APPENDIX G

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.

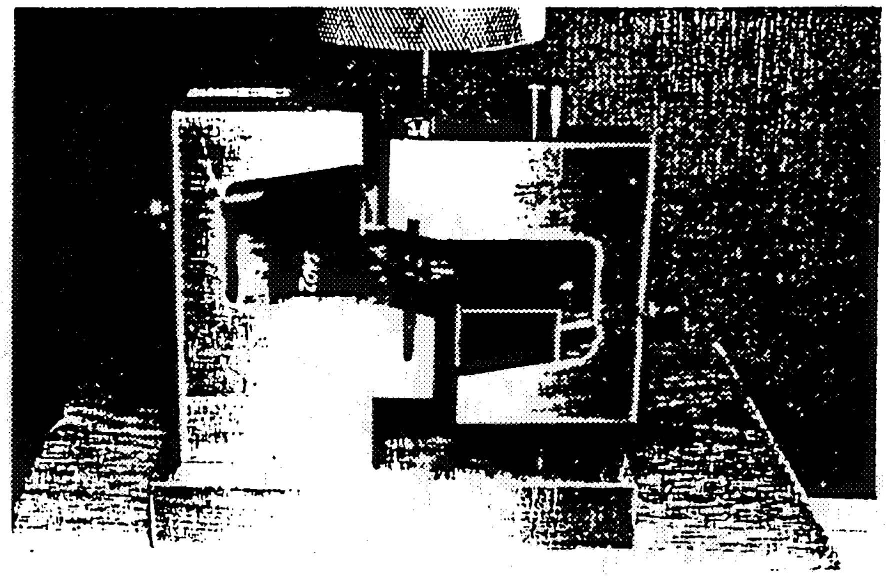

Figure A1. Iosipescu Shear Test Fixture, Front View.

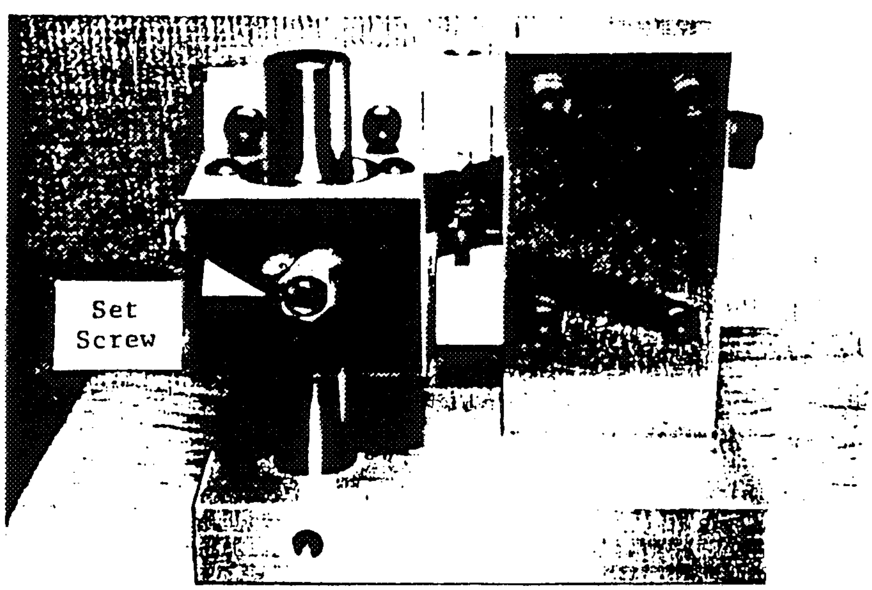

Figure A2. Iosipescu Shear Test Fixture, Rear View.

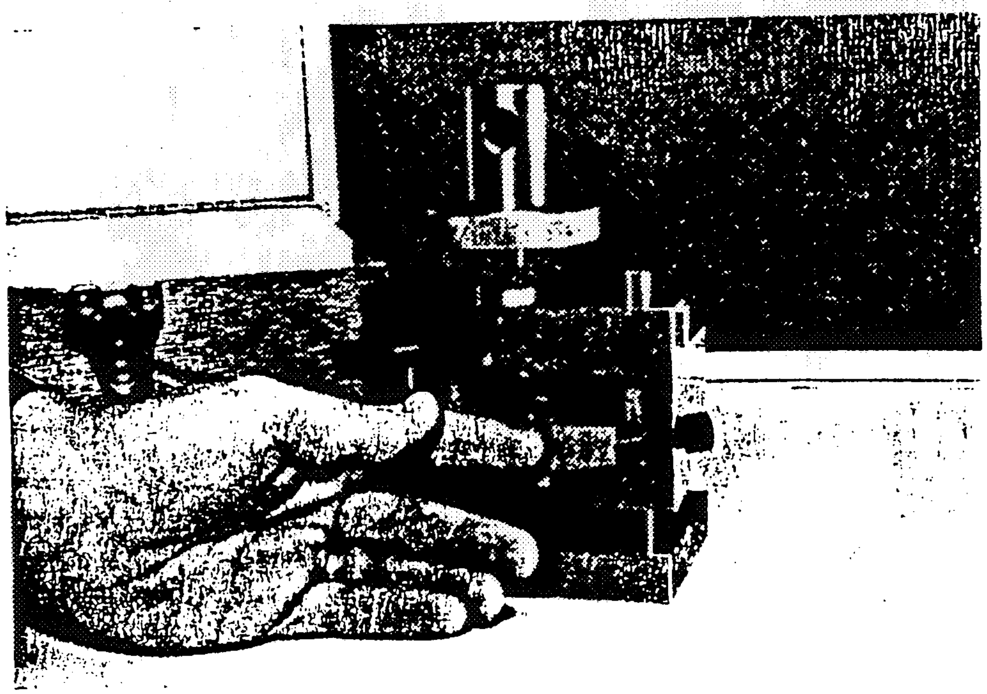

Figure A3. Alignment Tool Used During Specimen Installation.

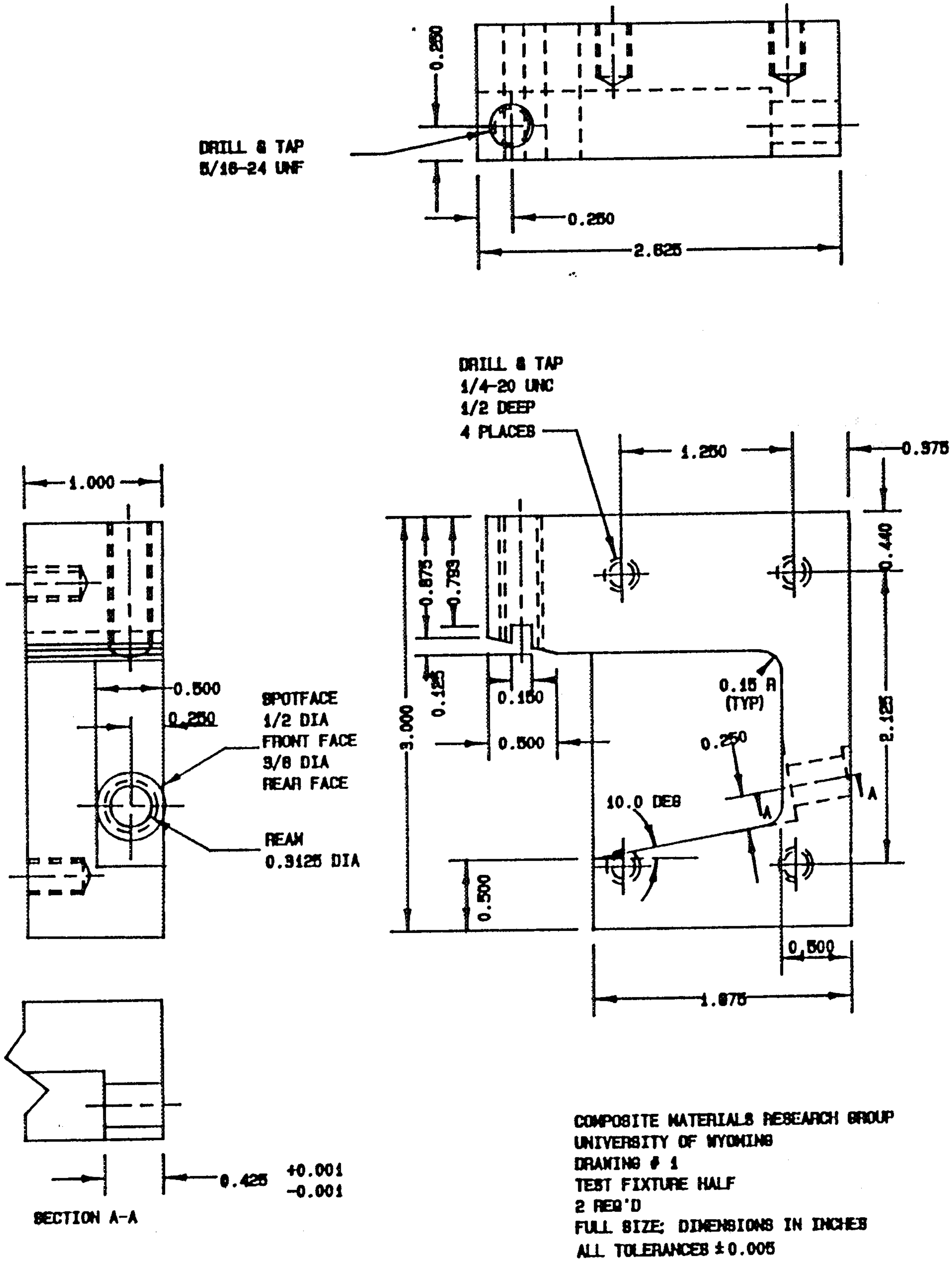

Figure A4. Iosipescu Shear Test Fixture Half.

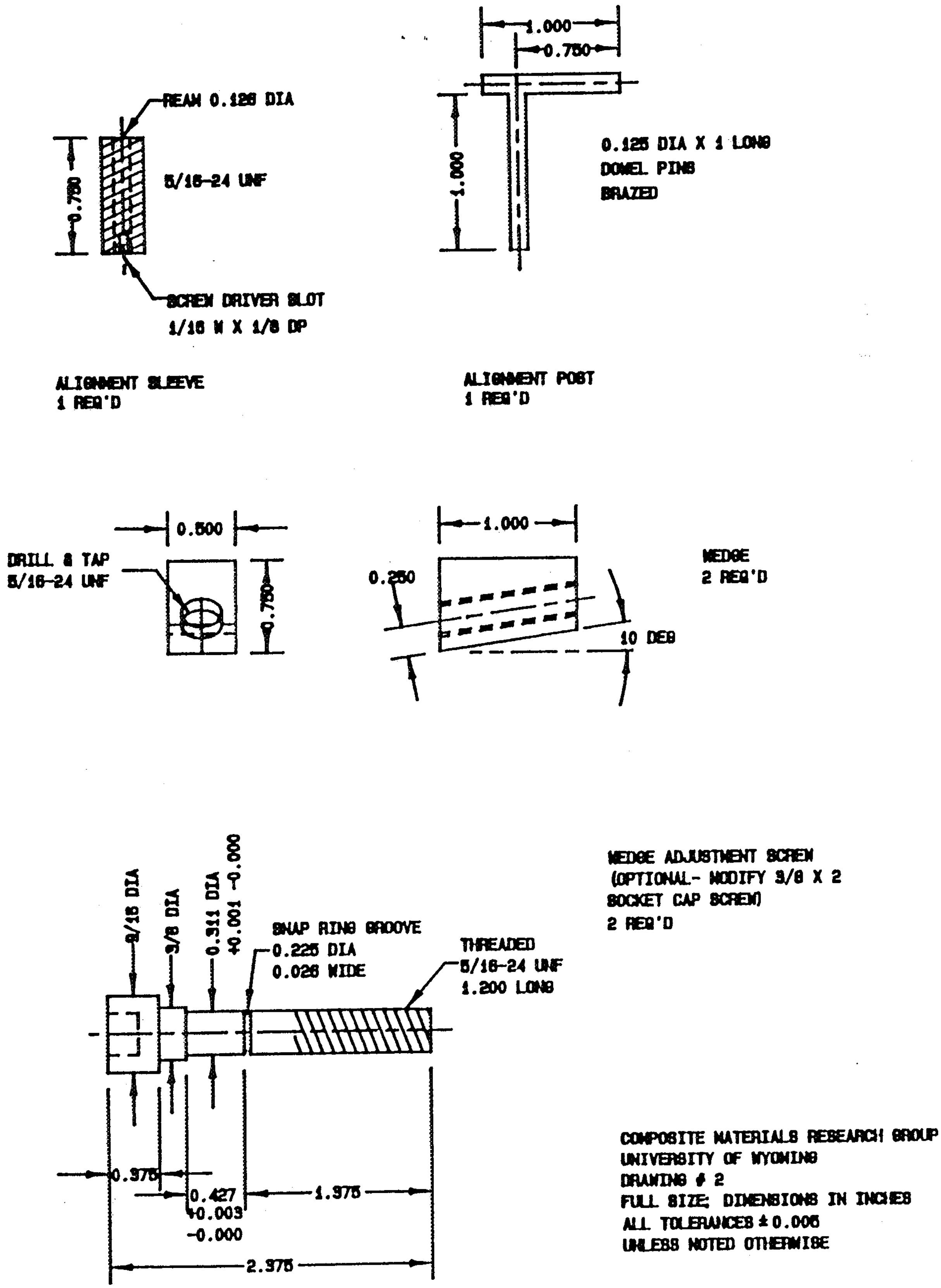

Figure A5. Iosipescu Shear Test Fixture Alignment Tool Assembly and Clamp Assembly.

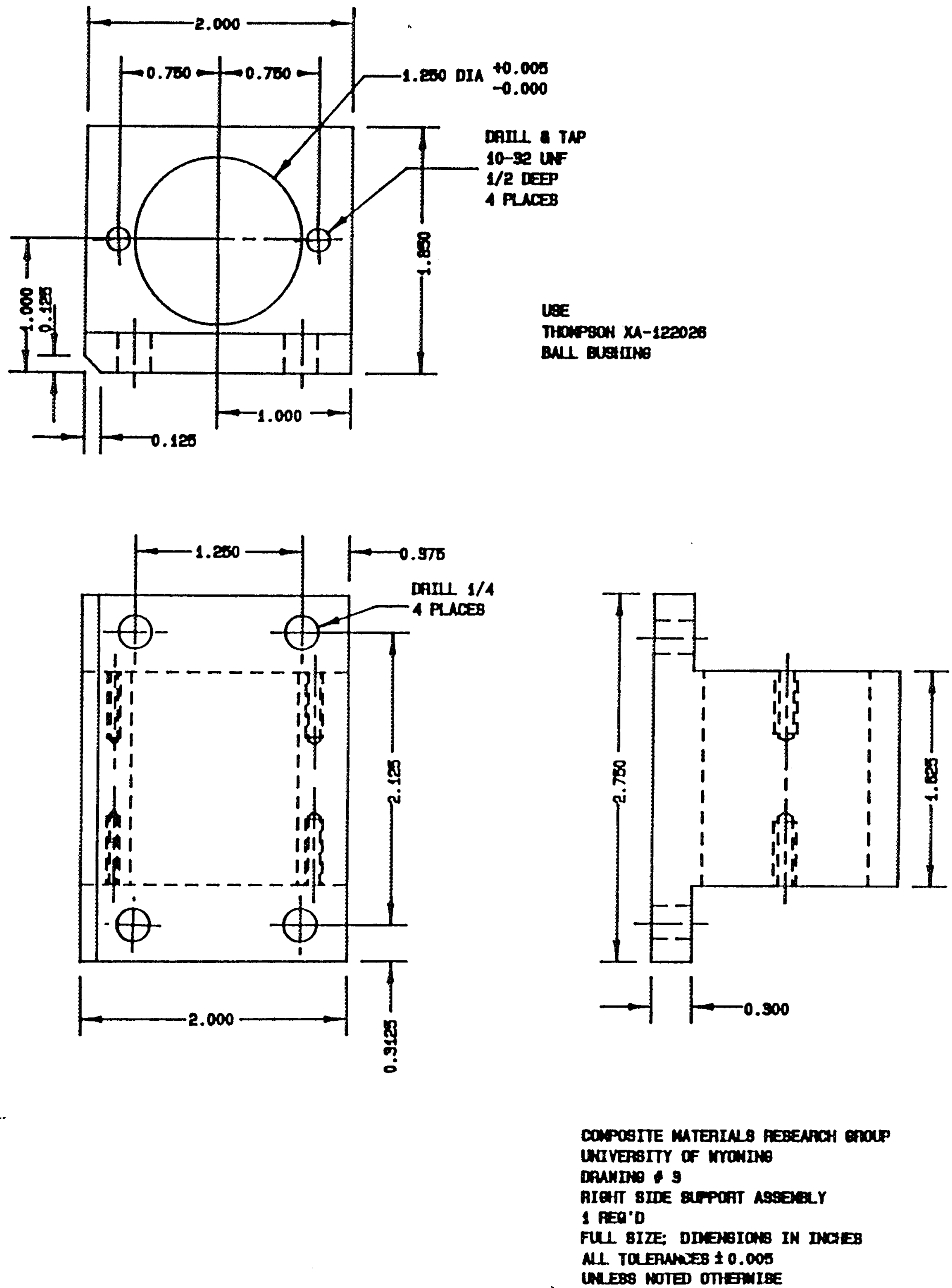

Figure A6. Iosipescu Shear Test Fixture Bushing Mounting Assembly.

