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Strength of Graphite/Epoxy Bolted Wing-Skin Splice Specimens Subjected to Outdoor Exposure Under Constant Load and Yearly Fatigue Loading

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SUMMARY

The results of an experimental study to provide long-term durability data on detailed full-scale graphite/epoxy wing-skin joint designs under environmental exposure and cyclic loading associated with commercial transport aircraft are reported. Simplified splice joint specimens representative of a wing-skin splice were fabricated from graphite/epoxy composite materials. The specimens consisted of a single-row bolt configuration fabricated from T300/5208 and a double-row bolt configuration fabricated from T300/5209. The unpainted specimens were exposed to the outdoor environment under a sustained tensile load, and at yearly intervals, the specimens were subjected to fatigue loading. At selected exposure times, tensile residual strength and joint elongation data were obtained for comparison with baseline data obtained from unexposed joint specimens. Experimental results showed a slight reduction in residual tensile strength for both graphite/epoxy bolted joints under the exposure times and fatigue loadings reported herein. A 7.5-percent decrease in residual strength was observed for the T300/5208 single-row joint after 5 years exposure and two lifetimes of fatigue loading. A 5.3-percent decrease in residual strength was observed for the T300/5209 double-row joint after 7 years exposure and 2.8 lifetimes of fatigue loading. The 5208 epoxy material was more susceptible to degradation by ultraviolet radiation than the 5209 epoxy material.

INTRODUCTION

In the early 1970's, rising fuel costs gave impetus to the research and development of advanced composite materials for commercial aircraft applications because of their potential for a decrease in structural weight and increased structural efficiency. One of the prerequisites to applying composite materials on aircraft structures was the establishment of a data base on the long-term durability of these materials. Programs were initiated to establish a data base through a world-wide ground-base exposure program, and flight service programs on commercial and military transport aircraft (refs. 1, 2, and 3). The ground-based program was initiated by the Langley Research Center to determine the outdoor environmental effects over a 10-year period on composite materials used in flight service components (ref. 1). Coupon specimens were mounted in outdoor racks at six different sites to determine the effects of outdoor exposure. At the Langley Research Center, one of the exposure sites, the coupon exposure program was augmented with full-scale bolted joint specimens in order to provide long-term durability data on detailed joint designs subjected to environmental exposure over a 10-year period and cyclic loading spectra typical of commercial transport flight service. Simplified splice joint specimens representative of side-of-body wing-skin splice in a commercial transport were designed and fabricated. This paper presents the durability data obtained to date on these bolted joint specimens.

The bolted wing-skin splice specimens had two bolt configurations with different graphite/epoxy composite materials. At selected exposure times, tensile residual strength and joint elongation data were obtained for comparison with data obtained from unexposed specimens. Experimental results are reported for the unpainted specimens with single- and double-row bolt configurations after 5 and 7 years outdoor exposure, respectively.

Measurements and calculations were made in the U.S. Customary Units. They are presented herein in the International System of Units (SI) with the equivalent values given parenthetically in the U.S. Customary Units.

MATERIALS AND SPECIMENS

The design and fabrication of the graphite/epoxy bolted joint specimens were accomplished contractually by two commercial aircraft companies. The Douglas Aircraft Company, Long Beach, California, provided the T300/5208 specimens; the Boeing Commercial Airplane Company, Seattle, Washington, provided the T300/5209 specimens. The graphite fibers were manufactured by Union Carbide Corporation, Danbury, Connecticut; the resins and resin impregnated products were manufactured by Narmco Materials, Inc., Costa Mesa, California. General design guidelines were established by the Langley Research Center (LaRC). The specimens were representative of a side-of-body wing-skin splice with a 20-year life expectancy in a commercial transport environment. A simplifed splice joint was specified with no loading eccentricities and an overall length limit to accommodate LaRC test equipment. The graphite/epoxy composite materials and bolt configurations were selected by the contractors.

Single-Row Bolt Configuration

One set of bolted joint specimens was designed with a single-row bolt configuration fabricated from T300/5208 graphite/epoxy. Overall specimen configuration, joint details, and basic dimensions are shown in figure 1. The bolted joint was designed to accommodate an ultimate tensile loading of 2.45 MN/m (14 kips/in.).

The wing skins, joint area, and splice plates were fabricated from T300/5208 tape with a balanced pseudo-isotropic lay up consisting of 50 percent ±45° plies, 25 percent 0° plies, and 25 percent 90° plies. The wing-skin and joint sections had 80 and 104 plies of tape, respectively. Each splice plate had 52 plies of tape. The 1.43-cm (0.562-in.) diameter titanium-alloy bolts had a spacing of 5.0 cm (1.98 in.) giving a ratio s/d (bolt spacing/hole diameter) of 3.5. The ratio e/d (edge distance/hole diameter) was 3.0. The bolted joint design was optimized by using a computer program based on the equations and data reported in reference 4. A net-tension failure was predicted at a design ultimate load of 493 kN (111 kips) for the 20.1-cm (7.92-in.) wide specimen.

Double-Row Bolt Configuration

Another set of bolted joint specimens was designed with a double-row bolt configuration fabricated from T300/5209 graphite/epoxy. Overall specimen configuration, joint details, and basic dimensions are shown in figure 2. The joint was designed for an ultimate tensile loading of 2.63 MN/m (15 kips/in.). The wing skins, joint area, and splice plates were fabricated from T300/5209 unidirectional tape and 8 harness satin cloth in a symmetric lay up consisting of 35 percent 0° plies, 50 percent ±45° plies, and 15 percent 90° plies. The wing-skin section had 16 tape and 22 cloth plies. The joint section had 20 tape and 32 cloth plies. Each splice plate had 10 tape and 16 cloth plies. The double row of 0.95-cm (0.375-in.) diameter titanium-alloy bolts had ratios of $s/d = 6.7$ and $e/d = 3.5$. The design ultimate failure load was 500 kN (112.5 kips) for the 19.0-cm (7.50-in.) wide specimen with failure expected to occur in a bearing mode. Details on the design and fabrication of these specimens are reported in reference 5.

TEST CONDITIONS AND APPARATUS

The bolted wing-skin specimens were exposed to an outdoor environment under constant tensile loads. On a yearly basis after outdoor exposure, the bolted joint specimens were subjected to fatigue loading. Static residual tensile strength tests were then performed at selected yearly intervals for comparison with tensile strengths obtained from unexposed specimens.

Outdoor Exposure Under Constant Load

The graphite/epoxy bolted joint specimens were exposed to the outdoor environment at the Langley Research Center, Hampton, Virginia. The bolted joint specimens were installed in loading frames as shown in figure 3. The specimen surfaces were facing the southeast and northwest. A loaded specimen is shown in figure 4. Support frames were used to support the weight of the specimen and load train and for axial alignment. A sustained tensile load of 27 percent of the design ultimate load was applied to the bolted joint specimens during exposure. The tensile loads were 132 kN (29.6 kips) and 133 kN (30.0 kips) for the single-row and double-row bolt configurations, respectively. Loading was accomplished with a motorized jack mounted on each test stand. Tensile loads were maintained by monitoring the load cell readings on a weekly basis. Based on these readings, the sustained loads were determined to be within ±1.3 kN (±300 lbf) of the applied loads.

Fatigue Loading

After 1 year of outdoor exposure, the bolted wing-skin splice specimens were removed from the outdoor test stands and mounted in a 250-kN (55-kip) capacity hydraulic testing machine for fatigue loading. A fatigue test spectrum was established in reference 5 for the lower wing surface side-of-body splice for a subsonic commercial transport aircraft. This test spectrum, consisting of 2000 flights involving five different flight types, was applied to the specimens. Each flight type consisted of alternating cyclic load levels about a 1g tensile load. The 1g cruise load was defined as 27.5 percent of limit load (ref. 5) which is 18 percent of design ultimate load. The 1g loadings were 90.3 kN (20.3 kips) and 91.6 kN (20.6 kips) for the single-row and the double-row bolt configurations, respectively. The fatigue loading consisted of tensile loading only at approximately 5 hertz. The test program was designed to subject the test specimens to a total of four lifetimes of fatigue cycling over a 10-year period. Each year the bolted joint specimens were subjected to 16 000 flights or 0.4 lifetime of fatigue loading, with a lifetime being defined as 40 000 flights. Further details on the fatigue loading are reported in the appendix.

Static Strength Tests

The bolted wing-skin splice specimens were tested in a 1.33-MN (300-kip) capacity hydraulic testing machine to determine tensile strength. Load was applied at a rate of 130 kN/min (30 kips/min) to failure and the maximum load recorded from the test machine load indicator. Displacements above and below the bolted joint splice were obtained by bonding two reference bars 30 cm (12 in.) apart on the wing skins at each end of the joint splice. Two linear variable displacement transducers (LVDT's) mounted on the lower loading-head were connected to the reference bars as shown in figure 5. The displacements and load were recorded on an X-Y recorder. In addition, load and lower loading-head displacement measured by a LVDT were recorded.

TEST RESULTS AND DISCUSSION

Single-Row Bolt Configuration

Residual strength tests.- Static tensile strength test results from the graphite/epoxy bolted wing-skin splice specimens are presented in table I. The T300/5208 single-row bolt configuration specimen with no outdoor exposure and no fatigue loading failed at a load of 524 kN (117.8 kips) which was used as the baseline strength. The failure load was 6 percent higher than the design ultimate strength, showing good correlation between predicted and test values. The failure occurred in net tension as did all the single-row bolt configuration specimens and the failed joint area is shown in figure 6. The unexposed specimen with four lifetimes of fatigue loading failed at 529 kN (119.0 kips). The four lifetimes of tensile fatigue loading had no apparent effect on joint strength. The effects of outdoor exposure under sustained load and fatigue loading on the tensile strength of the T300/5208 bolted joint specimens are shown in figure 7(a). A decrease in joint tensile strength was experienced with increasing exposure time and fatigue loading. A maximum reduction in tensile strength of 7.5 percent had occurred after 5 years exposure and two lifetimes of fatigue loading.

Data obtained to determine elongation across the built-up joint splice are given in table II. The joint elongation results are presented in figure 8. The load-elongation response was similar for all the T300/5208 single-row configuration specimens except the specimen with 3 years exposure and 1.2 lifetimes of fatigue loading. For the specimen with 3 years exposure, joint elongation over the first 180 kN (40 kips) was relatively low and total elongation at 400 kN (90 kips) was approximately 40 percent less than the elongations measured for the other single-row configuration specimens. The apparently stiffer joint response of the T300/5208 specimen was comparable with the T300/5209 joint response after 3 years exposure (to be discussed subsequently). The two residual strength tests were performed a year apart with no obvious anomalies recorded during testing. The stiffer joint responses were considered unlikely but could not be explained. The average joint elongation at 400 kN (90 kips) was 1.40 mm (0.055 in.) for all the T300/5208 single-row configuration specimens tested.

Surface examination.- After residual strength tests were performed on the T300/5208 specimens, the splice plates were removed to permit a visual comparison between the protected surface beneath the plates and the exposed surface next to the plates. A magnified view of this area for each of the exposure times is shown in figure 9. The appearance of the protected surfaces resulted from an imprint of the peel ply used in the curing process. After 1 year of exposure (fig. 9(a)), smoothing of the textured epoxy surface has occurred. Figure 9(b) shows definite degradation of the 5208 epoxy material after 3 years of outdoor exposure. The surface has a very faint textured appearance with graphite fibers exposed. The graphite fibers in the outer ply layer of the specimens were laid up in the 45° direction. Complete degradation of the outer epoxy layer after 5 years of exposure is evident in figure 9(c). The entire 45° layer of graphite fibers is exposed. Ultraviolet radiation from the Sun has degraded the 5208 epoxy matrix material and precipitation likely accelerated the removal of the degraded material leaving a shiny surface of exposed graphite fibers. Similar results were observed in accelerated laboratory tests reported in reference 6 for T300/5208 flexure specimens exposed in a chamber to continuous ultraviolet radiation and intermittent water spray. Outdoor exposure results indicate that protection of 5208 epoxy material from ultraviolet radiation is required for commercial transport applications. Based on the observed rate of degradation, in-service repair of protective paint or coatings on a yearly maintenance schedule would be adequate as far as ultraviolet radiation is concerned.

