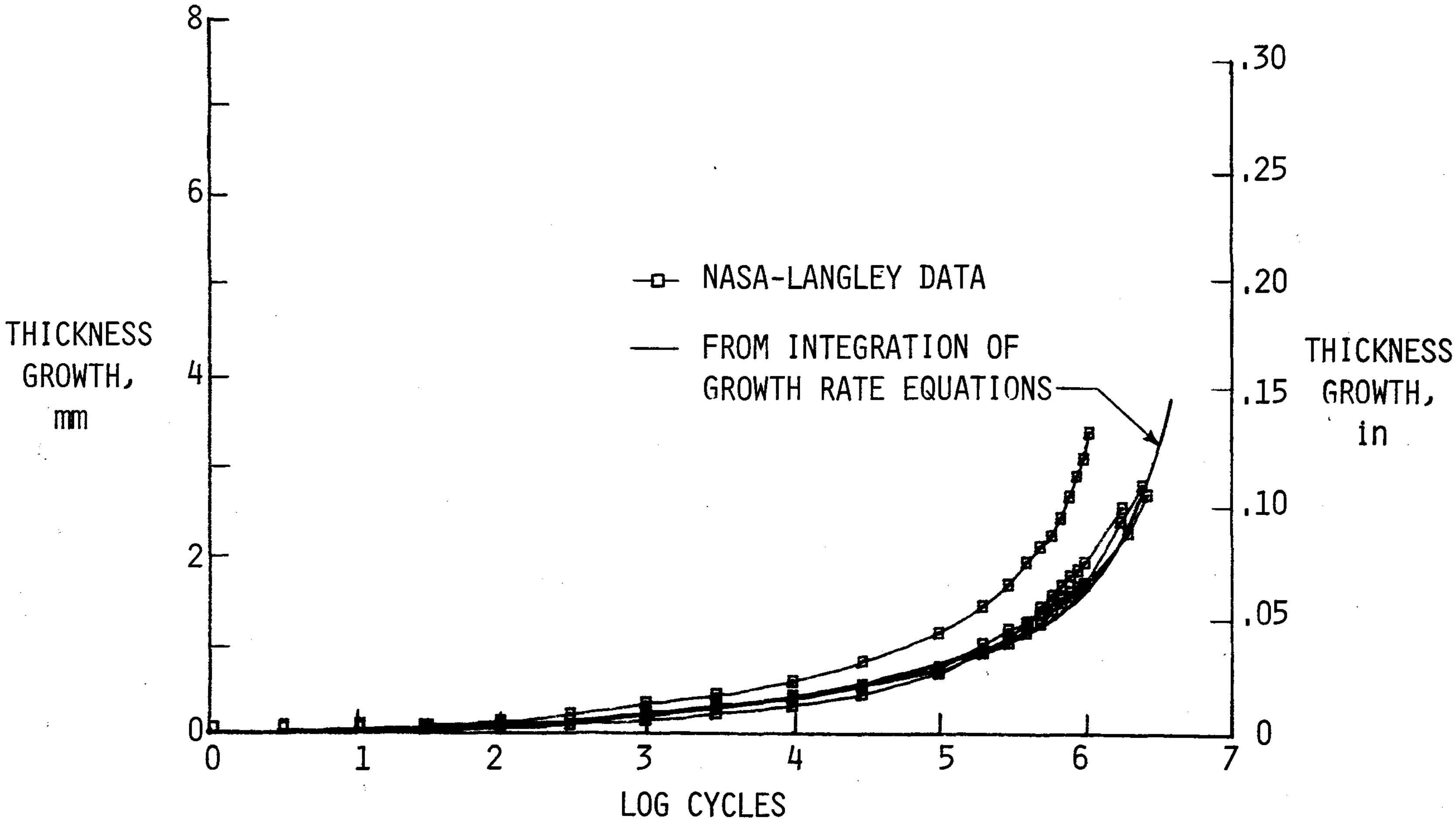
