GT Schjeldahl / ADVANCED PROGRAMS DIVISION

G. T. SCHJELDAHL COMPANY • NORTHFIELD, MINNESOTA 55057 • PHONE 507-645-5633

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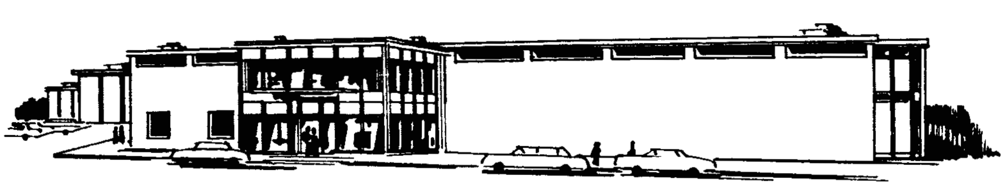


PUTTING TOMORROW'S MATERIALS TO WORK TODAY

G. T. SCHJELDAHL COMPANY
Northfield, Minnesota

DEVELOPMENT OF A 425 FOOT DIAMETER PASSIVE COMMUNICATION SATELLITE WITH SELF-ERECTING PROPERTIES

Submitted to:

National Aeronautics and Space Adminstration
Goddard Space Flight Center
Greenbelt, Maryland

Quarterly Progress Report No. 8
and
Monthly Progress Report for May ~~No. 24M~~

Contract NAS5-3943

Mr. A. L. Hedrich
Technical Officer

Mr. F. Ringe
Contracting Officer

Prepared By:

William Jacobi, Project Engineer

Approved By:

William J. Haugen, Program Manager

E. A. Basquin, Report Editor

1.0 INTRODUCTION

The objective of this program is to develop a material with the following characteristics:

1. Ability to erect without an inflation system or external aids.
2. Open mesh configuration, 90 per cent transparent to solar radiation.
3. Rigidity to withstand solar pressure with a safety factor of 5.0.
4. RF reflectivity (8-9 GHz) 95-98 per cent that of a similar solid surface.

This report discusses work carried on during the March-May period.

The investigation of various sizing materials was begun and these results are presented. An experiment was designed to determine the heat treatment necessary for highest rigidity. This report includes the results of a preliminary study of aluminum as the conductive coating. The aluminum was deposited in NASA-owned vacuum chambers. (NAS5-3515).

A means of evaluating the rigidity after folding was developed. Results of this testing are presented.

High speed motion pictures were taken of several cylinders in an attempt to examine this material during deployment studies.

2.0 SUMMARY

A production run was made in May. Hess Goldsmith Style No. 18601 was copper-plated using the equipment built under this contract. Two 4-ft by 6-ft panels were fabricated from this material and sent to Goddard Space Flight Center.

During this quarter the effect of sizing agents on self-erecting material was investigated. At this point, polyvinyl alcohol appears an excellent size.

A number of 7 1/2-inch diameter cylinders were made from the material produced in May. These 12-inch high cylinders were used in a series of rather crude deployment experiments. High-speed motion pictures were taken during these studies. Several frames of these are printed here to demonstrate the self-erecting properties.

A specification for evaluation of self-erecting materials is included in this report.

3.0 DISCUSSION

In April, a fiberglass scrim fabric was purchased from Hess Goldsmith. The fabric has a style designation of 18601. This fabric was very similar to the material processed in the past, style 18539. It is woven in a leno pattern and has ten threads to the inch. The difference lies in the yarn used. Style 18539 consisted of 900 ECB 1/0 1.0 Z thread whereas style 18601 was woven from 450 ECB 1/1 1.0 Z in the fill direction, and 450 ECB 1/0 1.0 Z in the machine direction. This results in a heavier fabric weighing 1.82 mg/cm^2, compared to 18539's weight of 0.69 mg/cm^2. The width of 18601 was received 39 inches wide with two trim edges 1/2-inch wide.

This material was processed the same as past material in the following manner:

1. Heat treatment,
2. Binding,
3. Electroless plating,
4. Sheath layer coating.

These steps will be discussed in more detail below.

3.1 HEAT TREATING

The material was rerolled onto a 3-inch OD aluminum core and placed in a forced air oven. Table I shows the temperature in the oven with respect to time.

TABLE I

Time (Min.)	Temperature (^{o}F)
0	370
15	450
30	460
45	470
60	480

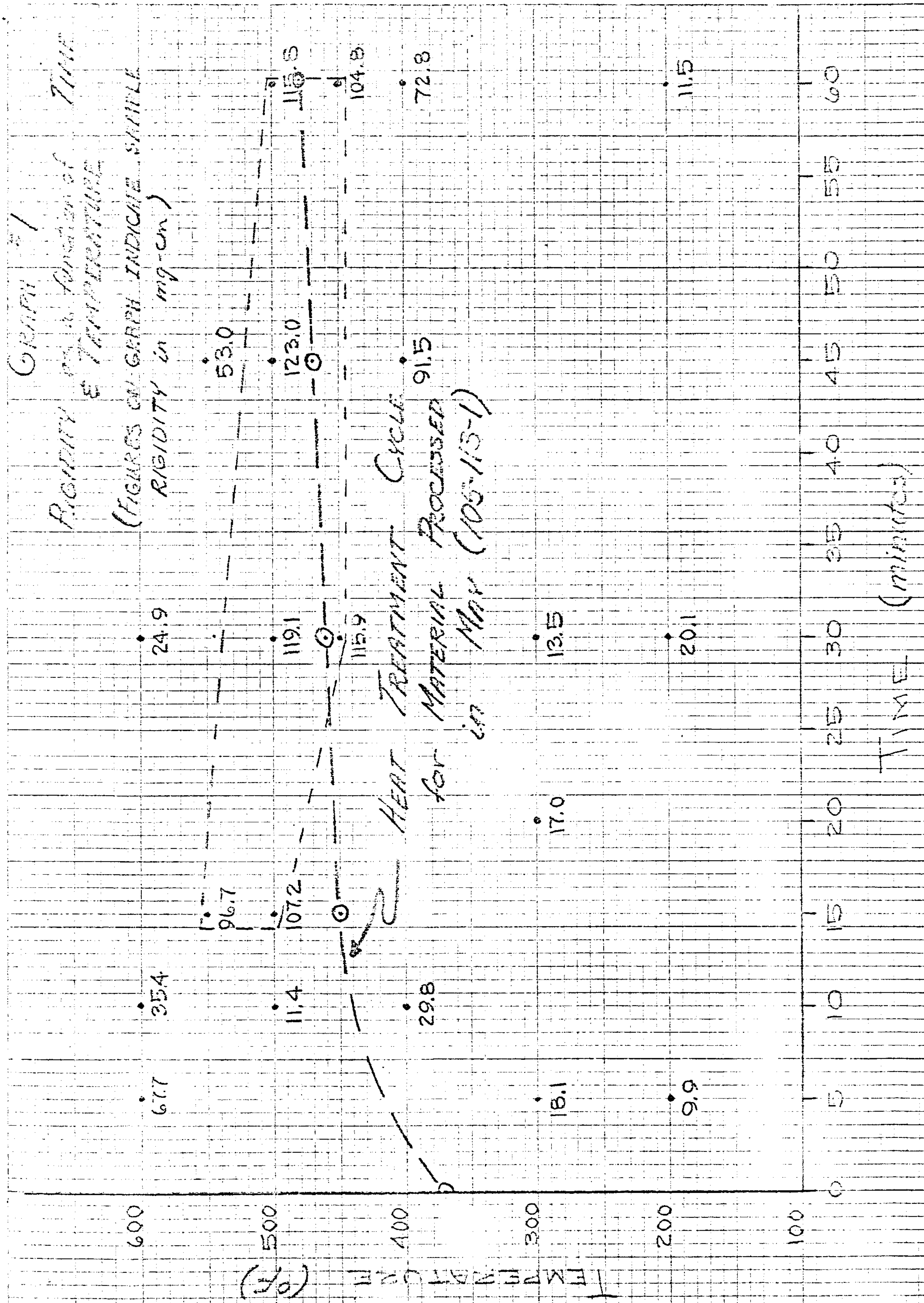
The weight after heat treating was 1.77 mg/cm^2. This amounts to a 2.75 per cent weight loss. The rigidity was calculated of this heat treated material and found to be 339 mg-cm on the inside of roll (end A). The rigidity was 255 mg-cm on the outside of the roll (end B). As in the case of the material heat treated in February, there is a permanent set in the material.