Double-Row Bolt Configuration

Residual strength tests.- Static tensile strength test results from the T300/5209 bolted joint specimens are presented in table I. The double-row bolt configuration specimen with no outdoor exposure and no fatigue loading failed at a load of 534 kN (120 kips) which was used as the baseline strength. The failure load was 7 percent higher than the design ultimate strength showing good correlation between predicted and test values. Failure of this specimen initiated in the bearing mode; the specimen broke in net tension while all the other double-row bolt configuration specimens failed in bearing. A typical bearing failure is shown in figure 10. Bolt bending had occurred during failure and the degree of bolt bending and damage to the outer surfaces of the splice plates are shown in figures 10(a) and (b). The difference in bearing damage between the outer surface of the splice plates and the joint area in the built-up wing skin is shown in figure 10(c). The unexposed specimen with four lifetimes of fatigue loading failed at a load of 529 kN (119.0 kips). The four lifetimes of tensile fatigue loading had no apparent effect on joint strength. The effects of outdoor exposure under sustained load and fatigue loading on the tensile strength of the T300/5209 bolted joint specimens are shown in figure 7(b). A decrease in tensile strength was experienced with increasing exposure time and fatigue loading. A maximum reduction in tensile strength of 5.3 percent had occurred after 7 years exposure and 2.8 lifetimes of fatigue loading.

Data obtained to determine elongation across the built-up joint splice are given in table III. The joint elongation results are presented in figure 11. The load-elongation response was similar for all the T300/5209 double-row configuration specimens except the specimen with 3 years exposure and 1.2 lifetimes of fatigue loading. For the specimen with 3 years exposure, joint elongation at 400 kN (90 kips) was approximately 24 percent less than the elongation recorded for the other double-row bolt configuration specimens. The apparently stiffer T300/5209 joint response was comparable with the T300/5208 joint response after 3 years exposure noted earlier and could not be explained. The average joint elongation was 1.52 mm (0.060 in.) at 400 kN (90 kips) for all the T300/5209 double-row bolt configuration specimens.

Surface examination.- After residual strength tests were performed on the T300/5209 specimens, the splice plates were removed to permit a visual comparison between the protected surface beneath the plates and the exposed surface next to the plates. A magnified view of this area for each of the exposure times is shown in figure 12. The surface texture of the protected surfaces resulted from an imprint of the peel ply used in the curing process. The specimens had an outer ply layer of 0°-90° graphite cloth. After 1 year exposure, shown in figure 12(a), some lightening of the surface texture had occurred with the faint appearance of the weave crimp pattern in the 8 harness satin weave. The yarns at the weave crimp are oriented in the 90° direction. Figure 12(b) shows the 90° yarns at the weave crimp exposed with some texture in the epoxy matrix material between the crimp pattern still visible after 3 years exposure. Figure 12(c) shows definite degradation of the 5209 epoxy material with all the graphite yarns exposed after 5 years of outdoor exposure. Some epoxy matrix material remains at the weave crimp where the 90° yarns pass under the 0° yarns. Figure 12(d) shows the surface of the T300/5209 specimen after 7 years exposure, and there was no trace of the 5209 epoxy matrix material on the exposed surfaces of the specimen. However, the cloth layer of graphite fibers was still intact. Visual observations after various exposure times indicate that the 5209 epoxy material was less susceptible to damage by ultraviolet radiation than the 5208 epoxy material. Similar results were reported in reference 6 for flexure specimens in accelerated laboratory tests. Surface degradation seems consistent with the decrease in residual tensile strengths. The T300/5208 specimens had a greater decrease in joint strength with increasing exposure time than the T300/5209 specimens. Outdoor exposure results indicate that protection of 5209 epoxy material from ultraviolet radiation is required for commercial transport applications. Based on the observed rate of degradation, in-service repair to protective paints on a yearly maintenance schedule would be adequate as far as ultraviolet degradation is concerned.

CONCLUSIONS

An experimental study was conducted to provide long-term durability data on detailed joint designs under environmental exposure and cyclic loading spectra associated with commercial transport aircraft. Data were obtained for T300/5208 single-row and T300/5209 double-row bolt configuration specimens. These unpainted specimens were exposed to the outdoor environment under a sustained tensile load of 27 percent of the design ultimate load. On an annual basis, the bolted joint specimens were subjected to fatigue loading equivalent to a 0.4 expected service lifetime. The following comments and conclusions are based on this experimental study:

1. Good correlation between design and experimental joint strength was obtained for both graphite/epoxy joint configurations. For the unexposed specimens with no fatigue loading, the T300/5208 single-row configuration had a strength 6 percent higher and the T300/5209 double-row configuration had a strength 7 percent higher than the design ultimate strength.

2. A slight reduction in residual tensile strength was experienced by both graphite/epoxy bolted joints for the exposure times and fatigue loadings reported. A 7.5-percent decrease in residual strength was observed for the T300/5208 single-row joint after 5 years exposure and two lifetimes of fatigue loading. A 5.3-percent decrease in residual strength was observed for the T300/5209 double-row joint after 7 years exposure and 2.8 lifetimes of fatigue loading.

3. Four lifetimes of fatigue loading on unexposed specimens had no apparent effect on the static tensile strength of either the single-row or double-row bolted joints.

4. The 5208 epoxy material was more susceptible to degradation by ultraviolet radiation than the 5209 epoxy material. Surface degradation seems consistent with the decreases in residual tensile strengths. The T300/5208 specimens had a greater decrease in joint strength with increasing exposure time than the T300/5209 specimens.

5. Both of the epoxy materials would require protective paints, but in-service repair of these paints on a yearly maintenance schedule would be adequate.

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November 13, 1985

APPENDIX

FATIGUE LOADING SEQUENCE

This appendix describes the fatigue loading sequence that was applied to the test specimens each year. The test program was designed to subject the test specimens to a total of four lifetimes of fatigue cycling over a 10-year period. Since one fatigue lifetime was assumed to be 40 000 flights, the annual flight loading was equivalent to 16 000 flights.

The flight-by-flight loading used in this study was based on the flight loads data presented in reference 5 for a side-of-body joint in the lower wing surface for a commercial transport aircraft. These flight loads data are presented in table IV in terms of the number of cycles at each alternating load level. The data in table IV represents 2000 flights which are grouped into five flight types (A', A, B, C, and D). The cyclic load levels in each flight are expressed as a fraction of the 1g load, which was the mean load level for all flights. The 1g load (defined as 0.275 times the limit load) which is 18 percent of design ultimate load was 90.3 kN (20.3 kips) for the single-row joints and 91.6 kN (20.6 kips) for the double-row joints.

Flight type A' has the largest alternating load (equal to the 1g load) which occurs only once during the block of 2000 flights represented by table IV. Flight A' is shown schematically in figure 13. The alternating load levels were arranged to produce an ascending-descending sequence of maximum load levels within the flight. The flight was initiated and terminated with zero load rather than mean load in order to take into account the ground-air-ground cycle. The other flight types were similar to the A' but involved fewer load cycles and lower alternating load levels as shown in table IV.

The following sequence was used to assemble the five flight types in the 2000 flight fatigue loading block:

(a) Ten D flights
(b) One C flight
(c) Repeat (a) and (b) 10 times
(d) One B flight
(e) Repeat (a) through (d) 6 times
(f) One A' flight
(g) Repeat (a) through (e)
(h) One A flight
(i) Repeat (a) through (e)

The block of 2000 flights was repeated eight times on a magnetic tape to obtain the 16 000 flight program that was applied to the specimen each year.

REFERENCES

1. Dexter, H. Benson; and Baker, Donald J.: Worldwide Flight and Ground-Based Exposure of Composite Materials. ACEE Composite Structures Technology - Review of Selected NASA Research on Composite Materials and Structures, NASA CP-2321, 1984, pp. 17-49.

2. Stoecklin, Robert L.: Commercial Composite Component Service Experience. Materials 1980, Volume 12 of National SAMPE Technical Conference Series, Soc. Advance. Mater. & Process Eng., 1980, pp. 197-209.

3. Watts, Donald J.; and Lee, Norman R.: Advanced Composite Applications in McDonnell Douglas Commercial Transport Aircraft. Materials 1980, Volume 12 of National SAMPE Technical Conference Series, Soc. Advance. Mater. & Process Eng., 1980, pp. 424-437.

4. Hart-Smith, L. J.: Bolted Joints in Graphite-Epoxy Composites. NASA CR-144899, 1976.

5. Johnson, R. W.; and McCarty, J. E.: Design and Fabrication of Graphite-Epoxy Bolted Wing Skin Splice Specimens. NASA CR-145216, 1977.

6. Gibbins, Martin N.; and Hoffman, Daniel J.: Environmental Exposure Effects on Composite Materials for Commercial Aircraft. NASA CR-3502, 1982.

TABLE I.- EFFECT OF OUTDOOR EXPOSURE AND LOAD HISTORY ON STRENGTH OF GRAPHITE/EPOXY BOLTED WING-SKIN SPLICE SPECIMENS

Static strength	Exposure time at constant load of 27 percent ultimate, years	Fatigue loading, lifetimes	Failure load, kN (kips), for - Material and joint configuration of - T300/5208 single row	T300/5209 double row
Baseline	0	0	524 (117.8)	534 (120.0)
	0	4.0	529 (119.0)	529 (119.0)
Residual	1	0.4	503 (113.0)	521 (117.2)
	3	1.2	492 (110.7)	521 (117.2)
	5	2.0	485 (109.0)	518 (116.5)
	7	2.8	N/A	505 (113.6)

TABLE II.- TOTAL ELONGATION ACROSS JOINT SPLICE OVER 30 cm (12.0 in.) GAGE LENGTH FOR T300/5208 SPECIMENS WITH SINGLE-ROW BOLT CONFIGURATION

Load		Lower reference reading		Upper reference reading		Joint elongation	
kN	kips	mm	in.	mm	in.	mm	in.
(a) No exposure and no fatigue							
0	0	0	0	0	0	0	0
44	10	0.36	0.014	0.41	0.016	0.05	0.002
89	20	0.58	0.023	0.74	0.029	0.16	0.006
133	30	0.81	0.032	1.14	0.045	0.33	0.013
178	40	1.07	0.042	1.62	0.064	0.55	0.022
222	50	1.37	0.054	2.08	0.082	0.71	0.028
267	60	1.65	0.065	2.54	0.100	0.89	0.035
311	70	1.90	0.075	2.97	0.117	1.07	0.042
356	80	2.18	0.086	3.43	0.135	1.25	0.049
400	90	2.46	0.097	3.86	0.152	1.40	0.055
445	100	2.72	0.107	4.32	0.170	1.60	0.063
489	110	2.97	0.117	4.80	0.189	1.83	0.072
520	117	3.18	0.125	5.16	0.203	1.98	0.078
(b) No exposure and 4.0 lifetimes of fatigue							
0	0	0	0	0	0	0	0
44	10	0.23	0.009	0.30	0.012	0.07	0.003
89	20	0.43	0.017	0.66	0.026	0.23	0.009
133	30	0.66	0.026	1.04	0.041	0.38	0.015
178	40	0.86	0.034	1.42	0.056	0.56	0.022
222	50	1.07	0.042	1.83	0.072	0.76	0.030
267	60	1.27	0.050	2.24	0.088	0.97	0.038
311	70	1.57	0.062	2.77	0.109	1.20	0.047
356	80	1.88	0.074	3.30	0.130	1.42	0.056
400	90	2.11	0.083	3.71	0.146	1.60	0.063
445	100	2.34	0.092	4.19	0.165	1.85	0.073
489	110	2.64	0.104	4.75	0.187	2.11	0.083
529	119	2.84	0.112	5.23	0.206	2.39	0.094