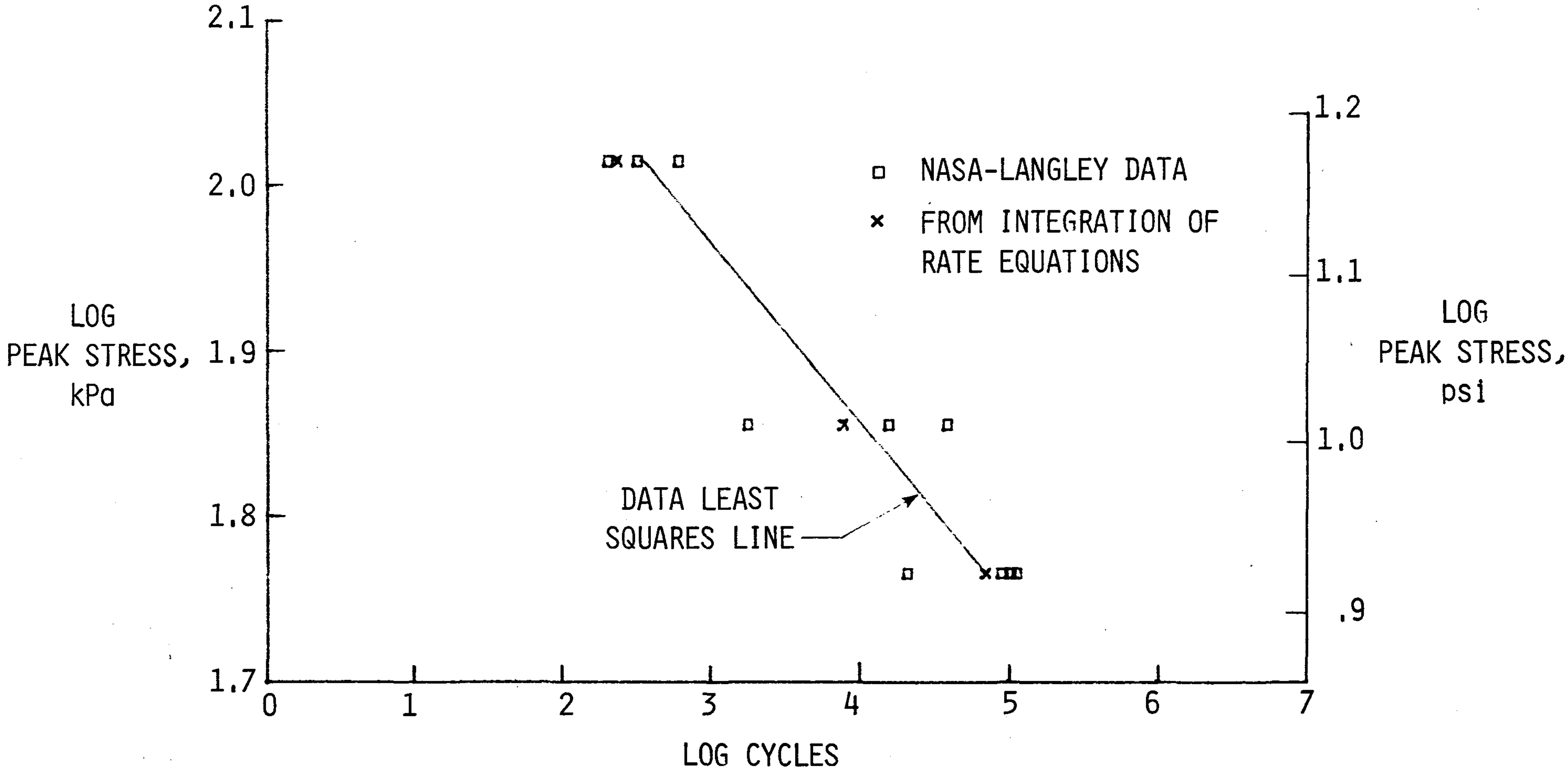


