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CONTRACT NAS 1-14000

FLIGHT SERVICE EVALUATION OF AN ADVANCED COMPOSITE EMPENNAGE COMPONENT ON COMMERCIAL TRANSPORT AIRCRAFT

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QUARTERLY TECHNICAL REPORT – NO. 3

This report is for the period 1 January 1976 through 31 March 1976

Lockheed Aircraft Corporation
Lockheed-California Company
Post Office Box 551
Burbank, California 91520

Approved By: R. L. Vaughn

R. L. Vaughn
Program Manager

15 April 1976

Prepared for Langley Research Center


L-1011
Advanced
Composite
Vertical
Fin
L-1011 TriStar
Lockheed
Lockheed TriStar

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FOREWORD

This report was prepared by the Lockheed-California Company, Lockheed Aircraft Corporation, Burbank, California, under contract NAS1-14000. It is the third quarterly technical report covering work completed between 1 January 1976 and 31 March 1976. The program is sponsored by the National Aeronautics and Space Administration (NASA), Langley Research Center. The Program Manager for Lockheed is Mr. Robert L. Vaughn. Mr. Louis F. Vosteen is Project Manager for NASA Langley. The Technical Representative for NASA Langley is Mr. R. Ronald Clary.

SUMMARY

The technical activities performed in this reporting quarter and documented in this report are related to tasks associated with Phase II, Detail Design. These tasks include: Component Definition; Material Verification; Fabrication; and Component and Subcomponent Tooling. The discussion of technical activities related to these tasks is presented separately for each of the Advanced Composite Vertical Fin (ACVF) team members. The team member responsibilities are: Lockheed-California Company for the covers and overall design, Lockheed-Georgia Company for the spars, and the Los Angeles Aircraft Division (Laad) of Rockwell International for the ribs.

The recommended concept for the covers continues to be graphite/epoxy hats bonded to a graphite/epoxy skin. The root end joint concept for the attachment of the covers to the fuselage has been reevaluated, and a new root end joint concept selected. The hat flare-out has been eliminated; instead the hat is continuous into the joint. This design concept could utilize hats which are pultruded thereby reducing manufacturing costs. This design concept has been substantiated by test. The recommended concept for the spars continues to be graphite/epoxy caps and a hybrid of Kevlar-49 and graphite/epoxy in the spar web. The spar cap, spar web stiffeners for attaching the ribs and intermediate stiffeners are planned to be fabricated as a unit. Access holes in the web will be reinforced with a donut type, zero degree graphite/epoxy wound reinforcement. A reevaluation of the recommended rib configurations resulted in a change to the upper three ribs. The miniwich design concept originally proposed has been changed to a graphite/epoxy stiffened solid laminate design concept. Preliminary analysis indicates an added weight saving will be realized with this design change. The recommended configuration for the lower seven ribs remains as graphite/epoxy caps with aluminum cruciform diagonals.

The indicated weight saving for the current ACVF configuration is 20.2 percent (173.4 lb) including a 24 lb growth allowance. Without the growth allowance, the weight saving is 23.0 percent. Composite material utilization is 75.2 percent of the redesigned fin box weight. The projected production cost saving is approximately 1 percent based in a cumulative average of 250 aircraft and including only material, production labor, and quality assurance costs.

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SECTION 1

INTRODUCTION

This is the third quarterly report of a program which provides for the design, development, and fabrication of three advanced composite empennage components. One component will be static and fatigue tested, and two components will be installed on commercial aircraft each for 5-year flight evaluation. This NASA contract was awarded to Lockheed-California Company, Burbank, California, in the amount of $6,510,000. The Program Manager for Lockheed is Mr. Robert L. Vaughn. Mr. Louis F. Vosteen is Project Manager for NASA, Langley. The Technical Representative for NASA, Langley, is Mr. R. Ronald Clary.

The objective of this program is the development and flight evaluation of an advanced composite empennage component, manufactured in a production environment, at a cost competitive with those of its metal counterpart, and at a weight saving of at least 20 percent. The empennage component selected for this program is the vertical fin box of the L-1011 aircraft. The box structure extends from the fuselage production joint to the tip rib and includes the front and rear spars; it is 25 feet tall with a root box chord of 9 feet and represents an area of 150 square feet.

The duration of this program is 106 months, with completion scheduled for March 1984. The master schedule for this program is shown in Figure 1-1. The dotted line in this figure represents the critical path for this program.

The Lockheed-California Company has teamed with the Lockheed-Georgia Company and the Los Angeles Aircraft Division of Rockwell International in the development of the Advanced Composite Vertical Fin (ACVF). Team member responsibilities are shown in Figure 1-2. Lockheed-California Company, as prime contractor, has overall program responsibility and will design and fabriciate the covers, conduct the full-scale ground tests, install the flight articles, and evaluate service experience; Lockheed-Georgia Company will design and

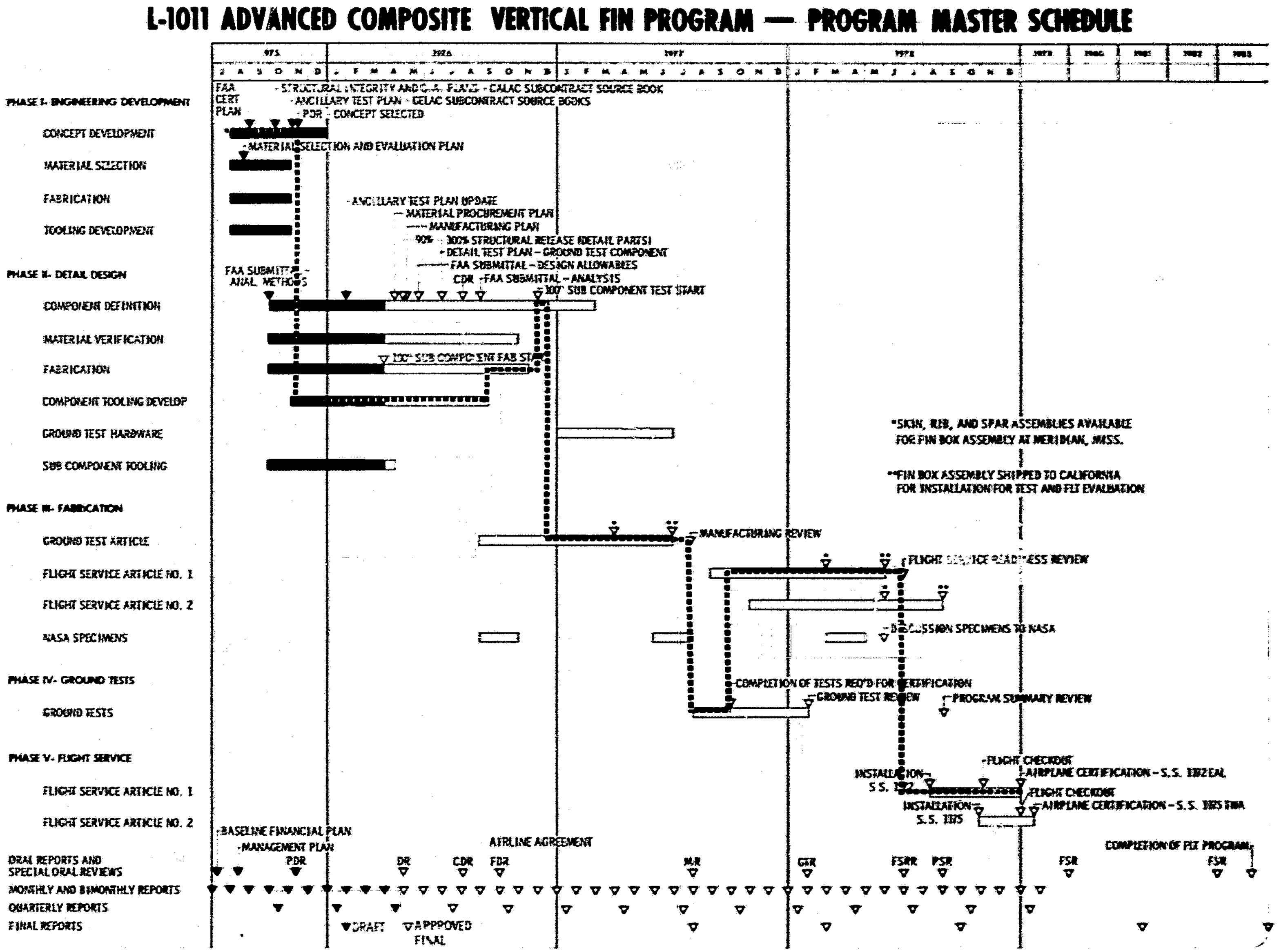


Figure 1-1. L-1011 Advanced Composite Vertical Fin Program - Program Master Schedule

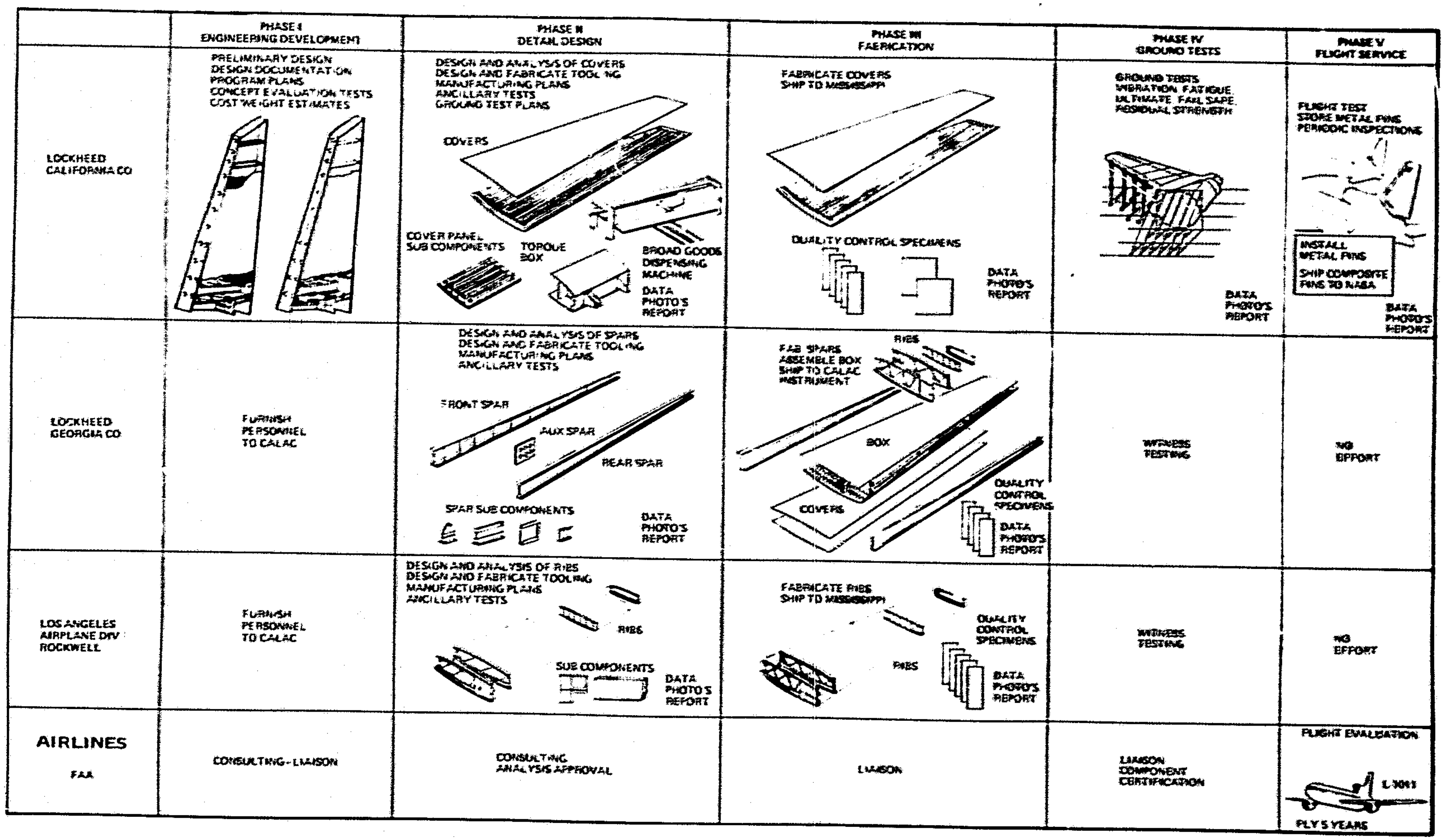


Figure 1-2. Program Responsibilities

fabricate the front, rear, and auxiliary spars, and assemble the component at their plant in Meridian, Mississippi, where the present L-1011 vertical fins are assembled; and LAAD will design and fabricate all ribs.

During Phase I, various design options such as stiffened covers and sandwich covers were evaluated to arrive at a configuration which would offer the highest potential for satisfying program objectives. The preferred configuration was selected in November 1975. Material screening tests were performed to select an advanced composite material system for the ACVF that would meet the program requirements from the standpoint of quality, reproducibility, and cost. The material selected for the ACVF program is Narmco T300/5209. Preliminary weight and cost analysis have been made, targets established, and tracking plans developed. Plans for subsequent phases were also developed in this phase. These include FAA certification, ancillary test program, quality control, and structural integrity control plans. The majority of the Phase I effort was concluded when the results of Phase I activities were presented to NASA at a Preliminary Design Review (PDR) held on 12 November 1975. All technical effort associated with Phase I tasks were concluded on 31 December 1975.

Phase II covers the main engineering effort. Detail design, analysis, and development testing are well under way. One significant test which will be accomplished in this phase will be on a subcomponent consisting of a major portion of the box structure. This component will be fabricated from representative production tooling and consists of 100 inches of the rear spar and 36 inches of the box chord and will include the fuselage/box joint. Limited production tooling are being designed and fabricated, and plans for the fabrication of the full-scale components are being written. Phase III provides for the fabrication of the full-scale ground test component and the two components to be used for flight service evaluation. Fabrication of the flight service articles will not begin until after certification tests on the full-scale ground test component have started. During fabrication, actual costs will be documented and components weighed to develop the weight update for the assembled structures.

Ground tests will be conducted on a full-scale vertical fin box beam structure mounted on a fuselage afterbody structure during Phase IV. The test plan will include vibration to determine modal response characteristics, static tests, spectrum fatigue tests to two lifetimes, ultimate load, damage tolerance and fail-safe, and residual strength tests. Repair techniques and procedures established for inservice maintenance and inspection will be employed throughout these tests, if necessary. The test results will be used to verify the analytical, design, and fabrication procedures, and are an essential input to the FAA for certification of the aircraft with the ACVF installed. Certification will be based on satisfying both static strength and fail-safe requirements. Phase V provides for the installation of two ACVF's on commercial aircraft for flight service evaluation for a period of 5 years. Inspection procedures and inspection intervals will be established in conjunction with the participating airlines. Prior to delivery and introduction into regular service, each aircraft will be processed through normal predelivery and other flight tests if required by Engineering and the FAA.

Throughout this program, technical information gathered during performance of the contract will be disseminated throughout the industry and Government. The methods used to distribute this information will be through Technical Highlight Bulletins, to be distributed bimonthly throughout the entire program; Quarterly Reports, which will coincide with calendar quarters; Final Reports, to be distributed at the completion of each phase; and Flight Service Reports. All test data and fabrication data will be recorded on Air Force Data Sheets for incorporation in the Air Force Design Guide and Fabrication Guide for Advanced Composites. Of particular interest are the Special Oral Reviews to be conducted at NASA, Langley, to acquaint industry and the Government with the process of the program. These reviews follow soon after the Preliminary Design Review (PDR), the Critical Design Review (CDR), and the Flight Service Readiness Review (FSRR). Specific information about the design reviews will be distributed later in the program.

This report describes work accomplished during the three-month period extending from 1 January 1976 to 31 March 1976. During this period all major milestones were met as scheduled. The design configuration was further refined; the design of the design of the 100-inch subcomponent test specimen was completed; the design and fab of the concept verification test specimens were initiated; and a significant portion of the design allowable coupon and element tests were completed.

SECTION 2

PHASE II - DETAIL DESIGN - SURFACES

Phase II Detail Design of the Surfaces covers the main engineering effort of Lockheed-California Company in the design, development, and fabrication of the covers for the L-1011 Advanced Composite Vertical Fin. This engineering effort covers five tasks: Component Definition, Material Verification, Fabrication, Component Tooling Development, and Subcomponent Tooling.

2.1 TASK 1 - COMPONENT DEFINITION

Component Definition covers the detail design and structural analysis of the selected cover configuration and ancillary tests.

2.1.1 Detail Design

The root end joint design of the covers has been reevaluated. Several design concepts for the joint have been considered and their structural behavior, weight, and producibility compared to the original design configuration. As a result of these investigations, a new root end joint concept has been selected for the ACVF. This configuration is shown in Figure 2-1.

The cover drawing for the 100-inch test unit, the cover assembly drawing, and the 100-inch test component assembly drawing have been completed and released. Thrust link fittings required at Vertical Stabilizer Station (VSS) 113 were also designed and released, though the actual parts will be assembled at Gelac. The design of the simulated front spar for the 100-inch specimen was completed. This part will be fabricated as part of the test specimen installation.

SKIN LAMINATES:

1. $\pm45^{\circ}_{G}\ 0^{\circ}_{3G}\ \pm45^{\circ}_{G}\ 0^{\circ}_{2G}\ \pm45^{\circ}_{G}\ 0^{\circ}_{G}\ \mp45^{\circ}_{G}\ 0^{\circ}_{2G}\ \mp45^{\circ}_{G}\ 0^{\circ}_{3G}\ \mp45^{\circ}_{G}\ +45^{\circ}_{K49}$
2. $\pm45^{\circ}_{G}\ 0^{\circ}_{4G}\ \pm45^{\circ}_{G}\ 0^{\circ}_{3G}\ \pm45^{\circ}_{2G}\ 0^{\circ}_{2G}\ \mp45^{\circ}_{2G}\ 0^{\circ}_{3G}\ \mp45^{\circ}_{G}\ 0^{\circ}_{4G}\ \mp45^{\circ}_{G}\ +45^{\circ}_{K49}$

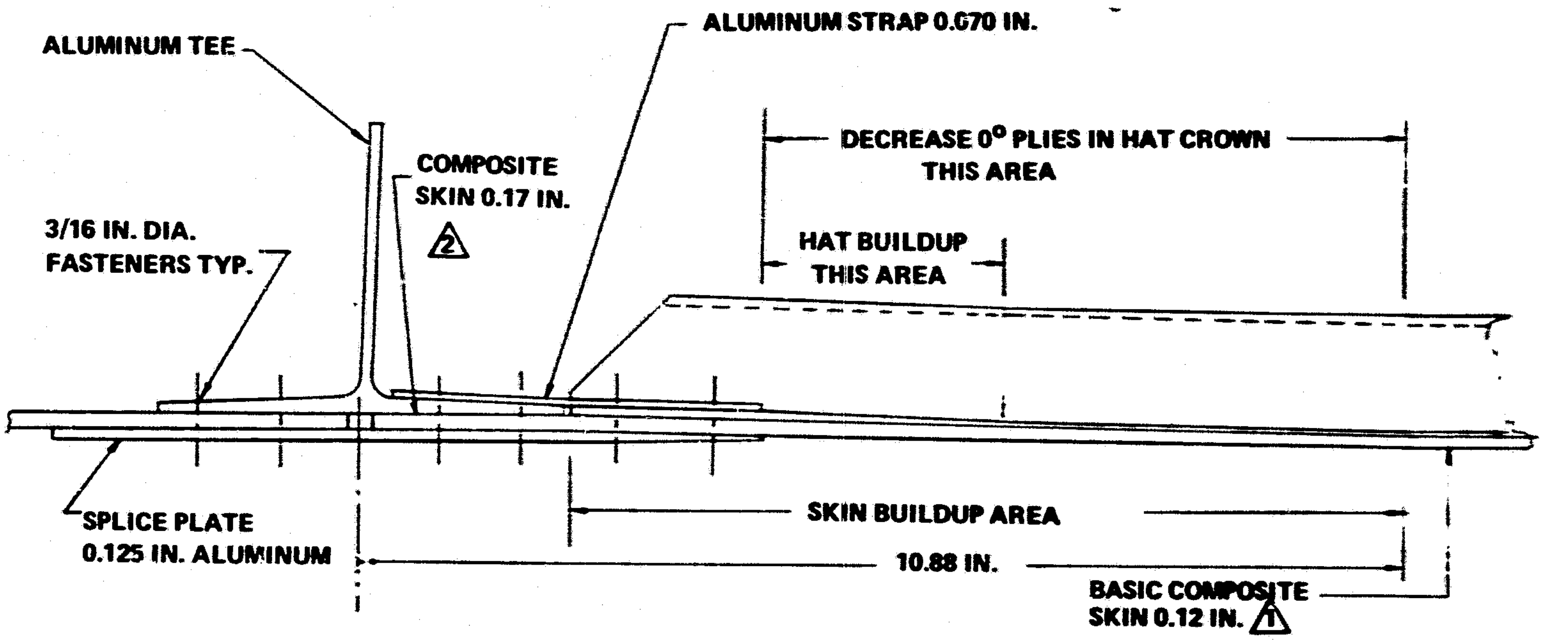


Figure 2-1. Root B Mod 2 Configuration

Design, fabrication and interfacing/coordination problems associated with the 100-inch specimen are directly applicable to the full size articles. Major areas requiring design layout and analysis include the skin laminate buildup in the area of both front and rear spar joint areas, the design of reaction structure for the rudder damper loads at VSS 307, and design and analysis of the hinge fittings to accommodate the thermal expansion/contraction differential along the rudder hinge axis.

Lightning Strike Evaluations

The evaluation of lightning strike hazards and attendant protection for aircraft structures is an on-going concern. The unique features associated with composite structures have re-focused development efforts to provide protection for the new aerospace concepts. To this end, the aircraft manufacturers, airlines, government sponsoring agencies and government regulatory agencies have all become involved.

A current on-going program is being conducted by the Boeing Aircraft Corporation for the Air Force (ref. 1). This program will establish: threat definition and damage assessment (unprotected), conduct protection system development, conduct full-scale hardware demonstrations and prepare a design manual for lightning protection for composite structures. One of the materials to be evaluated is Narmco T300/5208, a graphite/epoxy tape very similar to that intended for use on the L-1011 fin structure. The results of this program will be available to support Lockheed's final decisions regarding flight article protection.

Study results are also available from recent evaluations conducted by General Dynamics - Ft. Worth on the F-16 (ref. 2) in which several composite structure protection methods were evaluated. These studies are referred to only because of their current on-going status and the potential applicability to the fin program. The lightning protection system currently being considered is 150 mesh aluminum screen, bonded to the outer surface of the covers.

The activities to be conducted at Lockheed in regard to lightning hazard protection are:

1. Continuing surveillance of industry and agency developments in this area

2. Evaluation of the fin bonding and grounding systems to assure an adequate conducting path

3. Evaluation of impact on adjacent antenna systems

4. Specimen fabrication to evaluate the mesh protection system from a producibility standpoint

5. Evaluation of the aluminum mesh to establish corrosion potential and maintenance and repair capability.

Close cooperation has always existed within the aircraft industry where the issues of flight safety are involved. The data available to substantiate decisions regarding lightning protection is voluminous and rests in many areas. The B-1 being fabricated by Rockwell International (a subcontractor on the fin program) is doing development work to substitute composites for metal in three separate areas of the aircraft. The lightning protection systems proposed for the three areas are: horizontal stabilizer - flame sprayed aluminum strips; avionics bay door - aluminum mesh; vertical fin - a combination of aluminum mesh and strips.

Projected Cost Status

Currently projected production/maintenance costs for the ACVF are shown in Table 2-1. The estimated production cost has increased by $4,051 over the previous quarterly report. This change has incurred due to more in-depth analyses over ROM cost estimates. Detail analysis of the 100-inch test speciman drawing has been completed. This analysis has been projected to reflect a full scale rear spar and ratioed to the front spar. Included in the analysis are increased complexity of holes and an increase in the number of patterns requiring involved layups due to tapers and runouts. The increased complexity has occured in the skins and ribs as well as the spars.

The estimating premises have remained the same and the costs are stated in 1975 dollars. There are no data as yet to substantiate a change in the maintenance cost estimates.

TABLE 2-1. PROJECTED PRODUCTION/MAINTENANCE COST

(BASED ON CUMULATIVE AVERAGE OF 250 AIRCRAFT)

COMPONENT	METAL FIN			A.C.V.F.		
	LABOR	MATERIAL	TOTAL	LABOR	MATERIAL	TOTAL
Skin Covers (L/R)	14,467	2,960	17,724	5,890	12,957	18,847
Spars (FWD/AFT)	9,274	1,217	10,491	8,927	4,568	13,495
Aux Spar	382	42	424	382	42	424
Actuator Ribs Hinge Ribs Intermediate	9,300	843	10,143	8,561	2,194	10,755
Upper Closure Ribs	854	49	903	854	49	903
Rib/Spar Fittings	283	301	584	283	301	584
Assembly	17,185	5,752	22,937	13,375	3,831	17,206
Total	51,745	11,164	$62,909	38,272	23,942	62,214
Maintenance Inspection Repairing Costs	*180 M/H Per A/C Per Year		$ 4,500.00	*180 M/H Per A/C Per Year		$ 4,500.00

*Based on 3,000 Flight Hours Per Year

Weight Status

The current weight status is shown in Table 2-2. A weight savings of 20.2% (173.4 lb) is currently being predicted including a 24-lb growth allowance and composite material utilization is currently predicted to be 75.2 percent of the redesigned fin box weight. A summary of weight changes since the Second Quarterly Report (ref. 3) is presented in Table 2-3 and a weight-time history for the composite fin is provided in Figure 2-2.

2.1.2 Structural Analysis

NASTRAN Model

The NASTRAN model was completed during this reporting period. A comparison of the load distribution in the covers at the root, between the metal fin and advanced composite fin is shown in Figure 2-3.

The SIC model run showed that the composite fin is a little stiffer in bending than the metal fin. The tip deflection was 7% less. The torsional stiffness appears to be running up to 30% higher. This is due primarily to the fact that $\pm 45^{\circ}$ plies must be maintained as increments of $(\pm 45^{\circ})_2$ for a balanced laminate, and additional plies were required for stability.

The SICs have been supplied to the Loads Department for analysis of external loads and the resulting EI and GJ plots have been supplied to the Flutter Group for their analysis. See Figure 2-4 and 2-5.

The applied loads at the rib grid points were output and stored on tape for use with the 2D rib models.

2D Rib Models

Three two-dimensional rib models have been constructed. The models are currently being debugged and all three models should be run early in April. These models are using the NASTRAN system and are being handled through DCAS (Direct Computer Access System).

TABLE 2-2. WEIGHT STATUS REPORT

ITEM	METAL DESIGN TOTAL WEIGHT LB	COMPOSITE DESIGN TARGET WEIGHT LB	COMPOSITE DESIGN TOTAL WEIGHT LB	COMPOSITE DESIGN COMPOSITE MAT'L WT LB	WEIGHT CHANGE
COVERS	460.4	360.0	356.6	337.1	+9.0
SPARS	196.0	132.4	127.5	88.6	-4.9
RIBS	156.3	118.5	123.3	64.9	-0.2
ASSEMBLY HARDWARE	35.4	25.0	35.9	-	+3.0
PROTECTIVE FINISH	9.6	9.6	9.6	-	
LIGHTNING PROTECTION	-	15.5	7.4	-	-8.1
DESIGN GROWTH ALLOWANCE	-	-	24.0	24.0	
TOTAL FIN PREDICTED DELIVERY WEIGHT ~ LB	857.7		684.3	514.6	-1.2
WEIGHT SAVING ~ LB			173.4		
PERCENT WEIGHT SAVED			20.2%		
PERCENT COMPOSITE MATERIAL				75.2%	
TOTAL FIN CURRENT INDICATED WEIGHT ~ LB (PREDICTED LESS GROWTH)		661.0	660.3 (23.0%)	490.6 (74.3%)	
CURRENT INDICATED WEIGHT OF REDESIGNED COMPONENT	825.4	626.7 (24.1% WEIGHT SAVED)			
WEIGHT BASIS: 95% EST, 5% CALC, 0% ACT					

TABLE 2-3. SUMMARY OF WEIGHT CHANGES

ITEM	WEIGHT CHANGE ~ LB		REMARKS
	TOTAL	COMPOSITE	
COVERS	+3.6	+3.6	INCREASE STIFFENER FLANGE WIDTH TO 1.0 INCH (WAS 0.9) TO ENSURE SUFFICIENT EDGE DISTANCE FOR FASTENER INSTALLATION AT RIB CAP/STIFFENER FLANGE INTERFACE.
	+6.7	+1.8	FIN COVER TO FUSELAGE DESIGN REVISED PER STRESS REQUIREMENT: (1) ADD STIFFENER/TEE ATTACH STRAP, (2) EXTEND WIDTH OF EXTERIOR DOUBLER AND (3) BEEF UP STIFFENER RUNOUT.
	+1.0	0	ADD INTERCOSTAL AT VSS 113.37 TO DISTRIBUTE RUDDER HINGE LOADS.
	-2.3	-15.9	REVISED WEIGHT ESTIMATE AND MISCELLANEOUS CHANGES
SPARS	-4.9	-37.2	REVISED WEIGHT ESTIMATE PER LATEST STRESS SIZING.
RIBS	+0.9	0	ADD ALUMINUM STRIPS TO RIB FLANGES FOR PROTECTION DURING INSTALLATION OF BLIND FASTENERS.
	-0.8	-0.8	INCORPORATE SOLID-WEB DESIGN IN LIEU OF "MINIWICH" HONEYCOMB SANDWICH DESIGN
	-0.3	-0.8	REVISED WEIGHT ESTIMATE AND MISCELLANEOUS CHANGES
LIGHTNING PROTECTION	+1.0	0	150 X 150 (0.0026) IN LIEU OF 200 X 200 (0.0021) ALUMINUM WIRE MESH
	-9.1	0	ELIMINATE ADHESIVE FILM BETWEEN WIRE MESH AND KEVLAR
ASSEMBLY HARDWARE	+3.0	0	REVISED WEIGHT ESTIMATE
TOTAL	-1.2	-49.3	

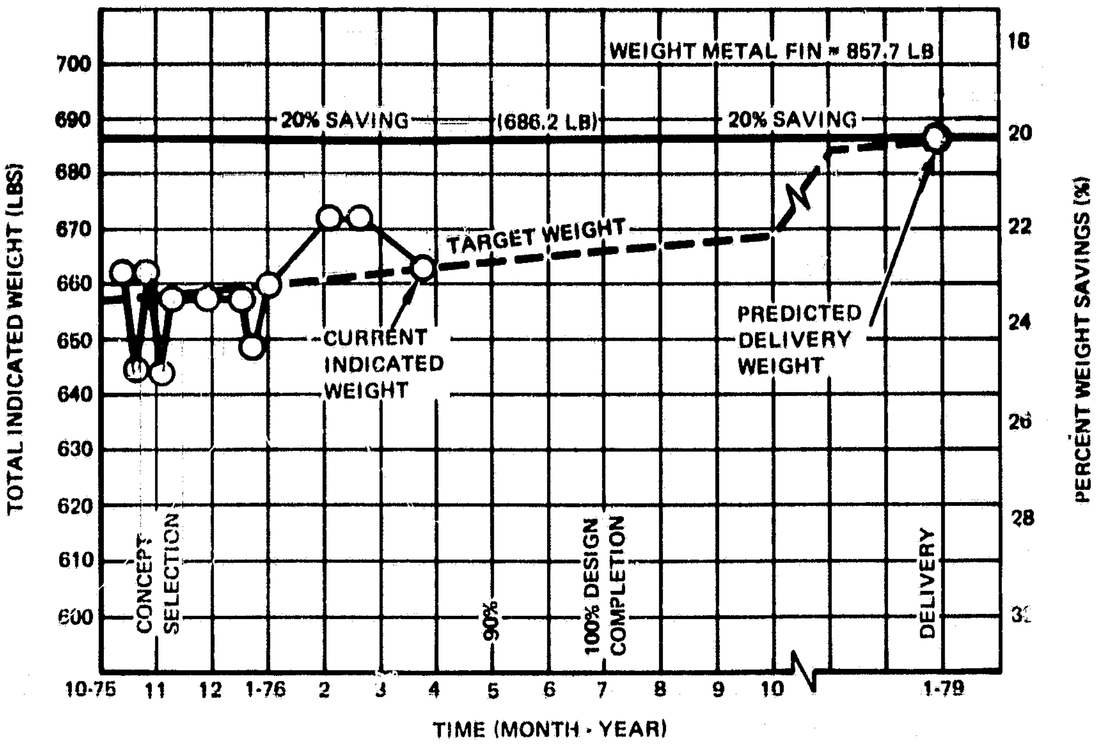


Figure 2-2. Weight-Time History

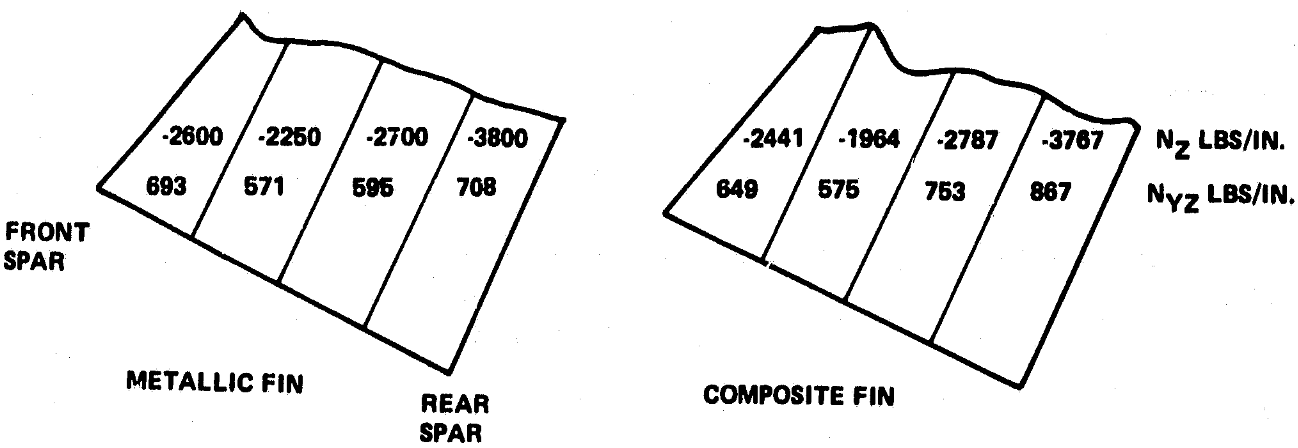


Figure 2-3. Root Load Distributions

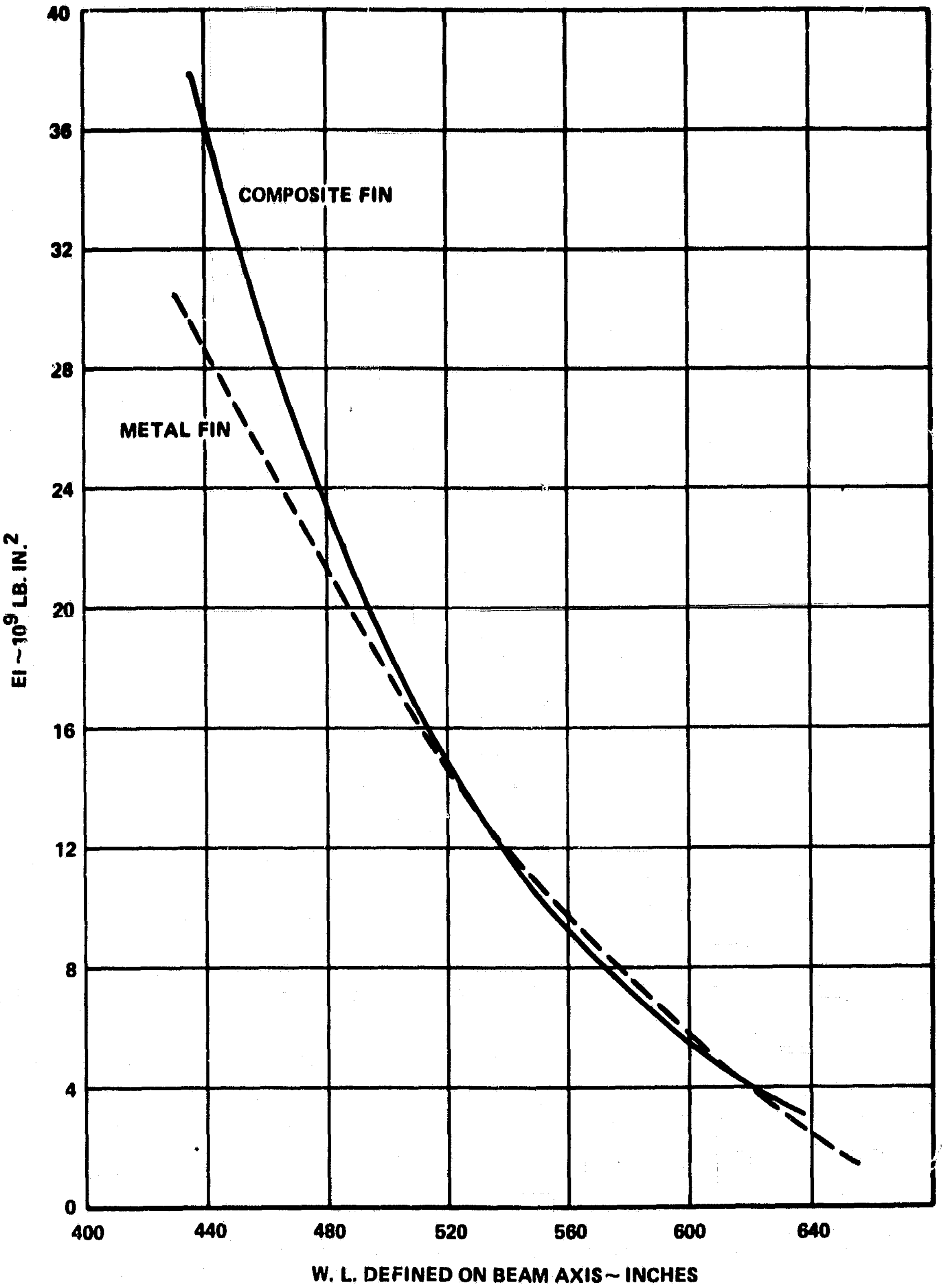


Figure 2-4. Vertical Stabilizer Bending Stiffness

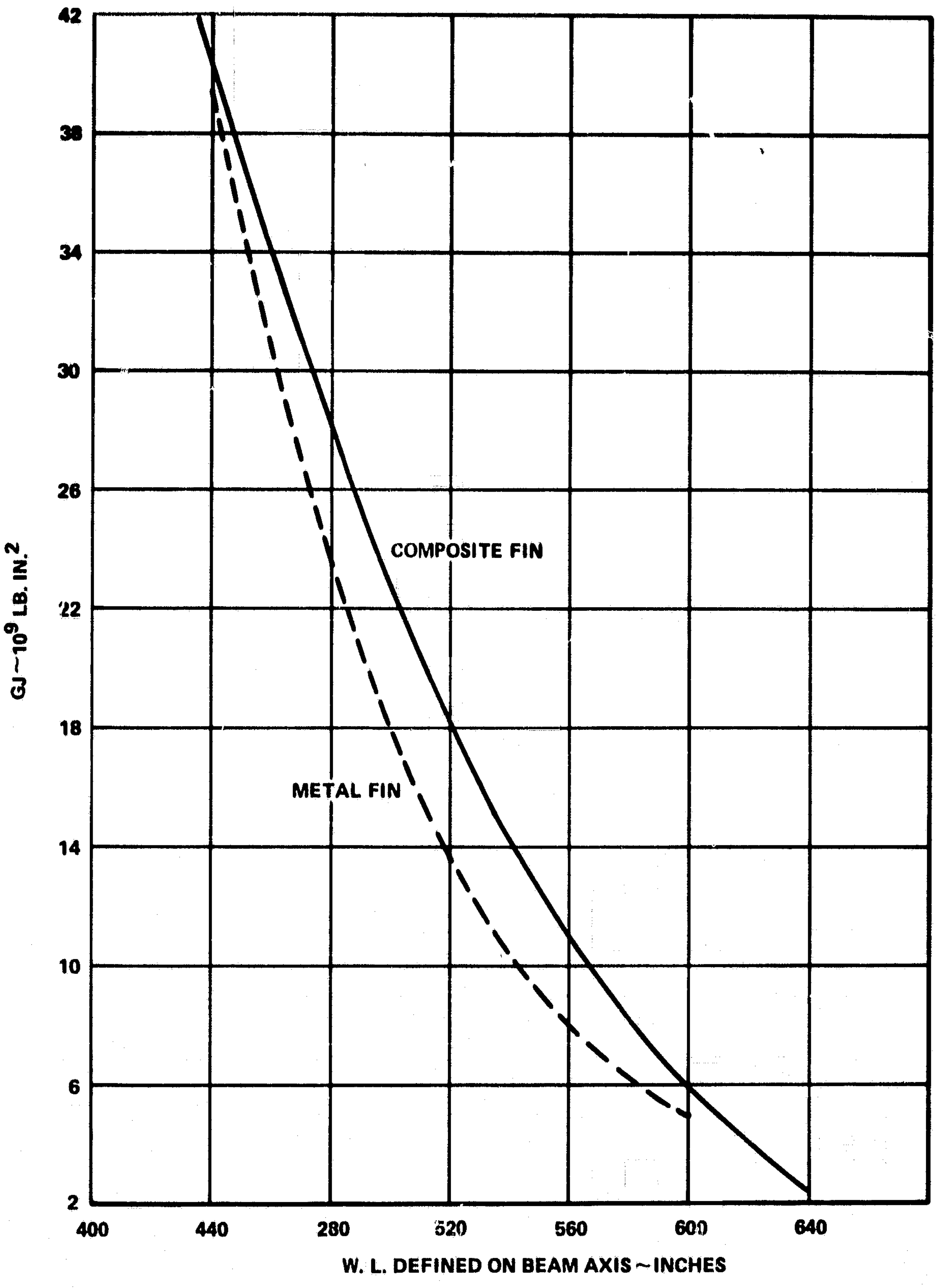


Figure 2-5. Vertical Stabilizer Torsional Stiffness

Cover Buckling

Construction of two finite element STRAP 5 buckling models representing two areas of the cover has been initiated. The models will each cover an area containing up to twelve stiffeners and running between two adjacent ribs. One model will cover the area between VSS 97.199 and VSS 121.42. The other model will cover the area between VSS 248.55 and VSS 274.26. These models will be handled through DCAS or Batch.

Cover Stress Analysis

A detailed analysis of the covers has been intiated. The skin panels are being analyzed using the HYBRID program. They will be analyzed using both the combined inplane loads from the NASTRAN model and using the spanwise loads alone. The margins of safety will be based on the lowest allowable of the two methods.

Fatigue Spectrum

Investigation of the limit loads for the subcomponent fatigue tests of cover and spar areas revealed that in all cases condition 56 was approximately 65% of condition 59. This enabled the two conditions to be combined into a normalized spectrum which contains 197,000 cycles for one lifetime. The steps on the exceedance curves for the original conditions were too shallow for the load levels applied to most specimens so that the normal tolerance in the lab equipment would cause overlap of some load steps. The modified combined spectrum eliminates this problem. The combined spectrum is shown in Table 2-4.

The actuator ribs at VSS 90.199 and VSS 97.199 are loaded primarily from the rudder actuators and hinges. The fatigue spectrum for these two ribs is thus totally different to the covers and spars. This spectrum has been developed from the rudder control system spectrum and is shown in Figure 2-6. It contains 250,000 cycles and represents two lifetimes.

TABLE 2-4. FATIGUE TEST SPECTRUM, COVERS AND SPARS

% LIMIT LOAD COND 59	N	ΣN	FLIGHT						
			1	36	360	1800	9000	18000	36000
15	166000	197020	4	22					
23	24860	31020		24	8	3			
31	4328	6160		4	3	1	2		
38	1279	1832		1	2	3	4	1	1
46	328	553			3	1	2		
54	134	225			1	1	3	1	
62	43	91				2		1	1
69	28	48				1	2		
77	9	20					2		1
81	3	11						1	1
85	3	8						1	1
88	3	5						1	1
92	1	2							1
100	1	1							1
		Count	4	51	17	12	15	6	8
		Multiplier	36000	1000	100	20	4	2	1

Structural Integrity Control Review Team

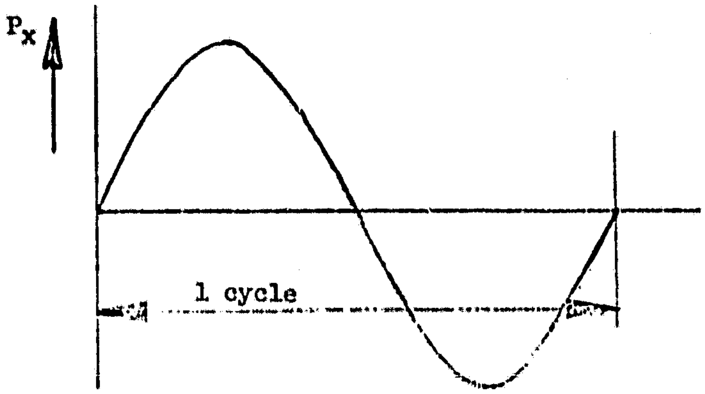
The Structural Integrity Control Review Team held weekly meetings starting in February. Discussions have covered such things as process controls, accept/reject criteria test requirements, inspection methods and criteria used by other companies involved in building composite structures.

A list of factors affecting structural integrity of composite structures and the methods of verifying that the requirements have been met is shown in Table 2-5. The cover assembly drawing for the 100-inch specimen was reviewed and a draft of the Structural Integrity Control Plan for this part is being prepared.

P_x(LB)	Block "A" Cycles	Block "B" Cycles	Block "C" Cycles	Total Cycles (Ref.)
1230	695			69,500
2280	1730			173,000
3800	70			7,000
5320		1	13	200
6840			1	15
1230			19	285
Number of Blocks	100	5	15	Sum: 250,000

1 Arrow indicates order of load application.

This truncated spectrum is representative of 72,000 flights. (2 lifetimes)



LOADING BLOCK APPLICATION SEQUENCE (Total 120 Blocks)

"A"	"B"	"C"
1-30	31	32
33-36		37
38-42		43
44-48	49	50
51-54		55
56-60		61
62-66	67	68
69-72		73
74-78		79
80-84	85	86
87-90		91
92-96		97
98-102	103	104
105-108		109
110-114		115
116-120		

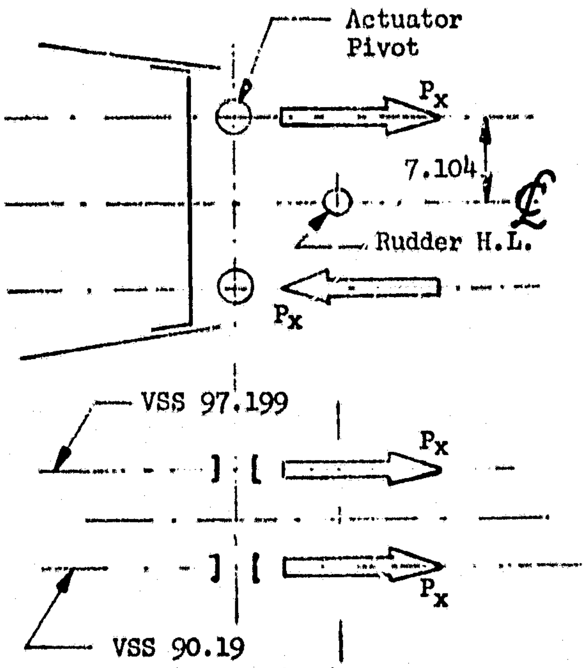


Figure 2-6. Fatigue Test Spectrum, Rudder Actuator Fitting/Compsite Rib Joint

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TABLE 2-5. STRUCTURAL INTEGRITY CONTROL

FACTORS AFFECTING STRUCTURAL INTEGRITY OF COMPOSITE STRUCTURE	METHOD OF VERIFYING REQUIREMENTS MET
Prepreg Tape	
Strength % Vol. Resin Resin Consistency Width Variation Thickness Variation	Material Spec. C-22-1379/211
Layup	
Filament Breakage Filament Alignment in Each Layer Space Between Adjacent Tapes Overlaps Between Adjacent Tapes Stacking Sequence	Process Bulletin PB 80-571
Cured Composite	
Curing Conditions	Autoclave records
Strength Verification	Process Bulletin
% Vol. Resin	Process Bulletin
Voids (size, location, % vol.)	C-Scan
Delaminated Areas (size and location)	C-Scan
Surface Integrity	Visual
Integrity of Holes	Open item
Integrity of Machined Edges	Open item
Thickness Variation	Open item
Wrinkles	Visual
Adhesive Bonding of Members	
Bonding Material	Adhesive Spec
Curing Conditions	Autoclave or Oven records
Unbonded Areas (size, location)	C-Scan
% Voids	C-Scan
Bond Thickness Variation	Open item

Operational Scenario

A survey of a typical day's operations (July 15, 1975) for L-1011's in service showed a total of 255 flights between 85 city pairs.

An analysis of temperature and humidity showed that the South and Puerto Rico had the highest temperatures and humidity on an average daily basis.

A summary of the hottest month seather conditions for several Southern U.S. cities on L-1011 routes is shown in Table 2-6.

The above data led to the selection of the Miami-San Juan route as being the most adverse. A flight profile for this route is shown in Table 2-7.

A temperature profile is being prepared for this route including ground time.

2.1.3 Ancillary Tests

Cover/Fuselage Joint Development

The root end joint of the covers for the ACVF has been reevaluated. Several design concepts for the joint have been considered and their structural behavior, weight, and producibility compared to the original design configuration. As a result of these investigations, a new root end joint concept has been selected for the ACVF. A single hat stiffener/skin specimen of the selected cover to fuselage joint configuration has been fabricated and statically tested in compression to evaluate the performance of this concept. The specimen failed at 33,050 lb, 121% of design ultimate load.