TABLE II.- Concluded

Load		Lower reference reading		Upper reference reading		Joint elongation	
kN	kips	mm	in.	mm	in.	mm	in.
(c) 1 year exposure and 0.4 lifetimes of fatigue							
0	0	0	0	0	0	0	0
44	10	0.20	0.008	0.28	0.011	0.08	0.003
89	20	0.43	0.017	0.61	0.024	0.18	0.007
133	30	0.71	0.028	0.99	0.039	0.28	0.011
178	40	0.94	0.037	1.35	0.053	0.41	0.016
222	50	1.17	0.046	1.83	0.072	0.66	0.026
267	60	1.40	0.055	2.29	0.090	0.89	0.035
311	70	1.62	0.064	2.72	0.107	1.10	0.043
356	80	1.85	0.073	3.18	0.125	1.33	0.052
400	90	2.21	0.087	3.71	0.146	1.50	0.059
445	100	2.41	0.095	4.16	0.164	1.75	0.069
489	110	2.67	0.105	4.67	0.184	2.01	0.079
503	113	2.74	0.108	4.88	0.192	2.14	0.084
(d) 3 years exposure and 1.2 lifetimes of fatigue							
0	0	0	0	0	0	0	0
44	10	0.18	0.007	0.25	0.010	0.07	0.003
89	20	0.56	0.022	0.66	0.026	0.10	0.004
133	30	0.96	0.038	1.09	0.043	0.13	0.005
178	40	1.27	0.050	1.42	0.056	0.15	0.006
222	50	1.55	0.061	1.85	0.073	0.30	0.012
267	60	1.83	0.072	2.29	0.090	0.46	0.018
311	70	2.11	0.083	2.72	0.107	0.61	0.024
356	80	2.39	0.094	3.15	0.124	0.76	0.030
400	90	2.64	0.104	3.56	0.140	0.92	0.036
445	100	2.92	0.115	3.96	0.156	1.04	0.041
480	108	3.12	0.123	4.32	0.170	1.20	0.047
(e) 5 years exposure and 2.0 lifetimes of fatigue							
0	0	0	0	0	0	0	0
44	10	0.05	0.002	0.15	0.006	0.10	0.004
89	20	0.30	0.012	0.53	0.021	0.23	0.009
133	30	0.51	0.020	0.84	0.033	0.33	0.013
178	40	0.68	0.027	1.14	0.045	0.46	0.018
222	50	0.84	0.033	1.52	0.060	0.68	0.027
267	60	0.99	0.039	1.90	0.075	0.91	0.036
311	70	1.14	0.045	2.29	0.090	1.15	0.045
356	80	1.32	0.052	2.67	0.105	1.35	0.053
400	90	1.50	0.059	3.07	0.121	1.57	0.062
445	100						

TABLE III.- TOTAL ELONGATION ACROSS JOINT SPLICE OVER 30 cm (12.0 in.) GAGE LENGTH FOR T300/5209 SPECIMENS WITH DOUBLE-ROW BOLT CONFIGURATION

Load		Lower reference reading		Upper reference reading		Joint elongation	
kN	kips	mm	in.	mm	in.	mm	in.
(a) No exposure and no fatigue							
0	0	0	0	0	0	0	0
44	10	1.14	0.045	1.22	0.048	0.08	0.003
89	20	1.83	0.072	2.08	0.082	0.25	0.010
133	30	2.31	0.091	2.79	0.110	0.48	0.019
178	40	2.72	0.107	3.40	0.134	0.68	0.027
222	50	3.07	0.121	3.96	0.156	0.89	0.035
267	60	3.38	0.133	4.47	0.176	1.09	0.043
311	70	3.71	0.146	5.03	0.198	1.32	0.052
356	80	4.04	0.159	5.59	0.220	1.55	0.061
400	90	4.37	0.172	6.15	0.242	1.78	0.070
445	100	4.70	0.185	6.76	0.266	2.06	0.081
489	110	5.05	0.199	7.47	0.294	2.42	0.095
534	120	5.41	0.213	8.48	0.334	3.07	0.121
(b) No exposure and 4.0 lifetimes of fatigue							
0	0	0	0	0	0	0	0
44	10	0.38	0.015	0.48	0.019	0.10	0.004
89	20	0.71	0.028	0.99	0.039	0.28	0.011
133	30	1.04	0.041	1.45	0.057	0.41	0.016
178	40	1.32	0.052	1.93	0.076	0.61	0.024
222	50	1.62	0.064	2.39	0.094	0.76	0.030
267	60	1.93	0.076	2.90	0.114	0.96	0.038
311	70	2.21	0.087	3.30	0.130	1.09	0.043
356	80	2.51	0.099	3.86	0.152	1.35	0.053
400	90	2.84	0.112	4.42	0.174	1.57	0.062
445	100	3.18	0.125	5.03	0.198	1.85	0.073
489	110	3.53	0.139	6.02	0.237	2.49	0.098
529	119	3.86	0.152	7.82	0.308	3.96	0.156

TABLE III.- Continued

Load		Lower reference reading		Upper reference reading		Joint elongation	
kN	kips	mm	in.	mm	in.	mm	in.
(c) 1 year exposure and 0.4 lifetime of fatigue							
0	0	0	0	0	0	0	0
44	10	0.23	0.009	0.30	0.012	0.07	0.003
89	20	0.51	0.020	0.71	0.028	0.20	0.008
133	30	0.91	0.036	1.24	0.049	0.33	0.013
178	40	1.27	0.050	1.75	0.069	0.48	0.019
222	50	1.62	0.064	2.31	0.091	0.69	0.027
267	60	2.01	0.079	2.84	0.112	0.83	0.033
311	70	2.34	0.092	3.38	0.133	1.04	0.041
356	80	2.69	0.106	3.94	0.155	1.25	0.049
400	90	3.07	0.121	4.55	0.179	1.48	0.058
445	100	3.45	0.136	5.21	0.205	1.76	0.069
489	110	3.86	0.152	6.32	0.249	2.46	0.097
516	116	4.06	0.160	7.42	0.292	3.36	0.132
(d) 3 years exposure and 1.2 lifetimes of fatigue							
0	0	0	0	0	0	0	0
44	10	0.20	0.008	0.23	0.009	0.03	0.001
89	20	0.48	0.019	0.61	0.024	0.13	0.005
133	30	0.81	0.032	1.07	0.042	0.26	0.010
178	40	1.14	0.045	1.52	0.060	0.38	0.015
222	50	1.50	0.059	2.01	0.079	0.51	0.020
267	60	1.80	0.071	2.49	0.098	0.69	0.027
311	70	2.16	0.085	3.00	0.118	0.84	0.033
356	80	2.49	0.098	3.50	0.138	1.01	0.040
400	90	2.82	0.111	4.04	0.159	1.22	0.048
445	100	3.18	0.125	4.62	0.182	1.44	0.057
489	110	3.58	0.141	5.38	0.212	1.80	0.071
520	117	3.96	0.156	7.06	0.278	3.10	0.122

TABLE III.- Concluded

Load		Lower reference reading		Upper reference reading		Joint elongation	
kN	kips	mm	in.	mm	in.	mm	in.
(e) 5 years exposure and 2.0 lifetimes of fatigue							
0	0	0	0	0	0	0	0
44	10	0.20	0.008	0.25	0.010	0.05	0.002
89	20	0.48	0.019	0.68	0.027	0.20	0.008
133	30	0.76	0.030	1.12	0.044	0.36	0.014
178	40	1.04	0.041	1.55	0.061	0.51	0.020
222	50	1.32	0.052	1.98	0.078	0.66	0.026
267	60	1.65	0.065	2.49	0.098	0.84	0.033
311	70	1.96	0.077	3.00	0.118	1.04	0.041
356	80	2.29	0.090	3.53	0.139	1.24	0.049
400	90	2.62	0.103	4.09	0.161	1.47	0.058
445	100	2.95	0.116	4.72	0.186	1.77	0.070
489	110	3.25	0.128	5.66	0.223	2.41	0.095
516	116	3.45	0.136	6.73	0.265	3.28	0.129
(f) 7 years exposure and 2.8 lifetimes of fatigue							
0	0	0	0	0	0	0	0
44	10	0.30	0.012	0.43	0.017	0.13	0.005
89	20	0.68	0.027	0.94	0.037	0.26	0.010
133	30	0.99	0.039	1.42	0.056	0.43	0.017
178	40	1.30	0.051	1.88	0.074	0.58	0.023
222	50	1.57	0.062	2.36	0.093	0.79	0.031
267	60	1.88	0.074	2.84	0.112	0.96	0.038
311	70	2.18	0.086	3.33	0.131	1.15	0.045
356	80	2.51	0.099	3.89	0.153	1.38	0.054
400	90	2.82	0.111	4.47	0.176	1.65	0.065
445	100	3.20	0.126	5.13	0.202	1.93	0.076
489	110	3.58	0.141	6.27	0.247	2.69	0.106
503	113	3.68	0.145	6.91	0.272	3.23	0.127

TABLE IV.- FATIGUE LOAD INFORMATION FOR 2000 FLIGHT BLOCK (REF. 5)

Flight type	Number of flights	Occurrences per flight at - Alternating load level, fraction of 1g load,[a] of -								Cycles per flight
		1.0	0.85	0.75	0.65	0.55	0.45	0.35	0.25	
A'	1	1	1	2	3	8	27	210	2500	2752
A	1		1	2	3	8	27	210	2500	2751
B	18				1	3	9	40	250	303
C	180						1	4	30	35
D	1800							1	6	7

[a]The 1g load is defined as 0.275 times limit load and the 1g load level is the mean value for each load cycle (for example, see fig. 13).

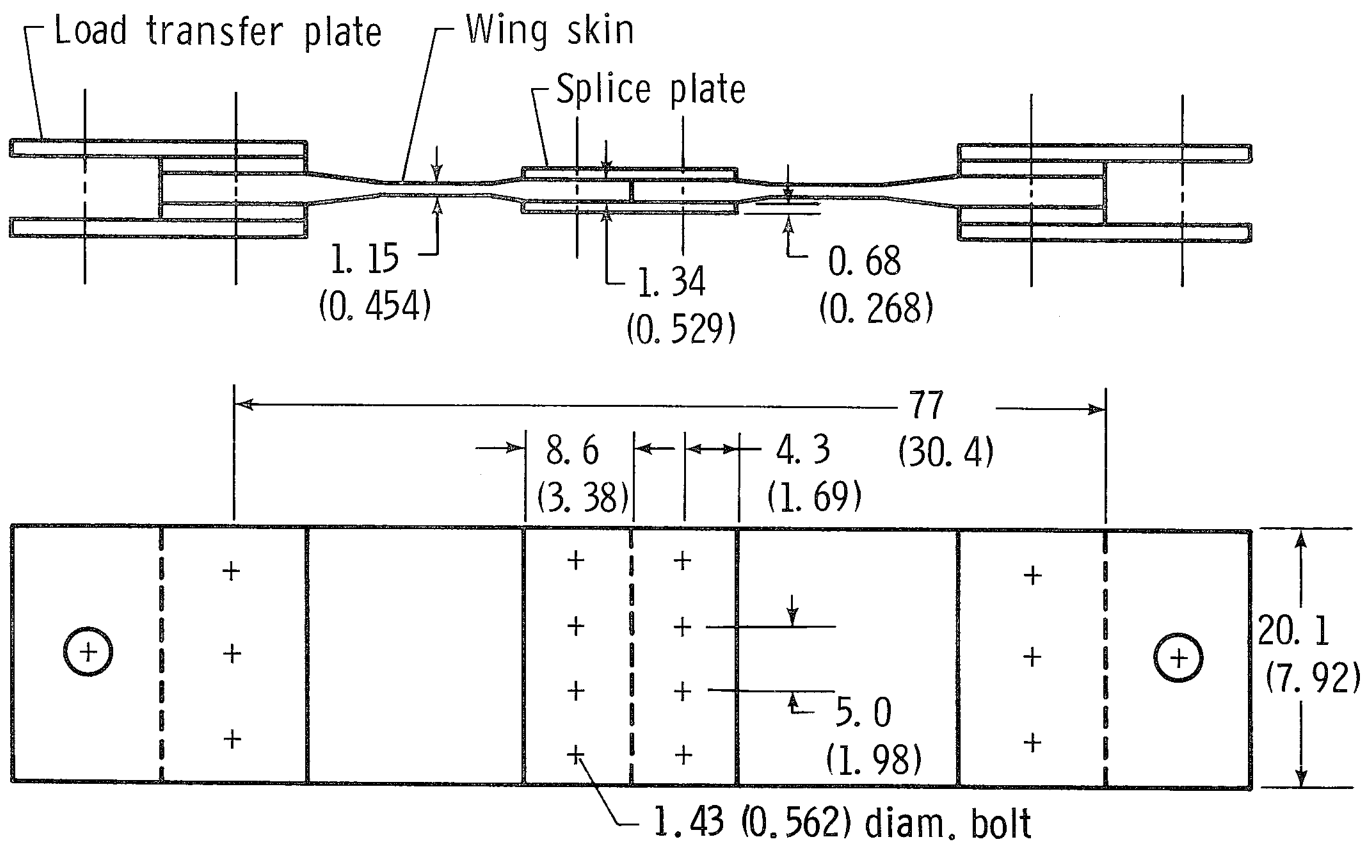


Figure 1.- Graphite/epoxy single-row bolt configuration specimen. Dimensions are in centimeters (inches).

