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NASA CR-174910
UDR-TR-85-45

DESIGN OF TEST SPECIMENS AND PROCEDURES FOR GENERATING MATERIAL PROPERTIES OF DOUGLAS FIR/EPOXY LAMINATED WOOD COMPOSITE MATERIAL; WITH THE GENERATION OF BASELINE DATA AT TWO ENVIRONMENTAL CONDITIONS

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JULY 1985

Date for general release JULY 1987

FINAL REPORT FOR PERIOD MARCH 1982 THROUGH MARCH 1985

CONTRACT NO. DEN3-286

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION/
LEWIS RESEARCH CENTER (NASA/LEWIS)
21000 BROOKPARK RD.
CLEVELAND, OH 44135

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The work reported herein was performed during the period March 1982 to March 1985 under Contract DEN 3-286 sponsored by NASA Lewis Research Center (NASA LeRC). Mr. Ray Lark was the NASA Project Engineer. Additional technical guidance was provided by Mr. T. Sullivan also of NASA LeRC. The University of Dayton Research Institute (UDRI) Principal Investigator for this effort was Mr. Paul E. Johnson. Mr. Johnson is part of the Structural Test Laboratory (STL) Group which in turn is part of the Experimental and Applied Mechanics Division of UDRI which is supervised by Mr. George J. Roth. The author gratefully acknowledges the capable support provided by the entire STL technical staff and the other UDRI technicians who assisted in the development of the test specimens fabrication procedures. We are also grateful for the assistance provided by the Gougeon Brothers Inc. engineers Messrs. Tom Stroebel and William D. Bertelsen.

SECTION 1

INTRODUCTION

Individually and in combination with many other materials wood has been utilized in many forms as a viable engineering material for many centuries. One of the latest developments in wood technology has been the high performance laminated Douglas Fir/West System epoxy composite material developed by Gougeon Brothers, Inc., Bay City, Michigan. This material system utilizes 0.10 inch nominal thickness Douglas Fir veneers laminated and sealed with the two-part West System® epoxy. One of the advantages of this system is that epoxy serves to buffer the moisture content of the wood (to maintain optimal levels) over the short term. The material under consideration in this effort had a unidirectional fiber orientation and was selected as a primary material for the airfoils in the NASA/DOE MOD 5A 7MW Wind Turbine Generator. Being a relatively new material a limited amount of material property data is available to design engineers. It was the intent of the current effort to develop specimens and procedures suited to this material to generate pertinent monotonic and cyclic data (Task I). Task (II) was the generation of the baseline data at two environmental conditions utilizing the specimens, griping system, and procedures developed in Task I.

The types of mechanical loadings to be considered was limited to monotonic tension, monotonic compression, monotonic shear, tension/tension fatigue and tension/compression fatigue. Since all large structures fabricated from this material must incorporate joints or fasteners the test matrix included specimens with joints (12/1 scarf). Many of the investigations completed to date involving this material have incorporated large volume structural type test specimens which were very costly to fabricate and test. This effort was somewhat unique in that relatively small volume coupon type test specimens were utilized to generate baseline mechanical property data to supplement the large scale structural work and to provide alternate economical methods for evaluating material behavior for many applications. Within this effort a cursory investigation on the effect of test specimen test section volume was undertaken for the monotonic tension specimen.

SECTION 2

TASK I - DEVELOPMENT OF SPECIMEN DESIGNS

The Task I section of the program included the evolution of the various test specimen designs along with the companion gripping systems and the development of suitable test procedures. All of the tests in both Task I and Task II were completed utilizing the MTS servohydraulic closed-loop test systems located in the University's Structural Test Laboratory (STL). The STL has nine test systems ranging in capacity from 3,300 pounds to 220,000 pounds. Most of the testing for this effort was conducted in only two of these test systems which were rated at 10,000 pounds. The laboratory maintains three shifts of full time technicians so long term tests can be carefully monitored and the machines are more fully utilized. The laboratory ambient environment is maintained at 72° + 3°F and 50 ± 5% RH. The test specimens for all tests to be conducted at the ambient condition were stabilized in the laboratory for a minimum of 14 days. The tests conducted at elevated temperatures (120°F) and moisture content (approximately 12 percent) were completed utilizing Instron environmental chambers installed between the uprights of the load frames. These chambers have closed-loop temperature control. The specimen test section local environment was maintained at approximately 100% RH during the hot/wet tests by wrapping the test section with a damp cloth and sealing the assembly with plastic wrap and duct tape. The hot/wet specimens were preconditioned in a constant temperature and humidity chamber (Blue M Model AC-7702HB-1) maintained at 120°F and approximately 100% RH for a length a time empirically determined to raise the moisture content to approximately 12 percent by weight for each respective specimen design.

1. MONOTONIC TENSION SPECIMEN DESIGN

The evolution of the monotonic tension specimen design began with the applicable ASTM standards (D143-52 and D3500-76) and the data presented by Markwardt and Loungquist in Reference 1. All of these references recommend a dogbone shaped specimen with large transition radii with a minimum grip to test section width ratio of 2:1. The minimum acceptable test section width for all laminate thickness was taken as the maximum nominal test section thickness or 1 inch for the 10 ply laminate.

The STL has in our grip inventory two pairs of 55,000 pound capacity MTS hydraulic activated wedge action grips. The wedges which clamp down on the specimens have a serrated surface approximately 4 inches square. Tensile and/or compressive loads are transferred from the grips to the specimen by shear at the grip/specimen interfaces.

The normal forces which the grips exert on the specimen faces is adjustable by means of varying the grip hydraulic pressure. These grips are convenient to use (specimen installation and removed in less than 60 seconds), provide very uniform gripping, and are ideal for fatigue work since they are hydraulically preloaded (backlash free).

These hydraulic MTS grips were utilized for the development of the tensile specimen. The first designs were 2 or 4 inches wide in the grips and dogboned to a smaller dimension in the test section. The specimen thickness was constant at 3, 5, 7, or 10 ply. Only the unjointed longitudinal material (largest axial forces) was utilized in the Task I phase. Specimen designs 1, 2, 3, and 6 shows in Figure 1 were all evaluated in conjunction with the MTS grips. Designs 4 and 5 were conceived as alternates to designs 3 and 6 respectively (with different test section volumes), but were not utilized. Immediately it was noted that the grips were excessively crushing the ends of the specimens causing a premature failure at the grip. This was caused by an axial force component exceeding the hydraulic wedge preload resulting in additional wedging action even though the crush produced by the initial hydraulic preload was sufficient to transfer the shear load from the grip to the specimen. This situation was remedied by designing U-shaped mechanical crush limiters to surround the ends of the specimen and limit the crush on the specimen to approximately 15 percent. With the crush limiters installed the specimen width in the grips was limited to 3 inches and the specimen test section width was taken as 1 inch (design 7 in Figure 1). With this specimen design good results (failure in the test section at stresses comparable with other investigators) were obtained for 3, 5 and 7 ply laminates. The 10 ply laminate generated loads sufficient to cause a shear failure in the outer wood plies in the grip. A scaled up version (approximately 2x) of design 7 would undoubtedly work for the 10 ply laminate but was outside of the scope of this effort. The Task I tensile test results are presented in Table 1. The modulus values reported in the table were gathered by utilizing a 2-inch gage length strain gage extensometer attached to the center of the test section. The tests were run at a static rate up to approximately 60 to 70 percent of the anticipated fracture load at which time the load was held while the extensometer was removed (to preserve the extensometer) then the loading was resumed to fracture. The extensometer was alternately placed on the front or back (across a single ply) and on the side (across all plies) on the specimens. The University recommends placing the extensometer across the side of the specimen which is what was done for the Task II tensile specimens. The 5 ply version of design 7 was selected for Task II testing since these results appeared to be about average and since the 5 ply laminate lends itself nicely to incorporating three scarf joints.

2. MONOTONIC COMPRESSION SPECIMEN DESIGN

The first attempt at a compression test specimen design was a tension design with lateral constraint (antibuckling fixture). Visual monitoring of these tests did not disclose any unusual behavior although the axial stress at fracture (approximately 8,000 psi) was lower than expected and indicated instability in the specimens (buckling). It was decided to try

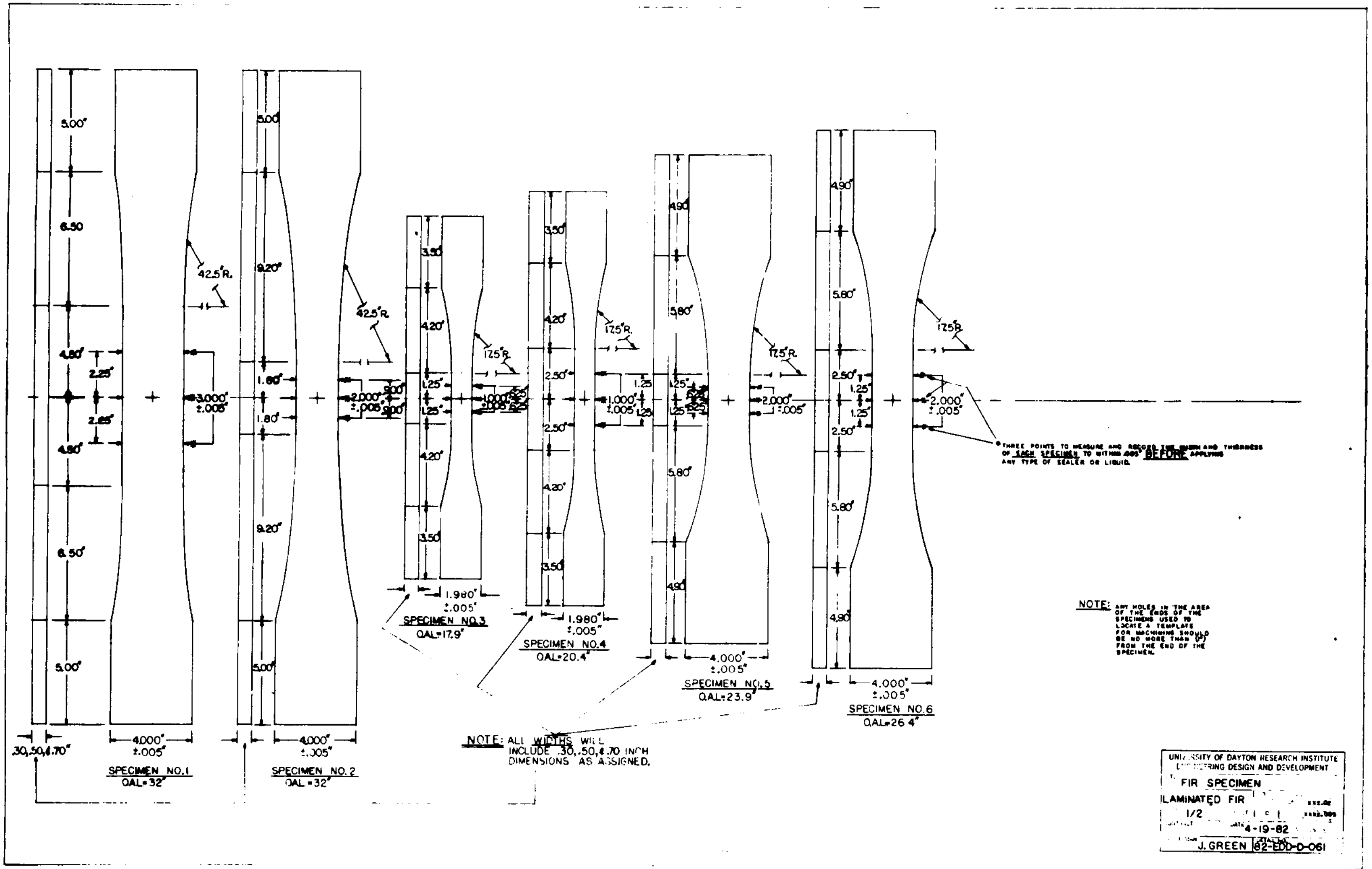


Figure 1. Monotonic and Cyclic Specimen Designs.