The heat treating cycle described above for 18601 has been added to Graph No. 1 as presented in the April progress report. It can be seen that the curve falls within the boundaries defined in the earlier heat treatment study. The data for which the graph was drawn covers Hess Goldsmith Style 18539; however, as the sizings are similar, this comparison is pertinent.

3.2 GT-201 COATING

The material was then coated with GT-201 in the silicone rubber coating section of the processing equipment. The solids content was controlled to apply a 0.12 mg/cm^2 coating, which appeared to be uniform throughout the roll. Upon completion of the coating step, the material was inspected and judged to have poor strength at the yarn intersections. The rigidity of end A was 611 mg-cm, and of End B, 346 mg-cm. The material weight was 1.89 mg/cm^2.

A second coat of GT-201 was applied to the material in an attempt to


GRAPH #1
RIGIDITY as a function of TIME & TEMPERATURE
(FIGURES ON GRAPH INDICATE SAMPLE RIGIDITY in mg-cm)
HEAT TREATMENT CYCLE for MATERIAL PROCESSED in MAY (105-115-1)
TEMPERATURE (°F)
600
500
400
300
200
100
TIME (minutes)
0
5
10
15
20
25
30
35
40
45
50
55
60
67.7
18.1
9.9
35.4
11.4
29.8
96.7
107.2
17.0
24.9
119.1
115.9
13.5
20.1
53.0
123.0
91.5
115.6
104.8
72.8
11.5

tie the yarn bundles together better. On this second application, the average weight gain was 0.14 mg/cm^2. The rigidity of end A after two coats was 823 mg-cm, and of end B, 1042 mg-cm. Strength of the mesh at the yarn intersections had increased after this second coat. The machine was slowed to 6 in/min for this operation, which allowed for a 20 min. drying time in the tunnel.

3.3 PLATING STEP

Using the 6 inch/min. speed, the material described above was plated. By running at half speed, only one plating tank and one-half the amount of sensitizer and activator solutions were needed to maintain the proper residence times. The same techniques as those developed during February were used on this run. The pH was controlled at 12.4 to 12.6 and the temperature was held at 20 to 21 C. The resistivity of the plated material was taken at the beginning and end. It was found to be 0.8 ohms per square and 0.7 ohms per square, respectively. The plating operation produced a good copper deposit. The weight of the material after the copper was deposited was 2.17 mg/cm^2, and the rigidity of end A was 701 mg-cm, while end B was 900 mg-cm.

3.4 SILICONE PRIME STEP

The silicone prime step was evaluated for the first time during this run. The weight addition due to this step is 0.11 mg.

3.5 SILICONE RUBBER COATING STEP

As before, the final coating of silicone rubber was applied to the mesh. Approximately 0.5 mg/cm^2 was added to the weight. This material was given a laboratory notebook number 105-113-1 and is complete. End B had a rigidity of 859 mg-cm. End A was not tested. Table II lists tensile strengths of 105-113-1.

TABLE II

TENSILE STRENGTH 105-113-1

Machine Direction

1.	29.0
2.	26.0
3.	27.3
4.	27.3
5.	28.5
Average	27.6 lb/inch of width

Transverse Direction

1.	14.0
2.	26.5
3.	20.2
4.	20.3
5.	18.1
Average	19.8 lb/inch of width

45° Angle

1.	0.7
2.	0.8
3.	0.8
4.	0.5
5.	0.6
Average	0.68 lb/inch of width

3.6 PANELS

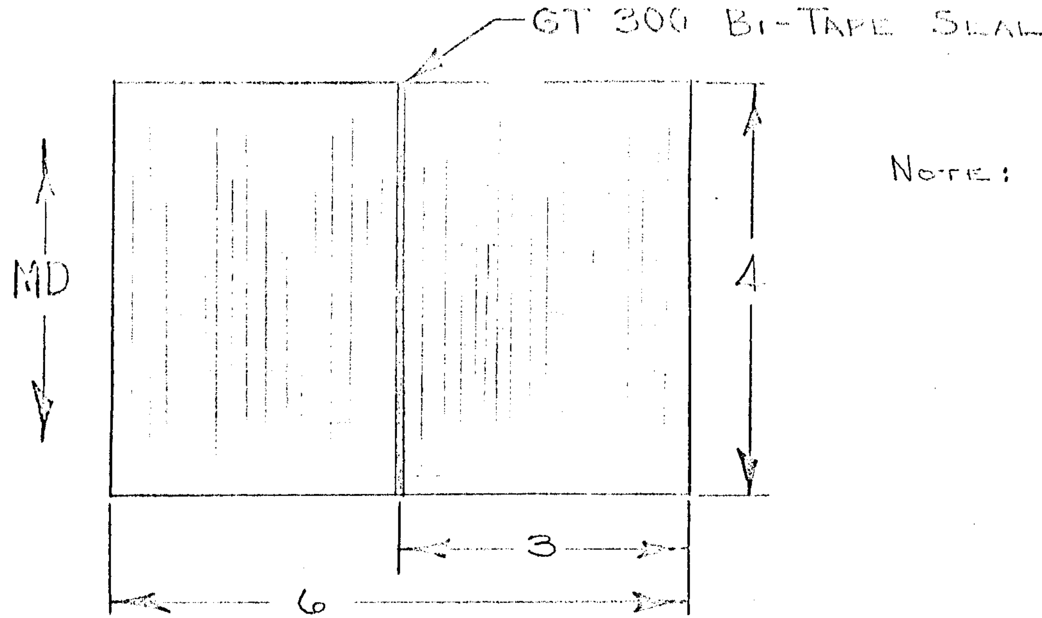
Two 4 by 6-foot panels were sent to Goddard Space Flight Center. Figure 1 shows the configuration. The seams are the same as those used on earlier hardware.

