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QUIET CLEAN SHORT-HAUL EXPERIMENTAL ENGINE (QCSEE)

Composite Fan Frame Subsystem Test Report

September 1977

by

C. L. Stotler and J. H. Bowden

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16. Abstract

The QCSEE Program provides for the design, fabrication, and testing of two experimental high bypass geared turbofan engines and propulsion systems for short-haul passenger aircraft. The overall objective of the program is to develop the propulsion technology required for future externally blown flap types of aircraft with engines located both under-the-wing and over-the-wing. This technology includes work in composite structures and digital engine controls.

This specific report deals with the element and subcomponent testing conducted to verify the composite fan frame design. The element tests confirmed that the processes used in the frame design would produce the predicted mechanical properties. The subcomponent tests verified that the detail structural components of the frame had adequate structural integrity.

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FOREWORD

The Quiet Clean Short-Haul Experimental Engine (QCSEE) Program is currently being conducted by the General Electric Company, Aircraft Engine Group, under NASA Contract NAS3-18021. The QCSEE Program is under the direction of Mr. C. C. Ciepluch, NASA Project Manager.

This report presents the results of the Composite Fan Frame Subsystem Test Program. The NASA program director and technical advisor for this effort was Mr. M. P. Hanson. The program was performed under the direction of Mr. C. L. Stotler, Jr., Technical Manager, General Electric Company.

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SECTION 1.0

INTRODUCTION

One of the major advanced technology items in the Quiet Clean Short-Haul Experimental Engine (QCSEE) Program is the design and fabrication of a fan frame utilizing advanced composite materials. This is the first attempt to apply these materials to such a large and highly loaded component of a high bypass turbofan engine. It was therefore deemed necessary to conduct test programs to verify both the strength of the materials used and the structural integrity of the various design concepts employed in the construction of the frame.

This required testing falls into two distinct categories. The first of these involved the verification of the basic mechanical properties of the specific materials and material layup configurations to be employed. It was beyond the scope of the program to develop statistically based design data for each laminate configuration, nor was it necessary. The Advanced Composite Design Guide contains extensive data on the mechanical properties of the material systems and family of orientations used for the QCSEE composite frame. The purpose of this part of the test program was to verify that the processing techniques to be used in the fabrication of the frame would produce mechanical properties in reasonable agreement with the data obtained from the Design Guide for typical laminate orientations.

The major portion of the test program concerned the testing of subcomponents representative of various critical portions of the frame structure. This portion of the test program was necessary due to the unique methods of construction used in the composite frame, which required structural verification before the frame could be submitted for engine test.

The results of this overall test program were then evaluated and formed the basis for the structural evaluation of the composite frame prior to the static test of the complete frame.

SECTION 2.0

SUMMARY

This report presents the results of the element and subcomponent testing done in conjunction with the composite fan frame design for the Quiet Clean Short-Haul Experimental Engine (QCSEE) Program. This test program has as its objective the verification of the mechanical properties of the materials used, and of the structural concepts employed, in the frame design. All of the advanced composite material used in the frame was graphite/epoxy AS 3501.

The material mechanical properties used in the design and analysis of the composite frame were taken from the Advanced Composites Design Guide, third edition. In order to determine if the processes to be used in the frame fabrication would actually produce the properties predicted by this document, an element test program was conducted. Investigated were several typical material and angle-ply configurations planned for the frame. Their tensile, compressive, and shear properties were determined through small coupon tests. In addition, a typical composite configuration, intended to be used in an area of the frame containing mechanical attachments, was investigated for bolt bearing, shear-out, and net tension properties. The only test value of the program (out of fifty sets of tests) that was significantly below the values predicted by the Design Guide was the 0° tensile value at room temperature of a specimen representing the forward core spokes and ring. Since the 0° elevated temperature tensile test 406 K (270° F) and the 90° tensile tests at both room temperature and elevated temperature were at least 16% higher than predicted, it was concluded that the results obtained during the 0° room temperature tensile testing were not valid. Based on the data obtained during this element test program, it was concluded that it was reasonable and valid to use the mechanical property data obtained from the Design Guide for the design and analysis of the frame.

In addition to the basic element tests, two series of tests were run to evaluate the effects on the composite material system of elevated temperature exposure to aircraft fluids. The first series of tests evaluated the effect of intermittent exposure to Skydrol 500C. Tensile and compressive tests were run before and after exposure. Although there was some test scatter, it appeared that there was no degradation due to the exposure. The second series of tests evaluated exposure to hot engine oil (MIL-L-23699). No degradation of mechanical properties was observed after one week exposure in the oil at 422 K (300° F).

Since one of the most critical areas of composite structures is the joining of the individually molded pieces, either by bonding or mechanical fastening, the critical joint areas of the frame were investigated by a series of individual subcomponent tests representing these areas. A total of 36 specimens representing 21 different areas of the frame were fabricated and tested to failure. These specimens ranged from simple beams representing the

basic fan casing structure up to the highly complex specimen representing the thrust mount region of the frame. In all cases, the failing load of the subcomponent was in excess of the maximum design requirements of the area represented.

In summary, the results of the element and subcomponent testing conducted in support of the QCSEE composite fan frame design has provided a high degree of confidence that the frame itself will meet the structural design requirements.

SECTION 3.0

ELEMENT TESTING

This section describes the element test program conducted in support of the QCSEE composite fan frame design. The test plan is defined and the results of the test program are presented and evaluated. It was concluded, based on this effort, that the mechanical property data presented in the Advanced Composite Design Guide was adequate for use in the frame design.

3.1 TEST PLAN

3.1.1 Test Objective

The purpose of the QCSEE composite frame element test program was to verify the predicted strength properties of representative materials and layup patterns employed in the frame design. The data obtained from this program were compared to mechanical property data, for the same materials and layup patterns, obtained from the Advanced Composite Design Guide. The purpose of this comparison was to verify that the data from the Guide could be used as the data base for the frame design. Some empirical bolt bearing and shear-out data were also obtained for a specific configuration for use in the frame design, since limited data were available. A summary of the test plan is shown in Table I.

3.1.2 Test Configurations

Ultimate tensile strengths were established through the testing of two principal types of uniaxial specimens. The first type of specimen was the IITRI (Illinois Institute of Technology Research Institute) specimen shown in Figure 1. This straight-sided specimen requires a thickened tab in the grip area, which will cause a stress concentration in the specimen surface plies at the start of the reinforcement. This effect is moderated by tapering the reinforcement and using relatively low modulus tab material. Straight-sided specimens were used for organic matrix laminate tensile tests.

Self-aligning grips which completely enclose the end tabs are used to hold the specimen. Grip surfaces with a relatively fine serration have been satisfactory. Serrations were kept clean and sharp. This test is very sensitive to misalignment in the test jig; therefore, the gripping jaws were accurately aligned and the specimen accurately centered to ensure that bending and twisting loads were not induced.

The second type of tensile specimen was the sandwich beam. Sandwich beam bending tests have less stress concentration than coupons, though there is some evidence on thicker laminates of shear lag, which overloads the inner ply and reduces the failing stress.

Table I. Test Specimen Configurations.

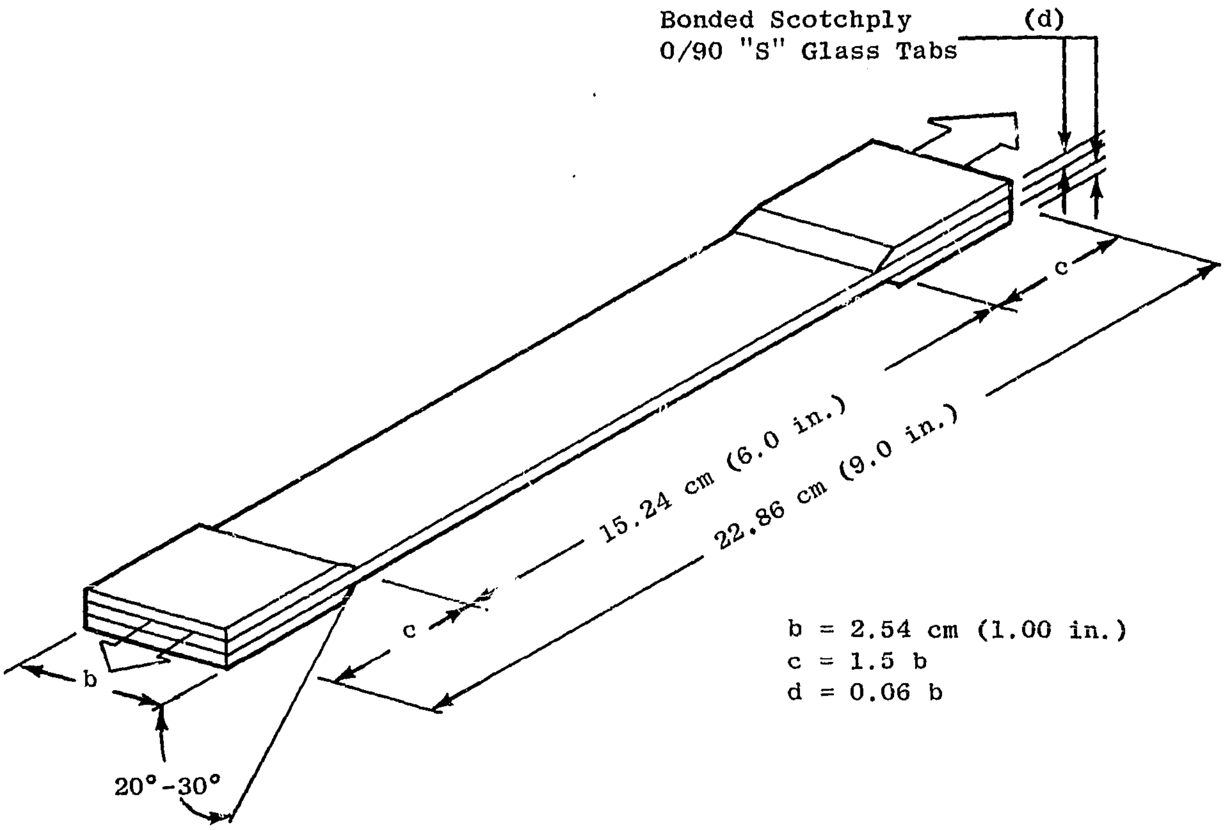
Serial Identification	General Configuration Representation	Material[1]	0° Datum	Test Dir.	Test Temp.	Test Mode[3]									
						IITRI[4] Tensile	Sandwich Beam Tensile	Sandwich Beam Compression	Rail Shear (Flat Panel)	Rail Shear (Sandwich Panel)	Interlaminar Shear	Bolt Hole Bearing	Bolt Hole Shear-Out	Bolt Hole Net Tension	Clamping
101	Outer Nacelle Shell	Boron-Graphite/ Epoxy	Axial	0°	R.T.	X	X	X	X	X					
				90°	R.T.	X	X	X	X	X					
102	Bypass Vane Panels	Graphite/Epoxy	Radial	0°	R.T.	X	X	X	X						
				90°	R.T.	X		X	X						
		Graphite/Epoxy (10% Open Area)		0°	R.T.	X	X	X	X	X					
103	Bypass Spoke	Boron-Graphite/ Epoxy[2]	Radial	0°	R.T.	X		X			X				
104	Forward Core Spoke and Rings	Graphite/Epoxy	Radial	0°	R.T.	X	X	X	X		X	X	X	X	
				0°	406 K (270° F)	X		X				X	X	X	X
				90°	R.T.	X		X	X		X	X	X	X	
				90°	406 K (270° F)	X		X				X	X	X	

(1) Boron/3501 and/or Graphite Epoxy (AS 3501), Hercules Prepreg

(2) 0° Plies - Boron ± 45° and 90° Plies are Graphite

(3) Each Test Mode Consists of Three Replicates

(4) IITRI - Illinois Institute of Technology Research Institute



(1) Specimens Were Cut to Width

(2) Inner Ply of Tab Material Fibers Were in the Longitudinal Direction

(3) Self-Aligning Grips Completely Enclosed the Tab Area

Figure 1. IITRI Tensile Coupon.

A typical sandwich beam test specimen is shown in Figure 2. A recent modification to this specimen, which has been successfully used to minimize the influence of the core, consists of placing a parting agent between the core and face in the test section, or alternatively, slotting the core adjacent to the face in this area. This is done only at the tensile face of the beam.

The primary means of obtaining compression strength allowables was the sandwich beam bending test. The specimen used to determine compressive allowables for a honeycomb stabilized structure is the type shown in Figure 3. As seen from Figure 3, the beam is simply supported at both ends and two equal loads are applied to the top face panel which is the test laminate.

Shear properties in the plane of the laminate were determined by the rail shear test. This test method is shown in Figure 4. It uses a thin laminate 10.16 cm (4 in.) wide and 20.32 cm (8 in.) long, loaded along its length by two pairs of rails, leaving an upsupported central test section. The use of knife-edged spacers which are located at both ends of the panel and which tilt with shear distortion allows transverse deflection of the rails.

The short-beam shear tests were performed in accordance with ASTM D2344-72 flat laminate specimen. Span to thickness ratio was 5 to 1.

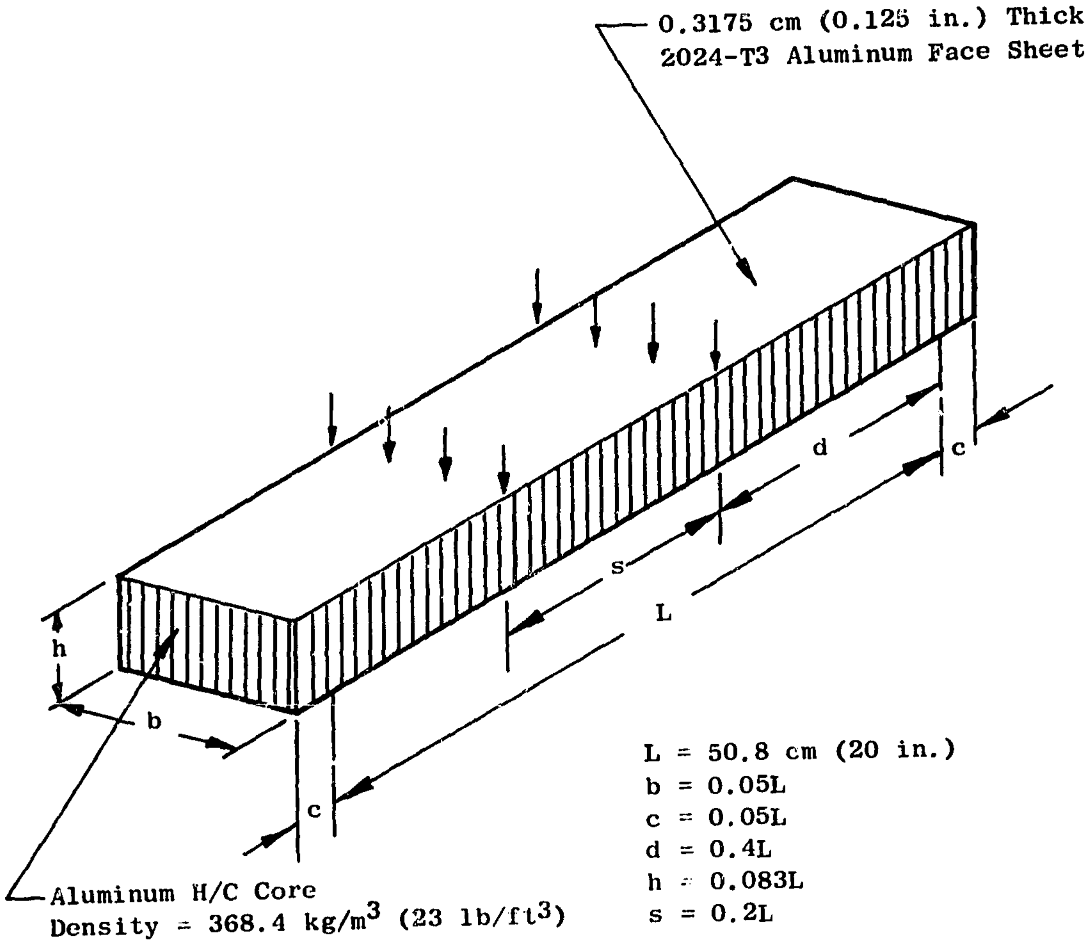
The strength of mechanical joints in composite laminates was evaluated in the same manner as that of bolted joints in metals. Test specimens were sized and data reduced to provide laminate allowables for the following modes of failure: net tension, shear-out, bearing, and clamping. The general specimen is shown in Figure 5.

3.1.3 Test Facility

All testing of specimens was conducted by Cincinnati Testing Laboratories (CTL). The entire testing facility meets full laboratory requirements of temperature and humidity control. Tests were conducted in accordance with required specifications such as ASTM, NEMA, Federal, Military, and Customer or CTL developed special test specifications. The facility test equipment is maintained under calibration traceable to the National Bureau of Standards.

3.2 TEST RESULTS

Four critical areas of the frame were selected and preliminary material configurations were defined. Since the purpose of the test program was to obtain relative data and not specific design data, it was not necessary to delay the test program until the final material configurations were determined. The test results for tension, compression, shear, and bolt hole testing are shown in the following paragraphs.

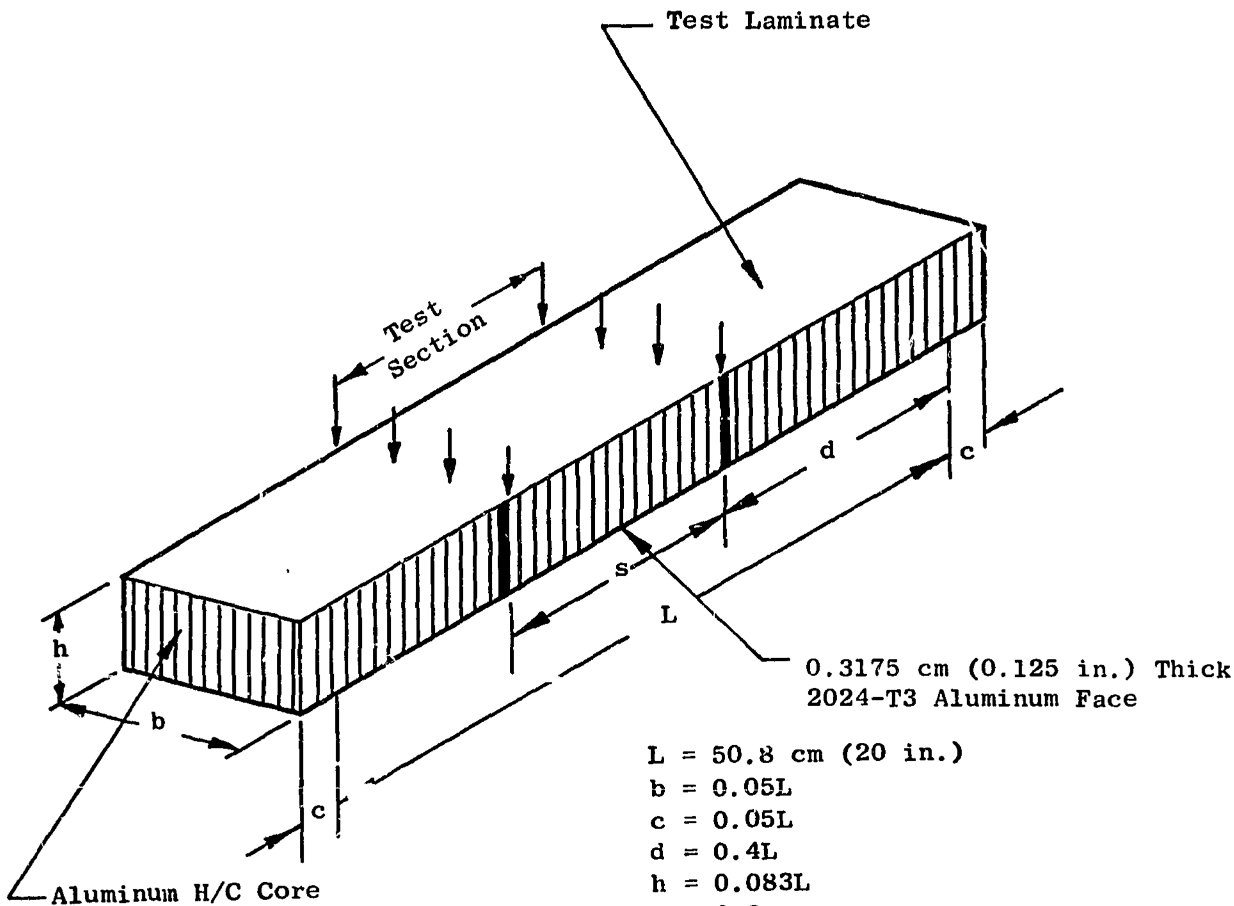


(1) 3.81 cm (1.5 in.) Wide Loading Pads Were Used Against the Test Laminate and 2.54 cm (1.0 in.) Wide Loading Pads on the Opposite Side.

(2) Stress was Computed Assuming Ineffective Core and Using a Bending Couple at Midplane of Facings

(3) Parting Agent is Used Between Core and Face in Test Section

Figure 2. Sandwich Beam Tensile Specimen.