Three design configurations will be discussed; the original design configuration (Figure 2-7) and two alternate concepts designated ROOT A (Figure 2-8) and ROOT B MOD 2 (Figure 2-1).

In the original design configuration, the skin laminate thickness increased from .12 in. to .17 in. within the joint region and the hat flared out terminating at the first row of fasteners. A beam column analysis of this joint indicated unacceptably high compressive stress levels within the skin laminate in the location of the first row of fasteners. This condition

TABLE 2-6. HOTTEST MONTH WEATHER CONDITIONS

CITY	TEMPERATURE °F			REL. HUM	DEW POINT °F		L-1011 FLIGHTS PER DAY
	AVERAGE DAILY MAX.	AVERAGE EXTREME	AVERAGE DAILY MIN.	AVERAGE 1 p.m. %	AVERAGE	AVERAGE MAX. 12 HR. PERSISTING	
Atlanta	89	103	70	58	68	78	82
Dallas	96	111	76	48	68	78	26
Jacksonville	91	105	73	59	72	78	6
New Orleans	91	100	76	63	73	78	10
Orlando	92	102	73	60	73	78	20
Tampa	90	98	70	64	73	78	8
Miami	91	98	74	64	74	78	26
San Juan	88	94	74	76	73		38

TABLE 2-7. MIAMI-SAN JUAN FLIGHT PROFILE

SEGMENT	SPEED KEAS	ALTITUDE FT X 10^3	TIME MINS
Taxi - Ramp to Runway	20	0	3.0
Take-Off Run	0-135	0	0.4
Climb 0 to 10,000 Ft	250	0-10	5.0
Climb 10,000 to 32,000 Ft	283	10-32	17.0
Cruise M.82 283 KEAS	283	32	96.6
Descent 32,000 to 10,000 Ft	283	32-10	17.0
Descent 10,000 to 0 Ft	250	10-1	4.0
Taxi - Runway to Ramp	20	0	3.0
			146

is a result of a low value of flexural stiffness being coincident with a large neutral axis eccentricity.

To decrease the stress levels at the critical location, the splice plate was lengthened to include an additional row of fasteners thus increasing the effectivity of the splice plate at the termination of the hat. Also, the splice plate thickness and skin laminate thickness were increased. This design was designated ROOT A (refer to Figure 2-8). These changes resulted in a dramatic increase in flexural stiffness within the joint region compared to the original design configuration. These changes also increased the compressive stability boundary of the panel to a level where the panel could carry ultimate load with no root rib rotational restraint. Structural analysis of this joint design indicated high margins of safety for the ultimate load condition. This design configuration would incur a weight penalty of +12.6 pounds compared to the original design.

SKIN LAMINATES:

1 $\pm 45^{\circ}_{G}\, 0^{\circ}_{3G} \pm 45^{\circ}_{G}\, 0^{\circ}_{2G} \pm 45^{\circ}_{G}\, 0^{\circ}_{G} \mp 45^{\circ}_{G}\, 0^{\circ}_{2G} \mp 45^{\circ}_{G}\, 0^{\circ}_{3G} \mp 45^{\circ}_{G} + 45^{\circ}_{K49}$

2 $\pm 45^{\circ}_{G}\, 0^{\circ}_{4G} \pm 45^{\circ}_{G}\, 0^{\circ}_{3G} \pm 45^{\circ}_{2G}\, 0^{\circ}_{2G} \mp 45^{\circ}_{2G}\, 0^{\circ}_{3G} \mp 45^{\circ}_{G}\, 0^{\circ}_{4G} \mp 45^{\circ}_{G} + 45^{\circ}_{K49}$

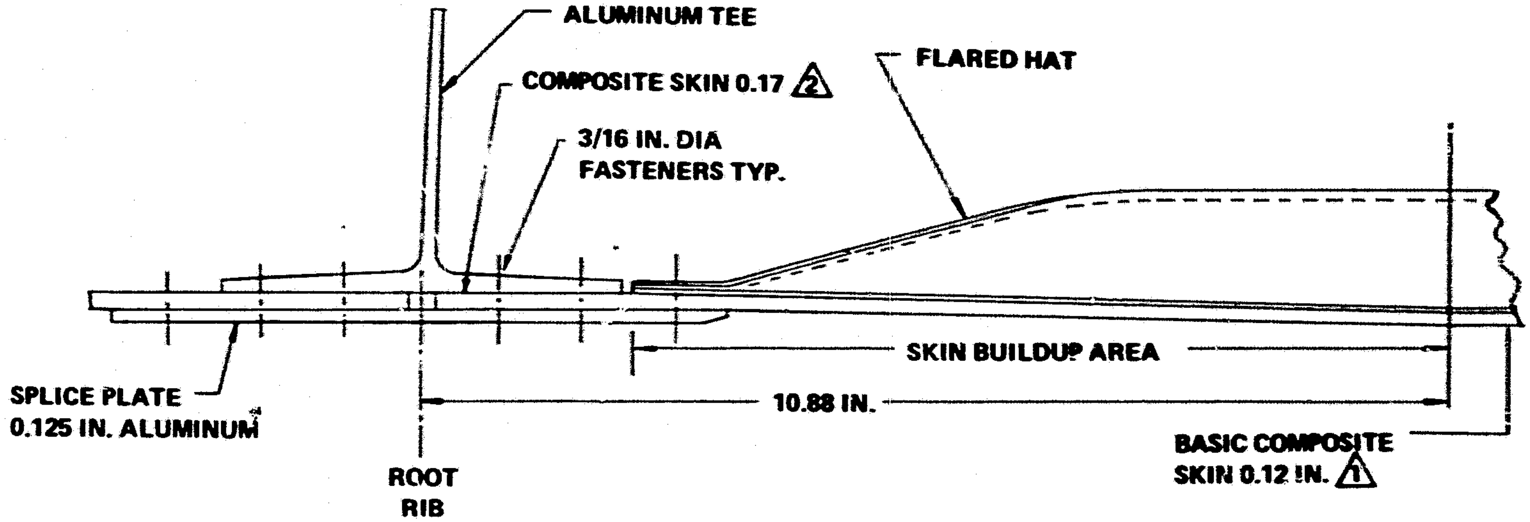

Figure 2-7. Original Configuration

SKIN LAMINATES:

1: $\pm45^\circ_G\ 0^\circ_{3G}\ \pm45^\circ_G\ 0^\circ_{2G}\ \pm45^\circ_G\ 0^\circ_G\ \mp45^\circ_G\ 0^\circ_{2G}\ \mp45^\circ_G\ 0^\circ_{3G}\ \mp45^\circ_G\ +45^\circ_{K49}$

2: $\pm45^\circ_G\ 0^\circ_{4G}\ \pm45^\circ_G\ 0^\circ_{3G}\ \pm45^\circ_{2G}\ 0^\circ_{2G}\ \mp45^\circ_{2G}\ 0^\circ_{3G}\ \mp45^\circ_G\ 0^\circ_{4G}\ \mp45^\circ_G\ +45^\circ_{K49}$

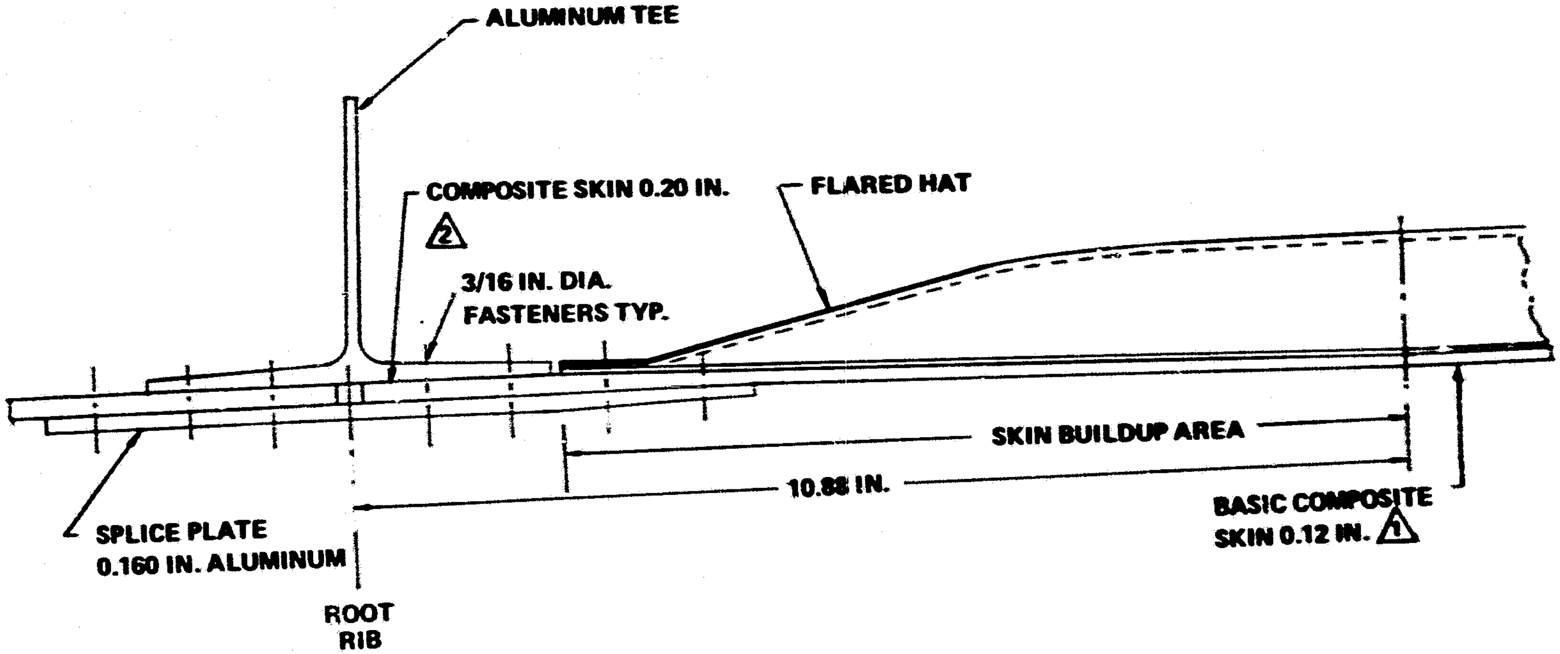

Figure 2-8. Root A Configuration

Although the ROOT A configuration was structurally acceptable on a static load basis, the single lap joint was considered a poor detail design which could potentially result in a premature fatigue failure. Subsequently, designs were investigated which eliminated the single lap joint and which also eliminated the hat flare-out to enhance the producibility of the assembly. Consideration of various schemes to bridge the interior surface to the aluminum TEE resulted in configuration ROOT B MOD 2 shown in Figure 2-1.

The ROOT B MOD 2 configuration is a complete redesign of the root splice area. The hat flare-out has been eliminated; instead the hat is cut off at a 45° angle. The number of 0° plies in the crown of the hat is decreased as the hat approaches termination thus providing a gradual load transition to the skin. At the end of the hat, the thickness of the flanges and webs has been increased to provide additional shear strength to the webs and to make the cut-off end of the hat less susceptible to damage during installation. Aluminum straps on both sides of the hat connect the interior of the skin to the aluminum TEE, thus resulting in a double lap joint.

Structural analysis of this joint design indicates high margins of safety for the ultimate loading condition. This joint design is 6.7 pounds heavier than the original design configuration.

From the producibility standpoint, the ROOT B MOD 2 configuration was judged superior to all the other designs considered. Note that this design could utilize hats which are pultruded thereby reducing manufacturing costs.

A single hat stiffener/skin specimen of the selected cover to fuselage joint has been fabricated and statically tested in compression to evaluate the performance of the concept. A photograph of the specimen is shown in Figure 2-9. Specimen instrumentation consisted of fourteen SR-4 strain gages oriented in the longitudinal direction. The specimen mounted in the test machine is shown in Figure 2-10.

The specimen was loaded statically in compression to failure which occurred at 33,050 lb, 121% of design ultimate load. Failure shown in Figures 2-11 and 2-12 occurred 17 inches from the root rib center line. It

Figure 2-9. Cover to Fuselage Joint Specimen

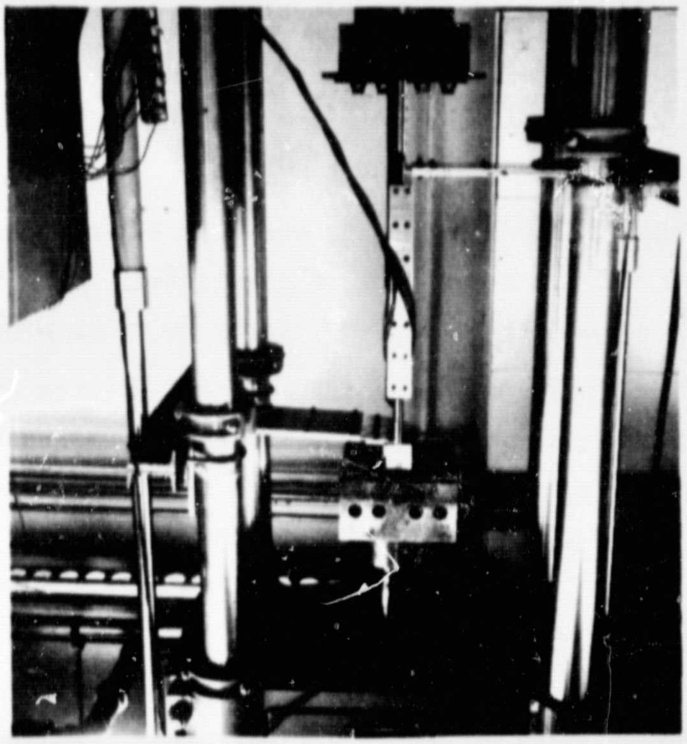

Figure 2-10. Specimen Installation in Test Machine

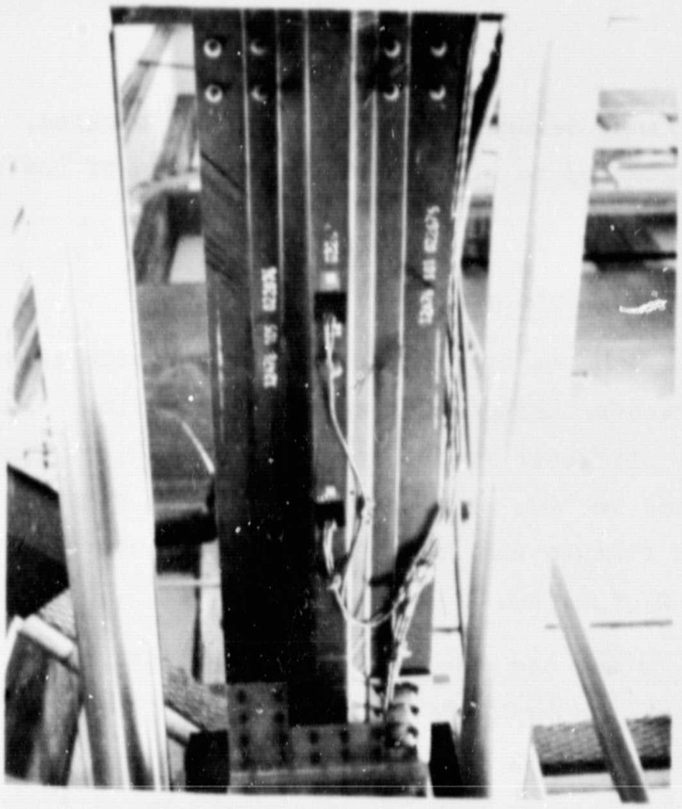

Figure 2-11. Failed Specimen

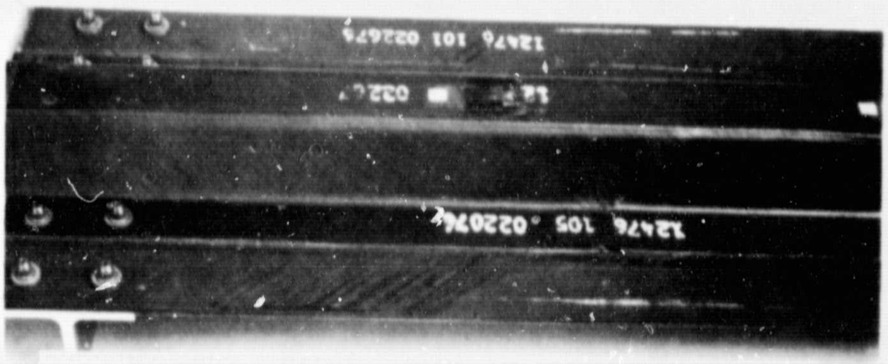

Figure 2-12. Close-Up View of Failure

appears that the flange debonded from the skin and buckled. The specimen is currently being segmented to allow visual inspection of the bond line at the failure location.

Ancillary Tests - Major Subcomponents

Drawings of all the major subcomponent test specimens of the covers have been released to Manufacturing Research for fabrication. Fabrication of test items No. 26, stiffener runout specimen, No. 28, surface panel fail-safety specimen, and No. 29, stiffener/skin disbond speciment is complete. Design of the test fixture and instrumentation layouts are complete for specimen Nos. 26, 27, 28, 29.

Specimen No. 29 has had end attachments and instrumentation installed and is ready for fatigue testing. A photograph of the specimen mounted in the test machine is shown in Figure 2-13.

Specimen No. 26 has had end attachments installed (see Figure 2-14) and is currently being instrumented.

Specimen No. 28 is in the process of having the end attachments installed.

2.2 TASK 2 - MATERIAL VERIFICATION

The Material Verification task covers the laminate property tests and mechanical joint tests.

2.2.1 Laminate Property Tests

Materials Status

Table 2-8 shows the current status (as of 29 March 1976) of materials and processes engineering documents (specifications and process bulletins) for the ACVF. MAPSCO, Materials And Processes Scheduling Committee, is the Lockheed committee responsible for the official issuing of the document. The approval of NAVPRO is required.

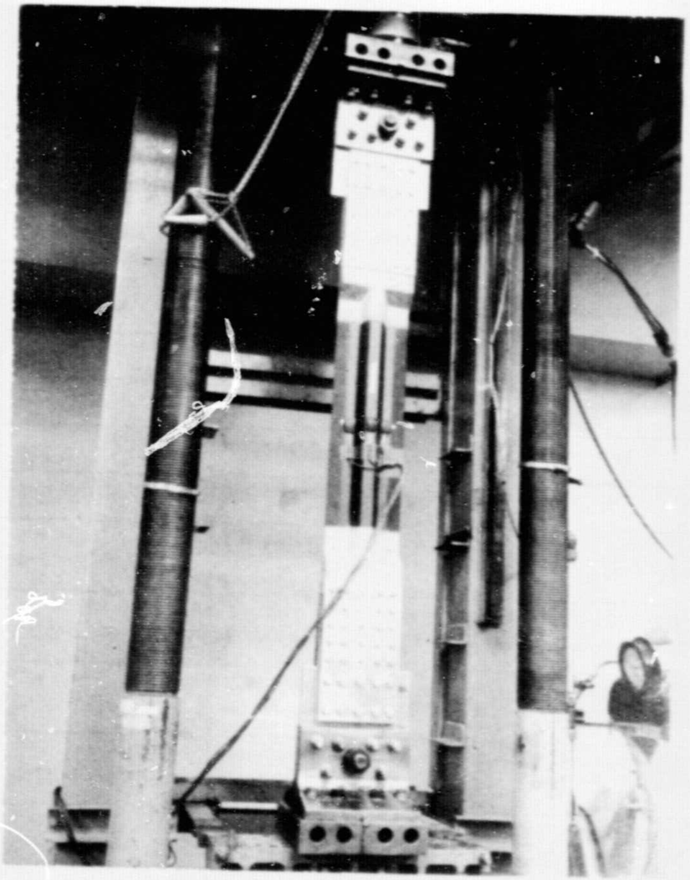

Figure 2-13. Specimen No. 29 Mounted in Test Machine

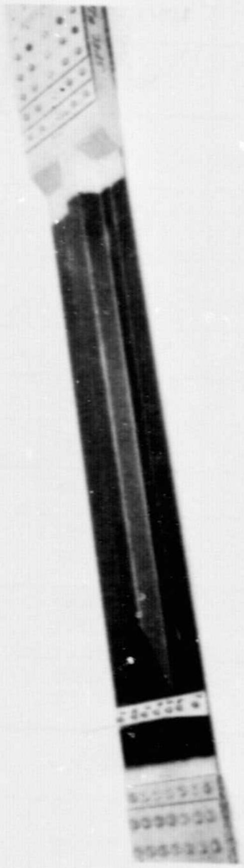

Figure 2-14. Specimen No. 26 with end attachments installed

TABLE 2-8. STATUS OF MATERIALS AND PROCESSES ENGINEERING DOCUMENTS FOR L-1011 COMPOSITE VERTICAL FIN BOX

Number	Subject	Current Status	ECD to MAPSCO	Prod. Rel. Reqd.
C-22-1379 (Basic)	Graphite Fiber Non-Woven Tape and Sheet, Resin Impregnated, General Specification For	Released		
C-22-1379/211	Graphite Fiber Non-Woven Tape and Sheet, 350 KSI Strength, 33 MSI Modulus, 160°F Service, Epoxy Preimpregnated	Released		
C-22-1350/131	Epoxy Preimpregnated Intermediate Modulus Organic Fiber Fabric, Type 1, 250°F Curing, 160°F Service, for Hybrid Application	In MAPSCO	3-24-76	4-21-76
C-22-1350/132	Epoxy Preimpregnated Intermediate Modulus Organic Fiber Fabric, Type 2, 250°F Curing, 160°F Service, for Hybrid Application	Draft Typed	4-7-76	4-21-76
C-22-1350 Amend. 3	Organic Fiber, Intermediate Modulus, Preimpregnated, General Specification For	In MAPSCO	3-24-76	4-21-76
LCM30-1085B	Adhesive, Structural Film, High Strength (250°F Cure)	Released		
LCM30-1222C	Adhesive Primer, Corrosion Inhibiting	Released		
PB75-425D(6)	Environmental Sealing of Model L-1011 Aircraft	Released		
PB78-433B(1)	Application of Exterior Coating System for the L-1011 Aircraft	Released		
PB70-575	Machining Practices, Tolerances and Allowances, For Composite Components	Draft in Type	4-12-76	5-3-76
PB71-576	Preparation For and Installation of Mechanical Fasteners in Composite Structure	Draft in Type	4-12-76	5-3-76
PB80-571	Fabrication of L-1011 ACVF Fin Skin Components, and Assembly of	In MAPSCO	3-17-76	4-8-76
PB80-573 LAAD	Advanced Composites, Fab. of Gr/Ep Solid Laminate Ribs, 160°F Service, Model L-1011	Awaiting Draft		
PB80-574 Lockheed-Georgia Co.	Elastomeric Molding of Vertical Fin Advanced Composites Spar, Model L-1011	Gelac Draft in Review		

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Table 2-9 shows the results of the qualification testing of batch 2 of Kevlar 49-181/5209 to the C22-1350/131 specification requirements. The material passed all requirements.

Environmental Effects

Lockheed has conducted an in-house (IRAD) investigation of the effects of moisture and temperature on Narmco's 5209 Epoxy (and other resins) by several different methods. The results to date indicate that 5209 has a low moisture absorption and performs satisfactorily in the transport aircraft environment.

Glass transition temperatures for T300/5209 graphite/epoxy were measured by the penetration method and the dilatometry method on dry specimens. The results were $T_g = 112^{\circ}C$ ($234^{\circ}F$) and $110^{\circ}C$ ($230^{\circ}F$) respectively. Penetration values on wet specimens were determined to be $T_g = 95^{\circ}C$ ($203^{\circ}F$) and $93^{\circ}C$ ($199^{\circ}F$) at 4.33% and 3.9% (of the resin weight) moisture gain, respectively.

Neat Resin Investigations

The percent moisture absorption of neat resin (i.e. without fiber reinforcements) castings of Narmco's 5209 is 4.9% of the dry resin at equilibrium. This is comparable to the data shown under material characterization tests. A six ply laminate of T300/5209 with 29% resin content had an equilibrium moisture content of 1.37% of the laminate weight, or 4.7% of the resin weight. By comparison, tests of U.S. Polymeric's E715 and Fiberites 934 showed equilibrium moisture gains 27% greater than 5209.

Design Allowables

Composite material design allowables for use during Phase II - Detail Design have been defined. They represent currently available test data. As test data from the design data test programs (ancillary tests 11-17) become available, these material design allowables will be suitably revised.

The data shown on Tables 2-10, 2-11, 2-12, and 2-13 are the result of a statistical analysis of qualification test data and limited results from Test 13A (transverse tension, transverse compression, and ± 45 tension) by the methods of MIL-HDBK-5A, Section 9 (ref. 4). The stiffnesses are mean values (normalized to 63% fiber volume), and the stresses and strains are based on

TABLE 2-9. QUALIFICATION TESTING RESULTS KEVLAR 49-188/5209

Fiber Properties

Property	Unit	Requirement
Tensile strength	psi (min)	350,000
Tensile Modulus, Nominal	psi x 10^6	18
Fiber Density, Nominal	gms/cc	1.44
Fiber Diameter, Nominal	inches	0.00043

181 Style Fabric Properties

Type	Filaments per Strand (min)	Strands per Ply	Plies per Yarn	Yarn Twist, Turns/Inch	Yarn Denier	Yarn End Count Yarns/Inch		Weave	Thickness (Inches)	Weight (oz/yd^2)
						Warp	Fill			
1	267	1	1	0.9	380	48 ± 2	48 ± 2	8 harness satin	0.008	5.0 ± 0.25

TABLE 2-9. QUALIFICATION TESTING RESULTS KEVLAR 49-181/5209 (Continued)

Uncured Properties

Property	Unit	Requirement	Test Results
Volatiles Test Temp 275°F Time at Temp. 10 ±2 min	% by wt max	2	0.8% (Ave)
Uncured Resin Content	% by wt	53 ±3	54
Flow 10 min. @ 275°F and 15 psi	%	22 - 37	34
Gel Time @ 275°F	min	Report for information only	5.3
Specification C22-1350/131 Batch #2 Lab Report 325442			

TABLE 2-9. QUALIFICATION TESTING RESULTS KEVLAR 49-181/5209 (Continued)

Mechanical and Physical Properties

Property	Unit	Test Temp. °F	Requirement (1)	Test Results	
				Average	Individual
Specific Gravity			1.30 - 1.39	1.33	
Cured Resin Content	%		38 - 50	41.5	
Water Absorption	% max		1.0	0.43	
Longitudinal Tensile Strength	ksi (min)	77 -67 160	79 70 78	85 77 85	84.5,85.5,85.5 76.0,76.7,77.4 83.5,83.8,87.0
Longitudinal Tensile Modulus	10^6 psi (min)	77 -67 160	4.2 5.0 4.0	5.1 5.7 4.6	4.9,5.1,5.2 5.6,5.6,5.8 4.5,4.5,4.7
Longitudinal Compressive Strength	ksi (min)	77 -67 160 160 wet (2)	26 30 21 21	29 38 23 23	28.5,29.0,29.1 37.5,37.6,38.7 23.0,23.4,23.9 21.9,22.9,23.1

(1) Average of 3 determinations for fiber volume, specific gravity, water absorption, and cured thickness per ply. Values for all other tests are minimum individual of a set of 3 determinations for qualification tests, except flexural tests are for 2 with warp **face up** and 2 with warp face down.

(2) After 7 days immersion in water at 125°F.

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TABLE 2-9. QUALIFICATION TESTING RESULTS KEVLAR 49-181/5209 (Concluded)

Mechanical and Physical Properties

Property	Unit	Test Temp. °F	Requirement (1)	Test Results	
				Average	Individual
Longitudinal Compressive Modulus	10^6 psi (min)	77 -67 160 160 wet (2)	3.6 3.7 3.5 3.5	4.0 4.1 3.9 4.1	3.6,4.0,4.5 3.9,4.0,4.5 3.7,3.8,4.1 4.1,4.1,4.2
Longitudinal Flexural Strength	ksi (min)	77 -67 160 160 wet (2)	45 55 38 38	58 67 53 53	55,57,60,61 66,68,68,68 52,52,53,53 51,54,54,55
Longitudinal Flexural Modulus	ksi (min)	77 -67 160 160 wet (2)	3.1 3.4 2.9 2.9	3.8 3.7 3.3 3.2	3.7,3.7,3.9,3.9 3.6,3.6,3.8,3.9 3.0,3.1,3.6,3.6 3.2,3.2,3.2,3.2
Longitudinal Short Beam Shear Strength	ksi (min)	77 -67 160 160 wet (2)	6.0 5.5 6.0 5.8	6.6 5.8 6.4 6.6	6.5,6.7,6.7 5.7,5.7,5.9 6.4,6.4,6.5 6.6,6.6,6.7
(Interlaminar) Tensile Strength	ksi (min)	77 -67 160 160 wet (2)	2.8 2.2 2.5 1.5	3.3 2.6 3.2 2.0	3.2,3.3,3.4 2.5,2.6,2.8 3.2,3.2,3.4 1.9,2.0,2.0
Cured Thickness per Ply	Inch		0.009-0.011	0.0097	

TABLE 2-10. DESIGN ALLOWABLES ANALYSIS T300/5209
LONGITUDINAL (0^o) TENSION - RTD

SPECIMEN I.D.	FIBER VOL. %	F_L^{tu} Ksi	E_L^t Msi	ϵ_L^{tu} μ IN/IN
Qual. Test				
1	65	229	21.23	10800
2		223	20.87	10700
3		200	21.05	9500
4		231	21.58	10700
5		214	20.9	10220
6		233		
7		230		
8		207		
9		213		
Mean	65	220	21.13	10380
Coef. Var.		5.5%	1.4%	5.2%
No. Spec.		9	5	5
"B" Basis		191		9000
Normalized	63	182	20	9000

LONGITUDINAL (0^o) COMPRESSION - RTD

SPECIMEN I.D.	FIBER VOL. %	F_L^{cu} Ksi	E_L^{cu} Msi
Qual. Test			
1	65.3	241	20.12
2		256	20.86
3		258	20.75
4		254	20.48
5		261	19.26
Mean	65.3	254	20.29
Coef. Var.		3%	3.2%
"B" Basis		228	
Normalized	63	220	19.5

TABLE 2-11. DESIGN ALLOWABLES ANALYSIS T300-5209
TRANSVERSE (90°) TENSION - RTD

SPECIMEN I.D.	DENSITY FIBER VOL. % BATCH/ROLL THICKNESS	F_T^{tu} PSI	E_T^t MSI	ε_T^{tu} μIN./IN.
Mat'l. Characterization INC 661	1.5836 gms/cc 65.5%			
(12 plies) -1	Batch 1473	8299		5800
-7	Roll 5	8371	1.448	5880
-13	t = .060 ± .001	7927	1.378	5680
-19		8247	1.413	5800
(AVERAGE)		(8211)	(1.413)	(5790)
COEF. OF VARIATION	%	2.4	2.5	1.4
INC 667	64.7%			
-1	1.5785 gms/cc	8224	1.441	5800
-7	Batch 1473	7936	1.407	5800
-15	Roll 5	8268	1.417	6000
-21	t = .060 ± .001	7880	1.486	5300
(AVERAGE)		(8077)	(1.438)	(5725)
COEF. OF VARIATION	%	2.4	2.4	5.2
INC 681	63.1%			
-4	1.5687 gms/cc	5503*	1.732	3180*
-11	Batch 1473	8127	1.697	4900
-18	Roll 6	7789	1.702	4700
(AVERAGE)	t = .058 ± .002	(7958)	(1.710)	(4800)
COEF. OF VARIATION	%	3.0	1.1	2.9
Qualification Test	64.5%			
(8 plies) -1	1.5652 gms/cc	7885	1.698	4591
-2	Batch 1473	8782	1.687	4705
-3	Roll 7	9295	1.733	5400
-4		9103	1.781	5250
-5	t = .040 ± .001	9295	1.756	5500
(AVERAGE)		(8872)	(1.731)	(5089)
COEF. OF VARIATION	%	6.65	2.27	8.14
COMBINING ALL SPECIMENS	MEAN	8362	1.585	5407
	COEF. OF VARIAT.	6.2	9.9	8.9
	NO. OF SPECIMENS	15	15	15
	"B" BASIS ALLOW.	7295		4414

NOTE: Data are from both the Material Characterization Test (13A) and from the Material Qualification Tests.

* Anomalous Failure - Data omitted from Averages

TABLE 2-12. DESIGN ALLOWABLES ANALYSIS T300/5209
TRANSVERSE (90°) COMPRESSION - RTD

SPECIMEN I.D.		DENSITY FIBER VOL. % BATCH/ROLL/THICK.	F_T^{CU} PSI	E_T^C MSI	ε_T^{CU} µIN./IN.
Material Charact.		1.5836 gms/cc			
1NC 661		65.5%			
(12 Plies)	-4	Batch 1473	26791	1.445	-20300
	-10	Roll 5	26926	1.381	-21400
	-16		29680	1.382	-28300
	-22	t = .060 ± .001 in.	28754	1.389	-26400
(AVERAGE)			(28038)	(1.399)	(-24125)
		1.5785 gms/cc			
1NC 667		64.7%			
	-4	Batch 1473	28374	1.429	-25200
	-11	Roll 5	27444	1.414	-22600
	-18	t = .060 ± .001	28723	1.435	-25500
(AVERAGE)			(28180)	(1.426)	(-24433)
		1.5687 gms/cc			
1NC 681		63.1%			
	-1	Batch 1473	28350	1.531	-20000
	-7	Roll 6	27120	1.640	-18300
	-15	t = .058 ± .002	27043	1.622	-19000
	-21		26279	1.570	-18500
(AVERAGE)			(27198)	(1.591)	(-18950)
REF. RN569204 COMBINING ALL SPECIMENS		MEAN	27771	1.476	-22300
		COEF. OF VAR.	3.8	6.6	15.8
		NO. OF SPEC.	11	11	11
		"B" BASIS ALLOW.	25366		-14300

DATA ARE FROM MATERIALS CHARACTERIZATION TEST 13A.

TABLE 2-13. DESIGN ALLOWABLES ANALYSIS
T300/5209 ±45° TENSION - RTD

SPECIMEN I.D.	FIBER VOL %	F_X^{tu} PSI	E_X^t MSI	* G_{LT} MSI	ε_X^{tu} µIN./IN.
2NC 690	63.3				
-1		21780	2.5	.7	>10000
-4		23100	2.34	.65	>10000
-7		21650	2.5	.7	21000
-10		23320	2.2	.61	>30000
(AVERAGE)		(22463)	(2.385)	(.665)	
1NC 665-A	62.7				
-1A		22450	2.75	.78	>50000
-4A		22600	2.5	.7	40000
-7A		23210	2.65	.75	>50000
-10A		22520	2.5	.7	74000
-13A		22580	2.5	.7	70000
(AVERAGE)		(22672)	(2.58)	(.726)	-
1NC 665-B	62.7				
-1A		22200	2.4	.67	>50000
-4A		22600	2.65	.75	>50000
-7A		24000	2.65	.75	>50000
-10B		23280	2.65	.75	>50000
(AVERAGE)		(23020)	(2.588)	(.73)	-
ALL SPECIMENS	MEAN	22715	2.52	.71	
	COEF. OF VAR.	2.9%	6.0%	6.7%	
	NO. SPECS.	13	13	13	
	"B" BASIS	21300			

DATA FROM MATERIAL CHARACTERIZATION TEST 13A

*G_{LT} is the in-plane (0°) Unidirectional Shear Modulus Transformed by Laminated Plate Theory from ±45° Tension Test.

a 90% probability of exceedance with a 95% confidence ("B" basis). The (0^o) longitudinal compression (sandwich beam) tests for the material qualification used strain gages for modulus. The strain readings were not taken to failure. To project to ultimate strain, the strains at 135.2 ksi (6,850 μin/in) and at 185.9 ksi (9720 μin/in) were used to obtain Ramberg-Osgood parameters, n = 4.097 and k - .00005313. With these parameters, E = 19.5 msi, and F_L^{CU} = 220 ksi, the compressive stress/strain curve shown on Figure 2-15 was derived. The bilinear "yield" point of 150 ksi is approximately 2/3 of the ultimate strength, and the bilinear approximation is shown by dashed lines.

The $\pm 45^o$ tensile test results are transformed to 0^o in-plane shear stress/strain data by taking the shear stress as one-half the tensile stress and the shear strain as the algebraic sum of the longitudinal and transverse tensile strains. Figure 2-16 shows the computer plot for a typical specimen transformed in this manner. The bilinear approximation of the curve is also shown as a dashed line.

The first two columns of Table 2-14 contain room temperature - dry (RTD) design allowables for T300/5209 graphite/epoxy for use in both bilinear (e.g., HYBRID) and linear computer programs. With the exception of Poisson's ratio and thermal expansion (from LTV data) these data are based on Calac tests of material conforming to specification C22-1379/211.

Until further data are available, the environmental reduction factors shown on Table 2-5 of the Second Quarterly Report (ref. 3) have been applied to the RTD properties to approximate 120°F wet properties, and the results are shown in the last two columns of Table 2-14.

Table 2-15 contains room temperature design properties for Kevlar 49-181 and 120 style fabrics with an epoxy matrix for use with bilinear computer programs. They are based on previous tests (including wet conditioning) of PRD 49 (Kevlar 49) with Hysol's 9704, U.S.P. E715, and Hexcel F-155 and documented in Section 4.4 of ref. 5. The results of qualification and acceptance testing of Kevlar 49-181/5209 were statistically analyzed and the data summarized on Table 2-16. These data were combined with the data discussed above to give the 181 cloth data. Since these data include the effects of moisture and temperature no further reduction factors are

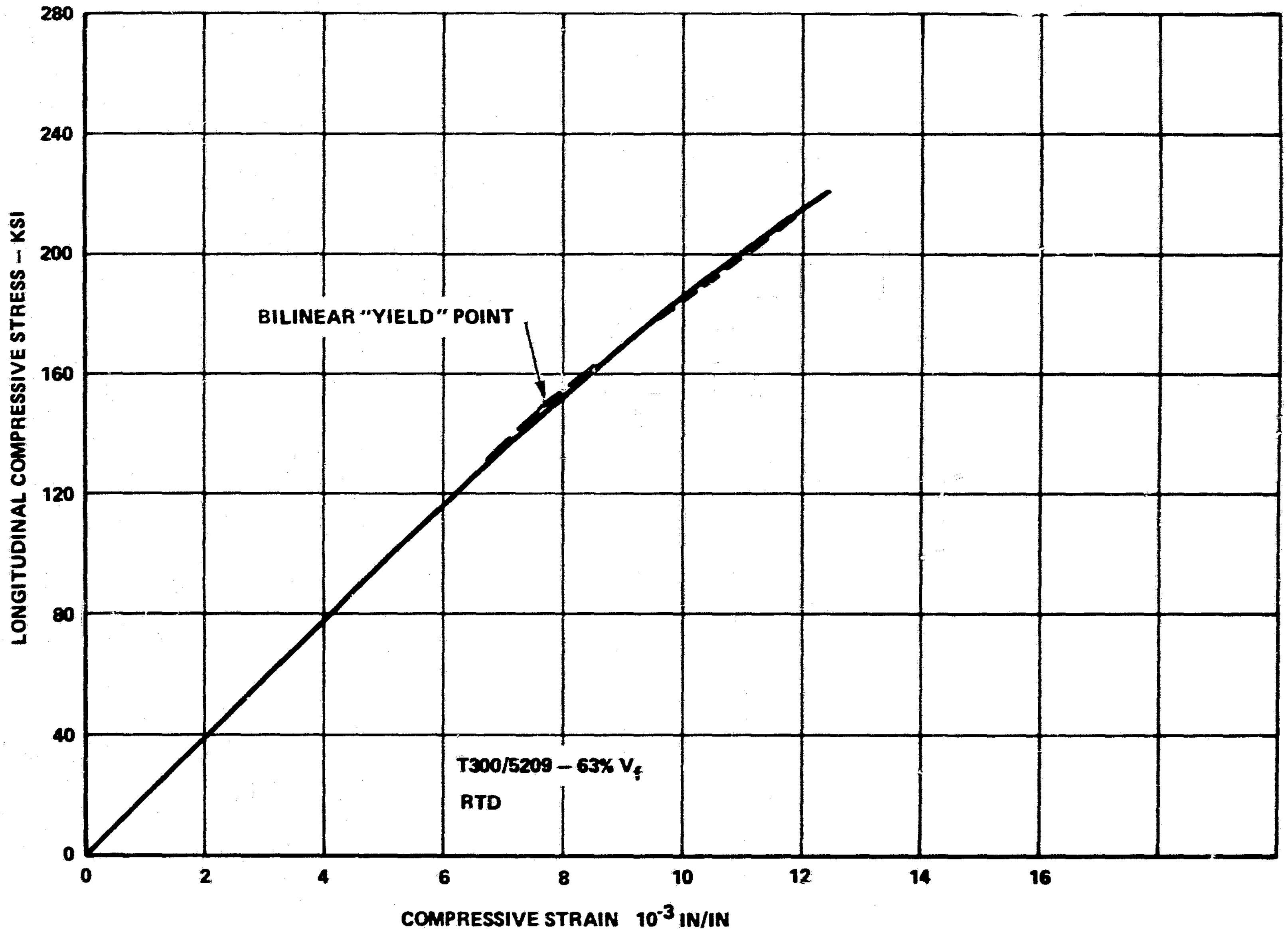

Figure 2-15. Predicted (0°) Longitudinal Compressive Stress/Strain

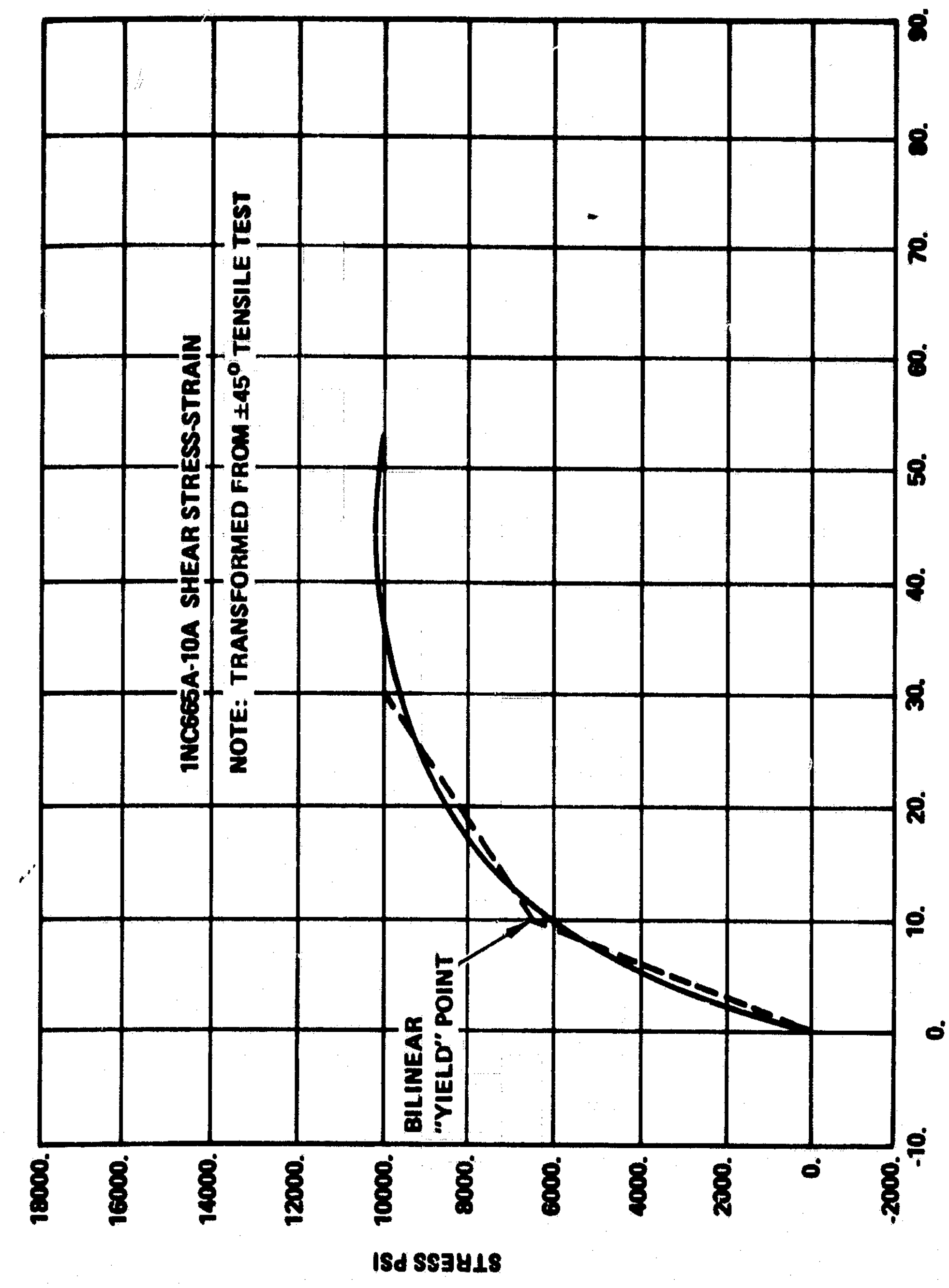

Figure 2-16. (0°) In-Plane Shear Stress/Strain (T300/5209)

TABLE 2-14. DESIGN ALLOWABLES FOR T300/5209 GRAPHITE/EPOXY FOR BOTH BILINEAR AND LINEAR COMPUTER PROGRAMS

	Direction, Type Of Property	Units	Bilinear T300/5209 GR/EP	Linear T300/5209 GR/EP	Bilinear T300/5209 GR/EP	Linear T300/5209 GR/EP
	CONDITION		RTD	RTD	120°F- WET	120°F - WET
Extensional Moduli	L, Initial Tensile	Psi	20,000,000	20,000,000	20,000,000	20,000,000
	L, Initial Compres.	Psi	19,500,000	19,500,000	19,500,000	19,500,000
	L, Second Tensile	Psi	20,000,000		20,000,000	
	L, Second Compres.	Psi	14,900,000		14,600,000	
	T, Initial Tensile	Psi	1,585,000	1,585,000	1,189,000	1,189,000
	T, Initial Compres.	Psi	1,480,000	1,480,000	1,110,000	1,110,000
	T, Second Tensile	Psi	1,585,000		1,189,000	
	T, Second Compres.	Psi	1,480,000		1,110,000	
Shear Mod.	LT, Initial Shear	Psi	650,000	650,000	488,000	488,000
	LT, Second Shear	Psi	175,000		129,000	
	LT, Major Poisson's		.21	.21	.19	.19
Therm Exp.	L, Coef. of Exp.	10^{-6} in./in./°F	0.3	0.3	0.3	0.3
	T, Coef. of Exp.	10^{-6} in./in./°F	15.0	15.0	15.0	15.0
Strains – Tensile	L, Yield Tensile	10^{-3} in./in.	9.0 (180)		9.0 (180)	
	T, Yield Tensile	10^{-3} in./in.	4.4 (7)		4.0 (4.8)	
	L, Ultimate Tensile	10^{-3} in./in.	9.0 (180)	9.0 (180)	9.0 (180)	9.0 (180)
	T, Ultimate Tensile	10^{-3} in./in.	4.4 (7)	4.4 (7)	4.0 (4.8)	4.0 (4.8)
Strains – Compr.	L, Yield Compr.	10^{-3} in./in.	7.7 (150)		6.6 (129)	
	T, Yield Compr.	10^{-3} in./in.	14.3 (21)		15.7 (17)	
	L, Ultimate Compr.	10^{-3} in./in.	12.4 (220)	11.3 (220)	10.7 (189)	9.7 (189)
	T, Ultimate Compr.	10^{-3} in./in.	14.3 (21)	14.3 (21)	15.7 (17)	15.7 (17)
Strains – Shear	LT, Yield Shear	10^{-3} in./in.	10 (6.5)		11 (5.4)	
	LT, Ultimate Shear	10^{-3} in./in.	30 (10)	15.4 (10)	33 (8.2)	16.8 (8.2)
Auxiliary Data	Fiber Volume	%	63	63	63	63
	Density	lbs/in.^{3}	.057	.057	.057	.057
	Ply Thickness	in.	.0051	.0051	.0051	.0051

NOTE: Values in Parenthesis are strengths in Ksi.

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TABLE 2-15. PRELIMINARY DESIGN ALLOWABLES FOR KEVLAR 49 FABRIC/EPOXY FOR BILINEAR COMPUTER PROGRAMS

	Direction, Type of Property	Units	Bilinear Kevlar-49/EP 181 Cloth (281 Cloth) *RT-Wet	Bilinear Kevlar 49/EP 120 Cloth RT
Extensional Moduli	L, Initial Tensile	psi	4,560,000	4,480,000
	L, Initial Compres.	psi	*4,000,000	3,650,000
	L, Second Tensile	psi	4,560,000	4,480,000
	L, Second Compres.	psi	* 800,000	280,000
	T, Initial Tensile	psi	4,840,000	4,480,000
	T, Initial Compres.	psi	*4,000,000	3,650,000
	T, Second Tensile	psi	4,840,000	4,480,000
	T, Second Compres.	psi	* 800,000	280,000
Shear Mod.	LT, Initial Shear	psi	350,000	350,000
	LT, Second Shear	psi	117,000	117,000
	LT, Major Poisson's		0.15	0.15
Therm Exp.	L, Coef. of Exp.	10^{-6} in./in./	0	0
	T, Coef. of Exp.		0	0

*Revised 3/26/76 based on Kev 49-181/5209 Qualification Test Data

NOTE: Values in Parenthesis are strengths in Ksi.

