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 Administration
Goddard Space Flight Center
Greenbelt, Maryland

Progress Report No. 27M
for
August 1966
and
Quarterly Progress Report No. 9

Contract NAS5-3943

Mr. W. C. Nyberg
Technical Officer

Mr. F. Ringe
Contracting Officer

Prepared by:

William Jacobi, Project Engineer

Approved by:

William J. Hangen
Program Manager

E. A. Basquin
Report Editor

TABLE OF CONTENTS

1.0 INTRODUCTION

The objective of this contract is to develop a material with the following properties:

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

This report discusses work performed during the June-August period. The information that would appear in an August monthly report is included as part of this report.

2.0 SUMMARY

N66- 39997

A fabric was prepared from a Dacron-glass combination yarn and compared to a similarly woven sample of fiberglass. It was found that the fiberglass fabric had superior flexural rigidity and tensile strength.

A number of sizing agents were evaluated, three commercial and ten laboratory sizes. Of these supplied by Hess, Goldsmith a polyvinyl chloride size appeared the best. Of the laboratory applied size Silane A1100 had the highest tensile strength and flexural rigidty.

Of the four seam designs tested a simple overlap had the lowest resistance.

Work on the determination of the fold resistance of the material is described. The effect of folding on electrical resistance is discussed.

Several pilot production runs were made during this period, and data are presented describing the properties.

Author

3.0 DISCUSSION

3.1 EVALUATION OF DACRON-GLASS COMBINATION FABRIC

A sample of a fiberglass-Dacron combination yarn was secured from Owens-Corning. This combination, GDD941(1/2) 4.4S, is a 40 denier Dacron yarn twined with ECD 900 1/0 glass yarn. To evaluate this yarn it was necessary to prepare a fabric so that a comparison to the present glass fabric could be made. A hand loom was used to make simple, basket-weave fabrics from both GDD941 4.4S and ECD 900 1/2 1.0 Z, a fiberglass yarn similar to the yarn used to weave Hess, Goldsmith Style 18539. After these fabrics were loomed and suitably sized, their tensile strength and flexural rigidity were measured.

Data presented in Tables I and II compare fabrics made of fiberglass yarn and of combination yarn. The weight increase with an alcohol size was not as high as was intended. However, this will serve as a guideline in comparing the two materials.

In a comparison of the sized fabrics the average tensile strength of the combination fabric was 66 per cent of the tensile strength of a fiberglass mesh. The rigidity of the combination fabric was approximately 52 per cent of that of the fiberglass mesh.

There appears to be no reason to carry this investigation further as there appears to be no advantage to a combination of Dacron and fiberglass.

Table I

Rigidity

Material Description	Rigidity (mg-cm)			
	10°	20°	41.5°	Average
Glass	354.0	309.2	336.1	333.1
Glass - A29	460.3	414.3	460.26	444.9
Glass PVOH	401.8	426.8	399.1	409.2
Glass A29, PVOH	462.9	493.9	429.7	462.2
Dacron/glass	180.4	176.7	145.0	167.3
Dacron/glass A29	298.4	276.8	258.8	278.0
Dacron/glass PVOH	175.2	226.7	197.3	199.8
Dacron/glass A29, PVOH	199.0	203.2	236.9	213.0

Table II

Tensile Strength

Material	Starch	A29	PVOH	Tensile	Elongation
Glass	X			11.5	4.1
Glass	X	X		15.9	4.1
Glass	X		X	15.2	4.7
Glass	X	X	X	16.6	4.3
Dacron/glass	X			7.9	4.3
Dacron/glass	X	X		11.0	5.8
Dacron/glass	X		X	8.8	5.0
Dacron/glass	X	X	X	11.4	4.83

3.2 EVALUATION OF SIZING AGENTS

3.2.1 Evaluation of Commercially Available Sizings

Samples of Hess, Goldsmith Style No. 451 were received during June. Style 451 is a 36 by 18 1 pick leno weave. The machine direction threads are B 150 1/0 and the transverse threads are B 150 1/2. The design weight is 2.98 oz/yd^2. Hess, Goldsmith's laboratory has applied three types of sizings to this fabric.

451-A has a polyvinyl chloride size

451-B has a neoprene size

451-C has an acrylic size

Table III shows tensile strength and elongation for each material in the machine direction. As can be seen from these data, the type of sizing has no marked effect on these properties. The initial samples were all sized at the weaver, but to determine the suitability of any of these sizes these same tests had to be run on unsized fabric. A sample of Hess, Goldsmith No. 451 was received in the latter part of August. The results of the tests on rigidity are included in Table IV. The weight of the fabrics is also shown in this table. The average weight increase of the three sizes was 8 per cent. The rigidity was measured, and these results are presented in Table IV. Hess, Goldsmith Style 451-A is the most rigid.

An experiment was designed to evaluate the feasibility of plating directly on these sizings. To determine this, samples were soaked twenty minutes in water, and the rigidity and tensile strength in the machine direction were measured, Table V shows the rigidity of No. 451-A, No. 451-B, and No. 451-C as received, after a 20-minute soak, and after drying. No. 451-A was affected least with a 60.7 per cent decrease in rigidity, whereas the rigidity of No. 451-B and No. 451-C decreased 91.2 per cent and 74.4 per cent respectively. After drying the

Table III

Tensile and Elongation of Hess, Goldsmith Styles 451-A,-B,-C

(1 inch wide samples)

	451-A		451-B		451-C	
	Tensile (lb)	Elongation (%)	Tensile (lb)	Elongation (%)	Tensile (lb)	Elongation (%)
Sample 1	120.0	9.0	109.0	7.0	108.0	8.0
Sample 2	122.0	9.0	114.0	7.5	95.0	8.0
Sample 3	120.0	8.0	109.0	9.0	111.0	8.0
Sample 4	120.0	8.0	115.0	8.0	105.0	8.5
Sample 5	125.0	8.0	110.0	8.5	98.0	8.5
Average	121.4	8.4	111.4	8.0	103.4	8.4

Table IV

Rigidity & Length to Meet Angle

(1 inch wide samples)

	451-A		451-B		451-C		451 No Size	
	Length to Meet Angle (cm)	Rigidity (mg-cm)	Length to Meet Angle (cm)	Rigidity (mg-cm)	Length to Meet Angle (cm)	Rigidity (mg-cm)	Length to Meet Angle (cm)	Rigidity (mg-cm)
10°	9.4	6,708.2	5.9	1,649.6	7.2	2,902.5	2.5	112
20°	11.2	5,183.6	7.7	1,745.6	8.8	2,677.7	3.8	179
41.5°	10.8	1,776.0	10.3	1,557.1	11.9	2,401.2	4.6	123
Average	---	4,555.9	---	1,650.8	---	2,660.5	---	138
Weight mg/cm^2		10.9		11.2		10.5		10.1

Table V

Water Sensitivity of Size as Supplied by Hess, Goldsmith

Figures in Table are Rigidities (mg-cm)

	451-A	451-B	451-C
As Received			
10^o	6,570	2,450	2,630
20^o	6,350	1,930	2,310
41.5^o	5,400	1,670	2,210
Average	6,107	2,017	2,383
Soaked in Water 20 Minutes			
10^o	2,460	202	750
20^o	2,480	156	540
41.5^o	2,260	177	540
Average	2,400	178	610
Dried			
10^o	10,500	5,230	4,080
20^o	8,900	4,000	2,780
41.5^o	6,300	3,920	2,380
Average	8,567	4,383	3,080

soaked samples, the rigidity of all three increased to a level higher than the rigidity before soaking. This is probably due to a more complete sizing of the fiberglass during the soaking when the resins became softened by the water.