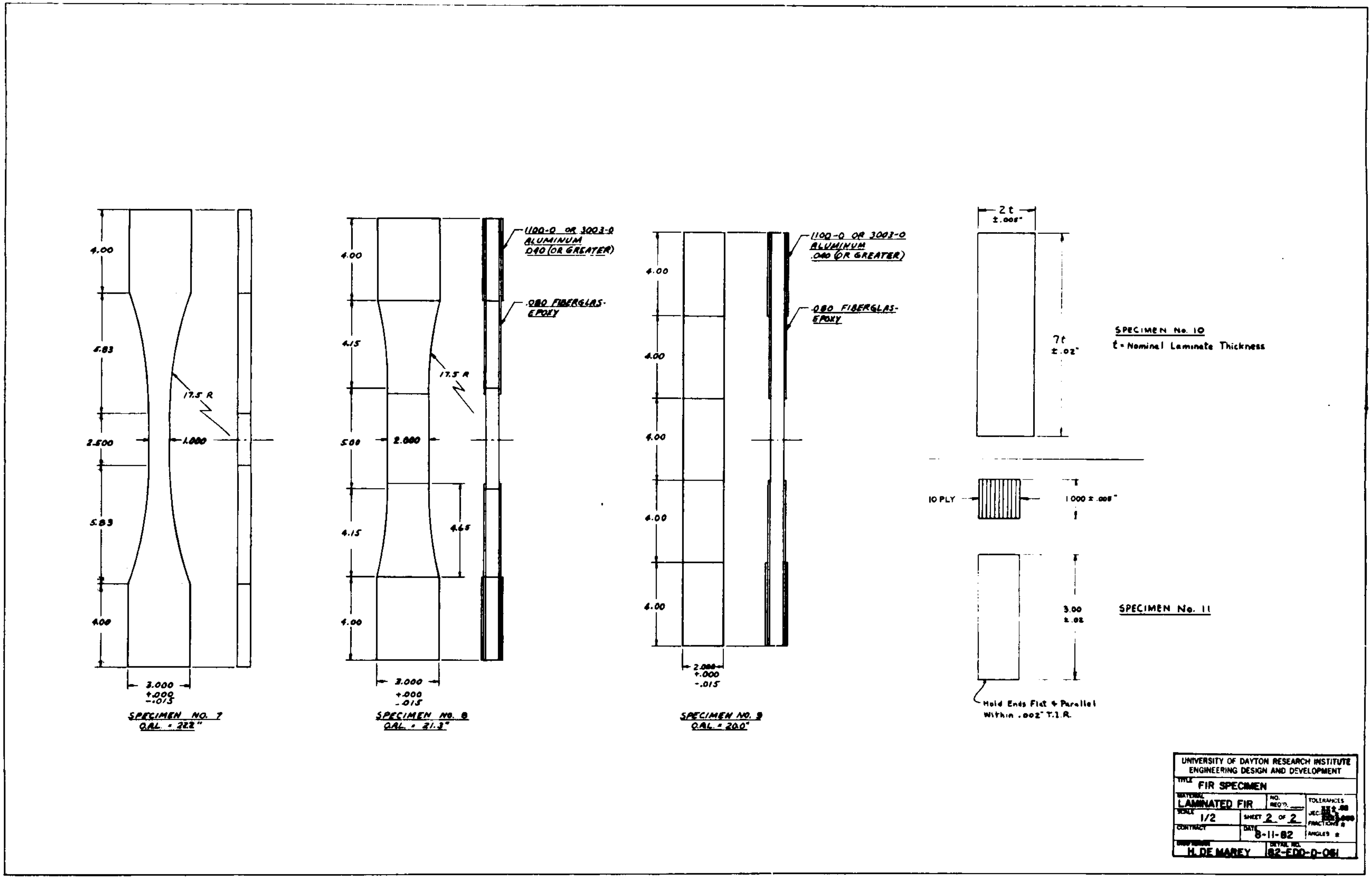


Figure 1. Monotonic and Cyclic Specimen Designs (Continued).

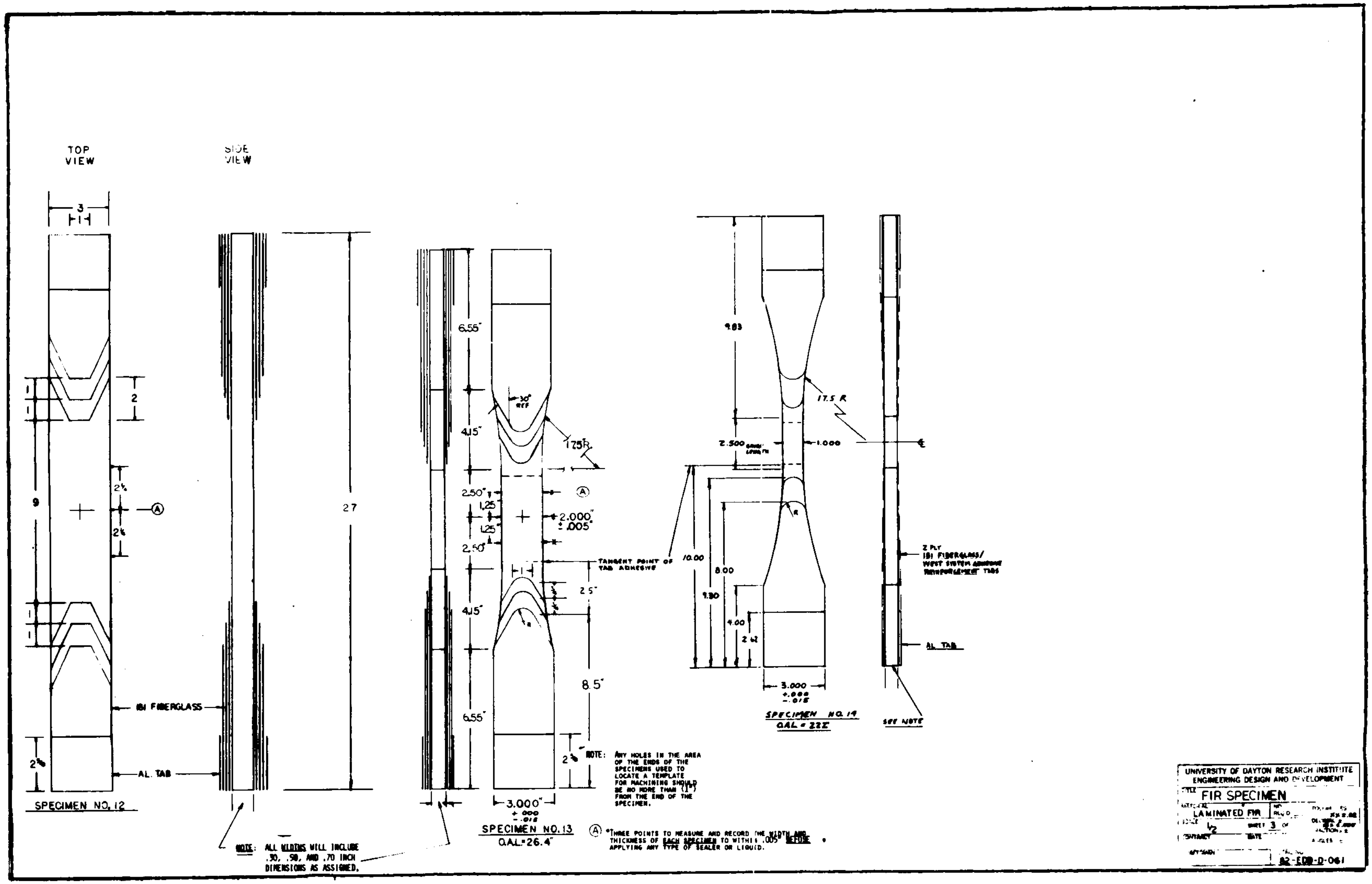


Figure 1. Monotonic and Cyclic Specimen Designs (Continued).

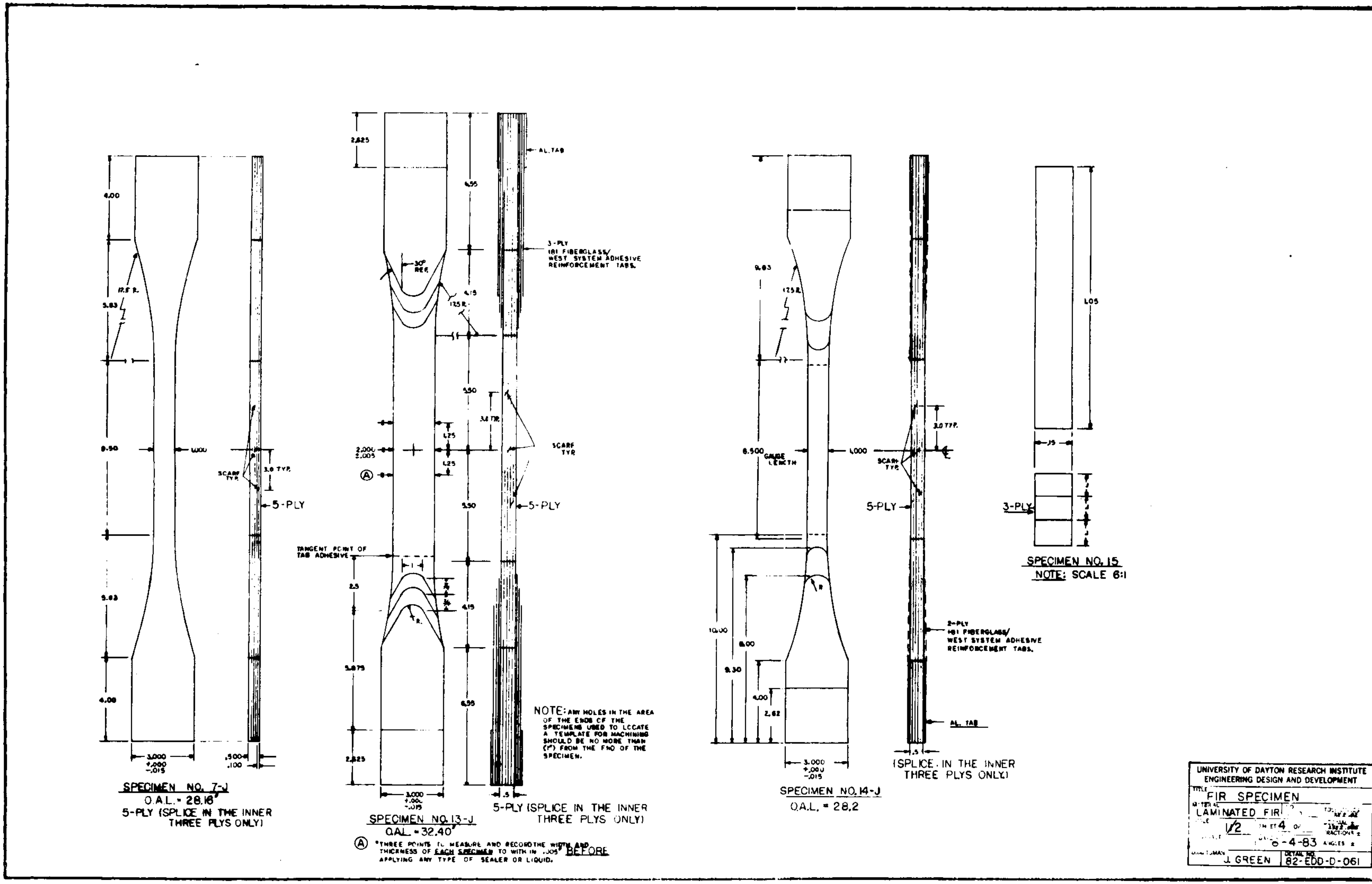


Figure 1. Monotonic and Cyclic Specimen Designs (Concluded).

TABLE 1

TASK I - TENSION TEST RESULTS

************************ NASA WOOD LAMINATE TENSILE TEST ************************

SPECIMEN NUMBER	MODULUS (psi)	ULTIMATE STRESS (psi)
3-1-3-7-038	1,900,482	13,610
3-1-3-7-039	1,827,329	14,470
3-1-3-7-040	2,036,857	13,100
3-1-3-7-041	2,257,746	15,450
3-1-3-7-051	2,037,652	15,781
3-1-3-7-052	2,369,281	14,216
3-1-3-7-053	2,394,137	14,495
3-1-3-7-054	2,396,479	13,042
3-1-3-7-055	2,460,887	14,994
3-1-3-7-056	2,662,167	16,732
3-1-3-7-057	2,514,059	12,984
3-1-3-7-058	2,531,436	14,394
5-1-3-7-042	1,557,632	13,380
5-1-3-7-043	1,566,731	13,100
5-1-3-7-044	1,934,465	12,950
5-1-3-7-046	2,050,781	13,260
5-1-3-7-059	1,927,849	14,507
5-1-3-7-060	2,040,031	12,702
5-1-3-7-061	1,941,934	11,729
5-1-3-7-062	1,920,492	13,636
5-1-3-7-063	2,272,270	12,796
5-1-3-7-064	2,074,298	13,012
5-1-3-7-065	2,054,404	11,413
5-1-3-7-066	2,072,141	13,622
7-1-3-7-047	1,965,595	12,020
7-1-3-7-048	1,969,604	13,070
7-1-3-7-049	2,052,486	14,260
7-1-3-7-050	1,941,417	15,120
7-1-3-7-067	1,999,167	12,495
7-1-3-7-068	1,814,211	11,037
7-1-3-7-069	2,136,437	15,379
7-1-3-7-070	1,849,432	12,827
7-1-3-7-071	1,914,231	16,056
7-1-3-7-072	1,936,299	12,558
7-1-3-7-073	1,934,995	14,158
7-1-3-7-074	2,028,500	13,104

SPECIMEN TYPE	MEAN MODULUS	MEAN ULTIMATE STRESS	STANDARD DEVIATION MODULUS	STANDARD DEVIATION ULTIMATE STRESS
3 PLY	2,282,376	14,439	257,967	1,118
5 PLY	1,951,086	13,009	197,039	793
7 PLY	1,961,865	13,507	83,216	1,433

a 10 ply right prism specimen design (design 11) with a 3 to 1 slenderness ratio. These specimens were tested between flat steel platens. Half of the specimens were tested with fixed platens the other half with one fixed and one swivel (spherical seat) platen. Half of each of these groups were tested with the strain gage extensometer placed on the front (or back) of the specimen (on a single ply) and the other half with the extensometer on the side of the specimen (across all 10 plies). The test results are presented in Table 2.

If the ends of the compression specimen are not flat and parallel and are tested between fixed platens the extensometer signal will generally be very nonlinear and the calculated modulus will not be representative of the material. The calculated modulus can either be lower or higher than the correct value depending upon the effective length of the specimen at the location of the extensometer. Two extensometers (or strain gages) placed 180 degrees apart could be used to partially compensate for this condition but the University recommends using a spherical seat platen with the extensometer across the plies and precisely machined specimens. All of the Task I compression specimen development was conducted in the longitudinal material direction. Scarf joints were not included in the compression tests since they were expected to have little effect in thick laminates where a single joint would be surrounded by many continuous plies.

