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STATIC AND FATIGUE TESTS OF F-111B BORON WING TIP

STRUCTURES DIVISION (FB)
EXPERIMENTAL BRANCH (FBT)

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AIR FORCE FLIGHT DYNAMICS LABORATORY
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

NOTICE

This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the structural integrity tests of the F-111B boron-epoxy wing tip. A single test specimen was subjected to static load tests, static load plus internal pressure in the fuel cell tests, a fatigue test simulating four service lifetimes and residual strength tests. A severe leak developed during the pressure test of the fuel cell which was impossible to repair. The pressure was maintained and no structural failure developed. During the fatigue

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20. Abstract (Continued)

test a doubler on the front spar failed and some delamination of the boron occurred on the front spar and the center spar after two lifetimes. These areas were repaired and no further damage occurred during the fatigue test. One-hundred-fifty percent of design limit loads were applied with no failure. Final failure occurred through the lower cover and front and rear spars at 179 percent of design limit load.

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FOREWORD

This report was prepared in the Experimental Branch (FBT), Structures Division, Air Force Flight Dynamics Laboratory (AFFDL), Wright-Patterson Air Force Base, Ohio. This work was accomplished under System Number 698CW, "Advanced Filament Composites," Project Number 01, "F-111B Boron Wing Tip Structural Tests," Work Unit Number 006, with Mr. Murray N. England as Project Test Engineer and Mr. John E. Pappas as Instrumentation Engineer. This report covers work conducted from June 1969 through December 1969. This report was released by the author in 1973 for publication as an AFFDL Technical Report. This is the final report on the F-111B Boron Wing Tip Structural Tests.

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INTRODUCTION

The Experimental Branch of the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base (W-PAFB), conducted a structural test program for a boron-epoxy structure which simulated an F-111B wing tip. The structure was designed and fabricated by the Grumman Corporation using Internal Research and Development Funds (IR&D). This report describes these tests which were performed from June 1969 through December 1969 by the Experimental Branch. The tests were conducted in accordance with instructions provided by the Grumman Corporation. Static load, static load plus internal pressurization of the fuel tank, fatigue, residual strength to 150% of Design Limit Load (DLL), and residual strength to failure tests were conducted on the wing tip.

SECTION II

TEST SPECIMEN AND CONDITIONS

1. TEST SPECIMEN

The test specimen was a structurally complete wing box, having two cells, three spars, upper and lower skins, ribs and tip closing members conforming to Grumman drawing AD 331-1020. It did not include the inboard tank closure rib at spar station 360, the fixed leading edge, slats, flaps, air deflector door, fixed spoiler, or tip structure outboard of spar station 400.25. A wing tip extension fixture made of steel was attached to the boron composite tip at spar station 400.25 to simulate loading outboard of the tip closure member. The wing box root connecting structure was fabricated of steel and was bolted to the loading plate which, in turn, was attached to the test jig (Figure 1).

The wing tip front and rear spars were constructed of eight plies of boron oriented as follows: 45°, 135°, 90°, 45°, 135°, 0°, 45° and 135° with ply number one inside on both the top and bottom flanges. The web was aluminum honeycomb and areas around cutouts and rib tie-in points were filled with Epocast, an epoxy potting compound. Titanium doublers were used around cutouts and tie-in points. The center spar had six plies of boron oriented at 45°, 135°, 90°, 0°, 135° and 45° with ply number one inside on both the top and bottom flanges. The web had a honeycomb core. The upper and lower covers were constructed of eight plies of boron: 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° with ply number one on the inside.

The test specimen was assembled with a great variety of bolts. Many of these bolts appeared to be too long since they had up to six washers installed under their nuts.

2. TEST CONDITIONS

The critical unpressurized design condition for the F-111B wing tip was condition B-1 (Reference 1)*. This condition had two associated centers of pressure (C.P.): the forward C.P. was at the 26% chord line; and the aft C.P. was at the 50% chord line. Negative loads were assumed to be 45% of positive loads.

For the forward C.P. case, vertical loads with forward acting (horizontal) components equaling 20% of the vertical loads were applied through an angle of 11° 18' with the Z axis. The aft C.P. case consisted of vertical loads applied with horizontal, aft acting components equaling 10% of the vertical loads and applied at an angle of 5° 42' with the Z axis. Figure 2 shows the forward C.P. case resultant loads and Figure 3 shows the aft C.P. case resultant loads.

a. Static Tests

Condition 1.

Forward C.P. positive loads to 125% of design limit load.

Condition 2.

Forward C.P. negative loads to 120% of design limit load.

Condition 3.

Aft C.P. loads to 100% of design limit load.

Condition 4.

60% of design limit load aft C.P. and design limit internal pressure (36.5 psig).

Condition 5.

60% of design limit load positive forward C.P. and design limit internal pressure (36.5 psig).

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*Reference 1. General Dynamics F-111 Wing Load Report FZS-12-165.

b. Fatigue Test

A fatigue test simulating four lifetimes of 4000 flying hours each was conducted on the boron composite wing tip. Both positive forward C.P. and negative forward C.P. loads were applied.

The fatigue test loads were applied in 400 simulated flying hour blocks with each block consisting of the following:

POSITIVE FORWARD C.P.

Load Increment	No. of Occurrences
55% DLL	2600
65% DLL	1800
75% DLL	1000
85% DLL	600
95% DLL	120
105% DLL	60
115% DLL	16
125% DLL	6*

* Every fifth block increase to 8

NEGATIVE FORWARD C.P.

Load Increment	No. of Occurrences
75% DLL	508
85% DLL	308
95% DLL	105
105% DLL	28
120% DLL	1**

** Every fifth block increase to 2

c. Residual Strength Tests

Condition 1.

150% DLL for the positive forward C.P. condition was applied.

Condition 2.

150% DLL for the positive aft C.P. condition was applied.

Condition 3.

The loads for the positive forward C.P. condition were applied until failure occurred.

SECTION III

TEST SETUP AND PROCEDURE

1. TEST SETUP

The boron wing tip was mounted as a cantilever beam to a 1-1/4 inch x 30 inch x 45 inch hot rolled steel plate which was in turn mounted to the test jig. The steel plate was machined and match drilled to mate with the wing tip root closure rib by Grumman before shipping to WPAFB.

The root closure rib structure of 4340 steel was warped, apparently during the final heat treatment, so shims had to be added between the root closure rib and the plate (up to a maximum of 0.025 inch) to obtain a good fit and not preload the closure rib (Rib A).

Dummy slat fittings were provided as well as wing tip extension fixture with a load fitting at the outboard end and a fitting to load the assymetry switch attachment. Formers were provided to load Rib B and a fitting to load Rib C.

A whiffle tree system was used to beam the loads to hydraulic load cylinders. Standard strain gaged load cells with calibrations traceable to the National Bureau of Standards were used to monitor the test loads. The loads were applied by hydraulic loading cylinders and the hydraulic pressure was controlled by Edison Cyclic Load Maintainers. The dead weight of the test specimen and all the test hardware was counterbalanced by lead weights.

An over travel switch was mounted on the outboard tip which would activate the electrical dump switch on the Edison Load Maintainers to prevent over load in the event of a failure of the test specimen or load equipment.

Figure 4 is a schematic of the pressure test setup. Figure 5 is a drawing showing the test specimen with the loading fixtures installed. Figures 6, 7 and 8 are photographs of the test setup.

The test specimen was instrumented with 52 0°, 45°, 90° strain gage rosettes installed by Grumman before the specimen arrived. The three gages in each rosette were stacked. This is an undesirable practice on a poor heat conductor such as boron-epoxy. The voltage across the strain gages produces heat which causes the strain gage outputs to drift, giving erroneous readings. Stacking the strain gages produced three times as much heat to dissipate as separating the three gages. Experience has shown that even a single strain gage has a heat dissipation problem when mounted on a nonmetallic structure such as boron-epoxy.

In an attempt to minimize the drift of the strain gages the Experimental Branch's strong recommendation of 350 ohm rather than 120 ohm gages was adopted by Grumman. Grumman ran a drift test on a single 350 ohm gage and showed minimal drift. However, during testing at WPAFB it was found that the stacked gages did drift. Therefore, a zero was taken before and after loading to aid in determining what the peak strain really was. Where the final zero strain reading exceeded the initial zero strain reading the final zero reading was subtracted from the peak reading since the peak loads were recorded last. The excessive heat generated was undoubtedly a factor in the early demise of several gages.

Sixteen internal gages were lost either in assembling or shipping the structure to WPAFB. By the end of the condition B-1 forward C.P. 125% limit load test, a total of 28 gages were inoperative due either to a bad gage or a bad data channel. Preceeding each test any faulty gage was examined and repaired if possible. By the end of Block 5 of the fatigue test there were a total of 23 bad gages and by the end of Block 20 there were 29 bad gages. Following the Block 21 failure repair and reinforcement, six gages were added to the front spar repaired doubler in the same location as the original gages. By the end of Block 35 a total of 29 gages were bad.

The specimen was instrumented with thirteen deflection transducers and four deflection transducers were installed on the mounting plate. All the deflection transducers were installed by the Experimental Branch and were terminated to a jig that was independent of the loading jig. Figures 9, 10 and 11 show the location of the strain gages and deflection transducers.

All strain gages, deflection transducers and load cells were connected into the Experimental Branch's High Speed Data Acquisition and Processing System (HSDAPS). Two load cells and two deflection transducers were connected to a Sanborn strip chart recorder for continuous monitoring during the fatigue test only. During data collection these four transducers were switched to the HSDAPS so their outputs could be recorded.

2. TEST PROCEDURE

a. Static Tests

Before loading the structure the Edison load maintainers were set to produce correct pressure at limit load using the pressure gage on the Edison unit. 20% of design limit load was then applied to the specimen and the load cell outputs read out by the Data System. The Edison units were then adjusted to produce the correct load. Load was applied in 20% increments and at each increment the output of all the load cells, strain gages and deflection transducers were recorded. The load was held for 15 seconds at each increment and the loads, strains, and deflections were recorded during the last five seconds.

b. Pressure Tests

The structure was loaded to 67% DLL, the internal pressure raised to 36.5 psig (Design Limit Pressure) and the strains, deflections, and loads recorded. Following each test the structure was inspected. The strain and deflection data were compared with analytical predictions and previously recorded values in order to determine if damage had occurred.

c. Fatigue Tests

Alternate blocks of positive and negative condition loads were applied during two shift testing. Loads, strains, and deflections were recorded at a rate of one sample per second at each load level while cycling after every five blocks. Processed data were immediately sent to Grumman in addition to telephone communication concerning progress and results of the test program.

SECTION IV

TEST RESULTS

1. STATIC TESTS

a. Condition 1.

During the positive forward C.P. test condition to 125% DLL an error was discovered in the Grumman test plan. This error caused 150% instead of 125% DLL torque to be applied to Rib B (the center rib) and all the structure inboard of the center rib. A review of the strain gages showed the front spar had experienced a stress level well below design ultimate. The moment and shear loads were correct. An inspection revealed no apparent damage and the test was continued after correcting the load error.

b. Condition 2.