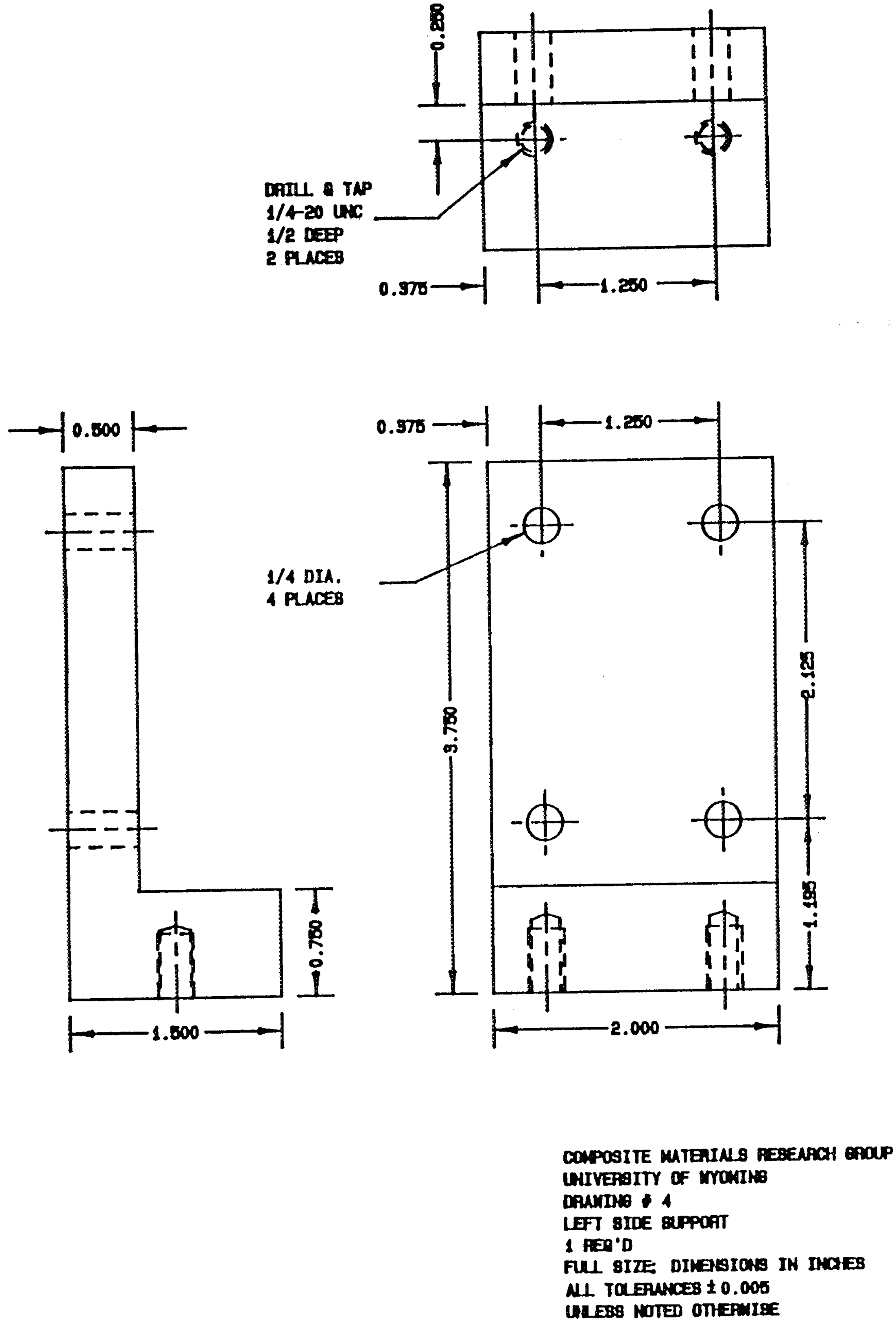

Figure A7. Iosipescu Shear Test Fixture Fixed Half Mounting Bracket.

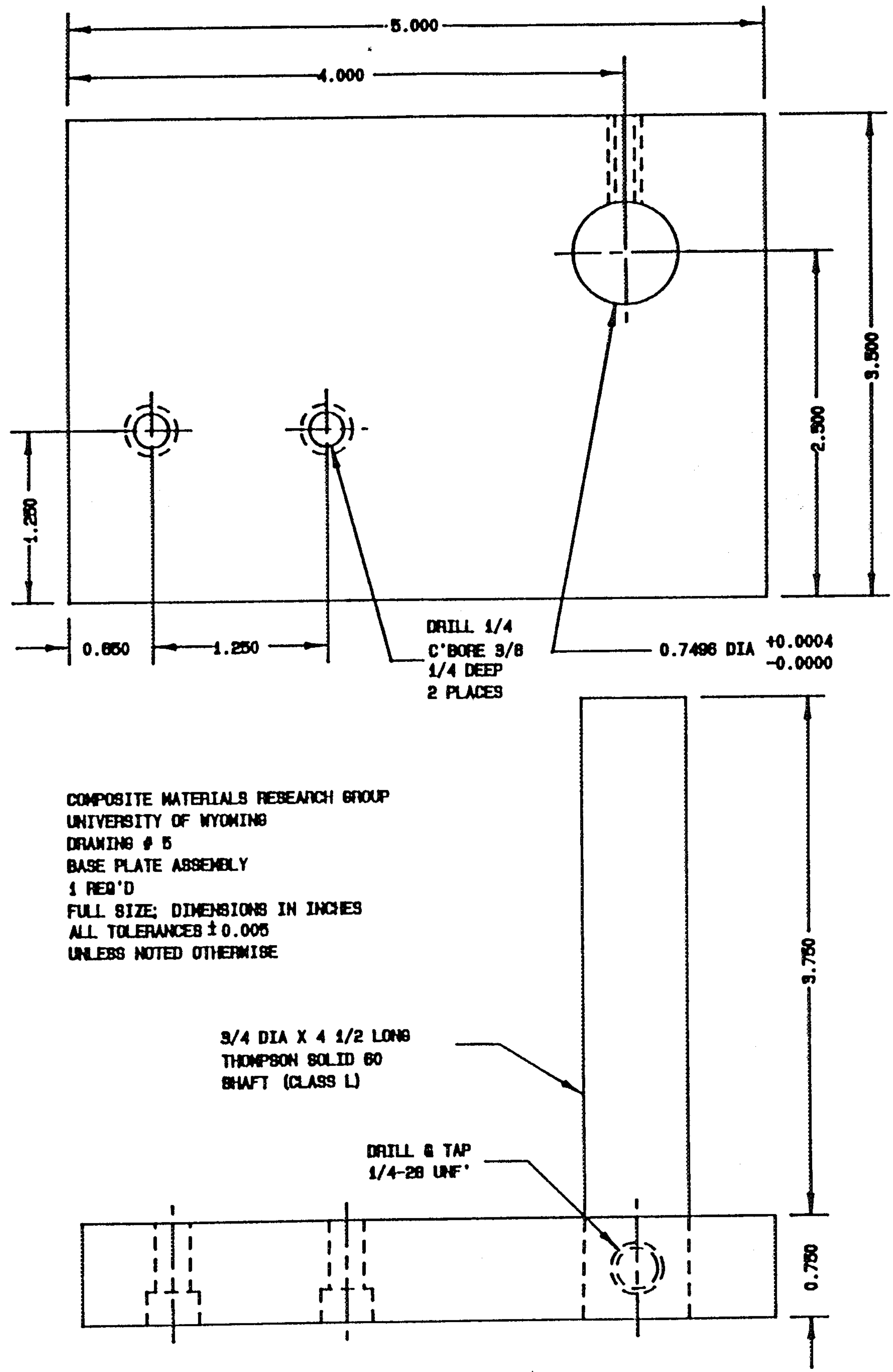

Figure A8. Iosipescu Shear Test Fixture Base and Post Assembly.

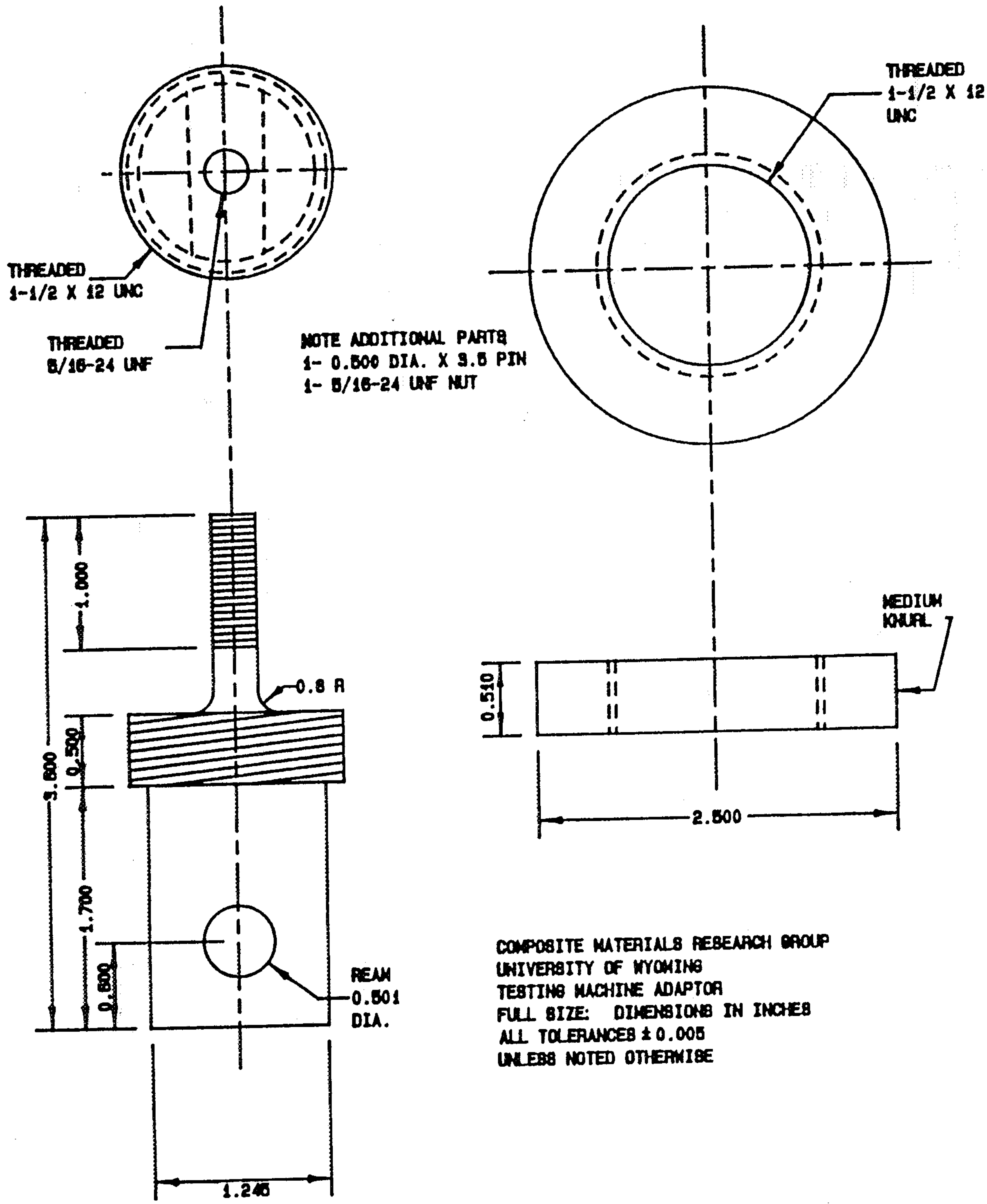

Figure A9. Iosipescu Shear Fixture Loading Adaptor.

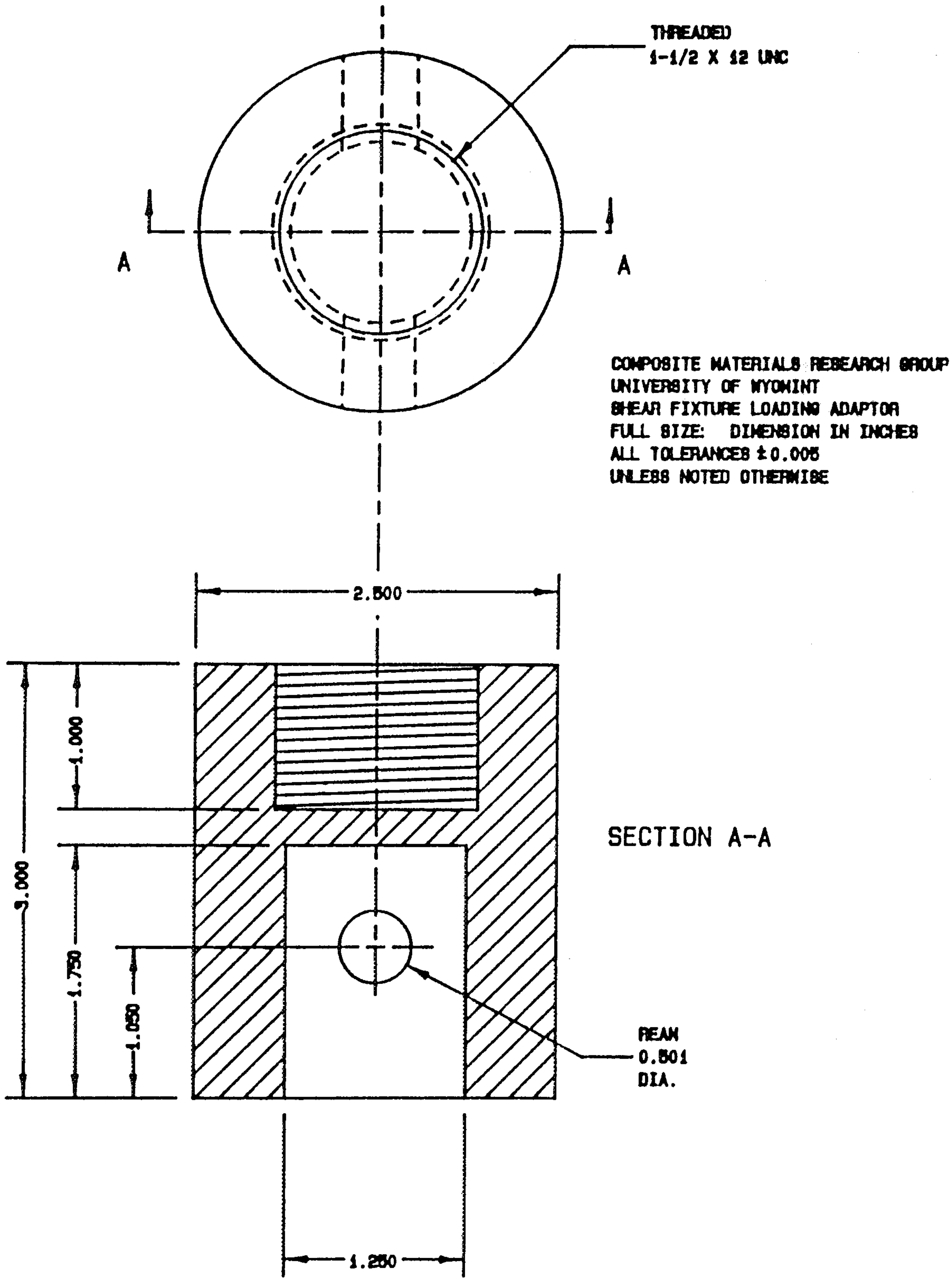

Figure A10. Iosipescu Shear Fixture Testing Machine Adaptor.

A.2. Test Specimen Fabrication

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

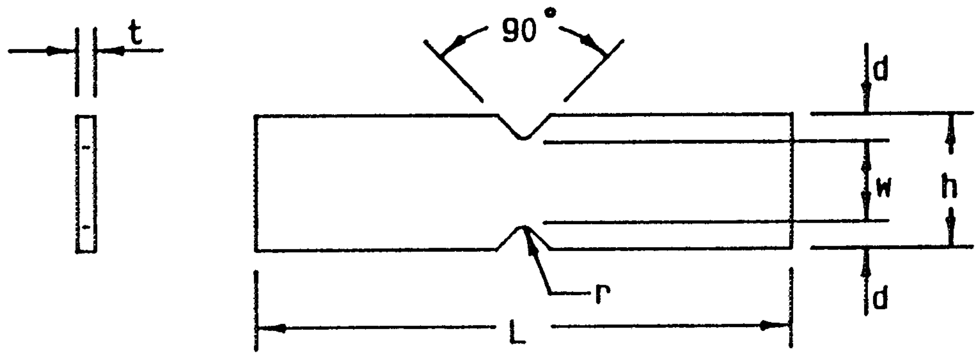

Figure A11. Iosipescu Shear Test Specimen.

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

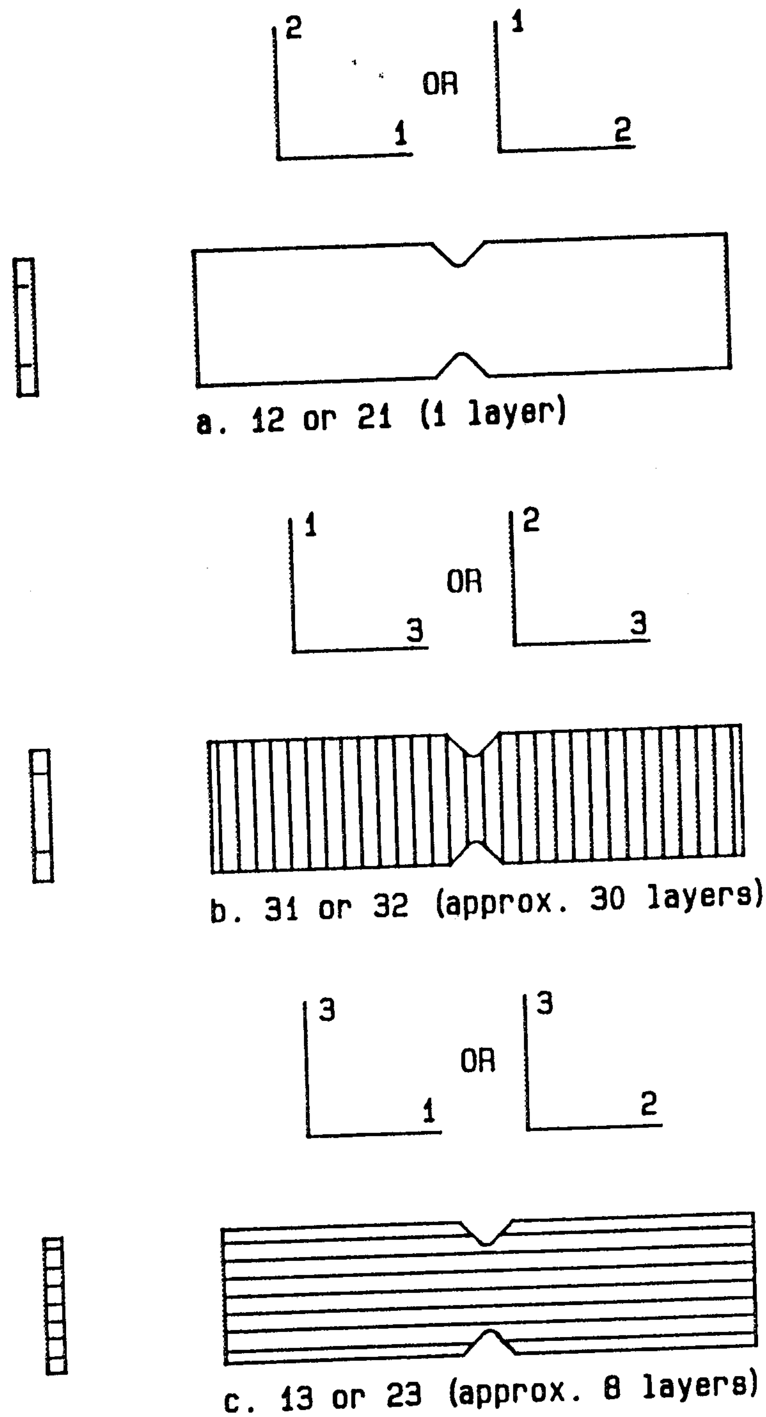

Figure A12. Possible Iosipescu Shear Test Specimen Configurations.