3. MONOTONIC SHEAR SPECIMEN DESIGN

The short beam shear test was selected for evaluating the shear strength of 3, 5 and 7 ply laminates. The specimen and procedures were modeled after those used for high modulus fiberous composites; ASTM D3518-76. The shear plane for all the Task I specimens was in the longitudinal-transverse material direction (fracture was designed to be in the middle of the center ply). The fixture span was five times the nominal specimen depth (0.3, 0.5, or 0.7 inch) the specimen width was

TABLE 2

TASK II - COMPRESSION TEST RESULTS

NASA LAMINATED WOOD STATIC COMPRESSION TESTS
Dimensions: 1"x1"x3"

Specimen Number	Modulus (psi)	Ultimate Stress (psi)	Extensometer Location
504	1,900,000	10,230	across plies
505	2,164,000	9,862	across plies
506	1,810,000	9,915	across plies
507	2,348,000	9,662	across plies
508	2,024,000	9,943	across plies
509	2,097,000	10,110	on side
510	2,059,000	10,140	on side
511	1,865,000	9,470	on side
512	1,378,000	9,093	on side
513	1,879,000	10,200	on side

Extensometer Location	Mean Modulus	Mean Ultimate Stress	Standard Deviation Modulus	Standard Deviation Ultimate Stress
across plies	2,049,000	9,922	191,100	182
on side	1,856,000	9,803	256,300	443
combined	1,952,000	9,862	245,900	344

** 1 FIXED PLATEN, 1 SWIVEL PLATEN **

TABLE 2

TASK II - COMPRESSION TEST RESULTS (CONCLUDED)

NASA LAMINATED WOOD STATIC COMPRESSION TESTS
Dimensions: 1"x1"x3"

Specimen Number	Modulus (psi)	Ultimate Stress (psi)	Extensometer Location
503	1,533,000	9,578	across plies
514	2,118,000	10,130	across plies
515	1,797,000	9,810	across plies
516	2,099,000	9,549	on side
517	2,073,000	10,060	on side
518	1,806,000	9,846	on side

Extensometer Location	Mean Modulus	Mean Ultimate Stress	Standard Deviation Modulus	Standard Deviation Ultimate Stress
across plies	1,816,000	9,840	239,200	226
on side	1,993,000	9,818	132,400	210
combined	1,904,000	9,829	212,600	218

** 2 FIXED PLATENS **

twice the depth and the overall length was seven times the depth (specimen design 10). As with all the monotonic tests the test machine displacement rate was selected so as to produce a failure in 1 to 2 minutes. The Task I short beam shear test results are presented in Table 3. The 3 ply specimen yielded the highest shear strength values although it must be remembered that with this specimen and material direction we are evaluating a single ply and for each laminate all the specimens were taken from the same board. The 3 ply specimen also seemed to have fewer occurrences of bending failures than either the 5 and 7 ply specimen. Based upon these results the 3 ply short beam shear specimen was selected for Task II.

4. FATIGUE SPECIMEN DESIGN

The starting point for the evolution of the fatigue specimen designs was the constant thickness dogboned width tensile specimen geometry. The fatigue evaluations were limited to the longitudinal material direction for both Task I and Task II. The same problem described for the tensile specimens of crushing the ends of the specimens with the wedging action of the grips existed for the early fatigue specimens and was remedied in the same manner (U-shaped crush limiters). A difficulty which occurred only on the fatigue specimens was the gradual cracking which started at the blend points of the transition radii and preceeded towards the grips leading to specimen failure at the grips. In effect the specimens were changing from a dogbone configuration to a straight sided configuration. All of the straight sided specimens subjected to cyclic loading, with (i.e., design Nos. 9 and 12) or without reinforcing tabs, inevitably failed in the grips since the laminate was being damaged by the grip crushing action. To be compatible with the MTS hydraulic grips and produce failures within the test section the fatigue specimen designs would need to be dogboned in the width direction and reinforced in the thickness direction in the transition area between the test section and the grip. Many

TABLE 3

SHORT BEAM SHEAR TEST RESULTS

************** NASA WOOD LAMINATE SHORT BEAM SHEAR TESTS **************

SPECIMEN NUMBER	THICKNESS (IN.)	WIDTH (IN.)	SHEAR LOAD (LBS.)	SHEAR STRESS (PSI)	MEAN SHEAR STRESS	STANDARD DEVIATION
3-10-5-401	.300	.600	430.0	1791.7	1778.49	136.301
3-10-5-402	.3067	.618	470.0	1859.8	"	"
3-10-5-403	.3073	.612	447.0	1782.6	"	"
3-10-5-404	.3073	.613	482.5	1921.0	"	"
3-10-5-405	.3063	.616	445.0	1768.9	"	"
3-10-5-406	.3013	.612	430.0	1749.0	"	"
3-10-5-407	.3083	.612	452.5	1798.7	"	"
3-10-5-408	.3113	.617	487.0	1901.6	"	"
3-10-5-409	.3113	.616	462.5	1808.9	"	"
3-10-5-410	.3043	.615	350.0	1402.7	"	"
5-10-5-411	.524	1.025	856.25	1195.7	1232.51	66.223
5-10-5-412	.5077	1.018	868.75	1260.7	"	"
5-10-5-413	.5057	1.021	831.25	1207.5	"	"
5-10-5-414	.5217	1.028	831.25	1162.5	"	"
5-10-5-415	.5157	1.015	862.5	1235.8	"	"
5-10-5-416	.519	1.026	887.5	1250.0	"	"
5-10-5-417	.5227	1.026	987.5	1381.0	"	"
5-10-5-418	.514	1.025	787.5	1121.0	"	"
5-10-5-419	.5213	1.021	900.0	1268.2	"	"
5-10-5-420	.5247	1.028	893.75	1247.2	"	"
7-10-5-421	.723	1.426	1662.5	1209.4	1146.01	47.071
7-10-5-422	.697	1.427	1550.0	1168.8	"	"
7-10-5-423	.699	1.419	1487.5	1124.8	"	"
7-10-5-424	.706	1.417	1462.5	1096.4	"	"
7-10-5-425	.700	1.424	1462.5	1100.4	"	"
7-10-5-426	.695	1.422	1612.5	1223.7	"	"
7-10-5-427	.699	1.422	1425.0	1075.2	"	"
7-10-5-428	.721	1.427	1562.5	1139.0	"	"
7-10-5-429	.707	1.422	1587.5	1184.3	"	"
7-10-5-430	.714	1.419	1537.5	1138.1	"	"

iterations of reinforcing the specimen gripping area were evaluated before a successful approach evolved. Initial attempts included dogboning the specimen thickness, adding urethane tabs and adding fiberglass tabs. Specimens with constant thickness reinforceing tabs (i.e., design No. 8 in Figure 1) responded to the fatigue loading by delamination of the tabs starting at the leading edge and progressing toward the grip as the specimen accumulated cycles. The scheme which proved successful utilized the approach of gradually transitioning from the low compliance of the grips to the relatively high compliance of the specimen test section while reinforcing the transition areas of the specimen especially in the transverse direction. This stiffness tapering and lateral support combined with increasing the test section width to 2 inches (the grip width is 3 inches with the crush limiters) generated specimen designs 13 and 13J. Generally these designs failed by cracking in the test sections for all combinations of R ratios and environments which were evaluated.

The longitudinal stiffness tapering in these specimens was accomplished by layering three different lengths of E glass combined with tapering the thickness of the West System epoxy used to bond the fiberglass to the laminate. The serrations of the MTS grips would not bite the West System epoxy without excessive crushing so dead soft (1100 series) aluminum tabs were added which yield to the serrations under the normal clamping forces. The strength of the aluminum tab/West System epoxy bond was sufficient for 3 ply 2-inch wide test section fatigue tests and 5 ply 2-inch wide (with three scarf joints) fatigue tests but was not sufficient for the 5 ply design without joints in the 2-inch width. The 3 ply design 13 specimen and the 5 ply design 13J (J denotes with 3 scarf joints) specimens were selected for Task II evaluation. Low volume versions of specimens 13 and 13J were also designed (14 and 14J) but were not utilized during the current effort.

SECTION 3

TASK II - GENERATING TEST DATA

The Task II monotonic and cyclic fatigue test matricies are presented in Tables 4 and 5 respectively. The 10 ply monotonic compression test specimens were GFE. The remaining specimens were fabricated by the University's subcontractor, Dayton Scale Model Inc., using UDRI established procedures and NASA supplied laminates. Due to the limited supply of material all the 3 ply and 5 ply monotonic test specimens were removed from a single sheet of the 3 and 5 ply laminates.

1. TENSILE TEST RESULTS

The Task II tensile test results are presented in Table 6. The modulus data for the 5 ply design 7J test specimens was obtained with a 2 inch gage length strain gage extensometer placed across the plies at the center of the test section so that the extensometer spanned the scarf joint of the center ply. The first batch of the design 7 hot/wet test specimens were preconditioned in the 120°F approximately 100% RH chamber without protecting the ends of the specimens from the environment. These samples failed by shearing in the outer plies in the grips before a test section failure occurred. We then retested three remaining samples after protecting their gripping surfaces with plastic wrap and duct tape while they were being preconditioned. Poisson's ratio (μLT) is reported for two specimens at the RT condition which were instrumented with high impedance high elongation strain gages with their axis aligned with the transverse material direction at the center of the specimen test section.

2. COMPRESSION TEST RESULTS

The Task II compression test results are presented in Table 7. As with many of the monotonic tests conducted in the STL the compression test data was collected and reduced using

TABLE 4

MONOTONIC TESTS
WOOD COMPOSITE LAMINATE SPECIMENS

	Number of Tests to be Conducted							
	Environmental Conditions							
	Room Temperature (70°F & 50% RH)				120°F & 100% RH			
	Longitudinal*		Transverse**		Longitudinal*		Transverse**	
Test Type	[1]Spec. A	[2]Spec. B	Spec. A	Spec. B	Spec. A	Spec. B	Spec. A	Spec. B
Tension***	5 (2***)	5	0	0	5	5	0	0
Compression***	5 (2***)	0	5	0	5	0	5	0
Shear (short beam)	5	0	5	0	5	0	5	0

* Loading axis parallel to wood fiber grain
** Loading axis perpendicular to wood fiber grain
*** Specimens to be equipped with strain gages
1 No scarf joints in veneers
2 Scarf joints in veneers

Total of 60 tests (includes 8 strain gage instrumented tests)

TABLE 5

CYCLIC FATIGUE TESTS
WOOD COMPOSITE LAMINATE SPECIMENS

Environmental Conditions	Room Temp. (70°F & 50% RH)						120°F & 100% RH			
Specimen Type	A*			B*			A		B	
R-Ratio	0	-0.5	-1.0	0	-0.5	-1.0	0	-1.0	0	-1.0
Number of Tests to be Conducted	10	5	10	10	5	10	5	10	5	10

All specimens to have longitudinal orientation
Contractor to equip all specimens with thermocouples
* No scarf joints in veneers
** Scarf joints in veneers

Total of 80 tests

TABLE 6

TASK II STATIC TENSILE TEST RESULTS

5 ply, Design 7 Specimen Configuration and

5 ply, Design 7J (with Scarf Joints) Specimen Configuration

Specimen Number	Design	Environmental Condition	Modulus E_L (psi)	Ultimate Stress, σ_L^U (psi)	Comments
5-1-3-7-80	7	RT,RH	2,350,000	14,500	μ_{LT} (Poisson's Ratio) = 0.437
-81	"	"	2,642,000	16,120	μ_{LT} (Poisson's Ratio) = 0.429
-82	"	"	2,377,000	14,020	
-83	"	"	2,297,000	13,130	
-84	"	"	2,779,000	15,200	
Mean (Std. Dev.)			2,489,000 (187,700)	14,600 (1,020)	0.433 (0.004)
5-1-3-7J-75	7J	"		12,960	No modulus data
-76	"	"		13,810	"
-100	"	"	2,388,000	14,100	
-101	"	"	2,278,000	12,150	
-102	"	"	2,262,000	10,100	
Mean (Std. Dev.)			2,309,000 (56,000)	12,620 (1,430)	
5-1-3-7-85	7	120°F, 100% RH	1,959,000	> 7,480	Slipped in Grips
-86	"	"	1,616,000	> 8,610	"
-105	"	"	2,039,000	14,000	
-106	"	"	2,089,000	13,490	
-107	"	"	2,017,000	13,700	
Mean (Std. Dev.)			1,944,000 (189,200)	13,730 (260)	
5-1-3-7J-90	7J	120°F, 100% RH	1,897,000	8,200	
-91	"	"	1,732,000	8,300	
-92	"	"	2,041,000	9,110	
-93	"	"	1,852,000	9,320	
-94	"	"	1,847,000	8,070	
Mean (Std. Dev.)			1,874,000 (99,800)	8,600 (510)	

TABLE 7

TASK II STATIC COMPRESSION TEST RESULTS

10 ply, Design 11 Specimen Configuration

Longitudinal Material Direction

Specimen Number	Environmental Condition	Modulus E_L (psi)	Ultimate Stress, σ_L^U (psi)	Comments
10-1-3-11-520	RT,RH	2,297,000	9,390	μ_{LT} (Poisson's Ratio) = 0.410
-521	"	2,234,000	10,270	μ_{LT} (Poisson's Ratio) = 0.394
-522	"	2,099,000	9,660	
-523	"	2,192,000	10,450	
-524	"	2,393,000	9,310	
Mean (Std. Dev.)		2,243,000 (99,000)	9,820 (460)	0.402 (0.008)
10-1-3-11-525	120°F, 100% RH	1,624,000	3,100	
-526	"	1,660,000	3,000	
-527	"	1,491,000	3,010	
-528	"	1,396,000	3,010	
-529	"	1,475,000	3,000	
Mean (Std. Dev.)		1,529,000 (98,000)	3,020 (40)	

