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QUIET CLEAN SHORT-HAUL EXPERIMENTAL ENGINE (QCSEE)

R-THE-WING (UTW) COMPOSITE NACELLE SUBSYSTEM TEST REPORT

JULY 1977

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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 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 under-the-wing composite nacelle design. This composite nacelle consists of an inlet, outer cowl doors, inner cowl doors, and a variable fan nozzle. The element tests provided the mechanical properties used in the nacelle design. The subcomponent tests verified that the critical panel and joint areas of the nacelle 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 Nacelle Subsystem Test Program. The NASA program director and technical advisor for this effort was Mr. H. G. Yacobucci. The program was performed under the direction of Mr. C. L. Stotler, Jr., Technical Manager, General Electric Company.

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1.0 INTRODUCTION

One of the advanced technology items of the Quiet, Clean, Short Haul, Experimental Engine (QCSEE) program is the design and fabrication of an advanced, composite nacelle which is flight weight in nature and incorporates the acoustic suppression treatment as integral structure. The basic materials used in the construction of the composite nacelle (See Figure 1) are as follows:

Inlet - Kevlar/epoxy

Outer Cowl Doors - Kevlar/epoxy and graphite/epoxy

Variable Fan Nozzle - Kevlar/epoxy and graphite/epoxy

Inner Cowl Doors - Graphite/PMR polyimide

Since these materials are relatively new and have not been used for this type of structure before, it was 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 nacelle.

This testing falls into two distinct categories. The first of these involved the selection of the Kevlar/epoxy system to be used during the program and the determination of the mechanical properties of the selected system. The material properties of the graphite/epoxy system used in the nacelle were obtained from the Advanced Composite Design Guide and were verified by the test program reported in Reference 1. The mechanical properties of the graphite/PMR polyimide system are being evaluated under another portion of the QCSEE program and will be incorporated into a separate report on the development of that system. Additional information on the PMR polyimide system may be found in Reference 2.

The other portion of the test program concerned the testing of the subcomponents representative of various critical portions of the nacelle structure. This portion of the program was necessary to verify the structural design of the various joint and latch areas of the nacelle which represented new applications for the materials involved.

The results of this overall test program were then evaluated and formed the basis for the final structural design and analysis of the QCSEF composite nacelle.

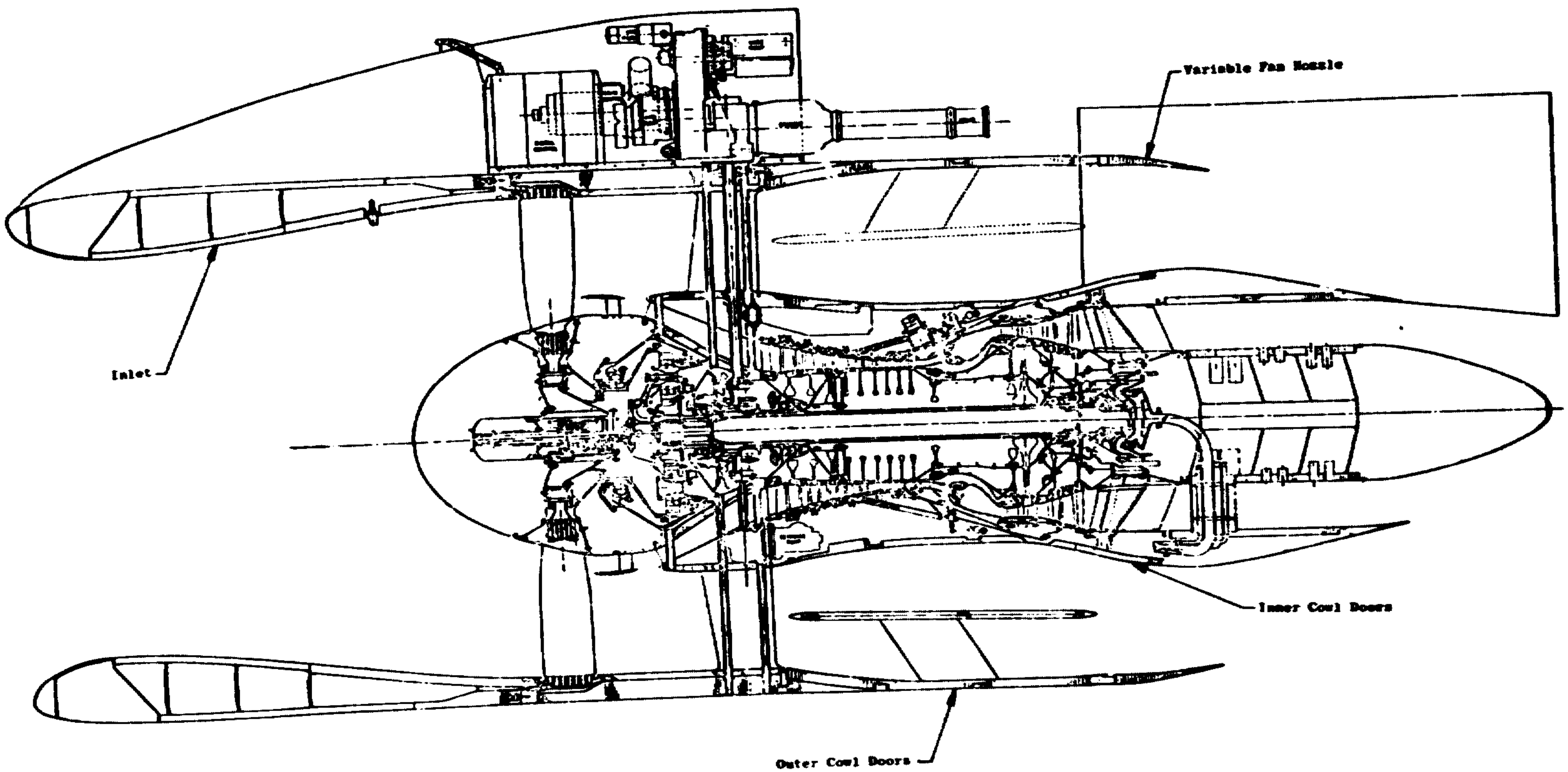


Figure 1. Composite Nacelle Components.

2.0 SUMMARY

This report presents the results of the element and subcomponent testing done in conjunction with the under-the-wing (UTW) composite nacelle design for the Quiet, Clean, Short-Haul, Experimental Engine (QCSEE) Program. This test program had the objective of development and/or verification of mechanical properties of materials suitable for use in the design of the composite nacelle and the demonstration of the structural adequancy of critical portions of the nacelle design.

The portions of the UTW nacelle which are constructed using composite materials are the inlet, outer cowl doors, inner cowl doors, and variable fan nozzle. The primary material used for the composite nacelle (except for the core cowl) is Kevlar 49 fabric in an epoxy matrix. The initial phase of this test program consisted of a series of screening tests to select a matrix system for use with the Kevlar. Examination of the data from these tests resulted in the selection of the Narmco 8517 resin system.

Subsequent to the selection of the resin system, an element test program was conducted to develop basic material properties for the Kevlar 49/Narmco 8517 system. All data was generated with the Kevlar material woven in a 181 style weave. As expected, the lowest material properties, relative to composite systems, were compression and bearing. However, even though these properties were relatively low, they were more than adequate in meeting the requirements of the intended applications.

In addition to the basic element tests, a brief investigation was made of the response of the Kevlar/epoxy system to exposure to typical aircraft fluids. Short-beam shear tests were conducted after immersion of the samples in 356 K (180° F) fluid followed by long term oven exposure at that temperature. The tests were conducted both at room temperature and at 356 K (180° F). No short-beam shear strength degradation was noted due to this exposure. Reaction to both Mobil Jet II and Skydrol 500C was examined during this program.

The inner face of the outer cowl doors and the inner face of the variable fan nozzle were changed from Kevlar/epoxy to graphite/epoxy late in the program, and this change is not reflected in the tests described herein. This will not adversely affect the results of these tests since the graphite/epoxy system is stronger than the Kevlar/epoxy system. The change was made to satisfy acoustic design requirements for a higher porosity facesheet in these areas that can be conveniently fabricated using Kevlar materials. Sufficient mechanical property data was available for the graphite/epoxy material to provide design data (see Reference 1).

Because of higher operating temperatures than other nacelle components, the core cowl utilizes the graphite/PMR polyimide system which was developed under a separate work package of the QCSEE program. The mechanical properties of that material are reported under that program, while the subcomponent tests for the core cowl are reported herein.

Since one of the most critical areas of composite structures is the joining of individually molded pieces, either by bonding or mechanical fastening, critical joint areas of the nacelle were investigated by a series of individual subcomponent tests representing these areas. A total of twenty-five specimens representing thirteen different areas were fabricated and tested to failure. As a result of these tests, several joint areas of the nacelle were redesigned to provide more doubler area and to reduce loads on potted-in inserts, either by adding more inserts or replacing them with through fasteners. These redesigns allowed all areas investigated to meet the design requirement of three times the expected maximum operating load.

In summary, the results of the element and subcomponent testing conducted in support of the QCSEE nacelle design has provided the information required to design the nacelle structure with a high degree of confidence in the structural integrity of these components.

3.0 ELEMENT TESTING

This section describes the element test program conducted to select and evaluate the material systems to be used in the design and construction of the QCSEE composite nacelle. Primary effort was directed towards the Kevlar/epoxy system for which very little data was available. No element testing of the graphite/epoxy system was conducted under this program; sufficient data was already available in the Advanced Composite Design Guide supported by the information in Reference 1. Results of the graphite/PMR material system will be presented in a subsequent report on the PMR development program.

3.1 TEST PLAN

3.1.1 Test Objective

The objective of this program was to provide data upon which to base the selection of the materials to be used in the QCSEE composite nacelle. Upon selection of the material systems, sufficient data was then generated to allow the design and analysis of the composite nacelle. The initial test plan is shown in Table I. Originally it was planned to test acoustic face-sheets with 10% and with 27% open areas. It was found, however, that the molding of a Kevlar/epoxy panel with porosity greater than 10% was not practical; therefore, no testing of 27% open area Kevlar/epoxy was conducted. Also, since it was later decided to develop the graphite/PMR system for the inner core cowl, no graphite/polyimide element tests were conducted. The data generated by the graphite/PMR development program will be published in a separate report.

3.1.2 Matrix Screening Program

Prior to performing the tests outlined in Table I, a screening program was conducted to select the resin matrix system to be used with the Kevlar material. Based on previous experience and contacts with the various material suppliers, a total of eight resin matrix systems were chosen to be evaluated by this screening program. The properties and criteria used to evaluate these systems were:

- Short-beam shear strength
- Edgewise compression strength
- Flatwise tensile (on honeycomb core)
- Climbing drum peel (on honeycomb core)
- Capable of operating at 394 K (250° F)
- Capable of being used as a cocured sandwich facing without the use of a separate adhesive layer.

Table I. Test Specimen Configurations.

Laminate Orientation (degrees)	Test Dir. (degrees)	Test Mode (2)					
		IITRI Tensile	Sandwich Beam Tensile	Sandwich Beam Compression	Rail Shear (Solid laminate)	Rail Shear (Sandwich Panel)	Loaded Hole
0,45,0	0	X	X	X	X	X	X
	90	X		X			
0,45,0 10% Open Area	0	X	X	X	X	X	X
	90	X		X			
0,+45,-45,0	0	X	X	X	X	X	X
	90	X		X			

(1) All material is Kevlar 49/181 impregnated with Narmco 8517 and all tests are at room temperature

(2) Each test mode consists of three replicates

NOTE: Two other configurations were originally planned, one was a 27% open area configuration in Kevlar/epoxy which could not be fabricated and the other was a graphite/PI material configuration which was replaced by graphite/PMR and is being evaluated under the PMR program.

All of the evaluation was done with the selected matrix system impregnated into Kevlar 49/181 style fabric. Two of the eight original systems to be tested were not evaluated due to the discontinuation of one of the system ingredients. These ingredients were Hexcel's F162 and F155 prepregs. Test panels (both solid laminate and honeycomb sandwich) were fabricated from the remaining six systems. Two of these systems, DuPont's 5105 and 5147, while having good room temperature properties as a solid laminate, had a very brittle core-face bond when used as cocured facings honeycomb sandwiches and did not appear to be suitable for use in cocured sandwich panels without an adhesive layer. The four systems that were further evaluated were Narmco 3203, Narmco 8517, Ferro CE9000, and Ferro CE9040. The results of the laminate short-beam shear tests (ASTM D-2344) and the edgewise compression tests (ASTM D-695) are shown in Table II. The results of the flatwise tensile test (ASTM C-297) and the climbing drum peel tests (ASTM D-618) conducted on cocured honeycomb sandwich panels (no adhesive used) are shown in Table III. The Narmco 3203 system was not included due to low compressive and short-beam shear strengths at elevated temperature.

Based on these data, particularly the edgewise compressive strengths and sandwich peel strengths, the Narmo 8517 resin system was selected for use with the Kevlar 49 fabric (181 style) for the QCSEE nacelle application.

Even though it was later decided that an adhesive would be used to bond the Kevlar facings to the honeycomb core, the various candidate materials were not reevaluated on this basis because the selected system was adequate.

3.1.3 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 2. 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.

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.

A typical sandwich beam test specimen is shown in Figure 3. To minimize the influence of the core, a parting agent was placed between the core and the face in the test section. This is done only at the tensile face of the beam.

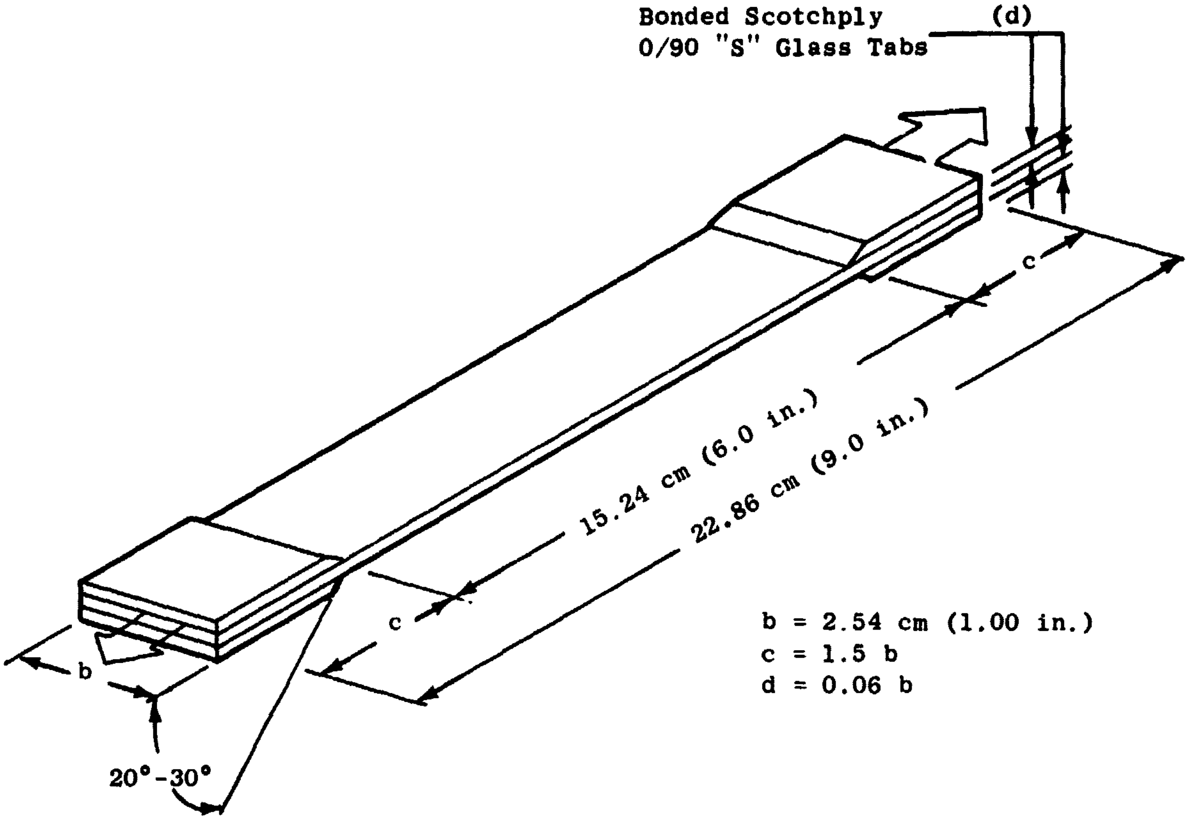
Table II. Kevlar/Epoxy Laminate Screening Test.

	Short-Beam Shear			
	Room Temperature		394 K (250° F)	
	MN/m^2	psi	MN/m^2	psi
Narmco 3203	36.34	5270	5.65	820
Narmco 8517	30.54	4430	26.68	3870
Ferro CE9000	31.10	4510	29.79	4320
Ferro CE9040	37.23	5400	25.79	3740
	Edgewise Compression			
	Room Temperature		394 K (250° F)	
	MN/m^2	psi	MN/m^2	psi
Narmco 3203	156.31	22670	33.51	4860
Narmco 8517	212.23	30780	140.45	20370
Ferro CE9000	194.02	28140	138.31	20060
Ferro CE9040	155.21	22510	110.39	16010

Table III. Kevlar/Epoxy Sandwich Screening Tests.

	Flatwise Tensile - ASTM C-297 - R. T.		
	MN/m^2	psi	Comments
Ferro CE9000	2.00	290	Core-to-face, bag side
Ferro CE9040	1.52	220	Core-to-face, bag side
Narmco 8517	4.06	590	Core-to-face, bag side

	Climbing Drum Peel - ASTM D-618 - R. T.			
	Bag Side		Plate Side	
	m-N/m	in.-lb/in.	m-N/m	in.-lb/in.
Ferro CE9000	6.23	1.4	11.57	2.6
Ferro CE9040	3.96	0.89	48.93	11.0
Narmco 8517	19.57	4.4	47.15	10.6

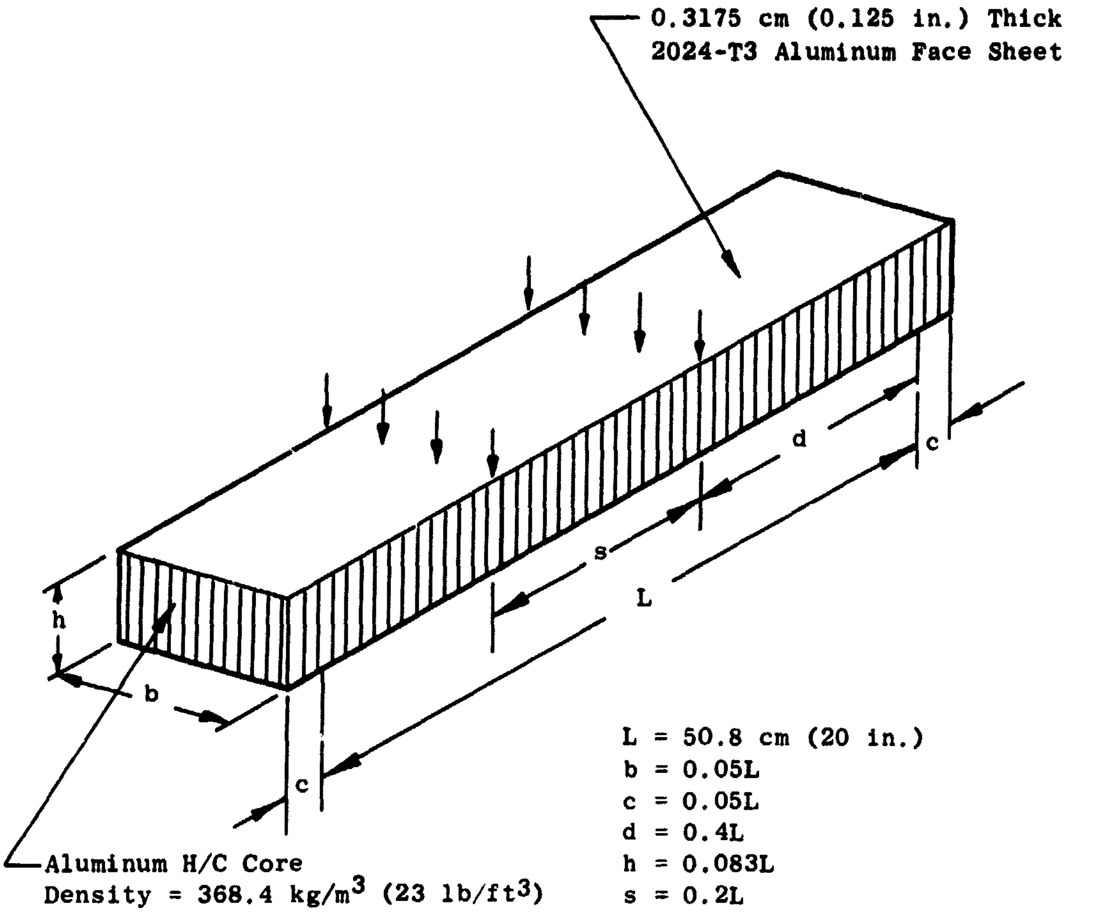


(1) Specimens were Cut to Width

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

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

Figure 2. IITRI Tensile Coupon.