Forward C.P. negative loads to 120% DLL were applied with no indication of failure.

c. Condition 3.

Aft C.P. loads to 100% DLL were applied with no indication of failure.

d. Condition 4.

Aft C.P. loads to 60% DLL were applied and the fuel cell was pressurized with water. The fuel cell began to leak as soon as the pressure was applied. The leakage was through the sealant on the outboard fuel cell rib (Rib C) around a bolted-on plate. An attempt was made to stop the leak by applying sealant externally but it became apparent that successful repairs could not be made without completely disassembling the wing tip. Therefore, the test was continued by overpowering the leak with increased water flow. Strain gages and deflection transducer outputs were recorded at 36.5 psig. No indication of structural failure was found after the test.

e. Condition 5.

Forward C.P. positive loads to 60% of DLL were applied. Again sufficient water flow was used to overcome the fuel cell leak and raise the pressure to 36.5 psig. Strains and deflections were recorded and no evidence of structural failure was found after the test. The measured and predicted stresses and deflections showed generally good agreement during all static and pressurization tests.

2. FATIGUE TESTS

The original plan was to maintain 15 psig pressure in the fuel cell during the fatigue test but the leakage problem prevented this. Therefore, no pressure was applied during the fatigue test.

The fatigue test proceeded without incident on two shifts until Block 16 when three steel studs attaching the closure rib fixture to the upper cover failed in fatigue. Two of the studs were in a pattern of four on the forward spar and one stud was in a pattern of four on the rear spar. The failed studs were replaced along with the remaining studs in the pattern. These eight along with the eight studs on the lower surface in the same location were replaced after Block 21, Block 30 and Block 40 before the residual strength load tests.

During Block 21 the following failures were found:

(1) A fatigue crack carried through a titanium doubler plate on the forward face of the front spar. Figure 12 shows the crack between the fasteners.

(2) The lower outboard fastener in a pattern of eight had failed in fatigue through the doubler plate.

(3) The forward and aft faces of the boron web of the front spar had become unbonded from the core under the titanium doubler plate at the inboard end. Figure 13 shows some of the debonding.

(4) Cracks were found at the inboard end of the front spar running fore and aft around the cutouts.

(5) A crack was found in the forward face of the front spar boron web at the mid rib. Figure 14 shows this damage.

(6) Between the inboard titanium plate on the front spar and the outboard slat fitting, voids were discovered between the front spar boron web and the vertical leg of the lower titanium cap.

(7) The titanium plate on the inboard end, aft face of the mid spar was debonded from the boron web.

The Block 15 bolt failures were caused by improper counter boring of the holes during assembly which allowed the fasteners to bend when the tip flexed.

The Block 21 failures were not discovered during the Block 20 inspection since most of the front spar was covered up with loading fixtures. The only visible evidence was a hair line crack in the front spar doubler and a crack in the bond under the doubler in an area not considered critical by the analysis. The Block 20 data were taken on 28 July 1969 and the inspection made the same day and cycling resumed. The damage was discovered 30 July 1969 when some bolts were being checked for tightness. The Block 20 data had not returned from processing when the damage was discovered.

Subsequent examination of the strain gage data did show a change in strain between the Block 15 and Block 20 data which, evidently, was when the failure occurred. No unusual noises or other indication of failure was noted prior to discovery of the failures. All the failures were in bonded or bolted and bonded material and all evidently progressed slowly and transferred load to adjacent structure preventing a catastrophic failure when subsequent loads were applied.

A complete inspection was conducted on the test article after removing all the loading fixtures using tap testing and ultrasonic inspection. Tap testing consists of tapping the surface with a small hammer and listening for a hollow sound indicating debonding.

A survey of the front spar shear stresses indicated that as the test progressed a greater portion of the shear was progressively carried by the forward face of the front spar, until Block 20 when a decrease occurred. The timing of these occurrences indicates that the mid spar failure occurred after the front spar failure. The failure is likely to have originated in the bond between the aft face of the boron and the titanium cap (Failure No. 6). As the bond line deteriorated, a greater portion of the load was carried by the forward face. This is substantiated by the increased shear stress in the forward face of the front spar web. The greater load in the forward face caused the bolt to fail (Failure 2). As a result, the titanium plate was over loaded and cracked (Failure 1). The load then transferred to the rear face, at the inboard end, and produced a bond failure between the boron and honeycomb core (Failure 3). With failure of both faces of the front spar at the inboard end, the load could no longer be transferred to the test fixture. The load, seeking another path to the test fixture, overloaded the front spar web of the mid rib (Failure 5). The load then redistributed itself through the outboard rib to the mid and aft spars and produced the mid spar failure (Failure 7).

The front spar failures No. 1, 3, 4, 5 and 6 were repaired by adding a 5/16 inch thick aluminum doubler plate which reinforced all the damaged areas on the front spar. Figure 15 shows this doubler plate installed.

The eight studs on the inboard end of the doubler (Failure No. 2) were replaced after Blocks 21, 30 and 40.

The mid rib debonding was repaired by adding an 0.060 inch aluminum doubler. Figure 16 shows this repair.

The repairs of the Block 21 failures were designed and installed by Grumman and took nearly three months to complete. The repaired wing tip completed the fatigue test with no additional failures.

3. RESIDUAL STRENGTH TESTS

The wing tip successfully sustained 150% DLL for the forward CP positive and aft CP cases with no apparent damage. The forward CP loads were then applied in 10% increments to 125% DLL and 5% increments from then on to failure. The load was held 15 seconds at each increment and the instrumentation was read during the last five seconds. Final failure occurred at 179% DLL through the lower cover at Rib B through the inboard row of fasteners and through the front and rear spars. Figures No. 17, 18 and 19 show the final failure.

Following the final failure, the test specimen was returned to Grumman along with the Grumman furnished test fittings and mounting plate.

Detailed test results including all strain gage, deflection transducer, and load cell tabulated results are on file at the Experimental Branch (FBT) of the Air Force Flight Dynamics Laboratory.

SECTION V

CONCLUSIONS

1. The boron epoxy wing tip, designed and fabricated to Grumman Drawing No. AD 331-1020, sustained 8400 equivalent flight hours (2.1 simulated lifetimes) without catastrophic failure. Extensive fatigue damage which was revealed during a tear down inspection at 8400 hours apparently initiated between 6000 and 8000 equivalent flight hours.

2. The repaired wing tip satisfactorily withstood an additional 8000 equivalent flight hours of loading.

3. The repaired wing tip satisfactorily supported design ultimate load for the positive forward C.P. condition and the positive aft C.P. condition and failed at 179 percent DLL of the most critical positive forward C.P. condition.

4. The fuel cell leakage problem could be corrected by applying the proper amount of sealant during assembly and is of no structural significance.

5. The addition of the repair doublers to the front and mid spars caused no appreciable change in internal load distribution of stiffness.

6. The stacked rosette strain gages used on boron-epoxy structures caused excessive drift due to poor heat dissipation properties.

SECTION VI

RECOMMENDATIONS

1. Do not use stacked strain rosettes on boron-epoxy structures.

2. Use extreme care when drilling holes through successive layers of steel and boron-epoxy to prevent out of round holes.

3. Perform ultrasonic and tap tests on boron-epoxy structures frequently during fatigue tests to locate debonded or delaminated areas.