Transverse Material Direction

Specimen Number	Environmental Condition	Modulus E_T (psi)	Ultimate Stress, σ_T^U (psi)	Comments
10-1-3-11-530	RT,RH	130,600	1,980	μ_{TL} (Poisson's Ratio) = 0.044
-531	"	163,400	1,950	μ_{TL} (Poisson's Ratio) = 0.036
-532	"	150,400	2,000	
-533	"	157,300	2,090	
-534	"	150,000	2,050	
Mean (Std. Dev.)		150,300 (11,000)	2,010 (50)	0.040 (0.004)
10-1-3-11-535	120°F, 100% RH	62,400	580	
-536	"	64,400	680	
-537	"	58,200	630	
-538	"	42,000	650	
-539	"	52,700	600	
Mean (Std. Dev.)		55,900 (8,000)	630 (35)	

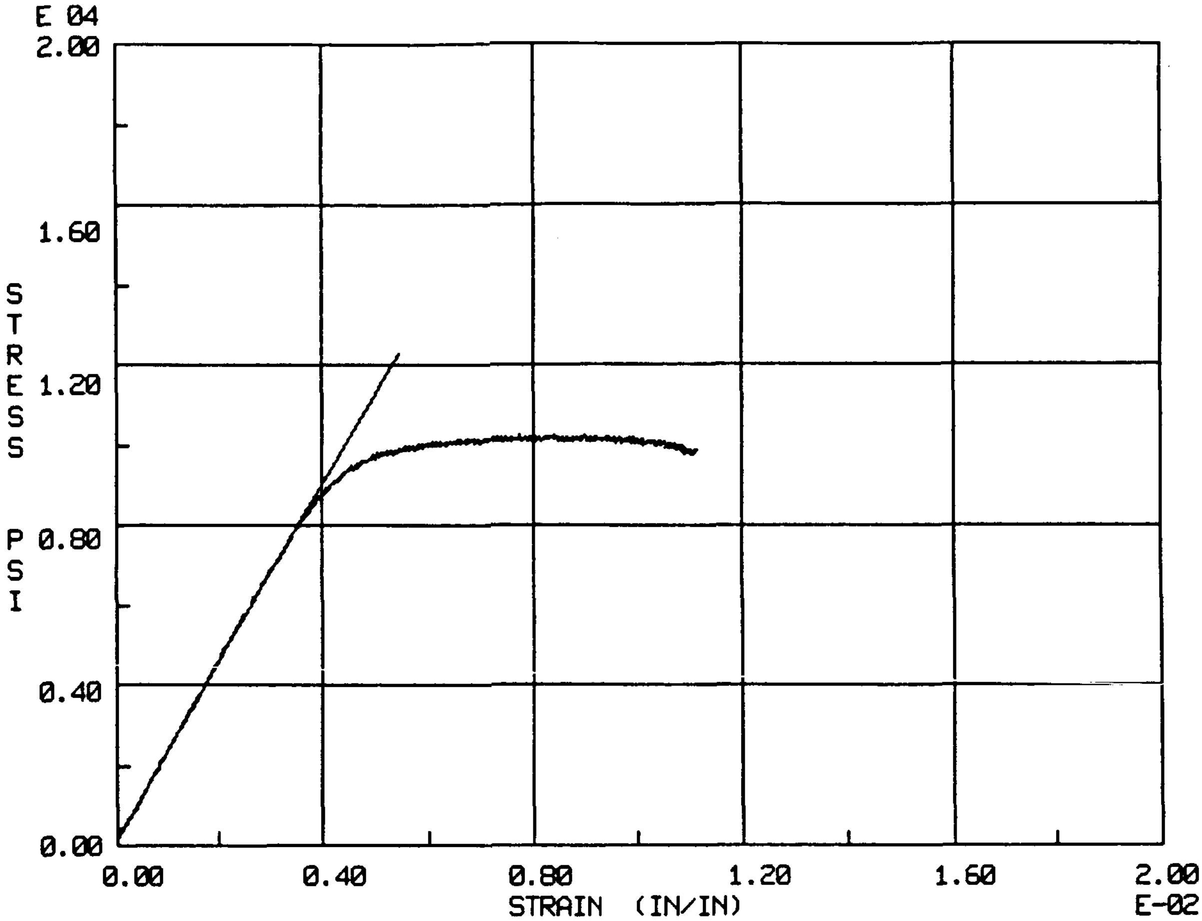
our DEC PDP 11/34 minicomputer data reduction system. A typical test curve is reproduced in Figure 2. Poisson ratio measurements, where listed in the table, were determined by mounting high impedance high elongation strain gages in the direction perpendicular to the loading axis on the face ply of the test specimens.

3. SHORT BEAM SHEAR TEST RESULTS

The Task II short beam shear test results are presented in Table 8. Several specimens failed in bending in the outer ply instead of shear in the center ply. The center ply shear stress was calculated for the load at which bending failure occurred and is reported for reference but was not included in determining the mean or standard deviation. Exposing the LT specimens to the hot/wet environment seemed to have more of an effect on the shear strength of the laminations that the strength of the Douglas Fir. Several of these specimens failed in shear in the West System epoxy lamination and again the neutral axis shear stress is reported but not included in the calculations.

4. TEN DEGREE OFF-AXIS TENSILE SHEAR TEST RESULTS

The 10 degree off-axis tensile shear test procedure for the intralaminar-shear characterization of unidirectional fiber composites is described by Chamis and Sinclair in Reference 2. A single specimen was evaluated which had the longitudinal material direction tilted 10 degrees from the axial loading direction. The specimen was 3 feet long, 2 inches wide and 3 ply thick and was equipped with 60 degrees delta rosette strain gages mounted back to back at the center of the specimen. The ends of the specimen were gripped utilizing the same hydraulic activated wedge action MTS grips with mechanical crush limiters that were used for the tensile test and the specimen was pulled to failure at a static rate. The fracture occurred within the test section in the longitudinal-radial plane (across the plies) as was desired. The calculated stress versus strain curve (σ_{LR}



*********************** LAMINATED WOOD COMPRESSION TEST ********************

* UNIVERSITY OF DAYTON RESEARCH INSTITUTE * STRUCTURES LAB * 9-JUL-84 *

U.D. TEST NUMBER: 2
RATE OF TEST: .01 IN/MIN
THICKNESS: .99 INCHES
CROSS-SECTIONAL AREA: .998 SQ.IN.

SPECIMEN NO.: 521
SPECIMEN LENGTH: 3 INCHES
WIDTH: 1.008 INCHES
GAGE LENGTH: 1 INCHES

**************************** ENGINEERING ANALYSIS ***************************

COMPRESSIVE MODULUS OF ELASTICITY: 2234 Ksi (15.41 GPa)

ULTIMATE COMPRESSIVE STRENGTH: 10.27 Ksi (70.8 MPa)

****

Figure 2. Typical Task II Compression Test Results.

TABLE 8

TASK II STATIC SHORT BEAM SHEAR TEST RESULTS

3 ply, Design 10 Specimen Configuration

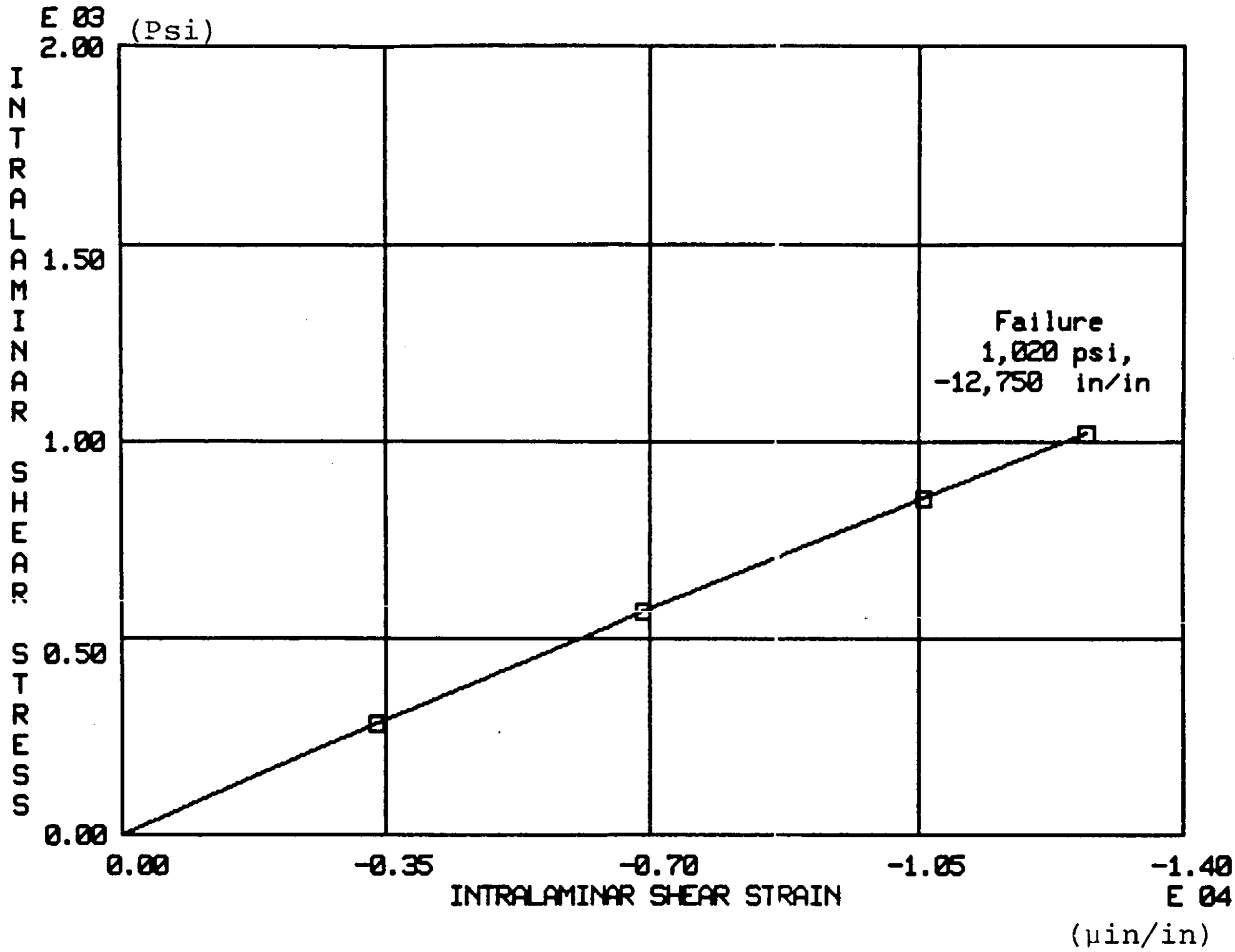
Shear Parallel to the Grain (Longitudinal) Direction

Specimen Number	Environmental Condition	Shear Strength, S_{LT}(psi)	Comments
3-10-5-431	RT,RH	>1170	Shear failure in outer ply
-432	"	1190	
-433	"	1070	
-434	"	>1220	Bending failure in outer ply
-435	"	1170	
Mean (Std. Dev.)		1140 (50)	
3-10-5-441	120°F, 100% RH	> 700	Shear Failure at ply interface
-442	"	> 592	"
-443	"	> 625	"
-444	"	> 663	"
-445	"	> 592	"
Mean (Std. Dev.)			

3 ply, Design 15 Specimen Configuration

Shear Across the Plies (Radial) Direction

Specimen Number	Environmental Condition	Shear Strength, S_{LR}(psi)	Comments
3-15-5-446	RT,RH	1830	
-447	"	1830	
-448	"	>1840	Bending failure
-449	"	>1730	"
-450	"	>1930	"
Mean (Std. Dev.)		1830 (0)	
3-15-5-457	120°F, 100% RH	>1070	Bending failure
-458	"	>1170	"
-459	"	>1010	"
-460	"	> 970	"
-464	"	>1020	"
Mean (Std. Dev.)			



NASA INTRALAMINAR SHEAR TEST

Pt.	Load	σ_{LR}	V_o	ε_o	V_{45}	ε_{45}	V_{90}	ε_{90}	ε_{LR}
1	1,000	285	+2.30	1,656	-1.22	-878	-0.87	-626	-3,398
2	2,000	570	+4.61	3,319	-2.52	-1,814	-1.72	-1,238	-6,923
3	3,000	855	+6.93	4,990	-3.90	-2,808	-2.55	-1,836	-10,575
4	3,575	1,020	+8.30	5,976	-4.72	-3,398	-3.02	-2,175	-12,745

$$G_{LR} = \frac{1020 \text{ psi}}{12750 \ \mu\text{in/in}} = 80{,}000 \text{ psi}$$

Figure 3. Ten Degree Off-Axis Tensile Shear Test Results.