Another property that was considered important in the evaluation of the water sensitivity was the tensile strength of a sample cut on a 45-degree angle. Measurement in this direction should define the water resistance of a sizing agent as strength of yarn intersections is being tested. The results are listed below. Styles No. 451-A and No. 451-C increased in strength after a 20-minute soak, while the tensile strength of No. 451-B decreased after the soak.

Tensile Strength of Samples Cut 45 Degrees to Machine Direction

(Figures are Pounds per Inch of Width)

	451-A	451-B	451-C
As received	38	29	24
After 20-min. soak	49	20	34

As a result of this experiment, it appears that a polyvinyl-chloride-sized fabric can survive the stresses of copper deposition. The platability of No. 451-A has been shown to be suitable.

3.2.2 Evaluation of Laboratory Prepared Sizing

As one of the requirements of the contract is to develop a material with high rigidity, it has been found that proper choice of a sizing agent can improve the stiffness of a fabric. A study of ten sizes was made. Those investigated are listed in Table VI. In most cases, two concentrations of size solids were used. The base glass fabric used in this study was Hess, Goldsmith Style I8601. Table VII shows the flexural rigidity and tensile strength of the laboratory samples. The sizing agents in this experiment that increased the rigidity the most were animal glue, polyvinyl alcohol, GT 201, and Silane A1100. The highest tensile strength was recorded in the Silane A1100 and GT 201 sized samples. The gain in weight with a given solids percentage was nearly the same regardless of the type size used. A five per cent solution increased the weight approximately 3 per cent while the increase with a 10 per cent solution was 6 per cent.

The sample sized with Silane A1100 showed a markedly higher tensile strength.

Table VI

Materials Used in Sizing Study

	Trade Name	Description	Supplier
1.	TS100	Polyvinyl acetate copolymer emulsion	Rhom & Haas
2.	HA16	Acrylic copolymer emulsion	"
3.	ASE60	Carboxylic terminated acrylic polymer	"
4.	Silane A1100	γ-Glycidoxypropyltrimethoxysilane	Union Carbide
5.	Selectus	Edible gelatin	Swift & Co.
6.		Starch	Corn Products
7.		Dextrin	Corn Products
8.	Hercules	Animal glue	Swift & Co.
9.	GT 201	Proprietary thermosetting resin	G.T.S. Co.
10.	52-40	Polyvinyl alcohol	E.I. du Pont

Table VII

Lab. No.	Size	Weight (mg/cm^2)	Rigidity (mg-cm)	Tensile Strength (lb/in)
18601		1.82	135.5	
301-14-1	Glue	1.93	1169.3	27.8
301-14-2	Glue	1.83	848.2	24.3
14-3	Gelatin	1.89	818.7	19.8
14-4	Gelatin	1.84	939.9	26.6
15-1	TS100	1.91	734.4	28.8
15-2	TS100	1.83	476.3	19.5
15-3	PVOH	1.90	1121.3	28.8
15-4	PVOH	1.84	999.2	26.3
15-5	HA16	1.87	515.9	18.7
15-6	HA16	1.77	419.	18.6
15-7	Dextrin	1.89	965.2	26.8
15.8	Dextrin	1.86	706.3	22.1
16-1	GT 201	2.24	1109.1	38.8
16-2	Starch	1.88	894.2	27.5
16-3	Starch	1.78	773.4	24.3
16-4	ASE60	1.84	710.3	24.0
16-5	ASE60	1.78	699.37	22.9
16-6	GT 201	2.33	1137.6	34.6

3.3 SEAM STUDY

Using aluminum-coated material, several seam designs were evaluated. This material was used because the conductive coating of aluminum is exposed and not masked in any way. The following designs were evaluated.

Design A	Standard overlapping bitape seal
Design B	3/8-in overlap with 1/8-in wide strip of 0.9-mil aluminum in a bitape seal
Design C	3/8-in overlap with 1/8-in wide strip of 1/2-oz copper foil in bitape seal
Design D	3/8-in overlap with a bitape seal using a conductive tape (lab book sample number 105-88-1)

Table VIII shows this as the preliminary work. The designs are compared to continuous material with respect to resistivity and tensile strength.

Sample 5 was an overlapped bitape seal using material processed in May. No resistivity measurement could be made on this seal because sample 105-113-1 has a sheath coating of RTV silicone rubber.

To determine the reproducibility of these seals, five samples of designs A, B, and D were made. Design C was not run because of its similarity to B. The material used was sample 105-119-2.

Table IX lists these results. The figures given are for the resistance of a 6-in sample divided by the length of the sample. This resistivity is false as the samples are not homogeneous, but since the same material was used in each seal a direct comparison can be made.

Table VIII

	Material Sample	Seal Configuration	Resistivity	Tensile Strength lb/in Width
1	105-119-1	continuous	16.7	40
2	105-119-1	A	75.0	18
3	105-119-1	B	38.3	13.6
4	105-119-1	C	71.7	15.0
5	105-113-1	A	---	0.8
6	105-119-1	D	48.2	10.0
7	105-119-2	continuous	4.7	32.0
8	105-119-2	D	18.3	16.8
9	105-119-2	A	8.0	18.8
10	105-119-2	B	8.3	12.7

Table IX

Seam Study of Sample 105-119-2

	Design A	Design B	Design D
	10.8	18.0	46.8
	8.8	16.0	30.0
	12.0	27.5	38.3
	13.3	21.7	32.5
	25.0	9.7	25.8
Average	13.98	18.58	34.68

The figures indicate that a simple overlapping seam provides the lowest resistance and therefore the best electrical contact.

3.4 FLEXING RESISTANCE TESTING

As this material will be used in large space structures that will need to be folded and packed in a canister, it is necessary to determine the fold resistance of the material. Fold resistance has no discrete units and there are several methods of evaluating it.

One of these is the bend radius tensile strength presently used to evaluate this material. This test determines the strength of a material as it is folded on 1/128-inch radius bend. This is described in more detail in GTS Company Q132.

Another is the folded rigidity test (Sec. 9 of Q132) which attempts to measure the stiffness remaining after the material has been creased 180 degrees while under a static load.