3.7 DEPLOYMENT STUDY

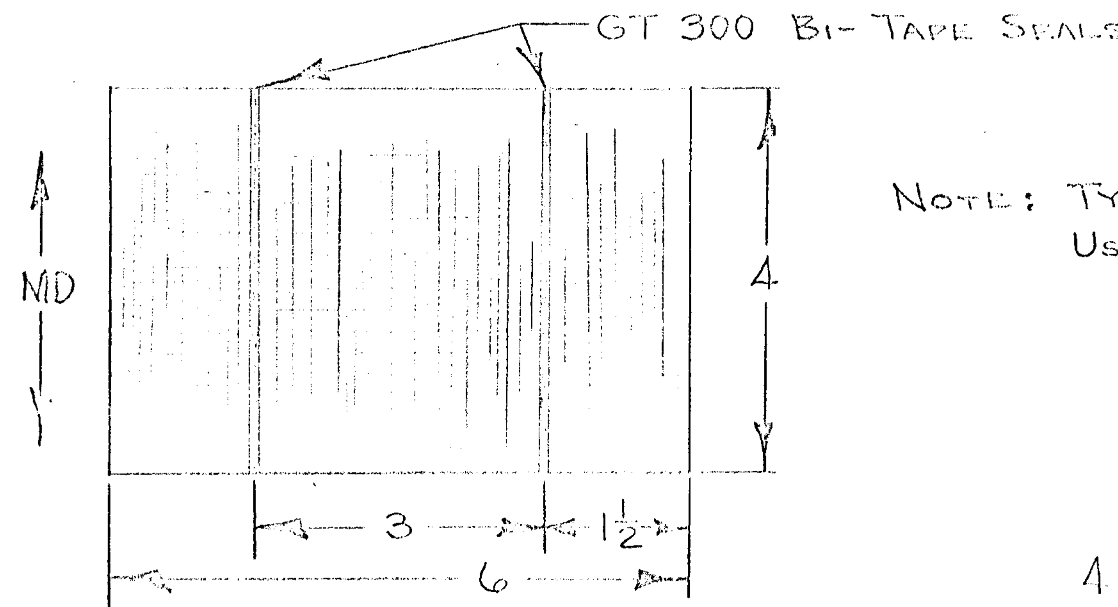
A canister was designed to package cylinders of 105-113-1. The cylinders are 7 1/2 inches in diameter and 12 inches in height, and the canister was designed to hold the cylinder in a space 12 inches by 2 inches by 1/8 inch. These dimensions are based on a packing factor of 3.0. Figure 2 is a descriptive drawing of this design. This canister was set up in front of a camera and slow motion pictures were taken during the cylinder erection. Frames of these sequences were selected and are grouped in Figure 3. Figure 3a shows the packed canister prior to the release, 3b the point where the canister is falling away. In Figure 3c, the cylinder is well on its way to deployment, while final picture 3d shows the ultimate shape of that cylinder.

Tests were also run on a cylinder with flat ends. Two sequences are shown in part here. Figure 4 shows how a right cylinder erects under 1 g. To evaluate this, the cylinder was merely flattened perpendicular to the axis. When released, the cylinder popped up quickly and competely.

The cylinder was then folded to a size approximately 2 in by 2 in by 3/4 in, and tossed lightly into the air. Figure 5 shows the manner in which the cylinder deployed. The elapsed time during these pictures was approximately 0.5 sec.