TABLE 2-15. PRELIMINARY DESIGN ALLOWABLES FOR KEVLAR 49 FABRIC/EPOXY FOR BILINEAR COMPUTER PROGRAMS (Concluded)

		Direction, Type of Property	Units	Bilinear Kevlar-49/EP 181 Cloth (281 Cloth) *RT-Wet	Bilinear Kevlar 49/EP 120 Cloth RT
Strains	Tensile	L, Yield Tensile	10^{-3} in./in.	14.6	14.6
		T. Yield Tensile	10^{-3} in./in.	17.0	16.0
		L. Ultimate Tensile	10^{-3} in./in.	14.6 (66.6)	14.6 (65.4)
		T. Ultimate Tensile	10^{-3} in./in.	*14.9 (72.1)	16.0 (71.7)
	Compr.	L, Yield Compr.	10^{-3} in./in.	* 3.2 (12.8)	3.4
		T, Yield Compr.	10^{-3} in./in.	* 3.2 (12.8)	3.4
		L, Ultimate Compr.	10^{-3} in./in.	*11.0 (19.0)	20 (17.0)
		T, Ultimate Compr.	10^{-3} in./in.	*11.0 (19.0)	20 (17.0)
	Shear	LT, Yield Shear	10^{-3} in./in.	20	20
		LT, Ultimate Shear	10^{-3} in./in.	50 (10.5)	50 (10.5)
Auxiliary Data		Fiber Volume	%	50	50
		Density	lbs/in.^{3}	0.05	0.05
		Ply Thickness	in.	0.010-0.009	0.005-0.004

TABLE 2-16. STATISTICAL ANALYSIS OF KEVLAR 49-181/5209 TESTS

Property	Temp. °F	Mean KSI or, (MSI)	Number of Spec's	Coef. of Variat. %	"B" Min Strength KSI
Tensile Strength	77 -67 160D	86.6 76.7 84.8	15* 3 3	3.5 0.9 2.3	80.3 72.4 72.8
Tensile Modulus	77 -67 160D	4.89 5.67 4.57	15* 3 3	3.7 2.0 2.5	
Compressive Strength	77 -67 160D 160W	28.9 37.9 23.4 22.6	3 3 3 3	1.1 1.8 1.9 2.8	26.9 33.8 20.7 18.7
Compressive Modulus	77 -67 160D 160W	4.03 4.13 3.87 4.13	3 3 3 3	11.2 7.8 5.4 1.4	
Short-Beam Shear Strength	77 -67 160D 160W	7.13 5.77 6.83 6.63	15* 3 15* 3	4.1 2.0 3.3 0.8	6.5 5.1 6.4 6.3
Flexural Strength	77 -67 160D 160W	52.3 67.4 46.1 53.3	19* 4 19* 4	6.6 1.5 10.0 3.2	45.6 63.2 37.1 46.2
Flexural Modulus	77 -67 160D 160W	3.52 3.73 3.32 3.2	19* 4 19* 4	5.6 4.0 6.1 0	

*Indicates a combination of qualification and four acceptance tests. All others are qualification test results only.

required. These data are treated as preliminary until results of current tests become available.

Figure 2-17 shows the variation of fiber volume and laminate density with resin content for Kevlar 49/5209.

Fastener bearing allowables (RTD) reported in Section 4.2 of the Second Quarterly Report (ref. 3) are being used as preliminary until further tests data become available.

As a preliminary design policy for determining laminate strengths by material characterization programs, the following criteria are established:

1. No ply failures in the filament direction are permitted at ultimate load.

2. No ply failures in in-plane shear or transverse to the filament direction are permitted at 2/3 of ultimate load.

3. Account must be taken of the reduction of laminate ultimate tensile and compressive strengths due to stress concentrations from holes. The method of accounting can be semi-imperical or the factors shown for cutouts in the Advanced Composites Design Guide.

Design Curves for Laminate Allowables

Laminate allowable curves suitable for design purposes were developed analytically for T300/5209 graphite/epoxy and are shown on Figures 2-18 through 2-26. Unless otherwise noted, the reduced properties for wet at 120°F are shown. The strength and stiffness curves were computed using the "HYBRID" program for the $(0_i/\pm45_j)_c$ family of laminates.

Figure 2-18 shows the initial compressive modulus for the $(0_i/\pm45_j)_c$ and $(90_i/\pm45_j)_c$ families of laminates as a function of percent ±45 degree plies. Based on laminated plate theory, the modulus is only a function of the proportion of plies at a given angle, not of the stacking sequence. For example, either laminate $(\pm45/0_6/\mp45)$ or $(45/0_3/-45_2/0_3/45)$ would have a modulus in the 0° direction, E_x^c = 12.6 MSI, and in the 90° direction, E_y^c = 2.7 MSI.

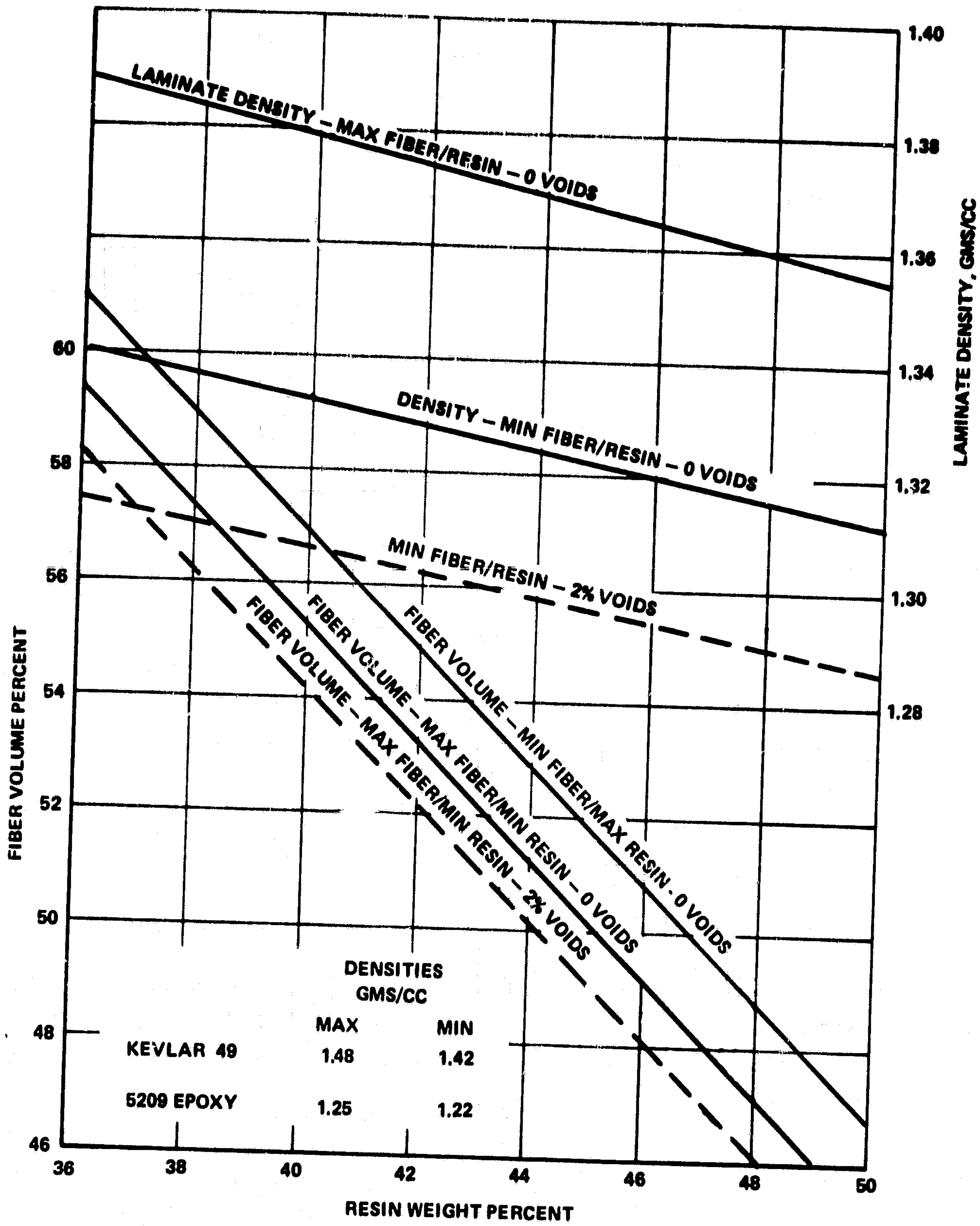

Figure 2-17. Kevlar 49/5209 Fiber Volume and Density

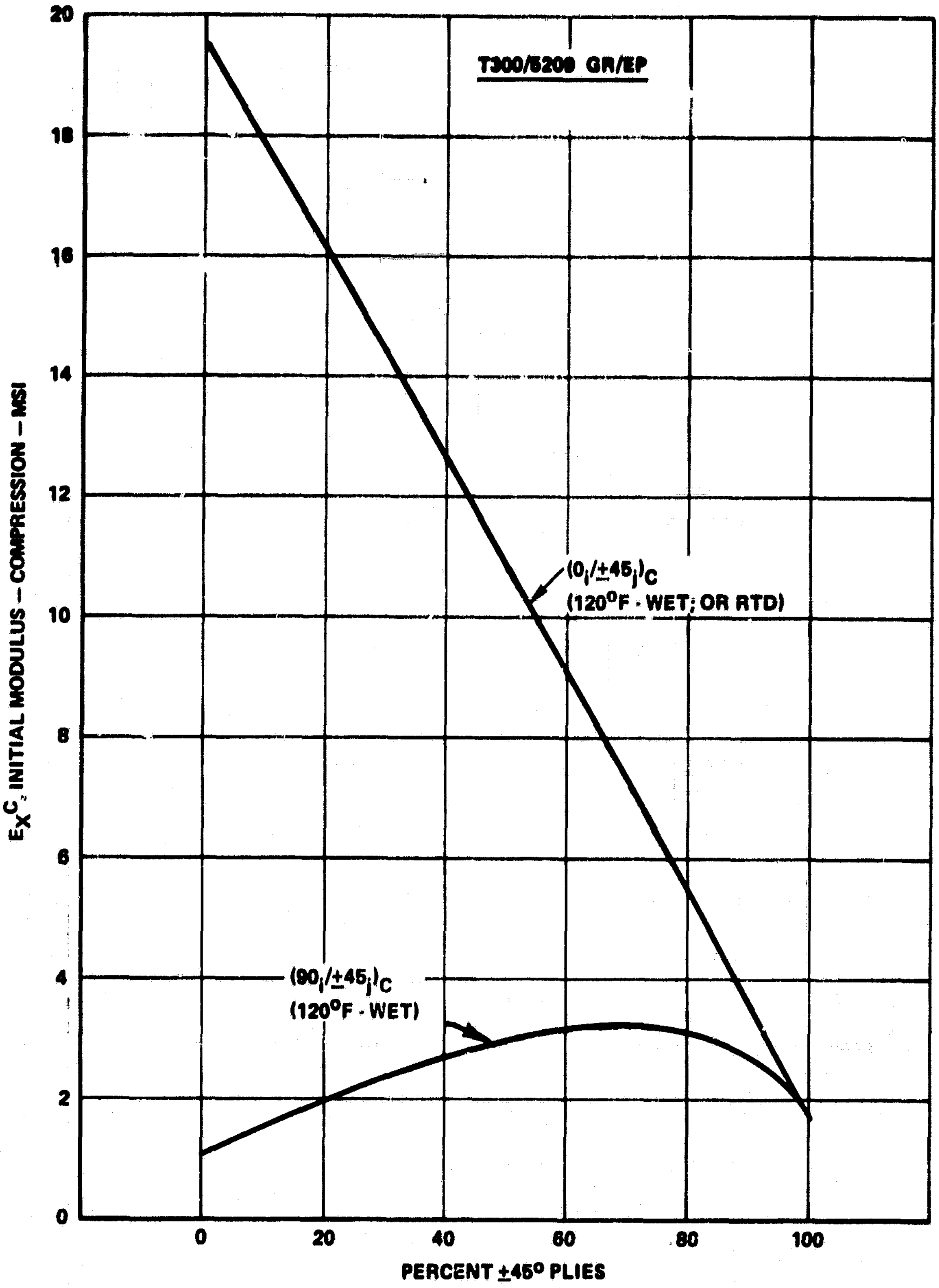

Figure 2-18. Laminate Compressive Modulus for T300/5209 GR/EP

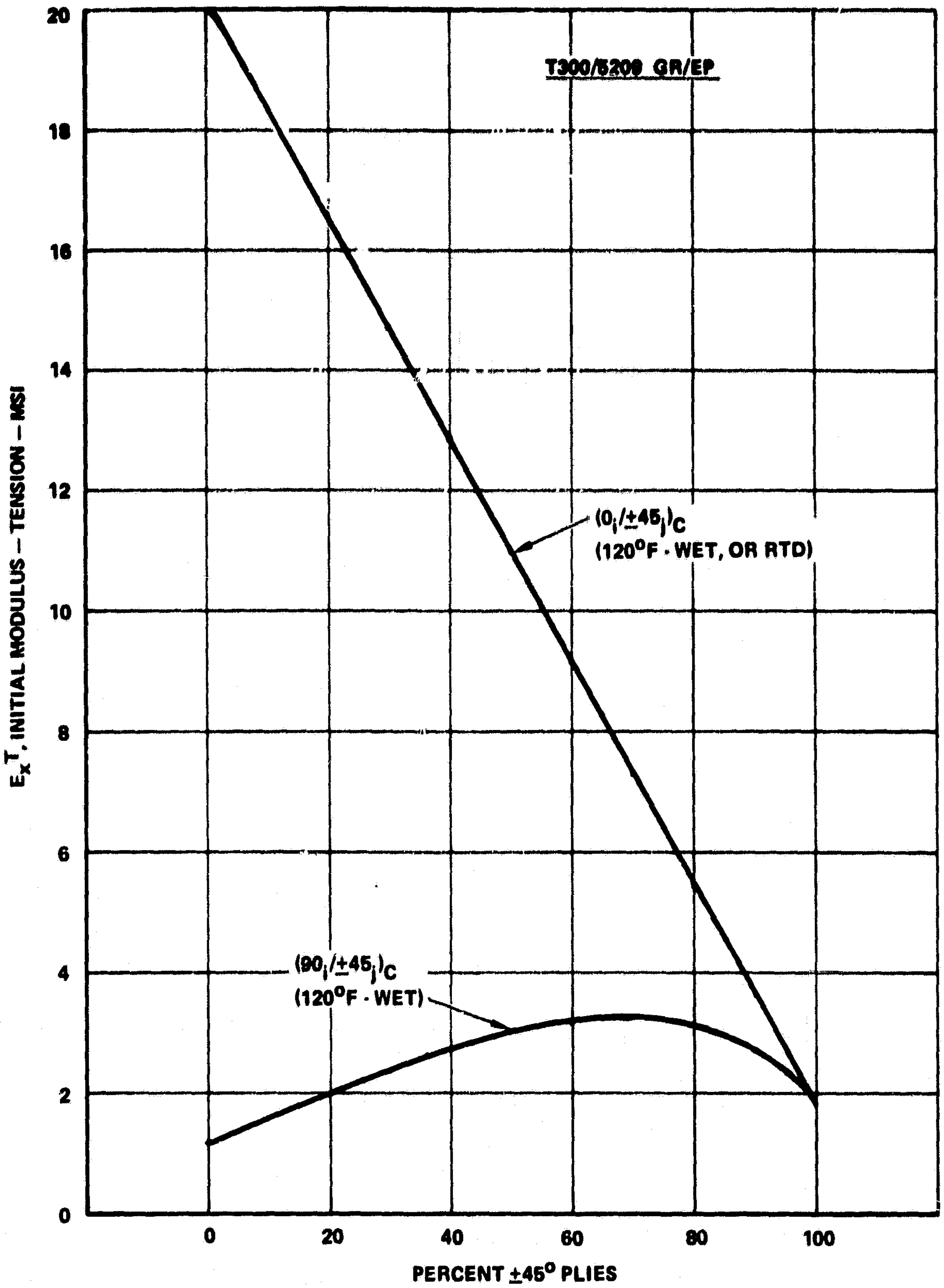

Figure 2-19. Laminate Tension Modulus for T300/5209 GR/EP

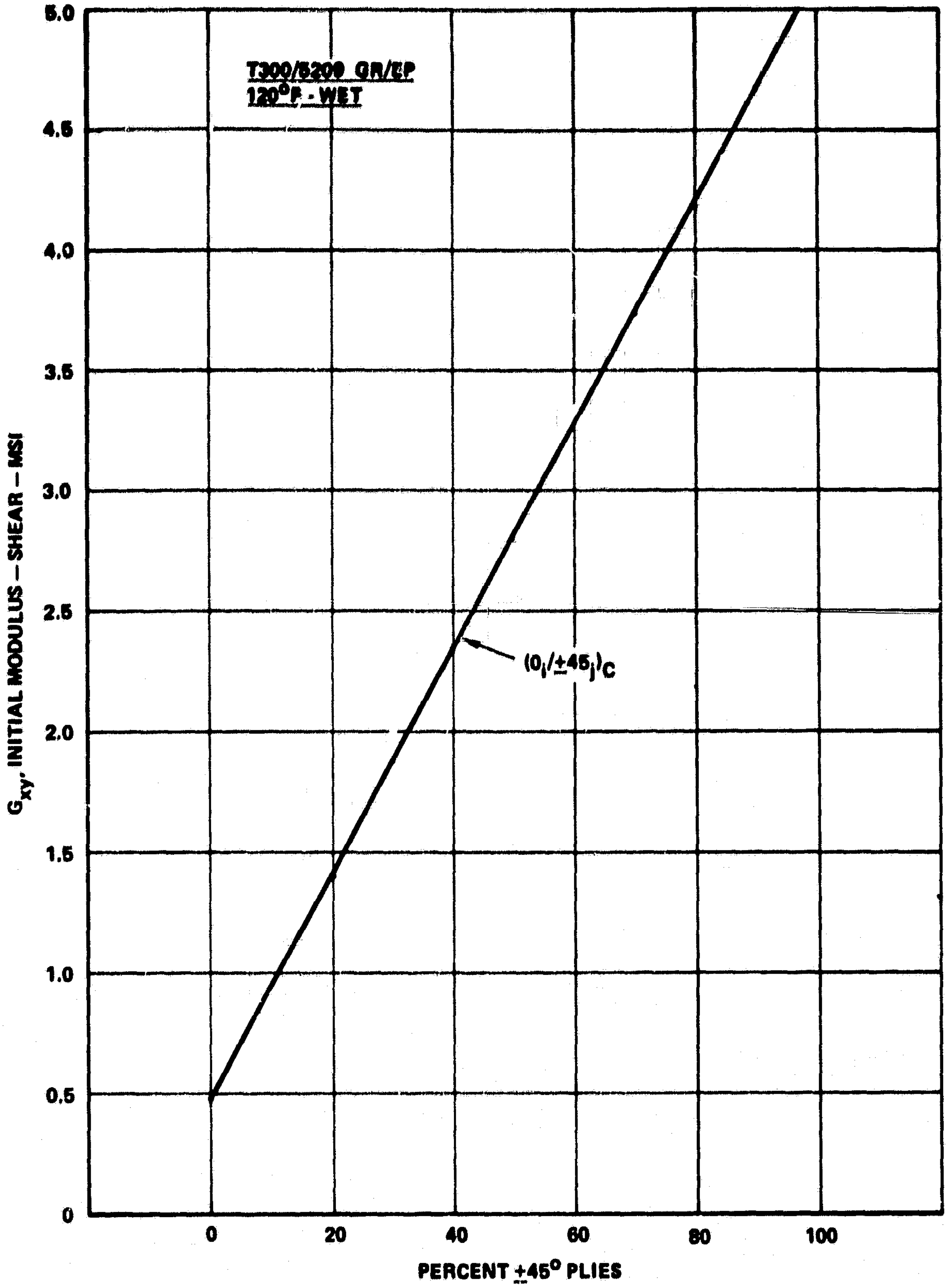

Figure 2-20. Laminate Shear Modulus for T300/5209 GR/EP

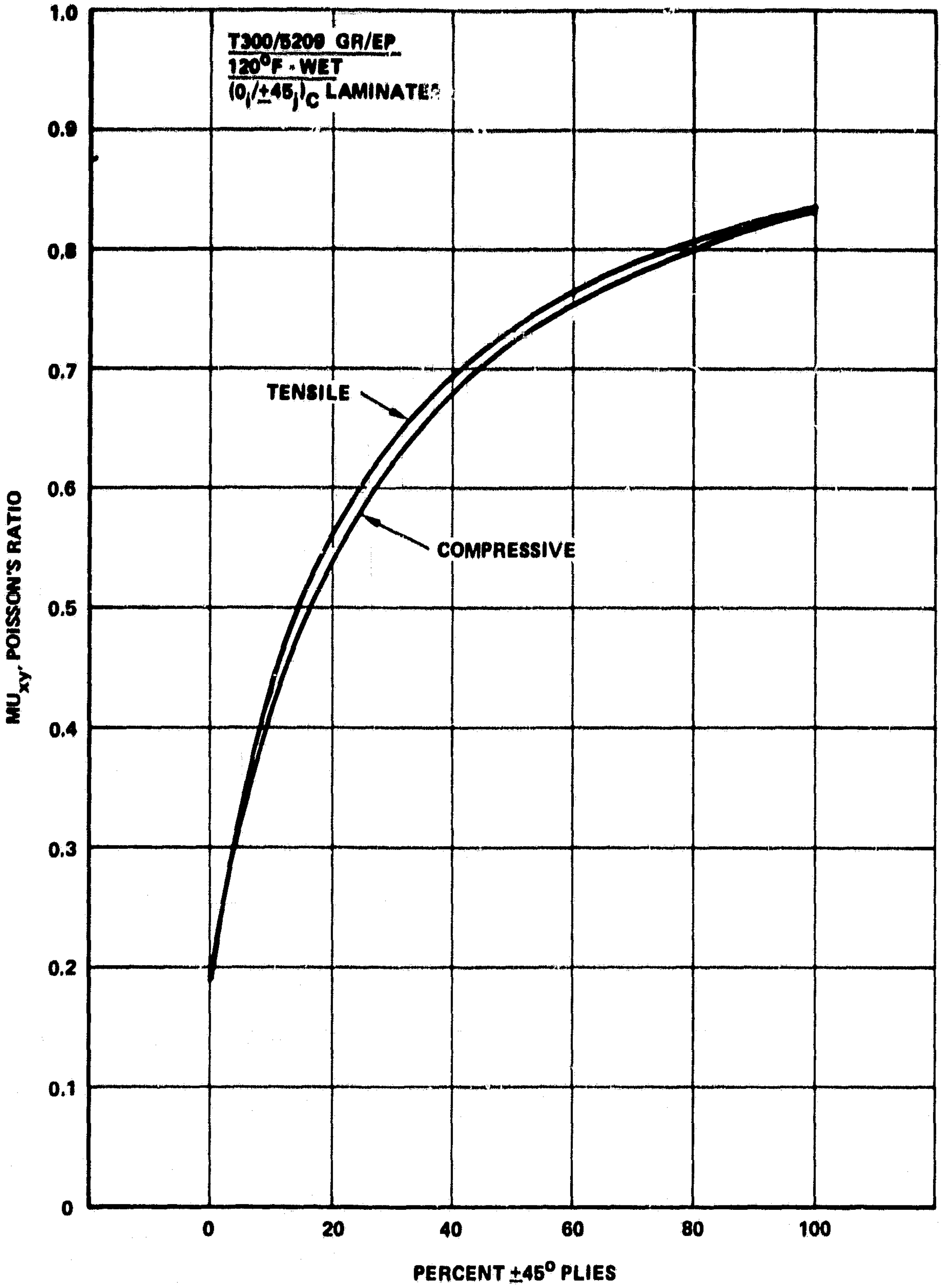

Figure 2-21. Poisson's Ratio in Tension and Compression T300/5209 GR/EP

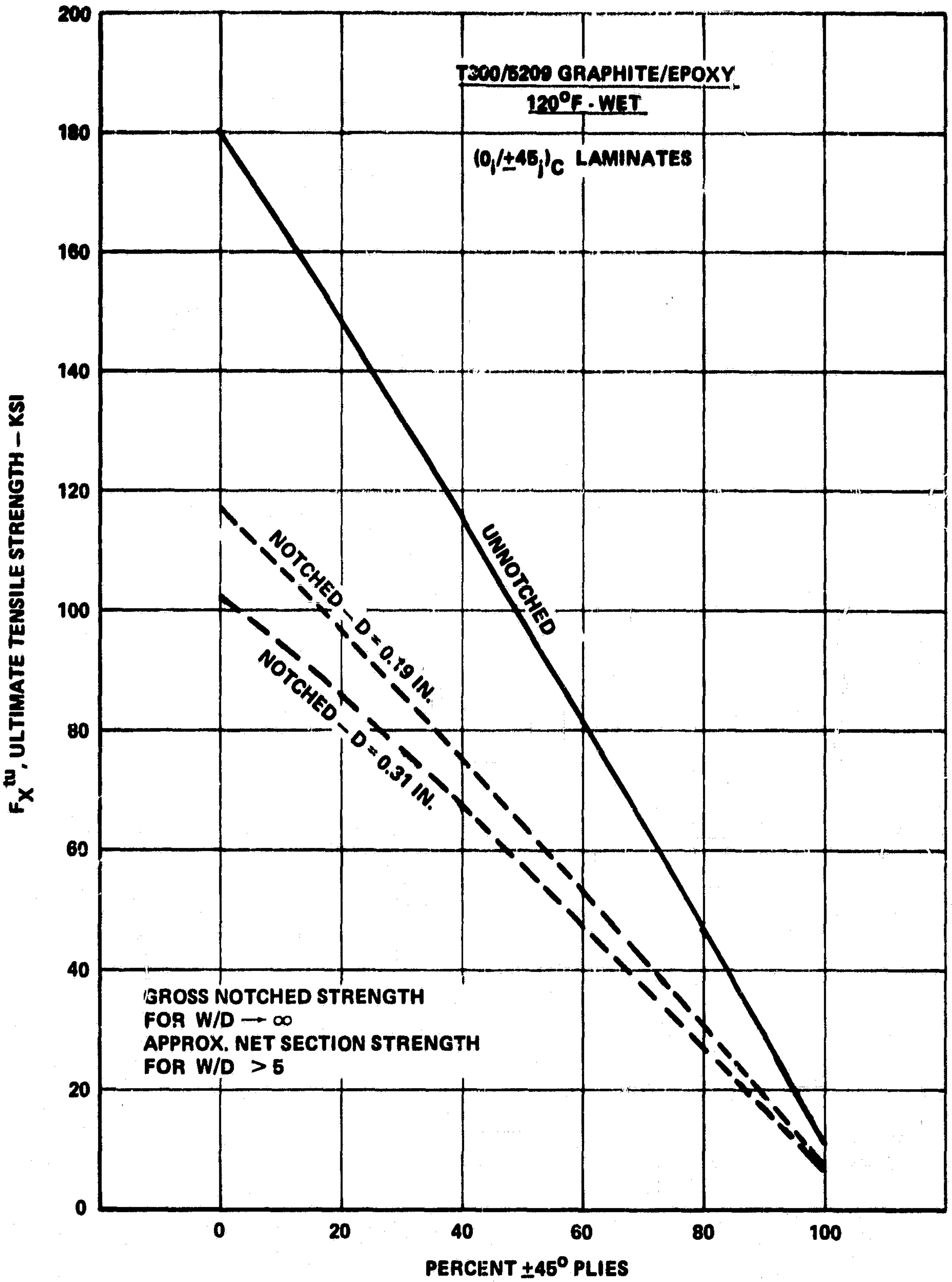

Figure 2-22. Preliminary Tensile Strength - T300/5209

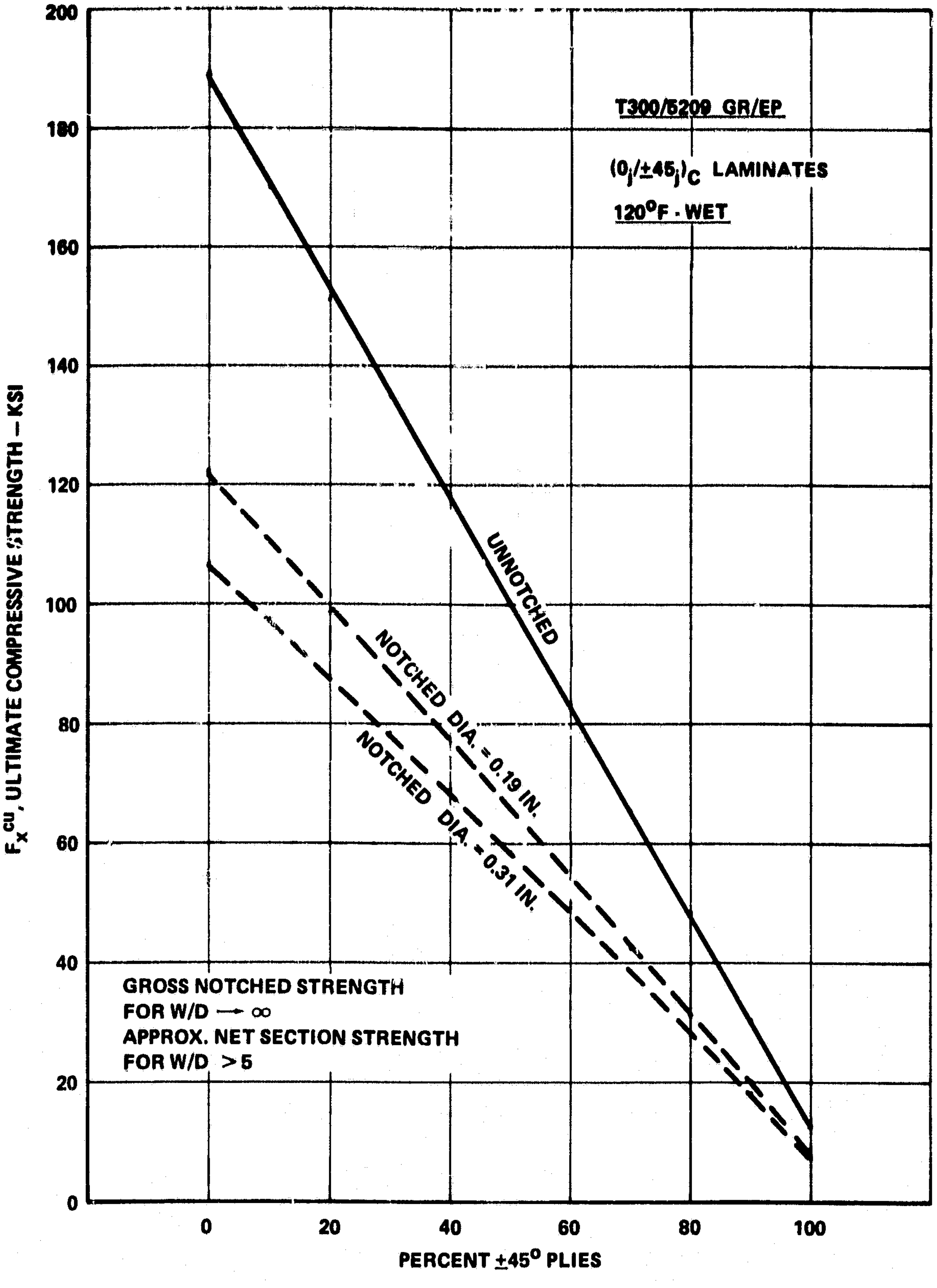

Figure 2-23. Preliminary Compressive Strength - T300/5209

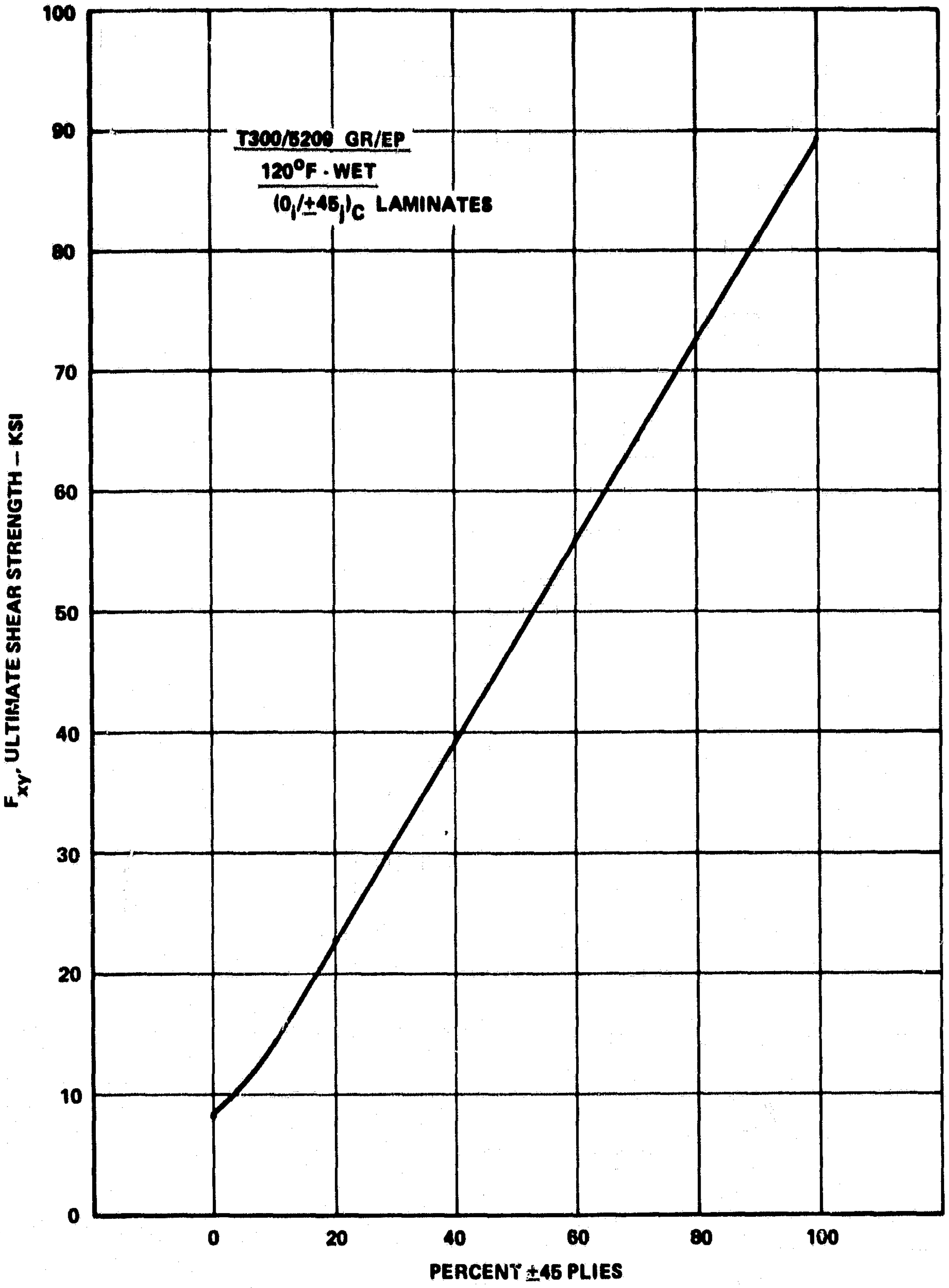

Figure 2-24. Preliminary Shear Strength - T300/5209

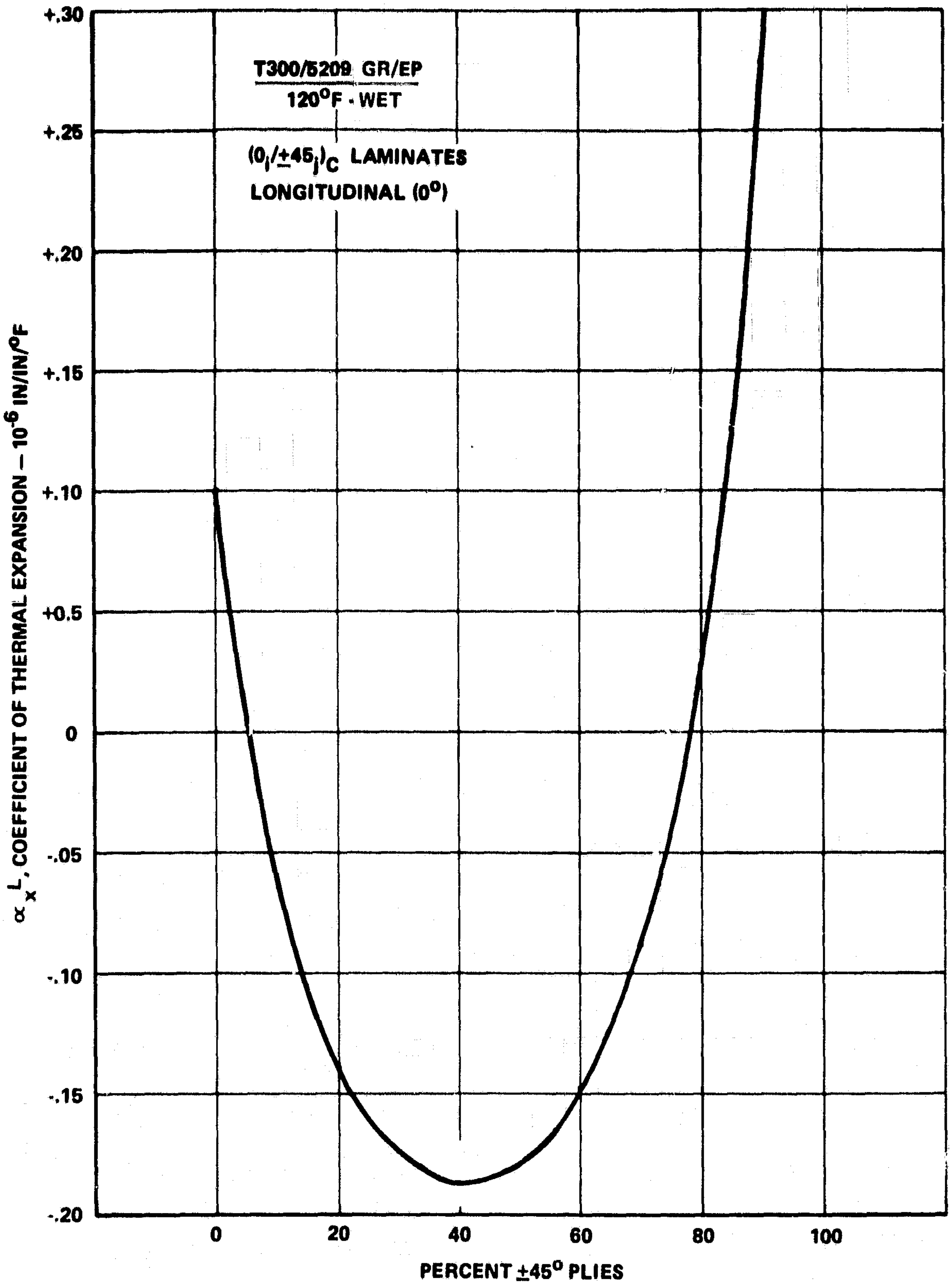

Figure 2-25. Thermal Expansion Coefficient T300-5209

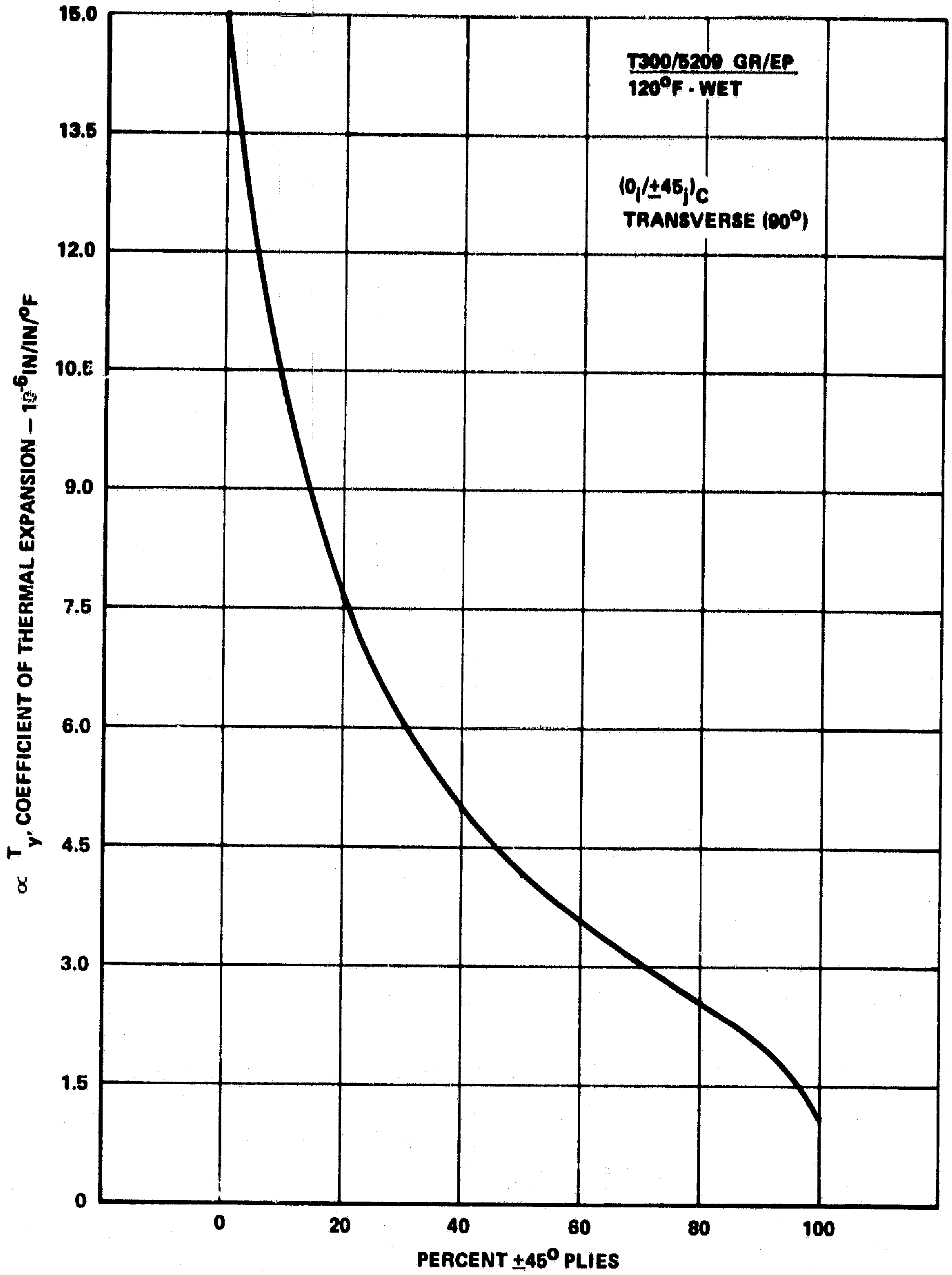

Figure 2-26. Thermal Expansion Coefficient T300/5209

Figure 2-22 shows the tensile strength of $(0_i/\pm45_j)_c$ laminates as a function of percent $\pm45^\circ$ plies. The unnotched strength is based on the output of the HYBRID program. The notched strengths for unloaded single holes of diameter 0.19 in. or 0.31 in. are the product of the unnotched strength and a notched strength ratio determined by the method of Nuismer and Whitney in ref. 6. This method uses the "average stress criterion" with a characteristic dimension, a_o = 0.15. Experimental results with graphite/epoxy have shown very good correlation for small holes (D = 0.12 to 0.31 inch) in laminates of 0/90, 0/$\pm$45/90, and $0_2/\pm45$ orientations. The curve for D = 0.19 inch corresponds quite well with Figure 3-42 of ref. 7 which was used for preliminary design of the ACVF. Figure 2-22 should be used in lieu of Figure 3-42 of ref. 7. The theory is based on the gross strength for a wide plate. However, for a width-to-diameter ratio of five, the theoretical stress concentration is increased by less than 10 percent and the strength for small holes is reduced less than 1 percent. Therefore, these strengths are satisfactory for net section strengths with width-to-diameter ratios greater than five.

The notched compressive strengths are based on the same method used for notched tensile strength.

Figure 2-24 shows the unnotched shear strength. The method of computing notched tensile strength has not yet been demonstrated to be applicable to computing notched shear strength. However, for preliminary design purposes, the notched to unnotched ratios for tensile strength will be applied to the shear strengths.

It should be noted that these curves are based on the best currently available data. However, as more test data becomes available, they will be subject to revision and update.

Material Characterization Tests

The material characterization test program is summarized in Table 2-17. Those tests that have been completed are indicated by the circled coupon numbers. The data that has been generated is being tabulated and carefully reviewed. They will be included in the next quarterly report. The 0° tensile

TABLE 2-17. MATERIAL CHARACTERIZATION TEST PROGRAM (#13A)
THRONEL 300/5209 UNIDIRECTIONAL

TEST TYPE	MAT'L BATCHES	PROCESS BATCHES	NO. PLIES	COUPON SIZE	NO. FIBER VOLUMES	** COUPON TESTS R.T. DRY	R.T. WET	-65°F WET	+120°F WET	+160°F WET	TOTAL NO. TESTS	STRAIN GAGES
0° Tension	3	1	6	0.5 x 11	1	9	-	-	-	-	9	T-Gage
	1	1	6		2 *	10	-	-	-	-	10	
	1	1	6		1	10	5	5	-	5	25	
	1	1	12		1	5	-	-	-	-	5	
0° Tension	1	1	16	0.5 x 11	1	5	-	-	-	-	5	T-Gage
±45° Tension	1	1	12	1.0 x 11	1	10	5	5	5	5	30	T-Gage
	1	1	12	1.0 x 11	2 *	10	-	-	-	-	10	T-Gage
90° Tension	1	1	12	Sandwich	1	10	5	5	5	5	30	Axial
				1.0 x 22	2 *	10	-	-	-	-	10	Axial
0° Compression	3	1	6	Sandwich	1	9	-	-	-	-	9	T-Gage
	1	1	6	1.0 x 22	1	10	5	5	5	5	30	
0° Compression	1	1	6		2 *	10	-	-	-	-	10	T-Gage
90° Compression	1	1	12	Sandwich	1	10	5	5	-	5	25	2-Axial
	1	1	12	1.0 x 22	2 *	10	-	-	-	-	10	2-Axial
0°-90° Rail Shear	1	1	12	3 x 6	1	5	-	-	-	-	5	Rosette
±45° Rail Shear	1	1	12	3 x 6	1	5	-	-	-	-	5	Rosette
0° Interlam. Shear	1	1	16	0.25 x 0.6	1	5	5	5	5	5	25	—
	1	1	16	0.25 x 0.6	2 *	10	-	-	-	-	10	—
					Total	153	30	30	20	30	263	

* Min. & Max. Fiber Volumes

** Circled tests have been completed by 3-26-76.

Material Systems: 5209/T300 Graphite
Determine: Density, fiber content, water gain each panel
Wet Conditioning and test per MIL-HDBK-17A, Para. 4.2.6: 1,000 hours at 125±5°F and 95-100% R.H.

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tests showed moduli approximately 10 percent below that obtained during qualification testing. It was found that the pebbled texture of the surface adjacent to the peel ply resulted in thickness errors when measured with an anvil micrometer. The specimens for qualification tests were measured with a point micrometer. When this was accounted for, the moduli were consistent between the two tests.

Table 2-18 summarizes thickness and width changes of the tensile coupons after moisture conditioning per MIL-HDBK-17A, Paragraph 4.2.6 (ref. 4): 1000 hours at 125 $\pm 5^{\circ}$F and 95-100 percent relative humidity. These coupons had a resin content of 28.8-29.0 percent and a weight gain of 1.28 to 1.37 percent of water. The expansion in the width direction would be constrained by adjacent plies in an angle-ply laminate. This imposes a stress similar to thermal expansion stresses in angle-ply laminates. It corresponds to thermal expansion stresses resulting from a $+400^{\circ}$F temperature differential. This effectively cancels out the stresses from contraction after cooling from curing to room temperature and puts the matrix in compression. A $0_2/\pm 45$ laminate was analyzed with HYBRID, and this effect was found to suppress matrix crazing and to have an overall beneficial effect on laminate strength.

The results of moisture weight gain measurements after MIL-HDBK-17A exposure for 6, 12, and 16-ply T300/5209 laminates are compared with that predicted for T300/5208 laminates on Figure 2-27. The prediction for T300/5208 was based upon McKague's diffusion model (based on Fick's Law) and the required material parameters from a paper by Shirrell and Mahoney presented at the Air Force Workshop on Durability Characteristics of Resin Matrix Composites at Battelle's Columbus Laboratories, September 30 - October 2, 1975.

