NASA TECHNICAL
MEMORANDUM

NASA TM X-71995

BONDED COMPOSITE-TO-METAL SCARF JOINT PERFORMANCE IN AN AIRCRAFT LANDING GEAR DRAG STRUT

by William E. Howell

Langley Research Center
Hampton, Virginia

SEP.1974

(NASA-TM-X-71995)   BONDED COMPOSITE TO
METAL SCARF JOINT PERFORMANCE IN AN
AIRCRAFT LANDING GEAR DRAG STRUT (NASA)
25 p HC $3.00   CSCL 01C

N74-31504

Unclas
G3/02 47745

1. Report No. NASA TMX-71995	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Bonded Composite-To-Metal Scarf Joint Performance in an Aircraft Landing Gear Drag Strut		5. Report Date July 1974
		6. Performing Organization Code 25.110
7. Author(s) William E. Howell		8. Performing Organization Report No.
9. Performing Organization Name and Address Langley Research Center Hampton, VA 23665		10. Work Unit No. 505-02-41-01
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The structural performance of a boron-epoxy reinforced titanium drag strut, which contains a bonded scarf joint and was designed to the criteria of the Boeing 747 transport, has been evaluated. An experimental and analytical investigation was conducted. The strut was exposed to two lifetimes of spectrum loading and was statically loaded to the tensile and compressive design ultimate loads. Throughout the test program no evidence of any damage in the drag strut was detected by strain gage measurements, ultrasonic inspection, or visual observation. An analytical study of the bonded joint was made using the NASA Structural Analysis Computer Program NASTRAN. A comparison of the strains predicted by the NASTRAN computer program with the experimentally determined values shows excellent agreement. The NASTRAN computer program is a viable tool for studying, in detail, the stresses and strains induced in a bonded joint.

17. Key Words (Suggested by Author(s)) (STAR category underlined) Bonded joint, composites, boron-epoxy	18. Distribution Statement

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 23	22. Price* $3.00

*Available from { The National Technical Information Service, Springfield, Virginia 22151

STIF/NASA Scientific and Technical Information Facility, P.O. Box 33, College Park, MD 20740

BONDED COMPOSITE-TO-METAL SCARF JOINT PERFORMANCE
IN AN AIRCRAFT LANDING GEAR DRAG STRUT

William E. Howell
Langley Research Center
Hampton, VA

SUMMARY

The structural performance of a boron-epoxy reinforced titanium drag
strut, which contains a bonded scarf joint and was designed to the criteria
of the Boeing 747 transport, has been evaluated. An experimental and
analytical investigation was conducted. The strut was exposed to two
lifetimes of spectrum loading and was statically loaded to the tensile and
compressive design ultimate loads. Throughout the test program no
evidence of any damage in the drag strut was detected by strain gage measure-
ments, ultrasonic inspection, or visual observation. An analytical study
of the bonded joint was made using the NASA Structural Analysis Computer
Program NASTRAN. A comparison of the strains predicted by the NASTRAN
computer program with the experimentally determined values shows excellent
agreement. The NASTRAN computer program is a viable tool for studying, in
detail, the stresses and strains induced in a bonded joint.

INTRODUCTION

Aircraft designers are continually endeavoring to develop more
efficient structures. The use of high modulus fibers, such as boron and
graphite, in a polymeric matrix is one such endeavor. Whether these
composite materials are used for entire structural components or for selective
reinforcement of metallic structures, almost all applications have structural

attachments consisting of metallic fittings or concentrated load points. Developing an efficient design for the transition from composite to metal has been one of the major problem areas encountered in the use of composites. To solve this problem, a number of different bonded joint configurations such as lap shear, scarf, and step joints have been proposed (refs. 1, 2, and 3). In the design of such bonded joints, an understanding of the stresses and strains induced in the joints by applied loads is needed in order to develop the most efficient structures.

The purpose of this investigation was to conduct an experimental and analytical evaluation of a bonded scarf joint in a boron-epoxy reinforced titanium landing gear drag strut for the Boeing 747 transport. The experimental investigation consisted of both cyclic and static loading. The analytical evaluation involved the use of the NASA Structural Analysis Program NASTRAN (ref. 4) to compute the stresses and strains induced in the bonded joint. Comparisons are made between the analytical and experimental strains in the bonded joint.

The units used for the physical quantities are given in the International System of Units (SI) and in the U.S. Customary Units. Factors relating the two systems are given in reference 5.

TEST SPECIMEN

The test specimen was a boron-epoxy reinforced titanium drag strut structure designed and fabricated by the Boeing Commercial Airplane Company as a company sponsored program. Concepts developed under NASA contract

(ref. 1) were used in the design in a manner to satisfy the performance specifications of the main body landing gear of the Boeing 747 transport aircraft (Fig. 1). Details of the strut are shown in figure 2. Except for the ends, where the strut is entirely laminated titanium, unidirectional boron-epoxy was used to stiffen the thin titanium cover skins and provides 80 percent of the load carrying capabilities of the strut. A titanium strap which had a uniform 0.017 rad. (1°) tapered scarf and a 16-ply boron-epoxy strap in which the plies terminated at 1.02 cm (0.4 in.) steps were bonded together in a co-cured process. Eight of these straps were secondary-bonded together to form the complete load carrying portion of the flanges. (See figure 2b.)

Figure 2c is a cross-sectional view of the I-beam configured strut and shows the boron-epoxy reinforcement at the extremities of the flanges. The remainder of the strut was fabricated of titanium faced aluminum honeycomb-core sandwich. No mechanical fasteners were used; the entire strut was adhesively bonded together. The total mass of the completed strut is 34.5 kg (76 lbs), 30 percent less than the production drag strut.

TEST PROCEDURES AND RESULTS

The experimental evaluation of the drag strut was conducted at the NASA-Langley Research Center. Three different tests were performed on the drag strut: fatigue test, static tension test to the design ultimate load, and static compression test to the design ultimate load. (See fig. 3.)

The behavior of the drag strut during these tests was monitored by strain gages located on the flanges in the vicinity of the bonded joints as shown in figure 2b, as well as at a number of other locations.

Fatigue Test

The drag strut was exposed to two lifetimes of spectrum loading in the 1.78 MN (400 kip) capacity fatigue test machine. A sample of the spectrum is shown in figure 4. This spectrum is associated with training flights, 1-hour flights, 3-hour flights, and 7-hour flights. Each of the four types of flights has distinct mean and alternating loads. The load spectrum consisted of these four different load levels randomly arranged in a block of 33 cycles. This block of loading was applied repeatedly until two lifetimes of loading (198,000 cycles) were accumulated. The cyclic load was applied at a rate of 5 Hz. No hysteresis heating was detected. The peak load in the spectrum, 355 kN (79,800 lbs) in tension, which is only 22 percent of the design ultimate load was applied once every 100 blocks of loading for a strain survey. These data were used to monitor any changes which might occur in the strut due to the cyclic loading. A sample of these data are shown in figure 5 where strain is plotted as a function of the number of cycles of loading and shows no significant change in the strain during the test. The small, random variation is believed to have been caused by ambient temperature changes during the test.

At the conclusion of two lifetimes of spectrum loading, the strut was visually and ultrasonically inspected and no damage was detected.

Tensile Test

After the fatigue test was completed, the drag strut was mounted in the 5.34 MN (1,200 kips) capacity static testing machine (fig. 3) and was loaded in tension to the design ultimate load of 1.65 MN (372 kips). Figure 6 is a plot of some of the strain gage data as a function of applied load. The measured strain from the four gages positioned over the end of the first ply of boron-epoxy (gages 1, 2, 3 and 4 in fig. 2) indicates that the strut behaved in a linear manner. Maximum strain in boron-epoxy sections was approximately 0.0038 at the tensile design ultimate load. There was no indication of any damage due to the loading.