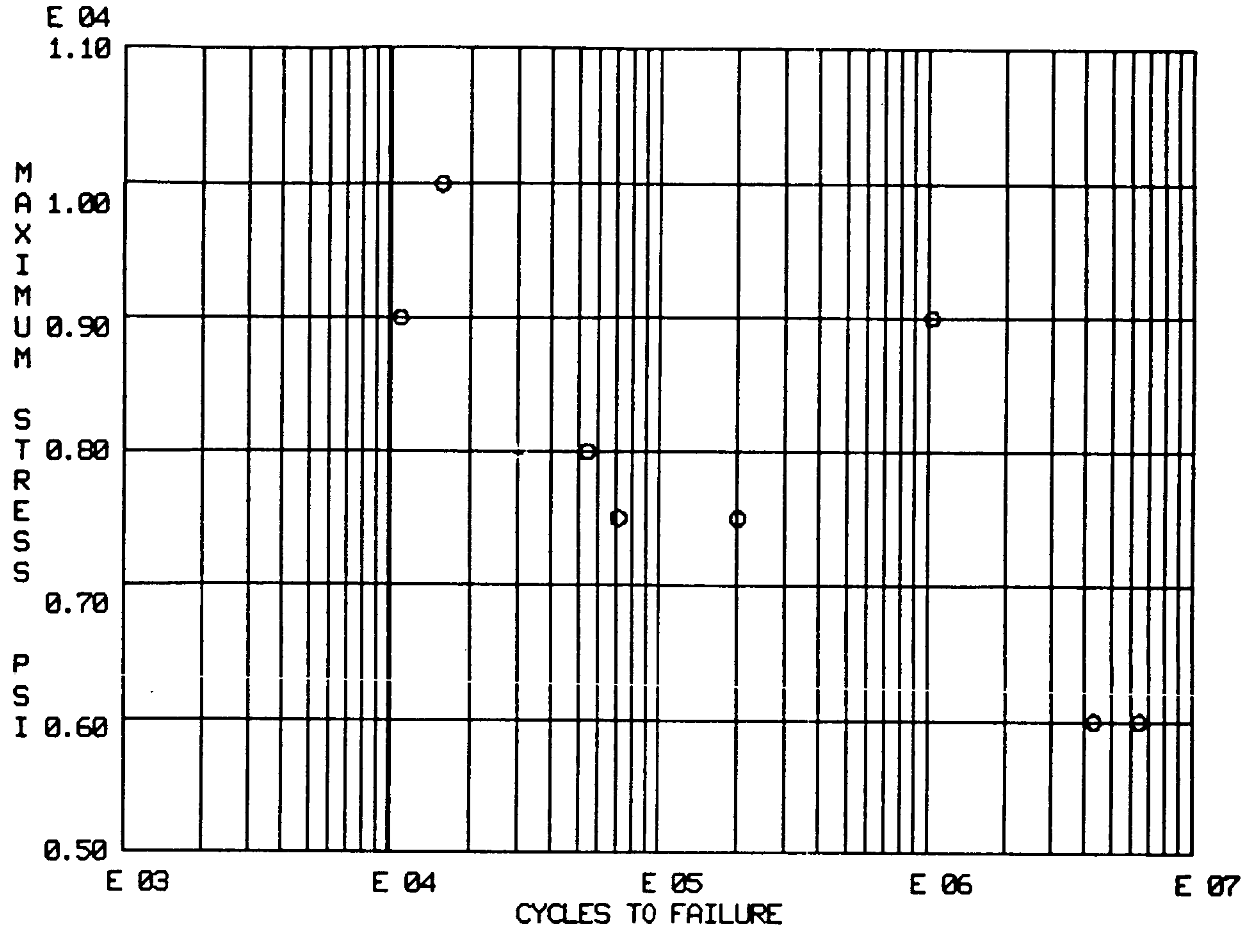
versus ϵ_{LR}) is reproduced in Figure 3. Fracture occurred at a stress of 1020 psi (σ_{LR}^{Ult}). The secant shear modulus (G_{LR}) for this test was calculated to be 80,000 psi.

5. CYCLIC TEST RESULTS

The Task II specimen design 13 (3 ply without joints) fatigue test results are presented in Figures 4 through 6 for R ratios of 0.0, -0.5, and -1.0 at RT and RH. Figures 7 and 8 present the fatigue results for R ratios of 0.0 and -1.0 at 120°F and 100% RH. The Task II specimen design 13J (5 ply with 3 scarf joints) fatigue test results are presented in Figures 9 through 11 for R ratios of 0.0, -0.5, and -1.0 at RT and RH. Figures 12 and 13 present the fatigue results for R ratios of 0.0 and -1.0 at 120°F and 100% RH. For all of these tests the failures originated within the test section and a failure is defined as when the specimen could no longer sustain the applied load.

The specimens tested at the negative R ratios and RT and RH were given lateral support with antibuckling fixtures with 0.25 inch thick Teflon coated aluminum plates contacting the test section at two equally spaced locations so that most of the test section could be viewed during the test. The specimens tested at the negative R ratios and 120°F, and 100% RH were given lateral support by clamping Teflon coated aluminum antibuckling plates over the entire length of the test section so that the entire test section was obscurred. These antibuckling plates were in turn enclosed by moist cloths and the entire assembly was sealed with plastic wrap and duct tape. The entire test specimen assembly was then placed inside the environmental chamber which was maintained at 120°F. A thermocouple was attached to the specimen test section and the test was started after the thermocouple stabilized at 120°F (1 to 2 hour soak). The specimens designated for hot/wet fatigue testing were soaked in a preconditioning chamber maintained at 120°F and approximately 100% RH for 12 to 14 days to raise their moisture

(text continued on page 37)

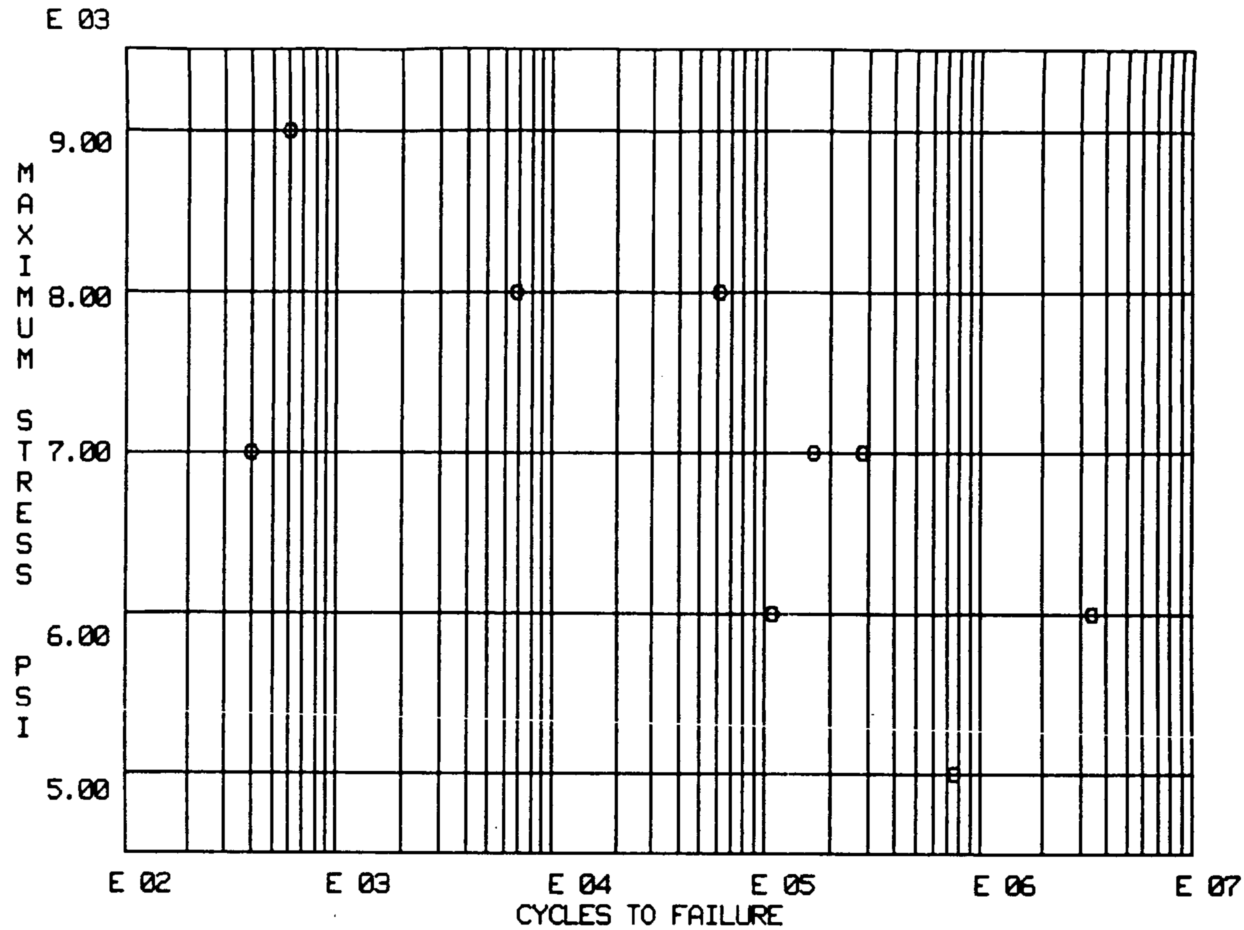


NASA LAMINATED WOOD FATIGUE TEST RESULTS
(design 13, R ratio = 0.0)

Specimen Description	Maximium Stress (psi)	Cycles to Failure
5-2-3-13-233	8000	54,000
5-2-3-13-239	6000	6,404,900
5-2-3-13-240	7500	N.A. *
5-2-3-13-241	7500	71,000
5-2-3-13-242	9000	1,040,100
5-2-3-13-243	6000	4,313,700
5-2-3-13-252	9000	11,000
5-2-3-13-253	7500	200,700
5-2-3-13-254	10000	15,600

* Transverse grain, static failure

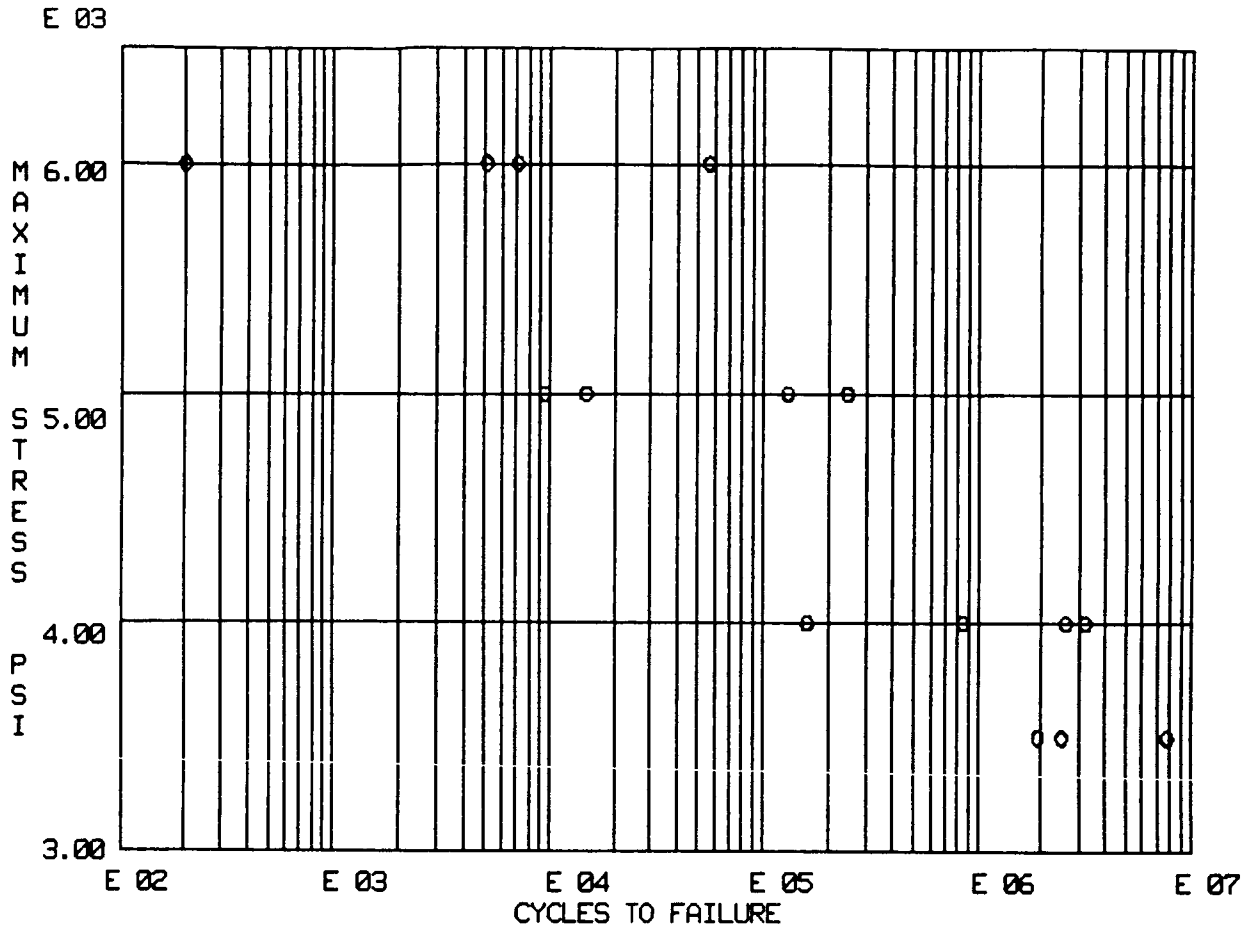
Figure 4. Room Temperature, 0.0 R Ratio, Specimen Design 13, Fatigue Results.