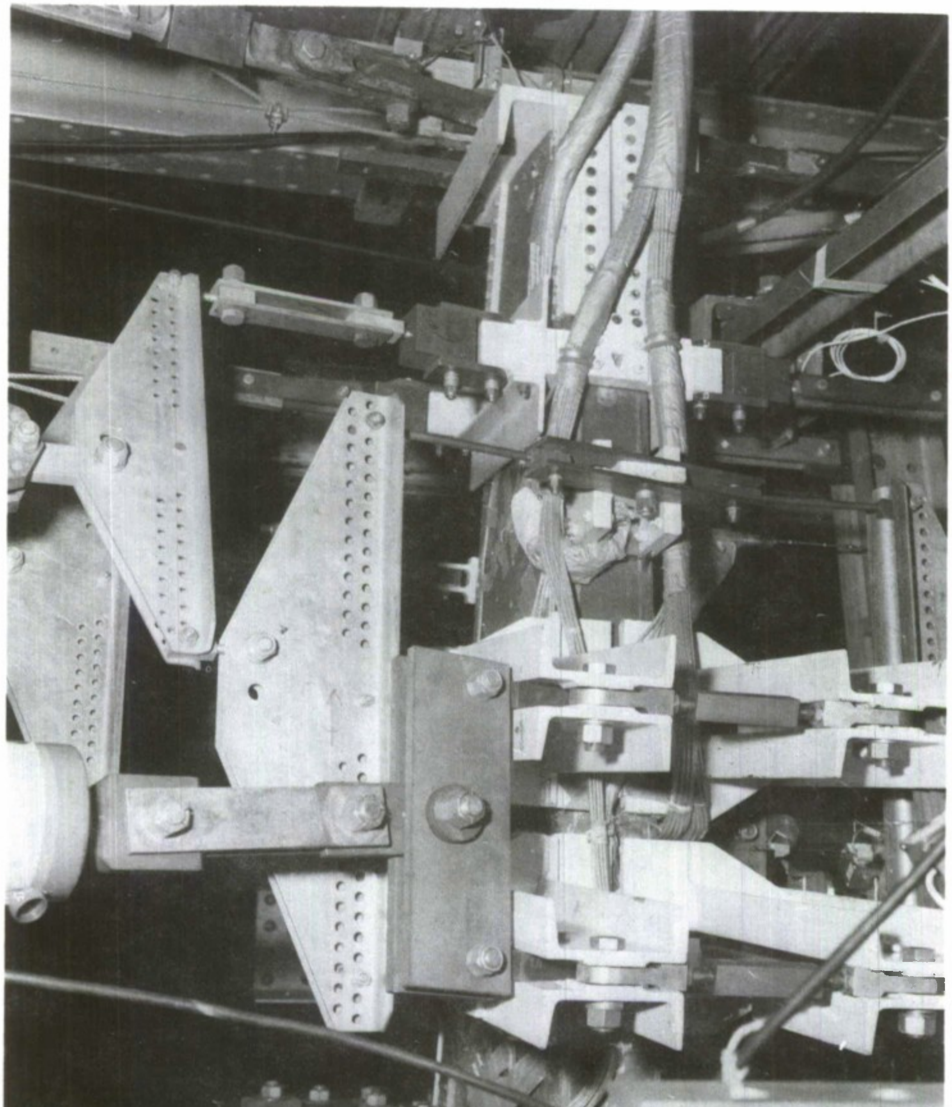

Figure 1. F-111B Boron Wing Tip Test Specimen

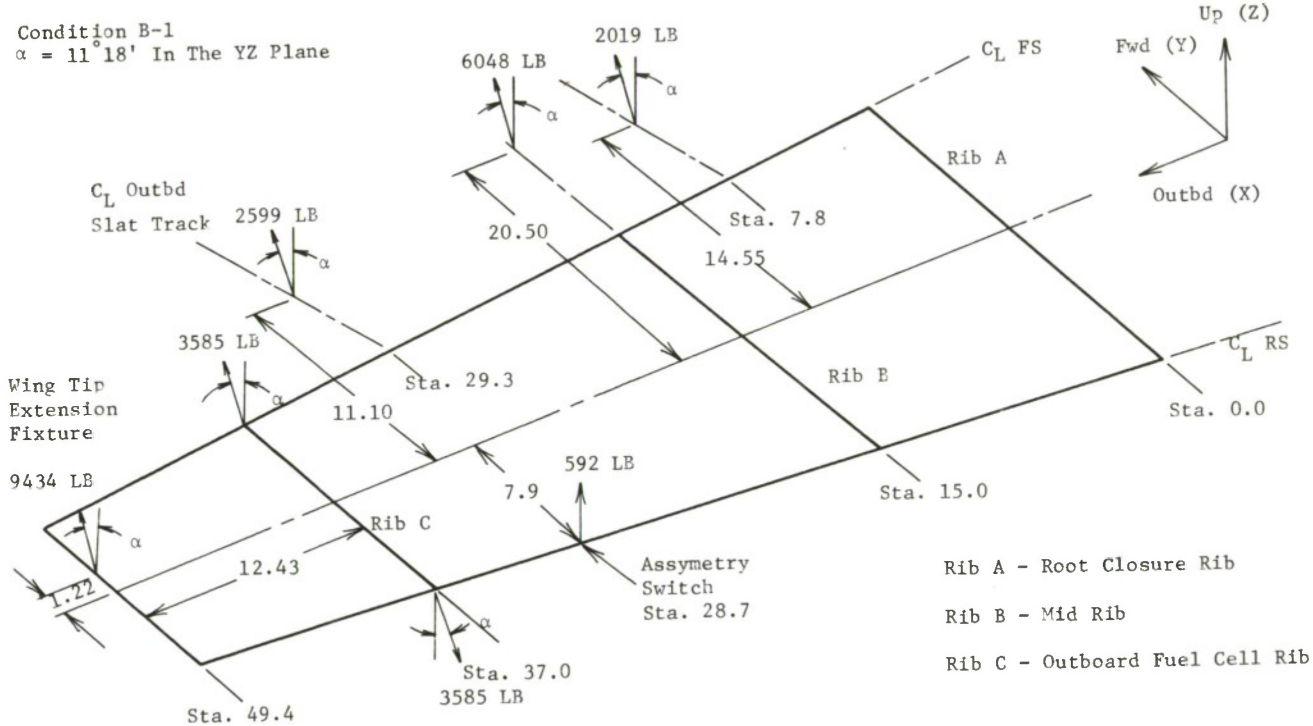

Figure 2. Condition B-1, Ultimate Test Loads, Positive Forward CP Case

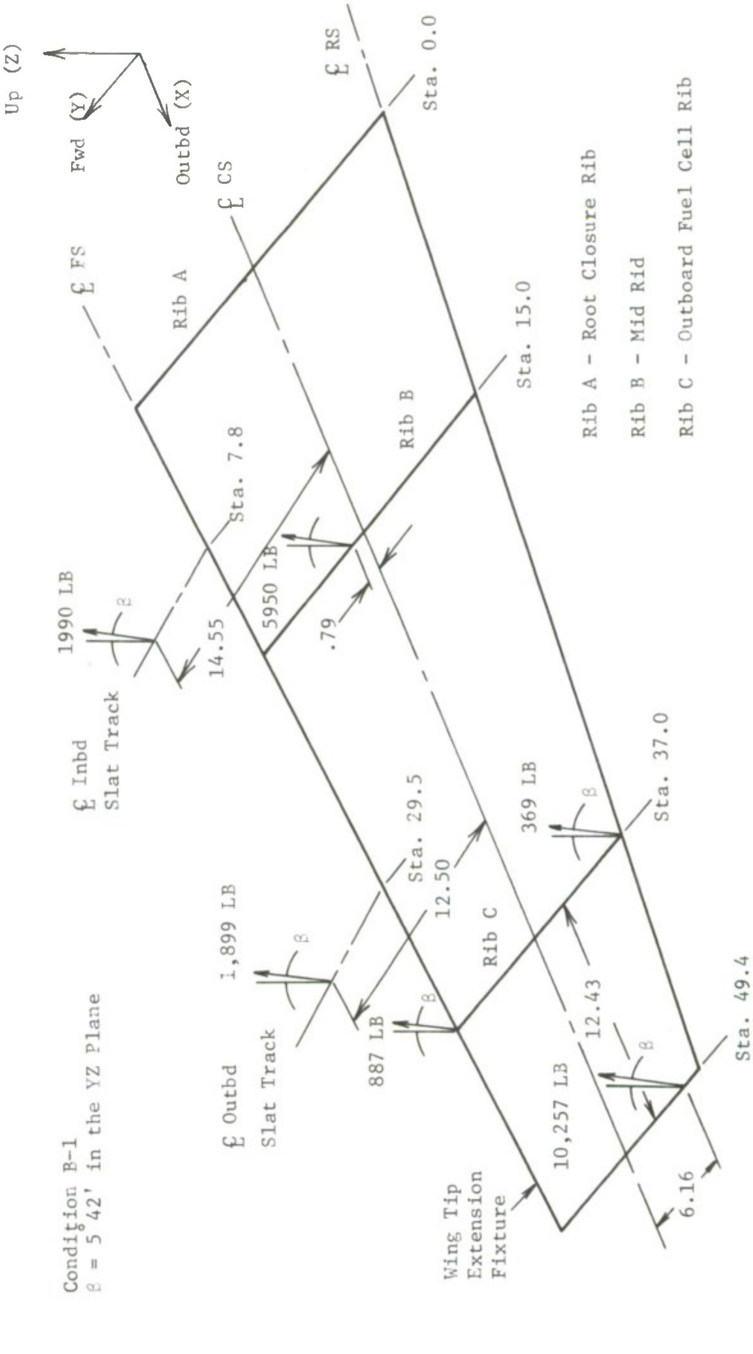

Figure 3. Condition B-1, Ultimate Test Loads, Aft CP Case