Compression Test

Following the tensile test the strut was mounted in the compression side of the 5.34 MN (1,200 kips) capacity static testing machine (fig. 3) and loaded to the compression design ultimate load of 2.83 MN (636 kips). Figure 7 is a plot of the compression data obtained from strain gages 1, 2, 3, and 4 shown in figure 2. Maximum strain at the compression design ultimate load was approximately 0.0060 in the boron-epoxy sections. Again, the data indicate that the strut behaved in a linear manner and survived the load with no apparent damage.

Similar data were obtained from strain gages at the other end of the strut and at several locations along the length of the strut. There was no indication of any buckling condition being approached.

NASTRAN MODEL

The finite element model developed was that of a bonded step joint
and represented a section of the drag strut bonded joint. The model
included the face sheet, adhesive layer, titanium strap with 16 steps,
one ply of boron-epoxy bonded to each step, and a second adhesive layer
which is located between the first and second straps (fig. 8). Since
each ply of boron-epoxy in the drag strut ended in a discrete step, a uni-
formly stepped joint was used to model the steps and the scarf portion of
the titanium strap. Each ply of boron-epoxy was divided into equal volumes
of boron and epoxy. The boron filament volume was assumed to be distributed
in a continuous, uniform layer sandwiched between equal volumes of epoxy.

The NASTRAN program used in this study computes stresses at the
centroid of each element. The boundary conditions consisted of constraining
the left edge of the model (fig. 8) while a uniform displacement (calculated
from strain measurements at tensile ultimate load) in the direction of the
fibers was applied to the right edge of the model. The parameters computed
in this study consisted of the shear, axial, and normal stresses; forces
at the constrained grid points; and displacements of the grid points.

NASTRAN RESULTS

Shear stress data obtained from the NASTRAN model are presented in
figure 9 where the normalized shear stress is plotted as a function of

position along the joint model. The curve shows the shear stress pattern of the row of elements containing the upper epoxy matrix of the first ply of boron-epoxy. At the left edge of the model, in the titanium strap, the shear stress is zero. The stress remains small until the first step, at which point the peak stress [70.0 MPa (10.2 ksi)] in the titanium occurs. The next element which is the first element of epoxy has a considerably lower stress value of 26.1 MPA (3.78 ksi); but the peak matrix shear stress 37.5 MPa (5.44 ksi) occurs in the second epoxy element. This peak matrix shear stress is approximately 50 percent of the matrix material shear strength (ref. 1). The stress drops very rapidly from this point to the second step where a second pair of shear stress peaks, of considerably lower values, occur. From this point to the right edge of the joint model, the shear stress is small, essentially zero, with negligible pertubations at subsequent steps.

In figure 10 the normalized axial stress of the first ply of boron is plotted as a function of distance along the model. The stress increases rapidly in the vicinity of the first step. At the second step there is an abrupt increase in the axial stress of the fiber to the maximum value of 1,420 MPa (206 ksi). This increase is caused by the decrease in effective area due to the epoxy bond at the end of the second fiber. From this point the stress continually decreases, with progressively decreasing pertubations at the successive steps, until the end of the titanium strap is passed. From the end of the strap to the end of the model there are no further changes in configuration and the axial stress is constant at 0.62 times the peak stress. This figure clearly shows

where the maximum stress occurs in the boron fiber and aids in understanding the axial stress profile of an individual ply in a bonded step joint.

The results of the analytical study show that the stresses induced in the critical matrix areas during the fatigue loading are small compared to the material strength. From previously developed data (ref. 6), the strut has essentially an indefinite lifetime at the load levels of the fatigue spectrum. The data in reference 6 indicate that the bonded joints in the drag strut would survive at least 10 times the number of cycles they were exposed to.

In order to verify the analytical study of the joint, computed strains were compared to experimental values. This comparison is presented in figure 11 where the applied load is plotted as a function of the measured strain. The solid lines are the experimental data obtained from strain gages during static loading to the tensile design ultimate load [1.65 MN (372 kips)]. The symbols represent computed values of strain at model locations that correspond to the specified strain gage locations. At the tensile design ultimate load, the agreement is excellent at the all-titanium area (gage 5), at the first ply of boron-epoxy (gage 1), and at the area beyond the joint in the all-boron-epoxy area (gage 6). This figure shows that the NASTRAN finite element analysis is a viable tool for predicting stresses and strains in a bonded step joint at the working stress levels.

CONCLUSIONS

An evaluation of structural performance has been conducted on a boron-epoxy reinforced titanium drag strut containing a bonded scarf joint. An experimental and analytical investigation was performed. The results of this investigation are summarized as follows:

1. Experimental strains obtained in static tensile and/or compressive loading of the drag strut can be predicted by a NASTRAN analysis.

2. The analytical study indicated that the peak shear stresses in the bonded joint were sufficiently low to preclude drag strut failure by disbonding the joint.

3. The drag strut was exposed to two lifetimes of spectrum loading and loaded in tension and compression to the respective design ultimate loads without the occurrence of any detectable damage.

REFERENCES

1. Oken, S.; and June, R. R.: Analytical and Experimental Investigation of Aircraft Metal Structures Reinforced with Filamentary Composites. Phase I - Concept Development and Feasibility. NASA CR-1859, 1971.

2. Corvelli, N.; and Carri, R. L.: Evaluation of a Boron-Epoxy Reinforced Titanium Tubular Truss for Applications to a Space Shuttle Booster Thrust Structure. NASA TN D-6778, 1972.

3. Hart-Smith, L. J.: Analysis and Design of Advanced Composite Bonded Joints. NASA CR-2218, 1973.

4. McCormick, Caleb W. (Editor): The NASTRAN User's Manual (Level 15). NASA SP-222(01), 1972.

5. Comm. on Metric Pract.: ASTM Metric Practice Guide. NBS Handbook 102, U. S. Dep. Com., Mar. 10, 1967.

6. Blichfeldt, B.; McCarty, J. E.: Analytical and Experimental Investigation of Aircraft Metal Structures Reinforced with Filamentary Composites. NASA CR-2039, 1972.