NASA LAMINATED WOOD FATIGUE TEST RESULTS
(design 13, R ratio = -0.5)

Specimen Description	Maximum Stress (psi)	Cycles to Failure
3-2-3-13-263	5000	759,100
3-2-3-13-260	6000	108,600
3-2-3-13-259	6000	3,416,400
3-2-3-13-261	7000	168,600
3-2-3-13-256	7000	400
3-2-3-13-257	7000	281,200
3-2-3-13-255	8000	61,500
3-2-3-13-262	8000	6,800
3-2-3-13-258	9000	600

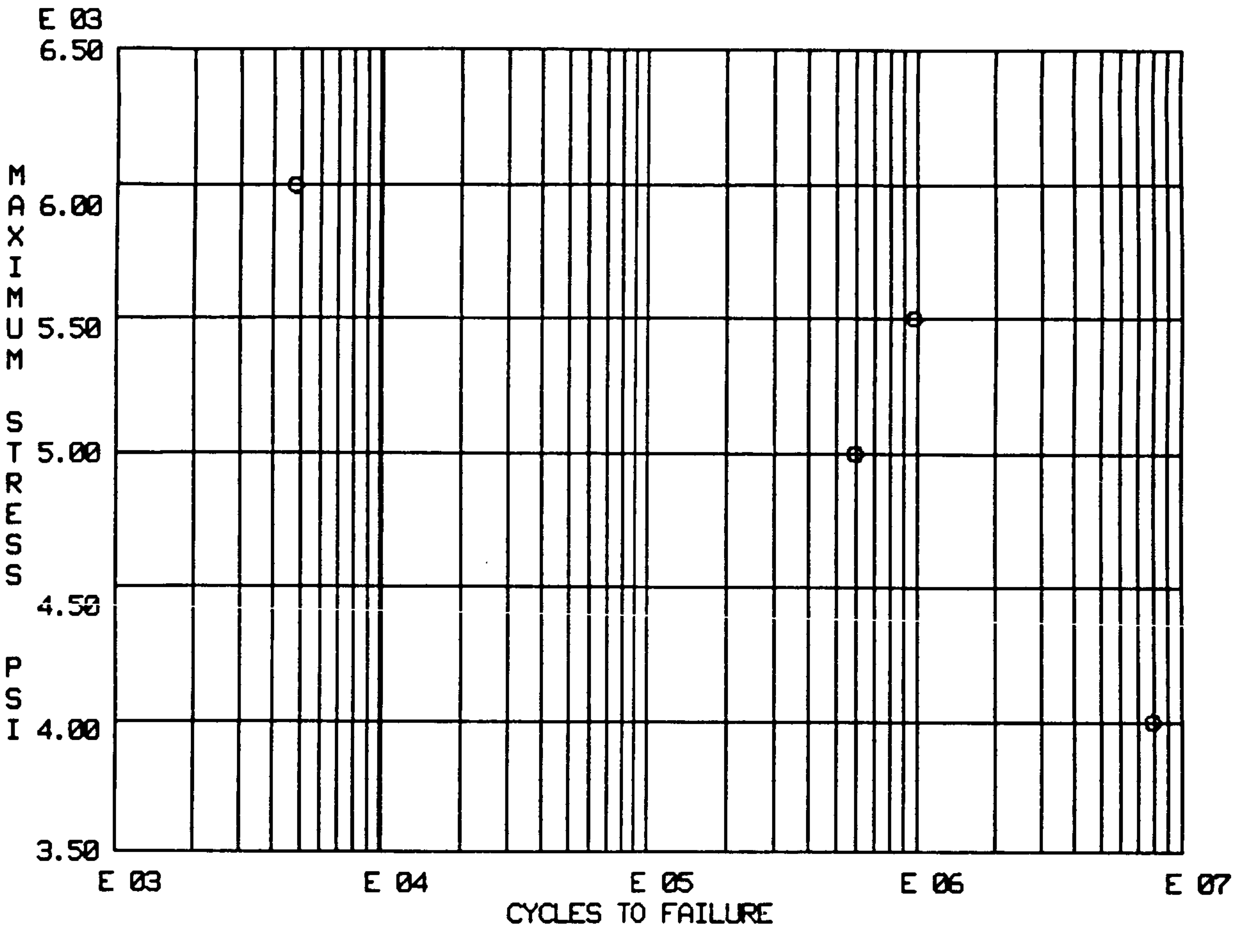
Figure 5. Room Temperature, -0.5 R Ratio, Specimen Design 13, Fatigue Results.



NASA LAMINATED WOOD FATIGUE TEST RESULTS
(design 13, R ratio = -1.0)

Specimen Description	Maximum Stress (psi)	Cycles to Failure
3-2-3-13-281	3500	2,504,500
3-2-3-13-296	3500	1,916,300
3-2-3-13-288	3500	7,822 100
3-2-3-13-285	4000	2,606,600
3-2-3-13-280	4000	847,200
3-2-3-13-277	4000	160,600
3-2-3-13-273	4000	3,217,500
3-2-3-13-270	5000	9,500
3-2-3-13-276	5000	14,900
3-2-3-13-278	5000	130,500
3-2-3-13-282	5000	245,300
3-2-3-13-284	6000	7,100
3-2-3-13-283	6000	5,100
3-2-3-13-279	6000	200
3-2-3-13-269	6000	56,600

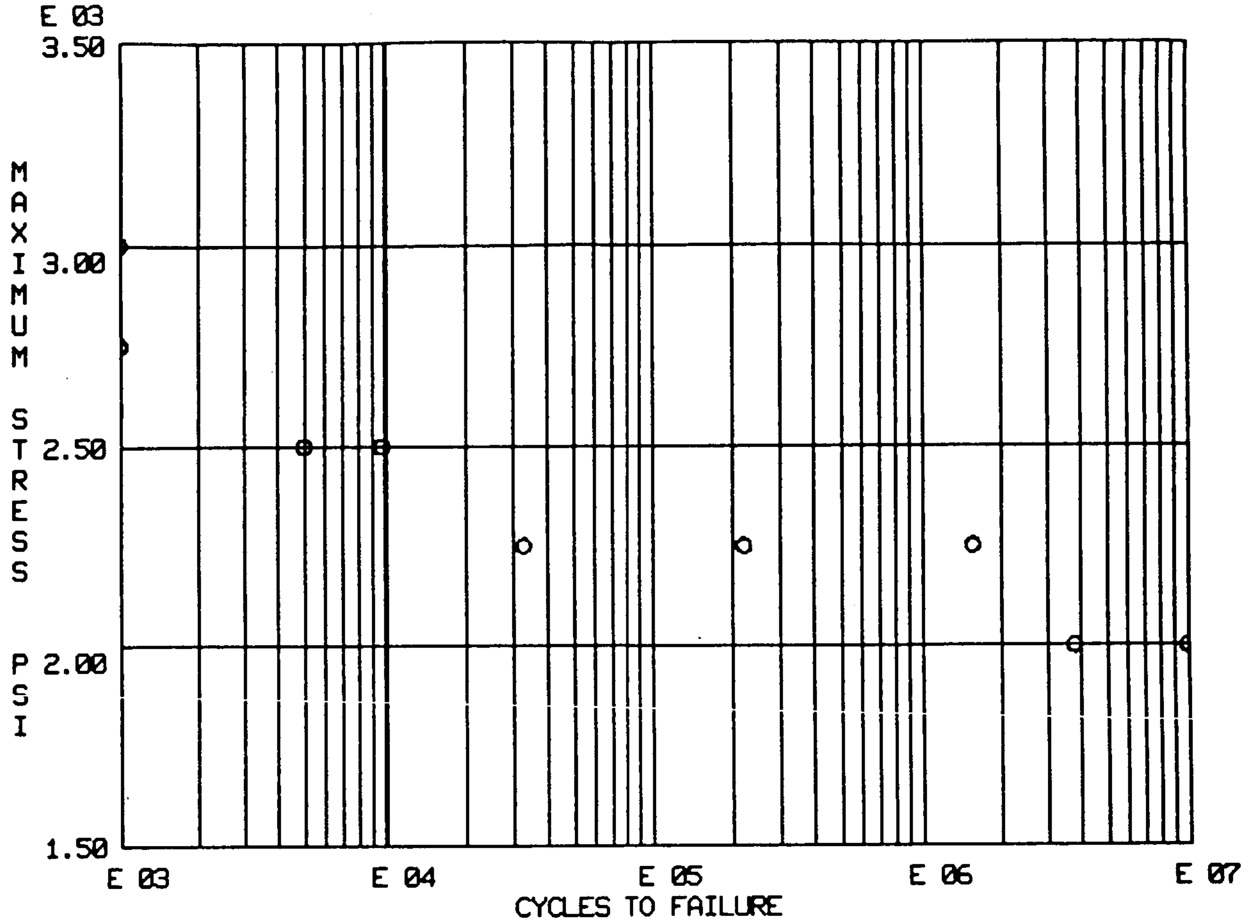
Figure 6. Room Temperature, -1.0 R Ratio, Specimen Design 13, Fatigue Results.



NASA LAMINATED WOOD FATIGUE TEST RESULTS
(design 13, R ratio = 0.0)

Specimen Description	Maximum Stress (psi)	Cycles to Failure
3-2-3-13-298B	6000	4,800
3-2-3-13-299B	5000	591,200
3-2-3-13-300B	4000	7,859,100
3-2-3-13-320	5500	977,200

Figure 7. 120°F, Approximately 100%RH, 0.0 R Ratio, Specimen Design 13, Fatigue Results.

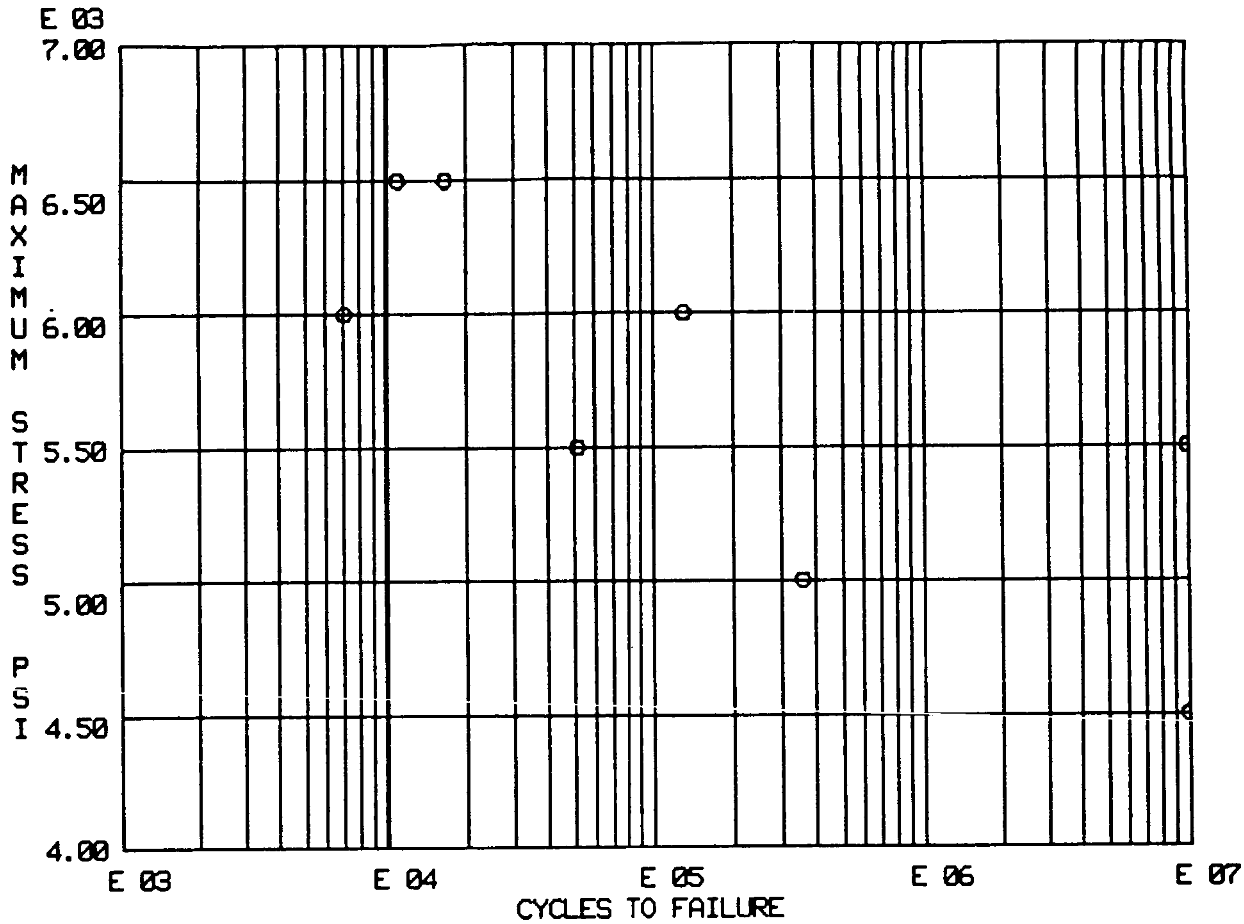


NASA LAMINATED WOOD FATIGUE TEST RESULTS
(design 13, R ratio = -1.0)

Specimen Description	Maximum Stress (psi)	Cycles to Failure
3-2-3-13-319	3000	400
3-2-3-13-325	2500	9,700
3-2-3-13-326	2000	3,747,500
3-2-3-13-328	2500	5,000
3-2-3-13-330	2750	500
3-2-3-13-332	2250	1,547,500
3-2-3-13-334	2250	219,300
3-2-3-13-336	2250	32,500
3-2-3-13-338	2000	10,000,000 *

* Runout

Figure 8. 120°F, Approximately 100% RH, -1.0 R Ratio, Specimen Design 13, Fatigue Results.