Figure 10.- Concluded.



(a) Thickness growth = 0.76 mm (0.030 in).

Figure 11.- S-N curve representation of experimental and calculated thickness growth.

(b) Thickness growth = 1.52 mm (0.060 in).

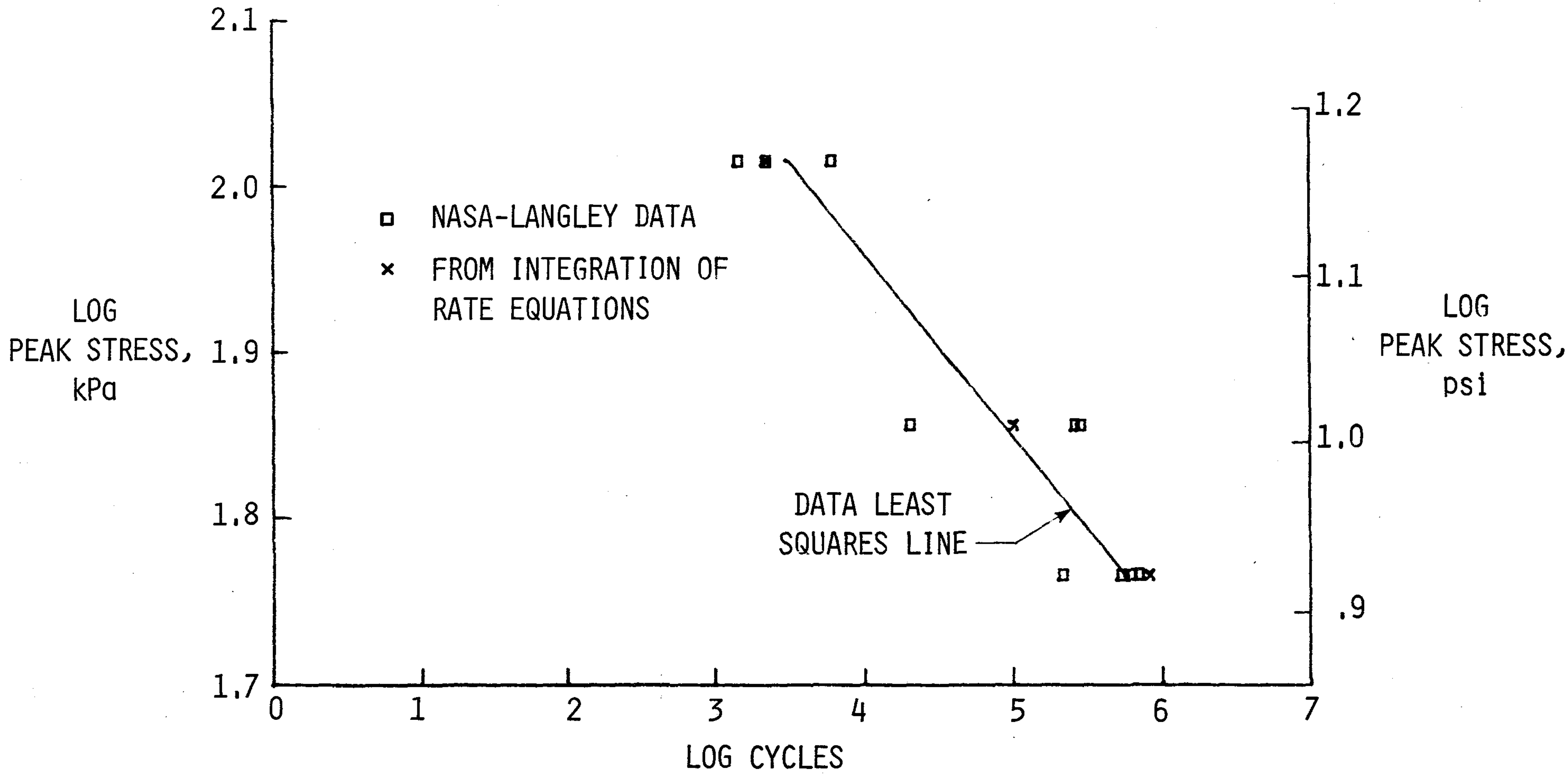


Figure 11.- Continued.

(c) Thickness growth = 2.29 mm (0.090 in).