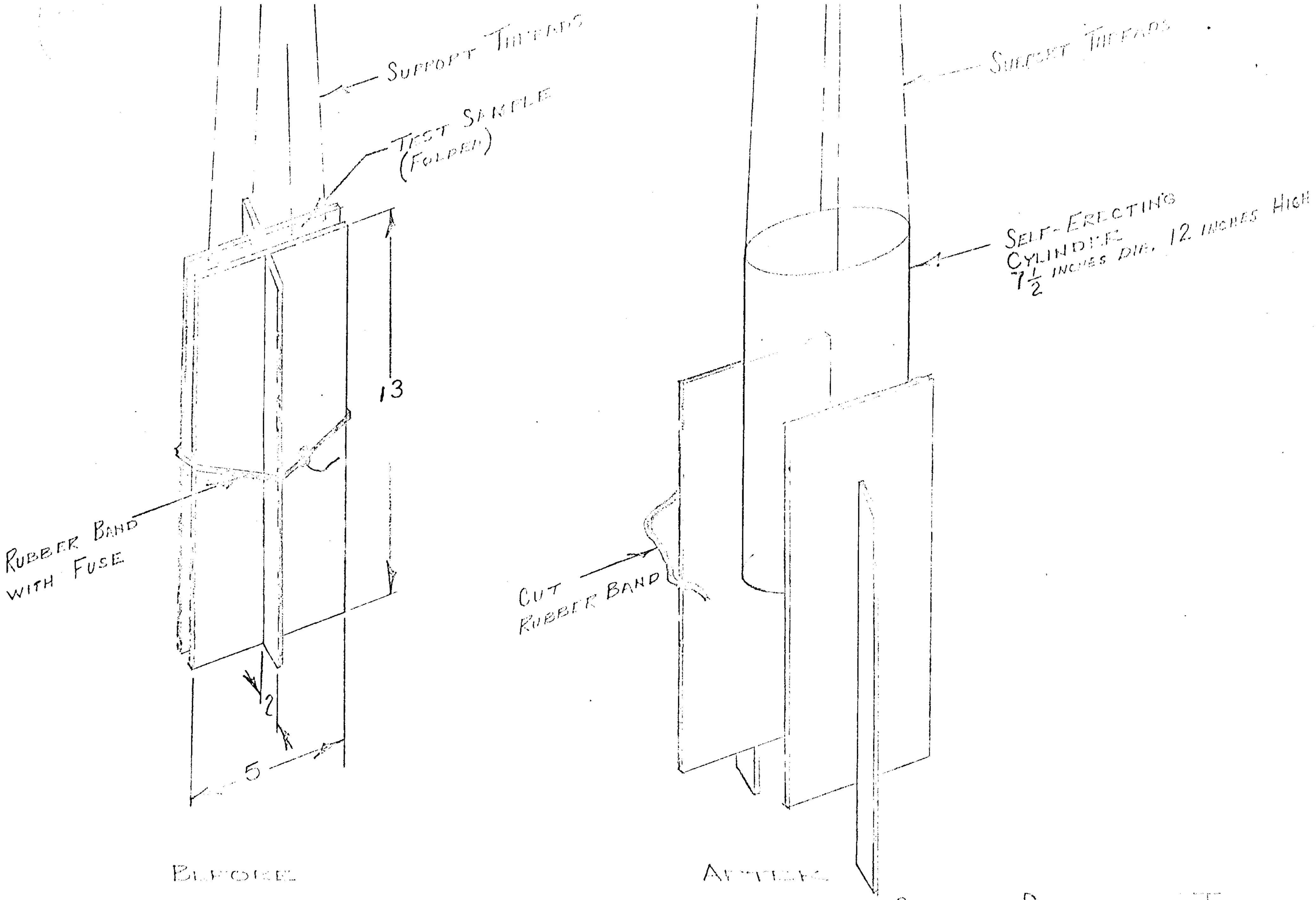


NOTE: TYPE A
USED ON 105-118-1

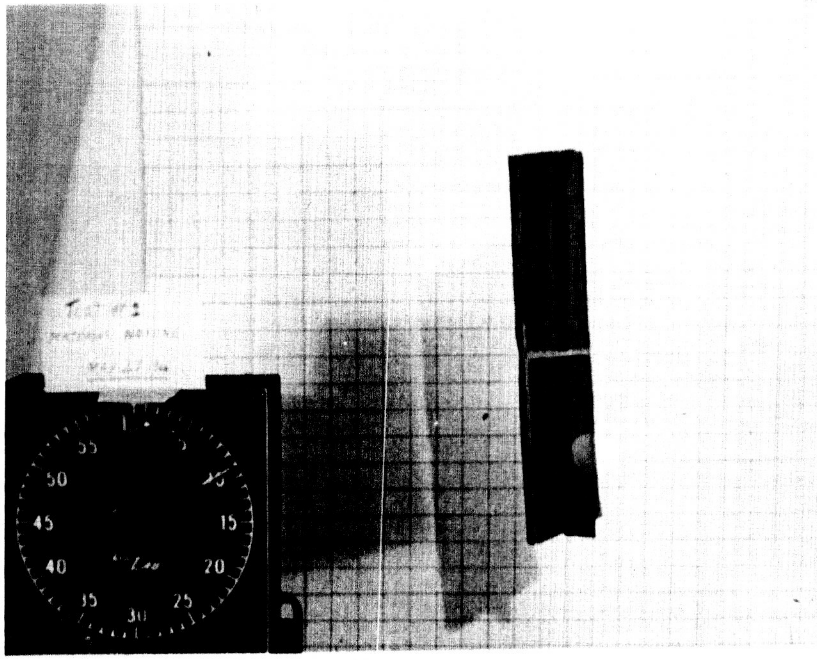


NOTE: TYPE B
USED ON 105-118-2

4 FT. X 6 FT. PANELS
24456-17 6-25-66



Cylinder Deployment Test
6-20-66



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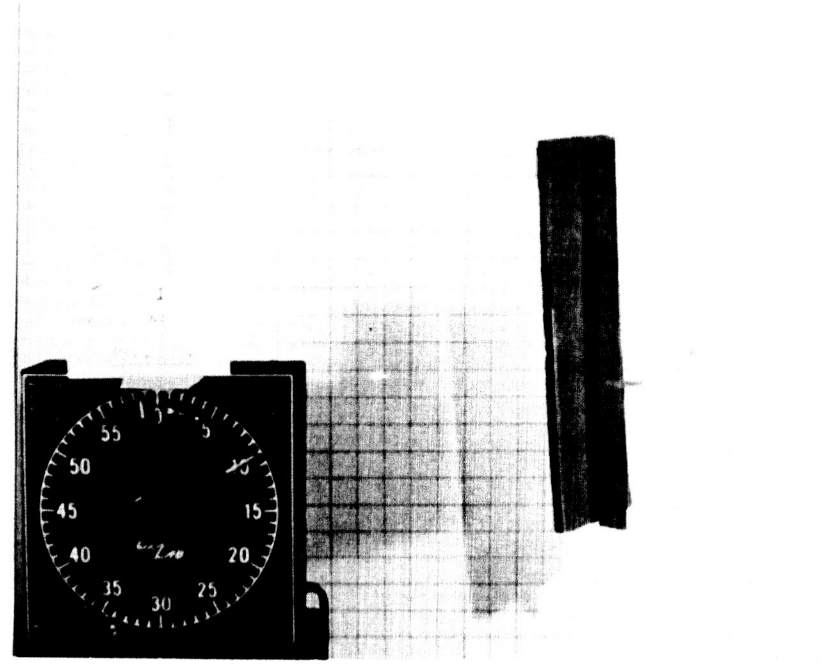

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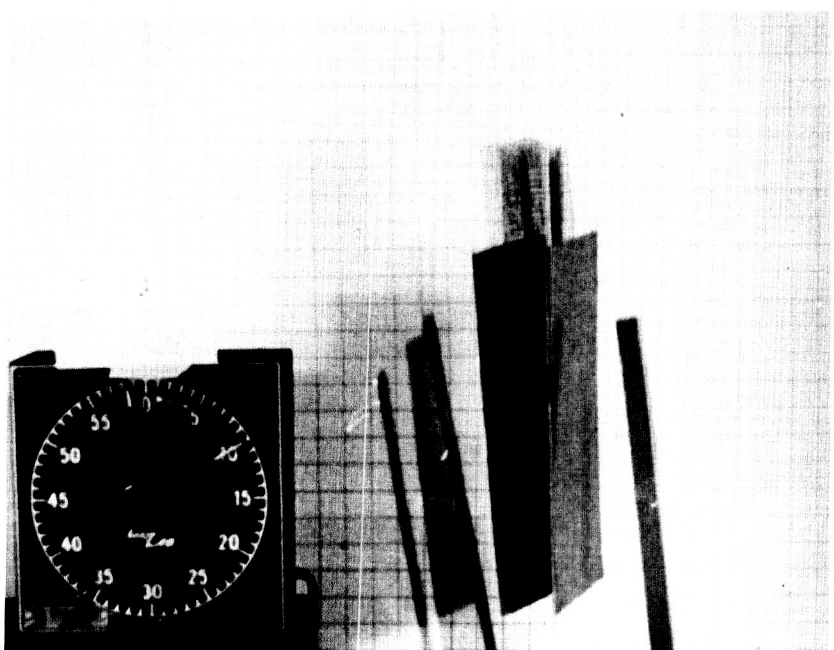

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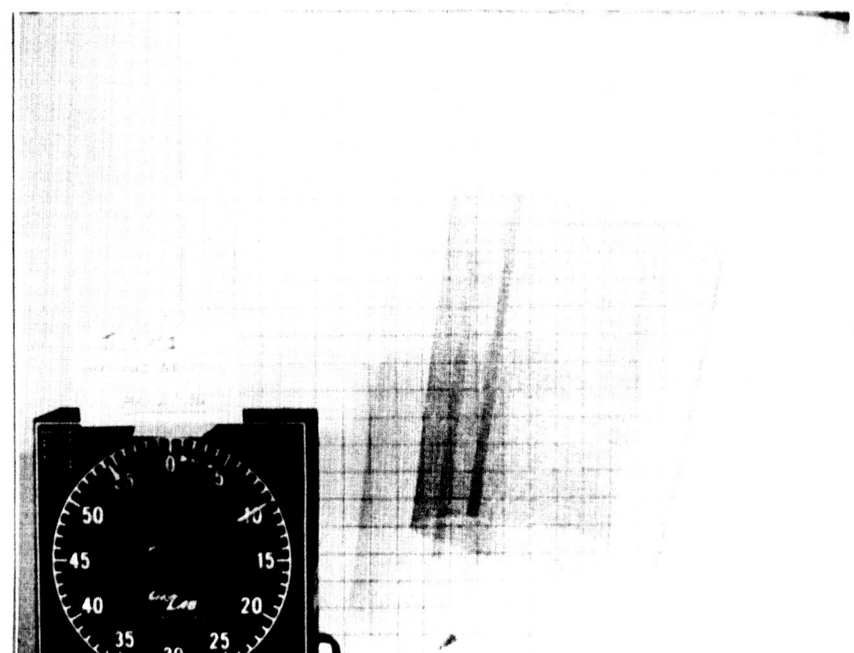

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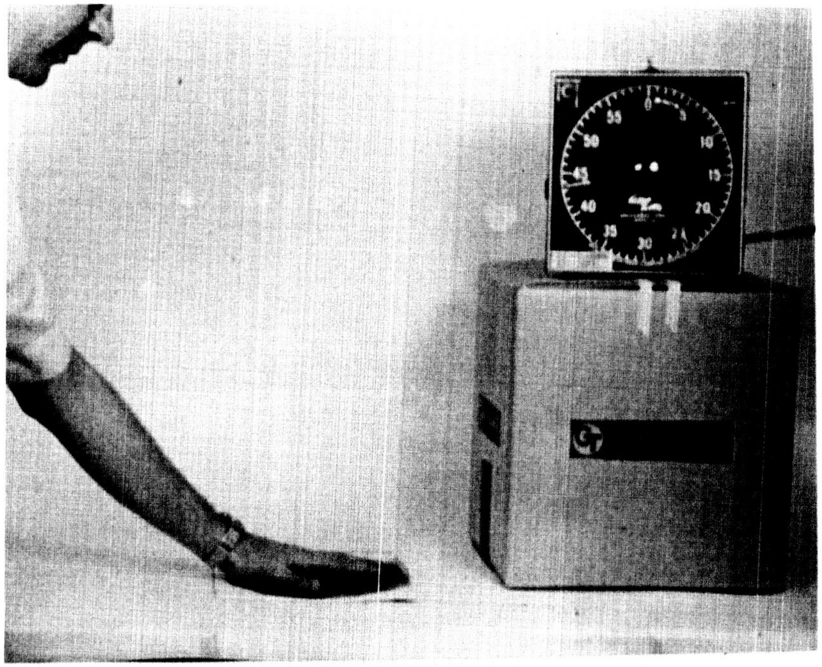
Figure 3