LANDING GEAR & DRAG STRUT

UPPER DRAG STRUT

BORON-EPOXY REINFORCED
DRAG STRUT

COMPOSITE TO METAL
LOAD TRANSFER ARRANGEMENT

TITANIUM
ADHESIVE
BORON-EPOXY
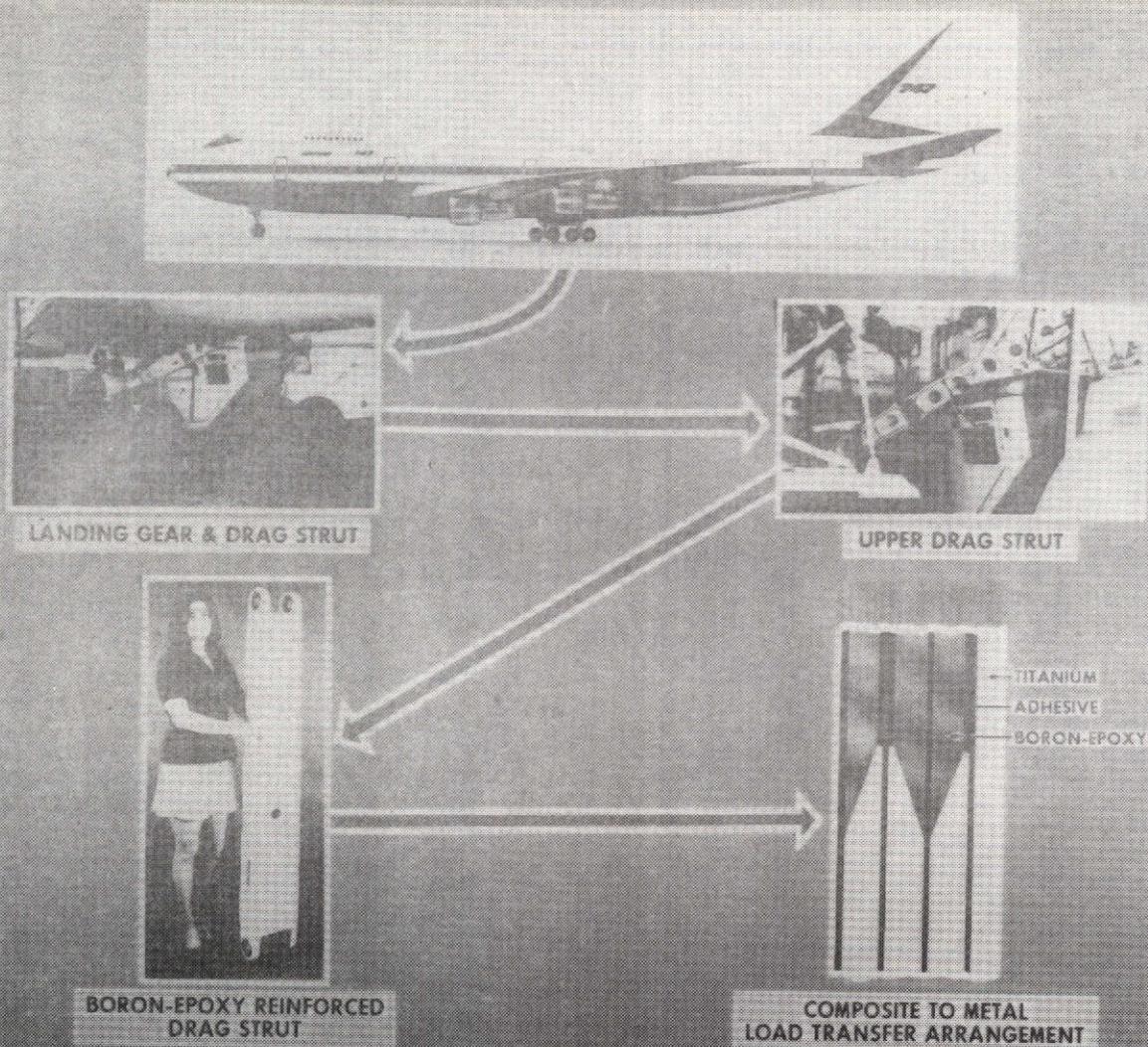
Figure 1. – Composite reinforced drag strut for the Boeing 747 transport.
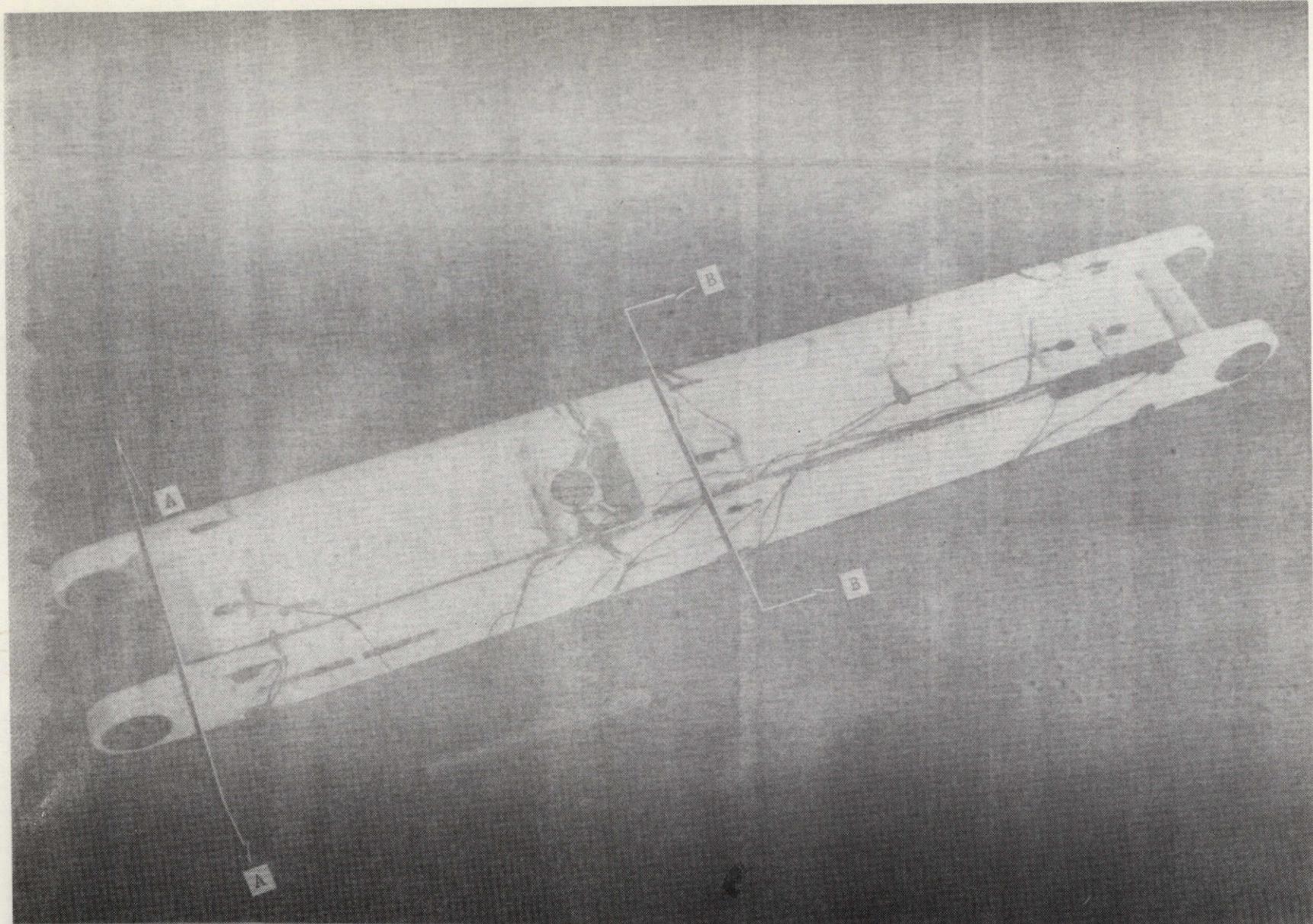
Figure 2a. – Detailed view of drag strut showing locations of view A-A
(fig. 2b) and section B-B (fig. 2c).