The available physical property test data for panels used for material characterization test 13A are summarized on Table 2-19. The calculated thickness per ply in mils is based on $t = A_W/25.4(1 - C_R)\, D_L$

where: A_W = Areal Weight = 144 ± 4 GMS/m^2

C_R = Resin Weight Fraction

D_L = Laminate Density, GMS/cc

TABLE 2-18. DIMENSIONAL CHANGE IN T300/5209 6-PLY UNIDIRECTIONAL TENSION SPECIMENS AFTER 40 DAYS CONDITIONING AT 95% RH/125°F

SPECIMEN NO.	THICKNESS (AVG OF 4 MSMTS)			WIDTH (AVG OF 4 MSMTS)		
	INITIAL	AFTER 40 DAYS CONDITIONING	% CHANGE	INITIAL	AFTER 40 DAYS CONDITIONING	% CHANGE
2NC695A						
3	.0335	.0340	1.49	.4997	.5027	0.60
5	.0329	.0333	1.22	.4975	.5006	0.62
6	.0338	.0341	0.89	.4971	.5005	0.68
9	.0318	.0322	1.26	.4976	.5010	0.68
10	.0331	.0334	0.91	.4979	.5012	0.66
12	.0336	.0341	1.49	.5003	.5037	0.68
2NC695B						
2	.0337	.0341	1.19	.4978	.5011	0.66
3	.0334	.0337	0.90	.4982	.5011	0.60
4	.0334	.0339	1.50	.4981	.5011	0.60
8	.0336	.0341	1.49	.4978	.5007	0.58
10	.0333	.0337	1.20	.4969	.5000	0.62
13	.0332	.0334	0.60	.4969	.5001	0.64
1NC698						
2	.0336	.0338	0.59	.5035	.5067	0.64
3	.0337	.0341	1.19	.5040	.5071	0.62
4	.0334	.0336	0.60	.5043	.5073	0.59
6	.0330	.0334	1.21	.5043	.5074	0.61
7	.0334	.0339	1.50	.5041	.5072	0.61
9	.0319	.0323	1.25	.5032	.5067	0.70
11	.0341	.0346	1.47	.5030	.5061	0.62
13	.0336	.0338	0.60	.5031	.5064	0.66
14	.0336	.0341	1.49	.5035	.5068	0.66
		$(1.14 \pm 0.34)\%$			$(0.63 \pm 0.03)\%$	

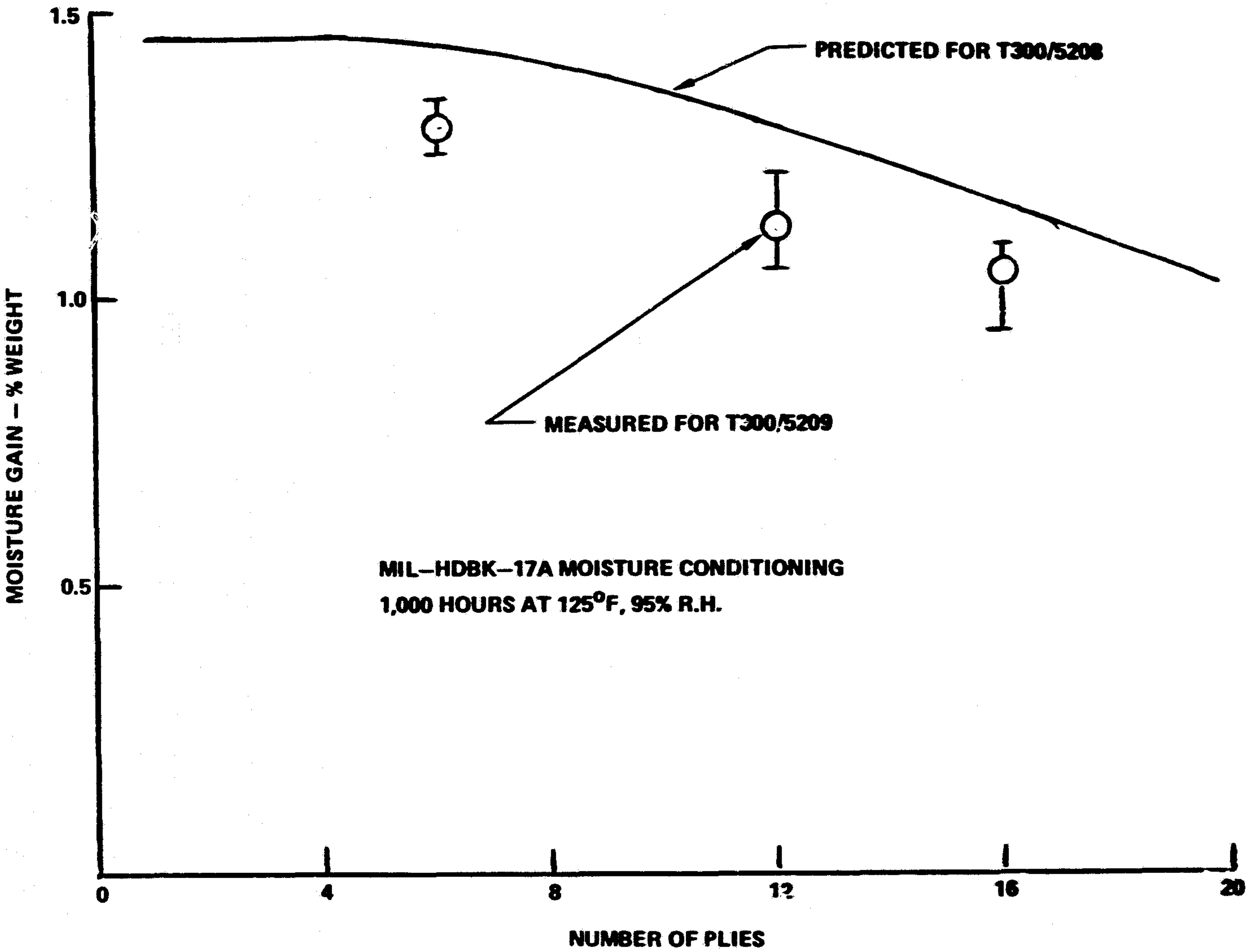

Figure 2-27. Comparison of Moisture Weight Gain for Graphite/Epoxy Coupons Subjected to MIL-HDBK-17A Exposure

TABLE 2-19. PHYSICAL PROPERTIES

Batch/Roll	Test Description	Orient.	Panel Specimen I.D.	No. of Plies	Measured Thickness Per Ply	Calculated Thickness Per Ply	Density	Resin Content	Fiber Volume
					Mils	Mils	GMS/CC	W%	V%
1473/6	Baseline Tension	0°	1NC698	6	5.56	5.07	1.5712	28.8	63.6
1473/6			2NC695A		5.59	5.01	1.5944	29.0	64.3
1473/6			2NC695B		5.59		1.5944	29.0	64.3
1473/5	Thick	0°	5NC659	12		4.98	1.5753	27.8	64.6
1473/5	Thick	0°	1NC660	16		5.00	1.5789	26.2	64.4
1473/6	High Resin	0°	1NC695	6		5.30	1.5640	31.6	60.8
1473/6	Low Resin	0°	1NC691	6		4.96	1.5825	27.8	64.9
1476/6	Batch Variables	0°	1NG698	6		5.04	1.5740	28.6	63.9
1983/6		0	6NU714	6		5.09	1.5740	29.2	63.3
1473/5		0	4NC659	6		5.09	1.5740	29.2	63.3
1473/5	±45 Tension	±45	1NC665	12	5.28	5.17	1.5681	30.1	62.3
1473/6	Baseline		2NC690	12	5.31	5.12	1.5658	29.3	63.0
1473/6	High Resin		1NC700	12		5.53	1.5416	33.5	58.2
1473/6	Low Resin		1NC701	12		4.93	1.5805	27.2	65.4
1473/5	±45 Shear	±45	1NC665	12	5.28	5.17	1.5681	30.1	62.3

TABLE 2-19. PHYSICAL PROPERTIES (Continued)

Batch/Roll	Test Description	Orient	Panel Specimen I.D.	No. of Plies	Measured Thickness Per Ply	Calculated Thickness Per Ply	Density	Resin Content	Fiber Volume
					Mils	Mils	GMS/CC	W%	V%
1473/5	90^o Tension and Compression	90^o	1NC661	12	4.95	4.92	1.5836	27.2	65.5
1473/5			1NC667	12	4.92	4.98	1.5785	27.9	64.7
1473/6			1NC681	12	4.96	5.10	1.5687	29.2	63.1
1473/5			1NC662	12				30.1	
1473/6	High Resin		2NC700	12		5.59	1.5353	33.9	57.6
1473/6	Low Resin		2NC701	12		4.88	1.5854	26.7	66.1
1473/5	(0/90) Rail Shear	0/90	4NC660	12	5.30	5.11	1.5683	29.3	63.0
1473/6	Interlaminar Shear	0	3NC683	16	5.22	5.01	1.5731	28.1	65.0
1473/6	High Resin	0	3NC700	16	5.75	5.62	1.5513	35.0	57.3
1473/6	Low Resin	0	3NC701	16	4.92	4.88	1.5887	26.9	65.9
	Baseline 0^o Compr.	0^o							
1473/4			1NC708	6		5.00	1.5795	28.2	64.4
1473/4			1NC710	6		5.95	1.5747	27.9	64.4
1473/4			4NC710	6		5.03	1.5779	28.6	64.0
1473/4	High Resin		1NC733	6		5.23	1.5628	30.6	61.6
1473/4	Low Resin	0	1NC713	6		4.92	1.5822	27.2	65.4
1483/6	Batch Variables	0	1NU733	6		5.19	1.5660	30.3	62.0
1476/15	Batch Variables	0	1NQ733	6		5.08	1.5752	29.2	63.4

The thickness has a tolerance of ±0.17 mils due to the tolerance on the areal weight.

The material characterization tests for transverse (90°) tension and compression at room temperature-dry (RTD) and at 160°F wet have been analysed and the results are summarized on Tables 2-20 through 2-23. These tables supercede, include more tests, and differ slightly from those shown on Tables 2-11 and 2-12. Table 2-20 shows that including the qualification test results did not significantly alter the 90° tension RTD "B" allowables. A careful analysis of the test specimens and results showed that some had ply butt splices for half of the plies in the gage length. For some of these the strain gage was located on the butt splice, and these gages showed higher strains than registered on a gage located one inch away. Consequently, the resultant modulus was not included in the analysis. In general, the allowables are slightly better than the preliminary design allowables shown in Table 2-14. Of the data analyzed to date the exception is the transverse compression strength and strain at 160°F wet which are slightly lower than the predicted 120°F-wet valves.

Poisson's ratio for 0° tension-RTD averages 0.30. At room temperature wet and 65°F wet it drops to 0.26. At 160°F wet the data has substantial scatter and is still being analyzed.

2.2.2 Mechanical Joint Tests

The fastener push-through dry specimen tests have been completed. The test setup is shown in Figure 2-28 and the results are shown in Table 2-24.

The single-lap shear specimens are being drilled and assembled.

2.3 TASK 3 - FABRICATION

This task covers the fabrication of ancillary test items and structural components, and nondestructive inspection techniques.

2.3.1 Ancillary Test Specimens

Fabrication of manufacturing verification ancillary test specimens NOs. 25 through 29 has commenced. These test specimens are fabricated to

TABLE 2-20. T300-5209 DESIGN ALLOWABLES ANALYSIS
TRANSVERSE (90°) TENSION - RTD

Specimen I.D.	Batch/ Roll	Fiber Vol %	F_T^{tu} psi	E_T^t msi	ϵ_T^{tu} μin./in.	Comments
1NC661	1473/5	65.5				
-1			8660	-	-	No gage, 2
-7			8370	(1.36)*	6080	1, 2
-13			8320	(1.36)*	5700	1, 2
-19			8320	(1.35)*	5800	1, 2
1NC667	1473/5	64.7				
-1			8460	1.47	5800	2
-7			8130	(1.41)*	5800	1, 2
-15			8500	(1.40)*	6000	1, 2
-21			8440	1.52	5300	2
1NC681	1473/6	63.1				
-4			(5350)*	1.64	(3180)*	
-11			8310	1.66	4900	2
-18			7670	1.60	4700	2
1NC706	1473/3	64.2				
-4			7100	(1.44)*	5000	1, 4
-11			8140	1.51	5480	2
-18			8000	(1.46)*	5700	1, 3
2NC706	1473/3	64.2				
-4			(4210)*	1.54	(2850)*	5
-13			8060	1.69	4840	2
-21			7730	1.56	5040	2
No. of Specimens			15	9	14	
Mean			8150	1.58	5440	
Coef. of Variat.%			4.9	4.8	8.6	
"B" Basis Allow			7300		4460	

NOTE: Material characterization test 13A, 12 plies
*Anomalous-data omitted from mean

COMMENTS:
1, Gage at ply butt splice
2, Valid failure within gage length
3, Failed adjacent to or under loading pad
4, Failed adjacent to ply butt splice
5, Damaged - failure stress invalid

TABLE 2-20. T300/5209 DESIGN ALLOWABLES ANALYSIS TRANSVERSE (90°) TENSION - RTD (Continued)

Specimen I.D.	Density Fiber Vol. % Batch/Roll Thickness	F_T^{tu} psi	E_T^t msi	ε_T^{tu} µin./in.
Qualification Test	64.5%			
(8 plies) -1	1.5652 gms/cc	7885	1.698	4591
-2	Batch 1473	8782	1.687	4705
-3	Roll 7	9295	1.733	5400
-4		9103	1.781	5250
-5	t = 0.040	9295	1.756	5500
(Qual. Test Only)				
No. of Specimens		5	5	5
Mean		8870	1.73	5090
Coeff. of Variat.%		6.7	2.3	8.1
"B" Basis Allow.		6860		3700
(Combing Qual. Test and Mat'l Char. Tests)				
No. of Specimens		20	14	19
Mean		8330	1.63	5350
Coeff. of Variat.%		6.5	6.1	8.8
"B" Basis Allow.		7300		4430

TABLE 2-21. T300/5209 DESIGN ALLOWABLES ANALYSIS
TRANSVERSE (90°) TENSION - 160°F WET

Specimen I.D.	Batch/ Roll	Fiber Vol %	F_T^{tu} psi	E_t^{tu} msi	ϵ_T^{tu} μin./in.	Comments
1NC661	1473/5	65.5				
-3			7330	1.38	6000	1
-18			6870	1.26	5600	1
1NC667	1473/5	64.7				
-10			6930	1.28	7300	1
-13			6490	1.26	6000	1
1NC681	1473/6	63.1				
-3			6780	1.39	5700	1
-10			7170	1.36	5900	1
1NC706	1473/3	64.2				
-5			6080	1.29	5620	4
-13			6060	1.35	5600	3
-21			5250	1.21	5680	1
2NC706	1473/3	64.2				
-5			(4510)*	1.23	(5000)*	2
-15			5470	1.26	5800	4
No. of Specimens			10	11	10	
Mean			6440	1.30	5900	
Coef. of Variat.%			11.0%	4.8%	8.6%	
"B" Basis Allow			4800		4700	

NOTE: Material characterization test 13A - 12 plies
*Anomalous - Data omitted from mean

COMMENTS:
1, Valid failure within gage length
2, Failed adjacent to or under loading pad
3, Failed at ply butt splice
4, Failed outside central span

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TABLE 2-22. T300/5209 DESIGN ALLOWABLES ANALYSIS
TRANSVERSE (90°) COMPRESSION - RTD

Specimen I.D.	Batch/ Roll	Fiber Vol %	F_T^{CU} Psi	E_T^{CU} Msi	ϵT^{CU} μin/in	Comments
1NC661	1473/5	65.5				
-4			28 300	1.55	-20300	2
-10			26 200	(1.38)*	-21400	1,2
-16			29 700	(1.40)*	-28300	1,2
-22			29 500	1.49	-26500	2
1NC667	1473/5	64.7				
-4			28 600	1.50	-25200	2
-11			28 100	1.52	-22600	2
-18			29 600	1.51	-25500	2
1NC681	1473/6	63.1				
-1			27 800	1.62	-20000	2
-7			27 700	1.81	-18300	2
-15			26 600	1.60	-19000	2
-21			25 600	1.55	-18500	2
1NC-706	1473/3	64.2				
-8			24 290	(1.40)*	-20700	1,3
-14			25 310	(1.49)*	-20200	1,2
2NC706	1473/3	64.2				
-2			28 470	1.47	-23500	3
-9			29 600	1.56	-23600	3
-17			29 760	1.56	-23000	3
No. of Specimens			16	12	16	
Mean			27 800	1.562	-22300	
Coef. of Variat. %			6.3%	5.7%	13.4%	
"B" Basis Allow			24 300		-16200	

Note: Material Characterization Test 13A, 12 Plies
*Anomalous - Data Omitted from Mean

Comments: 1, Gage at ply butt splice
2, Valid failure within gage length
3, Failed adjacent to or under loading pad

TABLE 2-23. T300/5209 DESIGN ALLOWABLES ANALYSIS
TRANSVERSE (90°) COMPRESSION-160°F WET

Specimen I.D.	Batch/ Roll	Fiber Vol %	F_T^{CU} Psi	E_T^{CU} Msi	ϵ_T^{CU} μin/in	Comments
1NC661	1473/5	65.5				
-11			18 100	1.34	-21900	1
-14			18 100	1.35	-19400	1
1N667	1473/5	64.7				
-3			17 300	1.31	-20800	1
-17			19 500	1.38	-23800	1
1NC681	1473/6	63.1				
-13			17 200	1.20	-21800	1
-17			18 700	1.20	-21800	1
1NC706	1473/3	64.2				
-1			15 050	1.37	-16000	2
-9			15 390	1.37	-18000	2
-17			16 340	1.32	-20000	2
2NC706	1473/3	64.2				
-12			17 230	1.21	-26100	1
-19			17 120	1.30	-18000	1
No. of Specimens			11	11	11	
Mean			17 400	1.30	-20700	
Coef. of Variat. %			6.9%	5.3%	13.8%	
"B" Basis Allow			14 600		-15000	

Note: Material Characterization Test 13A-12 Plies
Comments: 1, Valid failure within gage length
2, Failure at ply butt splice

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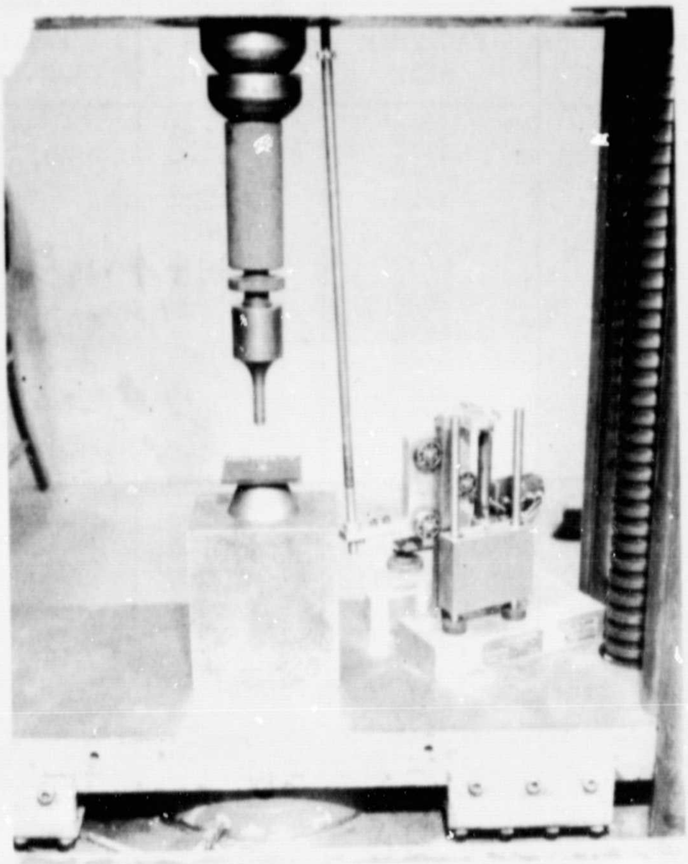


Figure 2-28. "Cookie" Push-Thru Test

shop orders which document the detailed sequence of operations required to correctly fabricate the specimens. They become the permanent record of the materials and processes used during fabrication. Appropriate entries are provided for Quality Assurance. Figure 2-29 shows the layup of hats for ancillary test specimens, with an inspector verifying compliance with the shop order.

The No. 26, No. 28, and No. 29 specimens are complete. A No. 26 specimen is shown in Figure 2-30. The No. 26 and No. 29 specimens were fabricated by Manufacturing Research personnel using Phase I development tooling. The remaining specimens, Nos. 25, 27, and 28 are being fabricated on the 100-inch subcomponent tooling in the Production clean room. Production personnel are working under Manufacturing Research guidance to learn the techniques required.

TABLE 2-24. FASTENER PUSH THROUGH TEST RESULTS

LAYUP	LAMINATE THICKNESS	FASTENER SIZE	HOLE DIAM.	FAILURE INITIAL	LOAD FINAL
1	0.0816	3/16	0.1903	374	374**
1	0.0799	3/16	0.1930	605	605
1	0.0795	3/16	0.1927	700	700
1	0.0804	5/32	0.1637	550	550
1	0.0819	5/32	0.1636	525	525
1	0.0849	5/32	0.1638	615	615
2	0.0945	3/16	0.1897	745	810
2	0.0935	3/16	0.1896	905	905
2	0.0946	3/16	0.1895	503	503
2	0.0935	5/32	0.1635	620	680
2	0.0938	5/32	0.1640	720	720
2	0.0929	5/32	0.1639	550	635
3	0.1314	3/16*	0.1905	1515	1730
3	0.1329	3/16*	0.1905	1365	1695
3	0.1298	3/16*	0.1905	847	847
2	0.0948	3/16	0.1895	490	490**

*Protruding head
**Laminate Bending Failure (Trial Pullthrough)

Layups: 1. $\pm45_2/0/\pm45/0/\mp45/0/\mp45_2$

2. $\pm45_2/0_2/\pm45/0_2/\mp45/0_2/\mp45_2$

3 $(\pm45/0_2/\pm45/0_2/\pm45/0_2)_s$

Figure 2-31 shows how the skin for Specimen No. 28 was laid up on the subcomponent tool. The graphite prepreg is being worked down with Teflon paddles to remove entrapped air. The skin was cured separately and the previously molded hats were secondarily bonded to the skin on the subcomponent tool as shown in Figure 2-32. The completed panel is shown in Figure 2-33.

Specimens No. 27A and 27B are 75 percent complete and layup of Specimen No. 25A has been started.

2.3.2 Nondestructive Inspection

With the initiation of Phase II - Detail Design activity, available nondestructive inspection (NDI) methods were evaluated for their potential applicability to this program. The methods considered were based on current state-of-the-art technology. Of primary interest was accurately locating and

Figure 2-29. Layup of Hats for Ancillary Test Specimens, Witnessed by Inspector

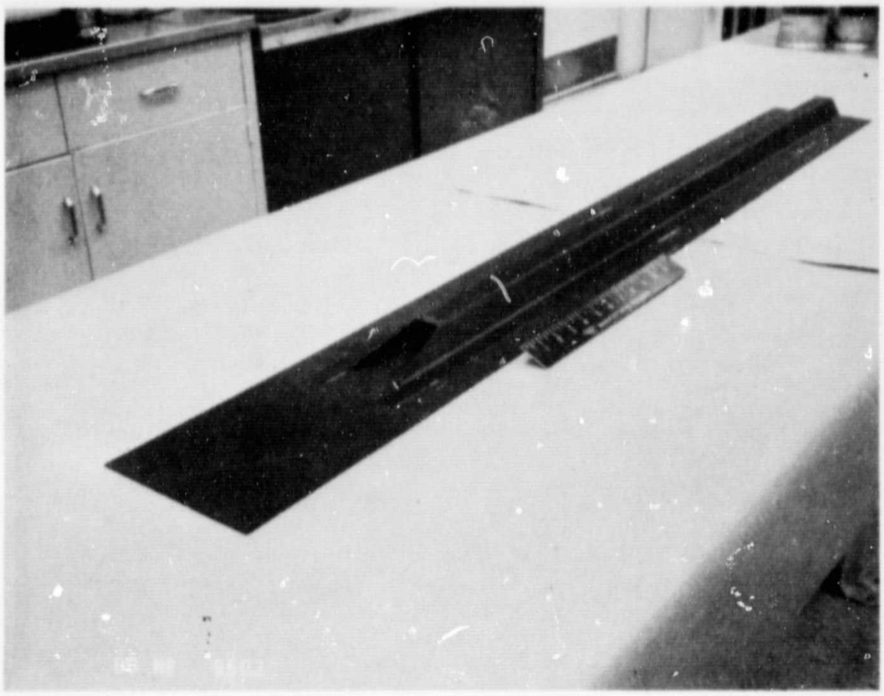


Figure 2-30. Ancillary Test Specimen No. 26, Hat Runout

Figure 2-31. Layup of Skin for Specimen No. 28

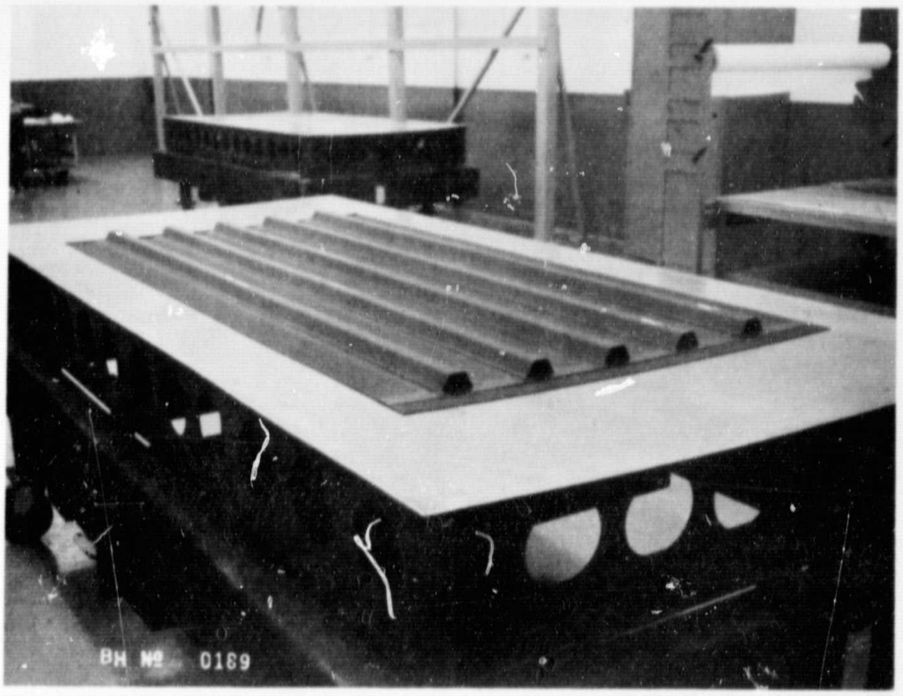


Figure 2-32. Specimen No. 28 After Bonding Hats to Skin on Bonding Tool

Figure 2-33. Ancillary Test Specimen No. 28

sizing voids, delaminations and concentrated porosity. The selected method of inspection would be required to meet the following criteria:

- Rapid and relatively economical inspection.
- The ability to detect and locate discontinuities in multilaminate composites and adhesive bonded structures.
- Provide a permanent record of inspection results.
- Provide a high degree of reliability.

Based on the above criteria, ultrasonic inspection utilizing an automated scanning system with C-scan capabilities was selected as the method to use in this phase of the program. The method lends itself to automation and has the capability of providing a two-dimensional plan view permanent record (i.e., C-scan recordings.).

The two basic ultrasonic techniques applicable to laminated and adhesive bonded structures are Pulse-Echo and Thru-Transmission. In the Pulse-Echo test mode, one crystal acts as both the transmitter and receiver. In this instance, it is the reflected signal from the flaw and/or the back surface that provides the pertinent data as to the presence or absence of a discontinuity.

The Thru-Transmission technique may be divided into two subcategories: two transducer and single transducer - Reflector Plate. In the two-transducer test mode, one transducer acts as the transmitter and a second transducer acts as the receiver. The amount of energy transmitted through a given section is then evaluated. In the single-transducer Reflector Plate mode, a single transducer acts as both the transmitter and receiver. The energy is transmitted through the section and reflected from a smooth surface back through the section and received by the transducer. The amount of energy received is then evaluated.

The selection of ultrasonics as the inspection method resulted in the requirement to develop suitable calibration standards. The primary objective was to obtain representative calibration standards containing planned subsurface discontinuities for specifi N.D.I. technique development. Meetings held with Engineering and Manufacturing personnel, resulted in the decision to place planned discontinuities in each specimen fabricated for the ancillary test program. Past experience indicated the use of teflon inserts to simulate internal discontinuities. Two (2) Mil teflon inserts 0.125, 0.250, and 0.500-inch diameters are placed between plies to simulate interlayer discontinuities, and 0.25-inch wide teflon strips are placed in bond lines to simulate disbonds.

Ultrasonic inspection utilizing Thru-Transmission techiques were determined to be most applicable for this program at this time. The physical size of the cover panels to be fabricated in the test program indicated the use of the single transducer, reflected Thru-Transmission technique.

Currently the facilities available for use on this program are shown in Figure 2-34 and consist of the following:

- 10 x 50 x 4 foot immersion tank
- Models 150 and 155 automated bridges with 19" Alden Recorders (1 to 1, 2 to 1, and 3 to 1 ratios)

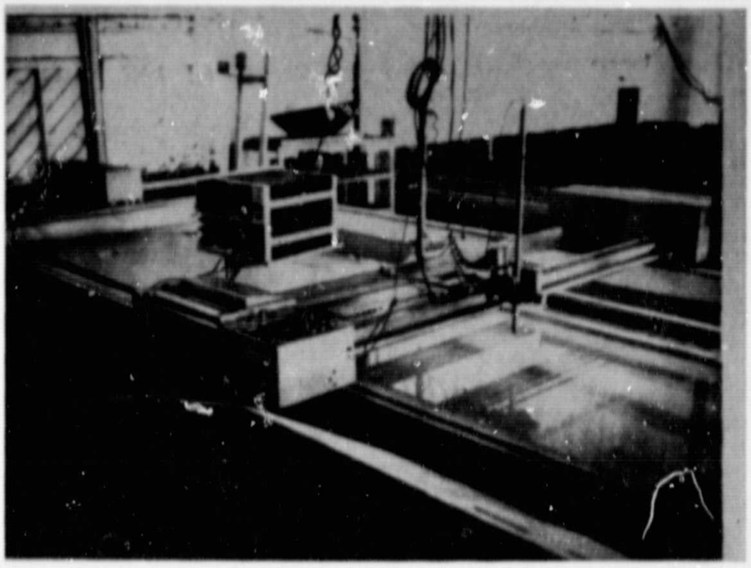


Figure 2-34. Model 155 Bridge W/UM721 and UM710 Special Function Cabinet

- UM 721 Sperry Reflectoscopes with 10N, 5N, and 1N Pulser/Receivers and Fast Transigates

The effectiveness of the N.D.I. system selected is illustrated below by reviewing the results of the inspection conducted on two identical ancillary test specimens. The test specimen (P/N 1606688-101) represents the hat stiffened cover configuration and consists of a skin panel (P/N 1606688-103) and one hat section stiffener (P/N 1606688-105) as shown in Figure 2-35. These individual components were ultrasonically inspected utilizing the single transducer reflected through transmission technique. Ultrasonic C-scans of the 2 skin panels are shown in Figure 2-36 and 2-37. The ultrasonic indication shown in Figure 2-36 is currently being sectioned for evaluation. The indications shown in Figure 2-37 were acceptable to Engineering.

Ultrasonic C-scans of 2 hat section stiffeners (0293002, 0293003) are shown in Figure 2-38. Stiffener Serial No. 0293002 was deemed unacceptable to Engineering and is currently being sectioned for evaluation.

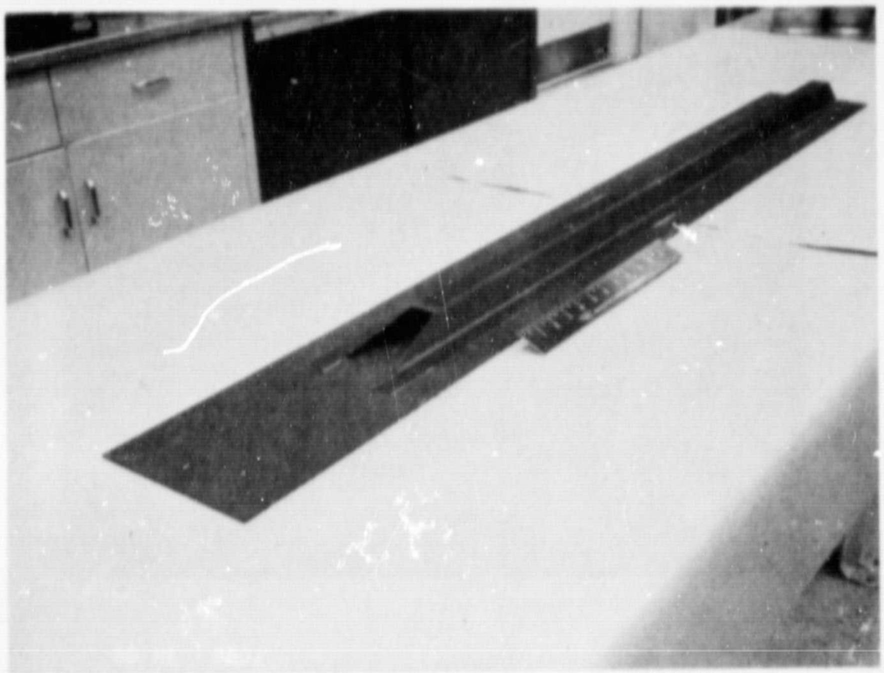


Figure 2-35. Ancillary Test Specimen P/N 1606688-101

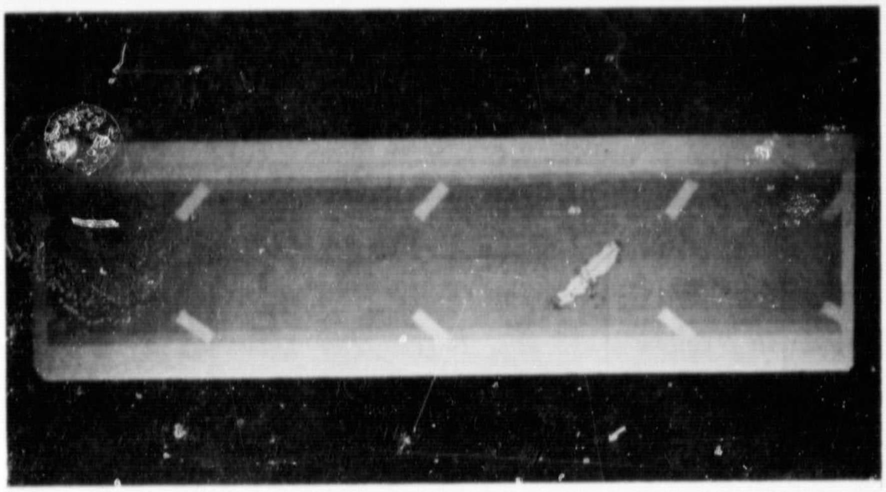


Figure 2-36. Ultrasonic C-Scan - Skin Panel (0293003) Ancillary Test Specimen

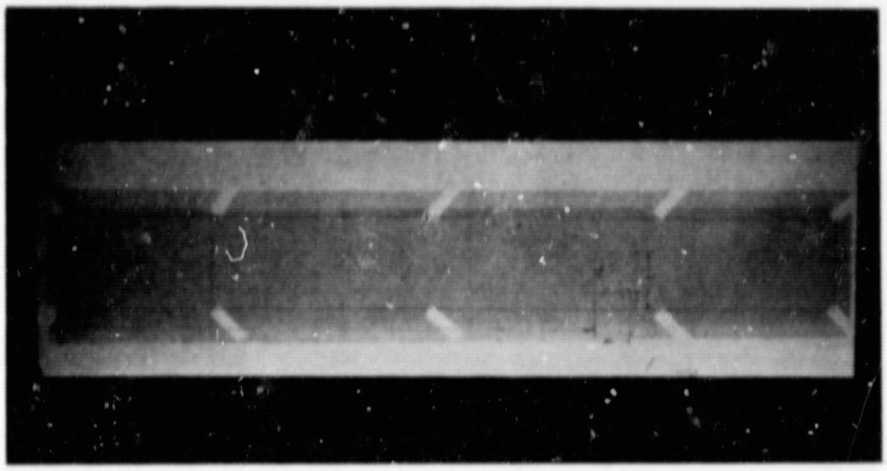


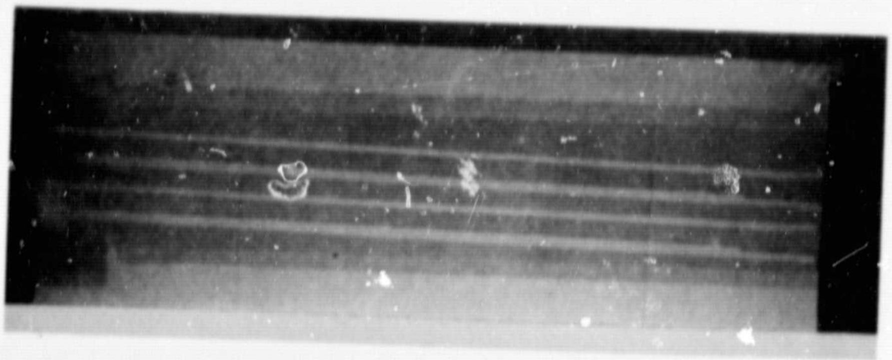
Figure 2-37. Ultrasonic C-Scan - Skin Panel (0293002) Ancillary Test Specimen

Two P/N 1606688-101 assemblies were subsequently bonded from acceptable components and submitted for ultrasonic inspection. The adhesives bond lines between the hat section stiffener and the skin were withheld for ultrasonic indications (Figure 2-39). These two areas were also X-rayed in an attempt to determine type of defects. The X-rays of S/N 0293001 shown on Figure 2-40 provided correlation to the ultrasonic results, in the detection of concentrated porosity. These assemblies have been reidentified as 1606688-201 and will be tested to evalute defect tolerance and defect repair.

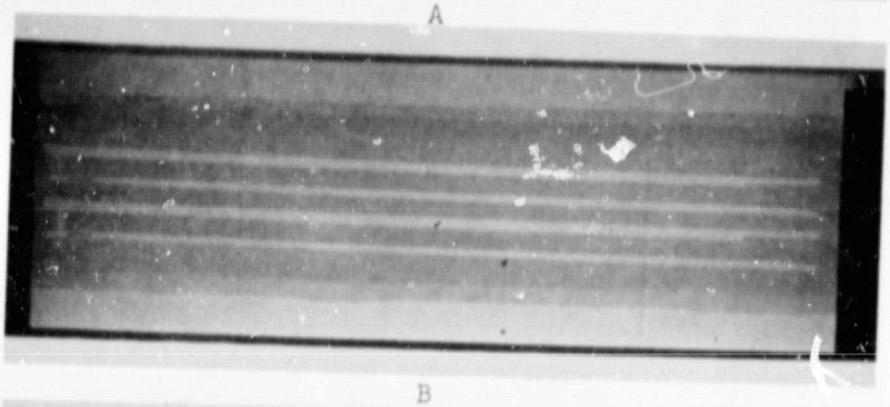
As a result of this inspection, the method of support of the stiffener runout utilized during the bonding operation was reviewed and found to be the primary cause for part rejection. This condition has been corrected and subsequent inspections have substantiated the revised method of support.

2.4 TASK 4 - COMPONENT TOOLING DEVELOPMENT

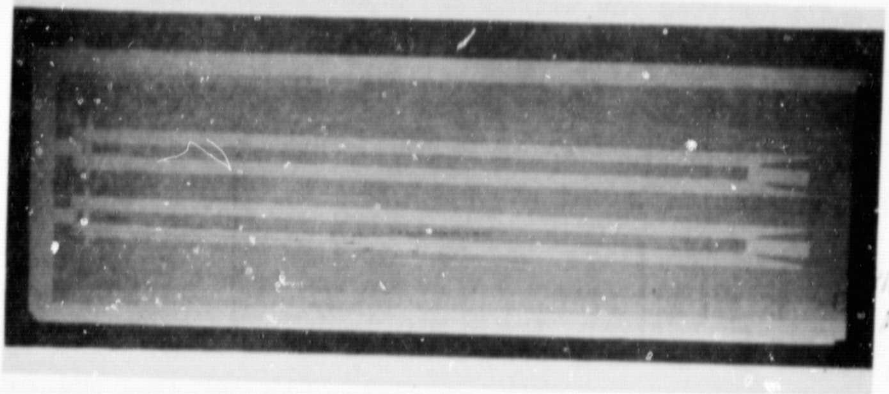
The work in this task covers the design and fabrication of tooling to be used in the fabrication of the covers.



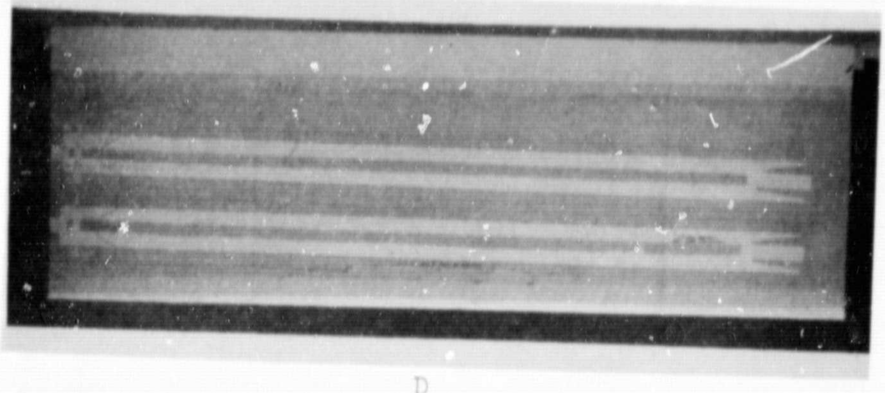
A



B

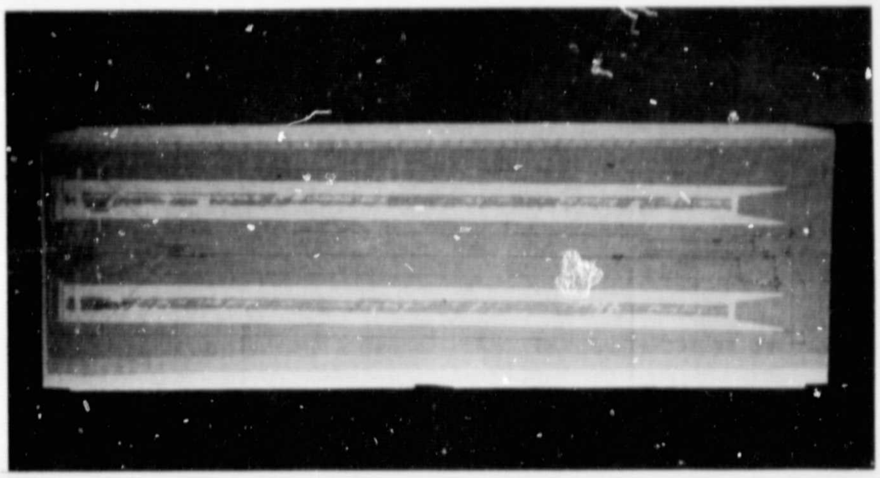


C

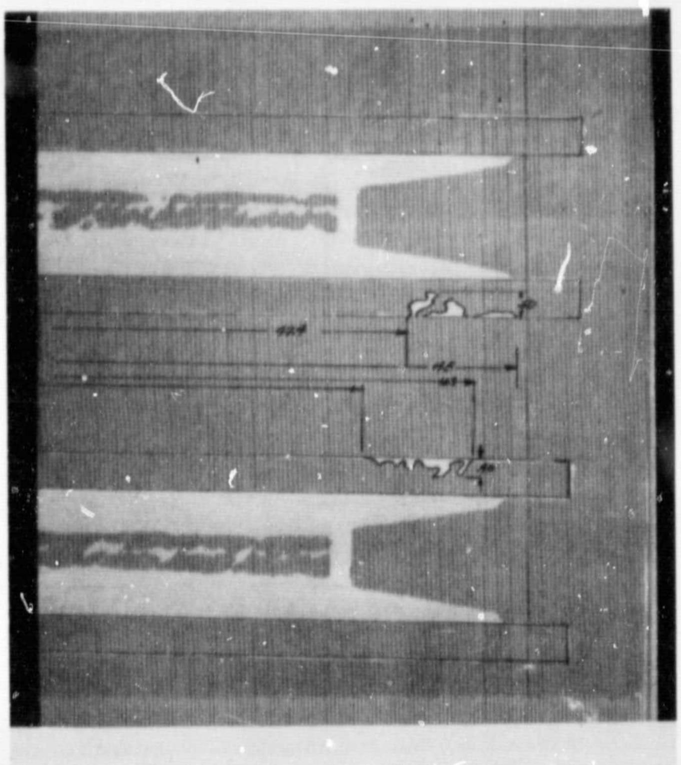


D

Figure 2-38. Ultrasonic C-Scans-Hat Stiffener Ancillary Test Specimen



A



B

Figure 2-39. Ultrasonic C-Scan - Stiffener/Skin Assembly Ancillary Test Specimen

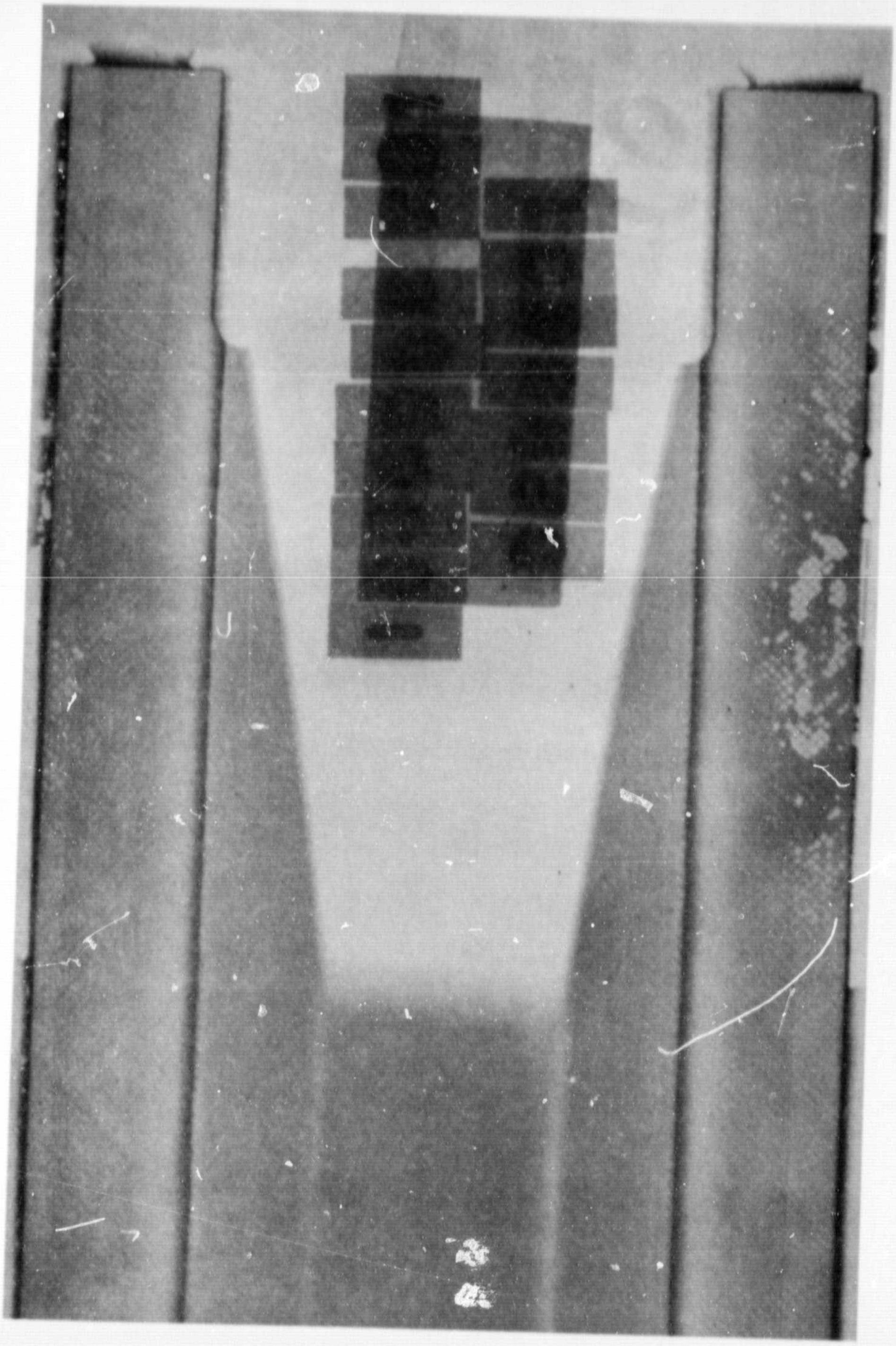


Figure 2-40. X-Rays of the Stiffener/Skin Assembly Shown in Figure 2-35

2.4.1 Limited Production Tool Design and Fabrication

During this quarterly period, fabrication and installation of the tape dispensing tool was completed. The tool has been installed in the Production Clean room where all layup of fin cover and hats is now being performed. See Figure 2-41. The arrangement for the support and rotation of the head is shown in Figure 2-42. The head is moved along the gantry manually. The head can also be rotated relative to the gantry and is locked into position with a pin. The material roll holder arrangement is shown in Figure 2-43. Various material widths can be accommodated. This requirement arose from the need to dispense both Kevlar cloth in 36-inch widths and graphite prepreg in 24-inch widths. In Figure 2-44 the pinch type guide rollers can be seen. The bottom roller in Figure 2-45 is the laydown pressure roller and the wooden roller above it is the paper backing takeup roller. The paper takeup roller is driven by the rotation of the pressure roller. The turnbuckle which can be seen in the left center of Figure 2-45 is used to make small adjustments in the height of the head.

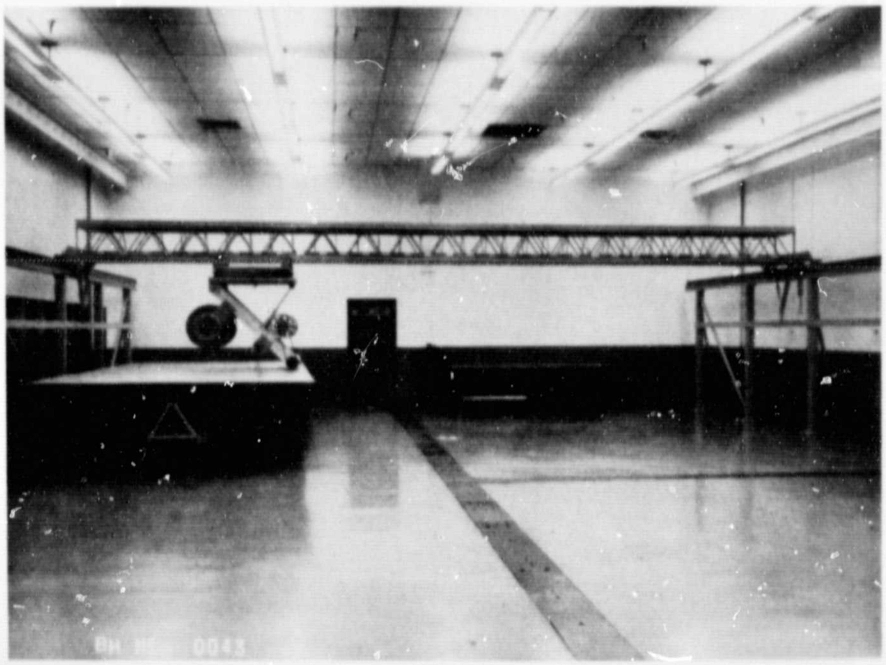


Figure 2-41. Installation of Tape Dispensing Tool
Note gantry, dispensing head, and laminating table in Production clean room.