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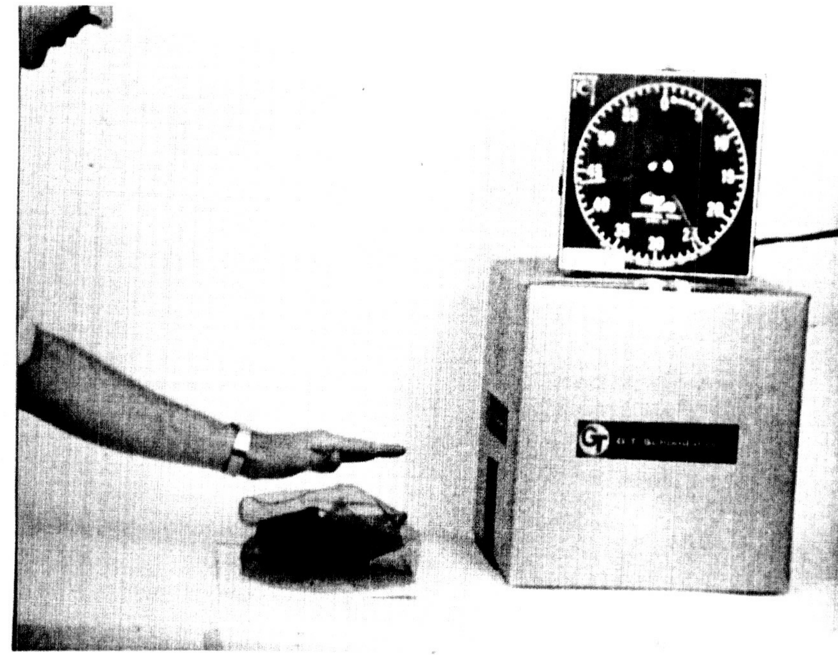

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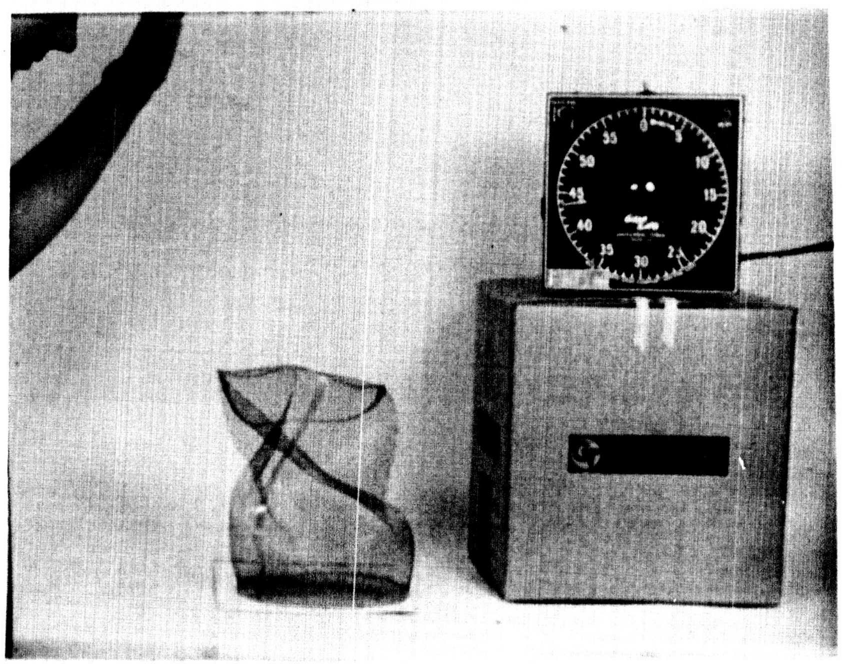

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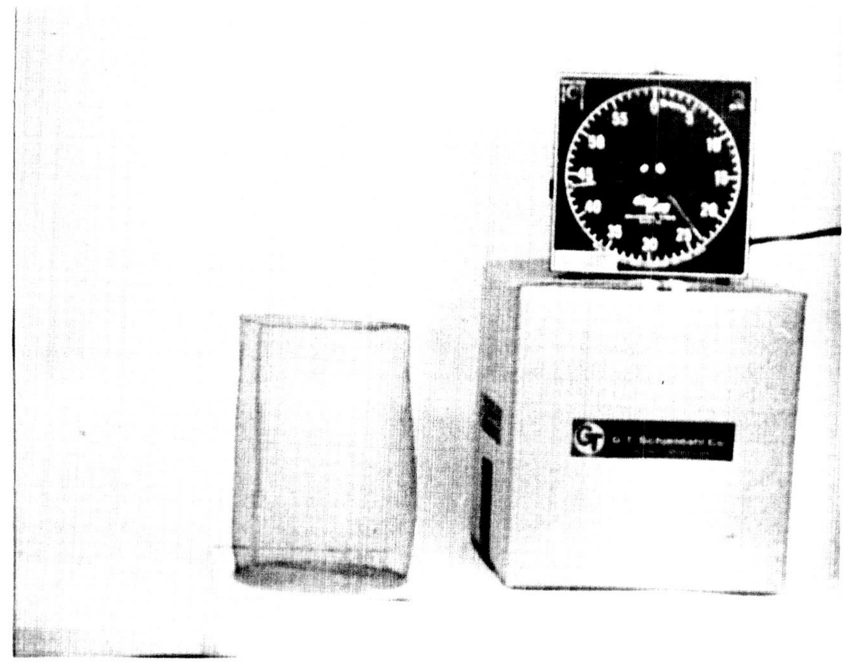

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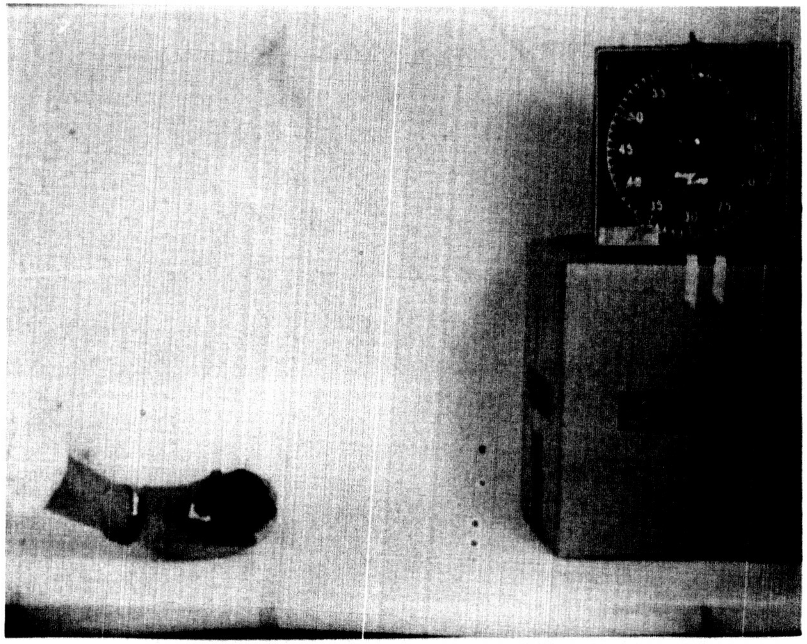
Figure 4



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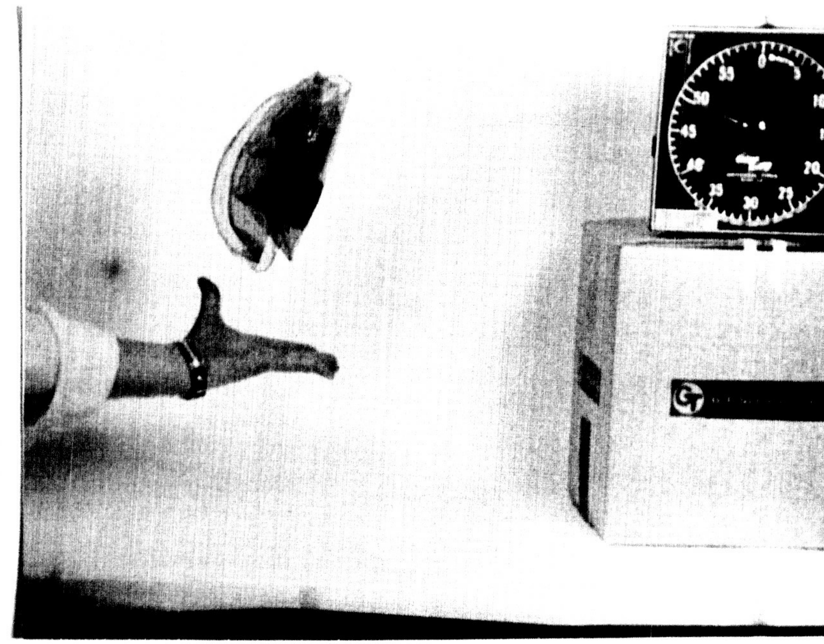