Strain gages

1   2

Boron-epoxy

6

Scarf joint not
drawn to scale

2

5

4

Titanium straps

Titanium face sheet
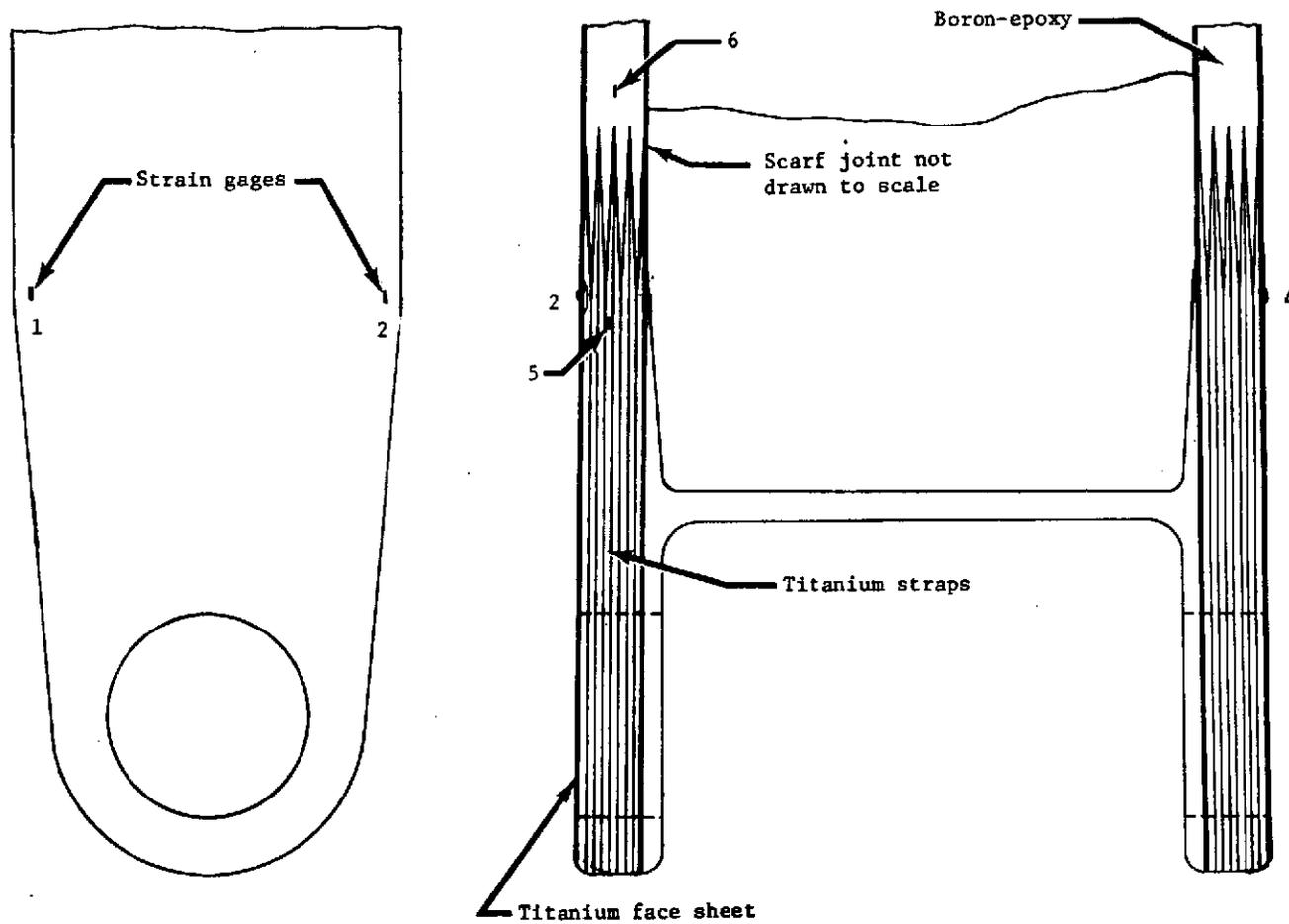
Figure 2b.- Strain gage locations at the boron-epoxy-titanium
joints near the ends of the drag strut.
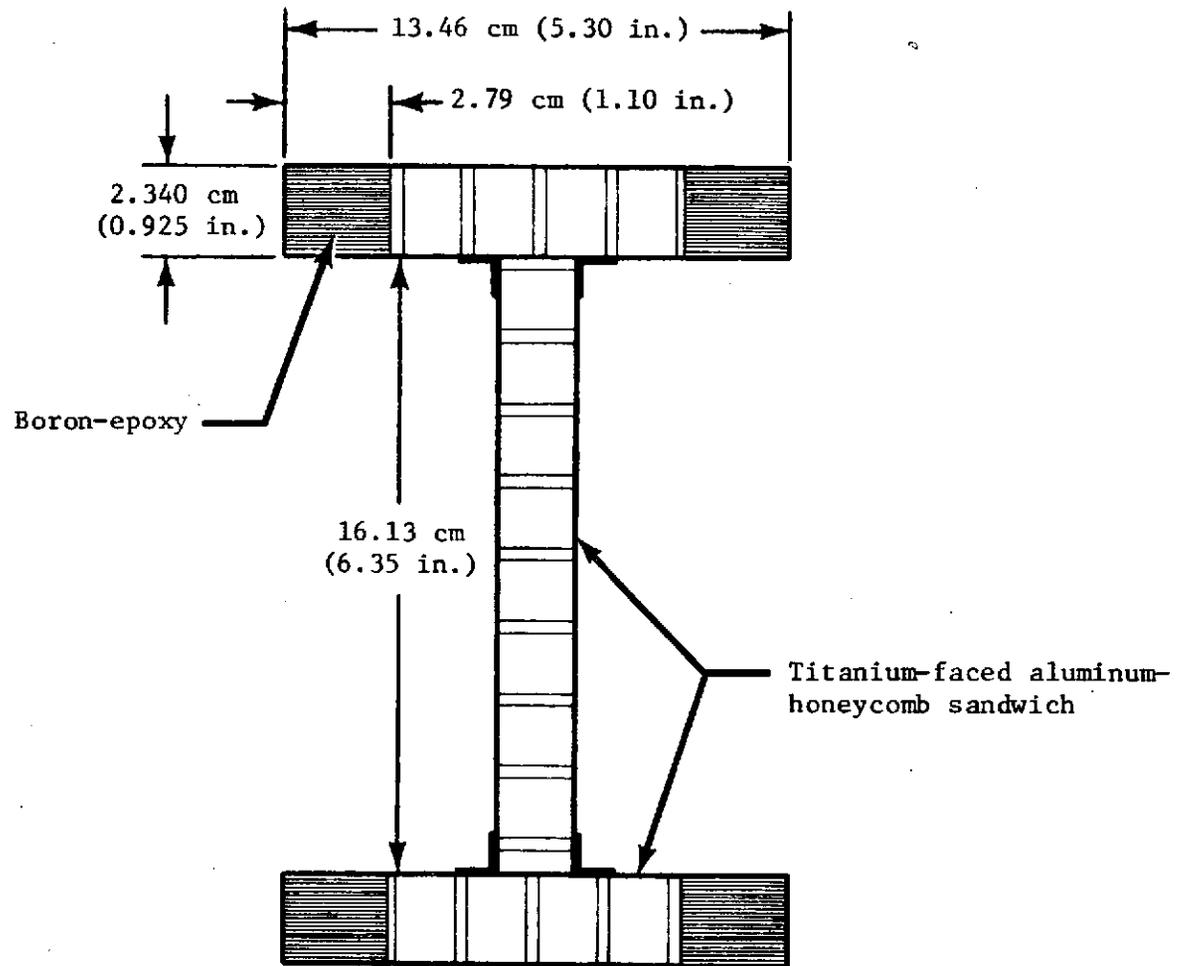
Figure 2c.- Drag strut cross-section at section B-B.
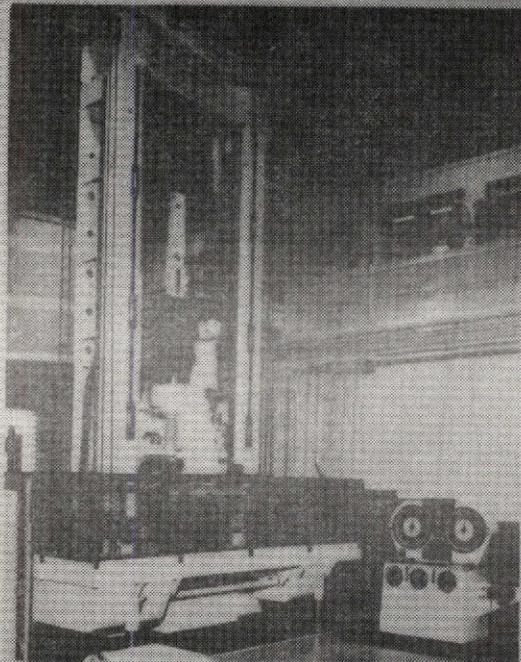
TENSILE TEST
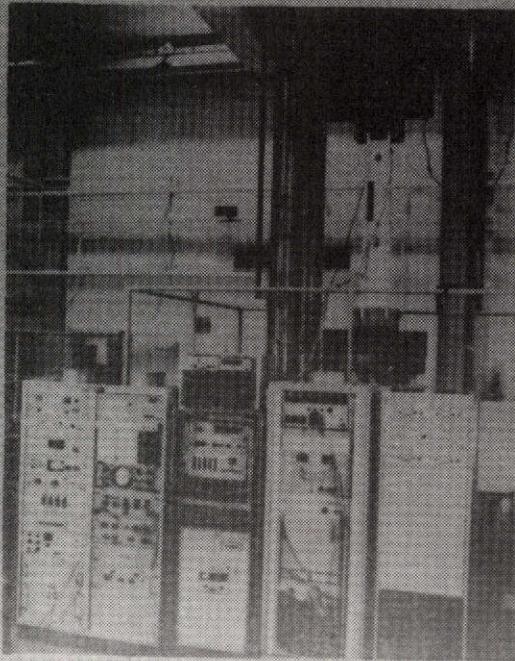
FATIGUE TEST
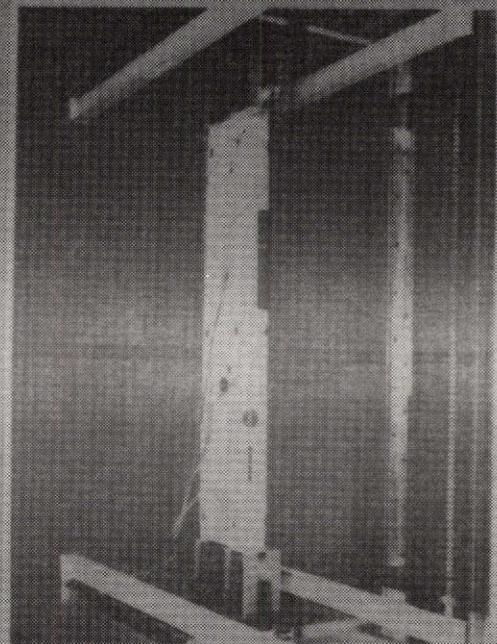
COMPRESSION TEST

