SSD94D0211

Test Plan

GCPS Task 4, Subtask 4.2
Thrust Structure Development

Cooperative Agreement NCC1-193

September 2, 1994

H. S. Greenberg, Principal Investigator

Rockwell Aerospace
Space Systems Division

NORTHROP GRUMMAN

Rockwell Aerospace
North American Aircraft

TABLE OF CONTENTS

APPENDICES

ILLUSTRATIONS

TABLES

Rockwell International - Proprietary Information

DETAILED TEST PLAN - SSTO THRUST STRUCTURE

1.0 INTRODUCTION

The Single Stage To Orbit (SSTO) vehicle is designed to lift off from a vertical position, go into orbit, return to earth for a horizontal landing, and be reusable for the next mission. (NASA baseline only) In order to meet its performance goals, the SSTO relies on light weight structure and the use of 8 tri-propellant engines. These engines are mounted to the thrust structure. This test plan addresses selection of the material for this structure, and the integrity of the design through testing of elements and a full-scale subcomponent.

This test plan supports the development of the design for an advanced composite thrust structure for a Single Stage to Orbit manned, heavy launch vehicle. The thrust structure is designed to transmit very high thrust loads from the engines to the rest of the vehicle (see Figure 1). The thrust structure will also be used for primary attachment of the twin vertical tails and possibly act as the aft attach point for the wing. The combination of high loading, high vibration, long service life and high acoustic environments will need to be evaluated by tests. To minimize design risk, a building block approach will be used. We will first screen materials to determine which materials show the most promise for this application. Factors in this screening will be the suitability of these materials for chosen design concepts, particularly concerning specific strength, environmental compatibility and applicability to fabrication processes. Next we will characterize two material systems that will be used in the design; the characterization will allow us to generate preliminary design data that will be used for the analysis. Element testing will be performed to evaluate critical structural locations under load. Final testing on the full-scale test article will be performed to verify the design and to demonstrate predictability of the analysis.

Additionally, risks associated with fabricating full scale thrust structures will be reduced through testing activities. One of the major concerns that stems from full scale fabrication is the realities of size and the associated complexities of handling, manufacturing, and assembly. The need exists to fabricate, assemble and test representative joint specimens to achieve confidence in the design and manufacturing technologies being proposed.

The full scale subcomponent test articles will be loaded TBD

2.0 SCOPE

This document is the Test Plan for a series of tests leading from initial material screening, material down-selection, element testing, and finally testing the full scale subcomponent SSTO Thrust Structure test specimen. The purpose of this plan is to summarize the test objectives, success criteria, test parameters and procedures, expected performance and data analysis plans, test schedule, and related safety provisions; and to describe the test articles, test instrumentation, and test facility requirements.

Testing will be performed to screen six materials for suitability for SSTO thrust structure loads and environments. Two materials will be down selected from screening testing. These two materials will be characterized for durability, damage tolerance and thermal cycling, and a preliminary design database will be established for these materials. Element tests of critical structural joints, using selected materials, will then be accomplished. Two full scale test articles, representing the engine thrust support structure of one engine, will be tested to verify the structural integrity of this full scale component.

This plan is submitted to satisfy the requirements of paragraph 2.4.3 of NRA8-12 and is submitted to LaRC for approval. This test plan will be updated as required to reflect continued refinements in the design.

3.0 OBJECTIVES

The primary purpose of this building block test plan is to minimize risk in implementing new light weight structure technologies in the SSTO vehicle. To this end, screening, characterization, element and full scale subcomponent testing will be done. The overall objectives of this test program are:

1) Demonstrate the full scale test article's ability to withstand peak static thrust and maneuvering loads and correlate the results with Finite Element Model (FEM)predicted results.
2) Verify the cyclic strength of the engine mount structure for limit longitudinal thrust loads before and after impact applications.
3) Demonstrate, during and after the tests, non destructive evaluation/integral health monitoring (NDE/IHM) techniques to discern delamination, flaw and crack growth conditions.

4.0 BACKGROUND

The Thrust Structure's function is to provide main engine attachment and act as interface structure for the main fuselage structure and tail. The test structure is representative of one of the engine mounting pads, together with its attaching support structure.

The thrust cone must shear the axial load from the longerons into near-uniform circumferential axial loading at the cone-to-aft skirt intersection. Kick loadings are imposed on the aft ring frame. For an RD704 engine, the ultimate structural load capability must be 618 kips at the longeron interface. The high loads, combined with an extreme acoustic and vibration environment, are anticipated to be key factors in the design of these structures.

Significant to the aft kick frame design is the requirement to sustain the loads due to any one engine out. The combination of actuator loads and engine-out conditions is a significant design requirement.

5.0 APPLICABLE DOCUMENTS

XXXXXXXXX	Master Project Plan
ANS B46.1-1978	Surface Texture
ASTM D3518	Test for Inplane Shear Stress-Strain Response of Unidirectional Reinforced Plastics.
ASTM D3039	Test for Tensile Properties of Oriented Fiber Composites
ASTM E 4-83	Load Verification of Testing Machines
ASTM E84	Verification and Classification of Extensometers
NASA 1092	Standard Tests for Toughened Composites
NASA 1142	NASA/Aircraft Industry Standard Specification for Graphite Fiber/Toughened Thermoset Resin Composite Material
SACMA SRM 2-88	SACMA Recommended Test Method for Compression After Impact Properties of Oriented Fiber-Resin Composites
SACMA SRM 7-88	SACMA Recommended Test Method for Inplane Shear Stress-Strain Properties of Oriented Fiber-Resin Composites
UWME-DR-501-103-1	Iosipescu Shear Properties of Graphite/Epoxy Composite Laminates Appendix A

All test equipment will be calibrated and verified to be within tolerance.

No safety specifications are referenced. Test facility personnel have the final responsibility and authority regarding test operation and safety. They may abort the test at any time if they perceive a threat to test personnel or the facility. During testing, non-essential personnel shall be excluded from the test operations. Essential personnel shall be defined as including these functions: site supervisor, test conductor, safety engineer, instrumentation engineers, control panel technicians, team member lead and monitors, and instrumentation monitors.

6.0 GENERAL REQUIREMENTS

6.1 Uncured Prepreg Physical and Chemical Properties

The supplier will furnish a TBD test report with each shipment of material procured. The supplier shall identify any anomalies in the material.

The material shall be examined by fabrication operators, as the laminates or test articles are being fabricated. Any fiber mis-alignment, gaps, splices, fuzzballs, or other gross irregularities shall not be placed in the layup. Laminates fabricated for coupon specimens will be tested for resin content, graphite fiber areal weight, and volatile content prior to fabrication of specimens. Material testing will be done to NASA 1142.

6.2 Specimen identification and tractability

Material used for all test specimens and articles, will be tracked from receipt from manufacturer through fabrication and testing. All laminates and specimens will be identified with indelible marking pens. This identification will be carried through the entire test procedure and test data reduction. An identification numbering system will be TBD. Laminate and specimen identification numbers will be logged in a laboratory notebook.

Coupon test specimens will be cut from identified fabricated panels. Each specimen shall be identified with a specimen number. This identification will be carried through the entire test procedure and test data reduction.

Element level specimens will be indelibly identified on each individual piece to maintain tractability. An additional specimen number shall identify the element test article in total. These identifications will be carried through the entire test procedure and test data reduction.

The static and fatigue/IHM test articles will be identified on each individual component to maintain tractability. An additional specimen number shall identify the static or fatigue test article in total. These identifications will be carried through the entire test procedure and test data reduction.

Moisturization time in and out, weight, etc., will be logged in a laboratory notebook. If specimens are shipped to an outside vendor or a team member, date and carrier will be logged in the laboratory notebook. All times in and out of the moisturization environment will be recorded. All moisturization data will be entered in a log book. Moisturization will be according to NASA 1142, B.2.5.

A Rockwell NAAD-Tulsa Laboratory Test Data, form T2962-Z-5a NEW 5/75 will be used to record test data. (See Figure 25).

6.3 Data acquisition

A data acquisition system will be used to collect data during test. A data sampling rate of at least one scan per second is specified. A sampling rate of 1 scan per second will be sufficient for the relatively gradual static loading applied to the test article. Data storage and especially data reduction tasks increase immensely with higher rates. The output must be in engineering units as follows:

1. Temperature = degrees Fahrenheit
2. Strain=Microstrain
3. Displacement = Inches
4. Pressure = Pounds per square inch.

6.4 Success Criteria

The following criteria can be used to measure the degree of success of the overall test program.

1. Selection of 6 candidate materials for the thrust structure applications.
2. Screening of the 6 candidate materials to determine the best 2 candidate materials
3. Completion of material property tests for these materials.
4. Selection of the appropriate element tests for the thrust structure.
5. Successful completion of the element tests to establish the ability of the design details, and the materials, to accomplish the desired load capability under the given test conditions.
6. Demonstration of structural capability on the full scale thrust structure test articles.

7.0 DETAILED REQUIREMENTS

7.1 Material Screening

Six materials will be screened by subjecting coupons cut from panels prepared per TBD to the following tests:

a. Tensile strength and modulus
b. Compressive strength and modulus.
c. Open hole tension
d. Open hole compression
e. Compression after impact
f. In plane shear

Table I specifies requirements for these tests.

7.2 Material Characterization

Two materials will be selected from the six material screening test data using the following criteria:

1. One material will be selected as most suitable for fabrication of the thrust structure cone based principally on the specific strength and modulus together with overall suitability for the application and for the fabrication processes.
2. A second material will be selected as most suitable for the other principal structural applications, such as longeron fabrication, based on the same type of criteria as shown above.

These two materials will be subjected to more extensive testing using the following tests:

a. Tensile strength and modulus
b. Compression strength and modulus
c. In plane shear
d. Open hole compression
e. Compression after impact
f. In plane shear
g. Durability testing
h. Thermal cycling
i. Impact tolerance

Table II provides details of these tests.

7.3 Laminate fabrication

All laminate fabrication will be done per NASA 1142, unless otherwise specified. The number of plies in a test panel, and the orientation of those plies, will be determined by the appropriate test specification. Peel plies shall be molded on surfaces that are to be (1) subsequently bonded or (2) tabbed secondarily. The laminate will be cured or consolidated, using the supplier's recommended procedures or specification TBD. When required, post curing shall be performed on test laminates prior to machining of specimens. Prior to determining mechanical properties, test panels shall b e verified to conform to physical property requirements TBD, for the applicable material. Cured ply thickness, resin content, void content, and density will be documented.

7.4 Specimen fabrication

Specimen layout shall allow for 1/2 inch minimum trim from all edges of the laminates. Physical test specimens shall be removed from non-adjacent multiple areas, inside the trim zone. Specimens shall be accurately laid out so that loading axes are closely parallel or normal to fiber axes, as determined by property requirements. Specimens shall be machined carefully to prevent delamination or other damage. Specimens shall be ground to final dimensions using 400 or finer grit abrasive. Peel plies shall be removed immediately prior to bonding operations to avoid contamination. Tabs shall be bonded prior to machining of individual test specimens. During machining, and secondary fabrication operations, and again prior to testing, specimens shall be examined for evidence of defects. Specimen defects shall include, but not be limited to, substandard or incorrectly processed test panels, substandard or delaminated secondary bonds, incorrect, or mis-aligned test axes, incorrect dimensions, fractures, rough machined edges, and the like. Defective specimens shall not be tested. Where practical, more than one type and/or alignment of test specimen may be removed from a single panel.

7.5 Testing

All specimens and test articles, representing this effort, will be tested using calibrated test machines and related equipment (load fixtures, ovens, etc.). The data obtained will be recorded automatically using TBD data acquisition equipment at NAAD-Tulsa or at an independent test laboratory. The data acquisition equipment located at SSD is TBD, and the equipment at MSFC is TBD. Data will be in force pounds and subsequently converted to engineering units. (See Section 6.0) Tests will be conducted in accordance with NASA 1142, referenced previously, unless otherwise noted.

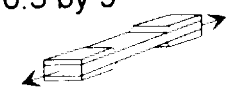
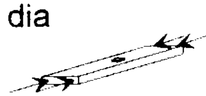
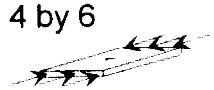
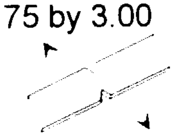
Test temperatures shall meet the requirements of B.2.4 NASA 1142. Moisture conditioning of specimens shall meet the requirements of B.2.4 of NASA 1142.

8.0 DETAILED TEST ARTICLE/TEST SPECIMEN DESCRIPTION

Screening tests will be conducted on 6 materials selected through design trades. Three specimens of each material will be tested at room temperature and at TBD hot/wet. All specimens will be tested per NASA 1142 unless otherwise noted. Table I is a matrix with the test, test article description, test description, instrumentation, and appropriate NASA 1142, SACMA and Iosipescu test identified.

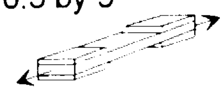
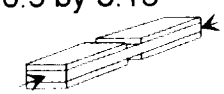
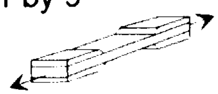
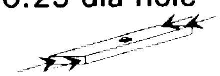
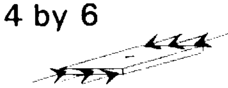
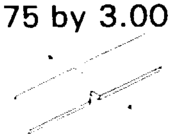
After the completion of screening tests, the six materials will be down selected to two materials, for characterization. Six specimens of each material will be fabricated, using two batches of material. A batch of material shall be defined as a quantity of material formed during the same process or in one continuous process, and having identical characteristics throughout. A batch may also be called a lot. A batch shall consist of uncured resin or dry fiber, or fiber impregnated with uncured resin. All specimens will be tested per the appropriate specification. Table II is a matrix with the test, test article description, test description, instrumentation, and appropriate test identified.

Using material selected from the characterization testing, critical structural elements will be defined and tested. (See Table III)

Test Item	Test Objective	Test Article Description	Replicates		Test Description	Instrumentation	Test Spec
			RT	Hot / wet			
4.1 a	Screen 6 materials for properties at operating temperatures	0.5 by 9  $(0)_8$	3 specimens x 6 materials = 18	3 specimens x 6 materials = 18	Tension strength and modulus per spec	per spec	NASA 1142 B.6
4.1 b	Screen 6 mat'l for properties at operating temperatures	0.5 by 3.15  $(0)_8$	3 specimens x 6 materials = 36	3 specimens x 6 materials = 36	Compression strength and modulus per spec	per spec	NASA 1142 B.7
4.1 c	Screen for open hole tension properties at operating temperatures	1.5 by 12, 0.25 dia  $(45/0/-45/90)_{2s}$	3 specimens x 6 materials = 18	3 specimens x 6 materials = 18	Open hole tension per spec	none	NASA 1142 B.9
4.1 d	Screen for open hole compression at operating temperatures	1.5 by 10, 0.25 dia  $(45/0/-45/90)_{2s}$	3 specimens x 6 materials = 18	3 specimens x 6 materials = 18	Open hole compression per spec	none	NASA 1142 B.10
4.1 e	Screen 6 materials for effects of impact	4 by 6  $(45/0/-45/90)_{4s}$	3 specimens x 6 materials = 18	3 specimens x 6 materials = 18	Compression after impact per spec	per spec	SACMA SRM2-88
4.1 f	Screen 6 materials for in plane shear strength	0.75 by 3.00  $(TBD)_{xs}$	3 specimens x 6 materials = 18	3 specimens x 6 materials = 18	In plane shear per spec	none	Iosipescu UWME-DR-501-103-1

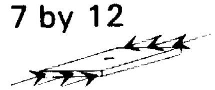
Tests at NAAD. Materials may include, but not limited to IM7, IM9, 977-2, Pultruded Rods, Fiber Placement, Hispidulous, RTM, thermoplastics and low temperature resins. Down select to two materials

Table I - SSTO Thrust Structure Screening of Material

Test Item	Test Objective	Test Article Description	Replicates			Test Description	Instrumentation	Test Spec
			-270 F	RT	Hot / wet			
4.1 g	Preliminary properties database	0.5 by 9  $(0)_8$	6 specimens x 2 materials x 2 batches=24	6 specimens x 2 materials x 2 batches=24	6 specimens x 2 materials x 2 batches=24	Tension Strength & Modulus	Instrumentation per Specification	NASA 1142 B.6
4.1 h	Preliminary properties database	0.5 by 3.15  $(0)_8$	6 specimens x 2 materials x 2 batches=48	6 specimens x 2 materials x 2 batches=48	6 specimens x 2 materials x 2 batches=48	Compression strength & modulus	Instrumentation per Specification	NASA 1142 B.7
4.1 l	Preliminary properties database	1 by 9  $(+45/-45)_{2s}$	6 specimens x 2 materials x 2 batches=24	6 specimens x 2 materials x 2 batches=24	6 specimens x 2 materials x 2 batches=24	In-Plane Shear	Instrumentation per Specification	SACMA SRM 7-88
4.1 i	Preliminary properties database	1.5 by 12 0.25 dia hole  $(45/0/-45/90)_{2s}$	6 specimens x 2 materials x 2 batches=24	6 specimens x 2 materials x 2 batches=24	6 specimens x 2 materials x 2 batches=24	Open-Hole Compression	None	NASA 1142 B.10
4.1 j	Preliminary properties database	4 by 6  $(45/0/-45/90)_{4s}$	6 specimens x 2 materials x 2 batches=24	6 specimens x 2 materials x 2 batches=24	6 specimens x 2 materials x 2 batches=24	Compression after impact	Instrumentation per Specification	SACMA SRM 2-88
4.1 k	Preliminary properties database	0.75 by 3.00  $(TBD)_{xs}$	6 specimens x 2 materials x 2 batches=24	6 specimens x 2 materials x 2 batches=24	6 specimens x 2 materials x 2 batches=24	In plane Shear	None	Iosipescu UWME-DR-501-103-1

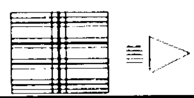
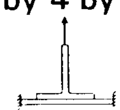
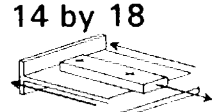
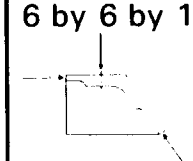
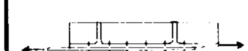
All testing at NAAD

Table II - SSTO Thrust Structure Characterization of Materials

Test Item	Test Objective	Test Article Description	Replicates		Test Description	Instrumentation	Test Spec
			RT	Hot / wet			
4.1 m	Durability Screening	0.5 by 3.15  $(0)_8$	6 specimens 2 materials 2 batches =24	6 specimens 2 materials 2 batches =24	2 LT spectrum load, Residual compression	Back to back strain gages	NASA 1142 B.7
4.1 o	Thermal cycling screening	0.5 by 3.15 	6 specimens 2 materials 2 batches = 24	6 specimens 2 materials 2 batches = 24	-270F to 300F 1 LT residual compression	Back to back strain gages	NASA 1142 B.7
4.1 p	Damage tolerance screening	7 by 12  $(45/0/-45/90)_{6s}$	6 specimens 2 materials 2 batches = 24	6 specimens 2 materials 2 batches = 24	2 Impact levels 2 LT, residual compression	Back to back strain gages	NASA 1142 B.7

Test o at NAAD
Ttest m & p MSFC

Table II - SSTO Thrust Structure Characterization of Materials

Test Item	Test Objective	Test Article Description	Replicates		Test Description	Instrumentation	Test Spec
			RT	Hot / wet			
4.1 n	Acoustic fatigue effects	22 by 22 	3 specimens x 2 batches = 6		170 dB for 2 LT inspect	Strain Gages	None
4.1 q	Thick cross-ply laminate Verify compression in longeron cap	1.2 by 9 	3 Specimens	3 Specimens	Test compression ultimate and failure	Strain Gages	None
4.1 r	Verify bond pull-off strength	4 by 4 by 6 	3 Specimens	3 Specimens	Tensile pull to ultimate and failure	Strain Gages	None
4.1 s	Ring Frame Joint Verify attachment to ring frame	14 by 18 	2 Specimens	2 Specimens	Test for kick load and fastener load Ultimate & Failure	Strain Gages	None
4.1 t	Engine Mount Test bathtub fitting loading	6 by 6 by 10 	2 Specimens	2 Specimens	Engine mount loading applied to longeron Ultimate & Failure	Strain Gages	None
4.1 u	Shell Joint ShearTest longeron attachment to shell	4 by 12 by 12 	2 Specimens	2 Specimens	Simulate shear attachment to longeron Ultimate & Failure	Strain Gages	None
4.1 v	Evaluate repair to thin structure	8 by 12 by 0.25 	2 Specimens x 2 Designs= 4	2 Specimens x 2 Designs x = 4	Damage and repair Ultimate & Failure	Strain Gages	None

Test t and u at SSD, test n at AFWL/FDD, all other tests at NAAD

Table III - SSTO Thrust Structure Element Testing

The static and fatigue - NDE/IHM tests are identified in Table IV.

9.0 TEST PROCEDURES

Figures 1 through 6 define the detailed test methods to be used in the screening tests. All screening testing will be conducted at NAAD-Tulsa. Figures 7 through 15 define the detailed test methods to be used in the characterization tests, and Figures 16 through 22 define the detailed test methods to be used in the element tests. All characterization testing conducted at room temperature, -270F, and TBD hot/wet, will be done at NAAD-Tulsa, except for durability screening and damage tolerance screening. These tests will be conducted at MSFC. All element testing will be done at NAAD-Tulsa except the engine mount. and shell joint test, which will be done at SSD, and the acoustic fatigue test, which will be done at AFWL/FDD. Test methods for the static test article are defined in Figure 23. Test methods for the fatigue/IHM test article are defined in Figure 24. Both of these test articles will be tested at MSFC.

Test fixtures will be defined at a later date, by NAAD-Tulsa.

10.0 SAMPLE DATA SHEETS

NAAD-Tulsa, form T2962-Z-5a, will be used for recording test data. (See figure 25) All data will be normalized to TBD fiber volume.

11.0 TEST EQUIPMENT

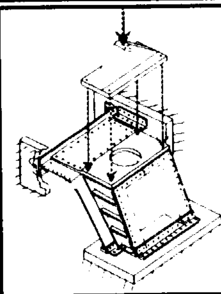
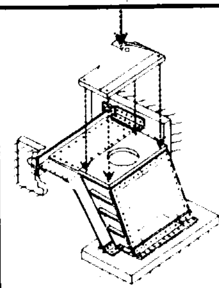
The following equipment located at NAAD-Tulsa is available for use on this test program. This includes the following:

Instron Test Machine	N396550
United Test Machine	N599415
Instron Test Machine	N599511
Instron Test Machine	N702325
Instron Missimer	
OV28	
Universal Testing Machine	AF376552
Extensiometer	

These machines are calibrated on a scheduled basis using Tulsa Division of North America Rockwell Corporation Calibration Procedures.

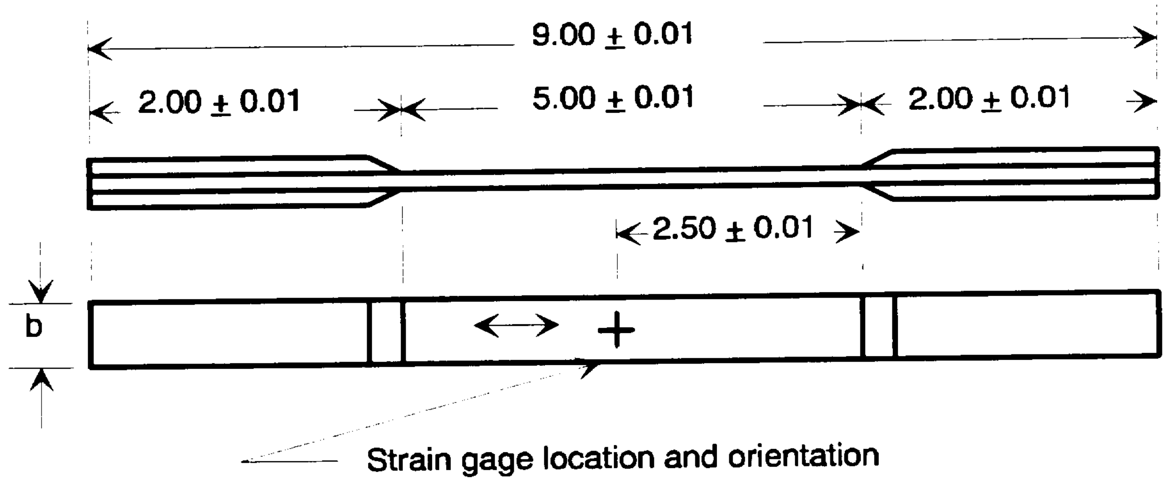
INSERT machines at SSD and at MSFC, and AFWL/FDD

12.0 SKETCHES AND SCHEMATICS

Test Item	Test Objective	Test Article Description	Replicates	Test Description	Instrumentation	Test Speci
			RT			
4.1 w	Verify peak static load capability and correlate with FEM predictions		1	Static Test	250 strain gauges with deflection monitoring, applied ultimate longitudinal thrust, Test to ultimate load, then failure.	None
4.1 x	Verify cyclic strength instability, shell construction, longeron and kick frame, incorporate and verify IHM techniques to discern delamination, flaw or crack growth		1	Durability and IHM Test	250 strain gauges with deflection monitoring Apply cyclic limit longitudinal thrust load in groups of 100 cycles for 2 LT, impact after 1 LT Inspect after each 100 cycles, additional IHM monitoring.	None

Testing to be performed at MSFC

Table IV - SSTO Thrust Structure Full-scale Subcomponent Testing



All dimensions are in inches.

Test	Test Method	Ply Orientation	Specimen width, b, in.
Tension Strength and modulus	Section B.6	(0)8	0.500 +/- 0.007

FABRICATION

1. Specimen edge parallel and perpendicular requirements shall be as specified in paragraph B.2.3.
2. Edge finish shall be 32✓ in accordance with ASA (ANSI) B46.1.
3. Specimen loading tabs shall be fabricated from TBD. Prior to bonding tabs, prepare specimen and tab surfaces by hand sanding (No. 150 grit sandpaper) or sandblasting. Clean surface thoroughly with acetone or MEK.

INSTRUMENTATION

1. For the requirements of section B.6, either a longitudinal strain gage or a suitable extensometer may be used to measure longitudinal strain.

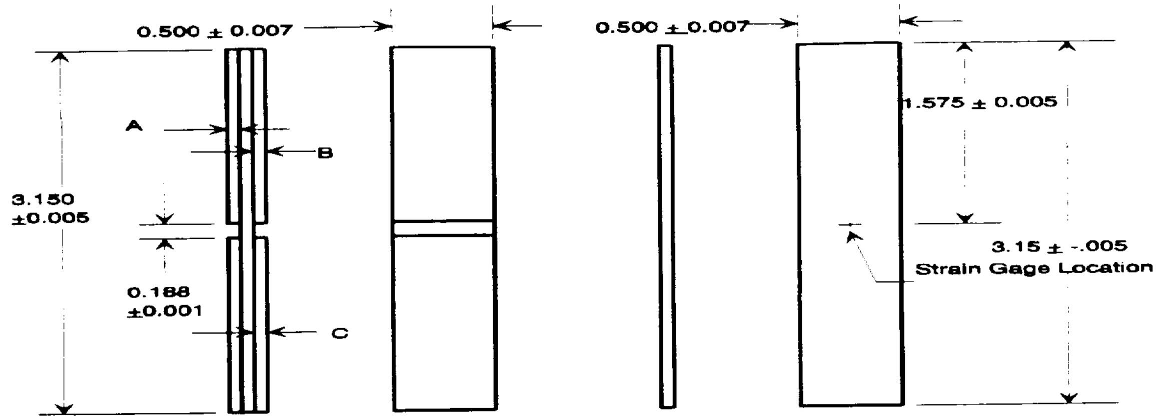
2. Locate strain gages adjacent to specimen centerline as indicated on drawing. Strain gage axis shall be aligned within 0.5' of specimen longitudinal or transverse centerline.

TEST

1. Moisturize hot/wet specimens per NASA 1142, B.2.5

2. Test specimens per NASA 1142, B.6

Figure 1 TENSION STRENGTH AND MODULUS



All dimensions are in inches

Test	Test Method	Ply Orientation	Specimen width
Compression Strength	Section B.7	(0)8	0.500 +/- 0.007
Compression Modulus	Section B.7	(0)8	0.500 +/- 0.007

FABRICATION

1. Laminate orientation: $(0)_8$

2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph B.2.3.

3. Edge finish shall be 32✓ in accordance with ASA (ANSI) B46.1.

4. Specimen loading tabs shall be fabricated from the same graphite/resin prepreg as the specimen, 12 plies thick, with the 0^o fiber direction parallel to the longitudinal axis within $\pm 1^o$. Prior to bonding tabs. prepare specimen and tab bonding surfaces by hand sanding (No 150 grit sandpaper) or sandblasting. Clean surface thoroughly with acetone or MEK. Bond tabs to specimens with 350^o F cure adhesive for 200^o F testing

5. Tab thickness tolerances: A=B $\pm$ 0.010
B=C $\pm$ 0.001

INSTRUMENTATION

1. Either back-to-back strain gages or a suitable extensometer shall be used to measure longitudinal strain on the modulus specimens. Locate straingage or extensometer on specimen centerline as shown. Strain gage axisshall be aligned within 0.5^o of the specimen longitudinal centerline.

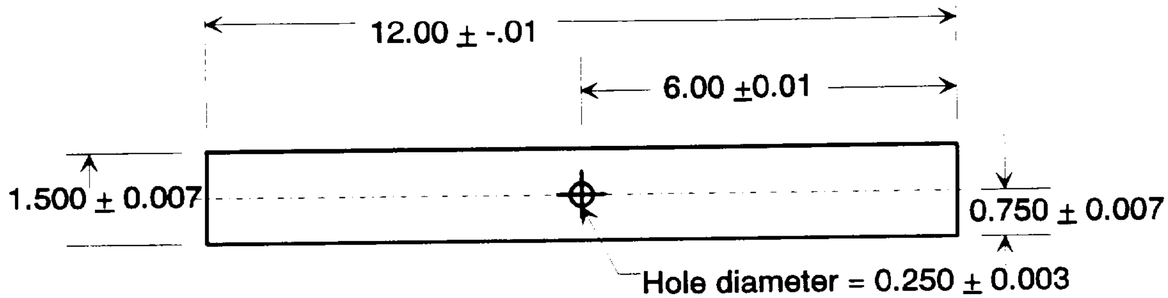
Figure 2 COMPRESSION TEST SPECIMENS

TEST

1. Moisturize hot/wet compression specimens and hot/wet compression modulus specimens per NASA 1142, B.2.5.

2. Test per NASA 1142, B.7

Figure 2 COMPRESSION TEST SPECIMENS (continued)



All dimensions are in inches.

FABRICATION

1. Laminate orientation: $(45/0/-45/90)_{2S}$

2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph B.2.3 of NASA 1142.

3. Edge finish shall be 32✓ in accordance with ASA B46.1.

4. Drill and/or ream hole as specifiec in paragraph B.9.2 of NASA 1142.

INSTRUMENTATION

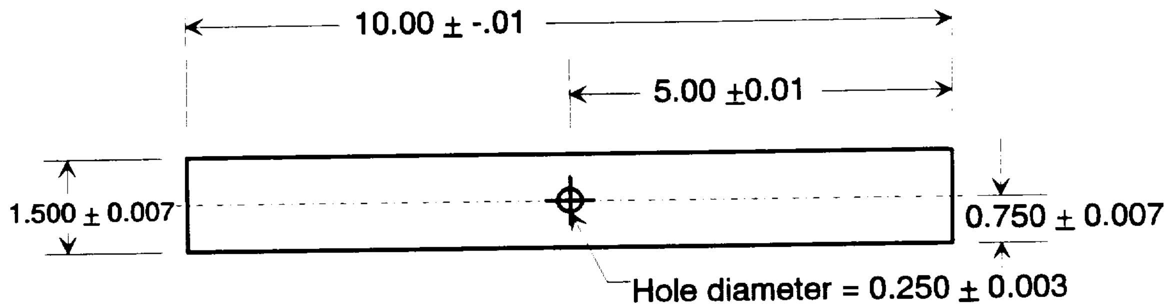
1. None

TEST

1. Moisturize hot/wet specimens per NASA 1142, B.2.5.

2. Test Per NASA 1142, B.9

Figure 3 OPEN HOLE TENSION SPECIMEN.



All Dimensions are in inches.

FABRICATION

1. Laminate orientation: $(45/0/-45/90)_{2S}$

2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph B.2.3 of NASA 1142.

3. Edge finish shall be 32✓ in accordance with ASA B46.1.

4. Drill and/or ream hole as specifiec in paragraph B.9.2 of NASA 1142.

INSTRUMENTATION

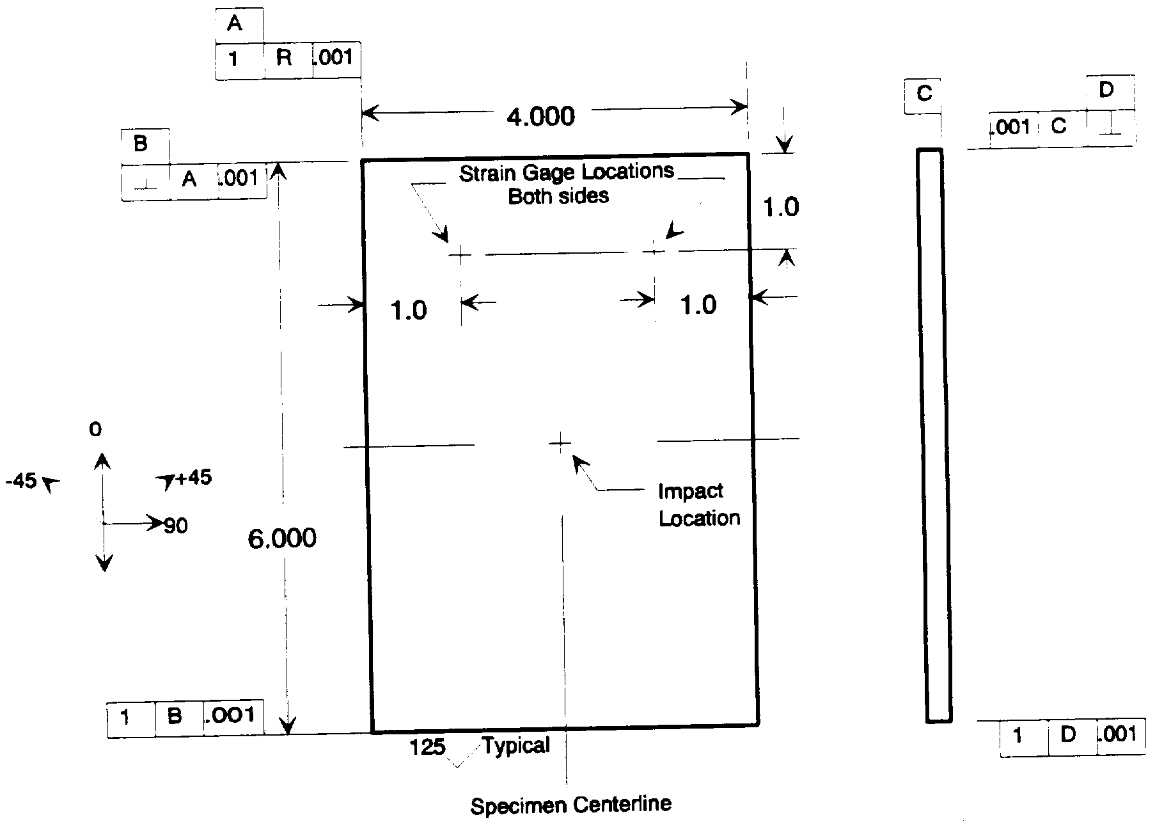
1. None

TEST

1. Moisturize hot/wet specimens per NASA 1142, B.2.5.

2. Test per NASA 1142, B.10

Figure 4 OPEN HOLE COMPRESSION



Unless otherwise specified, dimensional tolerances are ± 0.005
All dimensions are in inches.

FABRICATION

1. Laminate orientation: $(45/0/\text{-}45/90)_{4S}$ per 6.1.

2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph 6.2.

3. Measure thickness around the impact area before impacting. Measure per 6.2.3

INSTRUMENTATION

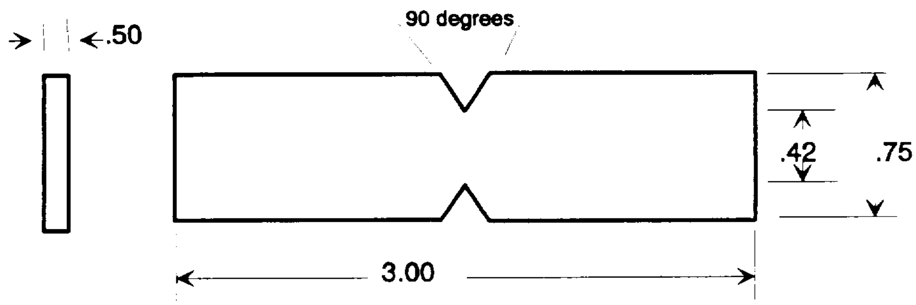
1. Mount back-to-back axial strain gages as shown.

TEST

1. Moisturize hot/wet specimens per NASA 1142, B.2.5.

2 Test Per SACMA SRM 2-88.

Figure 5 COMPRESSION AFTER IMPACT



All dimensions are in inches.

FABRICATION

1. Laminate orientation: (TBD)

INSTRUMENTATION

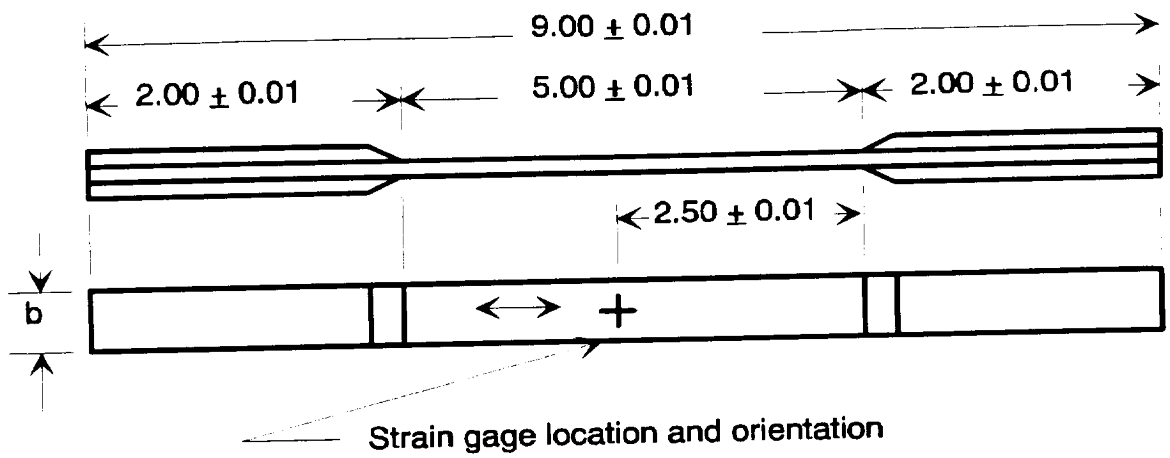
1. TBD

TEST

1. Moisturize hot/wet specimens per NASA 1142, B.2.5.

2. Test specimens per Isopescue UWME-DR-501-103-1

Figure 6 IOSIPESCU SHEAR SPECIMEN



All dimensions are in inches.

Test	Test Method	Ply Orientation	Specimen width, b, in.
Tension Strength and modulus	Section B.6	(0)8	0.500 +/- 0.007

FABRICATION

1. Specimen edge parallel and perpendicular requirements shall be as specified in paragraph B.2.3.
2. Edge finish shall be 32✓ in accordance with ASA (ANSI) B46.1.
3. Specimen loading tabs shall be fabricated fromTBD. Prior to bonding tabs, prepare specimen and tab surfaces by hand sanding (No. 150 grit sandpaper) or sandblasting. Clean surface thoroughly with acetone or MEK.

INSTRUMENTATION

1. For the requirements of section B.6, either a longitudinal strain gage or a suitable extensometer may be used to measure longitudinal strain.

2. Locate strain gages adjacent to specimen centerline as indicated on drawing. Strain gage axis shall be aligned within 0.5' of specimen longitudinal or transverse centerline.

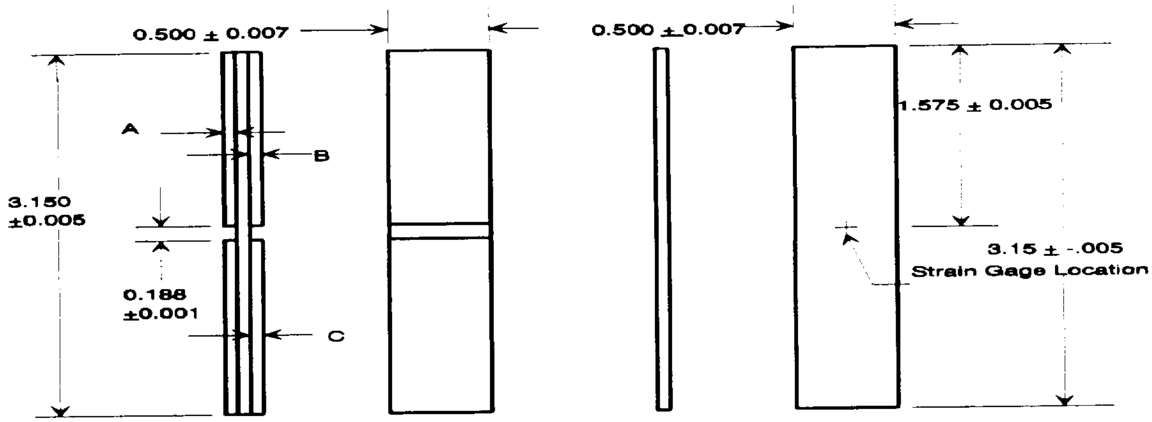
TEST

1. Moisturize hot/wet specimens per NASA 1142, B.2.5

2. Test room temperature and hot/wet specimens per NASA 1142, B.6.

3 Test -270F specimens per NASA 1142, B.6, and B.2.4

Figure 7 TENSION STRENGTH AND MODULUS



All dimensions are in inches

Test	Test Method	Ply Orientation	Specimen width
Compression Strength	Section B.7	(0)8	0.500 +/- 0.007
Compression Modulus	Section B.7	(0)8	0.500 +/- 0.007

FABRICATION

1. Laminate orientation: $(0)_8$

2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph B.2.3.

3. Edge finish shall be 32✓ in accordance with ASA (ANSI) B46.1.

4. Specimen loading tabs shall be fabricated from the same graphite/resin prepreg as the specimen, 12 plies thick, with the 0^{o} fiber direction parallel to the longitudinal axis within $\pm 1^{o}$. Prior to bonding tabs. prepare specimen and tab bonding surfaces by hand sanding (No 150 grit sandpaper) or sandblasting. Clean surface thoroughly with acetone or MEK. Bond tabs to specimens with 350^{o} F cure adhesive for 200^{o} F testing

5. Tab thickness tolerances: A=B $\pm$ 0.010
B=C $\pm$ 0.001

Figure 8 COMPRESSION TEST SPECIMENS

INSTRUMENTATION

1. Either back-to-back strain gages or a suitable extensometer shall be used to measure longitudinal strain on the modulus specimens. Locate strain gage or extensometer on specimen centerline as shown. Strain gage axis shall be aligned within 0.5^{o} of the specimen longitudinal centeraline.