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

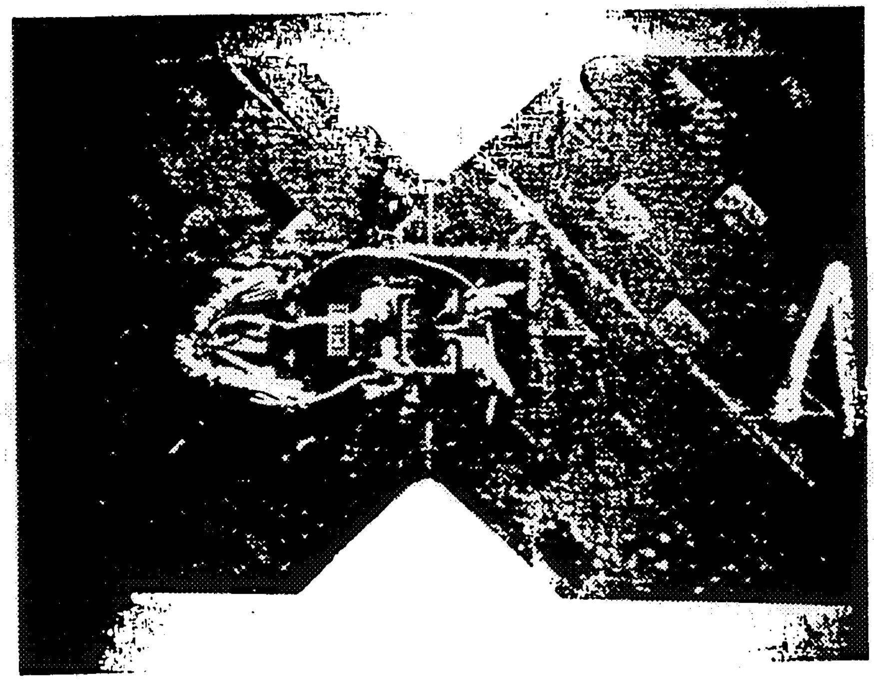

Figure A13. Iosipescu Shear Test Specimen Instrumented with a Strain Gage Rosette.

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.

Analyzing Joint Stresses Using an Extensometer

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An instrument called the KGR-1 Extensometer is being used for stress analysis of bonded metal-to-metal joints for aircraft primary structure. The stresses in the adhesive must be calculated and compared to the allowable stresses for the particular adhesive in order to accurately predict service performance. Allowable stresses are determined by testing the adhesive for strength in the pertinent environment of the "real-life" joint.

Shear stiffness is fundamental to stress analysis; shear strength is needed to establish allowable stresses. Therefore, a curve of shear movement (strain) versus shear load (stress) is required. The slope of the curve will be the stiffness, and the breaking point will be one of the allowable stresses. Other allowables will be determined by loads at which there is a non-linearity or a drop in stiffness.

Until the advent of the extensometer, techniques to obtain the shear stress-strain curve were either inaccurate or too expensive. For usefulness, the technique must measure movement in sixteenths of a micron (.0000025 in.). One technique is to obtain a tension stress-strain curve (relatively simple) and

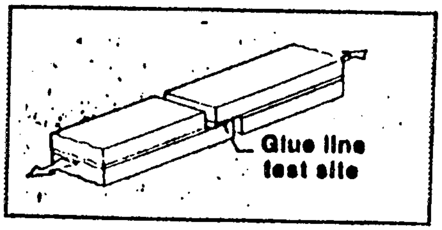

Figure 1. The extensometer uses a thick adherend lap shear specimen.

transform it to a shear curve arithmetically, using Poisson's ratio (comparing tensile stiffness to stiffness in shear). Unfortunately, this is valid only in the linear range.

The non-linear portions are not the same for both tension and shear. There are other tests based on the so-called "napkin ring" principle. Two thin-walled tubes are bonded together end-to-end and subjected to torsion. Shear stress is readily calculated. The strain is measured as the difference in rotation of the tubes divided by the glue line thickness. This method is classic, elegant and theoretically accurate. However, it is difficult to obtain pure shear without secondary bending, and the method is far too expensive, particularly in a hostile environment. This expense obviates the large number of tests necessary for statistical confidence.

Equipment Features

KGR-1 is an extensometer system which measures the movement of an actual glue line in the shear mode. The design was developed for economy and extreme sensitivity, since movement of $\frac{1}{16}\mu$ (.0000025 in.) must be detected. It is designed to perform between −67°F and 500°F. The specimens can easily be saturated with water and all fluids pertinent to aircraft.

The key to economy lies in the simplicity of the specimen. For this reason, the thick adherend lap shear specimen was chosen. To make this specimen, two plates 9-in. × 9-in. thick are bonded together. They are then cut into 1-in. widths and notched to form a ⅜-in. overlap, as shown in Figure 1.

Figure 2 is a schematic drawing of the extensometer with the thick adherend lap shear specimen. Two instruments are used; they are mirror images of each other and are mounted on opposite sides of the specimen. The signal of either individual instrument can be read, or their average signal can be obtained by combination.

The system depends on the principal of the linear variable differential transformer. A core is made to move in coils in the same amount of glue line deformation in shear. This generates a voltage which can be recorded as the shear movement. The black cylinder contains the coils. The core is fixed to the small threaded rod passing vertically through the coils. The core rod is mounted to the front frame, a vertical bar carrying a hard steel single point, which engages the specimen near the glue line. The coil is mounted to the rear frame. The rear frame has an extension arm reaching to the specimen; this arm carries hard steel double points which engage near the glue line on the opposite side from the single point.

The front and rear frames are attached to each other by a flat blade spring at their tops and another at their bottoms. These blade springs have their ends firmly fixed (clamped) to the

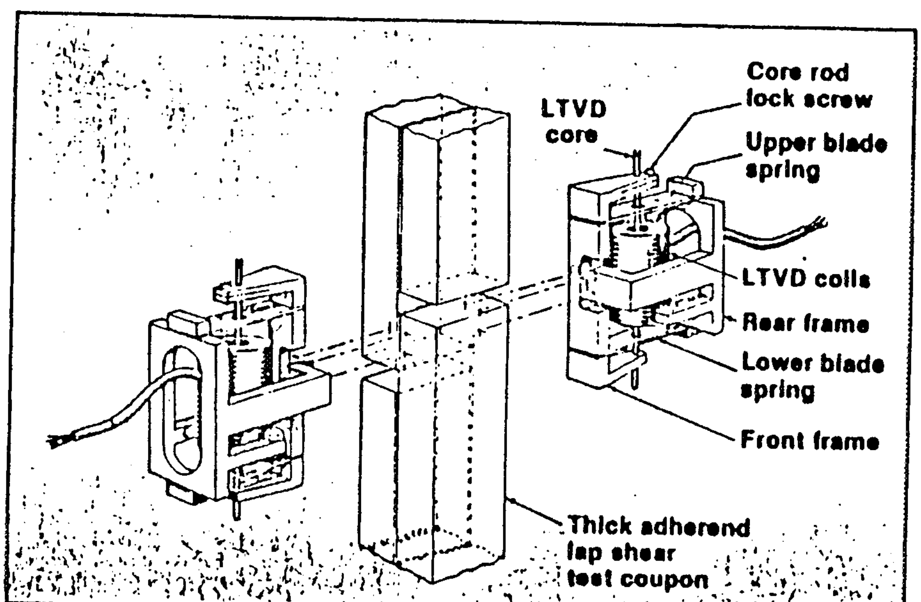

Figure 2. Schematic drawing of the KGR-1 extensometer.

This precludes all extraneous ...ent other than parallel to the di... of shear deformation of the glue. Also, this spring suspension pre...s all errors inherent in pivoting of rings or knife edges, i.e., loose fit, ...cklash or dull edges.

The instruments are mounted on the specimen by being mutually pulled together by two springs (Figure 3), one attached to the front frame of each instrument. These springs are connected to each other by ball chains, which are adjustable to produce sufficient force such that the instruments are suspended solely by their three points pressing into the specimen. Locking devices give a fixed reference setting between the front frame single point and the rear frame double point. The core is properly located relative to the coils while the lock is engaged. The instrument remains locked until it is mounted on the specimen. Then it is unlocked and the core is in its proper position for maximum travel with linear response.

The core is moved by turning the long threaded rod mounted on the front frame and passing through the coil. When correctly located, the rod is locked by tightening the screw on the rod support arm at the top of the front frame. The technique for proper core setting is simplified because the system ...cludes an amplifier to increase the ...tage signal to the recorder. When the core is properly located (at null), zero voltage is sent to the recorder. At this core location, increasing the amplifier gain causes no signal and thus the recorder will not move. If the core is not at null, a voltage will be sent to the recorder. After the recorder has responded to this signal, an increase in gain increases the signal, and the recorder will move. So, the core rod is simply located until gain increase causes no recorder movement, then the core is locked in its proper position.

The system also includes a tool which allows the points to be moved for any predetermined amount. This allows the amplifier gain to be accurately set for a useful, convenient scale on the recorder chart. This tool consists of two thick aluminum plates separated by an artificial glue line of Teflon film (Du Pont). One plate is fixed. The other plate is driven by a large micrometer to simulate the shear displacement of the adhesive in the actual test specimen. KGR-1 is mounted on this tool exactly as on the actual specimen. This tool is used to calibrate and functionally check the extensometer including positioning the ...re.

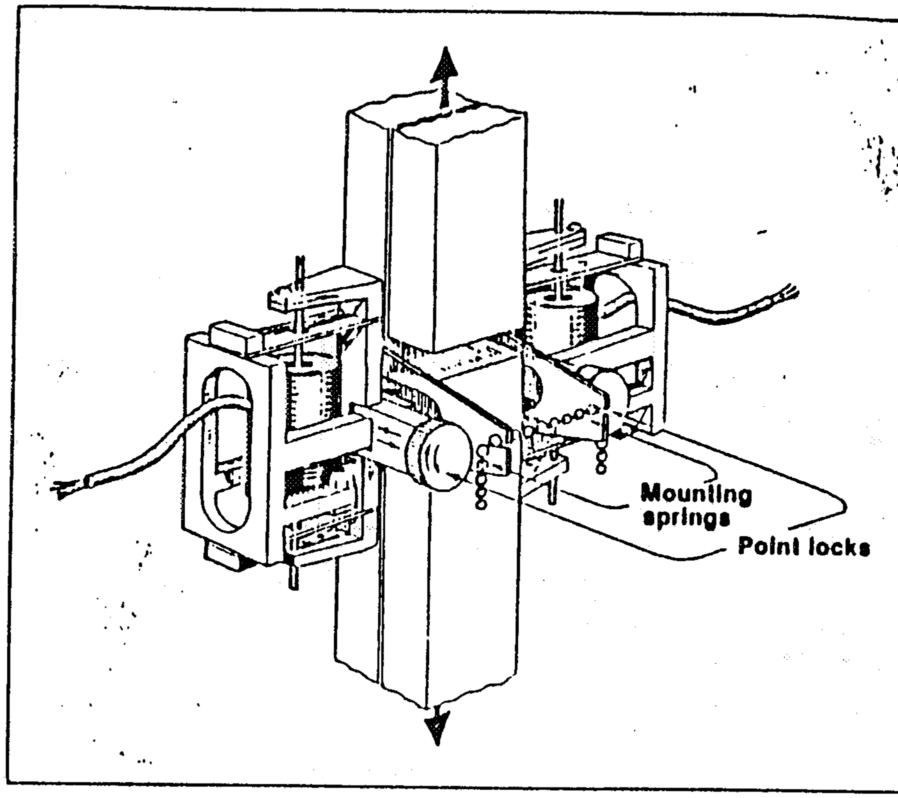

Figure 3. The instruments are mounted on the specimen by being pulled together by two springs connected to each other by ball chains.

Stress-Strain Curve Data

Figure 4 presents a typical shear stress-strain curve obtained with the extensometer. The recorder produces a curve of specimen load vs. total specimen deformation in shear. For any point on the curve, the shear stress is found by dividing the load by the bond area. The shear strain is found by first finding the shear deformation of the adhesive, and then dividing this by the bond line thickness. The adhesive shear deformation is found by subtracting the metal deformation from the total deformation signal. *(1)* The shear modulus (G) is found (for the initial linear portion of the curve) by dividing the shear stress by the shear strain.

Three basic points are presented to adequately define the curve. They are LL (Linear Limit), KN (Knee) and UL (Ultimate Strength). The rationale for simplifying the full curve to these three points is as follows:

Linear Limit (LL). This is arbitrarily chosen as that point at which the curve departs from a straight line through the origin. The coordinates of this point es-

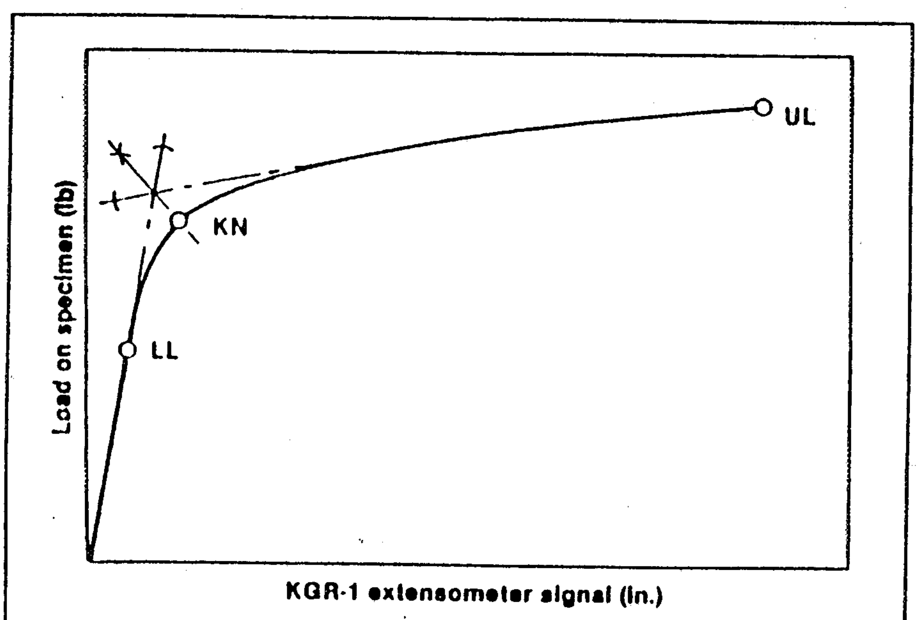

Figure 4. A typical shear stress-strain curve obtained with the extensometer.

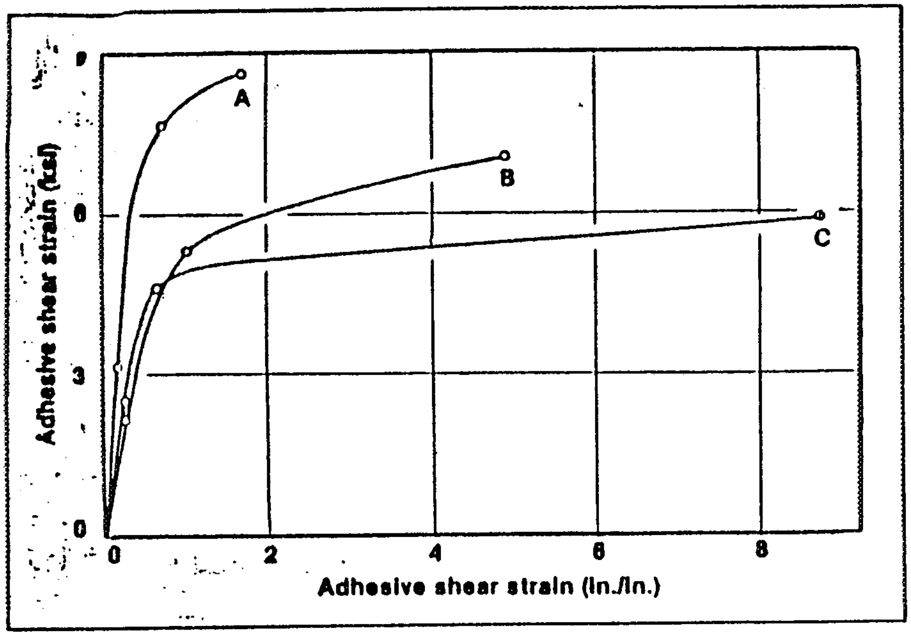

Figure 5. Shear stress-strain curves for the three adhesives tested.

Table I — Metal-to-Metal Peel And Lap Shear Comparisons

Adhesive	Metal-to-metal peel bell method	Lap shear MMM-A-132
A	100	100
B	300	140
C	900	170

tablish the shear modulus (G) for use in stress analysis in the linear range. Since modulus is the prime usefulness of the LL point, it does not matter if personal judgment produces a scatter in the stress values, so long as the point is taken on the curve. Should the curve have no straight line portion, the coordinates of LL are presented as zero stress and zero strain.

Knee (KN). This point is found by bisecting the angle between the initial tangent and another tangent drawn to the curve beyond the "knee" region. The worth of this technique can be judged from the following considerations:

- The purpose is to establish a *region*, not a point, where a rapid drop in stiffness occurs.
- This region has been found, so far, to be possibly decisive for repeated loads. For load above the knee region, there appears to be a loss of useful fatigue life. This suggests that irreversible mechanical damage has occurred, and that it may reduce environmental durability. Repeated loads quite near to KN have shown a reduction, *for each single cycle*, of LL stress and shear modulus. This seems to say that useful fatigue life exists below KN, but above LL.
- It is rational to assume a range, not a point, for fatigue life, i.e., higher stress with lower number of cycles and vice versa.
- This is considered to mean that the "yield" point concept for metals is *not* applicable. Metals can be taken beyond yield (forming parts by permanent set), yet still retaining stiffness, fatigue life and environmental durability. This cannot be safely assumed for structural adhesives.