Figure 3. – Experimental test arrangements for composite reinforced drag strut.
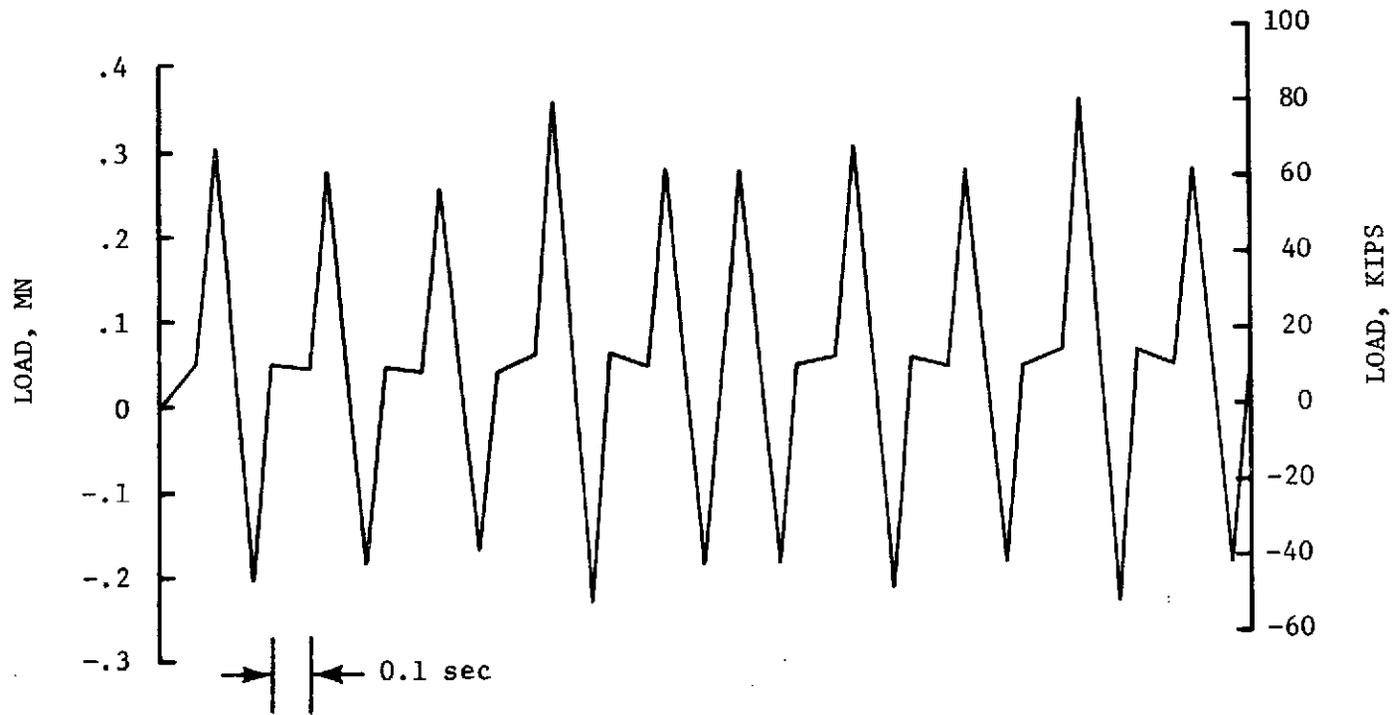
Figure 4.— Sample of the fatigue load spectrum.
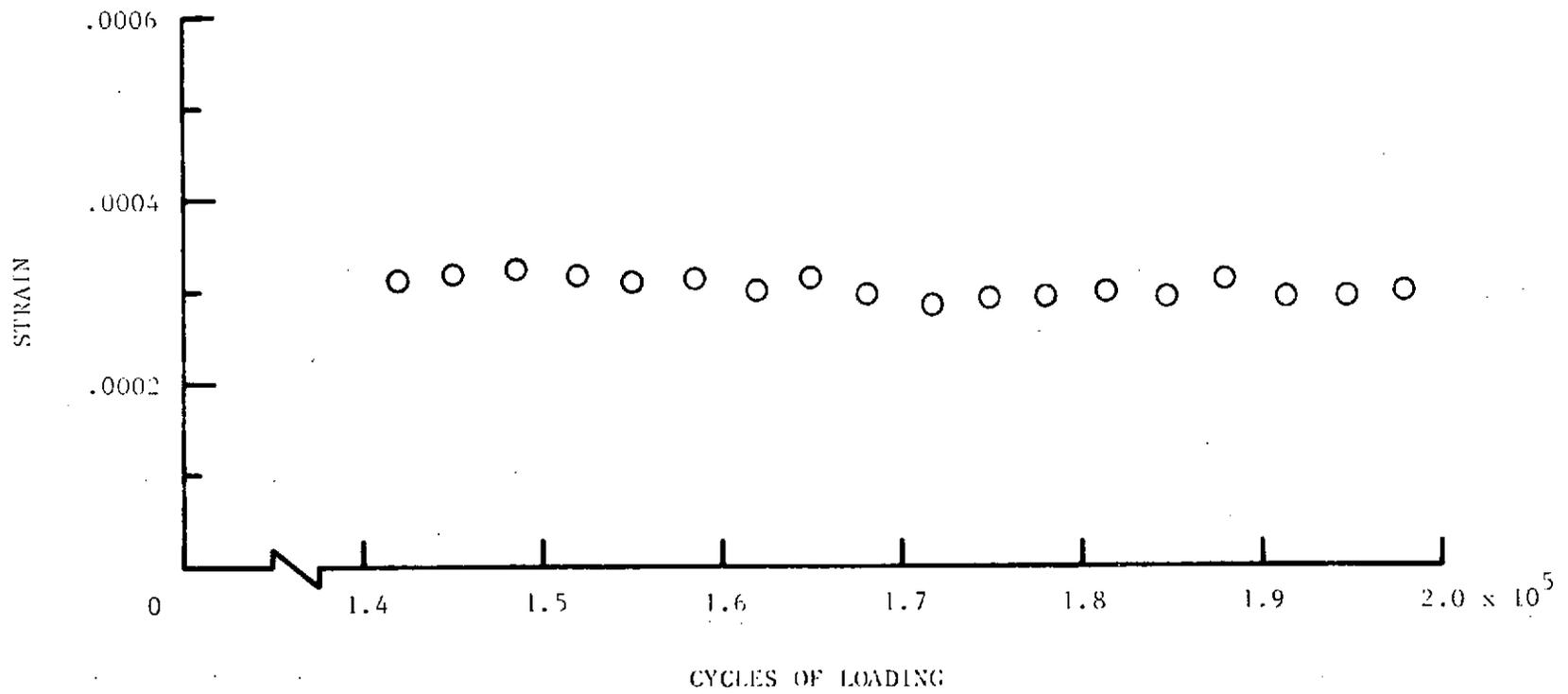
Figure 5.- Strain gage data from fatigue test (one location).