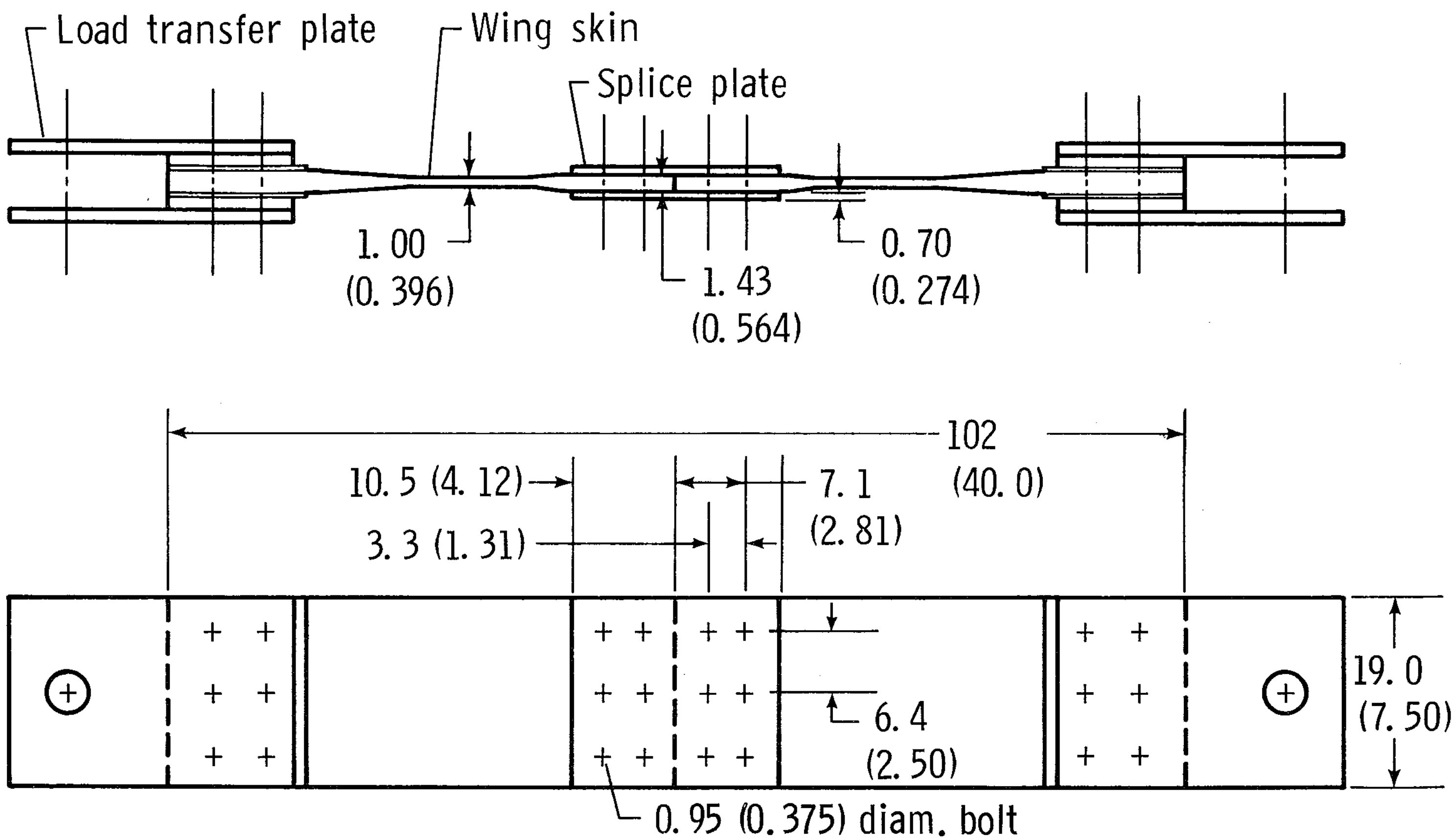
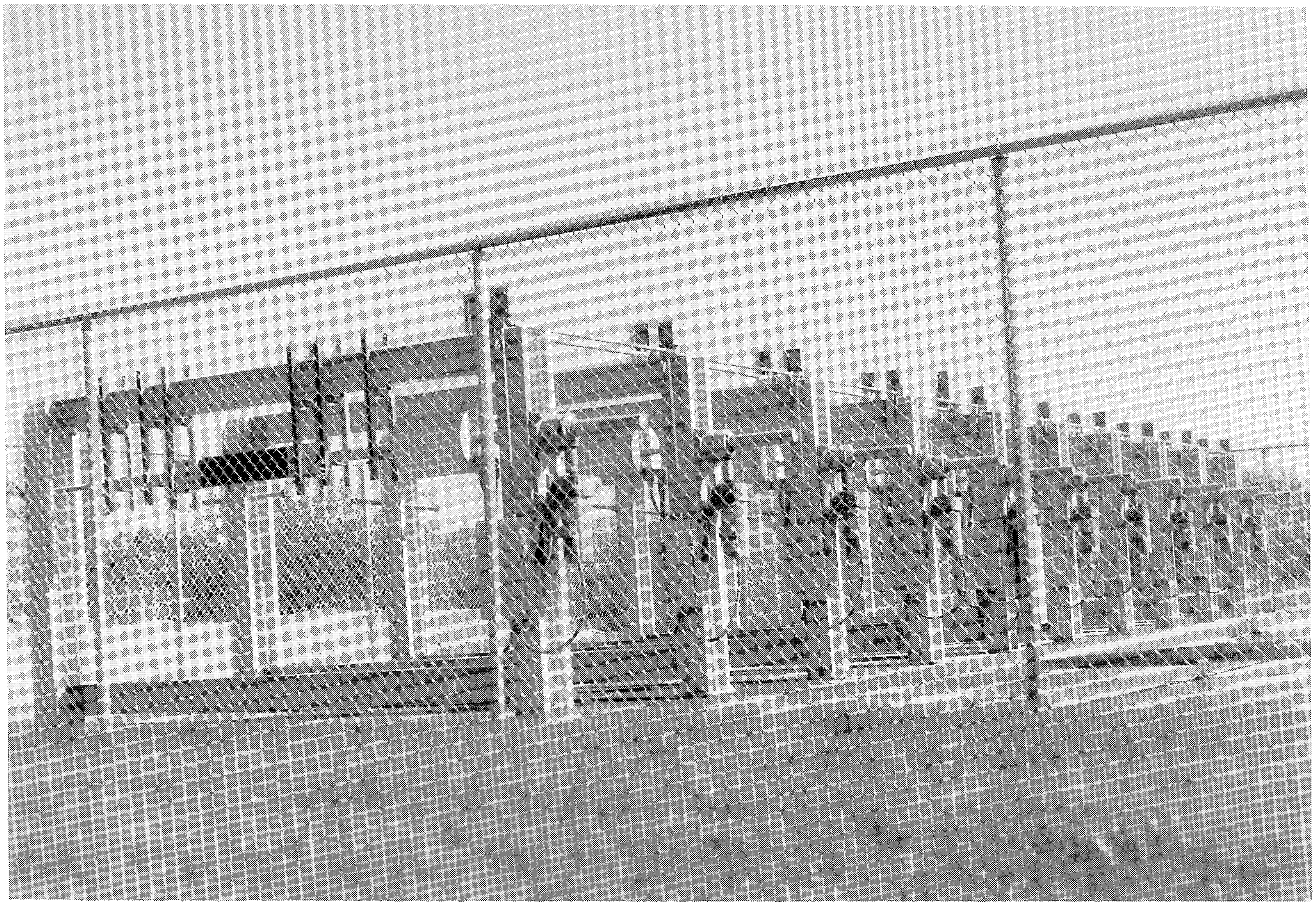
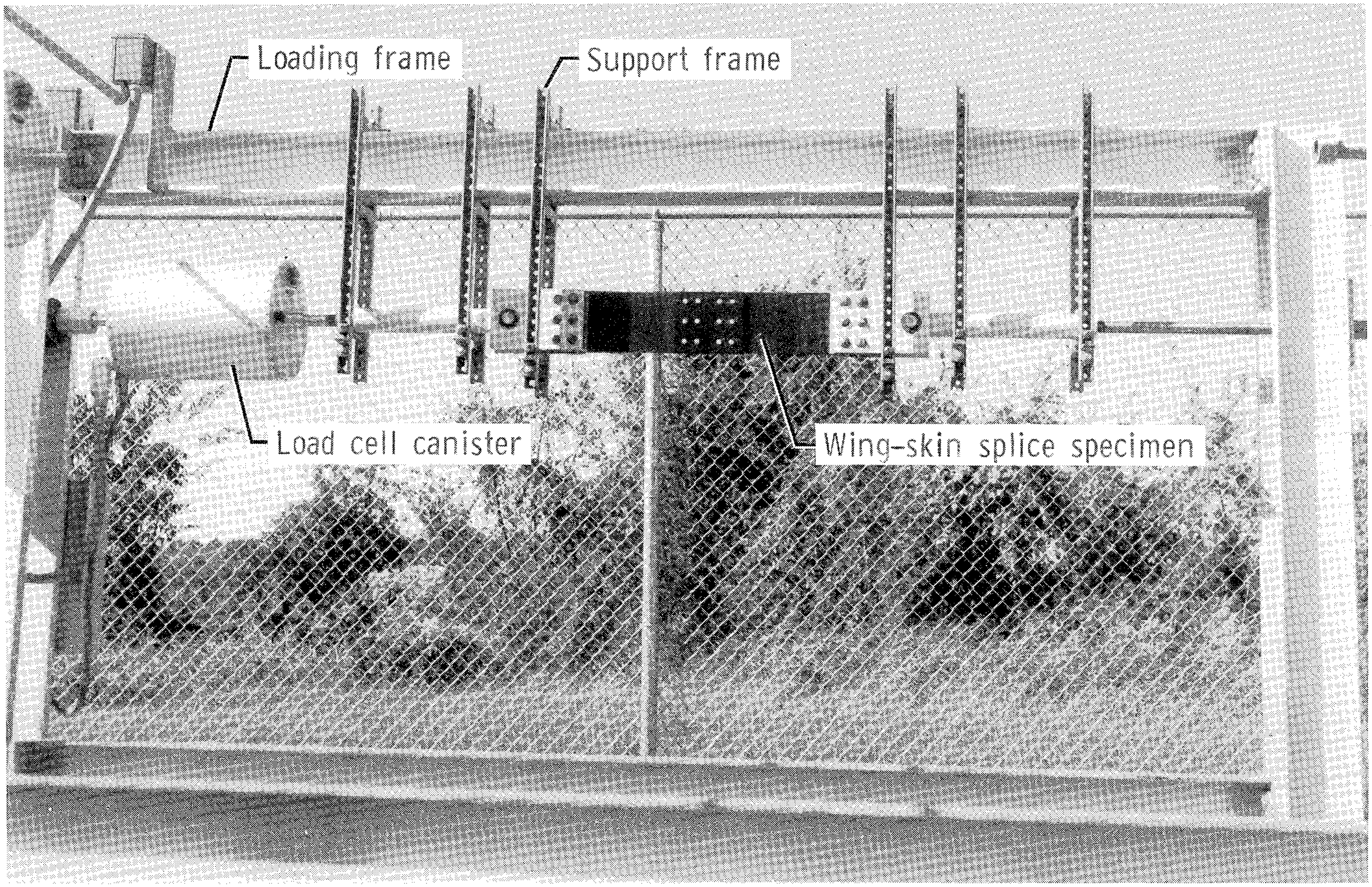


Figure 2.- Graphite/epoxy double-row bolt configuration specimen. Dimensions are in centimeters (inches).