(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 3. Sandwich Beam Tensile Specimen.

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 4. As seen from Figure 4, 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 5. It uses a thin laminate, 10.16 cm (4 in.) wide and 20.32 cm (8 in.) long, loaded along the length by two pairs of rails leaving an unsupported test section. The knife-edged spacers located at both ends of the panel tilt with shear distortion to allow transverse deflection of the rails.

The interlaminar shear properties were determined by the short-beam shear method. These tests were performed in accordance with ASTMD2344-72. The span-to-thickness ratio was 5:1.

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, shearout, and bearing. The general specimen is shown in Figure 6.

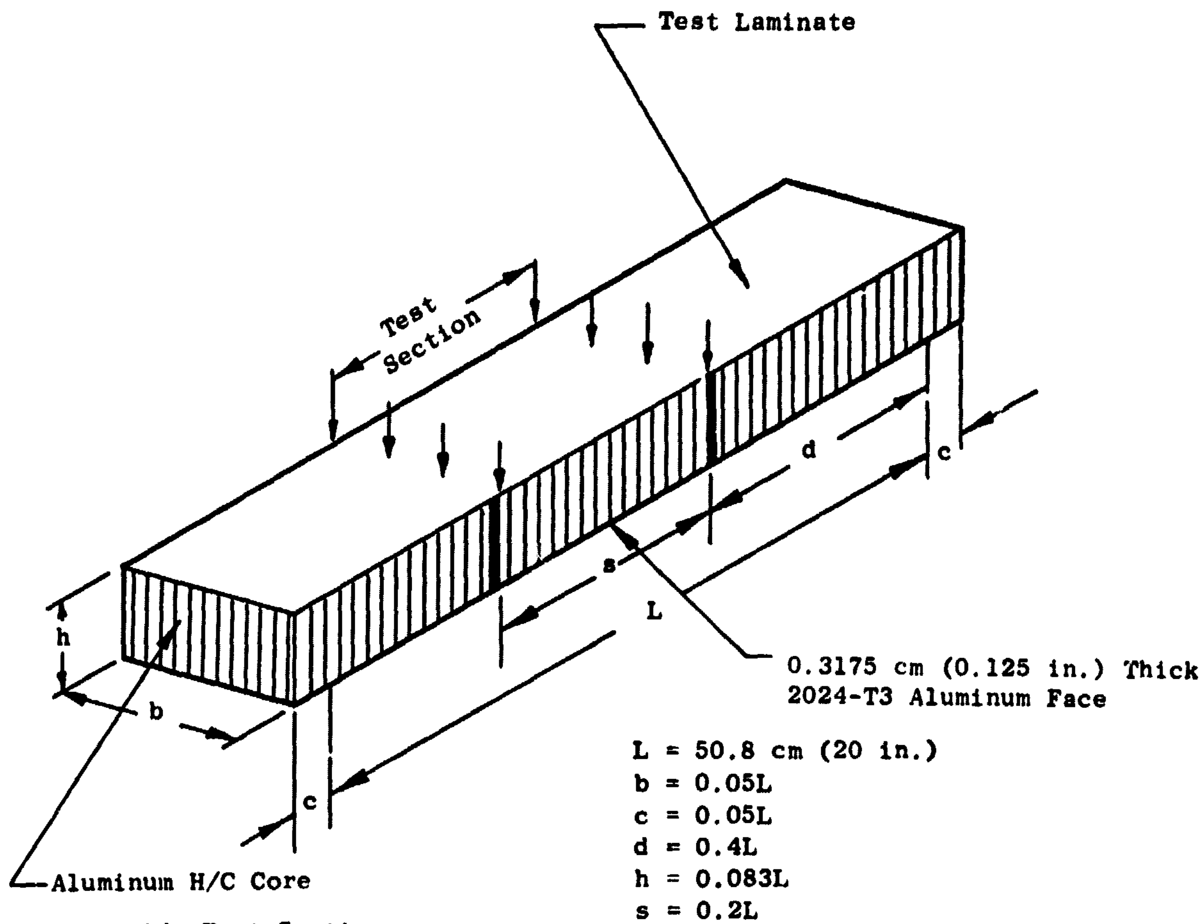
3.1.4 Test Facility

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

3.2.1 Tensile Testing

The results of the tensile testing conducted during this program are shown in Table IV. The stresses shown are based on an average ply thickness of 0.02794 cm (0.011 in.), rather than a measured thickness, in order to normalize the data. Two specific orientations were investigated. The three-ply (0,45,0) configuration is typical of the thickness and layup pattern used in the QCSEE composite inlet. The inner face of the inlet barrel honeycomb sandwich is perforated with approximately 5.5 holes [diameter of 0.1524 cm (0.060 in.)] per cm^2, which provides a 10% open area for acoustic suppression purposes, therefore data was also generated for this configuration. Although the acoustic configuration only occurs as part of a sandwich structure in the actual part, it was investigated, for comparison purposes, as both a solid laminate and a sandwich facing in these tests. As can be seen from the data in Table IV, the better lateral support supplied by the honey-



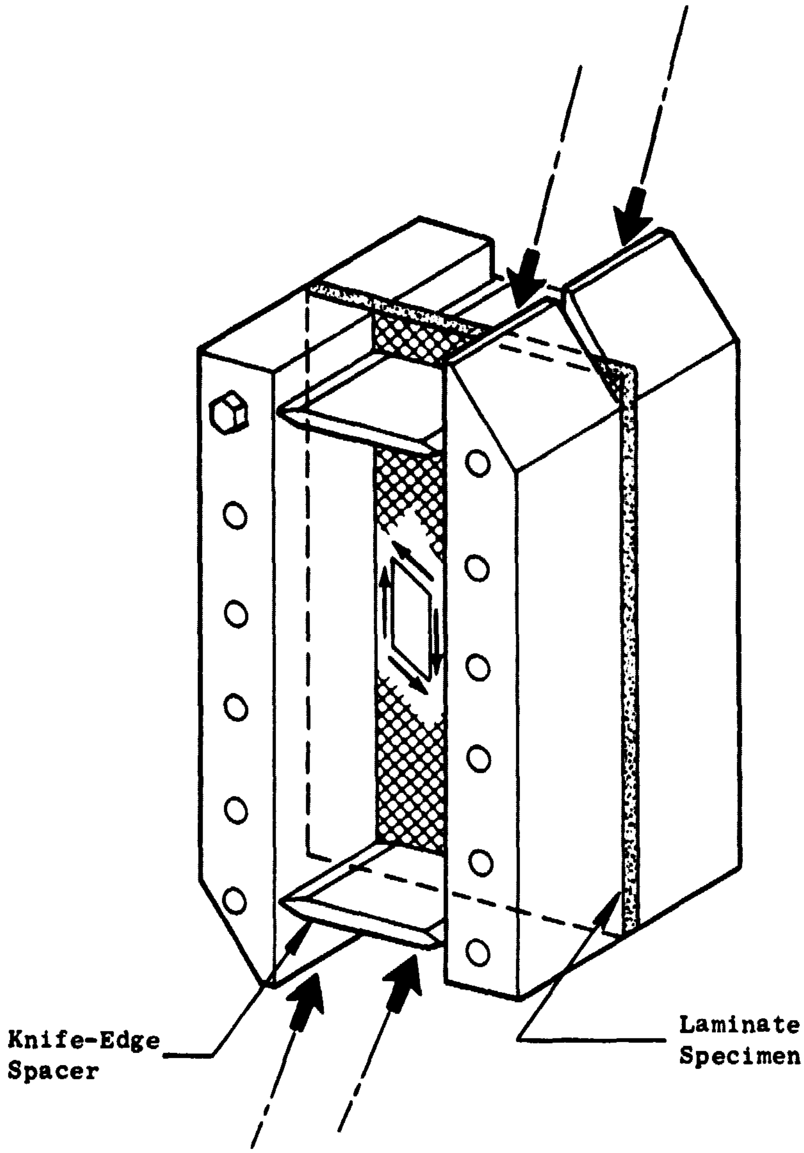
Density Outside Test Section =
368.4 kg/m^3 (23 lb/ft^3)

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.

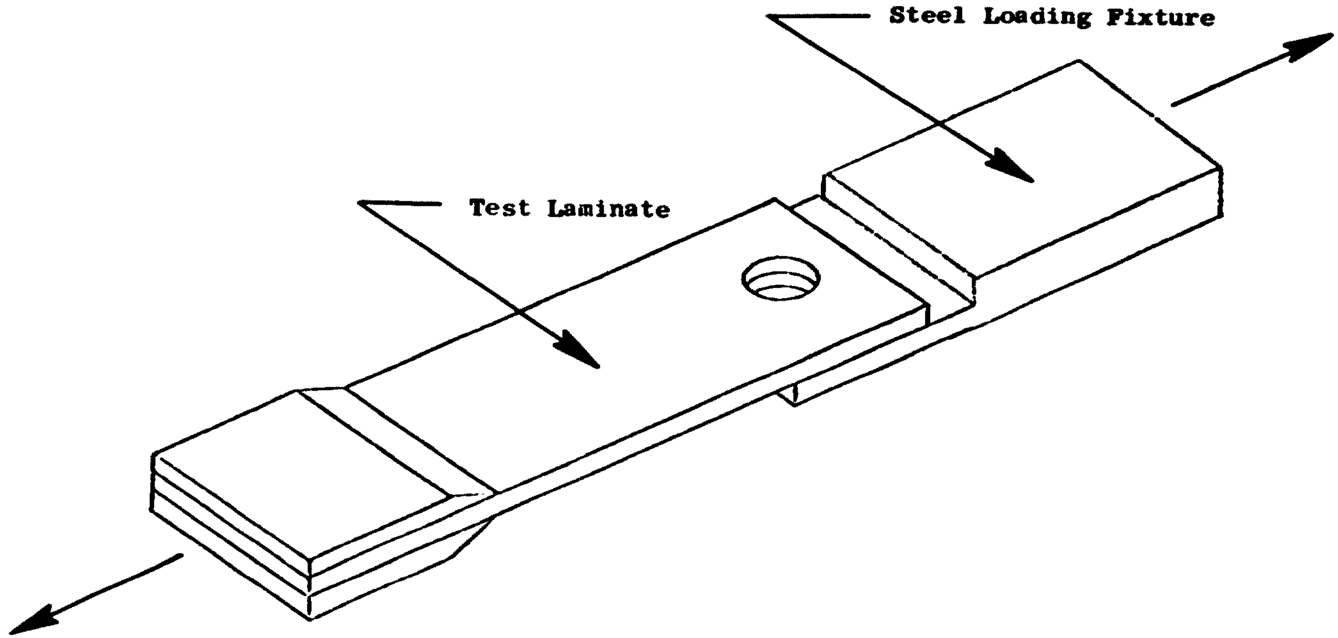
(2) Stress Computed Using Bending Couple at Midplane of Faces

Figure 4. Sandwich Beam Compression Specimen.



1. Rails Were Bonded to Avoid Failure Through Bolt Holes.

Figure 5. In-Plane Shear, Rail Test Method.



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

Figure 6. Bolt Hole Specimen.

Table IV. Tensile Testing.

Basic Material - Kevlar 49/181 with Narmco 8517

Laminate Orientation (degrees)	Load Direction (degrees)	Failure Stress - MN/m^2 (psi)			
		IITRI		Sandwich Beam	
		0% O.A. (1)	10% O.A.	0% O.A.	10% O.A.
0, 45, 0	0	377.16 (54700)	233.40 (33850)	407.08 (59040)	255.80 (37100)
	90	350.40 (50820)	215.60 (31270)	NR	NR
0, +45, -45, 0	0	312.90 (45380)	NA	337.65 (48970)	NA
	90	298.35 (43270)	NA	NR	NA

(1) Open Area

NOTE: All tests conducted at room temperature
NA - Not Applicable
NR - Not Required

comb core results in a slightly higher allowable when compared to the IITRI type test specimen for all configuraitons tested. The addition of the acoustic holes resulted in a 37% reduction in the allowable gross tensile stress.

The other ply configuration tested was the four ply (0, +45, -45, 0) orientation, typical of the construction of the outer skins of the outer cowl doors and the variable fan nozzle (Figure 1). Since the acoustic treatment for these parts occurs only on the graphite/epoxy inner facing, no testing of the (0,+45,-45,0) Kevlar/epoxy was conducted for perforated sheets. The design data used for the graphite/epoxy skins in these areas was extrapolated from the test data generated under Reference 1. As can be seen from the data, the sandwich beam test produced slightly higher values than the IITRI tensile coupon.

3.2.2 Compression Testing

The results of the compression testing conducted during this program are shown in Table V. All of these test results were obtained by the sandwich beam test method described in Section 3.1.3. The tests were done both with and without using an adhesive (FM400) layer between the sandwich facings and the honeycomb core. The results showed that a significant improvement was attained through the use of the adhesive layer, and it was these tests that resulted in the decision to use adhesive in all Kevlar/epoxy honeycomb structures in the QCSEE program even though the screening program evaluation (Section 3.1.3) was made based on the assumption that no adhesive would be used.

The laminate configurations tested were the same as those used for the tensile testing. As would be expected, the net compressive strength of the perforated acoustic skins reflected only the loss of net area due to the holes.

3.2.3 Shear Testing

The results of the in-plane shear testing conducted during this program are shown in Table VI. These tests were conducted both for solid laminates and for honeycomb sandwiches. All test specimens were of the rail shear type. The honeycomb sandwich specimens were all cocured using FM400 adhesive between the facings and the core. The lower failure stresses in the sandwich panel are a reflection of this cocuring which results in some face sheet dimpling and poorer pressure distribution on the facing as it is curing.

It was originally intended to test the (0,45,0) laminate with a 10% open area. The test specimen dimensions, however, were such that a laminate this thin with holes in it would not be stable. The only way to increase the thickness and maintain the same orientation ratio would be to double the thickness. This resulted in a laminate too thick to be used with the tip mandrels which are used to mold the holes; therefore, this configuration was not tested. Analysis showed that the (0,+45,-45,0) configuration with holes

Table V. Compression Testing.

Basic Material - Kevlar 49/181 with Narmco 8517
Sandwich Beam Tests

Laminate Orientation (degrees)	Load Direction (degrees)	Failure Stress			
		With Adhesive		Without Adhesive	
		MN/m^2	psi	MN/m^2	psi
(0, 45, 0)	0	173.83	25210	123.77	17950
	90	153.76	22300	90.19	13080
(0, 45, 0) 10% Open Area	0	146.11	21190	113.84	16510
	90	140.52	20380	68.47	9930
(0, 45, -45, 0)	0	175.82	25500	145.62	21120
	90	167.76	24330	148.31	21510

Note: All tests conducted at room temperature

Table VI. Shear Tests.

Basic Material - Kevlar 49/181 with Narmco 8517

Laminate Orientation (degrees)	Percent Open Area	Failure Stress			
		Solid Laminate		Sandwich Panel	
		MN/m^2	psi	MN/m^2	psi
0, 45, 0	0	149.90	21740	87.77	12730
	10	-	-	71.29	10340
0, +45, -45, 0	0	164.86	23910	84.88	12310
	10	111.90	16230	-	-

NOTE: (1) All tests at room temperature
(2) All sandwiches cocured with an adhesive layer included

was marginally stable; it was tested to get some comparative (holes versus no holes in solid laminates) data, even though the configuration is not used in an actual QCSEE component. Although this data is reported in Table VI, it appeared that this configuration was also unstable.

3.2.4 Bolt Hole Tests

Although there are no areas of the QCSEE components which have highly loaded bolts bearing in Kevlar/epoxy material, there are many instances of lightly loaded fasteners securing such items as instrumentation, covers, etc. In order to analyze these areas, a brief investigation was made into the bearing characteristics of (0,+45,-45,0) oriented Kevlar material. The three test-specimen configurations used were the same as those used for the graphite/epoxy material reported in Reference 1. These different specimen configurations were intended to produce three different kinds of failure: bearing, net tension, and shear-out. Due to the very low bearing (or crushing) allowable of the Kevlar/epoxy, all tests resulted in bearing failures. It appears that it would be very difficult to get any other type of failure in this material using normal design practices. The data obtained is shown in Table VII.

3.3 CONCLUSIONS

Based on the screen tests performed early in the program, the Narmco 8517 was selected for use with the Kevlar 49/181 style fabric. Compression testing of the material by use of the honeycomb sandwich beam method showed that an adhesive should be used between the facings and the core whenever the material was used in sandwich applications. The cocuring of the material on honeycomb core resulted in a significant degradation of the compressive and in-plane shear properties, but the operating stresses in the intended applications are sufficiently low to permit this method of construction (which has significant cost advantages). The loaded hole tests showed that the material has very low bearing properties, and care must be taken in any design applications to account for this feature. Sufficient emperical data was obtained from this test program to permit the design of the QCSEE nacelle components utilizing the Kevlar/epoxy material since these components are designed to withstand three times limit load.

Table VII. Loaded Hole Tests.

Intended Failure Mode	Bearing Stress at Failure	
	MN/m^2	psi
Bearing	100.11	14520
Shear-Out	112.18	16270
Net Tension	98.05	14220

Average Bearing Failure Stress - 103.42 MN/m^2 (15000 psi)

Notes: (1) All tests conducted at room temperature

(2) Laminate configuration (0, +45, -45, 0)

(3) All specimens failed in bearing

(4) Pin diameter - 0.79375 cm (0.3125 in.)

4.0 SUBCOMPONENT TESTING

This section describes the subcomponent test program conducted in support of the QCSEE composite nacelle design. This program was required because one of the most critical areas of composite structures is the attach areas, either internally as in bonded splices (or bonding of mating composite parts) or externally to adjoining structure by the use of mechanical fasteners. Therefore, the critical joint areas were individually tested prior to finalization of the nacelle designs.

4.1 TEST PLAN

4.1.1 Test Objectives

The objectives of these tests were to provide verification of the structural integrity of the various critical design features of the QCSEE under-the-wing composite nacelle. The nacelle components are the inlet, outer cowl, inner cowl, and nozzle flaps (Figure 1). The subcomponent tests for the inlet, outer cowl, and inner cowl to fan frame attachments were conducted under the composite frame subcomponent test program and the results are reported in Reference 1. The critical features are the attach points for the various components, other high load points as determined by analysis, and unique features for which there is limited design experience. Where practical, the tests were run to failure of the part, not only to establish the load capability of the subcomponent, but also to verify the structural analysis.

4.1.2 Test Configurations

A total of thirteen (13) areas of the composite nacelle were selected as critical areas for which subcomponent tests should be conducted. These areas are summarized in Table VIII and are discussed individually below. The test areas are grouped according to the nacelle component to which they belong. The results of the tests are discussed in Section 4.2.

4.1.2.1 Inlet

Inlet Wall - The QCSEE composite inlet consists of an inner and outer sandwich wall. The inner wall sandwich has one porous facing for acoustic attenuation. The first series of inlet wall tests consisted of flat sandwich beam specimens to be loaded in four-point bending. These tests evaluated the load carrying capability of the inlet outer barrel sandwich in the actual structural configurations to be used for the inlet. Tests were conducted using both precured and cocured facings to determine the strength differences caused by these different fabrication methods. These flat beam tests were then followed by curved sandwich beam tests representative of the inlet inner

Table VIII. Composite Nacelle Subcomponent Test Plan Summary.

Test Specimen Configuration	Test Mode	No. of Replicates (Tests)
Inlet		
Inlet Wall		
Sandwich Panel - Flat - Precured	Bending	3
Sandwich Panel - Flat - Cocured	Bending	3
Sandwich Panel - Curved - Precured	Bend - O.D. Comp.	2
Sandwich Panel - Curved - Cocured	Bend - O.D. Comp.	4
Axial Manufacturing Joint	Tension	1
Outer Cowl Doors		
Outer Cowl Wall - Curved	Bend - O.D. Comp.	2
Piano Hinge	Tension	1
Outer Cowl Latch	Tension	1
Actuator Mount Attachment	Tension	1
Splitter Attachment	Bending	1
Fan Nozzle Hinge - Cowl Side	Tension	1
Variable Fan Nozzle		
Fan Nozzle Hinge - Nozzle Side	Tension	1
Actuator Link Clevis	Tension	1
Inner Cowl Doors		
Inner Cowl Wall - Curved	Bend - O.D. Comp.	1
Inner Cowl Hinge	Tension	1
Inner Cowl Latch	Tension	1

barrel. These test specimens were made in the same manner and sequence intended for the actual inlet and included the molded holes for the acoustic treatment. For a direct comparison with the flat beam specimens, curved beams were also made with one of the faces (not the acoustic face) precured, even though this configuration was not intended for use in the actual part.