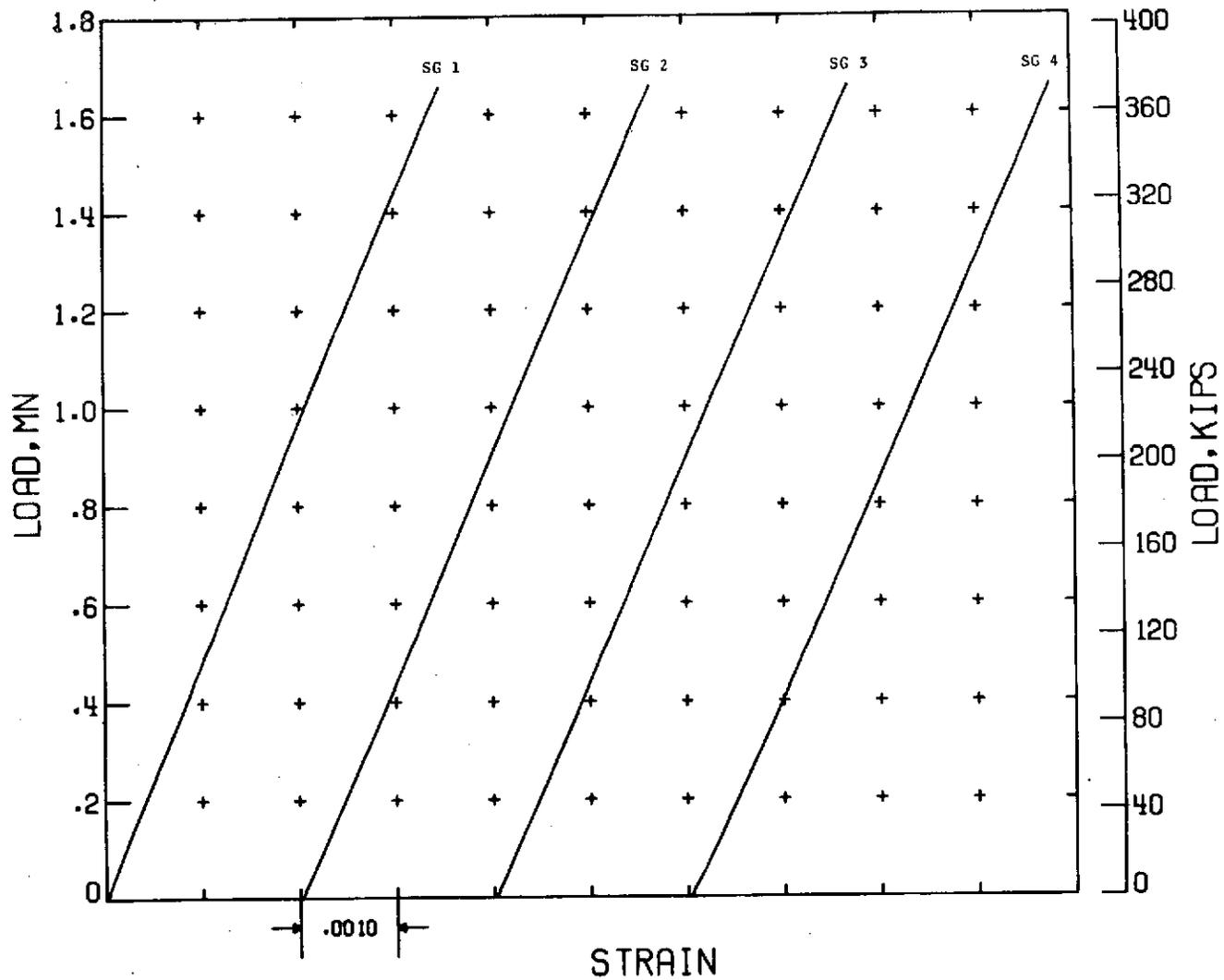
Figure 6.- Strain-gage data for the tensile design ultimate load
[1.65 MN (372 kips)].
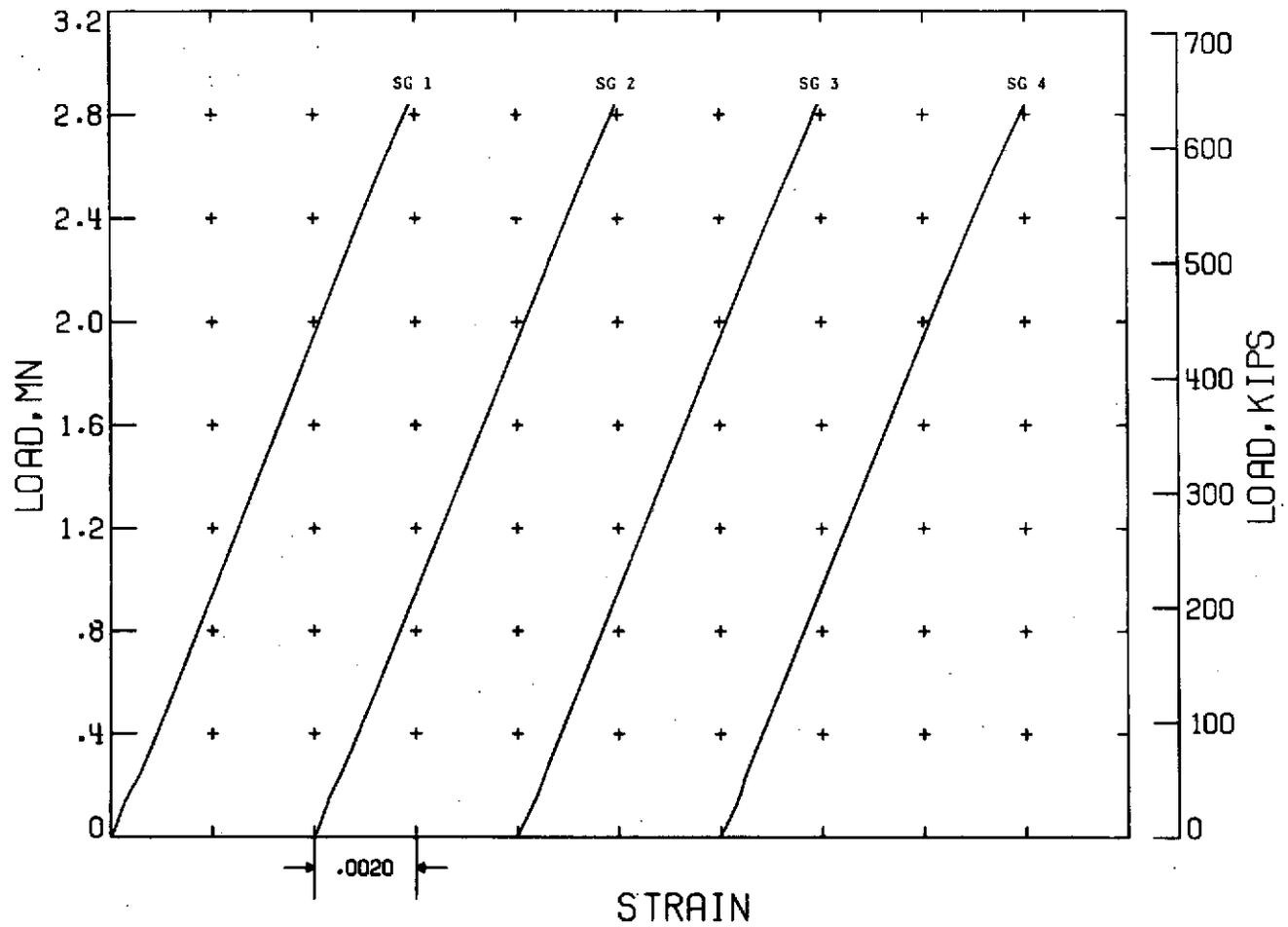
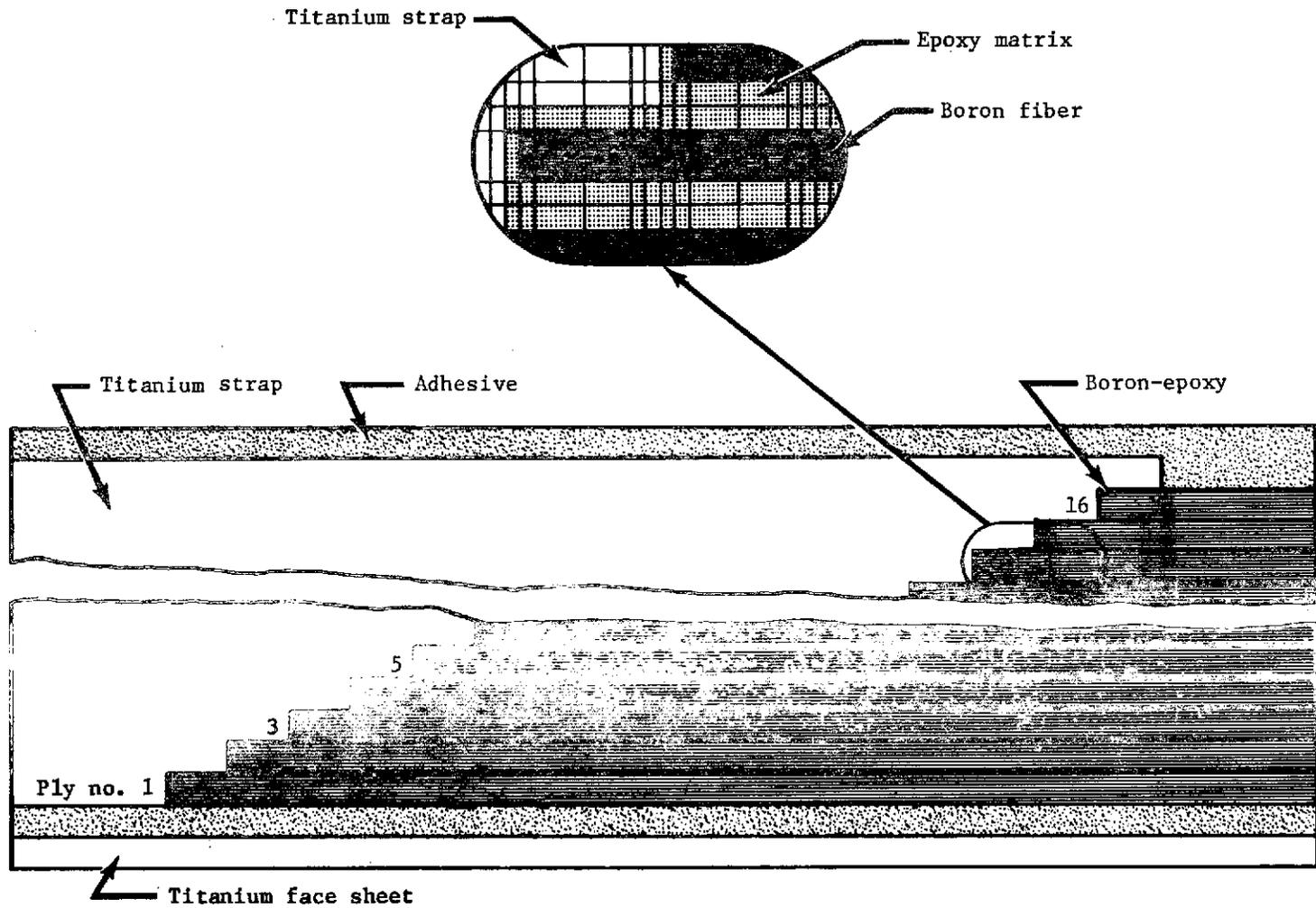Figure 7.- Strain-gage data for the compression design ultimate load
[2.83 MN (636 kips)].