In view of these considerations, it is considered fruitless to attempt to define a precise point of any value between LL and KN. Fatigue, cyclic load and environmental allowables will have to be determined in other ways.

Data Evaluation

Figure 5 presents the shear stress-strain curves for three adhesives tested at ambient temperature. These adhesives cover a range of maximum operating temperatures from 250°F to 400°F. Adhesive A is the high temperature formula, Adhesive B is the intermediate, and Adhesive C is the lowest. At a glance, we can see that A is the stiffest and strongest. C is the toughest, because of its high strain at failure. This concept is the same as that for metals.

It is next of great interest to compare these curves with data for the arbitrary and conventional tests of metal-to-met peel and lap shear. Table I presen metal to metal peel and Mil. Spec. l shear comparisons for adhesives A, and C, with Adhesive A taken at a val of 100. These tests, at ambient tempe ature, show Adhesive C to be t strongest and the toughest (lap she and peel, in that order). The stre strain curves in Figure 5 contradict showing Adhesive A to be the stron est. However, Adhesive C remains t toughest. We consider that shear stre strain data (Figure 5) are the fund mental properties of the adhesive while peel and lap shear values are si ply the strengths of arbitrary join This is primarily true because she stress is not uniform in the peel and l shear tests. There are high peaks concentrations of stress at the begi ning of these joints, and failure initia here before the remaining glue line c work. The thick adherend specime being ultra stiff, puts a uniform she stress on the adhesive, and so produ the fundamental properties. For exa ple, the reason Adhesive C appe strongest in lap shear is because of high elongation. When its entran stress, (at the beginning of the joi becomes high, it simply stretches a allows the rest of the bond area to pi up load. Adhesive A cannot stretch, a so its failure at the entrance causes p mature failure of the joint.

High toughness has great value in ducing stress concentrations in real l structure. This feature will greatly tend the fatigue life of complex join However, as Figure 5 data shows, hi temperature performance can me sacrifice of ambient temperature tou ness. This trade-off can be accurat dealt with by proper stress analys made possible by stress-strain data.

Conclusion

Before the extensometer technolo the designer was forced to estimate performance of bonded structure fr peel and lap shear data. Testing of tual parts was necessary as a des tool, far in excess of a single proof on a final design. Testing as a des tool was also necessary for fatigue hostile environments. For prim structure, such testing is prohibitiv expensive, especially for fatigue an variety of environments.

KGR-1 technology now permits curate performance predictions at l cost, regardless of structure size complexity. This capability will exp the use of structural bonding.

References

(1) Krieger, R.B. 1975. Stiffness ch acteristics of structural adhesives stress analysis in hostile environmen

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Standard Test Method for
PEEL RESISTANCE OF ADHESIVES (T-PEEL TEST)[1]

This standard is issued under the fixed designation D 1876; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This method has been approved for use by agencies of the Department of Defense as part of Federal Test Method Standard No. 175a and for listing in the DoD Index of Specifications and Standards.

INTRODUCTION

The accuracy of the results of strength tests of adhesive bonds will depend on the conditions under which the bonding process is carried out. Unless otherwise agreed upon by the manufacturer and the purchaser, the bonding conditions shall be prescribed by the manufacturer of the adhesive. In order to ensure that complete information is available to the individual conducting the tests, the manufacturer of the adhesive shall furnish numerical values and other specific information for each of the following variables:

(*1*) Procedure for preparation of the surfaces prior to application of the adhesive, the cleaning and drying of metal surfaces, and special surface treatments such as sanding, which are not specifically limited by the pertinent test method.

(*2*) Complete mixing directions for the adhesive.

(*3*) Conditions for application of the adhesive, including the rate of spread or thickness of film, number of coats to be applied, whether to be applied to one or both surfaces, and the conditions of drying where more than one coat is required.

(*4*) Assembly conditions before application of pressure, including the room temperature, length of time, and whether open or closed assembly is to be used.

(*5*) Curing conditions, including the amount of pressure to be applied, the length of time under pressure, and the temperature of the assembly when under pressure. It should be stated whether this temperature is that of the glue line, or of the atmosphere at which the assembly is to be maintained.

(*6*) Conditioning procedure before testing, unless a standard procedure is specified, including the length of time, temperature, and relative humidity.

A range may be prescribed for any variable by the manufacturer of the adhesive, if it can be assumed by the test operator that any arbitrarily chosen value within such a range or any combination of such values for several variables will be acceptable to both the manufacturer and the purchaser of the adhesive.

1. Scope

1.1 This method is primarily intended for determining the relative peel resistance of adhesive bonds between flexible adherends by means of a T-type specimen.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices*

[1] This method is under the jurisdiction of ASTM Committee D-14 on Adhesives and is the direct responsibility of D14.80 on Metal Bonding Adhesives.

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and determine the applicability of regulatory limitations prior to use.

2. Description of Terms

2.1 *T-peel Strength* is the average load per unit width of bond line required to produce progressive separation of two bonded, flexible adherends, under conditions designated in this method.

2.2 *Flexible*—as used in this method, indicates that the adherends shall have such dimensions and physical properties as to permit bending them through any angle up to 90 deg without breaking or cracking.

3. Apparatus

3.1 *Tension Testing Machine*, capable of applying a tensile load having the following prescribed conditions:

3.1.1 The machine and loading range shall be so selected that the maximum load on the specimen falls between 15 and 85 percent of the upper limit of the loading range.

3.1.2 The rate of movement between heads shall remain essentially constant under fluctuating loads.

NOTE 1—It is difficult to meet this requirement when loads are measured with a spring-type or pendulum-type weighing device.

3.1.3 The machine shall be equipped with suitable grips capable of clamping the specimens firmly and without slippage throughout the tests.

3.1.4 The machine shall be autographic, giving a chart that can be read in terms of inches of separation as one coordinate and applied load as the other coordinate.

3.1.5 The applied tension as measured and recorded shall be accurate within ±1 percent.

3.2 *Conditioning Room or Desiccators*—The conditioning room or desiccators (Note 2) shall be capable of maintaining a relative humidity of 50 ± 2 percent at 23 ± 1 C (73.4 ± 1.8 F).

NOTE 2—A saturated solution of calcium nitrate will give approximately 51 percent relative humidity at the testing temperature.

4. Test Specimen

4.1 Laminated test panels (see Fig. 1) shall consist of two flexible adherends properly prepared and bonded together in accordance with the adhesive manufacturer's recommendations. Specially prepared test panels shall be 152 mm (6 in.) wide by 305 mm (12 in.) long, but sha be bonded only over approximately 241 mm (in.) of their length. Test panels of these sam dimensions may also be cut from larger, full laminated panels.

NOTE 3—Direct comparisons of different adhesiv can be made only when specimen construction and te conditions are identical.

NOTE 4—Clad aluminum alloy 0.81 mm (0.032 in thick conforming to ASTM Specification B 209, fo Aluminum-Alloy Sheet and Plate,[2] Alloy 2024-T3, ha been found satisfactory as an adherend for structur adhesives. Canvas, coated fabrics, plastics films, an metal foils have also proven to be satisfactory adherenc for use with specific adhesives.

NOTE 5—It is not essential that the two adherenc be alike, either in material or thickness. They shal however, be capable of being bent through any angl up to 90 deg without breaking.

4.2 The bonded panels shall be cut into 25 mm (1-in.) wide test specimens (see Fig. 1) by means that is not deleterious to the bond. Th 76-mm (3-in.) long unbonded ends shall be ben apart, perpendicular to the glue line, for clampin in the grips of the testing machine.

4.3 At least ten test specimens shall be teste for each adhesive.

NOTE 6—Within the limitations imposed by Not 3, other specimen widths may be used, provided th test machine grips are of ample width to apply the loa uniformly across the width of the adherends.

NOTE 7—For obtaining a gripping area on speci mens that are completely bonded, one end of th bonded specimen may be chilled in dry ice until th adhesive becomes brittle, and then the adherends ma be carefully pried apart. The technique will not worl for all adhesives and adherends.

5. Conditioning

5.1 Condition specimens for 7 days at a relative humidity of 50 ± 2 percent at 23 ± 1 C (73.4 ± 1.8 F), except where the adhesive manufacturer may specify such an aging period to be unnecessary or a shorter period to be adequate.

NOTE 8—Conditioning is not required for laminated assemblies containing only metal adherends, unless specified as a part of the bonding procedure by the manufacturer of the adhesive.

6. Procedure

6.1 Clamp the bent, unbonded ends of the test specimen in the test grips of the tension testing machine. Apply the load at a constant head speed of 254 mm (10 in.)/min.

[2] *Annual Book of ASTM Standards*, Vol 02.02.

NOTE 9—This speed will cause separation of the bond at a rate of 127 mm (5 in.)/min.

6.2 During the peel test make an autographic recording of load versus head movement or load versus distance peeled.

6.3 Determine the peel resistance over at least a 127-mm (5-in.) length of the bond line after the initial peak.

7. Calculation

7.1 Determine from the autographic curve for the first 127 mm (5 in.) of peeling after the initial peak the average peeling load in pounds per inch of the specimen width required to separate the adherends. It is preferred that the average to be determined from the curve with the use of a planimeter.

NOTE 10—In case a planimeter is not used, the average may be calculated as the average of load readings taken at fixed increments of crosshead motion. For example, the load may be recorded at each 25-mm (1-in.) interval of head motion (or each 12.7 mm (0.5 in.) interval of bond separation) following the initial peak, until at least ten readings have been obtained.

8. Report

8.1 The report shall include the following:

8.1.1 Complete identification of the adhesive tested, including type, source, manufacturer's code number, batch or lot number, form, etc.,

8.1.2 Complete identification of adherends used, including material, thickness, surface preparation, and orientation,

8.1.3 Description of bonding process, including method of application of adhesive, glue-line thickness, drying or precuring conditions (where applicable), curing time, temperature, and pressure,

8.1.4 Average thickness of adhesive layer after formation of the joint, within 0.001 in. The method of obtaining the thickness of the adhesive layer shall be described including procedure, location of measurement, and range of measurements.

8.1.5 Complete description of the test specimens, including dimensions and construction of the test specimens, conditions used for cutting individual test specimens, number of test panels represented, and number of individual test specimens,

8.1.6 Conditioning procedure prior to testing,

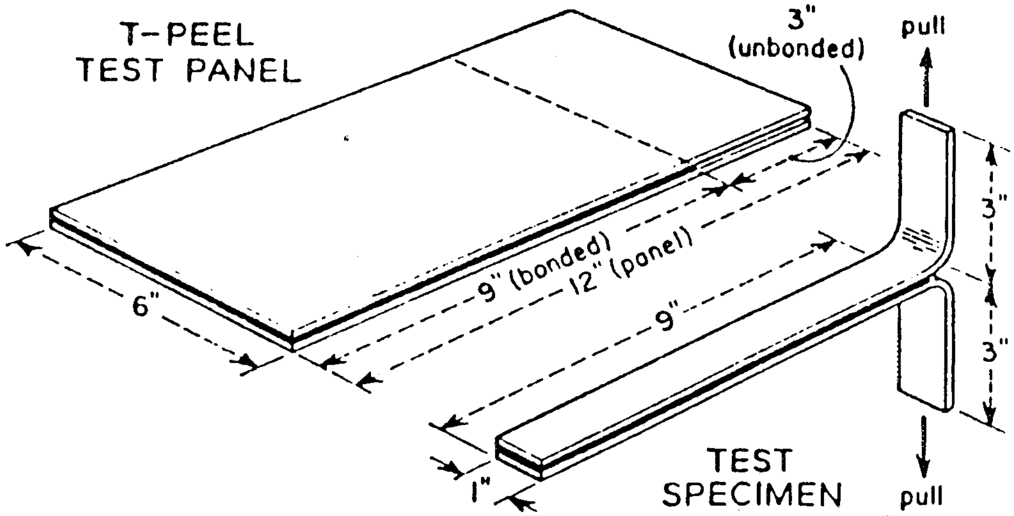
8.1.7 Type of test machine and crosshead separation rate used,

8.1.8 Method of recording load and determining average load,

8.1.9 Average, maximum, and minimum peeling load values for each individual specimen,

8.1.10 Average T-peel strength in pounds per inch of width for each combination of materials and constructions under test, and

8.1.11 Type of failure, that is, cohesive failure within the adhesive or adherend, adhesion to the adherend, or combinations thereof, for each individual specimen.



METRIC EQUIVALENTS

in	1	3	6	9	12
mm	25	76	152	229	305

FIG. 1 Test Panel and Test Specimen

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connec with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additi standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting o responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you sh make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103.

SSD94D0329

Milestone 4

Test Plan for Reusable Hydrogen Composite Tank System (RHCTS)

Task 3 - Composite Tank Materials

Cooperative Agreement NCC8-39

November 4, 1994

for H. S. Greenberg, Principal Investigator

Rockwell Aerospace
Space Systems Division

Rockwell Aerospace
North American Aircraft

HERCULES

INTRODUCTION

This document describes the Test Plan to be used for composite tank material development. This task will be performed by Rockwell's NAAD/Tulsa with support from Hercules and Rockwell SSD. The tasks described in this test plan will establish the most suitable composite prototype tank material and construction design for containment of Hydrogen and provide an 8 foot diameter composite test article for integrated tank/insulation/TPS Testing.

This effort is conducted by the Space Systems Division of Rockwell International as part of Milestone 4 of the Co-Operative Agreement No. NCC8-39 with NASA/MSFC.

This document will be updated on a timely basis as information becomes available throughout the project.

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DETAILED TEST PLAN - SSTO LIQUID HYDROGEN TANK

1.0 INTRODUCTION

The Single Stage To Orbit (SSTO) vehicle is a heavy launch vehicle which is designed for 100 missions, each involving lift-off from a vertical position, entry into orbit, and return to earth for a horizontal landing (NASA baseline). In order to meet its performance goals, the SSTO design must focus on lightweight structure, among many other considerations. One significant element of that structure is the Liquid Hydrogen (LH2) fuel tank which is nominally 32-feet in diameter by 40-feet long and which is designed to contain liquid hydrogen at a temperature of -423F and a limit pressure of 34 psi (see Figure 1). Depending on design trades now in progress, the LH2 tank may serve either as an integral portion of the vehicle's fuselage or, alternatively, as a standalone structure contained within the fuselage. The tank is currently baselined as a seamless graphite-reinforced composite structure to be fabricated by fiber placement.

This test plan supports the design/development of an advanced composite LH2 tank for SSTO by: (1) downselecting and characterizing the principal materials (prepreg and adhesives) to be used in its fabrication, and; (2) establishing the integrity of the design through testing of several critical structural elements, a 4 x 6-foot subcomponent panel, and an 8-foot diameter (nominally quarter-scale) tank article. The testing described herein is crucial to establishing the capability of the composite design and materials to provide sustained structural integrity and hydrogen containment when subjected to cryogenic temperatures, moderate internal pressure, thermal cycling between -425 and +250F (upon reentry), and external loads introduced from adjacent vehicle structures.

To minimize design risk and program costs, this test plan is based upon a progressive building block approach with the following sequential elements: (a) an initial trade study to select materials (both composite prepreg systems and adhesives) for preliminary screening tests; (b) screening tests to evaluate, rank, and downselect a single preferred material (of each type, i.e., prepreg, paste adhesive, and film adhesive); (c) additional characterization tests to enlarge and expand the database to provide pertinent and reliable mechanical property data to support the design/analysis; (d) element tests to evaluate critical structural locations under the most demanding representative conditions in order to validate the design approach and analytical predictions; (e) subcomponent fabrication and testing both to provide valuable experience in applying the baseline fabrication approach to a representative tank section as well as to assess the response of this section to a realistic simulation of service stresses and temperatures; (f) fabrication of a tool-proof article (half-thickness tank wall) and the full-thickness 8-foot diameter tank test article, and; (g) testing of the 8-foot tank test article to verify the design and to demonstrate the accuracy of the analytical predictions.

In addition to providing data on material properties and design performance, accomplishment of the effort described in this test plan will reduce the risks and unknowns associated with the fiber-placement of large-scale tank structures through the experience gained in fabrication of the test articles. In addition to demonstrating the capacity of a composite material to maintain structural integrity under the extreme temperature conditions, a secondary objective of this program will be to identify and resolve the major manufacturing challenges associated with the sheer size of the full-scale tank. Hence, the need exists to fabricate, assemble and test representative elements, subcomponents, and a subscale article to build confidence in the design and manufacturing approaches under evaluation on this program.

2.0 SCOPE

This document is the detailed Test Plan for the series of tests enumerated in the preceding section. The purpose of this plan is to present the test objectives, test parameters and procedures, expected performance and data analysis plans, criteria for success, test schedules, and related safety provisions; and to describe the test articles, test instrumentation, and test facility requirements.

Initial testing will be performed to screen four composite materials for suitability for SSTO LH2 tank loads and environmental conditions. The laminates for this testing will be fabricated by fiber placement, which is the manufacturing approach identified as baseline for the tank wall. Even though hand layup will be involved in fabricating many of the internal structural members of the tank, no hand-layup laminates will be evaluated in the screening or subsequent characterization testing. This decision is based on the understanding that mechanical properties measured for hand-layup material should be at least equivalent to properties measured for fiber-placed material, so that the latter should provide no less than a conservative approximation of the former.

A single material will be downselected from these screening tests. This material will be subsequently characterized for impact-damage tolerance and durability under conditions of mechanical and thermal cycling, and to establish a preliminary design database to support ongoing analysis. Next, testing will be performed on critical structural elements fabricated from the selected material. Finally, the 8-foot diameter tank article, containing the critical structural features of the full-scale tank, will be fabricated by fiber placement and tested to verify its structural integrity and LH2 containment.

3.0 TEST OBJECTIVES

The primary purpose of this test plan is to minimize risk in implementing new lightweight composite materials and the fiber-placement fabrication approach for the LH2 tank of the

SSTO vehicle. To this end, screening, characterization, element, subcomponent and subscale article testing will be performed. The overall objectives of this test program are to:

1. Provide sufficient material properties data to allow logical selection of one preferred material (a single graphite fiber/resin material, single paste adhesive, and single film adhesive) from several initial candidates as the baseline for the LH2 tank prototype design.

2. Develop -- for the selected materials -- a preliminary database of structural properties sufficient to support detail design and analysis of the SSTO prototype tank.