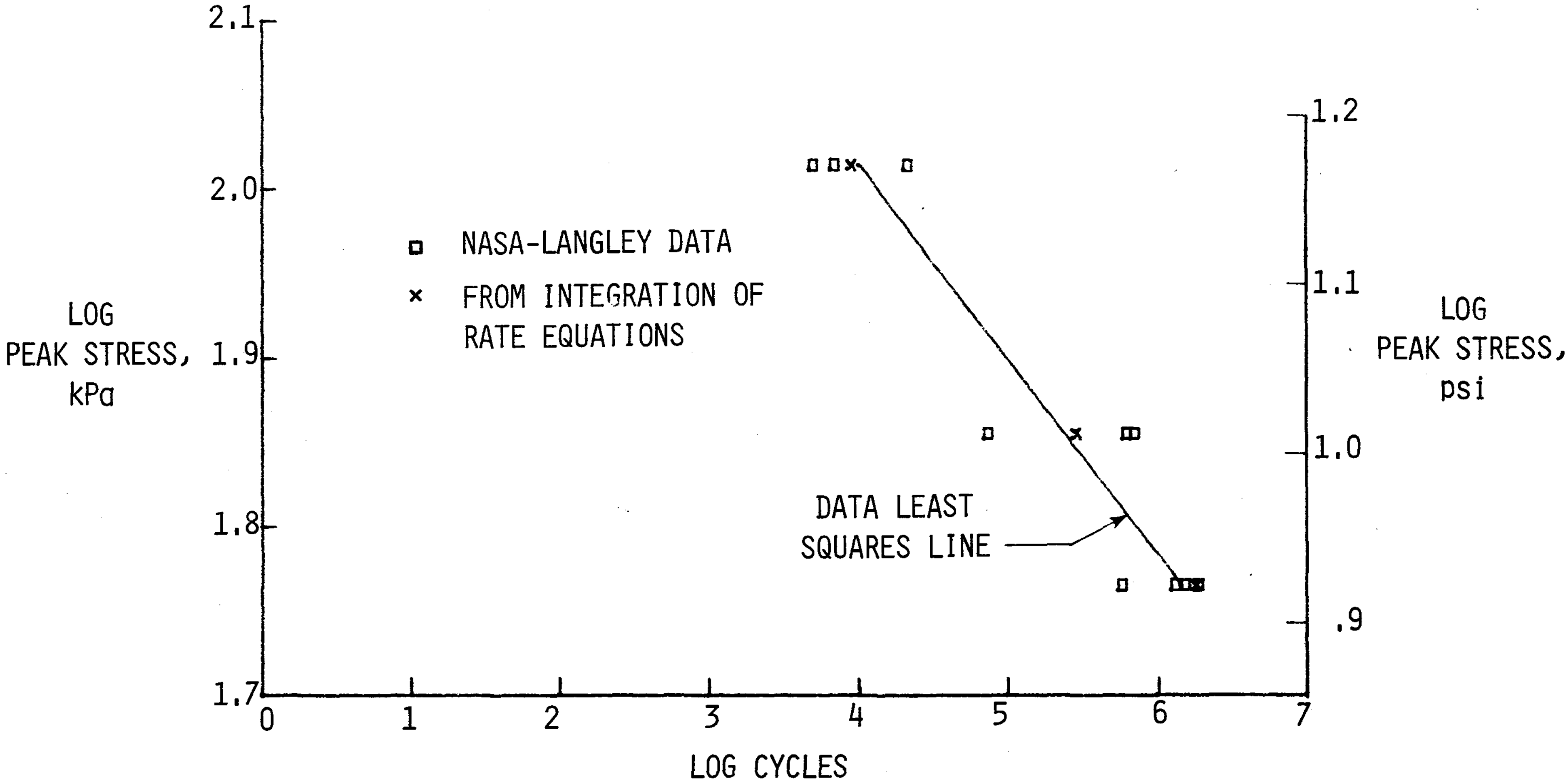


Figure 11.- Concluded.