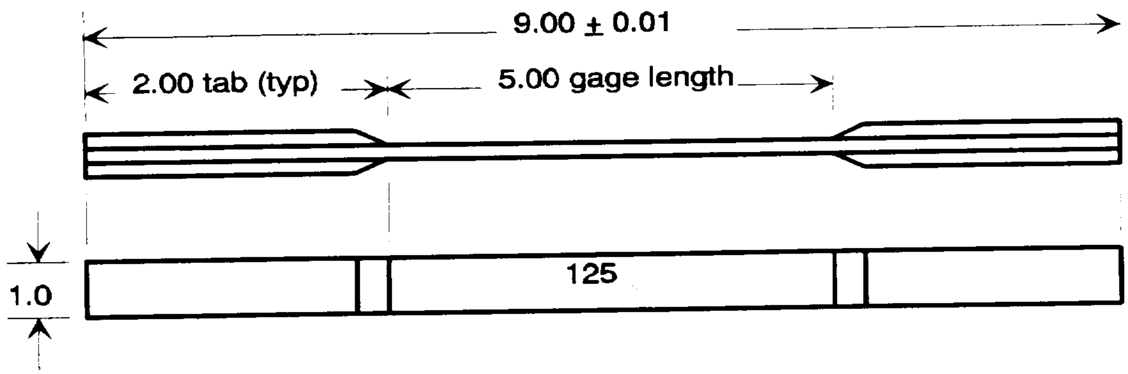
TEST

1. Moisturize hot/wet compression specimens and 18 compression modulus specimens per NASA 1142, B.2.5.

2. Test room temperature and hot/wet specimens per NASA 1142, B.7

3. Test -270 specimens per NASA 1142, B.7 and B.2.4.

Figure 8 COMPRESSION TEST SPECIMENS (continued)



All dimensions are in inches.

FABRICATION

1. The specimens shall be cut from laminates, preferably after bonding on tab material. The laminates shall be balanced 8 ply construction of the form $(\pm 45)_{2s}$. Precautions must be taken to avoid notches, undercuts, or rough or uneven surfaces during cutting. Fiber orientation tolerance shall be $\pm 1^{o}$.

   The test may be performed without the specimen being tabbed, however, if tabs are used, they shall be as follows: Balanced, 0/90 cross-ply or ± 45 unidirectional or fabric tabs, may be used. The tabs should be strain compatible with the composite being tested. Each tab shall be 2.0 inch long by the width of the specimen and a thickness of 1.5 to 4 times the thickness of the test specimen. The tabs shall have a 15^{o} typical bevel (5^{o} minimum). Any high-elongation (tough) adhesive system that will meet the temperature requirements may be used. Care should be taken that bonding temperature does not add any desired post-cure to the laminate.

INSTRUMENTATION

1. Longitudinal and transverse element strain gages.

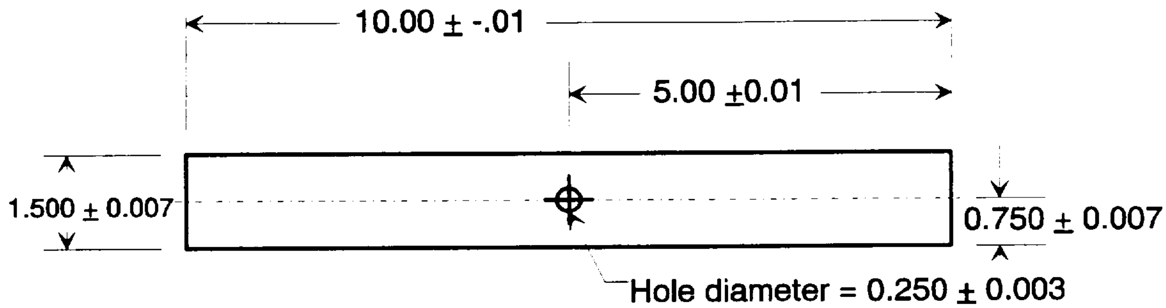
TEST

1. Moisturize hot/wet specimens per NASA 1142, B.2.5.

2. Test room temperature and hot/wet specimens per SACMA SRM 7-88.

3. Test -270 specimens per SACMA SRM 7-88, and NASA 1142, B.2.4.

Figure 9 INPLANE SHEAR



All Dimensions are in inches.

FABRICATION

1. Laminate orientation: $(45/0/-45/90)_{2S}$

2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph B.2.3 of NASA 1142.

3. Edge finish shall be 32✓ in accordance with ASA B46.1.

4. Drill and/or ream hole as specifiec in paragraph B.9.2 of NASA 1142.

INSTRUMENTATION

1. None

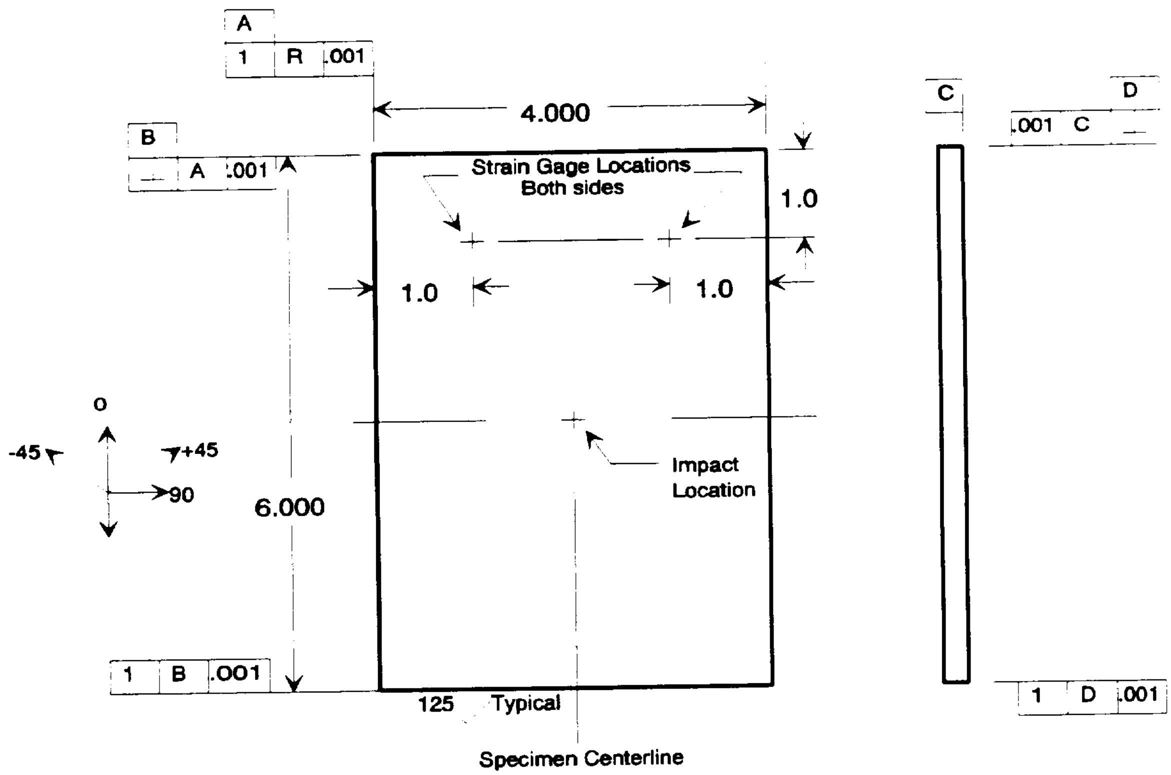
TEST

1. Moisturize hot/wet specimens per NASA 1142, B.2.5.

2. Test room temperature and hot/wet specimens per NASA 1142, B.10

3. Test -270F specimens per NASA 1142, B.10 and B.24.

Figure 10 OPEN HOLE COMPRESSION



All dimensions are in inches.

FABRICATION

1. Laminate orientation: $(45/0/\text{-}45/90)_{4S}$ per SACMA SRM 2-88, 6.1.

2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph 6.2.

3. Measure thickness around the impact area before impacting. Measure per 6.2.3

INSTRUMENTATION

1. Mount back-to-back axial strain gages as shown.

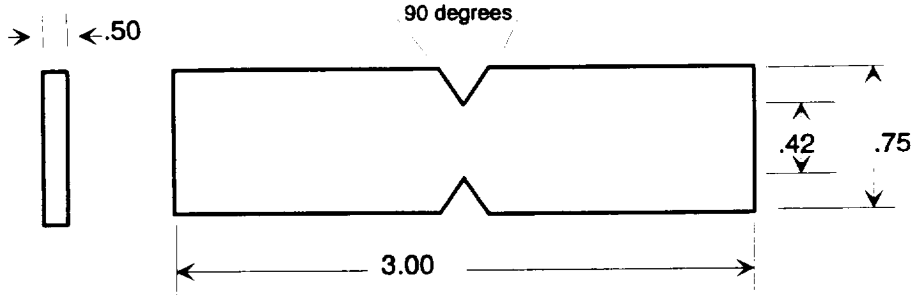
TEST

1. Moisturize hot/wet specimens per NASA 1142, B.2.5.

2 Test Per SACMA SRM 2-88.

3. Test -270F specimens per NASA 1142, B.2.4, and SACMA-SRM 2-88.

Figure 11 COMPRESSION AFTER IMPACT



All dimensions are in inches.

FABRICATION

1. Laminate orientation: (TBD)

INSTRUMENTATION

1. TBD

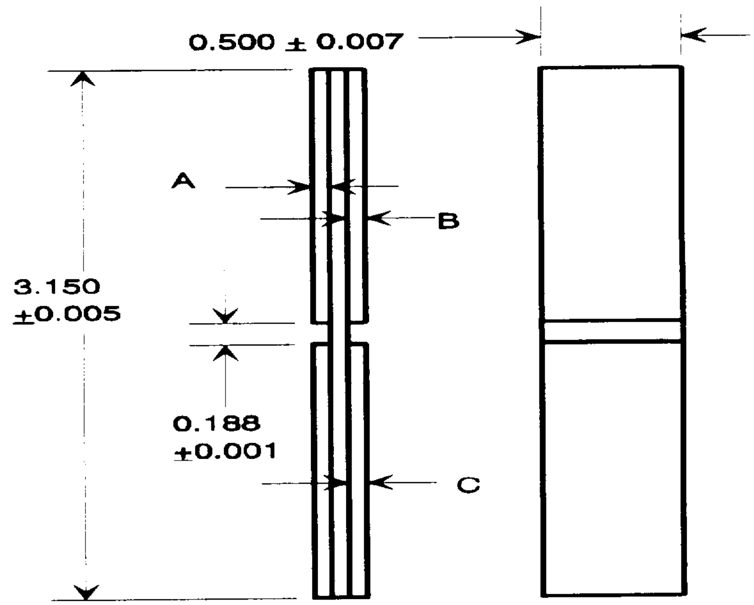
TEST

1. Moisturize hot/wet specimens per NASA 1142, B.2.5.

2. Test specimens per Iosipescu TBD

3. Test -270F specimens per NASA 1142, B.2.4 and Iosipescu TBD.

Figure 12 IOSIPESCU SHEAR SPECIMEN



All dimensions are in inches

Test	Test Method	Ply Orientation	Specimen width
Compression Strength	Section B.7	(0)8	0.500 +/- 0.007

FABRICATION

1. Laminate orientation: $(0)_8$

2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph B.2.3.

3. Edge finish shall be 32✓ in accordance with ASA (ANSI) B46.1.

4. Specimen loading tabs shall be fabricated from the same graphite/resin prepreg as the specimen, 12 plies thick, with the 0^{o} fiber direction parallel to the longitudinal axis within $\pm 1^{o}$. Prior to bonding tabs. prepare specimen and tab bonding surfaces by hand sanding (No 150 grit sandpaper) or sandblasting. Clean surface thoroughly with acetone or MEK. Bond tabs to specimens with 350^{o} F cure adhesive for 200^{o} F testing

5. Tab thickness tolerances: A=B $\pm$ 0.010
B=C $\pm$ 0.001

Figure 13 DURABILITY SCREENING

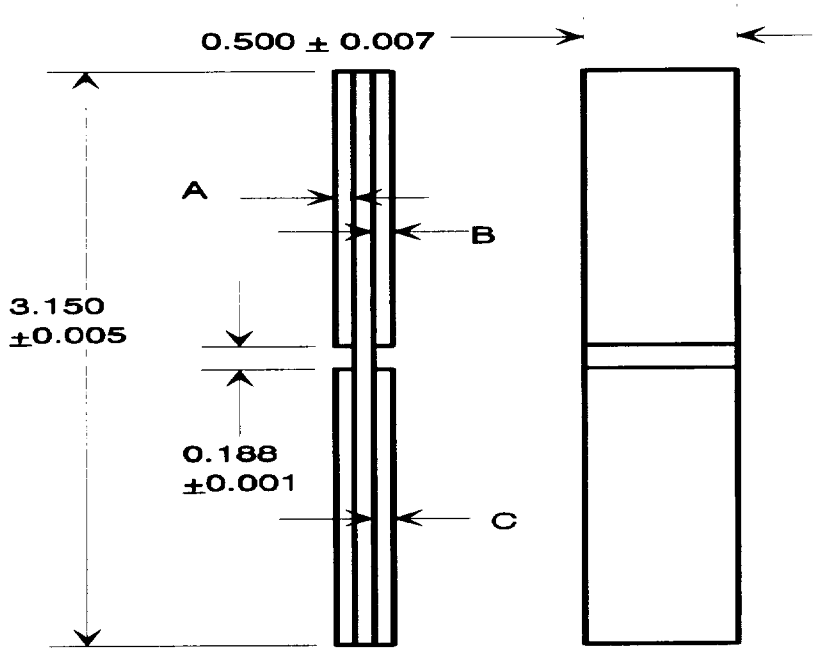
<u>TESTING</u>

1. Cycle 2 lifetime spectum loading. *Procedure to be written by MSFC*

2. Moisturize hot/wet specimens per NASA 1142, B.2.5

2. Test for residual compression per NASA 1142,B.7.

Figure 13 DURABILITY SCREENING (continued)



All dimensions are in inches

Test	Test Method	Ply Orientation	Specimen width
Compression Strength	Section B.7	(0)8	0.500 +/- 0.007

FABRICATION

1. Laminate orientation: $(0)_8$

2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph B.2.3.

3. Edge finish shall be 32✓ in accordance with ASA (ANSI) B46.1.

4. Specimen loading tabs shall be fabricated from the same graphite/resin prepreg as the specimen, 12 plies thick, with the 0^{o} fiber direction parallel to the longitudinal axis within $\pm$ 1^{o}. Prior to bonding tabs. prepare specimen and tab bonding surfaces by hand sanding (No 150 grit sandpaper) or sandblasting. Clean surface thoroughly with acetone or MEK. Bond tabs to specimens with 350^{o} F cure adhesive for 200^{o} F testing

5. Tab thickness tolerances: A=B $\pm$ 0.010
   B=C $\pm$ 0.001

Figure 14 THERMAL CYCLING SCREENING

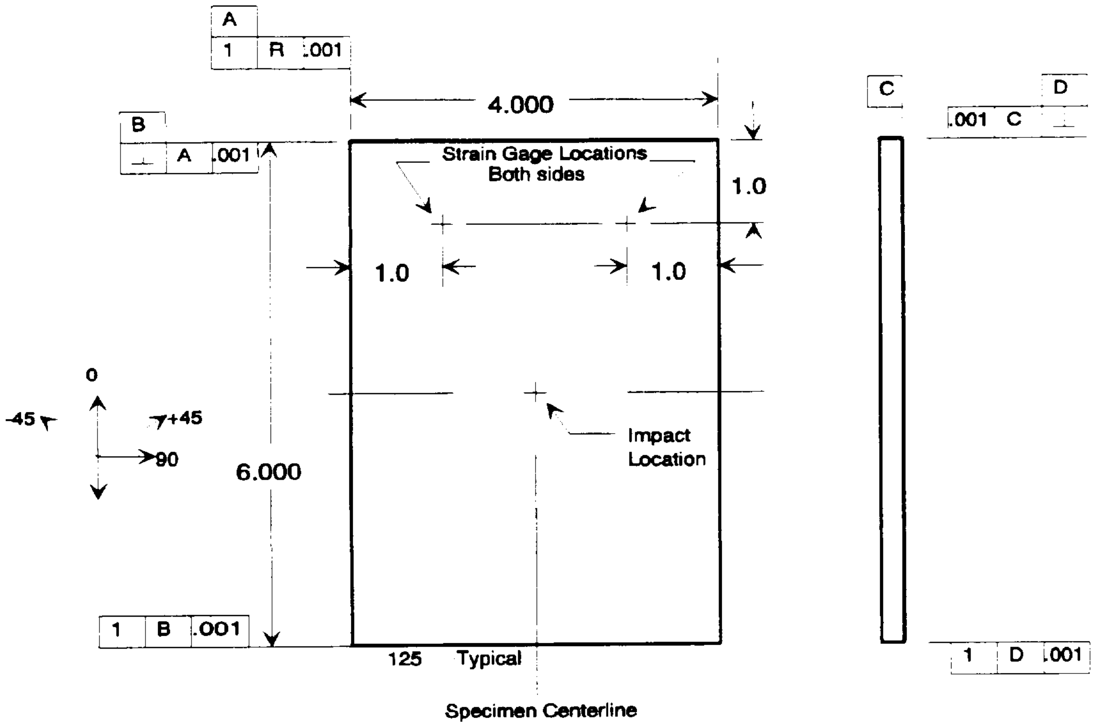
TESTING

1. Thermal cycle -270F to 300F for 1 lifetime.

2. Moisturize per NASA ll42, B.2.5

3. Test room temperature and hot/wet specimens for residual compression per NASA 1142,B.7.

Figure 14 THERMAL CYCLING SCREENING (continued)



All dimensions are in inches.

FABRICATION

1. Laminate orientation: $(45/0/\text{-}45/90)_{4S}$ per 6.1.

2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph 6.2.

3. Measure thickness around the impact area before impacting. Measure per 6.2.3

INSTRUMENTATION

1. Mount back-to-back axial strain gages as shown.

TEST

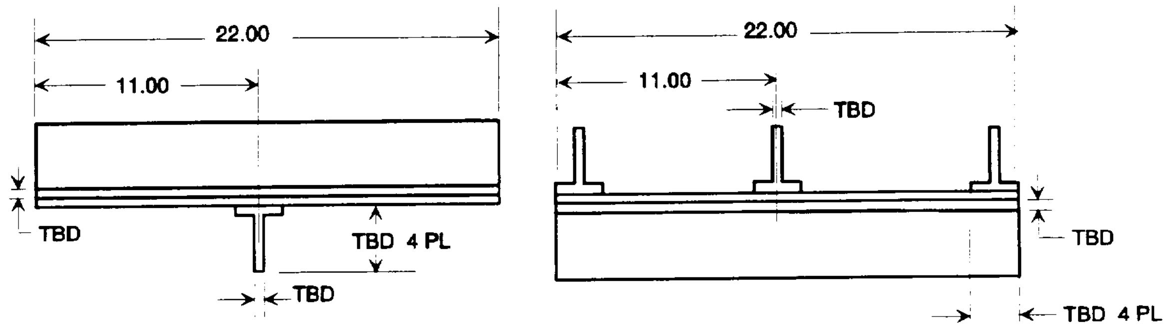
1. Impact specimens at 2 damage levels TBD.

1. Moisturize hot/wet specimens per NASA 1142, B.2.5.

2 Test Per SACMA SRM 2-88.

3. Test -270 specimens per NASA 1142, B.2.4, and SACMA-SRM 2-88.

Figure 15 DAMAGE TOLERANCE SCREENING



All dimensions are in inches

FABRICATION

1. Specimen design to be determined. This will include determination if joint will bonded and have fasteners.

2. Specimen edge parallel and end perpendicular requirements shall be specified in paragraph B.2.3.

3. Edge finish shall be 32✓ in accordance with ASA (ANSI) B46.1.

4. Fabricate specimens to TBD drawings and processing specifications

5. Dimension tolerance ±0.03 unless specified.

INSTRUMENTION

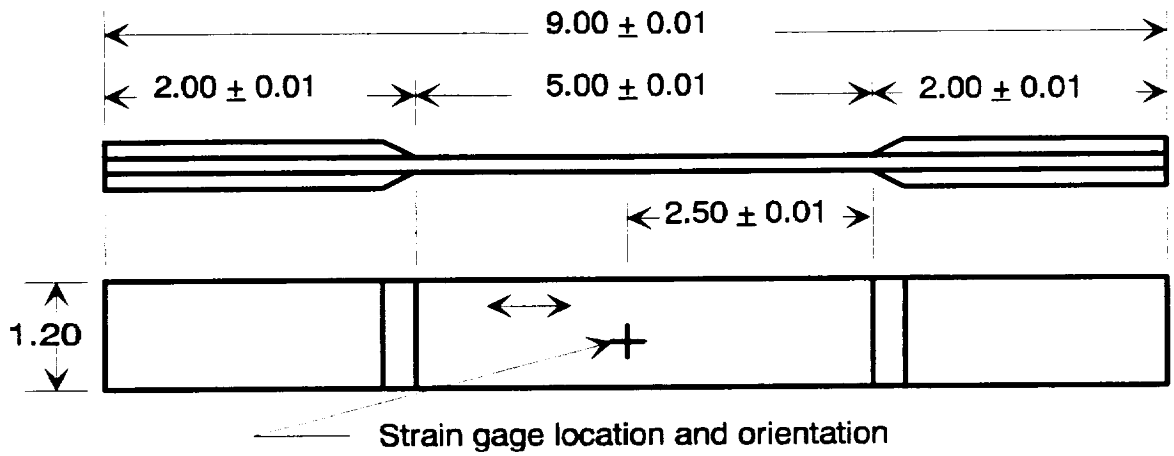
1. Instrumentation TBD.

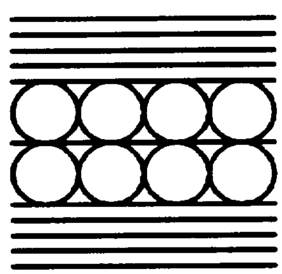
TEST

1. Details of acoustic fatigue TBD.

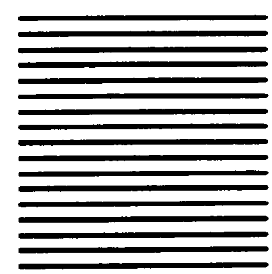
2. Test fixturing TBD

Figure 16 ACOUSTIC FATIGUE TEST ARTICLE.





Layup of test material will be determined after trade studies and analysis. Layup may or maynot include pultruded rods.



FABRICATION

1. Laminate orientation to be determined.

2. Specimen edge parallel and end perpendicular requirements shall be specified in paragraph B.2.3.

3. Edge finish shall be 32✓ in accordance with ASA (ANSI) B46.1.

4. Specimen loading tabs shall be fabricated from TBD. Taper is achieved by dropping one ply per 0.10 inch or by machining. Prior to bonding tabs, prepare specimen and tab surfaces by hand sanding (No. 150 grit sandpaper) or sandblasting. Clean surface thoroughly with acetone or MEK. Bond tabs to specimen using TBD .

5. Test per section B.6 in tension.

6. Dimension tolerance ± .03 unless specified.

Figure 17 LONGERON CAP THICK CROSS-PLY LAMINATE SPECIMEN

INSTRUCTIONS

INSTRUMENTATION

1. For the requirements of section B.6, either a longitudinal strain gage or a suitable extensometer may be used to measure longitudinal strain.

2. Locate strain gages adjacent to specimen centerline as indicated on drawing. Strain gage axis shall be aligned within 0.5' of specimen longitudinal or transverse centerline.

TEST

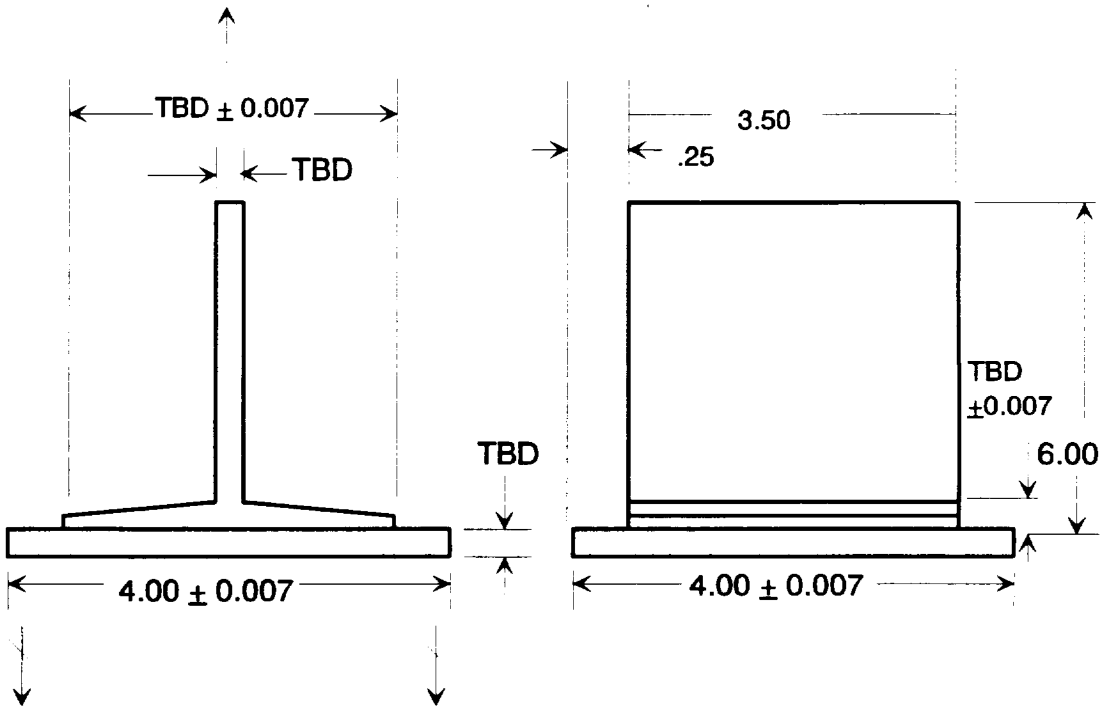
1. Moisturize specimens per NASA 1142, B.2.5.

2. Test by loading specimen in compression to ultimate and failure loading.

3. Record load and strain levels.

4. Calculate failure stress and strain levels.

Figure 17 LONGERON CAP THICK CROSS-PLY LAMINATE SPECIMEN (continued)



All dimensions are in inches.

FABRICATION

1. Specimen design to be determined.

2. Specimen edge parallel and end perpendicular requirements shall be specified in paragraph B.2.3.

3. Edge finish shall be 32✓ in accordance with ASA (ANSI) B46.1.

INSTRUMENTION

1. Instrumentation TBD. Sufficient to record force P deflections.

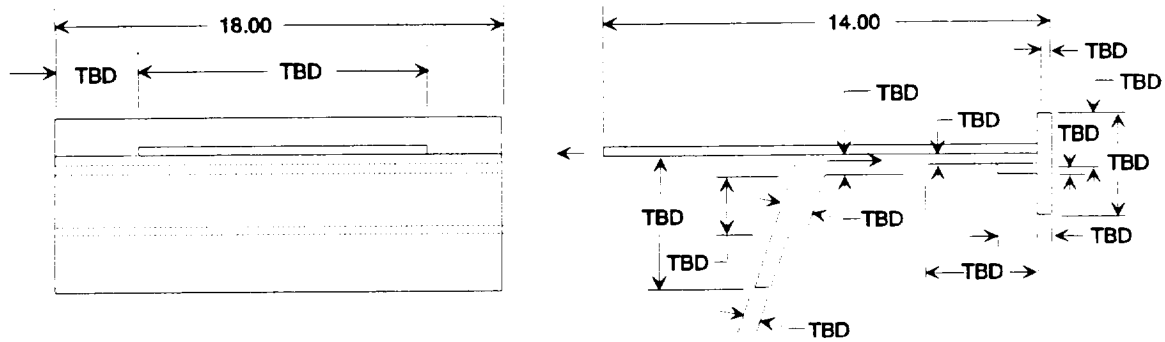
TESTING

1. Moisturise hot/wet specimens per NASA 1142, B.2.5.

2. Bond shall be determined by restraining edges of plate and applying pull-off load on upstanding leg of tee until failure.

3. Fixturing to be determined at a later date.

Figure 18 PULL OFF ARTICLE.



All dimensions are in inches.

FABRICATION

1. Specimen design to be determined. This will include determination if joint will bonded and have fasteners.

2. Specimen edge parallel and end perpendicular requirements shall be specified in paragraph B.2.3.

3. Edge finish shall be 32✓ in accordance with ASA (ANSI) B46.1.

INSTRUMENTION

1. Strain gages to be mounted in TBD locations.

TEST

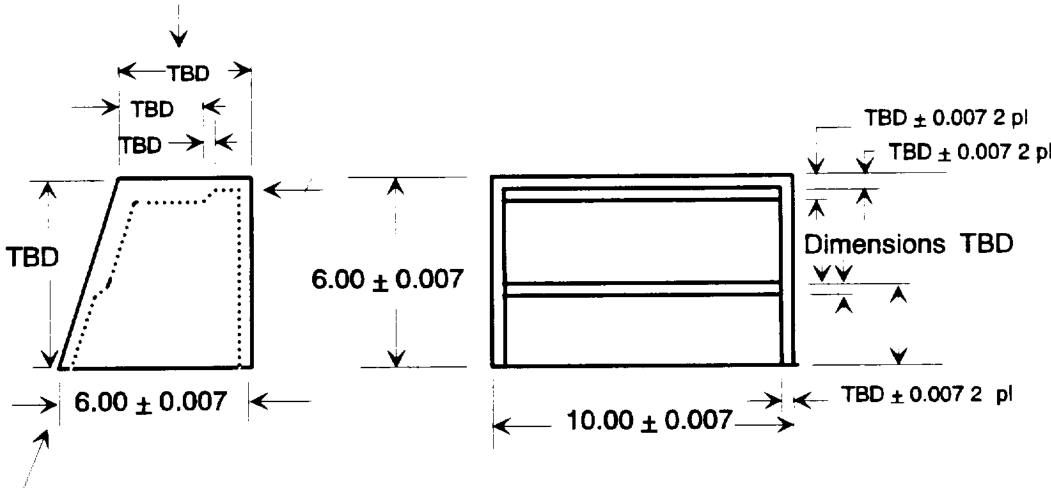
1. Restrain ring frame detail as shown in TBD.

2. Apply load P to ultimate and failure loading.

3. Read load and strain values.

4. Calculate stress and strain levels.

Figure 19 RING FRAME JOINT.



All dimensions are in inches.

FABRICATION

1. Part design and configuration TBD

2. Specimen edge parallel and end perpendicular requirements shall be specified in paragraph B.2.3.

3. Edge finish shall be 32✓ in accordance with ASA (ANSI) B46.1.

4. Dimension tolerances ± .03 unless otherwise specified.

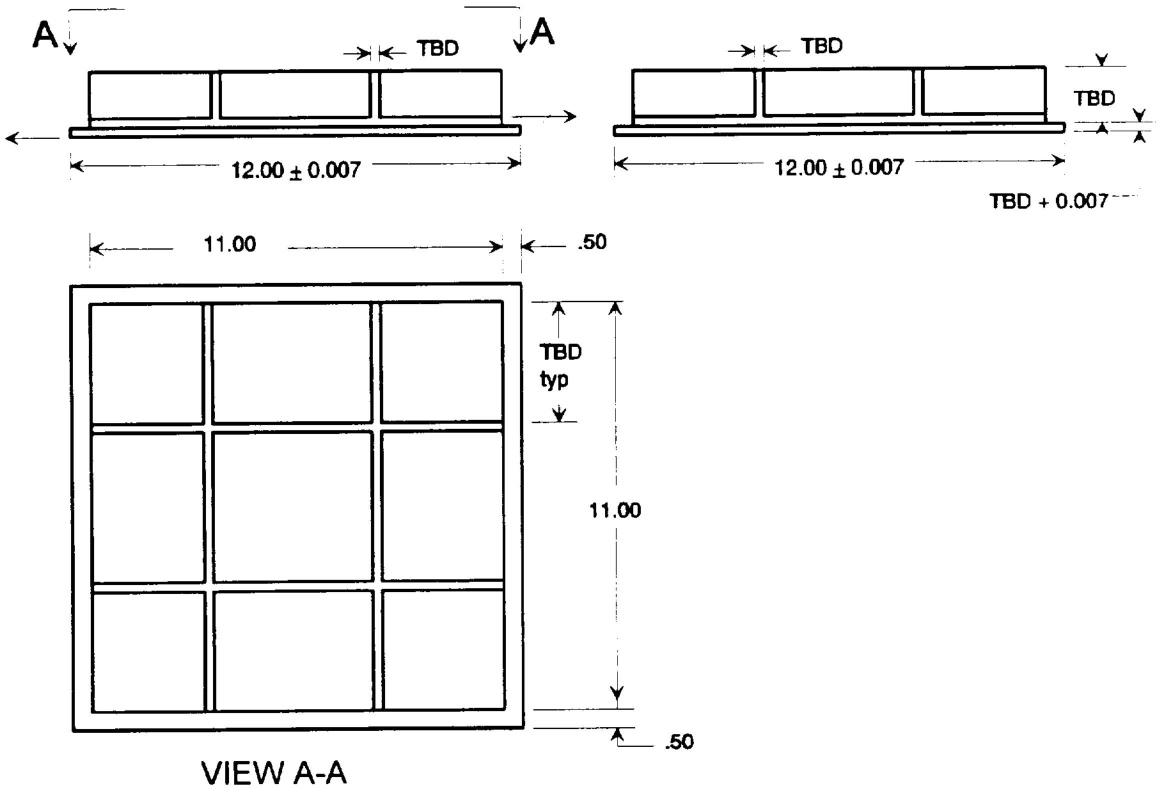
INSTRUMENTATION

1. Instrumentation is to be determined at a later date.

TEST

1. TBD

Figure 20 ENGINE MOUNT FITTING TEST ARTICLE



All dimensions are in inches.

FABRICATION

1. Part design and configuration TBD

2. Specimen edge parallel and end perpendicular requirements shall be specified in paragraph B.2.3.

3. Edge finish shall be 32✓ in accordance with ASA (ANSI) B46.1.

4. Dimension Tolerances of ± .03 unless specified.

INSTRUMENTATION

1. TBD

Figure 21 LONGERON SHEAR TEST ARTICLE

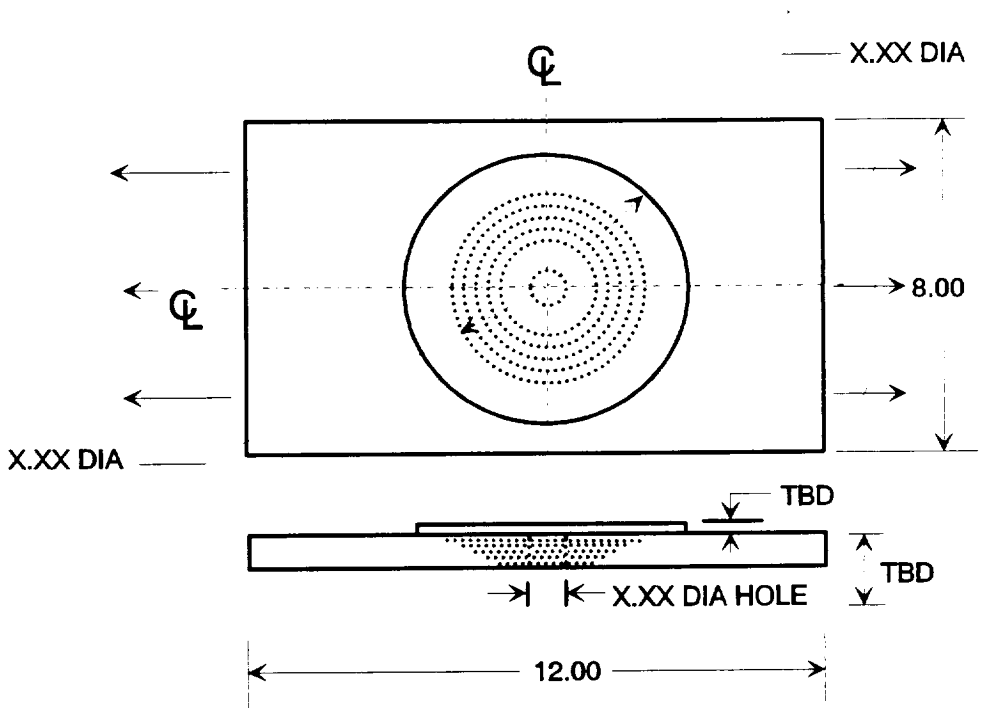
TEST

1. Test to ultimate and to failure loading by applying shear load as shown in sketch above.

2. Record load and strain levels.

3. Calculate shearing stress levels applied to bond line between longeron test article and plate, which simulates thrust cone shell.

Figure 21 LONGERON SHEAR TEST ARTICLE (continued)



All dimensions are in inches.

FABRICATION

1. TBD

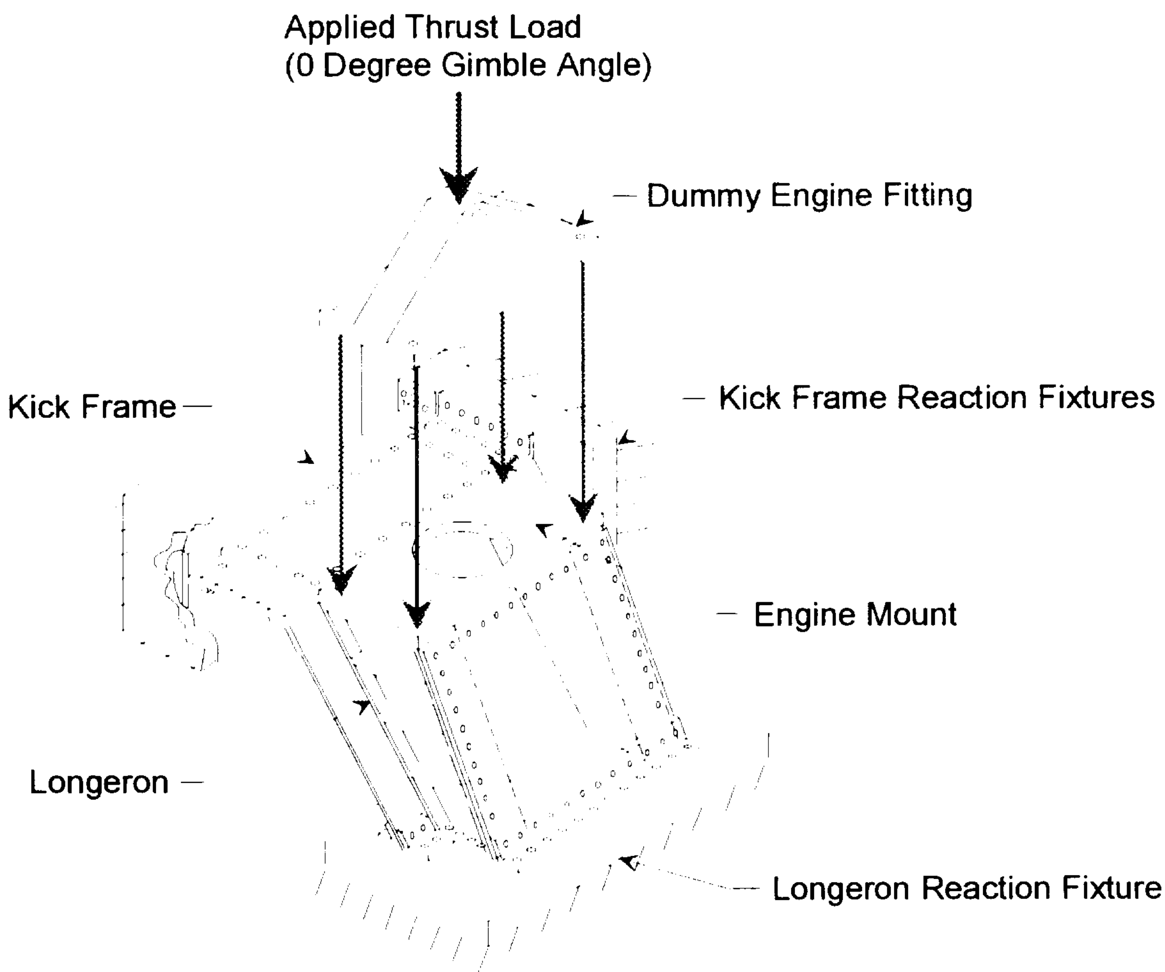
INSTRUMENTATION

TBD

TEST

TBD

Figure 22 REPAIR EVALUATION



TEST ARTICLE

FABRICATION

1. Fabricate individual components of the test article and assemble per the following drawings and specifications

XXX	Material Specifications TBD
XXX	Processing Specifications TBD
XXX	Assembly Drawing
XXX	Thrust Cone Detail Drawing
XXX	Kick Frame Cap Detail Drawing
XXX	Firewall Detail Drawing
XXX	Longeron Detail Drawing
XXX	Intercostal Detail Drawing

Figure 23 STATIC TEST ARTICLE

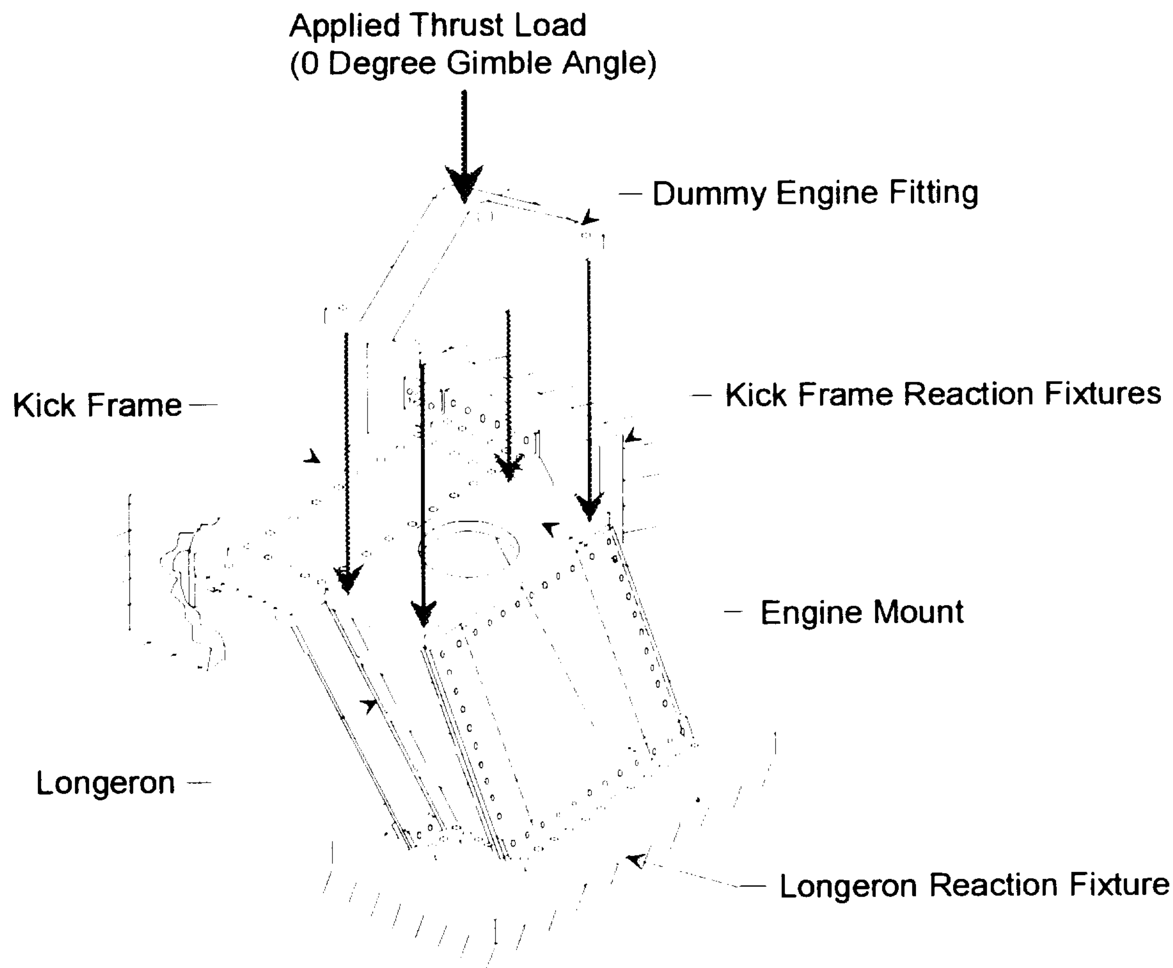
INSTRUMENTATION

TBD

TEST

TBD

Figure 23 STATIC TEST ARTICLE (continued)



TEST ARTICLE

FABRICATION

1. Fabricate individual components of the test article and assemble per the following drawings and specifications

XXX	Material Specifications TBD
XXX	Processing Specifications TBD
XXX	IHM Specifications TBD
XXX	Assembly Drawing
XXX	Thrust Cone Detail Drawing
XXX	Kick Frame Cap Detail Drawing
XXX	Firewall Detail Drawing
XXX	Longeron Detail Drawing
XXX	Intercostal Detail Drawing

Figure 24 FATIGUE AND NDE/IHM TEST ARTICLE

<u>INSTRUMENTATION</u>

TBD

<u>TEST</u>

TBD

Figure 24 FATIGUE AND NDE/IHM TEST ARTICLE (continued)

REQUEST BY:

DEPT NO.:

DATE:

Rockwell

NAAD - Tulsa Facility

LABORATORY TEST DATA

TESTED BY:

DEPT NO.:

DATE:

PAGE ____ OF ____

WITNESS:

DEPT NO.:

TEST PROGRAM →

NAME:

CONTRACT NO.:

TEST MATRIX REQUEST NO.:

ITEM NO.:

SPECIMEN TYPE:

(SANDWICH - LAMINATE - METAL - COMPOSITE - ETC)

TEST TYPE:

(TENSION - COMP - SHEAR - BENDING - FLATWISE TENSION ETC.)