The above methods have been used and data generated from these tests have been presented in past reports.

Two tests that will be evaluated in the near future are described in Federal Specification CCC-T-191b. These are Method 5210, Crease Resistance of Cloth, Cold Press Method, and Method 5212, Crease Resistance of Cloth, Angle of Recovery Method. Both measure the tendency of a fabric to "set" after creasing. This is an important variable as a material would be creased severely when being packed previous to launch. Obviously, any tendency of a material to "set" would preclude its use where close tolerances of flatness or sphericity are required.

During this last quarter two tests concerned with cyclic flexing were used. Both techniques involve the flexing of a sample around a known radius bend 180 degrees and then folding it back on itself around a similar radius bend. These tests flex a loaded sample cyclically until failure occurs. The number of cycles-to-failure is recorded as a property of the material.

NASA has designed and supplied us with a testing machine which, besides flexing the sample, has provision for a measurement of resistivity. The results of this testing are described in 3.4.1.

The paper industry uses the Schopper Tester as a standard means of determining the fold resistance of paper. The discussion of this work is in section 3.4.2.

3.4.1 Mesh Flex Tester

Samples of 105-113-1 material with no silicone rubber sheath coating were tested. Figure 1 compares the increase in sample resistance with the number of times folded. Each cycle on the machine is a 180 degree fold. Figure 2 covers only the first 350 cycles showing more clearly the initial increase in resistance. It is evident, from Figure 1, the resistance increases sharply in the machine direction between 200 and 300 cycles, and in the transverse direction between 300 and 400 cycles. This is the point at which there is a rapid deterioration of the plated copper. After this point, the resistance in the machine direction increases more slowly while the resistance in the transverse direction continues to increase rapidly. All samples were tested to failure except 105-113-2TD where flexing was terminated after 576,000 cycles (Table X). Figure 3 shows an enlarged view of the fiber bundles after failure.

Table X

105-113-1 Material - Cycles to Failure

Sample Number	Cycles to Failure	Comments
105-113-1-1MD	8,000	First sample tested 5 threads broke and sample pulled out of the top specimen holder. The holder was modified prior to the next test.
105-113-1-2MD	988	
105-113-1-3MD	56,618	Remained conductive up to 8600 cycles
105-113-1-4MD	1,403	Sample had been damaged prior to testing causing the premature failure
105-113-1-5MD	71,439	Remained conductive up to 7000 cycles
105-113-1-1TD	517	Sample had been damaged prior to testing causing the premature failure
105-113-1-2TD	>576,000	Remained conductive up to 234,000 cycles

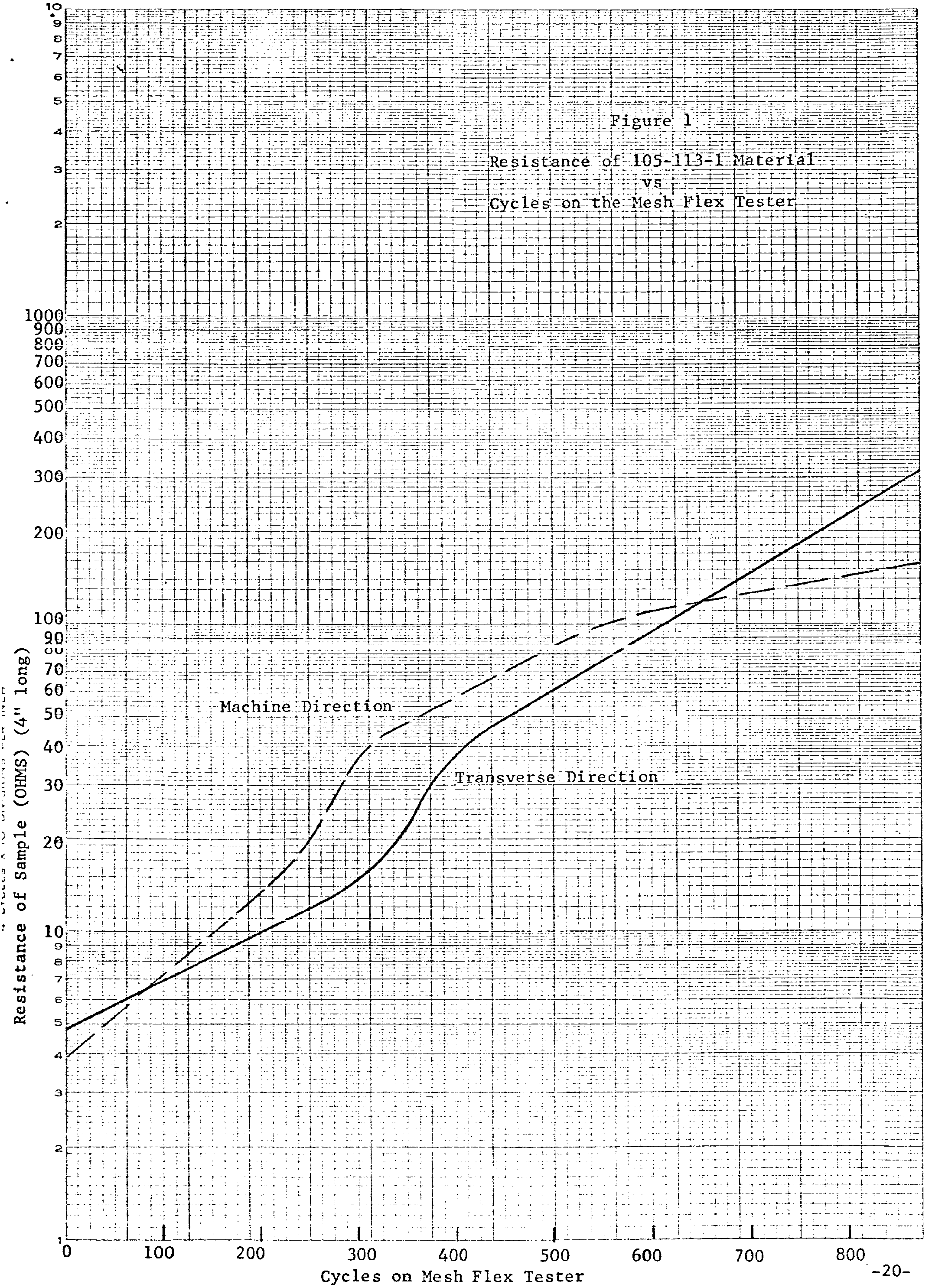


Figure 1
Resistance of 105-113-1 Material
vs
Cycles on the Mesh Flex Tester
Machine Direction
Transverse Direction
Resistance of Sample (OHMS) (4" long)
Cycles on Mesh Flex Tester
0
100
200
300
400
500
600
700
800
1000
900
800
700
600
500
400
300
200
100
90
70
60
50
40
30
20
10