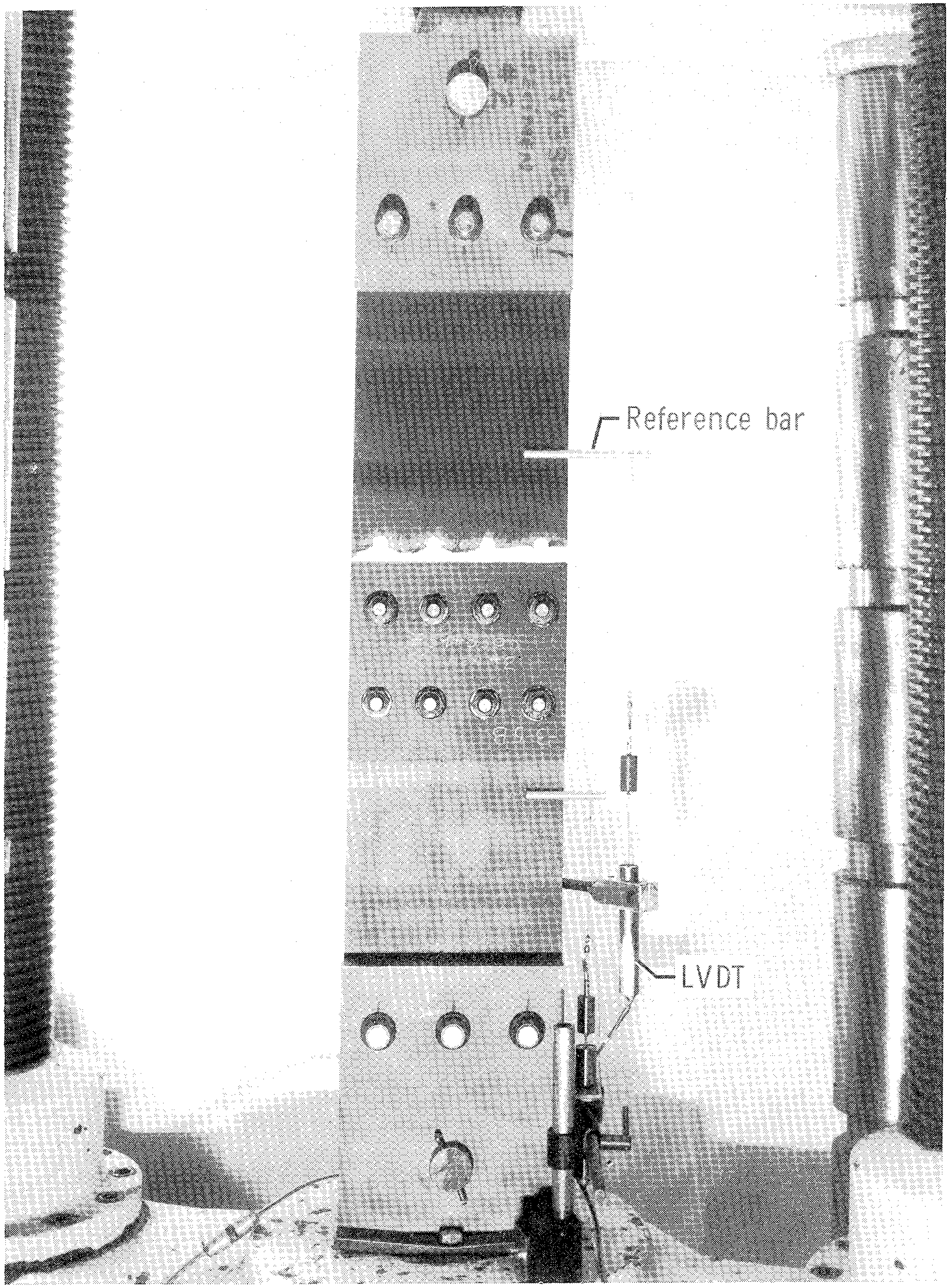
L-77-7358

Figure 3.- Bolted joint specimens under sustained load at outdoor exposure site.



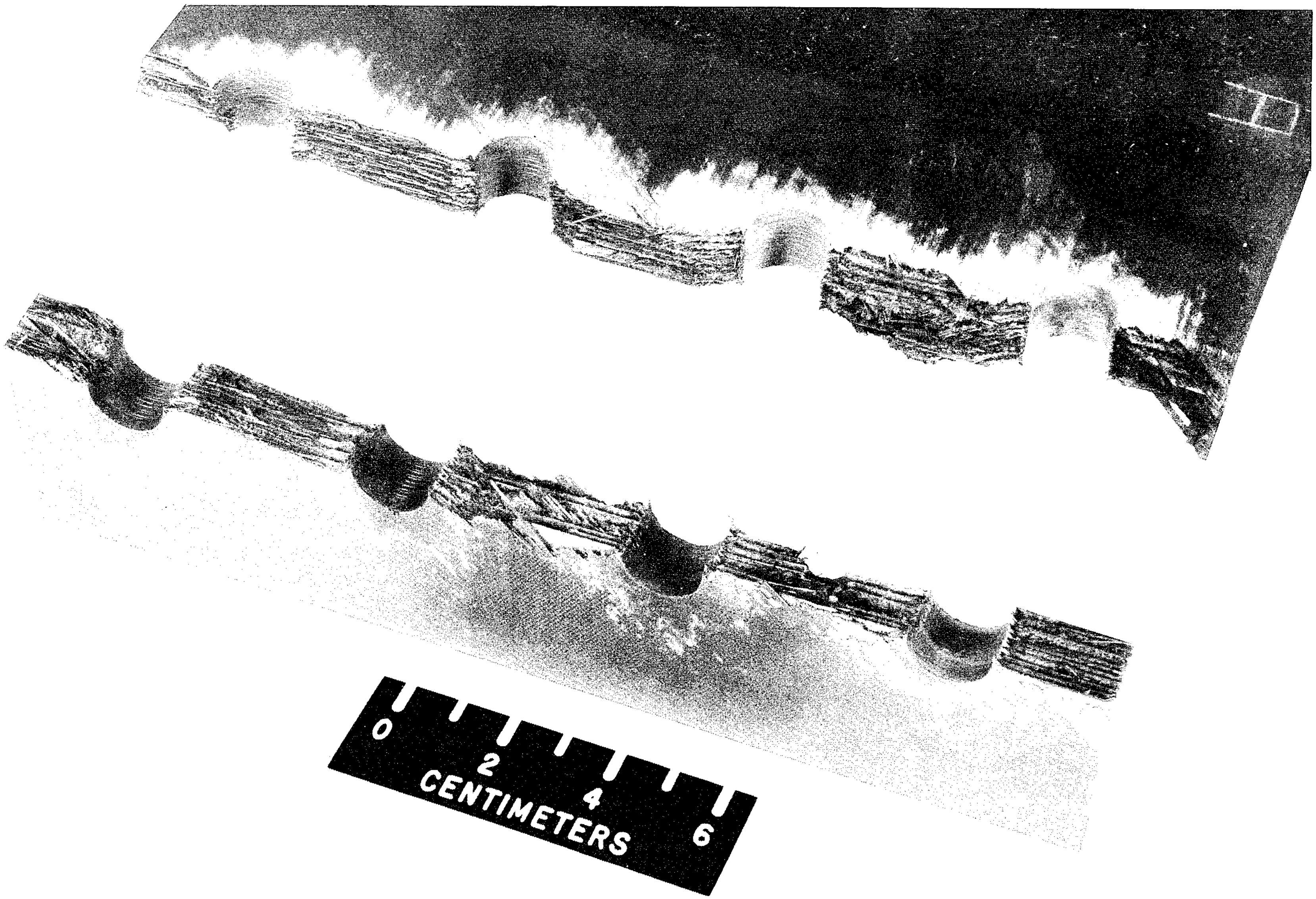
L-85-167

Figure 4.- Outdoor exposure test setup.



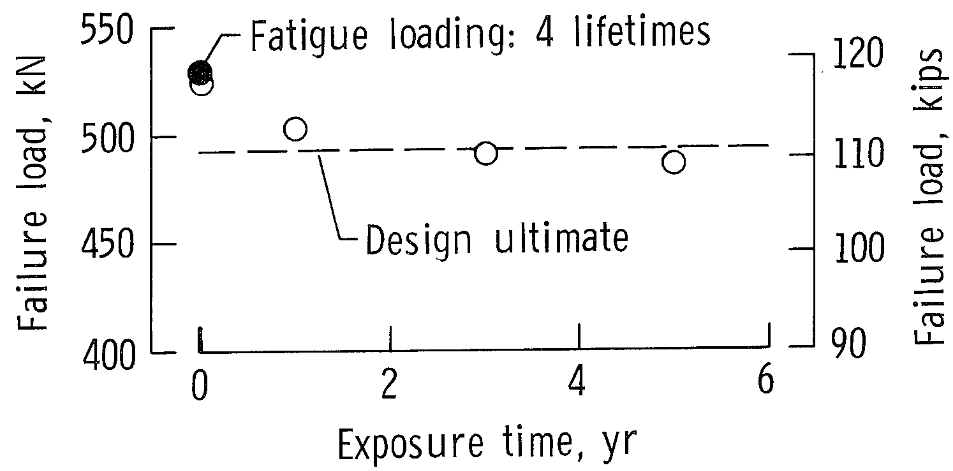
L-85-168

Figure 5.- Residual strength test setup with failed single-row bolt configuration specimen.

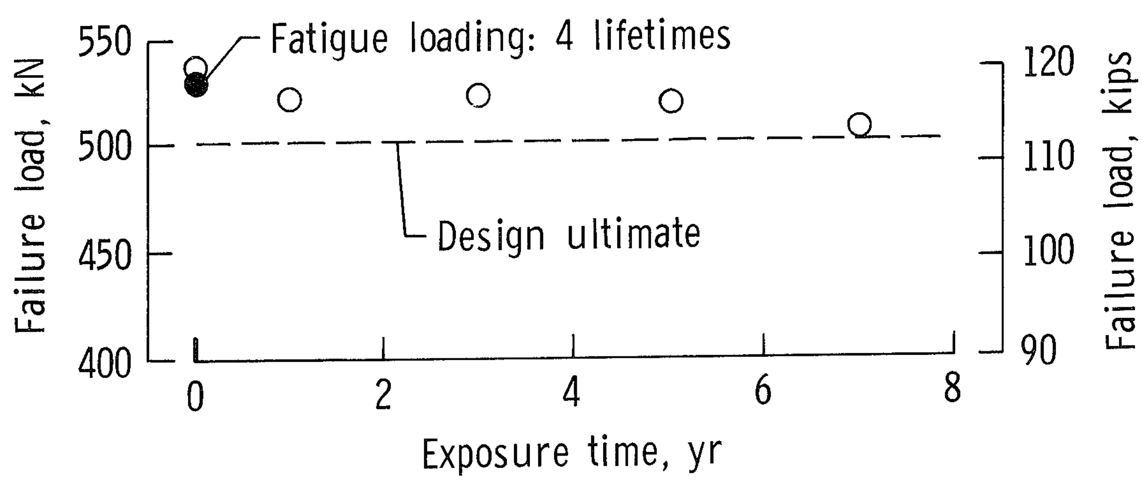


L-85-169

Figure 6.- Typical net tension failure in single-row bolt configuration specimens.