SPECIMEN NUMBER I.D.	TEST ENVIRONMENT TEMP (DEG F)	TEST ENVIRONMENT WET OR DRY	GEOMETRY (IN.) LENGTH	GEOMETRY (IN.) WIDTH	GEOMETRY (IN.) THICKNESS	FAILURE DATA LOAD (POUNDS)	FAILURE DATA STRESS LEVELS	FAILURE DATA STRESS LEVELS	FAILURE DATA STRESS LEVELS MEAN / SDEV	FAILURE DATA FAILURE MODE

MAT'L DATA ↕

	PREPREG	ADHESIVE	CORE	THICKNESS LAMINATE/PLY	THICKNESS FACESHEET	THICKNESS CORE
TYPE						
BATCH						

REMARKS:

SKETCH - TEST SET UP:

Figures 27 and 28 show facilities layout of equipment identified in 11.0, located at NAAD-Tulsa.
INSERT facilities layout at SSD and at MSFC, and AFWL/FDD

13.0 SCHEDULE

Attachment A is a detailed schedule showing all testing to be done by NAAD-Tulsa.
INSERT schedule developed by SSD, MSFC, AFWL/FDD to test after receipt from NAAD-Tulsa.

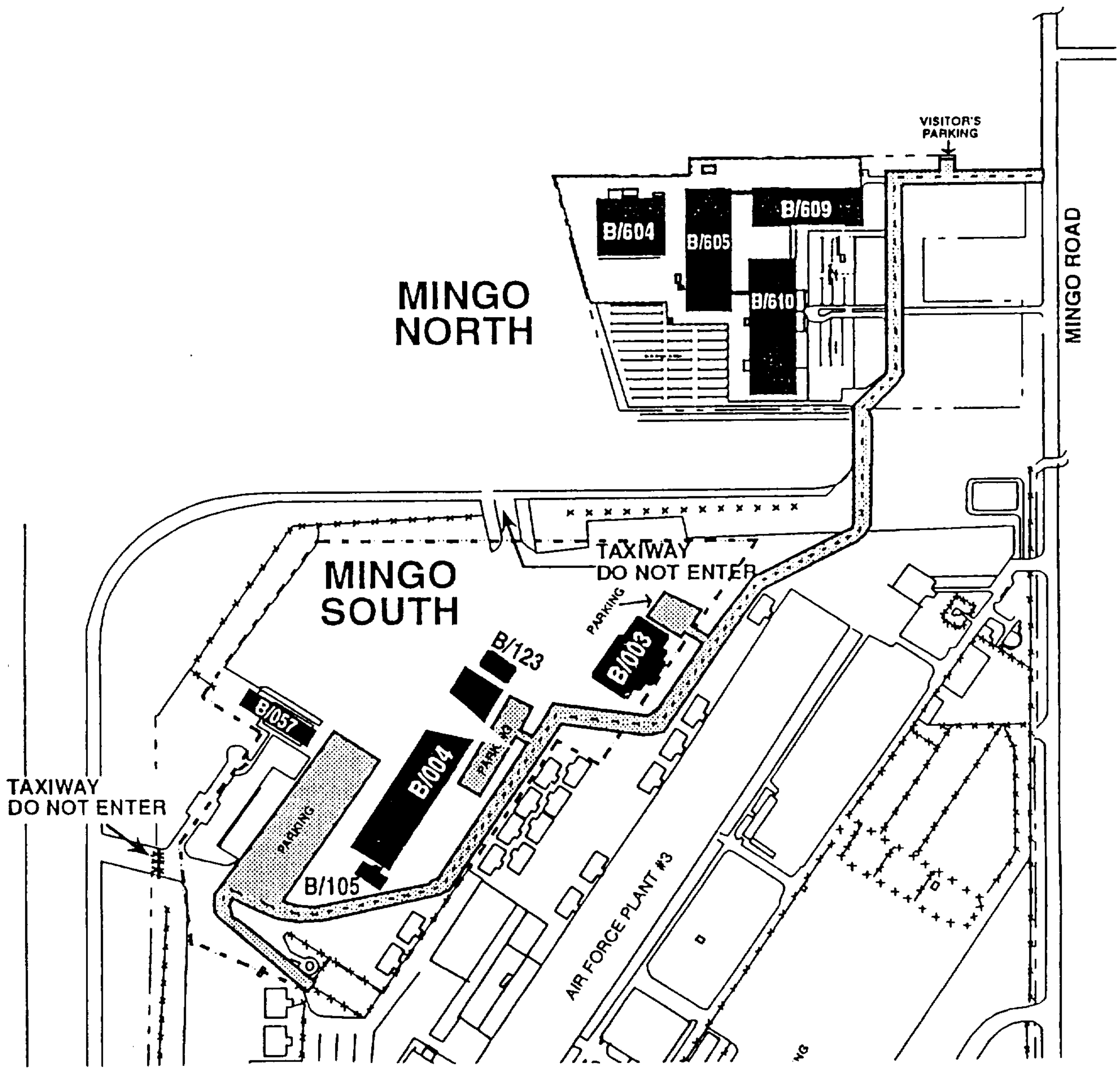
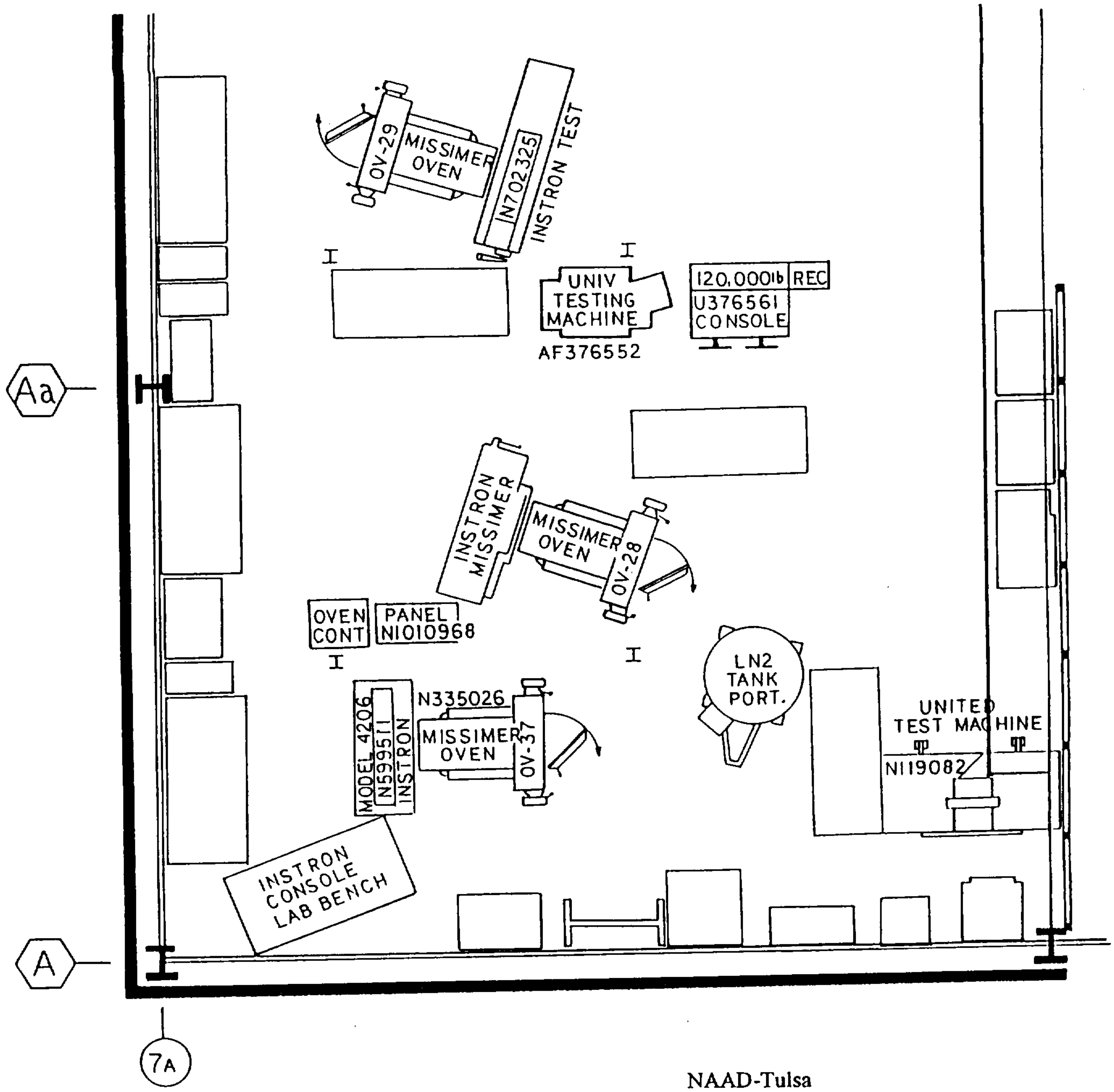


Figure 26

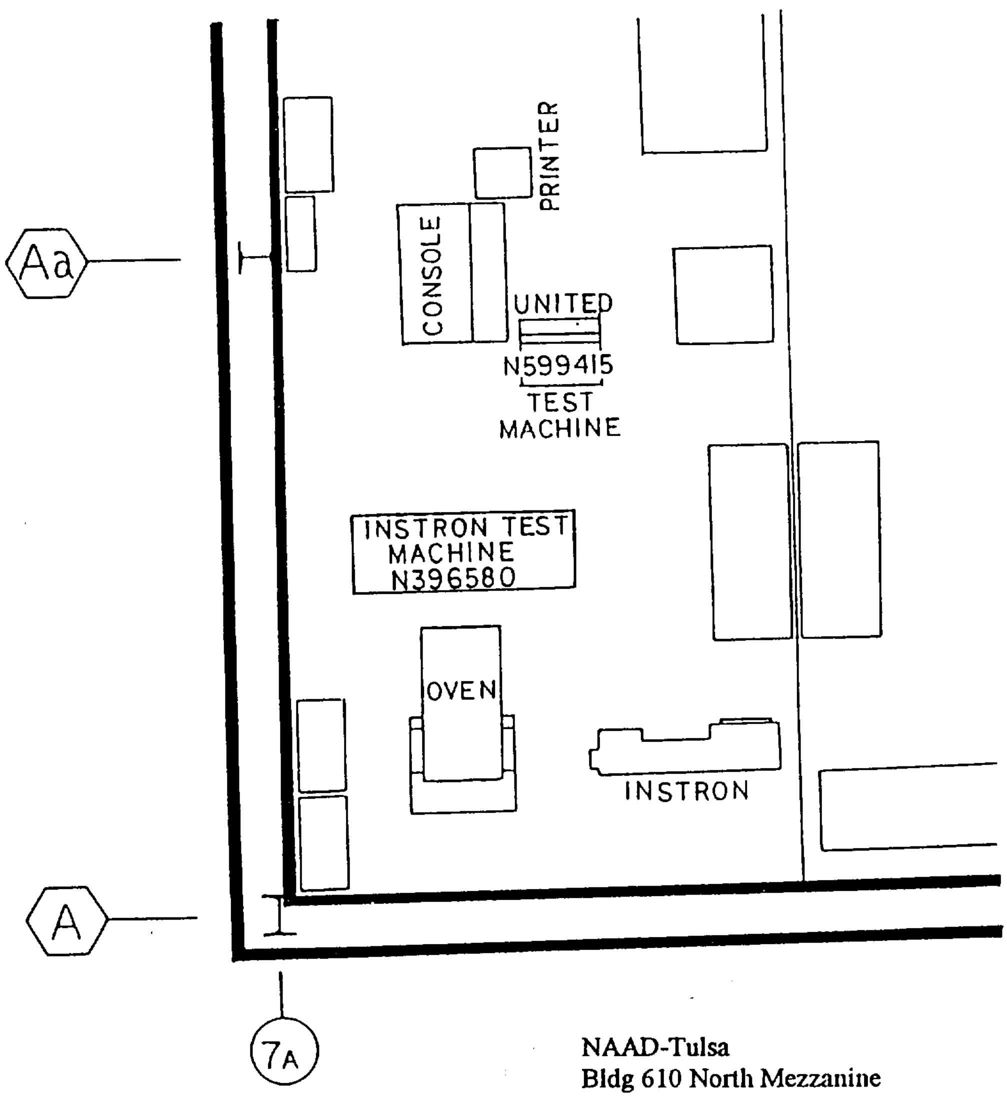
Rockwell

TULSA FACILITY



Note: Other equipment is available
but not shown on this layout

Figure 27 TEST EQUIPMENT LAYOUT



NAAD-Tulsa
Bldg 610 North Mezzanine

Figure 28 TEST EQUIPMENT LAYOUT

TA-2 Testing

ID	Name	
1	1 Task 1 .	0 7/20
2	2 Task 2	0 7/20
3	3 Task 3	0 7/20
4	4 Task 4	
5	4.1 Prototype Thrust Structure Design	8/1 4/25
6	4.2 Design Development Test	
7	4.2.1 Test Plan	8/19 ◆
8	4.2.2 Screening of Material	
9	4.2.2.1 Order Material	5 8/5
10	4.2.2.2 Receive Material	9/19 ◆
11	4.2.2.3 Fabricate Material 1 for test A & B	9/19 10/7
12	4.2.2.4 Fabricate Material 2 for test A & B	9/19 10/7
13	4.2.2.5 Fabricate Material 3 for test A & B	9/19 10/7
14	4.2.2.6 Fabricate Material 4 for test A & B	9/19 10/7
15	4.2.2.7 Fabricate Material 5 for test A & B	9/19 10/7
16	4.2.2.8 Fabricate Material 6 for test A & B	9/19 10/7
17	4.2.2.9 Machine Material 1 Tensile Specimens	10/10 10/19
18	4.2.2.10 Machine Material 2 Tensile Specimens	10/10 10/19
19	4.2.2.11 Machine Material 3 Tensile Specimens	10/10 10/19
20	4.2.2.12 Machine Material 4 Tensile Specimens	10/10 10/19
21	4.2.2.13 Machine Material 5 Tensile Specimens	10/10 10/19
22	4.2.2.14 Machine Material 6 Tensile Specimens	10/10 10/19
23	4.2.2.15 Machine Material 1 Compression Specimens	10/10 10/19
24	4.2.2.16 Machine Material 2 Compression Specimens	10/10 10/19

Timeline: 94: Jul, ug, Sep, Oct, ov, ec; 1995: Jan, eb, ar, pr, ay, Jun, Jul, ug, ep, Oct, ov, ec; 1996: Jan, eb, ar, pr, ay, Jun, Jul, ug, Sep

Project: TA-2
Date: 8/26/94

Critical — Noncritical — Progress — Interface Milestone ◆ — Summary — Rolled Up

1 THRUSTTP.MPP

TA-2 Testing

ID	Name	Start	Finish
25	4.2.2.17 Machine Material 3 Compression Specimens	10/10	10/19
26	4.2.2.18 Machine Material 4 Compression Specimens	10/10	10/19
27	4.2.2.19 Machine Material 5 Compression Specimens	10/10	10/19
28	4.2.2.20 Machine Material 6 Compression Specimens	10/10	10/19
29	4.2.2.21 Machine Material 1 Compression Modulus Specimens	10/10	10/19
30	4.2.2.22 Machine Material 2 Compression Modulus Specimens	10/10	10/19
31	4.2.2.23 Machine Material 3 Compression Modulus Specimens	10/10	10/19
32	4.2.2.24 Machine Material 4 Compression Modulus Specimens	10/10	10/19
33	4.2.2.25 Machine Material 5 Compression Modulus Specimens	10/10	10/19
34	4.2.2.26 Machine Material 6 Compression Modulus Specimens	10/10	10/19
35	4.2.2.27 Moisturize 1/2 Specimens A & B	10/20	11/4
36	4.2.2.28 Test Material 1 - Tensile (A) RT	10/20	10/21
37	4.2.2.29 Test Material 2 - Tensile (A) RT	10/20	10/21
38	4.2.2.30 Test Material 3 - Tensile (A) RT	10/20	10/21
39	4.2.2.31 Test Material 4 - Tensile (A) RT	10/20	10/21
40	4.2.2.32 Test Material 5 - Tensile (A) RT	10/20	10/21
41	4.2.2.33 Test Material 6 - Tensile (A) RT	10/20	10/21
42	4.2.2.34 Test Material 1 - Compression (B) RT	10/24	10/25
43	4.2.2.35 Test Material 2 - Compression (B) RT	10/24	10/25
44	4.2.2.36 Test Material 3 - Compression (B) RT	10/24	10/25
45	4.2.2.37 Test Material 4 - Compression (B) RT	10/24	10/25
46	4.2.2.38 Test Material 5 - Compression (B) RT	10/24	10/25
47	4.2.2.39 Test Material 6 - Compression (B) RT	10/24	10/25
48	4.2.2.40 Test Material 1 - Compression Modulus (B) RT	10/26	10/27

Timeline: 94: Jul, ug, Sep, Oct, ov, ec; 1995: Jan, eb, ar, pr, ay, Jun, Jul, ug, ep, Oct, ov, ec; 1996: Jan, eb, ar, pr, ay, Jun, Jul, ug, Sep

Project: TA-2
Date: 8/26/94

Critical	Progress
Noncritical	Interface Milestone ◆
Summary	Rolled Up

TA-2 Testing

ID	Name	Start	Finish
49	4.2.2.41 Test Material 2 - Compression Modulus (B) RT	10/26	10/27
50	4.2.2.42 Test Material 3 - Compression Modulus (B) RT	10/26	10/27
51	4.2.2.43 Test Material 4 - Compression Modulus (B) RT	10/26	10/27
52	4.2.2.44 Test Material 5 - Compression Modulus (B) RT	10/26	10/27
53	4.2.2.45 Test Material 6 - Compression Modulus (B) RT	10/26	10/27
54	4.2.2.46 Test Material 1 - Tensile (A) Hot/Wet	11/7	11/8
55	4.2.2.47 Test Material 2 - Tensile (A) RT Hot/Wet	11/7	11/8
56	4.2.2.48 Test Material 3 - Tensile (A) Hot/Wet	11/7	11/8
57	4.2.2.49 Test Material 4 - Tensile (A) Hot/Wet	11/7	11/8
58	4.2.2.50 Test Material 5 - Tensile (A) Hot/Wet	11/7	11/8
59	4.2.2.51 Test Material 6 - Tensile (A) Hot/Wet	11/7	11/8
60	4.2.2.52 Test Material 1 - Compression (B) Hot/Wet	11/9	11/10
61	4.2.2.53 Test Material 2 - Compression (B) Hot/Wet	11/9	11/10
62	4.2.2.54 Test Material 3 - Compression (B) Hot/Wet	11/9	11/10
63	4.2.2.55 Test Material 4 - Compression (B) Hot/Wet	11/9	11/10
64	4.2.2.56 Test Material 5 - Compression (B) Hot/Wet	11/9	11/10
65	4.2.2.57 Test Material 6 - Compression (B) Hot/Wet	11/9	11/10
66	4.2.2.58 Test Material 1 - Compression Modulus (B) Hot/Wet	11/11	11/14
67	4.2.2.59 Test Material 2 - Compression Modulus (B) Hot/Wet	11/11	11/14
68	4.2.2.60 Test Material 3 - Compression Modulus (B) Hot/Wet	11/11	11/14
69	4.2.2.61 Test Material 4 - Compression Modulus (B) Hot/Wet	11/11	11/14
70	4.2.2.62 Test Material 5 - Compression Modulus (B) Hot/Wet	11/11	11/14
71	4.2.2.63 Test Material 6 - Compression Modulus (B) Hot/Wet	11/11	11/14
72	4.2.2.64 Reduce Test Data	11/7	11/23

Timeline: 94: Jul ug Sep Oct ov ec | 1995: Jan eb ar pr ay Jun Jul ug ep Oct ov ec | 1996: Jan eb ar pr ay Jun Jul ug Sep

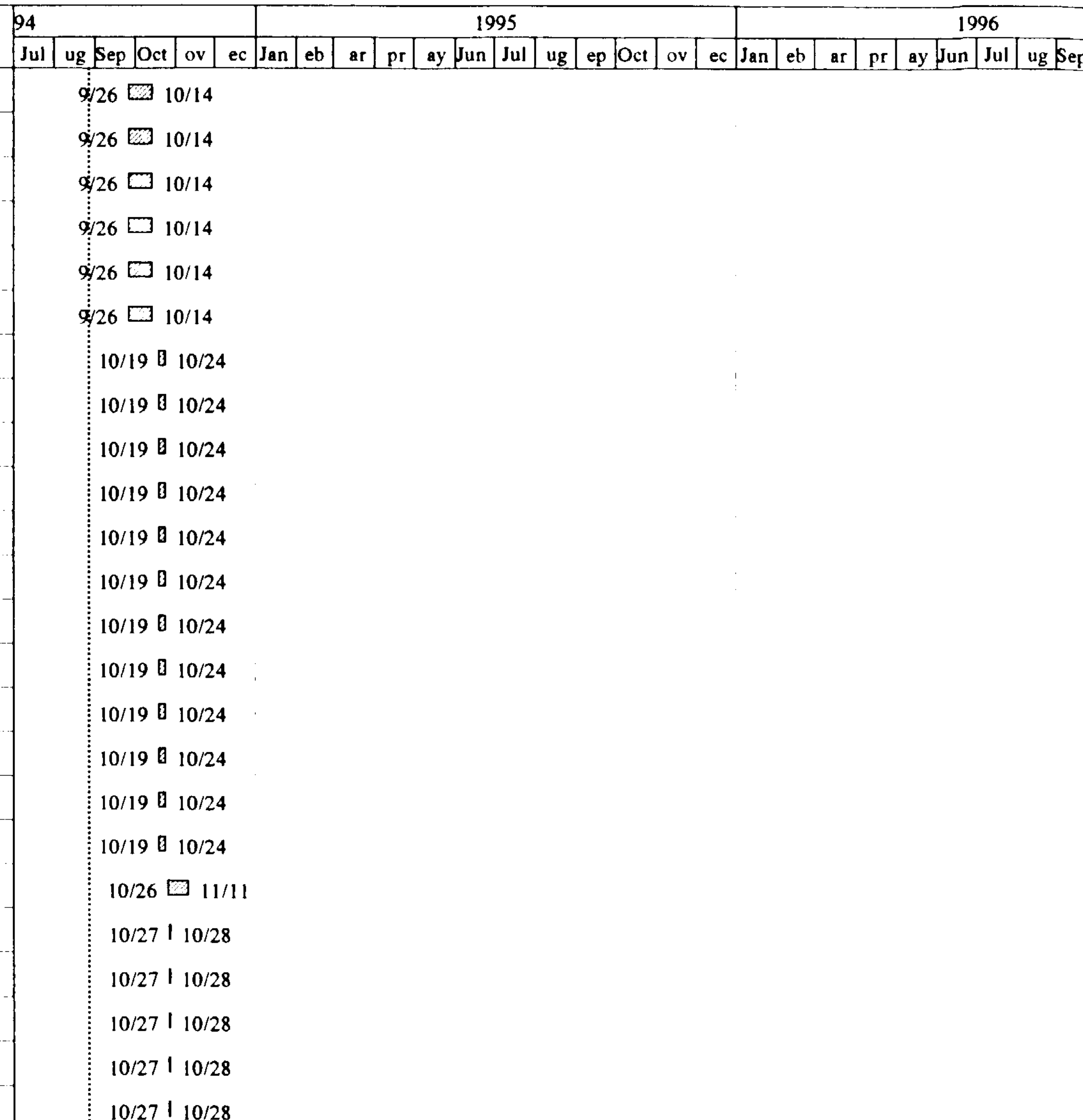
Project: TA-2
Date: 8/26/94

Critical — Progress — Summary
Noncritical — Interface Milestone ◆ — Rolled Up

3 THRUSTTP.MPP

TA-2 Testing

ID	Name	Start	Finish
73	4.2.2.65 Fabricate Material 1 for C & D	9/26	10/14
74	4.2.2.66 Fabricate Material 2 for C & D	9/26	10/14
75	4.2.2.67 Fabricate Material 3 for C & D	9/26	10/14
76	4.2.2.68 Fabricate Material 4 for C & D	9/26	10/14
77	4.2.2.69 Fabricate Material 5 for C & D	9/26	10/14
78	4.2.2.70 Fabricate Material 6 for C & D	9/26	10/14
79	4.2.2.71 Machine Material 1 Open-hole Tension (C)	10/19	10/24
80	4.2.2.72 Machine Material 2 Open-hole Tension (C)	10/19	10/24
81	4.2.2.73 Machine Material 3 Open-hole Tension (C)	10/19	10/24
82	4.2.2.74 Machine Material 4 Open-hole Tension (C)	10/19	10/24
83	4.2.2.75 Machine Material 5 Open-hole Tension (C)	10/19	10/24
84	4.2.2.76 Machine Material 6 Open-hole Tension (C)	10/19	10/24
85	4.2.2.77 Machine Material 1 Open-hole Compression (D)	10/19	10/24
86	4.2.2.78 Machine Material 2 Open-hole Compression (D)	10/19	10/24
87	4.2.2.79 Machine Material 3 Open-hole Compression (D)	10/19	10/24
88	4.2.2.80 Machine Material 4 Open-hole Compression (D)	10/19	10/24
89	4.2.2.81 Machine Material 5 Open-hole Compression (D)	10/19	10/24
90	4.2.2.82 Machine Material 6 Open-hole Compression (D)	10/19	10/24
91	4.2.2.83 Moisturize 1/2 Specimens C & D	10/26	11/11
92	4.2.2.84 Test Material 1 Open-hole Tension (C) RT	10/27	10/28
93	4.2.2.85 Test Material 2 Open-hole Tension (C) RT	10/27	10/28
94	4.2.2.86 Test Material 3 Open-hole Tension (C) RT	10/27	10/28
95	4.2.2.87 Test Material 4 Open-hole Tension (C) RT	10/27	10/28
96	4.2.2.88 Test Material 5 Open-hole Tension (C) RT	10/27	10/28



Project: TA-2
Date: 8/26/94

Critical | Progress | Summary
Noncritical | Interface Milestone ◆ | Rolled Up

4 THRUSTTP.MPP

TA-2 Testing

ID	Name	Start	Finish
97	4.2.2.89 Test Material 6 Open-hole Tension (C) RT	10/27	10/28
98	4.2.2.90 Test Material 1 Open-hole Compression (D) RT	10/31	11/1
99	4.2.2.91 Test Material 2 Open-hole Compression (D) RT	10/31	11/1
100	4.2.2.92 Test Material 3 Open-hole Compression (D) RT	10/31	11/1
101	4.2.2.93 Test Material 4 Open-hole Compression (D) RT	10/31	11/1
102	4.2.2.94 Test Material 5 Open-hole Compression (D) RT	10/31	11/1
103	4.2.2.95 Test Material 6 Open-hole Compression (D) RT	10/31	11/1
104	4.2.2.96 Test Material 1 Open-hole Tension (C) Hot/Wet	11/15	11/16
105	4.2.2.97 Test Material 2 Open-hole Tension (C)Hot/Wet	11/15	11/16
106	4.2.2.98 Test Material 3 Open-hole Tension (C) Hot/Wet	11/15	11/16
107	4.2.2.99 Test Material 4 Open-hole Tension (C) Hot/Wet	11/15	11/16
108	4.2.2.100 Test Material 5 Open-hole Tension (C) Hot/Wet	11/15	11/16
109	4.2.2.101 Test Material 6 Open-hole Tension (C) Hot/Wet	11/15	11/16
110	4.2.2.102 Test Material 1 Open-hole Compression (D) Hot/Wet	11/17	11/18
111	4.2.2.103 Test Material 2 Open-hole Compression (D) Hot/Wet	11/17	11/18
112	4.2.2.104 Test Material 3 Open-hole Compression (D) Hot/Wet	11/17	11/18
113	4.2.2.105 Test Material 4 Open-hole Compression (D) Hot/Wet	11/17	11/18
114	4.2.2.106 Test Material 5 Open-hole Compression (D) Hot/Wet	11/17	11/18
115	4.2.2.107 Test Material 6 Open-hole Compression (D) Hot/Wet	11/17	11/18
116	4.2.2.108 Reduce Data	11/7	11/30
117	4.2.2.109 Fabricate Material 1 for E & F	10/3	10/21
118	4.2.2.110 Fabricate Material 2 for E & F	10/3	10/21
119	4.2.2.111 Fabricate Material 3 for E & F	10/3	10/21
120	4.2.2.112 Fabricate Material 4 for E & F	10/3	10/21

Timeline: 94: Jul ug Sep Oct ov ec; 1995: Jan eb ar pr ay Jun Jul ug ep Oct ov ec; 1996: Jan eb ar pr ay Jun Jul ug Sep

Project: TA-2
Date: 8/26/94

Critical — Progress — Summary
Noncritical — Interface Milestone ◆ — Rolled Up

TA-2 Testing

ID	Name	Start	Finish
121	4.2.2.113 Fabricate Material 5 for E & F	10/3	10/21
122	4.2.2.114 Fabricate Material 6 for E & F	10/3	10/21
123	4.2.2.115 Machine Material 1 - Compression After Impact (E)	10/25	10/28
124	4.2.2.116 Machine Material 2 - Compression After Impact (E)	10/25	10/28
125	4.2.2.117 Machine Material 3 - Compression After Impact (E)	10/25	10/28
126	4.2.2.118 Machine Material 4 - Compression After Impact (E)	10/25	10/28
127	4.2.2.119 Machine Material 5 - Compression After Impact (E)	10/25	10/28
128	4.2.2.120 Machine Material 6 - Compression After Impact (E)	10/25	10/28
129	4.2.2.121 Machine Material 1 - Interlaminar Shear (F)	10/25	10/28
130	4.2.2.122 Machine Material 2 - Interlaminar Shear (F)	10/25	10/28
131	4.2.2.123 Machine Material 3 - Interlaminar Shear (F)	10/25	10/28
132	4.2.2.124 Machine Material 4 - Interlaminar Shear (F)	10/25	10/28
133	4.2.2.125 Machine Material 5 - Interlaminar Shear (F)	10/25	10/28
134	4.2.2.126 Machine Material 6 - Interlaminar Shear (F)	10/25	10/28
135	4.2.2.127 Impact Material 1 - Compression After Impact (E)	10/31	11/4
136	4.2.2.128 Impact Material 2 - Compression After Impact (E)	10/31	11/4
137	4.2.2.129 Impact Material 3 - Compression After Impact (E)	10/31	11/4
138	4.2.2.130 Impact Material 4 - Compression After Impact (E)	10/31	11/4
139	4.2.2.131 Impact Material 5 - Compression After Impact (E)	10/31	11/4
140	4.2.2.132 Impact Material 6 - Compression After Impact (E)	10/31	11/4
141	4.2.2.133 Machine post-impact specimens	11/1	11/7
142	4.2.2.134 Moisturize 1/2 of E & F	11/7	11/22
143	4.2.2.135 Test Material 1 - Compression After Impact (E) RT	10/31	11/1
144	4.2.2.136 Test Material 2 - Compression After Impact (E) RT	10/31	11/1

Timescale: 94: Jul, ug, Sep, Oct, ov, ec; 1995: Jan, eb, ar, pr, ay, Jun, Jul, ug, ep, Oct, ov, ec; 1996: Jan, eb, ar, pr, ay, Jun, Jul, ug, Sep

Project: TA-2
Date: 8/26/94

Critical | Progress | Summary
Noncritical | Interface Milestone ◆ | Rolled Up

TA-2 Testing

ID	Name	Start	Finish
145	4.2.2.137 Test Material 3 - Compression After Impact (E) RT	10/31	11/1
146	4.2.2.138 Test Material 4 - Compression After Impact (E) RT	10/31	11/1
147	4.2.2.139 Test Material 5 - Compression After Impact (E) RT	10/31	11/1
148	4.2.2.140 Test Material 6 - Compression After Impact (E) RT	10/31	11/1
149	4.2.2.141 Test Material 1 - Interlaminar Shear (F) RT	11/2	11/3
150	4.2.2.142 Test Material 2 - Interlaminar Shear (F) RT	11/2	11/3
151	4.2.2.143 Test Material 3 - Interlaminar Shear (F) RT	11/2	11/3
152	4.2.2.144 Test Material 4 - Interlaminar Shear (F) RT	11/2	11/3
153	4.2.2.145 Test Material 5 - Interlaminar Shear (F) RT	11/2	11/3
154	4.2.2.146 Test Material 6 - Interlaminar Shear (F) RT	11/2	11/3
155	4.2.2.147 Test Material 1 - Compression After Impact (E) Hot/	11/23	11/28
156	4.2.2.148 Test Material 2 - Compression After Impact (E) Hot/	11/23	11/28
157	4.2.2.149 Test Material 3 - Compression After Impact (E) Hot/	11/23	11/28
158	4.2.2.150 Test Material 4 - Compression After Impact (E) Hot/	11/23	11/28
159	4.2.2.151 Test Material 5 - Compression After Impact (E) Hot/	11/23	11/28
160	4.2.2.152 Test Material 6 - Compression After Impact (E) Hot/	11/23	11/28
161	4.2.2.153 Test Material 1 - Interlaminar Shear (F) Hot/Wet	11/29	11/30
162	4.2.2.154 Test Material 2 - Interlaminar Shear (F) Hot/Wet	11/29	11/30
163	4.2.2.155 Test Material 3 - Interlaminar Shear (F) Hot/Wet	11/29	11/30
164	4.2.2.156 Test Material 4 - Interlaminar Shear (F) Hot/Wet	11/29	11/30
165	4.2.2.157 Test Material 5 - Interlaminar Shear (F) Hot/Wet	11/29	11/30
166	4.2.2.158 Test Material 6 - Interlaminar Shear (F) Hot/Wet	11/29	11/30
167	4.2.2.159 Reduce Data	11/28	12/16
168	4.2.2.160 Test Report	12/5	2/3

Timeline: 94: Jul, ug, Sep, Oct, ov, ec; 1995: Jan, eb, ar, pr, ay, Jun, Jul, ug, ep, Oct, ov, ec; 1996: Jan, eb, ar, pr, ay, Jun, Jul, ug, Sep

Project: TA-2
Date: 8/26/94

Critical — Noncritical — Progress — Interface Milestone ◆ — Summary — Rolled Up

7 THRUSTTP.MPP

TA-2 Testing

ID	Name	Start	Finish
169	4.2.2.161 Downselect Materials to A & B	12/1	
170	4.2.3 Characterization of Materials		
171	4.2.3.1 Preliminary Design Database		
172	4.2.3.1.1 Order Material	12/1	12/15
173	4.2.3.1.2 Receive Material	1/13	
174	4.2.3.1.3 Fabricate Material A for G, H, M & O	1/9	1/20
175	4.2.3.1.4 Fabricate Material B for G, H, M & O	1/9	1/20
176	4.2.3.1.5 Machine Material A - Tensile (G)	1/18	1/19
177	4.2.3.1.6 Machine Material B - Tensile (G)	1/20	1/23
178	4.2.3.1.7 Strain Gauge	1/23	1/24
179	4.2.3.1.8 Machine Material A - Compression (H)	1/24	1/26
180	4.2.3.1.9 Machine Material B - Compression (H)	1/24	1/26
181	4.2.3.1.10 Machine Material A - Compression Modulus (H	1/24	1/26
182	4.2.3.1.11 Machine Material B - Compression Modulus (H	1/24	1/26
183	4.2.3.1.12 Strain Gauge	1/25	1/27
184	4.2.3.1.13 Machine Material A - Durability Screening (M)	1/27	1/30
185	4.2.3.1.14 Machine Material B - Durability Screening (M)	1/27	1/30
186	4.2.3.1.15 Strain Gauge	1/30	1/31
187	4.2.3.1.16 Ship Durability Screening Specimens to MSFC	2/1	2/2
188	4.2.3.1.17 Machine Material A - Thermal Cycling Screeni	1/31	2/1
189	4.2.3.1.18 Machine Material B - Thermal Cycling Screenin	1/31	2/1
190	4.2.3.1.19 Moisturize 1/3 Specimens G & H	2/2	2/17
191	4.2.3.1.20 Test Material A - Tensile (G) RT	1/25	1/26
192	4.2.3.1.21 Test Material B - Tensile (G) RT	1/25	1/26

Timescale: 94: Jul, ug, Sep, Oct, ov, ec; 1995: Jan, eb, ar, pr, ay, Jun, Jul, ug, ep, Oct, ov, ec; 1996: Jan, eb, ar, pr, ay, Jun, Jul, ug, Sep

Project: TA-2
Date: 8/26/94

Critical | Progress | Summary
Noncritical | Interface Milestone ◆ | Rolled Up

TA-2 Testing

ID	Name	Schedule (Jul 94 – Sep 96)
193	4.2.3.1.22 Test Material A - Tensile (G) -270F	1/27 – 2/1
194	4.2.3.1.23 Test Material B - Tensile (G) -270F	1/27 – 2/1
195	4.2.3.1.24 Test Material A - Compression (H) RT	2/2 – 2/3
196	4.2.3.1.25 Test Material B - Compression (H) RT	2/2 – 2/3
197	4.2.3.1.26 Test Material A - Compression (H) -270F	2/6 – 2/9
198	4.2.3.1.27 Test Material B - Compression (H) -270F	2/6 – 2/9
199	4.2.3.1.28 Test Material A - Compression Modulus (H) R	2/10 – 2/13
200	4.2.3.1.29 Test Material B - Compression Modulus (H) RT	2/10 – 2/13
201	4.2.3.1.30 Test Material A - Compression Modulus (H) -2	2/14 – 2/17
202	4.2.3.1.31 Test Material B - Compression Modulus (H) -27	2/14 – 2/17
203	4.2.3.1.32 Test Material A - Thermal Cycling Screening (	
204	4.2.3.1.32.1 Cycle -270F to 300F, 1 LT	2/2 – 2/7
205	4.2.3.1.32.2 Strain Gauge	2/8 – 2/8
206	4.2.3.1.32.3 Moisturize 1/2 Specomens	2/9 – 2/24
207	4.2.3.1.32.4 Test Material RT	2/20 – 2/21
208	4.2.3.1.33 Test Material B - Thermal Cycling Screening (	
209	4.2.3.1.33.1 Cycle -270F to 300F, 1 LT	2/2 – 2/7
210	4.2.3.1.33.2 Strain Gauge	2/8 – 2/8
211	4.2.3.1.33.3 Moisturize 1/2 Specomens	2/9 – 2/24
212	4.2.3.1.33.4 Test Material RT	2/20 – 2/21
213	4.2.3.1.34 Test Material A - Tensile (G) Hot/Wet	2/22 – 2/23
214	4.2.3.1.35 Test Material B - Tensile (G) Hot/Wet	2/22 – 2/23
215	4.2.3.1.36 Test Material A - Compression (H) Hot/Wet	2/24 – 2/27
216	4.2.3.1.37 Test Material B - Compression (H) Hot/Wet	2/24 – 2/27

Project: TA-2
Date: 8/26/94

Critical | Progress | Summary
Noncritical | Interface Milestone ◆ | Rolled Up

9 THRUSTTP.MPP

TA-2 Testing

ID	Name	Schedule (1994–1996)
217	4.2.3.1.38 Test Material A - Thermal Cycling Screening (	2/28 3/1
218	4.2.3.1.39 Test Material B - Thermal Cycling Screening (	2/28 3/1
219	4.2.3.1.40 Test Material A - Compression Modulus (H) Ho	3/2 3/3
220	4.2.3.1.41 Test Material B - Compression Modulus (H) Ho	3/2 3/3
221	4.2.3.1.42 Reduce Test Data	2/8 3/17
222	4.2.3.1.43 Fabricate Material A for I & L	1/20 2/9
223	4.2.3.1.44 Fabricate Material B for I & L	1/20 2/9
224	4.2.3.1.45 Machine Material A In-plane Shear (L)	2/2 2/7
225	4.2.3.1.46 Machine Material B In-plane Shear (L)	2/2 2/7
226	4.2.3.1.47 Machine Material A Open-hole Compression (I)	2/8 2/14
227	4.2.3.1.48 Machine Material B Open-hole Compression (I)	2/8 2/14
228	4.2.3.1.49 Moisturize 1/3 Specimens I & L	2/15 3/2
229	4.2.3.1.50 Test Material A In-plane Shear (L) RT	3/6 3/7
230	4.2.3.1.51 Test Material B In-plane Shear (L) RT	3/6 3/7
231	4.2.3.1.52 Test Material A In-plane Shear (L) -270F	3/8 3/9
232	4.2.3.1.53 Test Material B In-plane Shear (L) -270F	3/8 3/9
233	4.2.3.1.54 Test Material A Open-hole Compression (I) RT	3/10 3/13
234	4.2.3.1.55 Test Material B Open-hole Compression (I) RT	3/10 3/13
235	4.2.3.1.56 Test Material A Open-hole Compression (I) -27	3/14 3/15
236	4.2.3.1.57 Test Material B Open-hole Compression (I) -27	3/14 3/15
237	4.2.3.1.58 Test Material A In-plane Shear (I) Hot/Wet	3/16 3/17
238	4.2.3.1.59 Test Material B In-plane Shear (I) Hot/Wet	3/16 3/17
239	4.2.3.1.60 Test Material A Open-hole Compression (L) Ho	3/20 3/21
240	4.2.3.1.61 Test Material B Open-hole Compression (L) Ho	3/20 3/21

Timescale: 94: Jul, ug, Sep, Oct, ov, ec; 1995: Jan, eb, ar, pr, ay, Jun, Jul, ug, ep, Oct, ov, ec; 1996: Jan, eb, ar, pr, ay, Jun, Jul, ug, Sep