Inlet Axial Manufacturing Joint - In order to fabricate the inlet, there are several axial manufacturing joints which need to be permanently bonded together to form the final inlet configuration. This test evaluated a typical type of axial splice that could be used in the inlet. The objective was to obtain a test failure outside of the splice area to demonstrate that the splice was stronger than the basic structure. The splice tested was a simple butt joint consisting of external overlapping plies of material cured onto both sides of the sandwich structures and spanning the joint area.

4.1.2.2 Outer Cowl Doors

Outer Cowl Wall - The outer cowl doors are basically full-depth sandwich structures with a hole pattern in the inner facing to provide acoustic suppression. Since the average core thickness and the radius of curvature of the outer cowl doors are somewhat different from the inlet, curved beam specimens using the outer cowl dimensions were fabricated and tested to see if the dimensional changes had a significant effect on the apparent strength of the materials used. Due to later design changes, these tests do not reflect the use of graphite/epoxy for the inner skin, nor do they reflect the higher acoustic porosity that was finally selected for the outer cowl doors. The use of graphite for the inner skin, even with the higher porosity, makes these tests conservative.

Piano Hinge - The outer cowl doors are attached to the pylon with an axial piano hinge which permits the doors to be opened for access to the interior of the engine. This subcomponent test investigated the strength of the attachment of the hinge to the outer cowl doors through tension testing of an axial segment of the hinge/door joint.

Outer Cowl Latch - The outer cowl doors are latched together at the bottom centerline by seven hook latches spaced axially along the doors. These latches are attached to metal housings which fit into bathtub-like depressions in the cowl doors and are attached to the doors with mechanical fasteners through the housing flanges into inserts in the door. The latches are loaded by the delta pressure across the cowl doors. This test was intended to verify the attachment of the latch housings to the cowl doors under maximum tensile load on the most critical side of the latch (the hook side). This side is most critical because it requires a smaller housing, and this housing has fewer fasteners to the door than does the housing for the other side of the latch, thus causing a higher load per fastener.

Actuator Mount Attachment - The outer cowl doors house the actuators that drive the variable fan nozzle. These actuators are semiburied in the cowl doors and are attached to them by the actuator fairing which picks up both the end of the actuator and a peripheral pattern of inserts in the door. The purpose of this test was to determine the maximum load the arrangement could withstand in the direction of the actuator pull.

Splitter Attachment - For a portion of the UTW testing, an acoustic splitter will be installed in the fan exhaust stream. This splitter is supported by a total of six struts (three in each door) which are bolted onto the doors. This attachment is loaded primarily in bending due to an axial load on the splitter. This test was intended to determine the adequacy of the joint.

Variable Fan Nozzle Hinge - Cowl Side - In order to provide sufficient flow when the UTW engine is in the reverse mode of operation, a variable fan nozzle is installed at the rear of the fan exhaust which can open up to provide more area when the fan exhaust nozzle is acting as an inlet. This variable nozzle consists of four doors hinged off the outer cowl doors and powered by actuators mounted in the outer cowl doors. This test investigates the attachment strength of the hinge to the outer cowl doors.

4.1.2.3 Variable Fan Nozzle

Variable Fan Nozzle Hinge - Nozzle Side - This test investigates the attachment of the nozzle side of the hinge, mentioned in the above paragraph, to the nozzle door.

Variable Fan Nozzle Actuator Link Clevis - The actuators that power the fan nozzle doors are attached to the doors by the actuator link clevis which is bonded into the forward close-out of the door. This test evaluated the attachment of the clevis fitting to the variable fan nozzle doors.

4.1.2.4 Inner Cowl Doors

Inner Cowl Wall - The QCSEE inner cowl doors are of a glass/polyimide honeycomb sandwich construction utilizing graphite facings impregnated with a polyimide-type resin system called PMR (Polymerization of Monomer Reactants). A typical curved section of the cowl door was fabricated and tested to verify the actual strength of this configuration using the same fabrication procedures and sequences as will be used for the actual part.

Inner Cowl Hinge - The inner cowl doors are hinged to the pylon so that they may be opened for access to the core engine. Due to the saddle shape of the doors, the hinges consist of four discreet hinge points for each door. The hinges are mechanically fastened to the door through reinforced edge close-outs. This test investigates the structural adequacy of the arrangement to withstand normal operating loads.

Inner Cowl Latch - Like the outer cowl doors, the inner cowl doors are latched together at the bottom. A total of seven hook-type latches secure the doors together. They are mounted in the inner cowl doors in a very similar manner as the latches in the outer cowl doors, but, since the inner cowl doors are made of a different material, this test was conducted to verify that the inner cowl latch housing attachment to the graphite/PMR system is structurally adequate.

4.1.3 Test Facilities

Tension/compression facilities for the simpler tests consisted of a Baldwin tensile machine and an Instron tensile machine, both located in the Materials and Process Test Laboratory. The more complex and higher loaded tests were conducted in the Static Load Laboratory.

4.2 TEST RESULTS

A total of 25 individual specimens (Table VIII) were fabricated and tested under this program. The results of these tests are summarized in Table IX and discussed in detail in the following paragraphs.

4.2.1 Inlet Wall

4.2.1.1 Flat Panels

The purpose of these tests was to verify adequate structural strength of the inlet duct sandwich wall and establish validity of the design values used. Six flat sandwich panels, 10.16 cm (4 in.) wide, 50.8 cm (20 in.) long, and 2.54 cm (1 in.) deep were fabricated to simulate the inlet outer barrel wall. Both face sheets were three-ply Kevlar/epoxy material with 0°, 45°, 0° layup and an overall nominal thickness of 0.84 mm (0.033 in.). In half of the specimens the face sheets were precured and then secondarily bonded to the core with film adhesive. In the remainder of the specimens the face sheets were cured and bonded to the core simultaneously in one operation (cocured). In the latter case, the epoxy resin in the prepreg was the sole bonding agent between the face sheets and core.

The core material was aluminum flexcore with 0.048 mm (0.0019 in.) ribbon thickness and a density of 49.657 kg/m^3 (3.1 lb/ft^3). The core cell walls were slotted between joint nodes at the face sheet intersection edges for moisture drainage.

The test specimen panels were 10.16 cm (4.0 in.) wide with a span distance between reaction load strips of 40.64 cm (16 in.). Input load strips were 12.7 cm (5.0 in.) apart, centered between the reaction load strips on the opposite side of the panel. Loading arrangement is shown in Figure 7.

Table IX. Subcomponent Test Results.

Test Specimen Configuration	Condition (1)	Test Mode	Design Load (2)	Average Test Failure Loads
Inlet				
Inlet Wall				
Sandwich Panel - Flat - Precured	a	Bending	51.85 MN/m^2 (7520 psi)	215.05 MN/m^2 (31,190 psi)
Sandwich Panel - Flat - Cocured	a	Bending	51.85 MN/m^2 (7520 psi)	179.20 MN/m^2 (25,990 psi)
Sandwich Panel - Curved - Precured	a	Bend. - O.D. Comp.	51.85 MN/m^2 (7520 psi)	171.89 MN/m^2 (24,930 psi)
Sandwich Panel - Curved - Cocured	a	Bend. - O.D. Comp.	51.85 MN/m^2 (7520 psi)	115.18 MN/m^2 (16,705 psi)
Axial Manufacturing Joint	b	Tension	28.62 MN/m^2 (4152 psi)	213.60 MN/m^2 (30,980 psi)
Outer Cowl Doors				
Outer Cowl Wall - Curved	c	Bend. - O.D. Comp.	29.00 MN/m^2 (4206 psi)	210.60 MN/M^2 (30,545 psi)
Piano Hinge	c	Tension	32347 N (7272 lb)	34474 N (7750 lb)
Outer Cowl Latch	c	Tension	25995 N (5844 lb)	25666 N (5770 lb) (3)
Actuator Mount Attachment	c	Tension	52364 N (11772 lb)	49598 N (11,150 lb) (3)
Splitter Attachment	d	Bending	133 N (30 lb)	5703 N (1282 lb)
Fan Nozzle Hinge - Cowl Side	e	Tension	48040 N (10800 lb)	52267 N (11,750 lb)
Variable Fan Nozzle				
Fan Nozzle Hinge - Nozzle Side	e	Tension	48040 N (10800 lb)	70816 N (15,920 lb)
Actator Link Clevis	c	Tension	13385 N (3009 lb)	59437 N (13,362 lb)
Inner Cowl Doors				
Inner Cowl Wall - Curved	c	Bend. - O.D. Comp.	146.14 MN/m^2 (21195 psi)	157.89 MN/m^2 (22,900 psi)
Inner Cowl Hinge	f	Tension	3737 N (840 lb)	68502 N (154,000 lb)
Inner Cowl Latch	f	Tension	13112 N (2948 lb)	25577 N (5750 lb)

(1) a - 3-g Stall at M = 0.4 at Sea Level
b - Maximum Cruise at M = 0.6 at Sea Level
c - Maximum Cruise at M = 0.92 at 6400 m (21000 ft)
d - Takeoff
e - Jammed Actuator
f - Reverse Thrust

(2) Three times operating load for composites, 1.5 times for metal parts.

(3) Design was strengthened based on this test, but the test was not Rerun.

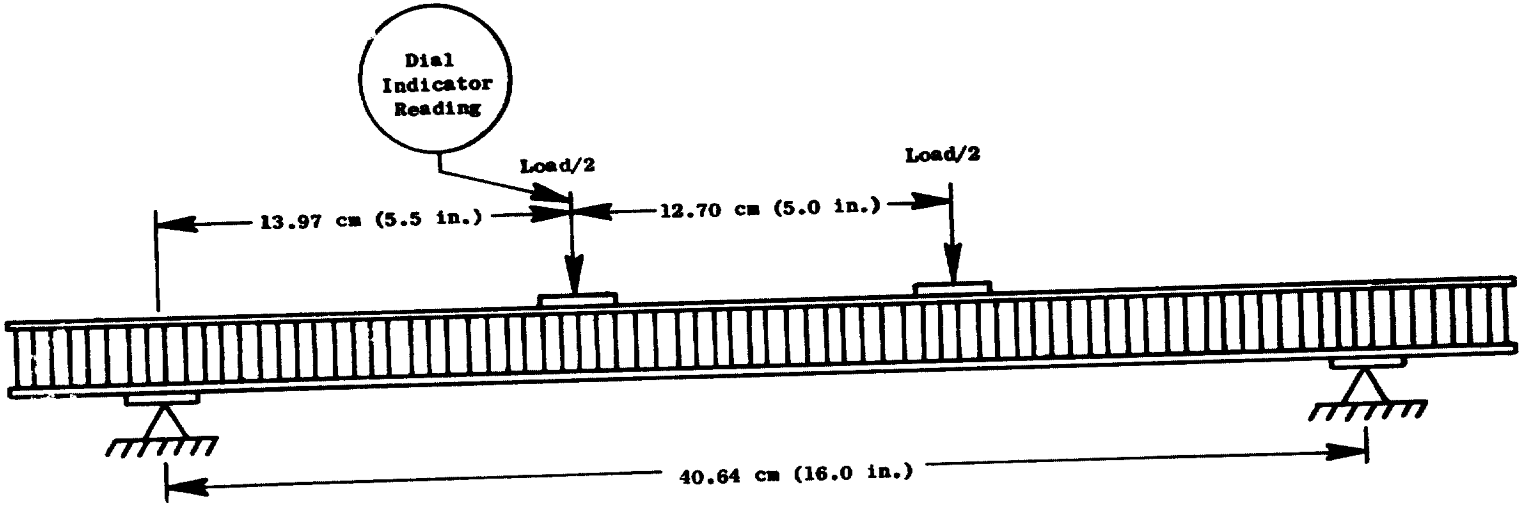


Figure 7. Inlet Wall Flat Sandwich Beam Loading.

After testing the first specimen, the remainder of the specimens were necked down to a 3.81 cm (1.5 in.) or 5.08 cm (2.0 in.) width at the center. This is shown in the photograph in Figure 8. Designations and corresponding characteristics of the six panels tested are tabulated below.

Specimen No.	Face Sheet Fabrication Method	Minimum Width at Center
No. 1 - G01	Precured	10.16 cm (4.0 in.)
No. 2 - G01	Precured	3.81 cm (1.5 in.)
No. 3 - G01	Precured	3.81 cm (1.5 in.)
No. 1 - G02	Cocured	5.08 cm (2.0 in.)
No. 2 - G02	Cocured	5.08 cm (2.0 in.)
No. 3 - G02	Cocured	5.08 cm (2.0 in.)

Panel No. 1 - G01 was tested first. Load was gradually increased at a constant rate until the specimen failed by core shear at 2447 N (550 lb). The remainder of the specimens were necked down, as indicated in the above tabulation, so as to increase the stresses in the face sheets and thus test face sheet compressive strength. Core shear stresses and face sheet tensile/compressive stresses at failure load are shown for each specimen in Table X.

The lowest face sheet compressive strength, 179.2 MN/m^2 (25,992 psi) occurred in cocured specimen No. 1 - G02. This is 260% of the 68.95 MN/m^2 (10,000 psi) design value used. The lowest face sheet compressive strength for a precured specimen (No. 3 - G01) was 211.07 MN/m^2 (30,613 psi) or 306% of the design value. Average of the two face sheet comparative strengths for precured specimens was 215.05 MN/m^2 (31,190 psi) with close correlation between the two specimens. The difference between the precured specimens and the cocured specimen is attributed to:

- Better core-to-face sheet bonding, due to the use of an adhesive, for the precured specimens may produce better stabilization for compressive buckling loads in the face sheets.

- Dimpling of the face sheets in the cocured specimens in conformance with the core cell pattern causes any cross section along the face sheet to be wavy. This makes the face sheet a poorer column in any direction.

- The precured facings are stronger due to better pressure distribution during cure.

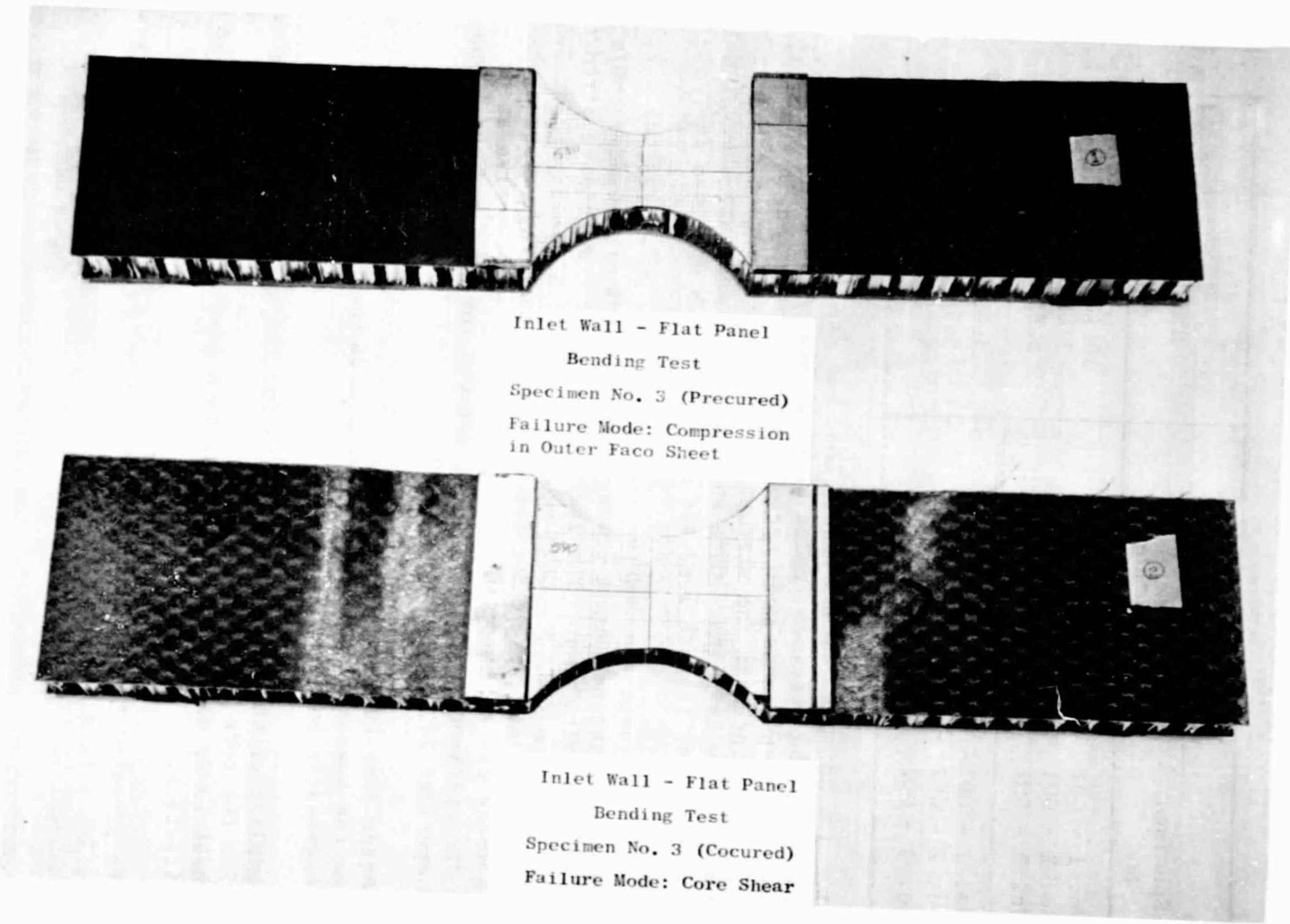


Figure 8. Inlet Wall Flat Sandwich Beam Specimens.

Table X. Flat Panel Bending Test Specimen Stresses at Failure Loads.

Specimen	Face Sheet Fabrication Method	Minimum Width at Center		Failure Load		Failure Mode	Stress at Panel Failure Load			
							Core Shear		Facing Compression	
		cm	in.	N	lb		MN/m^2	psi	MN/m^2	psi
No. 1-G01	Precured	10.16	4	2447	550	Core Shear	0.49	71	82.14	11,913
No. 2-G01	Precured	3.81	1.5	2447	550	Facing Compression	0.49	71	219.03	31,768
No. 3-G01	Precured	3.81	1.5	2358	530	Facing Compression	0.48	69	211.07	30,613
No. 1-G02	Cocured	5.08	2	2669	600	Facing Compression	0.54	78	179.20	25,992
No. 2-G02	Cocured	5.08	2	2491	560	Core Shear	0.50	72	167.26	24,259
No. 3-G02	Cocured	5.08	2	2624	590	Core Shear	0.52	76	176.22	25,559

4.2.1.2 Curved Panels

The purpose of bending tests on the curved sandwich wall panels was to evaluate the effect of curvature and acoustical perforations on the strength of the structure by comparing test results with those from the flat panel bending tests previously described. Six curved panel bending test specimens were fabricated with an inner radius of curvature of 78.74 cm (31 in.). Overall panel thickness; face sheet material, thickness and layup; and core material, cell size, density, and cell wall slotting were identical to the flat panel bending test specimens described above except the inner radius face sheet was perforated with 1.524 mm (0.06 in.) diameter holes spaced to produce a hole area equal to 10% of the total face sheet area. The holes were formed by pushing the plies of prepreg over a "spiked" mandrel which was kept in place during cure. This prevents excessive cutting of Kevlar fibers in obtaining the holes.

In the first four specimens, the face sheets were cocured with the core. In the last two specimens the inner radius face sheet was cocured with the core and a precured outer radius face sheet was secondarily bonded to the core.

The test specimen panels were 10.16 cm (4.0 in.) wide with a span distance between reaction load strips of 40.64 cm (16 in.) as in the case of the flat specimens. The distance between input load strips, however, was reduced to 10.16 cm (4.0 in.). All specimens, except the first one tested, were necked down to a 5.08 cm (2.0 in.) wide section at the center. In all cases the nonperforated outer radius was loaded in compression while the perforated inner radius was loaded in tension. The loading arrangement is shown in Figure 9. Photographs of the test setup are shown in Figure 10.