L = 50.8 cm (20 in.)
b = 0.05L
c = 0.05L
d = 0.4L
h = 0.083L
s = 0.2L

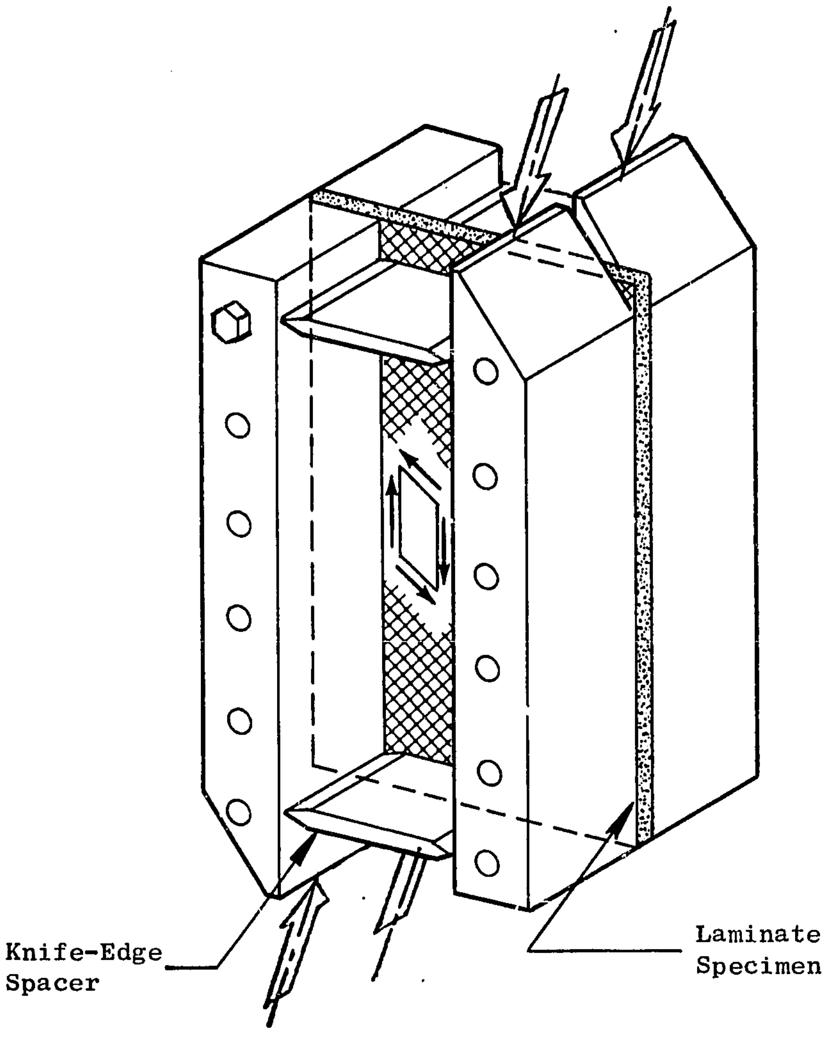
Density Outside Test Se[illegible]n = 368.4 kg/m^3 (23 lb/ft^3)

Density in Test Section = 64.1 kg/m^3 (4 lb/ft^3)

(1) 3.81 cm (1.5 in.) Wide Loading Pads Were Used Against the Test Laminate and 2.54 cm (1.0 in.) Wide Loading Pads on the Opposite Side.

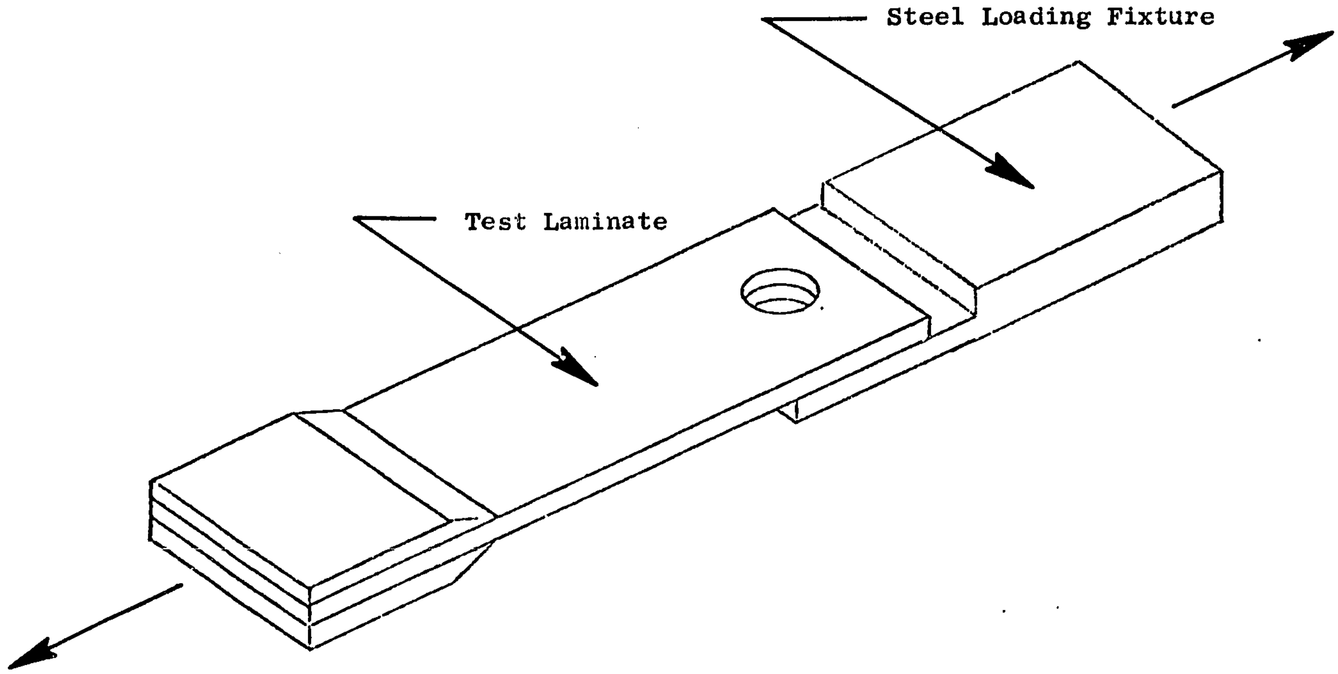
(2) Stress Computed Using Bending Couple at Midplane of Faces

Figure 3. Sandwich Beam Compression Specimen.



1) Rails Were Bonded to Specimen to Avoid
Failure Through Bolt Holes

Figure 4. In-Plane Shear, Rail Test Method.



Note: Specimen dimensions were determined by the material layup configuration under consideration and the specific property (bearing, shear-out, net tension) investigated.

Figure 5. Bolt Hole Specimen.

3.2.1 Tensile Testing

The results of the tensile testing conducted during this program are shown in Table II. The configurations identified as serial numbers 101 and 102 in Table II were relatively thin {<0.127 cm (0.05 in.)} test laminates to be tested using the IITRI type tensile test specimen. Several tab failures occurred during the testing. Comparable sandwich beam tests indicated that the tensile values obtained from the tests in which tab failures occurred were not representative. The configurations identified as serial numbers 103 and 104 were relatively thick {>0.254 cm (0.10 in.)} test laminates. The sandwich beam data could not be obtained due to shear failure of the core-to-face bond, as indicated in Table II. The only test value that was significantly below predicted was the 0° loading at room temperature test of serial number 104. Other tests of this configuration {0° loading at 400 K (270° F)} and 90° loading at both room temperature and 406 K (270° F) were considerably above predicted strength, indicating that the results of the 0° orientation at room temperature were not valid.

To evaluate the effect of acoustic treatment holes in the vane skins, IITRI tensile tests were run using a 10% open area pattern of holes in the layup pattern identified as serial number 102 in Table II. The gross tensile strength was 29,600 N/cm^2 (43,000 psi) and the net tensile strength was 37,700 N/cm^2 (54,700 psi) compared to a baseline (no holes) value of 53,900 N/cm^2 (78,000 psi), Table II. This gives a stress concentration factor of 1.43. This information was taken into account in the stress analysis of the bypass vanes. The same stress concentration was assumed for the acoustically treated outer casing.

3.2.2 Compression Testing

The results of the compression testing conducted during this program are shown in Table III. All compression testing was done on sandwich beam type specimens. As was the case with the tensile test, it was not possible to fail the thicker laminates (serial numbers 103 and 104), owing to failure of the bond between the honeycomb core and the tension side aluminum face. The data obtained from the thinner laminates were in reasonably good agreement with the predicted values.

3.2.3 Shear Testing

The results of the shear testing conducted during this program are shown in Table IV. In-plane shear tests were run on both solid laminates and sandwhich panels to simulate the two types of applications in the frame. All of these specimens were of the rail shear type. The only significant area in which the test values were lower than predicted was in the case of the thin serial number 101 panels where the failure mode was in buckling, and the end conditions are sensitive to the procedure used to mount the specimens in the test fixture. All of the ultimate strength values were higher than predicted for all configurations, although the load deformation curve for one of the

Table II. Tensile Testing.

Basic Material - Graphite/Epoxy

Serial Identification	Laminate Configuration % Fiber at 0°	45°	90°	Load Direction (degrees)	Temperature K (° F)	Predicted Stress N/cm² (psi)	Avg. Test Results: IITRI(4) N/cm² (psi)	Avg. Test Results: Sandwich Beam N/cm² (psi)	Average % Difference
101	14(1)	57	29	0	Room Temperature	23305 (33800)	23395 (34800)	24408 (35400)	+4
				90	Room Temperature	39439 (57200)	32682 (47400) (2)	40405 (58600)	+2
102	40	40	20	0	Room Temperature	56539 (82000)	53919 (78200)	51575 (74800)	-7
				90	Room Temperature	37923 (55000)	27856 (40400) (2)	--- ---	--- ---
103	80(1)	20	0	0	Room Temperature	93083 (135000)	94875 (137600)	--- ---	+2
104	50	20	30	0	Room Temperature	64124 (93000)	51023 (74000)	(3)	-20
				0	406 (270)	59987 (87000)	69364 (100600)	--- ---	+16
				90	Room Temperature	44128 (64000)	51988 (75400)	--- ---	+18
				90	406 (270)	42060 (61000)	63020 (91400)	--- ---	+50

(1) Boron/Epoxy (3) Excessive Beam Deflection Failed Core-to-Face Bond

(2) Tab Failures (4) IITRI - Illinois Institute of Technology Research Institute

Table III. Compression Testing.

Sandwich Beam Tests

Serial Identification	Load Direction	Temperature K (° F)	Predicted Stress		Avg Test Results		% Difference
			N/cm^2	psi	N/cm^2	psi	
101	0	Room Temperature	39370	57100	43645	63300	+11
	90	Room Temperature	40749	59100	37026	53700	- 9
102	0	Room Temperature	56539	82000	54195	78600	- 4
	90	Room Temperature	30338	44000	29580	42900	- 3
103	0	Room Temperature	144795	21000	(1)	---	---
104	0	Room Temperature	65503	95000	(1)	---	---
	0	406 (270)	48265	70000	(1)	---	---
	90	Room Temperature	43439	63000	(1)	---	---
	90	406 (270)	33786	49000	(1)	---	---

(1) Laminate did not Fail - Aluminum-to-Honeycomb Core Bond Failure.

Table IV. Shear Tests.

All Tests at Room Temperature

Serial Identification	Load Direction (degrees)	In Plane (Rail) Shear					Interlaminar (Short Beam) Shear Test Results	
		Predicted/Stress		Average Actual Stress		% Difference		
		N/cm²	psi	N/cm²	psi		N/cm²	psi
101 (Laminated)	0	16203	23500(1)	13928	20200	-14	---	---
	90	16203	23500(1)	18065	26200	+11	---	---
101 (Sandwich)	0	19306	28000	24133	35000	+28	---	---
	90	19306	28000	24133	35000	+28	---	---
102 (Laminated)	0	17238	25000	19651	28500	+14	---	---
	90	17238	25000	18410	26700	+ 7	---	---
103	---	---	---	---	---	---	8964	13000
104 (Laminated)	0	10687	15500	9860	14300(2)	- 8	5033	7300
	90	10687	15500	16962	24600	+59	6343	9200

(1) Buckling.

(2) Load deformation curve stepped at this value. Final failure at 17,376 N/cm² (25,200 psi).

thicker laminates was not linear to failure. Several interlaminar shear tests were conducted, using the short beam shear test, to determine the range of values that could be expected. These data were for use in quality control only.

3.2.4 Bolt Hole Tests

Empirical data concerning loading bolt holes were generated for the frame configuration which occurs in the highly loaded bolted attachment of the engine bearing cones. The results of these tests are shown in Table V. The properties investigated were bearing stress in the hole, net tension stress between holes, and shear-out strength of the fastener installation. A stress concentration factor was determined for the net tension tests using the appropriate tension value from Table II as the baseline. The values determined by these tests were used for the structural design and analysis of the frame.

3.3 CONCLUSIONS

Based on the data obtained during the element test program, it was concluded that it was valid to use the mechanical properties shown in the Advanced Composite Design Guide for the design and analysis of the QCSEE composite fan frame. Empirical data were also obtained for laminates with acoustic treatment holes in thin laminates and for loaded holes in thick laminates.

Table V. Bolt Hole Tests.

All Tests Done on Serial Number 104 Type Laminates

Temperature K (° F)	Load Direction (degrees)	Bearing Stress		Net Tension Stress			Shear Out Stress	
		N/cm^2	psi	N/cm^2	psi	K	N/cm^2	psi
Room Temperature	0	48058	69700	42266	61300	1.2	18823	27300
Room Temperature	90	48265	70000	43439	63000	1.2	19030	27600
406 (270)	0	53505	77600	43576	63200	1.6	16272	23600
406 (270)	90	55160	80000	39370	57100	1.6	16617	24100

SECTION 4.0

SUBCOMPONENT TESTING

This section describes the subcomponent test program conducted in support of the QCSEE composite fan frame design. This program was required since one of the critical areas of composite structures is the joining of the individually molded pieces, either by bonding or mechanical fastening, therefore, the critical joint areas of the fan frame were individually tested prior to the final frame assembly.

4.1 TEST PLAN

4.1.1 Test Objective

The test objective is to confirm the loading capability of critical structural subcomponents incorporated in the composite frame in order to verify their structural adequacy and to provide early knowledge of configurations that may require design modifications. This was accomplished by loading each subcomponent to failure, observing the deflection versus load, and by studying the failed specimen.

4.1.2 Test Configurations

Prior to fabrication of the composite frame, representative subcomponent parts were selected for testing to investigate and verify various design features unique to the composite frame. A total of seven basic types of structure were selected as requiring structural test verification. These are identified in Figure 6. Several variations of each of these basic structures were investigated in order to represent several specific, but similar, areas of the frame. These basic structures and their variations are discussed below.

1. Ring Structures - The QCSEE composite frame is basically a series of comsite "wheels" tied together by shear panels. These wheels consist of radial spokes and circumferential rings. The objective of the tests conducted under the heading of ring structures was to verify the structural integrity of the more critical of these ring configurations. The two areas which were investigated are sections of the forward inner ring and the aft inner ring as identified in Figure 6. The forward inner ring was chosen because analysis has shown this to be the highest loaded ring. The aft inner ring was selected because it has the maximum curvature and is subjected to the maximum operating temperature. These rings are primarily loaded in bending. Therefore, these tests were conducted as beam tests.

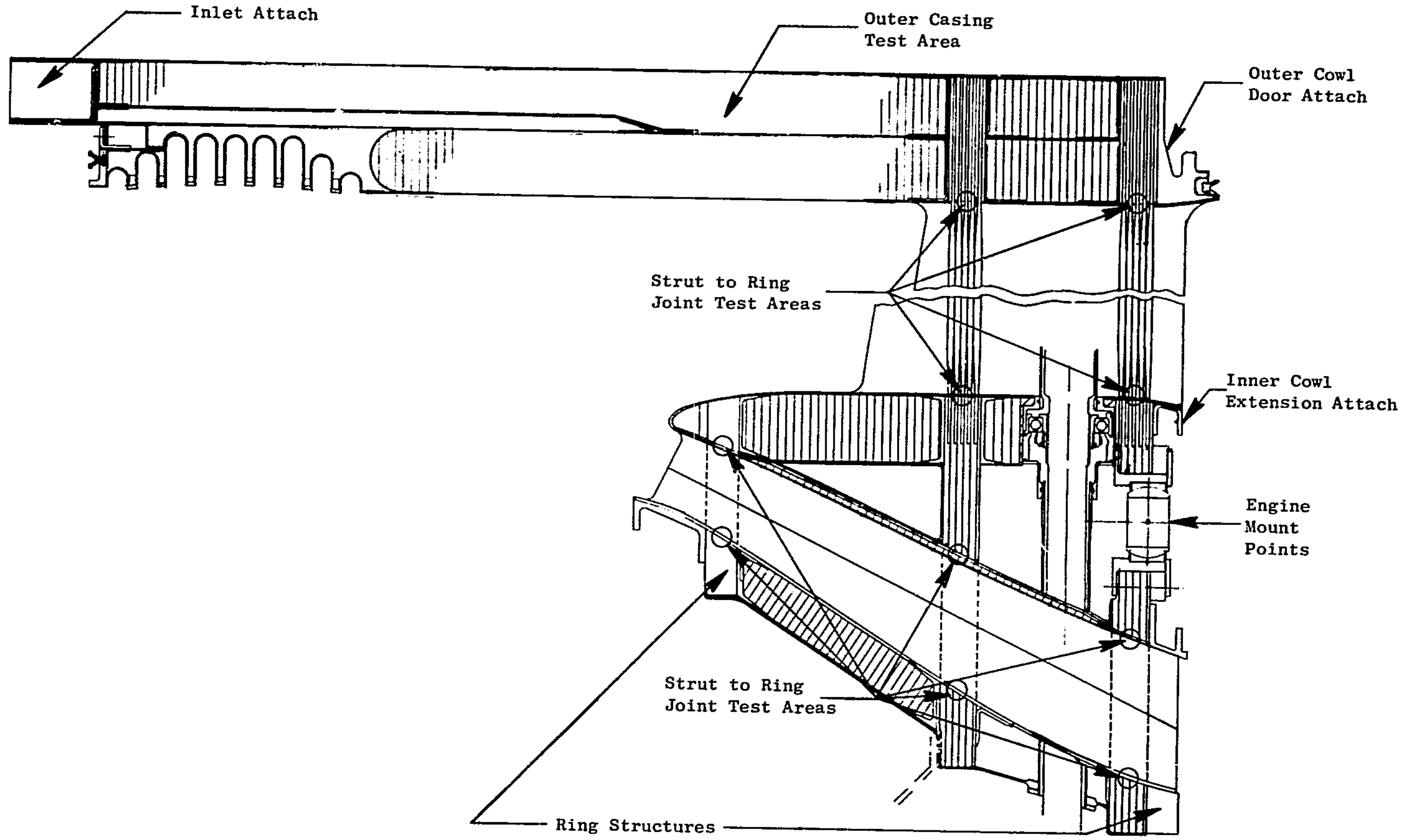


Figure 6. Frame Subcomponent Test Areas.

2. Strut-to-Ring Joints - One of the major load transfer points in the QCSEE composite frame is the joint between the wheel spokes and the wheel rim. The more highly loaded joint areas (Figure 6) were selected for structural verification. Due to the nature of the joints they are more critical in tension than compression. Therefore, the majority of the testing was done as tension tests. These joints also are subjected to some local bending and the joint with the highest bending load was tested under that mode of loading. These joints in the core flow path area were tested at elevated temperature {406 K(270° F)} as well as room temperature.

3. Engine Mount Attachments - The fan frame is the forward attach point for the engine. A uniball attached to the back of the frame at the top of the flow path splitter ring (Figure 6) is designed to take vertical and side loads but no thrust. The attachment strength of this uniball to the frame was experimentally verified. The side load on this structure is small compared to the vertical load, so only the vertical load was applied during the subcomponent test in order to avoid needless complexity in the test setup. In addition to the uniball attachment, two thrust links are attached to the rear splitter ring. These links are designed to transmit axial load only and their attachment to the composite frame was verified by test.

4. Outer Casing - The outer casing, forward to the fan,is an integral part of the fan frame and consists of a honeycomb sandwich panel with a solid skin on the outer surface and a perforated skin on the inner (fan flowpath) surface with a separator sheet, or septum, at some depth inside the sandwich to provide the required acoustical treatment. This configuration was tested in beam bending. Although the actual component will see very little local bending, this test was performed to verify the structural capability of the total sandwich structure, especially the perforated face and the bond to the septum sheet.

5. Inlet-to-Frame Attachment - The composite inlet is attached to the composite fan frame by a total of 16 rotary latches. A test investigated the integrity of this latching arrangement. The test specimen included the latch itself as well as the latch installation in both the inlet and the frame. Strain data were obtained from a row of rosette strain gages on the upper surface of the frame casing sandwich panel to determine the local load distribution in the latch area and just how the distributed load in the casing was channeled into a discrete load at the latch point.

6. Frame-to-Inner Cowl Extension Joint - The inner cowl joint to the back of the fan frame must be somewhat aft of the frame itself in order for the inner cowl door to clear the outer cowl door circumferential attachment to to the frame. This required an extension to be bolted on to the back of the frame. This joint was tested to verify its tensile load capability.

Table VI. Test Results of Graphite Epoxy (AS/3501) Subcomponents.

Test Specimen Configuration	Test Temperature	Test Mode	Required for Safe Design	Average Test Results: Predicted	Average Test Results: Test Average
Ring Structures					
Forward Inner Ring	Room temperature	Bend - ID tension	48590 N•cm	257640 N•cm	300580 N•cm/ 26600 in-lb
Forward Inner Ring	Room temperature	Bend - ID compression	18090 N•cm	298320 N•cm	427140 N•cm/ 37800 in-lb
Aft Inner Ring	Room temperature	Bend - ID tension	59100 N•cm	354140 N•cm	297472 N•cm/ 26325 in-lb
Aft Inner Ring	406 K (270° F)	Bend - ID tension	59100 N•cm	354140 N•cm	312083 N•cm/ 27618 in-lb
Aft Inner Ring	Room temperature	Bend - ID compression	59100 N•cm	442734 N•cm	498330 N•cm/ 44100 in-lb
Aft Inner Ring	406 K (270° F)	Bend - ID compression	59100 N•cm	442734 N•cm	519303 N•cm/ 45956 in-lb
Strut-to-Ring Joints					
Core Vane Forward	Room temperature	Spoke tension	177920 N	273552 N	245530 N / 55200 lb
Core Vane Mid	Room temperature	Spoke tension	213950 N	269550 N	298016 N / 67000 lb
Core Vane Aft	Room temperature	Spoke tension	20016 N	114314 N	105418 N / 23700 lb
Core Vane Aft	406 K (270° F)	Spoke tension	20016 N	-	123210 N / 27700 lb
Fan Vane Forward	Room temperature	Spoke tension	34660 N	153130 N	105868 N / 23800 lb
Fan Vane Aft	Room temperature	Spoke tension	42667 N	108092 N	71172 N / 16000 lb
Maximum Moment Joint	Room temperature	Spoke bending	128820 N•cm	160460 N•cm	164980 N•cm/ 14600 in-lb
Engine Mount Attachment					
Uniball attachment	Room temperature	Radial load	149,838 N	230435 N	253015 N / 56880 lb
Uniball attachment	406 K (270° F)	Radial load	-	-	207732 N / 46700 lb
Thrust Link attachment	Room temperature	Axial load	111206 N	182377 N	120102 N / 27000 lb
Outer Casing					
Honeycomb sandwich panel	Room temperature	Bend - ID tension	23906 N/cm^2	31164 N/cm^2	31268 N/cm^2/45350 psi
Honeycomb sandwich panel	Room temperature	Bend - ID compression	23906 N/cm^2	31164 N/cm^2	36236 N/cm^2/52555 psi
Inlet-to-Frame Attachment	Room temperature	Tension	9341 N	28800 N	28636 N / 6438 lb
Core Cowl Extension-to-Frame Joint	406 K (270° F)	Tension	297.7 N/cm	774 N/cm	788 N/cm / 450 lb/in.
Frame-to-Outer Cowl Door Joint	Room temperature	Tension	447 N/cm	630.4 N/cm	447 N/cm / 255 lb/in.