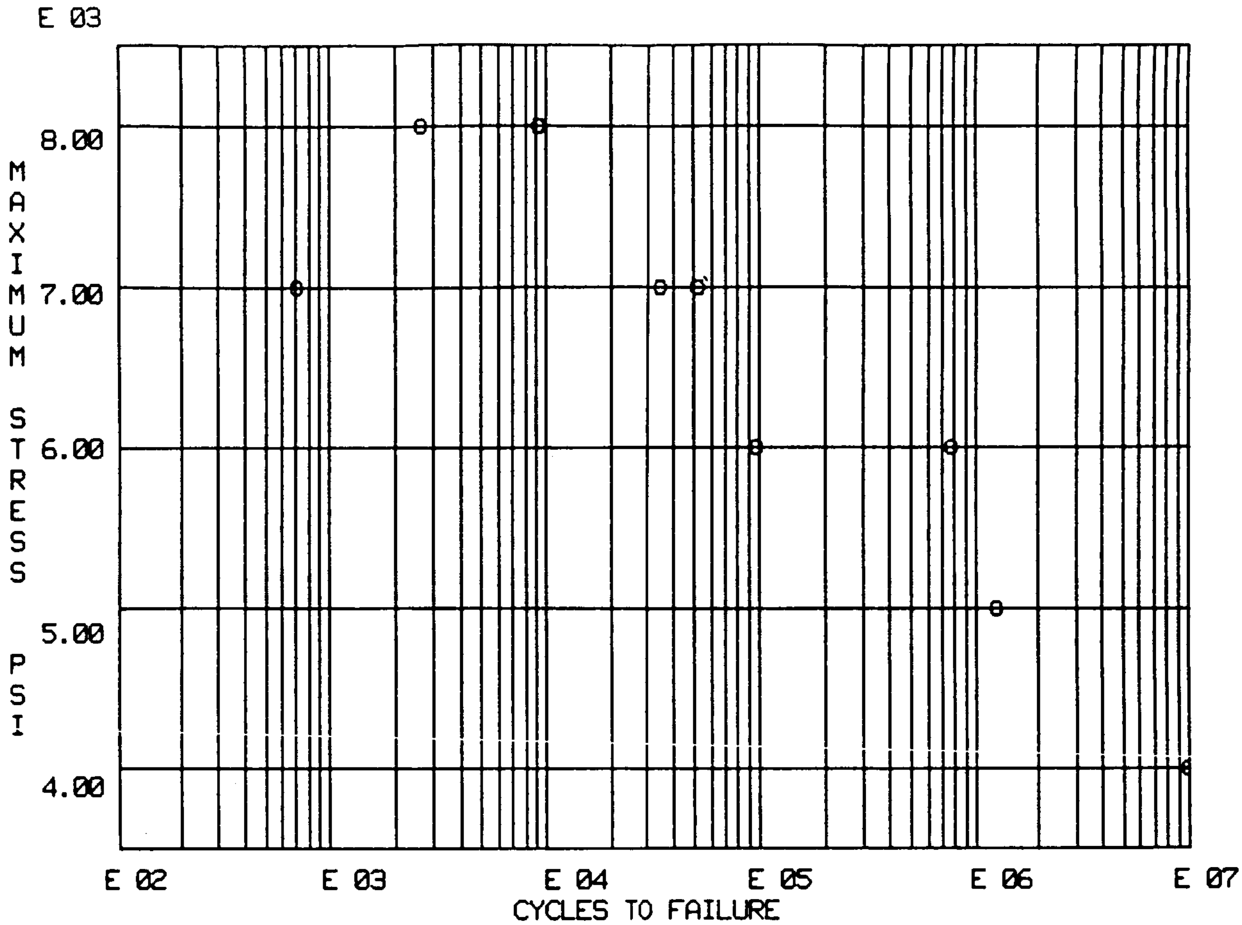


NASA LAMINATED WOOD FATIGUE TEST RESULTS
(design 13J, R ratio = 0.0)

Specimen Description	Maximum Stress (psi)	Cycles to Failure
5-2-3-13J-235	5000	355,100
5-2-3-13J-236	6000	7,000
5-2-3-13J-245	4500	10,000,000 *
5-2-3-13J-246	5500	51,600
5-2-3-13J-247	5500	10,000,000 *
5-2-3-13J-248	6000	130,000
5-2-3-13J-249	6500	11,000
5-2-3-13J-250	6500	16,500

* Runout

Figure 9. Room Temperature, 0.0 R Ratio, Specimen Design 13J, Fatigue Results.

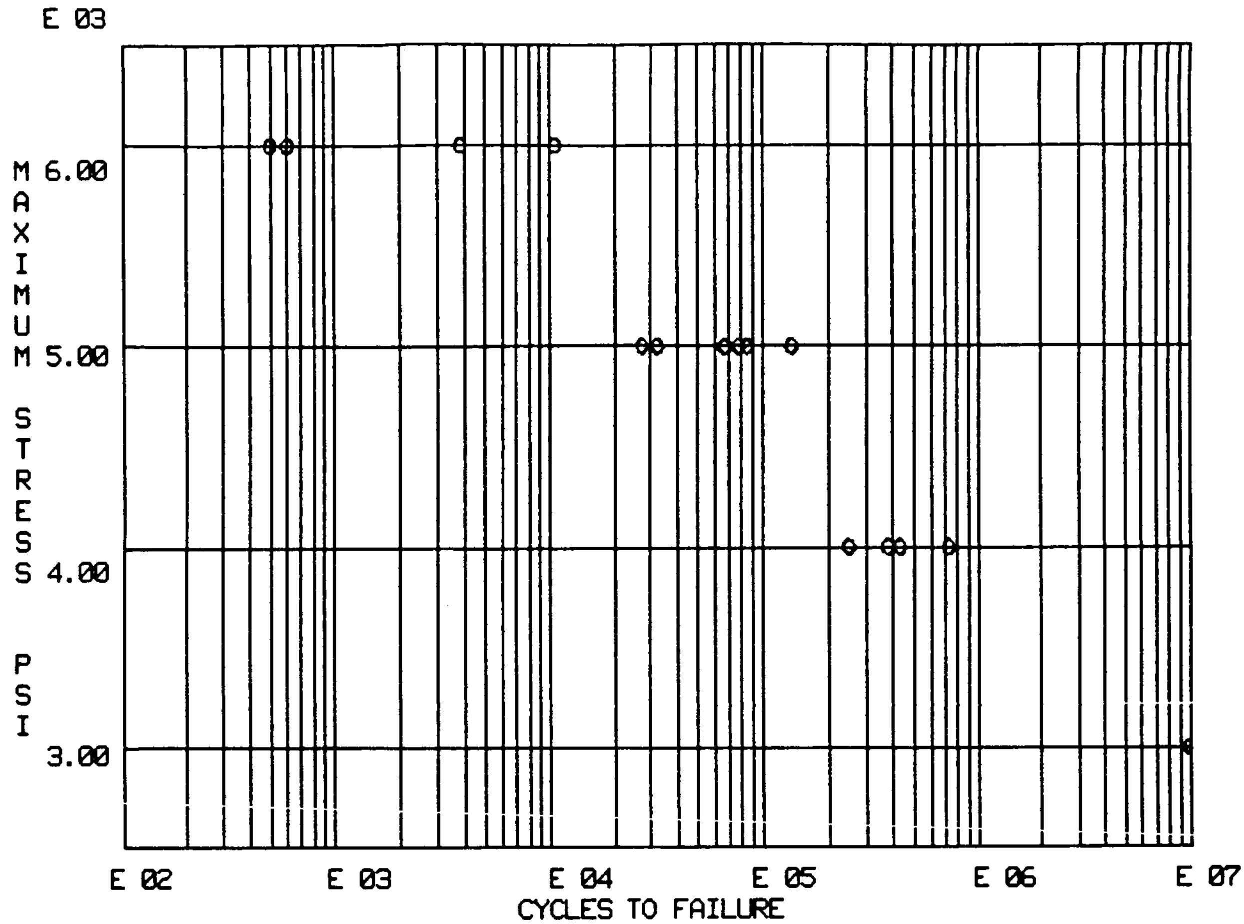


NASA LAMINATED WOOD FATIGUE TEST RESULTS
(design 13J, R ratio = -0.5)

Specimen Description	Maximum Stress (psi)	Cycles to Failure
5-2-3-13J-251	4000	10,000,000 *
5-2-3-13J-275	4000	10,000,000 *
5-2-3-13J-274	5000	1,259,200
5-2-3-13J-264	6000	774,100
5-2-3-13J-272	6000	97,500
5-2-3-13J-268	7000	52,000
5-2-3-13J-267	7000	700
5-2-3-13J-266	7000	34,800
5-2-3-13J-271	8000	2,600
5-2-3-13J-265	8000	9,200

* Runout

Figure 10. Room Temperature, -0.5 R Ratio, Specimen Design 13J, Fatigue Results.

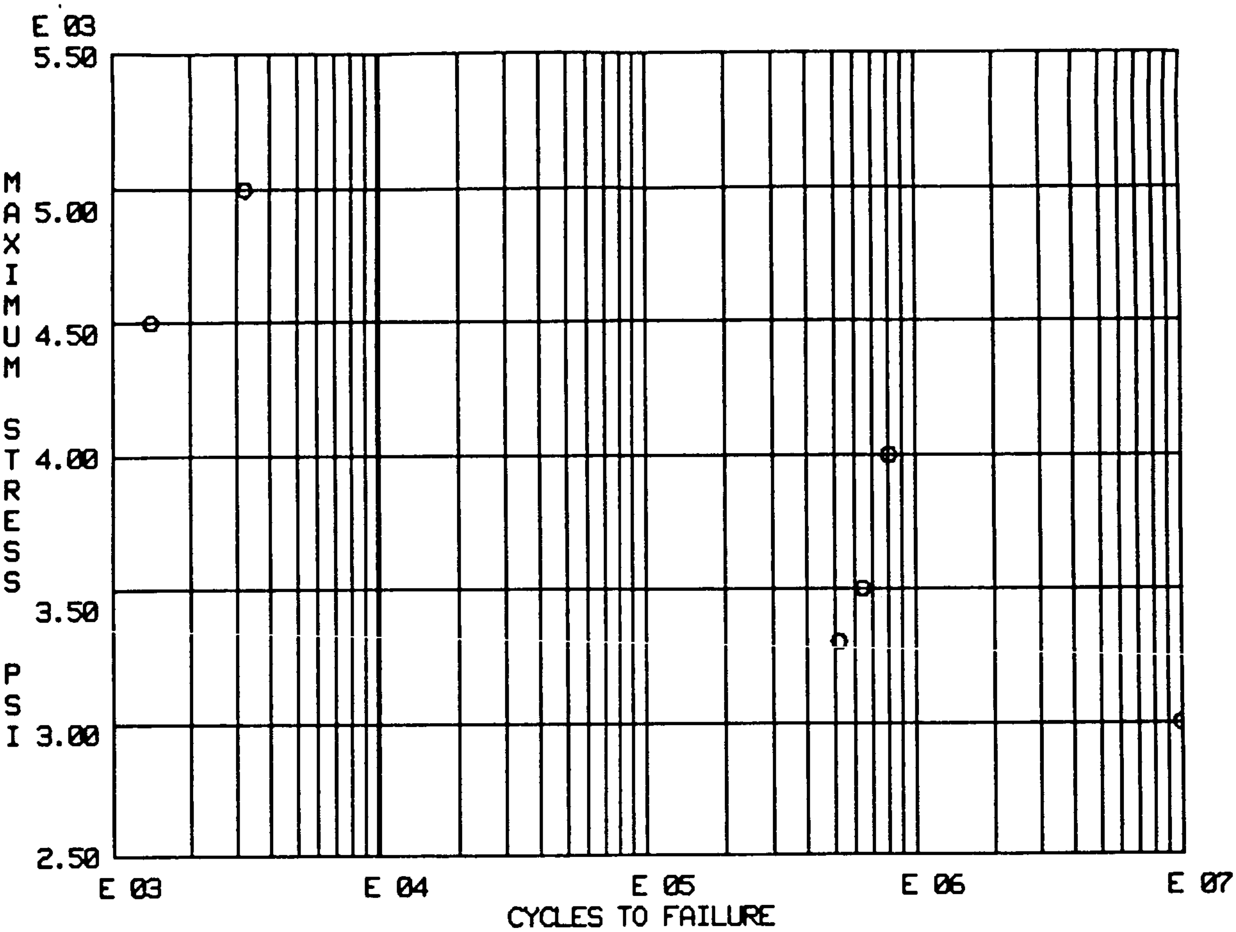


NASA LAMINATED WOOD FATIGUE TEST RESULTS
(design 13J, R ratio = -1.0)

Specimen Description	Maximum Stress (psi)	Cycles to Failure
5-2-3-13J-295	3000	10,000,000 *
5-2-3-13J-287	4000	376,700
5-2-3-13J-289	4000	248,700
5-2-3-13J-304	4000	427,600
5-2-3-13J-303	4000	726,400
5-2-3-13J-286	5000	135,700
5-2-3-13J-290	5000	67,000
5-2-3-13J-302	5000	77,500
5-2-3-13J-301	5000	32,500
5-2-3-13J-300	5000	84,600
5-2-3-13J-298	5000	27,100
5-2-3-13J-294	6000	3,800
5-2-3-13J-293	6000	600
5-2-3-13J-292	6000	500
5-2-3-13J-291	6000	10,500

* Runout

Figure 11. Room Temperature, -1.0 R Ratio, Specimen Design 13J, Fatigue Results.