Project: TA-2
Date: 8/26/94

Critical | Progress | Summary
Noncritical | Interface Milestone ◆ | Rolled Up

10 THRUSTTP.MPP

TA-2 Testing

ID	Name	Start	Finish
241	4.2.3.1.62 Reduce Data	3/6	3/24
242	4.2.3.1.63 Fabricate Material A for J, K & P	2/10	2/23
243	4.2.3.1.64 Fabricate Material B for J, k & P	2/10	2/23
244	4.2.3.1.65 Machine Material A - Damage Tolerance Scree	2/20	2/23
245	4.2.3.1.66 Machine Material B - Damage Tolerance Screen	2/20	2/23
246	4.2.3.1.67 Ship Damage Tolerance Screening Specimens t	2/24	2/24
247	4.2.3.1.68 Machine Material A - Compression After Impac	2/24	3/2
248	4.2.3.1.69 Machine Material B - Compression After Impac	2/24	3/2
249	4.2.3.1.70 Machine Material A - Compression Interlaminar	3/3	3/8
250	4.2.3.1.71 Machine Material B - Compression Interlaminar	3/3	3/8
251	4.2.3.1.72 Impact Material A - Compression After Impact	3/1	3/7
252	4.2.3.1.73 Impact Material B - Compression After Impact (	3/1	3/7
253	4.2.3.1.74 Machine post-impact specimens	3/2	3/7
254	4.2.3.1.75 Moisturize 1/3 of J & K	3/7	3/22
255	4.2.3.1.76 Test Material A - Compression After Impact (J)	3/22	3/23
256	4.2.3.1.77 Test Material B - Compression After Impact (J)	3/22	3/23
257	4.2.3.1.78 Test Material A - Compression After Impact (J)	3/24	3/27
258	4.2.3.1.79 Test Material B - Compression After Impact (J)	3/24	3/27
259	4.2.3.1.80 Test Material A - Compression Interlaminar She	3/28	3/29
260	4.2.3.1.81 Test Material B - Compression Interlaminar She	3/28	3/29
261	4.2.3.1.82 Test Material A - Compression Interlaminar She	3/30	3/31
262	4.2.3.1.83 Test Material B - Compression Interlaminar She	3/30	3/31
263	4.2.3.1.84 Test Material A - Compression After Impact (J)	4/3	4/4
264	4.2.3.1.85 Test Material B - Compression After Impact (J)	4/3	4/4

Timeline: 94 — Jul, ug, Sep, Oct, ov, ec; 1995 — Jan, eb, ar, pr, ay, Jun, Jul, ug, ep, Oct, ov, ec; 1996 — Jan, eb, ar, pr, ay, Jun, Jul, ug, Sep

Project: TA-2
Date: 8/26/94

Critical | Progress | Summary
Noncritical | Interface Milestone ◆ | Rolled Up

11 THRUSTTP.MPP

TA-2 Testing

ID	Name	Schedule (Jul 1994 – Sep 1996)
265	4.2.3.1.86 Test Material A - Compression Interlaminar She	4/5 – 4/6
266	4.2.3.1.87 Test Material B - Compression Interlaminar She	4/5 – 4/6
267	4.2.3.1.88 Reduce Data	3/27 – 4/11
268	4.2.3.1.89 Test Report	3/1 – 4/15
269	4.2.3.2 Design Validation	
270	4.2.3.2.1 Durability Screening incoorperated in 4.2.3.1.3 (	1/9 – 2/2
271	4.2.3.2.2 Thermal Cycling Screening incoorperated in 4.2.	1/9 – 3/2
272	4.2.3.2.3 Damage Tolerance Screening incoorperated in 4.	2/10 – 3/9
273	4.2.4 Element Testing	
274	4.2.4.1 Acoustic Fatigue (N)	
275	4.2.4.1.1 Design Acoustic Fatigue (N)	1/3 – 1/6
276	4.2.4.1.2 Tool Design	1/3 – 1/23
277	4.2.4.1.3 Fab Tool	1/23 – 2/17
278	4.2.4.1.4 Fabricate 6 Parts	
279	4.2.4.1.4.1 Fab Skins	2/10 – 2/16
280	4.2.4.1.4.2 Fab Stringers	2/20 – 2/21
281	4.2.4.1.4.3 Cocure Assembly	2/22 – 2/23
282	4.2.4.1.4.4 Fab Stringers	2/24 – 2/27
283	4.2.4.1.4.5 Cocure Assembly	2/28 – 3/1
284	4.2.4.1.4.6 Fab Stringers	3/2 – 3/3
285	4.2.4.1.4.7 Cocure Assembly	3/6 – 3/7
286	4.2.4.1.4.8 Fab Stringers	3/8 – 3/9
287	4.2.4.1.4.9 Cocure Assembly	3/10 – 3/13
288	4.2.4.1.4.10 Fab Stringers	3/14 – 3/15

Project: TA-2
Date: 8/26/94

Critical | Progress | Summary
Noncritical | Interface Milestone ◆ | Rolled Up

12 THRUSTTP.MPP

TA-2 Testing

ID	Name	Start	Finish
289	4.2.4.1.4.11 Cocure Assembly	3/16	3/17
290	4.2.4.1.4.12 Fab Stringers	3/20	3/21
291	4.2.4.1.4.13 Cocure Assembly	3/22	3/23
292	4.2.4.1.4.14 Inspect specimens	2/27	3/24
293	4.2.4.1.4.15 Instrumentation	3/6	3/27
294	4.2.4.1.5 Ship to AFWL/FDD	3/28	3/28
295	4.2.4.1.6 Data Reduction	0	7/20
296	4.2.4.2 Thick Cross-Ply Laminate (Q)		
297	4.2.4.2.1 Design Thick cross-ply laminate (Q)	1/9	1/20
298	4.2.4.2.2 Fabricate 6 specimens	1/23	2/3
299	4.2.4.2.3 Inspect Specimens	2/6	2/6
300	4.2.4.2.4 Instrumentation	2/7	2/7
301	4.2.4.2.5 Moisturize 3 specimens	2/8	2/28
302	4.2.4.2.6 Test 3 specimens at RT	2/8	2/8
303	4.2.4.2.7 Test 3 specimens Hot/Wet	3/1	3/1
304	4.2.4.2.8 Data Reduction	2/9	3/3
305	4.2.4.3 Verify Bond Pull-off Strength		
306	4.2.4.3.1 Design Pull-off Specimens (R)	1/16	1/20
307	4.2.4.3.2 Tool Design	1/23	2/3
308	4.2.4.3.3 Fab Tool	2/6	3/3
309	4.2.4.3.4 Fabricate 6 Parts		
310	4.2.4.3.4.1 Fab Preform	2/6	3/3
311	4.2.4.3.4.2 Inject & Cure	3/6	3/10
312	4.2.4.3.4.3 Fab Skins	2/27	3/3

Timescale: 94: Jul, ug, Sep, Oct, ov, ec; 1995: Jan, eb, ar, pr, ay, Jun, Jul, ug, ep, Oct, ov, ec; 1996: Jan, eb, ar, pr, ay, Jun, Jul, ug, Sep

Project: TA-2
Date: 8/26/94

Critical | Progress | Summary
Noncritical | Interface Milestone ◆ | Rolled Up

13 THRUSTTP.MPP

TA-2 Testing

ID	Name	Start	Finish
313	4.2.4.3.4.4 Assemble	3/10	3/13
314	4.2.4.3.4.5 Inspect specimens	3/6	3/17
315	4.2.4.3.4.6 Instrumentation	3/18	3/20
316	4.2.4.3.4.7 Moisturize 3 specimens	3/20	4/3
317	4.2.4.3.4.8 Test Three Specimens at RT	3/21	3/22
318	4.2.4.3.4.9 Test Three Specimens at Hot/Wet	4/4	4/7
319	4.2.4.3.4.10 Data Reduction	3/22	4/14
320	4.2.4.4 Verify Ring Frame Joint (S)		
321	4.2.4.4.1 Design Ring Frame Joint Specimens	1/30	2/3
322	4.2.4.4.2 Tool Design	1/30	2/24
323	4.2.4.4.3 Fab Tool	2/27	3/24
324	4.2.4.4.4 Fabricate preforms	2/27	3/24
325	4.2.4.4.5 Fabricate 4 Parts		
326	4.2.4.4.5.1 Fab Stringers	3/27	3/31
327	4.2.4.4.5.2 Fab Mounting Plate	3/27	3/31
328	4.2.4.4.5.3 Assemble & Install Fasteners	4/3	4/7
329	4.2.4.4.5.4 Inspect specimens	4/8	4/10
330	4.2.4.4.5.5 Instrumentation	4/10	4/10
331	4.2.4.4.5.6 Fab Stringers	4/3	4/7
332	4.2.4.4.5.7 Fab Mounting Plate	4/3	4/7
333	4.2.4.4.5.8 Assemble & Install Fasteners	4/10	4/17
334	4.2.4.4.5.9 Inspect specimens	4/17	4/17
335	4.2.4.4.5.10 Instrumentation	4/17	4/17
336	4.2.4.4.5.11 Moisturize 2 specimens	4/18	5/2

Timescale: 94: Jul, ug, Sep, Oct, ov, ec; 1995: Jan, eb, ar, pr, ay, Jun, Jul, ug, ep, Oct, ov, ec; 1996: Jan, eb, ar, pr, ay, Jun, Jul, ug, Sep

Project: TA-2
Date: 8/26/94

Critical — Progress — Summary
Noncritical — Interface Milestone ◆ — Rolled Up

TA-2 Testing

ID	Name	Schedule (Jul 1994 – Sep 1996)
337	4.2.4.4.5.12 Fab Stringers	4/10 – 4/17
338	4.2.4.4.5.13 Fab Mounting Plate	4/10 – 4/17
339	4.2.4.4.5.14 Assemble & Install Fasteners	4/17 – 4/21
340	4.2.4.4.5.15 Inspect specimens	4/24 – 4/24
341	4.2.4.4.5.16 Instrumentation	4/24 – 4/24
342	4.2.4.4.5.17 Fab Stringers	4/17 – 4/21
343	4.2.4.4.5.18 Fab Mounting Plate	4/17 – 4/21
344	4.2.4.4.5.19 Assemble & Install Fasteners	4/24 – 4/28
345	4.2.4.4.5.20 Inspect specimens	5/1 – 5/1
346	4.2.4.4.5.21 Instrumentation	5/1 – 5/1
347	4.2.4.4.5.22 Test Two Specimens at RT	5/9 – 5/10
348	4.2.4.4.5.23 Test Two Specimens at Hot/Wet	5/3 – 5/8
349	4.2.4.4.5.24 Data Reduction	5/8 – 5/19
350	4.2.4.5 Engine Mount Specimen (T)	
351	4.2.4.5.1 Design Enginer Mount Specimens	2/6 – 2/10
352	4.2.4.5.2 Fabricate specimens 1	2/13 – 2/17
353	4.2.4.5.3 Inspect Specimens	2/20 – 2/20
354	4.2.4.5.4 Instrumentation	2/20 – 2/20
355	4.2.4.5.5 Fabricate specimens 2	2/20 – 2/24
356	4.2.4.5.6 Inspect Specimens	2/27 – 2/27
357	4.2.4.5.7 Instrumentation	2/27 – 2/27
358	4.2.4.5.8 Ship part 1 & 2 to SSD for moisturization	2/28 – 2/28
359	4.2.4.5.9 Fabricate specimens 3	2/27 – 3/3
360	4.2.4.5.10 Inspect Specimens	3/6 – 3/6

Project: TA-2
Date: 8/26/94

Critical | Progress | Summary
Noncritical | Interface Milestone ◆ | Rolled Up

15 THRUSTTP.MPP

TA-2 Testing

ID	Name	Start	Finish
361	4.2.4.5.11 Instrumentation	3/6	3/6
362	4.2.4.5.12 Fabricate specimens 4	3/6	3/10
363	4.2.4.5.13 Inspect Specimens	3/13	3/13
364	4.2.4.5.14 Instrumentation	3/13	3/13
365	4.2.4.5.15 Ship to SSD	3/14	3/14
366	4.2.4.5.16 Data Reduction	4/17	4/28
367	4.2.4.6 Shell Joint Shear Test (U)		
368	4.2.4.6.1 Design Shell Joint Shear Test Specimen	12/16	12/23
369	4.2.4.6.2 Tool Design	1/3	1/30
370	4.2.4.6.3 Fab Tool	1/31	2/27
371	4.2.4.6.4 Fabricate Preforms	1/31	2/27
372	4.2.4.6.5 Fabricate 4 Parts		
373	4.2.4.6.5.1 Fab Stringers (4 parts)	3/1	3/28
374	4.2.4.6.5.2 Fab Shear Tie (4 parts)	3/1	3/28
375	4.2.4.6.5.3 Fab skins (4 parts)	3/1	3/7
376	4.2.4.6.5.4 Fab Longeron (part 1)	3/1	3/7
377	4.2.4.6.5.5 Fab Longeron (part 2)	3/8	3/14
378	4.2.4.6.5.6 Fab Longeron (part 3)	3/15	3/21
379	4.2.4.6.5.7 Fab Longeron (part 4)	3/22	3/28
380	4.2.4.6.5.8 Assemble 1	3/13	3/17
381	4.2.4.6.5.9 Assemble 2	3/18	3/24
382	4.2.4.6.5.10 Inspect specimens	3/20	3/27
383	4.2.4.6.5.11 Instrumentation	3/27	3/27
384	4.2.4.6.5.12 Ship part 1 & 2 to SSD for moisturizatio	3/28 ◆	

Timeline: 94: Jul, ug, Sep, Oct, ov, ec; 1995: Jan, eb, ar, pr, ay, Jun, Jul, ug, ep, Oct, ov, ec; 1996: Jan, eb, ar, pr, ay, Jun, Jul, ug, Sep

Project: TA-2
Date: 8/26/94

Critical | Progress | Summary
Noncritical | Interface Milestone ◆ | Rolled Up

TA-2 Testing

ID	Name	Start	Finish
385	4.2.4.6.5.13 Assemble 3	3/27	3/31
386	4.2.4.6.5.14 Assemble 4	4/3	4/7
387	4.2.4.6.5.15 Inspect specimens	4/3	4/10
388	4.2.4.6.5.16 Instrumentation	4/10	4/10
389	4.2.4.6.5.17 Ship to SSD	4/11	4/11
390	4.2.4.6.5.18 Data Reduction	5/15	6/2
391	4.2.4.6.6 Repair Thin Structure (V)		
392	4.2.4.6.6.1 Design Two Repair Specimens	1/23	1/27
393	4.2.4.6.6.2 Fabricate 4 Repair Specimens - Design 1	1/30	3/3
394	4.2.4.6.6.3 Fabricate 4 Repair Specimens - Design 2	1/30	3/3
395	4.2.4.6.6.4 Inspect Panels	3/6	3/6
396	4.2.4.6.6.5 Ship Panels for Damage	3/7	3/7
397	4.2.4.6.6.6 Receive Panels	3/21	3/21
398	4.2.4.6.6.7 Inspect Panels	3/22	3/22
399	4.2.4.6.6.8 Evaluate Damage	3/23	3/29
400	4.2.4.6.6.9 Repair Panel 1 - Design 1	3/30	4/12
401	4.2.4.6.6.10 Repair Panel 1 - Design 2	3/30	4/12
402	4.2.4.6.6.11 Inspection	4/13	4/13
403	4.2.4.6.6.12 Instruementation	4/13	4/13
404	4.2.4.6.6.13 Moisturize	4/13	4/28
405	4.2.4.6.6.14 Repair Panel 2 - Design 1	4/13	4/27
406	4.2.4.6.6.15 Repair Panel 2 - Design 2	4/13	4/27
407	4.2.4.6.6.16 Inspection	4/28	4/28
408	4.2.4.6.6.17 Instruementation	5/1	5/1

Timeline: 94 (Jul, ug, Sep, Oct, ov, ec); 1995 (Jan, eb, ar, pr, ay, Jun, Jul, ug, ep, Oct, ov, ec); 1996 (Jan, eb, ar, pr, ay, Jun, Jul, ug, Sep)

Project: TA-2
Date: 8/26/94

Critical | Progress | Summary
Noncritical | Interface Milestone ◆ | Rolled Up

TA-2 Testing

ID	Name		
409	4.2.4.6.6.18 Test Panel 1, Design 1 & 2 at RT	5/1	5/5
410	4.2.4.6.6.19 Test Panel 2, Design 1 & 2 at Hot/Wet	5/1	5/5
411	4.2.4.6.6.20 Data Reduction	5/8	5/19
412	4.2.4.6.7 Test Report	5/1	6/2
413	4.3 Fabricate Full-scale Test Article		
414	4.3.1 Structural Design/Tool Design	4/3	9/13
415	4.3.2 FEM and analysis	4/3	7/14
416	4.3.3 Fabrication		
417	4.3.3.1 Fabricate Tool	6/12	9/18
418	4.3.3.2 Fabricate Static Test Article		
419	4.3.3.2.1 Detail Part Fab		
420	4.3.3.2.1.1 Order Material	6/5	6/5
421	4.3.3.2.1.2 Receive Material	8/15	8/15
422	4.3.3.2.1.3 Kick Frame	7/10	7/19
423	4.3.3.2.1.4 Kick Frame Cap	6/23	7/10
424	4.3.3.2.1.5 Firewall	7/30	8/11
425	4.3.3.2.1.6 Longeron	9/14	10/4
426	4.3.3.2.1.7 Intercostal	8/26	9/6
427	4.3.3.3 Fabricate Durability and IHM Test Article		
428	4.3.3.3.1 Detail Part Fab		
429	4.3.3.3.1.1 Kick Frame	7/20	7/31
430	4.3.3.3.1.2 Kick Frame Cap	7/20	8/2
431	4.3.3.3.1.3 Firewall	8/12	8/25
432	4.3.3.3.1.4 Longeron	10/4	10/24

Timescale: 94: Jul, ug, Sep, Oct, ov, ec; 1995: Jan, eb, ar, pr, ay, Jun, Jul, ug, ep, Oct, ov, ec; 1996: Jan, eb, ar, pr, ay, Jun, Jul, ug, Sep

Project: TA-2
Date: 8/26/94

Critical | Progress | Summary
Noncritical | Interface Milestone ◆ | Rolled Up

TA-2 Testing

ID	Name	94 / 1995 / 1996 (Jul ug Sep Oct ov ec Jan eb ar pr ay Jun Jul ug ep Oct ov ec Jan eb ar pr ay Jun Jul ug Sep)
433	4.3.3.3.1.5 Intercostal	9/7 9/15
434	4.3.3.4 Inspection	8/1 10/27
435	4.3.3.5 Assembly	
436	4.3.3.5.1 Static Test Article	9/7 4/1
437	4.3.3.5.2 Durability & IHM Test Article	10/30 4/1
438	4.3.3.6 Inspection	4/1 4/26
439	4.3.3.7 Ship to MSFC	6/14 ◆
440	4.4 FSTA	
441	4.4.1 Test FSTA	6/3 8/16
442	4.4.2 Test Report	8/19 9

Project: TA-2 Date: 8/26/94	Critical Noncritical	Progress Interface Milestone ◆	Summary Rolled Up

MIL-STD-10A
Notice 3
3 January 1966

JUL 6 1966

MILITARY STANDARD

SURFACE ROUGHNESS, WAVINESS AND LAY

Military Standard MIL-STD-10A, dated 13 October 1955, is hereby cancelled for use by all Departments and Agencies of the Department of Defense. Use American Standard ASA B46.1 1962, Surface Texture (Surface Roughness, Waviness and Lay.) (See Acceptance Notice ASA B46.1, dated 21 December 1965).

This Notice supersedes all existing Notices relating to MIL-STD-10A.

(Copies of specifications, [illegible] draw[illegible] required by contractors in con[illegible] should be obtained from the procurin[illegible] contracting officer.)

Errata

NASA Reference Publication 1142

NASA/Aircraft Industry Standard Specification for
Graphite Fiber/Toughened Thermoset Resin Composite Material

ACEE Composites Project Office, Compiler

June 1985

This errata is issued to correct the dimensions on figure 10(b), page 46. Please replace page 46 with the enclosed page.

ISSUE DATE: JULY 1988

FOREWORD

A standard specification for a selected class of graphite fiber/toughened thermoset resin matrix material has been developed through a joint NASA/Aircraft Industry effort involving technical personnel from the NASA Langley Research Center and from the three commercial transport producers: Boeing Commercial Airplane Company, Douglas Aircraft Company, and Lockheed-California Company. This standard specification has been compiled to provide uniform requirements and tests for qualifying prepreg systems and for acceptance of prepreg batches. Significant advantages are expected to accrue through the availability and use of the standard specification, both to the using aircraft industry and to the suppliers. Potential advantages to the users include multiple sources of suppliers, one material requirement, more uniform quality, greater availability, and lower costs. Potential advantages to suppliers include uniform testing, quality control, formulation, and processing and improved market opportunities.

The specification applies specifically to a class of composite prepreg consisting of unidirectional graphite fibers impregnated with a toughened thermoset resin that will produce laminates with service temperatures from -65°F to 200°F when cured at temperatures below or equal to 350°F. The specified prepreg has a fiber areal weight of 145 g/m^2. The specified tests are limited to those required to set minimum standards for the uncured prepreg and cured laminates and are not intented to provide design allowable properties. Qualification and subsequent use of a material through this specification does not constitute or imply endorsement by NASA.

NASA
Reference
Publication
1142

1985

NASA/Aircraft Industry Standard Specification for Graphite Fiber/Toughened Thermoset Resin Composite Material

Compiled by
ACEE Composites Project Office

Langley Research Center
Hampton, Virginia

NASA
National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

CONTENTS

1 SCOPE

This specification establishes requirements for qualification and batch acceptance of a carbon fiber toughened thermoset resin prepreg that will provide a laminate with service temperature from -65°F to +200°F when cured in an autoclave at temperatures not higher than 350°F and at pressures no greater than 100 psi.

2 CLASSIFICATION

Prepreg materials shall be of the following types, classes, and grades.

2.1 Types

The types shall specify the prepreg nominal resin content.

Type 1 - Resin content 35 percent by weight

2.2 Classes

The class shall specify the prepreg form.

Class 1 - Unidirectional prepreg tape

2.3 Grades

The grades shall specify the areal weight of carbon fibers in grams per meter^2.

Grade fiber areal weight, g/m^2	Nominal cured ply thickness, in.
Grade 145	0.0056

3 APPLICABLE DOCUMENTS

3.1 ASTM Standards

Standard Recommended Practice for Inplane Shear Stress-Strain Response of Unidirectional Reinforced Plastics. ANSI/ASTM Designation: D 3518 - 76. Part 36 of 1981 Annual Book of ASTM Standards, c.1981, pp. 891-896.

Standard Test Methods of Load Verification of Testing Machines. ASTM Designation: E 4 - 79. Part 35 of 1982 Annual Book of ASTM Standards, c.1982, pp. 1056-1063.

Standard Test Methods for Void Content of Reinforced Plastics. ASTM Designation: D 2734 - 70 (Reapproved 1980). Part 36 of 1982 Annual Book of ASTM Standards, c.1982, pp. 570-573.

Standard Test Method for Compressive Properties of Rigid Plastics. ASTM Designation: D 695 - 80. Part 35 of 1982 Annual Book of ASTM Standards, c.1982, pp. 291-298.

3.2 Military Standards

Military Standard - Surface Roughness, Waviness and Lay. MIL-STD-10A, Jan. 3, 1966. (Supersedes MIL-STD-10, Aug. 2, 1949.)

3.3 NASA Documents

Chen, J. S.; and Hunter, A. B.: Development of Quality Assurance Methods for Epoxy Graphite Prepreg. NASA CR-3531, 1982.

ACEE Composites Project Office, compiler: Standard Tests for Toughened Resin Composites - Revised Edition. NASA RP-1092, 1983. (Supersedes NASA RP-1092, 1982.)

4 DEFINITION OF TERMS

a. Resin batch: Resin mixed with the same lots of ingredients in one continuous operation with traceability to individual component lots.

b. Prepreg batch: Prepreg containing one distinct yarn lot of graphite fiber reinforcements impregnated with one distinct batch of resin in one continuous operation.

c. Yarn or tow lot: The quantity of carbon fibers formed during a single production run having the same continuous process and identical characteristics throughout.

d. Prepreg lot: Prepreg from one batch submitted for acceptance at one time.

e. Storage life: The time in storage at 10°F or below, while contained in a moisture barrier bag made of 6 mil or thicker continuous polyethylene, during which the material maintains its handling life, processing life, and all other requirements of this specification.

f. Processing life: The out-of-refrigeration exposure time that the material can sustain and produce specification-acceptable mechanical properties in laminates when processed by the specified standard cure cycle.

g. Handling life: The out-of-refrigeration exposure time during which the material retains tack, forming, and draping characteristics.

h. Surface resin starvation: Incomplete resin filling of the prepreg surface.

i. Puckers: Areas on prepreg materials that are locally blistered or puckered from the separator film or release paper.

j. Fuzz balls: Balls of fibers that occur when individual filaments are abraded or broken during manufacture of the prepreg. These fibers collect as loose filament bundles or balls which are occasionally incorporated into the prepreg.

k. Roll: Originally produced prepreg roll before slitting.

l. Basic surface roughness symbol: √ designates surface roughness.

5 REQUIREMENTS

5.1 Qualification Approval

The materials qualified under this specification shall have passed all qualification requirements specified herein. Qualification requirements shall include all those indicated in tables 1, 2, 3, and 4. After qualification approval, the properties and methods of manufacture shall not be changed without written approval from the buyer. The supplier shall conduct qualification tests on three batches of prepreg material. Suppliers shall provide two copies of all required qualification test results, including individual test values.

5.2 Acceptance Approval

The materials delivered under this specification shall have passed the acceptance tests specified in tables 2, 3, and 4.

5.2.1 Supplier Specifications

Suppliers shall submit their quality control specifications and obtain buyer approval for control of the equipment, processes, test procedures, and raw materials for the manufacture of the product. If necessary, the buyer will stipulate an agreement of secrecy to safeguard the interest of the supplier.

5.2.2 Acceptance Test Results

The supplier shall provide two copies of all required acceptance test results, including individual test values.

5.3 Component Requirements

5.3.1 Fiber

Specifications for graphite fibers used to produce prepreg follow.

5.3.1.1 Fiber classification.- The graphite fiber reinforcements shall be of the following filament count:

3000:	shall be 3000 filaments per tow or yarn
6000:	shall be 6000 filaments per tow or yarn
12 000:	shall be 12 000 filaments per tow or yarn

5.3.1.2 Fiber splices.- The graphite fiber shall contain no more than one splice per pound of tow or yarn with a minimum spacing of 500 ft between splices. The length of any fiber splice shall be 1.50 ± 0.75 in.

5.3.1.3 Fiber requirements.- The graphite fiber reinforcement yarn or tow shall meet the requirements shown in table 1.

5.3.1.4 Fiber certification.- The prepreg supplier shall certify for each prepreg batch that the fiber reinforcement meets the requirements of table 1 and shall provide documentation upon request. The prepreg supplier shall provide a chromatogram of fiber sizing extracted from each yarn lot made by high pressure liquid chromatography (HPLC).

5.3.1.5 Fiber test methods.- Test methods shall be established by the prepreg supplier and documented in a material specification approved by the buyer.

5.3.2 Resin

The resin shall be a toughened thermoset polymer which shall meet the require-...s of this specification. Resin processing temperatures shall be no higher than 350°F and processing pressures shall be no higher than 100 psig. Cured laminates made from this material shall be capable of performing continuously at temperatures from -65°F to +200°F.

5.3.3 Prepreg Requirements

Prepreg material shall be tested in accordance with the procedures specified in appendix A and shall meet the requirements specified in table 2.

5.3.3.1 Tape dimensions.- The length and width of the prepreg material shall be as specified by the buyer. The width tolerance shall be ±0.040 in. over the full length of the roll. The weight of 12-in-wide prepreg material on all but a single roll in a batch shall be between 20 and 70 lb unless otherwise specified. The weight shall be proportionally less for narrower widths.

5.3.3.2 Carrier.- The prepreg shall have a moisture resistant carrier (60-lb kraft paper unless otherwise specified) suitable for use with automated dispensing equipment. The carrier shall be the same width as the prepreg tape (+0.040 to 0 in.) specified on the purchase order. The carrier may have a release coating. The carrier shall be easily removable from the material at ambient temperature without transfer of the release coating to the resin and without distortion of the fibers. e prepreg shall contact the carrier at all places on the roll. The carrier shall ı the outside of the roll.

5.3.3.3 Roll core configuration.- Each roll of prepreg shall be supported by a core that does not deform by the material weight. The core shall be supported during shipping and storage in such a way that the material will not be damaged by its own weight. The core inside diameter shall not be less than 8 in. The core length shall be 3 in. longer than the prepreg width.

5.3.3.4 Alignment.- The alignment of the collimated tows or yarns within the prepreg shall not deviate from the material centerline by more than 0.030 in. in a linear foot. The edge of the material shall not deviate from a reference straight line by more than 0.020 in. in any linear foot. The fibers must be flush with the edge of the carrier within 0.025 in.

5.3.3.5 Gaps.- Gaps are defined as the individual open spaces between adjacent, parallel tows or yarns that are 0.010 in. wide or greater. Gaps shall be no more than 0.020 in. wide and not more than 3 in. long. No more than one such gap shall appear in any 50 linear ft of prepreg.

5.3.3.6 Splices.- Yarn or tow splices shall overlap 1.50 ± 0.75 in. and their location shall be clearly indicated on the prepreg or carrier. Not more than one splice shall occur in any 48-in. length of prepreg.

5.3.3.7 Handling characteristics.- In the temperature range 65°F to 85°F, the material shall have the required tack to permit easy removal from the carrier without loss of resin, tearing, shredding, or otherwise becoming damaged. The material shall be capable of being cut without disarray of the filaments or other visible damage.

5.3.3.8 Workmanship.- The prepreg tape shall be free of foreign material, crossed or broken tows, broken tow splices, cured resin particles, fuzz balls, resin rich or starved areas, puckers, and wrinkles which cannot be smoothed out by hand pressure. The material shall be uniform in quality and condition.

5.3.3.9 Tagging of defective areas.- Prepreg rolls containing unacceptable defects shall be tagged on the roll so that the tags are clearly visible before unrolling. The supplier shall provide a linear listing of all defective areas, indicating the length of the defective area and footage at the start and end of the defective area. The supplier shall label the locations of all defects. Rolls containing more than 5 percent defective yardage shall be rejectable. The defective areas shall not be considered as deliverable quantity under the purchase order. Defective areas shall not be closer than 50 linear ft. Prepreg material may be cut to remove defects, but supplied prepreg shall be in lengths of not less than 50 ft. For prepreg supplied for automated layup, all defective material must be removed by cutting and splicing. Splices shall meet the requirement of section 5.3.3.6.

5.3.3.10 Effect of storage.-

1. Storage life shall be 6 months or longer from date of shipment when stored at 10°F or lower in the original sealed shipping package.

2. Handling life shall be 10 days or longer when exposed to room temperature, 80°F maximum in a closed container.

3. Processing life shall be 30 days or longer when exposed to room temperature, 80°F maximum on a tooling surface.

5.3.3.11 Cure.- Material supplied to this specification shall be capable of being cured with the bagging procedure shown in figure 1 and the standard cure cycle ~~ified in figure 2.

5.3.4 Laminate Properties

Test panels fabricated in accordance with section 5.3.3.11 and tested in accordance with the procedures specified in appendix B shall meet all the requirements indicated in tables 3 and 4.

6 QUALITY ASSURANCE PROVISIONS

6.1 Supplier Responsibilities

The supplier is responsible for the performance of all test and inspection requirements specified herein. The supplier may use his own or any other test facilities acceptable to the buyer. Test and inspection records shall be retained for a minimum of 5 years and shall be made available to the buyer.

6.2 Material Qualification

?.1 Qualification and Approval

A supplier shall not begin to supply material to this specification until all qualification requirements have been met and approval has been granted by the buyer. Thereafter, the materials and method of manufacture shall not be changed without prior approval by the buyer.

6.2.2 Sample Material Requirement

Qualification shall be based upon the manufacture and successful test of three batches of prepreg. Each prepreg batch shall consist of only one distinct graphite fiber yarn lot and one distinct resin batch. Two separate and distinct fiber lots and two separate and distinct resin batches shall be used to make the three prepreg batches. The supplier shall submit two copies of test data, including individual and average test values, to the buyer, which show that the material meets all of the requirements of the specification.

6.2.3 Audit

Suppliers seeking qualification to this specification shall submit to an audit of their product manufacturing operations, raw material traceability, process records, test procedures, and Quality Assurance records. Nondisclosure agreements will be signed between the supplier and the buyer if deemed necessary.

6.2.4 Process Plan

The supplier shall have on file a Process Control Document that contains all manufacturing baseline chemical and in-process test information approved by the buyer. No change to approved product formulation, critical raw materials or suppliers, basic methods of manufacture, testing, or geographic location shall be made without prior approval by the buyer. Requalification of a revised material may be required, and a revised supplier designation may be required if the Process Control Document is changed.

6.2.5 Qualification Tests

Materials shall satisfy all qualification requirements listed in tables 1, 2, 3, and 4 before qualification is approved.

6.3 <u>Acceptance</u>

6.3.1 Certification

The supplier shall certify that the components (graphite fiber, resin, and carrier) and processing used in the manufacture of each production batch and lot of material procured under this specification meet the specifications used for qualification.

6.3.2 Test Reports

The supplier shall furnish with each lot of prepreg two copies of a report that states the quantitative results of all acceptance tests and inspections specified in tables 2, 3, and 4. Both individual and average test results shall be included. The report shall include all necessary identification to correlate the inspections and test results with the roll and lot of material and the purchase order or contract.

6.3.3 Acceptance Tests

6.3.3.1 <u>Prepreg resin content</u>.- The supplier shall test every roll of material to verify that the resin content and fiber areal weight meet the specifications in table 2.

6.3.3.2 <u>Chemical characterization</u>.- The supplier shall characterize one roll of each prepreg lot by liquid chromatography.

6.3.3.3 Prepreg properties.- The supplier shall conduct volatile content, tack, viscosity profile, and handling life tests listed in table 2 in accordance with the lowing schedule:

Material quantity, lb in each lot	Sample selection
1 to 250 251 to 500 500 or more	Test one roll, random choice Test first and last roll Test first, every tenth, and last roll

6.3.3.4 Laminate properties.- The supplier shall fabricate panels, by using the methods described in section 5.3.3.11, and shall conduct acceptance tests listed in tables 3 and 4. The properties of each panel shall meet the requirements listed in tables 3 and 4. The following schedule shall be used:

Material quantity, lb in each lot	Sample selection
1 to 250 251 to 500 500 or more	Test one roll, random choice Test first and last roll Test first, every tenth, and last roll

ddition, the supplier shall fabricate a processability test panel as specified in section A.10 and perform tests specified in table 4 for each lot of prepreg.

6.3.3.5 Defects.- The supplier shall submit the roll defect log with each shipment and attach a copy inside the roll core.

7 ACCEPTANCE/REJECTION CRITERIA

7.1 Acceptance

Each prepreg lot submitted for acceptance shall meet the requirements of tables 1, 2, 3, and 4.

7.1.1 - If one roll among those tested fails, two additional rolls may be tested for at least the failing property. Both rolls must pass for the lot to be acceptable.

7.2 Rejection

7 2.1 - Material rejected on retest shall not be tested again for acceptance without tten authorization from the buyer. Following buyer approval, rejected material be reworked, retested, and resubmitted for acceptance. However, it shall be accompanied by the data concerning previous rejection, and a detailed description of the action taken to correct the defect or reason for failure.

7.2.2 - The buyer reserves the right to select any prepreg roll from a lot for testing. Failure of these tests to meet acceptance requirements shall be grounds for rejection of the entire lot.

8 PACKING AND SHIPPING

8.1 General

Material shall be packed and shipped in such a manner as to ensure the conformance of the properties and the storage life required by this specification.

8.2 Packing

8.2.1 Interior Packing

The prepreg material shall be packaged in rolls wound on a hollow core 8 in. or larger in diameter. A listing of the defective areas in the tape shall be attached to the inside of the core. A bag of desiccant shall be secured inside the core to absorb moisture. Each roll and the supporting core shall be sealed in a sleeve or bag to prevent moisture entry or loss of volatiles. The roll shall be fully supported from the core ends in such a manner that the prepreg does not telescope and the core end supports shall be at least 1 in. larger than the roll outside diameter. Each roll shall be packaged in a separate box.

8.2.2 Color Coding

Each prepreg roll shall be color coded either by colored carrier or by color marking of the roll core end or center. The color code shall be as follows:

Grade	Type	Class	Color Code
145	1	1	Green

8.2.3 Shipping Container

Clean dry containers constructed so as to ensure acceptance by common or other specified carrier and safe transportation to the place of delivery shall be used. Containers shall be constructed and insulated so that solid carbon dioxide may be packed in sufficient quantities to maintain the material at a temperature not to exceed 10°F (-15°C) for 18 hours, or the time required for shipment, whichever is longer. The gross weight of the container and contents, when packed for shipment, shall not exceed 130 lb.

8.3 Shipping

Material shall be shipped in such a manner that the temperature does not exceed [illegible]. If solid carbon dioxide is used to maintain required temperature, a quantity shall be present upon receipt by the buyer. If refrigerated shipment is used, a recorder shall be included to indicate temperature history during shipment.

8.4 Storage

Upon delivery to the buyer, the material shall immediately be placed in storage below 10°F.

8.5 Marking

8.5.1 Package

Each roll of prepreg shall be legibly and permanently marked by means of a tag, securely attached, in such a manner that it remains in place until all material on the roll is completely used. Each package that contains a roll of prepreg shall also be labeled. Information on the tags and labels shall include, but not be limited to, the following items:

Manufacturer's name

Manufacturer's trademark and identification number

Fiber identification and lot number

Number and revision letter of this specification

Type, class, and grade per section 2.

Nominal width

Impregnation date

Lineal feet in roll and net weight

Manufacturer's lot and roll number

<u>CAUTION:</u> Store below 10°F

Storage life expiration date

Purchase order number

8.5.2 Shipping Container

Shipping containers shall be legibly and permanently marked and shall include, but not be limited to, the following information:

Graphite fiber, 350°F cure, 200°F resistant toughened resin prepreg

This specification number

Type number, class number, grade

Manufacturer's name

Material trademark

Manufacturer's lot number

Roll number(s) in container

Nominal width

Nominal length or weight per roll

Shipping and storage requirements

Purchase order

Shipping date

<u>CAUTION:</u> Ship below 10°F

Store below 10°F

APPENDIX A

TEST METHODS FOR UNCURED PREPREG PROPERTIES

Prepreg properties required for qualification and acceptance shall be obtained by tests performed according to the procedures specified in the following sections. CAUTION: The use of solvents is specified herein. Solvents are potential health hazards as they are flammable and are rapidly absorbed through the skin which can produce serious effects when direct contact with hot solvent occurs. Proper ventilation, fire hazard protection, and precautions to avoid skin contact must be assured before these tests are initiated.

A.1 Sampling Procedure

Remove the material from cold storage and store at room temperature for a minimum of 4 hr. Remove the material from the moisture-proof bag and cut enough material to perform all tests listed in table 2. Replace the roll of material in the moisture-proof bag, reseal, and replace in cold storage. All prepreg tests and laminate fabrication should be completed within 24 hr of sampling. If material testing is delayed beyond 24 hr, store sample by placing in a sealed moisture-proof bag and refrigerate.

A.2 Wet Resin Content

The wet resin content by weight of the prepreg material shall be determined by the following procedure.

A.2.1 - For tapes that are at least 12 in. (30 cm) wide, cut three specimens, 3 by 3 in. (7.6 by 7.6 cm) minimum, from equidistant locations across the width of the tape but not closer than 1 in. (2.5 cm) to the edge of the tape. For tapes that are less than 12 in. (30 cm) wide, cut three rectangular specimens that are 9 in^2 (58 cm^2) in area and equal distant from the tape edges. Record specimen location in the tape. Remove the carrier from the back of each specimen. Weight each specimen to the nearest 0.001 g. Record as W_1. Measure specimen length and width to the nearest 1 mm. Calculate specimen area:

$$\text{Area} = \text{Length} \times \text{Width, m}^2$$

A.2.2 - Desolve resin by the method specified in paragraph A.2.2.1 or A.2.2.2 and separate fibers from specimens.

A.2.2.1 - Wash specimens separately in a suitable boiling solvent for 2 min. Time starts when solvent starts to boil. Decant the solvent. The solvent used shall be selected on the basis of being able to completely dissolve the resin under the conditions of this test.

A.2.2.2 - Soak specimens at room temperature in methyl ethyl ketone (MEK) or methylene chloride until resin is completely dissolved.

A.2.3 - Separate fibers from solvent by filtering and rinsing three times with solvent, each time decanting or filtering carefully to retain the fibers.

A.2.4 - Dry fibers by placing them in a circulating-air oven maintained above 225°F until a constant weight is reached. Remove and place in a desiccator. Constant weight shall be defined as a weight change of less than ±0.005 g.

A.2.5 - After a minimum of 10 min., remove specimens from desiccator and weigh to the nearest 0.001 g. Record as W_2.

A.2.6 - Calculate wet resin content as follows:

Wet resin content by weight:

$$\text{Resin content} = \frac{W_1 - W_2}{W_1} \times 100 \text{ percent weight}$$

where

W_1 original weight of specimen, g

W_2 final weight of specimen, g

A.2.7 - Record individual and average results.

A.3 Graphite Fiber Areal Weight

The graphite fiber areal weight shall be determined from the data of the uncured resin content specimen by using the following equation. The weight of the solvent cleaned fibers was recorded as W_2.

$$\text{Fiber areal weight} = \frac{\text{Weight of specimen, g}}{\text{Area of specimen, m}^2} = \frac{W_2}{A} \text{ g/m}^2$$

A.3.1 - Record individual and average results.

A.4 Volatile Content

The volatile content by percent weight of the prepreg shall be determined by the following procedure.

A.4.1 - Cut three specimens from material adjacent to that used for the resin content specimens in paragraph A.2.1. The specimens shall be the same size as the resin ~~ent specimens. For tape that is greater than 12 in. (30 cm) wide, the specimens sh~~ not be cut closer than 1 in. (2.5 cm) to the edge of the tape. Record specimen location in the tape. Remove the carrier from each specimen. Weigh each specimen to the nearest 0.001 g. Record as W_3.

A.4.2 - Place the specimens in a porous Teflon[1] coated fiberglass envelope, or suspended on an aluminum tray (areas of the tray in contact with the specimens shall be covered with a Teflon parting film). Place the specimens in a circulating-air oven, preheated to 350° ± 10°F and hold for 15 ± 1 min. Hanging specimens in the oven is acceptable, provided there is no resin loss due to dripping.

A.4.3 - Remove the specimen from the oven and place in a desiccator at room temperature for 30 min minimum prior to weighing to the nearest 0.001 g. Record weight as W_4.

A.4.4 - Calculate the volatile content as follows:

$$\text{Volatile content} = \frac{W_3 - W_4}{W_3} \times 100 \quad \text{percent weight}$$

.5 - Record individual and average values.

A.5 Tack

The tack at ambient temperature of 75° ± 5°F of the prepreg shall be determined by the following procedures.

A.5.1 - If the width of the prepreg tape is 5 in. (12.7 cm) or greater, cut one specimen 10 in. (25.4 cm) long by 3 in. (7.6 cm) wide minimum, not closer than 1 in. (2.5 cm) to the edge of the tape. If the width of the prepreg tape is less than 5 in. (12.7 cm), cut one specimen 10 in. (25.4 cm) long by 3 in. (7.6 cm) or full-tape wide, whichever is less, from the tape. Leave the specimen on the carrier until immediately before conducting the test.

A.5.2 - Apply and dry a coat of mold release (Frekote #33 releasing interface or equivalent) to a 2-in-diameter metal mandrel with a surface roughness value of 100 μin. (rms) or better.

A.5.3 - Wrap the prepreg around the mandrel with the fibers oriented in the circumferential direction and the exposed surface in contact with the mandrel. Remove the rrier from the prepreg as it is wrapped on the mandrel and apply light pressure to

[1]Trademark of E. I. du Pont de Nemours & Co.

the prepreg. The pressure may be produced either by rolling on a flat table top with downward pressure on the mandrel or by using a squeege or separate roller over the prepreg.

A.5.4 - Examine the rolled material for proper carrier release as noted in section 5.3.3.7, Handling characteristics.

A.5.5 - After 30 min, examine the rolled material for adherence to the mandrel and to itself.

A.5.6 - Report the results as pass or fail. Failure is defined as inability of the prepreg to adhere to itself for at least 30 min.

A.6 Viscosity Profile

The neat resin melt viscosity profile of the prepreg shall be determined by the following procedure.

A.6.1 Materials

A.6.1.1 Polyimide film (3 to 5 mm thick)

A.6.1.2 Polyimide pressure sensitive tape

A.6.1.3 Certified viscosity standard S30000, calibrated at 50° and 100°C, Cannon Instrument Company or equivalent.