All panels were loaded at the constant rate until failure. Core shear stresses, outer radius face sheet compressive stresses, inner radius face sheet tensile stresses, and core-to-face sheet flatwise tensile stresses at the outer and inner radii are shown for each specimen at failure load in Table XI. The first panel (not necked down at center) failed by core shear at a load of 3247 N (730 lb). The next three panels, cocured and necked down to a 5.08 cm (2.0 in.) width at the center, failed at loads of 1478, 1632, and 1290 N (332, 367, and 290 lb), respectively. The failures appeared to result from a combination of face sheet compression and core-to-face sheet flatwise tension stresses. The last two panels, with precured outer radius (compression side) face sheets and with centers also necked down to a 5.08 cm (2.0 in.) width, failed at loads of 2104 and 2273 N (473 and 511 lb), respectively. These were entirely face sheet compression failures. Photographs of these panels are shown in Figure 11. All values for face sheet compression and tensile stresses and for core-to-face sheet flatwise tensile stresses include the following effects:

- Bending load from horizontal component of load at reaction points as well as vertical component.

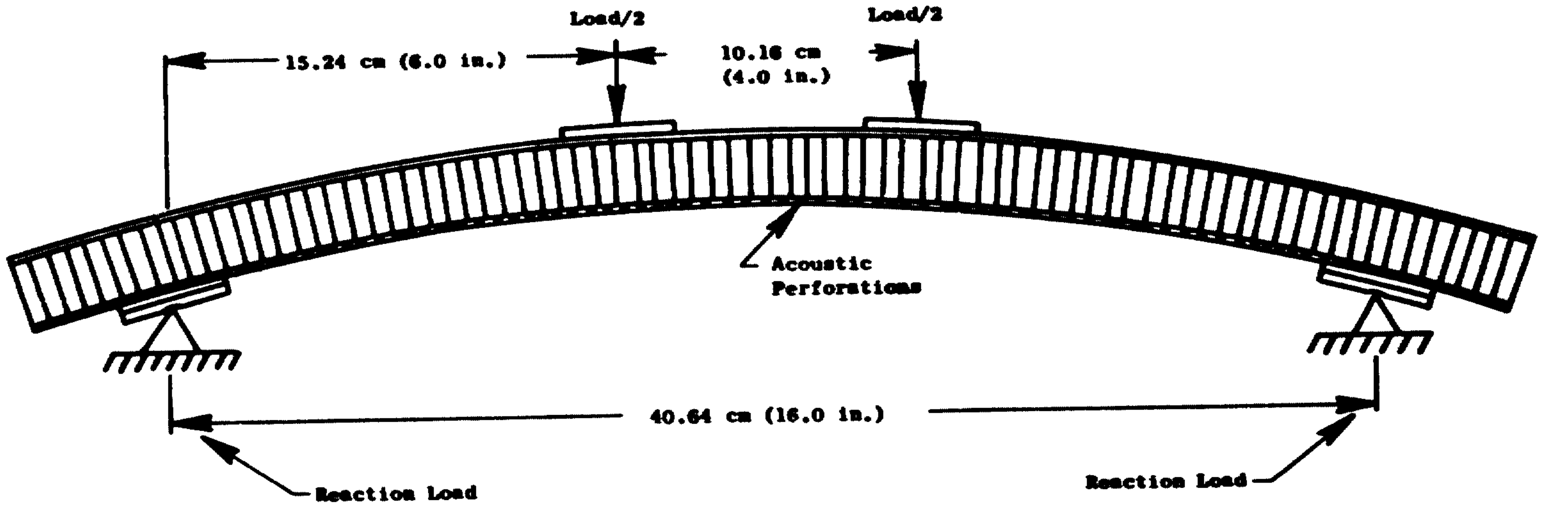


Figure 9. Curved Inlet Wall Sandwich Panel.

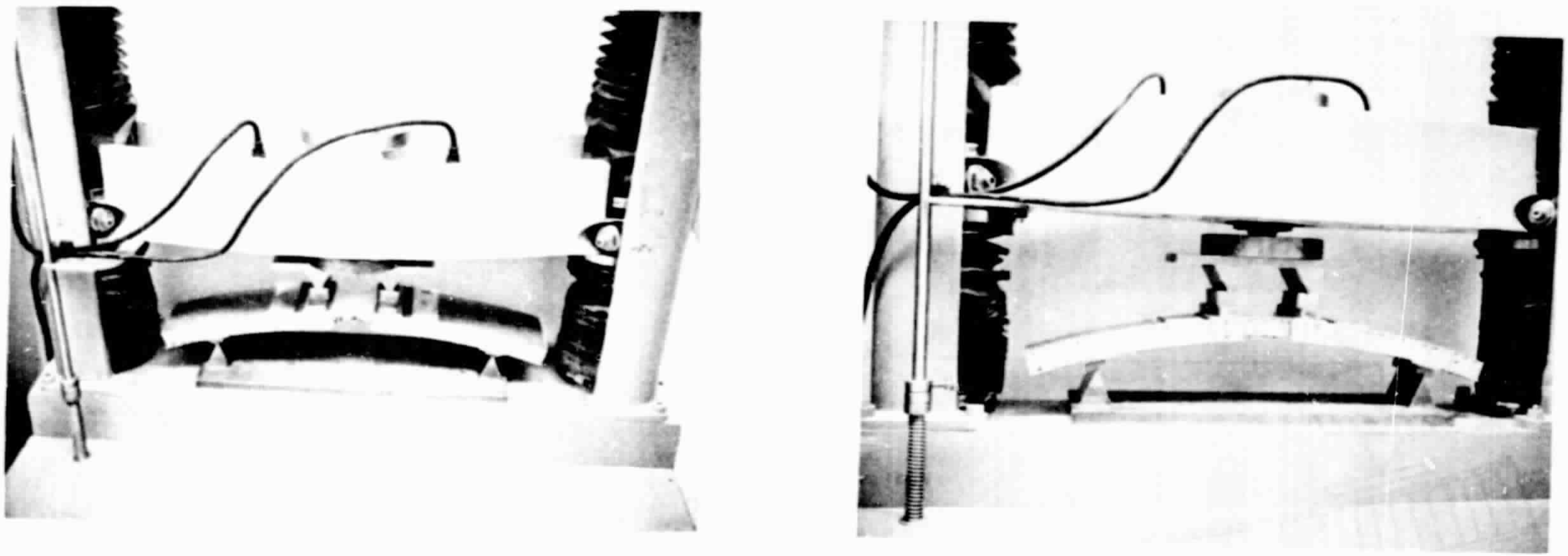


Figure 10. Curved Sandwich Panel Test Setup.

Table XI. Curved Panel Bending Test Specimen Stresses at Failure Loads.

Specimen* No.	Minimum Width at Center		Primary Failure Mode	Calculated Stresses at Panel Failure Load									
				Core Shear		Outer Radius Face Sheet Compressive		Inner Radius Face Sheet Tensile		Core-to-Face Sheet Flatwise Tensile			
										Outer Radius		Inner Radius	
	cm	in.		MN/m^2	psi	MN/m^2	psi	MN/m^2	psi	MN/m^2	psi	MN/m^2	psi
1	10.16	4.0	Core Shear	0.59	86	115.93	16814	201.36	29205	0.12	18	0.16	23
2	5.08	2.0	Flatwise Tension	0.30	43	115.99	16823	201.47	29221	0.12	18	0.16	23
3	5.08	2.0	Face Sheet Comp.	0.32	47	128.22	18597	222.71	32301	0.14	20	0.17	25
4	5.08	2.0	Flatwise Tension	0.26	38	101.32	14695	175.98	25524	0.11	16	0.14	20
5	5.08	2.0	Face Sheet Comp.	0.42	61	165.25	23968	287.04	41631	0.17	25	0.23	33
6	5.08	2.0	Face Sheet Comp.	0.46	66	178.53	25894	310.09	44975	0.19	23	0.24	35

*All inner radius face sheets were cocured. The outer radius face sheets were cocured on specimens 1, 2, and 3 and precured on specimens 4, 5, and 6.

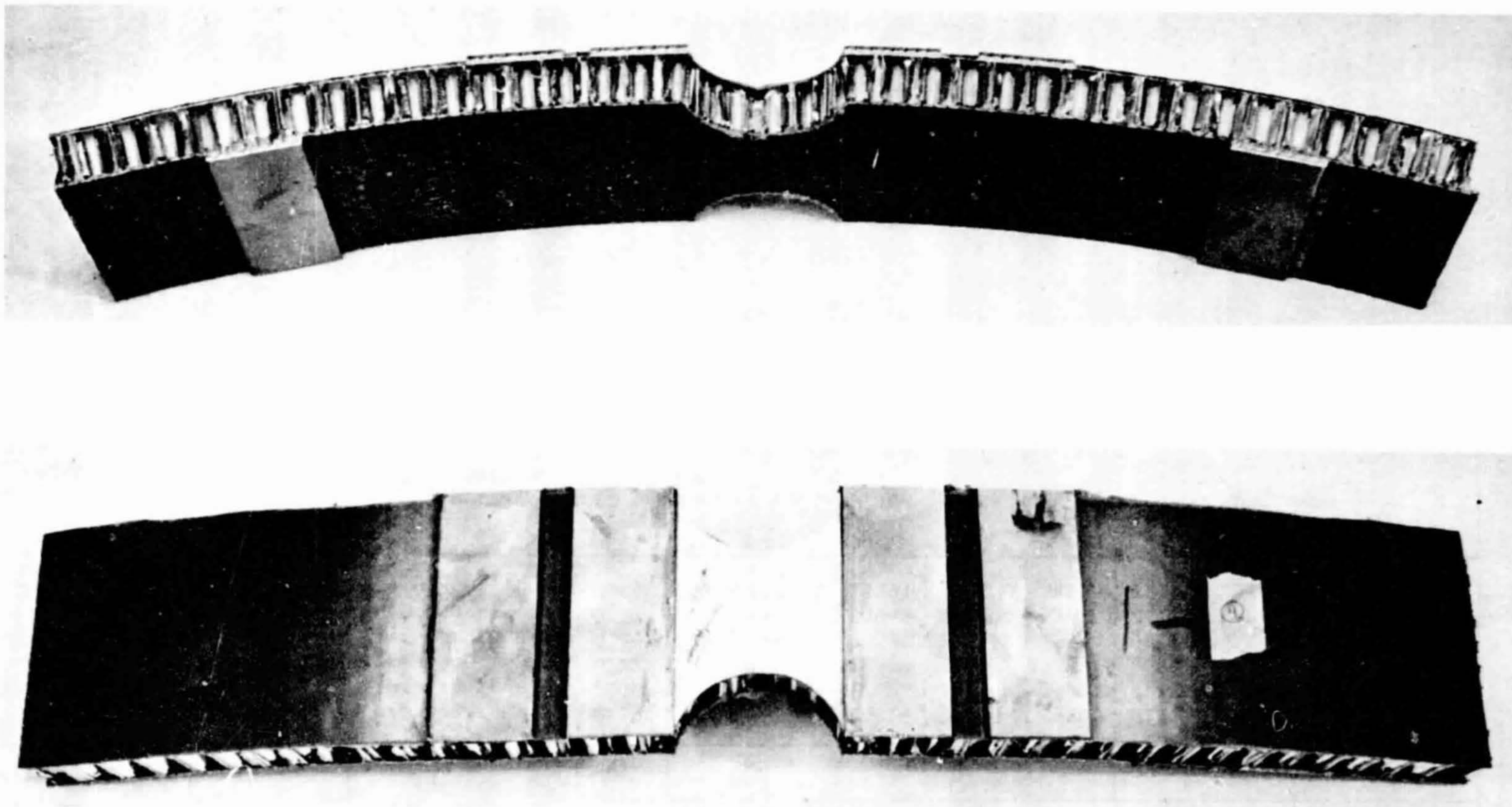


Figure 11. Failed Specimens of Inlet Wall Curved Sandwich Panels.

- Shift of bending neutral axis caused by increased elasticity of inner radius face sheet as a result of acoustical perforations.
- Shift of bending neutral axis caused by panel curvature.
- Direct tensile stresses caused by horizontal component of load at reaction points.

In addition, the inner radius face sheet tensile stresses are based on net cross section between holes. No stress concentration for the holes was included, however.

Effective face sheet compressive strengths are all lower for the curved panels than for the straight panels. The average reduction for cocured panels is 36% while the average reduction for precured panels is 20%.

In conclusion, the average compressive strength of the precured Kevlar/epoxy face sheets in curved panels was 171.89 MN/m^2 (24,931 psi). This is 80% of the straight panel value and is 2.5 times as strong as the 68.95 MN/m^2 (10,000 psi) design value used. The compressive strength of the cocured Kevlar/epoxy face sheets in curved panels is 128.22 MN/m^2 (18,597 psi). This is 72% of the straight panel value and is 1.86 times as strong as the design values used. The design requirement was 51.85 MN/m^2 (7520 psi).

4.2.2 Inlet Axial Manufacturing Joint

The purpose of the inlet axial joint test was to verify the structural capacity of a typical joint design for this type of structure. The splice test specimen consisted of butting two sandwich panels together and joining them with external plies of glass/epoxy as shown in Figure 12.

Construction of the panel to be spliced was identical to that used for the straight panel bending tests (see Section 4.2.1) in terms of face sheet material and layup and core material and configuration. The 0° direction and core ribbon direction were perpendicular to the long direction of the panel, however, to simulate the intended relationship with the splice in the actual part. The face sheets were precured.

The splice for each face sheet consisted of three plies of style 181 glass/epoxy externally bonded-on as shown in Figure 12.

The panel was originally 25.4 cm (10.0 in.) long and 10.16 cm (4.0 in.) wide with the spliced joint running across the panel at the center of the 25.4 cm (10.0 in.) length. A 3.175 mm (0.125 in.) thick steel plate was bonded to each face sheet on each end (four plates total) as load transmission adaptors to load pick-up connections on the tensile test machine. The plates overlapped the ends of the panel about 3.81 cm (1.5 in.), leaving about 17.78 cm (7.0 in.) between the edges of the steel plates.

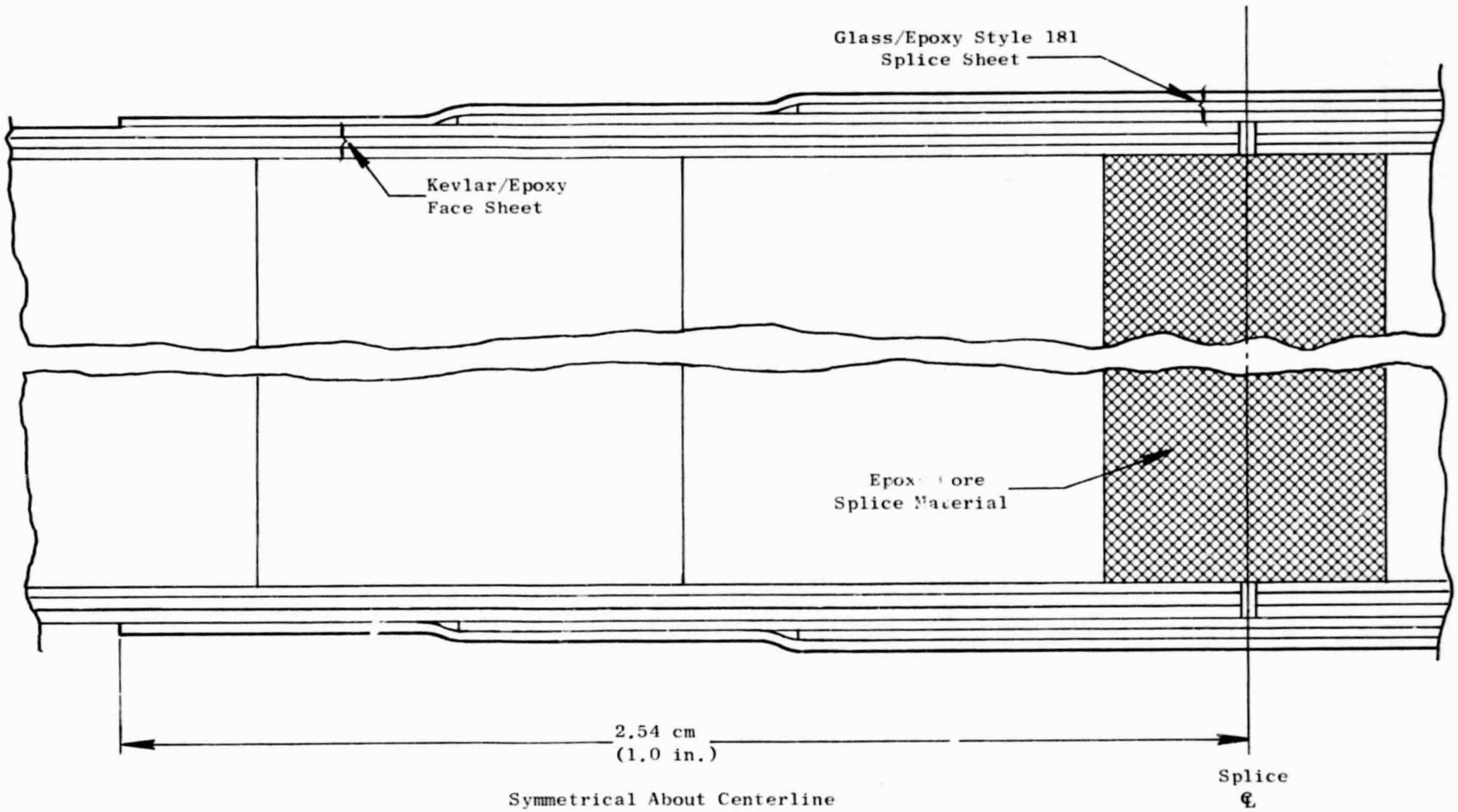


Figure 12. Inlet Manufacturing Joint Splice Test Specimen.

The load was gradually increased at a constant rate until the specimen failed in face sheet tension (one face sheet) and combined tension/interlaminar shear (the other face sheet) adjacent to the termination point of the bonded-on load adapter plates at one end. Failure load was 29.358 kN (6600 lb). Photographs of the test setup and failure (upper end of specimen in the picture) are shown in Figure 13.

Since the specimen failed without showing the ultimate strength of the splice, and since the failure point was near one end of the specimen, the specimen was repaired for a second test. The repair was accomplished by removing the separated end of the specimen from the steel load-adaptor plates and bonding the plates to the shortened specimen.

The specimen failed in the second test at a load of 32.472 kN (7300 lb). The failure mode was very similar to that of the first test except that both face sheets failed in combined tension/interlaminar shear.

Since the specimen again failed without demonstrating the joint strength, the specimen was again repaired for a third test. This time the specimen was necked-down to a 3.81 cm (1.5 in.) width at the midpoint of the splice to ensure a test of joint strength.

On the third test the specimen failed at a load of 14.056 kN (3160 lb). This was caused by tensile failure of the splice sheets (both sides) at the point where the face sheets of the spliced pieces butted. A photograph of the failed specimen is shown in Figure 14.

Calculated average splice sheet and face sheet tensile stresses and adhesive shear stresses at failure load are shown for each test in Table XII. Stresses at the failure locations are starred.

These tests verified that the splice design tested will meet strength requirements in the intended application. The splice sheet was supporting 184.4 kN/m (1053 lb/in.) at the time of failure in test No. 3. This indicates the capability of inducing a 213.6 MN/m^2 (30,980 psi) stress in the face sheets and thus exceeds the design compressive load by more than a factor of three.