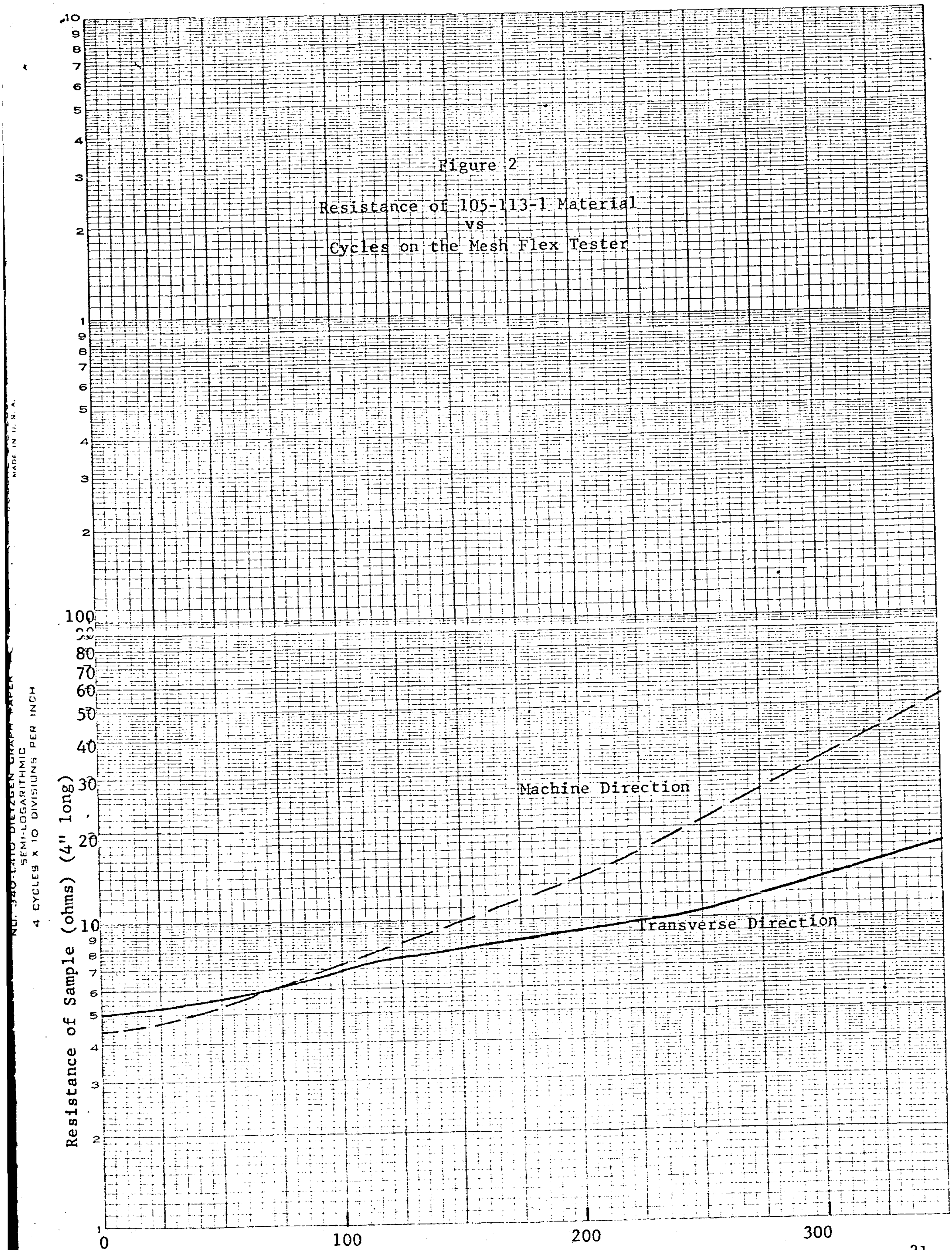


Figure 2

Resistance of 105-113-1 Material
vs
Cycles on the Mesh Flex Tester

Figure 3

3.4.2 Schopper Tester (ASTM 643-63T)

Samples of 105-113-1 material, having no silicone rubber sheath coating, were tested on a Schopper-type folding apparatus by ASTM method D 643-63T. Table XI contains these data. More samples will be tested to evaluate this method of testing self-erecting material.

3.5 MATHEMATICAL TREATMENT RELATING MEASURABLE PROPERTIES TO ULTIMATE USES OF THIS MATERIAL

3.5.1 Comparison of Theoretical Stiffness to Experimental Stiffness

The theoretical moment of inertia, I, was calculated for fabric using the following formula -

$$I = \frac{bd^3}{12}$$

where b is dimension in direction of axis

and d is dimension perpendicular to axis

This quantity was calculated for three fabric samples. The modulus of elasticity of glass is reported to be 10^7 psi. From the relationship

$$G = EI$$

where G is the flexural stiffness, a theoretical stiffness was calculated. This value, theoretical G, is compared to the experimental rigidity as determined by Q132.

Sample No.	Theoretical G	Actual G	G Theoretical/G Experimental
216-86-2	7.84×10^3	250	31.3
105-94-3	12.3×10^4	3.2×10^3	38.7
105-113-1	2.67×10^4	10^3	26.7

It should be noted here that the above calculations are for a flat plate with a rectangular cross section. It was also assumed that the entire

Table XI

105-113-1- Material

Schopper Folding Endurance Test

Direction	Sample	Cycles to Failure	Sample	Cycles to Failure
Machine Direction	1	12	6	6
	2	17	7	7
	3	17	8	3
	4	22	9	13
	5	30	10	6
	Average	Cycles to Failure - 13.2		
Transverse Direction	1	9	6	25
	2	10	7	3
	3	23	8	6
	4	9	9	5
	5	10	10	16
	Average	Cycles to Failure - 11.6		

composite has a modulus of elasticity equal to that of E glass. The actual material tested is a scrim fabric with threads spaced on 0.1 inch centers. By correcting for this fact, the theoretical rigidity might be less by a factor of 20. However, for this comparison and future comparisons using the theoretical rigidity for a flat glass plate as a standard should be sufficient.

3.5.2 Mathematical Derivation of the Relationship Between Flexural Rigidity and Cylinder Radius

To determine the size object that can be built from self-erecting material a computer program was written. This program was derived from the equation for the bending of a flat beam. When this equation was solved, it was found that the largest diameter cylinder possible made with self-erecting material with rigidity of 1,000 mg-cm is is 178 ft. A ten-fold increase in rigidity increases this diameter to 380 ft.

Further work is planned that will extend this derivation to the case of a sphere. This would investigate the interaction of a number of cylindrical bands that would be fabricated into a sphere.

Appendix A contains this derivation in detail. The computer program is included also.