A.6.1.4 Poly(dimethylsiloxane) calibration standard

A.6.2 Equipment

A.6.2.1 Rheometrics Dynamic Spectrometer RDS-7700 or eqivalent

A.6.2.2 Disposable plates (50 mm) for rheometer

A.6.2.3 Desiccator

A.6.2.4 Vacuum oven with viewing window

A.6.2.5 Millivolt source and cold junction compensator

A.6.2.6 Extra heavy-duty aluminum foil

A.6.2.7 Heated press, minimum platen size, 8 by 8 in.

\.6.3 Prepreg Resin Sampling

A.6.3.1 - Prepare a unidirectional stack of prepreg; 80 plies, 1.5 by 6 in. This laminate is formed from 1.5- by 12-in. strips of prepreg which are folded with :heir ends in the center (fig. 3). The laminate is then wrapped with a 6- by 24-in. ection of prepreg (fig. 3), by three strips of extra heavy-duty aluminum foil 3/4 by 20 in. (fig. 3), and finally by a strip of foil 6 by 20 in. (fig. 3). The luminum on the edges of the laminate is perforated on each side (fig. 3) at five laces evenly spaced. Perforations should be approximately 1 by 2 cm in size.

A.6.3.2 - Preheat the press to 200° ± 5°F, or other specified temperature agreed pon by the supplier and the buyer, to allow flow without onset of cure.

A.6.3.3 - Place a sheet of polyimide film on the heated lower platen of the ress.

A.6.3.4 - Place the aluminum foil covered laminate on the polyimide film in the enter of the heated press and cover with another sheet of polyimide film.

A.6.3.5 - Apply a pressure of 500 ± 5 psi and allow the laminate to heat for $^{+0.5}_{-0}$ minutes, then gradually increase the pressure at 7000 ± 1000 psi/min until 0 000 ± 500 psi is achieved.

A.6.3.6 - Release pressure, remove upper polyimide sheet and discard. Remove 'aminate and lower polyimide sheet from the press and separate the laminate from h ower polyimide sheet.

A.6.3.7 - Fold the resin-coated lower polyimide sheet over on itself, seal in a olid polyethylene bag and chill to 0°F or below.

A.6.3.8 - Remove the resin from the polyimide sheet by rapidly flexing the polymide sheet while the resin is below 0°F.

.6.4 Degassing of the Resin

A.6.4.1 - Form a 1/2-in-high (13-mm) dam around the circumference of one of the 0-mm disposable plates with polyimide film and seal in place with pressure sensitive olyimide tape.

A.6.4.2 - Preheat plate, with dam affixed, in a vacuum oven at reduced pressure or 20 ± 5 min at a temperature equal to or lower than the temperature employed in aragraph A.6.3.2. Remove plate from oven.

A.6.4.3 - Place approximately 3 g of resin on the plate and return plate to the acuum oven.

A.6.4.4 - Gradually apply vacuum (5 in. (127 mm) Hg below atmospheric pressure) egass the resin sample. Do not allow resin to froth over the dam during degass- Allow sample to remain in the oven at the temperature used for paragrap.. A.6.4.2 for a total of 15 to 20 min after establishing constant temperature and ressure.

A.6.4.5 - Remove plate from oven, place in a desiccator and allow to cool to room temperature. Remove the polyimide film and tape when the plate has cooled.

A.6.4.6 - Place resin sample in a desiccator and store at 0°F or below until immediately prior to testing.

A.6.5 Initial Calibration of the Dynamic Mechanical Rheometer

A.6.5.1 - The torque output of the transducer is calibrated by the standard methods recommended by the manufacturer.

A.6.5.2 - A parallel plate geometry is employed. The storage (G') and loss (G") shear moduli of the poly(dimethylsiloxane) viscosity standard are measured as a function of frequency at 26 ± 1.0°C in the rate sweep mode.

A.6.5.3 - The log of the storage modulus for the poly(dimethylsiloxane) should increase linearly with the log of the frequency between 0.1 and 0.398 rad/sec. When G' = G" the frequency must be 7 ± 0.5 rad/sec. See calibration curve in figure 4.

A.6.5.4 - The thermocouple which monitors the temperature of the sample is calibrated by using a millivolt source and a cold junction compensator.

A.6.5.5 - The gap spacing in the rheometer is adjusted so that, with no sample present, the spacing is zero at 50°C.

A.6.6 Calibration With Certified Viscosity Standard

<u>NOTE:</u> Temperatures given are equipment settings which are accurate to ±1°C. Thus, there is no tolerance on the specified temperature.

A.6.6.1 - Place a 2 to 4 mL sample of Cannon Viscosity Standard S30000 on the parallel plate.

A.6.6.2 - Close the gap between the plates until the solution reaches the edge of the plates. Record the gap setting.

A.6.6.3 - Heat the sample to an equipment setting of 50°C.

A.6.6.4 - Set the rheometer to a strain of 40 percent and perform a calibration scan.

A.6.6.5 - During the rate sweep scan, record loss and storage moduli, complex viscosity, temperature, and torque and plot the complex viscosity as a function of frequency.

A.6.6.6 - The measured viscosity must agree with the calibrated value within ±10 percent.

A.6.6.7 - The calibration shall be repeated on the same sample as described in paragraphs A.6.6.3 through A.6.6.5 except at a temperature of 100°C. The measured viscosity must agree with the calibrated value within ±10 percent.

A.6.7 Determination of Viscosity

A.6.7.1 - Remove the desiccator containing the 3-g resin sample (see para- ͻh A.6.4.6) from the 0°F storage and allow to warm to room temperature prior to .ng the desiccator.

A.6.7.2 - Set the rheometer to an equipment setting of 50°C.

A.6.7.3 - Transfer the sample from the desiccator to the rheometer in an expe- lient manner.

A.6.7.4 - Close the gap between the plates until the resin reaches the edge of :he plates. Record the gap setting.

A.6.7.5 - Determine a range of maximum strain in which the complex viscosity, .oss shear modulus, and storage shear modulus are constant. This range may be ichieved by setting the rheometer to a frequency of 10 rad/sec and conducting several ·uns in the range 0.1 to 50 percent strain. Select a maximum strain value that pro- luces a minimum torque greater than 2 g-cm and meets the other requirements of this ›aragraph.

A.6.7.6 - Set the rheometer to the maximum strain value selected in para- ·raph A.6.7.5 and raise the temperature of the sample from 50°C to 177°C (or the ·ecommended curing temperature) at 1°C/min. Exercise care to avoid heating the sam- ›le above 177°C, and when 177°C is achieved, maintain constant temperature. Measure .nd record complex viscosity, loss shear modulus, storage shear modulus, torque, and :emperature as a function of time. Terminate the test when the viscosity exceeds ' ˀ poise. Plot the logarithm of complex viscosity as a function of time.

..7 HPLC Characterization

A chemical characterization of the prepreg shall be determined by high pressure .iquid chromatography (HPLC).

..7.1 HPLC Analysis Method

The supplier shall develop an HPLC analysis to provide a chromatographic "fin- ·erprint" of key ingredients of the matrix resin. Sample extraction, analysis, and ·eport shall be patterned after the general approach given in NASA CR-3531.

..7.2 Report

A chromatogram with appropriate peak integration records for standards which can ›e used to obtain quantitative determinations of major components shall be supplied. 'he report shall record and compare the batch sample chromatogram with the resin tandard chromatogram to detect contaminants or gross change in formulation.

. ᵅ Handling Life

Cut one piece of material 10 in. long and 3 in. minimum width (as described in aragraph A.5.1) and seal in a moisture-proof bag. After 10 days at room temperature

(80°F maximum) remove from the sealed bag and test for tack as described in section A.5.

A.9 Processing Life

Cut material from the roll and laminate a 3- by 6-in. (minimum dimensions), 16-ply, 0° layup on a prepared tooling surface. Expose the layup for 30 days at room temperature (maximum of 80°F) and then bag and cure the layup by the standard procedure defined in paragraph 5.3.3.11. Test the cured panel for resin and void content as specified in sections B.3 and B.4.

A.10 Processability Test Panels

Laminate processability shall be determined by the following procedures.

A.10.1 Layup

Cut material from an opened roll of prepreg and lay up two panels 24 by 26 in. by 48 plies (0.24 in. nominal thickness) with a quasi-isotropic fiber pattern $[45°/0°/-45°/90°]_{6s}$. Four Teflon disks (0.14 ± 0.01 mm thick) shall be placed in one corner at least 1 in. from the edge and between the two center plies. Two 1/2-in-diameter disks and two 1/4-in-diameter disks shall be used and all disks shall be separated at least 1/4 in.

A.10.2 Bagging

Bag the panels by the method shown in figure 1.

A.10.3 Cure

Cure each panel in an autoclave by using the cure cycle shown in figure 2. The first panel shall have a temperature rise of 2° ± 0.2°F/min and the second panel shall have a temperature rise of 8° ± 0.2°F/min. Temperature shall be measured using thermocouples located at mid-thickness of the panels $0.10\,^{+0.10}_{-0}$ in. from the panel edge.

A.10.4 Nondestructive Inspection

The process qualification panels shall be inspected for internal defects by an ultrasonic nondestructive inspection (NDI) method approved by the buyer. A record of nondestructive inspection results shall be retained for a minimum of 5 years and shall be made available to the buyer.

A.10.5 Thickness Per Ply

Measure panel thickness and calculate thickness per ply as prescribed in section B.5.3.

A.10.6 Micrographic Analysis

Six specimens 1 in. long by 0.5 in. wide shall be cut from representative areas across the width of each processability laminate. No specimen shall be taken closer than 1 in. to the edge of the laminate. One edge of each specimen shall be polished and observed by light microscopy. Report visual observations, and if a permanent pictorial record is required by the buyer, prepare photomicrographs.

A.10.7 Resin Content, Void Content, and Density

Test a minimum of three samples from each processing panel for resin content, void content, and density as prescribed in sections B.3 and B.4.

APPENDIX B

TEST METHODS FOR CURED LAMINATE PROPERTIES

Laminate properties required for qualification and acceptance shall be obtained by tests specified in the following sections. The laminates shall be fabricated by using the procedures prescribed in section 5.3.3.11.

B.1 Symbols

The symbols used for the calculations in this appendix are defined in this section.

b	specimen width, in.
D_F	density of graphite fiber, g/cm^3
D_L	density of cured laminate specimen, g/cm^3
D_R	density of cured resin (from supplier), g/cm^3
E_c	compression modulus, lb/in^2
E_o	laminate modulus, lb/in^2
E_t	tensile modulus, lb/in^2
F	fiber volume
F_c	compression strength, lb/in^2
F_{cs}	compression interlaminar shear strength, lb/in^2
F_t	tensile strength, lb/in^2
G_c	interlaminar fracture toughness, $\frac{in\text{-}lb}{in^2}$
G_{LT}	longitudinal shear modulus of unidirectional composite, lb/in^2
L	overlap length, in.
ℓ	gage length of extensometer, in.
m	initial slope of load deflection curve, (change in load divided by change in extensometer length, lb/in.
P	ultimate load, lb
P_1	load at 0.001 in/in strain, lb
P_5	load at 0.005 in/in strain, lb
P_6	load at 0.006 in/in strain, lb

specimen thickness, in.

original weight of specimen, g

2 final weight of specimen, g

resin content of cured laminate specimen, percent weight

c strain at onset of delamination

f strain at failure

y transverse strain at 0.005 in/in longitudinal strain

.2 General

.2.1 - Laminates shall meet the property requirements indicated in table 3. In ddition, laminates shall meet the ply thickness, resin content, void content, and ensity requirements specified in table 4. The values indicated in table 3 are the inimum required average of the specified replicates. The minimum value for any one est shall equal or exceed 80 percent of the required average value.

.2.2 - Perform all mechanical property tests with test machines complying with ᐟ ᐠ E 4.

.2.3 - The unloaded edges of each specimen shall be machined to ±1° of the 0° fiber irection. The ends of the specimen that are being loaded or gripped shall be achined to ±1° of perpendicular to the 0° fiber direction. For specimens not having ° fibers, the unloaded edges shall be machined to ±1° of the longitudinal axis, and he ends of the specimens that are loaded or gripped shall be machined to ±1° of erpendicular to the longitudinal axis.

.2.4 - Test temperatures shall not vary more than ±10°F from the values indicated in able 3. Room temperature is defined to be 75°F. Specimens to be tested without oisture conditioning at -100°F or 200°F shall be held at the test temperature for 0 ± 3 min prior to testing. Moisture-conditioned specimens to be tested at 200°F hall be held at this temperature for 2 ± 1 min prior to testing.

.2.5 - Moisture conditioning for specimens to be tested at the wet condition indi-ated in table 3 shall be achieved by using the following procedure:

B.2.5.1 - Dry specimens in a circulating-air oven at $175 {}^{+0}_{-10}$ °F for $160 {}^{+4}_{-0}$ hr.

B.2.5.2 - Measure and record specimen weight after drying.

B.2.5.3 - Soak specimens in demineralized water at $160 {}^{+10}_{-0}$ °F for $340 {}^{+4}_{-0}$ hr.

B.2.5.4 - Wipe excess moisture from the surface of the specimen. Measure speci-en weight and record weight gain.

B.2.5.5 - Calculate and record specimen moisture content as percent of dry weight.

B.2.5.6 - Test specimens within 30 min after moisture conditioning, or, if not possible, store in a saturated atmosphere (95- to 99-percent relative humidity) at room temperature for no more than 75 hr before testing.

B.3 Resin Content

The resin content of cured laminates shall be determined as follows.

B.3.1 - Carefully cut three specimens weighing between 0.5 and 2.0 g each not closer than 1 in. from the laminate edges. Specimen edges must be free of surface roughness so that an accurate density can be obtained. Do not use broken specimens.

B.3.2 - Dry specimen for a minimum of 1 hr at 300° ± 10°F (149° ± 6°C), cool in an ambient temperature dessicator for 10 ± 1 min. Weigh each specimen to the nearest 0.001 g. Record weights as W_1.

B.3.3 - Determine the density of each specimen by any method that is accurate to within 0.005 g/cm^3. Record the method used. Record the density as D_L. If specimens are submerged in a fluid to determine density, repeat B.3.2 before performing B.3.4.

B.3.4 - Place the specimen in concentrated nitric acid that has been stabilized at a temperature of 140° ± 5°F (60° ± 3°C). Digest at this temperature for 3 hr ± 10 min. Digestion at 200° ± 5°F (93° ± 3°C) for 45 ± 5 min is also acceptable. Record method used.

B.3.5 - Filter in a suitable device or decant so that all the carbon fibers are retained, and rinse thoroughly with MEK or acetone.

CAUTION: Do not allow MEK or acetone to come in contact with nitric acid.

B.3.6 - Dry for a minimum of 1/2 hr at 300°F (149°C).

B.3.7 - Desiccate for at least 10 min and weigh. Record as W_2.

B.3.8 - Calculate resin content as follows:

$$\text{Resin content} = Z = \frac{W_1 - W_2}{W_1} \times 100 \quad \text{percent weight}$$

B.3.9 - Report individual and average values of Z.

'oid Content

Void content shall be determined in accordance with ASTM D 2734, with the following exceptions.

B.4.1 - Resin content and density shall be as determined per section B.3 of this specification.

B.4.2 - Calculate void content as follows:

$$\text{Void content} = \left\{1 - D_L\left[\frac{1}{D_F} + \frac{Z}{100}\left(\frac{1}{D_R} - \frac{1}{D_F}\right)\right]\right\} \times 100 \quad \text{percent volume}$$

B.4.3 - Report individual and average values.

B.5 Fiber Volume and Ply Thickness

r ‾.1 Fiber Volume

Calculate fiber volume as follows:

$$\text{Fiber volume} = F = \left(1 - \frac{Z}{100}\right) \times \frac{D_L}{D_F} \times 100 \quad \text{percent}$$

where the terms are defined in section B.1.

B.5.2 - Report individual and average values.

B.5.3 Ply Thickness

Measure the thickness of the cured laminate in at least five locations, spaced to represent the laminate including the center, but not closer than 2 in. to the edge, with a flat-nose or ball-nose micrometer, to the nearest 0.0001 in. Average the readings and divide by the number of plies. Report as "thickness per ply."

B.6 Tensile Strength and Modulus Tests

.1 - Machine tensile specimens from the same panel in accordance with instructions anc imensions shown in figure 5. Measure and record specimen width and thickness to the nearest 0.001 in.

B.6.2 - Test specimens in a universal test machine at a deflection rate of 0.05 in/min.

B.6.3 - Measure the failure load and the longitudinal strain as a function of applied load with a strain gage or a 1-in. gage length extensometer.

B.6.4 - Calculate the tensile strength F_t:

$$F_t = \frac{P}{bt} \ \text{lb/in}^2$$

B.6.5 - If strain was measured with an extensometer, calculate tensile modulus E_t:

GAGE LENGTH

$$E_t = \frac{m\ell}{bt} \ \text{lb/in}^2$$

W X T

B.6.6 - If strain was measured with strain gages, calculate tensile modulus:

$$E_t = \frac{1}{bt} \frac{P_6 - P_1}{(0.005)} \ \text{lb/in}^2$$

B.6.7 - Report individual and average values for tensile strength and modulus. Required values are listed in table 3.

B.7 - Compression Strength and Modulus Tests

B.7.1 - Machine the compression modulus and strength specimens from the same panel in accordance with the instructions and dimensions shown in figure 6. Measure and record specimen width and thickness to the nearest 0.001 in.

B.7.2 - Test specimens in a universal test machine by using the ASTM D 695 compression fixture. Test at a deflection rate of 0.05 in/min.

B.7.3 - Definitions of symbols used in calculations are given in section B.1.

B.7.4 - Compression strength shall be determined by testing the tabbed specimen shown in figure 6.

.7.5 - Calculate compression strength F_c as

$$F_c = \frac{P}{bt} \quad lb/in^2$$

.7.6 - Compression modulus shall be determined by testing the untabbed specimen
ıown in figure 6. Test the modulus specimen to a minimum strain of 0.006 in/in.
easure the applied load, and the longitudinal strain as a function of applied load
ith an extensometer or strain gage.

.7.7 - If strain was measured with an extensometer, calculate the compression modu-
ıs E_c as follows:

$$E_c = \frac{m\ell}{bt} \quad lb/in^2$$

.7.8 - If strain was measured with a strain gage, calculate the compression modulus:

$$E_c = \frac{1}{bt} \frac{P_6 - P_1}{(0.005)} \quad lb/in^2$$

.7.9 - Report individual and average values for compression strength and modulus.
equired values are listed in table 3.

.8 <u>Compression Interlaminar Shear Test</u>

.8.1 - Fabricate compression interlaminar shear specimens as shown in figure 7.
easure and record specimen width, thickness, and notch overlap length to the nearest
.001 in.

.8.2 - Test at a deflection rate of 0.05 in/min by using the fixture and procedures
f ASTM D 695.

.8.3 - Calculate compressive interlaminar shear strength as follows:

$$F_{cs} = \frac{P}{bL} \quad lb/in^2$$

.8.4 - Report individual and average values. The required values are listed in
3.

B.9 Open-Hole Tension Test

B.9.1 - Fabricate open-hole tension specimens as shown in figure 8.

B.9.2 - A hole having a nominal diameter of 0.250 in. shall be drilled and/or reamed so as to avoid any delamination in the test specimen. After machining, measure and record hole diameter and specimen dimensions.

B.9.3 - Test in tension at a deflection rate of 0.05 in/min

B.9.4 - Calculate strength as follows:

$$\text{Open-hole tensile strength} = \frac{P}{bt} \ \text{lb/in}^2$$

B.9.5 - Report individual and average values for open-hole tension strength. Required values are listed in table 3.

B.10 Open-Hole Compression Test

B.10.1 - Fabricate open-hole compression specimens as shown in figure 9.

B.10.2 - A hole having a nominal diameter of 0.250 in. shall be drilled and/or reamed so as to avoid any delamination in the test specimen. After machining, measure and record hole diameter and specimen dimensions to the nearest 0.001 in.

B.10.3 - Test specimen by using a fixture such as that shown in figure 10. The longitudinal axis of the specimen must be maintained parallel to the load axis of the machine and centered in the machine, and the side supports on the edges parallel to the loading axis must not constrain transverse deformation due to Poisson's effect.

B.10.4 - Test at a deflection rate of 0.05 in/min.

B.10.5 - Calculate strength as follows:

$$\text{Open-hole compression strength} = \frac{P}{bt} \ \text{lb/in}^2$$

B.10.6 - Report individual and average values for open-hole compression strength. In addition, report failure location and description of failure.

B.10.7 - Required values are listed in table 3.

.11 Compression After Impact Test

.Tr;, - Fabricate the 12.0- by 7.0-in. compression after impact specimen as shown in .gure 11.

.11.2 - The impact test apparatus shall consist of a support fixture shown in fig-re 12 and an impactor. The impactor shall weigh 10.0 to 12.0 lb and shall have a .5-in. hemispherical steel tip on the end that impacts the specimen. A guide tube, .ned with Teflon film or equivalent, shall be used to direct the vertical path of ie impactor.

.11.3 - Place the test specimen in the support fixture so that the impact location at the exact center of the specimen. Clamp the top plate over the test specimen id attach to the base plate by installing nuts on the four tie-down studs and torqu-ig each one to a nominal 20 ft-lb. Locate the guide tube above the test specimen so iat the impactor will strike the center of the specimen. Coat the striker end of ie impactor with white chalk dust or white grease to allow easy location of the :tual impact point. The lower end of the guide tube should be approximately 10 in. ove the surface of the specimen. Drop the impactor from a height above the test ecimen to generate an impact energy of $20 {}^{+0.50}_{-0}$ ft-lb. Care should be taken to rest the impactor after the strike so that a restrike does not occur. Remove the ipacted specimen from the support fixture and visually determine and record the nt of damage to the specimen on the impacted surface and the back surface. onically inspect the specimen to determine the extent of internal delamination.

.11.4 - For each specimen, record the specimen identification number, thickness, ont surface and back surface visual damage measurements, total delamination area om the ultrasonic measurement, and maximum width of the delamination from the .trasonic inspection, measured perpendicular to the longitudinal axis of the ecimen.

.11.5 - Machine a 10- by 5-in. specimen from the impacted laminate as shown in .gure 11.

.11.6 - After machining, the postimpact compression specimen dimensions shall be asured to the nearest 0.001 in. at the locations shown in figure 11. Record indi-.dual and average values for thickness, width, and length.

.11.7 - Install back-to-back axial strain gages on each specimen as shown in .gure 11.

.11.8 - Test the specimens by using a compression test fixture such as that shown in e 10 so that (1) the longitudinal axis of the specimen is parallel to the load the machine and is centered in the machine and (2) the side supports on the lges parallel to the loading axis do not constrain transverse deformation due to isson's effect.

B.11.9 - Test at a deflection rate of 0.05 in/min. Record strain values from all strain gages as a function of load throughout the test.

B.11.10 - Calculate compression strength as follows:

$$F_c = \frac{P}{tb} \quad \text{lb/in}^2$$

B.11.11 - Report individual and average values of strength. Required values are listed in table 3.

B.12 <u>Longitudinal Shear Modulus</u>

B.12.1 - Fabricate the $[\pm 45]_{3s}$ laminate specimen and install longitudinal and transverse strain gages as shown in figure 5. Measure and record specimen width and thickness to the nearest 0.001 in.

B.12.2 - Test in a universal test machine in accordance with ASTM D 3518 at a deflection rate of 0.05 in/min.

B.12.3 - Measure and record longitudinal and transverse strain as a function of applied load.

B.12.4 - Calculate the longitudinal shear modulus as

$$G_{LT} = \frac{P_5/bt}{0.01 - 2\varepsilon_y} \quad \text{lb/in}^2$$

B.12.5 - Calculate tensile strength of $[\pm 45]$ laminate F_t as

$$F_t = \frac{P}{bt} \quad \text{lb/in}^2$$

B.12.6 - Report individual and average values for longitudinal shear modulus and tensile strength. Required values are listed in table 3.

B.13 - <u>Edge Delamination Tension Test</u>

B.13.1 - Fabricate edge delamination tension specimens as shown in figure 13.

B.13.2 - Measure the specimen thickness at the six locations along each edge as shown in figure 13 and record the individual and average thickness. Measure the specimen width at the three locations along the specimen length, as shown in figure 13, and ~cord individual and average values.

B.13.3 - Test specimens in accordance with NASA RP-1092, ST-2. Use either a stroke-controlled or a strain-controlled hydraulic test machine. "Stroke controlled" controls crosshead displacement, "strain controlled" controls displacement over the gage length of the strain-measuring device mounted on the specimen. Do not run tests in a load-controlled machine.

B.13.4 - Use an extensometer (clip gage) with an appropriate extender arm to measure strain. The gage length is 4 in. with the gage mounts 1.5 in. from either grip.

B.13.5 - Mount specimen in test machine so as to grip an equal length on each end of the specimen and to expose 7 in. between grips. Emery cloth or tungsten carbide grit insets may be used to improve the gripping surface. If end tabs are used on specimens, the tabs should be squared off, not tapered.

B.13.6 - Test at a deflection of 0.006 in/min.

B.13.7 - Record the extensometer and load cell output on an x-y plotter (real-time ~~alog display). Record deflection on the X-axis and load on the Y-axis.

B.13.8 - Load specimen until visible detection of edge delamination and a corresponding abrupt (not continuous) deviation occur in the load deflection plot as shown in figure 14. Record deflection level at onset of delamination. Note this point on the load deflection curve. If thickness variations greater than 0.003 in. were measured (paragraph B.13.2), record thickness at location closest to the delamination site.

B.13.9 - Calculate the strain at delamination onset ε_c as follows:

$$\varepsilon_c = \frac{\text{Deflection at delamination onset}}{\text{Gage length of extensometer}}$$

B.13.10 - Continue loading until the specimen fractures into two pieces. Calculate and record the strain at failure ε_f:

$$\varepsilon_f = \frac{\text{Deflection at failure}}{\text{Gage length of extensometer}}$$

~.11 - Determine the laminate modulus E_o from the initial portion of the load ~~ction curve (before delamination) as follows:

$$E_o = \frac{m\ell}{bt} \quad lb/in^2$$

B.13.12 - An exact method for calculating interlaminar fracture toughness G_c is given in NASA RP-1092 as ST-2. This method requires separate tests to measure individual laminate properties. The following method is an approximation to establish a minimum resistance to delamination for materials qualified under this specification. This method assumes that the tension modulus of a completely delaminated laminate is approximately 0.7 of the laminate tension modulus. This approximation is based on data from tests of selected toughened resin laminates and may not represent all materials which may be submitted for qualification. The supplier may, as an alternative to the method given below, determine G_c as specified in NASA RP-1092; if this method is chosen, the supplier shall measure and report all data specified in NASA RP-1092.

B.13.13 - Calculate an approximate interlaminar fracture toughness G_c as follows:

$$G_c = 0.16\ \varepsilon_c^2 t E_o \quad \frac{in\text{-}lb}{in^2}$$

B.13.14 - Report individual and average values of G_c, ε_c, and E_o.

TABLE 1.- GRAPHITE FIBER REQUIREMENTS

Property	Unit	Value
Ultimate tensile strength ...	psi	5.20×10^6 (minimum)
Tensile modulus	psi	33×10^6 (minimum)
Elongation at failure	percent	1.5 (minimum)
Density	g/cm^3	1.70 to 1.83
Weight/unit length	g/m	
Grade 3000		0.18 (minimum)
Grade 6000		0.36 (minimum)
Grade 12 000		0.72 (minimum)
Sizing[a]	percent	0.0 to 1.6
Twist	turns per inch	0.0 to 0.8

[a]The prepreg supplier shall provide HPLC chromatogram of fiber sizing extract from each yarn lot.

TABLE 2.- UNCURED PREPREG REQUIREMENTS

Property	Requirement	Test method (section)	Qualification requirement	Acceptance requirement
Wet resin content	35 ± 2 percent by weight	A.2	Verify requirements as specified in section 5.2	Test each roll (sec. 6.3.3.1)
Graphite fiber areal weight	145 ± 5 g/m^2	A.3		Test each roll (sec. 6.3.3.1)
Volatile content	0.5 percent by weight maximum	A.4		Test as specified in sec. 6.3.3.3
Tack	Pass	A.5		
Viscosity profile	Test and report	A.6		
Chemical characterization	Test and report HPLC	A.7		Test one roll of each lot (sec. 6.3.3.2)
Storage life at 10°F maximum temperature	Supplier guarantee to meet all specification requirements after 6-month storage			
Handling life	Pass tack test after 10 days at 80°F	A.8		Test as specified in sec. 6.3.3.3
Processing life	Cure laminate after prepreg exposed 30 days at 80°F maximum and passed requirements of sections B.2 and B.3	A.9		

TABLE 3.- LAMINATE MECHANIC ROPERTY REQUIREMENTS

Test	Ply orientation	Specimen configuration, in.	Required data	Test temperature, °F	Value (a)	Test replicates/batch		Test method (section)
						Qualification[b]	Acceptance[c]	
Tension	$(0)_8$	0.5 by 9 tabbed	Strength	-100 RT	270 ksi 270 ksi	3 5	 3	B.6
Tension	$[\pm 45]_{3s}$	1.0 by 9 tabbed	Modulus	-100 RT	18m psi 18m psi	3 3		B.6
			Strength	RT 200	35 ksi 35 ksi	5 3		B.12
			Shear modulus	RT 200	0.8m psi 0.8m psi	3 3		B.12
Compression	$(0)_8$	0.5 by 3.15 tabbed	Strength	-100 RT 200 200 wet[d]	200 ksi 200 ksi 180 ksi 160 ksi	3 5 5 3	 3 3 	B.7
			Modulus	-100 RT 200	18m psi 18m psi 18m psi	3 3 3		B.7
Open-hole tension	$[45/0/-45/90]_{2s}$	1.5 by 12 0.25 diam. hole	Strength	-100 RT	50 ksi 50 ksi	3 3		B.9
Open-hole compression	$[45/0/-45/90]_{2s}$	1.5 by 10 0.25 diam. hole	Strength	RT 200 200 wet[d]	33 ksi 30 ksi 26 ksi	3 3 3		B.10
Compression after impact	$[45/0/-45/90]_{6s}$	~~5 by 10~~ 7 X 12 PER DWG.	Strength	RT	30 ksi	3		B.11
Compression interlaminar shear	$[45/0/-45/90]_{6s}$	0.5 by 3.15	Strength	RT 200	10 ksi 8 ksi	3 3	3 	B.8
Edge delamination tension test	$[(\pm 30)_2/90/\overline{90}]_s$	1.5 by 10	Interlaminar fracture toughness	RT	$1.0\ \frac{\text{in-lb}}{\text{in}^2}$	3		B.13

[a]Values are minimum required for average of specified test replicates. Minimum value of any one test shall equal or exceed 80 percent of required average value.

[b]All tests indicated in this table are required for qualification. For qualification requirements see sections 5.1 and 6.2.

[c]Tests indicated in this column are required for acceptance. For acceptance requirements see sections 5.2 and 6.3.

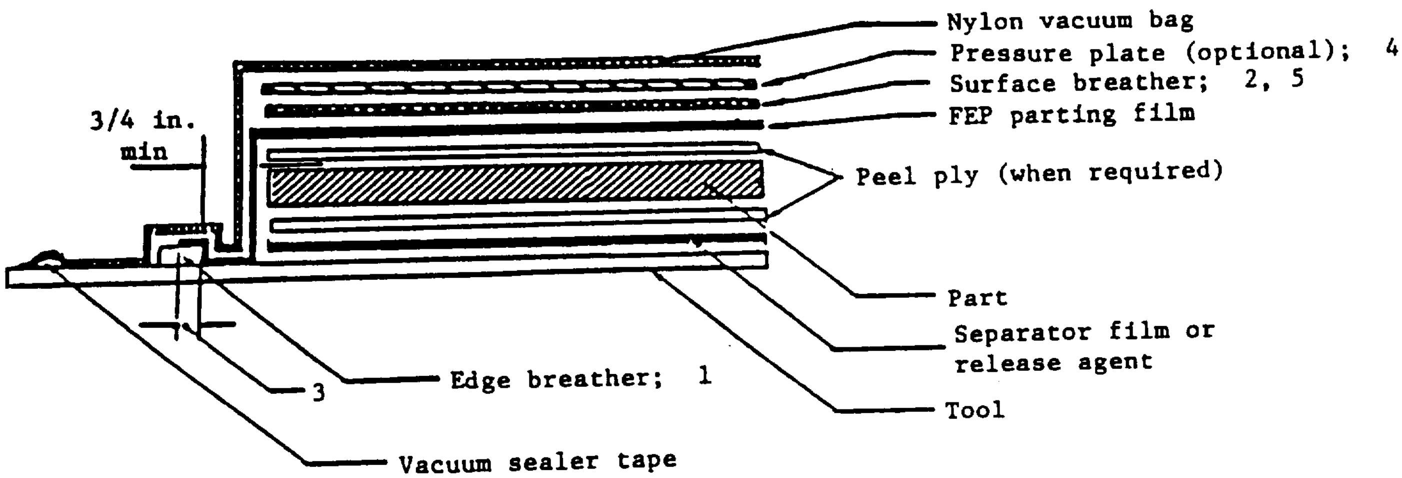
[d]Wet conditioning: procedure is defined in paragraph B.2.5.

TABLE 4.- LAMINATE PROCESSABILITY REQUIREMENTS

[Processability test panel shall be 24 by 26 in. by 48 plies quasi-isotropic fabricated as specified in section A.10]

Property	Requirement	Test method	Qualification requirement	Acceptance requirement
Laminate thickness per ply	0.0054 to 0.0056 in.	Section B.5.3	As specified in section 6.2	As specified in section 6.3.3.4
Resin content	29 to 35 percent by weight	Section B.3		
Void content	2 percent maximum	Section B.4		
Density	1.53 to 1.62 g/cm^3	Paragraph B.3.3		

Defects	Limits	Test method	Qualification requirements	Acceptance requirements
Single void area	0.25 in^2 maximum	Section A.10.4	Specified in section 6.2.5	As specified in section 6.3.3.4
Total accumulated void area	1.00 in^2 in any 1 ft^2			
Single porous area	1.00 in^2 maximum			
Total accumulated porous area	4.00 in^2 in any 1 ft^2			
Distance between voids	4.00 in. minimum			
Defect distance from finished edge	1.00 in. minimum			



Not to scale

1. 1 in. minimum width with connection to vacuum source; at one corner of the layup, place a single fiberglass yarn between the edge of the layup and the edge breather to allow evacuation of air from the layup. Additional yarns may be required on larger parts to provide adequate removal of trapped air.

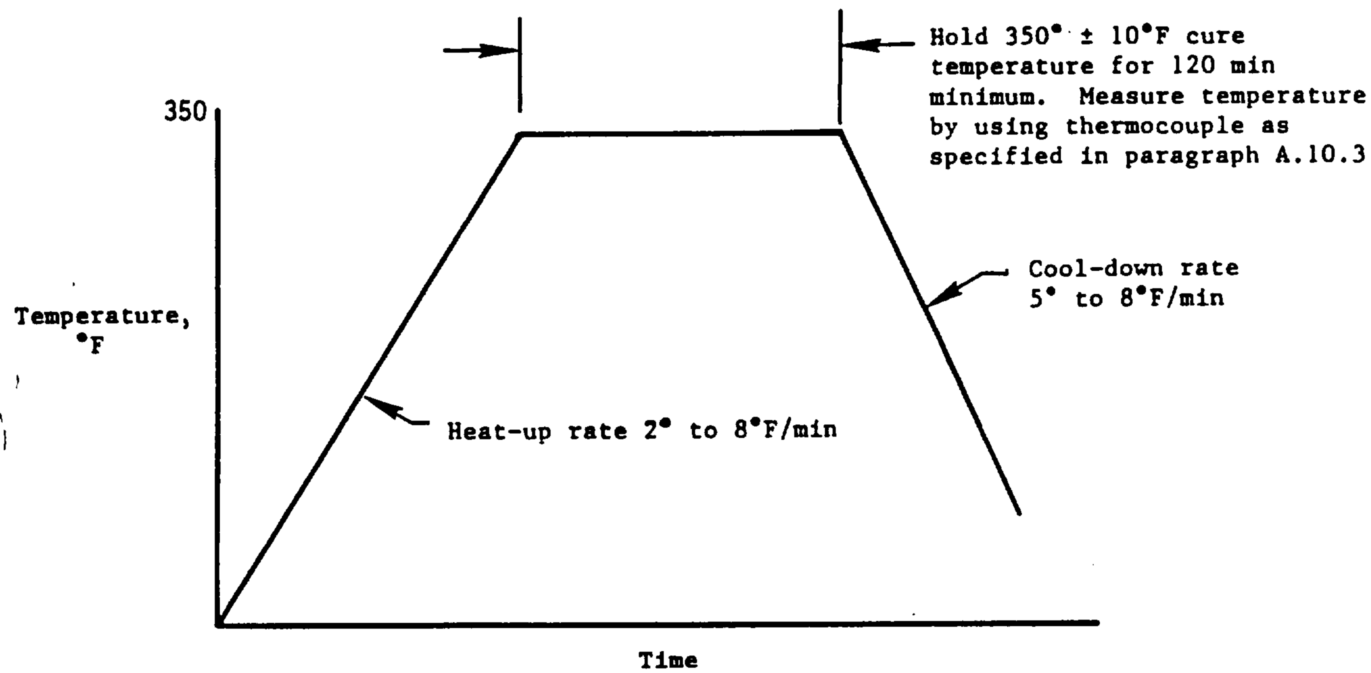
2. If fiberglass is used for surface breathers, it shall be net trimmed to the edge of the layup. At one position, connect the surface breather to the edge breather by using a single fiberglass yarn; if AIRTECH Air Weave SS is used for surface breathers, it may extend to connect with the edge breather.

3. Teflon FEP film extends to centerline of edge breather.

4. Pressure plate, 0.20 in. thick minimum.

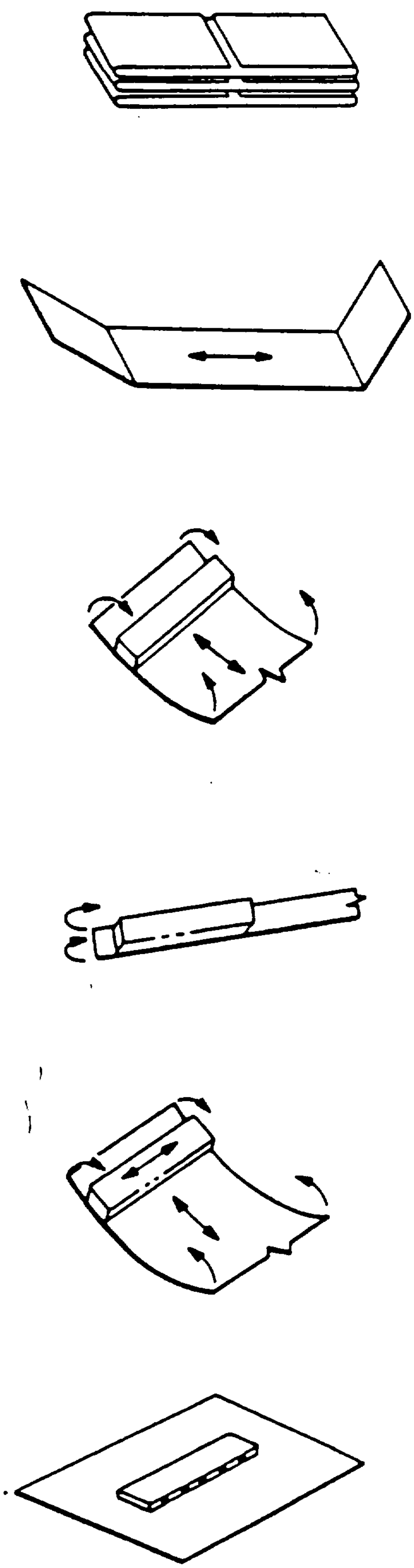
5. Surface breather required unless pressure plate is used, then breather is not required.

Figure 1.- Standard bagging procedure.



1. Apply 25 in. H_g vacuum minimum.
2. Apply 85 $^{+15}_{-0}$ psig pressure to laminates.
3. Vent vacuum bag to atmosphere when autoclave pressure reaches 20 psig.
4. Start heat cycle.
5. At completion of heating cycle, when laminate cools to 140°F, release pressure and remove part fro autoclave.

Figure 2.- Standard cure cycle.



Fold and stack 80 prepreg strips 1.5 by 12 in. with fiber orientation as indicated by arrow

Wrap folded prepreg stack with 6- by 24-in. prepreg sections

Wrap stack in longitudinal direction with 3 strips of 1 3/4- by 20-in. aluminum foil

Wrap stack in transverse direction with 3 strips of 6- by 20-in. aluminum foil

Perforate 1- by 2-cm holes in aluminum foil on both sides of stack at five places evenly spaced; wrap stack with Kapton sheet

Figure 3.- Prepreg resin sampling specimen.

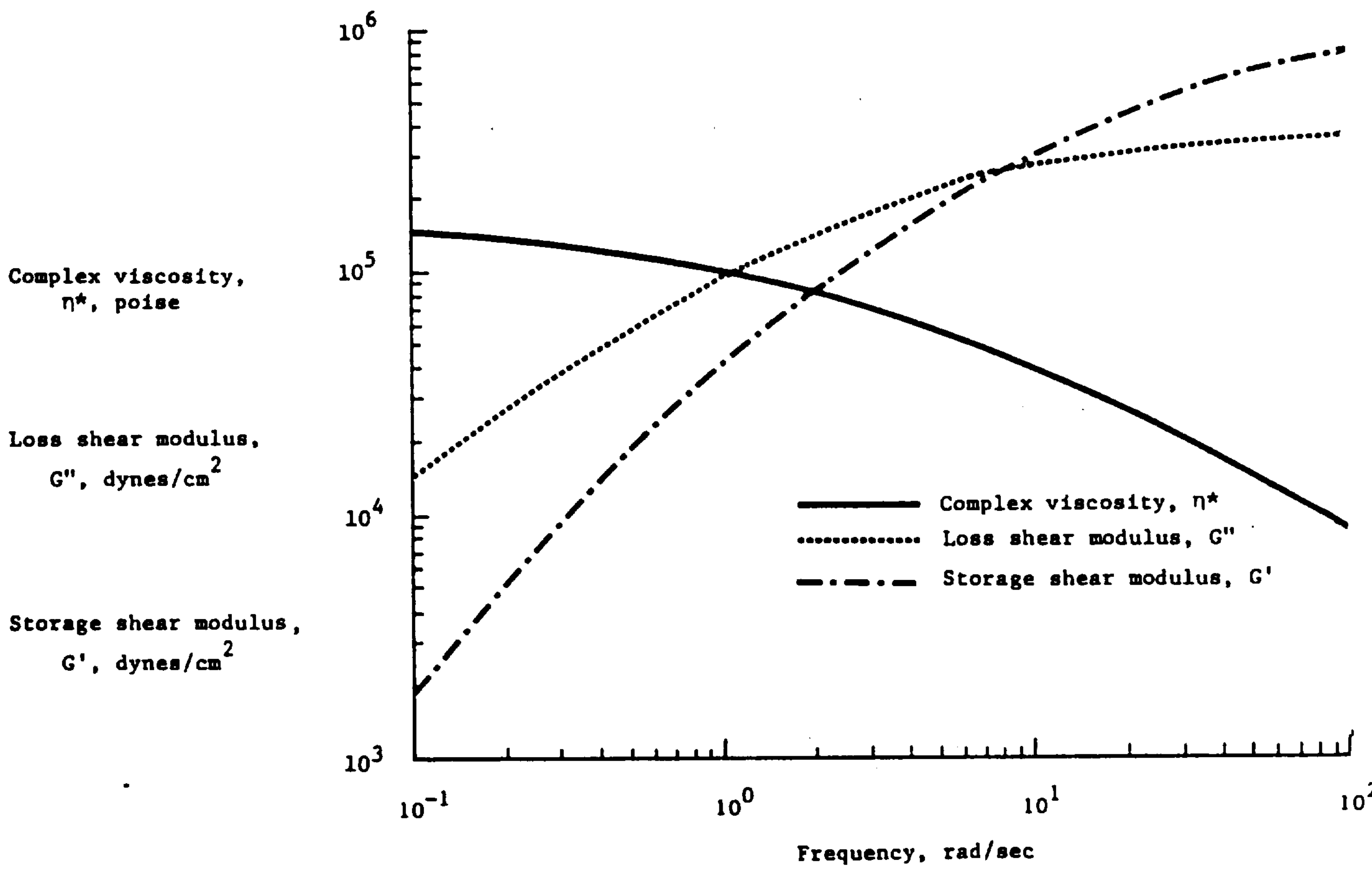
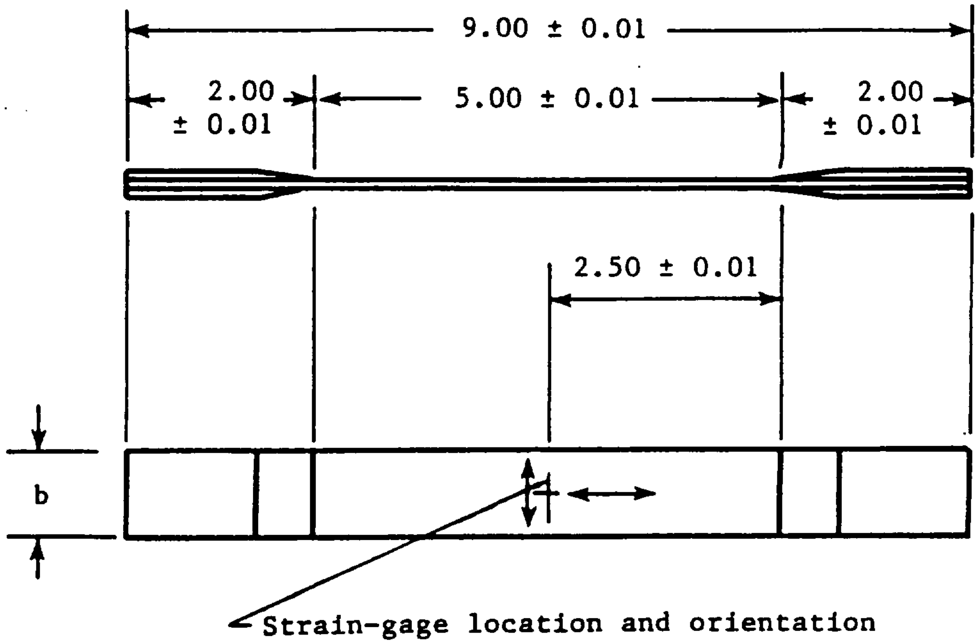


Figure 4.- Calibration data for dynamic mechanical rheometer. Dynamic rate sweep of poly(dimethylsiloxane) at 26°C.