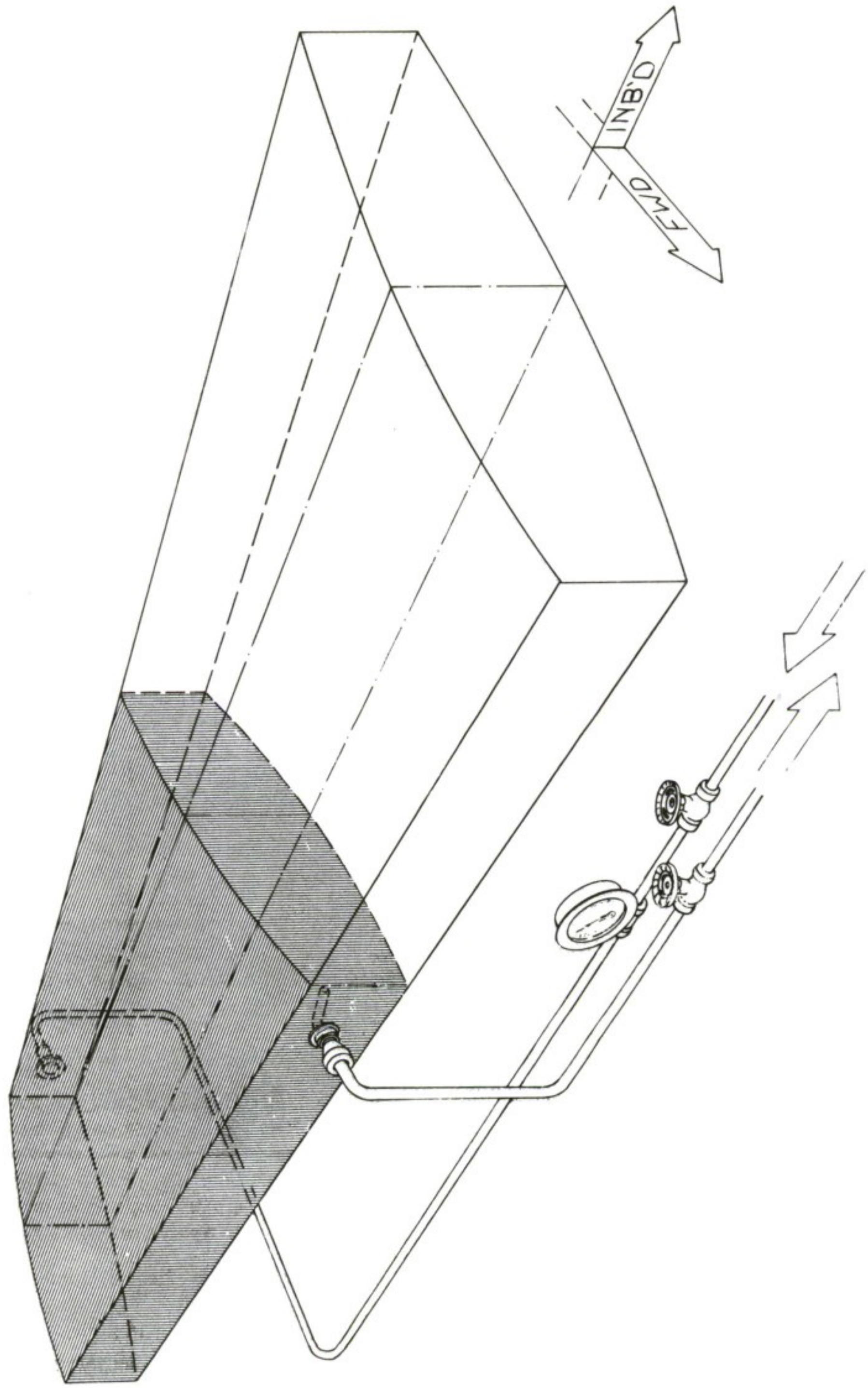

Figure 4. Pressurization Test Setup

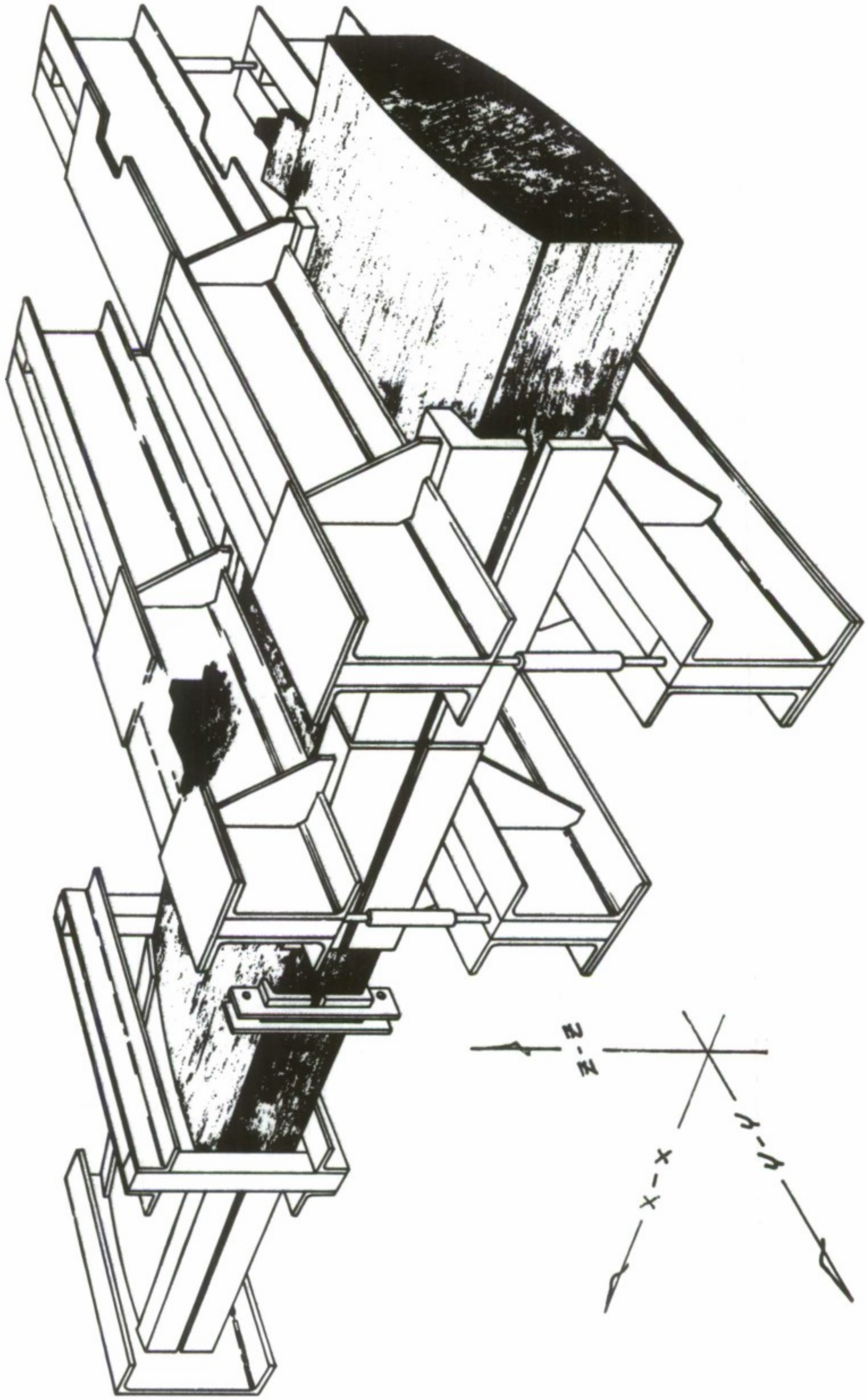

Figure 5. Test Specimen With Loading Fixtures Installed

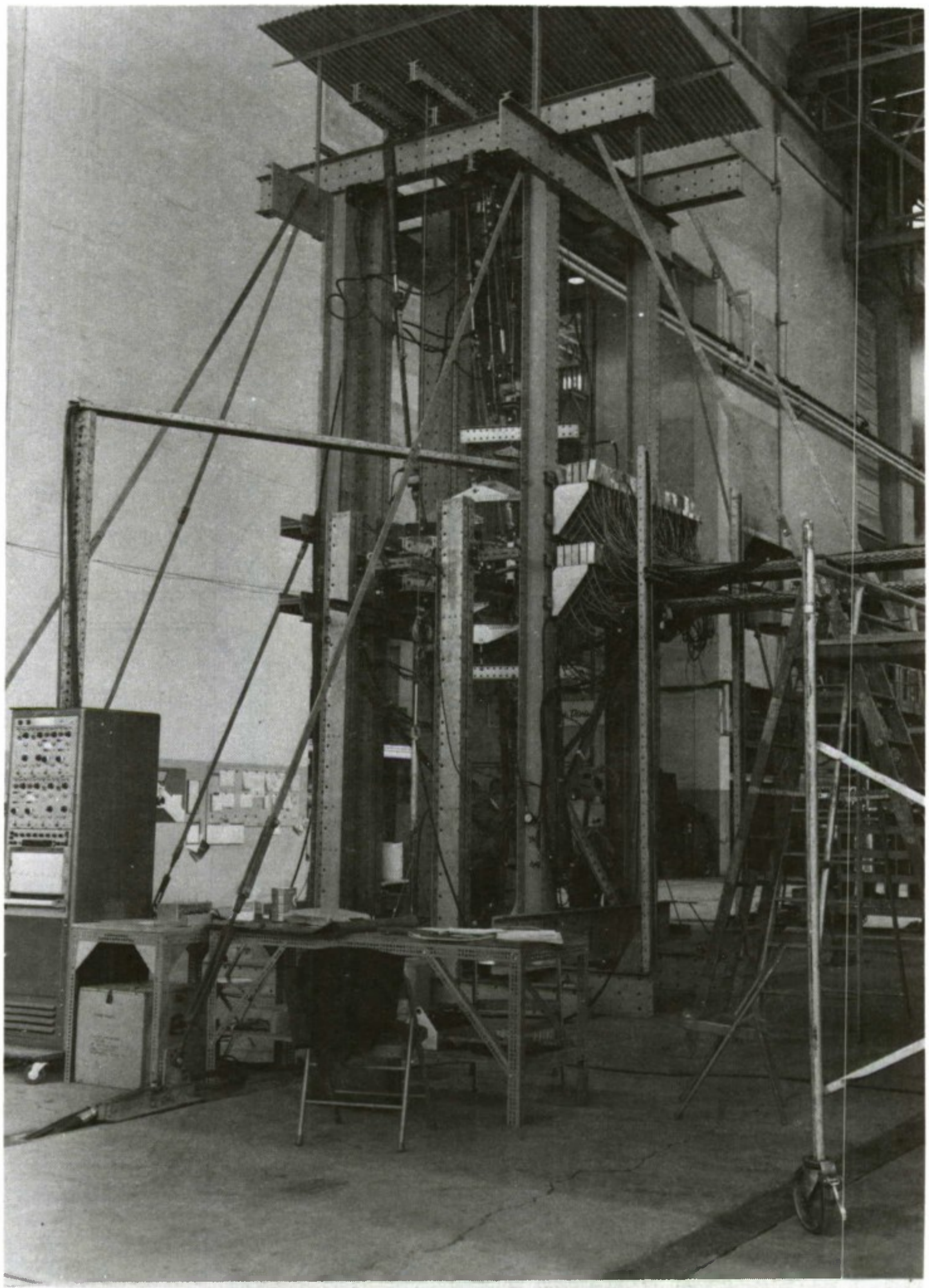

Figure 6. Overall Test Setup

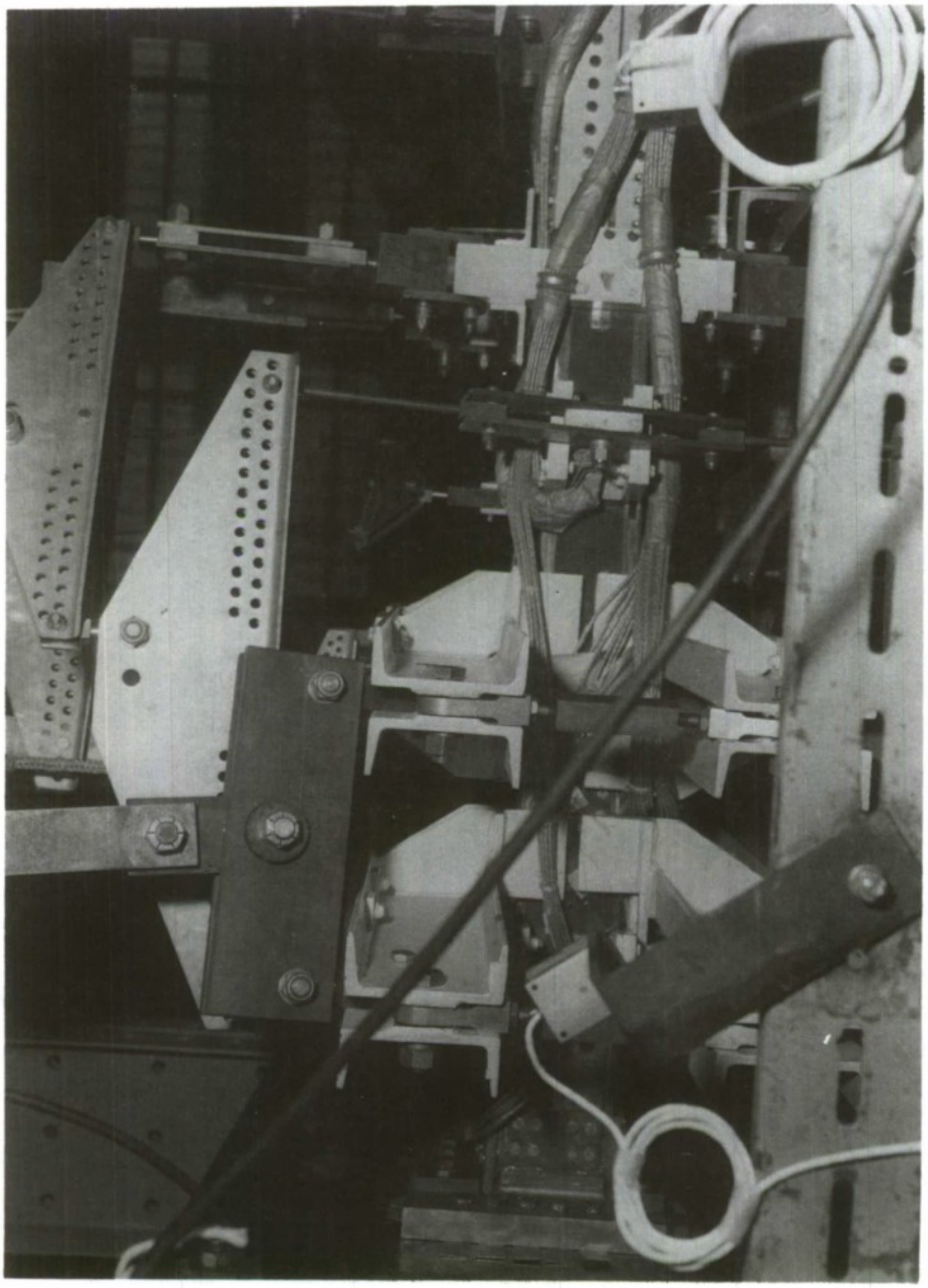

Figure 7. Fatigue Test Linkage