3.6 PRODUCTION RUNS

Past efforts have shown that a sizing applied to the fiberglass fabric will markedly increase the rigidity. The most efficient size found is polyvinyl alcohol. To thoroughly examine the properties of a polyvinyl alcohol coating, it had to be applied to a fiberglass mesh. Hess, Goldsmith Style No. I8601 was used in this operation, as this was the base fabric for material processed in May. The process used was as follows:

1. A coating of polyvinyl alcohol was applied in continuous plating equipment.

2. Using vacuum chambers held at G. T. Schjeldahl under NAS5-3515 facilities contract, a conductive aluminum coating was applied.

The process used on these runs was quite different from the normal sequence which is as follows:

1. A heat treatment consisting of placing a length of fabric on an aluminum core in a 500 F oven for 60 minutes.

2. A coating of GT 201 is then applied in Section B of the plating equipment.

3. This coating is allowed to cure for 48 hours at 100 ± 5 F and 95 ± 5 per cent R.H.

4. The coated fabric is then copper plated electrolessly in Section A.

5. Two coats of RTV silicone rubber are applied to the copper plate; one immediately after plating, and the second after a 24-hour cure at ambient conditions.

3.6.1 Vapor Deposited Aluminum Coating

For the run in June, polyvinyl alcohol was chosen as the sizing agent. It was felt that for this intial work a small quantity of this solution could be obtained from any one of several suppliers. Swift and Company formula No. 2534 was used for this purpose. It was diluted with water to two solid concentrations for application to fabric style 18601. Using Section B of the continuous plater, a 6 per cent solution of polyvinyl alcohol was applied to 40 feet. Using a web speed of 6 in/min produced a residence time in the drying tunnel of 20 min. This material was assigned the laboratory sample number 105-119-1. The coating was completely dry upon emerging from the tunnel. The 6 per cent solution was then replaced with a 10 per cent solution and 15 feet more was coated. The material sized with 10 per cent solution will be referred to as sample 105-119-2. Table XII lists weights and rigidities of each material.

The fact that sample 105-119-1 is more rigid than sample 105-119-2 cannot be explained at this time and further investigation will be made. These samples were tested on different days. The size is extremely water sensitive, and varying humidity conditions undoubtedly would affect the rigidity. The higher viscosity of the 10 per cent solution could have prevented proper coating of the fiber bundles.

Approximately 11 feet of each of the materials coated above was placed in a vacuum chamber. A layer of aluminum approximately 10 microinches thick was deposited on the surface. Only one surface of one material could be "shot" at a time; thus, a total of four shots were made. Table XIII shows the rigidity, weight per unit area and tensile strength.

Table XII

		105-119-1	105-119-2
Sizing solution solids per cent by weight		6	10
Weight mg/cm^2		1.99	1.93
Rigidity mg-cm	10° angle	1980	1290
	20° angle	1580	1115
	41.5° angle	1250	848
Average rigidity mg-cm		1603	1084

Table XIII

Base Material		Sample 105-119-1	Sample 105-119-2
Weight mg/cm^2		1.9	2.0
Rigidity (mg-cm)		601.6	497.8
Folded Rigidity (41.5°)		44.0	43.3
Tensile Strength (lbs/in)	MD	39.5	32.0
	TD	32.0	12.0
	45°	0.6	0.4
Bend Radius Tensile Strength (lbs/in)	MD	13.5	13.3
	TD	0.6	2.7
	45°	0.7	.35

3.6.2 Description of Numbering System

A new numbering system has been developed for any materials produced in this study contract. Each material produced under this contract will be consecutively numbered. The processing of this material involves five operations: fabric procurement, pretreatment, binding, metal deposition, and sheath coating. These process steps are so numbered that if the properties of the material are desired, they can be recorded properly as to run number and process step. The process steps are defined below.

-1.	Fabric Procurement -	This is simply an identification of the base fabric e.g. Hess, Goldsmith I8601
-2.	Pretreatment -	Any sizing operation would be considered a pretreatment. Any other process that a fabric is subjected to, such as heat treating, would also be described in this subheading.
-3.	Binder -	This process is analogous to the sizing process described above; however, for our purposes it is advantageous to split it off as separate item. This will allow us to consider materials whose primary purpose is to tie or bind the threads together to increase the integrity of the fabric.
-4.	Metal Deposition -	This, as the title implies, is the subheading that will contain the description of the process that was used to deposit a metallic coating on the self-erecting material.
-5.	Sheath Coating -	This process step protects the metal deposit and as it is the final coating on the material, it becomes a major factor in the ultimate surface properties.

The incorporation of this numbering system in this contract was done for the material processed in August. Arbitrarily, the first run was numbered 132. Sample data sheets are included.

3.6.3 Description of Runs 132, 133 and 134

3.6.3.1 Run 132

This was the first run identified with the new numbering system. The base fabric was Hess, Goldsmith style I8601. The pretreatment step consisted of the application of an aqueous solution of Silane A-1100. Data had shown that sizing with this material markedly increased the tensile strength and the rigidity. The weight increase of the dip coating was very small as the weight after this step was 1.82 mg/cm^2 or virtually the same as the fabric weight as received from the weaver. Approximately 66 feet were coated in this manner.

The material was then bound with a GT 201 coating. The weight increase was approximately 0.18 mg/cm^2 making a total weight at this point of 2.0 mg/cm^2. The rigidity in the machine direction was 1052 mg-cm (per ASTM D 1388). The tensile strength at this point was 40.1 lb/in. The metal deposition was done by the electroless copper plating process described in the past.

No sheath coating was applied to the material in this run as it is intended for use in the sheath coating study phase of the contract.

3.6.3.2 Run 133

This run also used Hess, Goldsmith style I8601 as the base fabric. The pretreatment consisted of a heat treatment (500 F for 30 min.). As in the past there was a weight loss during this process. For this particular run a production oven was used. The material processed in April, 105-113-1, was processed in a similar manner. Table XIV compares the weight loss and associated rigidity increase of this material and No. 133.

Table XIV

Comparison of Weight and Rigidity Through Process

	105-113-1 Wt Mg/Cm^2	Rigidity Mg-Cm	Run 133 Wt Mg/Cm^2	Rigidity Mg-Cm
Heat Treatment	1.77	297	1.78	57
Binding	2.03	931	2.15	657
Metal Deposition	2.17	850	2.25	646

The binding operation and metal deposition was done in the same manner as Run 132. Again, as in the case of 132 material, no attempt was made to apply the sheath coating. The material was sealed in a nitrogen-filled Scotchpak bag.

3.6.3.3 Run 134

This material run again used Hess, Goldsmith style I8601 fiberglass fabric, but there was no pretreatment step. The binder was GT 201 as in the case of 132 and 133. The copper was deposited in the same plating run as 132 and 133.