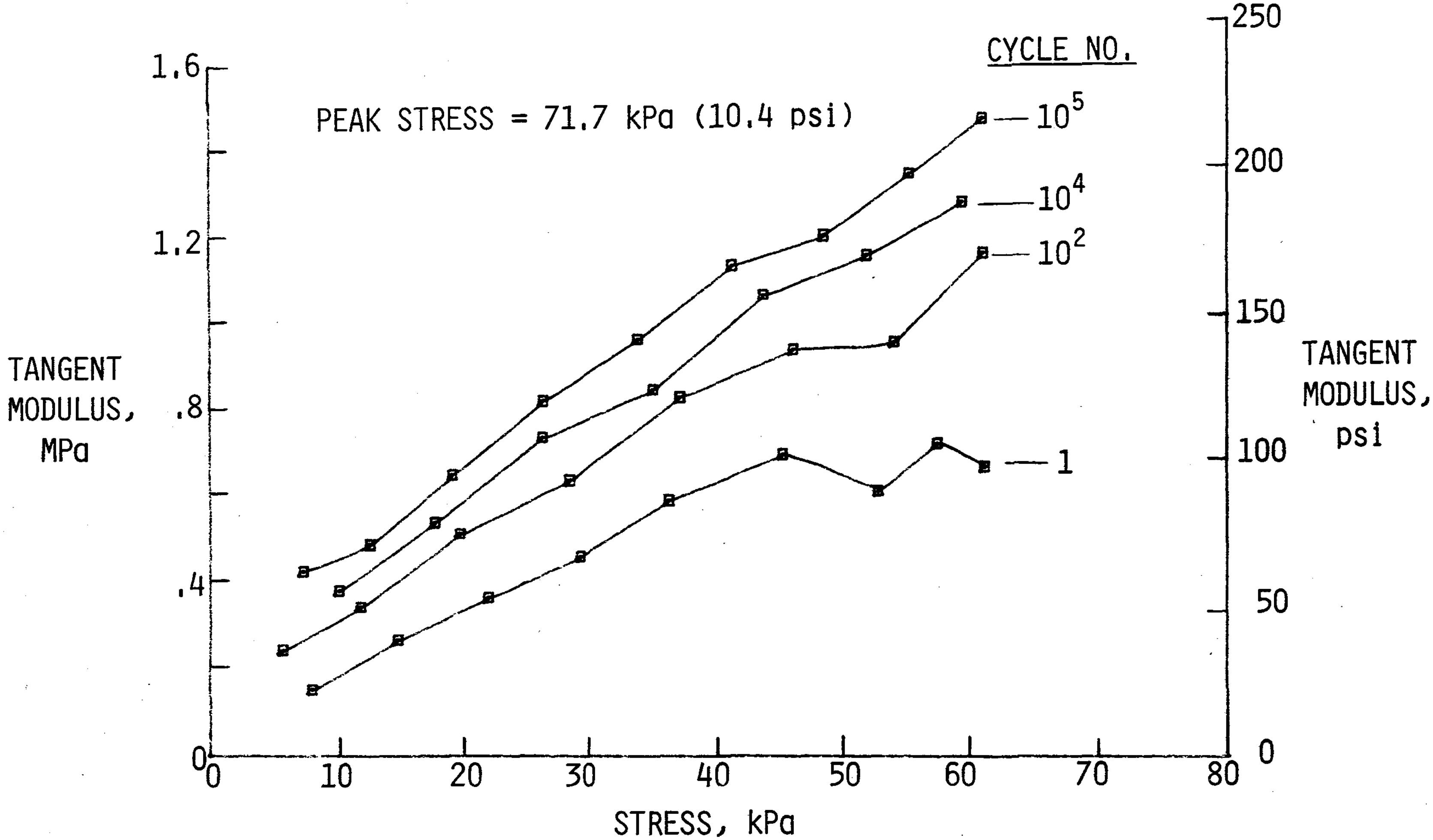


Figure 12.- Typical variation of tangent modulus with stress level after various numbers of fatigue load cycles.

(a) Variation with the logarithm of load cycles.