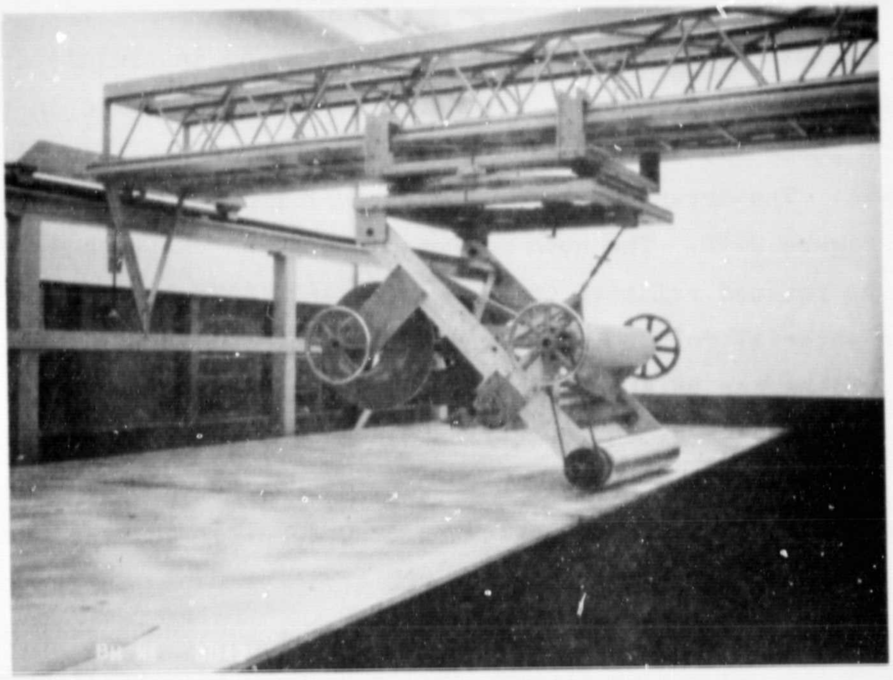


Figure 2-42. Tape Dispenser Head.
Note turret track for rotation and roller for pressure application of tape on flat table.

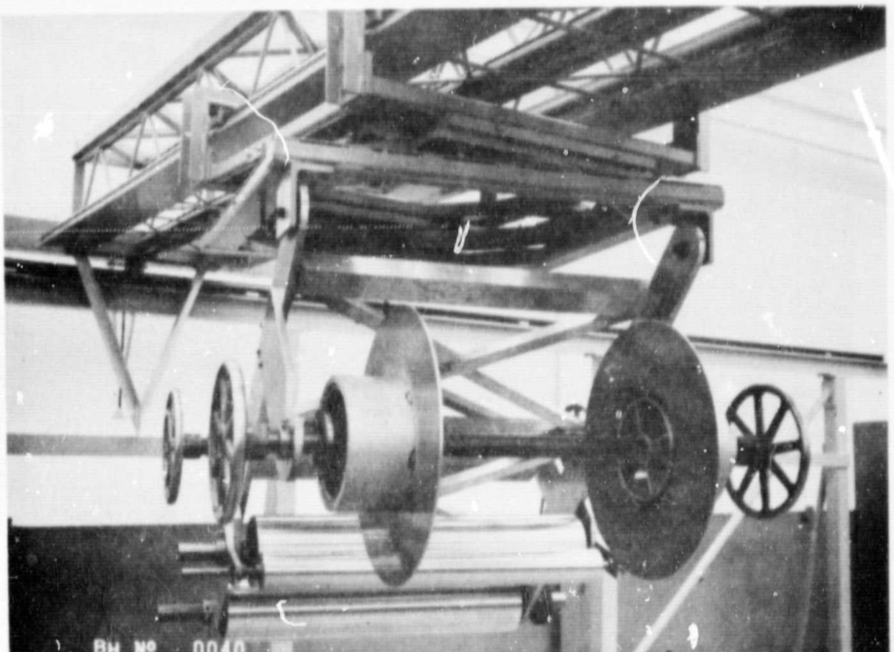


Figure 2-43. Roll Holding Arrangement.
Various material widths can be accommodated.

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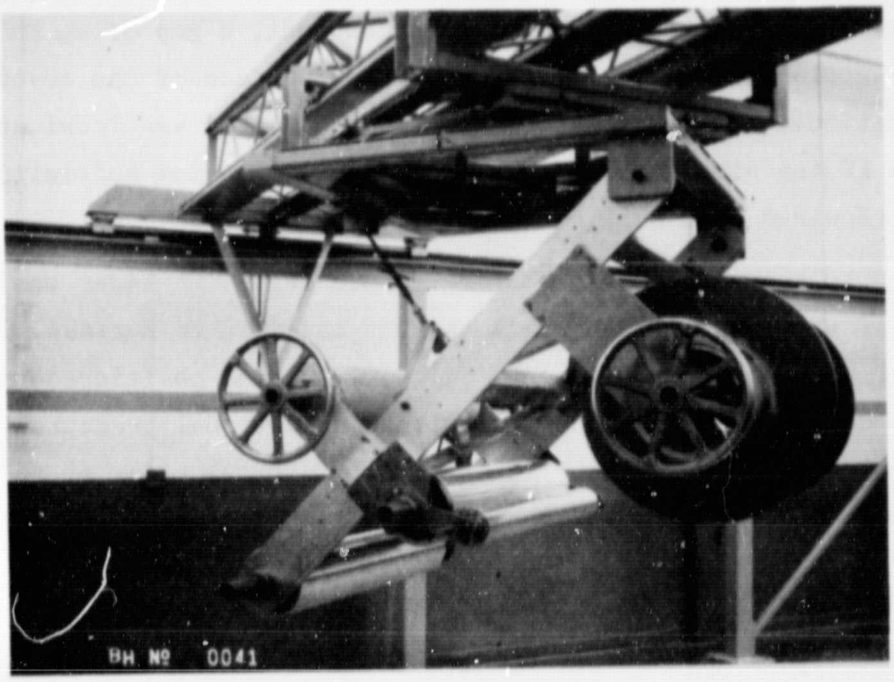


Figure 2-44. View of Dispensing Head Showing Material Guide Rollers

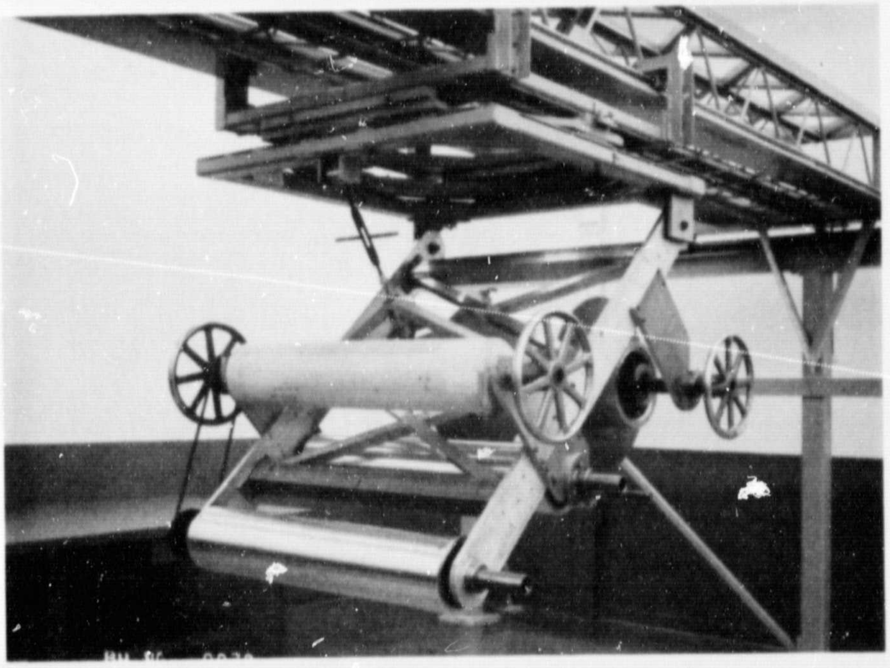


Figure 2-45. View of Head Showing Pressure Roller and Paper Takeup Roller

Since the stiffeners are parallel to the rear spar rather than on element lines and are fabricated on a straight tool, a gap of up to 0.470 inches exists between flanges of the hat and the inner surface of the cover when the hats are positioned for bonding to the cover. A mockup was fabricated and used to determine if the straight stiffeners could be deflected sufficiently to produce the required bond line contact.

Figure 2-46 shows the mockup during construction. A laser was used to set the surface of the mockup which simulated the cover inner surface. A 21-foot long straight hat section was molded (Figure 2-47) and positioned on the mockup. The hat laid into the contour without additional pressure. See Figure 2-48. This demonstrates that there will be no preloading or built-in stress in the bond line when straight tools are used to mold the hat stiffeners.

2.5 TASK 7 - SUBCOMPONENT TOOLING

The work in this task covers the design and fabrication of tooling to be used in the fabrication of subcomponent test specimens.

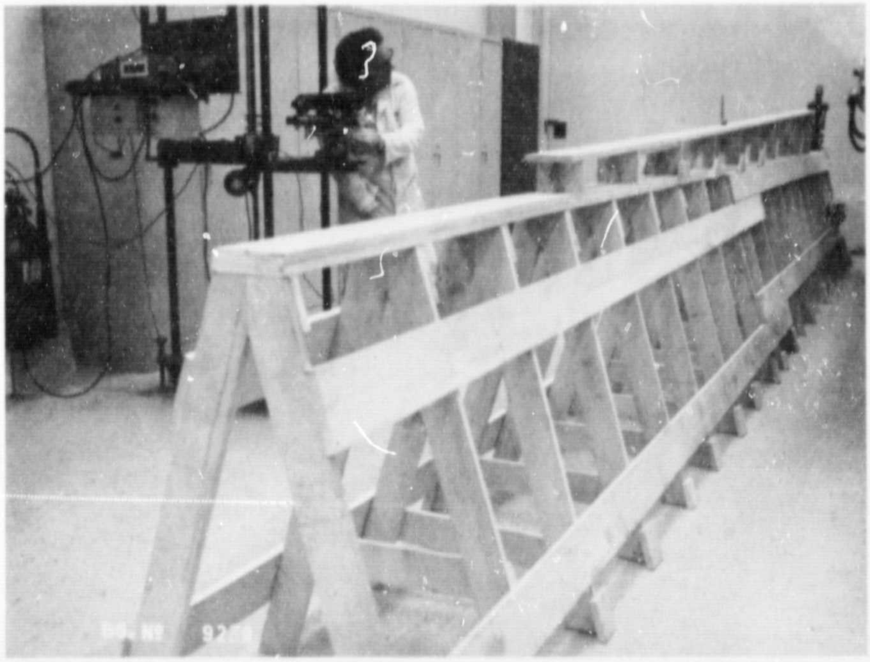


Figure 2-46. Construction of Inner Skin Surface Mockup

Figure 2-47. 21 Ft-Long Hat Section

Figure 2-48. 21 Ft-Long Hat Stiffener Nested on Mockup of Inside Skin Surface

2.5.1 Subcomponent Tool Design and Fabrication

Tool designs have been released for fabrication of the master tooling templates to be used for coordinating the location of the rib cutouts with the hat stiffeners at five rib locations. Two sets of templates are being machined, one set will be sent to LAAD and the other retained by Calac.

Tool design of full-size cover bonding tool is complete and fabrication has begun.

Fabrication of the cover bonding tools (one left hand and one right hand) for the 100 inch subcomponent has been completed. These tools will be used for cure of the subcomponent cover and for the hat-to-cover bonding operation. The tools are of steel construction and are designed to minimize mass and provide ample airflow under the tool face. Figure 2-49 shows the tools under construction with the first contoured support in place. All supports were N/C cut for accuracy. The 1/4 inch steel surface plate was then mated to supports by clamping and welding in place. One of the completed tools is shown in Figure 2-50.

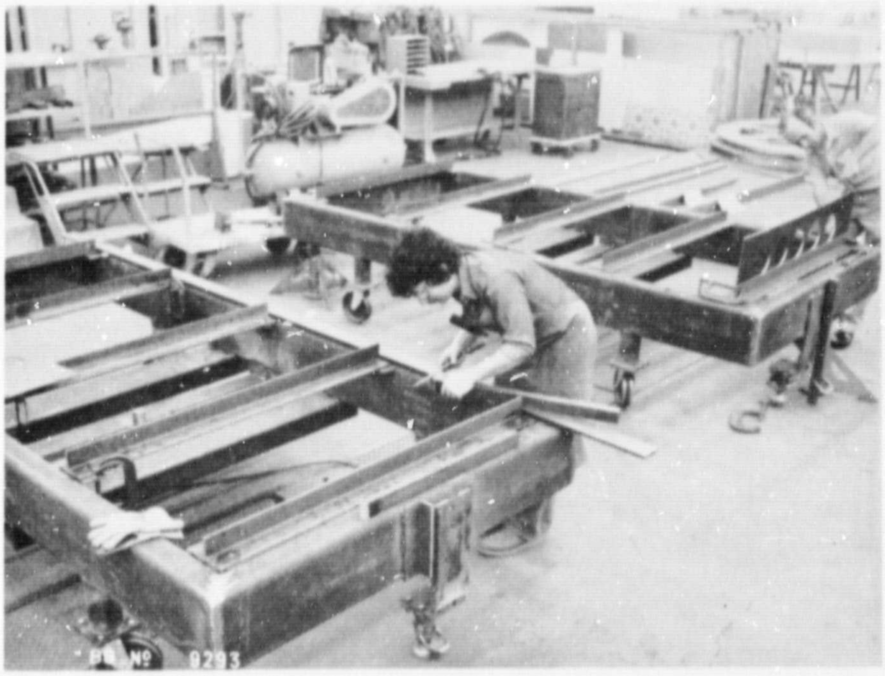


Figure 2-49. Fabrication of Cover Bonding Tools for 100-Inch Subcomponent

Figure 2-50. Completed Cover Bonding Tool for 100-Inch Subcomponent

Fabrication of the 300-inch broadgoods layup table is complete. This is a rigid, lightweight table designed for use with the tape dispensing tool for layup of broadgoods to be used for doublers, hats, etc. The substructure is shown in Figure 2-51 and the table with the top in place in Figure 2-52. The top is vacuum tight for debulking but is not intended for curing.

To support the requirements of the 100 inch subcomponent, a 12-foot long hat tool was fabricated. See Figure 2-53. The excess length of the tool over the requirement for the subcomponent will provide for process verification specimens.

Figure 2-51. Fabrication of Substructure for Layup Table

Figure 2-52. Broadgoods Layup Table
Table top in place but not yet fastened to substructure.

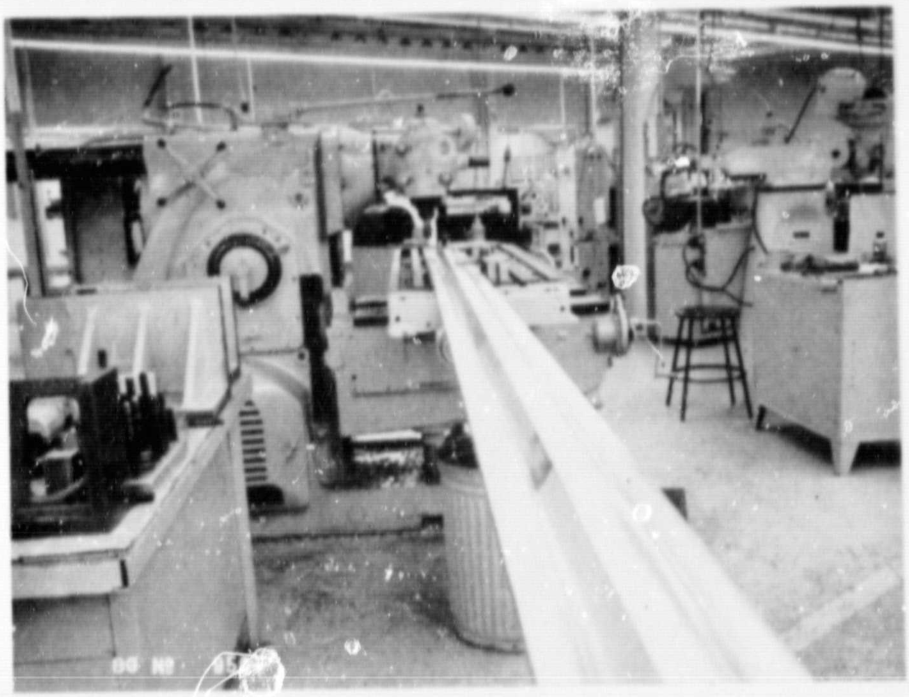


Figure 2-53. Machining of Hat Tool for 100-Inch Subcomponent

SECTION 3

PHASE II - DETAIL DESIGN - SPARS

Phase II Detail Design of the Spars covers the main engineering effort of Lockheed-Georgia Company in the design, development, and fabrication of the front, rear, and stub spars for the L-1011 Advanced Composite Vertical Fin. The engineering effort during this quarter covers four tasks: Component Definition, Material Verification, Fabrication, and Subcomponent Tooling.

3.1 TASK 1 - COMPONENT DEFINITION

Component Definition covers the detail design and structural analysis of the selected spar configuration and ancillary tests.

3.1.1 Detail Design

The recommended concept for the spars continues to be graphite/epoxy caps and a combination of Kevlar and graphite epoxy in the spar web. The spar cap, spar web stiffeners for attaching the ribs and intermediate stiffeners are planned to be fabricated as a unit. Access holes in the web will be reinforced with a donut type, zero degree graphite-epoxy wound reinforcement. A change in the intersection of the rib cap to spar with integral stiffener was made to allow the rib cap to fit between the spar cap and stiffener.

The design of the full size front and rear spars has continued on schedule. In the design effort of the front spar, the root area was sized first to provide data for use in the front spar auxiliary test specimen number 23. This stub spar specimen is representative of the final design of the front spar and spar to fuselage attachment. Two specimens will be fabricated for static and fatigue tests, and these will be the last specimens scheduled for the prototype tool. The detail design of the No. 23A Front Spar to Fuselage Static Test Specimen was completed and released for fabrication.

The detail design of the 100-inch rear spar test specimen has been completed and the drawing for this component has been released. The Front Spar Tool Control Drawing, the Rear Spar Tool Control Drawing, and the Auxiliary Spar Assembly Drawing have als- been released, completing Lockheed-Georgia Company's design effort for the 100-inch test component.

Design of ancillary test specimen number 20, representative of the mid-section of the front spar, was completed and released for fabrication.

3.1.2 Structural Analysis

Structural analysis of the spars and test specimens is proceeding as scheduled. A computer DEMAND Program was modified to predict local stresses and strains around the spar web access holes for use in sizing the hole reinforcements in the spars and test specimens.

Stress sizing of ancillary test specimen number 20 was completed. Specimen test loads and critical test fixture dimensions were developed and sent to the test lab. Results of the shear panel tests, ancillary test number 21, are being evaluated, and actual versus predicted panel buckling, and local stresses and strains around the holes are being determined from the strain gage data obtained during the tests. The results of this analysis are being incorporated in the design.

Structural analysis of the 100-inch rear spar specimen has been completed and checked. The final sizing of the specimen was based on the latest NASTRAN loads. Table 3-1 shows the NASTRAN internal spar design loads. The revised material allowables for Phase II were received along with the "wet" reduction factors, and the effects of these were incorporated in the sizing of the 100-inch specimen. Local fitting and attachment loads were obtained from the L-1011 Fin Internal Loads Report.

The NASTRAN loads were also used to size the full length front and rear spars. The stiffness of the spars will be maintained at the present level in order to maintain the current stiffness used in the NASTRAN model.

TABLE 3-1. COMPARISON OF NASTRAN DESIGN LOADS WITH METALLIC FIN LOADS USED DURING PHASE I

V.S.S. (IN.)	FRONT SPAR CAP LOAD (LB)	REAR SPAR CAP LOAD (LB)	FRONT SPAR SHEAR (LB)	REAR SPAR SHEAR (LB)
	23241	28284	1489	773
97.19				
	17834	22929	1246	1061
113.37				
	10637	13282	1156	1025
129.54				
	8378	10951	1088	1002
145.71				
	7489	8635	1152	759
162.85				
	6022	6992	1098	758
179.99				
	5298	6328	1024	774
197.13				
	5623	6730	1117	653
214.27				
	4685	6346	1104	672
231.41				
	4517	5471	910	706
248.55				
	4339	4908	916	610
265.69				
	3761	4206	852	638
282.83				
	2884	3674	755	682
299.97				
	2485	3232	650	582
317.11				
	1901	3018	590	627
344.25				
	2089	1371	489	772

3.1.3 Ancillary Tests

Testing of specimens 18A and 19 has begun. These are the dry, fatigue test specimens representing the spar cap to cover attachment and the spar cap to fuselage joint. These are fatigue test specimens consisting of five specimens each for four different configurations. Specimen 18A-1 represents the front spar cap to cover attachment at VSS 248. Specimen 18A-2 represents the front spar cap to cover attachment at VSS 121. Specimen 19-1 represents the front spar cap attachment to fuselage and Specimen 19-2 represents the rear spar cap to fuselage splice. One specimen of each configuration is a static control specimen, and the other four are scheduled for four lifetimes of fatigue testing followed by a residual strength test.

Figure 3-1 shows the test setup for Specimens 18A-1 and 18A-2. Specimen 18A-1, shown in Figure 3-2, sustained a static load of 10,700 pounds. Strain readings were erratic during the 18A-1 static test, and numerous adjustments were made to the test fixture in an attempt to get more equal strains in the back-to-back strain gages. An examination of the specimen found some warpage which may explain the erratic strain readings. The failure load was less than the predicted 13,000 pounds for a uniform shear distribution along the in section of the cap tee. Eight plies of $\pm 45^{\circ}$ graphite-epoxy at the intersection of the tee and an ultimate shear allowable of 50,000 psi give the predicted 13,000 pounds. The design shear load at VSS 248 where the 18A-1 simulates the front spar is 900 pounds per inch versus the specimen failing shear load of 1646 pounds per inch.

Specimen Number 18A-2 representing the front spar to cover attachment at VSS 121 sustained a static load of 11,600 pounds before failure of the cover through the net section of the fasteners. The design shear at this location is 1156 pounds per inch versus the failure load of 1785 pounds per inch.

The static control specimen for the fatigue tests of the rear spar splice (No. 19-2), shown in Figure 3-3, sustained a static load of 13,300 pounds before failure. The predicted static load for this specimen was 13,260 pounds.

The testing of items 18B, 18C, and 18D has been completed. The all graphite-epoxy specimens were cut out of the first 8-foot tool development spar.

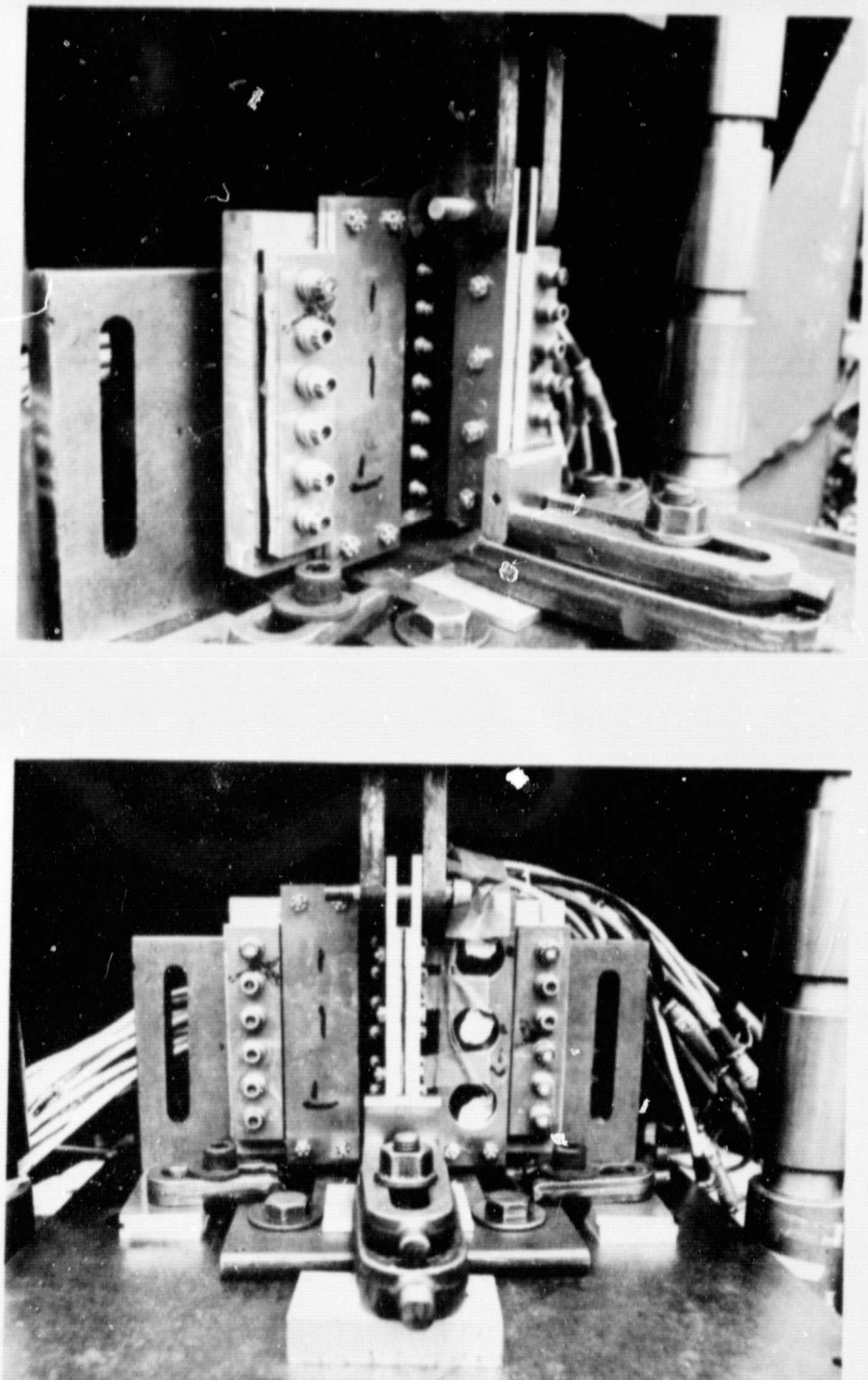
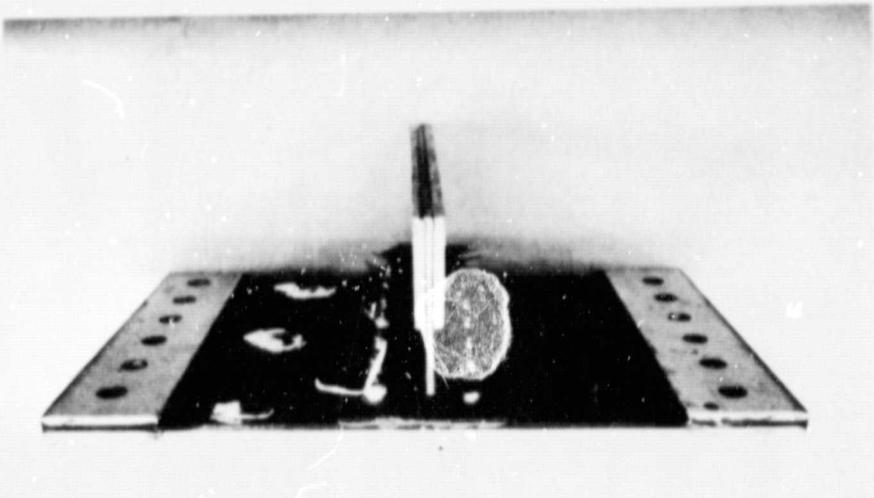


Figure 3-1. Static and Fatigue Test Setup for 18A



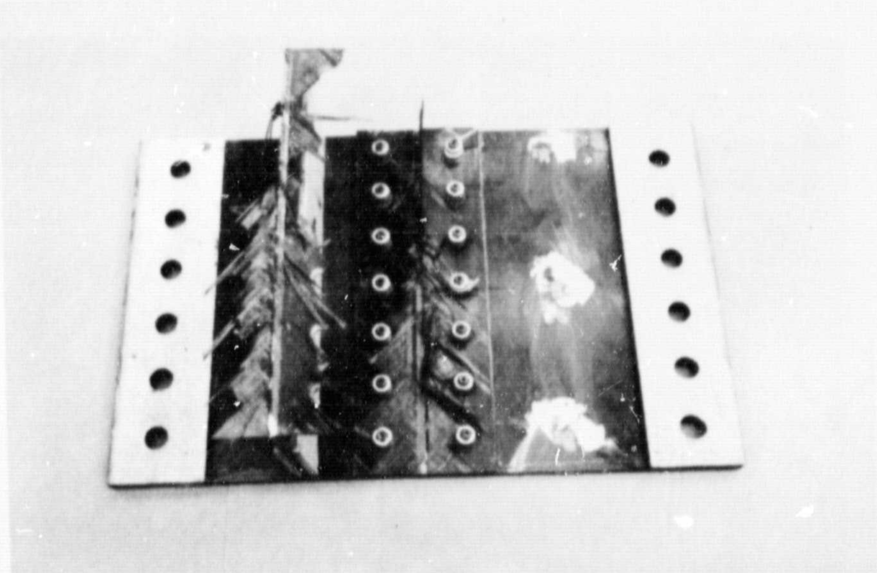


Figure 3-2. Static Tested 18A-1 Specimen

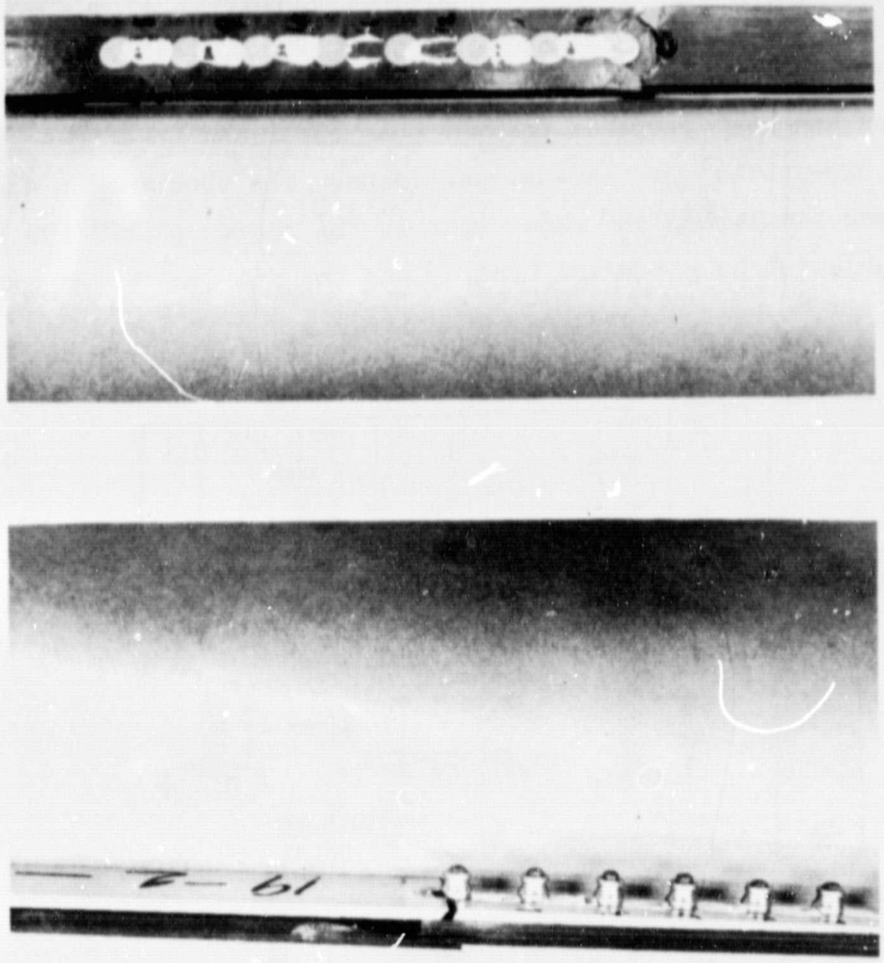


Figure 3-3. 19-2 Rear Spar Splice Static Test Specimen

The locations of the 18 series of specimens on the prototype spar are shown in Figure 3-4. The test setups and failure modes for the 18B cap to web tension tests, the 18C cap to web shear tests, the 18D stiffener to web tension test, and the 18E stiffener to web shear tests are shown in Figures 3-5 through 3-8. The test results from the 18 series specimens are presented in Tables 3-2 through 3-5.

Test specimen number 20 representing a section of the front spar has been released for dry structural test. The specimen has been set up in the test fixture and has been prepared for the beam shear and bending tests. Figure 3-9 shows the dimensions, ply lay-up, and loads. The specimen is a constant cross-section beam simulating the front spar in the region of VSS 190 to VSS 210. It will be subjected to shear and bending and used to verify the cap, web, stiffener, and access hole design concepts.

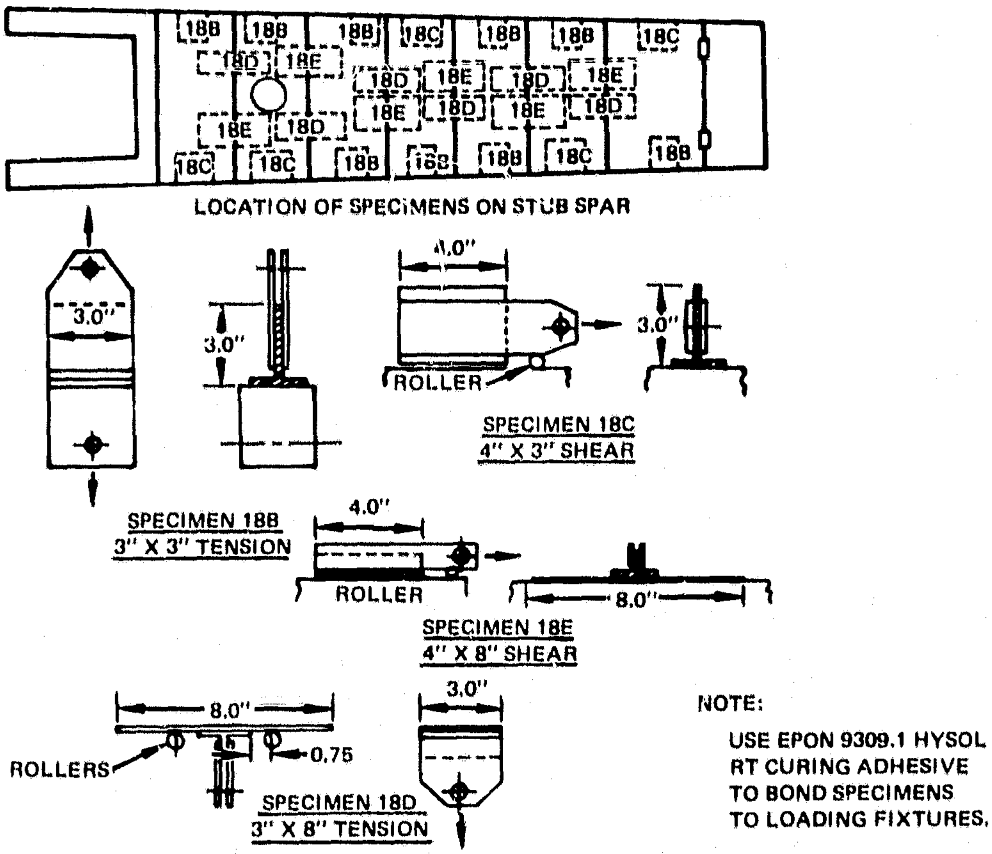


Figure 3-4. Stub Spar Test Specimens (Items 18B - 18E)

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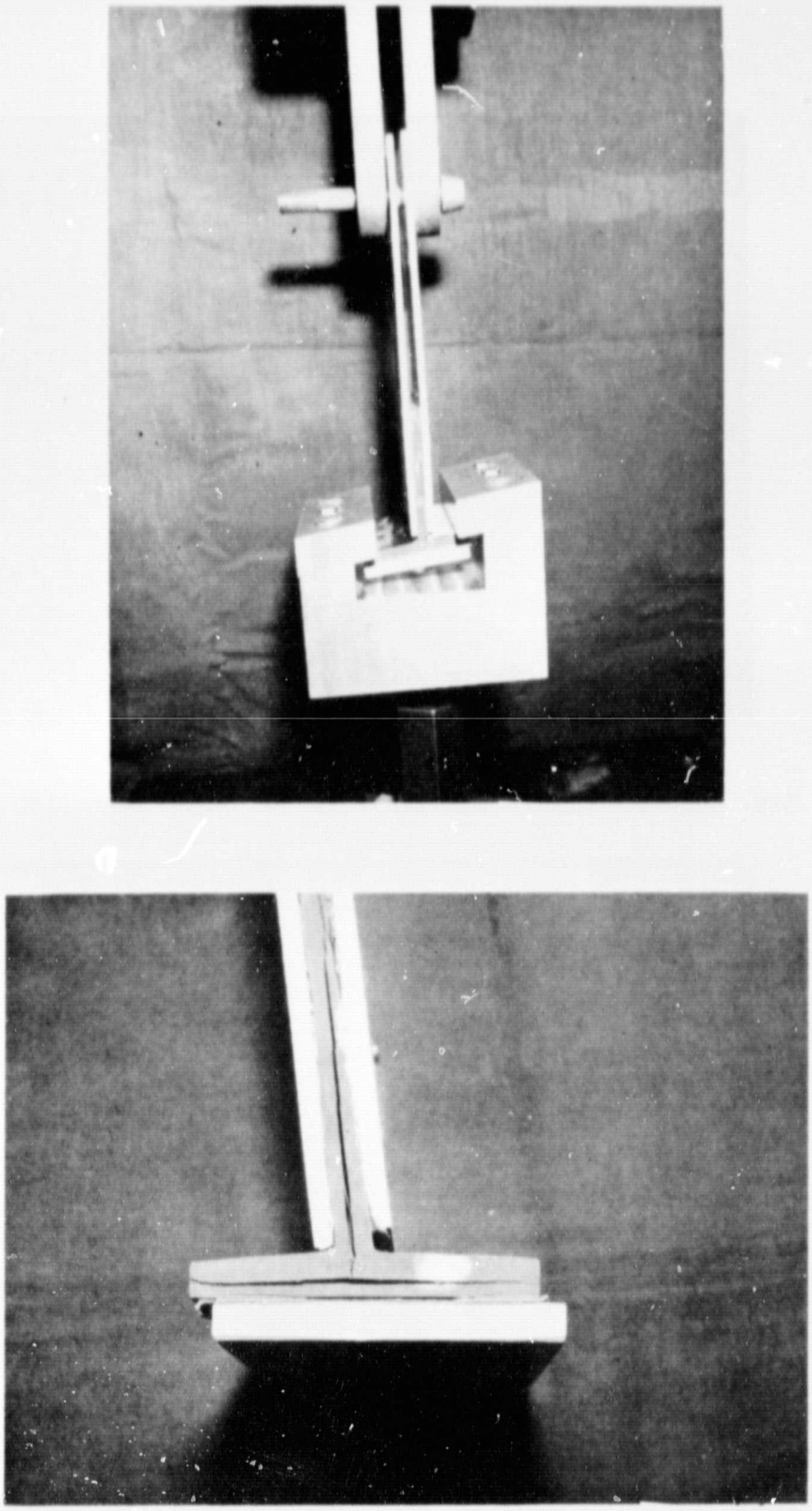


Figure 3-5. Test Setup and Failure Mode for Spar to Web Tension Test, 18B

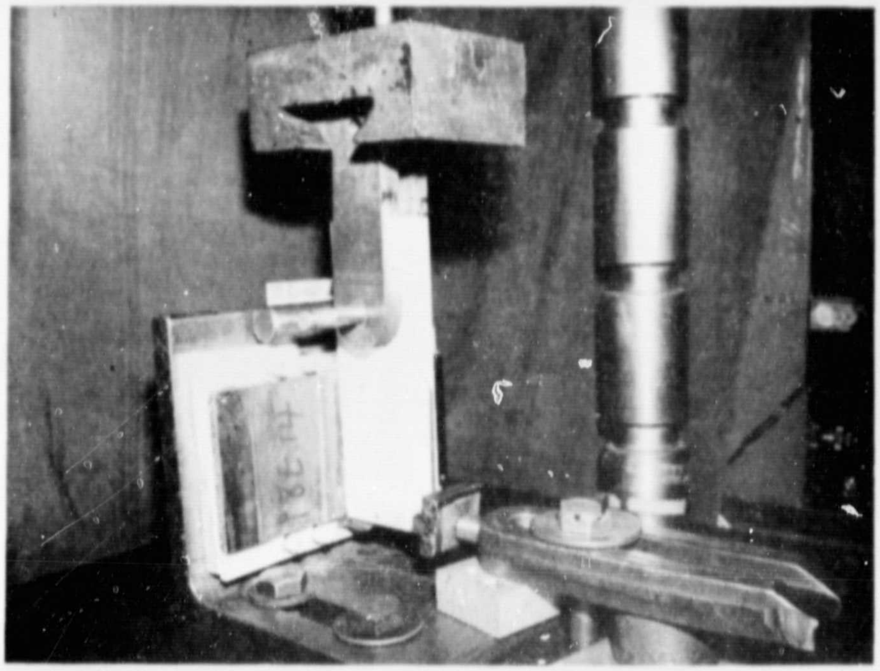


Figure 3-6. Cap to Web and Stiffener to Web Shear Test, 18C and 18E

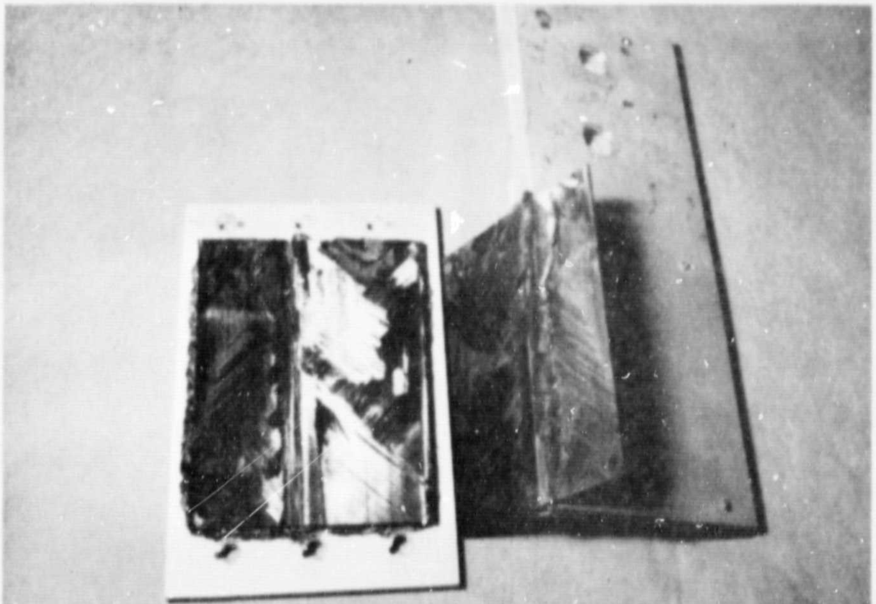
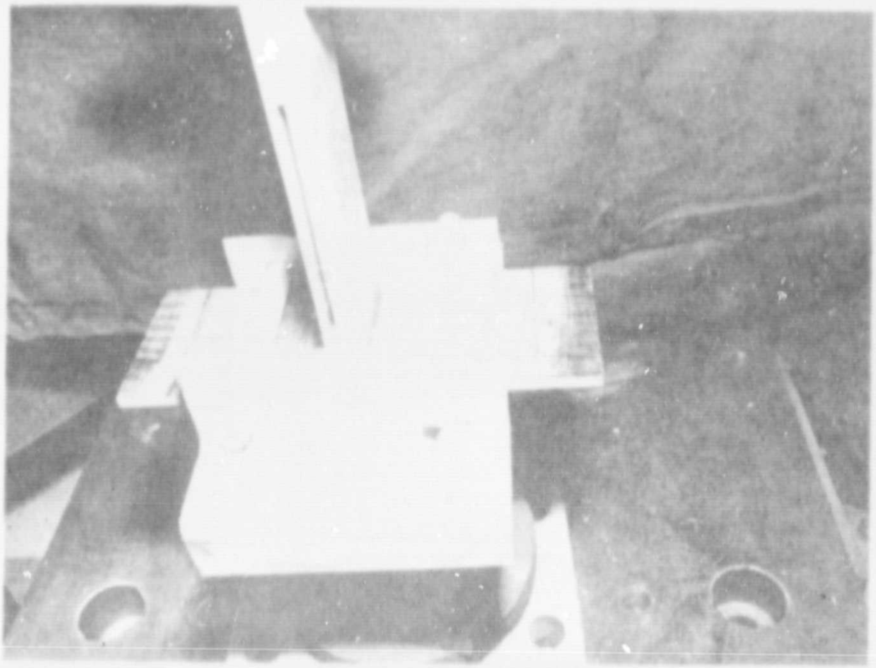


Figure 3-7. Failure Mode of Cap to Web Shear Test, 18C



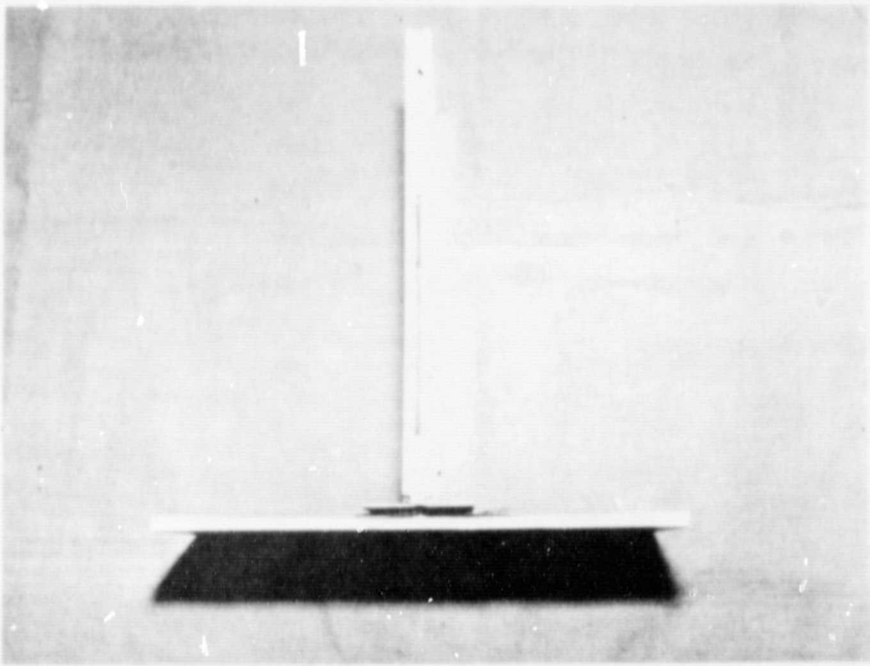
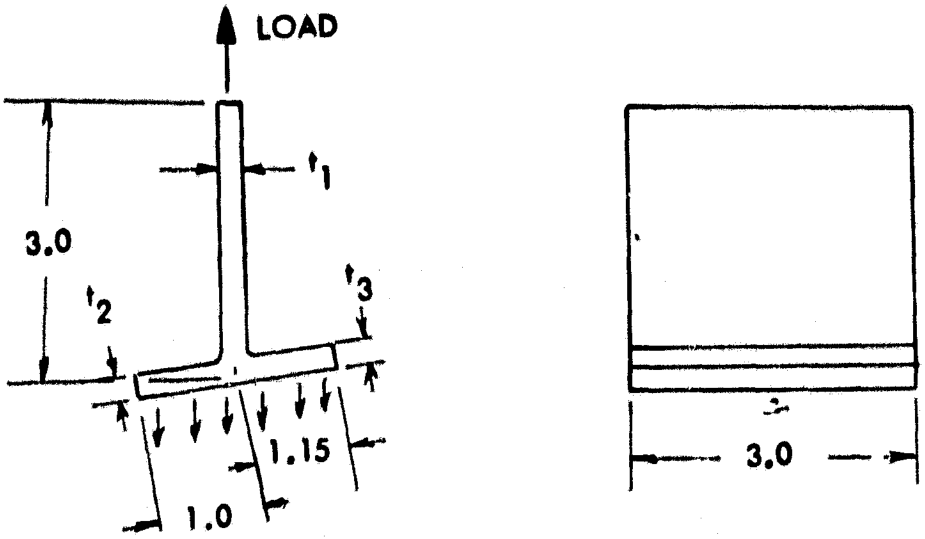


Figure 3-8. Test Setup and Failure Mode for 18D

TABLE 3-2. SPAR CAP TO SPAR WEB TENSION TESTS 18-B



SPECIMEN NUMBER	MAX LOAD (LBS)	THICKNESS t_1 (in.)	THICKNESS t_2 (in.)	THICKNESS t_3 (in.)	FAILURE MODE	FAILURE STRESS $= \frac{LOAD}{t_1 \times L}$	PREDICTED FLATWISE TENSILE STRESS	EVALUATION OF RESULTS
18B-1	2660	0.20	0.28	0.18	Fig 3-5	4433	4000	
-2	3340	0.24	0.22	0.31		4639		
-3	2680	0.18	0.27	0.32		4963		
-5	3040	0.20	0.23	0.28		5067		18B Series indicates acceptable Flatwise Tensile Strength
-6	2445	0.21	0.23	0.30		3881		
-22	5660	0.18	0.27	0.28		10481		
-23	4800	0.20	0.25	0.28		8000		
-24	4000	0.15	0.22	0.28		8889		
-26	3660	0.23	0.25	0.25	Fig 3-5	5340		

ROOM TEMPERATURE, DRY SPECIMENS

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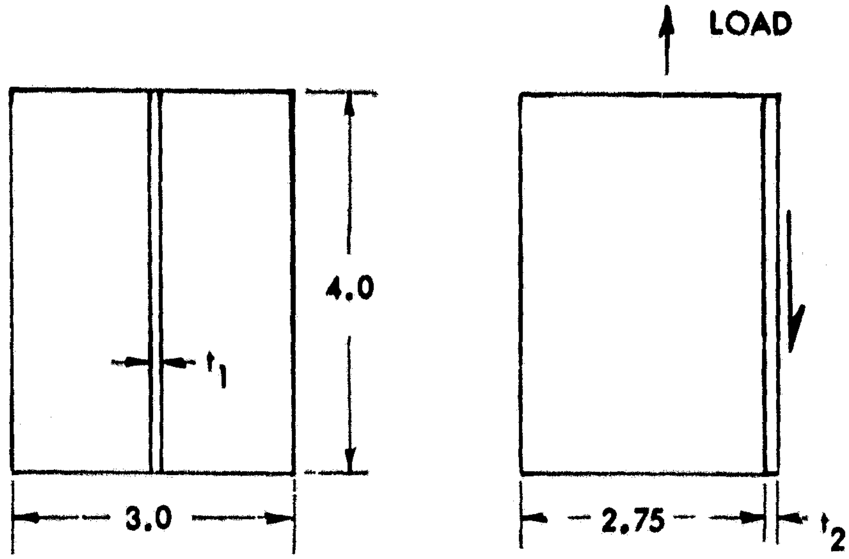
TABLE 3-3. SPAR CAP TO SPAR WEB SHEAR, 18C



SPECIMEN NUMBER	MAX LOAD (LBS)	t_1 (in.)	t_2 (in.)	FAILURE MODE	FAILURE STRESS = $\frac{LOAD}{t_1 \times L}$	PREDICTED INTER-LAMINAR AVE SHEAR STRESS	EVALUATION OF RESULTS
18C-4	1360 △1	0.21	0.24	△3	1619	2000	Specimen Peeled - Roller Supports did not react couple
-7	1540 △1	0.22	0.25	△3	1750	↑	
-20	3960	0.20	0.23	△4	4950	|	Acceptable
-21	2840 △2	0.22	0.24	△4	3227	↓	Acceptable
-25	3120	0.21	0.23	△4	3714	2000	Acceptable

ROOM TEMPERATURE, DRY SPECIMENS

NOTES:

△1 Roller supports did not react couple (Fig 3-4).