(a) T300/5208 specimens with single-row configuration.



(b) T300/5209 specimens with double-row configuration.

Figure 7.- Effect of outdoor exposure and load history on static strength of graphite/epoxy bolted joint specimens.

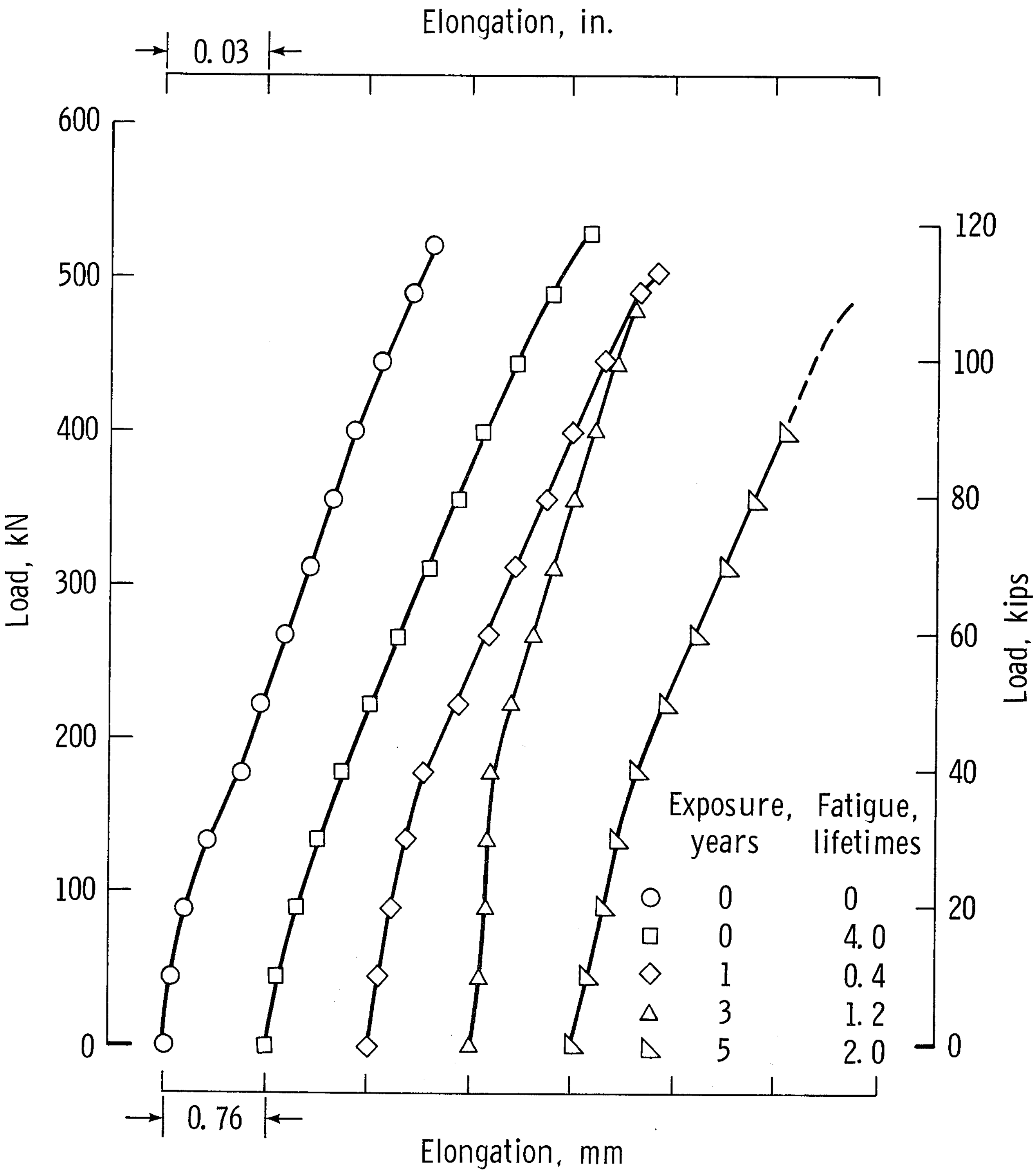
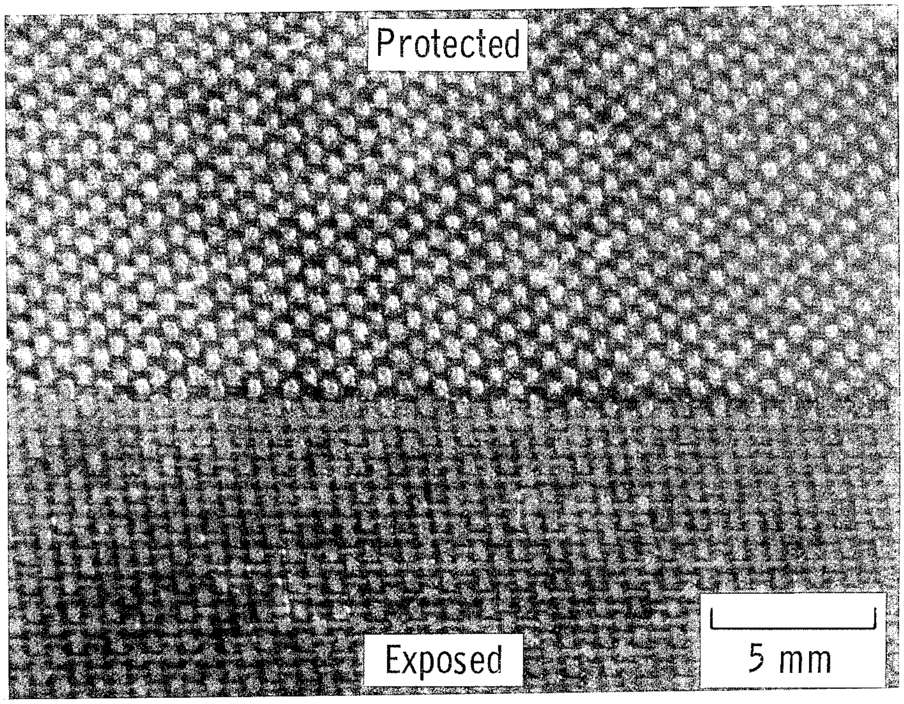
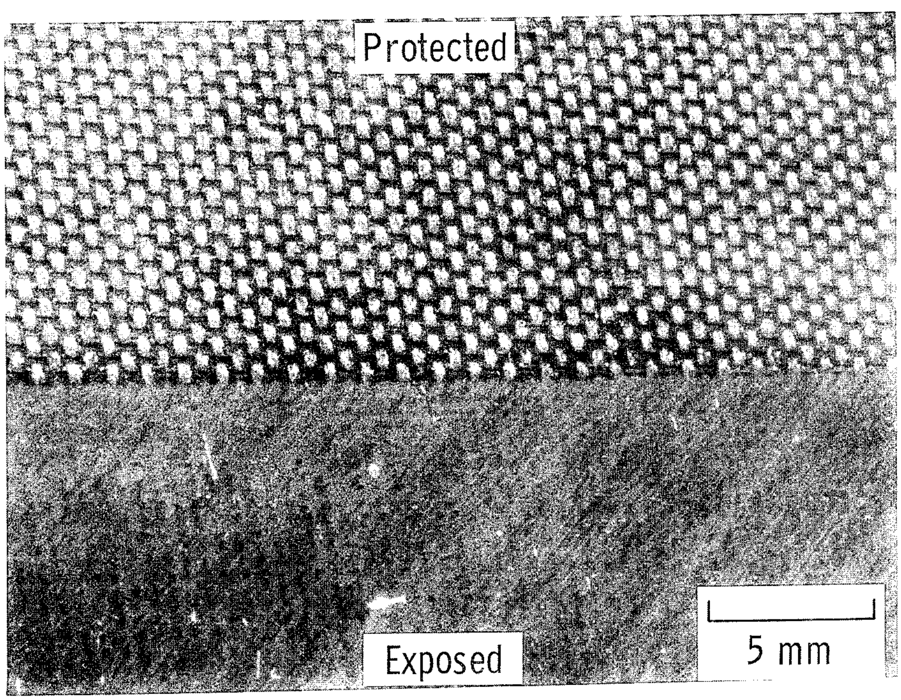


Figure 8.- Total elongation across joint splice for T300/5208 specimens with single-row bolt configuration.



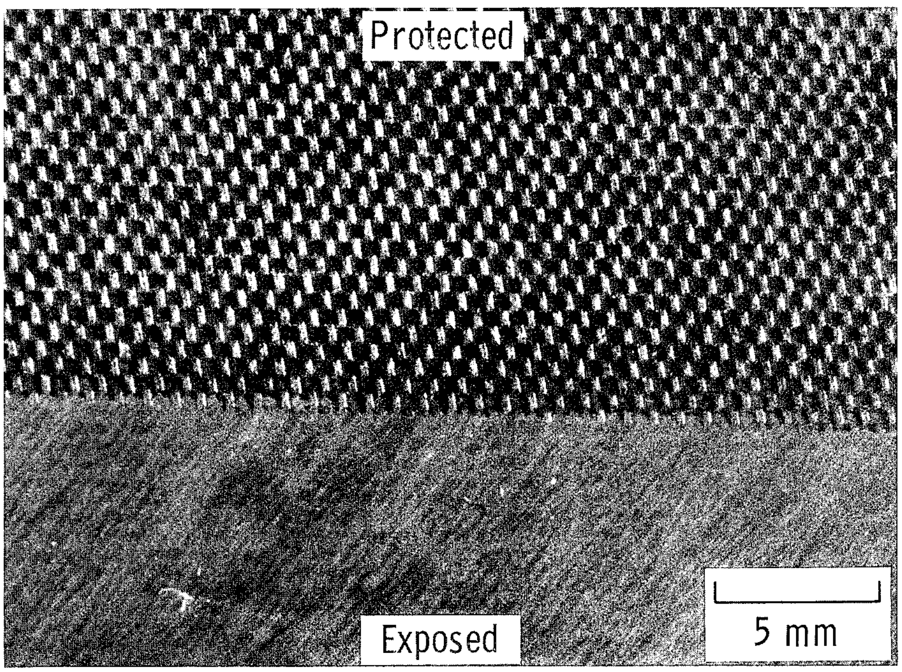
(a) After 1 year exposure.



(b) After 3 years exposure.