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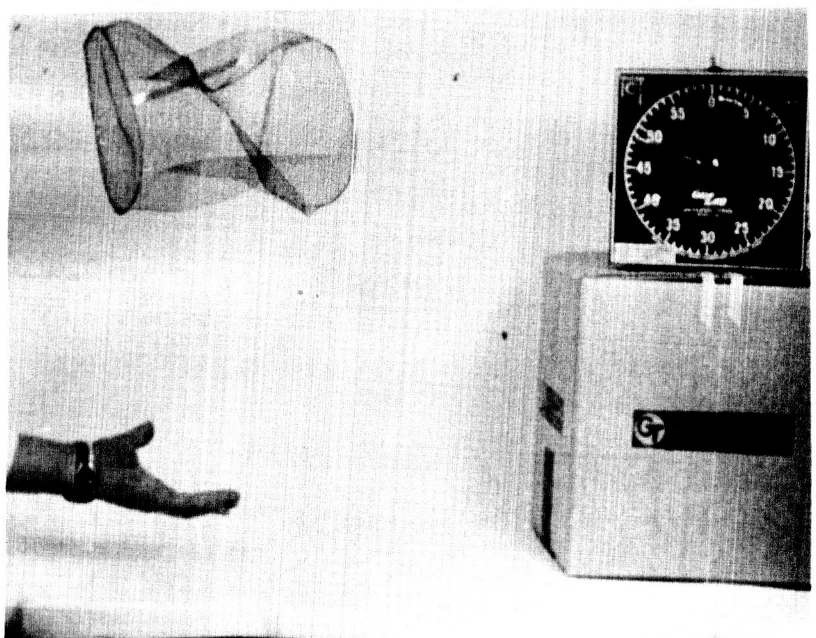

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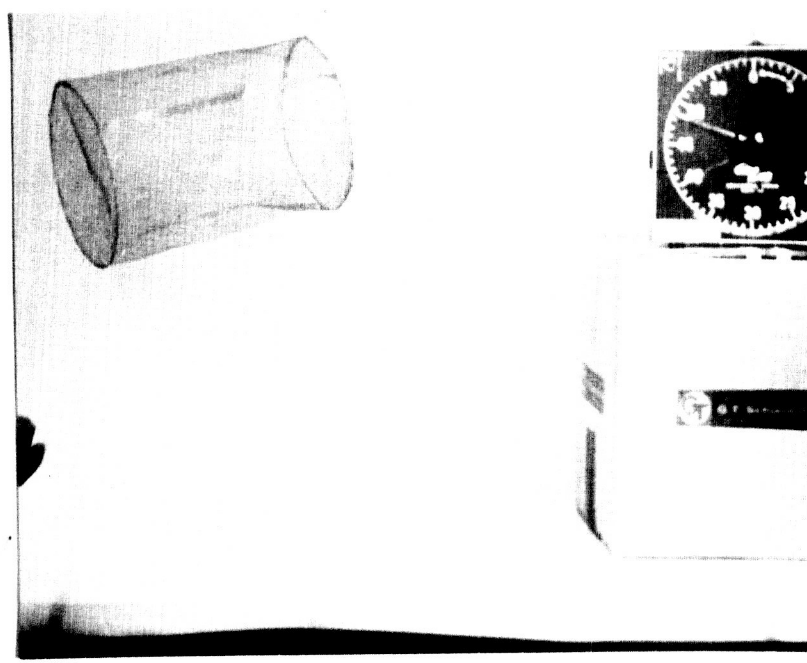

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Figure 5

3.8 SIZING STUDY

The investigation of sizing the fiberglass fabric continues through this period. Table III shows the results. Various types of materials are included in this work. The weight increase is listed for each sample in per cent over uncoated weight. A ratio of rigidities of the sized samples to the uncoated material is shown.

A rigidity factor is also presented which attempts to classify the coating by dividing rigidity ratio by the per cent weight increase. These figures indicate that polyvinyl alcohol is the most efficient sizing evaluated, as shown by sample No. 6 in the Table.

Further work will be done to determine the best sizing agent for this material.

TABLE III

Sample No.	Fabric Style	Size	Weight	% Increase Weight	Rigidity	Ratio Sized Rigidity Original	Rigidity Factor
1.	18601	---	1.82	---	135.5	---	---
2.	18601	7011(Dextrin)	1.96	7.7	831	6.13	0.803
3.	18601	HA16 (Acrylic)	2.81	54.4	1,456	10.70	0.197
4.	18601	HA16 (Acrylic)	1.94	6.6	701	5.17	0.78
5.	18601	E32 (Acrylic)	1.93	6.05	451	3.32	0.552
6.	18601	50-42 (PUOH)	1.90	4.5	1,373.5	10.1	2.22
7.	18601	50-42 + (PUOH) GT 200	2.12	16.5	1,485.0	11.0	0.67
8.	18601	72-05 + PUOH	2.11	16.0	1,357.0	10.0	0.63

TABLE IV

Length of Time Folded Under 7-lb. Weight	Angle Tested At	Length to Meet Angle Sample 1	2	3	Average	Stiffness of Fold mg-cm	
5 minutes	10	---	5.4	5.35	5.38	318	
	20	6.4	6.9	6.6	6.64	259	306
	41.5	9.0	10.55	9.85	9.80	341	
30 minutes	10	3.8	---	---	3.80	112	
	20	4.45	---	---	4.45	86	93.5
	41.5	6.7	4.75	6.8	6.08	81.5	
16 hours	10	3.6	3.3	2.6	3.2	67	
	20	5.45	5.25	5.45	5.38	152	134.3
	41.5	7.1	8.05	7.9	7.68	164	
122 hours	10	2.2	1.7	---	1.95	15.2	
	20	3.4	2.7	---	3.05	27.7	36.7
	41.5	6.4	5.0	---	5.70	67.1	

3.9 FOLDING TEST

A simple test was developed to determine the rigidity after creasing by merely placing a weight on a folded one inch wide sample. These creased samples were then placed on the rigidity tester (as per ASTM D-1388). The overhanging portion was cut so that it deflected more than 41.5 degree. The sample was then trimmed until the overhanging portion was at a 41.5 degree angle. This distance was recorded and a rigidity was calculated from this. The sample was then trimmed further until the overhang was at a twenty degree angle and rigidity calculated. The sample was then further shortened until the overhanging portion paralleled the 10 degree mark on the tester. Table IV lists these results with the calculated rigidity of the crease. The values reported in this table are an average of the inside and outside of the fold. The data indicate that the rigidity is affected by creasing and further work is planned to determine how appropriate this test procedure is. Table V summarizes these findings by comparing the average rigidity at each time interval with 105-113-1 that has not been folded.