4.2.3 Outer Cowl Wall

Outer wall sandwich curved panel tests were very similar to the curved panel tests conducted for the inlet and discussed in Section 4.2.1. The differences were in the slightly larger radius of curvature, 96.77 cm (38.1 in.) versus 78.74 cm (31 in.), for the outer cowl wall and the greater core thickness, 3.3 cm (1.3 in.) versus 2.54 cm (1.0 in.). In addition, the inner face of the outer cowl test specimen was not acoustically treated. Two 10.16 cm (4.0 in.) by 50.8 cm (20.0 in.) specimens were fabricated. The first specimen was loaded as shown in Figure 9. This specimen, as with the constant-width curved inlet specimens, failed in core shear at a core shear

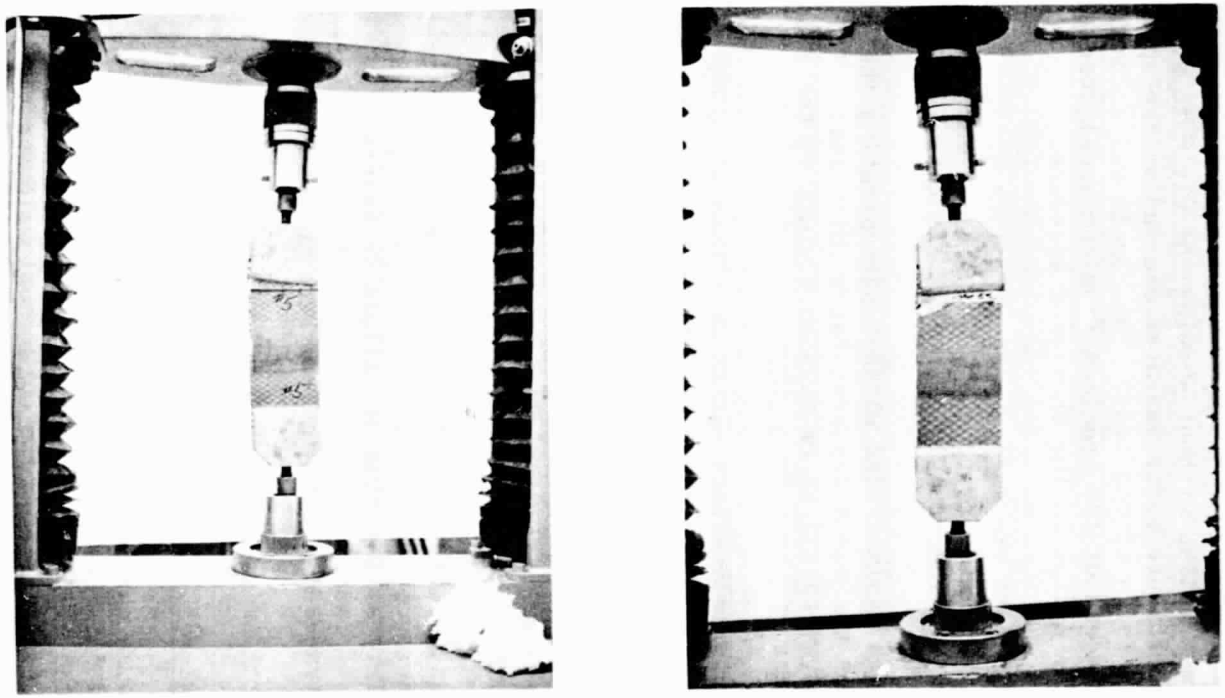


Figure 13. Inlet Manufacturing Joint: Test Failure No. 1.

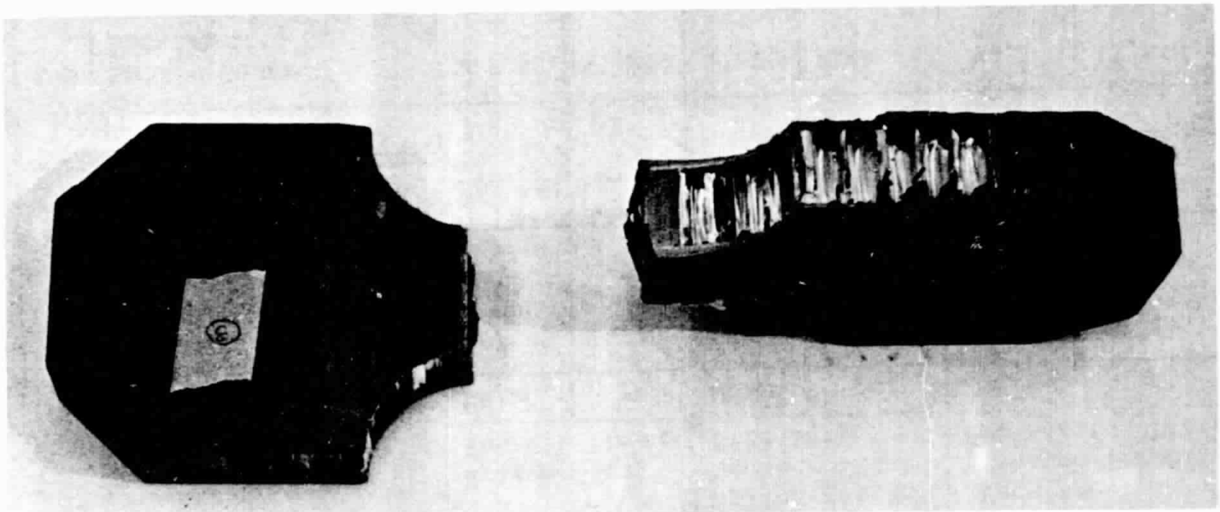


Figure 14. Inlet Manufacturing Joint: Test No. 3 Failure.

Table XII. Axial Splice Test Specimen Stresses at Failure Loads.

Test No.	Test Width		Failure Mode	Calculated Average Stresses at Failure Load							
				Splice Sheet Tensile Stress		Splice Sheet-to-Face Sheet Bond Stress		Face Sheet Tension Stress at Adaptor Plate		Face Sheet-to-Adaptor Bond Stress	
	cm	in.		MN/m^2	psi	MN/m^2	psi	MN/m^2	psi	MN/m^2	psi
1	10.16	4	Face Sheet Tension and Combined Face Sheet Tension/Interlaminar Shear	167.30	24,265	5.69	825	167.30	24,265	3.79	550
2	10.16	4	Combined Face Sheet Tension/Interlaminar Shear	182.51	26,471	6.21	900	182.51	26,471	4.14	600
3	3.81	1.5	Splice Sheet Tension	213.60	30,980	7.26	1053	80.1	11,618	1.81	263

stress of 0.62 MN/m^2 (90 psi). The second specimen was necked down in the test section to a width of 3.81 cm (1.5 in.). This specimen failed at a facing compressive stress of 210.6 MN/m^2 (30,545 psi). This stress is more than three times the 68.95 MN/m^2 (10,000 psi) used as an allowable stress for the outer cowl design; the actual design requirement is 29 MN/m^2 (4206 psi). Photographs of the failed specimens are shown in Figure 15.

4.2.4 Outer Cowl Piano Hinge

The piano hinge subcomponent specimen simulated a portion of the outer cowl comprising a section of the honeycomb sandwich bondment, the upper axial close-out, and one piano hinge segment. This panel section was 3.3 cm (1.30 in.) thick by 20.32 cm (8 in.) wide by 22.1 cm (8.7 in.) long. The piano hinge segment was attached to this panel by means of two flush-head screws threaded into inserts bonded in the honeycomb section and three protruding head fasteners through the inner leg of the close-out and the inner skin. The materials, configurations, and the number and location of fasteners were the same as in the outer cowl door design. Bonded to the end of the honeycomb panel was a steel block and trapezoidal load-distributing plates. Pinned to the piano hinge was an aluminum block machined to match the piano hinge at one end with a threaded hole at the other for an eyebolt connection.

The test panel was mounted in an Instron tensile/compression testing machine by means of eyebolts in each end of the test specimen and an increasing tensile load applied. The test was stopped at 6672 N (1500 lb) when excessive deflection was noted. Examination of the specimen revealed that the outer skin had failed in bearing at the inserts and that the inserts had started to pull out due to a tension load. This tension loading was from a resistance to the overturning moment from the hinge segment. As this failure load was considerably less than the loading of 32.347 kN (7272 lb) required for a composite factor of safety of three, the joint attachment was redesigned as follows:

- The two (2) flush-head screws and inserts were removed and replaced with four (4) flush-head blind fasteners of the "jo-bolt" type.
- A 0.13 cm (0.050 in.) thick stainless steel strip was added internally to the bondment between the close-out leg and the honeycomb core. This strip serves as a backup plate against which to pull the formed head of the blind bolt and to distribute the fastener loading.

The test specimen was modified accordingly and the test repeated. Failure occurred at an applied load of 34.474 kN (7750 lb) when the heads of three (3) of the blind fasteners simultaneously separted from their shanks due to a tension force. Examination of the specimen revealed no other damage. The predicted failure was 32.472 kN (7300 lb) in fastener tension. As the failure load was 3.2 times the calculated limit load, with no failures in any of the other components, the design requirements for these components were met. A photograph of the failed test specimen is shown in Figure 16.

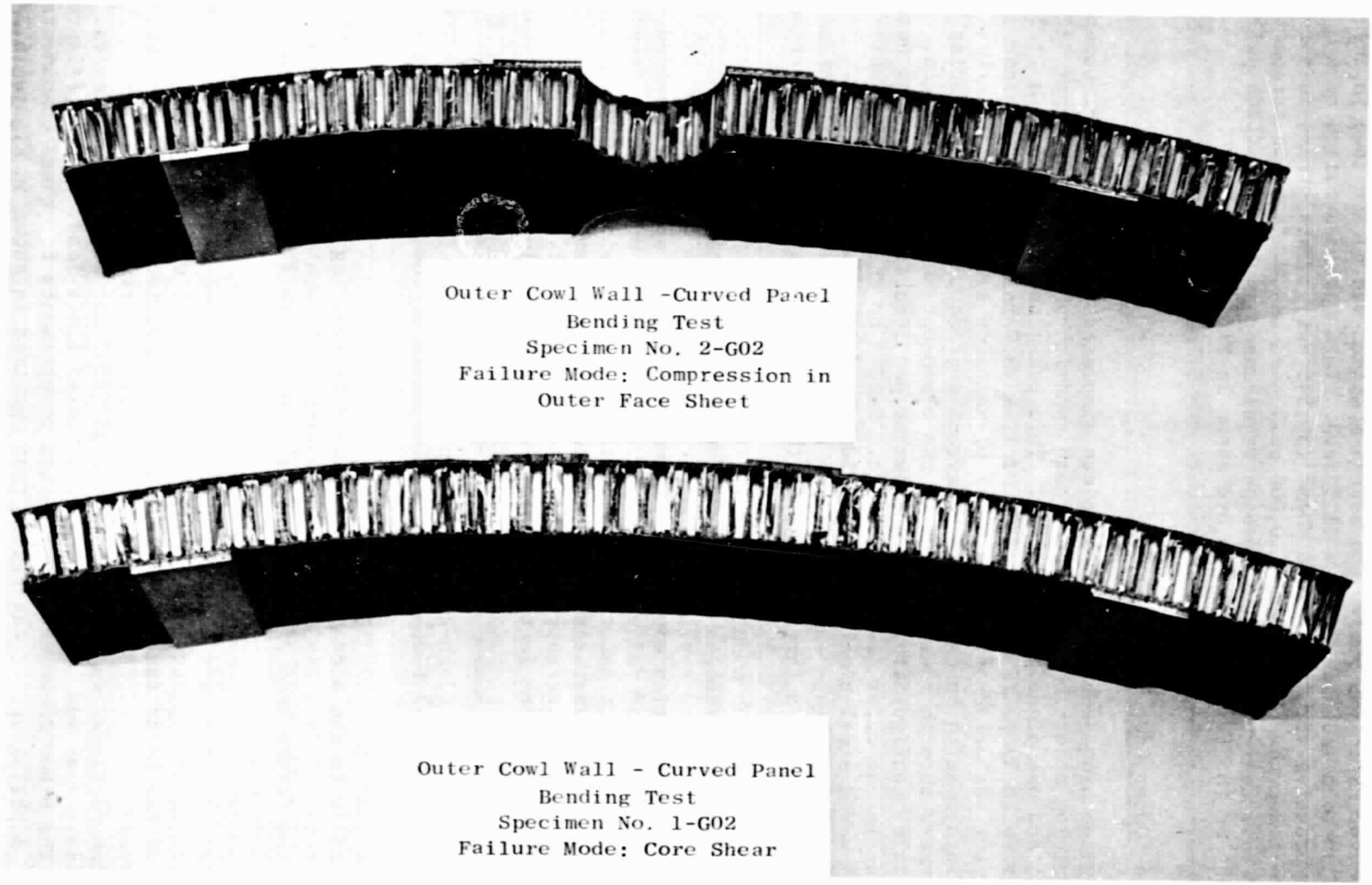


Figure 15. Outer Cowl Wall Curved Panel Test Specimens.

Figure 16. Outer Cowl Piano Hinge Test Specimen After Test.

4.2.5 Outer Cowl Latch

The outer cowl latch test specimen consisted of a honeycomb sandwich panel 20.32 cm (8 in.) wide by 19.05 cm (7.5 in.) long simulating a portion of the outer cowl containing a latch pan. The materials, dimensions, and hardware were the same as those in the actual outer cowl door with the exception that the panel was made flat (no circumferential curvature) and the inner skin was made from Kevlar/epoxy rather than the graphite/epoxy of the actual cowl, this being a design change made after fabrication of the test specimen. As the load is a tension load on the latch and the critical stress area is in the outer skin, which remains Kevlar/epoxy, it was deemed that these differences would have no effect on the test results. A steel block, along with trapezoidal load-distributing plates, was bonded to one end of the panel. As the latch is a proven, off-the-shelf, vendor-supplied piece of hardware, it was not a component in the test; the latch and latch housing were simulated by single-piece aluminum machining. One end of this machining was manufactured to the configuration of the latch housing (i.e., identical flanges, external contour, fastener holes) and the other end was internally threaded to accommodate an eyebolt fitting. This machining was attached to the simulated cowl panel by flush-head fasteners of the same type used in the actual nacelle.

The test specimen was mounted in an Instron tensile/compressive testing machine by means of eyebolts in the ends of the latch housing machining and the sandwich panel. An increasing tensile load was applied until ultimate failure occurred at 25.666 kN (5770 lb) (see Figure 17). Examination of the part revealed that one of the inserts in the honeycomb had insufficient adhesive surrounding it, thereby providing inadequate support for the insert; this allowed the insert to transfer the full load to the outer skin, causing the skin to fail in bearing. In addition, the cylindrical portion of the flush holes in the housing flanges had yielded in bearing.

The maximum calculated load for this installation is 8.665 kN (1948 lb) resulting in a design requirement (3 × limit load) of 25.995 kN (5844 lb) versus the failure load of the specimen 25.666 kN (5770 lb).

In order to assure an adequate safety margin in the actual cowl, the following design changes were instituted:

- The insert was changed to a type with a thicker flange for a greater bearing area in the skin and with adhesive fill holes in the flange to assure that adequate adhesive would flow around the insert during installation.

- The thickness of the latch housing was increased and the cylindrical portion of the fastener hole was reduced in diameter so that this part of the hole can carry the entire fastener load in bearing without relying on the conical portion of the hole for support.

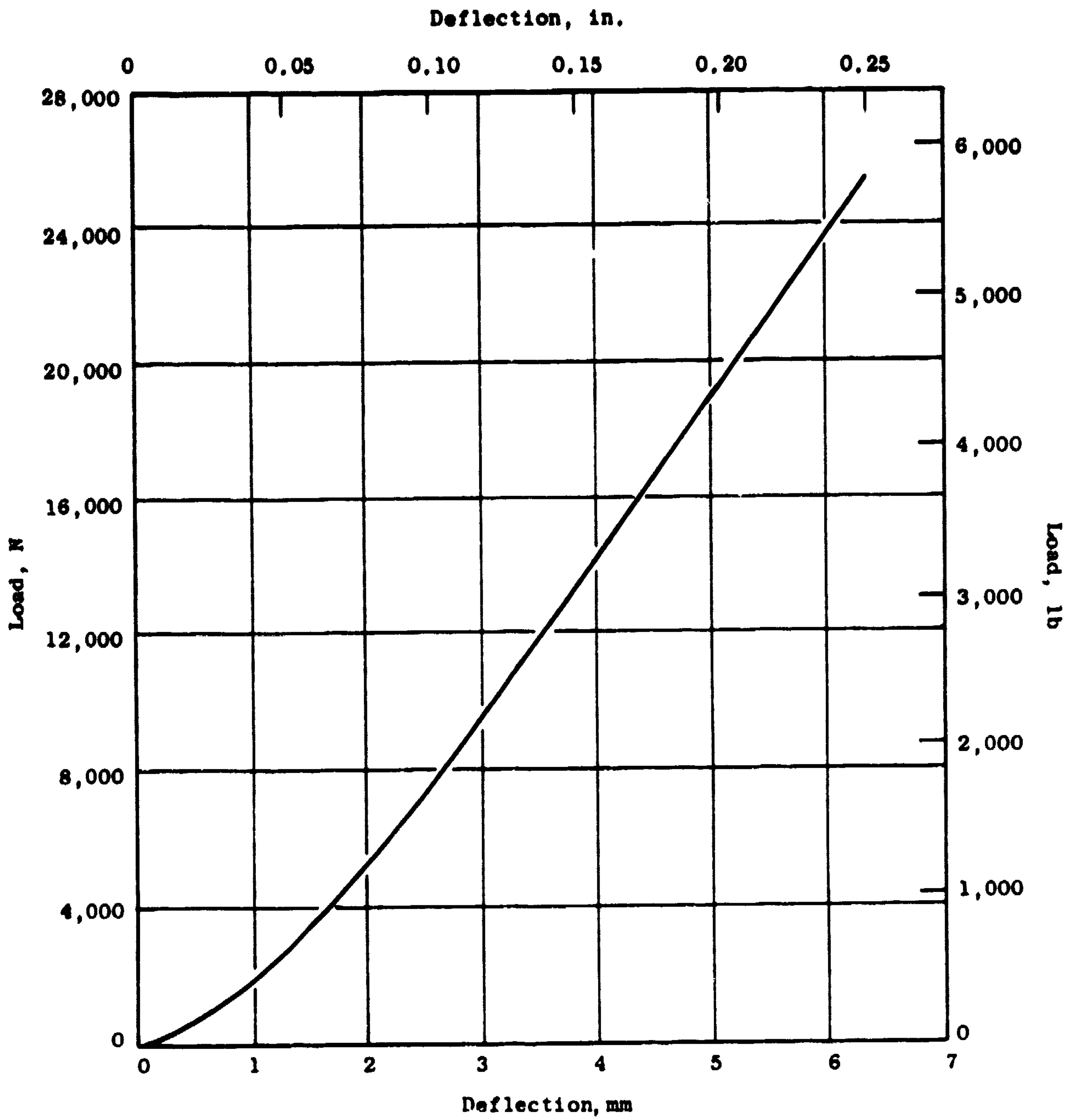


Figure 17. Outer Cowl Latch Test, Load Vs. Deflection.

Since the strength of the specimen without these design changes was so close to the design requirement, this test was not repeated with the changes incorporated. A photograph of the failed specimen is shown in Figure 18.

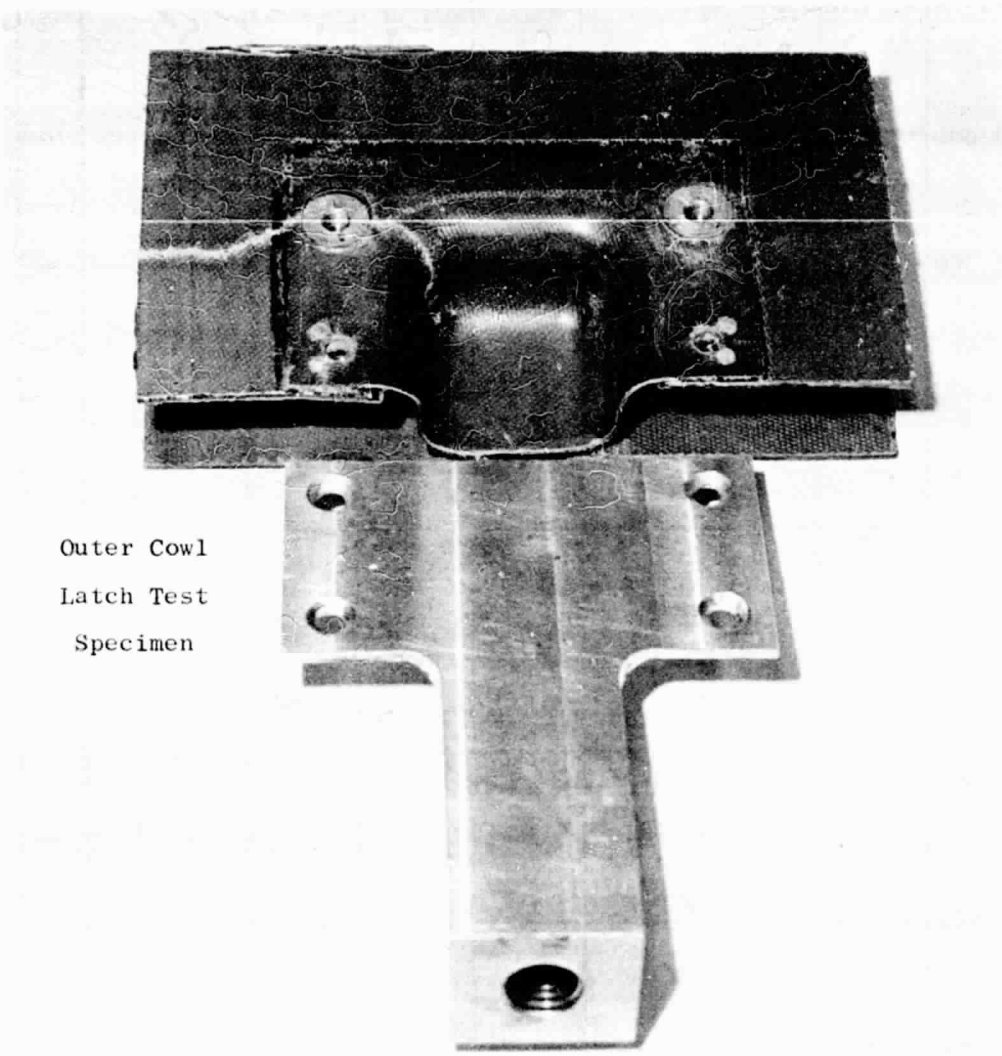
4.2.6 Actuator Mount Attachment

The actuator mount subcomponent test specimen simulated a 22.86 cm (9 in.) by 35.56 cm (14 in.) portion of the outer cowl honeycomb sandwich containing the actuator mount and covering an area from just aft of the mount to the forward end of the actuator cover. As the actuator cover is a load-carrying member, it was simulated by a flat aluminum plate doweled to the mount and bolted to the sandwich panel, the number and location of the fasteners being the same as in the actual part. A steel spacer block with trapezoidal load-distributing plates was bonded to the forward end of the specimen for attachment to the tensile testing machine by an eyebolt. The materials and dimensions of the test specimen were the same as those in the cowl with the exception that the specimen was made flat instead of curved. As the load in this case is normal to the curve, the deviation was postulated to have negligible effect on the test results. The specimen was pulled to a total load of 49.598 kN (11,150 lb) at which time failure occurred (see Figure 19). Prior to that load, the deflection curve started to deviate from a constant deflection rate versus load at approximately 40.924 kN (9200 lb). Examination of the specimen showed that the access cover fastener most forward insert had pulled loose due to a tensile load attributed to the overturning moment from the actuator mount, this occurring at the 40.924 kN (9200 lb) point. When this happened the full bending load was transferred back to the honeycomb panel at the mount attachment. Continued application of an increasing load then caused the Kevlar outer skin to fail in tension at the applied load of 49.598 kN (11,150 lb). The maximum load capable of being transmitted by the actuation system is 17.455 kN (3924 lb). This gives the design a factor of safety of 2.86 versus a design requirement of 3.0. In order to increase the safety factor the following design changes were made:

- Another cover fastener was added at the most forward attachment location, doubling the tension (pull out) capability at this point.
- A two-ply doubler was added to the Kevlar outer skin in the area of the actautor access covers and mounts increasing the skin tensile strength from 227.7 KN/m (1300 lb/in.) to 437.8 KN/m (2500 lb/in.). Due to the closeness of the test result to the design requirement, this test was not repeated with the design improvements included. A photograph of the failed test specimen is shown in Figure 20.