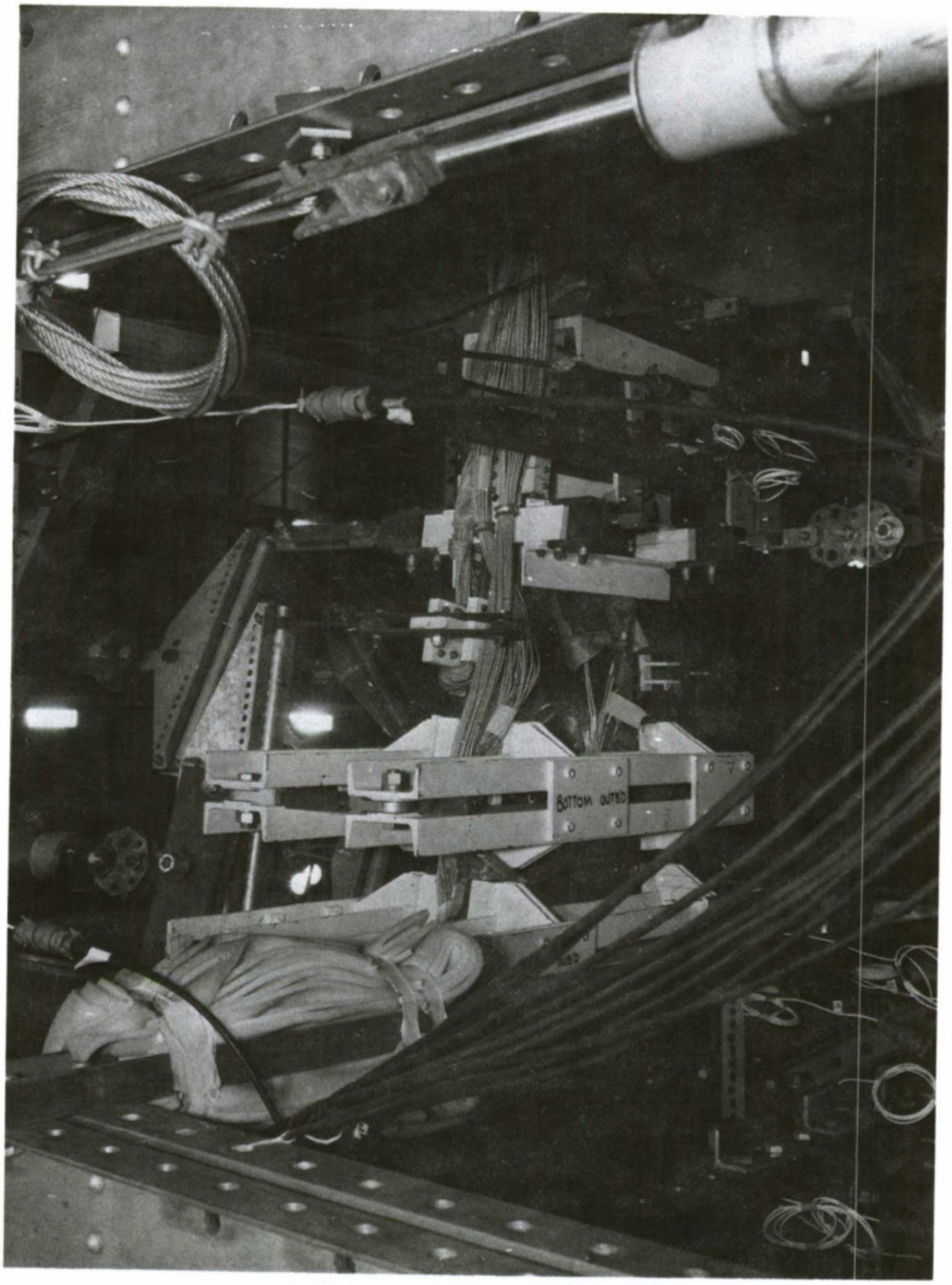

Figure 8. Residual Strength Test Linkage

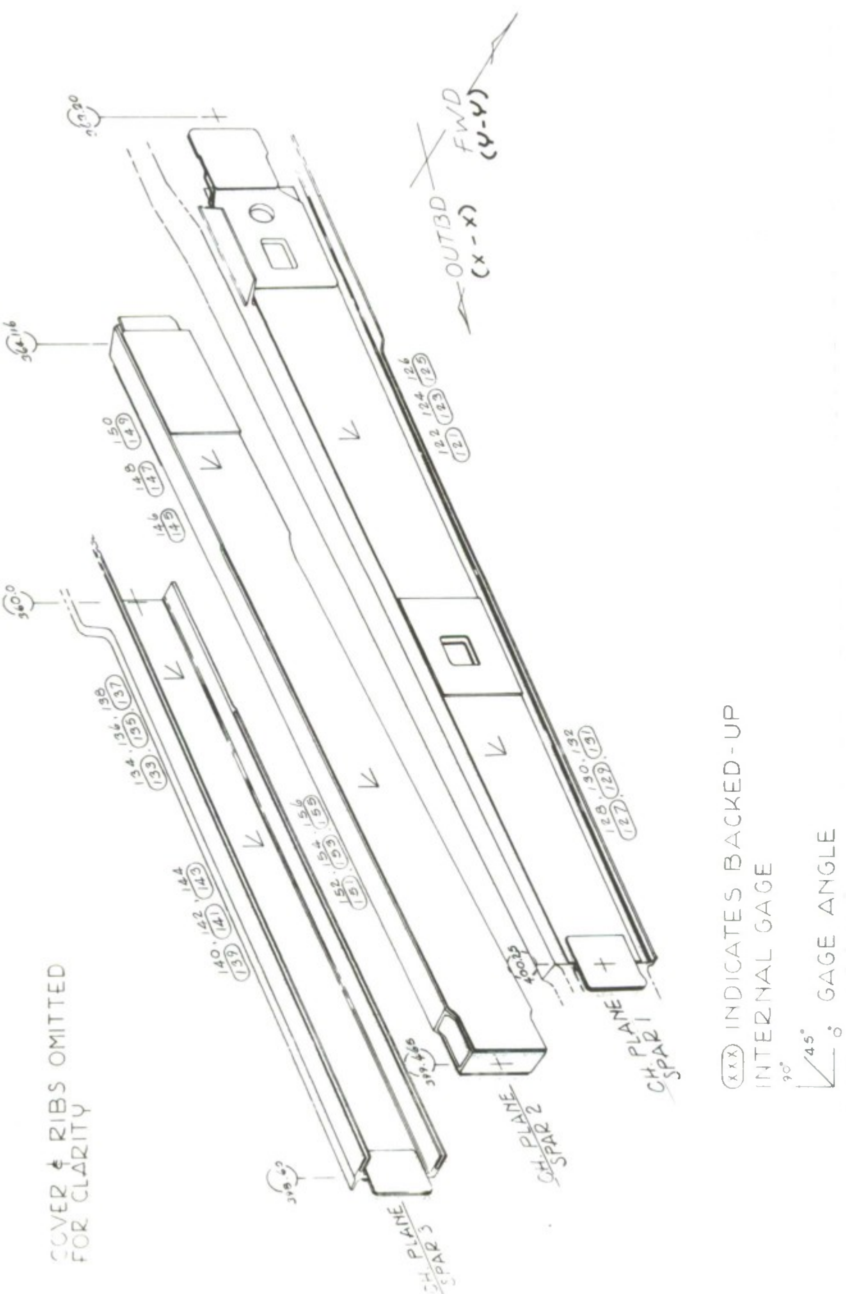

Figure 9. Strain Gage Locations on the Spars

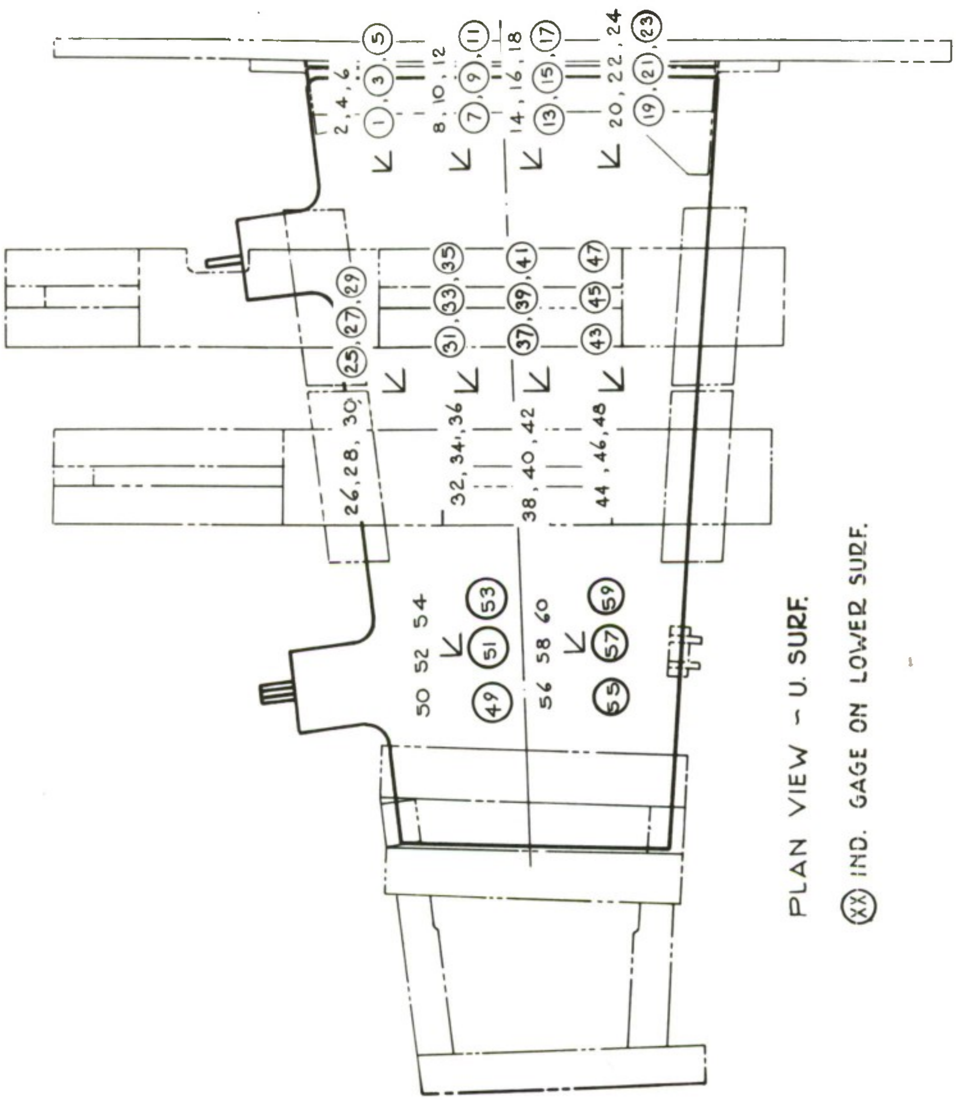

Figure 10. Strain Gage Locations on the Skin

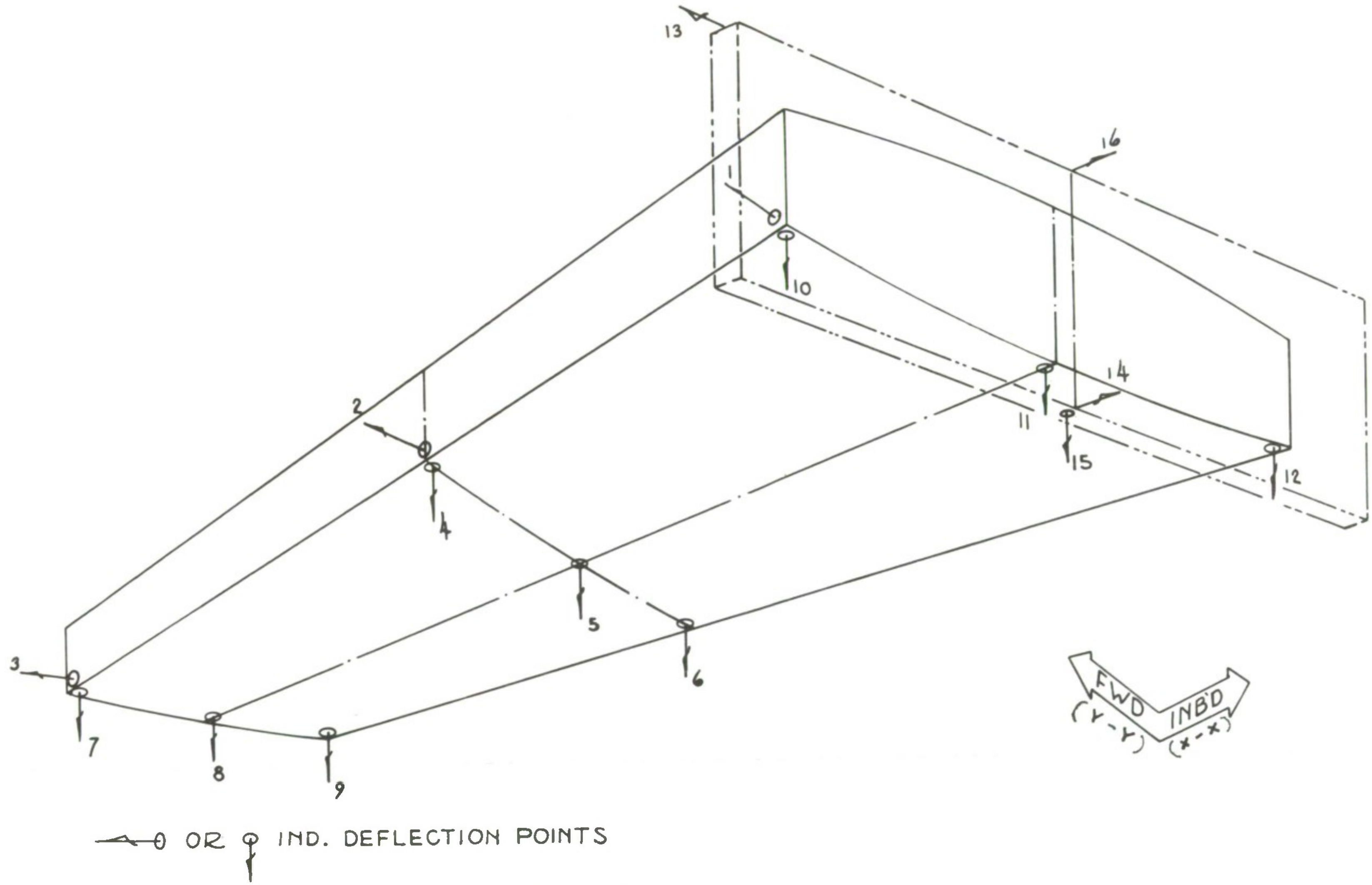