Test	Test method	Ply orientation	Specimen width, b, in.
Tension strength and modulus	Section B.6	$(0)_8$	0.500 ± 0.007
Shear modulus	Section B.12	$[\pm45]_{3s}$	1.00 ± 0.01

FABRICATION

1. Specimen edge parallel and perpendicular requirements shall be as specified in paragraph B.2.3.

2. Edge finish shall be 32√ in accordance with MIL-STD-10A.

3. Specimen loading tabs shall be fabricated from 5 plies of fiberglass/epoxy prepreg style 181 (1851 or 7781). Taper is achieved by dropping one ply per 0.10 inch or by machining. Prior to bonding tabs, prepare specimen and tab surfaces by hand sanding (No. 150 grit sandpaper) or sandblasting. Clean surface thoroughly with acetone or MEK. Bond tabs to specimen using AF-132, Narmco Metlbond 1133 adhesive, or equivalent.

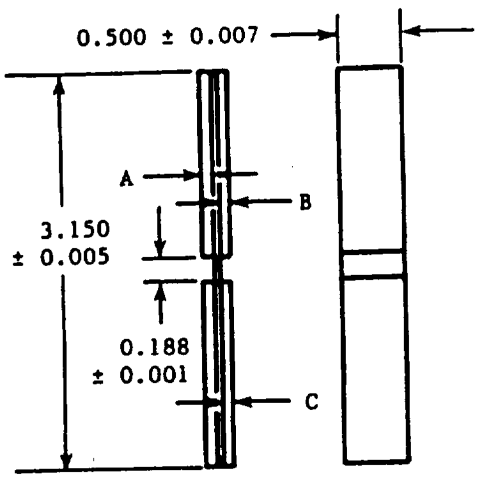
INSTRUMENTATION

1. For the requirements of section B.6, either a longitudinal strain gage or a suitable extensometer may be used to measure longitudinal strain.

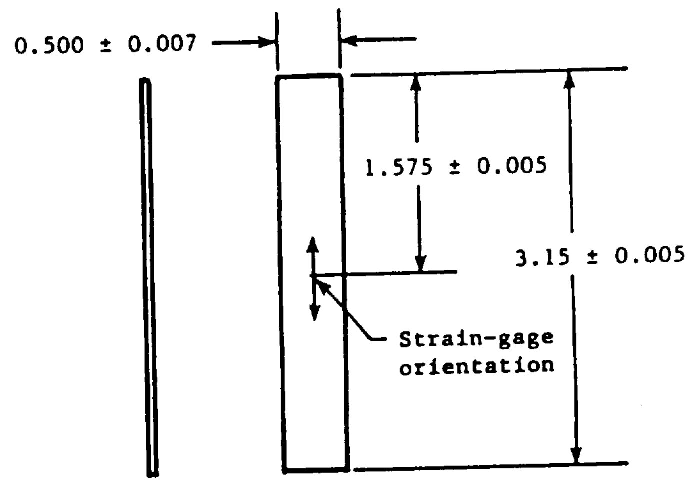
2. For the requirements of section B.12, longitudinal and transverse strain gages shall be mounted as shown in the drawing.

3. Locate strain gages adjacent to specimen centerline as indicated on drawing. Strain gage axis shall be aligned within 0.5° of specimen longitudinal or transverse centerline.

Figure 5.- Tension and shear test specimen. All dimensions are in inches.



Compression strength specimen



Compression modulus specimen

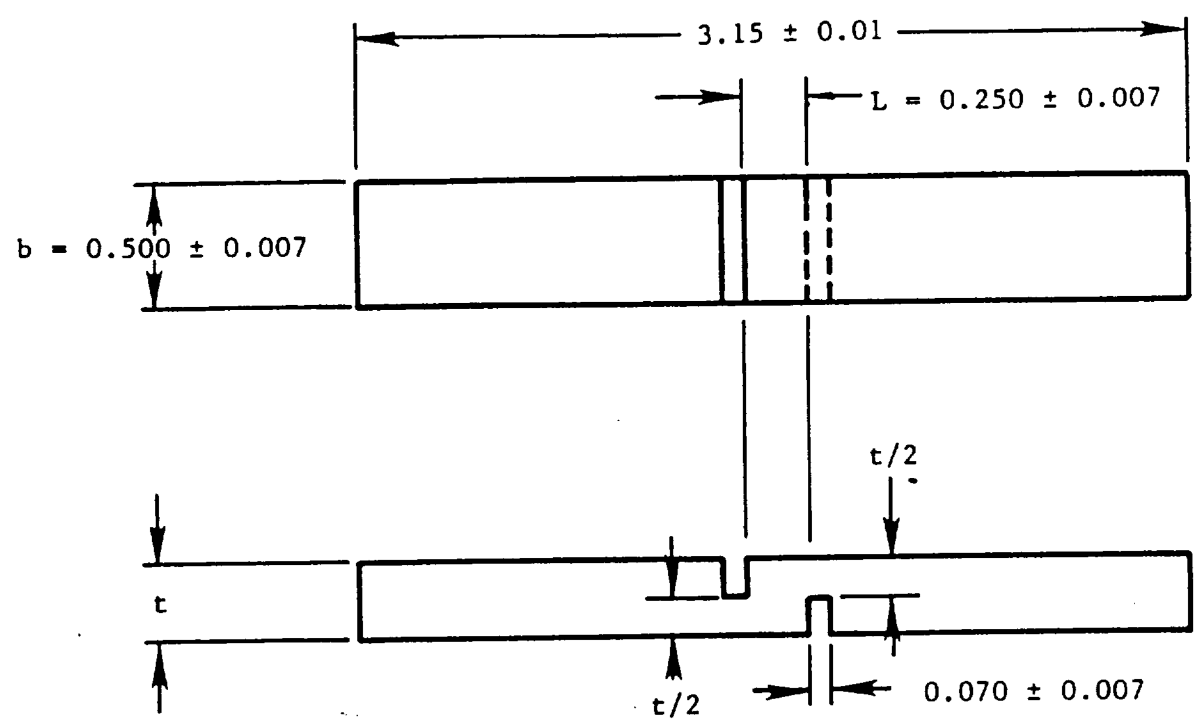
FABRICATION

1. Laminate orientation: $(0)_8$
2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph B.2.3.
3. Edge finish shall be 32/ in accordance with MIL-STD-10A.
4. Specimen loading tabs shall be fabricated from the same graphite/resin prepreg as the specimen, 12 plies thick, with the 0° fiber direction parallel to the longitudinal axis within ±1°. Prior to bonding tabs, prepare specimen and tab bonding surfaces by hand sanding (No. 150 grit sandpaper) or sandblasting. Clean surface thoroughly with acetone or MEK. Bond tabs to specimens with 250°F cure adhesive for room temperature and -100°F testing. Bond tabs to specimens with 350°F cure adhesive for 200°F testing.
5. Tab thickness tolerances: A = B ± 0.010
   B = C ± 0.001

INSTRUMENTATION

1. Either back-to-back strain gages or a suitable extensometer shall be used to measure longitudinal strain on the modulus specimens. Locate strain gage or extensometer on specimen centerline as shown. Strain gage axis shall be aligned within 0.5° of the specimen longitudinal centerline.

Figure 6.- Compression test specimens. All dimensions are in inches.



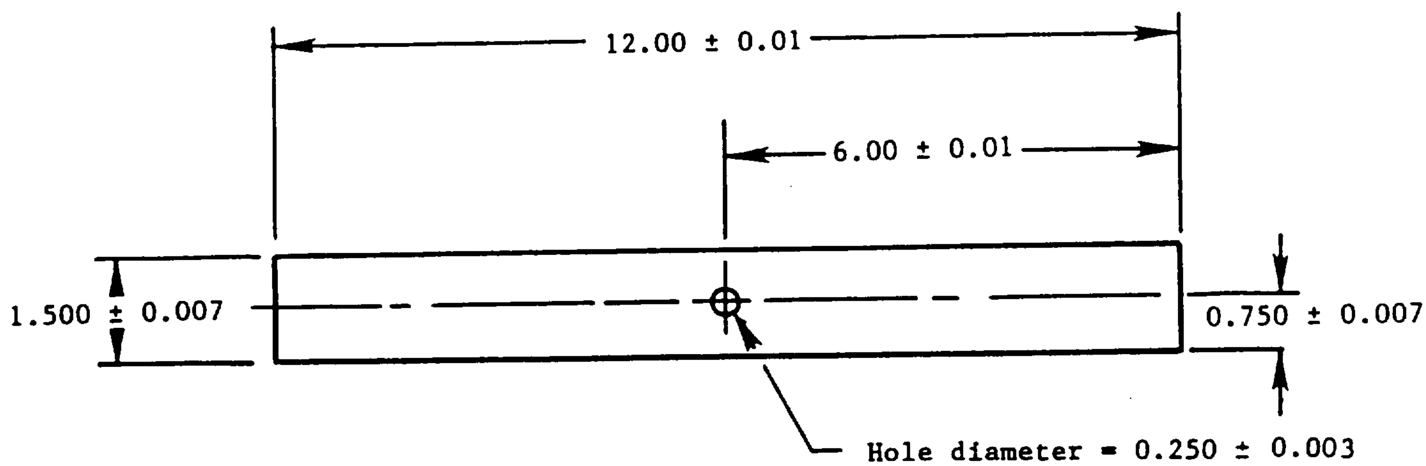
FABRICATION

1. Laminate orientation: $[45/0/-45/90]_{6s}$
2. Specimen edge parallel and end perpendicular requirements shall be specified in paragraph B.2.3.
3. Edge finish shall be 32√ in accordance with MIL-STD-10A.
4. Cut specimen notches with an abrasive wheel such that:

   Notch depth = $t/2 \begin{smallmatrix} +\ 0.010 \\ -\ 0.000 \end{smallmatrix}$ and notch penetrates centerply of laminate

   Notch corner radius = $0.005 \begin{smallmatrix} +0.001 \\ -0.000 \end{smallmatrix}$

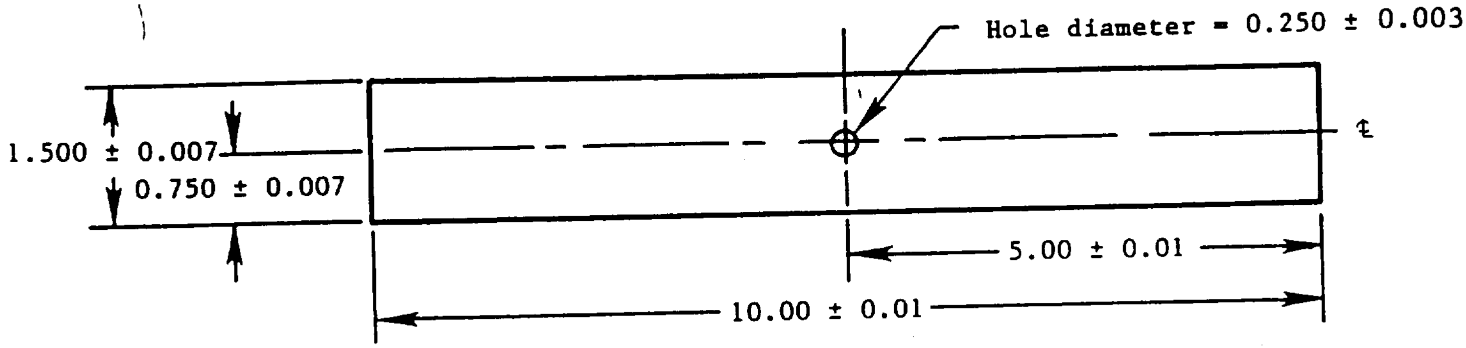
Figure 7.- Compression interlaminar shear specimen. All dimensions are in inches.



FABRICATION

1. Laminate orientation: $[45/0/-45/90]_{2s}$
2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph B.2.3.
3. Edge finish shall be 32√ in accordance with MIL-STD-10A.
4. Drill and/or ream hole as specified in paragraph B.9.2.

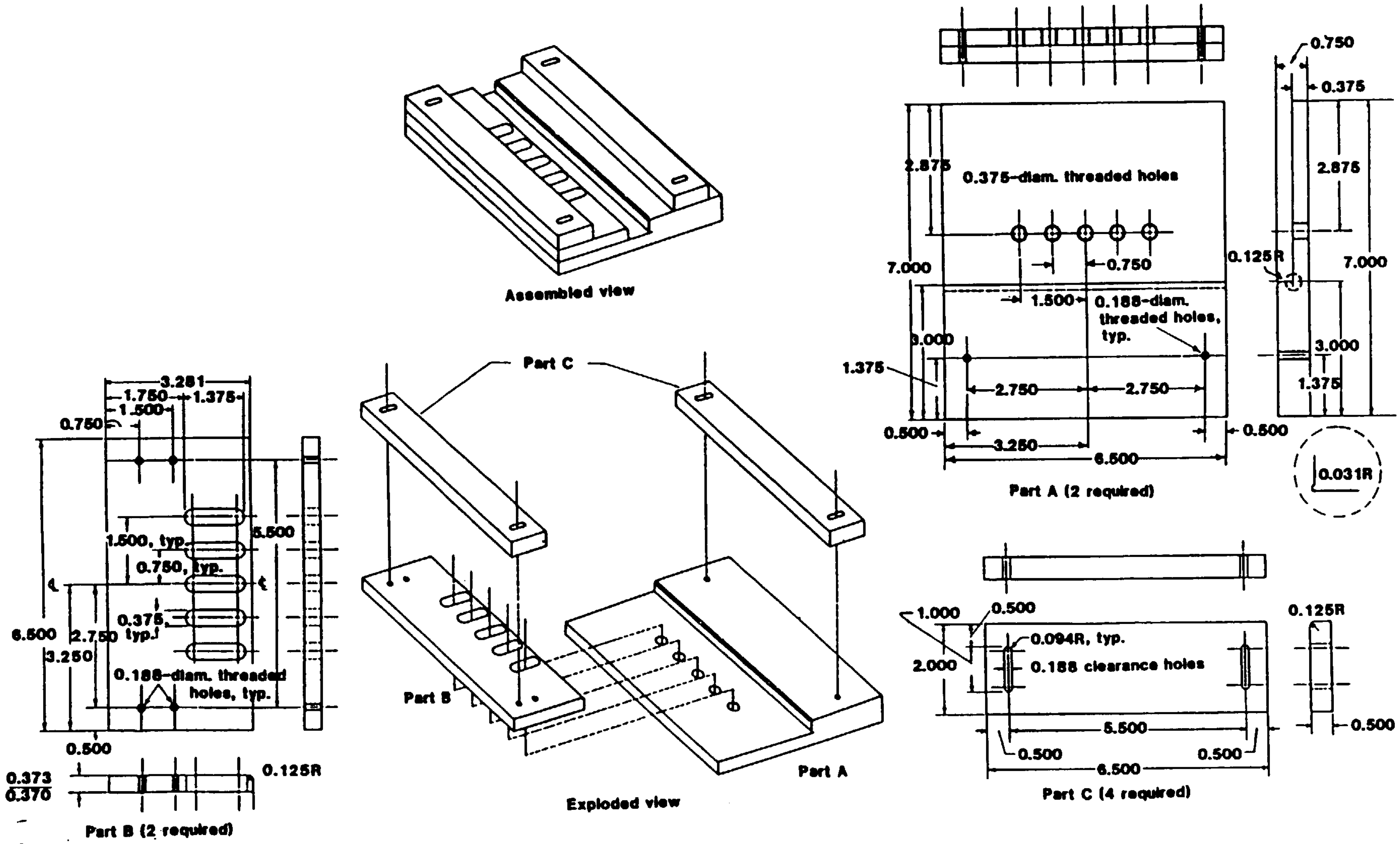
Figure 8.- Open-hole tension specimen. All dimensions are in inches.



FABRICATION

1. Laminate orientation: $[45/0/-45/90]_{2s}$
2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph B.2.3.
3. Edge finish shall be 32√ in accordance with MIL-STD-10A.
4. Drill and/or ream hole as specified in paragraph B.10.2.

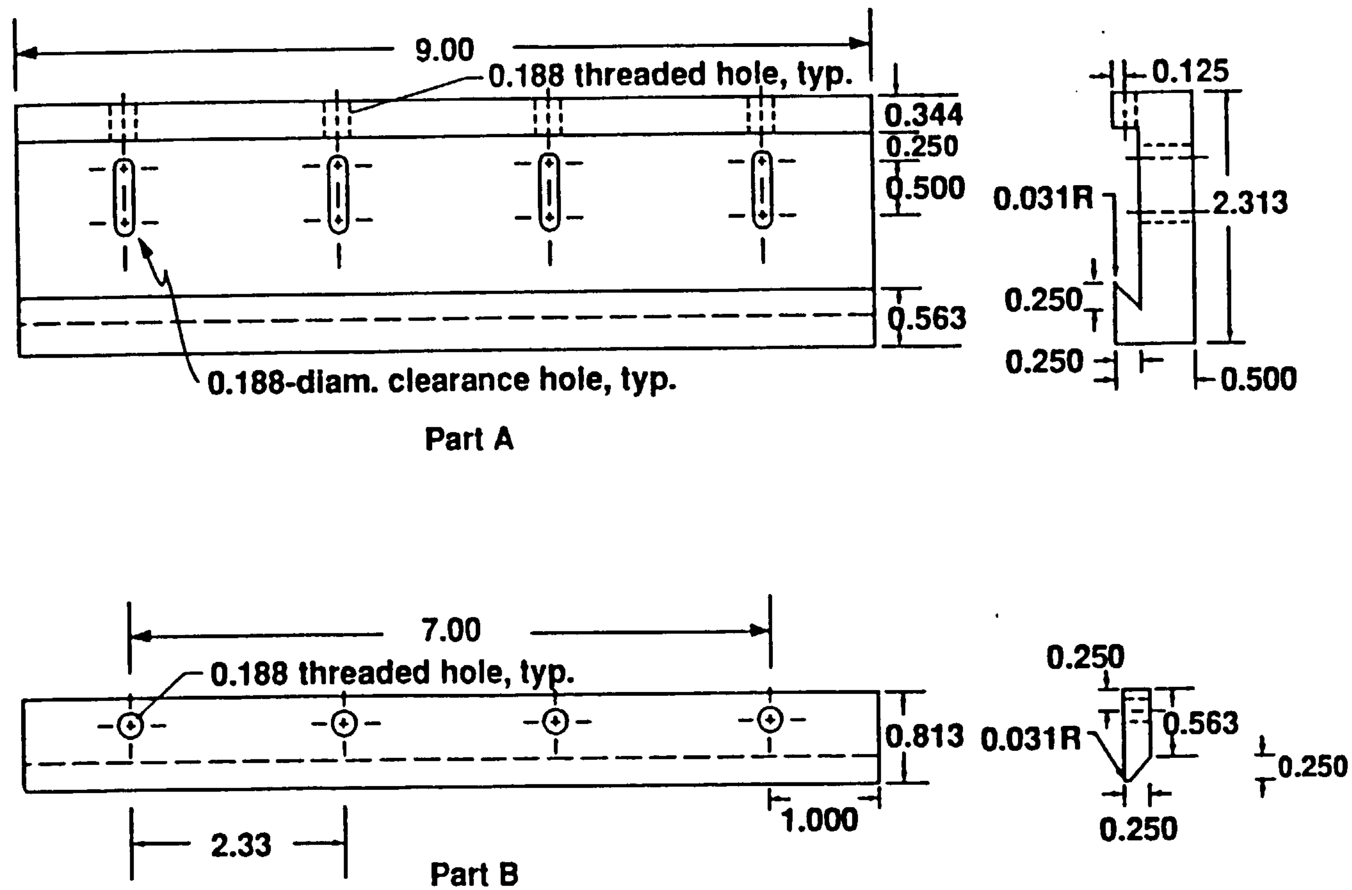
Figure 9.- Open-hole compression specimen. All dimensions are in inches.



(a) Loading plate, top and base, parts and assembly.
Material: 17-4 PH stainless steel.

Figure 10.- Compression test fixture. All dimensions are in inches.

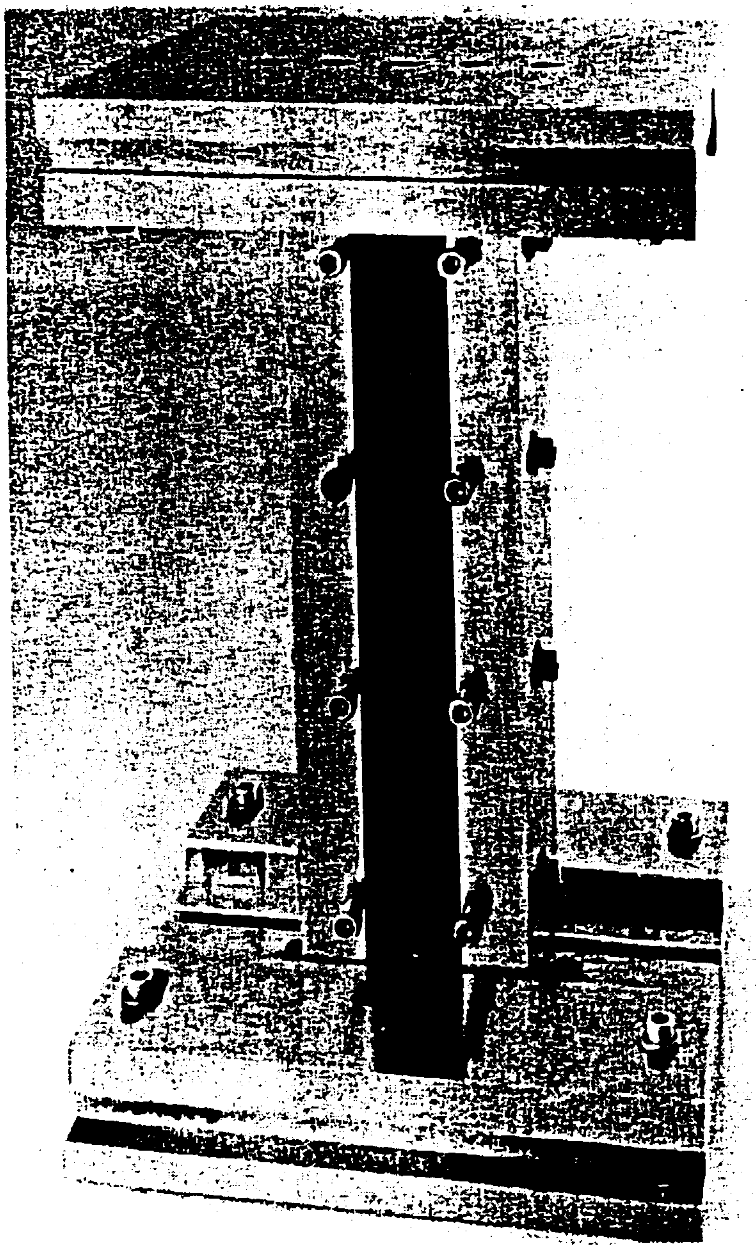
Two needed of each part
Rounds 0.313R



Center bolts and clearance holes equally spaced

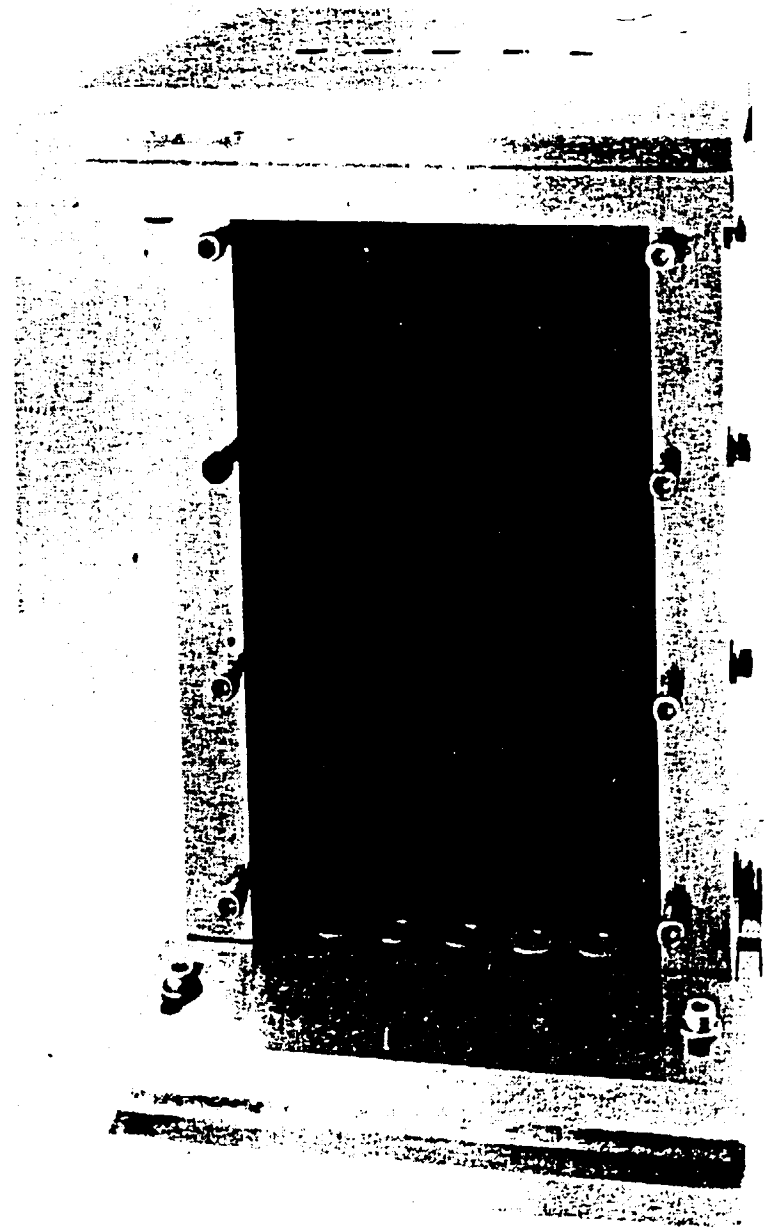
(b) Side supports.

Figure 10.- Continued.



L-85-108

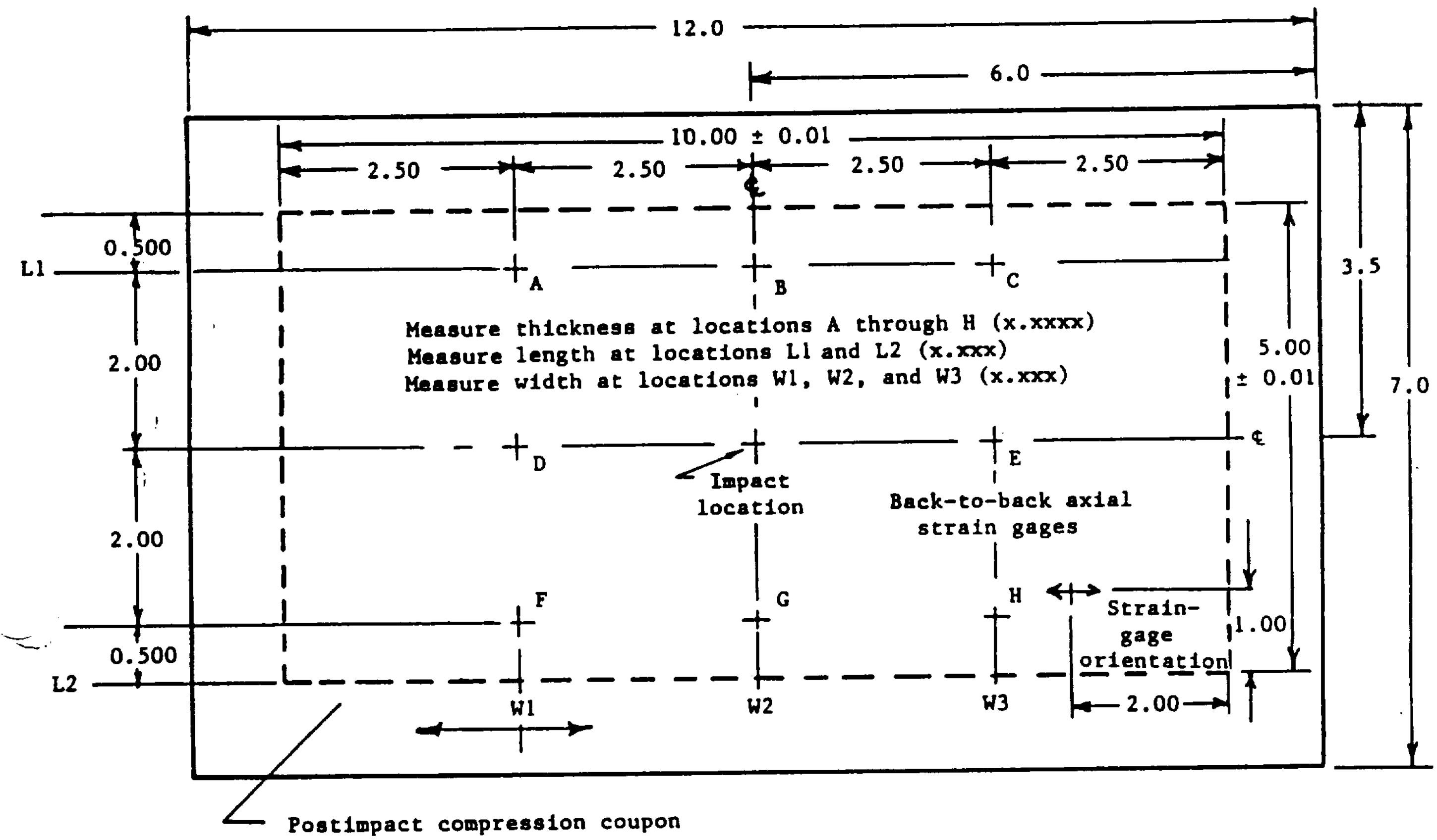
(c) Open-hole compression test setup.



L-85-109

(d) Compression after impact test setup.

Figure 10.- Concluded.



FABRICATION

1. Laminate orientation: $[45/0/-45/90]_{6s}$
2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph B.2.3.
3. Edge finish shall be 32$\surd$ in accordance with MIL-STD-10A.

Figure 11.- Compression after impact specimen. All dimensions are in inches.

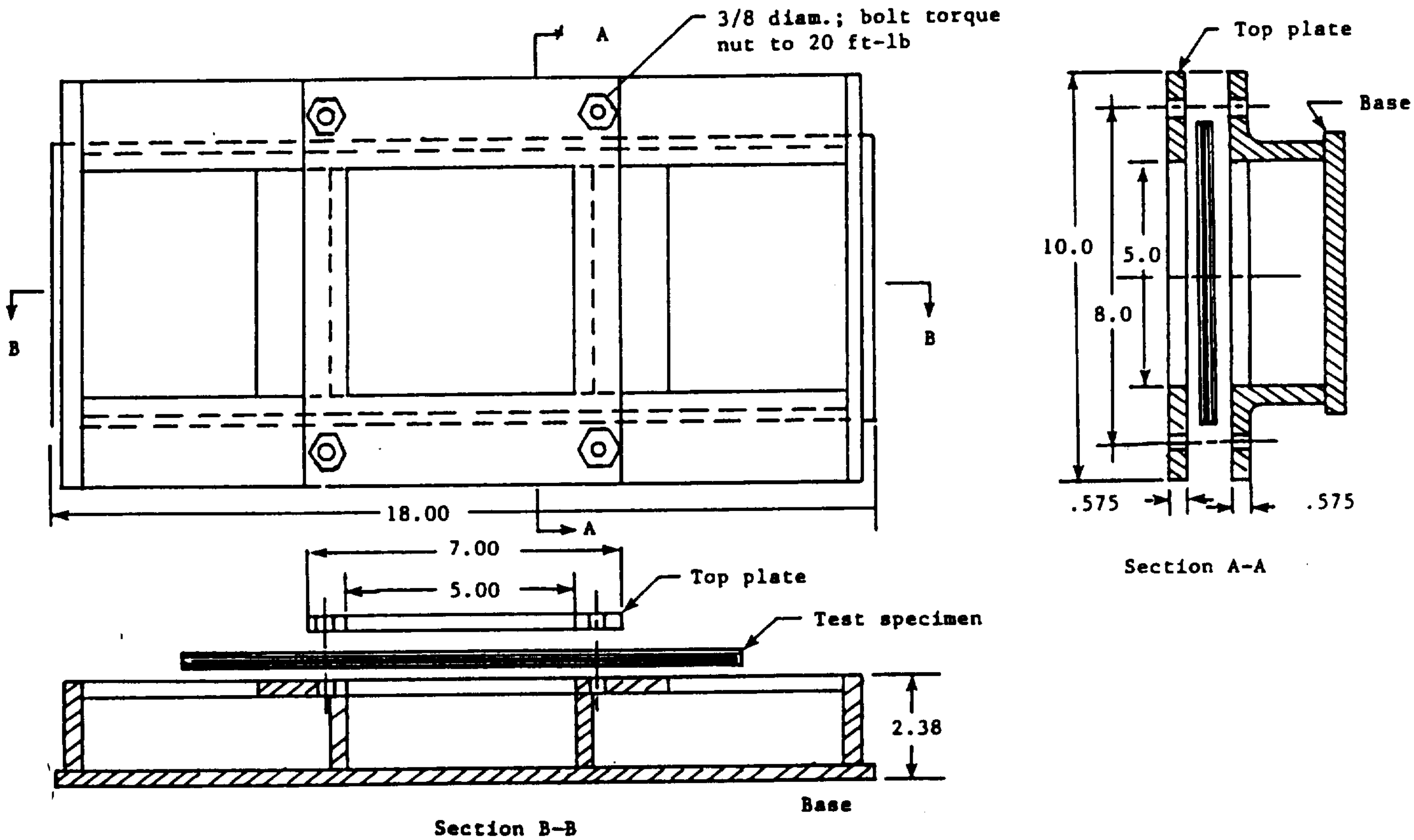
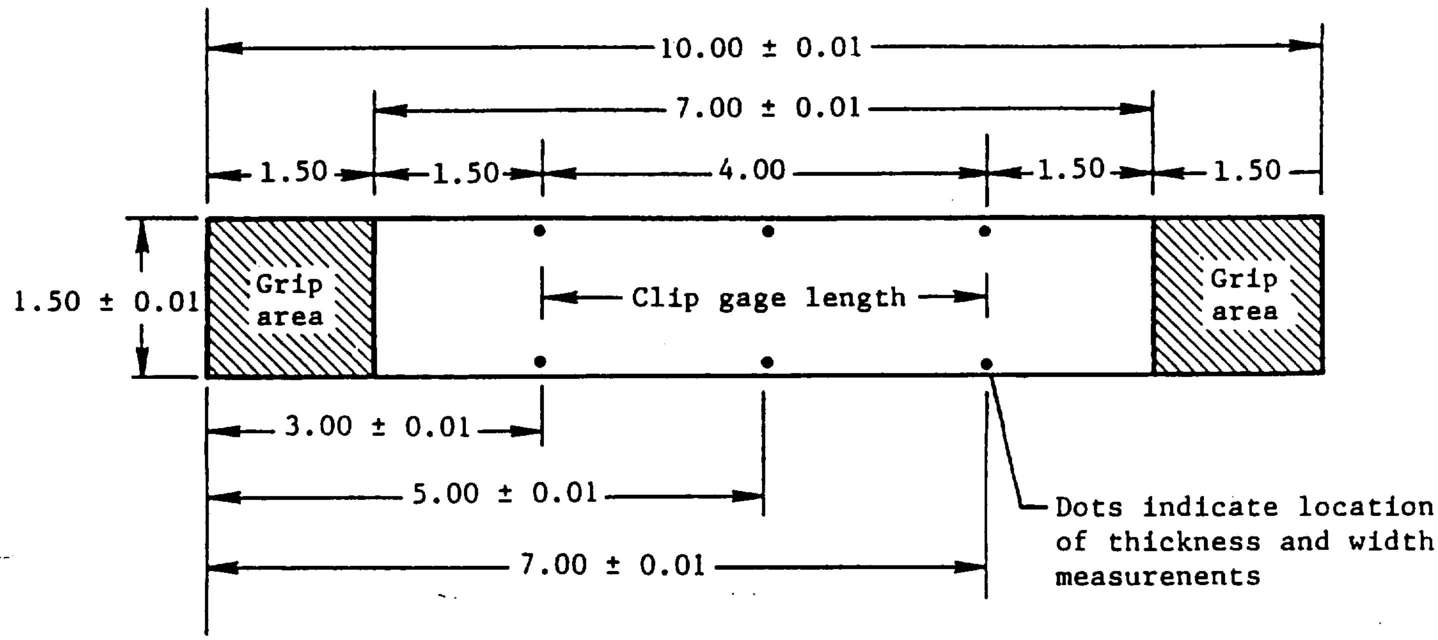


Figure 12.- Impact support fixture. Material: 17-4 PH stainless steel; all dimensions are in inches.



FABRICATION

1 Laminate orientation: $[\pm 30/\pm 30/90/\overline{90}]_s$

2. Specimen edge parallel and end perpendicular requirements shall be as specified in paragraph B.2.3.

3. Edge finish shall be 32/ in accordance with MIL-STD-10A.

Figure 13.- Edge delamination tension specimen. All dimensions are in inches.

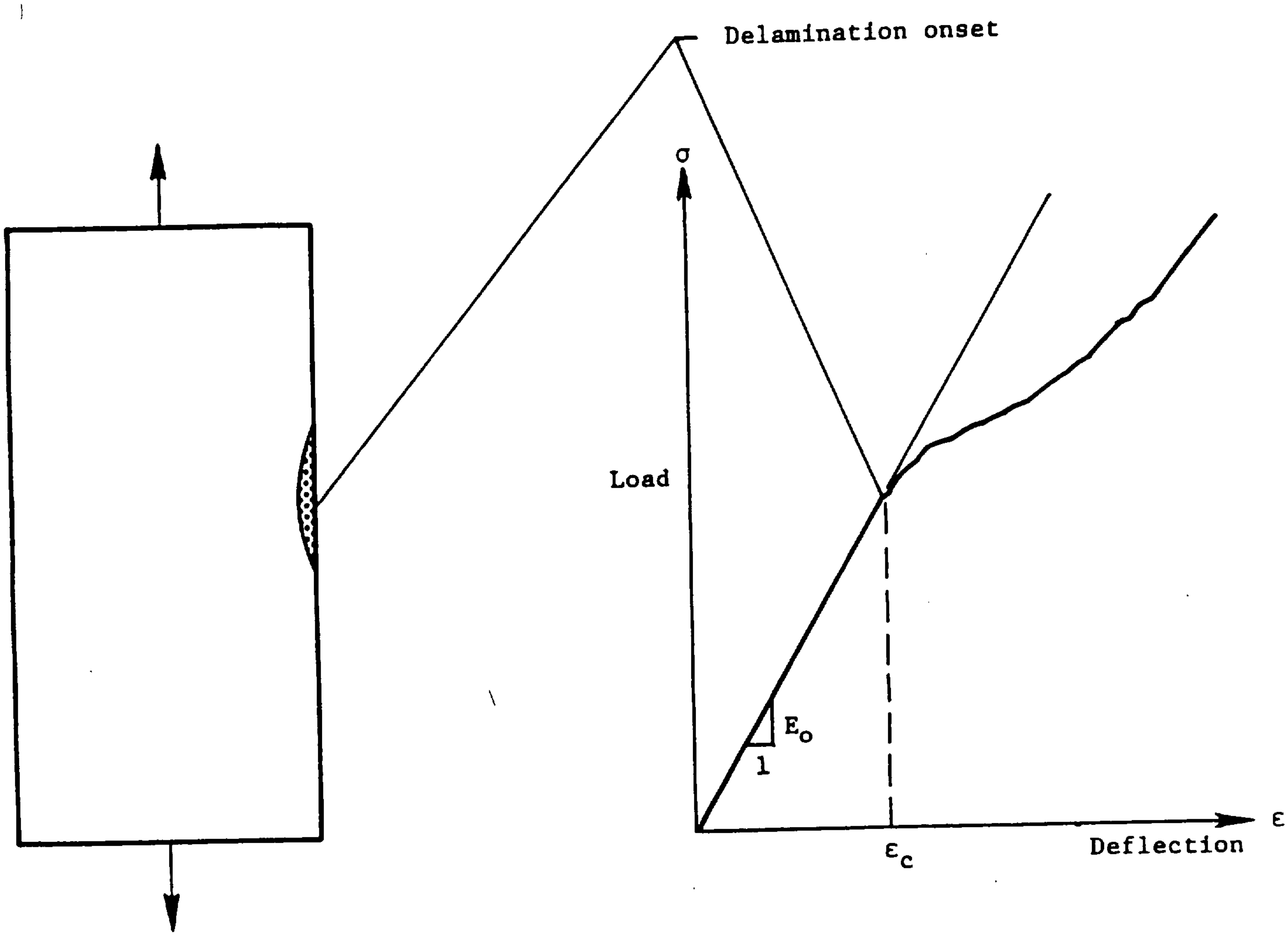


Figure 14.- Load deflection diagram for critical edge delamination determination.