4.2.7 Splitter Strut/Outer Cowl Attachment Test

The fan duct splitter strut attachment specimen consisted of a honeycomb sandwich panel, 20.32 cm (8 in.) wide by 45.72 cm (18 in.) long, which simulated the portion of the outer cowl wall in the area of the splitter strut



Outer Cowl
Latch Test
Specimen

Figure 18. Failed Outer Cowl Door Latch Specimen.

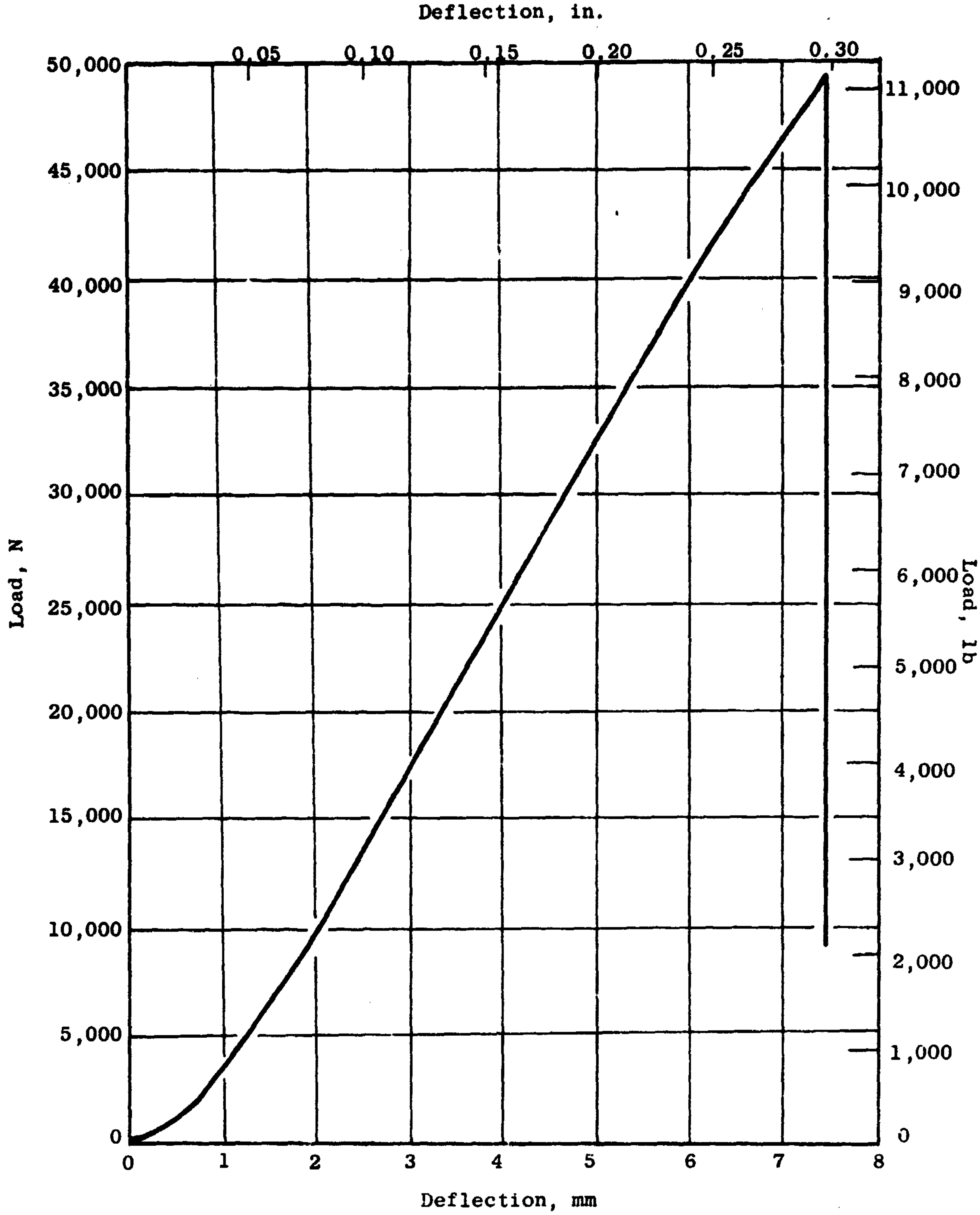


Figure 19. Actuator Mount Test, Load Vs. Deflection.

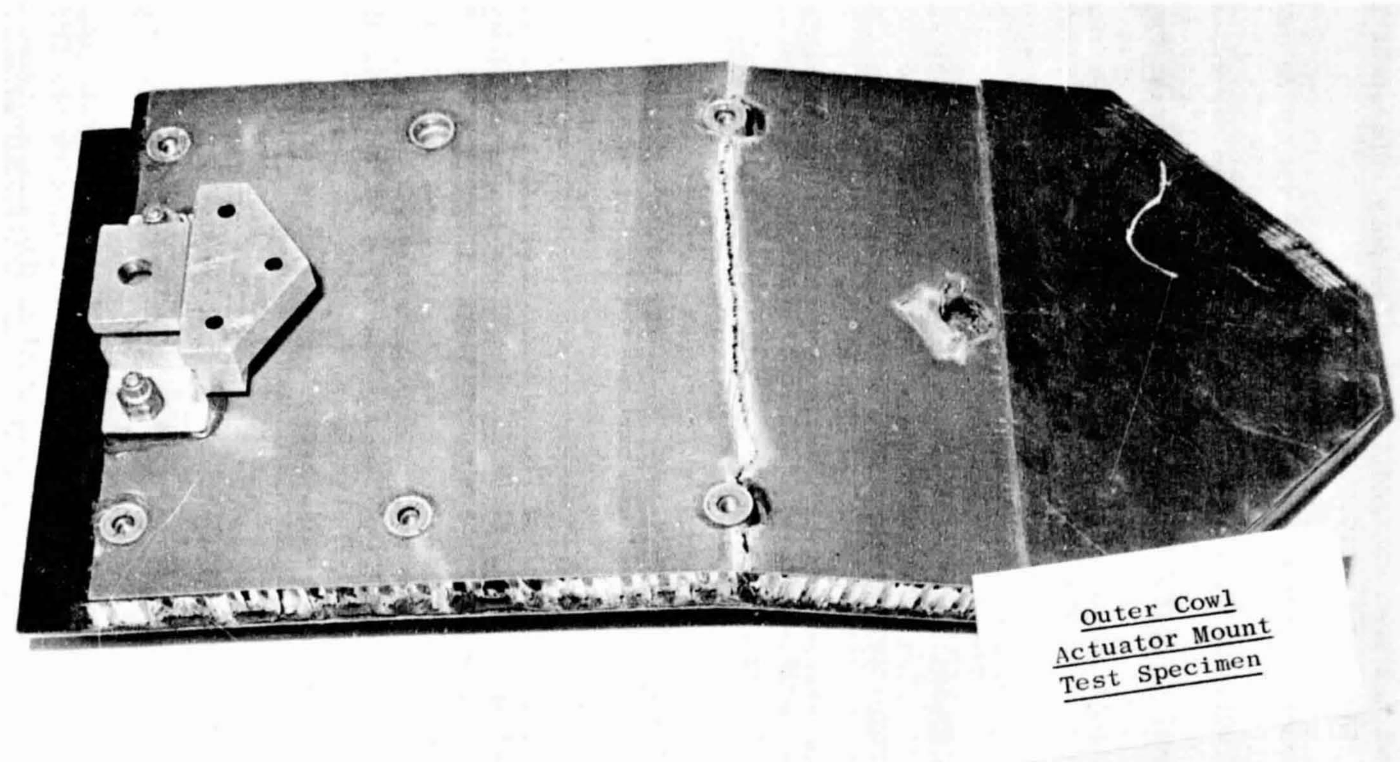


Figure 20. Failed Actuator Mount Test Specimen.

attachment. The materials and dimensions of the panel were the same as those for the actual outer cowl, including potting in the honeycomb for through fasteners, with the exceptions that the panel was made flat (no circumferential curvature) and the inner skin was Kevlar with no perforations. The inner skin on the cowl had been changed to graphite/epoxy subsequent to the fabrication of the test specimen.

As the amount of curvature in a 20.32 cm (8.0 in.) wide section of the cowl is very slight [5.08 mm (0.2 in.)], the absence in the test panel was deemed to have very little effect on the test results. In addition, the use of graphite/epoxy inner skins in the actual cowl gives the cowl slightly better structural properties over those obtained from Kevlar/epoxy skins (except for tension in the axial direction where they are equal). Thus it can be assumed that the actual part is as good as, or better than, the test specimen (depending on the stress mode). In addition, the forward and aft ends of the panel honeycomb were filled with potting compound for a depth of two cells for clamping of the specimen to the test bed.

A 7.62 cm (3 in.) wide by 35.56 cm (14 in.) long by 0.64 cm (0.25 in.) thick steel plate simulated the splitter strut foot. Welded to it was a 1.27 cm (0.50 in.) thick triangular plate, 35.56 cm (14 in.) wide at the base and 26.67 cm (10.50 in.) high, which simulated the splitter strut. A load-application hole was located at the apex of the triangular plate, 25.4 cm (10 in.) from the face of the foot. This simulated strut was fastened to the test panel by 18 through bolts, the same as the actual design.

The test specimen was mounted on blocks located under the potted ends of the panel and clamped to the floor. An axial actuator with an intermediate 22.241 kN (5000 lb) load cell was secured to the hole in the triangular plate (see Figure 21).

An increasing tension load from the actuator was applied until ultimate failure occurred at 5.703 kN (1282 lb). Failure consisted of a shearing of the panel along the edge of the support block closest to the actuator support (see Figure 22). The drag load from the splitter at a point equivalent to the actuator attachment location is approximately 44 N (10 lb). In addition, the portion of the splitter weight supported by a strut is equal to 182 N (41 lb). The outer cowl/splitter attachment is therefore more than capable of supporting the boilerplate splitter.

4.2.8 Fan Nozzle Hinge - Cowl Side

The fan nozzle hinge clevis test specimen simulated a portion of the outer cowl containing the aft ring, the sandwich bondment, and the hinge clevis. The specimen was 15.24 cm (6 in.) wide by 28.58 cm (11.25 in.) long with a steel block and load-transmittal plates bonded to the forward end. The materials, dimensions, and fasteners were the same as those of the actual components with the exception that the specimen was made flat rather than curved. As the load is a tensile force normal to the curve, it was postulated that this deviation would have negligible effect on the test results.

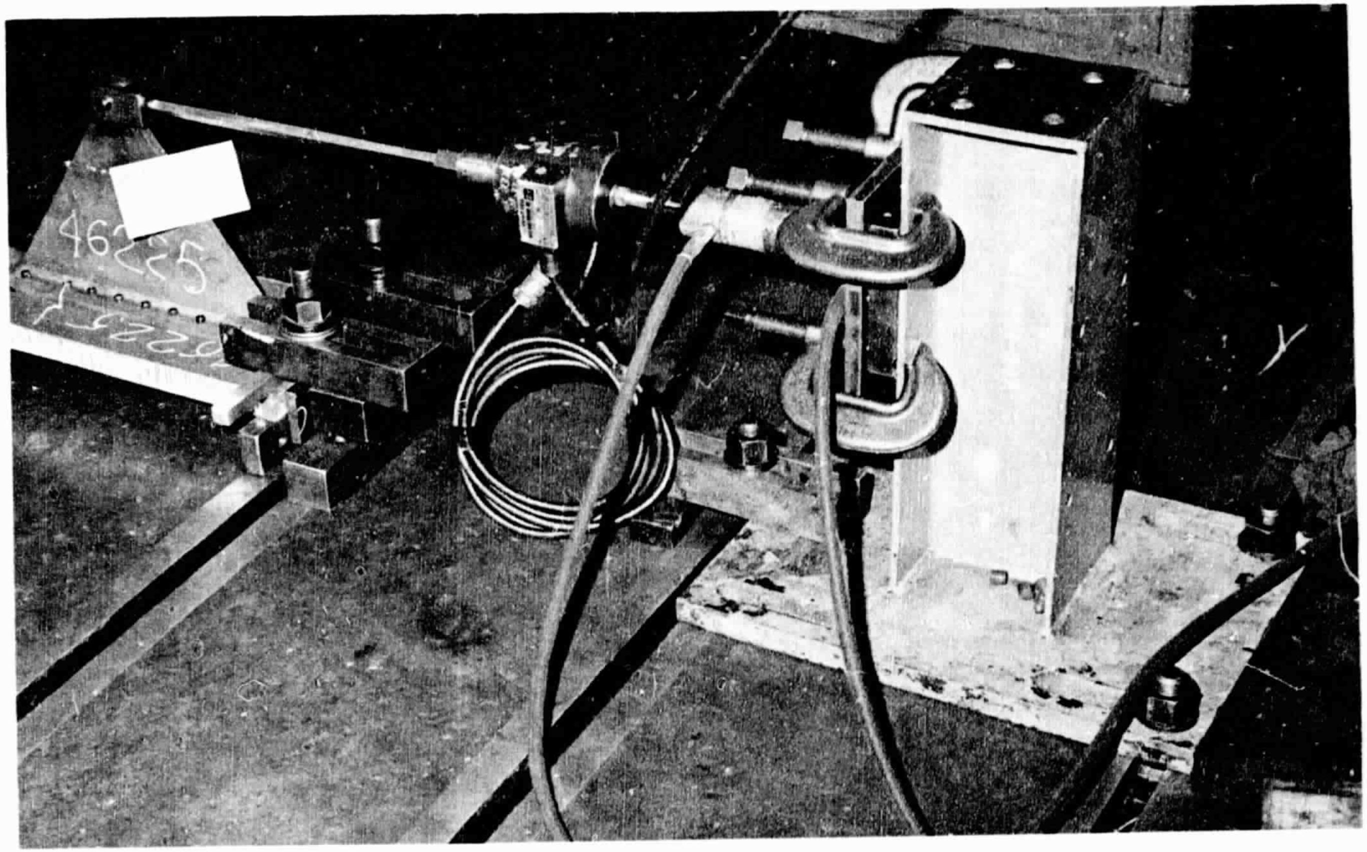


Figure 21. Splitter Attachment Subcomponent Test Setup.

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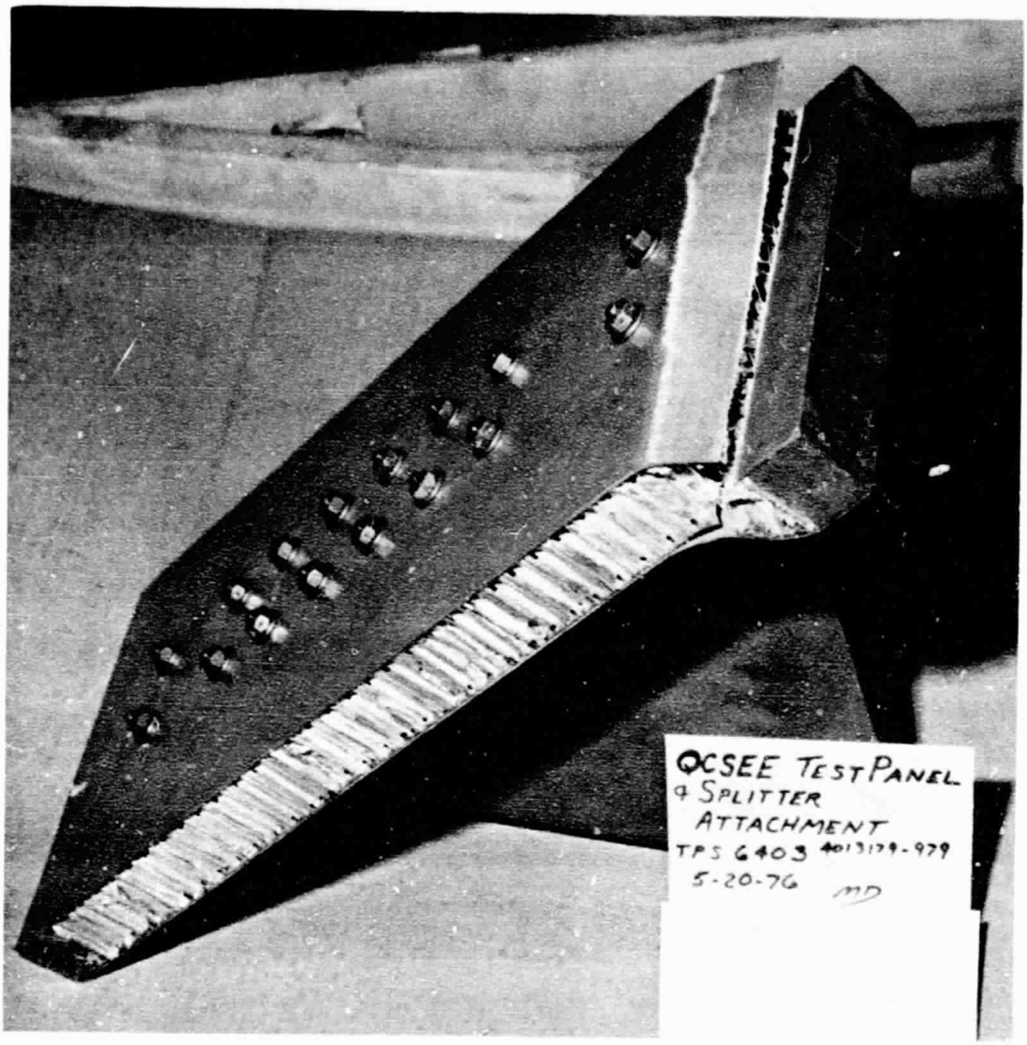


Figure 22. Splitter Attachment Subcomponent Failure.

The test specimen was mounted in an Instron testing machine by means of a pin through the hinge clevis and an eyebolt threaded into the steel block. An increasing tensile load was applied until a bearing/shearout failure of the aluminum clevis lugs occurred at a load of 52.267 kN (11,750 lb).

The predicted failure load for this component was 55.096 kN (12,386 lb) and the design requirement (3 × limit load) was 48.048 kN (10,800 lb). The failed specimen is shown in Figure 23.