Titanium strap

Epoxy matrix

Boron fiber

Titanium strap

Adhesive

Boron-epoxy

16

5

3

Ply no. 1

Titanium face sheet

Figure 8.- Structural model used for the analytical study (NASTRAN).
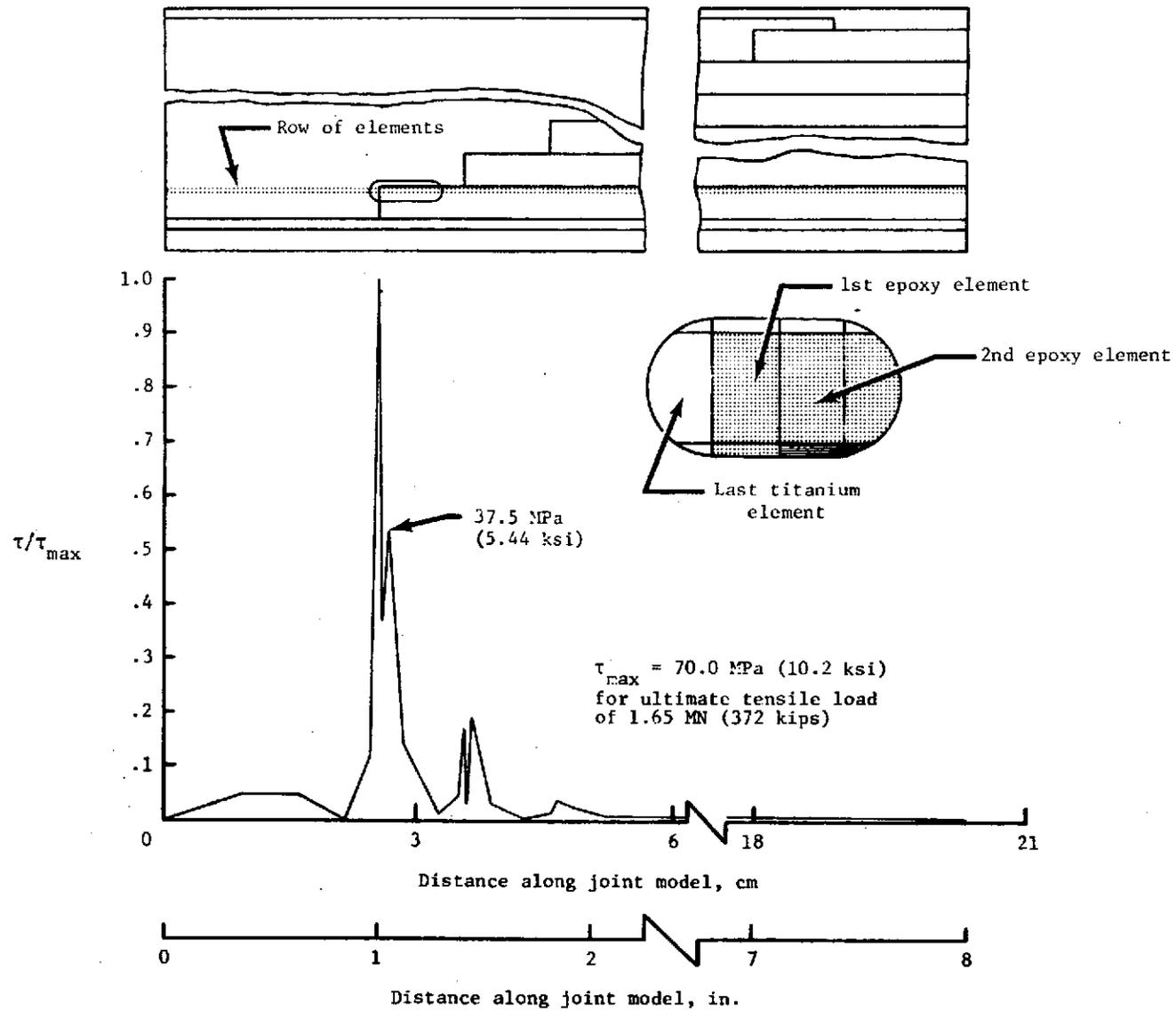
Figure 9. - Shear stress pattern of the row of elements containing epoxy matrix of the first ply of boron-epoxy.
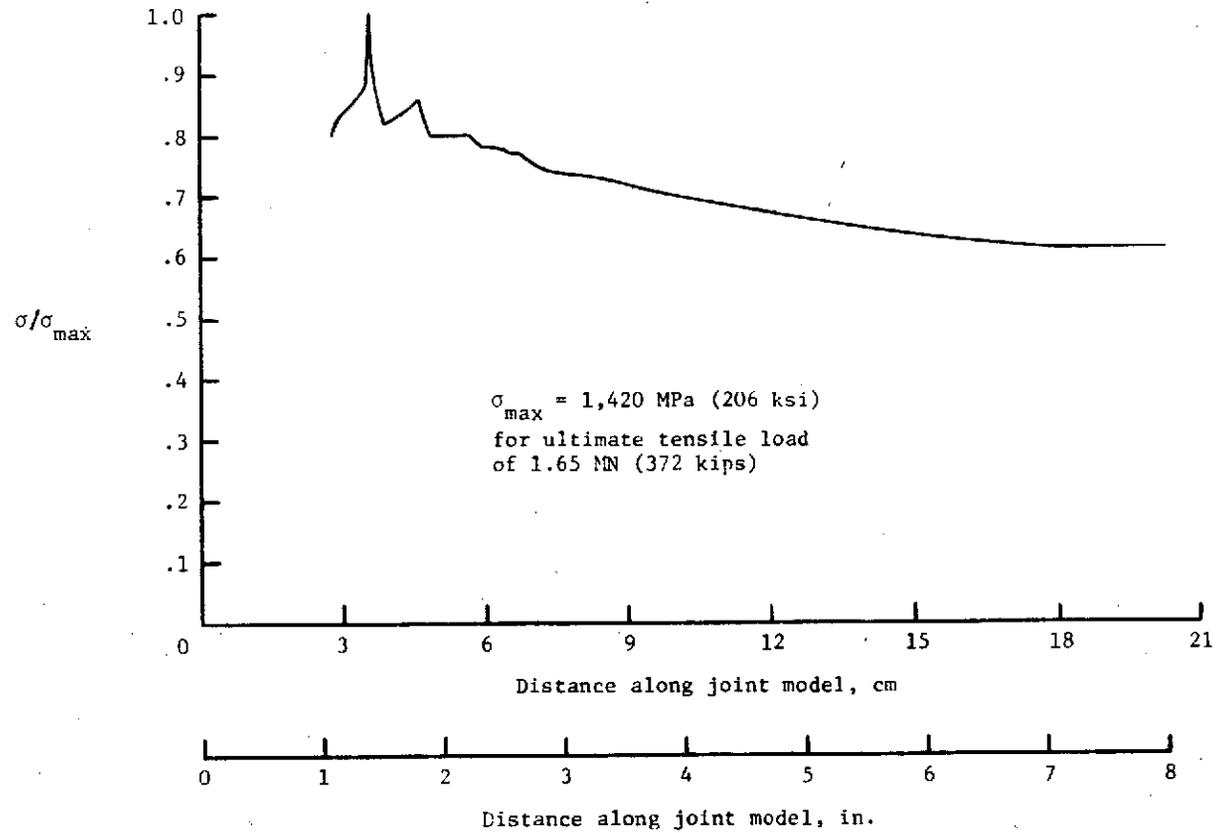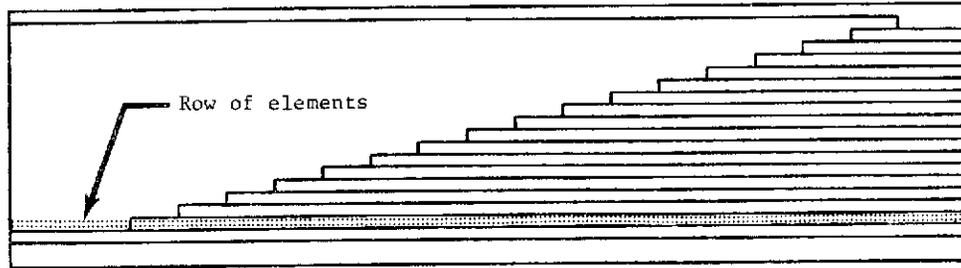