7. <u>Frame-to-Outer Cowl Door Joint</u> - The outer cowl is attached to the frame by a tongue and groove joint shown in Figure 6. The strength of this joint was verified by test. This test not only involved the joint itself but also how it is attached to both the frame and the outer cowl door. Spring load bars were used to provide out-of-plane support. Engine temperatures in this area are not critical so the test was conducted at room temperature.

4.1.3 Test Facilities

Tension/compression facilities for the simpler tests consisted of a Baldwin tensile machine and an Instron tensile machine. Facilities for maintaining the specimens at elevated temperature were incoroprated into the tensile machine. The more complex and the higher loaded tests were conducted in the Static Load Laboratory, which is used to test basic engine structures.

4.2 TEST RESULTS

A total of 36 individual specimens were fabricated and tested under this program. The results of these tests are shown in Table VI and discussed in detail in the following paragraphs.

4.2.1 Ring Structures

1. <u>Forward Inner Ring (See Figure 6)</u> - The forward inner ring, which is the highest loaded hub ring, was tested in four-point bending. Two specimens were tested with the inner diameter in tension and two were tested with the inner diameter in compression. The maximum moments which the forward inner ring is required to sustain are 182,400 N·cm (16,140 in-lb) for the ID in compression and 48,600 N·cm (4,300 in-lb) for the ID in tension.

A summary of the test results for the four specimens is shown below:

Specimen	Mode	Load		Moment	
		N	lb	N·cm	in-lb
1	ID in Tension	57,800	13,000	293,800	26,000
2	ID in Tension	60,500	13,600	307,300	27,200
3	ID in Compression	80,400	18,085	408,700	36,170
4	ID in Compression	88,100	19,800	447,400	39,600

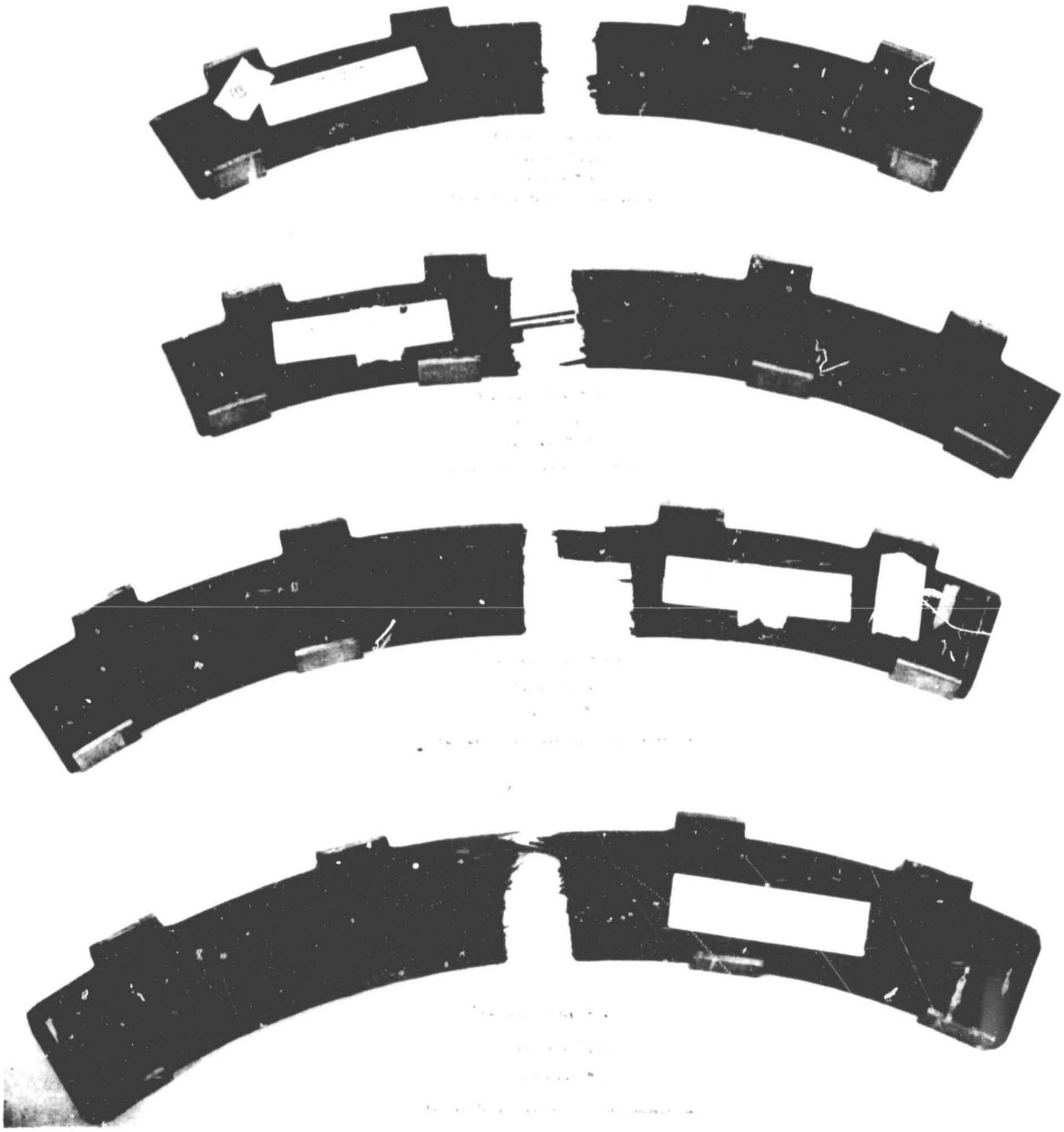


Figure 7. Forward Inner Ring Specimens, After Test.

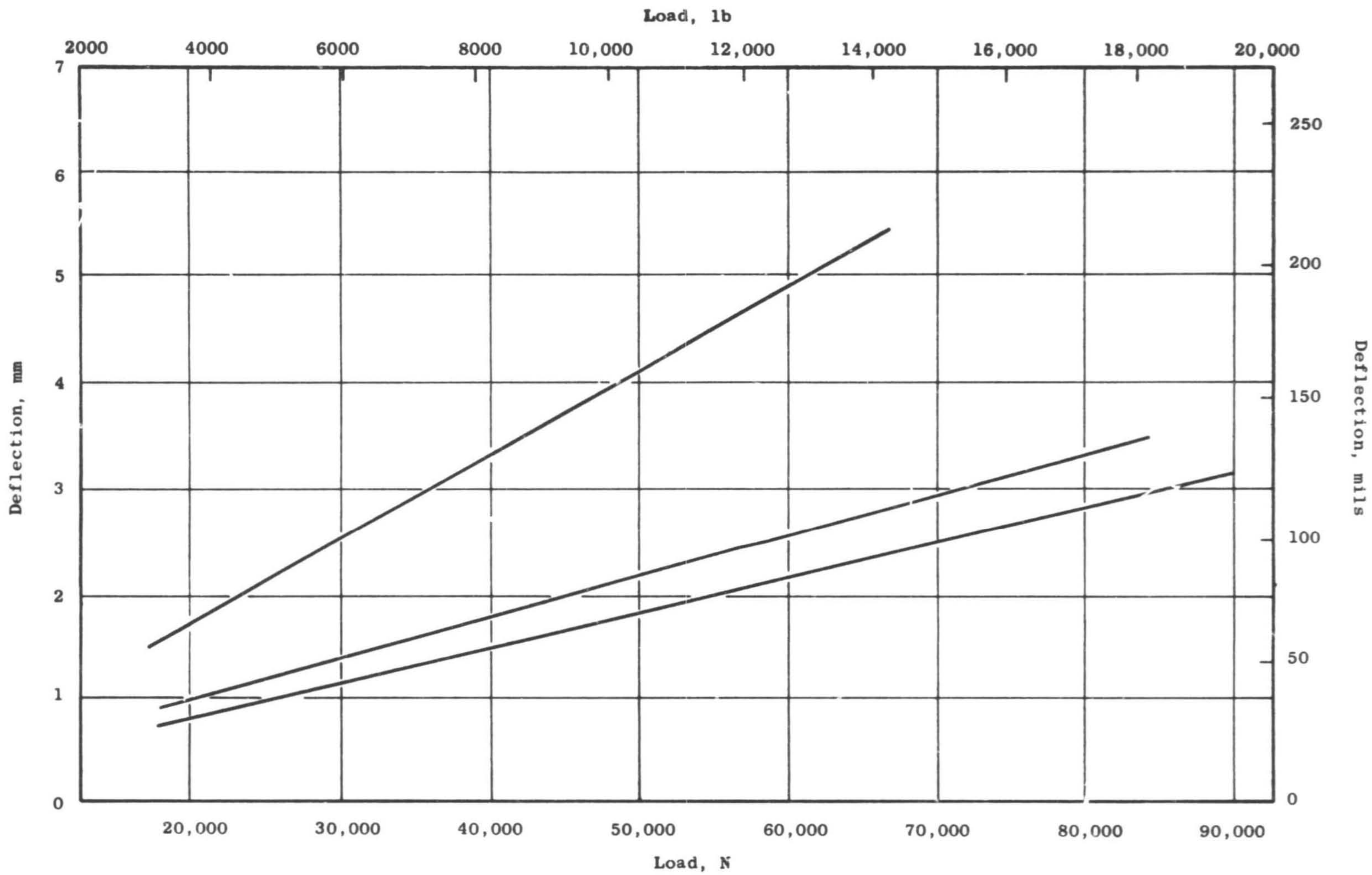


Figure 8. Forward Inner Ring Load Versus Deflection.

Table VII. Aft Inner Ring Test Results.

Specimen	Mode	Temp.	Bending Moment at Failure		Required Bending Moment	
			N·cm	in-lb	N·cm	in-lb
1	ID in Tension	RT	292600	25900	32800	2900
2	ID in Compression	RT	577400	51100	66700	5900
3 (1)	ID in Tension	RT	302800	26800	32800	2900
4 (1)	ID in Compression	RT	419200	37100	66700	5900
5	ID in Tension	406 K	297200	26300	32800	2900
6	ID in Compression	406 K	461000	40800	66700	5900
7	ID in Tension	406 K	326500	28900	32800	2900
8	ID in Compression	406 K	577400	51100	66700	5900

(1) Failed through load pad

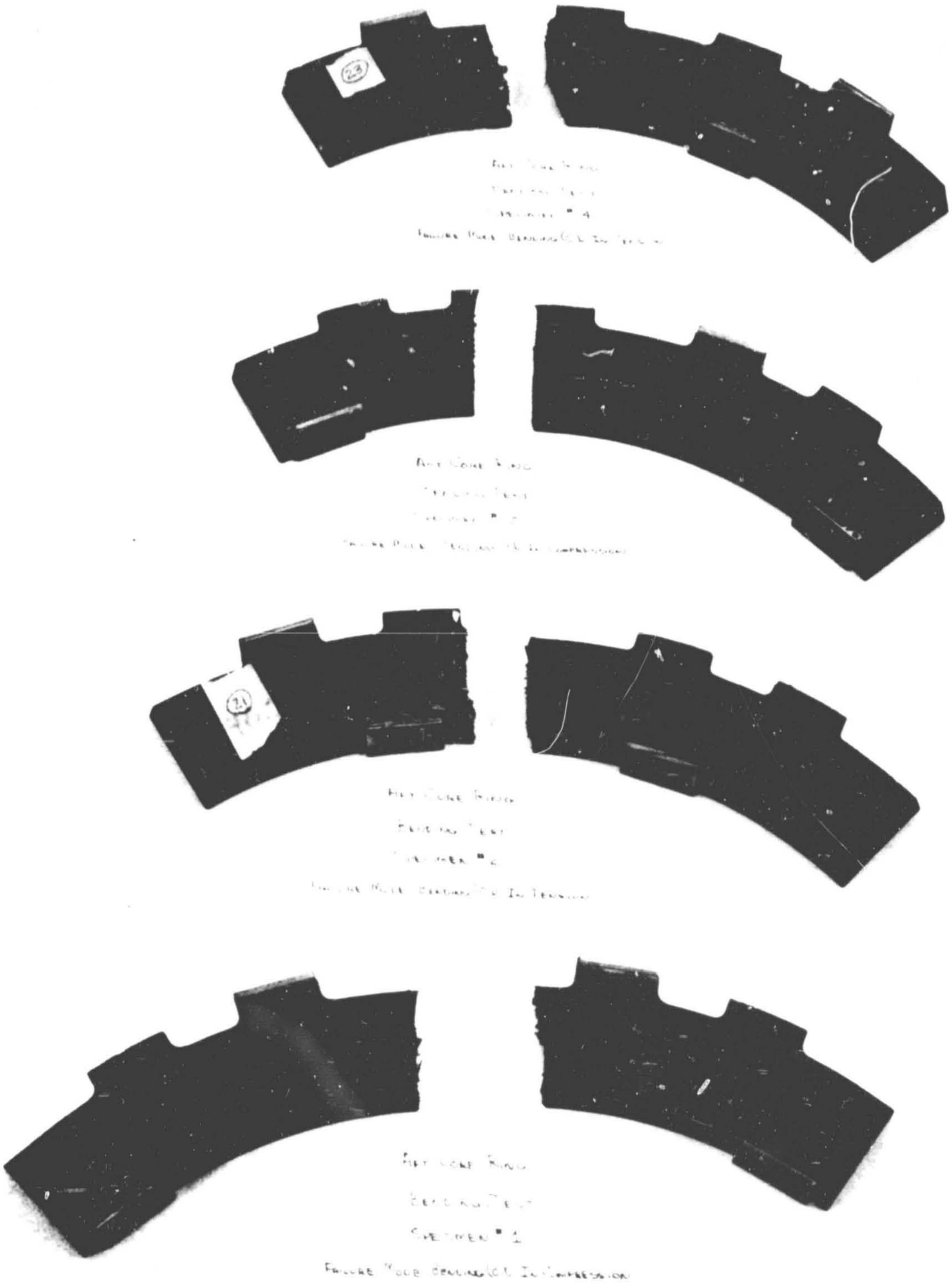


Figure 9. Aft Inner Ring Test Specimens, Room Temperature Tests.

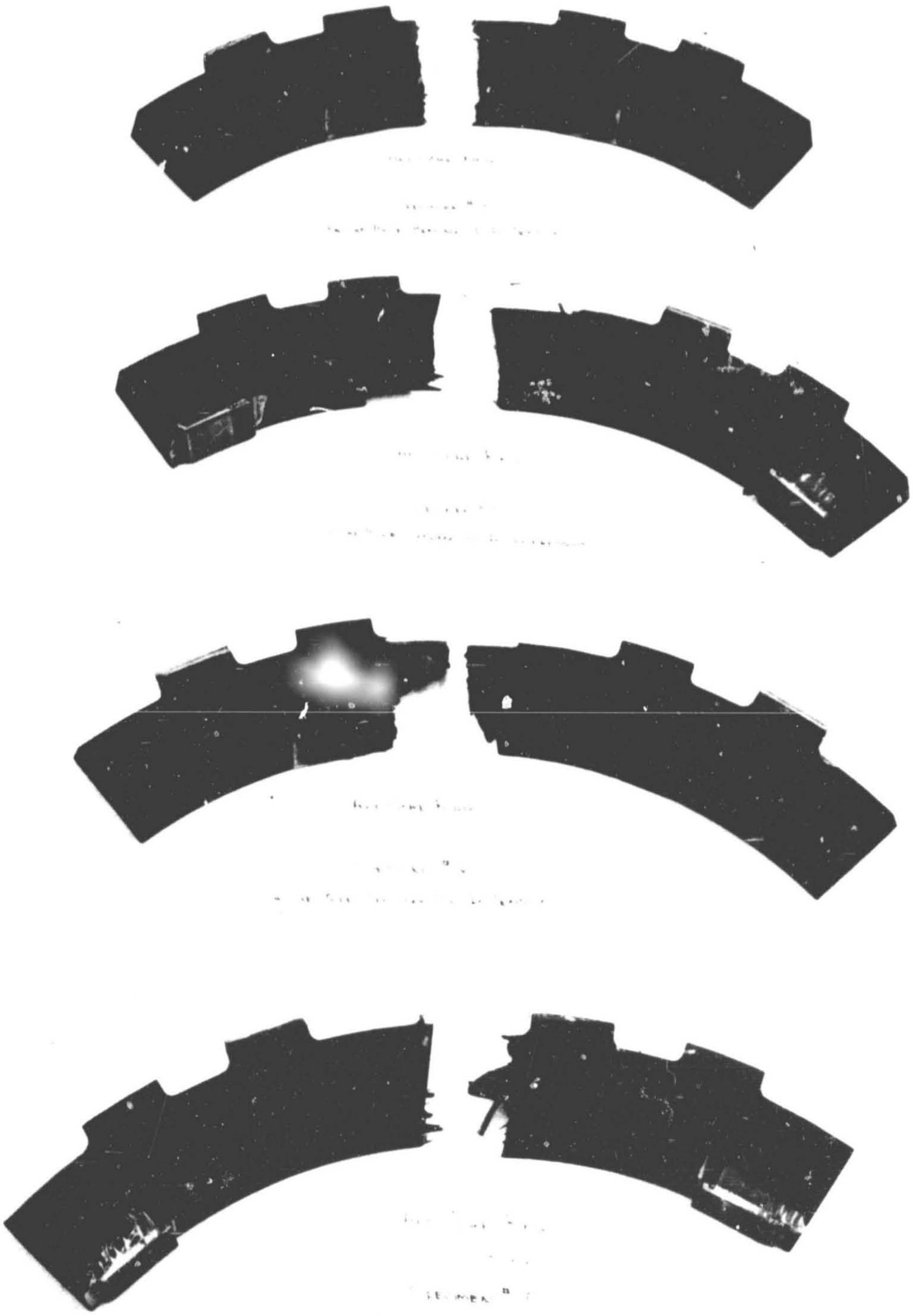


Figure 10. Aft Inner Ring Test Specimen, 406 K Tests.

The test specimens are shown in Figure 7. A plot of load versus deflection for specimens 2 through 4 is shown in Figure 8.

Failure loads were calculated based on the measured dimensions of the test specimens and the layup at the failure location. Depending upon the location in which the laminations in each layer were butted together, the layup in the test section could have been any one of three different layups:

Layup Designation	% 0°	% 45°	% 90°*	F_{tu} at 90°	
				N/cm^2	psi
Basic	50%	20%	30%	44800	65000
A	60%	20%	20%	35900	52000
B	70%	10%	20%	33100	48000

* 90° designates circumferential

By using the F_{tu} listed above and I_{max} and $C_{I max}$ values for the ring cross section, a value for P_{max} ranging from 54700 N (12,300 lb) to 73800 N (16,600 lb) is obtained. A comparison of these values to the test values indicates two possibilites: (1) The specimens tested with the inner diameter in compression failed in the basic layup configuration and those with inner diameter in tension failed in a section corresponding to layup A or B, or (2) due to the fact that each gore segment is cut from a sheet of unidirectional graphite/epoxy and encompasses an angle of 20°, 30°, or 40°, the fiber angle at the end of the gore segment is 10°, 15°, or 20° off of the fiber angle at the center of the gore segment, thus causing a significant variation in the compressive and tensile properties.

Possibility number (2) was not explored in the analysis of the forward core ring tests; however, this possibility was extensively investigated (with some success) in the analysis of the aft core ring tests which follow. Based on the analysis of the aft core ring tests, it appears that the second explanation is the correct one.

2. Aft Inner Ring (see Figure 6) - The aft inner ring was tested in four-point bending at both room temperature and 406 K (270° F) prior to testing. The test results for the eight specimens tested {four at room temperature and four at 406 K (270° F)} along with the required moments are summarized in Table VII.

Pictures of the test specimens, after test, are shown in Figures 9 and 10. The lack of uniformity in the test results of the specimens which were tested with the OD in tension {two failed at approximately 151,200 N (34,000 lb) and two failed at 201,950 N (45,400 lb)} led to a thorough investigation of the specimen manufacture, geometry, and mode of failure.

The eight specimens which were tested were cut from actual aft wheels. At 30° increments around the wheel there are butt lines where gore segments end. Also, there are sections ±5° from these 30° increments where different gore segments butt together. These sections are locations in which a failure would be likely to occur. The strength of the layup in these locations was determined using a material properties program and the basic material properties of a unidirectional single laminate. The layup angles w e modified according to the angular position of each ply relative to the centerline of the gore segment. Failure loads were calculated based upon where the failure occurred. A comparison of the test to calculated failure loads is shown below:

Specimen	Calculated Load		Test Load		% Difference
	N	lb	N	lb	
1	105,300	23,680	102,300	23,000	-2.9%
2	168,100	37,800	201,900	45,400	20.1%
3(1)	125,600	28,245	105,900	23,800	-15.7%
4(1)	134,600	30,266	146,800	33,000	9.0%
5	112,700	25,327	104,100	23,400	7.6%
6	141,100	31,728	161,500	36,300	14.4%
7	117,700	26,457	114,300	25,700	-2.9%
8	165,400	37,186	201,900	45,400	22.1%

(1) Failed through load pad - results questionable

The differences in calculated versus test load values are probably due to variations in material strength from what was used and that the butt lines of the gore segments do not occur exactly at the same location so that strengths are approaching the basic layup for part of the material through the failed section.