4.2.9 Fan Nozzle Hinge - Flap Side

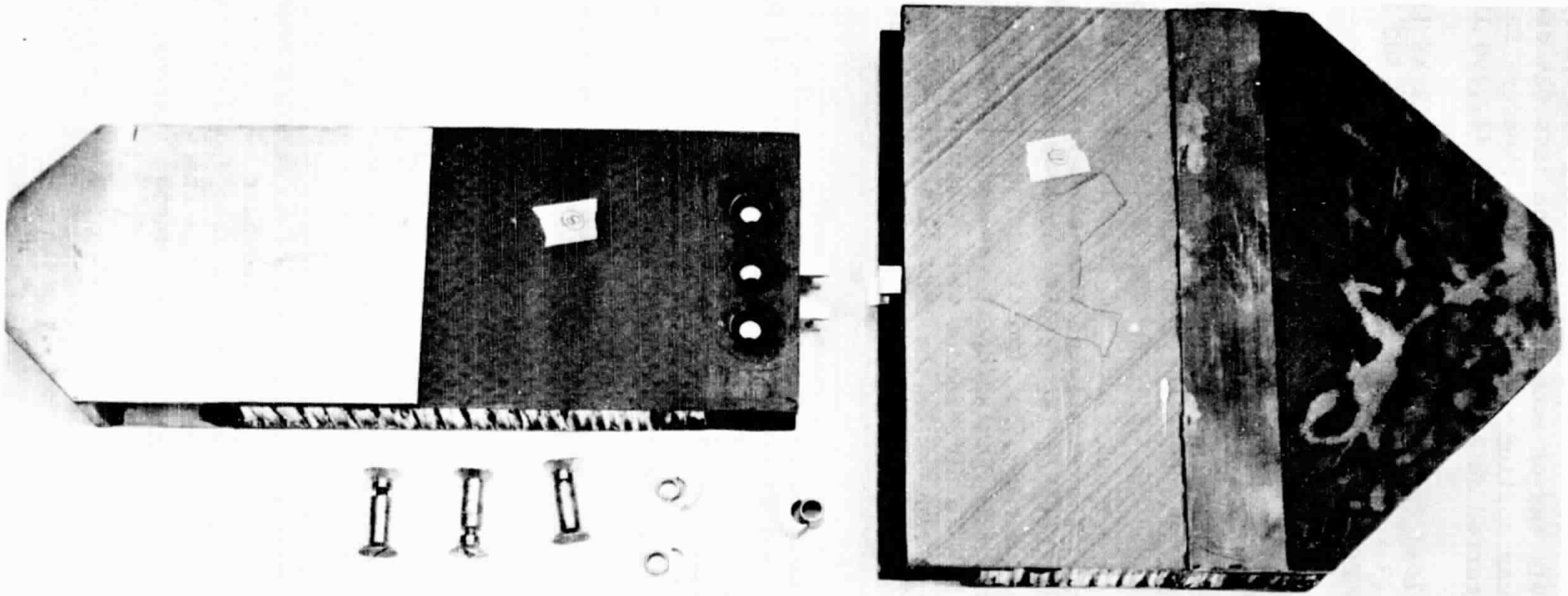
The fan nozzle hinge subcomponent test specimen simulated a portion of the variable fan nozzle containing the honeycomb bondment with the forward close-out and the integral lug. The specimen was 30.48 cm (12 in.) wide by 22.23 cm (8.75 in.) long with a steel block and trapezoidal load-transmitting plates bonded to the aft end. The materials, dimensions, and method of fabrication were the same as those of the actual components, with the exception that the specimen was made flat (no circumferential curvature) and the inner skin was fabricated from Kevlar/epoxy versus graphite/epoxy, which was a later design change. These differences were postulated to have negligible effect on the test results as the load is normal to the curvature and the critical stress area was determined to be in the hinge lug and not the skins.

The test specimen was mounted in an Instron testing machine by means of a pin through the hinge lug and an eyebolt threaded into the end block. An increasing tensile load was applied until a bearing/shearout failure of the hinge lug occurred at an applied load of 70.816 kN (15,920 lb).

The predicted failure load was 67.257 kN (15,120 lb) based on allowable material strengths, and the design ultimate load (3 × limit load) is 48.041 kN (10,800 lb). A photograph of the failed specimen is shown in Figure 23.

4.2.10 Actuator Link Clevis

The actuator link clevis test specimen simulated a portion of the variable fan nozzle consisting of the forward corner containing an integral aluminum link clevis. This specimen was 30.48 cm (12 in.) by 33.02 cm (13 in.) long and simulated the flap in all aspects (i.e., forward close-out, edge close-out, skin, core, clevis, etc.) with the exception that the specimen was flat (no circumferential curvature) and there were no perforations in the inner skin. These differences were postulated to have negligible effect on the test results as the load is normal to the curvature and the critically stressed area is in the clevis lugs rather than the skins. A steel block was bonded into the aft end for attachment to a base during testing.



Nozzle F. ıp Hinge - Cowl Size
Tensile Test
Specimen No. 1

Failure Mode: Tensile in Clevis

Nozzle Flap Hinge - Flap Side
Tensile Test
Specimen No. 1

Failure Mode: Tensile in Lug

Figure 23. Failed Specimens of Fan Nozzle Hinge Subcomponent.

A test specimen was attached by a series of through bolts to a baseplate clamped to the laboratory floor and connected at the clevis, through a 66.723 kN (15,000 lb) load cell, to an actuator mounted on an I-beam frame (see Figure 24).

An increasing tensile load was applied until an ultimate failure occurred at 59.437 kN (13,362 lb). Examination of the specimen determined that one of the clevis lugs had failed in bearing/shearout and that the pin connector had sheared next to the inner face of the opposing clevis lug. It was determined that the pin sheared first, transferring the full actuator load to the lug which ultimately failed. The ultimate design load (3 × limit load) for this component is 13.385 kN (3009 lb). The predicted failure was 62.275 kN (14,000 lb) based on the allowable mechanical properties of the aluminum lug. The failed specimen is shown in Figure 25.

4.2.11 Inner Cowl Wall - Curved

The core cowl curved panel bending test specimen was fabricated as shown in Figure 26. Both face sheets were six-ply PMR material with a 0°, 45°, 0° layup. The core material was HRH327 with 9.5 mm (0.375 in.) cell size and a density of 64 kg/m^3 (4 lb/ft^3). Overall thickness of the panel was 2.54 cm (1.0 in.).

The panel was 10.16 cm (4.0 in.) wide with a span distance between reaction load strips of 40.64 cm (16.0 in.). The reaction load strips were located on the inner radius side of the panel. Input load strips were 10.16 cm (4.0 in.) apart, centered between reaction load strips, on the opposite side of the panel. Outer radius curvature of the panel was 50.8 cm (20.0 in.). Loading arrangement was similar to that used for the inlet duct curved panel tests shown in Figure 9.

Load was gradually increased at a constant deflection rate until the specimen failed by core shear at a load of 3.946 kN (887 lb) and a deflection of 8.69 mm (0.342 in.). The location of the core shear failure was adjacent to one of the reaction load strips. Load versus deflection for the entire cycle is shown in Figure 27.

Calculated core shear stress at the time and location of failure was 0.88 MN/m^2 (127 psi). Other calculated stresses at the time of the core shear failure were:

Face Sheet Compressive Stress 157.89 MN/m^2 (22,900 psi)

Face Sheet Tensile Stress 167.54 MN/m^2 (24,300 psi)

Facing stresses due to the actual loads in the cowl door are 48.71 MN/m^2 (7065 psi) resulting in a design stress (3 × limit) of 146.14 MN/m^2 (21,195 psi).

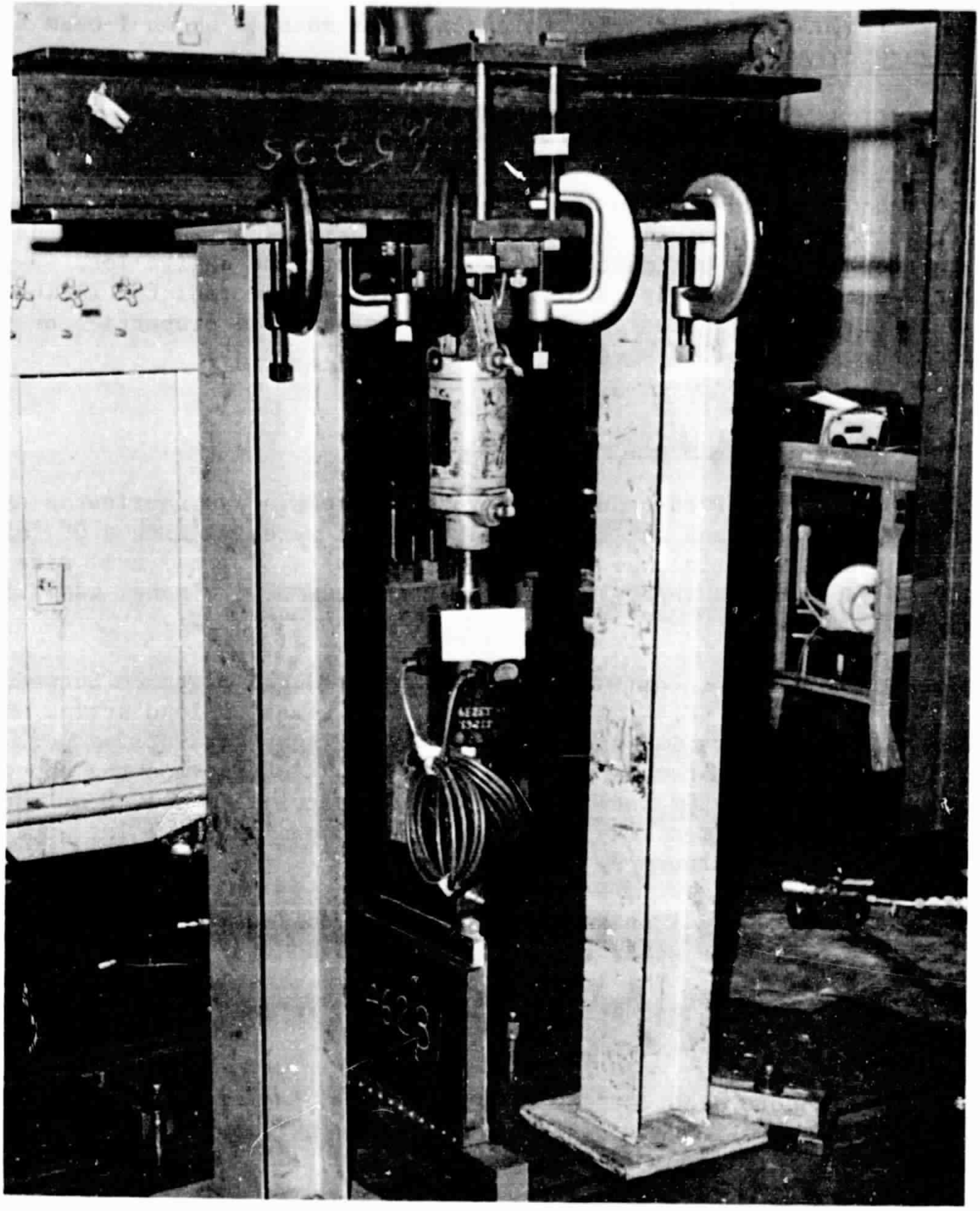


Figure 24. Actuator Link Clevis Subcomponent Test Setup.

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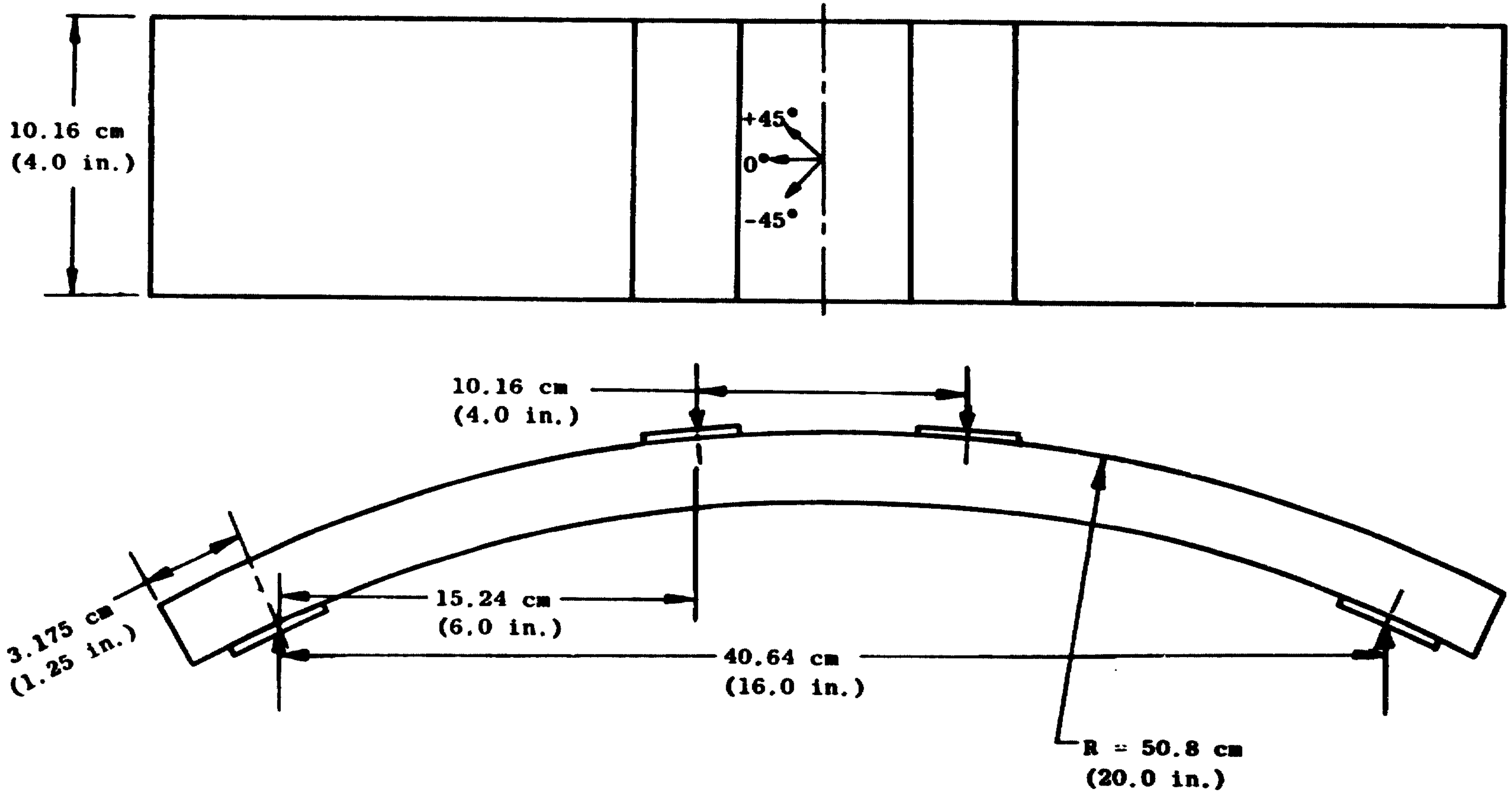
Figure 25. Failed Test Specimens of Nozzle Flap Actuator Link Clevis.



- Skins are 6-Ply Graphite/PMR $[0/45/0]_s$ 181 Style Weave Core is HRH327 with a Density of 64 kg/m^3 (4 lb/ft^3)

Figure 26. Core Cowl Wall Subcomponent Test Specimen.

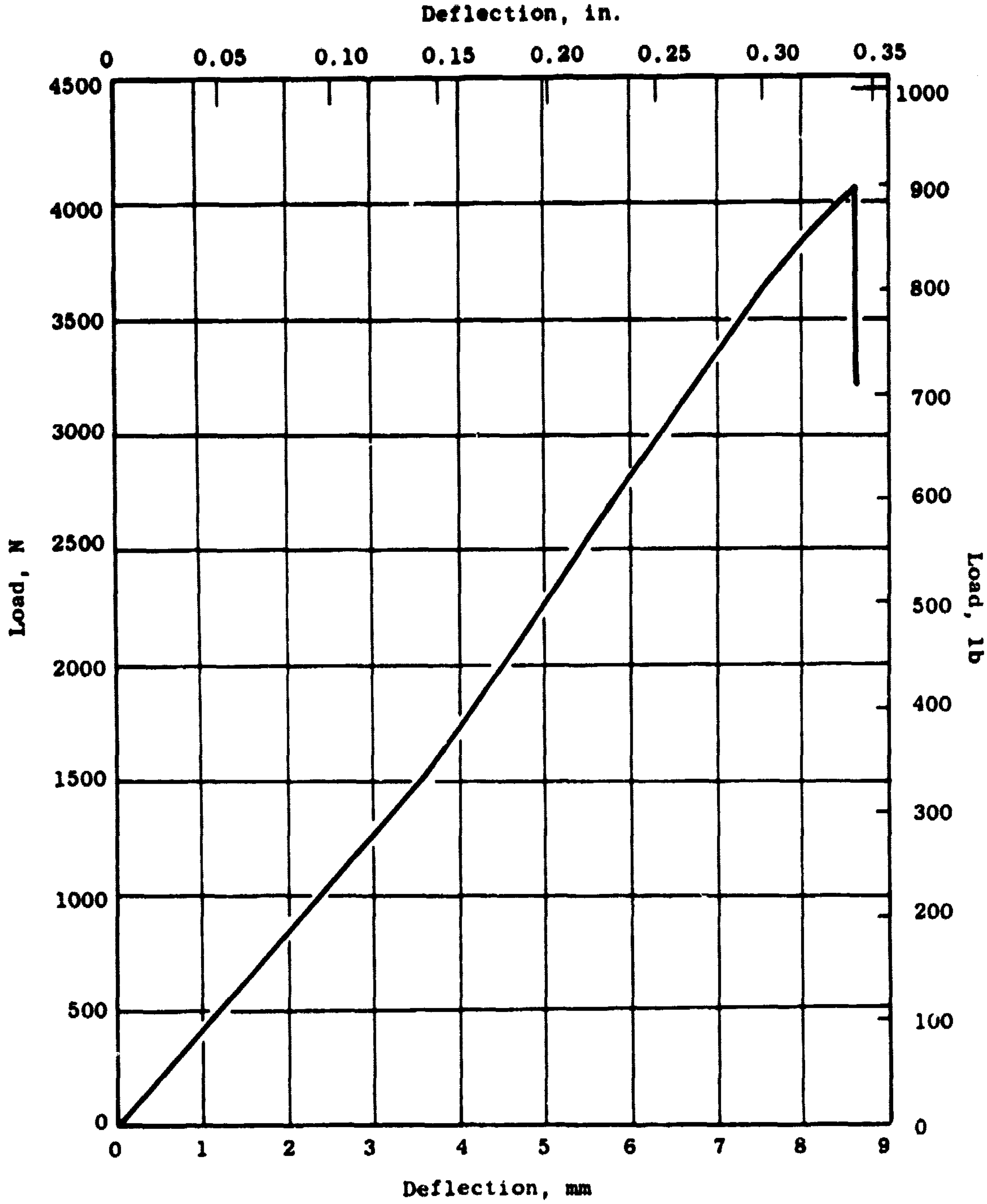


Figure 27. Core Cowl Wall Subcomponent, Load Vs. Deflection.

When load was removed from the specimen, the failure region recovered the original shape to a degree that made visual detection of the failure very difficult and measured permanent deflection of the panel almost zero. The failed specimen is shown in Figure 28.

Demonstrated core shear strength of 0.88 MN/m^2 (127 psi) exceeded the maximum calculated shear load (induced by hinge pivot offset and hinge attachment bracket) of 0.25 MN/m^2 (36 psi) by more than the required design factor of three. In addition, the face sheet strengths attained prior to core shear failure are adequate for the core cowl design.

4.2.12 Inner Cowl Hinge

The hinge-to-door edge attachment system was tested to show adequate strength of the proposed design.

The hinge attachment test specimen was fabricated with face sheets made of six-ply PMR material with a 0°, 45°, 0° layup. The core material was HRH327 with 9.53 mm (0.375 in.) cells and a density of 64 kg/m^3 (4 lb/ft^3). Overall thickness of the sandwich wall was 4.88 cm (1.92 in.).

On one end of the specimen the close-out formed a doubler extending 8.89 cm (3.5 in.) inward from the simulated door edge on both sides of the wall. The hinge attachment was made in the region of these doublers. The portion of the metal hinge that attached to the door was 3.175 mm (0.125 in.) thick and U-shaped to wrap around the door edge. Attachment to the door was via four 6.35 mm (0.25 in.) bolts passing through one side of the U, through the wall, and screwed directly into the other side of the U, which was threaded. Bolt heads were placed on the nonflow-path side to eliminate the risk of bolts becoming loose and damaging the fan or core compressor during reverse-thrust operation.