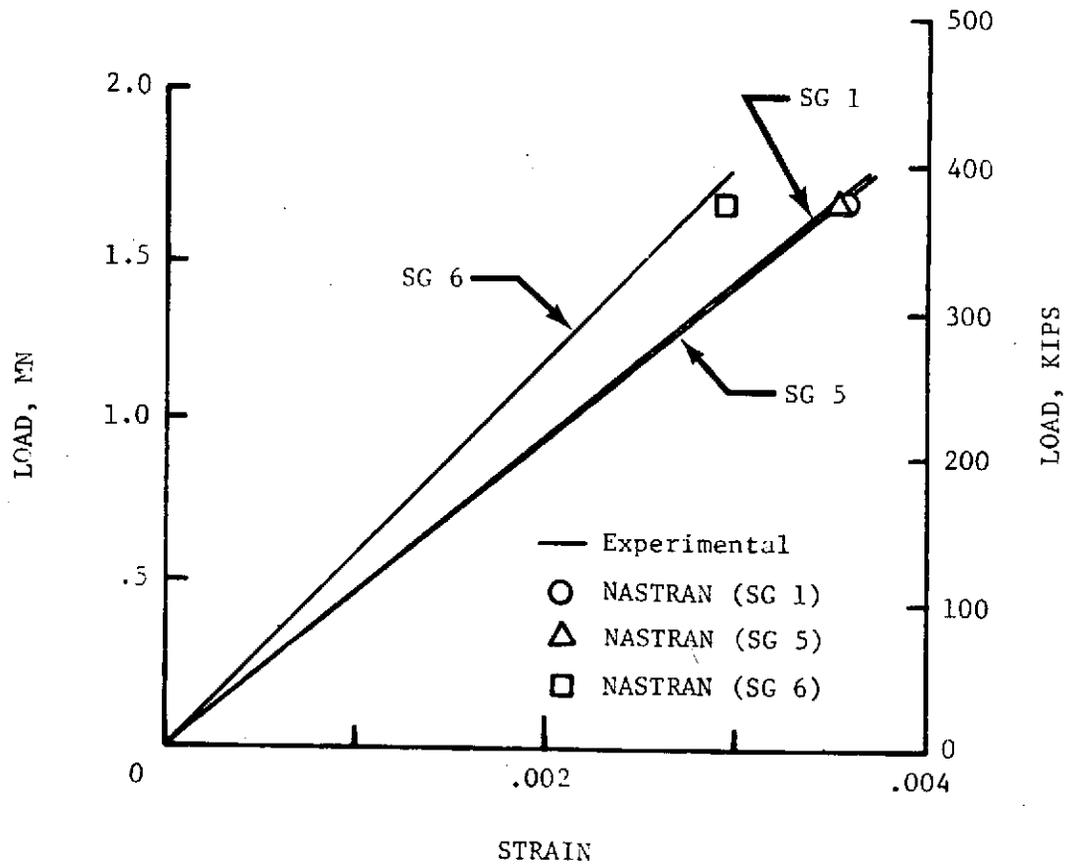Figure 10. – Axial stress in the first ply of boron fibers.

Figure 11. – Comparison of experimentally and analytically determined strains.

National Aeronautics and Space Administration

WASHINGTON, D. C.   20546

OFFICIAL BUSINESS

Penalty For Private Use, $300.00

NASA
SCIEN & TECH INFO FACILITY
ATTN. INPUT
P O BOX 33
COLLEGE PARK MD 20740

30 cys