Table XV

Comparison of Tensile Strength

	MD (lb/in)	TD (lb/in)	45^{o} Angle (lb/in)
105-113-1	27.6	19.8	.68
132	26.6	25.8	.95
133	23.5	16.8	.66
134	28.9	25.4	1.2

Table XVI

Flexural Rigidity of Runs 132, 133, & 134

	Machine Direction Mg-Cm	Transverse Direction Mg-Cm	45^{o} Angle Mg-Cm	Weight Mg/Cm^2
132-4	916.4	592.2	175.2	2.1
133-4	646.9	450.4	152.3	2.25
134-4	848.0	595.6	228.9	2.11

3.7 CONTROLLED ATMOSPHERE CHAMBERS

To evaluate the use of sheath layers on self-erecting material, the last three runs were not coated but placed in bags containing a nitrogen atmosphere. Four controlled atmosphere chambers were built. With these chambers it will be possible to expose ten, one-inch wide samples to the same conditions. The resistance of 12-inch long samples can be periodically checked with as little error as possible. The first set of samples will evaluate the following:

A.	105-123-1	vapor-deposited aluminum
B.	105-113-1	copper-plated (no coating)
C.	132-4	described in this report
D.	133-4	described in this report
E.	134-4	described in this report

The first test series will subject the samples to four different atmospheres.

Chamber No. 1	air 0 per cent relative humidity
Chamber No. 2	air 100 per cent relative humidity
Chamber No. 3	100 per cent oxygen atmosphere
Chamber No. 4	100 per cent nitrogen atmosphere

Two samples each of the above described materials will be placed in each chamber. These will be exposed to these conditions for 30 days or until there is a significant change.

The samples will be connected to leads by means of a conductive epoxy adhesive, E-solder No. 3021. To prevent contamination, the holes where the leads come out of the chamber will be sealed with a paraffin modified with E 1 Vax 150, an ethylene-vinyl acetate copolymer.

Once the effect of the above conditions is established on these materials, the study of protective coatings or sheath layer can begin.

Material No. ______________

Lab No. ______________

Metal Deposition

Date ______________ Amount Processed ______________ ft

Type ______________ Electroless Plating (Use "Plating Log" Below)

______________ Vapor Deposition (Use "Remarks")

______________ Other (Use "Remarks")

Remarks - Type of Metal ______________

Thickness ______________ Angstroms

No. of Shots ______________

Plating Log: Machine Speed__________ fpm

Feet	Time	Plating Tank pH #1	Plating Tank pH #2	Temperature	Resistivity	Remarks

Chemical Consumption: (Record Time & Amt.)	Sensitizer	Activator	Cu400A	Cu400B	NaOH
	Deionized Water Tanks Start ______ End ______				

Material No. ____________

Lab. Number ____________

Pretreatment & Binder In Process Sheet

Pretreatment Date ______________ Amount Processed ____________ ft

Fabric ____________________________

Description of Pretreatment -

Remarks -

Sample Taken ____________

Binder Date ______________ Amount Processed ____________

Description of Binding Operation (type, solids, machine speed, drying) -

Remarks -

Sample Taken ____________

Lab No. ________

Summary Sheet for Material ____________

Date Completed		Description
______	1) Fabric Description	______
______	2) Pretreatment	______
______	3) Binding	______
______	4) Metal Deposition	______
______	5) Sheath Coating	______

Material Inventory

Date	Amount	Article Used For

Test Results:

	Process Step	1	2	3	4	5
A. Tensile lb per inch	MD (5)					
	TD (5)					
	45^{o} (5)					
B. Rigidity 41.5^{o} mg-cm	MD (5)					
	TD (5)					
	45^{o} (5)					
C. Conductance	MD					
	TD					
D. Weight mg/sq. cm.						
E. Folded Rigidity						
F. Cyclic Flex Test						

4.0 FUTURE PLANS

Tests will be started in the controlled atmosphere chambers. Means of determining conductivity will be investigated.

The fold resistant tests will be continued.

APPENDIX A

TECHNICAL DISCUSSION

It is desired to know how large a self-erecting sphere can be before solar pressure prevents its proper deployment. This question will be answered only indirectly here. Instead, a self-erecting cylinder will be considered. If a cylinder can have a certain maximum radius before trouble sets in, then it is thought wise not to plan spheres of this radius or larger.

Sunlight impinges on a fully erected cylinder from the right. It is assumed that a constant fraction, f, of the sunlight which hits <u>any</u> portion of the cylinder boundary for the first time is completely absorbed (the mesh fibers are assumed black here). The remaining light (1-f) goes on across the cylinder. When it traverses the cylinder boundary for the second time, a fraction f is again absorbed. The force, then, exerted by sunlight on the right-hand half of the cylinder per unit length is:

$$\frac{S_c f(2r)}{c}$$

Here S is the solar constant, and c the speed of light. The force exerted by sunlight on the left-hand side of the cylinder per unit length is:

$$\frac{S_c (1-f)f(2r)}{c}$$

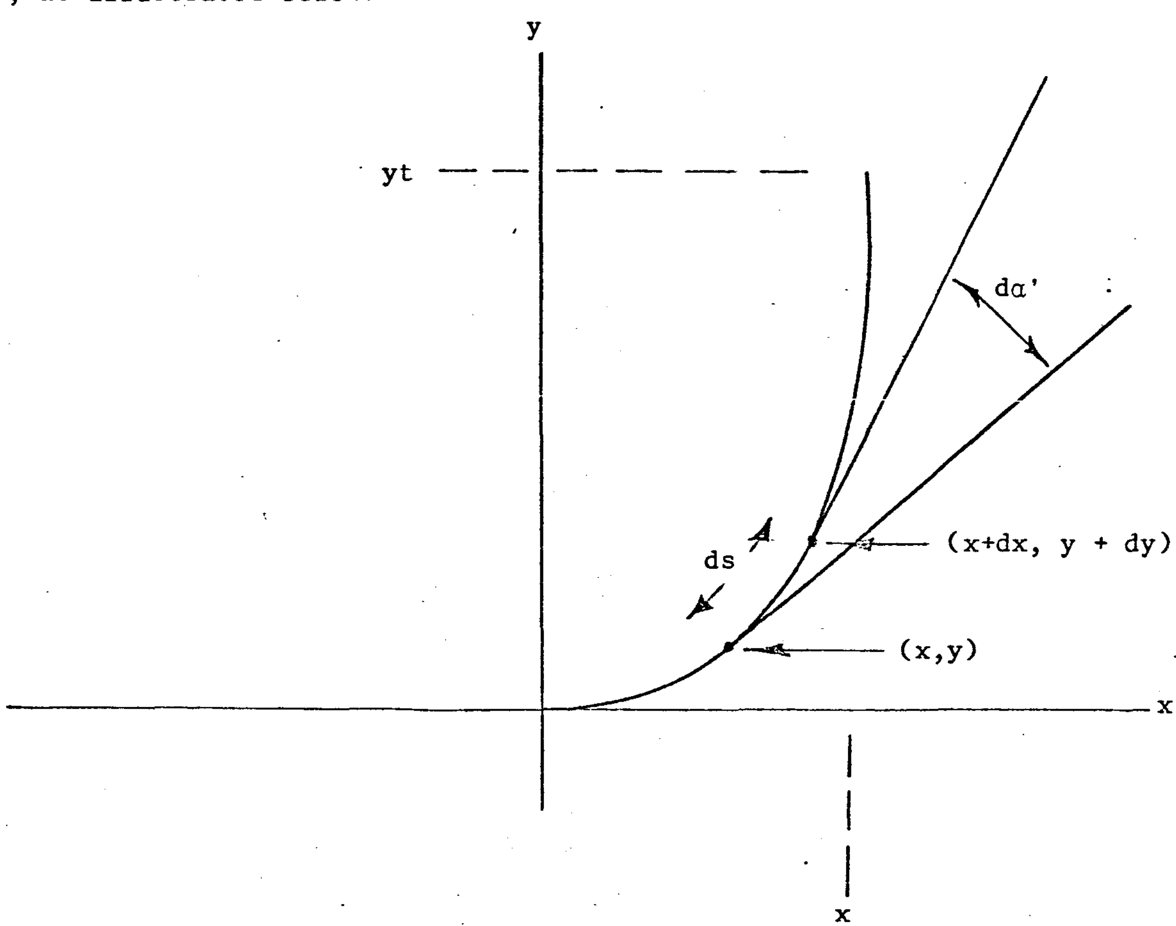
If the mass per unit length of the cylinder is m, then the acceleration of the cylinder to the left is given by:

$$\frac{S_c f(2r) + S(1-f)f(2r)}{cm}$$

The force exerted on the right-hand half of the cylinder is greater than that exerted on the left-hand half. Consequently, the cylinder should flatten somewhat, the width of the figure now being smaller than its height. The cylinder flattens until stresses set up in the self-erecting material make all portions of the cylinder accelerate at the same rate.

It is arbitrarily assumed here that trouble in deployment can be expected if the radius of the fully erected cylinder, say in the absence of sunlight, is just large enough so that in the presence of sunlight the right and left extremities of the figure are regions of zero curvature. A cylinder of any larger radius would exhibit a dog-bone appearance.

Now the cylinder is accelerating to the left so one should have the x-y coordinate system also accelerating to the left at the same rate, and then perform the analysis in this accelerating system. Here we approximate this procedure by assuming that another sun produces light which shines on the cylinder from the left. The acceleration of the cylinder is now zero. Consider that "quarter" of the distorted cylinder which lies at the lower right hand, as illustrated below.



The moment equation is:

$$EI \frac{d\alpha'}{ds} = \frac{Sf^2(yt-y)^2}{2c}$$

Here E is Young's Modulus of the material and I its moment of inertia.

Rewrite the equation as:

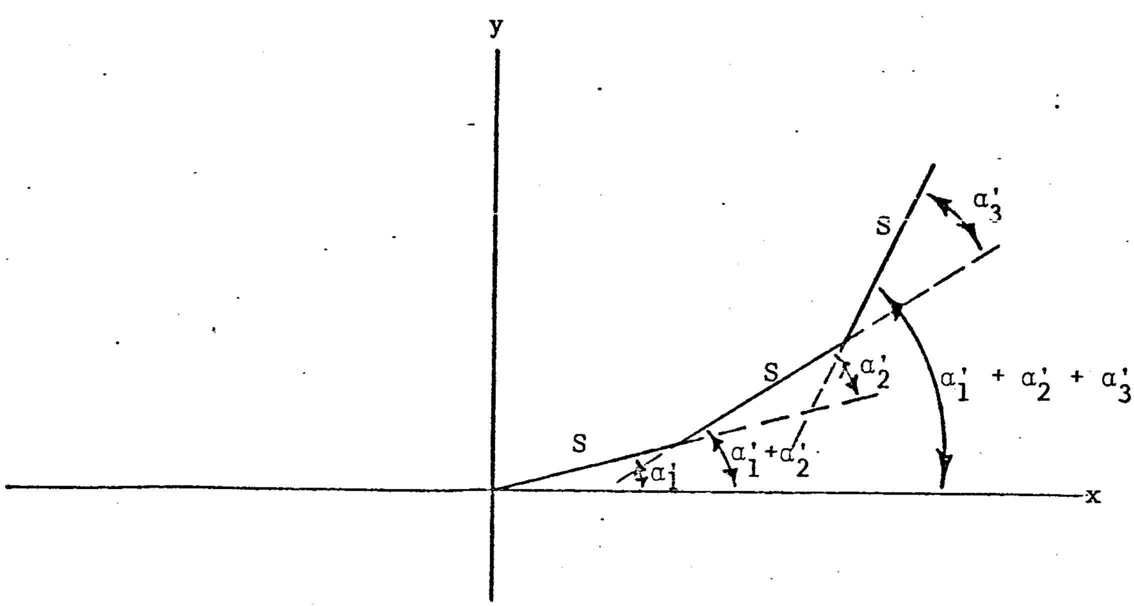
$$d\alpha' = ds \; \frac{Sf^2(yt-y)^2}{2\ EIc}$$

Define a new constant C by:

$$C = \frac{Sf^2}{2EIc}$$

Replace ds by S and replace dα' by α'_n where n=1,2,3....F-1,F. Note that the length, Z, of the illustrated band is FS and that the radius R of the undistorted cylinder which gave rise to this distorted band is given by $4Z/\alpha\pi$.

A computer program (see last pages) was written which gives (x,yt), Z, and R as a function of C. The basic fact which simplifies the computation is illustrated in the figure below:



Note that:

$$y_1 = S \sin (\alpha_1' + \alpha_2')$$

$$y_2 = y_1 + S \sin (\alpha_1' + \alpha_2')$$

$$y_3 = y_2 + S \sin (\alpha_1' + \alpha_2' + \alpha_3')$$

etc.

And that

$$x_1 = S \cos \alpha_1'$$

$$x_2 = x_1 + S \cos (\alpha_1' + \alpha_2')$$

$$x_3 = x_2 + S \cos (\alpha_1' + \alpha_2' + \alpha_3')$$

etc.

The computation must stop when n becomes just large enough, say N, to make

$$\sum_{m=1}^{N} \alpha_n' = \pi/2$$

Since the expression for α_n' involves yt and since yt can only be known after the problem is solved the program initially requires the insertion of a large yt as a starter which the program then adjusts as it proceeds so that it eventually converges to the correct value. The program prints out the correct value of yt and the associated x.