SACMA
Suppliers of Advanced
Composite Materials
Association

RECOMMENDED METHOD
SRM 2-88

SACMA Recommended Test Method for COMPRESSION AFTER IMPACT PROPERTIES OF ORIENTED FIBER-RESIN COMPOSITES

The test method contained in this document is recommended by the Suppliers of Advanced Composite Materials Association (SACMA). It is intended as a guide to aid manufacturers and users of advanced composite products. The use of a SACMA Recommended Test Method is entirely voluntary. It does not preclude anyone from manufacturing, marketing, selling, purchasing or using products that have not been tested in accordance with it. SACMA does not test, certify, or approve any test method or product and publication of a Recommended Test Method does not constitute endorsement of any product or product type.

The statements contained in this Recommended Test Method are those of SACMA and are not warranties, nor are they intended to be warranties of SACMA or any of its member companies. Inquiries for information on specific products, their attributes and recommended uses and the manufacturer's warranty should be directed to individual manufacturers and suppliers.

1.0 Scope

1.1 This method covers the procedure for the determination of the compression after impact properties of fiber-resin composites reinforced by oriented continuous high modulus, $>3 \times 10^6$ psi, fibers.

1.2 This test procedure is applicable primarily to prepreg or similar product forms and other product forms may require deviations to the test method.

1.3 This test method may involve hazardous materials, operations, and equipment. This test method does not address safety problems associated with its use. It is the responsibility of whoever uses this test method to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2.0 Applicable Documents

2.1 ASTM Standards:

E4 Load Verification of Testing Machines
E84 Verification and Classification of Extensometers

2.2 SACMA Recommended Test Methods:

SRM10 Calculation of Fiber Volume of Composite Test Laminates
SRM11 Conditioning of Composite Test Laminates

3.0 Summary of Method

3.1 A quasi-isotropic test specimen as shown in Fig. 1 is placed in a holding fixture (see Fig. 2), impacted at a specified energy, non-destructively inspected, and placed in a test fixture (Fig. 3) and loaded to failure in compression. Load-strain curves are obtained when modulus or strain data are required.

4.0 Significance and Use

4.1 This test is designed to provide property data for material specifications qualification, research and development, and data base generation. Factors that influence the test properties and should therefore be reported are: material, methods of specimen preparation, specimen conditioning, environment of testing, time at temperature, speed of test, and fiber volume.

4.2 This test is sensitive to fiber alignment and surface qualities.

Caution: If over half the width is damaged, edge effects will predominate. Reduced energy levels should be agreed upon by all parties. Comparison of results for different materials with different laminate thicknesses are not valid.

5.0 Apparatus

5.1 Micrometers - 0.2 inch nominal diameter double ball (thickness) and 0.25 inch diameter flat-flat (width) suitable for reading to 0.001 inch accuracy for measuring the specimen thickness and width.

5.2 Impact Support Fixture - Refer to Fig. 2. The fixture shall be attached to and firmly supported by the base of the impact instrument.

5.3 Impacting Machine - This is comprised of an impact tip which is steel and has a hemispherical tip (0.625 inch diameter). This weight is dropped through a nominally frictionless guide tube to contact the center of the specimen.

Note: Recommended weight is a nominal 11 pounds.

5.4 Testing machine as defined by ASTM E4.

5.5 Strain-Indicating Device - Strain should be determined by means of strain gages. The gages, surface preparation, and bonding agents should be chosen to provide for optimal performance on the subject materials and shall be located as shown in Fig. 1 and suitable strain-recording equipment shall be employed.

5.6 Compression Fixture - A drawing for the compression specimens and a schematic of the test fixture are given in Fig. 1 and 3. Referring to Fig. 3, the fixture is comprised of edge retention bars which support the specimen and inhibit buckling when the specimen is end loaded in a vertical plane.

6.0 Test Specimen

6.1 Laminate Preparation - Care should be taken to obtain a flat, smooth laminate.

6.1.1 Tape - Adequate panels should be fabricated to allow 1 inch edge trim. Typical laminate construction shall consist of 24 plies of 190 Grade Tape $(+45/0/-45/90)_{3S}$; 32 plies of 145 Grade Tape $(+45/0/-45/90)_{4S}$ and 48 plies of 95 Grade Tape $(+45/0/-45/90)_{6S}$ (see Fig. 1 and 2).

6.1.2 Fabric - Precured laminates shall be adequate to allow 1 inch edge trim. Typical laminate construction shall consist of sufficient plies of fabric to achieve 0.18 inch - 0.22 inch thickness and shall have the orientation of $[(\pm 45), (0/90)]_{NS}$ with N being a whole number.

6.2 Test Specimen Preparation

6.2.1 Specimen Configuration - Test specimens shall be cut from a precured laminate of sufficient size. At least 1 inch should be removed from all edges. The compression after impact specimen shall be a 6 inch by 4 inch plate with the 6 inch dimension in the 0° direction as shown in Fig. 1. Each specimen shall be of uniform cross-section over the entire surface and shall not have a taper greater than 0.003 inch in any direction.

6.2.2 Specimen Machining - Test specimens shall be machined from the laminate to the dimensions shown in Fig. 1. Ply orientation and number shall be as specified in Paragraph 6.1.1, 6.1.2, and Fig. 1. All machined surfaces shall be smooth and free of nicks, scratches, or other defects. The ends of the specimen shall be machined perpendicular to the longitudinal surfaces to within 0.001 inch.

6.2.3 Specimen Measurement - The thickness of the specimen shall be recorded as the average value of four thickness measurements taken around the impact area prior to impacting. The width of the specimen shall be measured to the nearest 0.001 inch at no less than 2 points near the specimen center to obtain the cross-sectional area. Measure laminate and specimen thickness using a ball nose micrometer having a diameter of approximately 0.25 inch maximum.

6.2.4 Fiber Volume - Fiber volume shall be determined in accordance with SRM10.

7.0 Conditioning

7.1 Use SACMA Recommended Procedure SRM11 for Conditioning of Composite Test Laminates.

8.0 Test Procedure

8.1 Impacting.

8.1.1 Each specimen shall be clearly marked and a record maintained of its test history. The specimens shall be impacted at room temperature with a 0.625 inch diameter spherical tip impactor while supported by a 3 inch by 5 inch cutout frame (Fig. 2) held in place with a support base as shown in Fig. 4. Tests shall be run on a minimum of five specimens.

8.1.2 The energy level used shall be 1500 inch-pounds/inch thickness or as otherwise specified. This can be achieved by the following methods:

Method 1: Energy = drop weight x drop height ÷ specimen thickness
Method 2: Energy = 1/2 mass $(\text{velocity})^2$ ÷ specimen thickness

The velocity is measured just prior to impact. The velocity measurement should be corrected for any travel between the flag and the specimen. Since Method 2 takes into account friction losses, it is the preferred method.

Note: Avoid any rebound hits of the specimen.

8.1.3 If instrumentation is used during impacting, report the actual energy, and record the energy versus time plot for each specimen.

8.1.4 An ultrasonic scan shall be made of the impacted specimen and the area and the general configuration of the delamination shall be recorded.

8.2 Specimen Testing - A compressive loading fixture shall be used to ensure axial loading in the desired plane of action (see Fig. 3). Four strain gages shall be used to measure the strain (see Fig. 1 for strain gage locations). The testing speed shall be 0.05 inch/min. The output of each gage shall be plotted individually to check for buckling. Appropriate clearance shall be left so that specimen can be dropped in place.

8.3 Calculations

8.3.1 Compressive Strength - The compressive strength shall be expressed in ksi. The following equation shall be used for calculating the ultimate compressive strength.

$$\sigma_{ULT} = P/bd = P/bt$$

Where:

σ_{ULT} = ultimate compressive strength, ksi.
P = ultimate compressive load, lbs.
b = average width, in.
d = thickness, in.

8.3.2 Compression Modulus

$$E_x = \frac{P_3 - P_1}{0.002bd}$$

Where:

P_3 = load at 3000 microstrain
P_1 = load at 1000 microstrain
b = specimen average width, in.
d = specimen thickness, in.

Note: Strain based on the average of all four strain gages.

8.3.3 For each series of tests, calculate the average value, standard deviation and coefficient of variation for each property.

$$\bar{X} = 1/n \sum_{i=1}^{n} X_i$$

$$s = \sqrt{\frac{\left(\sum_{i=1}^{n} X_i^2 - n(\bar{X})^2\right)}{n-1}}$$

$$CV = \frac{100s}{\bar{X}}$$

Where:

$\bar{X}$ = average value

X_i = test value of the i^{th} test

s = estimated standard deviation

n = number of specimens

CV = coefficient of variation

9.0 Retests

9.1 Values for ultimate properties shall not be calculated for any specimen that breaks at some obvious flaw, unless such flaw constitutes a variable being studied. Retests shall be performed for any specimen on which values are not calculated.

10.0 Report

10.1 The report shall include the following:

10.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, form, fiber areal weight, filament count, weave style, processing details, stacking sequence, test orientation and deviations from this test method.

10.1.2 Complete description of the method of fabricating the composite.

10.1.3 Date of test, facility, and identification of individual(s) performing the test.

10.1.4 The number of specimens tested and all pertinent specimen dimensions.

10.1.5 Fiber volume fraction for each specimen.

10.1.6 Method of preparation of the test specimens.

10.1.7 Relative humidity and temperature in test room.

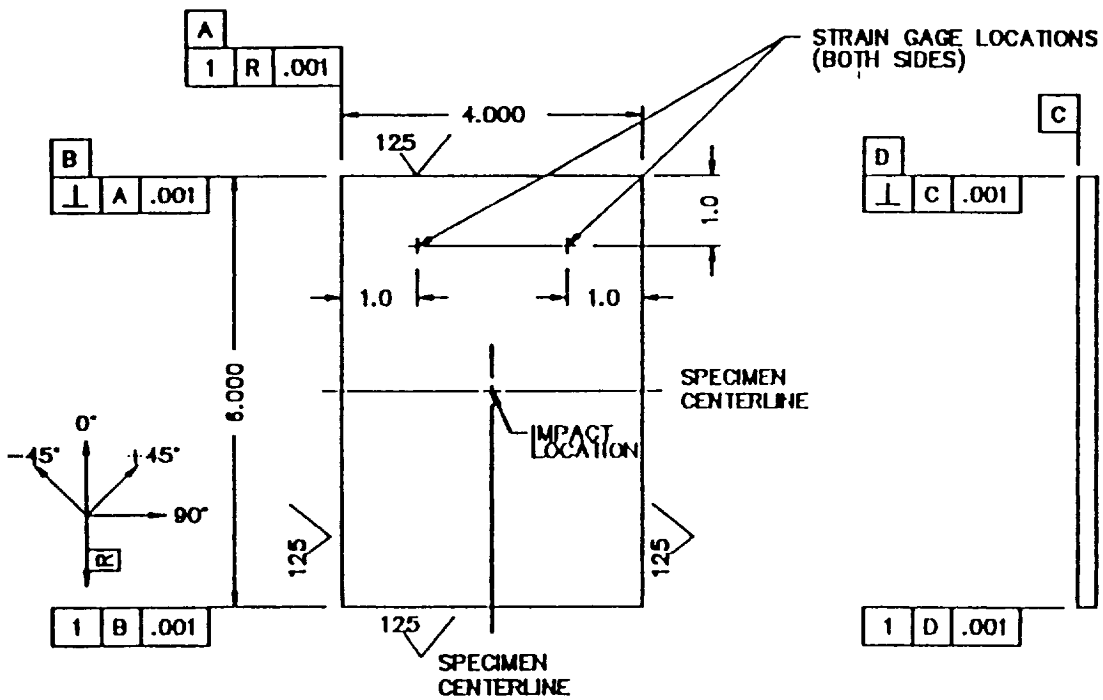
10.1.8 Specimen pre-test conditioning history.

10.1.9 Impact energy level damage area and method used to determine the configuration of damaged area.

10.1.10 Compressive strength, individual values, average value, standard deviation, and coefficient of variation. Normalization must be recorded in the report.

10.1.11 Elastic moduli, individual values, average value, standard deviation, and coefficient of variation. Normalization must be recorded in the report.

10.1.12 Mode of failure.



<u>LAY-UP:</u>
SEE SECTION 6.1

<u>NOTES:</u>

1. UNLESS OTHERWISE SPECIFIED, DIMENSIONAL TOLERENCES ARE ±0.005 INCHES.
2. ALL DIMENSIONS IN INCHES.

<u>COMPRESSION AFTER IMPACT TEST SPECIMEN</u>

Figure 1. Compression After Impact Test Specimen

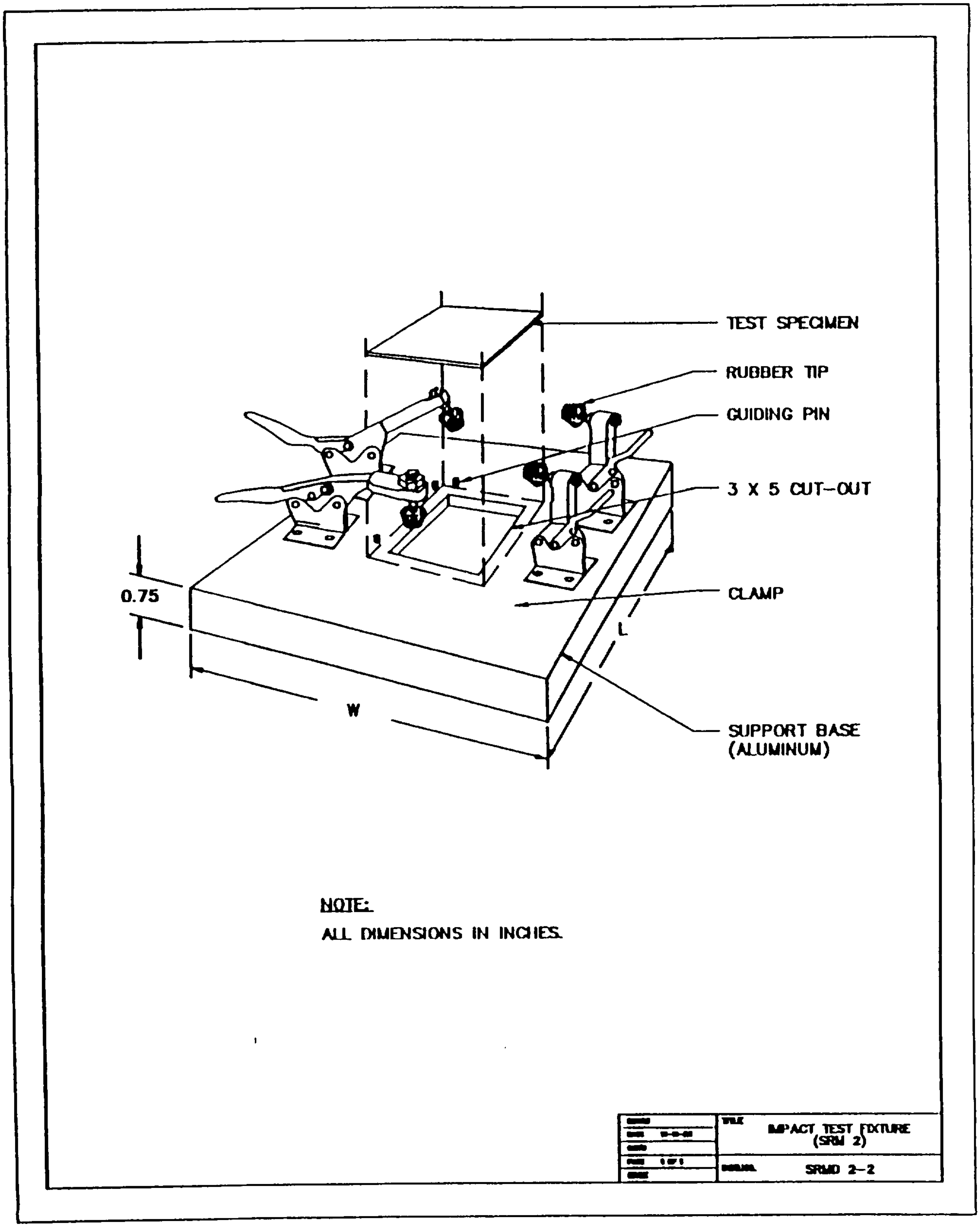


Figure 2. Impact Test Fixture

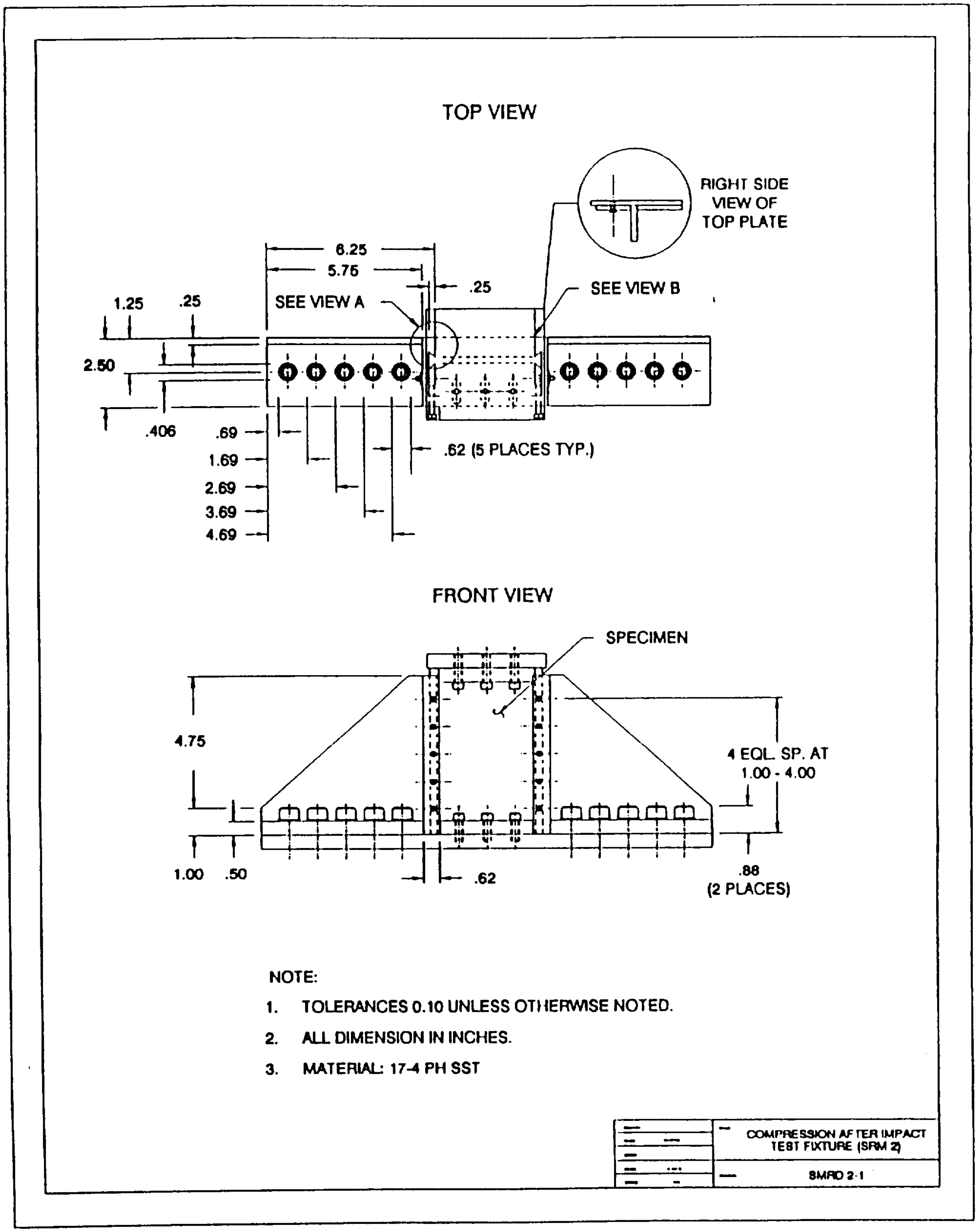


Figure 3A. Compression After Impact Test Fixture

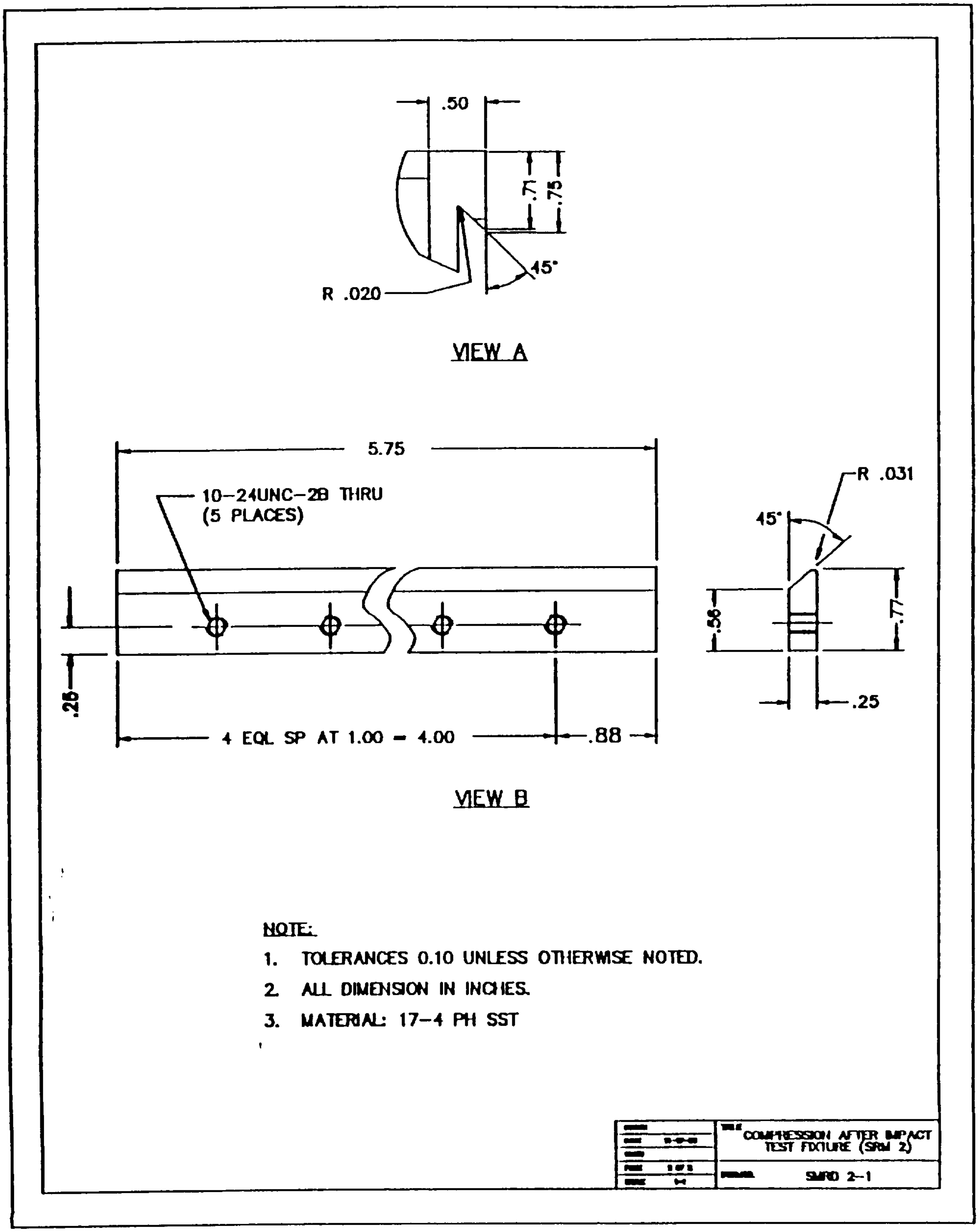


Figure 3B. Compression After Impact Test Fixture

SACMA
Suppliers of Advanced Composite Materials Association

RECOMMENDED METHOD
SRM 7-88

SACMA Recommended Test Method for INPLANE SHEAR STRESS-STRAIN PROPERTIES OF ORIENTED FIBER-RESIN COMPOSITES

1.0 Scope

1.1 This method covers the procedure for the determination of the inplane shear stress-strain properties of fiber-resin composites reinforced by oriented continuous high modulus, $>3 \times 10^6$ psi, fibers. The method is based on the uniaxial tensile stress-strain response of a $\pm 45^\circ$ laminate which is symmetrically laminated about the midplane. This method is derived from ASTM Method D3518.

1.2 This test method is applicable primarily to prepreg or similar product forms and other product forms may require deviations to the test method.

1.3 This test method may involve hazardous materials, operations, and equipment. This test method does not address safety problems associated with its use. It is the responsibility of whoever uses this test method to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2.0 Applicable Documents

2.1 ASTM Standards:

D3518 Test for Inplane Shear Stress-Strain Response of Unidirectional Reinforced Plastics
D3039 Test for Tensile Properties of Oriented Fiber Composites
E4 Load Verification of Testing Machines
E84 Verification and Classification of Extensometers

2.2 SACMA Recommended Test Methods:

SRM4 Tensile Properties of Oriented Fiber-Resin Composites
SRM10 Calculation of Fiber Volume of Composite Test Laminates
SRM11 Conditioning of Composite Test Laminates

3.0 Summary of Method

3.1 Through the use of relations derived from laminated plate theory, expressions are presented which allow the inplane 0° shear stress-strain curve to be generated from a uniaxial tension test of a ±45° laminate. Experimental test data from a tensile test as described in ASTM Method D3039 are used as the basis for generating the ±45° laminate stress-strain curves.

4.0 Significance and Use

4.1 This test is designed to provide property data for material specifications, qualifications, research and development, and data base generation. Factors that influence the test properties and should therefore be reported are: material, methods of specimen preparation, specimen conditioning, environment of testing, time at temperature, speed of test, and fiber volume.

4.2 This test is sensitive to fiber alignment and surface qualities.

5.0 Apparatus

5.1 Micrometers - 0.2 inch nominal diameter double ball (thickness) and 0.25 inch diameter flat-flat (width) suitable for reading to 0.001 inch accuracy for measuring the specimen thickness and width.

5.2 Testing Machine - As described in ASTM D3039 and E4.

5.3 Strain Indicator - This procedure requires load-strain data in both the longitudinal and transverse directions. This is accomplished by instrumenting the specimen with longitudinal and transverse element strain gages. The gages, surface preparation, and bonding agents should be chosen to provide for optimal performance on the subject material, and suitable automatic strain-recording equipment shall be employed.

6.0 Test Specimen

6.1 Geometry - The test specimen must be as shown in Fig. 1 where the specimen has a constant cross-section with tabs bonded to the ends. Variation in specimen width must be within ±0.005 inches. Variation in specimen thickness shall be within ± 0.002 inches.

6.1.1 The specimens shall be cut from laminates, preferably after bonding on tab material. The laminates shall be balanced 8 ply construction of the form $[\pm 45°]_{2S}$. Precautions must be taken to avoid notches, undercuts, or rough or uneven surfaces during cutting.

6.2 Tabs - The test may be performed without the specimen being tabbed; however, if tabs are used, they shall be as follows: balanced, 0/90 cross-ply, or ±45° unidirectional or fabric tabs, may be used. The tabs should be strain compatible with the composite being tested. Each tab shall be 2.0 inch long by the width of the specimen and a thickness of 1.5 to 4 times the thickness of the test specimen. The tabs shall have a 15° typical bevel, (5° minimum). Any high-elongation (tough) adhesive system that will meet the temperature requirements may be used. Care should be taken that bonding temperature does not add any undesired post-cure to the laminate.

6.3 Number of Test Specimens - At least five specimens shall be tested per test condition.

6.4 The fiber orientation tolerance shall be ±1°.

7.0 Conditioning

7.1 Use SACMA Recommended Procedure SRM11 for Conditioning of Composite Test Laminates.

8.0 Test Procedure

8.1 Tension Test - Perform a tension test on a ±45° symmetric laminate in accordance with the method described in ASTM Method D3039.

8.2 Before testing, measure and record the specimen dimensions.

8.3 Install test specimen into wedge action or hydraulic tension grips.

8.4 The test should be run at a crosshead speed of 0.05 inch/min.

8.5 Load the specimen monotonically to failure while recording load, and both longitudinal and transverse strains (or deformations) continuously.

8.6 Record the maximum load carried by the specimen during the test.

9.0 Retests

9.1 Values for ultimate properties shall not be calculated for any specimen that breaks at some obvious flaw, unless such flaws constitute a variable being studied. Retests shall be performed for any specimen on which values are not calculated.

10.0 Calculations

10.1 Shear Stress-Strain Curve – Using the uniaxial stress-strain curves of the ±45° tensile coupon, tabulate values of longitudinal strain and transverse strain, corresponding to particular values of load, and determine points on the unidirectional shear stress-strain curve using the following equations, and report results to three significant figures.

$$\tau_{12}^{i} = \frac{P_x^i}{2bd}$$

$$\gamma_{12}^{i} = \varepsilon_x^i - \varepsilon_y^i$$

Where:

P_x^i = load at i^{th} point of ±45° tensile load-deformation curve, lbf.

τ_{12}^{i} = shear stress at the i^{th} point of the unidirectional shear stress-strain curve, psi.

γ_{12}^{i} = shear strain at the i^{th} point of the unidirectional shear stress-strain curve

ε_x^i = longitudinal strain at the i^{th} point of the ±45° tensile load-deformation curve

ε_y^i = transverse strain at the i^{th} point of the ±45° load-deformation curve

b = specimen average width, in.

d = specimen thickness, in.

10.2 Shear Strength - Calculate the inplane shear strength using the following equation and reporting the results to three significant figures.

$$\tau = \frac{P}{2\,bd}$$

Where:

τ = ultimate inplane shear strength, psi.

P = maximum load on the ±45° tensile load-deformation curve, lbf.

b = specimen average width, in.

d = specimen thickness, in.

10.3 Shear Modulus - Calculate inplane shear modulus using the following equation and report results to three significant figures.

$$G_{12} = \frac{\Delta_{\tau 12}}{\Delta_{\gamma 12}}$$

Where:

G_{12} = shear modulus of ±45° composite, psi.

$\frac{\Delta_{\tau 12}}{\Delta_{\gamma 12}}$ = slope of the line drawn from the origin of the stress-strain curve to 3000 microstrain (Fig. X2).

10.4 For each series of tests, calculate the average value, standard deviation and coefficient of variation for each property.

$$\bar{X} = 1/n \sum_{i=1}^{n} X_i$$

$$s = \sqrt{\frac{\left(\sum_{i=1}^{n} X_i^2 - n(\bar{X})^2\right)}{n-1}}$$

$$CV = \frac{100s}{\bar{X}}$$

Where:

$\bar{X}$ = average value

X_i = test value of the i^{th} test

s = estimated standard deviation

n = number of specimens

CV = coefficient of variation

11.0 Report

11.1 The report shall include the following:

11.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, form, fiber areal weight, filament count, processing details, stacking sequence, test orientation and deviations from this test method.

11.1.2 Complete description of the method of fabricating the composite.

11.1.3 Date of test, facility, and identification of individual(s) performing the test.

11.1.4 The number of specimens tested and all pertinent specimen dimensions.

11.1.5 Fiber volume for each specimen.

11.1.6 Method of preparation of the test specimens including tab material, tab adhesive, and curing condition of this adhesive.

11.1.7 Relative humidity and test conditions in test room.

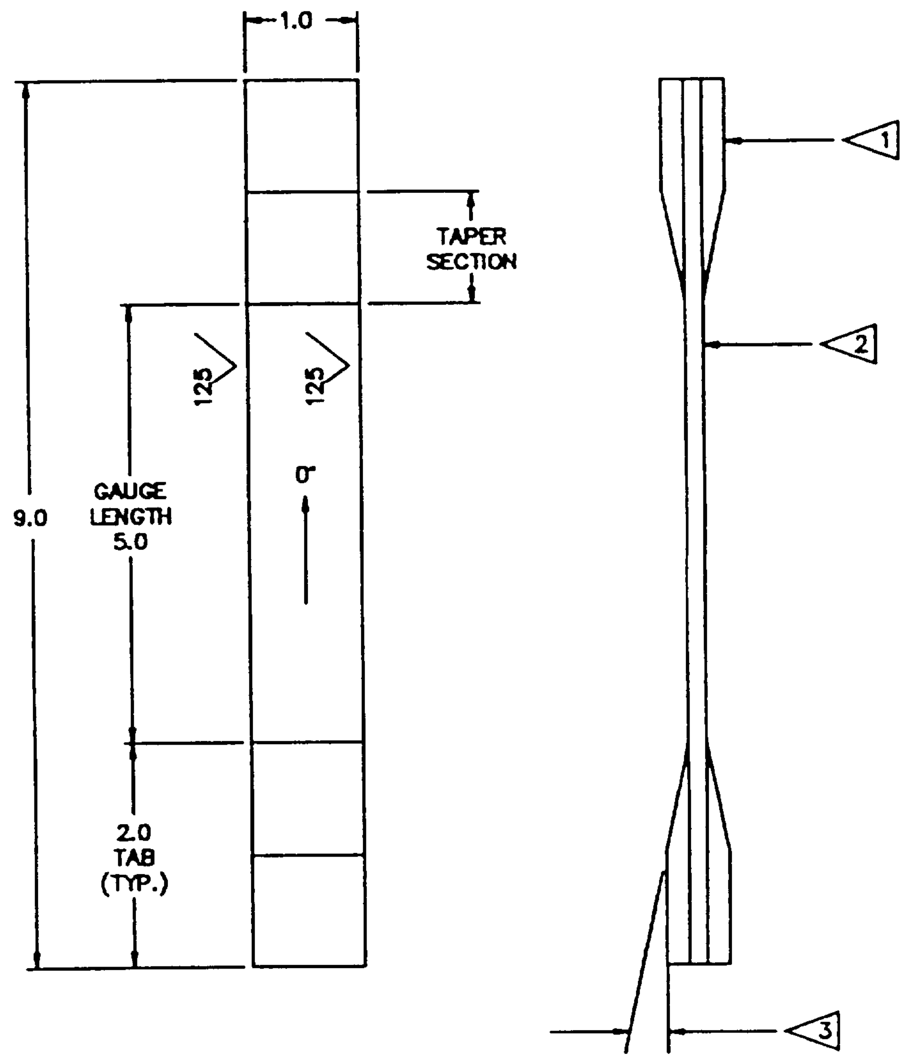
11.1.8 Specimen pre-test conditioning history.

11.1.9 Speed of testing (crosshead speed).

11.1.10 Plus or minus 45° laminate load-deformation curves, longitudinal and transverse.

11.1.11 Tabulate ±45° laminate load strain data; longitudinal load and strain and transverse strain.

11.1.12 Shear modulus; individual values, average value, standard deviation, and coefficient of variation.



NOTES:

1. BOND LAMINATE TABS ON TWO SIDES AND AT BOTH ENDS. TABS ARE APPLIED TO THE END OF THE TEST COMPOSITE WITH A SUITABLE ADHESIVE. TAB SHOULD HAVE A THICKNESS OF APPROXIMATLEY 1.5 TO 4 TIMES THE THICKNESS OF THE TEST COMPOSITE.
2. SPECIMEN THICKNESS IS DETERMINED BY 8 PILES OF PREPREG. VARIATION SHALL BE WITHIN ±2%.
3. 15° TYPICAL; 5° MINIMUM.
4. ALL DIMENSIONS IN INCHES.

INPLANE SHEAR TEST SPECIMEN

Figure 1. Inplane Shear Test Specimen

APPENDIX

X1. SAMPLE CALCULATION

X1.1 The following example is given to aid in the understanding of the method. Fig. X1 depicts a typical ±45° uniaxial tension stress-strain curve obtained for a carbon fiber-epoxy material. In Table X1, the results from seventeen points on the ±45° stress-strain curve are presented. The value of the longitudinal stress was calculated using the following equation.

$$S_x^l = \frac{P_x^l}{bd}$$

Where:

S_x^l = longitudinal stress in the ±45° tensile coupon, lbf.

P_x^l = load applied to the ±45° tensile coupon, lbf.

b = width, in.

d = thickness, in.

X1.2 Resulting values of τ_{12} and γ_{12} are presented in Table X2 and the shear stress-strain curve resulting from these data is shown in Fig. X2.

Table X1. Plus or Minus 45° Carbon Fiber/Epoxy Laminate Test Data

S_x	ϵ_x	ϵ_y
1000	0.0003	-0.00020
1900	0.0006	-0.00043
2800	0.0009	-0.00068
3700	0.0012	-0.00087
4500	0.0015	-0.00110
5400	0.0018	-0.00133
6250	0.0021	-0.00157
8700	0.0030	-0.00225
11100	0.0040	-0.00307
13300	0.0050	-0.00388
15050	0.0060	-0.00470
18000	0.0080	-0.00642
20300	0.0100	-0.00810
22350	0.0120	-0.00990
23750	0.0140	-0.01183
24800	0.0160	-0.01346
25520	0.0196	-0.01733

Table X2. Calculated Lamina Shear Stress-Strain Data

τ_{12}	γ_{12}
500	0.00050
950	0.00103
1400	0.00158
1850	0.00207
2275	0.00260
2700	0.00313
3125	0.00367
4350	0.00525
5550	0.00707
6650	0.00888
7525	0.0107
9000	0.0144
10150	0.0181
11175	0.0219
11875	0.0258
12400	0.0295
12760	0.03693

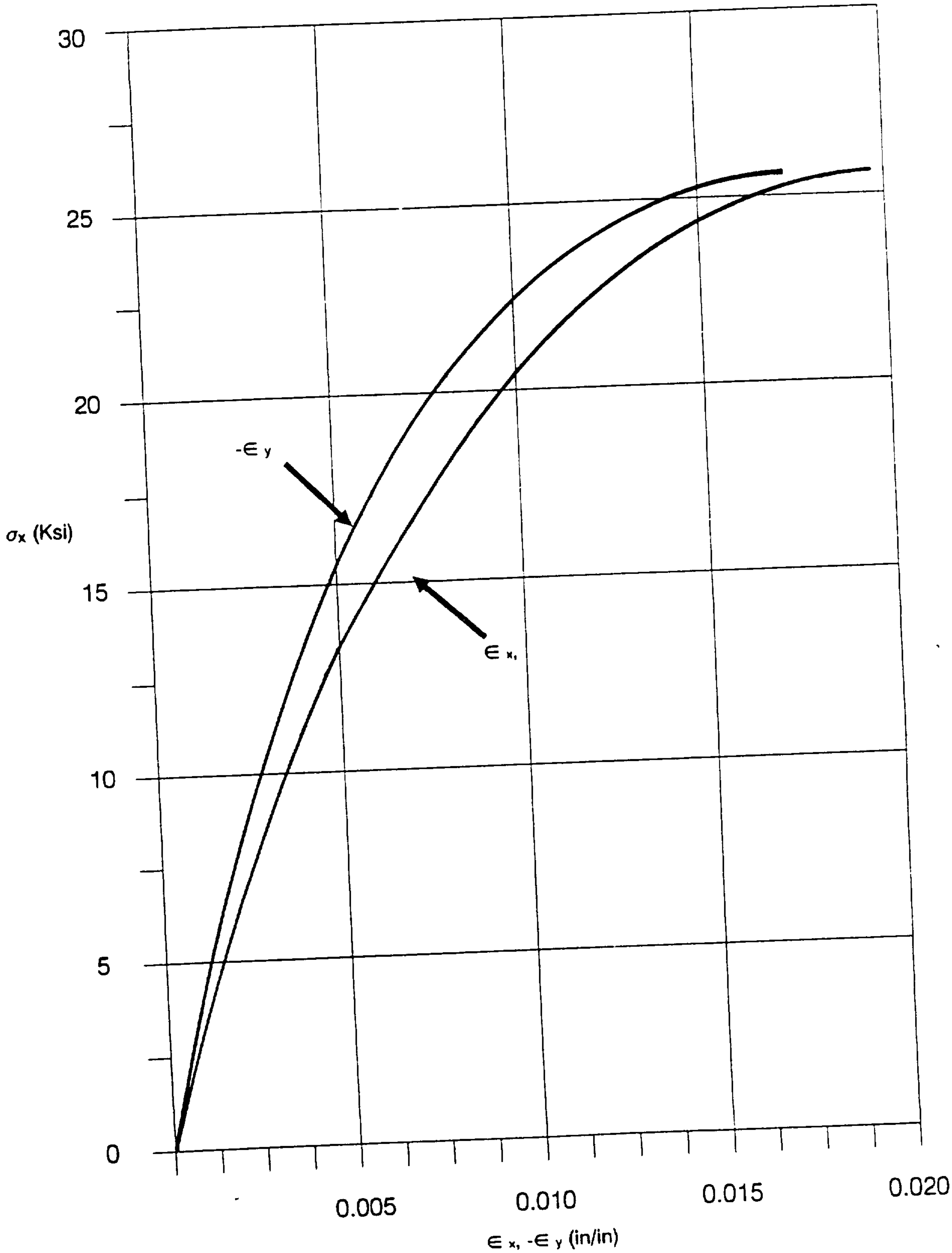


Figure X1. Plus or Minus 45° Carbon Fiber/Resin Laminate Stress-Strain Curve

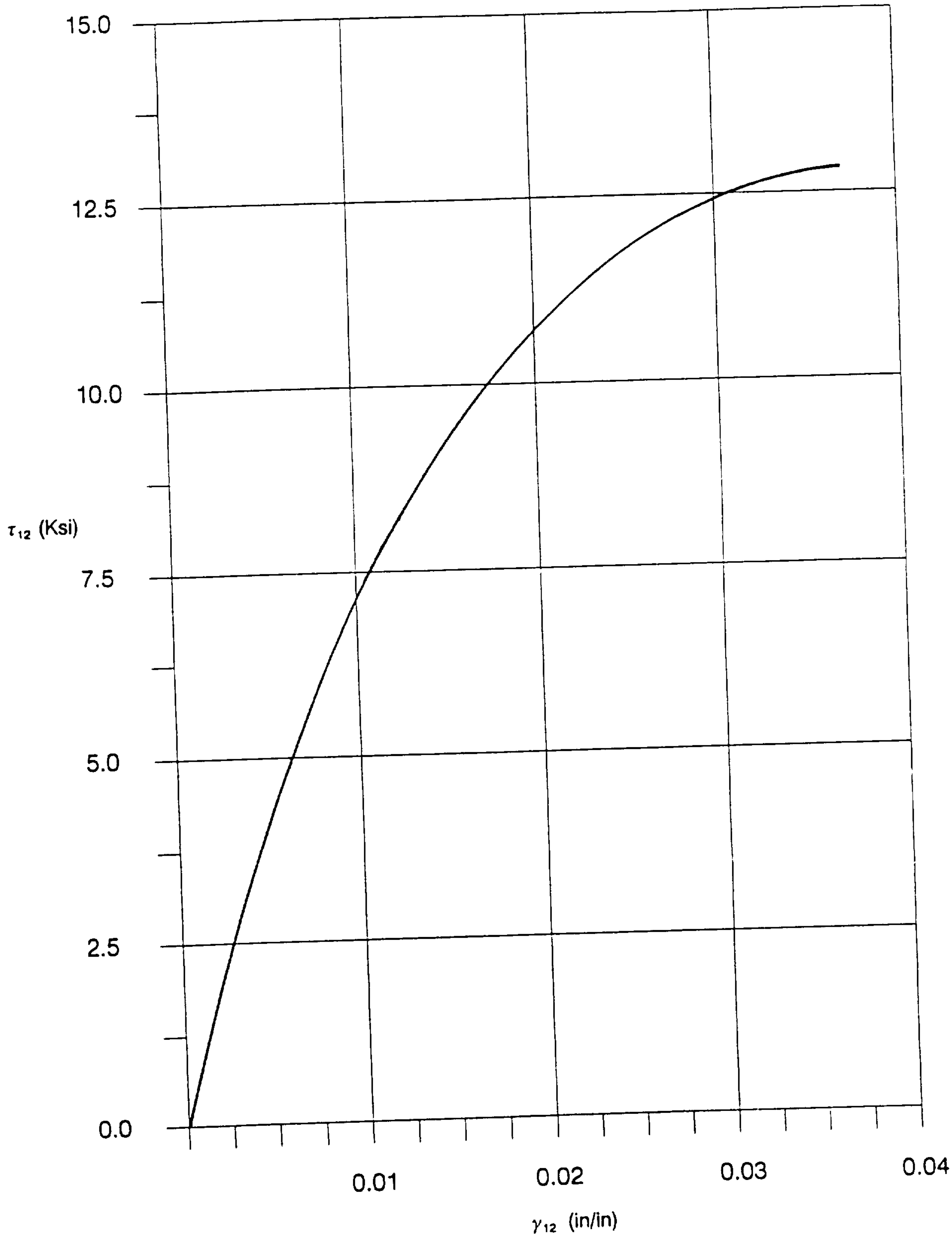


Figure X2. Carbon Fiber/Epoxy Shear Stress-Strain Curve

IOSIPESCU SHEAR TEST PROCEDURES

A.1. Test Fixture

The University of Wyoming's current version of the Iosipescu shear test fixture was designed to test flat specimens nominally 7.62 cm (3 in) long, 1.91 cm (0.75 in) wide, and up to 1.27 cm (0.5 in) thick. The test fixture is shown in Figures A1 and A2. This test fixture is used in a testing machine set up in a compression loading mode. The fixture can be inserted between two flat compression platens. However, it is usually more convenient to attach the right fixture half to the upper testing machine load surface using the center hole provided in the fixture. An example adaptor for this purpose is also shown in Figure A1. This fixture has been loaded to 22 kN (5000 lbs) applied force without damage to the fixture.