TABLE V

Material	Condition	Time	Rigidity mg-cm
105-113-1	Unfolded	--	859
105-113-1	Folded	5 minutes	306
105-113-1	Folded	30 minutes	93.5
105-113-1	Folded	16 hours	134.3
105-113-1	Folded	122 hours	36.7

Material processed in February was evaluated during this period. Table VI and VII show the results of tensile strength tests. The base fabric for this run was Hess Goldsmith style No. I8539, which consisted of 10 yarns in the fill direction and 20 yarns in the machine direction in a lens pattern weave. Each yarn had the description of 900 ECD 1/0 1.0 Z. From this material two spherical caps were fabricated. These will be tested for RF Reflectance on a facility being constructed at Goddard Space Flight Center.

TABLE VI

Tensile Test of Self-Erecting Material in the Various Processing Stages

Process Step		Tensile Strength (lbs) Sample Configuration		
		Machine Direction	Transverse	45°
As Received	Avg.	14.6	6.2	*
Heat Treated	Avg.	16.4	6.7	*
Adhesive Coated	Avg.	18.2	8.2	1.4
Copper Plated	Avg.	13.6	4.9	0.7
Silicone Coated	Avg.	10.9	2.5	0.5

* No measurable strength

TABLE VII

Bend Radius Tensile Test Data Shown for Processing Steps

Process Step		Bend Radius Tensile Strength (lbs) Sample Configuration		
		Machine Direction	Transverse	45^{o}
As Received	Avg.	2.3	0.6	*
Heat Treated	Avg.	2.9	1.2	0.1
Adhesive Coated	Avg.	3.6	2.2	1.6
Copper Plated	Avg.	2.6	1.7	1.0
Silicone Coated	Avg.	2.9	1.5	1.0

* No measurable strength

3.10 TESTING

In the evaluation of the self-erecting material five tests are being used. The test methods are specifically explained in GTS Q-132. The specification outlines the manner in which--

(1) Resistivity

(2) Rigidity

(3) Tensile Strength

(4) Bend Radius Tensile Strength, and

(5) Folded Rigidity, are measured.

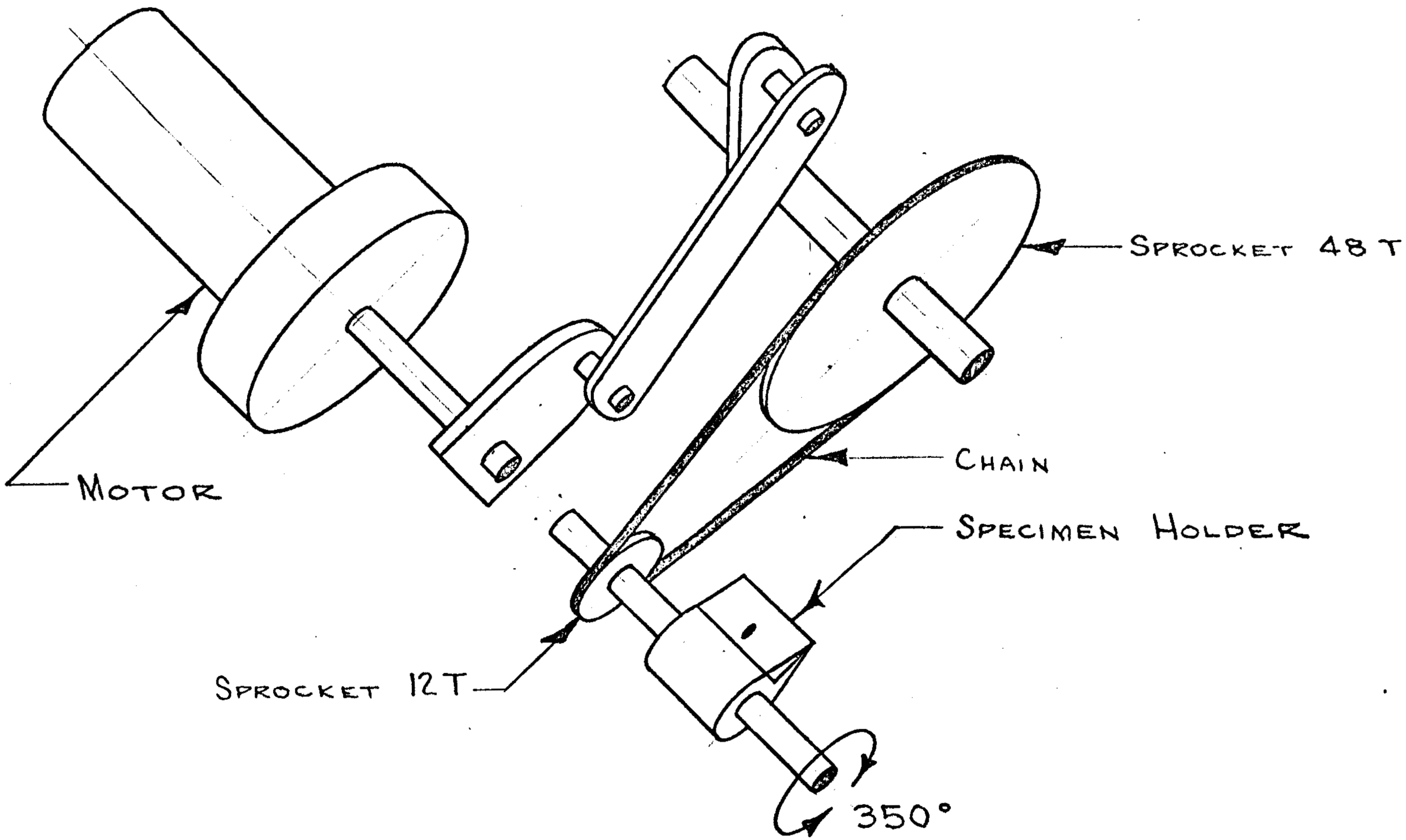
A copy of Q-132 is included in this report.

When the proposed modifications to the mesh flex tester are completed a specification will be written covering its use.

3.11 MODIFICATIONS TO THE MESH FLEX TESTER

It was found necessary to modify the mesh flex tester sent to G. T. Schjeldahl by NASA. When the machine was used to measure the resistivity of the mesh during flexing it was noted that the direct connection of motor to the sample made the ohmmeter inoperable. This is being corrected by replacing the steel shaft with a nylon one.

The drive will also be altered so that the motor will run continuously in one direction. It presently reverses itself for each cycle. Figure 6 shows the new drive assembly.



MESH - FLEX TESTER, MODIFICATION

24456-13 6-29-66

4.0 FUTURE PLANS

A solution of polyvinyl alcohol will be applied to Style No. I8601. This material will be subsequently coated with aluminum. Two 4 ft by 6 ft panels will be fabricated from this and sent to NASA Goddard.

The seam study will begin and the use of conductive seals will be investigated.

G. T. SCHJELDAHL COMPANY
NORTHFIELD, MINNESOTA

SPECIFICATION

CLASSIFICATION
CUSTOMER USE ONLY

Specification NO. Q-132
Date Issued 6-28-66
Revision

TESTING OF SELF-ERECTING MATERIAL

REV	ECO	CHANGED

Prepared By: Tony T. O...

Approved By:

Approved By:

Released By: ...

1.0 SCOPE

This specification is applicable to the testing and evaluation of self-erecting material made to deploy without an inflatant or additional hardware.

2.0 PURPOSE

The purpose of this specification is to describe the apparatus and procedures for performing the following tests:

1. Resistivity measurement
2. Ultimate tensile (MD, TD, 45^{o})
3. Bend radius tensile
4. Rigidity
5. Folded rigidity

3.0 MATERIALS

The sample shall be properly identified with the roll number and an arrow indicating machine direction.