△2 This specimen contained 0.9 and 0.5 inch built in boids in the shear plane for use in NDI standards.

△3 Specimen peeled and sheared because of △1 .

△4 Interlaminar shear in cap approximately 0.1 inch from bondline.

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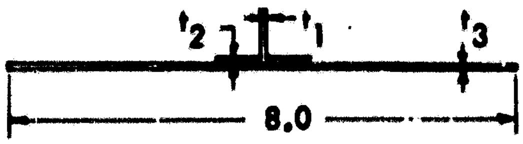
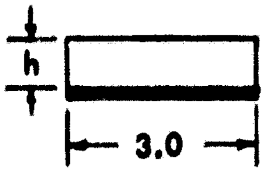
TABLE 3-4. STIFFENER TO WEB TENSION, 18D

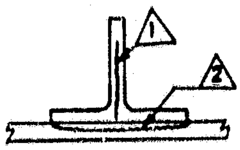




SPECIMEN NUMBER	MAX LOAD (LBS)	t_1 (IN.)	t_2 (IN.)	t_3 (IN.)	h (IN.)	FAILURE MODE	FAILURE STRESS $= \frac{LOAD}{t_1 \times L}$	PREDICTED INTERLAMINAR AVE SHEAR STRESS	EVALUATION OF RESULTS
18D-17	1200	0.190	0.238	0.208	1.0		2105		
-8	985	0.180	0.228	0.198	1.35		1824	Combined Stresses reduce predicted Flatwise Tensile Stress	Consistent Results - High Bonding and Shear Stresses combined with Flatwise Tensile Stresses indicate Acceptable Strength
-10	1160	0.160	0.256	0.221	1.70		2417		
-12	1155	0.190	0.225	0.195	1.00	SEE NOTES	2026		
-15	1185	0.190	0.230	0.207	1.23		2079		
-10	1150	0.150	0.248	0.213	1.60		2556		

TEST TEMPERATURE 75°F, DRY SPECIMENS

NOTES:



1. Ply separation in the vertical plane
2. Fibers pulled from the spar web at the interface of the stiffener to web

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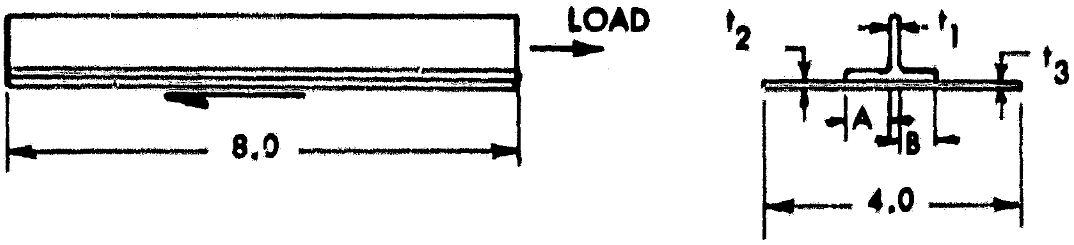
TABLE 3-5. STIFFENER TO SPAR WEB SHEAR, 18E



SPECIMEN NUMBER	MAX LOAD (LBS)	t_1 (IN.)	t_2 (IN.)	t_3 (IN.)	A (IN.)	B (IN.)	FAILURE MODE	FAILURE STRESS = $\frac{LOAD}{t_1 \times L}$	PREDICTED INTERLAMINAR AVE SHEAR STRESS	EVALUATION OF RESULTS
18E-9	3060	0.20	0.25	0.21	0.70	2.75	△1	1913	1500	Acceptable
-11	3120	0.20	0.24	0.19	0.70	0.70		1950		Acceptable
-13	3700	0.20	0.25	0.22	0.70	0.70		2313		Acceptable
-14	2760	0.20	0.24	0.19	0.70	2.75		1725		Acceptable
-16	2000	0.20	0.23	0.20	0.70	0.70		1250		Low
-18	3140	0.20	0.24	0.20	0.70	0.70	△1	1962	1500	Acceptable

ROOM TEMPERATURE, DRY SPECIMENS

NOTES:

△1 Stiffener sheared at interface of web taking approximately 2 plies of the web.

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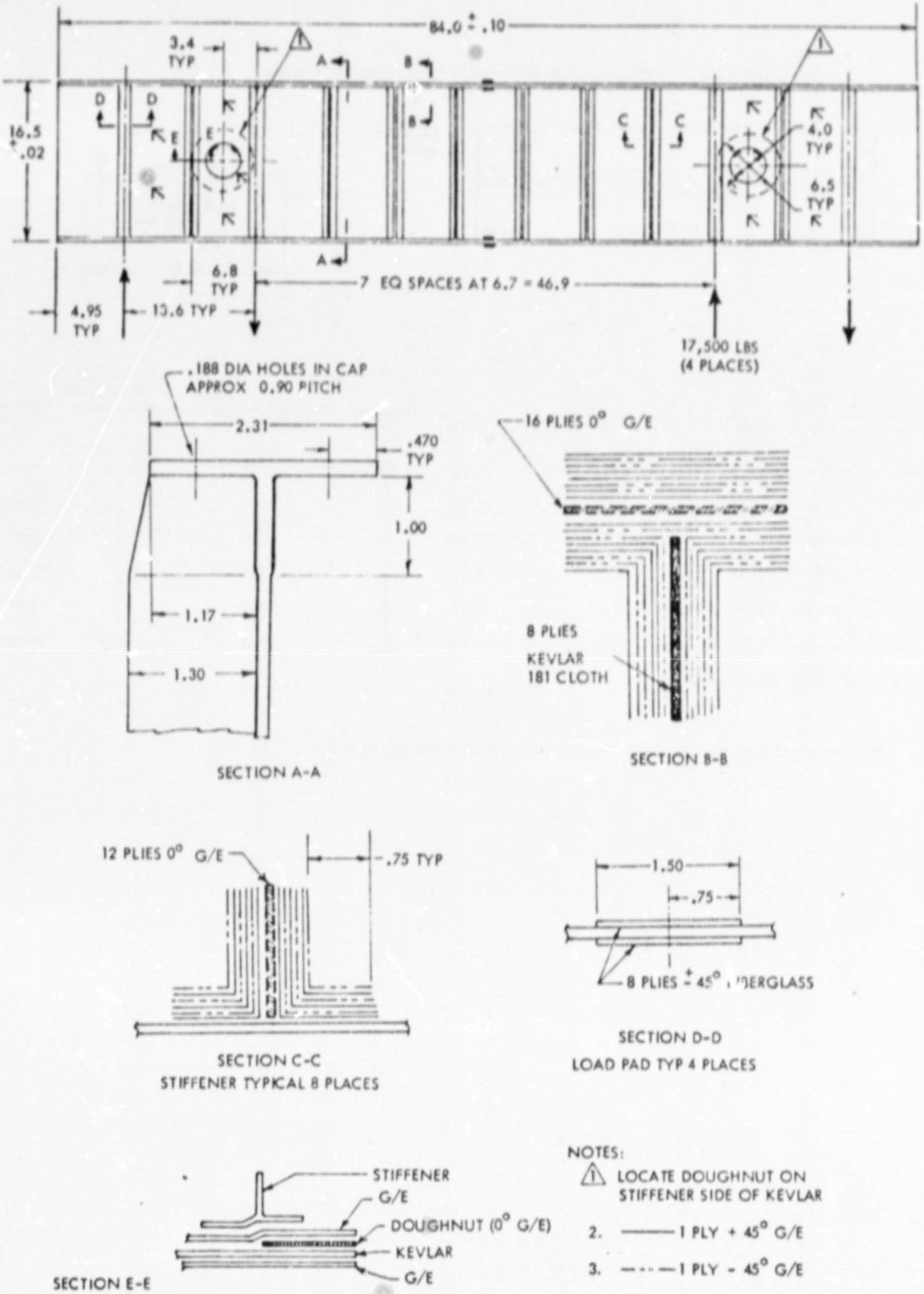

Figure 3-9. Front Spar Specimen Number 20

Testing of shear panels with access hole and two stiffeners shown in Figures 3-10 and 3-11 was completed. These panels are identified as ancillary tests number 21. In the early test plan, test number 22 called for a stiffened panel to be tested in compression, and test item 21 called for a flat panel to be tested in shear. As the design developed and the access holes and stiffeners became better defined, the test plan was revised to combine the two shear panels in 21 and the two stiffened panels in 22 into a series of five shear panels with stiffeners and access holes. These panels were identified as item 21. The failing load for each of the five panels tested is summarized in Table 3-6. Six panels were fabricated. The first was resin rich and was not considered a satisfactory panel; it did, however, sustain the highest buckling load because of its thicker web.

The tool and series of panels used for test number 21 are shown in Figures 3-12 through 3-17. Figure 3-12 shows the tool used to mold the panels. Figure 3-13 shows the test set-up and diagonal-tension (type) failure for the first panel with the thicker, resin rich web. Figure 3-14 through 3-17 show the remaining panels tested. Panel number 3 originally planned for testing after impact damage has been set aside for a test to be identified later.

Analysis of panel number 1 predicted a failure load of 73,000 pounds versus the actual 67,000 pound load. Panel number 2 which had the reinforcement around the access hole on one side of the web only sustained approximately the same load as the symmetrically reinforced panel number 1. The configuration of panel number 2 was selected for design; because with the reinforcement on one side only, it is considerably easier to tool and fabricate. Strain data for panel number 2 is summarized in Figure 3-18.

Analysis of panel number 5 indicated a predicted failure at 35,500 pounds. This panel, with no hole reinforcement, sustained an actual failure load of 49,800 pounds. Panel number 4, with a mylar separator at the midplane of the web, sustained a load equivalent to the flaw free panel number 1.

The Front Spar to Fuselage Static Test Specimen No. 23A has been released for fabrication. This specimen, representative of the front spar and spar to fuselage attachment, is illustrated in Figure 3-19. A second front spar specimen identical to 23A, No. 23B will be fabricated for fatigue tests.

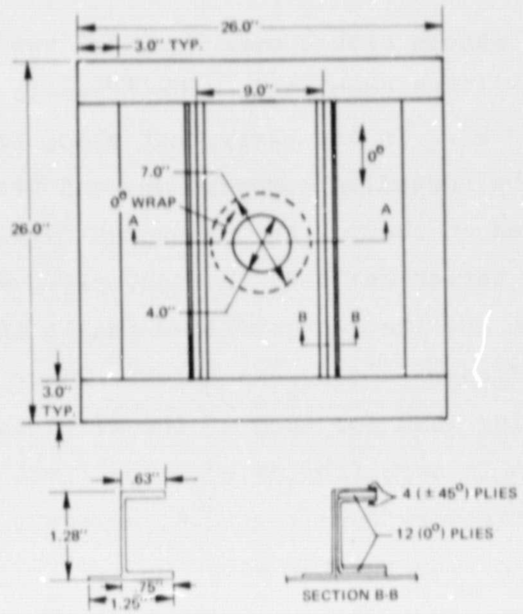

Figure 3-10. Spar Web Test Specimen (Item 21)

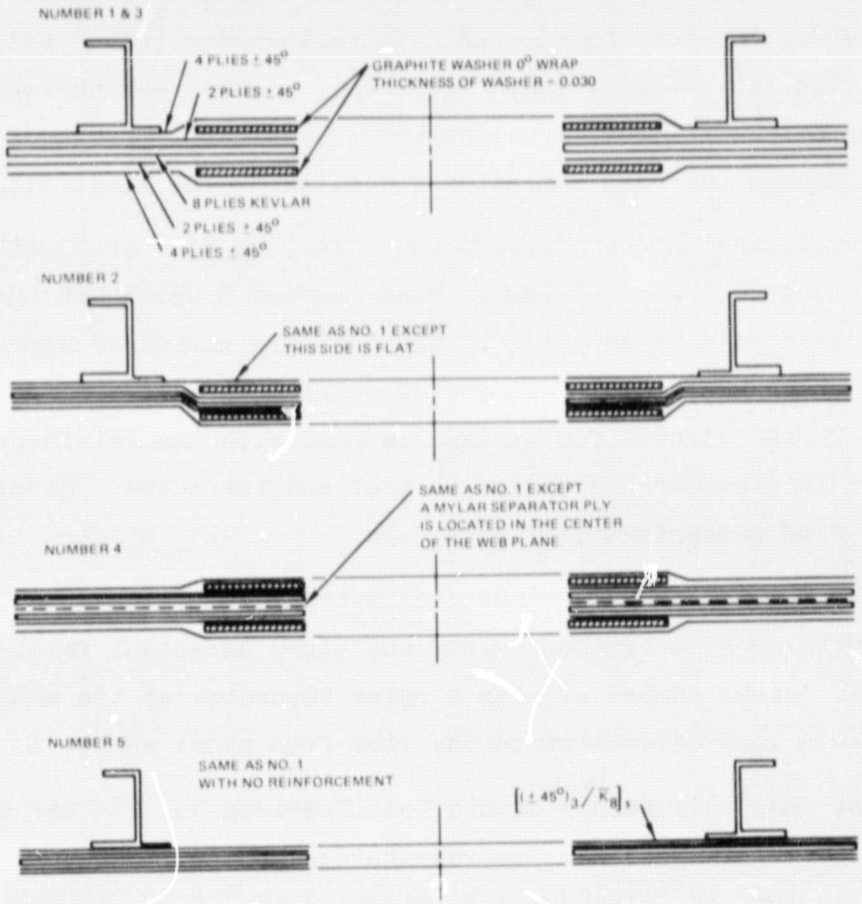

Figure 3-11. Cross Section A-A of Spar Web Test Specimens

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TABLE 3-6. SUMMARY OF SHEAR PANEL TESTS WITH ACCESS HOLE AND STIFFENER

Panel No.	Failure Load (Lbs)	Type of Failure
1	72,000	Panel was resin rich, failed diagonally across panel in tension
1 Retest	67,000	Tension diagonally across panel
2	66,400	Buckling across center bay
3	-	On hold for later test
4	67,000	Buckling arross center bay
5	49,800	Buciling across center bay

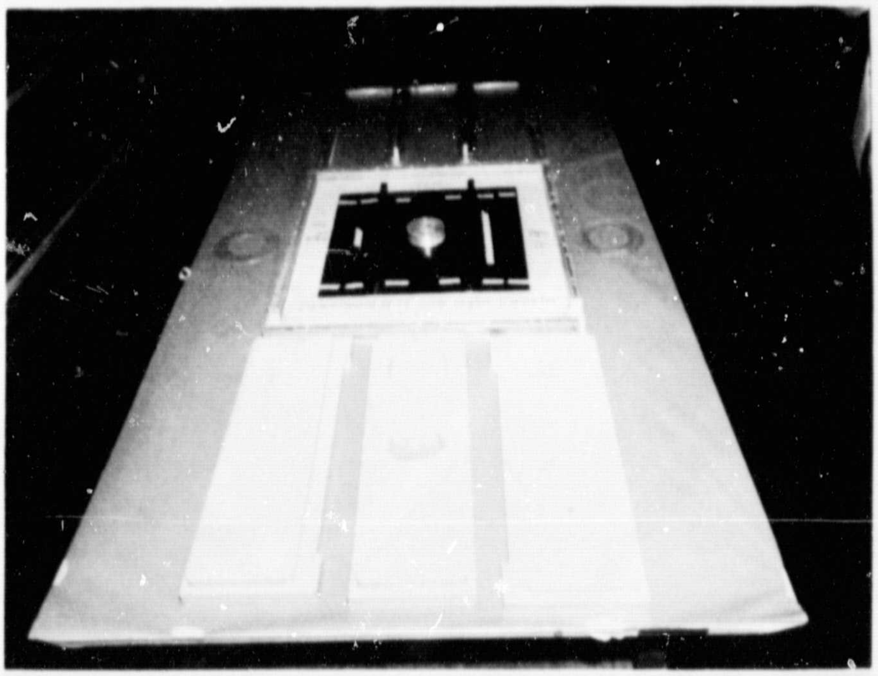
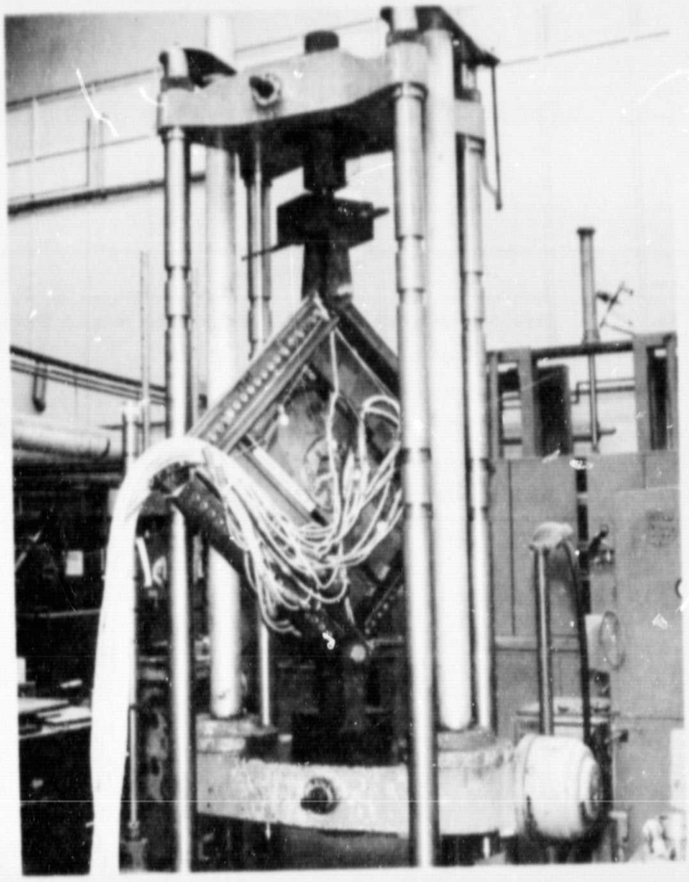


Figure 3-12. Tool Used to Mold Shear Test Panels (Test Item 21)



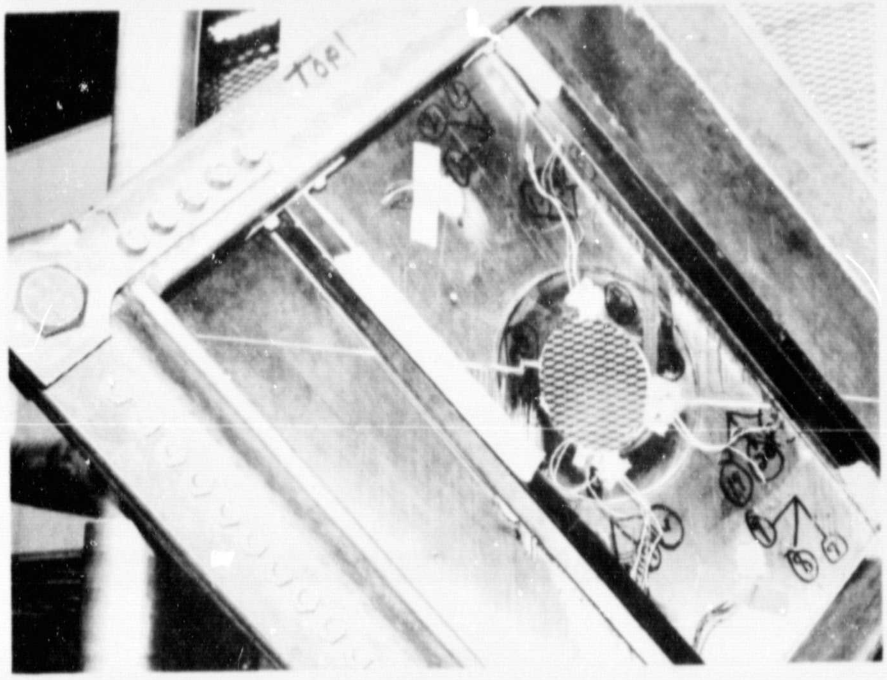


Figure 3-13. Test Setup and Failure Mode (Item 21, 1st Test with Resin Rich Panel)

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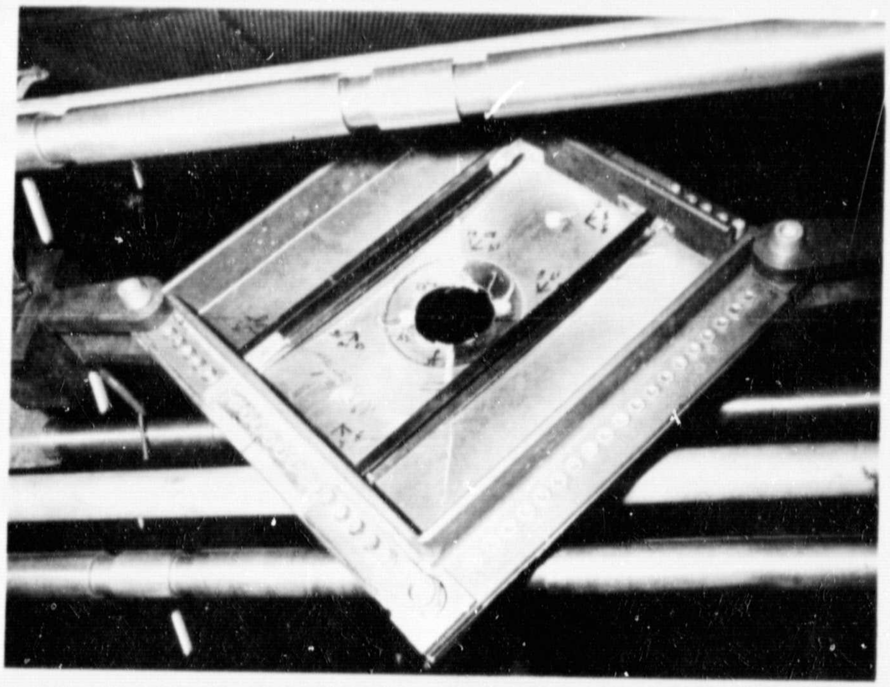


Figure 3-14. Ancillary Test No. 21 (Panel No. 1 Retest)

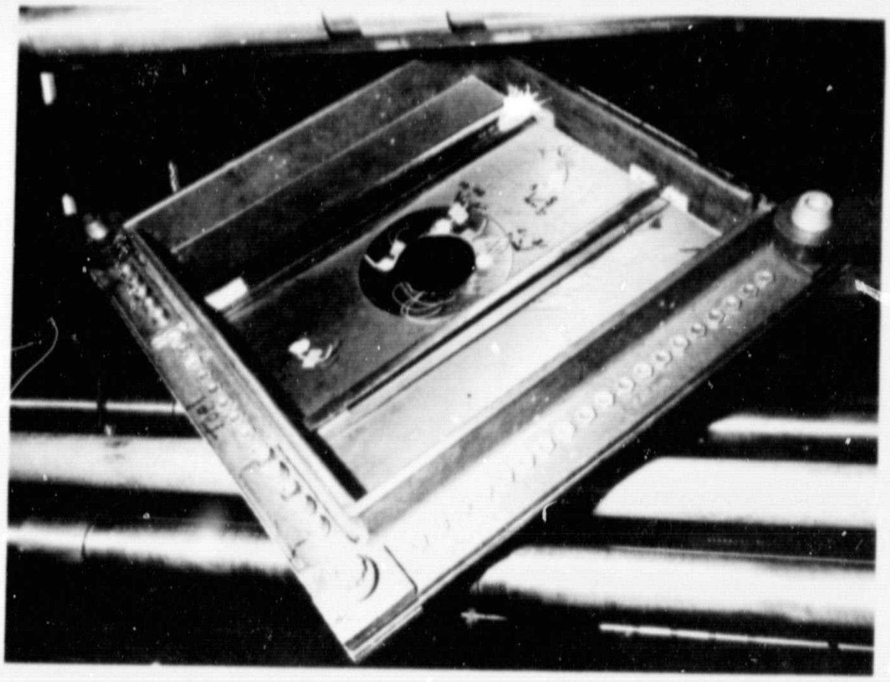


Figure 3-15. Ancillary Test No. 21 (Panel No. 2)

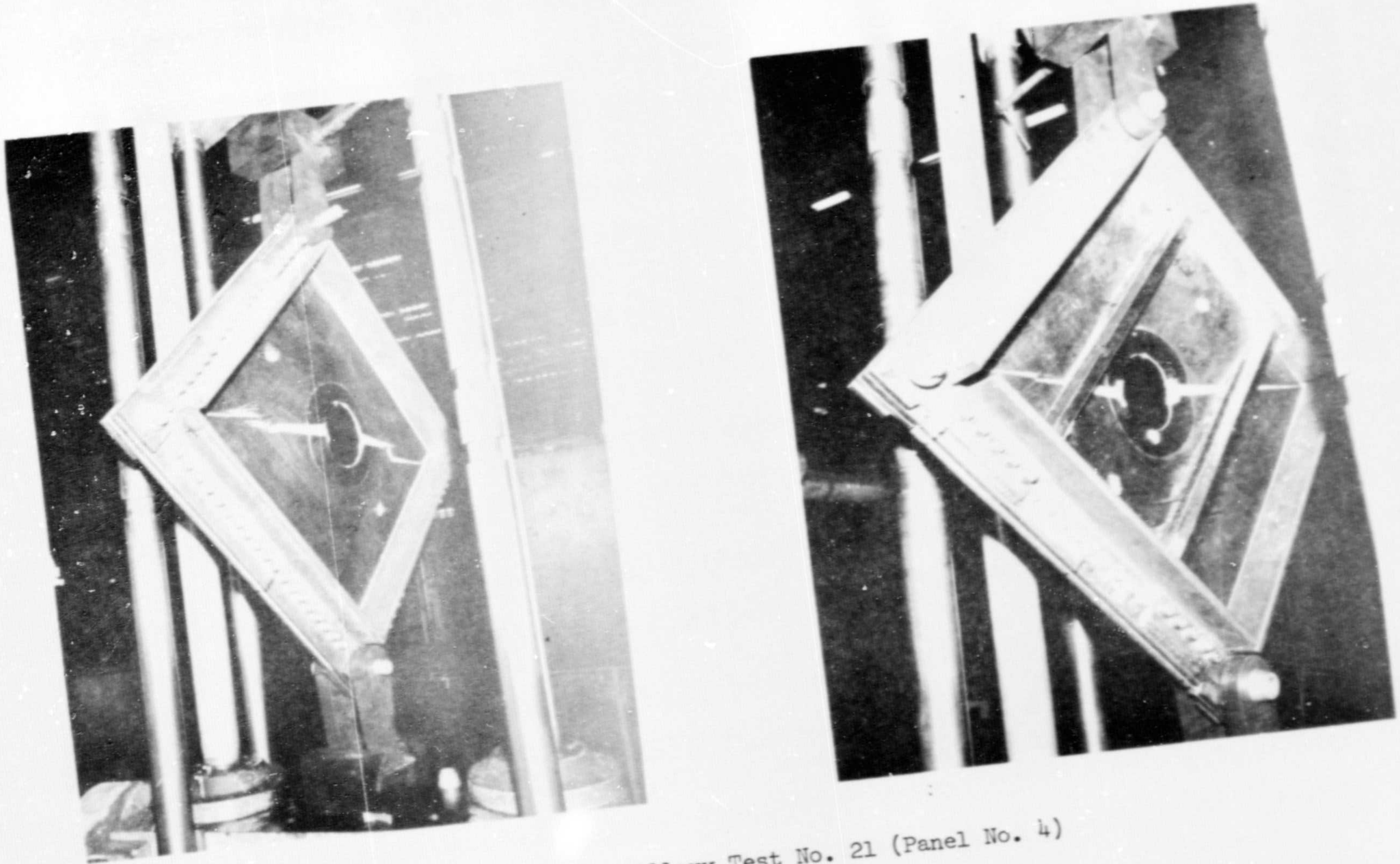


Figure 3-16. Ancillary Test No. 21 (Panel No. 4)

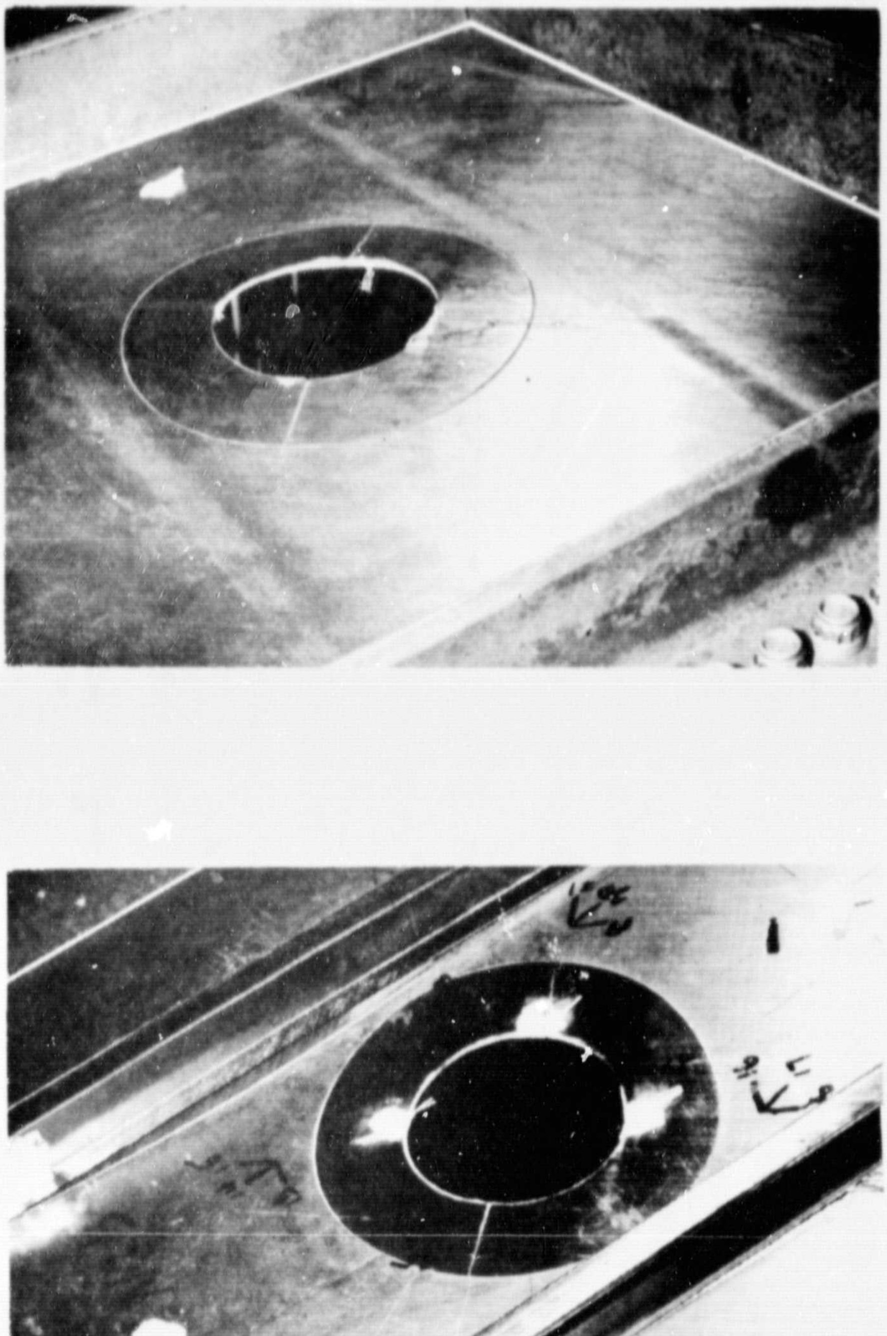


Figure 3-17. Ancillary Test No. 21 (Panel No. 5)

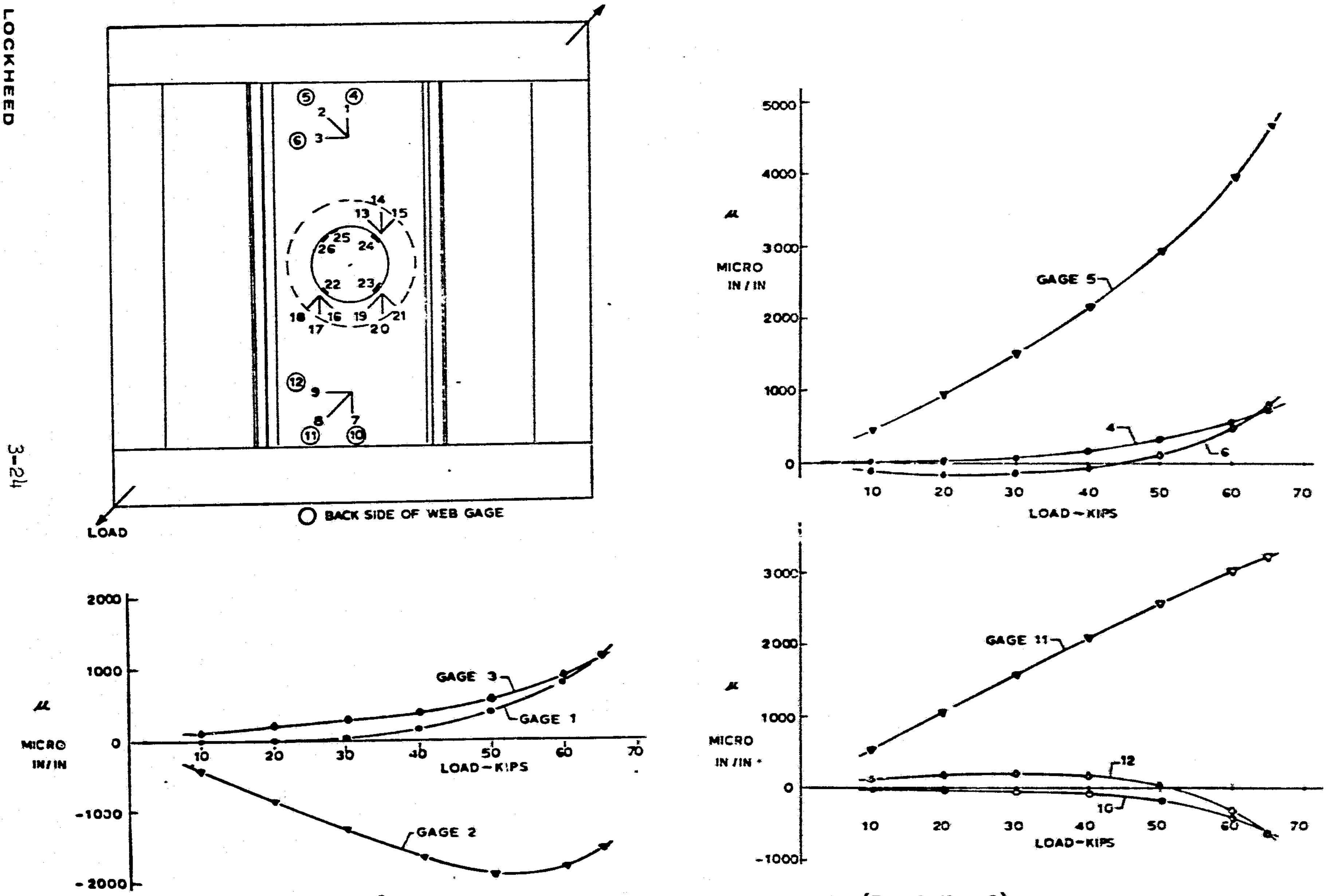


Figure 3-18. Strain Data for Ancillary Test No. 21 (Panel No. 2)

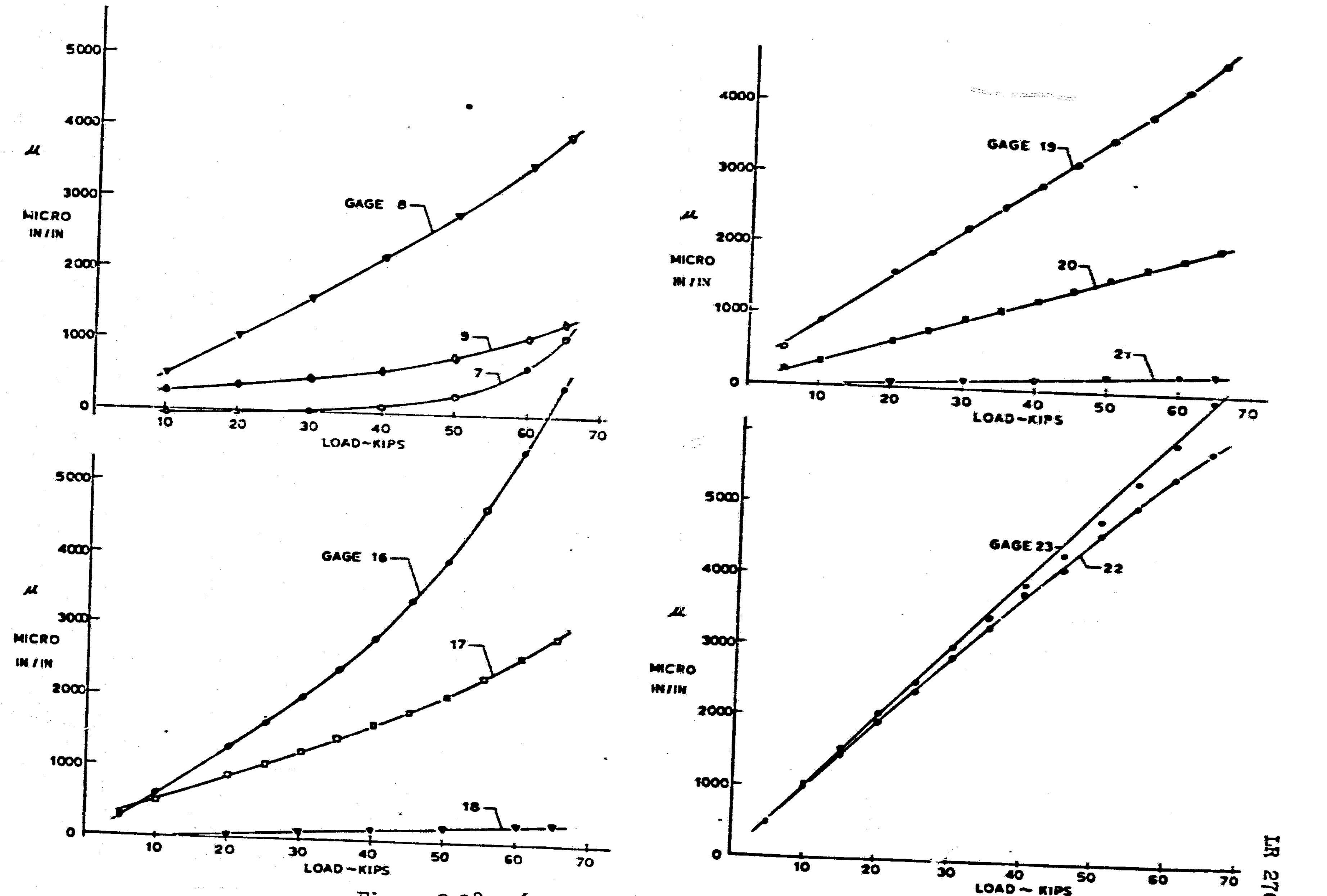


Figure 3-18. (Continued) Strain Data

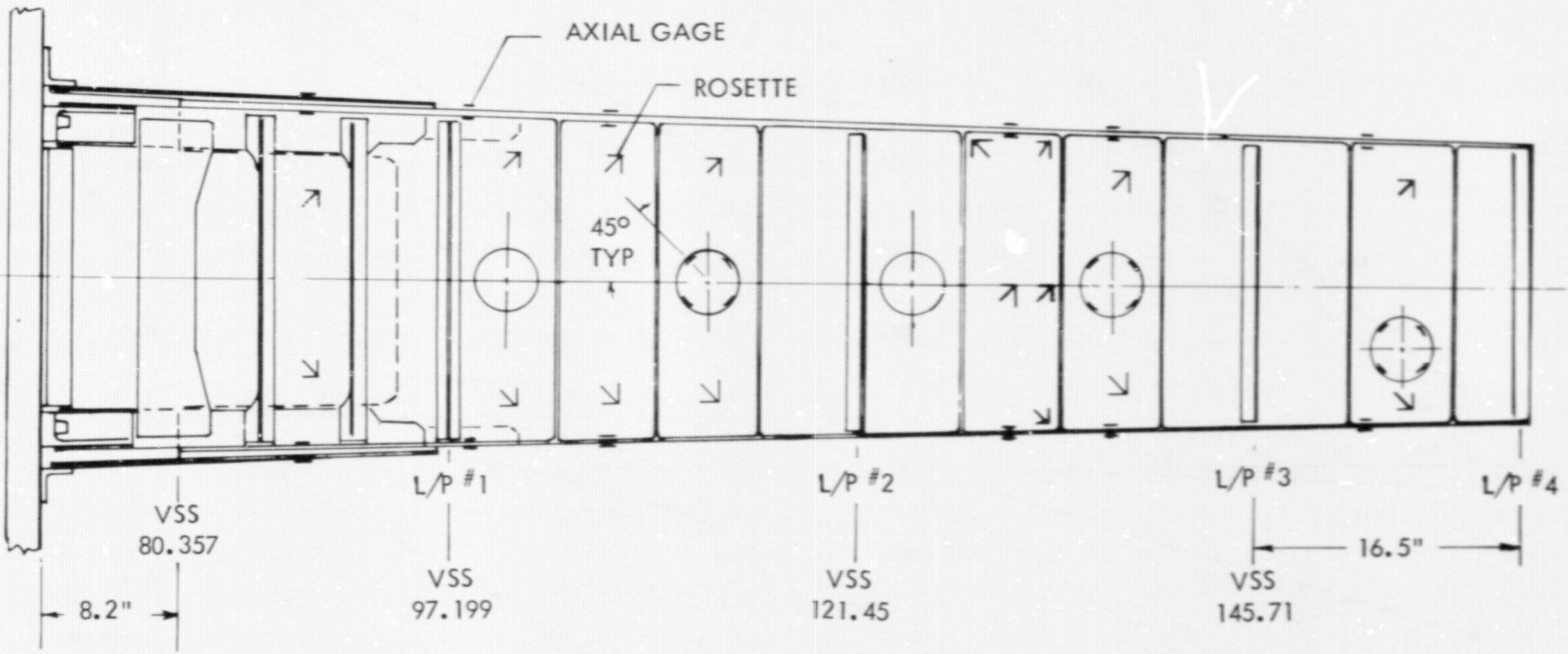


Figure 3-19. Ancillary Test No. 23A - Front Spar to Fuselage Static Test

3.2 TASK 2 - MATERIAL VERIFICATION

The Material Verification task covers the laminate property tests and mechanical joint tests.

3.2.1 Laminate Property Tests

The testing of items 14A, 14B, and 14C has been completed. The 14 series specimens were cut out of the second graphite-epoxy 8-foot tool development spar which had Kevlar in the spar web. The locations of the 14 series specimens are shown in Figure 3-20. The test setup for the 14A spar cap to spar web specimen was identical to the test setup shown for specimen 18B in Figure 3-5. The test setups and failure modes for the rail shear specimens 14B and the spar cap compression specimens are shown in Figures 3-21 and 3-22. The test results and evaluation of the results are shown in Tables 3-7 through 3-9.

A simplified analysis was used to predict the failing stresses based on average flatwise tension stresses and average interlaminar shear stresses. Compression and shear strengths of the cross-plied caps and rail shear specimens were based on information given for Intermediate-Strength Graphite/Epoxy in the AFML Structural Design Guide for Advanced Composites (Ref. 8). An evaluation of the test data for the 14A, 14B, and 14C specimens indicated the strength of these specimens was lower than predicted.