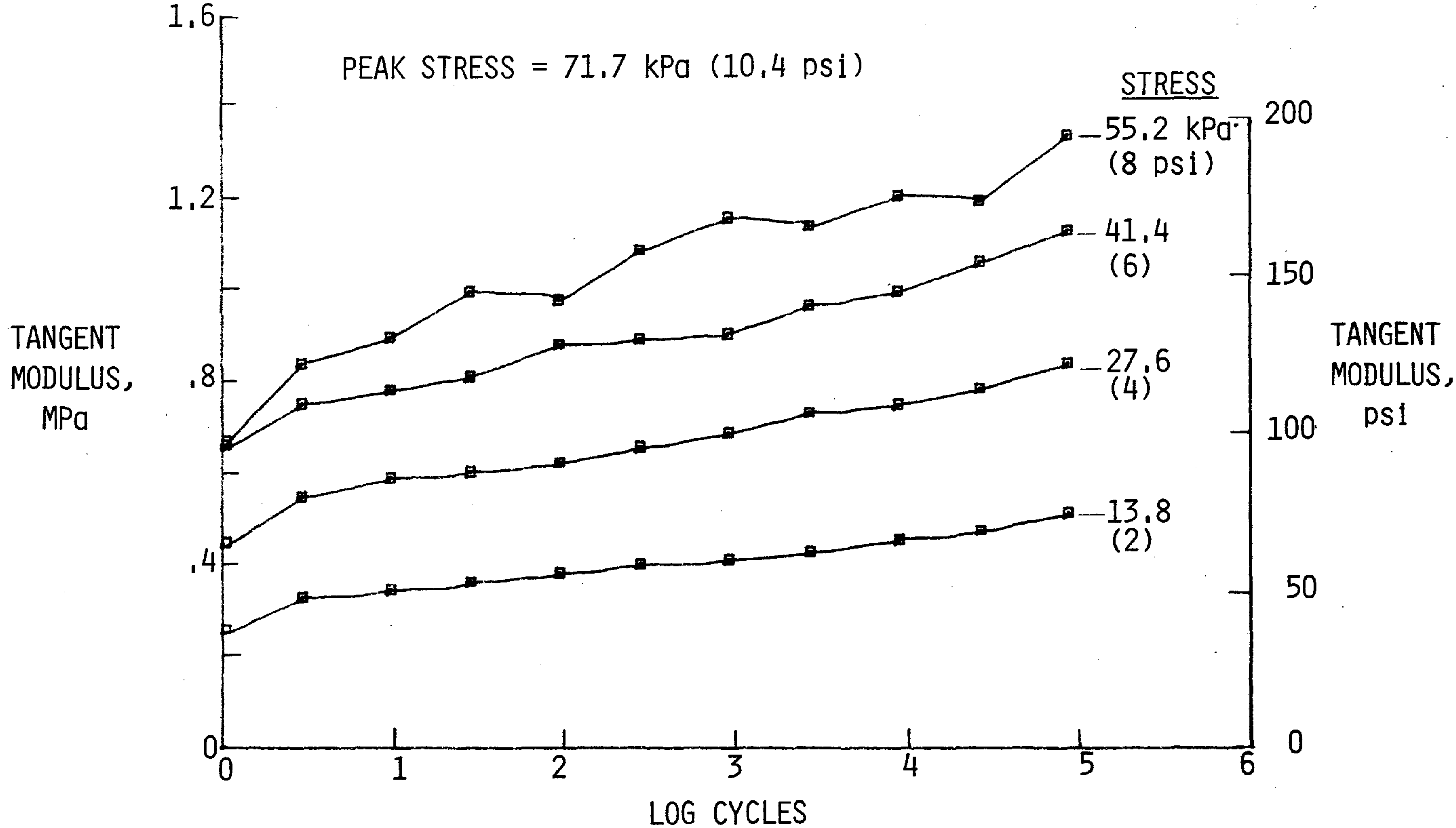


Figure 13.- Typical variation of tangent modulus at several stress levels during the course of a fatigue test.

(b) Variation with load cycles.