4.0 APPARATUS

4.1 Ohm meter

4.2 Test jig for resistivity measurement (ST-21-1)

4.3 Instron tester with CT load cell and chart recorder

4.4 Five (5) pound weight accurate within 2.0 grams

4.5 Rigidity test fixture per ASTM-D-1388

4.6 Bend radius test fixture

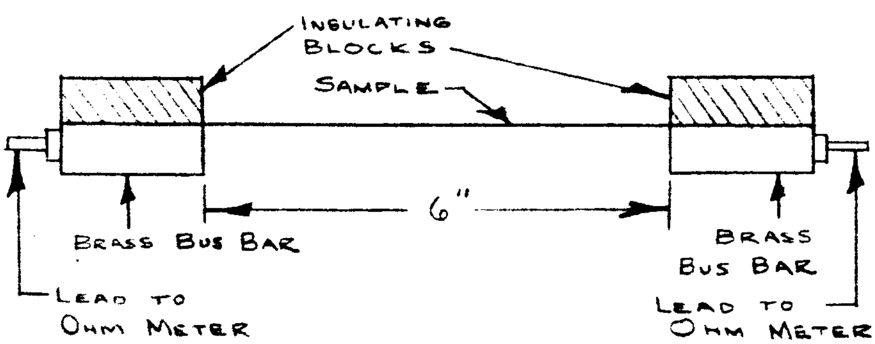
REV	ECO	CHANGED

4.7 Mettler gram-atic balance

5.0 **RESISTIVITY MEASUREMENT**

The resistivity measurement shall be made on a 1" x 8" sample with brass bus bars contacting one square inch of area on each end of the sample. This leaves a 1" x 6" test area.

5.1 Connect the ohm meter to the resistivity jig (ST-21-1) and zero ohm meter.



5.2 Cut sample of material (1" x 8") and place in resistivity jig (jig has spring loaded clamps which exert constant pressure on the specimen) as shown in sketch above.

5.3 Take reading on ohm meter and record on data sheet. Remove specimen from resistivity jig.

5.4 Calculate ohms per square as follows and record on data sheet. Ohms per square is calculated from the resistance in ohms divided by 6.

6.0 **ULTIMATE TENSILE**

One inch wide samples shall be tested having the threads running in either the machine direction, transverse direction, or at a 45° angle.

REV	ECO	CHANGED

6.1 Cut the required number of one inch samples (note the direction which the threads run in the sample). The threads in the samples shall be straight and continuous from one end to the other.

6.2 The Instron shall be operated in accordance with Q-101.

6.3 Balance, zero, and calibrate the load weighing and recording system using the five pound calibrated weight.

6.4 Set crosshead speed at two (2) inches per minute, chart speed at two (2) inches per minute, and jaw separation at two (2) inches.

6.5 Set the "Full Scale Load" at a setting which will put the breaking point between the lower one quarter (1/4) and upper one quarter (1/4) portion of the graph.

6.6 Mount the specimen in the Instron jaws in such a manner that the length of the specimen is parallel to the lines of force exerted on it.

6.7 Run test, record elongation and ultimate tensile on chart.

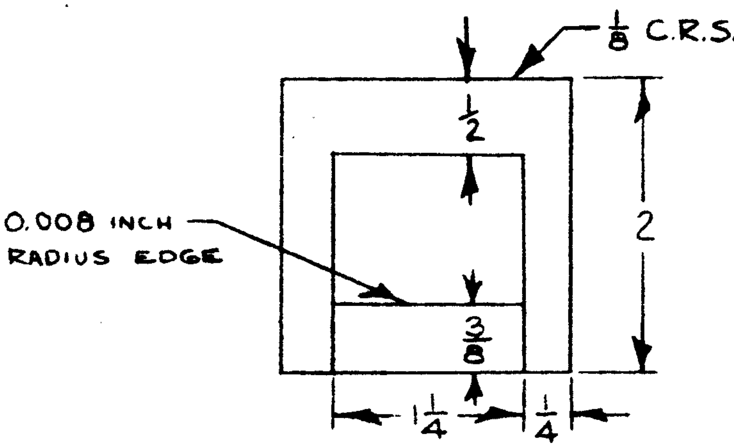
6.8 Record elongation and ultimate tensile on data sheet.

7.0 **BEND RADIUS TENSILE**

One inch wide samples shall be tested having the threads running in either the machine direction, transverse direction, or at a 45° angle.

REV	ECO	CHANGED

7.1 Clamp the bend radius fixture (see sketch below) in the upper jaw of the Instron.



7.2 Repeat steps 6.1 through 6.5.

7.3 Mount the specimen in the Instron so that the material makes a 180° bend over the bend radius fixture (.008 inch radius edge) and clamp both ends in the lower jaw. The specimen should be mounted in such a manner that the length of the specimen is parallel to the lines of force exerted on it.

7.4 Run test, record elongation and ultimate tensile on chart.

7.5 Record elongation and ultimate bend radius tensile on data sheet.

8.0 **RIGIDITY TEST**

One inch wide samples shall be tested having the threads running in either the machine direction, transverse direction or at a 45° angle.

8.1 The test shall be performed according to the procedures outlined in ASTM-D-1388. Measurements will be made at 10°, 20°, and 41.5°.

	REV	ECO	CHANGED

8.2 Cut the necessary samples (1" x 8"). The threads should be straight and continuous from one end to the other. Also cut a sample 6" x 6", this will be weighed later.

8.3 Place one specimen (1" x 8") on the smooth surface of the test fixture. The end of the sample should be even with the edge of the test fixture. Place the top weight, with the rubber pad against the sample, on the test fixture.

8.4 Slide the sample over the edge until the overhanging edge of the sample meets the desired angle 10°, 20°, or 41.5°. Note the length of overhang (in centimeters) and record this value on the data sheet.

8.5 This should be repeated for the top and bottom and each end of the sample (four measurements will be taken).

8.6 Average the readings obtained in 8.4 and 8.5 for each angle. This value will be used to calculate the flexural rigidity.

8.7 Weigh the 6" x 6" sample cut in 8.2 on the Mettler gram-atic balance.

$$\frac{\text{Weight of 6" x 6" sample}}{232} = \text{weight of sample in grams/cm}^2$$

Record the weight of the sample and the weight in grams/cm^2 on the data sheet.

8.8 The formula for calculating flexural rigidity, G, is as follows:

$$G = W\,C^3$$

where W is the weight of the material expressed in mg/cm^2 and C is the bending length in cm. The bending length is determined as follows:

REV	ECO	CHANGED

10° - multiply the length of overhang (length to meet 10° angle) (value from 8.6) by 0.890

20° - multiply the length of overhang by 0.695

41.5° - multiply the length of overhang by 0.500

Record the flexural rigidity on the data sheet.

9.0 FOLDED RIGIDITY TESTS

The folded rigidity test is similar to the standard rigidity test (ref. 8.0) only the sample will be folded and creased prior to testing.

9.1 Cut the samples per 8.2.

9.2 Fold the sample to be tested in the center (approx. at the 4 inch mark) 180° and press under a seven pound weight for the desired amount of time (to be indicated on the test data sheet).

9.3 After folding, place the sample on the test fixture so that the fold is even with the edge. Place the top weight, with the rubber pad against the sample, on the test fixture to hold the specimen in place.

9.4 Starting with the 41.5° angle, cut off the sample (the overhanging end) until it meets 41.5°. Measure the remaining length of material overhanging (measured in centimeters).

9.5 Repeat step 9.4 for 20° and 10°. The same end of the sample may be used for the three measurements. Record the remaining overhang on the data sheet each time.

9.6 Steps 9.3 through 9.5 should be repeated for the other end of the sample.

	REV	ECO	CHANGED
9.7 Average the readings obtained in 9.4, 9.5 and 9.6 for each angle. This value will be used to calculate the flexural rigidity. 9.8 Weigh the 6" x 6" sample cut in 9.1 and calculate the weight (in grams/cm^2) of the material (ref 8.7). Record the weight of the sample and the weight in grams/cm^2 on the data sheet. 9.9 Calculate the flexural rigidity as in 8.8. Record the flexural rigidity (after folding) on the data sheet.			