The right (movable) fixture half moves on a linear ball bushing and a hardened steel post as shown on Figure A2. The fit of the linear ball bushing on the post may be adjusted via the set screw marked in Figure A2. Caution must be taken to not overtighten this set screw, however. Overtightening will result in binding of the linear ball bushing on the post and possible damage to the ball bushing.

A specimen alignment tool has been incorporated into the test fixture as shown in Figure A3. When preparing to adjust the clamping wedges, the alignment tool is lifted to index on the lower notch of the test specimen.

Machine drawings of this test fixture are included as Figures A4 through 10. All parts are fabricated from low carbon cold rolled steel with the exception of the linear bushing and post. These items are manufactured by Thompson Industries, Manhasset, New York, and may be purchased from any of their distributors.

The Iosipescu shear fixture, as shown in Figure A1, was designed to test specimens nominally 1.91 cm (0.75 in) wide. The wedge clamp blocks allow approximately 1 mm (0.04 in) variation on that height. Only light clamping is required, to ensure that no specimen rotation takes place within the fixture during a test. Narrower specimens may be tested by using thicker wedges, changing the height dimension of the wedge in Figure A5.

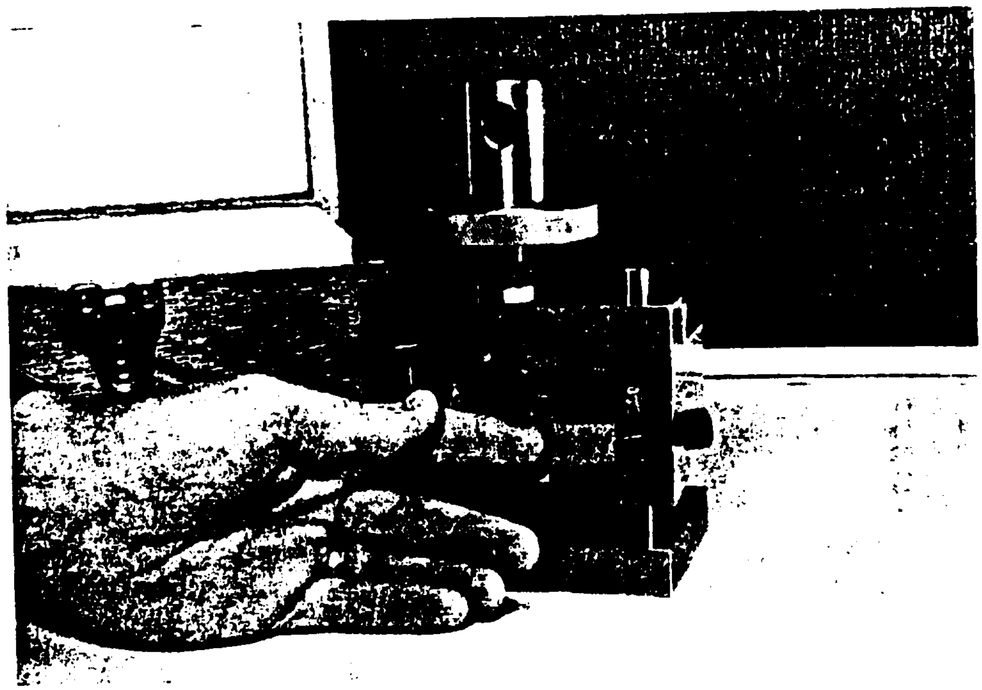


Figure A3. Alignment Tool Used During Specimen Installation.

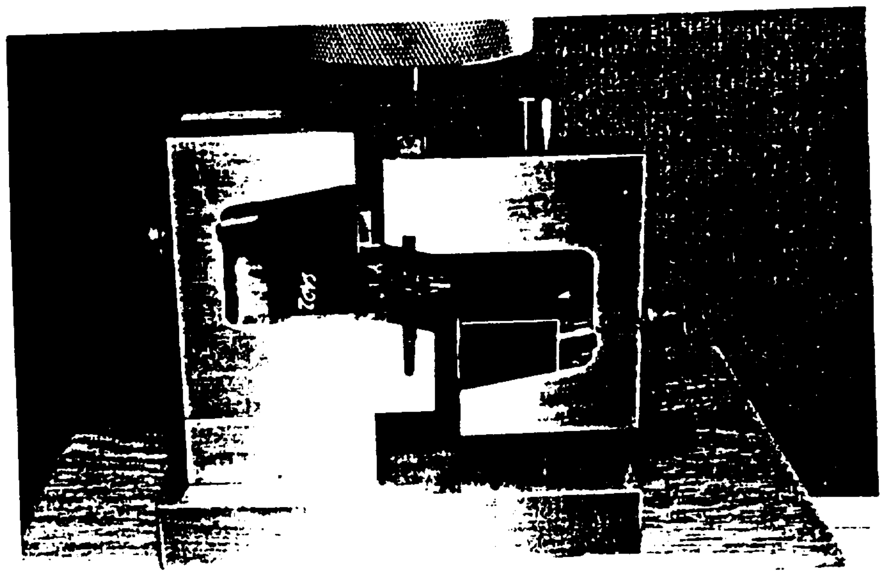


Figure A1. Iosipescu Shear Test Fixture, Front View.

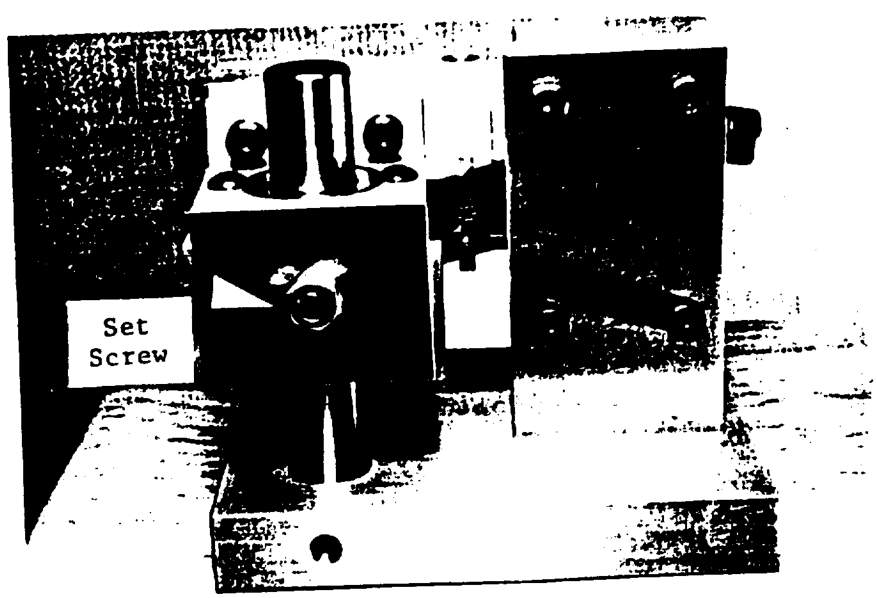


Figure A2. Iosipescu Shear Test Fixture, Rear View.

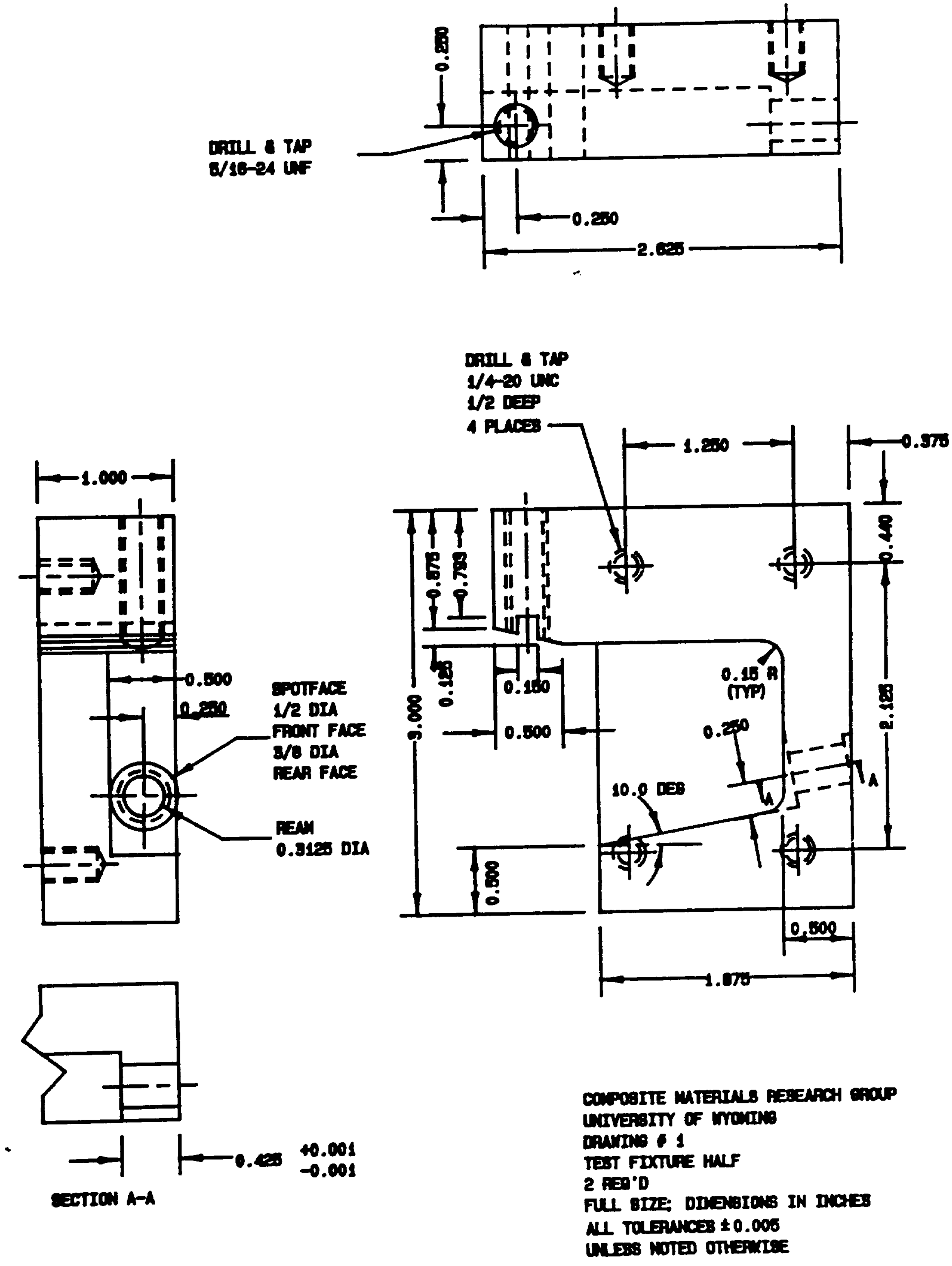


Figure A4. Iosipescu Shear Test Fixture Half.

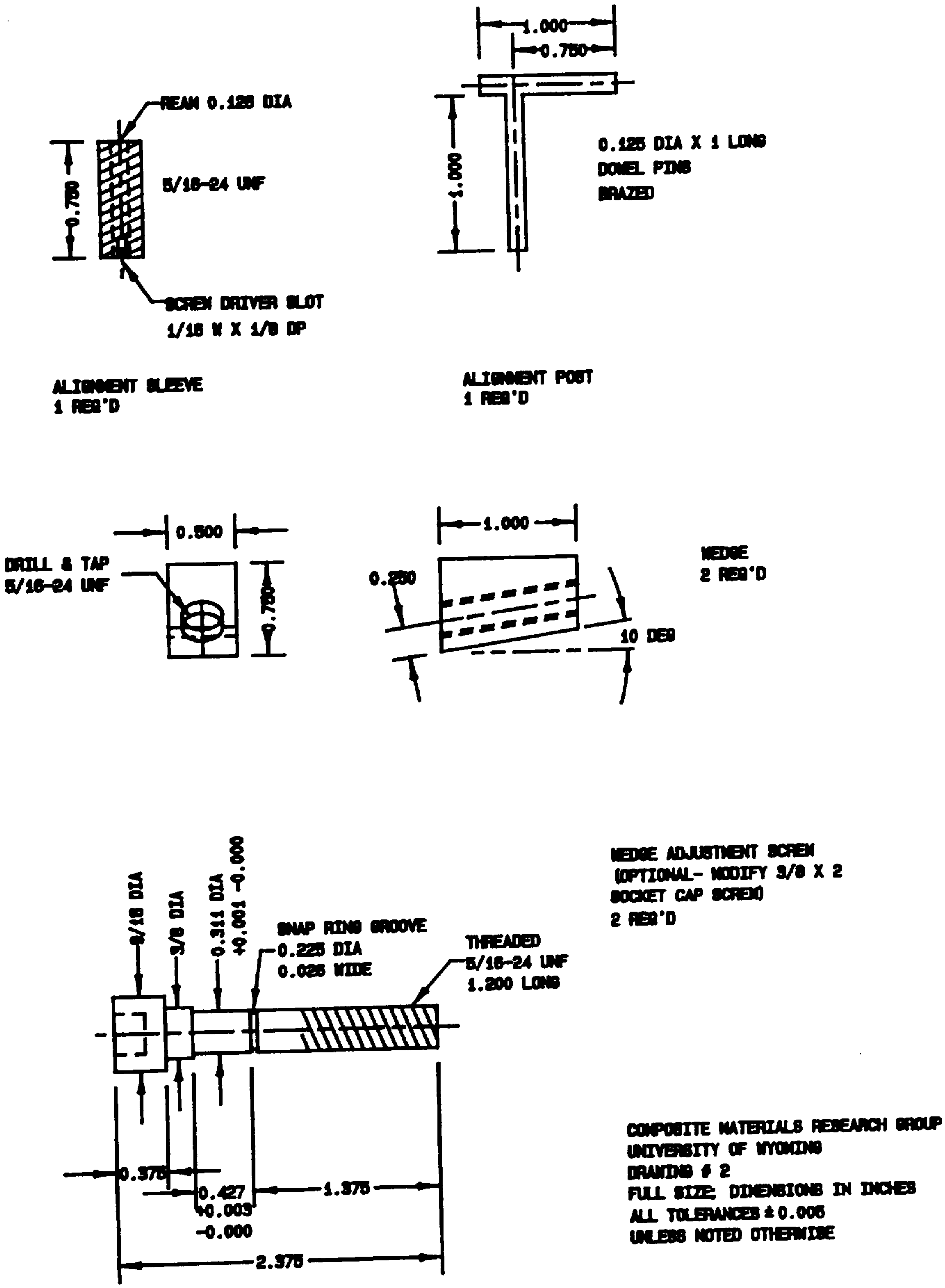


Figure A5. Iosipescu Shear Test Fixture Alignment Tool Assembly and Clamp Assembly.

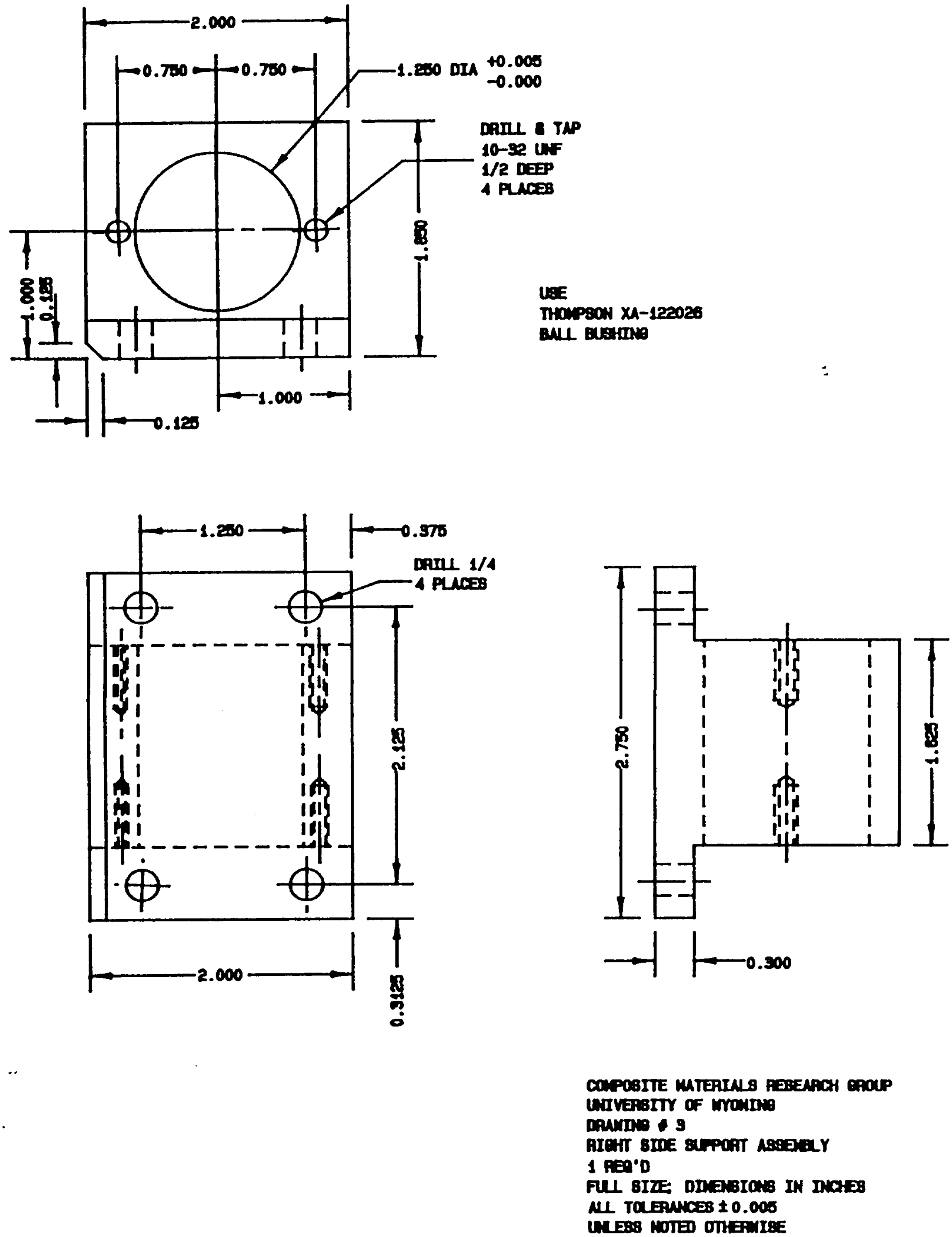
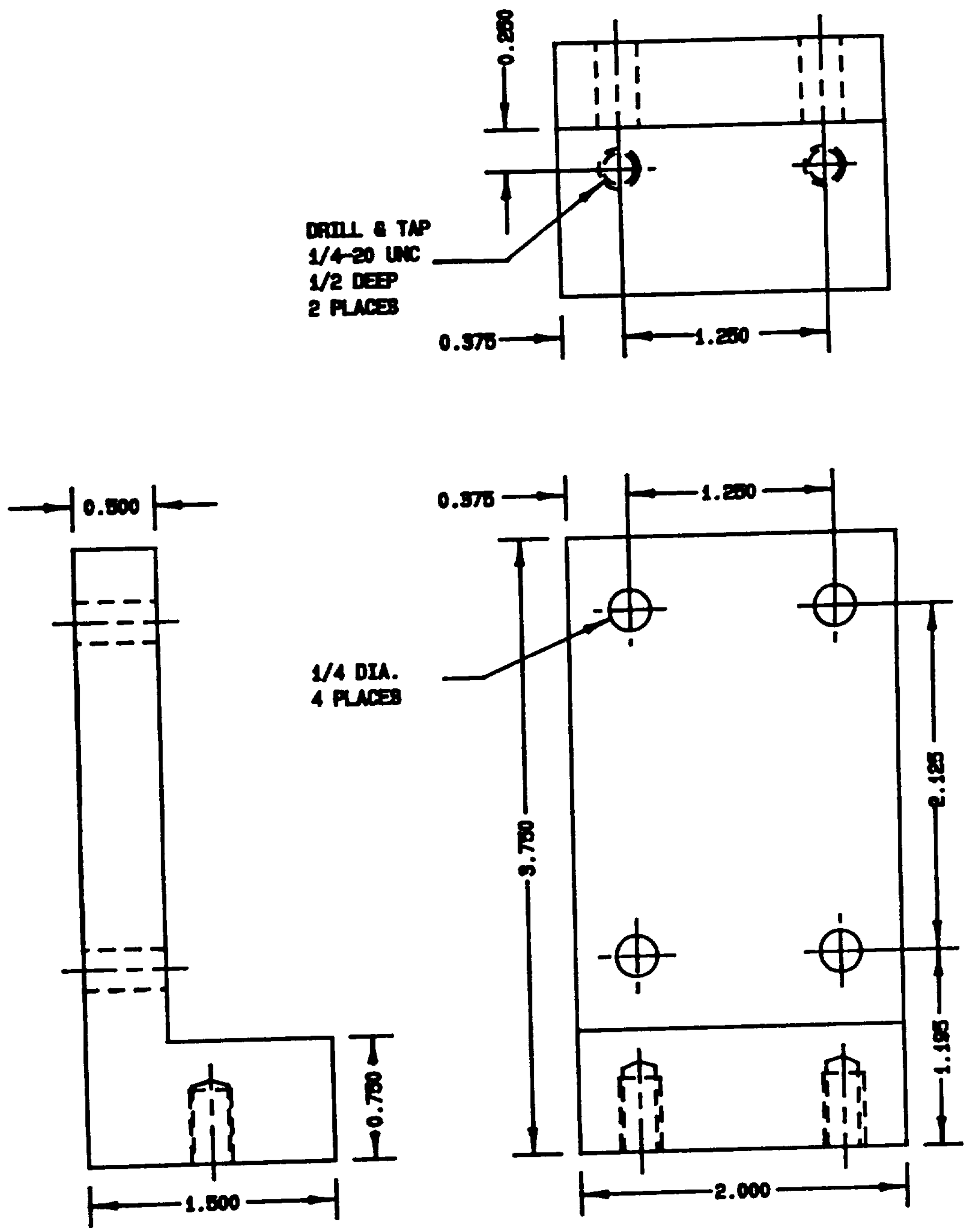


Figure A6. Iosipescu Shear Test Fixture Bushing Mounting Assembly.



COMPOSITE MATERIALS RESEARCH GROUP
UNIVERSITY OF WYOMING
DRAWING # 4
LEFT SIDE SUPPORT
1 REQ'D
FULL SIZE: DIMENSIONS IN INCHES
ALL TOLERANCES ± 0.005
UNLESS NOTED OTHERWISE

Figure A7. Iosipescu Shear Test Fixture Fixed Half Mounting Bracket.

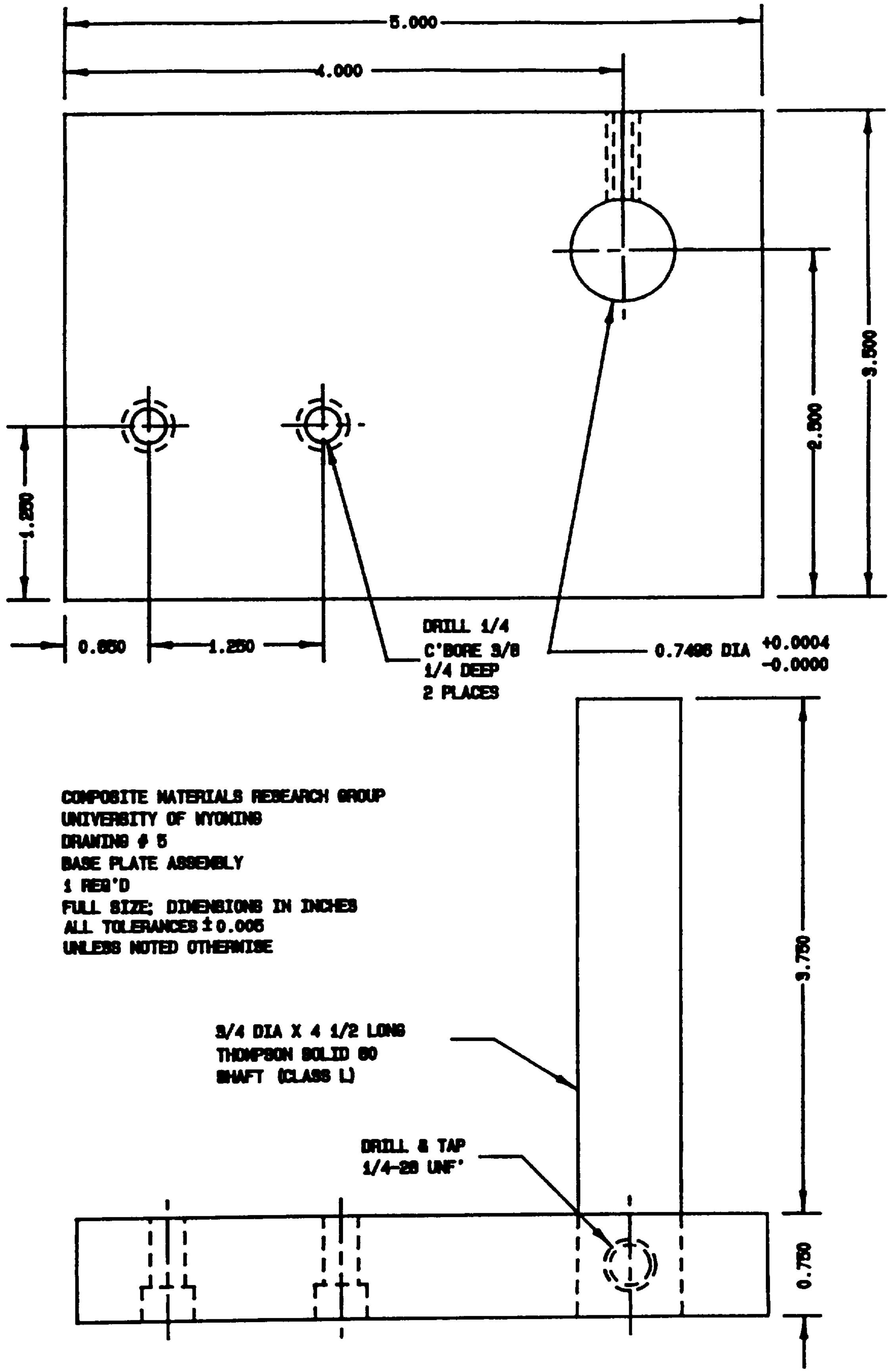


Figure A8. Iosipescu Shear Test Fixture Base and Post Assembly.

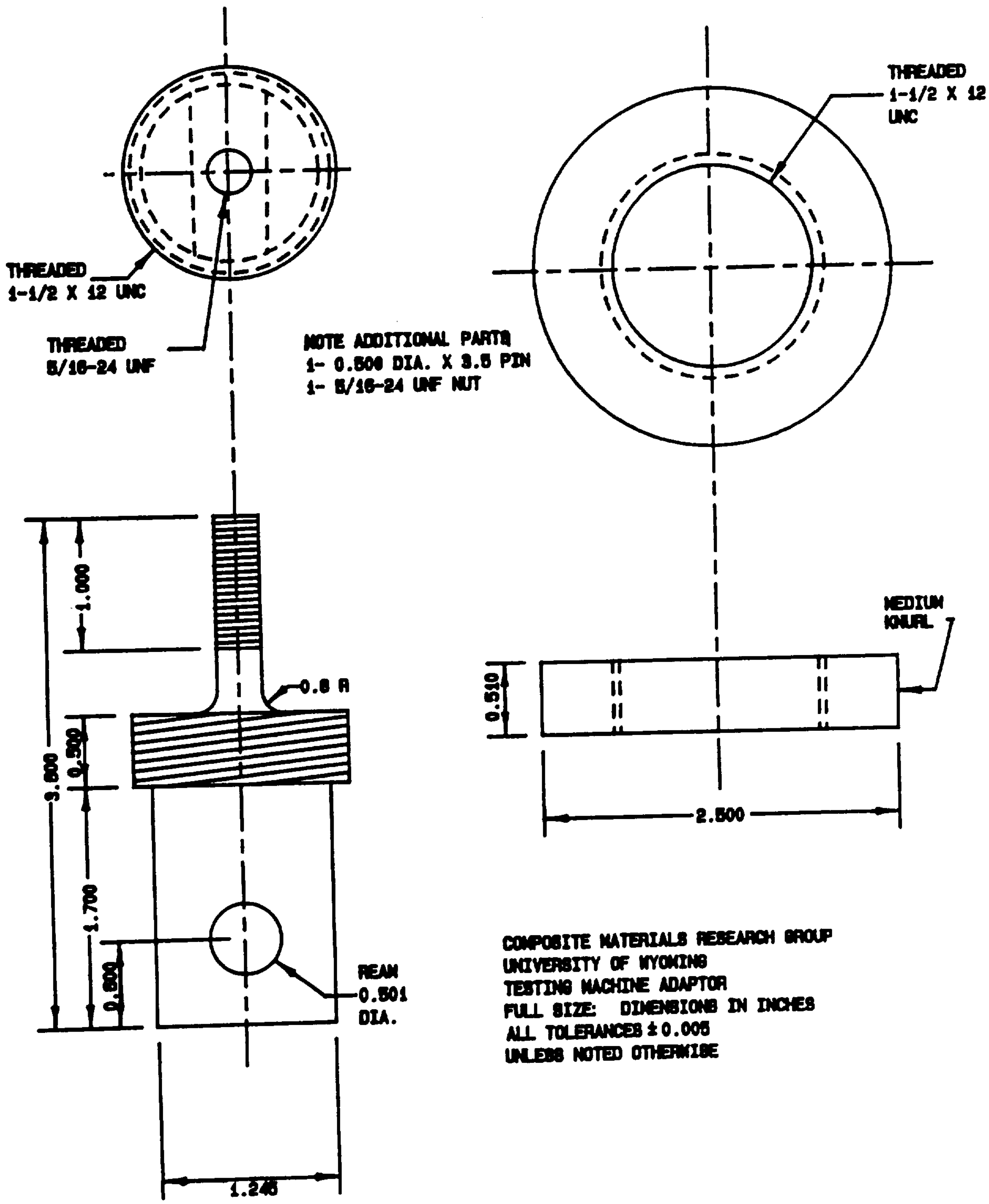


Figure A9. Iosipescu Shear Fixture Loading Adaptor.

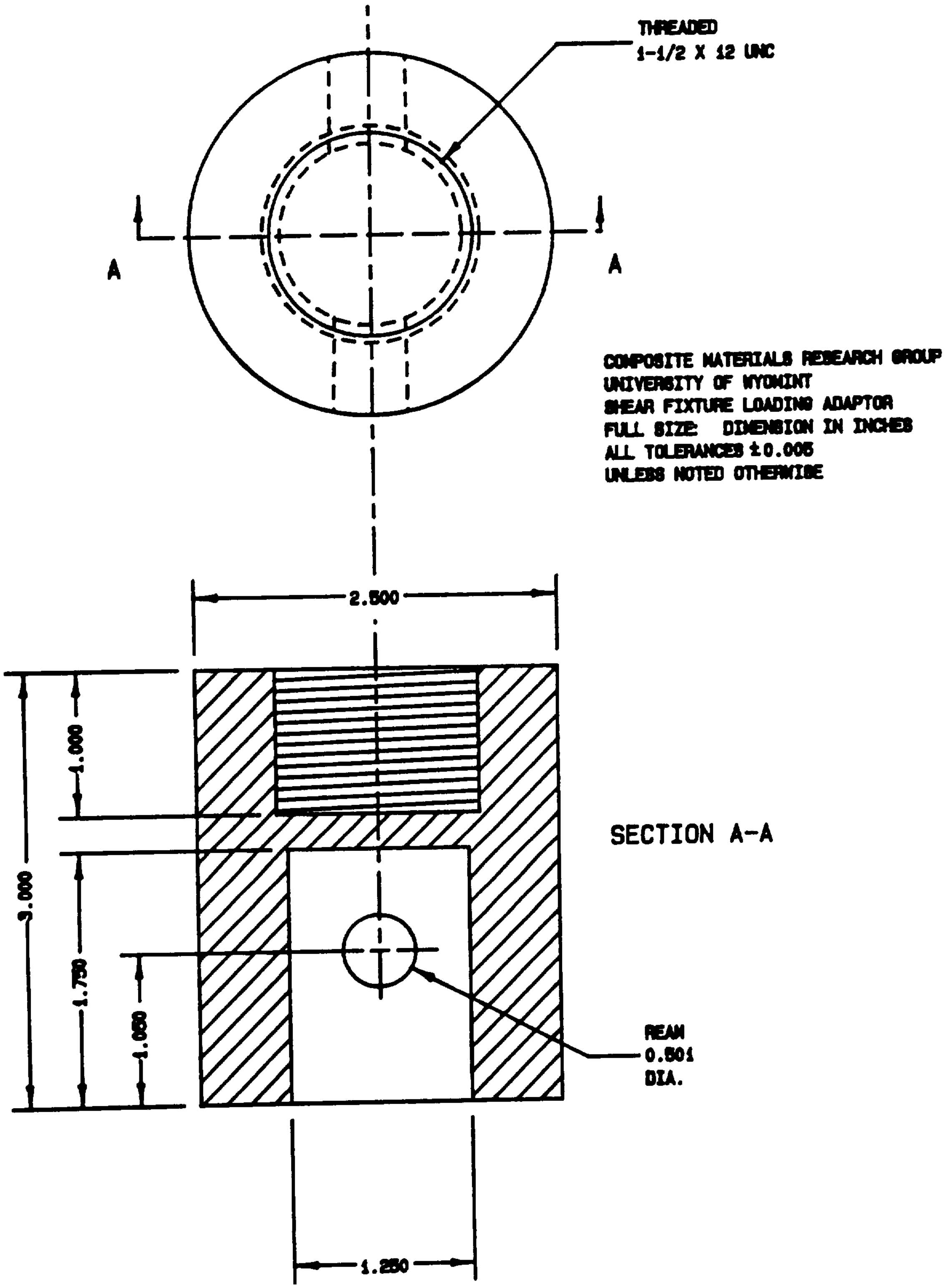


Figure A10. Iosipescu Shear Fixture Testing Machine Adaptor.

A.2. <u>Test Specimen Fabrication</u>

Iosipescu shear specimens for use with the present test fixture should nominally be 7.62 cm (3 in) long, 1.91 cm (0.75 in) and of any thickness up to 1.27 cm (0.5 in) thick, as shown in Figure A11. Very thin specimens may be tested, but care must be taken to ensure that compressive buckling does not occur. These specimens can be stiffened (away from the test region) by bonding tabs or backup plates to the front and back faces of the specimen.

Composite specimens are typically cut at the University of Wyoming with diamond abrasive tooling; metal specimens are normally prepared using conventional metal-working tools. Notches are ground in the composite specimens using a 60-grit abrasive wheel in a standard surface or tool grinder. This wheel is dressed to grind the prescribed notch angle and root radius shown in Figure A11. Care must be taken to avoid delaminating specimens during notch grinding. Stacking and clamping specimens in the tool grinder vise have been found to be effective. The specimens provide mutual edge support to each other during notch grinding. Notches are usually cut in metal specimens with a 90° angle milling cutter, with the desired notch root radius ground onto the cutter.

Shear tests may be performed with the Iosipescu shear test fixture in any of the six material shear planes. It is conventional to define a material coordinate system where the 1-coordinate is parallel to the principal in-plane material direction, the 2-coordinate is the second in-plane axis, and the 3-coordinate is perpendicular to the plane of the plate. The shear stress is then defined as being applied in the plane perpendicular to the first coordinate axis, in the direction parallel to the second coordinate axis. Therefore 12 and 21 are the in-plane shear components, while the interlaminar shear components are denoted 13, 31, 23, and 32. Specimens to impose any one of these four interlaminar shear components can be fabricated from a thin composite laminate by stacking and bonding sufficient layers of the composite to obtain the desired specimen as indicated in Figure A12. An in-plane 12 or 21 specimen is simply cut from a material plate, as also shown in Figure A12. The specimen type depicted in Figure A12b can be very fragile, potentially producing poor results for brittle material systems. The specimen type

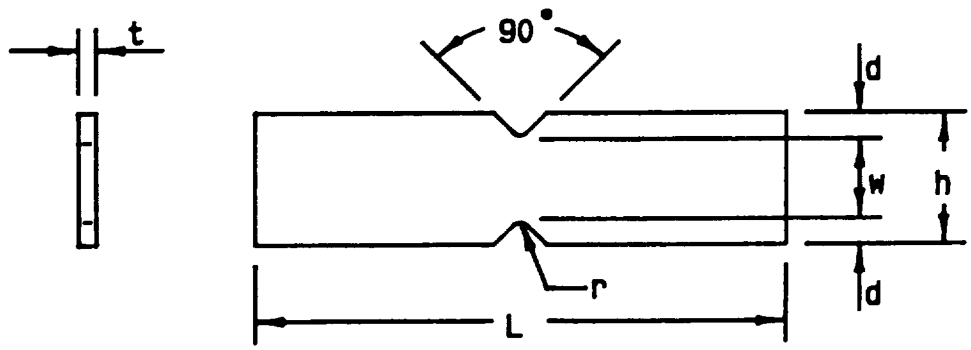


Figure A11. Iosipescu Shear Test Specimen.

t = 12.7 mm (0.5 in) maximum
h = 19.1 mm (0.75 in)
d = 4.3 mm (0.17 in)
L = 76 mm (3 in)
r = 1.3 mm (0.05 in) minimum

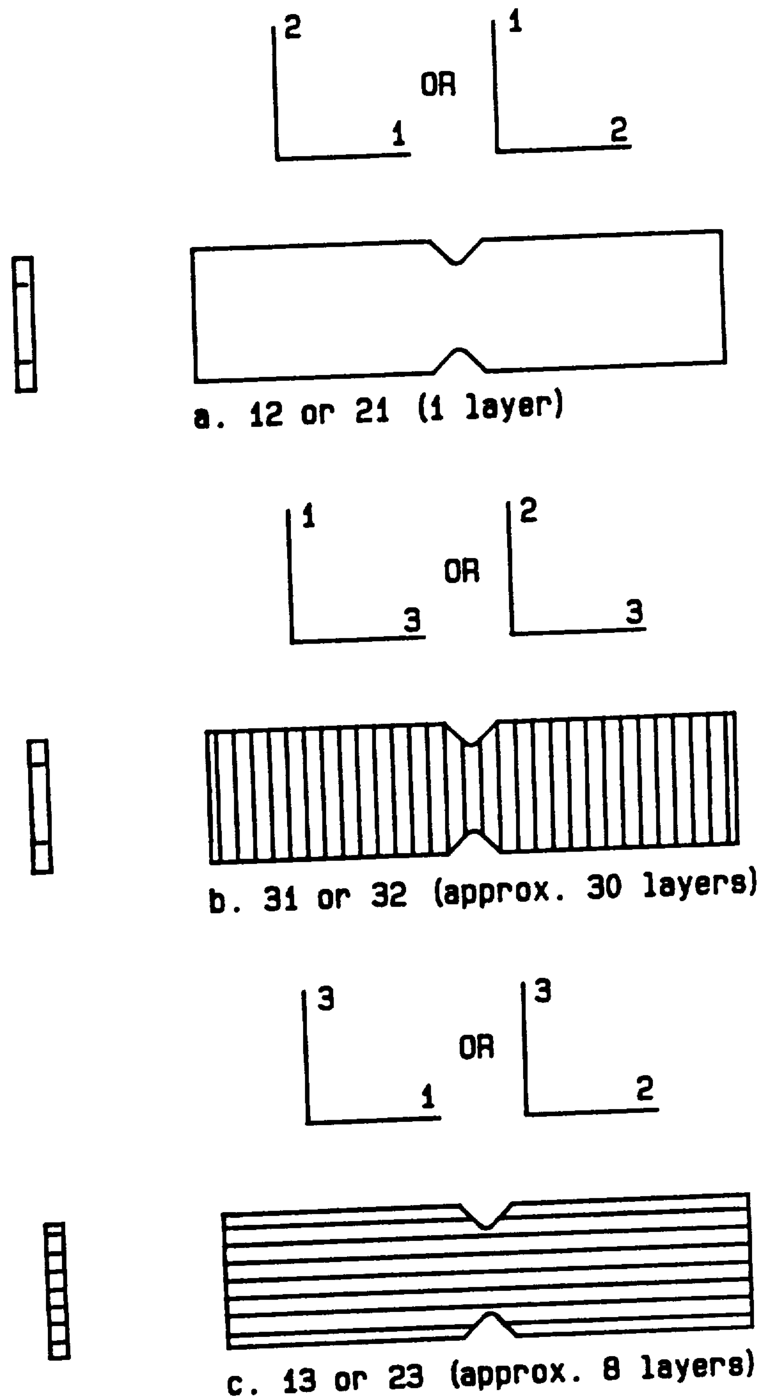


Figure A12. Possible Iosipescu Shear Test Specimen Configurations.

of Figure A12c is then preferred. As previously noted, narrower specimens may be tested if different clamping wedges are used.

A.3 Shear Instrumentation

To measure shear strains, specimens may be instrumented with a strain gage rosette incorporating two strain gages oriented at ±45°, as indicated in Figure A13. The specific strain gage rosette shown in Figure A13 consists of two 350-ohm strain gages, Micro Measurements Number EA06-062TV-350. The gages may be wired as individual channels in quarter bridge circuits, or as a single channel in a half bridge configuration. This particular strain gage rosette has a maximum shear strain range of approximately 6 percent. It is recommended that two-element strain gage rosettes be used rather than a single strain gage oriented at either +45° or -45°.

A.4 Test Procedures

The specimen is centered in the test fixture using the lift-up alignment tool to index on the lower specimen notch. The wedge clamps can then be tightened to hold the specimen firmly in place. These clamps need only be tightened "finger tight". The purpose of the wedges is to prevent the specimen from rotating during a test. Excessive tightening oft hew edge clamps is not necessary or desirable. A wrench is not required to tighten the wedges.

Tests may be performed at any desired loading rate. A convenient quasi-static rate is 2 mm/min (0.08 in/min). Cyclic loading may also be conducted, making appropriate provisions for attaching the fixture base in the test machine, if necessary.

Shear stress is calculated by dividing the applied load P by the specimen cross-sectional area between the notch tips, (see Figure A1), i.e.,

$$\tau = \frac{P}{wt}$$

Ultimate shear strength is not necessary calculated from the maximum force attained during loading. During and after actual shear failure, the reinforcing fibers in a composite material may reorient, subsequently bearing some portion of the applied force in a tensile

Figure A13. Iosipescu Shear Test Specimen Instrumented with a Strain Gage Rosette.

mode. This reorientation is more likely to occur in composites with matrix materials which are very nonlinear in shear. The point at which this happens can usually be determined from a load (stress) versus displacement plot. The point at which the stress-displacement plot abruptly changes slope is the point at which shear failure occurred. Test results must thus be carefully examined.