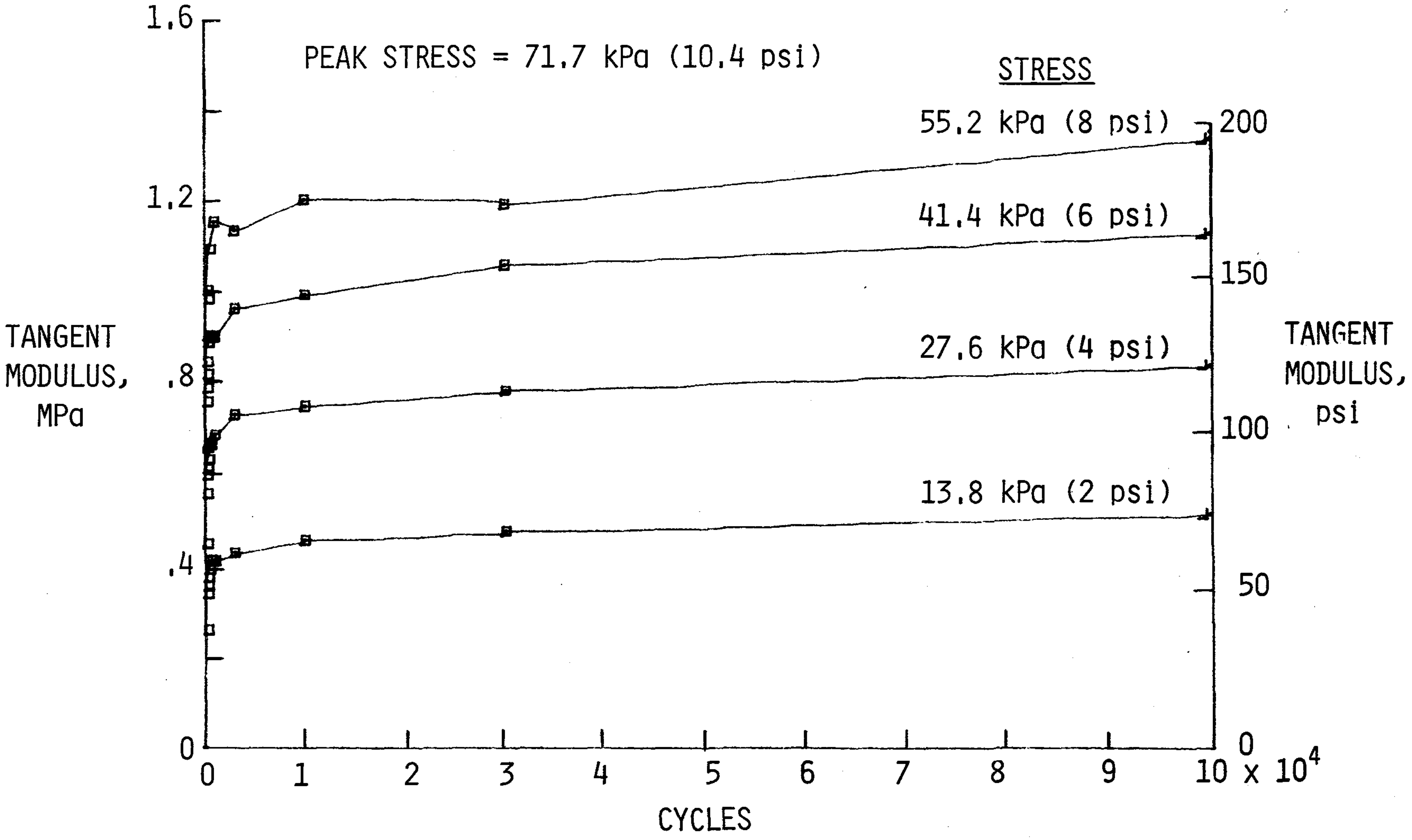


Figure 13.- Concluded.