L-85-170

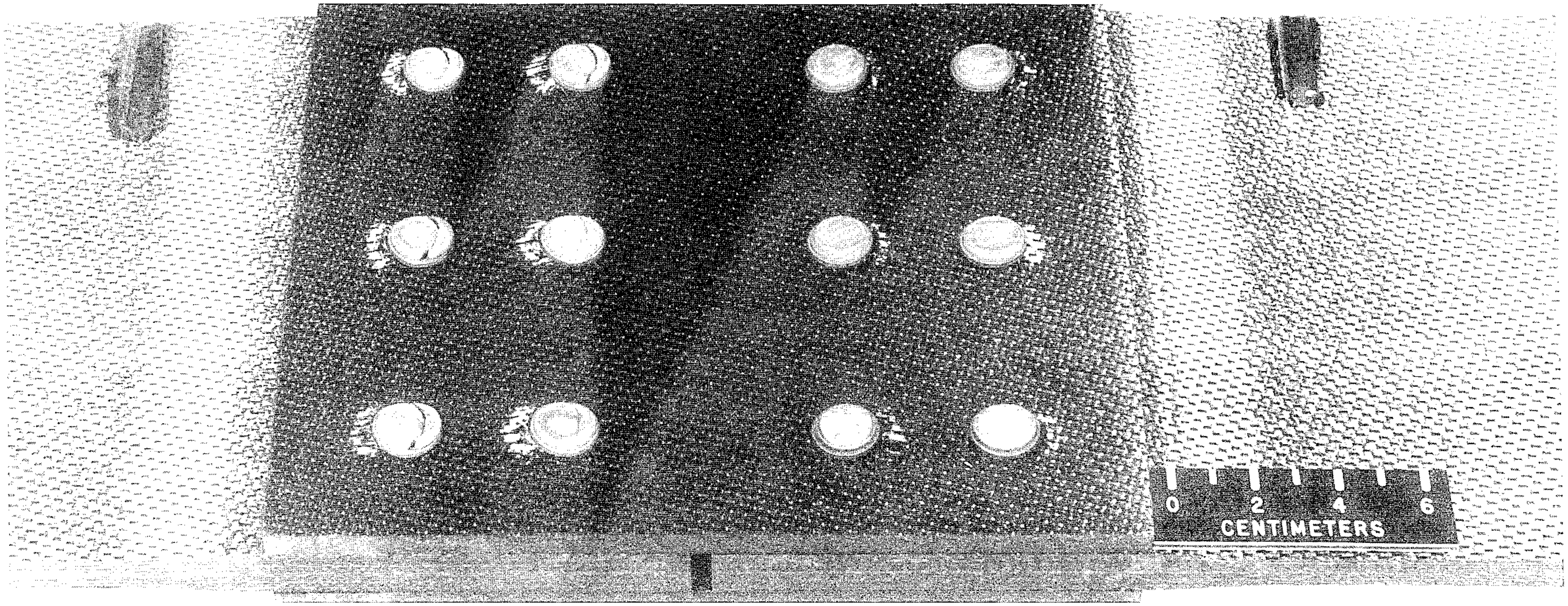
Figure 9.- Effects of outdoor exposure on surfaces of T300/5208 specimens.



L-85-171

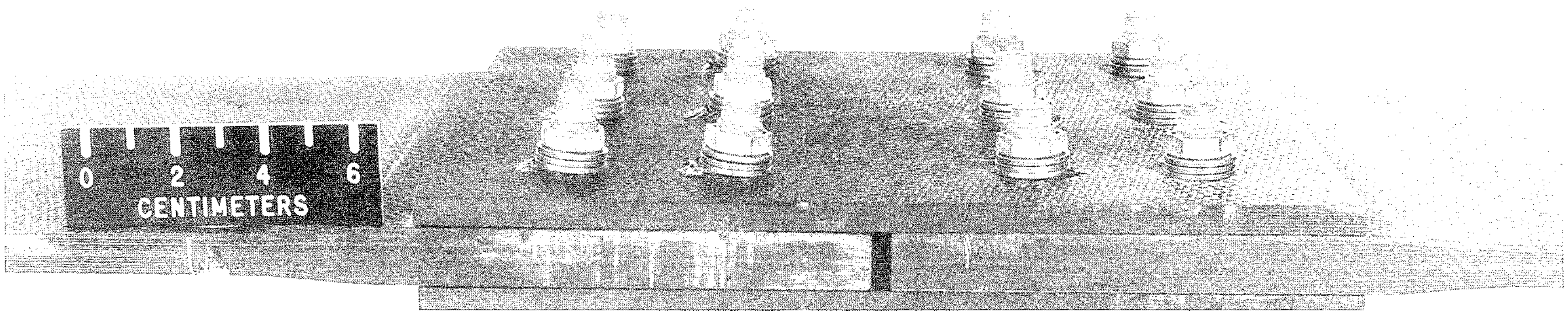
(c) After 5 years exposure.

Figure 9.- Concluded.



L-84-5033

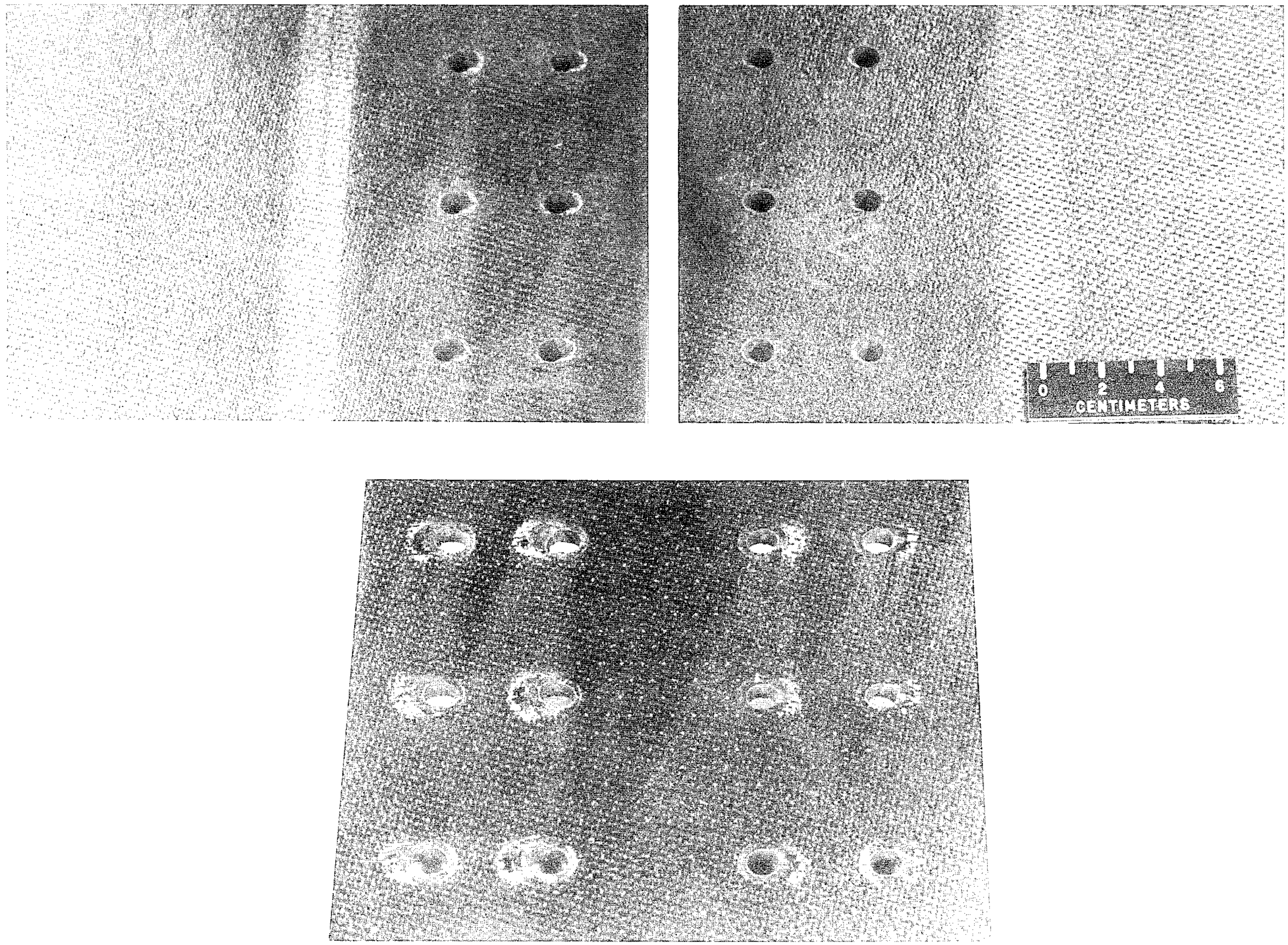
(a) Splice plate damage at bolt heads.



L-84-5032

(b) Splice plate damage at bolt heads and bolt bending.

Figure 10.- Typical bearing failure in double-row bolt configuration specimens.



L-84-5034

(c) Damage to splice plate and built-up wing skin.

Figure 10.- Concluded.

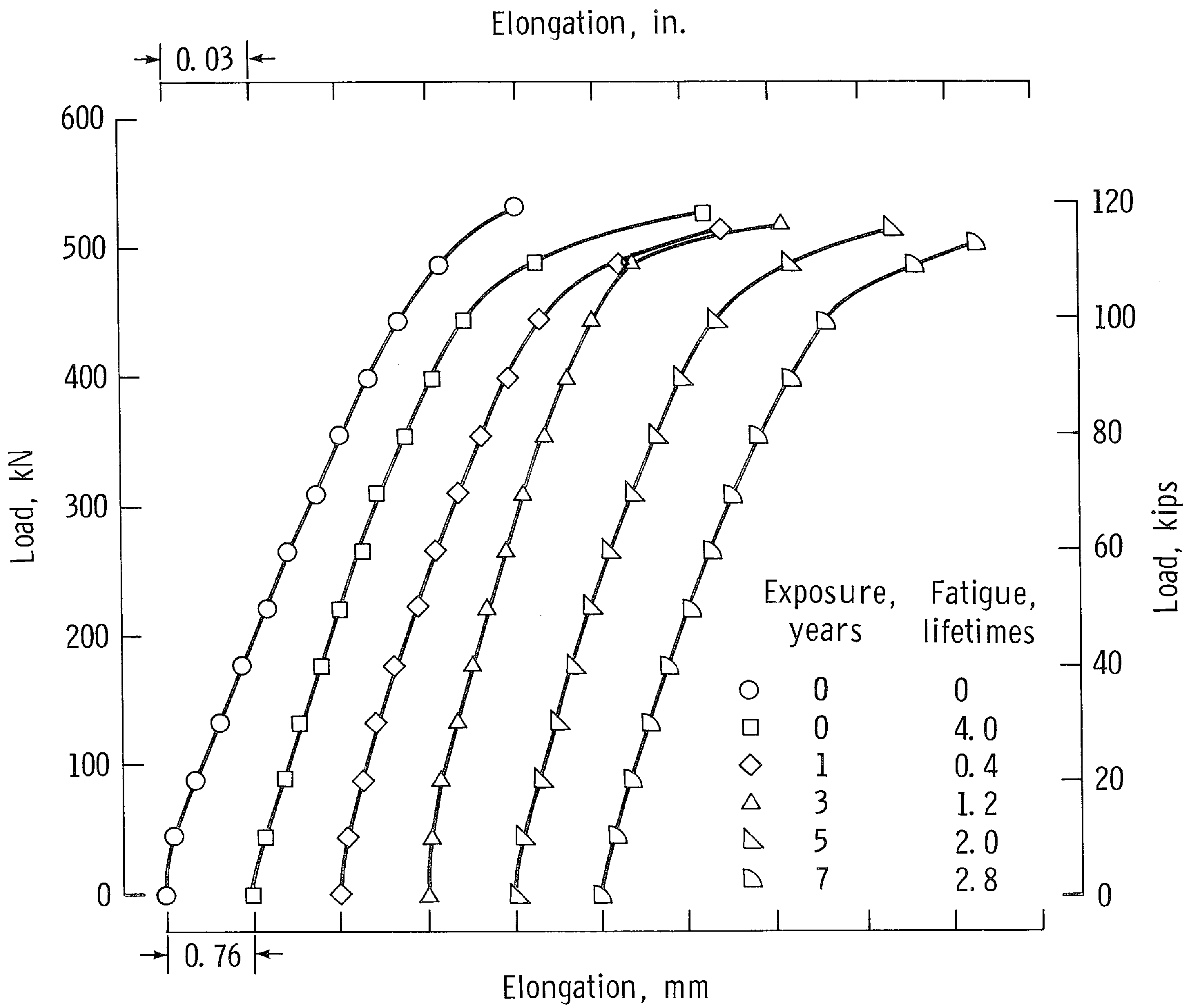
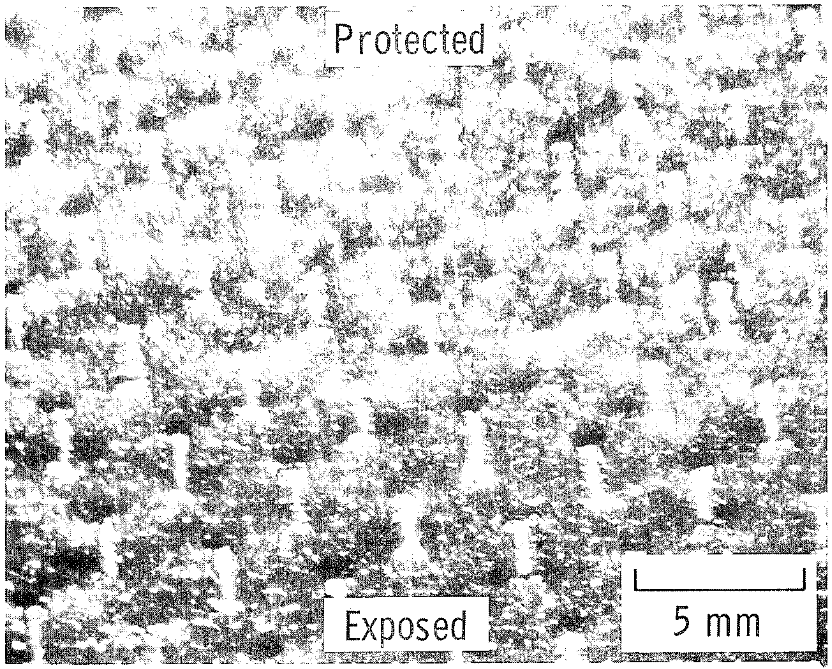
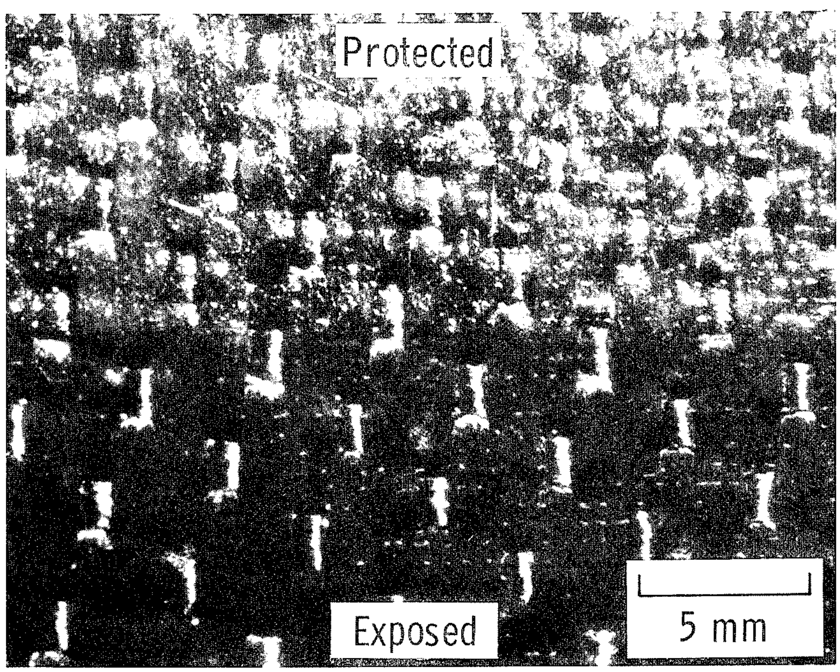