In summary, both the forward core ring and the aft core ring demonstrated adequate strength as seen by the data summarized in Table VI.

4.2.2 Strut-to-Ring Joints

Tensile tests were carried out on the forward, mid, and aft core vane struts and on the forward and aft bypass vane struts. In addition the forward core vane strut, which has the maximum moment load of any of the struts, was also tested in bending. For the tensile tests, two uniaxial strain gages were located on each side of the strut 0.635 cm (0.25 in.) below the ring/strut fillet tangency line to preclude any bending during the tensile tests. A universal testing fixture capable of testing all configurations was used for the tensile tests. A specimen installed in one-half the fixtures is shown in Figure 11 while the complete test assembly installed in the test machine can be seen in Figure 12. The test specimens are shown in Figure 13.

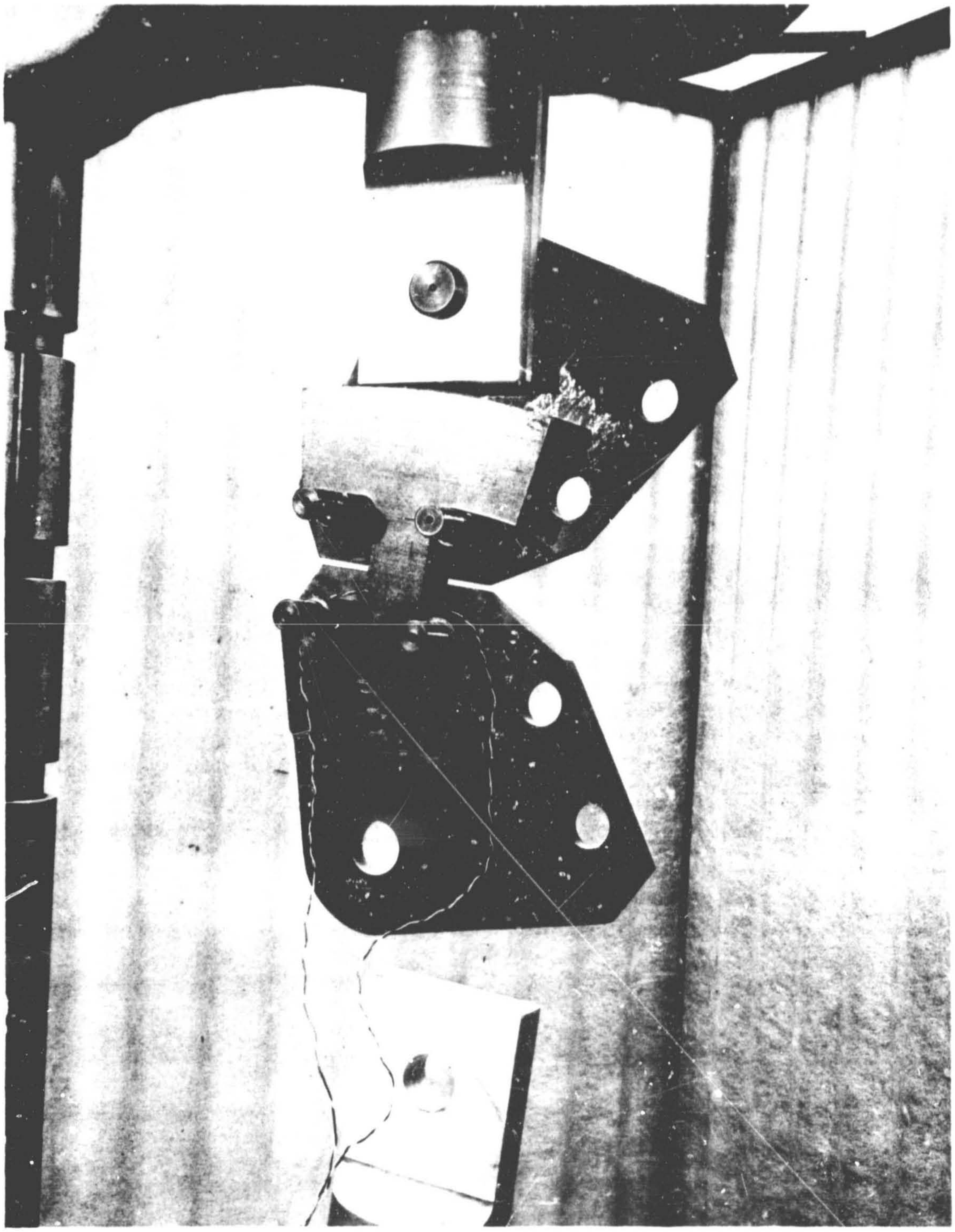


Figure 11. Strut-to-Ring Test Specimen in Fixture.

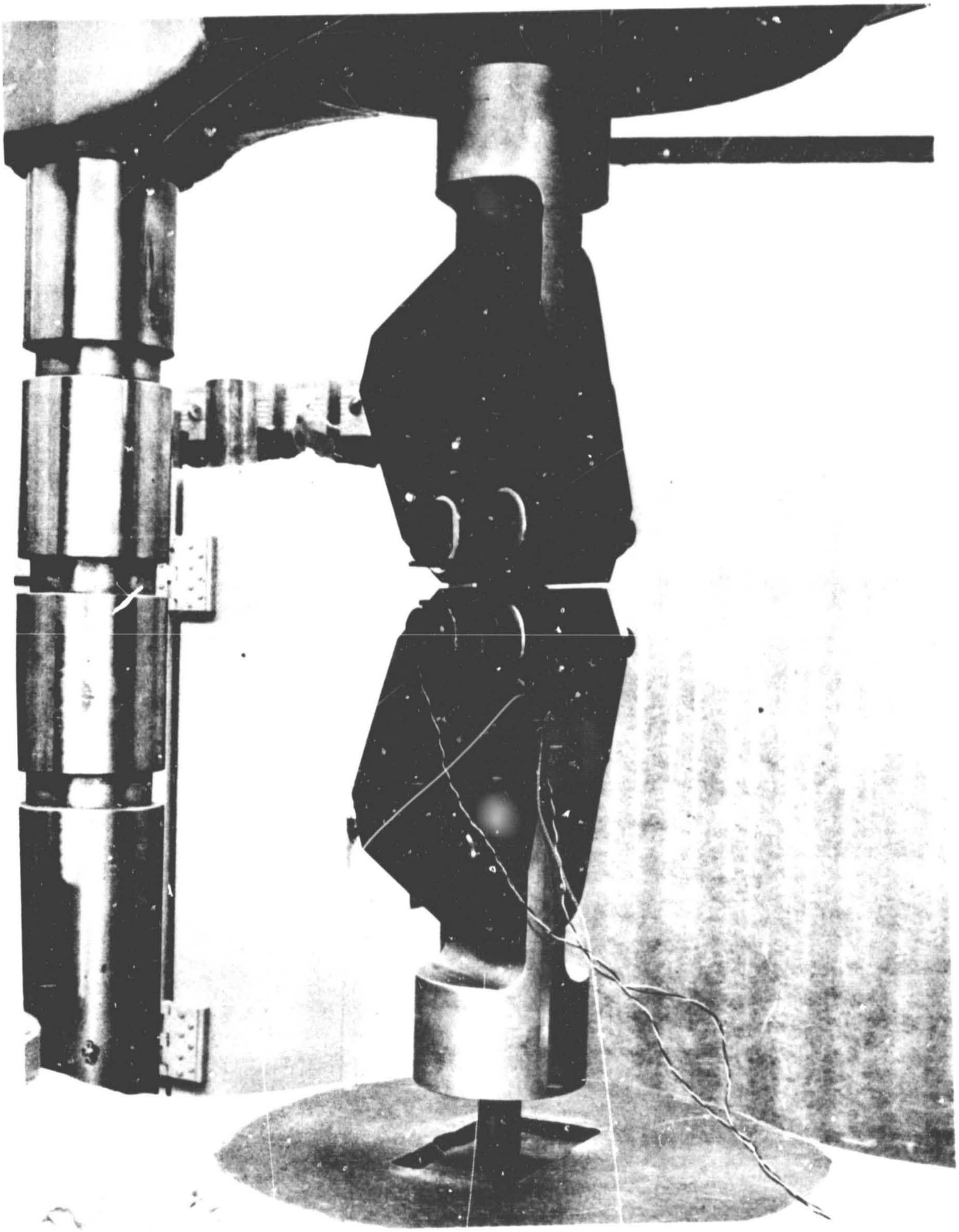


Figure 12. Strut-to-Ring Test Specimen Under Test.

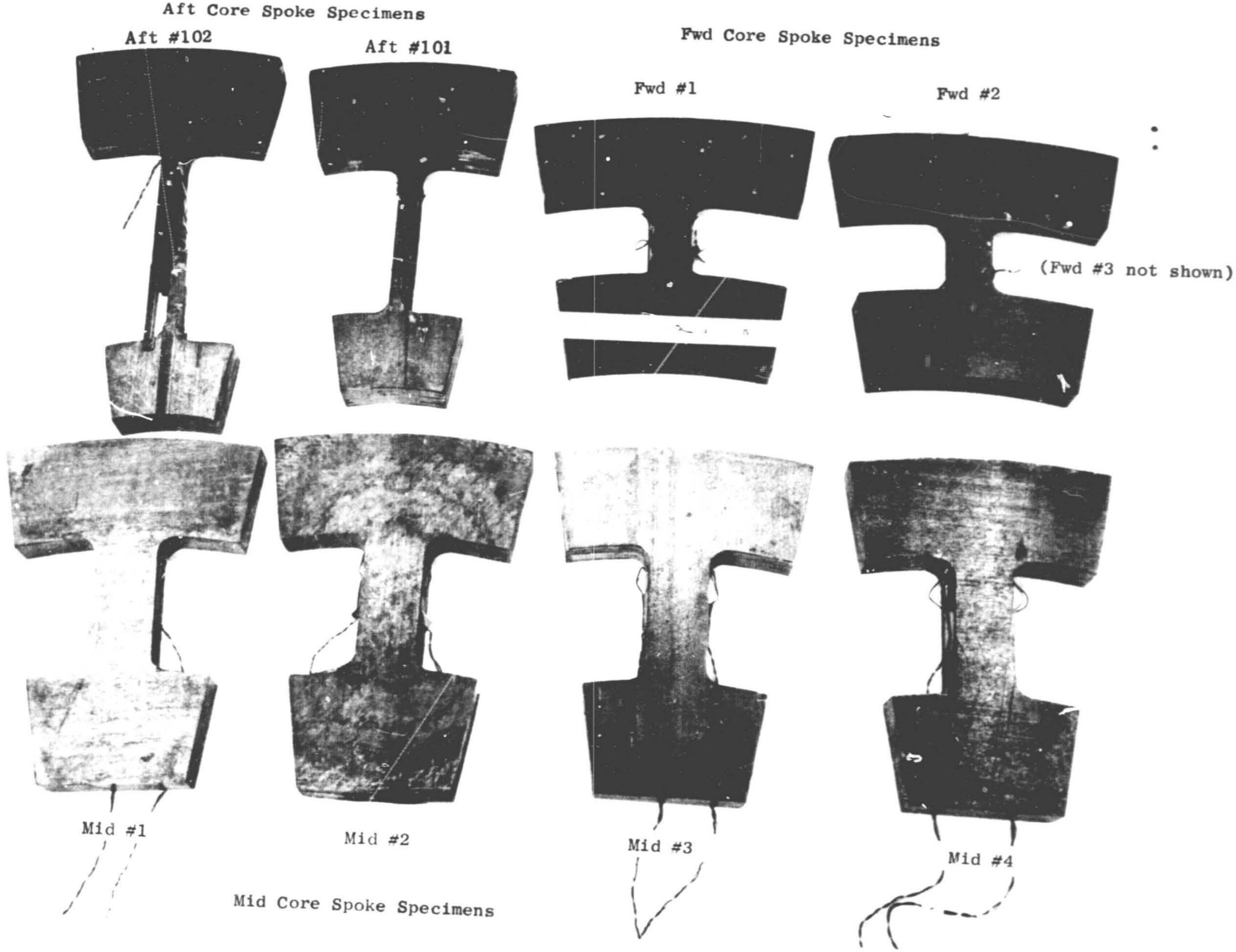


Figure 13. Core Strut Test Specimens.

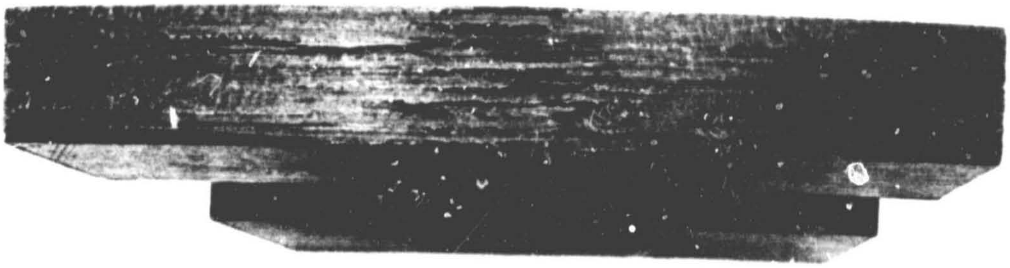
1. Core Forward Strut/Ring Joint - Two core spoke specimens representative of the ring/strut joint in the forward wheel of the QCSEE frame were tested and failed at an average load of 221,700 N (49850 lb) which was considerably higher than the required load of 177,900 N (40,000 lb) but less than the tensile capability of the spoke. The mode of failure was a shearing out of the radial spoke plies from the circumferential ring plies (see Figure 14). In order to improve the load capability of the joint, the ply sequence (not orientation) was changed to reduce the number of adjacent plies oriented in the same direction. For example, the portion of the layup that was $(90°_3, 45°, 0°_3, -45°, 0°_2)_s$ became $(90°, 0°, 45°, 0°, 90°, 0°, -45°, 0°, 90°, 0°)_s$. Test specimen Fwd No. 3 (Table VIII) was constructed and tested using this revised ply sequence. This specimen produced a tensile failure in the spoke as desired. A typical plot of load versus strain for a forward spoke test specimen is shown in Figure 15.

2. Core Mid Strut/Ring Joint - Three of the four mid spoke room temperature specimens failed in shear-out as predicted. However, mid spoke specimen No. 3 failed only partially in shear-out. Approximately half of the cross section failed by shear-out with the other half failing by tensile fracture as is shown in Figures 16 and 17. A comparison of predicted to actual failure loads is shown in Table VIII. The required load capability from "MASS" analysis is 214,000 N (48,100 lb).

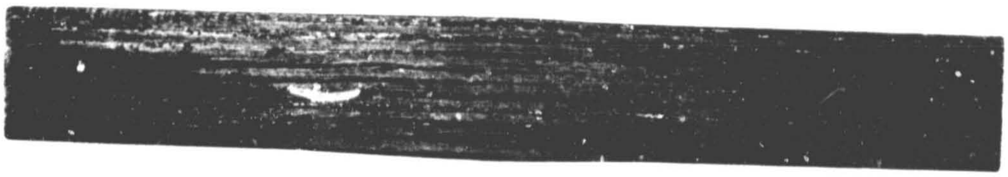
3. Core Aft Strut/Ring Joint - Two aft spoke specimens were tested in tension at room temperature. The predicted and actual ultimate loads are shown in Table VIII. The specimens failed in tension at the fillet stress concentration as shown in Figures 13 and 17.

   Since the aft core spokes see the highest temperature of any of the core vane spokes, two aft spoke specimens were also tested at 406 K (270° F). The same setup that was used in the room temperature testing was used, with the addition of an oven to heat the specimen to 406 K (270° F) and hold that temperature during testing. Strain gages were applied approximately at the same locations as the room temperature specimens. Tensile failures occured at 125,000 N (28,100 lb) and 121,900 N (27,400 lb) on the two specimens. As a comparison, the room temperature specimens failed at an average load of 105,200 N (23,650 lb). The predicted failure load was 114,300 N (25,700 lb) and the required load capability of the aft spoke from "MASS" analysis was 20,000 N (4,500 lb).

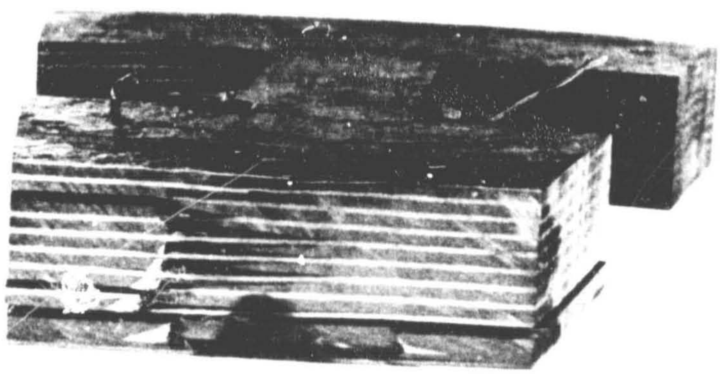
4. Forward Core Strut/Ring Bending Testing - Two forward core strut/ring specimens were tested in bending to determine the ultimate bending load capability of this structure in the QCSEE frame. The test setup is shown in Figure 18. The predicted failure load was 10,500 N (2,370 lb). The actual failure loads were 10,210 N (2,300 lb) and 11,500 N (2,590 lb). The corresponding moments are 155,580 N·cm (13,770 in-lb) and 175,650 N·cm (15,550 in-lb). The maximum required moment for design is 128,800 N·cm (11,400 in-lb). A photograph of a failed specimen is shown in Figure 19.



Fwd #2



Fwd #1



Mid #2

Figure 14. End View of Shear-Out Failures.

Table VIII. Core Strut-to-Ring Segment Subcomponent Load Test Summary (Room Temperature).

Specimen	Predicted Load		Actual Load	
	N	lb	N	lb
Fwd No. 1	189,900	42,700	227,700	51,200
Fwd No. 2	189,900	42,700	215,700	48,500
Fwd No. 3[(1)]	273,600	61,500	245,500	55,200
Mid No. 1	233,500	52,500	261,600	58,800
Mid No. 2	233,500	52,500	250,000	56,200
Mid No. 3[(1)]	269,600	60,600	311,400	70,000
Mid No. 4[(1)]	269,600	60,600	284,700	64,000
Aft No. 101	114,300	25,700	99,600	22,400
Aft No. 102	114,300	25,700	110,800	24,900

(1) Revised ply sequencing to improve shear-out strength

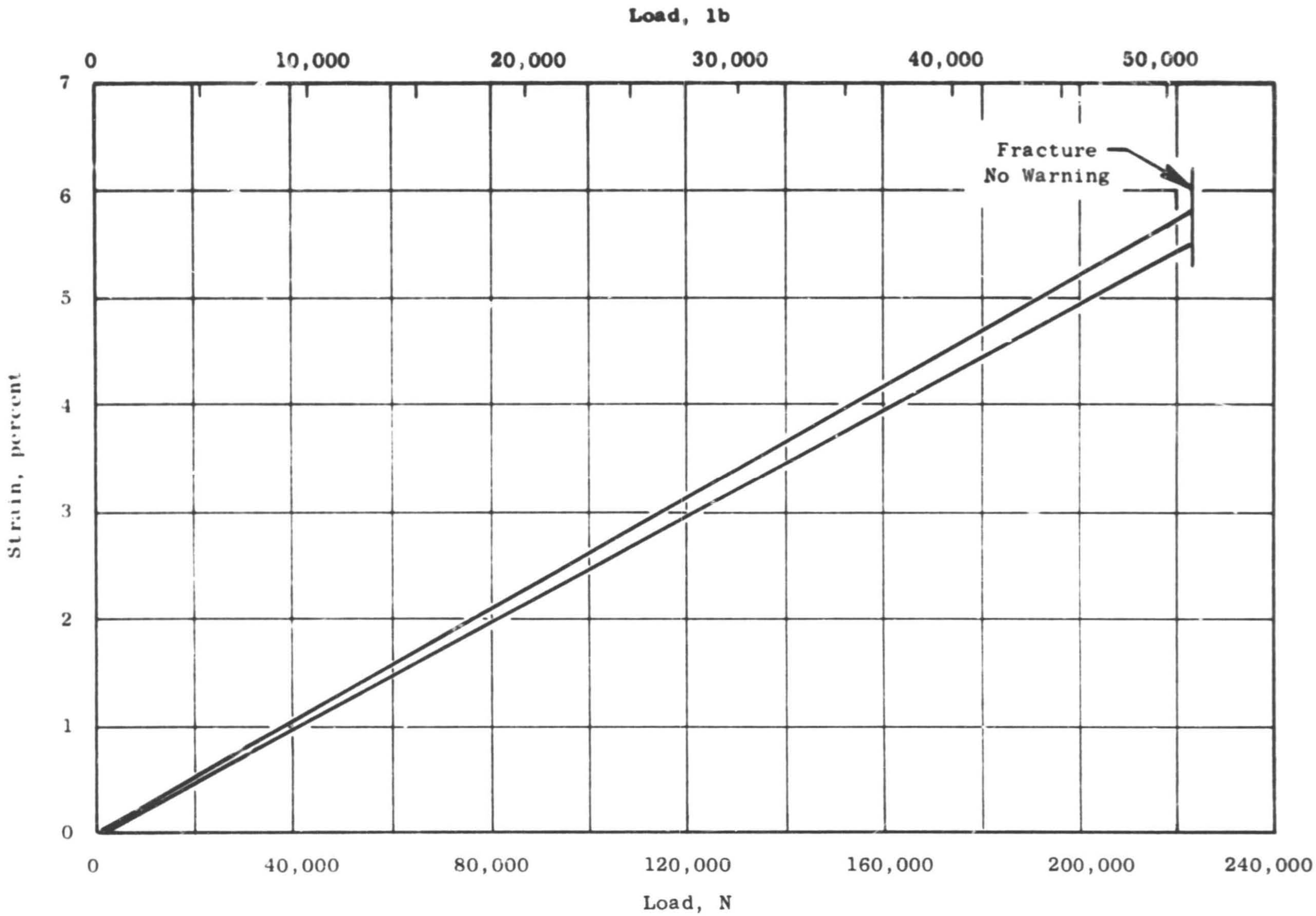


Figure 15. Typical Load-Strain Diagram of Core Forward Spoke Specimen.