3. Verify the structural integrity of key elements of the prototype tank in realistic environments and reduce risk in testing the subscale tank.

4. Verify the structural integrity and hydrogen containment of a complete subscale version of the prototype tank with elements fabricated using full scale methods and subjected to critical full scale cyclic stresses and thermal environment. All significant elements of the prototype will be included for realism.

5. Verify analysis methods by correlation of measured strains and deflections in the element, subcomponent, and subscale tank tests with results predicted by analysis and Finite Element Modeling.

6) Demonstrate, both during and after testing, the capacity of non destructive evaluation/integral health monitoring (NDE/IHM) techniques to detect any and all significant changes in the structural integrity of the tank, including delaminations, disbonds, and microcrack-related changes in hydrogen permeability through the tank wall.

4.0 BACKGROUND

The function of the LH2 tank is to contain the liquid hydrogen fuel while serving as an integral part of the fuselage structure (baseline), enduring flight loads as well as thermal stresses induced by the internal cryogenic temperatures and external elevated temperatures developed during re-entry.

A trade study (TA-1 Task 2) is currently underway to select the preferred SSTO vehicle design. This will determine the position of the tank (forward or aft), whether the tank is integral with the fuselage or supported within an external shell, and whether the tank wall is a skin/stringer or sandwich construction. The tank position will determine whether large point load application, such as the wing support attachments, must be accommodated by the tank and also whether the tank is cylindrical or conical. The tank insulation and the TPS attachment will be affected by the wall construction to be selected.

The primary design driver for the tank skin will be the 34 psi. limit pressure at -423°F. The skin stiffening and frames will be designed to stabilize the shell from compression loads which may be as much as 4500 lb/in, depending on tank location and whether or not the tank is integral. The tank has both ends closed out with ellipsoidal domes. The aft dome includes the sump for fuel drainage, and the forward dome includes a removable port cover for person access and vent and instrumentation pass-thru's.

To minimize risk of leakage, the tank is baselined to be fiber-placed and cured as a complete unit without bonded joints in the tank shell. At each end of the integral tank, a short skirt extending beyond the shell/dome junction provides an interface with the adjacent vehicle aerostructure. A critical feature of this concept is the "y-joint" that connects the end dome, the shell, and the skirt in a continuous co-cured joint.

Secondary bonded joints in the pressurized skin will be kept to an absolute minimum to reduce the risk of leakage but will be necessary in the composite sump and feed line attachments. Attachment of external structures to the tank wall such as the wing or fairings may be required and presents a challenge to transfer loads without penetrating the tank. In the areas where penetrations are essential, such as the manhole, vent and instrumentation lines, a mechanical seal similar to that used on the Space Shuttle External Tank is baselined.

All of the above elements and components are critical to the success of the LH2 tank and will be included in the element, subcomponent, or scale model testing in order to prove their reliability.

The extreme weight criticality of the vehicle dictated the baselining of high specific strength graphite/epoxy material systems for the tank structure. The NASP program has shown with small scale test articles that toughened epoxy composites may be suitable for cryogenic flight structures. This program will leverage the experience of NASP; however the structural configuration and load environment will be significantly different for the SSTO. This building block test program is designed to address the unknowns and reduce the risk in developing the full scale tank structure.

5.0 APPLICABLE DOCUMENTS

SSD94D0109-1	Proposal for Advanced Structures and TPS Technologies TA1
[no document number]	Project Plan for Reusable Hydrogen Composite Tank System (RHCTS), June 22, 1994
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 (Appendix D)
SACMA SRM 2-88	SACMA Recommended Test Method for Compression After Impact Properties of Oriented Fiber-Resin Composites (Appendix E)
SACMA SRM 7-88	SACMA Recommended Test Method for Inplane Shear Stress-Strain Properties of Oriented Fiber-Resin Composites (Appendix F)
UWME-DR-501-103-1	Iosipescu Shear Properties of Graphite/Epoxy Composite Laminates (Appendix G)
(no document number)	Analyzing Joint Stresses Using an Extensometer (Appendix H)

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 test report with each shipment of material procured, including (as a minimum) test results on the resin content and fiber areal weight, along with batch identification and date of manufacture of the prepreg. The supplier shall also 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 misalignment, gaps, splices, fuzzballs, or other gross irregularities, including those that are peculiar to the fiber-placement layup process (e.g., twisted tows, etc.), shall not be placed in the layup.

6.2 Cured Laminate Physical and Chemical Properties

Laminates fabricated for coupon specimens will be non-destructively inspected by thru-transmission ultrasonic c-scan and tested for thickness per ply, resin content, fiber volume, and void content prior to machining into test specimens. The fiber volume will be controlled to 62 +/- 3% (and all subsequent mechanical properties normalized to the nominal value, 62%), and the void content to less than 1%. Material testing will be done per NASA 1142.

6.3 Specimen identification and traceability

All test specimens and articles will be traceable back to the material manufacturer's batch and lot numbers. Each individual panel layup will be identified on the vacuum bag (using indelible marking pens) with its unique I.D. number which will be logged in a laboratory notebook with the material identification and all processing records. Each cured and/or trimmed laminate will be likewise marked, and the corresponding c-scan identified to each laminate. Coupon test specimens machined from each laminate will be identified to that laminate by a numbering system to be established for this test program. This identification will be maintained through the entire test procedure and test data reduction.

Similarly, for all test articles which contain multiple details (such as elements or static and fatigue/IHM test articles), each detail will be indelibly identified to maintain traceability back to the material. An additional specimen number shall be applied to the fully assembled test article. This identification will be maintained through the entire test procedure and test data reduction.

All times into and out of preconditioning environments (e.g., humidity cabinet), along with any weight measurements on identified traveller coupons, will be recorded in a laboratory notebook. Moisturization will be according to NASA 1142, B.2.5. If specimens are shipped to an outside vendor or to another team member, the date of shipment and carrier will be logged in the laboratory notebook, along with the method of packaging, if relevant to the condition of the material and/or to subsequent testing.

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. The output shall 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. The testing modes identified for the screening tests shall provide a reliable indication of the suitability of the screened materials for the intended application.
2. The test results shall be comparable to one another without ambiguities arising from unintended variations in material quality, processing, test specimen preparation, or test conditions.
3. One or more of the screened materials shall yield acceptable test results, both in the screening tests and characterization tests, which are indicative of its ultimate performance in its intended application.
4. The variety of element tests to be performed shall provide a reliable basis for validating the predicted performance of the cryotank structure or, alternatively, for improving the design of the quarter-scale tank test article.
5. Fabrication of the subcomponent and quarter-scale tank test articles shall provide a representative test of the fiber-placement manufacturing approach and provide a realistic assessment of its likely success on a full-scale tank, including the identification of limitations and critical issues which may need to be addressed prior to implementation.
6. Testing of the subcomponent and quarter-scale tank test articles shall validate their structural capability and integrity.

7.0 DETAILED REQUIREMENTS

7.1 Material Screening Tests

Four candidate graphite fiber/resin materials and six candidate adhesives will be evaluated for application to the LH2 cryotank; in addition,six candidate neat resin materials will be evaluated for potential application (as a reinforced composite) to the LOX (Liquid Oxygen) tank.

Screening of the graphite fiber/resin materials will involve subjecting coupons to the tests listed in Table I as Test Items 2a through 2e (note: these designations refer back to the Project Plan, Task 3.2.2). All coupons will be cut from panels prepared by fiber placement in order to obtain properties representative of the baseline manufacturing approach.

The adhesive screening will include candidate paste and film adhesives, nominally three of each, depending on the results of an initial review of available data on potential candiate adhesive systems. The initial screening will involve lap shear testing, as called out in Task 3.2.3.3 of the Project Plan. The designation "2r" is assigned to this Test Item to replace the temporary designation "New" called out in the Project Plan. Based on the results of this testing, one paste adhesive and one film adhesive will be selected for further characterization by Test Items 2s and 2t described in Section 7.2.

Finally, six candidate resin systems will be screened for application to the LOX tank by examining these for evidence of ignition caused by impact in a LOX environment per MSFC-SPEC-101B (ABMA Tester). (This is Test Item 2i of the Project Plan under Task 3.2.3.4). These coupons will be tested initially as neat resin samples, since the likelihood of adverse performance under these test conditions is expected to be almost wholly dependent on the resin matrix, rather than the reinforcing graphite fiber; furthermore, this approach reduces the flowtime and costs associated with obtaining the candidate materials and preparing samples for test. Any neat resin materials which successfully pass this test would then be evaluated further in the form of graphite fiber-reinforced laminates, as Test Item 2j and 2k (refer to Section 7.2).

7.2 Material Characterization

Materials downselected from the Screening tests will next be subjected to more extensive "Characterization" testing to generate a larger and more comprehensive database for use in the design and analysis of the element, subcomponent, and quarter-scale tank test articles. The single downselected graphite fiber/resin material will be evaluated per Table II, Test Items 1a through 1i (no 1h), which also refer back to the Project Plan, Task 3.2.3. Some of these tests (1a, 1b, 1e and 1i) intentionally duplicate some of the "Screening" tests in order to provide a more statistically representative database of properties needed for design analysis, while other tests (1c, 1d, 1f and 1g) expand the database to test modes not previously evaluated on this program. Two batches of material will be evaluated by these tests, one of which may be identical to the batch used in the Screening tests.

One paste adhesive and one film adhesive of those evaluated by the initial Screening tests will be carried forward for further evaluation by Test Items 2s and 2t of Table II. Two batches of each type of adhesive will be evaluated, one of which may be identical to the batch used in the Screening lap shear testing (Test Item 2r). The thick-adherend test (KGR-1, per Test Item 2s) will provide stress/strain data on the selected adhesives at the two test temperatures. Note that this latter represents a change from the Project Plan, which originally called for additional lap shear testing to expand the database initiated under the Screening tests. However, lap shear testing does not provide a value which is directly applicable to the analysis of a bonded joint. The quantitative stress/strain performance provided by the thick-adherend test is regarded as more relevant to the analysis of bonded joints. It is also noted that the minimum temperature at which this test can be performed by any currently known source is -250F; the behavior at this temperature, in combination with comparable behavior at room temperature, will provide a basis (however approximate) for extrapolating to -425F.

The T-Peel test will provide a value which is regarded as approximately representative of the loading condition expected from a pressure-induced bulging of the tank wall between adjacent frames.

Finally, with regard to the LOX-compatibility evaluation, if any of the six neat resin materials evaluated under the Screening tests perform acceptably, these will be further evaluated in the form of graphite-fiber reinforced laminate coupons (again, two batches), initially by the same impact/ignition test as above (Test Item 2j). If these results are still encouraging, then mechanical testing will be performed per Test Item 2k, which will involve tension testing before and after progressively more severe combinations of thermal and mechanical cycling.

7.3 Laminate fabrication for coupon testing

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 subsequently bonded or tabbed secondarily. The laminate will be cured or consolidated, using the material supplier's recommended procedures or, in the case of "cure-on-the-fly", by procedures developed by the laminate fabricator. In either case, the cure conditions will be documented and records provided to those responsible for the analysis and reporting of test results. Post-curing, if applicable, and ultrasonic inspection shall be performed on test laminates prior to machining of specimens. Prior to the submittal of coupons for mechanical testing, the physical properties listed in Section 6.2 will be determined for each separately fabricated test panel to characterize the material and to ensure conformance of fiber volume within the indicated tolerances; the purpose of this is to avoid a situation in which an anomalous condition would introduce some ambiguity into the interpretation of subsequent mechanical test data.

7.4 Specimen fabrication

Specimen layout shall allow for 1-inch minimum trim from all edges of the as-cured laminates. Specimens for physical testing (typically three per laminate) shall be removed from several non-adjacent areas inside the trim zone. Specimens for mechanical testing shall be accurately laid out so that loading axes are closely parallel or perpendicular to fiber axis, as specified for each particular test. Specimens shall be machined carefully to prevent delamination, splintering, or other damage. Specimens shall be ground to final dimensions using 400 or finer grit abrasive. Peel plies shall not be removed until just prior to bonding operations to avoid contamination. Tabs shall be bonded prior to machining of individual test specimens. Specimens shall be examined for evidence of defects during machining and secondary fabrication operations and again prior to testing. Specimen defects shall include, but not be limited to, substandard or incorrectly processed test panels, substandard or delaminated secondary bonds, incorrect, or misaligned 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 on this program will be tested using calibrated test machines and related equipment (load fixtures, ovens, etc.). The data obtained will be recorded automatically using data acquisition equipment at NAAD-Tulsa or at an independent test laboratory. (Information on the data acquisition equipment at each test facility, including SSD and MSFC, will be provided in subsequent amendments to this test plan as the requirements are established.) 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 unless otherwise specified herein. Control of test temperatures shall meet the requirements of NASA 1142, B.2.4.

8.0 DETAILED TEST ARTICLE/TEST SPECIMEN DESCRIPTION

Details on the configuration, layup, instrumentation location, etc., for test coupons, test elements, subcomponents, and quarter-scale tank test article are presented in Figures 1 through 16 to the extent that such details are currently defined. This test plan will be updated throughout this program to incorporate additional details as they are defined and agreed upon.

The Screening tests will be performed on a single batch of each material. Three replicates of each test coupon type will be tested at room temperature and at -423F, in some cases after "preconditioning", such as by thermal cycling or by the introduction of impact damage. All specimens will be tested per NASA 1142 unless otherwise noted.

Table I identifies the Test Item number, test article description, number of specimens to be tested (based on the number of replicates and batches), instrumentation requirements, and the applicable test specification.

After the completion of screening tests, the candidate materials will be downselected to: (a) one material in the case of the prepreg, paste adhesive, and film adhesive; and (b) one or more materials in the case of the LOX-compatible neat resins. These will then be subjected to more detailed characterization testing, involving six specimens from each of two batches of material (Table II). 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, adhesive, or dry fiber, or fiber impregnated with uncured resin.

Using material selected from the characterization testing, critical structural elements (Figures 10 through 14) will be defined and tested as described in Table III.

A 4 by 6-foot subcomponent representing a section of the stiffened tank wall (Figure 15) will also be tested in biaxial tension at [tbd] temperature after 100 simulated pressurization cycles using LH2 , as described in Table IV.

The quarter-scale tank test article (Figure 16) will be instrumented and proof-tested by Hercules per [procedures to be defined] and shipped to MSFC for final testing as described in a separate test plan document [tbd].

9.0 TEST PROCEDURES

For those standardized coupon-level tests, the test procedures are defined by the applicable test specification identified in Tables I and II. For the element, subcomponent, and quarter-scale tank article, detailed test procedures will be defined concurrently with the development of the test requirements and test article/fixture configuration.

Responsibility for performing the various tests is defined in Tables I through IV. In general, all room temperature testing of coupons will be done at NAAD-Tulsa, while coupon tests which require exposure to -423F will be performed at SSD. LOX-compatibility testing (Test Items 2i and 2j) will be performed at MSFC.

Test fixtures will be defined at a later date, by the responsible testing agency.

10.0 SAMPLE DATA SHEETS

A Rockwell NAAD-Tulsa Laboratory Test Data sheet, form T2962-Z-5a NEW 5/75 (Figure 17) will be used to record test data generated at Tulsa. Comparable forms shall be used at other test sites. All mechanical properties data will be normalized to 62% 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
Extensometer	[tbd]
Data Acquisition System	[tbd]

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

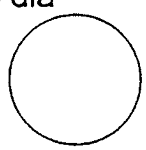
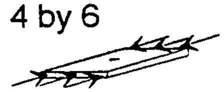
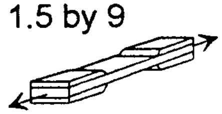
INSERT machines at SSD and at MSFC, and AFWL/FDD

12.0 SKETCHES AND SCHEMATICS

Figures 18 and 19 show facilities layout of equipment identified in 11.0, located at NAAD-Tulsa.
INSERT facilities layout at SSD and at MSFC, and AFWL/FDD

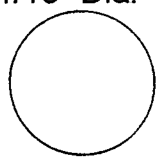
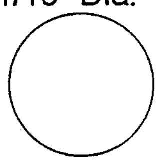
13.0 SCHEDULE

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.