Metal inserts were potted into the composite sandwich wall to provide through holes at the bolt locations and to resist the bolt tightening loads. The inserts used were oversize, I.D. for 7.94 mm (0.3125 in.), to eliminate the need for great accuracy in locating them. The hinge attachment U-channel was bonded directly to the face sheet doublers along the door edge. The loose-fitting bolts were used to clamp the U-channel in place before the metal-to-composite adhesive was cured. A 9.525 mm (0.375 in.) thick simulated hinge tang was welded to the U-channel and used to load one end of the specimen. The hinge tang was arranged such that specimen loading was centered and in the plane of the specimen (no bending loads).

Metal load-transmission adaptor plates were bonded to each of the face sheets at the other end of the specimen to transmit tensile load from the test machine into the specimen.

Tensile load was applied to the specimen and increased gradually until failure occurred at 68.503 kN (15,400 lb). Both face sheets failed in ten-

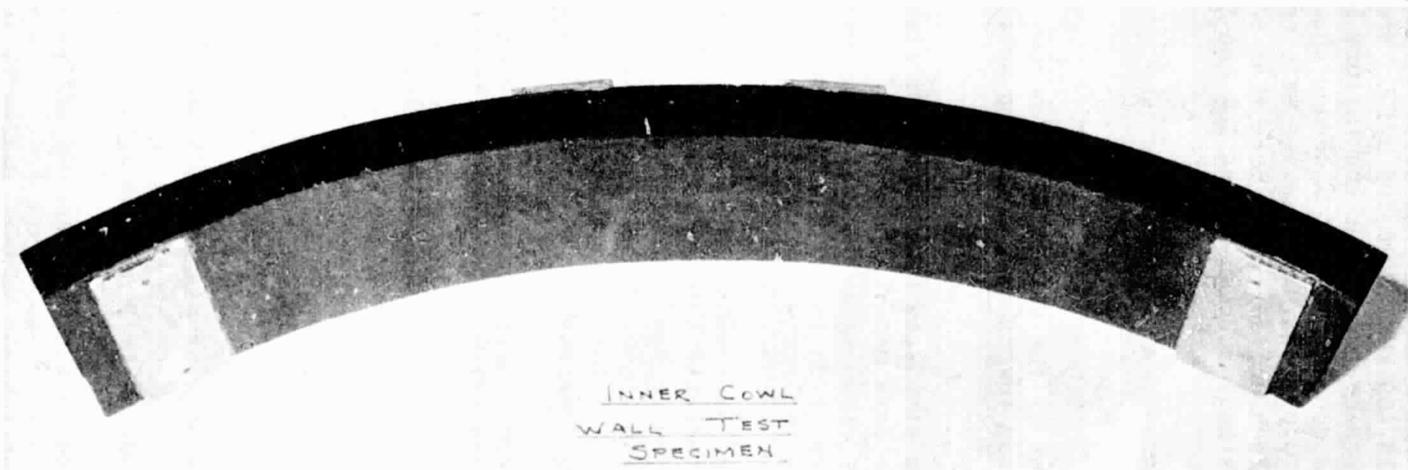


Figure 28. Failed Specimen of Core Cowl Wall Subcomponent.

sion at the location where the hinge attachment composite edge doublers terminated. A photograph of the failed specimen is shown in Figure 29.

Calculated average tensile stress in the 20.32 cm (8.0 in.) wide face sheets at failure load was 18.409 kN/m^2 (26,700 psi). Specimen geometry caused a substantial stress concentration at the failure location due to the termination of the composite doubler causing a sudden change in thickness from 1.83 mm (0.072 in.) to 0.091 mm (0.036 in.). This test demonstrated that the core cowl hinge attachment design is more than adequate for the intended application. The design load requirement for the failed part is 3.737 kN (840 lb).

4.2.13 Inner Cowl Latch

The simulated attachment of the core cowl latch body to the edge of the core cowl door was static-load tested to demonstrate sufficient load-carrying capacity of the proposed design.

Both face sheets of the simulated door edge were six-ply PMR material with 0°, 45°, 0° layup. The core material was HRH327 with 9.525 mm (0.375 in.) cell size and a density of 64 kg/m^3 (4 lb/ft^3). Overall thickness of the sandwich wall was 3.40 cm (1.34 in.). The specimen was 20.32 cm (8.0 in.) wide.

One end of the simulated door edge has a close-out configuration with a cavity to accommodate the simulated latch attachment adaptor. The metal attachment adaptor was secured to the composite door edge by means of four 6.35 mm (0.25 in.) bolts which passed through the wall and were inserted from the inner (nonflow-path) side of the wall. The bolts screwed directly into the threaded latch attachment adaptor on the outer (flow path) side of the wall, without the use of nuts. Metal inserts were potted into the composite sandwich wall to provide through holes at the bolt location and to resist the tensile tightening load of the bolts. The inserts used were oversize, I.D. for 7.94 mm (0.3125 in.) bolts, to eliminate the need for great accuracy in locating them. When the bolts were assembled, they were potted into the inserts by filling the inserts with epoxy potting material before the bolts were installed and torqued. This eliminated the loose fit between the bolts and inserts that resulted from the use of the oversize inserts and thus insured equal bolt-to-bolt load transmission. The other end of the metal latch attachment adaptor was designed for load pick-up by the tensile machine.

Metal load-transmission adaptor plates, 6.35 mm (0.125 in.) thick aluminum, were bonded to each of the face sheets at the other end of the specimen to transmit tensile load from the test machine into the specimen.

Tensile load was applied to the specimen and increased gradually until failure occurred at 25.577 kN (5750 lb). The face sheet which supports the entire load from the latch attachment adaptor failed in tension at the location where the bonded-on metal load-adaptor plate terminated.

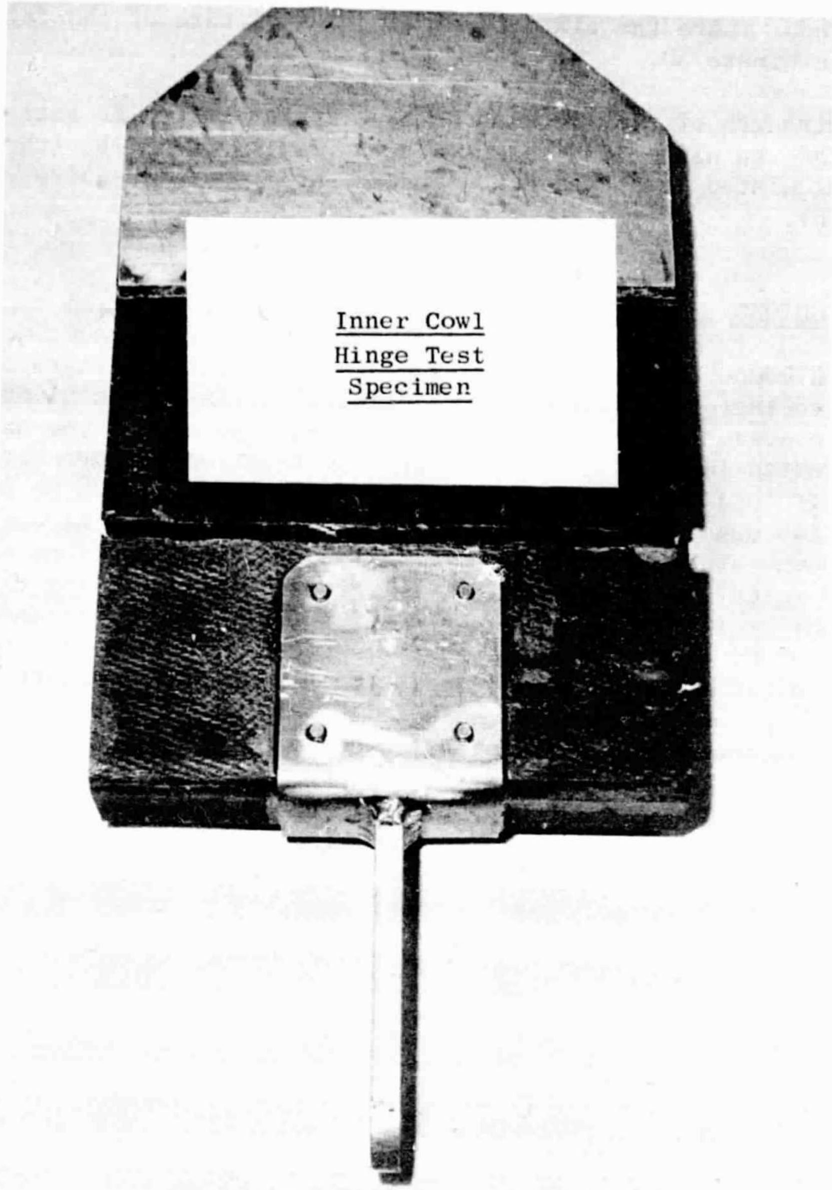


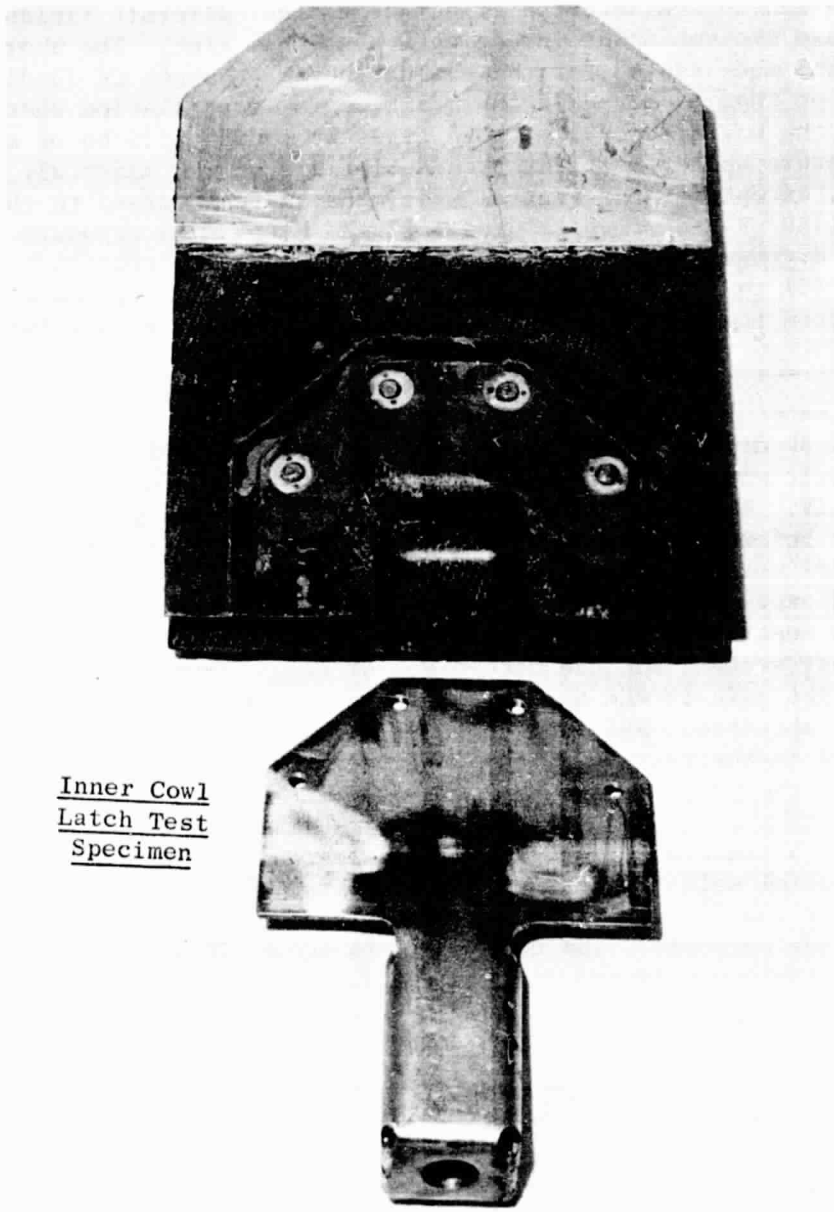
Figure 29. Failed Specimen of Inner Cowl Hinge Subcomponent.

Calculated average tensile stress in the 20.32 cm (8.0 in.) wide face sheet at the failure load was 137.65 MN/m^2 (19,965 psi). Specimen geometry caused a severe stress concentration in the failure location because the thicker, higher modulus, bonded-on metal plate was many times stiffer than the composite face sheet and therefore induced a high stress concentration in the face sheet where the plate terminated. A picture of the failed specimen is shown in Figure 30.

The strength of the latch attachment system tested is satisfactory for the intended use since load capacity of 25.577 kN (5750 lb) (three times maximun calculated load) was demonstrated. The design requirement is 13.112 kN (2948 lb).

4.3 CONCLUSIONS

The subcomponent tests described in the preceding paragraphs have demonstrated that the designs in the critical areas of the QCSEE composite nacelle are adequate to meet the strength requirements of the nacelle. The loads presented in Table IX as "Design Load Requirement" are three times the actual limit load expected during engine operation. As can be seen from Table IX, two areas, the outer cowl latch attachment and the outer cowl actuator mount attachment, were marginal in the configurations tested. These areas were redesigned to significantly increase load-carrying capability but the original design was so close to meeting the requirements that it was not deemed necessary to retest using the much stronger configurations. All other areas tested had more than adequate strength to meet the design requirements, thus providing confidence that the nacelle composite components will have more than adequate structural integrity.



Inner Cowl
Latch Test
Specimen

Figure 30. Failed Specimen of Inner Cowl Latch Subcomponent.

5.0 FLUID EXPOSURE TESTS

During the screening program discussed in Section 3.1.2, a series of tests were run to evaluate the effect of typical aircraft fluids on the Kevlar/epoxy systems under investigation at that time. The short-beam shear test was the mode tested for the evaluation. The exposure condition selected was based on that expected in the QCSEE engine installation where any exposure of the Kevlar/epoxy to these types of fluids will be of an intermittent nature which will leave residual fluid on the material. The test specimens, except for the control specimens, were immersed in the test fluids at 356 K (180° F) for five minutes followed by an oven exposure (without wiping or drying the specimens) at 356 K (180° F) for time periods ranging from zero (0) to fifteen (15) days. Ultimate strength values were then obtained from the specimens thus exposed at both room temperature and 356 K (180° F).

This exposure testing was done using two different fluids, namely Mobil Jet II and Skydrol 500C. The results of the tests performed using the Kevlar 49/181 fabric with the selected Narmco 8517 resin system are shown in Tables XIII and XIV. Also shown are the percent weight gains due to the oil immersion, both before and after oven aging. For comparison, similar data generated on 181 weave "E" glass cloth impregnated with the Hexcel F-155 resin system and exposed to Skydrol 500C is shown in Table XV. As can be seen, the short-beam shear strength of the glass/epoxy is considerably higher than the Kevlar/epoxy system, and the percentage of weight gain is much less. The larger weight gain in the Kevlar/epoxy system, however, did not seem to affect the short-beam shear strength at all, nor did the exposure to the fluids used in the tests have any effect on the ultimate strength of the material in the mode tested.

Although resistance to exposure to aircraft fluids was not a criterion in the material selection phase of the program, data was generated on several of the other competing systems and is included in Tables XVI through XVIII for reference purposes. The data shown in these tables is the average for the two fluids investigated since there was no apparent difference.

Table XIII. Fluid Exposure Testing: Mobil Jet II - Kevlar 49/181 - Narmco 8517.

Condition	Short-Beam Shear Stress				% Weight Change	
	Room Temperature		356 K (180° F)			
	MN/m^2	psi	MN/m^2	psi	Before Oven Age	After Oven Age
Control	28.41	4120	29.41	4265	-	-
Exposed - No Oven Aging	28.58	4145	30.27	4390	3.63	-
Exposed - 2 days Aging*	29.03	4210	32.44	4705	3.72	0.95
Exposed - 5 days Aging	27.03	3920	30.37	4405	3.60	0.87
Exposed - 10 days Aging	27.44	3980	29.54	4285	3.60	0.33
Exposed - 15 days Aging	27.92	4050	30.51	4425	2.92	0.54

* All oven aging was at 356 K (180° F)

NOTE: All values are average of three replicates tested per ASTM 2344-72

Table XIV. Fluid Exposure Testing: Skydrol 500C - Kevlar 49/181 - Narmco 8517.

Condition	Short-Beam Shear Stress				% Weight Change	
	Room Temperature		356 K (180° F)			
	MN/m^2	psi	MN/m^2	psi	Before Oven Age	After Oven Age
Control	27.06	3925	30.23	4385	-	-
Exposed - No Oven Aging	29.92	4340	29.03	4210	2.29	-
Exposed - 2 days Aging*	28.72	4165	29.58	4290	3.10	0.04
Exposed - 5 days Aging	28.89	4190	30.06	4360	3.19	0.22
Exposed - 10 days Aging	29.96	4345	31.30	4540	2.86	0.36
Exposed - 15 days Aging	29.34	4255	30.27	4390	3.09	0.26

* All oven aging was at 356 K (180° F)

NOTE: All values are average of three replicates tested per ASTM 2344-72

Table XV. Fluid Exposure Testing: Skydrol 500C - 181 E Glass - Hexcel F-155.

Condition	Short-Beam Shear Stress				% Weight Change	
	Room Temperature		356 K (180° F)			
	MN/m^2	psi	MN/m^2	psi	Before Oven Age	After Oven Age
Control	51.81	7515	36.75	5330	-	-
Exposed - No Oven Aging	52.78	7365	37.40	5425	0.42	-
Exposed - 2 days Aging*	52.30	7585	37.61	5455	0.58	0.05
Exposed - 5 days Aging	53.16	7710	39.16	5680	0.45	0.03
Exposed - 10 days Aging	53.43	7750	39.85	5780	0.55	0.01
Exposed - 15 days Aging	52.64	7635	40.47	5870	0.45	0

* All oven testing was at 356 K (180° F)

NOTE: All values are average of two replicates tested per ASTM 2344-72

Table XVI. Fluid Exposure Testing: Kevlar 49/181 - Narmco 3203.

Condition	Short-Beam Shear Stress				% Weight Change	
	Room Temperature		356 K (180° F)			
	MN/m^2	psi	MN/m^2	psi	Before Oven Age	After Oven Age
Control	37.22	5398	25.84	3748	-	-
Exposed - No Oven Aging	36.23	5255	24.13	3500	3.81	-
Exposed - 2 days Aging*	37.58	5450	26.39	3828	4.81	3.53
Exposed - 5 days Aging	38.01	5513	27.15	3938	5.09	3.07
Exposed - 10 days Aging	38.05	5518	26.58	3855	5.61	3.66
Exposed - 15 days Aging	37.71	5470	28.32	4108	5.26	2.55

* All oven aging was at 356 K (180° F)

NOTE: All values are average of four tests, two exposed to Mobil Jet II and two to Skydrol 500C tested per ASTM 2344-72

Table XVII. Fluid Exposure Testing: Kevlar 49/181 - Ferro CE9040.

Condition	Short-Beam Shear Stress				% Weight Change	
	Room Temperature		356 K (180° F)			
	MN/m^2	psi	MN/m^2	psi	Before Oven Age	After Oven Age
Control	35.23	5110	31.30	4540	-	-
Exposed - No Oven Aging	35.47	5145	30.53	4428	4.70	-
Exposed - 2 days Aging*	34.65	5025	31.41	4555	4.30	2.70
Exposed - 5 days Aging	34.78	5045	31.75	4605	4.49	2.12
Exposed - 10 days Aging	35.27	5115	31.36	4548	5.35	2.66
Exposed - 15 days Aging	34.06	4940	32.25	4678	5.02	1.44

* All oven aging was at 356 K (180° F)

NOTE: All values are average of four tests, two exposed to Mobil Jet II and two exposed to Skydrol 500C tested per ASTM 2344-72

Table XVIII. Fluid Exposure Testing: Kevlar 49/181 - Ferro CE9000.

Condition	Short-Beam Shear Stress				% Weight Change	
	Room Temperature		356 K (180° F)			
	MN/m^2	psi	MN/m^2	psi	Before Oven Age	After Oven Age
Control	30.13	4370	29.13	4225	-	-
Exposed - No Oven Aging	29.68	4305	30.24	4385	2.48	-
Exposed - 2 days Aging*	29.20	4235	30.06	4360	3.00	1.78
Exposed - 5 days Aging	30.16	4375	30.60	4438	2.88	0.92
Exposed - 10 days Aging	29.12	4223	30.30	4395	3.38	1.00
Exposed - 15 days Aging	28.32	4108	29.53	4283	3.19	0.98

* All oven aging was at 356 K (180° F)

NOTE: All values are average of four tests, two exposed to Mobil Jet II and two exposed to Skydrol 500C tested per ASTM 2344-72

6.0 REFERENCES

1. General Electric Company, "QCSEE Composite Fan Frame Subsystem Test Report," NASA CR135010, April 1976.

2. Serafini, T.T., "Processable High Temperature Resistant Polymer Matrix Materials," NASA TMX-71682, 1975.