Figure 11.- Total elongation across joint splice for T300/5209 specimens with double-row bolt configuration.



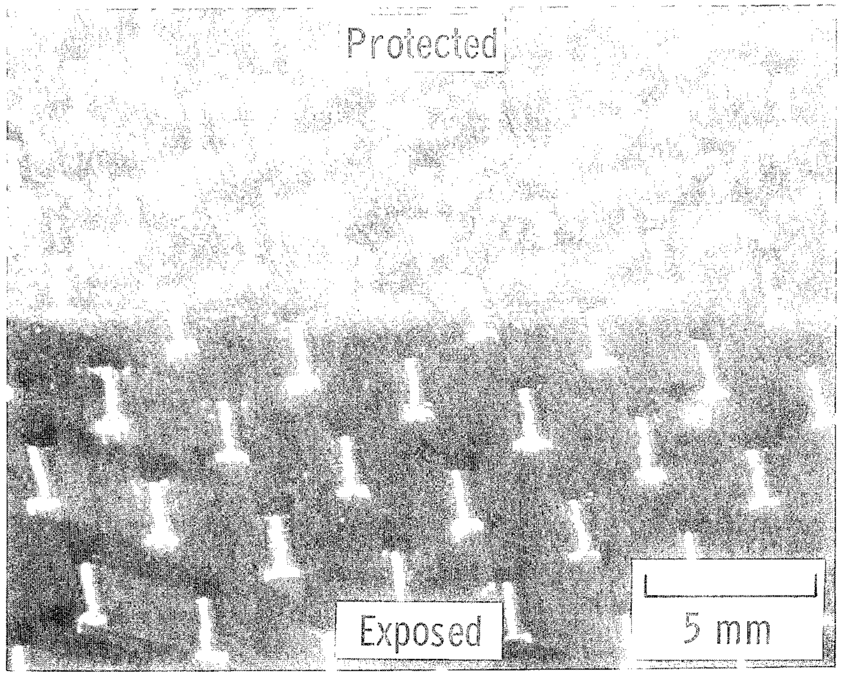
(a) After 1 year exposure.



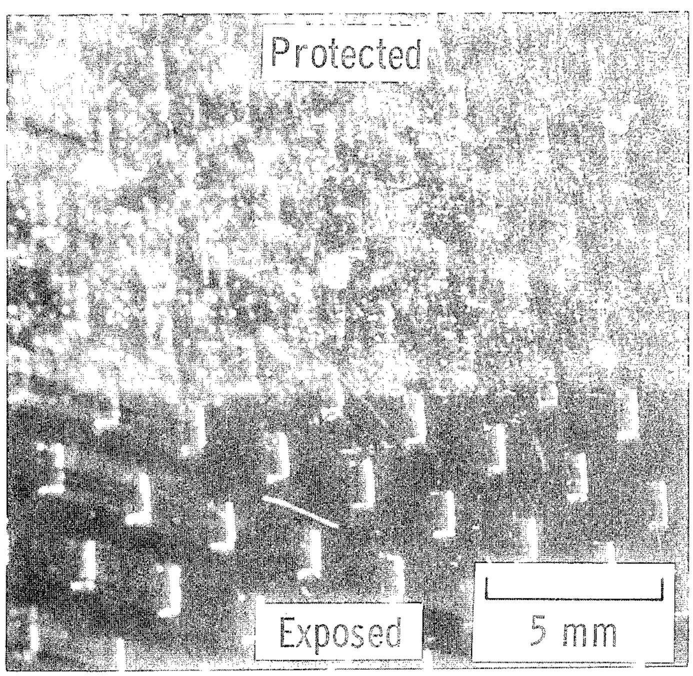
(b) After 3 years exposure.

L-85-172

Figure 12.- Effects of outdoor exposure on surfaces of T300/5209 specimens.



(c) After 5 years exposure.



(d) After 7 years exposure.

L-85-173

Figure 12.- Concluded.

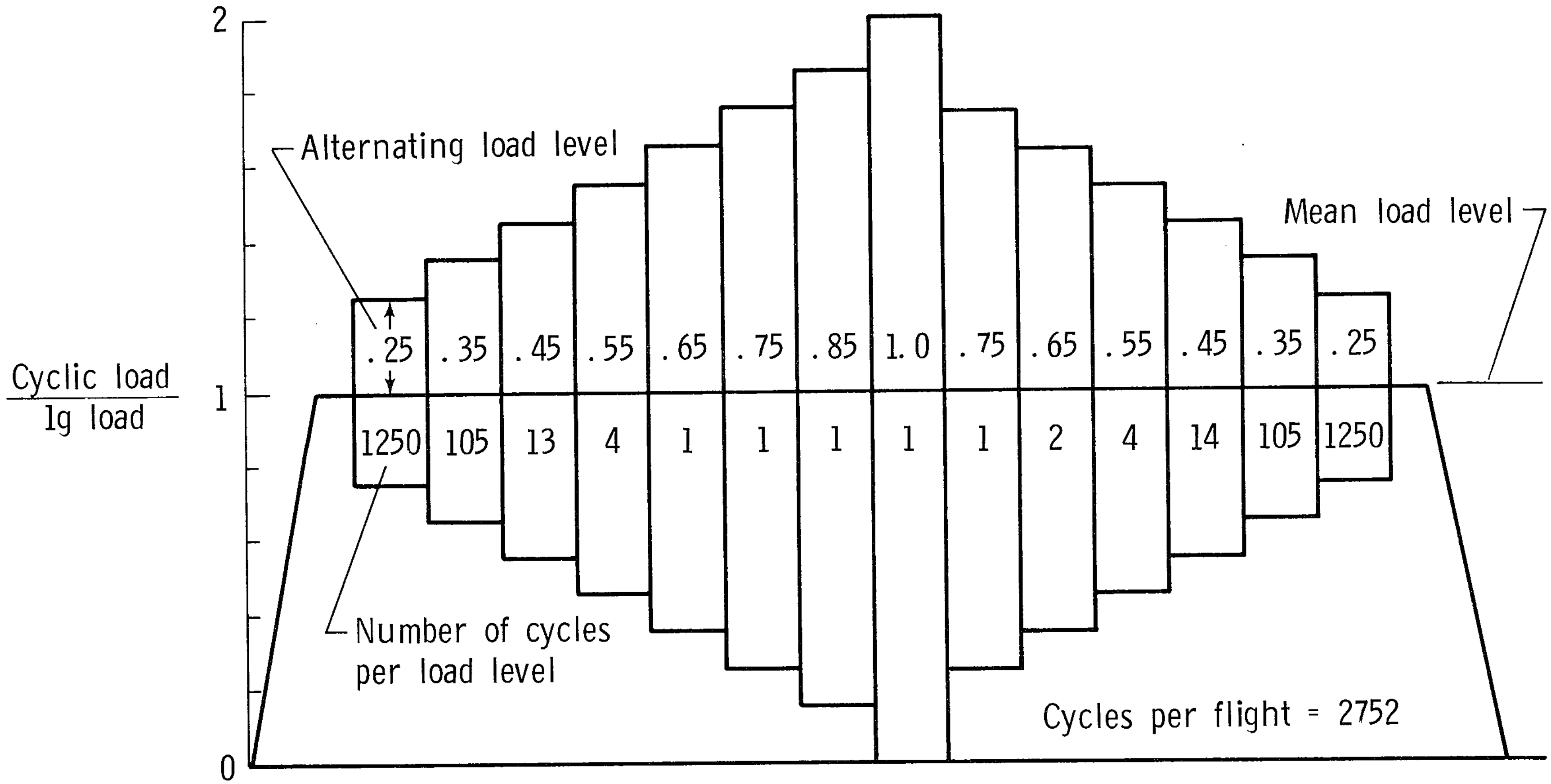


Figure 13.- Loading levels for flight type A'.

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15. Supplementary Notes

16. Abstract

The results of an experimental study to provide long-term durability data on detailed full-scale graphite/epoxy wing-skin joint designs under environmental exposure and cyclic loading associated with commercial transport aircraft are reported. The specimens consisted of a single-row bolt configuration fabricated from T300/5208 and a double-row bolt configuration fabricated from T300/5209. The unpainted specimens were exposed to the outdoor environment under a sustained tensile load, and at yearly intervals, they were subjected to fatigue loading. Experimental results showed a slight reduction in residual tensile strength for both graphite/epoxy joints under the exposure times and fatigue loadings reported. A 7.5-percent decrease in residual strength was observed for the T300/5208 single-row joint after 5 years exposure and two lifetimes of fatigue loading. A 5.3-percent decrease in residual strength was observed for the T300/5209 double-row joint after 7 years exposure and 2.8 lifetimes of fatigue loading. The 5208 epoxy material was more susceptible to degradation by ultraviolet radiation than the 5209 epoxy material.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Composite material Graphite/epoxy Full scale Outdoor exposure Fatigue loading Residual strength Bolted joint	Unclassified - Unlimited Subject Category 24

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
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