An accelerated program was undertaken to determine what caused the low strength of the 14 Series of specimens. First, the 14 Series of specimens were remade outside the tool under laboratory-controlled conditions to conform to the specified material process and cure specifications. A typical cap cross-section identical to the mid-span of the second stub spar was fabricted with two lay-ups. The first lay-up consisted of graphite and Kevlar, the same as used in the second stub spar; but it was pre-bled and cured as specified in the material specification. The second lay-up was identical to the first except graphite was substituted in place of Kevlar. These specimens were ultrasonically inspected and prepared for cap-to-web tension (14A) and cap compression tests (14C). Results of these tests are tabulated in Table 3-10. Rail shear specimens identical to the 14B specimens were also remade in accordance with the

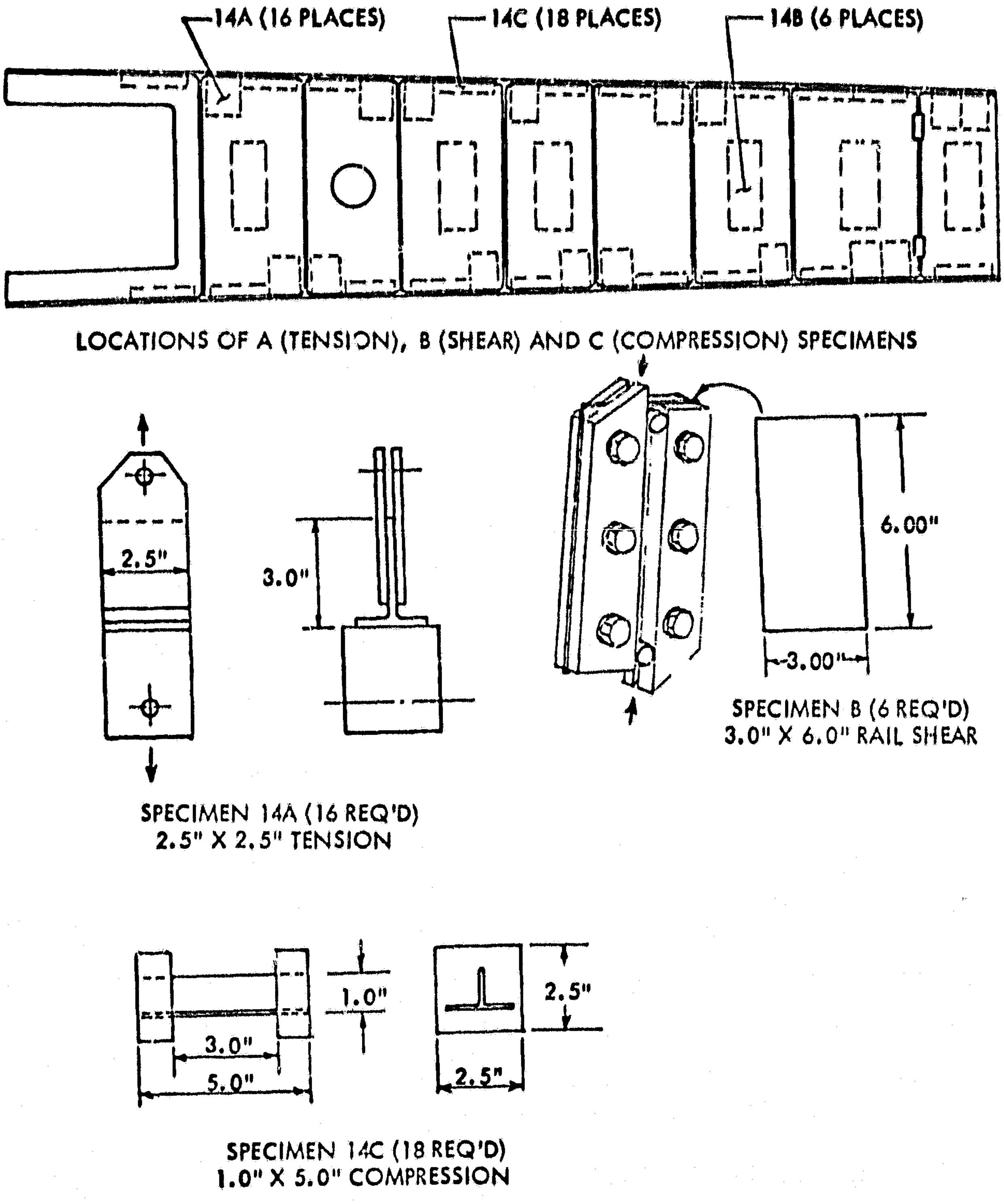


Figure 3-20. Stub Spar Test Specimens Nos. 14A, 14B, and 14C

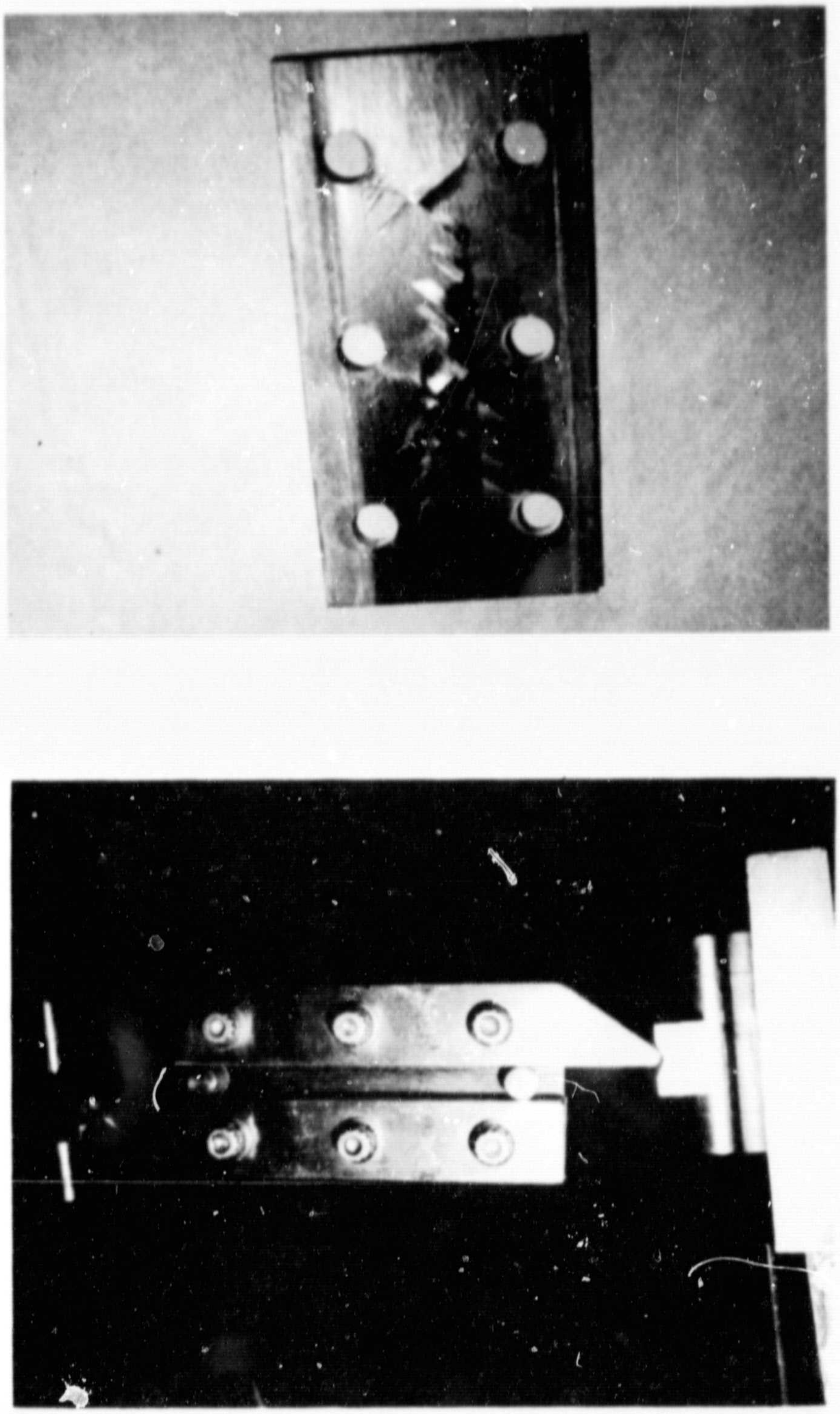
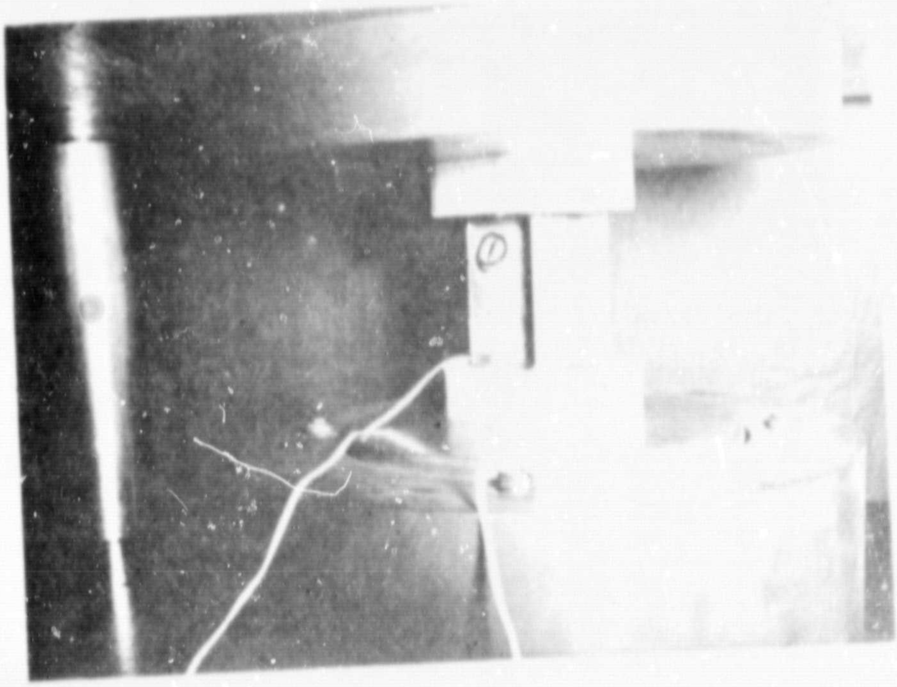


Figure 3-21. Rail Shear Test Setup and Failure Mode, 14B



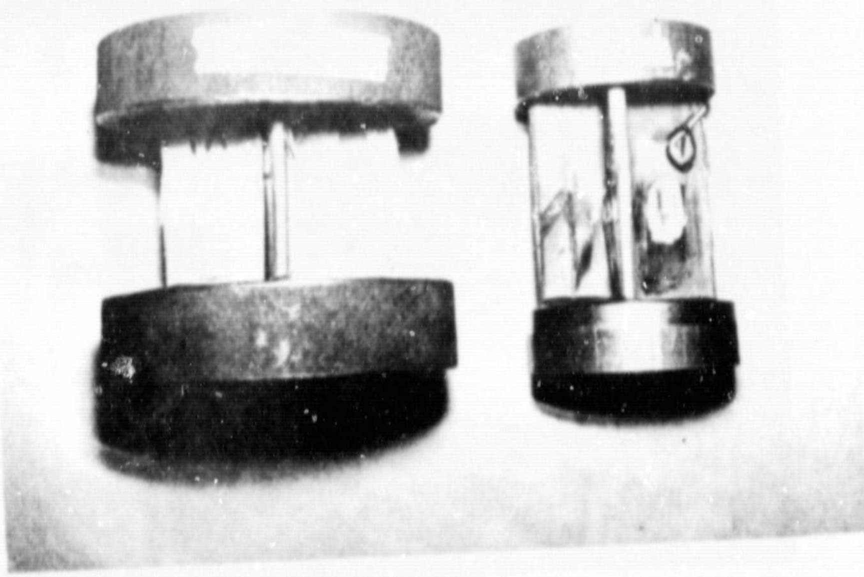
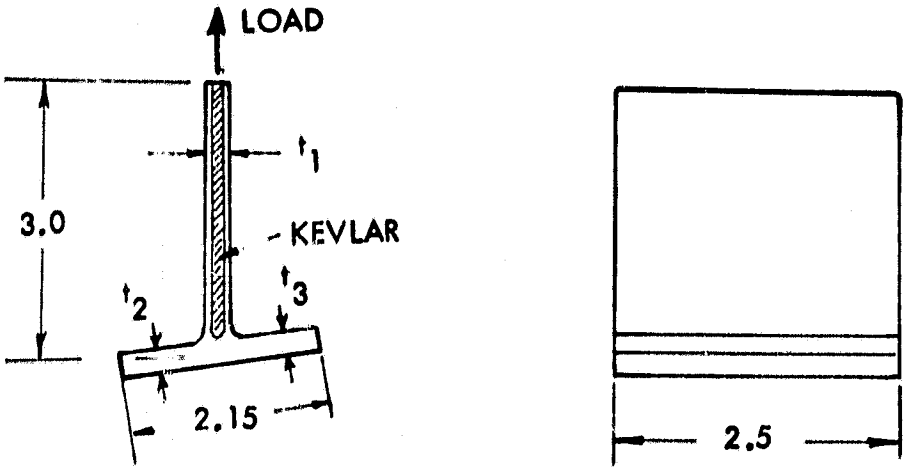


Figure 3-22. Spar Cap Compression Test Setup and Failure Mode, 14C

TABLE 3-7. SPAR CAP TO SPAR WEB TENSILE TESTS, 14A



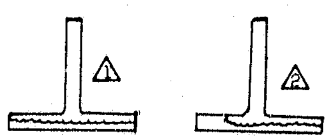
SPECIMEN NUMBER	MAX LOAD (LBS)	t_1 (IN.)	t_2 (IN.)	t_3 (IN.)	FAILURE MODE	FAILURE STRESS	PREDICTED FAILURE STRESS	EVALUATION OF RESULTS
14A-1	2040	0.161	0.182	0.242	△1	5068	4000	Acceptable
-2	1260	0.215	0.262	0.212	△1	2344		Low*
-3	1220	0.177	0.252	0.218	△1	2750		Low*
-4	2075	0.173	0.253	0.255	△2	4798		Acceptable
-5	900	0.168	0.247	0.257	△2	2141		Low*
-6	1440	0.176	0.246	0.238	△2	3273		Low*
-7	1885	0.165	0.221	0.207	△2	4570		Acceptable
-8	2400	0.160	0.205	0.203	△2	6000		Acceptable
-9	2450	0.172	0.230	0.218	△1	5698		Acceptable
-10	2380	0.176	0.228	0.234	△1	5409		Acceptable
-11	2760	0.179	0.242	0.237	△1	6168		Acceptable
-12	1840	0.166	0.243	0.242	△1	4434		Acceptable
-13	1330	0.175	0.246	0.245	△1	3040		Low*
-14	1110	0.184	0.254	0.262	△1	2413		Low*
-15	1010	0.220	0.195	0.253	△1	1836		Low*
-16	2410	0.180	0.181	0.250	△1	5356	4000	Acceptable

ROOM TEMPERATURE, DRY SPECIMENS

NOTES:

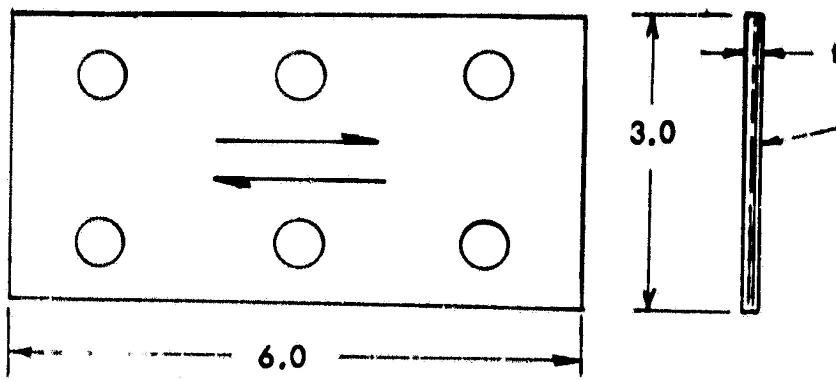
△1 Failure Mode

△2 Failure Mode



*An accelerated program was undertaken to remake 14 Series and retest.

TABLE 3-8. RAIL SHEAR TESTS OF SPAR WEB, 14B



SPECIMEN NUMBER	MAX LOAD (LBS)	AVERAGE SHEAR STRESS (PSI)	t (IN.)	FAILURE STRESS	PREDICTED FAILURE STRESS	EVALUATION OF RESULTS
14B-1	18400	18200	0.168	18200	28000 ⚠	
-2	15100	14500	0.174	14500		
-3	15800	15000	0.176	15000		
-4	14700	14200	0.172	14200		Shear Failure Appears Low
-5	15450	15800	0.163	15800		
-6	13300	14300	0.155	14300	28000	

ROOM TEMPERATURE, DRY SPECIMENS

NOTE:

⚠ G/E carries ≈ 86% of Shear and K/E Core carries ≈ 14% of Shear. F_{su} of G/E is ≈ 50,000 psi and K/E F_{su} is 8000 psi.

$$\text{Stress} = \frac{\text{Max Load}}{6.0\ t}$$

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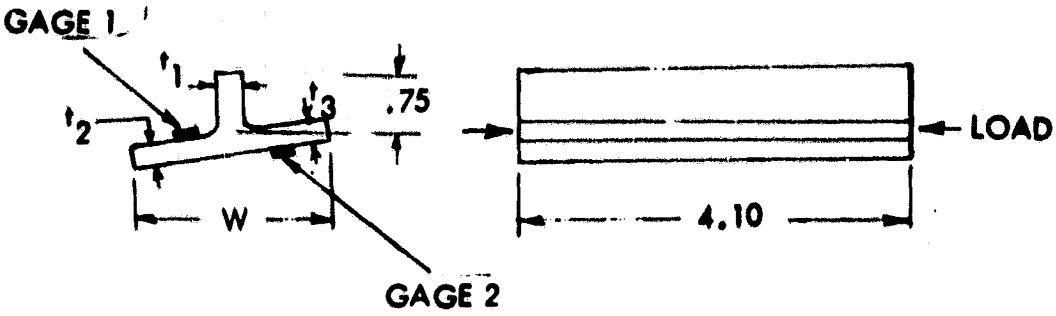
TABLE 3-9. SPAR CAP COMPRESSION TESTS, 14C



SPECIMEN NUMBER	MAX LOAD (LBS)	t_1 (IN.)	t_2 (IN.)	t_3 (IN.)	W	FAILURE MODE	FAILURE STRESS	PREDICTED FAILURE STRESS	EVALUATION OF RESULTS
14C-2	47100	0.164	0.251	0.157	2.95		75.9	88 ksi (Note 2)	
-3	51300	0.216	0.197	0.247	2.78		80.6		
-4	53900	0.176	0.266	0.238	2.70		76.8		
-5	41100	0.174	0.247	0.258	2.18		72.4		
-6	41000	0.167	0.249	0.253	2.15	Compression Failure by Delamination in all Three Legs	73.7		Compression failures of all caps were below predicted. A committee was formed to evaluate possible causes of low strength in 14 Series. A program to retest additional specimens was initiated.
-7	37000	0.194	0.247	0.232	2.18		68.7		
-8	39100	0.185	0.274	0.245	2.15		68.0		
-9	38700	0.176	0.234	0.237	2.15		74.1		
-10	41400	0.166	0.221	0.207	2.18		86.1		
-11	38300	0.176	0.253	0.172	2.18		80.2		
-12	41500	0.177	0.238	0.240	2.15		78.3		
-13	41400	0.165	0.241	0.238	2.18		76.9		
-14	39700	0.171	0.252	0.244	2.15		72.2		
-15	48000	0.178	0.228	0.264	2.70		70.1		
-16	44300	0.218	0.195	0.256	2.83		67.3		
-17	43600	0.175	0.239	0.238	2.98		59.5	88 ksi (Note 2)	

ROOM TEMPERATURE, DRY SPECIMENS

AXIAL GAGES 1 and 2 were used to balance specimen in spherical head compression fixture.

NOTE:

(2) Cap carries ≈ 97% of Axial Load. Ply lay-up in cap is 55% ±45° and 45% 0° giving Predicted Failure based on Design Guide for Intermediate Strength Graphite of 88 ksi.

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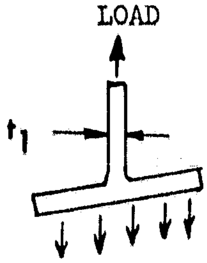
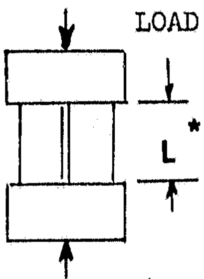
TABLE 3-10. EVALUATION OF REMADE 14A AND 14C SPECIMENS

SPECIMEN NUMBER	TYPE TEST	MAX LOAD	FAILURE STRESS	PREDICTED STRESS	EVALUATION OF RESULTS
14A-1 R	CAP TO WEB TENSION	2660	6296	4000 psi	Acceptable
-2 R		860	2036	↑	Low
-3 R	LOAD	2300	5444		Acceptable
-4 R		2480	5904		Acceptable
-5 R		2960	7006		Acceptable
-6 R		880	2070		Low
-7 *		890	1825		Low
-8 *		3100	6392		Acceptable
-9 *	L = 2.5"	960	1979		Low
-10 *		3280	6728		Acceptable
-11 *	$\text{Stress} = \frac{\text{Max Load}}{\text{L x } t_1}$	800	1649	↓	Low
-12 *		No Test	---	4000 psi	Void at "T" Intersection
14C-1 R	LOAD 	46000	89.0 △1	88 ksi	Marginal
-2 R		45200	87.4	↑	Marginal
-3 R		46200	89.4		Marginal
-4 R		50000	96.7		Acceptable
-5 R		48600	94.0		Acceptable
-6 R		46200	89.4 △1		Marginal
-7 *	$\text{Stress} = \frac{\text{Load x \% in Cap}}{\text{Area of Cap}}$	52500	82.5 △2		Low
-8 *		47700	74.9		Low
-9 *		48200	75.7		Low
-10 *	*L = 2.6 for -1, -2, -3, -7, -8, -9	51100	80.3		Low
-11 *		47400	74.5	↓	Low
-12 *	L = 1.1 for -4, -5, -6, -10, -11, -12	51700	81.2 △2	88 ksi	Low

*All G/E

△1 97% of Load carried in Cap

△2 78% of Load carried in Cap

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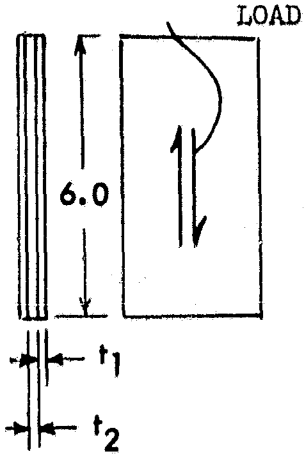
material specification. One configuration was identical to the specimens made in the tool. A second series of 14B specimens was made with graphite substituted for the Kevlar, and a third set of 14B specimens was made identical to the first without bleeding. Table 3-11 summarizes the results of the 14B rail shear specimens. As noted in the table, lower than predicted values were obtained for all specimens. The low values were similar to those previously obtained from the specimens made in the prototype tool. These consistent low values indicated that the rail shear test setup was not giving good results and the data should be used for comparisons only.

In addition to the cap and web specimens, a series of process control specimens were made to evaluate all probable variables in the cure cycle. The minimum flex strength required by the material specification is 210 ksi, and the minimum short beam shear strength is 13 ksi. The results of these tests, shown in Table 3-12, indicate that the material system is tolerant of process variations and will develop acceptable strengths as long as it is cured under a reasonable positive pressure. Specimen No. 1 appeared to have been subjected to a high pressure causing fiber wash and was discounted. Specimen No. 3 processed with the No. 20 Front Spar Specimen appeared to have some fiber wash. A quality control specimen No. 4 processed according to the material specification at the same time as the specimen processed with the No. 20 spar also gave similar results indicating the quality control tests may have been suspect.

An evaluation of the test data obtained from the remade 14 Series of specimens did show some improvement, but the cap-to-web tension specimens had more scatter than the 14A specimens made in the tool. One reason for this scatter was the bond between the cap and web. Although the laboratory controlled part has a uniform pressure surrounding the "T", the force at the intersection of the cap and web is suspect because fibers tended to pull away as compared to fibers being forced into the cap in specimens made in the tool. The spar web cured inside the tool generates a magnified pressure at the intersection of the spar cap, because the web is sandwiched between steel and rubber and the spar caps.

TABLE 3-11. EVALUATION OF REMADE 14B RAIL SHEAR SPECIMENS

SPECIMEN NUMBER	TYPE TEST	MAX LOAD	FAILURE STRESS	PREDICTED STRESS	EVALUATION OF RESULTS
14B-1 R (1)		14500	18400	28200 (4)	Low values indicate possible premature failures due to insufficient clamp-up or interlaminar shear failures.
-2		15000	18200		
-3		13000	16300		
-4		21000	26900		
-5		19250	23600		
-6 R (1)		14100	17900	28200 (4)	
14B-1 (2)		16750	18600	26200 (4)	
-2		21850	24400		
-3		20700	23300		
-4		21100	23400		
-5		19400	22000		
-6 (2)		21800	24700	26200 (4)	
14B-1 R (3)		19200	19900	28200 (4)	
-2	Stress = $\frac{LOAD}{6.0t}$	26250	27500		
-3		26250	27200		
-4	$t = 2t_1 + t_2$	23050	24000		
-5		19100	19900		
-6 R (3)		21400	22000	28200 (4)	

(1) Pre-bled Graphite-Kevlar-Epoxy

(2) Pre-bled All Graphite Epoxy

(3) No Pre-bled Graphite-Kevlar-Epoxy

(4) Predicted Stress = $\dfrac{2F_{su_1} t_1 + F_{su_2} t_2}{t_1 + t_2}$

F_{su_1} = 50 ksi for all ±45° F/E (REF. DESIGN GUIDE)

F_{su_2} = 8 ksi for 0°, 90° K/E (FOR TYP. 0°, 90° CLOTH)

TABLE 3-12. SUMMARY OF PROCESS CONTROL SPECIMENS TO EVALUATE EFFECT OF PROCESS VARIABLES

PROCESS CONTROL SPECIMEN \ VARIABLE	HEAT UP RATE °F/MIN	CURE TEMP °F	CURE PRESSURE PSI	FLEX. STRENGTH KSI	SHORT BEAM SHEAR KSI
1. With No. 14 Spar	0.5	200/260	△1 /0	163*	9.9*
2. Per Material Spec.	4 - 6	260	85	251	14.7
3. With No. 20 F. Spar	0.35	200/260	△1 /0	208*	11.5*
4. Per Material Spec.	4 - 6	260	85	210	11.4*
5. Per Material Spec.	4 - 6	260	85	223	16.0
6. Step Cure	4 - 6	200/260	85/0	206*	14.4
7. Step Cure - No Bleed	4 - 6	200/260	85/0	234	15.5
8. Low Pressure	4 - 6	260	38	235	15.0
9. Low Pressure	0.5	200/260	35+VAC	215	13.9
10. No Bleed - Stops	3.5	260	△2	211	13.2
11. No. Bleed - Stops	4 - 6	260	△2	218	15.6
12. Spec - No Bleed	3.5	260	92	240	14.1
13. Spec - No Dwell	3.5	260	92	256	15.4
14. Slow Heat-up	0.5	260	150+VAC	248	15.2
15. Low Cure Temperature	0.5	200	150+VAC	244	14.1

△1 150 psi Autoclave Pressure; pressure on P.C. Specimen unknown--appeared to have high pressure causing fiber wash.

△2 Forced Laminate to Specification Thickness; pressure on part unknown.

* Less than minimum strength required by Material Specification C-22-1379/211.

A revision was made to the ply stacking in the spar cap to better balance the $\pm45^\circ$ and 0° plies. Six $\pm45^\circ$ plies were interspersed in the 0° plies at the center of the cap. A third set of 14A specimens was made with this revised ply lay-up and will be tested. This lay-up has been incorporated in the design of the front and rear spars.

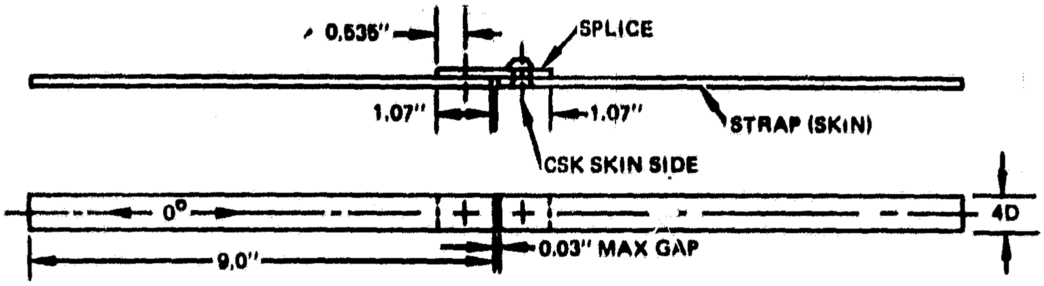
In addition to the test specimens, temperature recordings taken during cure indicated the pressure generated by heat-up of the rubber may have lagged the resin cure in the second spar. Heat-up rates, rubber sizing, and cure temperatures were evaluated and adjustments are being made to the rubber sizes and temperature schedules.

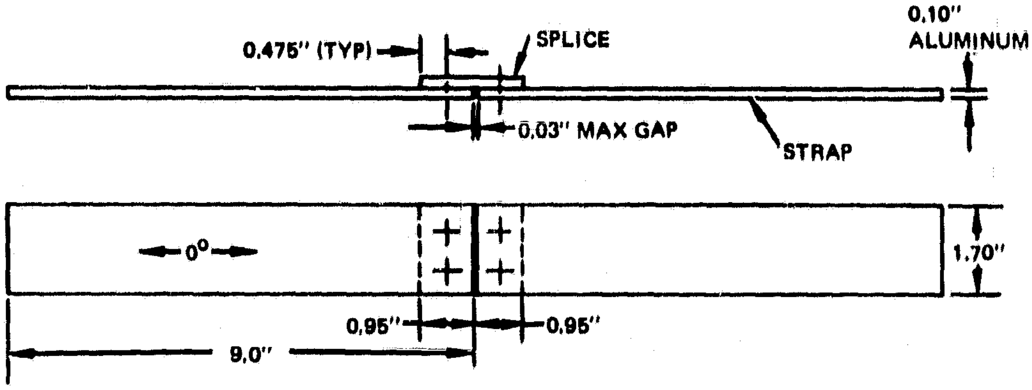
3.2.2 Mechanical Joint Tests

Test items 16B shown in Figures 3-23 and 3-24 have been completed. These specimens were mechanically-fastened joint specimens using HL13 pins in configurations 1 through 4 (Figure 3-23) and HL410-6 pins in configuration number 5. HL97V collars were used on all specimens. The fasteners were installed per specifications. The holes drilled in the specimens were clearance fit for standard fit fasteners. For example, the diameter of a -6 pin is 0.1890-0.1895 and the hole is 0.1895 to 0.1925.

Analysis of the test data for configurations 1 through 4 is presented in Table 3-13 and Figure 3-25. Figure 3-25 is a nondimensional joint strength plot for 5/32 and 3/16-inch diameter HL13 pins. These data are applicable only to specimen configurations 1 through 4 and may be used only to determine the ultimate strength per fastener within the graphite/epoxy laminate thickness range tested.

Specimen configuration number 5 (Figure 3-23) was similar to the butt joint splice used for the 16A specimens except eight plies of Kevlar were in the splice plate versus the all-graphite splice previously tested. The bearings allowable in the hybrid specimen was comparable to the data for the 16A all-graphite specimens reported previously. Table 3-14 presents the test data for configuration number 5.





CONFIGURATION	SPLICE LAYUP	STRAP LAYUP
1	$[\pm45/\mp45/\pm45/0_2/\mp45/0]_S$	$[(\pm45/0/\mp45/0)_2]_S$
2	$[\pm45/\mp45/\pm45/0_4/\mp45/0_3]_S$	$[(\pm45/0/\mp45/0)_2]_S$
3	$[\pm45/\mp45/\pm45/0_2]_S$	$[(\pm45/0/\mp45/0)_2]_S$
4	$[\pm45/\mp45/0_2]_S$	$[(\pm45/0/\mp45/0)_2]_S$
5	$[(\pm45/\mp45/\pm45)_G/(0_4)_{KEVLAR}]_S$	ALUMINUM

Figure 3-23. Mechanical Joint Specimens (Item 16B)

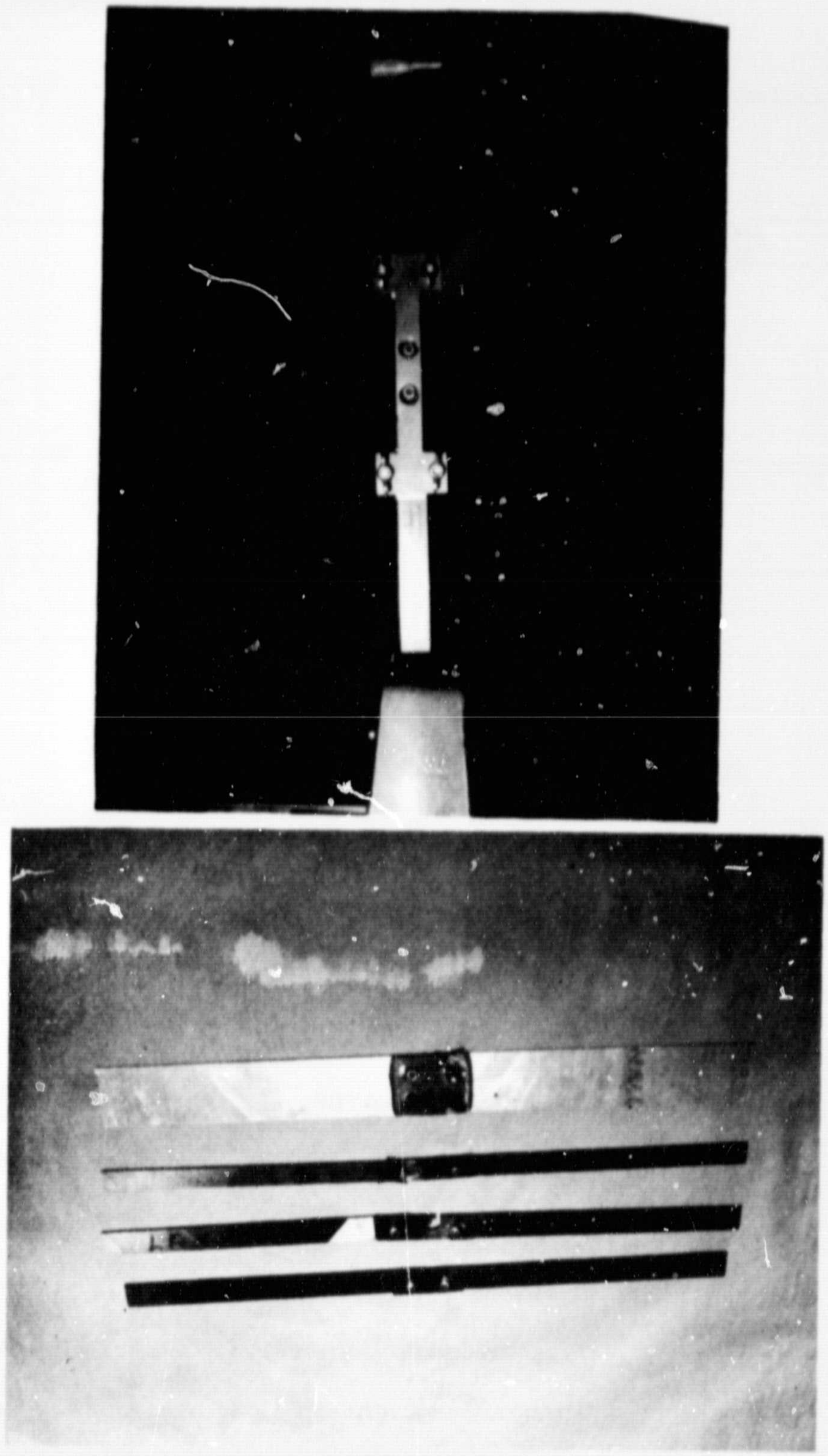


Figure 3-24. Test Setup and Typical Failure Modes for Mechanical Joint Specimens (Item 16B)

TABLE 3-13. TEST DATA FOR MECHANICAL JOINT SPECIMENS (ITEM 16B)

Configuration	t Splice (in)	t Strap (in)	Pin Diameter D (in)	Pu (Lbs)	Pu/D^2 (Psi)	Type of Failure
1	.1115	.126	.189	1735	48571	⚠1
	.1165	.126		1780	49830	
	.1180	.123		1775	49690	
	.1125	.1255		1785	49970	
	.1190	.124	.189	1800	50390	
Avg				1775		
2	.158	.125	.189	1800	50390	⚠1
	.160	.125		1910	53470	
	.159	.125		1815	50810	
	.160	.121		1820	50950	
	.160	.125	.189	1840	51510	
Avg				1837		
3	.0845	.127	.164	1270	47219	⚠2
	.0805	.125		1202	44690	
	.083	.125		1245	46289	
	.0835	.127		1197	44505	
	.084	.123	.164	1180	43873	
Avg				1219		
4	.0625	.130	.164	990	36808	⚠2
	.0650	.128		1057	39300	
	.0660	.128		1015	37738	
	.0630	.1295		1032	38370	
	.0650	.128	.164	1030	38296	
Avg				1025		

⚠1 Countersunk head pulled through loading strap causing ply separation and tearout

⚠2 Ply separation across hole in splice plate

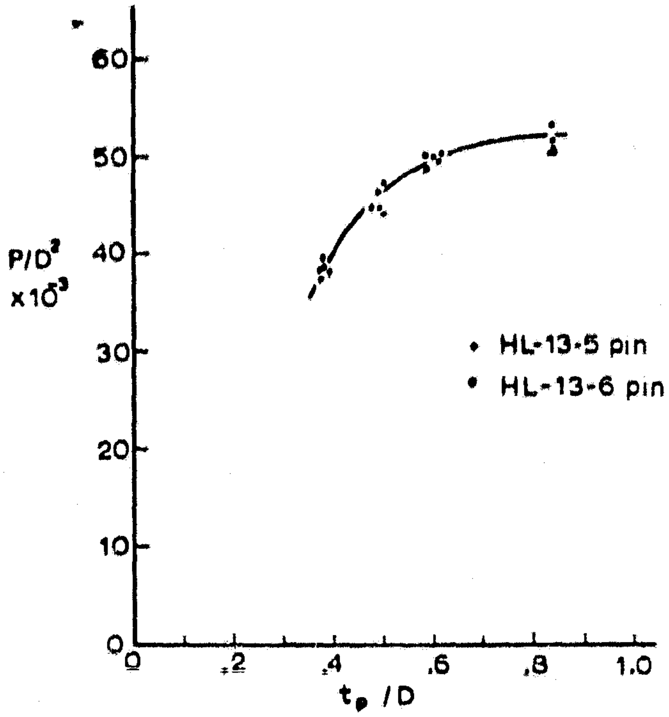


Figure 3-25. Non-Dimensional Joint Strength Curve for Mechanical Joint Specimens (Item 16B)

TABLE 3-14. TEST DATA FOR MECHANICAL JOINT SPECIMENS (ITEM 16B, CONFIGURATION NO. 5)

Configuration	e/D	P_{bru} (Lb)	t_{Splice} (in)	D (in)	F_{bru} (Ksi)	Failure Mode
5	2.5	3680	.114	.1905	84.8	Hole Tearout and Ply Separation in Splice Plate
		3800	.113	.1900	88.5	
		3780	.114	.1910	86.8	
		3960	.112	.1910	92.6	
	2.5	3880	.112	.1900	91.2	
Avg					88.7	
Allow					79.2	

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3.3 TASK 3 - FABRICATION

The fabrication procedures used for the ancillary test items and structural components are described in the following paragraphs.

3.3.1 Test Specimen Fabrication

The second stub spar was completed, cut into specimens, and sent to the test laboratory. The second spar as removed from the tool is shown in Figure 3-26. Prior to cutting the spar into test specimens 14A, 14B, and 14C, a thorough NDI and dimensional inspection were conducted. The ultrasonic inspection did not show any significant flaws, but the dimensional check did show some variation in web thickness which are being evaluated. The first spar was all graphite-epoxy and the second spar had Kevlar in the spar web. Figure 3-27 illustrates the difference in layup of the first and second spars.

Fabrication of spar number 3 and 4 were completed. Spar number 3 was used for making the added wet and dry 14A, 14B and 14C ancillary test specimens. Spar number 4 will be used for the dry ancillary test number 20 front spar.

Spar number 4 was completely different from the first three spars made in the prototype tool. The depth, width, thicknesses, stiffener locations, access holes and laminate layup were all changed. The change in configuration of the fourth spar required a complete rework of the inside of the tool before fabrication. This rework was accomplished on schedule and a satisfactory spar was made on the first try.

The fourth spar fabricated in the prototype tool was cured and prepared for testing. This was Front Spar Specimen No. 20. It is a constant cross-section beam with two access holes and four load points. Figure 3-28 shows the lay-up of the reinforced access hole and the cured spar. Closely spaced holes were drilled in the spar cap representing the holes for attaching the covers and leading edges.

The second No. 20 Front Beam Specimen is expected to be cured in April. It was originally planned for a second, dry development test; but, later, it was rescheduled for a humidity-conditioned specimen.

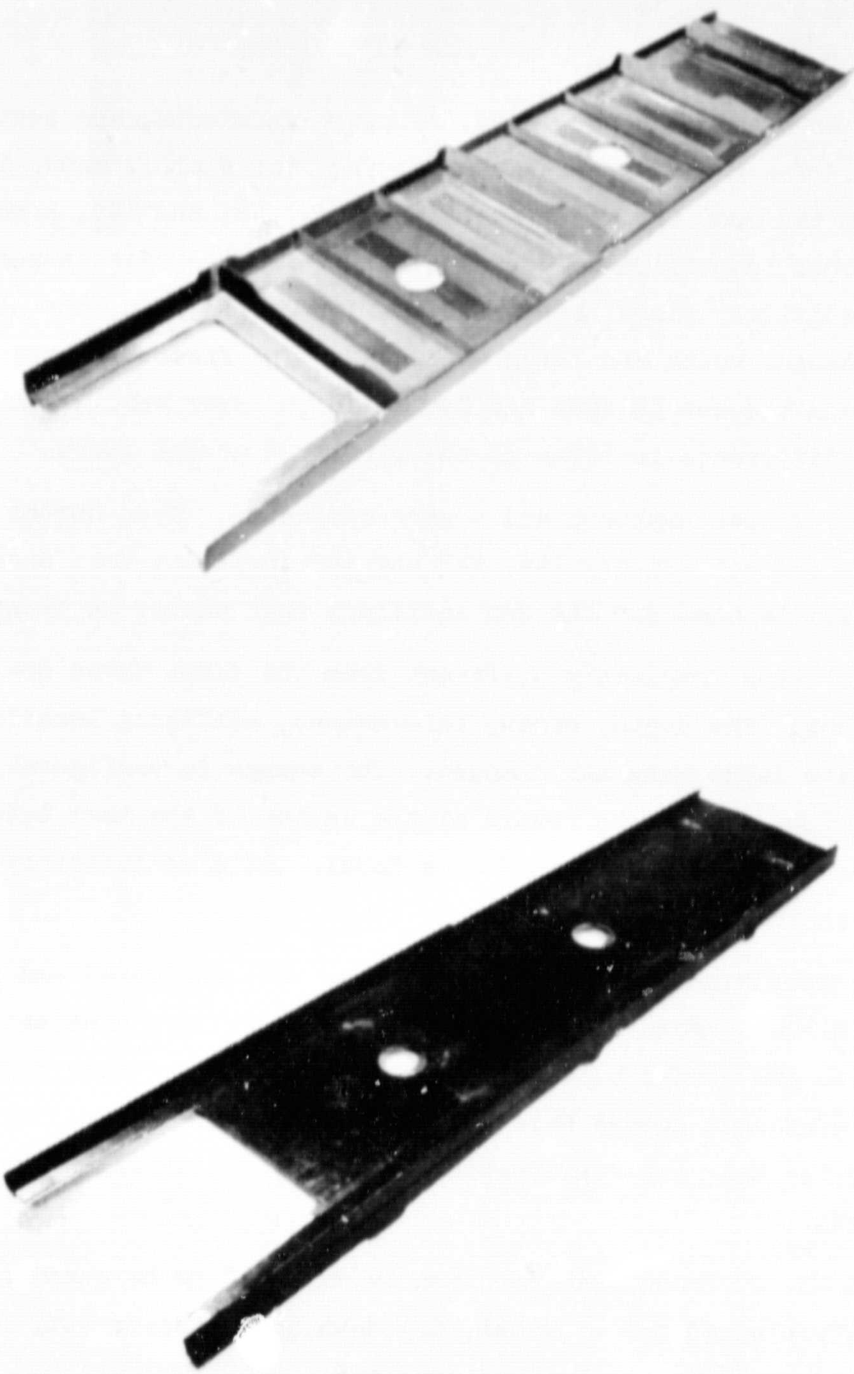


Figure 3-26. Second 7' Stub Spar as Removed from Tool
(Flashing Not Removed)

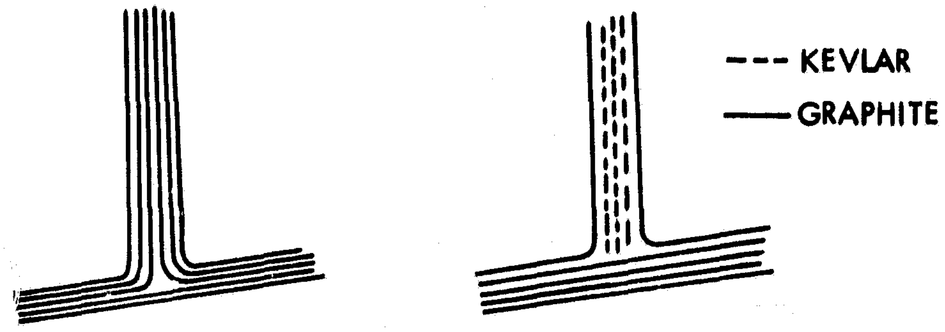
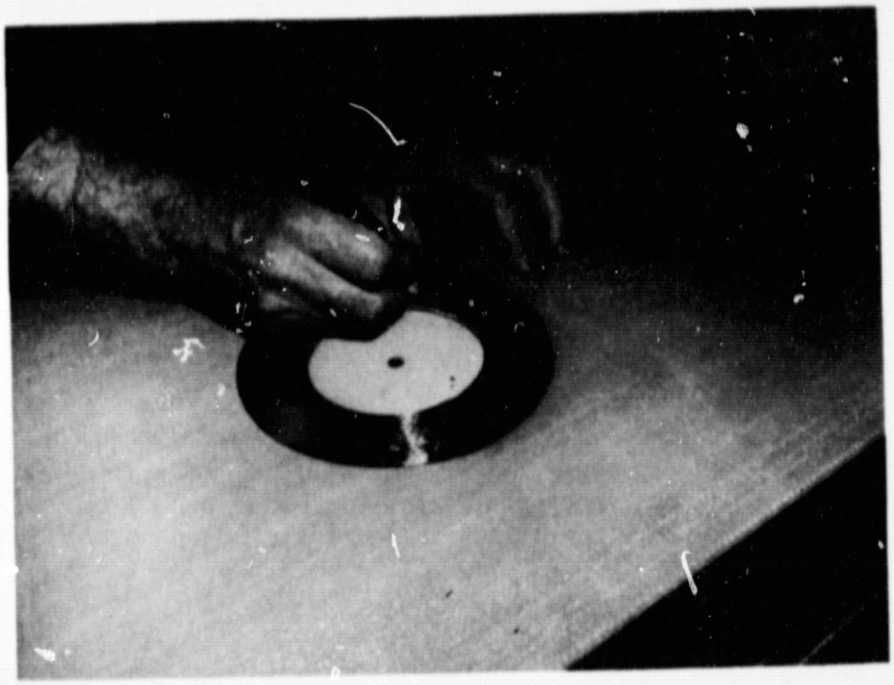


Figure 3-27. Comparison of 1st and 2nd Tool Development Spars

The cure cycle being used on the stub spars is as follows:

- heat rise rate - less than 1°F/minute
- pressure - full vacuum plus 150 psi during entire cure cycle
- cure - 3 hours at 200°F, cool to 150°F or lower, remove spar from tool
- postcure - unrestrained (no tool) but supported for 90 minutes at 260°F.

A program to evaluate the lower than expected failure loads on the 14A, B, C Ancillary Test specimens cut out the second stub spar was completed. The prime suspect causing these low strengths was the rubber temperature and resulting pressure during cure. The pressure generated by the rubber may have lagged the necessary cure pressure when the resin began to gel. Steps are being taken to adjust the rubber sizes and temperature-time schedules during cure. These adjustments are normal stages in the development of the elastomeric molding tool.



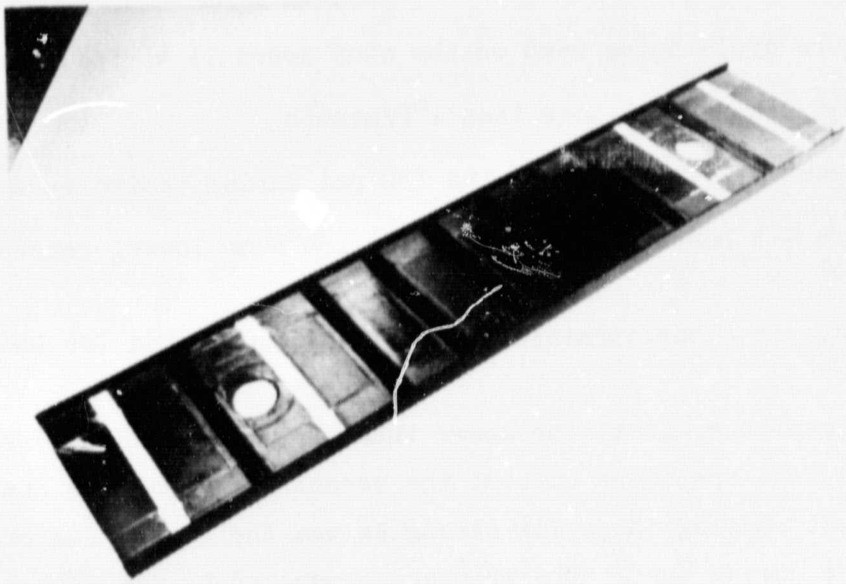


Figure 3-28. No. 20 Front Spar Specimen - Lay-up of Access Hole and Cured Beam

3.4 TASK 7 - SUBCOMPONENT TOOLING

The work in this task covers the design and fabrication of tooling to be used in the fabrication of subcomponent test specimens.

3.4.1 Subcomponent Tool Design and Fabrication

Planning began for the last two stub spars to be fabricated in the prototype tool. These are Test Specimens Nos. 23A Static and 23B Fatigue. Both specimens will be identical, and they will conform to the requirements established for the design of the front spar. Conformity inspection is required for No. 23A. The tool used to fabricate the 21" x 84" prototype spars is shown in Figure 3-29.

Machining of the steel billets for the full size rear spar has begun. The lower part of this tool will be used to fabricate the two ancillary test specimens (No. 20), rear spar specimens, and the 100-inch component spar.

Figure 3-29. Completed Tool Used to Mold Prototype Spars

SECTION 4

PHASE II - DETAIL DESIGN - RIBS

Phase II Detail Design of the Ribs covers the main engineering effort of LAAD in the design, development, and fabrication of the 11 ribs for the L-1011 Advanced Composite Vertical Fin. The engineering effort during this quarter covers four tasks: Component Definition, Fabrication, Component Tooling Development, and Subcomponent Tooling.

4.1 TASK 1 - COMPONENT DEFINITION

Component Definition covers the detail design and structural analysis of the selected rib configuration and ancillary tests.

4.1.1 Detail Design

Recommended concepts for the ribs call for the use of graphite/epoxy caps with aluminum cruciform diagonals for the lower seven ribs, graphite/epoxy caps with stiffened solid laminate web for the rear portions of the ribs at VSS 90.19, and graphite/epoxy caps with integrally stiffened solid webs for the upper three ribs.

The upper rib design concept differs from that proposed in Phase I. At the Preliminary Design Review (PDR) "a miniwich" design concept for the upper three ribs was proposed as being the preferred configuration. An evaluation of in-service inspection and repair procedures for the "miniwich ribs" indicated a potential problem associated with adequately inspecting or repairing the ribs while in service. For this reason, alternate concepts were evaluated for the upper three ribs. The concept currently under consideration is a stiffened solid laminate design. Preliminary analysis indicates an added weight saving will be realized with this change. Production cost inpact has not been determined as yet.

The detail design of the rib components for the 100-inch box has continued during this reporting period. Drawings for the ribs at VSS 90.19, 97.199, 121.45, and 145.71 respectively have been prepared and released. The actuator fitting drawing was released for the 100-inch specimen and other tests. All 100-inch specimen drawings have now been released.

Redesign efforts have begun on the ribs located at VSS 274.26, 299.97, and 323.62 due to the replacement of miniwich with solid web laminates. Work on the Production Rib Drawing for the rib at VSS 90.19 has continued on schedule. Formal release of bevel angles, spar cap offsets, and stiffener spacing has been made to manufacturing.