Figure 11. Deflection Transducer Locations

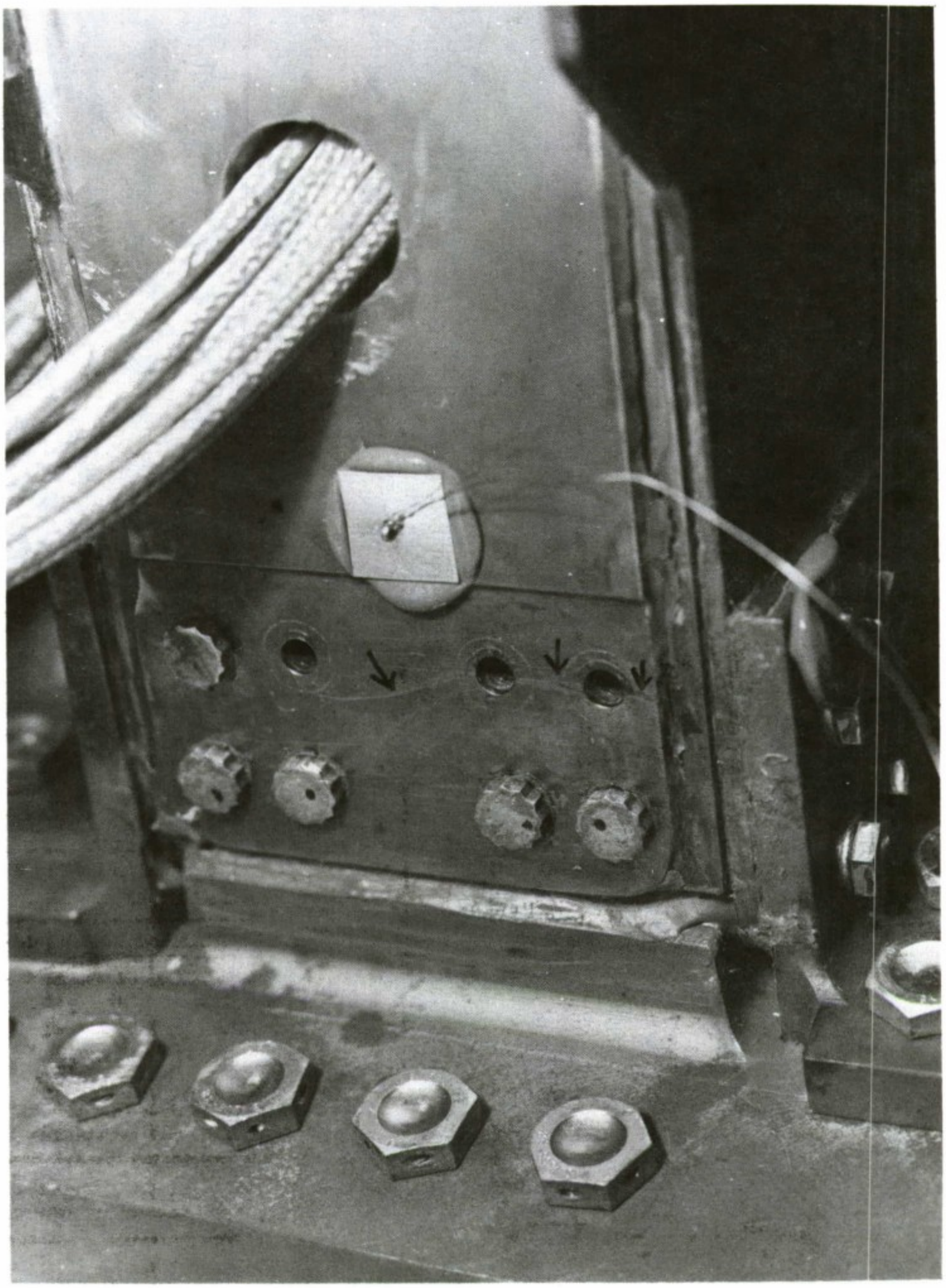

Figure 12. Block 21 Failure of Front Spar Doubler

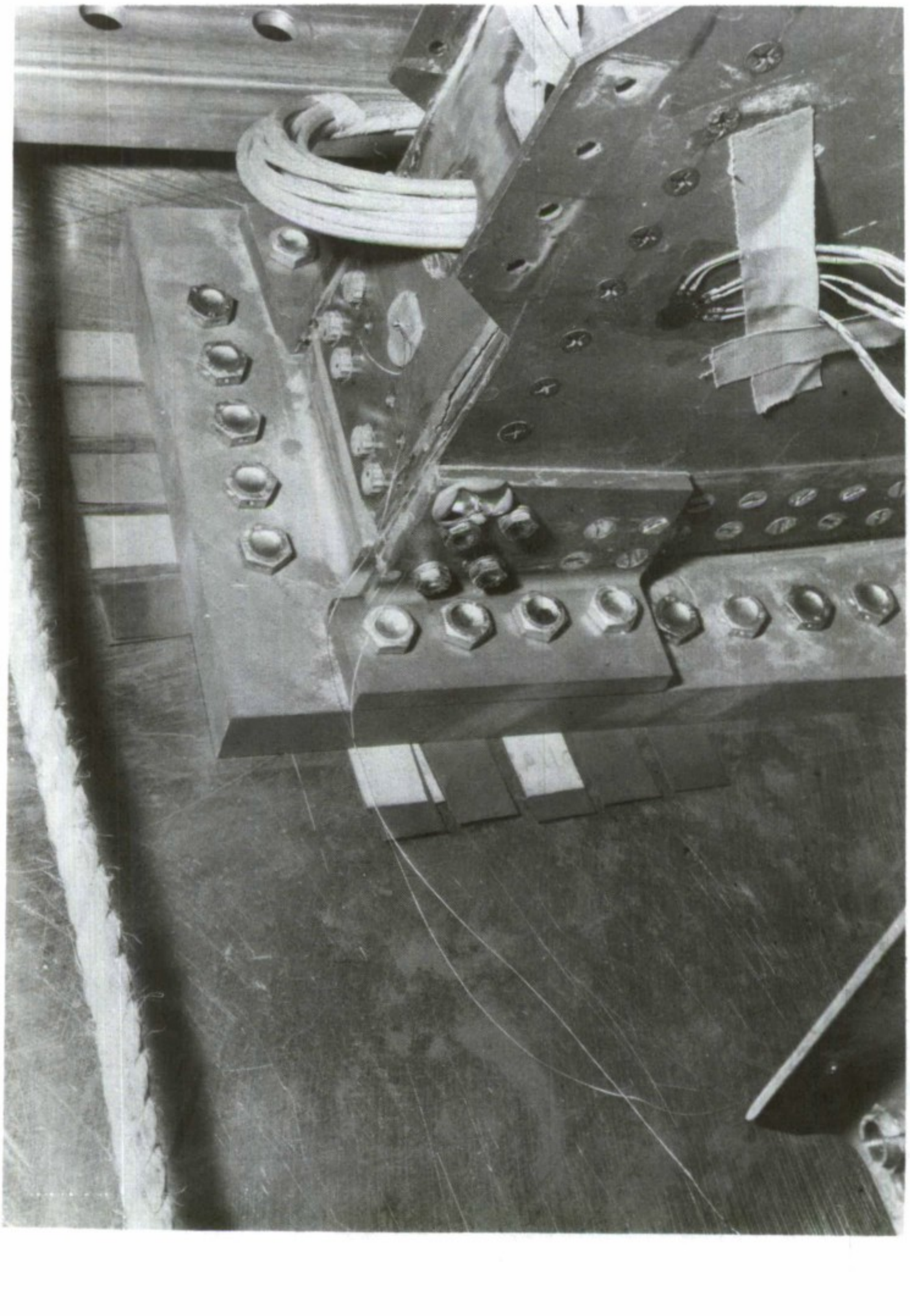

Figure 13. Block 21 Failure Showing Unbonding of Front Spar Doubler

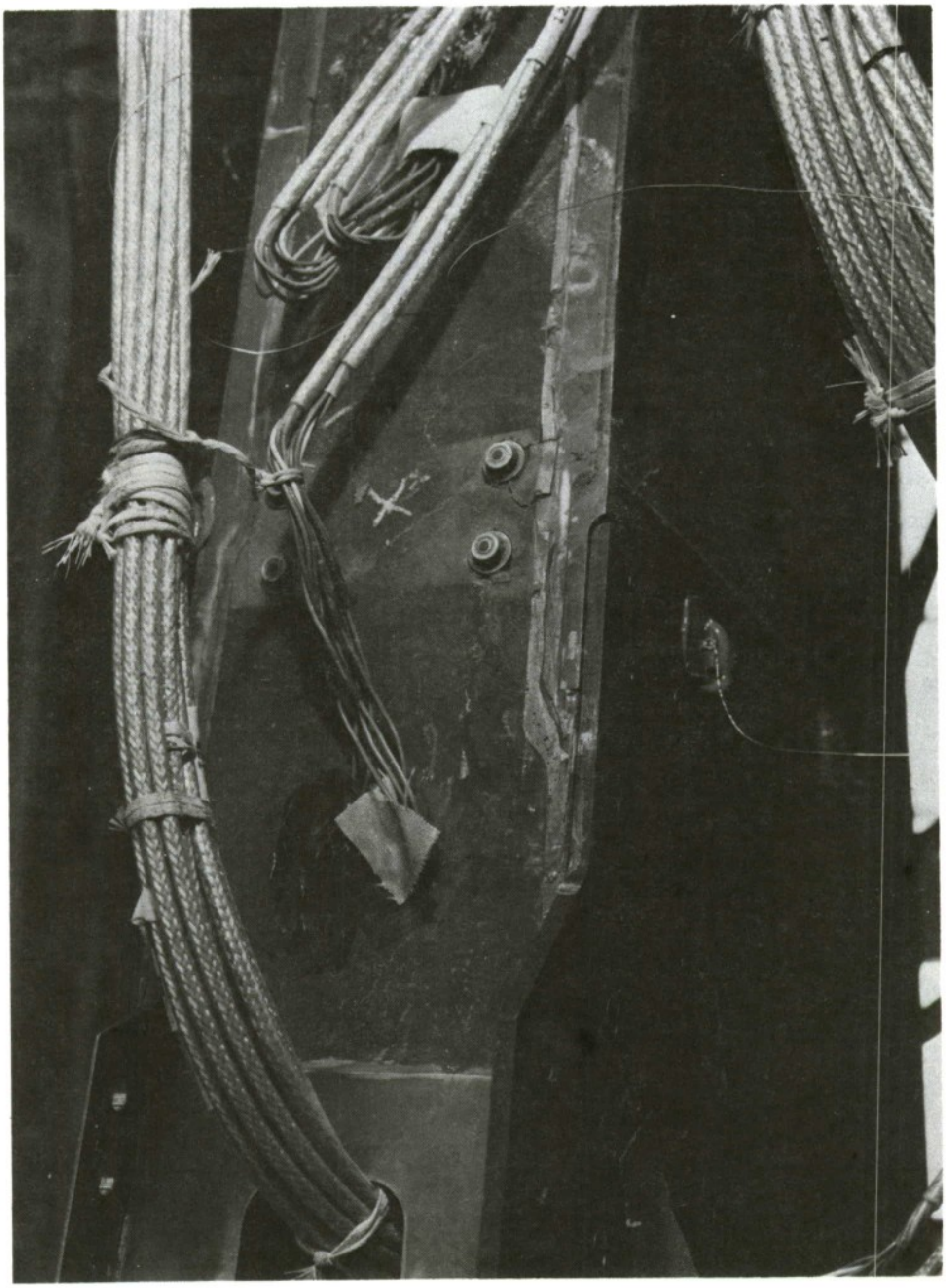