Test Item	Test Objective	Test Article Description	# Replicates		Test Description	Instrumentation	Test Spec
			-423 F	RT			
2a	Screen 4 materials for tensile properties	0.5 by 9 tabs  $(0)_8$	3 specimens x 4 materials = 12	3 specimens x 4 materials = 12	Tensile Strength and Modulus	Strain gage or 1"-gage extensometer	NASA 1142 B.6
2b	Screen 4 materials for compression properties	0.5 by 3.15 tabs  $(0)_8$	3 specimens x 4 materials x 2 tests = 24	3 specimens x 4 materials x 2 tests = 24	Compression Strength and Modulus	Strain gage or compressometer on modulus specimens only	NASA 1142 B.7
2c	Screen 4 materials for permeability of GH2	2.5 dia  $[0_2/45/90_2/-45/0_2]_s$	None	3 specimens x 4 materials = 12	GH2 permeability of shell layup	None	ASTM-D1434 (modified)
2d	Screen 4 materials for effects of impact	4 by 6  $(45/0/45/90)_{4s}$	3 specimens x 4 materials = 12 (no "controls")	3 specimens x 4 materials = 12 (no "controls")	Compression after impact	Back-to-back pairs of axial strain gages	SRM 2-88
2e	Screen 4 materials for residual tension after thermal cycling	1.5 by 9  $[0_2/45/90_2/-45/0_2]_s$	3 specimens x 4 materials = 12 (no "controls")	3 specimens x 4 materials = 12 (no "controls")	Residual tension & cross-section after 1 LT at -423 to 250F	Strain gage or 1"-gage extensometer	NASA 1142 B.6 (revised layup & width)

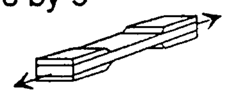
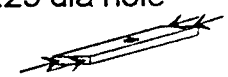
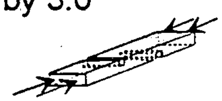
Room Temperature Testing at NAAD -423F Testing at SSD

Table I - SSTO Cryogenic Tank Structure Screening of Materials

Test Item	Test Objective	Specimen Configuration	Replicates		Test Description	Instrumentation	Test Spec
			-300 F	RT			
2i	Determine neat resin thermo-dynamic compatibility with LO_2	11/16" Dia.  $[0_2/45/90_2/-45/0_2]_s$	3 specimens x 6 materials = 18	None	Standard LO_2 compatibility test (impact/ignition)	None	MSFC-SPEC-101B
2j	Determine composite thermodynamic compatibility with LO_2	11/16" Dia.  $[0_2/45/90_2/-45/0_2]_s$	3 specimens x 2 batches = 6 (for each mat'l that passes 2i)	3 specimens x 2 batches = 6 (for each mat'l that passes 2i)	Standard LO_2 compatibility test (impact/ignition)	None	MSFC-SPEC-101B
2k	If 2j materials are LO_2-compatible, characterize one selected material after thermal and mechanical fatigue	1.5 by 9 tabs  $[0_2/45/90_2/-45/0_2]_s$	6 specimens x 2 batches x 3 layups x 4 tests = 144	6 specimens x 2 batches x 3 layups x 4 tests = 144	Tensile test at RT 3-to-4 conditions: (1)as-fabbed; (2)after RT mech fatigue-300 cycles; (3)after 100 thermal cycles-300°F/250°F; (4)after (2) + (3) combined	Conventional strain gage. Measure LO_2 permeability for test #3 (before and after thermal cycling)	NASA 1142 B.6 & ASTM D284-424 D1434

LOX Testing at MSFC; Permeability & -423 Testing at SSD; RT-Testing at NAAD

Table II - SSTO Cryogenic Tank Structure Characterization of Materials

Test Item	Test Objective	Test Article Description	Replicates		Test Description	Instrumentation	Test Spec
			-423 F	RT			
1a	Preliminary tensile properties database	0.5 by 9 tabs  $(0)_8$	6 specimens x 2 batches =12	6 specimens x 2 batches =12	Tension Strength & Modulus	Strain gage or 1" gage extensometer	NASA 1142 B.6
1b	Preliminary compression properties database	0.5 by 3.15 tabs  $(0)_8$	6 specimens x 2 batches x 2 tests =24	6 specimens x 2 batches x 2 tests =24	Compression strength & modulus	Strain gage or compressometer on modulus specimens only	NASA 1142 B.7
1c	Preliminary in-plane shear database	1.0 by 9  $(+/-45)_{2s}$	6 specimens x 2 batches =12	6 specimens x 2 batches =12	In-Plane Shear	Strain gages (longitudinal & transverse)	SRM-7-88
1d	Preliminary open-hole tension database	1.5 by 12 0.25 dia hole  $(45/0/-45/90)_{2s}$	6 specimens x 2 batches =12	6 specimens x 2 batches =12	Open-Hole Tensile Strength	None	NASA 1142 B.9
1e	Preliminary impact tolerance database	4 by 6  $(45/0/-45/90)_{4s}$	6 specimens x 2 batches=12	6 specimens x 2 batches=12	Residual compression after impact	Back-to-back pairs of axial strain gages	SRM-2-88
1f	Preliminary interlaminar shear database	0.75 by 3.0  $(45/0/-45/90)_{4s}$	6 specimens x 2 batches=12	6 specimens x 2 batches=12	Iosipescu Shear	[TBD]	UWME-DR-501-103-1

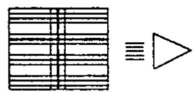
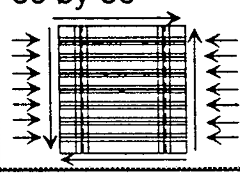
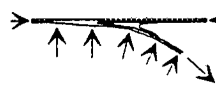
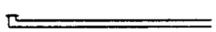
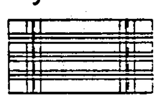
Room Temperature Testing at NAAD / -423 Testing at SSD

Table II - SSTO Cryogenic Tank Structure Characterization of Materials

Test Item	Test Objective	Test Article Description	Replicates		Test Description	Instru-menta-tion	Test Spec
			-423 F	RT			
1g	Durability testing	1.5 by 9 tabs [0$_2$/45/90$_2$/-45/0$_2$]s	None	3 specimens (control data from 2e)	Residual RT tension & permeability after thermal cycle (1i) and 2 LT spectrum load,	Strain Gages	NASA 1142 B.7 & ASTM D284-424 D1434
1i	Thermal cycling screening	1.5 by 9 tabs [0$_2$/45/90$_2$/-45/0$_2$]s	None	3 specimens (control data from 2e)	Residual RT tension & permeability after 1 LT at-423F to 250F	Strain Gages	NASA 1142 B.7 & ASTM D284-424 D1434
1j	Screening 6 adhesives for shear strength	1 by 9 Aluminum adherend	3 specimens x 6 materials (film &paste) =18	3 specimens x 6 materials (film & paste) =18	Lap shear	None	ASTM D1002
1k	Preliminary properties database	1 by 9 Aluminum adherend	3 specimens x 2 materials x 2 batches =12**	3 specimens x 2 materials x 2 batches =12	Thick-adherend (KGR-1) [** = -250F]	LVDT	n/a
1l	preliminary properties database	[TBD]	3 specimens x 2 materials x 2 batches = 12	3 specimens x 2 materials x 2 batches = 12	T-Peel	Strain Gages	MMM-A-132

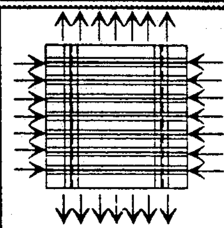
RT Tests at NAAD; -423 Tests at SSD, except 1k at -250F and RT @ vendor)

Table II - SSTO Cryogenic Tank Structure Characterization of Materials

Test Item	Test Objective	Test Article Description	Replicates		Test Description	Instrumentation	Test Specification
			-423 F	RT			
2f	Verify acoustic fatigue strength of a thin skin panel	22 by 22 	None	3 controls + 3 fatigued taken from 1 element	Residual tension after sonic fatigue for 1 LT @ 150 db	Strain gages + c-scan before and after fatigue	None
2g	Verify structural stability of a critical segment	30 by 30 	2 panels	2 panels	Evaluate panel instability under combined load	Strain gages	None
2h	Verify Y joint load transfer strength capability	6 by 15 	2 specimens	2 specimens	Check Y-joint load transfer	Strain gage	None
2m	Verify feed line and feed line attachments design	8 by 72 	2 specimens	None	Evaluate feed line pressure capability with LH_2, 100 cycles	None	None
2n	Evaluate stiffened panel damage tolerance	12 by 30 	None	3 specimens 2 impact levels = 6	Impact & test residual strength in 4 point bend, 2 LT	Strain gages	None

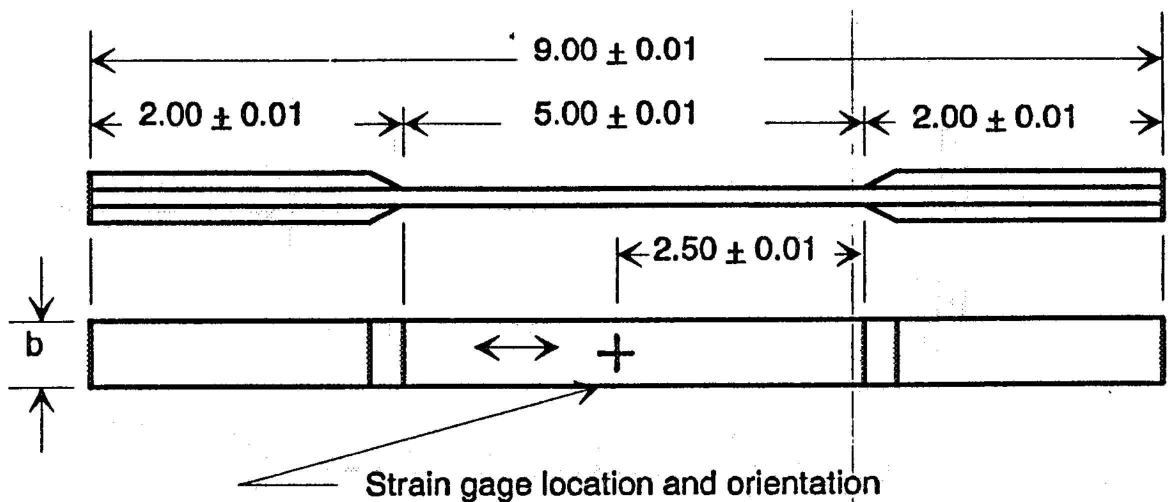
Tests 2f, 2g, and 2h by NASA MSFC / Test 2n by NAAD / Test m by SSD

Table III - SSTO Cryogenic Tank Structure Element Testing

Test Item	Test Objective	Test Article Description	Replicates	Test Description	Instrumentation	Test Specification
New	Verify biaxial tension load capability of full-scale structure		1	100, fill with pressurize and drain (100 cycles)	Strain gages	None

Test NASA LaRC

Table IV - SSTO Cryogenic Tank Structure 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 parallellism and perpendicularity 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 the same prepreg as the specimen $[0]_{12}$, with the 0^{o} fiber direction parallel to the longitudinal axis within $\pm 1^{o}$. 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. For -425^{o} F testing, bond tabs to specimens with EA9330 adhesive cured at 180F for 2 hours.

INSTRUMENTATION

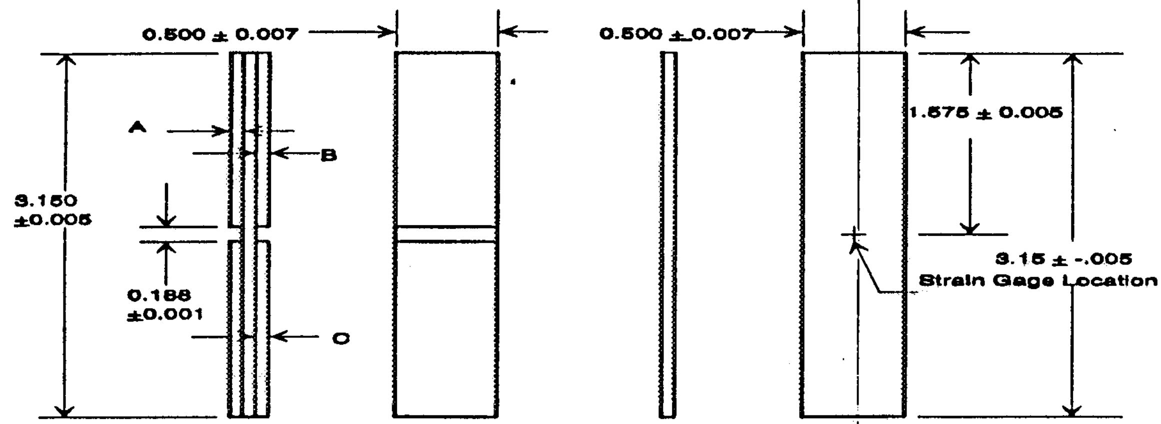
1. For the requirements of section B.6, either a longitudinal strain gage or a suitable extensometer may be used to measure longitudinal strain. For tests at -425F, gages should be bonded with EA9330 adhesive and cured 2 hours at 180F.

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

TEST

1. 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 parallellism and end perpendicularity 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 $[0]_{12}$, 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. For -425^{o} F testing, bond tabs to specimens with EA9330 adhesive cured at 180F for 2 hours.
5. Tab thickness tolerances: A=B $\pm$ 0.010
   B=C $\pm$ 0.001

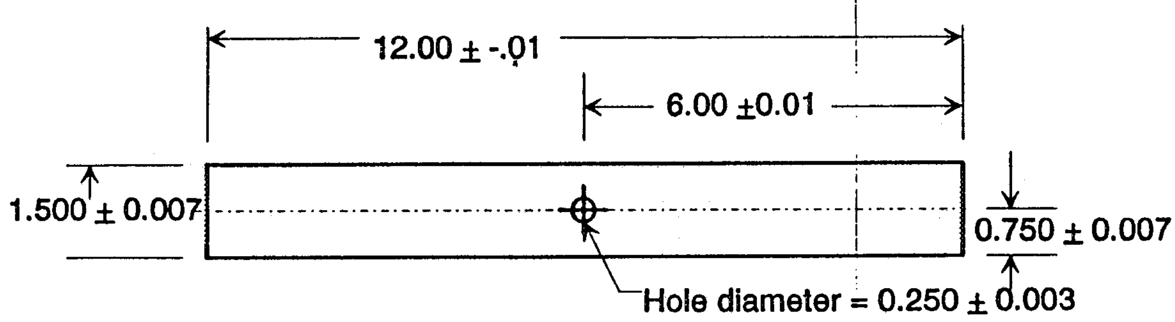
INSTRUMENTATION

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

TEST

1. Test per NASA 1142, B.7

Figure 2 COMPRESSION TEST SPECIMENS



All dimensions are in inches.

FABRICATION

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

2. Specimen edge parallellism and end perpendicularity 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 specified in paragraph B.9.2 of NASA 1142.

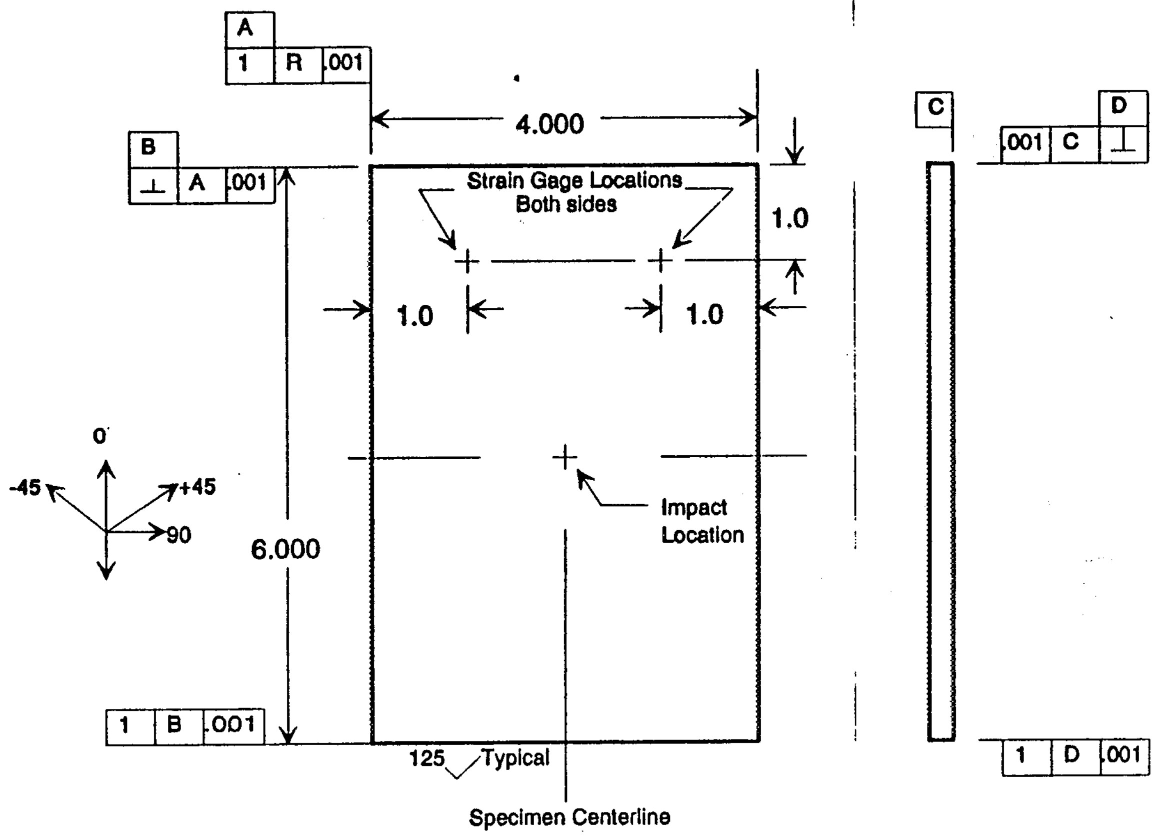
INSTRUMENTATION

1. None

TEST

1. Test Per NASA 1142, B.9

Figure 3 OPEN HOLE TENSION SPECIMEN.



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

FABRICATION

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

2. Specimen edge parallellism and end perpendicularity requirements shall be as specified in para. 6.2 (SRM 2-88).

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

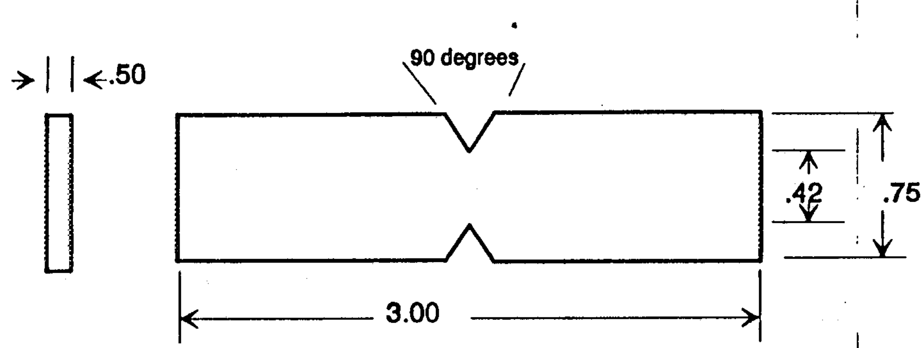
INSTRUMENTATION

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

TEST

1. Test Per SACMA SRM 2-88.

Figure 4 COMPRESSION AFTER IMPACT



All dimensions are in inches.

FABRICATION

1. Laminate orientation: $(45/0/-45/90)_{4S}$. Approximately 8 layers bonded together to make 0.75-inch thick panel, then machined as shown.

INSTRUMENTATION

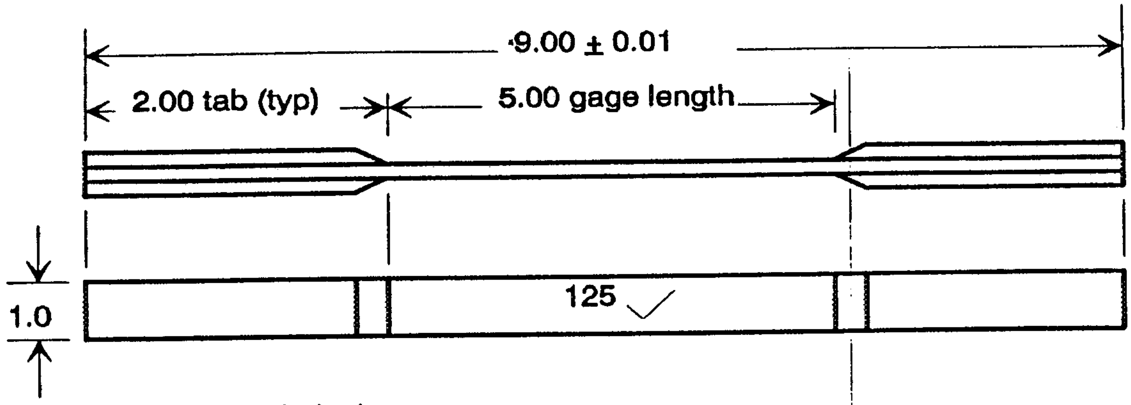
1. To measure shear strains, specimens may be instrumented with a strain gage rosette incorporating two strain gages oriented at $\pm 45^{o}$. These will be 350 ohm strain gages equal or equivalent to Micro Measurements EA06-062TV-350. The gages may be wired as individual channels in quarter bridge circuits, 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 $+ 45^{o}$ or $- 45^{o}$.