The detail design for the ancillary test program is progressing in accordance with the phase II schedule. Two new layup configurations $(90_2/\pm45)_{2s}$ and $(0_2/\pm45)_2$ for Ancillary Test 14C and two new layup configurations $(90)_{16T}$ and $(90_2/\pm45)_s$ for Ancillary Test 16A have been released. The ancillary test coupon drawings 18A, 18B (fastener pull-through), 19A, and 19B (single lap joint) have all been released. Element drawings for test elements 20A (rib bending), 21A (inplane shear), 22A (rib crushing), and 24A (rudder hinge attachment) have been released. Subcomponent drawing for test 24B (actuator fitting attachment) has also been completed and released.

4.1.2 Structural Analysis

Phase II activities were directed primarily at continuation of the ancillary coupon tests, subcomponent test specimens detail design and test methods development, tabulation of data for Lockheed's development of substructured rib models for generation of internal loads for detail design, and refinement of joints analysis for the VSS 90.199 and VSS 97.199 shear web/spar clip/rib cap interface.

Concepts were rough sized and mini-trade studies were conducted of alternate concepts for the ribs at VSS 274.26, 299.97, and 323.62 to replace the miniwich rib design. It was determined to use the solid laminate rib configuration. Detailed sizing was done and the solid laminate change was incorporated into the ancillary test coupons and test elements. The ancillary test plan was also updated by incorporating the impact of these changes on the environmental test requirements.

Work was done on the fail-safe analysis for the VSS 97.199, 121.45, and 145.71 ribs. The fail-safe computer run substructured models of the ribs is to be conducted prior to submittal of the analysis.

Test authorizations for mechanical joint specimens item 16, the single and double lap shear specimens, and item 19, the multiple joint single lap shear specimens, have been initiated.

4.1.3 Ancillary Tests

Tension Test

All IITRI type tension coupons (Test No. 14) have been fabricated and tested for the $(0)_{6T}$, $(0_2/\pm45)_s$ and $(0/\pm45/90)_s$ laminate orientations. From the summary of data presented in Tables 4-1, 4-2, and 4-3, it appears that temperature would have little or no degradation effect on these laminate orientations average ultimate failure stresses. Figures 4-1 and 4-2 are typical plots of stress versus strain from both strain gage and extensometer data for $(0_2/\pm45)_s$ and $(0/\pm45/90)_s$ orientations respectively, and illustrate the good correlation of gage and extensometer data. For all tested tension coupon orientations, both ultimate tensile stresses and strains are within 2.0 percent of the published Phase II design allowables.

Additionally, good correlation is found for Poisson's ration by comparing those values generated from test data and those values generated for cross-plied laminates by the linear analysis computer program AC-50.

Tables 4-4, 4-5, and 4-6 summarize the compression-bending beam data for the $(0)_{6T}$, $(0_2/\pm45)_s$ and $(0/\pm45/90)_s$ orientations, respectively. From these tables the effect of temperature is much more readily apparent. Although all test, and calculated design values, were well above the Phase II design allowables for both ultimate stress and strain capability, it should be noted that a strength reduction of some 18 percent was experienced by the $(0/\pm45/90)_s$ orientation laminates (avg.) at 160°F. This type of laminate strength reduction is greater than expected at this test temperature; and its

TABLE 4-1. $(0)_{6T}$ IITRI TYPE TENSION COUPON TEST DATA T300/5209

Specimen Number	Test Temperature (°F)	Area $(In)^2$	Max Load (Lbs)	Ultimate Stress (KSI)	Ultimate Strain (μIN/IN)
1	RT	.043	8950	208.0	(1)
2	RT	.043	9310	227.5	(1)
3	RT	.040	9800	243.7	10,800
4	160	.039	9340	236.7	10,500
5	160	.042	9400	219.2	10,700
6	160	.042	8650	205.4	10,800
7	-65	.040	8900	221.4	10,600
8	-65	.042	9500	224.2	(1)
9	-65	.042	9550	223.1	(1)

(1) Extensometer slipped and specimens not strain gaged.

TABLE 4-2. $(0_2/\underline{+}45)_s$ IITRI TYPE TENSION COUPON TEST DATA T300/5209

Spec No.	Test Temperature (°F)	Area (In^2)	Max. Load (Lbs)	Ultimate Stress (KSI)	Modulus (MSI)	Ultimate Strain (μ IN/IN)
22	RT	.044	4,690	106.6	10.66	10,000
25	RT	.044	4,760	108.2	10.61	10,200
28	RT	.043	5,065	117.8	10.71	11,000
21	-65	.043	4,945	115.0	10.95	10,500
24	-65	.044	4,810	109.3	(1)	(1)
27	-65	.044	4,665	106.0	10.49	10,100
23	160	.044	4,800	109.1	8.73	12,500
26	160	.044	5,060	115.0	11.5	10,030
29	160	.043	4,930	114.6	10.33	11,100

(1) Gage Failure

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TABLE 4-3. $(0/\pm45/90)_s$ IITRI TYPE TENSION COUPON TEST DATA T300/5209

Spec No.	Test Temperature (°F)	Area (In^2)	Max. Load (lbs)	Ultimate Stress (KSI)	Modulus (MSI)	Ultimate Strain (μ IN/IN)
12	RT	.044	2,990	67.95	6.23	10,900
15	RT	.044	3,100	70.45	6.18	11,400
18	RT	.044	2,960	67.3	6.29	10,700
11	-65	.044	3,085	70.1	6.40	10,950
14	-65	.044	3,000	68.2	7.53	9,050
17	-65	.044	2,970	67.5	6.62	10,200
13	160	.044	2,970	67.5	6.43	10,500
16	160	.044	3,135	71.25	6.95	10,256
19	160	.043	2,900	67.4	7.13	9,450

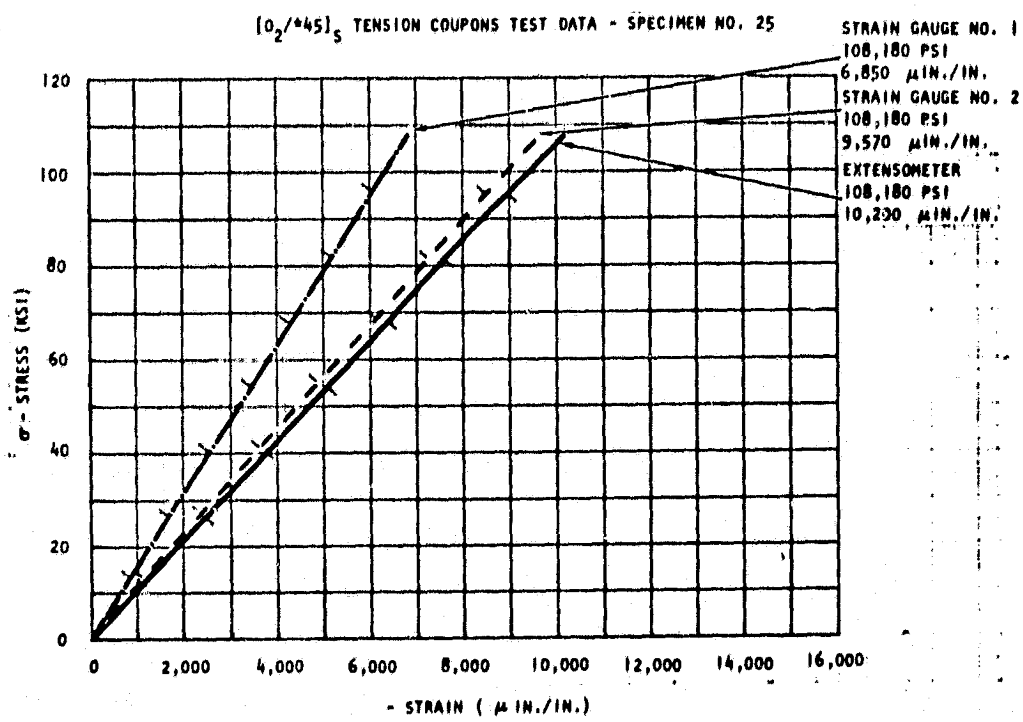

Figure 4-1. Typical Stress Versus Strain Plot of Strain Gage Versus Extensometer Data (T300/5209)

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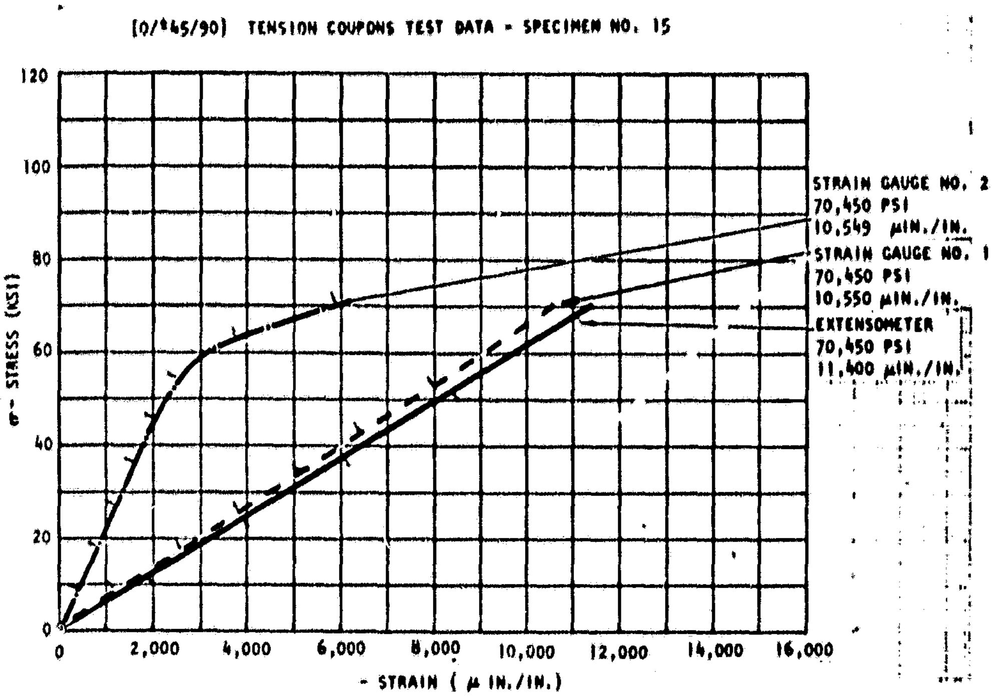

Figure 4-2. Typical Stress-Strain Plot of Strain Gage Versus Extensometer Data (T300/5209)

impact, if any, will be considered in the detail design of compression critical joints as they are encountered.

All IITRI type tension coupons have also been fabricated and tested for the $(90)_{16T}$ and $(90_2/\pm45)_s$ orientations with the exception of those which are being environmentally conditioned.

A summary of the tension test data is shown in Table 4-7. The test strengths were 81 and 91 percent of predicted for the $(90)_{16T}$ and $(90/\pm45)_s$ orientations respectively. Average modulus values were calculated to be within six percent of the predicted modulus values, from curves typical of those shown in Figures 4-3 and 4-4.

It should be noted that predicted strength values are based on calculated AC-50 design allowables increased by a 20 percent test/design allowable factor.

TABLE 4-4. $(0)_{6T}$ LONGITUDINAL COMPRESSIVE SANDWICH BENDING BEAM TEST DATA T300/5209

Spec No.	Thickness (In.)	Width (In.)	Test Temperature (°F)	Load (lbs)	Ultimate Stress (KSI)	Ultimate Strain (μ IN/IN)
2	.03203	1.005	RT	3630	285.22	19,300
5	.03140	.985	RT	3385	276.76	19,234
8	.03100	.985	RT	3600	296.22	21,793
1	.03063	.975	-65	3555	300.95	23,900
4	.03017	1.000	-65	3600	301.62	22,109
7	.03180	1.000	-65	3750	310.00	23,919
3	.03033	.990	160	2615	220.15	14,910
6	.03177	1.000	160	3235	257.52	18,497
9	.03067	.995	160	2885	239.01	16,504

TABLE 4-5. $(0_2/\pm45)_s$ LONGITUDINAL COMPRESSIVE SANDWICH BENDING BEAM TEST DATA T300/5209

Spec No.	Thickness (In.)	Width (In.)	Test Temperature (°F)	Load (lbs)	Ultimate Stress (KSI)	Ultimate Strain (μ IN/IN)
22	.04087	1.000	RT	2,330	143.235	18,460
25	.04240	1.000	RT	2,600	154.14	19,071
28	.04210	1.000	RT	2,400	143.28	17,455
21	.04170	1.000	-65	2,700	162.72	(1)
24	.04170	1.000	-65	2,780	167.54	21,000
27	.04140	.995	160	2,100	128.105	16,869
26	.04210	1.000	160	2,175	129.85	17,064
29	.04200	1.000	160	2,200	131.65	17,593

(1) Gage failed below ultimate

The AC-50 design allowables are developed from unidirectional design allowables. Predicted modulus values from AC-50 are compared directly with test data.

In-Plane Shear Test

All in-plane shear type coupon tests (Item 14C) have been completed, with the exception of those undergoing environmental exposure, for the $(0/\pm45/90)_{2s}$, $(\pm45)_{4s}$, $(90_2/\pm45)_{2s}$, and $(0_2/\pm45)_{2s}$ orientations. These orientations are

TABLE 4-6. $(0/\pm45/90)_s$ LONGITUDINAL COMPRESSIVE SANDWICH BENDING BEAMS TEST DATA T300/5209

Spec No.	Thickness (In.)	Width (In.)	Test Temperature (°F)	Load (lbs)	Ultimate Stress (KSI)	Ultimate Strain (μIN/IN)
12	.04160	1.000	RT	1645	99.69	16,214
15	.04180	1.000	RT	1680	101.01	16,287
18	.04097	.995	RT	1665	102.62	16,398
11	.04110	1.000	-65	1970	120.435	18,600
14	.04160	1.000	-65	1910	115.38	18,400
17	.04100	1.000	-65	2000	122.56	19,486
13	.04120	1.000	160	1300	79.28	13,027
16	.04093	1.000	160	1410	86.55	14,667
19	.04090	1.000	160	1360	83.54	13,789

representative of previous and current configurations planned for use in the various rib substructures.

Due to the limited number of coupons available and the various orientations required to be tested, all tests were conducted at room temperature. A summary of the rail shear test data is presented in Table 4-8. The recorded strength values were generally less than predicted (average 70 percent of predicted discounting the $(\pm45)_{4s}$ strength values). The modulus values for the $(0/\pm45/90)_{2s}$ and $(\pm45)_{4s}$ orientations were 92 percent of predicted. Typical shear stress-strain curves are presented in Figures 4-5 and 4-6. Modulus values for the $(90_2/\pm45)_{2s}$ and $(0_2/\pm45)_{2s}$ orientations were not obtained. The lower than expected test values are thought to be the fault of test fixturing as cracks were observed initiating from the bolt holes, indicating fixturing slippage. Additionally, it is known industry wide that full predicted shear strength is never obtained for the $(\pm45)_{4s}$ orientation due to the inherent stress concentrations present in the rail shear type test.

TABLE 4-7. TENSION TEST DATA SUMMARY (T300/5209)

Test Orientation	Specimen Number	Area (in^2)	Test Temp (°F)	Maximum Load (lb)	Ultimate Stress (ksi)	Modulus (1) (Test) (msi)	Ultimate (1) Strain (μin/in)
$[90]_{16T}$	31	.0853	RT	553	6.48	1.253	5,450
$[90]_{16T}$	32	.0877	RT	580	6.61	1.274	5,900
$[90]_{16T}$	33	.0863	RT	575	6.66	1.324	5,900
$[90]_{16T}$	34	.0851	RT	565	6.64	1.240	5,700
$[90_2/\pm45]_S$	35	.0431	RT	1010	23.4	3.02	14,100
$[90_2/\pm45]_S$	36	.0439	RT	1080	24.6	2.93	10,200
$[90_2/\pm45]_S$	37	.0435	RT	1040	23.9	2.83	10,200
$[90_2/\pm45]_S$	38	.0437	RT	1008	23.1	2.86	9,800

(1) Based on Extensometer Data

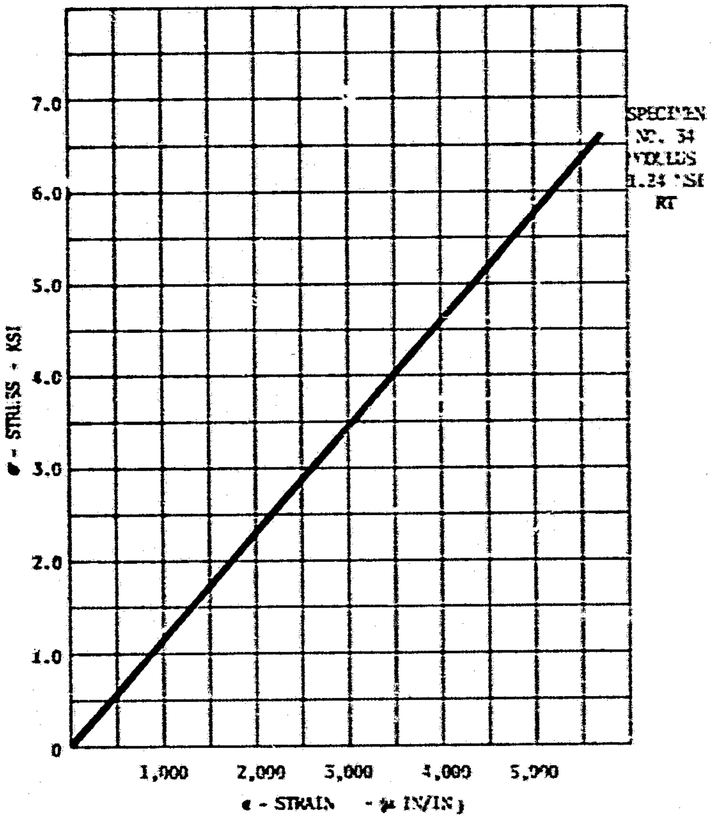

Figure 4-3. Longitudinal Tension Stress-Strain Curve $(90)_{16T}$ (T300/5209)

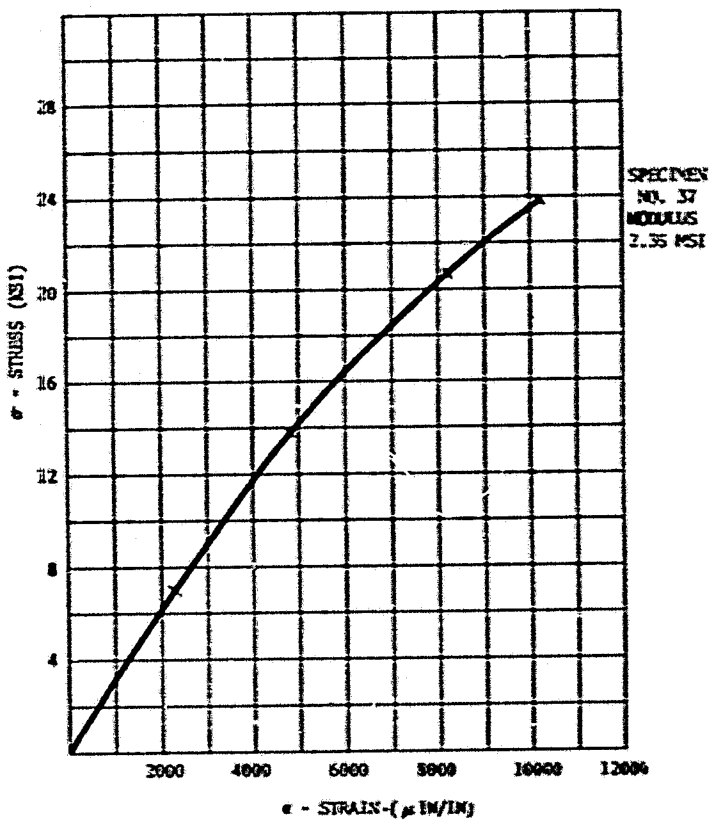

Figure 4-4. Longitudinal Tension Stress-Strain Curve for $(90/\pm45)_s$ (T300/5209)

TABLE 4-8. RAIL SHEAR TEST DATA SUMMARY (T300/5209)

Test Orientation	Specimen Number	Thickness (In)	Test Temp (°F)	Ultimate Stress (KSI)	Modulus (1) (MSI)	Ultimate Strain (2) (μ In/In)
$[0/\pm45/90]_{2S}$	1	.087	RT	37.28	2.65	16,870
$[0/\pm45/90]_{2S}$	2	.087	RT	33.55	2.36	14,997
$[0/\pm45/90]_{2S}$	3	.087	RT	40.09	2.42	19,562
$[\pm45]_{4S}$	5	.087	RT	35.81	5.44	8,308
$[\pm45]_{4S}$	6	.087	RT	33.70	5.12	7,818
$[\pm45]_{4S}$	7	.087	RT	36.51	4.11	9,887
$[90_2/\pm45]_{2S}$	9	.085	RT	34.39	-	-
$[90_2/\pm45]_{2S}$	10	.085	RT	46.81	-	-
$[90_2/\pm45]_{2S}$	11	.086	RT	25.86	-	-
$[0_2/\pm45]_{2S}$	13	.086	RT	37.60	-	-
$[0_2/\pm45]_{2S}$	14	.087	RT	44.27	-	-
$[0_2/\pm45]_{2S}$	15	.088	RT	39.19	-	-

(1) Gased on strain gage data.

(2) Extrapolated value from strain gage data.

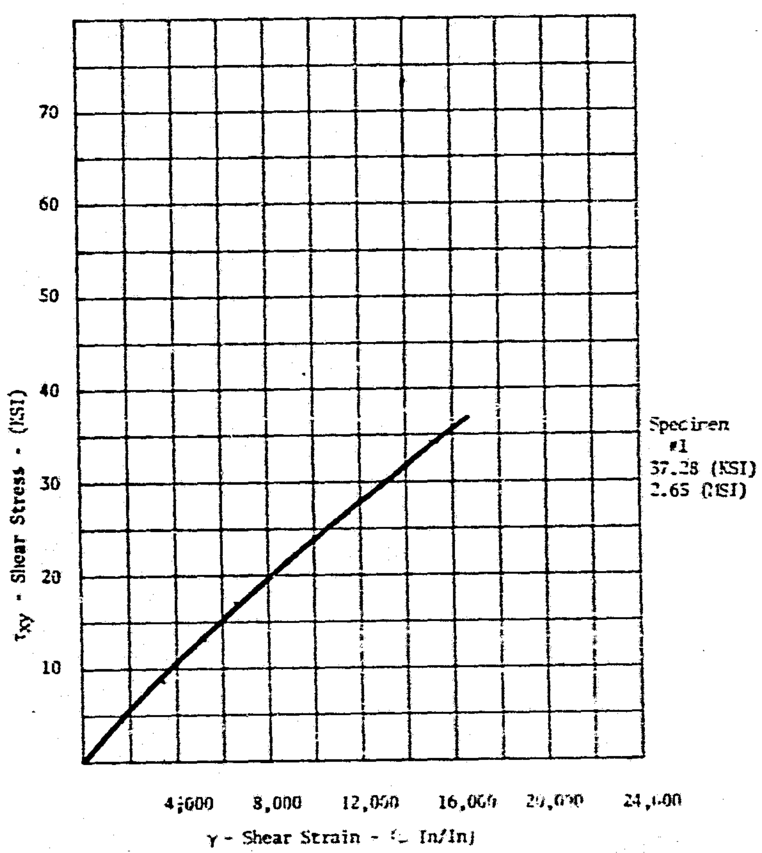

Figure 4-5. Rail Shear Stress-Strain Curve for $(0/\pm45/90)_{2S}$ (T300/5209)

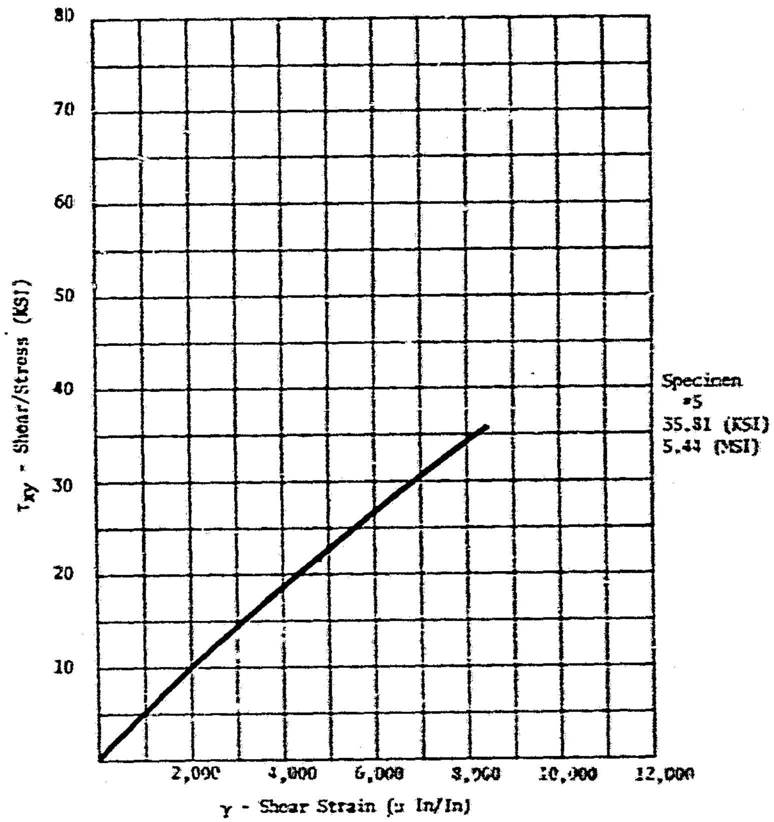

Figure 4-6. Rail Shear Stress-Strain Curve (±45) (T300/5209)

4.2 TASK 3 FABRICATION

This task covers the fabrication of ancillary test items and structural components.

4.2.1 Ancillary Test Specimens

Ancillary test specimen fabrication and testing is continuing. The fabrication of the tension and rail shear specimens (Item 14) was completed and the specimens were submitted for mechanical property static testing. The mechanical joint specimens (Item 16) were fabricated and submitted for static test. The dry tension "pull-thru" specimens (Item 18) have been completed. The fabrication of the "wet" test laminate and joint specimens is continuing. Completed specimens are being environmentally conditioned in accordance with the requirements of MIL Handbook 17A, paragraph 4.2.6 (Ref. 4).

All flatwise tensile tests for miniwich adhesive selection and materials compatibility validation were completed prior to configuration change from miniwich to solid laminate ribs. Flatwise tensile strength and failure mode for two film weights of Narmco Metlbond 1133 and 3M AF-55 adhesive utilizing two core materials are presented in Tables 4-9 and 4-10.

Specimen panels were cocure fabricated from prebled $(0_2/\pm 45)_T$ facings utilizing a hard picture frame dam around the panel and between 0.50-inch silicone-rubber blankets. The assembly was envelope-bagged and autoclave cured in this manner to simulate the planned miniwich rib fabrication method. The autoclave temperature cure schedule was in accordance with existent procedures. However, cure pressure schedule was changed from 85$\pm$ psig to 45$\pm$ psig because the 4.0-pounds per square foot core would crush during an 85 psig cure.

The flatwise tensile test results at room temperature and at 160°F in both weights favored the slightly heavier Metlbond 1133 adhesive. In general, adhesive filleting for the two adhesives were equivalent. Both adhesives demonstrated compatibility with the 5209 epoxy resin and could be utilized for the miniwich rib. The AF55 adhesive was selected as it is qualified to existing L-1011 material procurement and supporting process specifications.

TABLE 4-9. COCURED HONEYCOMB SANDWICH FLATWISE TENSILE STRENGTH (1)

Specimen No. (2)	Test Temp (°F)	Metlbond 1133/0.030 PSF (4) Stress (PSI)	Metlbond 1133/0.030 PSF (4) Mode of Failure (3)	AF55/0.030 PSF (4) Stress (PSI)	AF55/0.030 PSF (4) Mode of Failure (3)
AF30-1	RT	1300	80% COH, 20% IL	1363	50% COH, 50% IL
AF30-2	RT	1300	90% COH, 10% IL	1385	90% COH, 10% IL
AF30-3	RT	1300	80% COH, 20% IL	1388	90% COH, 10% IL
		(1300)		(1379)	
AF30-4	160	817	40% COH, 10% IL, 40% AC	990	95% COH, 5% IL
AF30-5	160	1005	50% COH, 50% IL	998	95% COH, 5% IL
AF30-6	160	885	50% COH, 10% IL, 40% AC	995	95% COH, 5% IL
		(902)		(994)	
HRP30-1	RT	883	90% CT, 10% IL	913	80% CT, 20% AF
HRP30-2	RT	883	90% CT, 10% IL	830	70% CT, 30% AF
HRP30-3	RT	808	80% CT, 10% IL	890	60% CT, 40% AF
		(858)		(878)	
HRP30-4	160	823	100% CT	775	95% CT, 5% AF
HRP30-5	160	845	90% CT, 10% AF	881	95% CT, 5% AF
HRP30-6	160	810	80% CT, 20% AF	978	100% CT
		(826)		(861)	

NOTES:
1. Specimen facesheets are Batch #1473, roll 16 Narmco 5209/T. 300 $(0_2/\pm45)_T$ Gr/Ep.
2. Core material is 3/16-5052-.003 HP x 1.000 inches thick for AL specimens and HRP 3/16-GF11-4.0 x 0.5000 inches thick for HRP specimen numbers.
3. Notation code for mode of failure: AC = Adhesive to Core COH = Cohesive
   IL - Interlaminar in Gr/Ep facing AF = Adhesive to facing CT = Core in Tension
4. Measured adhesive film weights were Metlbond 1133-0.036 PSF and AF55-0.032 PSF

TABLE 4-10. COCURED HONEYCOMB SANDWICH FLATWISE TENSILE STRENGTH (1)

Specimen No. (2)	Test Temp (°F)	Metlbond 1133/0.045 PSF (4) Stress (PSI)	Metlbond 1133/0.045 PSF (4) Mode of Failure (3)	AF 55/0.045 PSF (4) Stress (PSI)	AF 55/0.045 PSF (4) Mode of Failure (3)
AF45-1	RT	1698	40% IL, 60% AF	1338	80% COH, 20% IL
AF45-2	RT	1645	60% IL, 40% AF	1338	80% COH, 20% IL
AF45-3	RT	1703	40% IL, 60% AF	1508	70% COH, 30% IL
		(1682)		(1395)	
AF45-4	160	1243	20% IL, 80% COH	958	95% COH, 5% IL
AF45-5	160	1225	80% IL, 20% COH	980	95% COH, 5% IL
AF45-6	160	1275	40% IL, 60% COH	970	95% COH, 5% IL
		(1248)		(953)	
HRP45-1	RT	973	40% CT, 30% AF, 30% AC	825	90% CT, 10% IL
HRP45-2	RT	998	20% CT, 10% AF, 70% AC	890	95% CT, 5% IL
HRP45-3	RT	888	100% CT	856	95% CT, 5% IL
		(953)		(857)	
HRP45-4	160	825	50% CT, 50% AC	808	100% CT
HRP45-5	160	843	100% CT	815	100% CT
HRP45-6	160	848	80% CT, 20% AC	743	100% CT
		(839)		(789)	

NOTES:
(1) Specimen facesheets are batch No. 1473, roll 16 Narmco 5209/T-300 $[0_2/\pm45]_T$ graphite/epoxy
(2) Core material is 3/16-5052-.003NP x 1.000-inch thick for aluminum specimens and HRP3/16-GF11 4.0 x 0.500-inch thick for HRP specimen numbers
(3) Notation code for mode of specimen failure: AC = Adhesion to Core, AF = Adhesive to Facing, COH = Cohesive, CT = Core in Tension, IL = Interlaminar in Graphite/Epoxy Facing
(4) Measured adhesive film weights were Metlbond 1133-0.049 PSF and AF55-0.039 PSF

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Process control compression test specimen development is continuing. Compression test results of specimens taken from the second trial rib cap section are shown in Table 4-11. These specimens were machined from the web of the rib section.

Correlation of M&P versus Quality Control Laboratory comparative testing has been performed. The test data for several laminate configurations are presented in Tables 4-12 through 4-15. Test data show the Quality Control results were generally somewhat lower than M&P test data. The reason for this discrepancy is under investigation.

Manufacturing Engineering Concept Outline (MECO) for fabrication of truss rib elements has been released. Work orders on truss type beam bending (20A), in-plane shear (21A), static compression (22A), and rudder hinge fitting elements (24A) have been initiated; work is in progress on the common rib cap shape supporting these elements.

A sketch of a truss rib cap section has been submitted to Manufacturing for fabrication with built-in defects. The test section will be evaluated by nondestructive inspection to validate proposed inspection techniques.

4.3 TASK 4 - COMPONENT TOOLING DEVELOPMENT

The work in this task covers the design and fabrication of tooling to be used in the fabrication of the ribs.

4.3.1 Limited Production Tool Design and Fabrication

Design for the 100-inch test article ribs was completed. Layup blocks (LUB) have been ordered from an outside source. As of 25 March, the first set of LUB's, for VSS 97.199, was 50 percent complete. Assembly tooling is in work.

TABLE 4-11. TRIAL RIB CAP NO. 2 WEB SECTION PROCESS CONTROL COMPRESSION TEST DATA (T300/5209)

SPECIMEN NO.	THICK (IN.)	TEST SECTION AREA (IN.^{2})	TEST TEMP. (^{o}F.)	ULTIMATE STRENGTH (PSI)
2-1	0.1212	0.0928	RT	79,741
2-2	0.1183	0.0899	RT	79,533
				(79,637)
2-3	0.1309	0.0995	160	71,819
2-4	0.1282	0.0970	160	77,423
				(74,621)

The layup table is complete with the exception of hard anodizing. LUB tool designs for 100-inch test article ribs are being completed to reflect recently received dimensional information on contours and spar joint step-offs.

Fabrication studies have been conducted on lay-up and integral cure of the spacers required adjacent to spar cap joint. Satisfactory dimensional control was obtained with the off-set step tooling concept employed, as demonstrated by thickness measurements made on Specimen No. 2:

Part Section	No. of Plies	Thickness, mills
Lower Clip Leg	24	121, 120.5, 121, 121.5
Lower Clip Leg plus Spacer	48	242, 246, 243
Upper Clip Leg	24	124, 122, 123, 120
Web	24	123, 118.5, 122, 121
Lower Chord Leg	32	158, 155.5, 158
Upper Chord Leg	32	156.5, 158, 158

Spiral blade band sawing has been identified as the preferred machining method for hat section cutouts in the ribs. Paperwork has been initiated to equip the bandsaw in the Composites Manufacturing area with an appropriate blade and guides. A trial layup and cure has been performed on a T-type cap

TABLE 4-12. LAMINATE COMPRESSION TEST DATA(3)

(T300/5209)

Specimen No.	Thick (No.)	Test Section Area (in^2)	Test Temp. (°F)	Ultimate Strength (PSI)
$[0_2/\pm45]_{3s}$				
PC3-1	0.126	0.0963	RT	85,700 (1)
-2	0.127	0.0952	RT	89,900 (1)
-3	0.126	0.0952	RT	89,400 (1)
				88,300
-4	0.125	0.0942	160	77,500 (1)
-5	0.130	0.0955	160	79,600 (1)
-6	0.129	0.0945	160	75,700 (1)
				77,600
-7	0.130	0.0954	160	75,000 (2)
-8	0.128	0.0947	160	66,900 (2)
				70,900
$[90_2/\pm45]_{3s}$				
PC4-1	0.130	0.0977	RT	34,300 (1)
-2	0.128	0.0962	RT	32,000 (1)
-3	0.131	0.0993	RT	32,900 (1)
				33,100
-4	0.128	0.0969	160	29,700 (1)
-5	0.129	0.0979	160	29,600 (1)
-6	0.128	0.0964	160	32,000 (1)
				30,500
-7	0.129	0.0975	RT	28,500 (2)
-8	0.126	0.0953	RT	33,600 (2)
-9	0.129	0.0971	RT	28,200 (2)
				30,100
-10	0.128	0.0966	160	25,500 (2)
-11	0.128	0.1065	160	23,300 (2)
-12	0.126	0.1052	160	23,900 (2)
				24,200

Notes: 1. Specimens tested in the MSP laboratory.
2. Specimens tested in the Quality Control laboratory.
3. Tests performed per preliminary issue of Rockwell specification LA0605-055.

TABLE 4-13. LAMINATE $(0/\pm45/90)_{2s}$ COMPRESSION TEST DATA(4)

(T300/5209)

Specimen No.	Thick (In.)	Test Section Area (in^2)	Test Temp. (°F)	Ultimate Strength (psi)
PC2-10	0.0862	0.0654	RT	64,500 (1) (3)
-11	0.0864	0.0653	RT	75,200 (1)
-12	0.0860	0.0646	RT	81,900 (1)
-13	0.0852	0.0645	RT	74,400 (1)
-14	0.0862	0.0645	RT	82,200 (1)
				78,400
PC2-15	0.0873	0.0664	160	69,300 (1)
-16	0.0866	0.0657	160	63,100 (1)
-17	0.0855	0.0654	160	68,000 (1)
-18	0.0856	0.0646	160	69,400 (1)
-19	0.0862	0.0646	160	68,700 (1)
				67,700
-20	0.086		RT	65,500 (2)
-21	0.086		RT	50,800 (2) (3)
-22	0.086		RT	61,600 (2)
-23	0.086		RT	63,800 (2)
-24	0.086		RT	60,100 (2)
				62,700
PC2-25	0.085		160	42,800 (2)
-26	0.085		160	53,500 (2)
-27	0.085		160	57,400 (2)
-28	0.085		160	41,900 (2)
-29	0.086		160	43,100 (2)
				47,800

Notes: 1. Specimens tested in the MSP laboratory.
2. Specimens tested in the Quality Control laboratory.
3. Data point omitted from average.
4. Test performed per preliminary issue of Rockwell specification LA0605-055.

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TABLE 4-14. LAMINATE COMPRESSION TEST DATA (1) (T300/5209)

Specimen No.	Thick (In.)	Test Section Area (In^2)	Test Temp. (°F)	Ultimate Strength (KSI)
$[0/\pm45/90]_{3S}$				
1	0.127	0.0956	RT	77.2 (2)
2	0.127	0.0956	RT	84.2 (2)
3	0.127	0.0970	RT	78.3 (2)
				79.3 Avg.
7	0.129	0.0973	RT	66.5 (3)
8	0.130	0.0975	RT	66.0 (3)
9	0.129	0.0973	RT	66.3 (3)
				66.3 Avg.
4	0.129	0.0970	160	74.3 (2)
5	0.130	0.0980	160	71.4 (2)
6	0.130	0.0983	160	Damaged Specimen
				72.9 Avg.
10	0.130	0.0930	160	62.0 (3)
11	0.130	0.0982	160	64.6 (3)
12	0.129	0.0974	160	64.9 (3)
				63.8 Avg.
$[90_2/\pm45]_{2S}$				
1	0.086	0.065	160	32.6 (2)
2	0.085	0.064	160	32.7 (2)
3	0.086	0.065	160	33.1 (2)
4	0.085	0.065	160	33.1 (2)
				32.9 Avg.
5	0.086	0.065	160	29.3 (3)
6	0.086	0.065	160	28.8 (3)
7	0.085	0.064	160	28.9 (3)
8	0.086	0.065	160	28.1 (3)
				28.8 Avg.
$[0_2/\pm45]_{2S}$				
1	0.084	0.063	160	68.0 (2)
2	0.083	0.064	160	70.5 (2)
3	0.086	0.064	160	73.7 (2)
4	0.086	0.065	160	64.2 (2)
				69.1 Avg.
5	0.083	0.062	160	74.6 (3)
6	0.084	0.063	160	72.2 (3)
7	0.083	0.062	160	78.6 (3)
8	0.084	0.063	160	70.7 (3)
				74.0 Avg.

Notes: 1. Tests performed per preliminary issue of Rockwell Specification LA0605-055.

2. Specimens tested in the M&P Laboratory.

3. Specimens tested in the Quality Control Laboratory.

TABLE 4-15. TRIAL RIB CAP WEB $(45/0/-45/90)_{3s}$ PROCESS CONTROL SPECIMEN 160°F COMPRESSION STRENGTH[1] (T300/5209)

SPECIMEN NO.	THICKNESS (IN.)	TEST SECTION AREA (IN.^{2})	ULTIMATE STRENGTH (KSI)
Web Adjacent to Mold Line Flange			
1	0.130	0.0976	77.8 (2)
2	0.128	0.0963	75.3 (2)
3	0.130	0.0983	73.2 (2)
			75.4 Avg
4	0.126	0.0950	69.6 (3)
5	0.130	0.0979	70.6 (3)
6	0.131	0.0988	65.6 (3)
			68.6 Avg
Web Adjacent to Stiffening Flange			
1	0.127	0.0836	73.6 (2)
2	0.130	0.0842	69.5 (2)
3	0.128	0.0840	77.4 (2)
			73.5 Avg
4	0.125	0.0934	67.5 (3)
5	0.124	0.0906	72.6 (3)
6	0.123	0.0921	66.6 (3)
			68.9 Avg

NOTES: [1]Tests performed per preliminary issue of Rockwell Specification LA0605-055

[2]Specimens tested in the Materials and Producibility Laboratory

[3]Specimens tested in the Quality Control Laboratory

element representative of the VSS 97.199 rib cap configuration. This configuration requires extraction of a C-channel layup tool member from a closed angle section.

In order to check cocuring possibility for the damage protection system which will be necessary for blind fastener installations, the layup of the interior side of the rib flange included a representative array (120 Kevlar-49 barrier ply) over a portion of its run.

Tool extraction, due to the removable silicone rubber cap design, posed no problems. Integral cure of the damage protection system was achieved without difficulty. Thickness and fiber content measurements on the specimen meet stipulated requirements. Filament displacement was noted in the first two interior plies of the web sections of the C-channel layups. This is believed to be mainly associated with employment of Armalon on the silicone rubber caps of the C-channel layup members in an effort to improve building trade. Corrective action will consist of removal of Armalon and close attention to compacting practices.

The Do-All saw in D/463 was equipped with appropriate guides and a Tyler Spyral blade, 0.074 diameter was installed. Clip cutout trials showed good conformance of the cut with template dimensions. Optimum feeds, speeds, and tool wear are being determined.

Based on previous observations, the following process and tool changes, shown in Table 4-16, were instituted in fabricating another 36-inch curved simple angle truss cap trial element.

Observations made during layup and physical inspection of the cured trial element indicate that the changes made achieved their purpose. In particular, incorporation of metal core in the C-section layup member and an aluminum caul in the intensifier contributed materially to improvements in flatness and flushness of the web face. Slight crowning was still present in the trial element fabricated which is shown in conjunction with the tooling used in Figure 4-7. This tendency will be completely obviated in the future by:

a) Increasing the width of the metal caul in the intensifier to the vicinity of radius areas.

TABLE 4-16. PROCESS AND TOOL CHANGES

PROCESS OR TOOL CHANGE	INTENDED PURPOSE
16 reinforcing plies exterior chord cap and 8 reinforcing plies interior chord cap.	Design change to web configuration with increased number of "continuous fiber" plies.
 -Section prebled fillers at exterior chord cap/web location.	Filler shape to accommodate new ply configuration. Prebled in lieu of straight precured filler for easier contour conformance and building tack during layup.
Elastomeric membrane with riser arrangement in lieu of conventional vacuum debulking.	Wiping action for better radius definition; avoidance of pinch-off tendencies.
1/4-inch silicone rubber faced aluminum core C-channel layup tool member.	Reduce distortion tendencies on all silicone rubber tool member.
1/16-inch aluminum flush caul embedded in silicone rubber intensifier.	Flushness of web surface with continuous areas at upper chord cap locale.
Wedge clamp provisions for C-channel against caul tool member.	Avoidance of springback after clip 3-section and C-section layup and debulking operations. Positive locking at proper position of tool members.

b) Reducing the thickness of the silicone rubber facing of the C-channel layup member from 1/4 to 1/8-inch.

Figure 4-8 is a schematic of the new arrangement, including intensifier and cover fillers.

RTV 560 is showing promise as a sealer/release system for cast ceramic tooling. More extensive testing is planned with respect to surface definition and pinholing tendencies under autoclave pressure.

The spar joint step development tool and filler mold have been received. The truss T-cap development tool is 80 percent complete.

Quality Engineering has been requested to submit a plan for fabrication of a specimen with intentional defects in order to establish NDT standards.

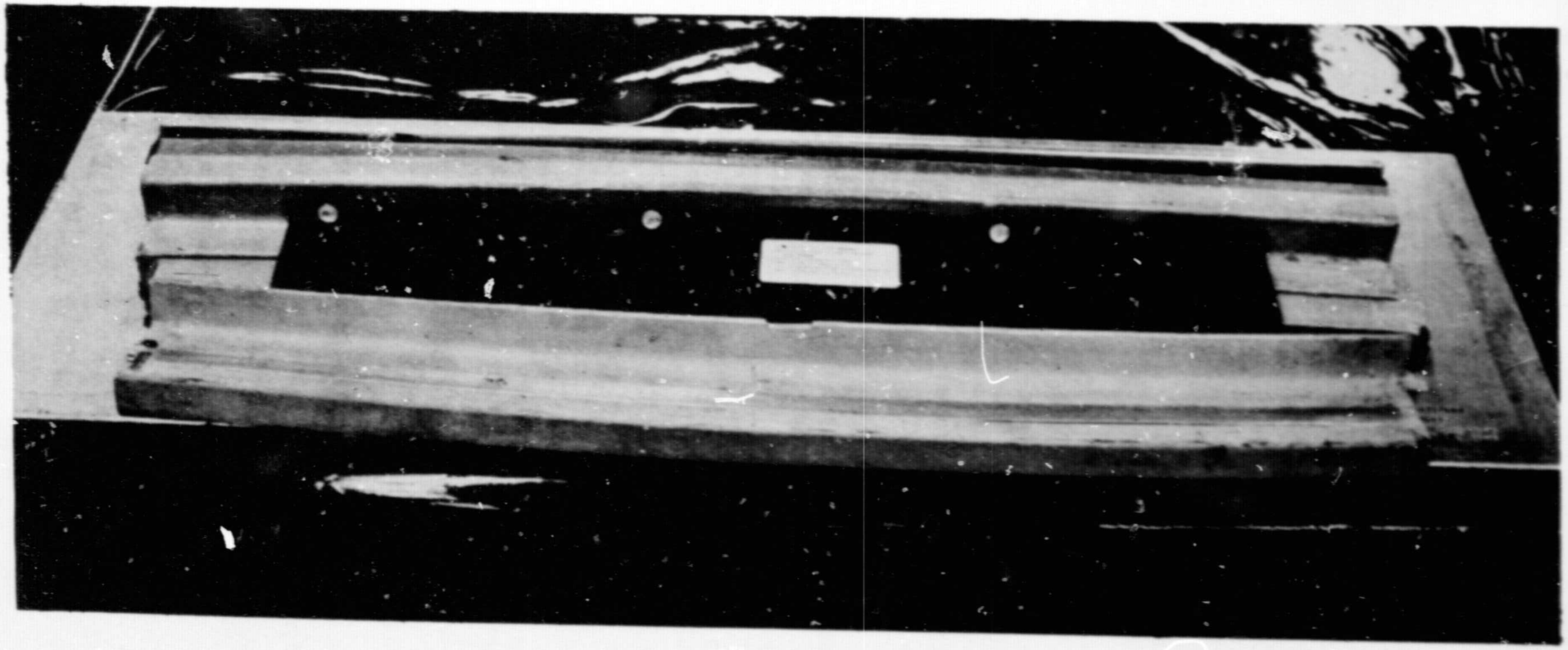

Figure 4-7. 36-Inch Curved Simple Angle Truss Cap - Trial Element

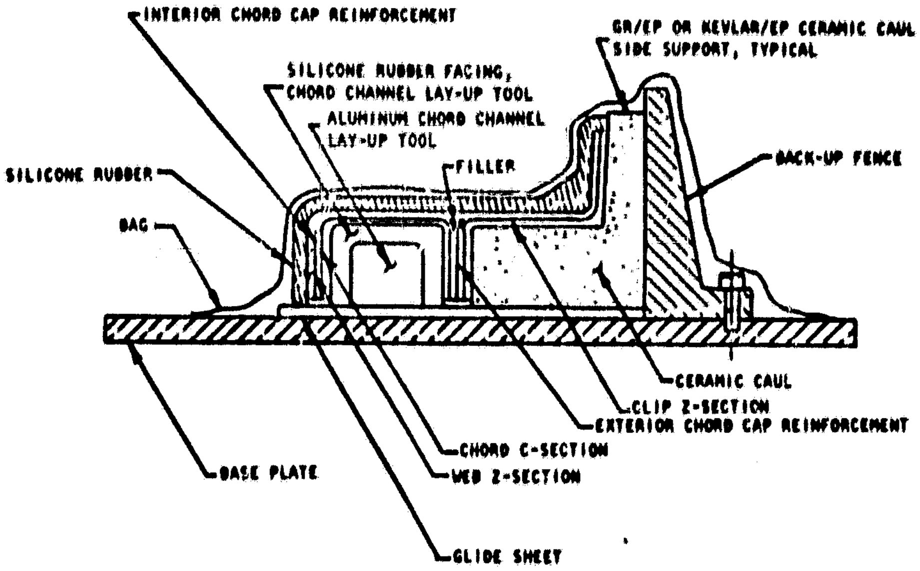

Figure 4-8. Baseplate Tooling Concept Truss Rib Caps

4.4 TASK 7 - SUBCOMPONENT TOOLING

The work in this task covers the design and fabrication of tooling to be used in the fabrication of the subcomponent test specimens.

4.4.1 Subcomponent Tool Design and Fabrication

The configuration of the cap shape of truss rib elements and their intended manufacturing procedure is now considered defined. Tooling has consequently been put in work for Rib Cap P/N 1606647-107 which will support the following elements and subcomponents:

Item No.	Designation	P/N
20-A	Beam Bending, Truss	1606646-111
21-A	In-Plane Shear, Truss	1606647-111
22-A	Static Compression, Truss	1606648-111
24-A	Rudder Hinge Fitting, Truss	1606649-111

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A Manufacturing Engineering Concept Outline (MECO) for fabrication of these elements has been drafted and is being coordinated with the various functions involved.

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