Figure 14. Block 21 Failure Showing Cracked Boron on Front Spar at Mid Rib

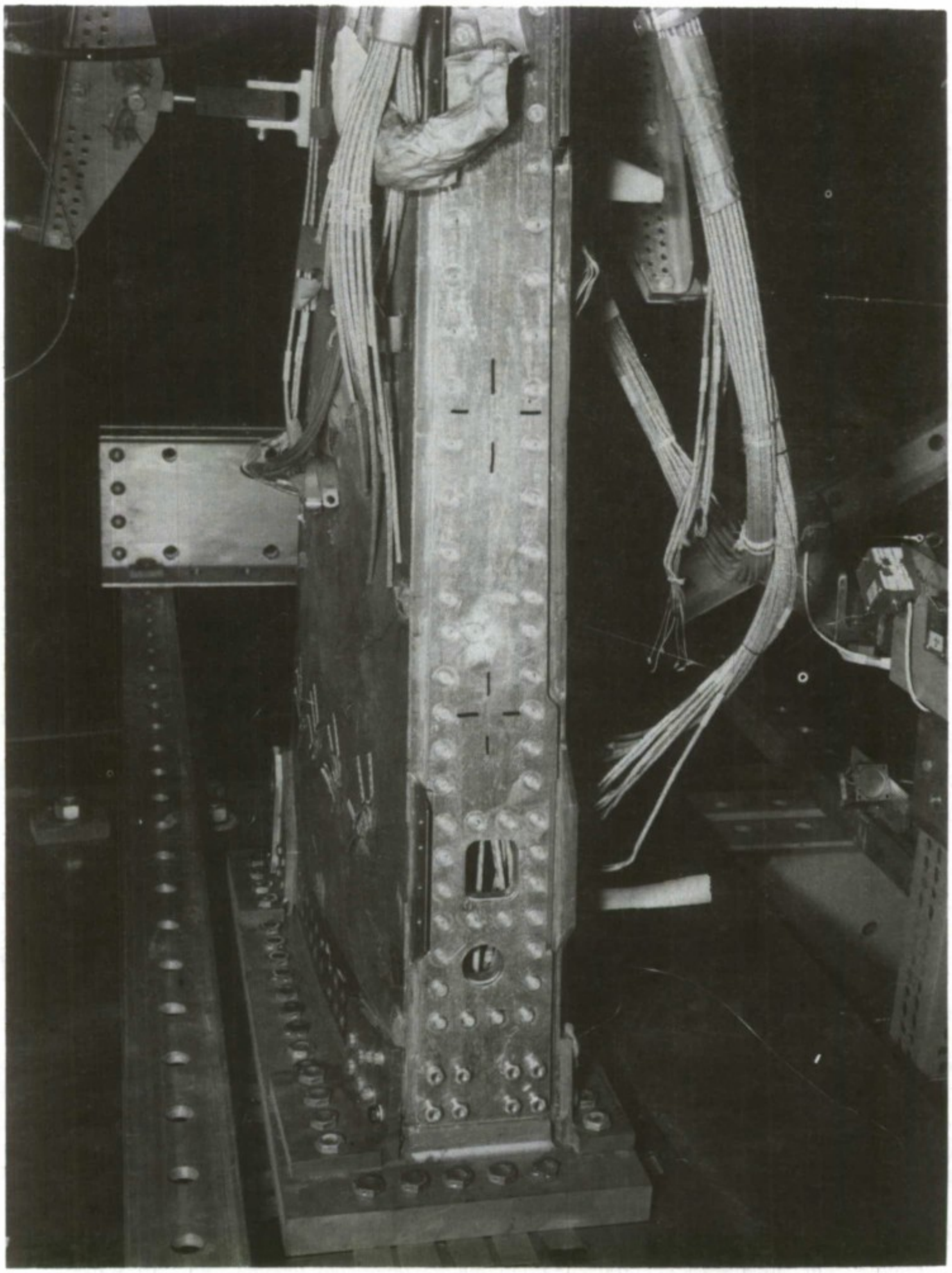

Figure 15. Repair Doubler Installed on Front Spar After Block 21 Failure

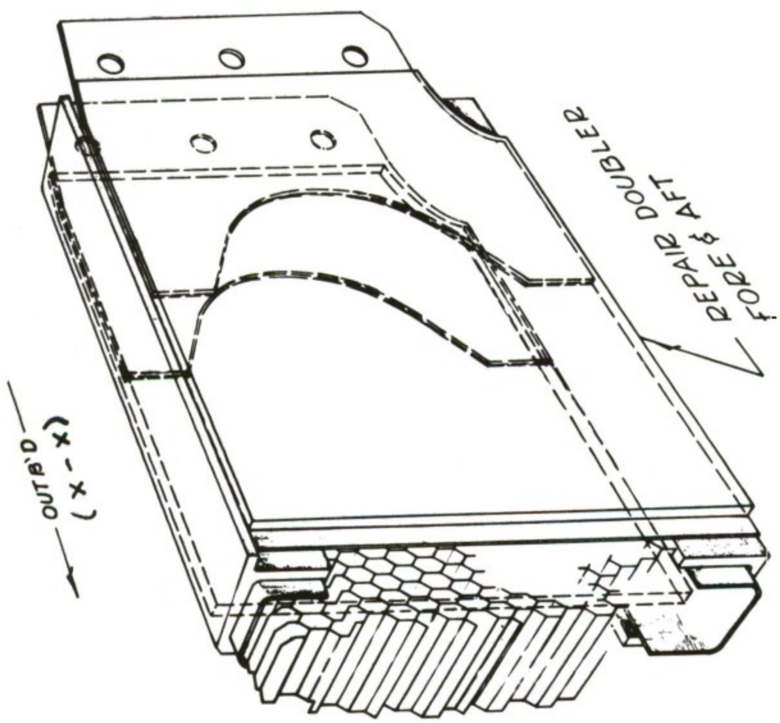

Figure 16. Repair Doubler Added to Center Spar After Block 21 Failure

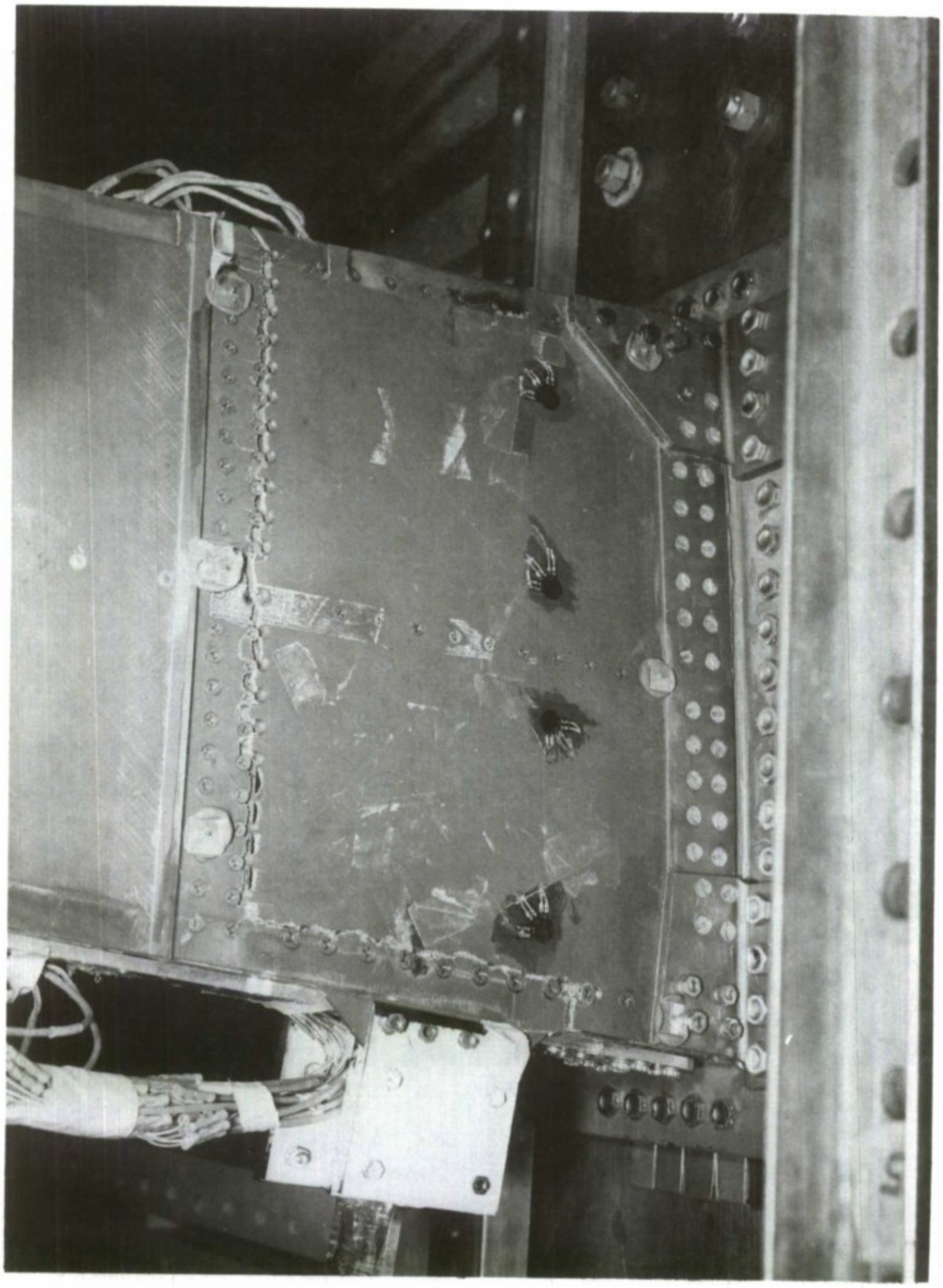