TEST

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

Figure 5 IOSIPESCU SHEAR SPECIMEN

ORIGINAL PAGE IS OF POOR QUALITY



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 $\pm 1^{\circ}$.

   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). For tests at -425F, EA9330 adhesive shall be used to bond the tabs, curing at 180F for 2 hours.

INSTRUMENTATION

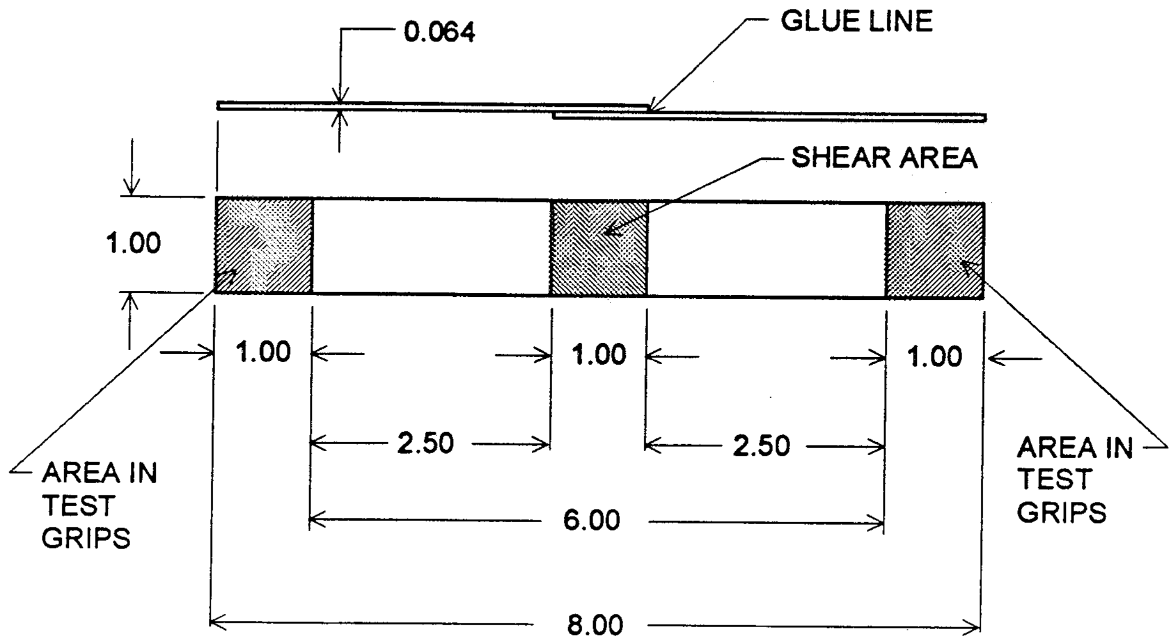
1. Longitudinal and transverse element strain gages.

TEST

1. Test room temperature specimens per SACMA SRM 7-88.

2. Test -425F specimens per SACMA SRM 7-88, and NASA 1142, B.2.4.

Figure 6 INPLANE SHEAR



All dimensions are in inches.

FABRICATION

1. For each adhesive, machine two adherend blanks 5.0 x 4.0-inch from 0.064 +/- 0.005-inch thick 2024-T3 aluminum sheet.
2. Clean and prepare adherend bond surface and apply and cure adhesive per manufacturer's recommendations.
3. Section bonded adherend blanks into individual specimens per the dimensions above.

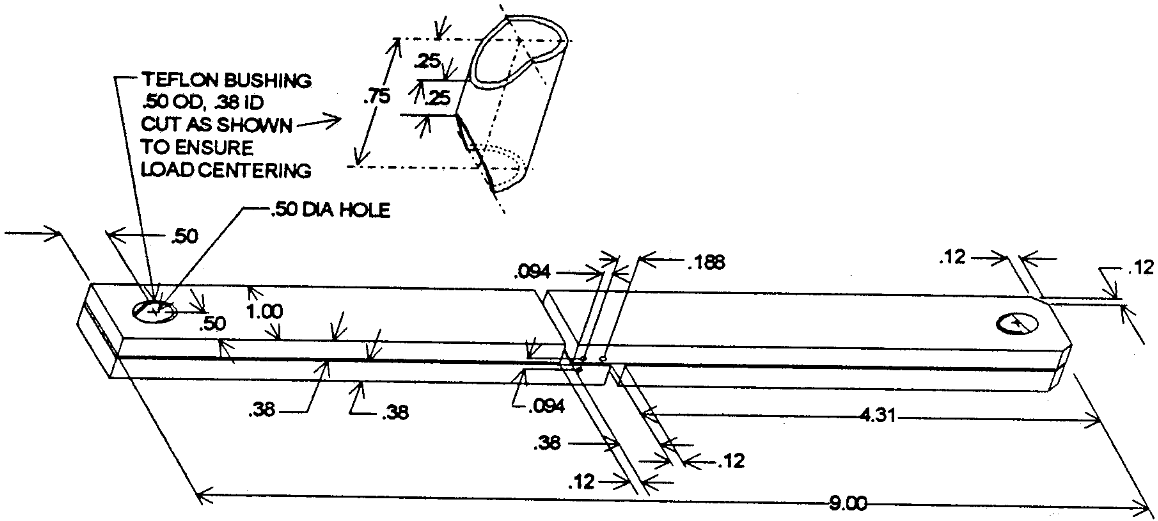
INSTRUMENTATION

None

TEST

1. Test specimens per ASTM D1002.

Figure 7 ADHESIVE LAP SHEAR STRENGTH



All dimensions are in inches.

FABRICATION

1. Machine two adherend blanks 6.0 x 9.0-inch from 3/8-inch thick 2024-T3 aluminum sheet.
2. Clean and prepare adherend bond surface and apply and cure adhesive per manufacturer's recommendations.
3. Machine notches into bonded blank and section into individual specimens per the dimensions above.

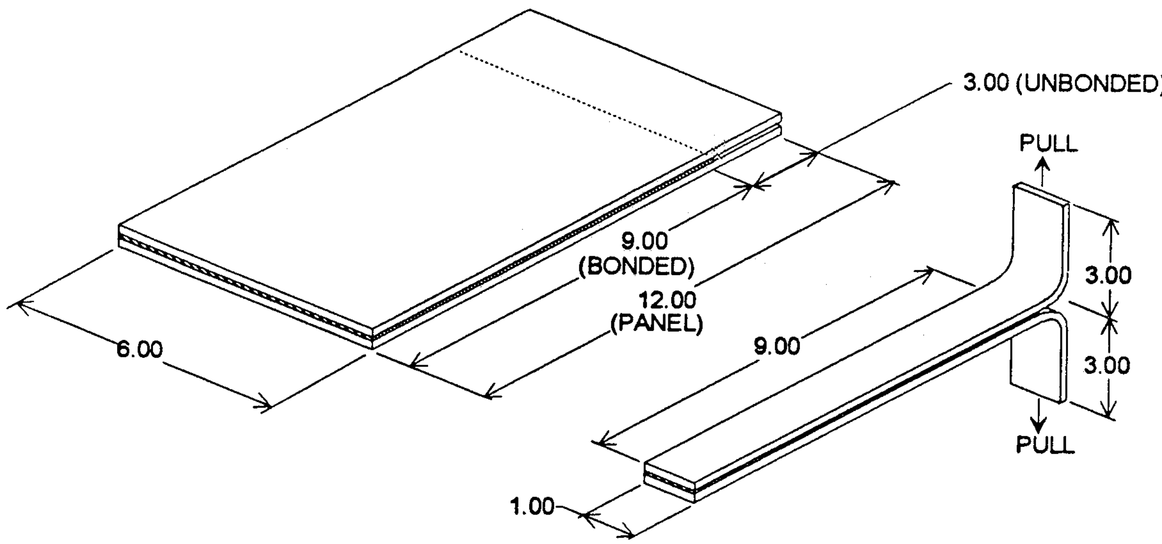
INSTRUMENTATION

Extensometer (or LVDT).

TEST

1. Test specimens at 75 and -425F.

Figure 8 THICK-ADHEREND ADHESIVE TEST



All dimensions are in inches.

FABRICATION
1. Machine two adherend blanks 6.0 x 9.0-inch from 0.032-inch thick INVAR.
2. Clean and prepare adherend bond surface and apply and cure adhesive per manufacturer's recommendations.
3. Section bonded adherend blanks into individual specimens per the dimensions above.

INSTRUMENTATION
None

TEST
1. Test specimens per ASTM D1876 at 75 and -425F.

Figure 9 ADHESIVE T-PEEL STRENGTH

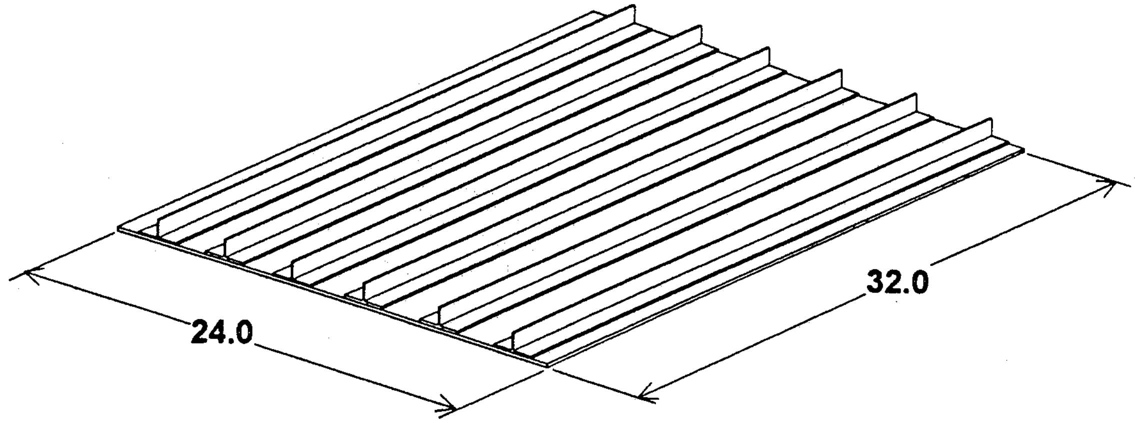


FIGURE 10: Acoustic Fatigue Test Panel (Item 2f)

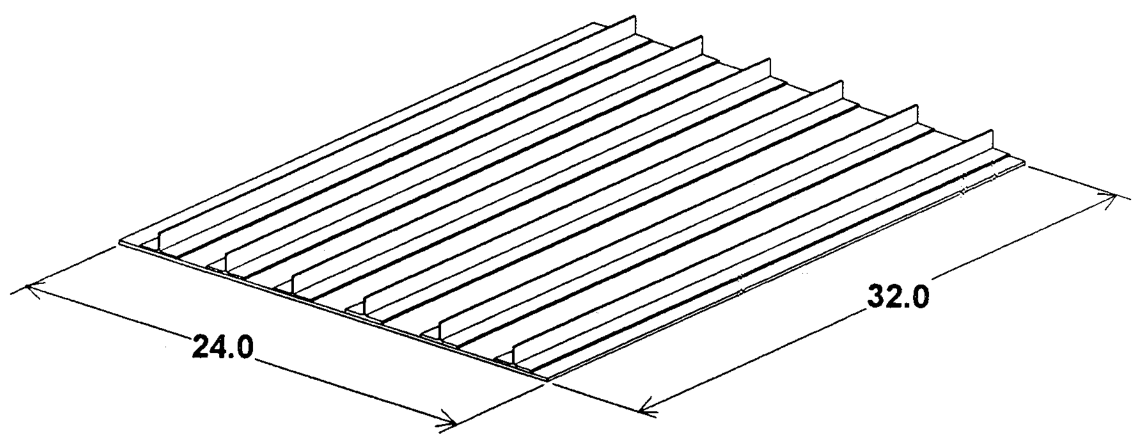


FIGURE 11: Structural Stability Test Panel (Item 2g)

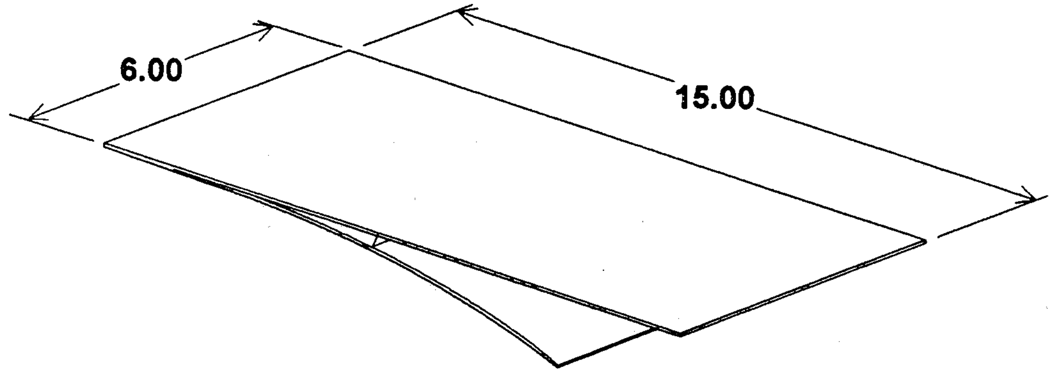


FIGURE 12: Y-Joint Test Article (Item 2h)

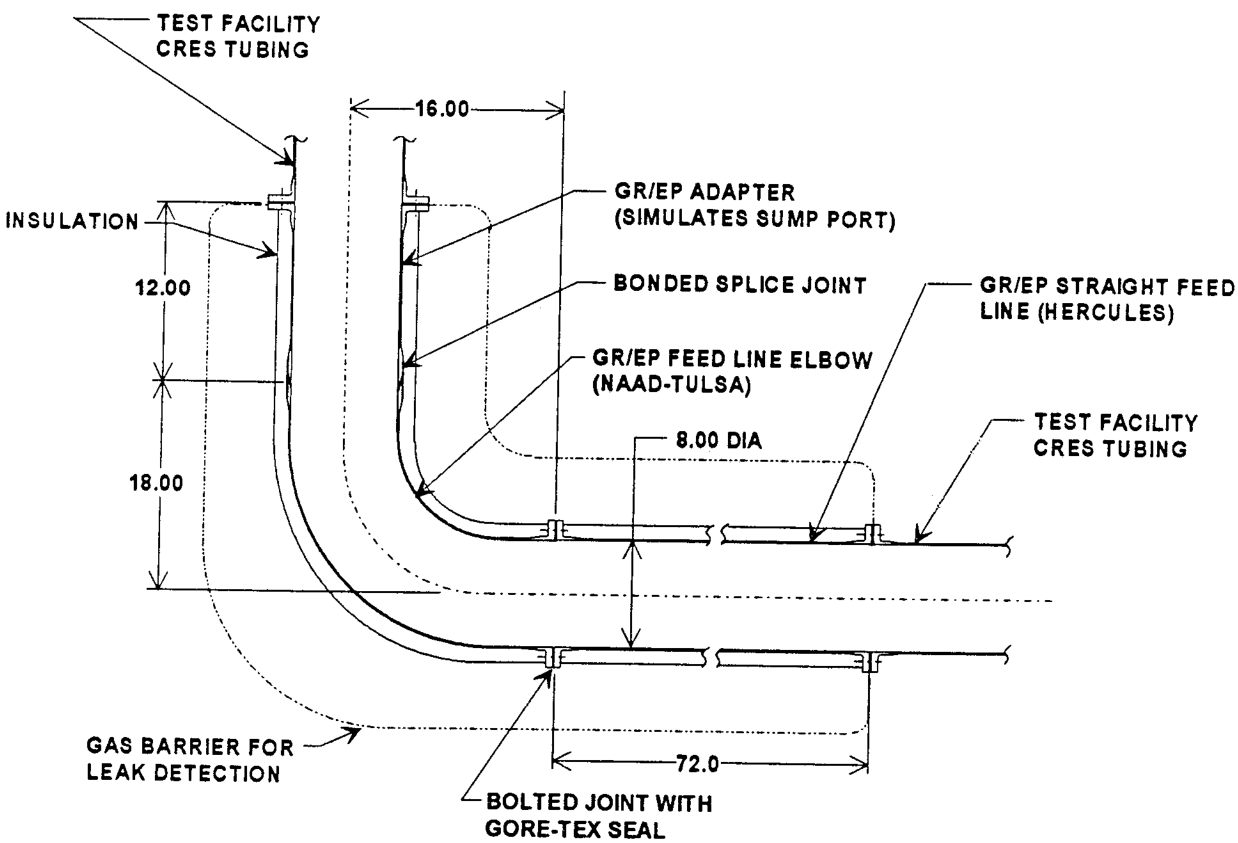


FIGURE 13: Feed Line and Attach Joint Test Article (Item 2m)

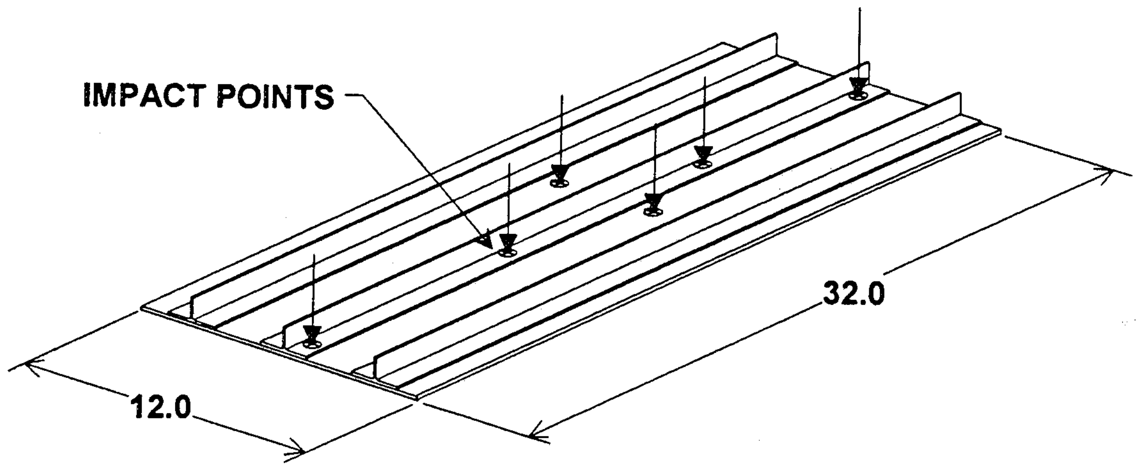


FIGURE 14: Stiffened Panel Damage Tolerance Test Article (Item 2n)