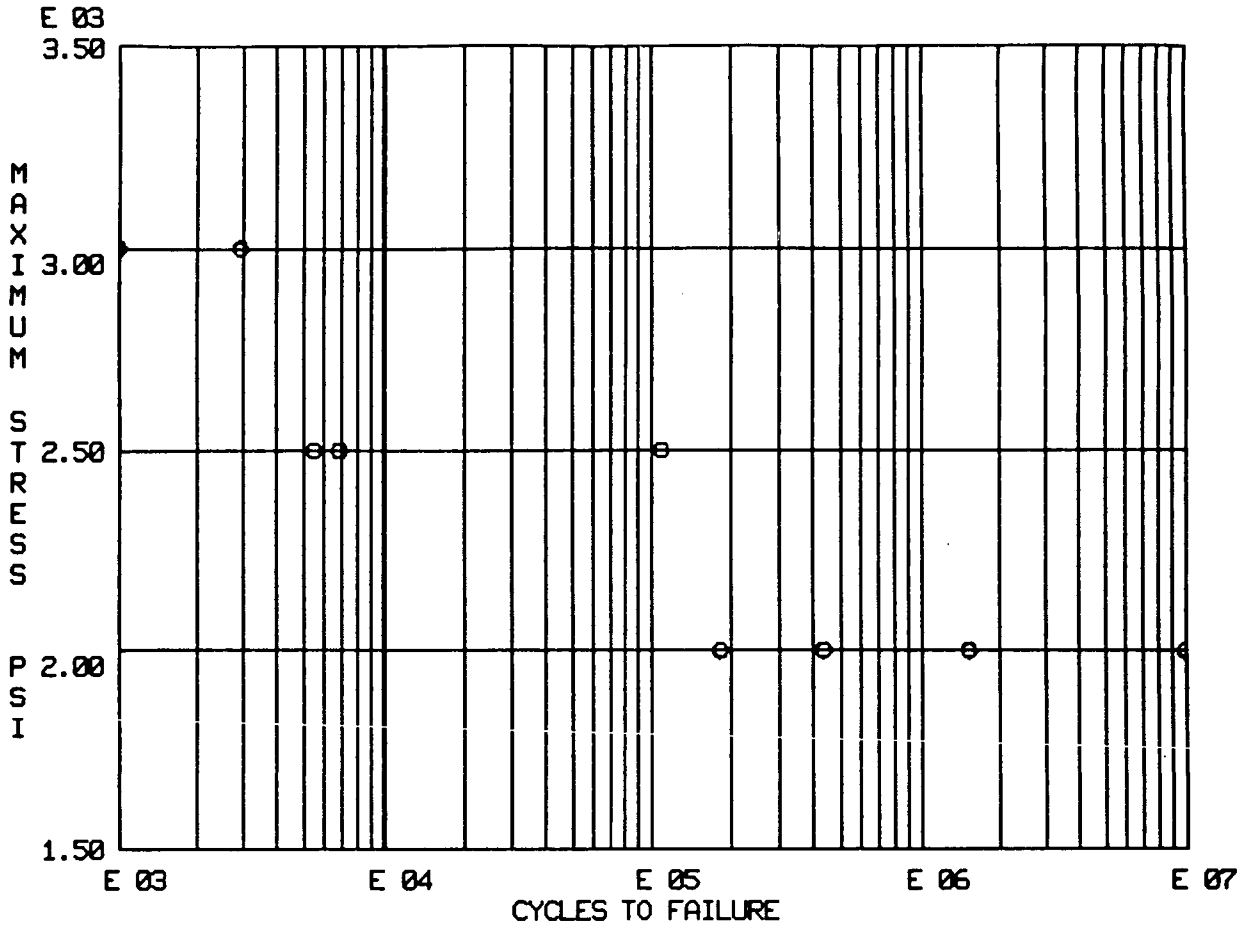


NASA LAMINATED WOOD FATIGUE TEST RESULTS
(design 13J, R ratio = 0.0)

Specimen Description	Maximum Stress (psi)	Cycles to Failure
5-2-3-13J-311	4000	800,800
5-2-3-13J-312	5000	3,200
5-2-3-13J-313	4500	1,400
5-2-3-13J-314	3500	628,800
5-2-3-13J-315	3300	522,000
5-2-3-13J-316	3000	10,000,000 *

* Runout

Figure 12. 120°F, Approximately 100% RH, 0.0 R Ratio, Specimen Design 13J, Fatigue Results.



NASA LAMINATED WOOD FATIGUE TEST RESULTS
(design 13J, R ratio = -1.0)

Specimen Description	Maximum Stress (psi)	Cycles to Failure
5-2-3-13J-318	2000	180,700
5-2-3-13J-321	2000	10,000,000 *
5-2-3-13J-323	3000	2,900
5-2-3-13J-324	2500	6,800
5-2-3-13J-327	2500	109,900
5-2-3-13J-329	3000	900
5-2-3-13J-331	2500	5,500
5-2-3-13J-333	3000	500
5-2-3-13J-335	2000	1,518,600
5-2-3-13J-337	2000	434,500

* Runout

Figure 13. 120°F, Approximately 100% RH, -1.0 R Ratio, Specimen Design 13J, Fatigue Results.

content to approximately 12 percent. The first batch of specimens soaked all exhibited severe delamination of the glass/epoxy grip reinforcing after the required exposure and were scraped.

All the subsequent specimens were sealed with plastic wrap and duct tape so that only their test sections were exposed to the moist environment. Our system used to maintain approximately 100% RH during the test also caused the moisture content to rise during the test especially on the high cycle test. All the fatigue tests were run at a loading frequency of 5 Hz so that the 10^7 runout tests required 23.1 days. On several of the runout specimens we removed the test sections and baked them out at 220°F and found moisture contents as high as 17 percent by weight. Two of the STL MTS fatigue test systems with attendant hydraulic grips and antibuckling fixtures for RT and RH testing are shown pictorially in Figure 14.

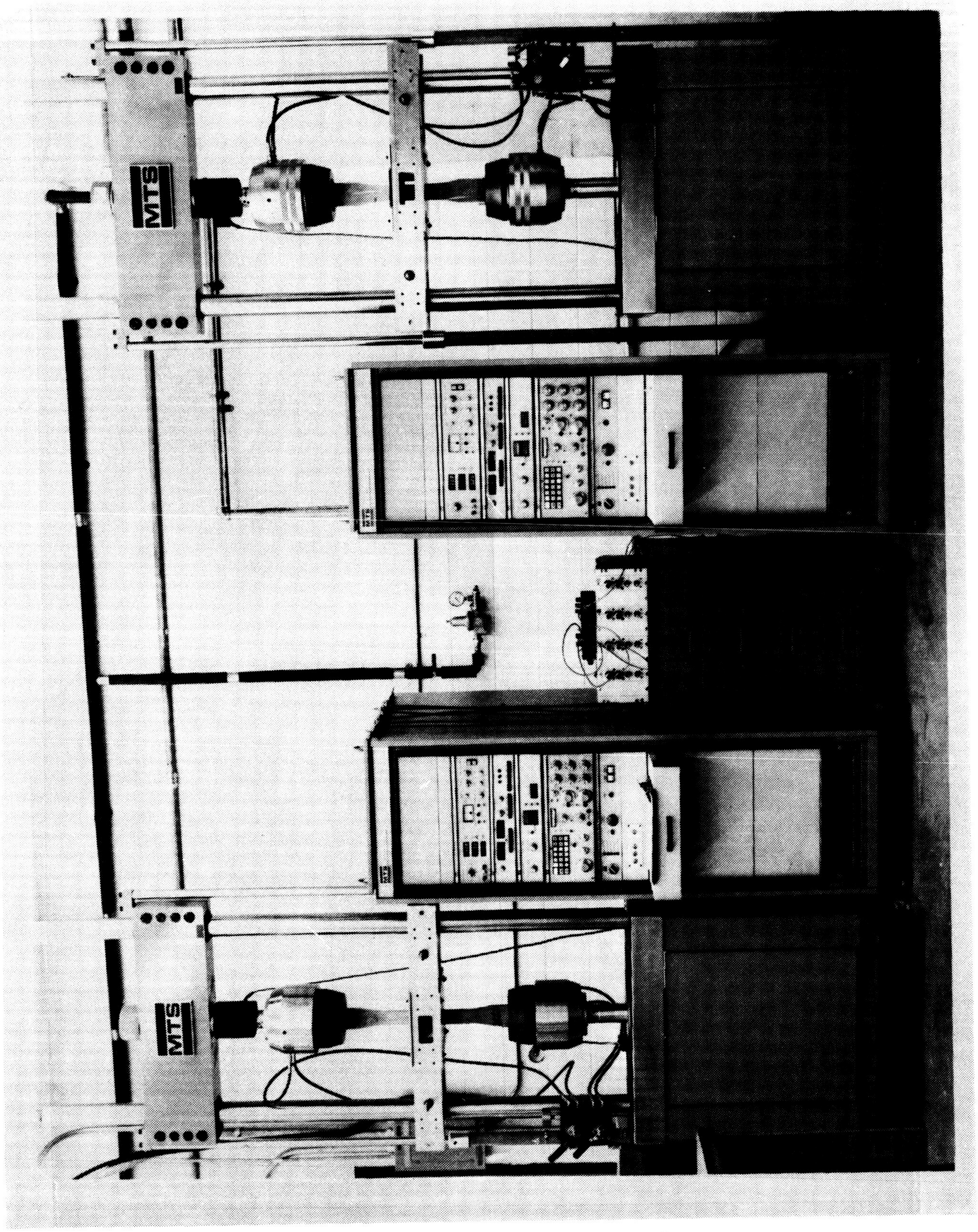


Figure 14. Typical Negative R Ratio RT and RH Fatigue Test Set-Up.

SECTION 4
CONCLUSIONS AND RECOMMENDATIONS

The static monotonic tension and compression test results compare favorably with results obtained by other investigators with much larger samples (i.e., Reference 3). The 5/1 span/depth ratio short beam shear test specimen geometry appears marginal for this application. Although the short beam shear test is very straight-forward and economical the failure mode is variable. The 10 degree off-axis tensile shear test appears to be a viable alternative to the short beam shear test (at least in the LR material direction) although the specimens are more difficult to prepare and the procedure is much more involved. Adding three scarf joints to the monotonic tensile specimen seemed to produce no effect of the material modulus but did reduce the ultimate strength at both environmental conditions. Increasing the temperature and moisture content of the monotonic specimens apparently produced significant reductions in modulus and strength.

The University believes the Task II cyclic fatigue test results are conservative in comparison with much larger volume specimens. A single low strength ply in a 3 ply laminate would produce relatively low cycle results and account for considerable scatter. The same low strength ply may not have the same effect in a 20 or 30 ply laminate. The author had some success in visually inspecting the fatigue specimens before test and ranking the test results based upon appearance.

Any effects produced by increasing temperature or moisture content or adding scarf joints in the fatigue tests was much less apparent than with the monotonic tests. The University recommends that a statistical evaluation of the Task II results be undertaken to determine what variables, if any, have a statistically significant effect on the mechanical properties or if any additional testing would be in order.

REFERENCES

1. Markwardt, L.J. and W.G. Loungquist, "Tension Test Methods for Wood, Wood-Base Materials and Sandwich Construction," Forest Products Laboratory Report No. 2055, June 1956.

2. Chamis, C.C. and J.H. Sinclair, "Ten-Degree Off-Axis Test for Shear Properties in Fiber Composites," Experimental Mechanics, September 1977.

3. Bertelsen, W.D., "Fatigue Strength Testing of Scarf Jointed Douglas Fir/Epoxy Laminates Containing High and Low Levels of Moisture," Gougeon Brothers Inc., Bay City, Michigan, Report No. GB-12, May 1984.

1. Report No. NASA CR-174910

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Design of Test Specimens and Procedures for Generating Material Properties of Douglas Fir/Epoxy Laminated Wood Composite Material; With the Generation of Baseline Data at Two Environmental Conditions

5. Report Date JUNE 1985

6. Performing Organization Code

7. Author(s)
Paul E. Johnson

8. Performing Organization Report No. UDR-TR-85-45

9. Performing Organization Name and Address
University of Dayton Research Institute
300 College Park
Dayton, OH 45469

10. Work Unit No.

11. Contract or Grant No. DEN 3-286

12. Sponsoring Agency Name and Address
U. S. Department of Energy
Wind Energy Technology Division
Washington, DC 20545

13. Type of Report and Period Covered Contractor Report

14. Sponsoring Agency ~~Code~~ Report No. DOE/NASA/0286-1

15. Supplementary Notes
Final Report. Prepared Under Interagency Agreement DE-A101-79ET20320. Project Manager, R. F. Lark, Wind Energy Project Office, NASA Lewis Research Center, Cleveland, OH 44135

16. Abstract

In support of the design of wind turbine generator airfoils/blades utilizing Douglas Fir/West System Epoxy laminated composite material a program was undertaken to define pertinent material properties utilizing small scale test specimens. Task I was the development of suitable monotonic tension, compression, short beam shear and full reversed cyclic specimen designs and the companion grips and testing procedures. Task II was the generation of the material properties at two environmental conditions utilizing the specimens and procedures developed in Task I.

The monotonic specimens and procedures generated results which compare favorably with other investigators while the cyclic results appear somewhat conservative. Adding moisture and heat or scarf joints degraded the monotonic performance but had a more nebulus effect with cyclic loading.

17. Key Words (Suggested by Author(s))
Douglas Fir; West System Epoxy, Wood Composite; Wind Turbine; Material Properties

18. Distribution Statement
[redacted]

19. Security Classif. (of this report) Unclassified

20. Security Classif. (of this page) Unclassified

21. No. of pages 45

22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161