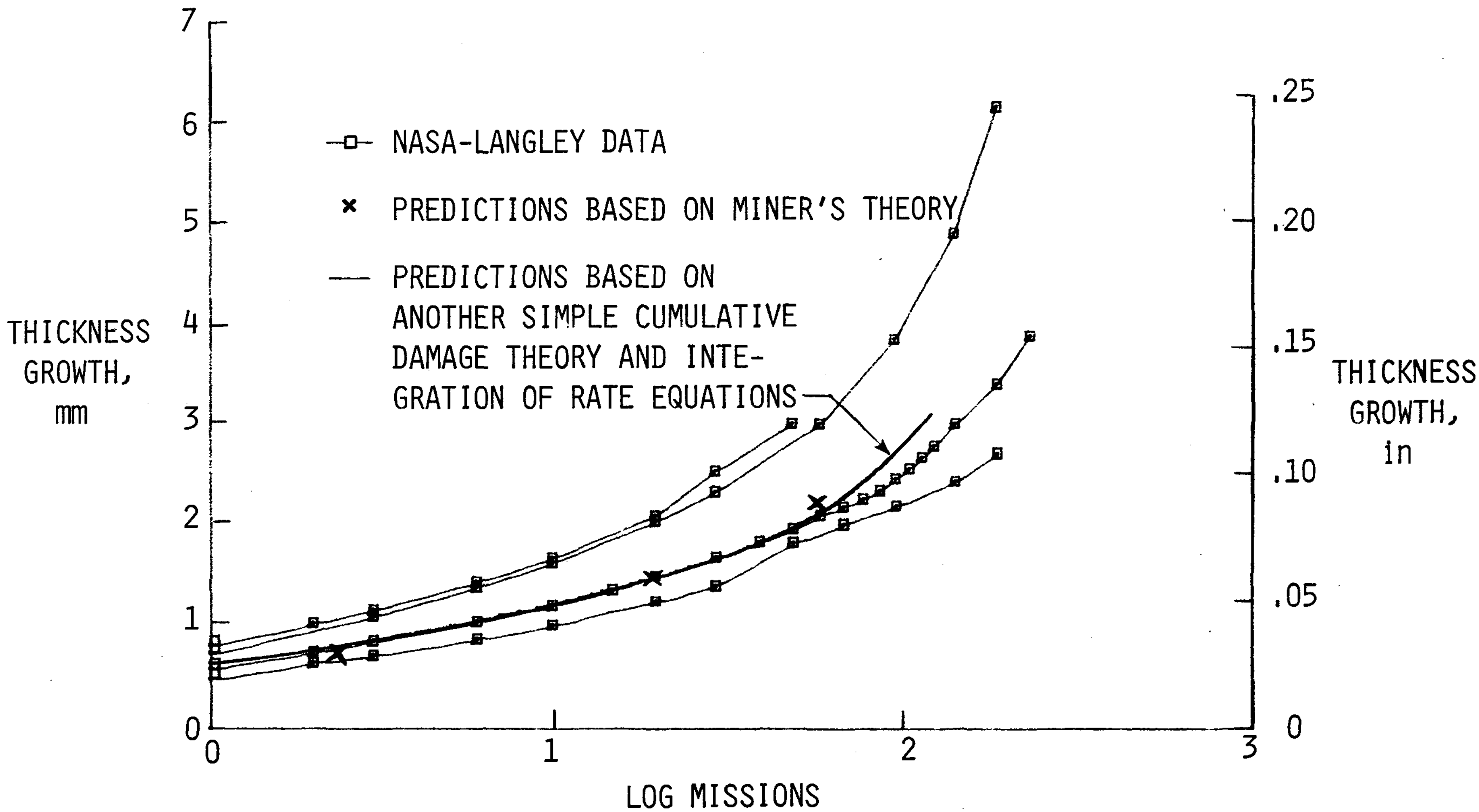


Figure 14.- Comparison of thickness-growth data from random-amplitude fatigue tests to thickness growth predicted by cumulative damage fatigue models.

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15. Supplementary Notes

16. Abstract

The room temperature fatigue behavior of 0.41-cm (0.16-in) thick strain-isolation-pad (SIP) material was explored in a series of constant- and random-amplitude loading tests. The SIP material is used on the Space Shuttle to isolate the ceramic insulating tiles from the strains and deflections of the aluminum alloy airframe. In all tests, 12.7- by 12.7-cm (5.0- by 5.0-in) SIP specimens were subjected to tension-tension loading in the through-the-thickness direction at a frequency of 10 Hz.

When subjected to cyclic loading, the SIP material exhibited a monotonic increase in thickness and a monotonic increase in tensile tangent moduli. The rate of thickness growth increased with increasing test stress level and decreased with increasing number of cycles endured. Power law equations were found to provide a good representation of the thickness growth rate data. Tensile tangent moduli increased by as much as 80 percent during fatigue tests. Simple cumulative damage fatigue models predicted the mean thickness growth under random-amplitude loading with reasonable accuracy (factor of 2 on life).

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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