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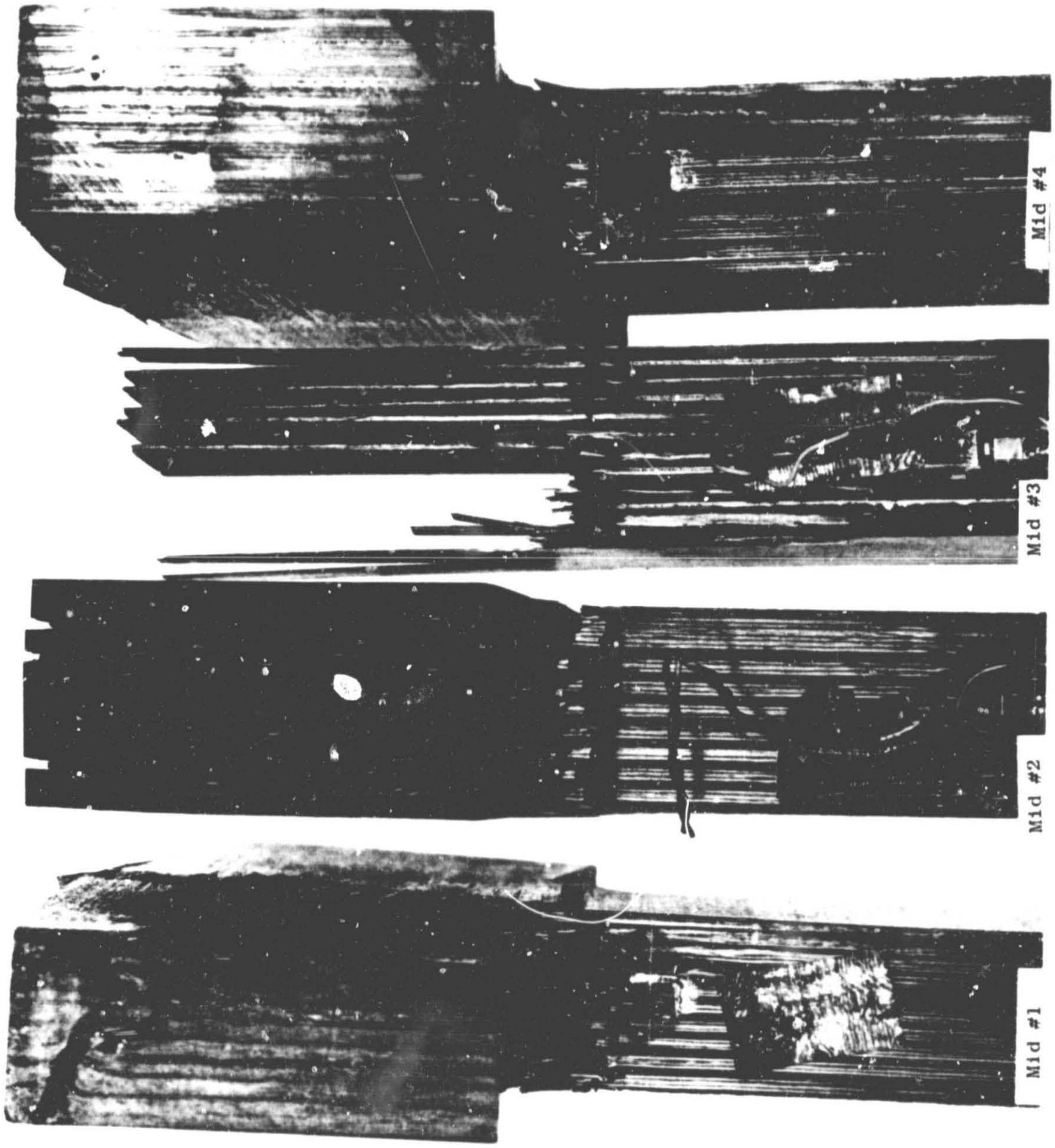

Figure 16. Mid Core Spoke Failed Specimens.

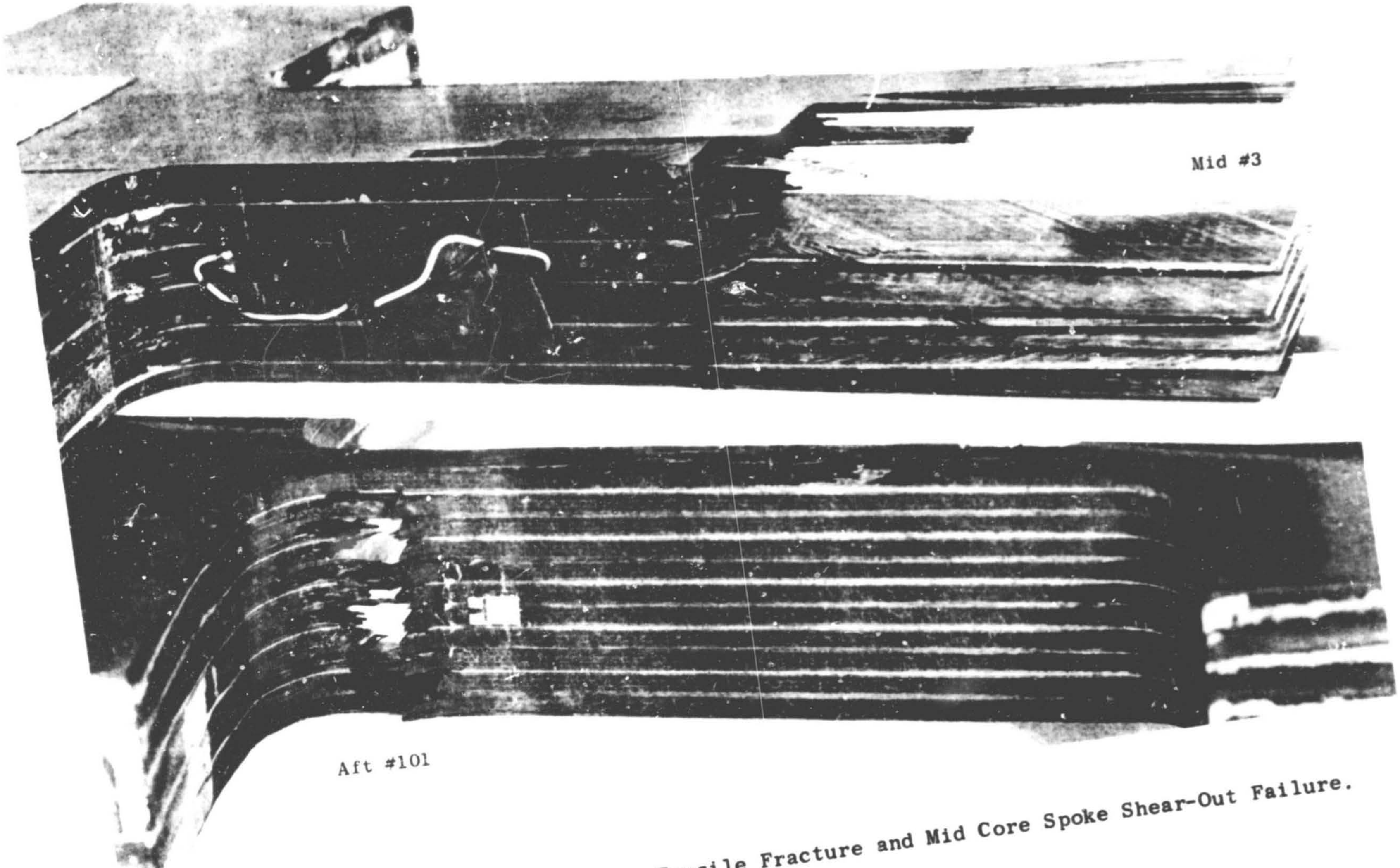

Figure 17. Closeup of Aft Core Spoke Tensile Fracture and Mid Core Spoke Shear-Out Failure.

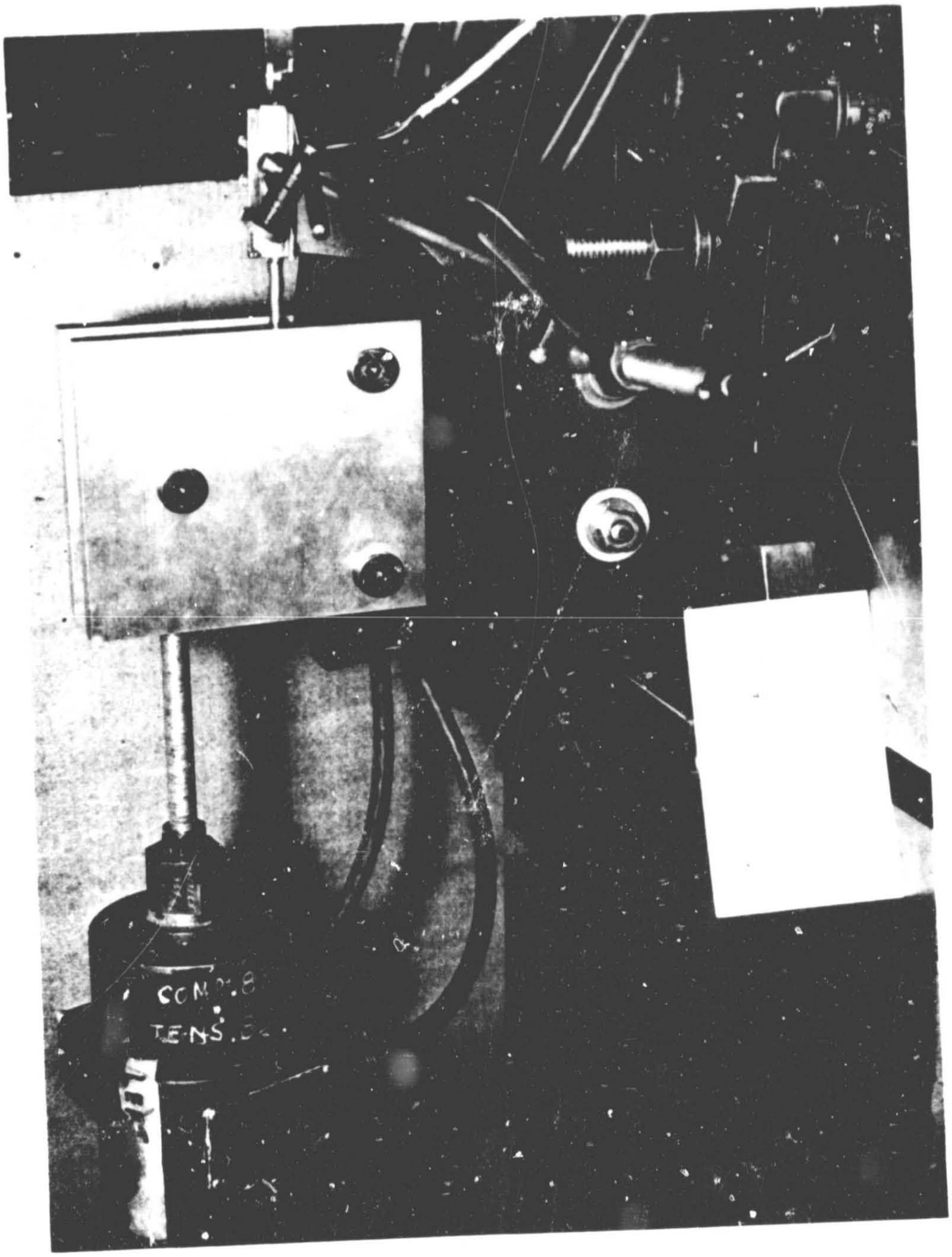

Figure 18. Forward Core Strut/Ring Bending Test Setup.

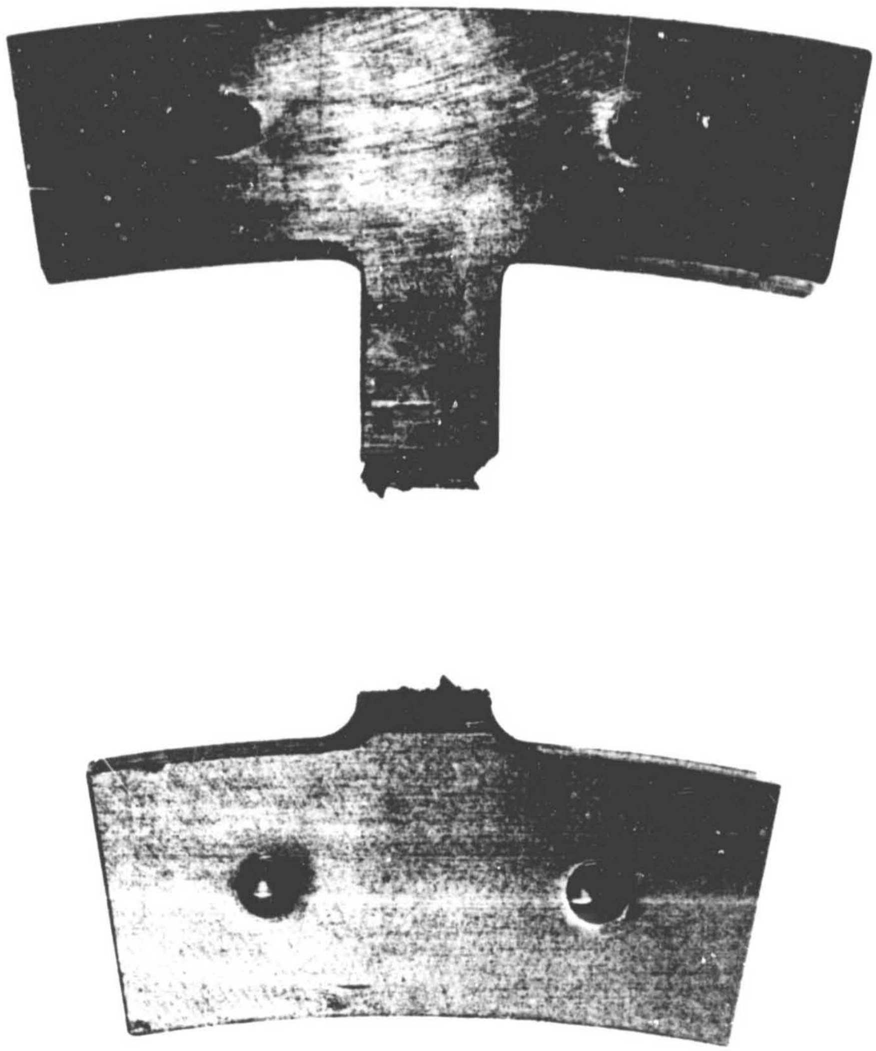

Figure 19. Failed Specimen, Core Vane Forward Spoke Bending Test.

5. Bypass Vane/Strut Tests - Tensile tests were run on specimens which represented the minimum area sections of the forward and aft bypass vane spokes. The two bypass vane spoke specimens failed at loads of 73,400 N (16,500 lb) and 68,900 N (15,500 lb) {predicted failure load 64,300 N (14,464 lb)}. The two specimens are shown after test in Figure 20. The maximum tensile load anticipated from "MASS" analysis is 42,700 N (9,600 lb). The two forward spoke specimens failed in shear-out between the radial spoke plies and the circumferential ring plies. The failure loads were 106,800 N (24,000 lb) and 104,900 N (23,580 lb) while the calculated shear-out load was 113,200 N (25,440 lb). The two specimens, after test, are shown in Figure 21. The required tensile capability from "MASS" analysis is 34,700 N (7,800 lb).

4.2.3 Engine Mount Attachments

1. Uniball Attachment - Tests were run at both room temperature and 406 K (270° F) to determine the radial load capability of the engine mount (uniball attachment) installation in the aft splitter ring portion of the aft wheel in the QCSEE frame. The room temperature specimen failed at a load of 253,000 N (56,880 lb). The failure consisted of an initial tensile failure in the inserts in the OD of the ring segment (inserts correspond to the ends of aft spoke segments) followed by a shear failure through the minimum section (see Figure 22). The second specimen was tested at 406 K (270° F) and failed in a similar mode at 207,900 N (46,736 lb). Failure loads of 245,000 N (55,080 lb) and 204,200 N (45,900 lb) were predicted.

2. Thrust Link Attachment - The engine mount (thrust mount) test specimen shown in Figure 23 represents a 90° segment of the frame extending clockwise from the top vertical centerline and including the part of the frame structure radially out from the core outer flowpath to the bypass inner flowpath and axially from the mid core wheel to the aft core wheel. As can be seen in Figure 23, the load was applied using a 100K load cell set up at the same angle as the thrust link on the QCSEE engine. The ends of the specimen were blocked off to provide constraint in the plane of the specimen. No axial constraints were applied to the test specimen.

Deflection indicators No. 1 (axial) and No. 2 (radial) were located on the ID of the aft wheel near the thrust mount. Deflection indicator No. 3 (axial) and No. 4 (radial) were located on the OD of the aft wheel near the thrust mount and indicator No. 5 was located on the thrust mount and measured axial deflections. The maximum axial and radial deflections are shown in Figure 24.

The test specimen was also instrumented with eight strain gage rosettes as shown in Figures 23 and 25. The critical strains occurred on the lower (radially inward) surface midway between the two wheels (gages 4 and 5), and are shown in Figure 26.

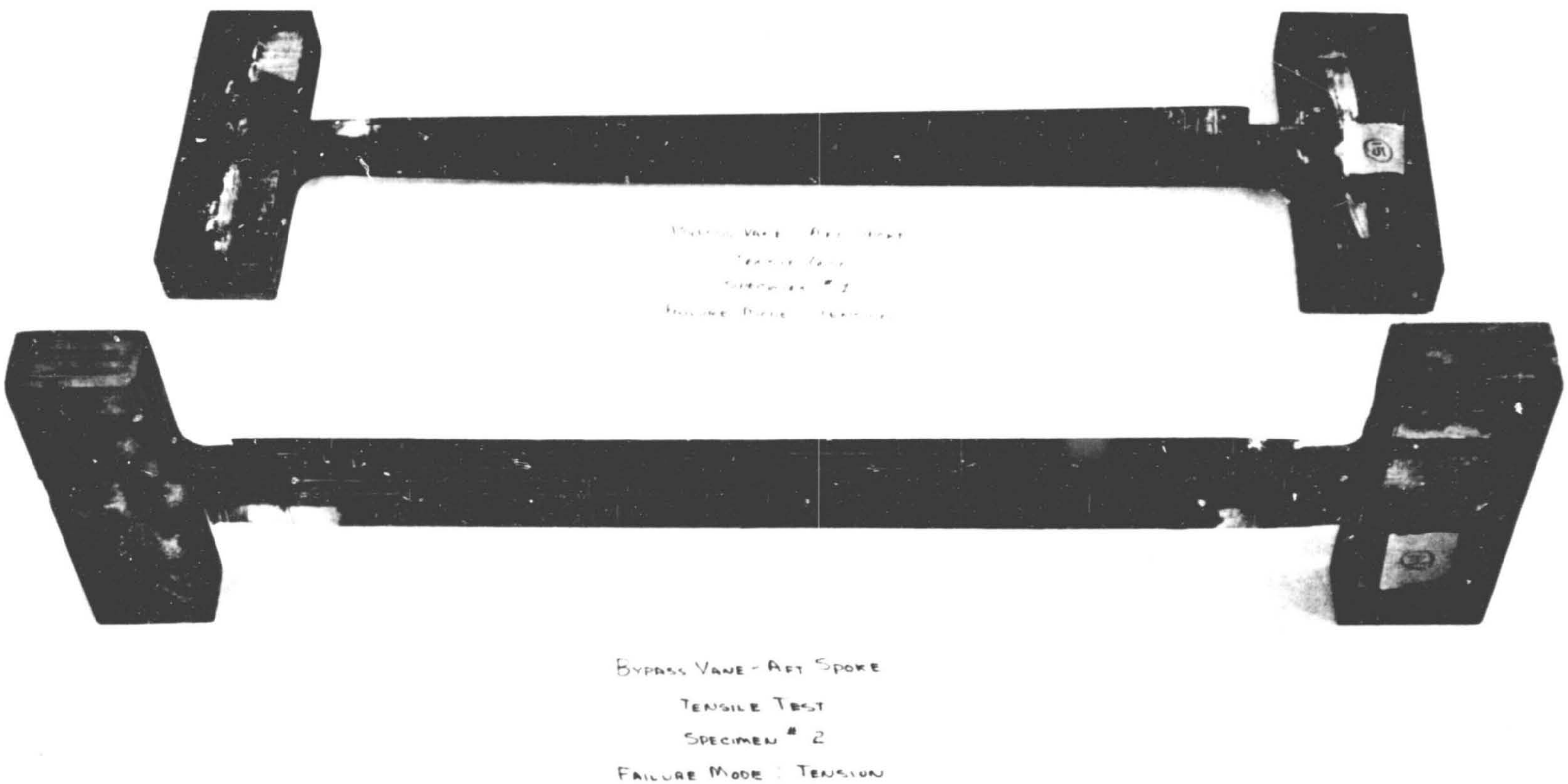

Figure 20. Aft Bypass Spoke Specimens, After Test.