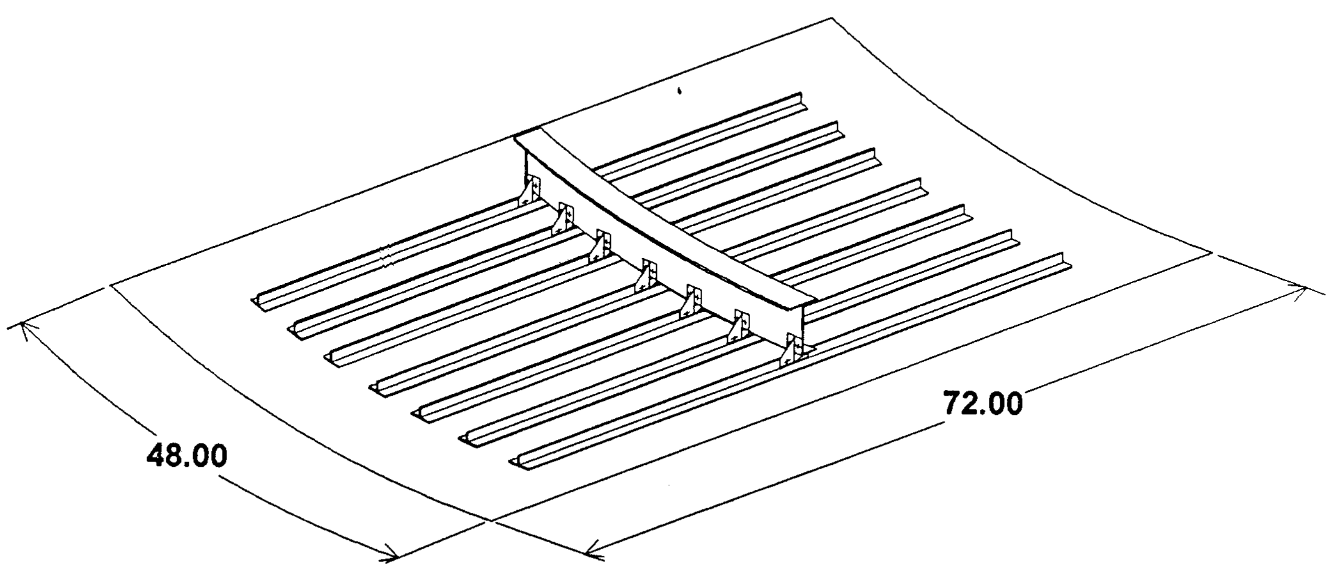
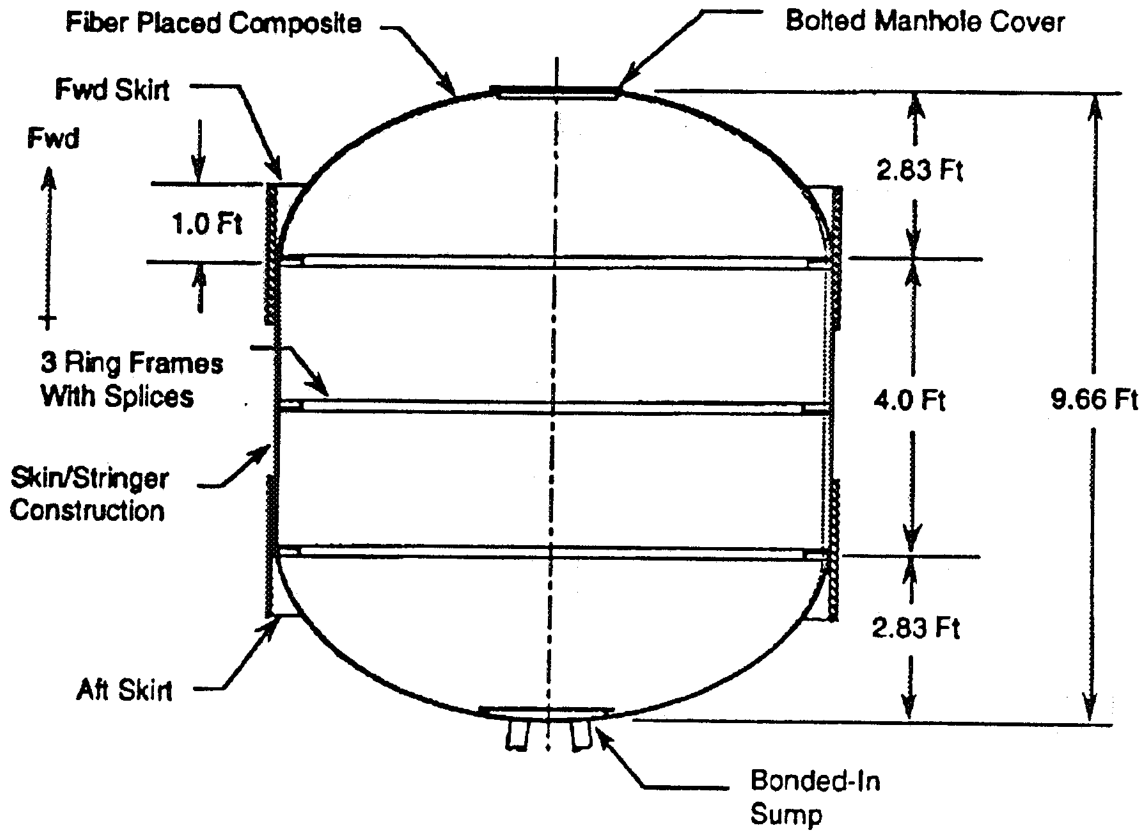


FIGURE 15: Full Scale Subcomponent Test Article



Inboard Profile - 8 Ft. Dia. Tank

FIGURE 16: Scale Model Tank Test Article

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

- 32 -

SKETCH - TEST SET UP:

REMARKS:

MAT'L DATA	TYPE	BATCH
PREPREG		
ADHESIVE		
CORE		
LAMINATE/PLY		

DATE:
DEPT NO.:
REQUEST BY:

Rockwell
NAAD - Tulsa Facility
LABORATORY TEST DATA

DEPT NO.:
WITNESS:
DATE:
DEPT NO.:
TESTED BY:
PAGE ___

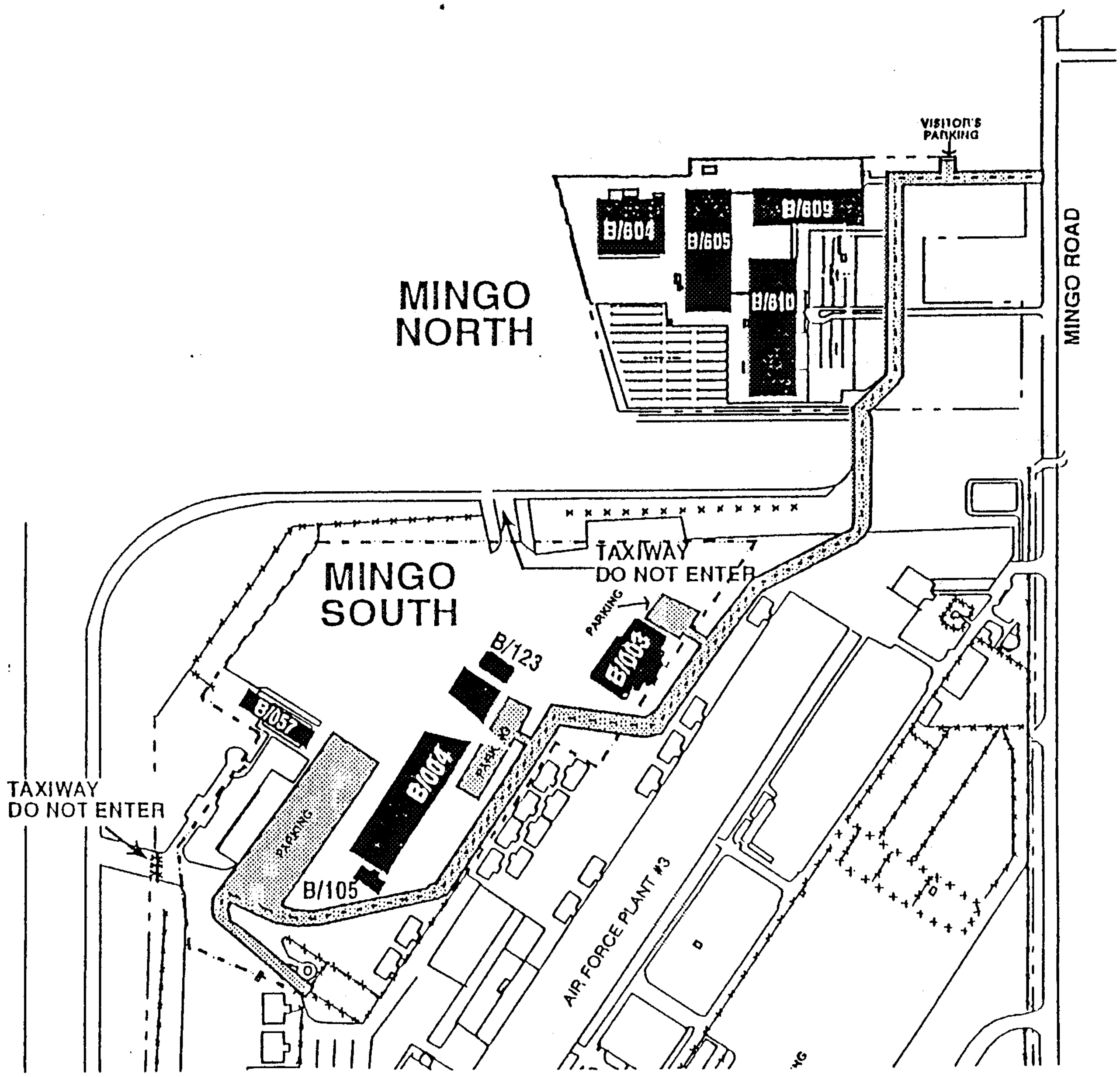
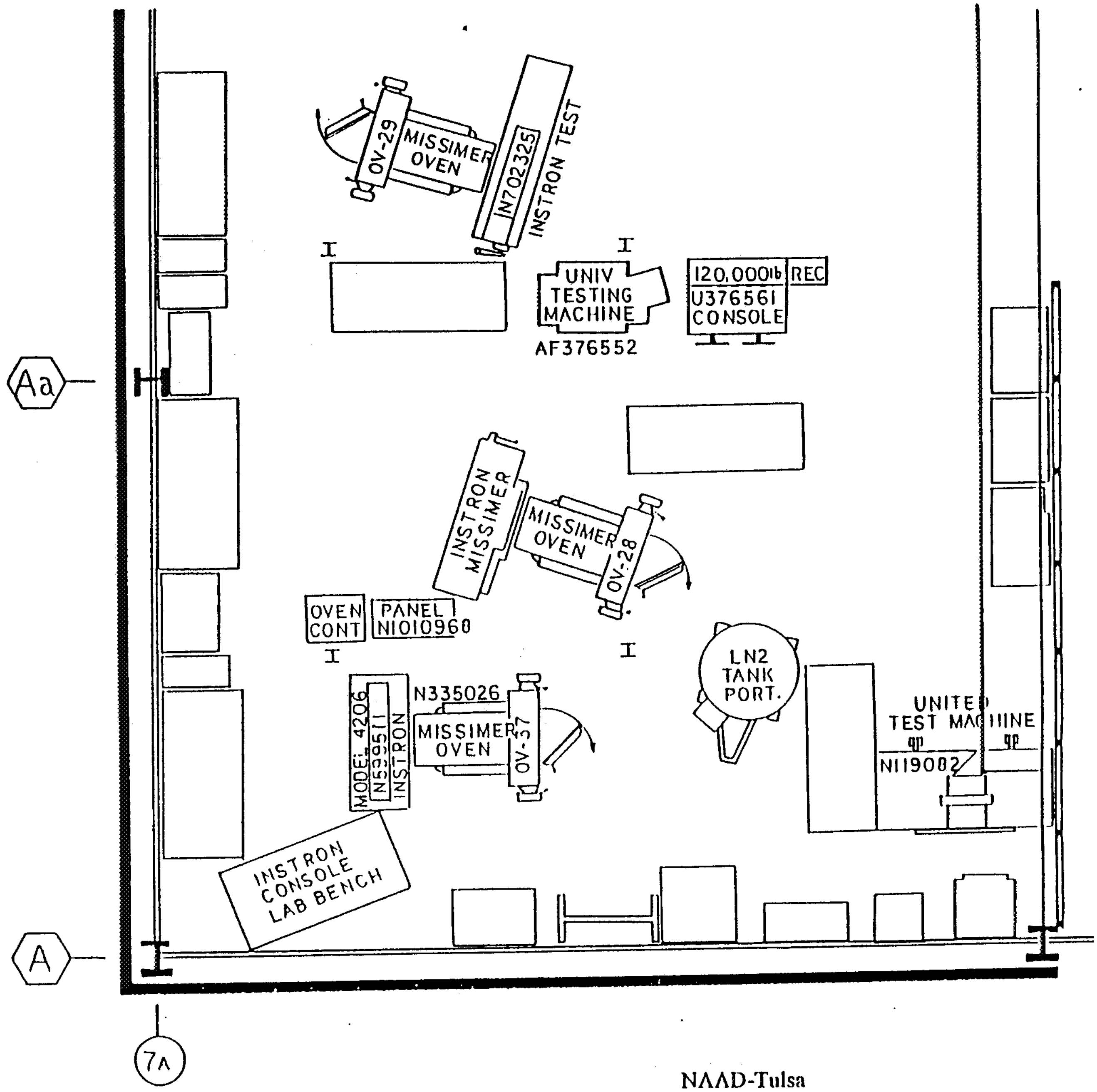


Figure 18

Rockwell

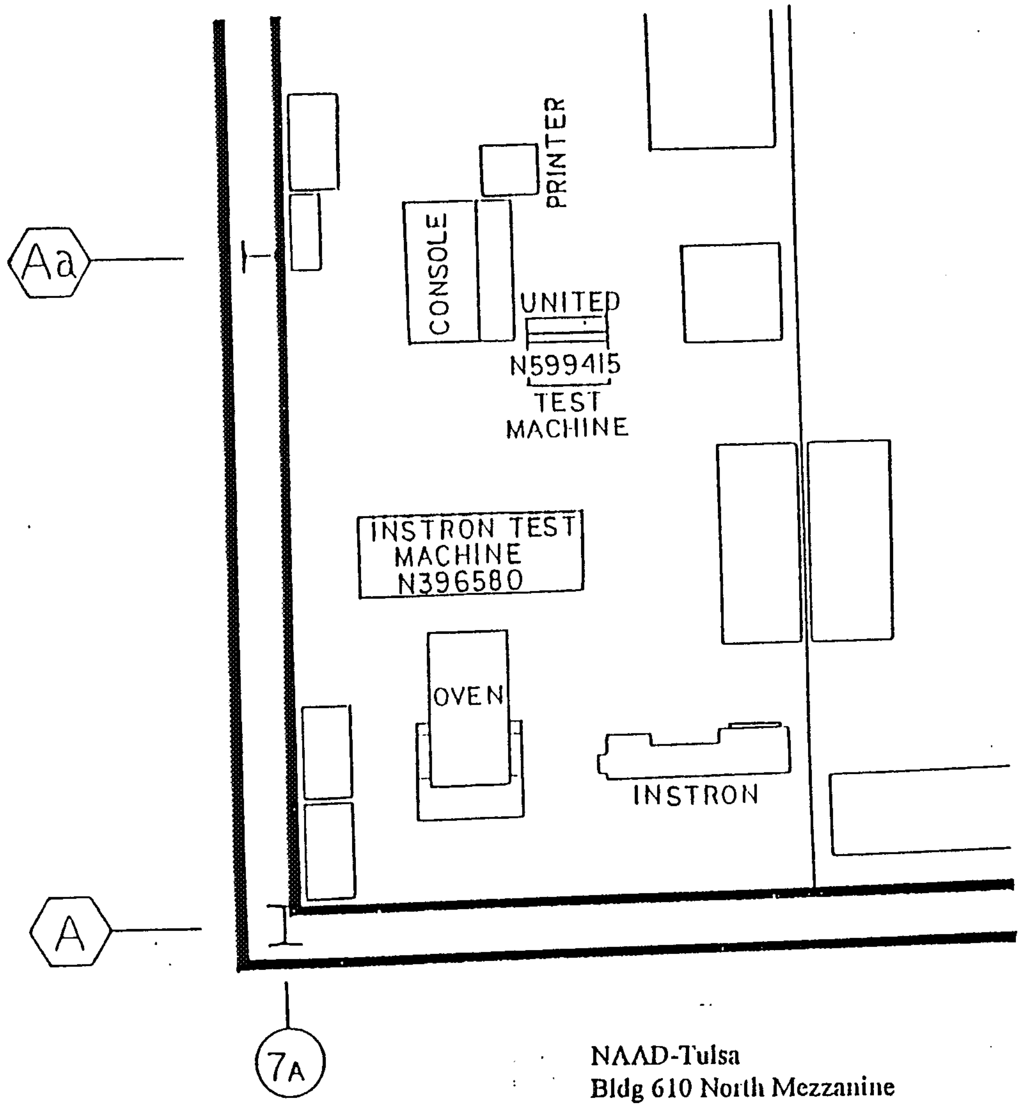
TULSA FACILITY



NAAD-Tulsa
Bldg 610 North First Floor

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

Figure 19 TEST EQUIPMENT LAYOUT



NAAD-Tulsa
Bldg 610 North Mezzanine

Figure 20 TEST EQUIPMENT LAYOUT

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

SACMA
Suppliers of Advanced Composite Materials Association

ORIGINAL PAGE IS OF POOR QUALITY

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.

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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

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Association

RECOMMENDED METHOD
SRM 7-88

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

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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