Now the material under study has an EI = 1000 milligram-cm = 980 dyne-cm. The speed of light is 3×10^{10} cm/sec. The solar constant, S_c is $\frac{(2.0)(4.18)\times 10^7}{60} \frac{\text{ergs}}{\text{cm}^2\text{-sec}}$

Consequently C is:

$$C = 2.42 \times 10^{-6}/\text{ft}^3$$

With this C, an R of about 89 ft was obtained, yt being 108 ft and x about 78 ft. When the material strength EI was made ten times greater so that C was

$2.42 \times 10^{-7}/ft^3$, the R obtained was about 190 ft, yt being about 231 ft, and x about 160 ft. Note that $10^{1/3} \cong 190/89$.

```
04000 C     DR-2 -- 3/1[illegible]/66 -- GIEGLER
04100       B=1.5708
04124       IF(SENSE SWITCH 9)1,1
04204 1     READ11,C,YT,E,S,G
04216 11    FORMAT(5E14.7)
04[illegible]  PRINT12,C,YT,E,S,G
04[illegible] 12 FORMAT(///3HC =E14.7/4HYT =F[illegible].2/3HE =F[illegible].2/3HS =F[illegible].2/3HG =F[illegible].2)
05[illegible] 3  A=0.0
051[illegible]  X=0.0
05212       Y=0.0
0523[illegible] F=0.0
05300 4     A=A+S*C*(YT-Y)**2
0531[illegible] F=F+1.0
05404       IF(A-B)5,6,6
0541[illegible] 5 X=X+COS(A)
05504       Y=Y+SIN(A)
05540       GO TO 4
055[illegible] 6 X=S*X
05574       Y=S*Y
05[illegible]20 Z=F*S
05[illegible]5[illegible] R=4.0*Z/6.2832
05704       D=YT-Y
05740       IF(D-E)8,8,7
06[illegible]4 7 PRINT17,YT,A,D,X
06[illegible]4 17 FORMAT(/4HYT =E14.7,3X3HA =E14.7,3X3HD =E14.7,3X3HX =E14.7)
06[illegible]   PRINT27,Y,Z,R,F
06[illegible]4 27 FORMAT(4H Y =E14.7,3X3HZ =E14.7,3X3HR =E14.7,3X3HF =E14.7)
06102       YT=YT-G*D
06222       GO TO 3
06230 8     PRINT10
06254 10    FORMAT(//17HFINAL SOLUTION...)
06320       PRINT17,YT,A,D,X
06380       PRINT27,Y,Z,R,F
06440       IF(SENSE SWITCH 9)100,1
06460 100   STOP
06468       END
END OF COMPILATION 0716519430
```

```
C =  2.4100000E-06
YT =   150.00
E =   1.00
S =    .50
G =   .500

YT = 1.5000000E+02    A = 1.5755527E+00    D = 1.2205725E+02    X = 2.0945420E+01
 Y = 2.9642717E+01    Z = 3.2700000E+01    R = 2.4501055E+01    F = 7.7000000E+01

YT = 1.1300203E+02    A = 1.5027716E+00    D = 5.7585400E+00    X = 6.9525115E+01
 Y = 1.0731920E+02    Z = 1.3550000E+02    R = 6.5261777E+01    F = 2.7100000E+02

YT = 1.1135376E+02    A = 1.5755161E+00    D = 4.1370000E+00    X = 7.1572045E+01
 Y = 1.0721670E+02    Z = 1.3700000E+02    R = 8.7215704E+01    F = 2.7400000E+02

YT = 1.1011265E+02    A = 1.5811949E+00    D = 2.5935600E+00    X = 7.3945930E+01
 Y = 1.0751909E+02    Z = 1.3850000E+02    R = 6.0171632E+01    F = 2.7700000E+02

YT = 1.0833459E+02    A = 1.5737420E+00    D = 2.0034700E+00    X = 7.5361410E+01
 Y = 1.0724112E+02    Z = 1.3900000E+02    R = 8.0491411E+01    F = 2.7800000E+02

YT = 1.0070035E+02    A = 1.5633004E+00    D = 1.0920500E+00    X = 7.6515415E+01
 Y = 1.0711000E+02    Z = 1.4000000E+02    R = 6.9126551E+01    F = 2.8000000E+02

YT = 1.0030104E+02    A = 1.5740005E+00    D = 1.0930000E+00    X = 7.7116170E+01
 Y = 1.0720204E+02    Z = 1.4000000E+02    R = 8.9126551E+01    F = 2.8000000E+02

FINAL SOLUTION...

YT = 1.0005134E+02    A = 1.5783457E+00    D = 6.0674000E-01    X = 7.7720590E+01
 Y = 1.0744250E+02    Z = 1.4050000E+02    R = 6.9444000E+01    F = 2.8100000E+02
```

C = [illegible].4200000E-07
YT = 400.00
E = 1.00
S = .50
G = .300

YT = 4.0000000E+02 A = 1.5732375E+00 D = 3.7002322E+02 X = 2.72670[illegible]E+01
Y = 2.[illegible]7[illegible]7[illegible]4E+01 Z = 4.5500000E+01 R = 2.[illegible]6131E+01 F = [illegible].1000000E+01

YT = 2.[illegible]304E+02 A = 1.[illegible]71702[illegible]E+00 D = 1.00773[illegible]E+02 X = 6.[illegible]7[illegible]65E+01
Y = 1.[illegible]21[illegible]1[illegible]E+02 Z = 2.2050000E+02 R = 1.4037433E+02 F = 4.4100000E+02

YT = 2.[illegible]076[illegible]E+02 A = 1.570[illegible]75[illegible]E+00 D = 3.1[illegible]7[illegible]30E+01 X = 1.2041[illegible]E+02
Y = 2.2[illegible]125E+02 Z = 2.7[illegible]00000E+02 R = 1.7[illegible]07002E+02 F = 5.5000000E+02

YT = 2.4[illegible]1[illegible]700E+02 A = 1.574[illegible]40[illegible]E+00 D = 1.[illegible]72[illegible]0E+01 X = 1.377[illegible]251E+02
Y = 2.2[illegible]402E+02 Z = 2.[illegible]50000E+02 R = 1.[illegible]175[illegible]51E+02 F = 5.7100000E+02

YT = 2.4[illegible]1511E+02 A = 1.5752[illegible]E+00 D = 1.25[illegible]60E+01 X = 1.4[illegible]31[illegible]1[illegible]E+02
Y = 2.30[illegible]7[illegible]75E+02 Z = 2.[illegible]150000E+02 R = 1.[illegible]7422E+02 F = 5.[illegible]00000E+02

YT = 2.3[illegible]5421E+02 A = 1.570[illegible]7E+00 D = [illegible].7717[illegible]00E+00 X = 1.551773[illegible]E+02
Y = 2.30[illegible]2[illegible]2E+02 Z = 2.[illegible]500000E+02 R = 1.[illegible]7[illegible]023[illegible]E+02 F = 5.[illegible]000000E+02

YT = 2.3702[illegible]E+02 A = 1.5743540E+00 D = 5.[illegible]0000E+00 X = 1.5[illegible]552E+02
Y = 2.3133[illegible]E+02 Z = 2.[illegible]000000E+02 R = 1.[illegible]71[illegible]4E+02 F = 5.[illegible]00000E+02