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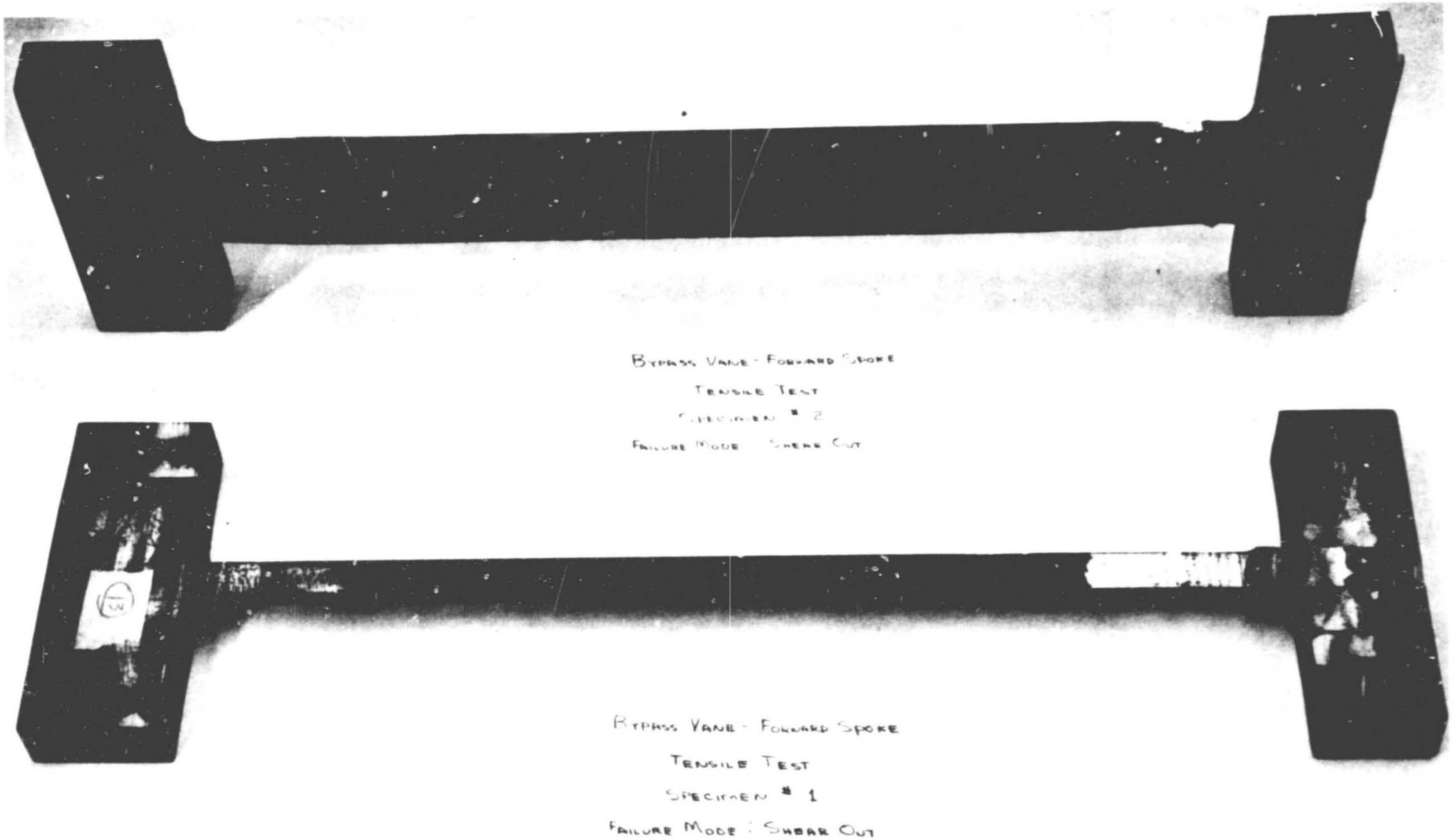

Figure 21. Forward Bypass Spoke Specimens, After Test.

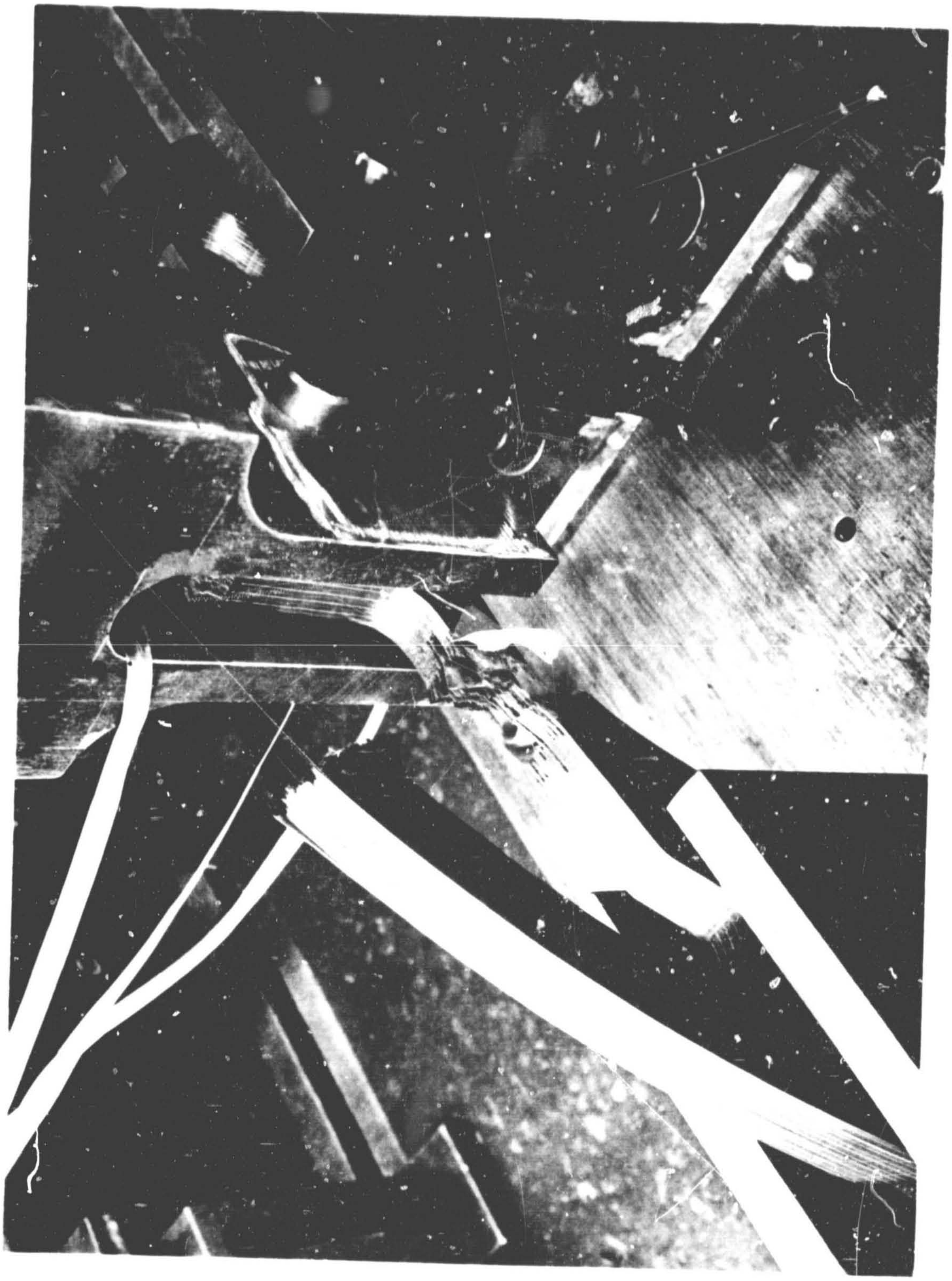

Figure 22. Uniball Attachment Specimen, After Test

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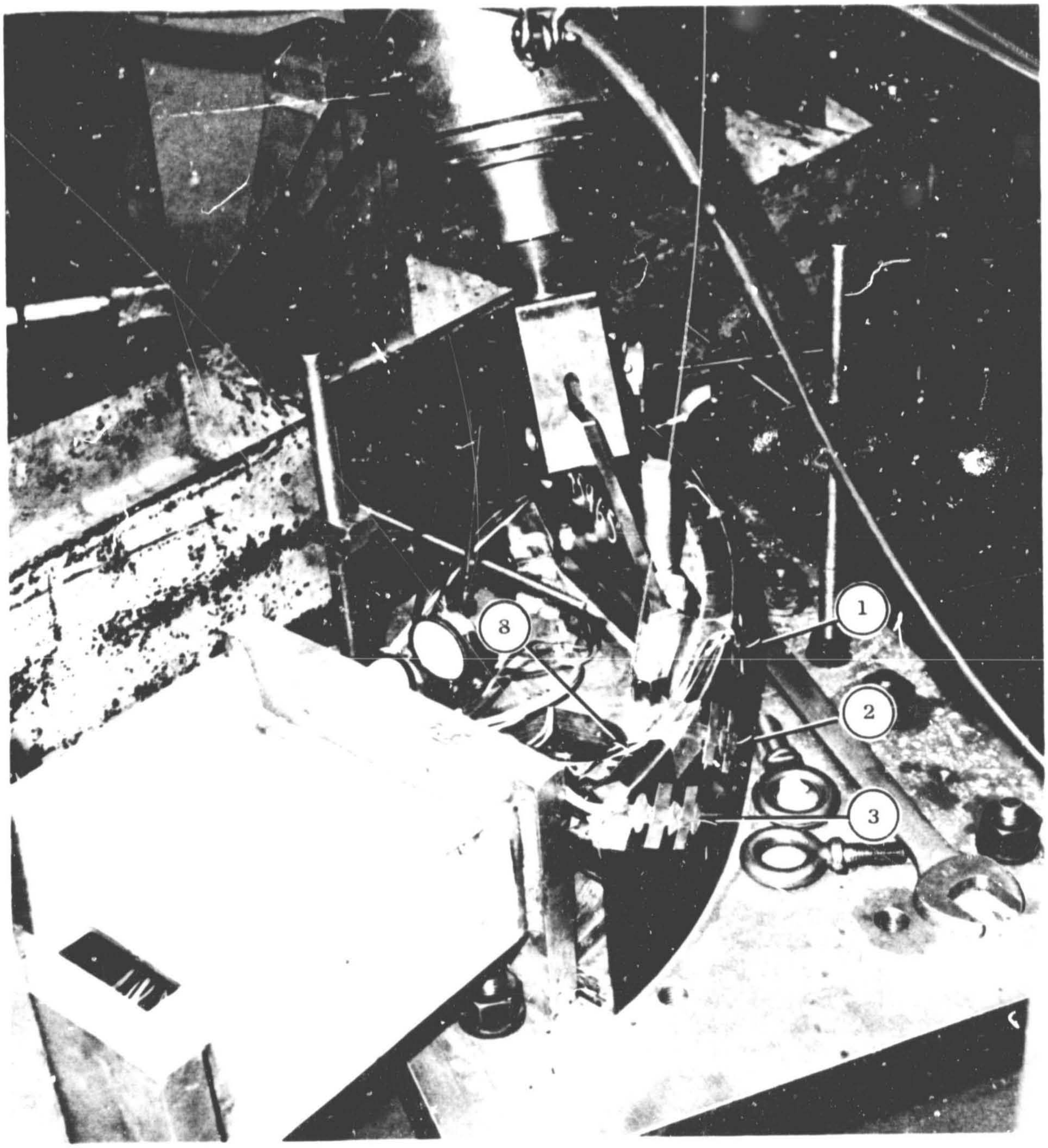


Figure 23. Thrust Mount Specimen Test Setup.

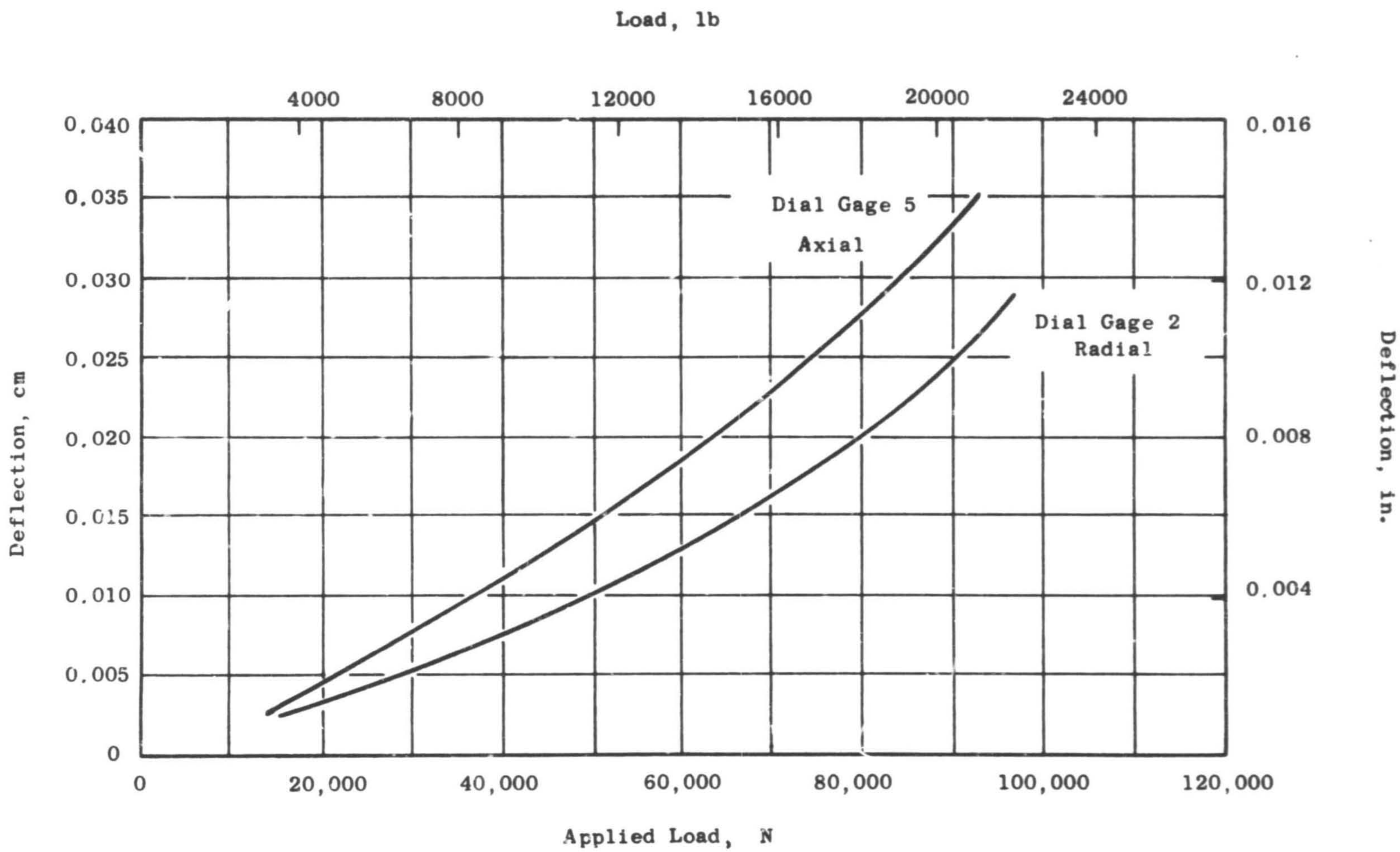


Figure 24. Maximum Deflections Versus Load, Thrust Mount Test.

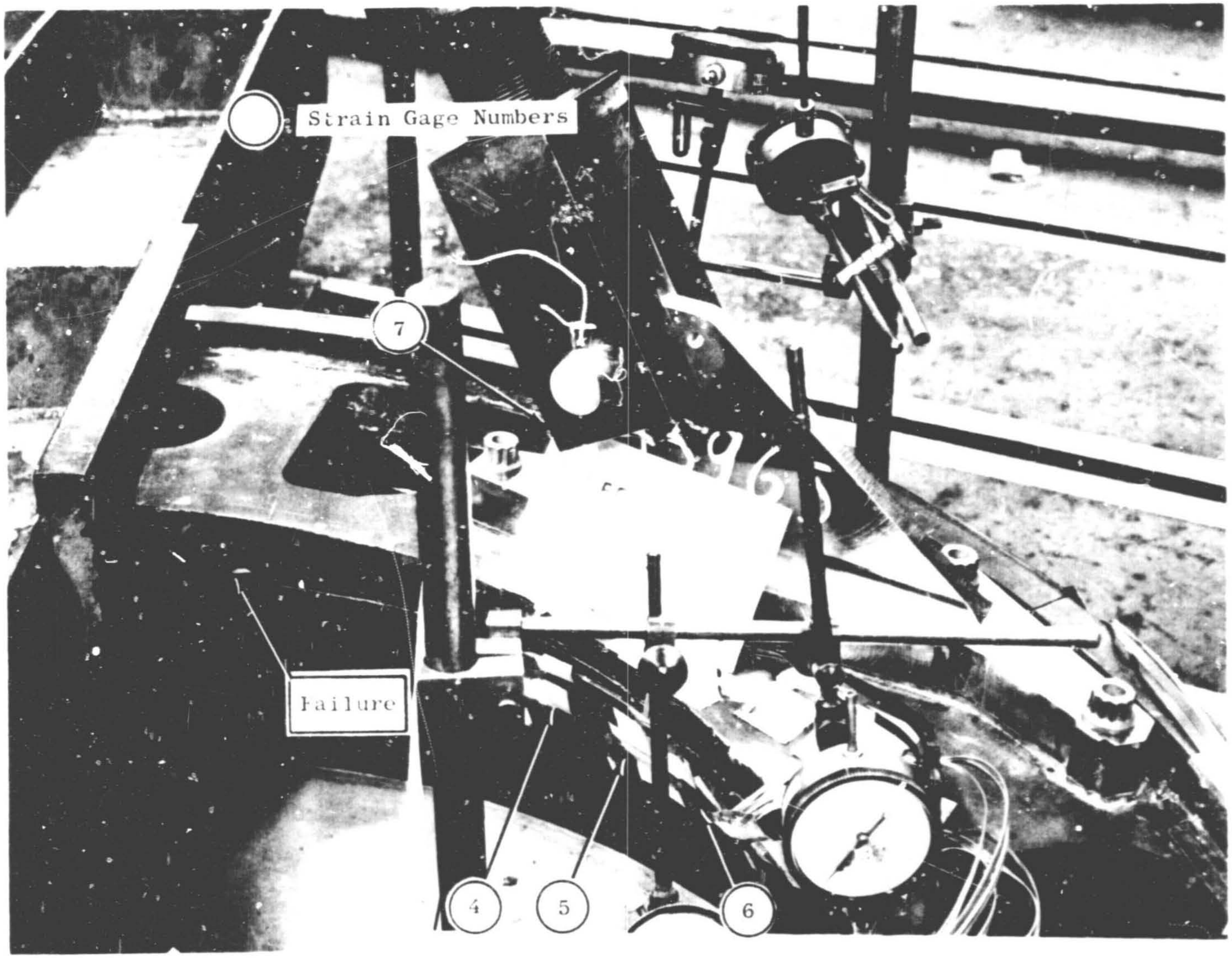


Figure 25. Thrust Mount Test Specimen, After Test.

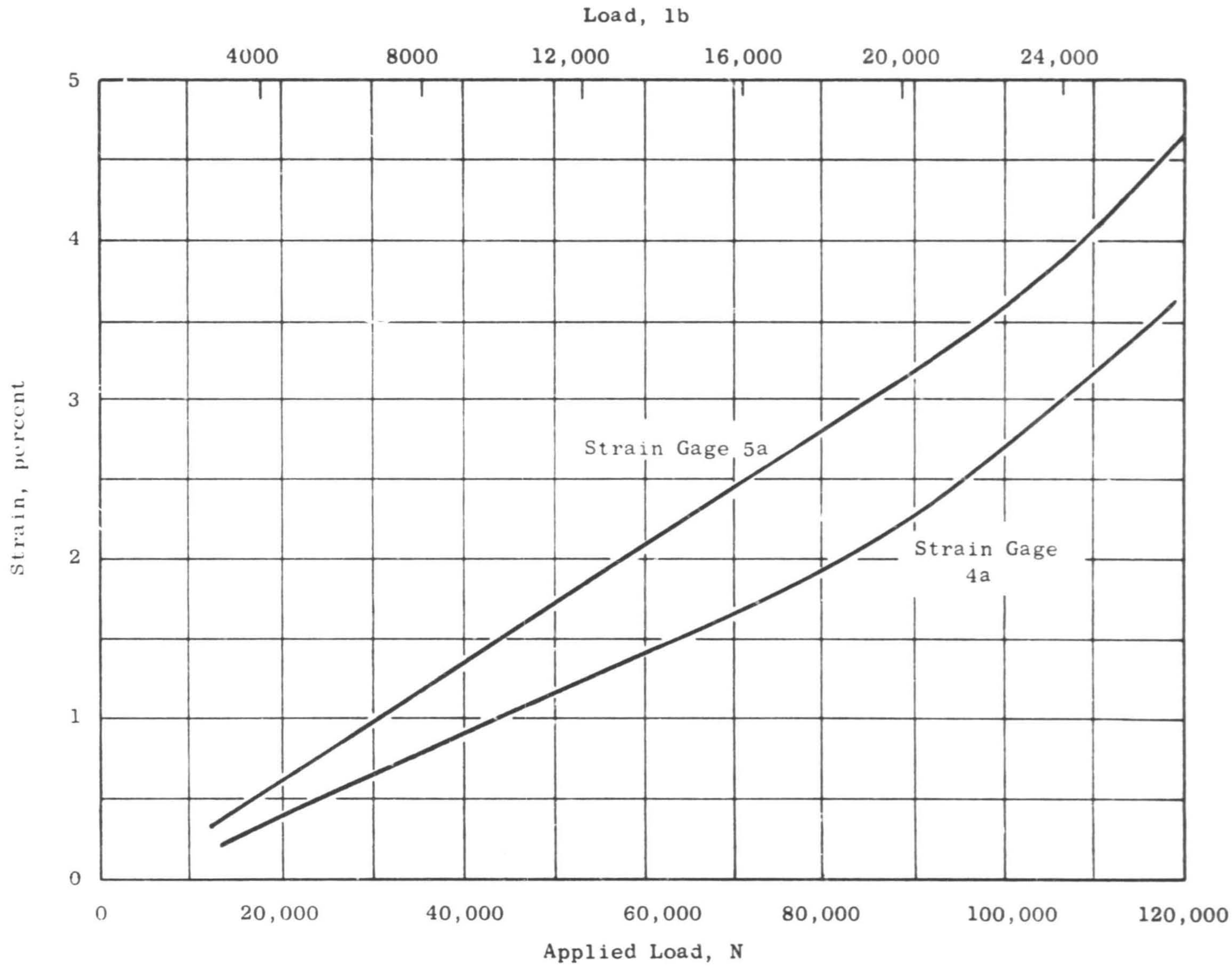


Figure 26. Critical Load Versus Strain Curves, Thrust Mount Test.