Figure 17. Final Failure of Lower Cover

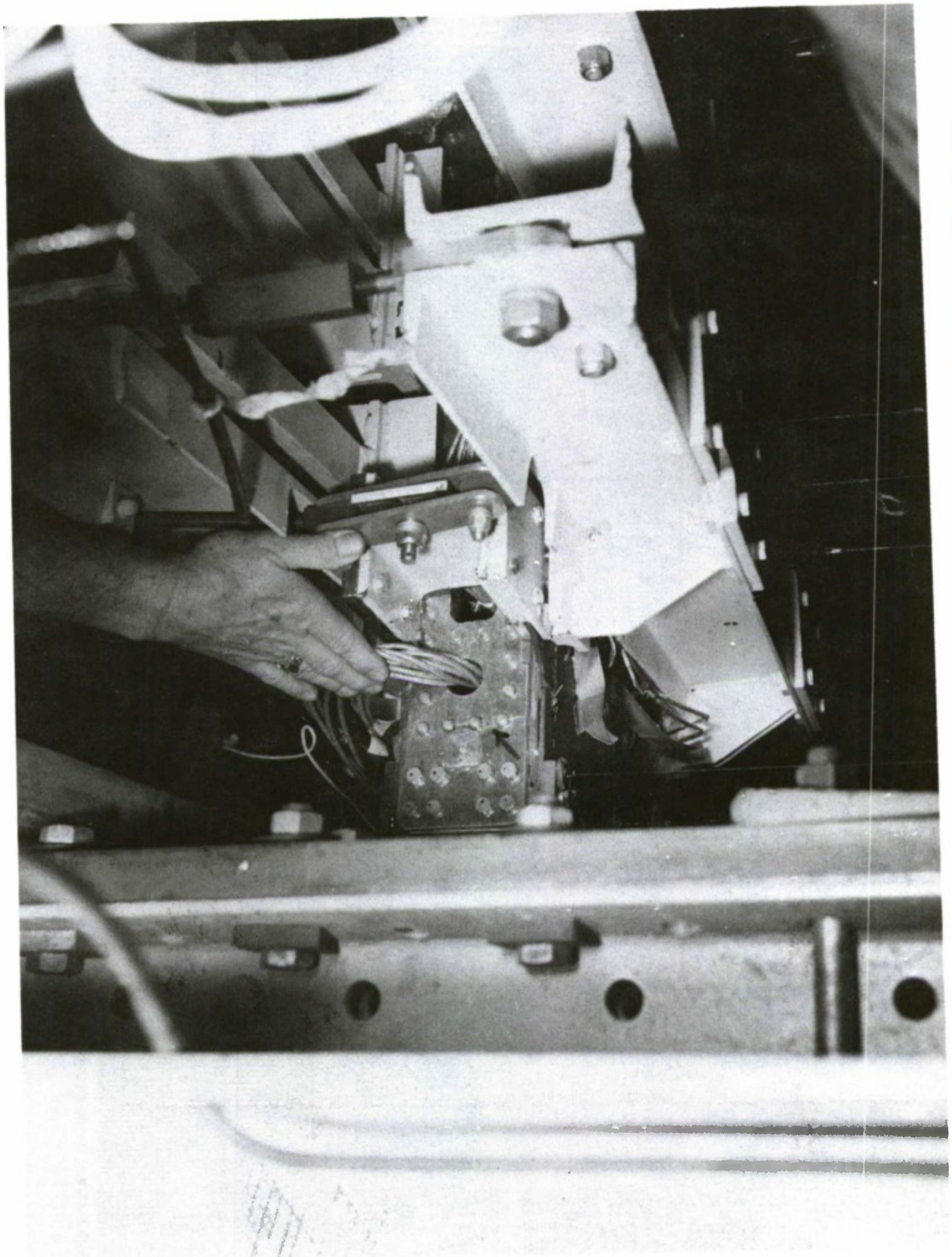

Figure 18. Final Failure of Front Spar Doubler Added After Block 21 Failure

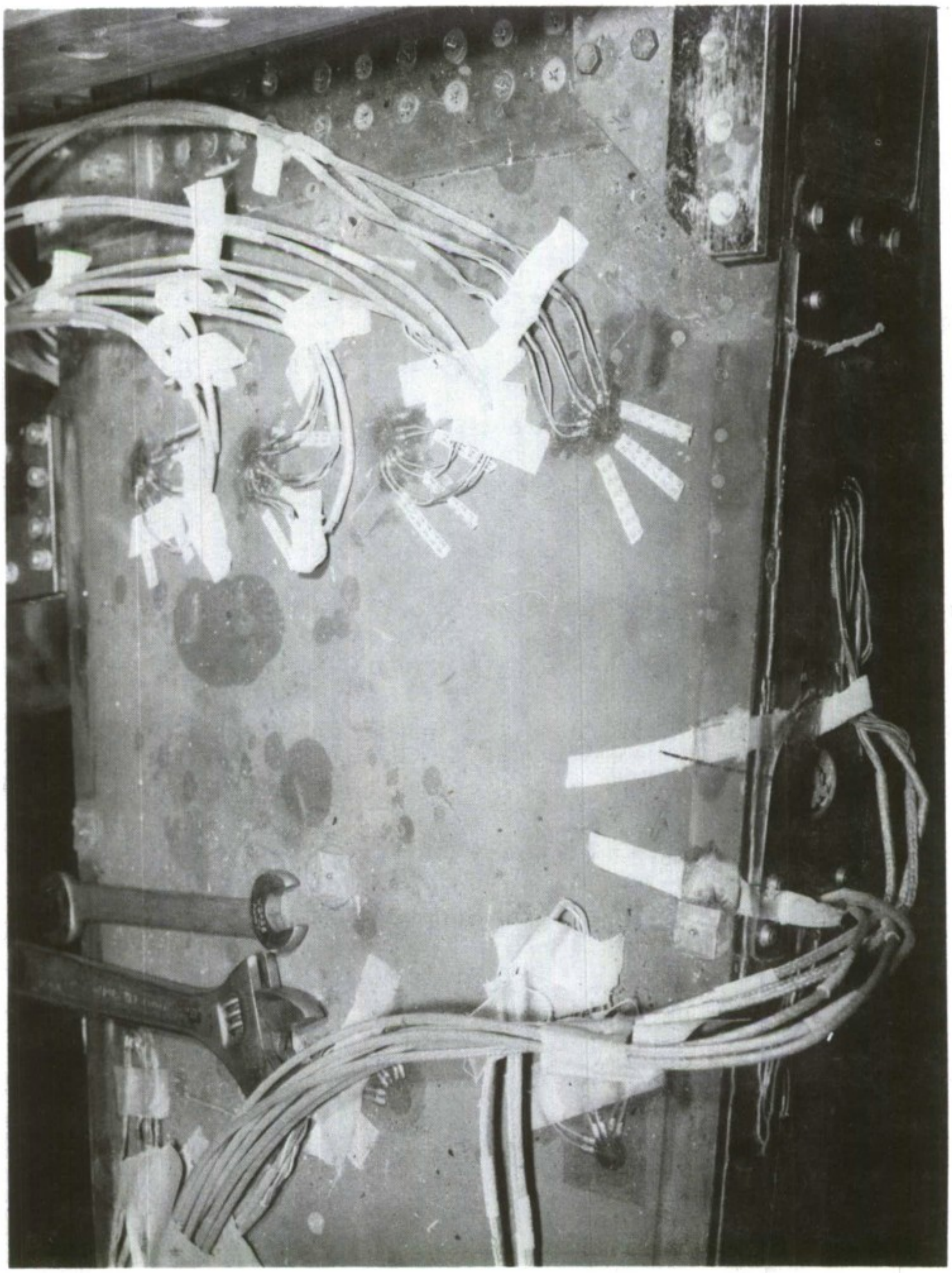

Figure 19. Final Failure of Rear Spar Showing the Core Failure

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