The test was run at room temperature with 13340 N (3000 lb) load increments. Strain and deflection data were recorded at each load increment. Failure occurred at a load of 120,100 N (27,000 lb) and involved interlaminar shear and flatwise tensile failure in the skins and doublers attaching the aft wheel to the mid wheel. The critical loading condition for this area is a 12g forward condition which produces a load of 111,200 N (25,000 lb). A photo of the specimen after test is shown in Figure 25.

4.2.4 Outer Casing

The purpose of these tests was to determine the strength in bending of panels which are representative of the outer casing of the QCSEE UTW Frame. The panel consisted of graphite/epoxy face sheets, a graphite/epoxy septum, and an aluminum flexcore core. One face sheet had laser drilled holes in it for acoustic purposes.

The first two panels were tested in bending (one with the acoustic surface in tension and one with the acoustic surface in compression). Both failed in core shear at 16300 N (3665 lb) and 13970 N (3140 lb), respectively. Honeycomb data had shown a decrease in core shear strength with increased thickness. For a 5.08 cm (2 in.) thickness, which was the thickness of honeycomb used in the panel, the core shear strength is only 62% of the rated value of 124 N/cm^2 (180 psi), or only 77 N/cm^2 (112 psi). Using this value, the calculated load for a shear failure is 15400 N (3463 lb).

The two remaining panels were then modified into a dogbone configuration to reduce the cross section in the test area. The panels were then tested in four-point bending with the failure occurring in the acoustic face sheet at 13390 N (3010 lb) (tension) and 15520 N (3490 lb) (compression). The corresponding stress at failure is 31270 N/cm^2 (45,350 psi) (tension) and 36240 N/cm^2 (55,555 psi) (compression). A picture of one of the failed specimens is shown in Figure 27. A plot showing load versus measured deflection is shown in Figure 28.

4.2.5 Inlet-to-Frame Attachment

The test specimen which simulates the latch attachment between the QCSEE composite inlet and QCSEE frame was tested in tension. The two halves of the specimen are shown in Figure 29 with the test setup shown in Figure 30. The test specimen had eight axial strain gages which were located as shown in Figure 31. Figure 31 also shows the strain distribution at gage locations for a 22,240 N (5000 lb) load. The latch was rated at 28800 N (6475 lb).

Test No. 1

The test specimen was initially loaded to 27130 N (6100 lb) at which time the bond between the spacer and the support plates failed as shown in

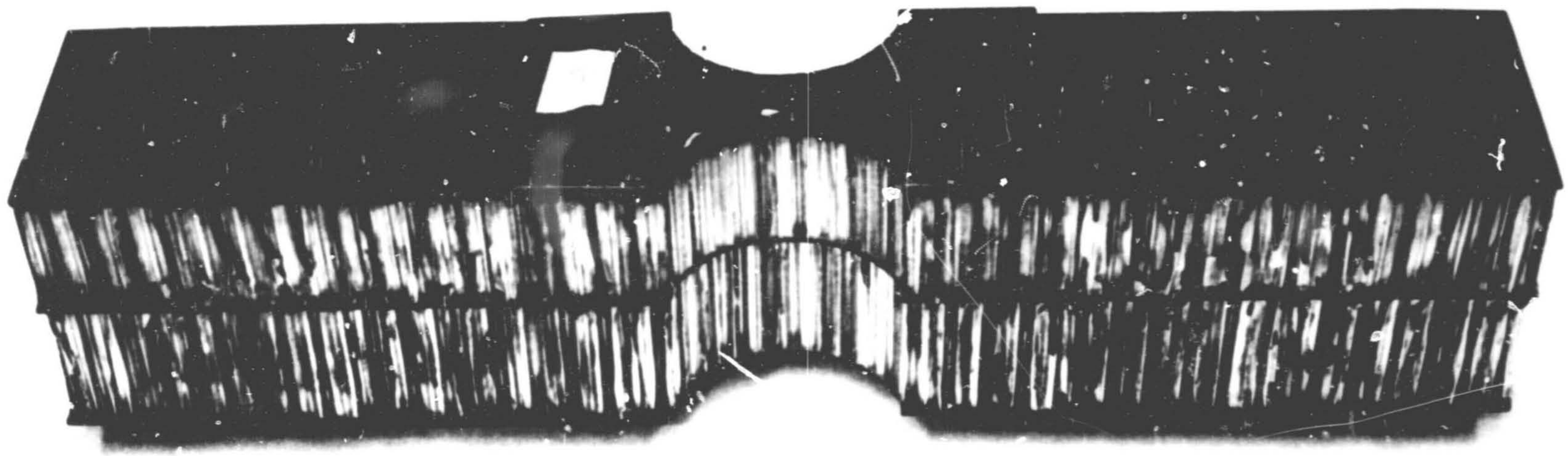


Figure 27. Outer Casing Test Panel, After Test.

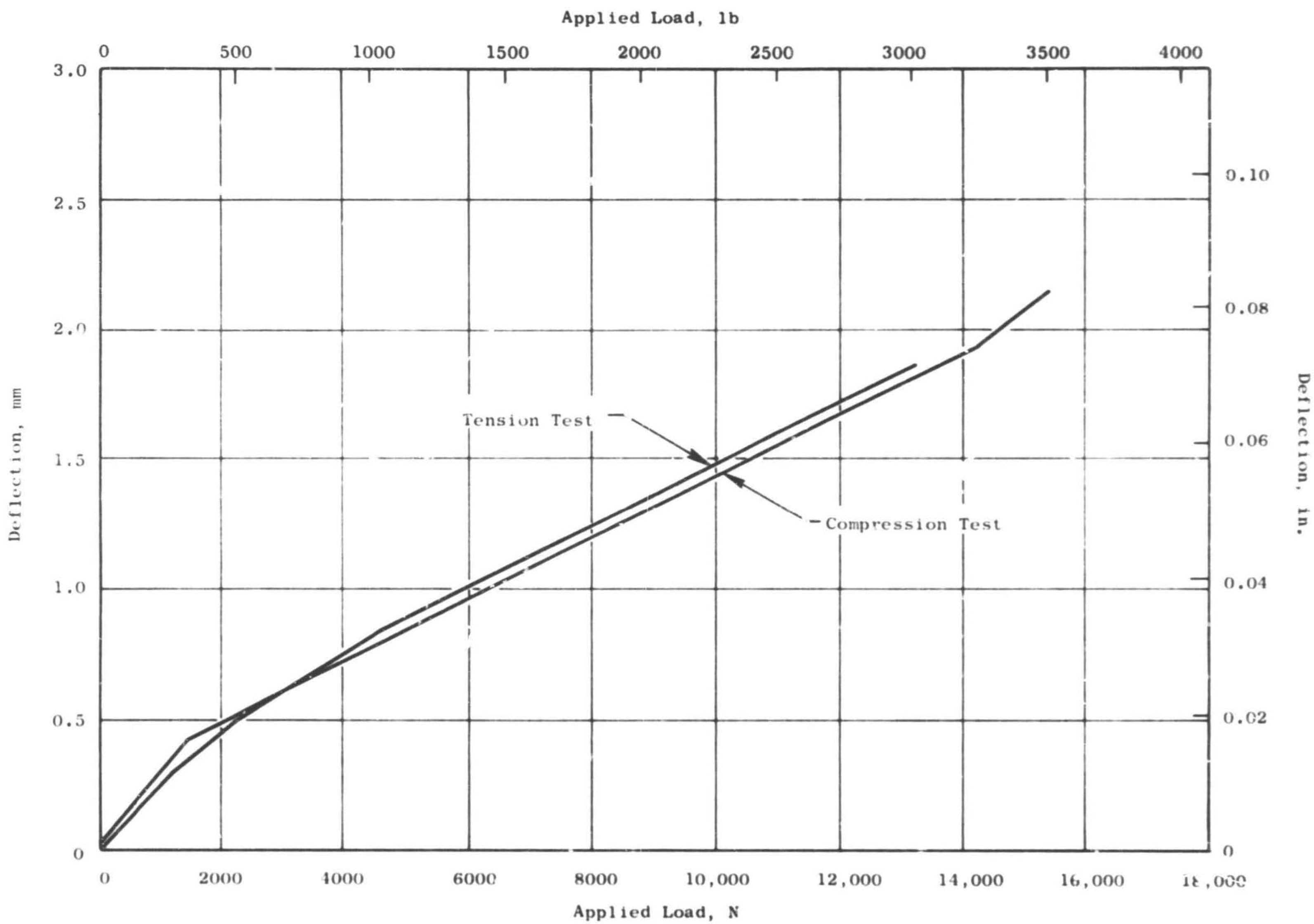


Figure 28. Outer Casing Test Panel, Load Versus Deflection.

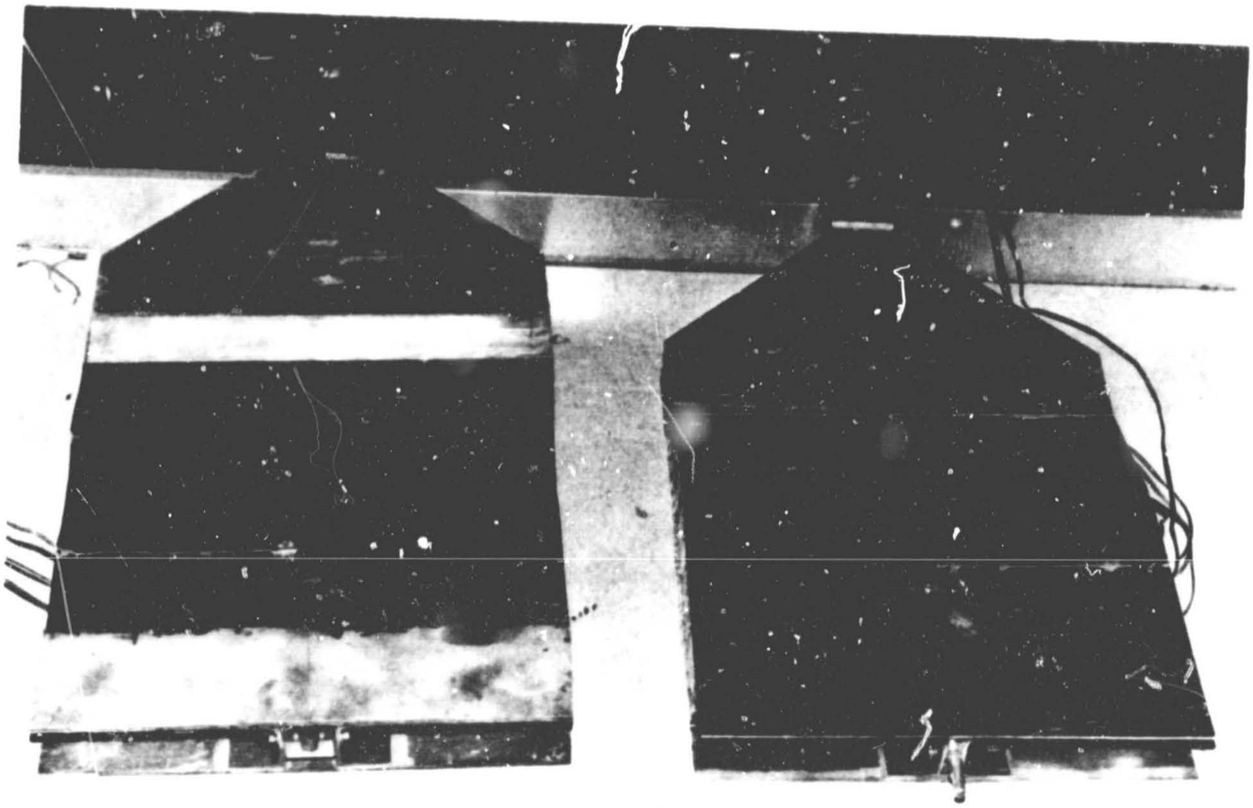


Figure 29. Inlet-to-Frame Attachment.

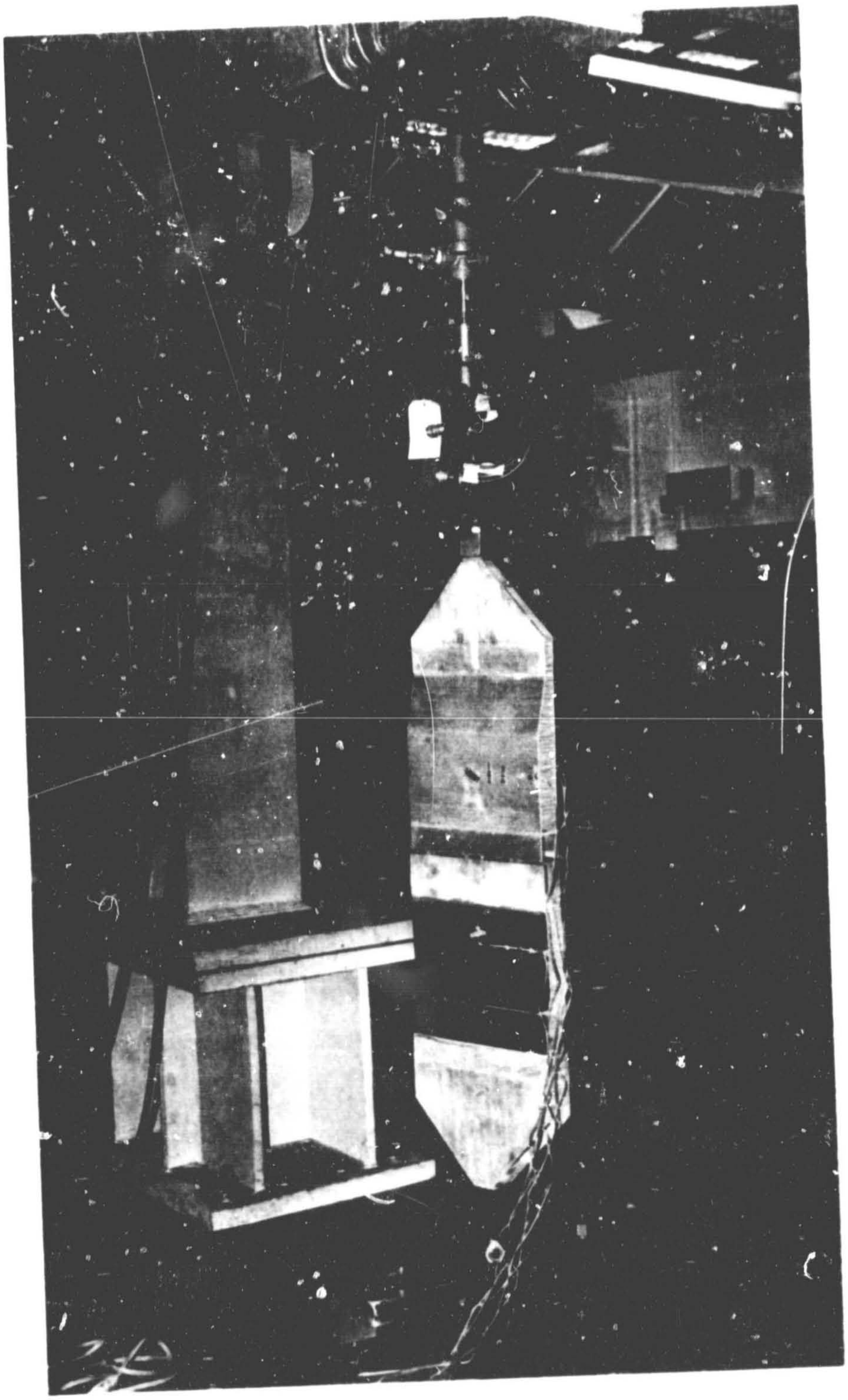
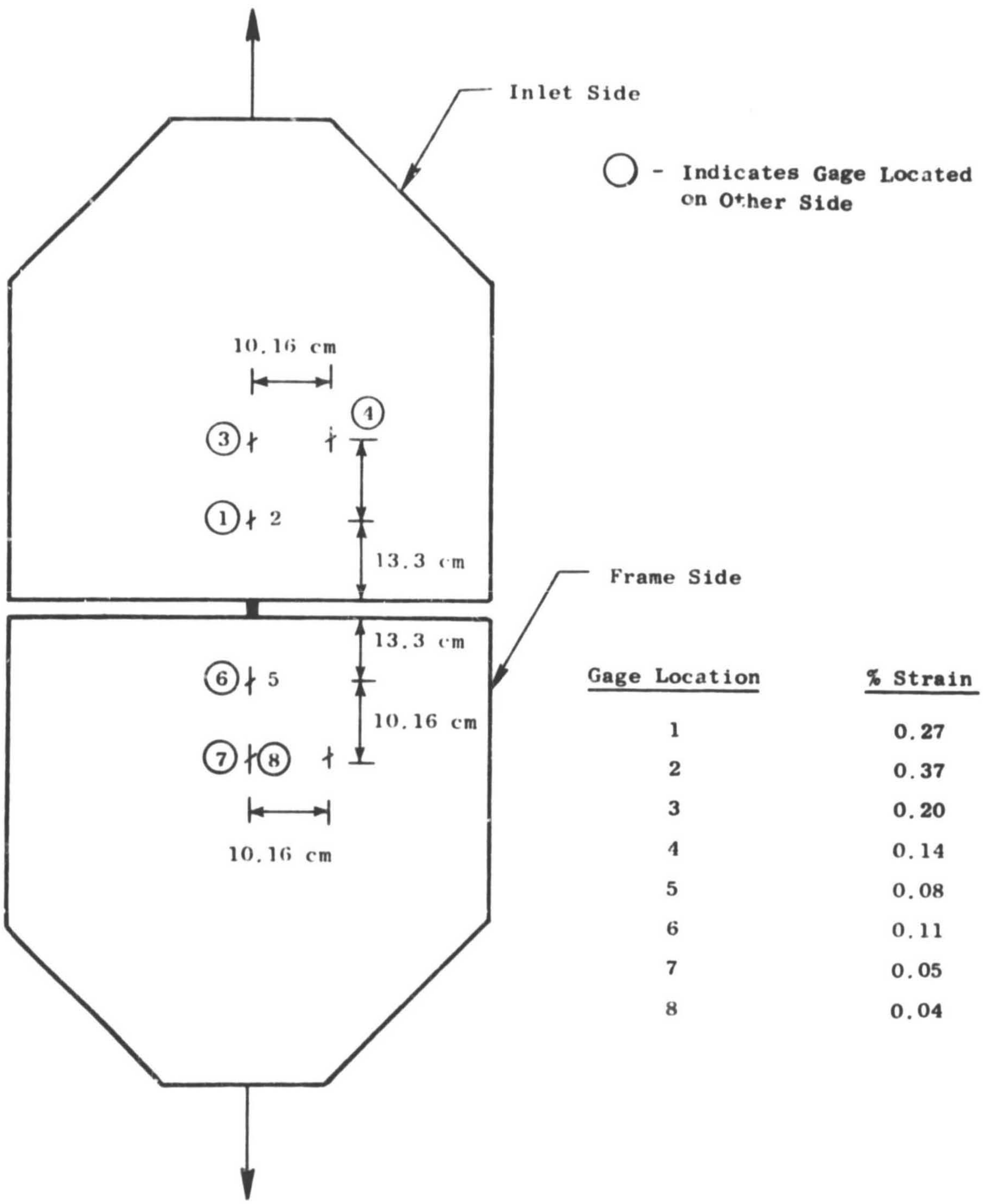


Figure 30. Inlet-to-Frame Attachment Test Setup.



Gage Location	% Strain
1	0.27
2	0.37
3	0.20
4	0.14
5	0.08
6	0.11
7	0.05
8	0.04

Figure 31. Inlet-to-Frame Test Specimen Gage Location and Strains.

Figure 32. Upon inspection of the latch area, there were signs of distress where the latch is bolted to the glass/epoxy bracket. The distress was primarily in the forward bolt hole area. It was decided that a repair would be attempted and the test would be continued. The repair included:

- Drilling two 1.27 cm (0.5 in.) holes through the spacer and plates on the ends of the specimen and bolting them together with 1.27 cm (0.5 in.) bolts.

- Bonding 1.27 cm (.050 in.) thick steel shims to the brackets where the latch is bolted to help reinforce the hole (Figure 33).

Test No. 2

The repaired specimen was tensile tested for a second time. A bond failure occurred in the latch area at a load of 28640 N (6438 lb). No additional testing was performed as the demonstrated load of 28640 N (6438 lb) was very close to the rated ultimate load capability of the latch. The required load for engine operation is 9340 N (2100 lb).

4.2.6 Frame-to-Inner Cowl Extension Joint

The frame-to-inner cowl extension joint test specimen was tested in tension. In order to obtain the required 406 K (270° F) test temperature, the specimen was enclosed in an air circulating electric oven and heated to a stable 406 K (270° F) prior to testing. The specimen was loaded in tension with the initial failure occurring at 25040 N (5630 lb). This failure appeared to be a bending failure in the bolted flange. Subsequent loading produced a shear-out through the bolt holes at a load of 26690 N (6000 lb). The predicted failure load for a bending failure was 24470 N (5500 lb). The required load capability of the joint is 298 N/cm (170 lb/in.) while failure occurred at a load of 788 N/cm (450 lb/in.) which is a substantial margin. The test specimen (after test) is shown in Figure 34.

4.2.7 Frame-to-Outer Cowl Door Joint

The specimen was loaded in tension with failure occurring at a load of 13630 N (3064 lb). The failure mode appeared to be a combination of peel and flatwise tension in the graphite/epoxy plies where the hook was bonded to the simulated aft outer wheel. The apparent cause was a rotation of the hook assembly. The required limit load capability of the joint is 149 N/cm (85 lb/in.). Using three times this load as the design load gives a value of 447 N/cm (255 lb/in.). The demonstrated capability from the static load test is 447 N/cm (255 lb/in.). A picture of the specimen after test is shown in Figure 35.

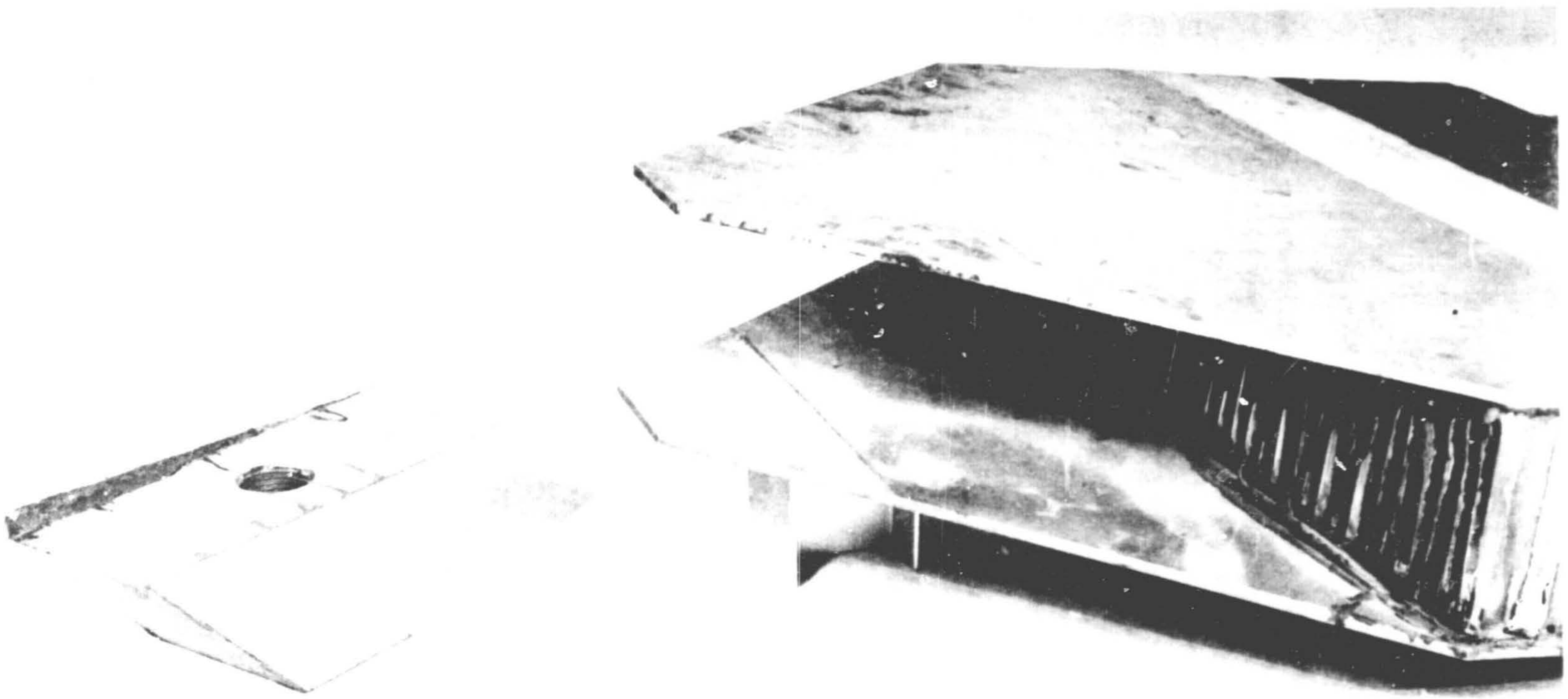


Figure 32. Inlet-to-Frame Attachment Test Failure, After Test No. 1.

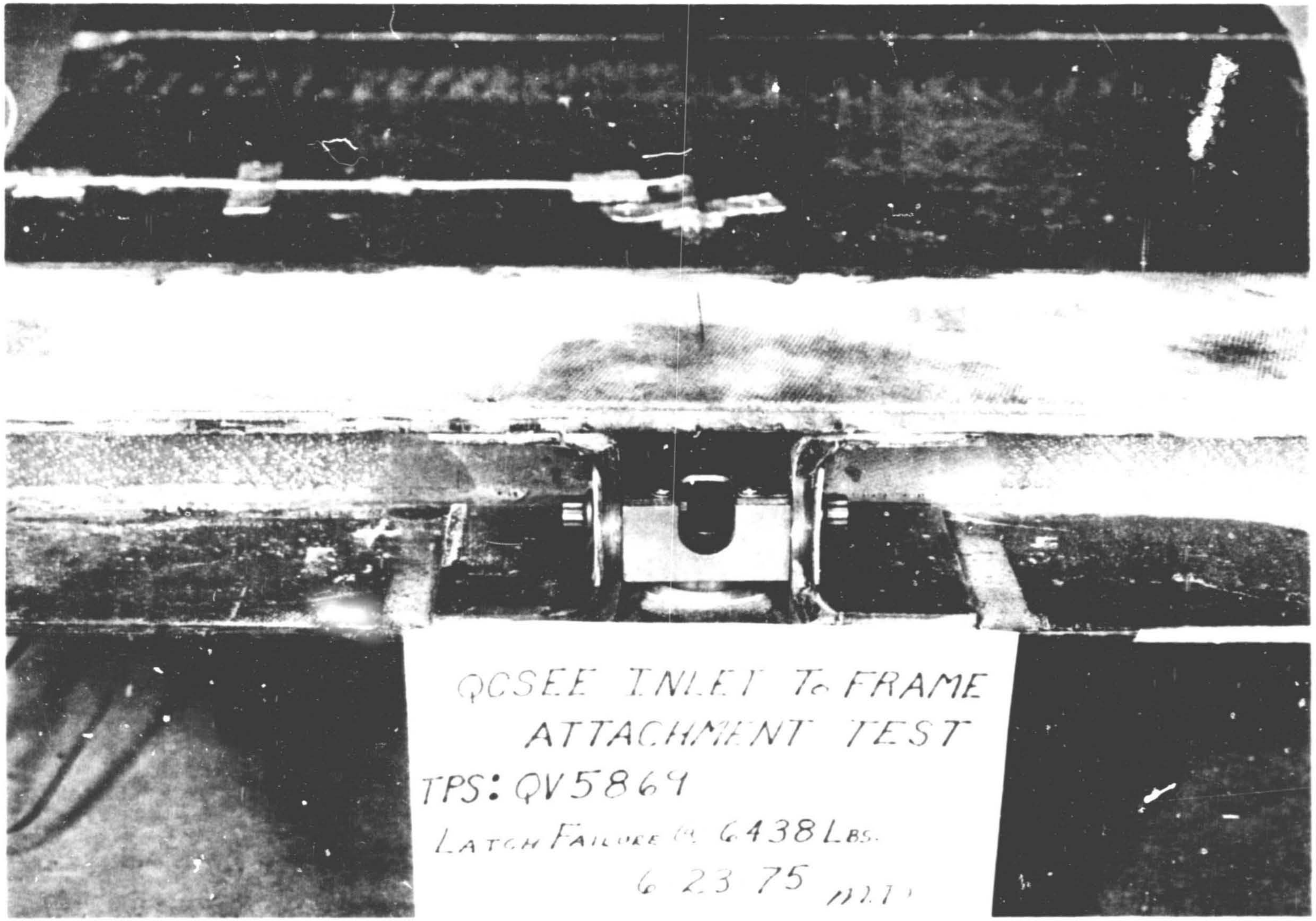


Figure 33. Inlet-to-Frame Attachment Retest.

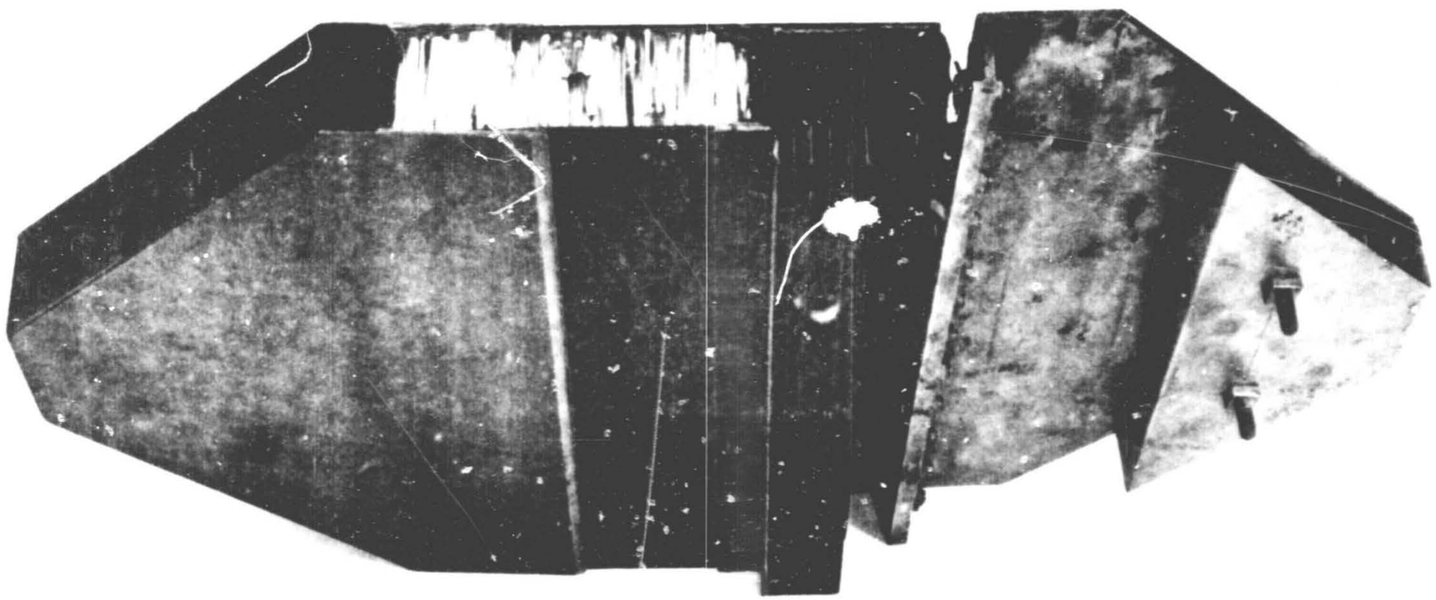


Figure 34. Frame-to-Inner Cowl Extension Test Specimen, After Test.

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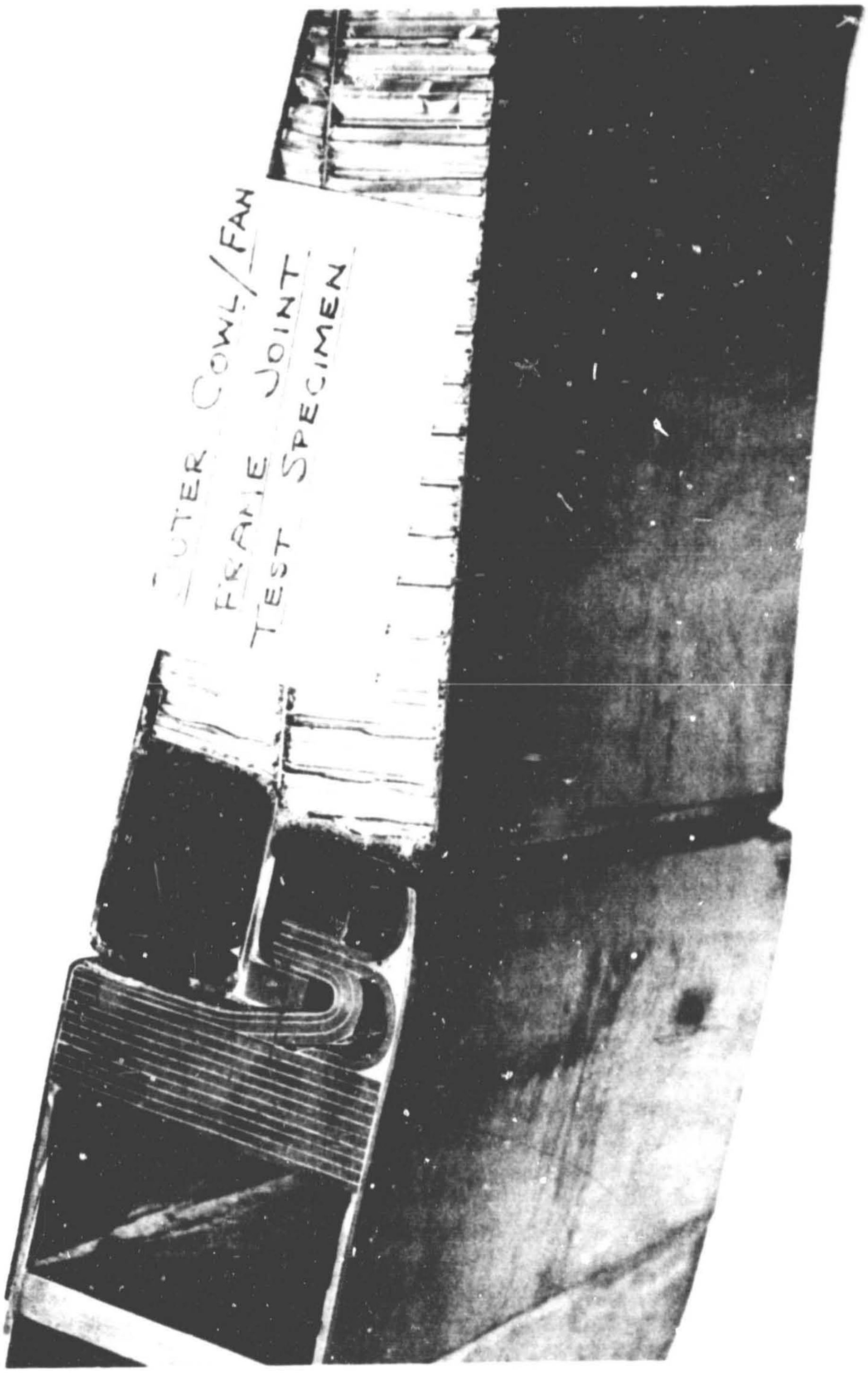

Figure 35. Frame-to-Outer Cowl Door Test Specimen, After Test.

4.3 CONCLUSIONS

The subcomponent tests described in the preceding paragraphs have demonstrated that the designs of the critical areas of the QCSEE composite fan frame are adequate to meet the strength requirements of the frame. The load presented in Table VI as "Required for Safe Design" are three times the actual limit load if a flight condition is critical, or the effect of five composite blades-out if this emergency condition is critical. The lone exception to this is the thrust mount for which a 12 g forward condition is critical. As can be seen from Table VI, the critical frame components more than meet even these severe requirements, thus providing confidence that the total frame will have more than adequate structural integrity.

SECTION 5.0

FLUID EXPOSURE TESTS

Two series of tests were run to evaluate the effect of elevated temperature exposures to aircraft fluids. The specific composite material system tested was the type AS graphite fiber in Hercules 3501 epoxy resin matrix. The first series of tests evaluated the exposure to "Skydrol 500C". The concern was of intermittent exposure to residual fluid left on the frame. Another series of tests was made to determine if the hot sump oil could be in direct contact with the composite frame without causing degradation in the composite material properties. The primary purpose of these tests was to determine if a metal oil shield was required in the sump region. The following paragraphs describe the results of these tests.

5.1 EXPOSURE TO SKYDROL C

Due to concern regarding the possible degradation of graphite/epoxy material when exposed to engine and aircraft fluids, an exploratory test program was conducted on the material system selected for use on the QCSEE fan frame. The exposure conditions were selected based on that expected in the QCSEE engine installation, where any exposure of the graphite/epoxy to these types of fluids will be of an intermittent nature that will leave residual fluid on the frame. The fluid used for the exposure tests was "Skydrol 500C", since past experience has shown that Skydrol is one of the more destructive fluids on organic materials.

The degradation due to exposure was measured as changes in the compression and tension values of the exposed material. The composite material was molded and fabricated into individual test specimens eight plies thick, with a $(0, \pm 45, 90)_s$ orientation. The tension specimens were of the IITRI type shown in Figure 1, while the compression specimens were modified ASTM D695-69 with a test section of 1.02 × 6.35 mm (0.040 × 0.25 in.). The specimens, except for the control specimens, were exposed to "Skydrol 500C" hydraulic fluid for five minutes at 356 K (180° F) followed by an oven exposure (without wiping or drying the specimens) at 356 K (180° F) for time periods ranging from 0 to 15 days. Ultimate strength values were then obtained, from the specimens thus exposed, at both room temperature and 356 K (180° F).

A total of 24 specimens of each type were fabricated. Four specimens of each type were used as baseline data. The remaining specimens were exposed as described above. Tests were conducted on these specimens at varying periods of 356 K (180° F) over exposures ranging from 0 time to 15 days. Ultimate strength values were then obtained from the specimens.

The results of these tests are shown in Figure 36. Although there is some test scatter, it appears that the material system tested was not degraded by the exposure.

5.2 EXPOSURE TO MIL-L-23699 OIL

Another series of tests was made to determine if the hot sump oil could be in direct contact with the composite frame without causing degradation in the composite material properties. The primary purpose of these tests was to determine if a metal oil shield was required in the sump region.

Tensile test specimens (IITRI) were fabricated using the AS 3501 graphite epoxy system. The layup pattern was (45, -45, 90, 45, 45, 90, -45, 0, 45), which is representative of the composite sandwich facing in the sump region, which would be in contact with the hot oil. Several of the specimens were coated with different coatings to see if they would provide any additional protection to the bare composite. The coatings used were Nubulan, Valspar, and Metlbond 328 adhesive. The specimens were soaked in hot MIL-L-23699 oil for one week at an oil temperature of 422 K (300° F). The specimens were then tested to failure at 405 K (270° F). In addition to the oil exposure specimens, several unexposed specimens were tested at 405 K (270° F) after 30 minutes in 422 K (300° F) air and several after one week in 422 K (300° F) air. The resulting test data are shown in Table IX. The predicted unexposed tensile strength, as obtained from the Design Guide for these specimens is 31,720 N/cm^2 (46,000 psi) at 405 K (270° F). Based on these data it was concluded that there was no degradation of the bare graphite/epoxy due to exposure to hot MIL-L-23699 oil, and neither the oil shield nor the protective coatings are required.

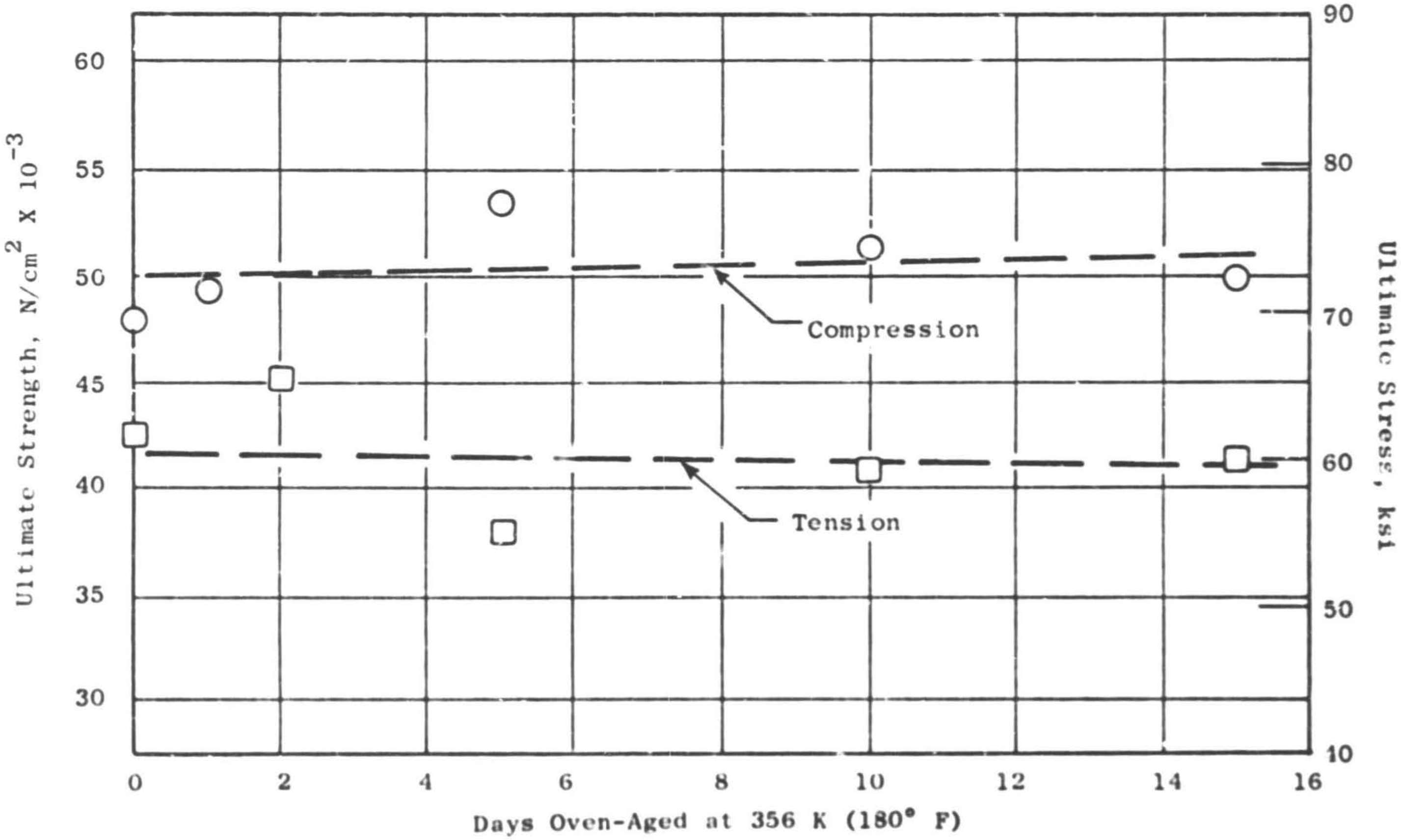

Figure 36. Graphite/Epoxy AS3501 Exposed to Skydrol 500C for Five Minutes at 356 K (180° F), Tested at 356 K (180° F).

Table IX. Exposure Evaluation of MIL-L-23699 Oil.

Specimens	Exposure Environment	Coating	Stress	
			N/cm^2	psi
A	422 K (300° F) air for 30 min.	None	32173	46661
B	422 K (300° F) air for 1 week	None	33103	48010
C	Set 1 422 K (300° F) oil for 1 week	None	31758	46060
C	Set 2 422 K (300° F) oil for 1 week	None	33269	48251
D	422 K (300° F) oil for 1 week	Nubulan	33765	48970
E	422 K (300° F) oil for 1 week	Valspar	30283	43920
F	422 K (300° F) oil for 1 week	Metlbond	32949	47787