ABSTRACT

AN INFLATABLE THERMAL RADIATION SHIELD FOR SPACE APPLICATIONS

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A structural materials study and test program have been conducted in connection with an inflatable thermal radiation shield feasibility study at GD/FW. This program, sponsored by NASA/MSFC, is directed toward the development of thermal protection systems for cryogenic-fueled space vehicles.

Preliminary investigations and analyses indicated the desirability of an inflation deployed spherical shield with permanent rigidity independent of internal pressure. The spherical shape is compatible with the inflatable concept and possesses the required thermal characteristics for minimum heat transfer. Inherent shell rigidity is required to maintain shield shape and position for an extended period considering possible leaks and meteoroid penetrations. Venting is also desirable to minimize conduction heat transfer. The required rigidity is obtained by utilizing a peculiar property of the thermal shield, the extreme low temperature on its shaded surface. This surface, carrying the highest stresses due to shield inertia loads during attitude corrections, is coated with an elastomer which is flexible at normal room temperatures. When the shield is inflated and the vehicle is properly oriented in relation to the sun, the temperature of the elastomer is reduced to something below -150°F, resulting in a simple, reliable rigidizing mechanism; the stiffening of the elastomer into a rigid hemispherical cap.

Determination of material properties and sphere rigidizing characteristics was accomplished through a series of tests. Elastomer specimens were exposed to vacuum and low temperature and tested in tension and bending at low temperature to evaluate their structural properties. Model spheres were coated with elastomers, rigidized by cooling, and test-loaded on a centrifuge to determine their load carrying capability. Extrapolations were made to estimate mass penalties required for full scale radiation shields. Results indicated that a 27-1/2 foot diameter shield, roughly that required for the earth braking stage of a proposed Mars vehicle, could withstand accelerations of at least .03 g, a reasonable value based on attitude control requirements. The mass penalty for such a sphere would be approximately 45 LBM.

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SUMMARY

A test program has been conducted to determine the structural feasibility of a low-temperature rigidized inflatable thermal radiation shield for cryogenic fueled space vehicles. Some elastomers have been evaluated for use as rigidizing coatings. Model spherical shields coated with a vinyl-base lacquer have been rigidized by cooling and centrifuge tested to determine allowable loading. These data are extrapolated for estimation of mass penalty and allowable loading of full scale shields. Results indicate that a 330-inch diameter inflatable spherical shield utilizing the low-temperature rigidizing concept would weigh approximately 45 pounds and endure lateral accelerations of about .03 g's.

INTRODUCTION

Efforts to improve the performance of space propulsion systems have resulted in much interest in and some utilization of high energy cryogenic fuels. In order to successfully incorporate a cryogenic fueled propulsion system in any extended mission space vehicle, extremely high fuel storage efficiency must be achieved. Fuel boil-off losses due to solar radiation heating become increasingly important as the mission length increases. Tank insulation, both conventional and "super-insulation", while decreasing losses, cannot approach the efficiency of a separate thermal radiation shield, standing off from the tank structure and greatly reducing tank incident energy.

For such a stand-off shield to be structurally efficient, and thus of minimum weight, it must be designed for its specific operational environment. For certain missions of interest, this operational environment is one which is almost entirely free of significant inertia or aerodynamic loading. For a Mars mission, for instance, a shield would be subjected only to loads due to solar

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pressure, micrometeoroid impact, and attitude control impulses; for periods of several months. Designing for the high aerodynamic and/or inertia loadings of boost or other high thrust mission phases will result in an unnecessarily heavy structure. Therefore, in order to minimize shield weight through avoiding these extreme loadings, it is necessary to investigate the possibilities of variable geometry or expandable structure. This concept will permit the design of a compact structural configuration suited to the extreme loading of the high thrust periods and yet efficient in its primary application, when it may be expanded to attain its required size, shape, and position.

From thermal considerations, a spherical shield is desirable. This configuration is also suitable for the design of a minimum weight inflatable structure. For the very lightly loaded shields, a reinforced or stiffened inflatable sphere and circular cylinder support appear feasible. Minimum weight and stored volume, flexibility of shape of storage container, simplicity, and reliability are some of the features of such a system. To minimize heat transfer across the shield, the inflating gas will be allowed to escape following complete inflation. This venting removes the shell's stabilizing pressure and makes it necessary to supply, by other means, rigidity sufficient to resist excessive shield deflections or deformation. After reviewing several possible rigidization methods, it was decided to investigate a system utilizing a peculiar property of the shield; the low temperature existing on its shaded side. This low temperature would be used to rigidize a coating of a normally flexible elastomer applied to the spherical surface. Solar orientation of the vehicle would insure the maintenance of this low temperature on the support side of the spherical shield. This temperature is estimated to be from -100 to -300°F.

Figure 1 shows a typical configuration, with the spherical shield mounted on the aft end of a vehicle along the longitudinal centerline. The vehicle attitude control system maintains the necessary solar orientation. Attitude control system pulses generate vehicle angular accelerations causing lateral inertia loads on the shield structure. These are the principal shield loads.

The preliminary investigation of this self-rigidizing system required evaluation testing of possible coating materials to determine their relative value as low temperature structural reinforcement. The basic sphere was to be constructed of an aluminum-mylar-aluminum sandwich material. This material, used in the Echo II balloon satellite and designated by the manufacturer (G. T. Schjeldahl Co., Northfield, Minn.) as X-15 laminate, has a total thickness of .00075 in. Due to the lack of an adequate analytical technique for the design of a spherical shell under the expected loading, further testing was necessary to determine the degree and extent of reinforcement required to rigidize a given shield.

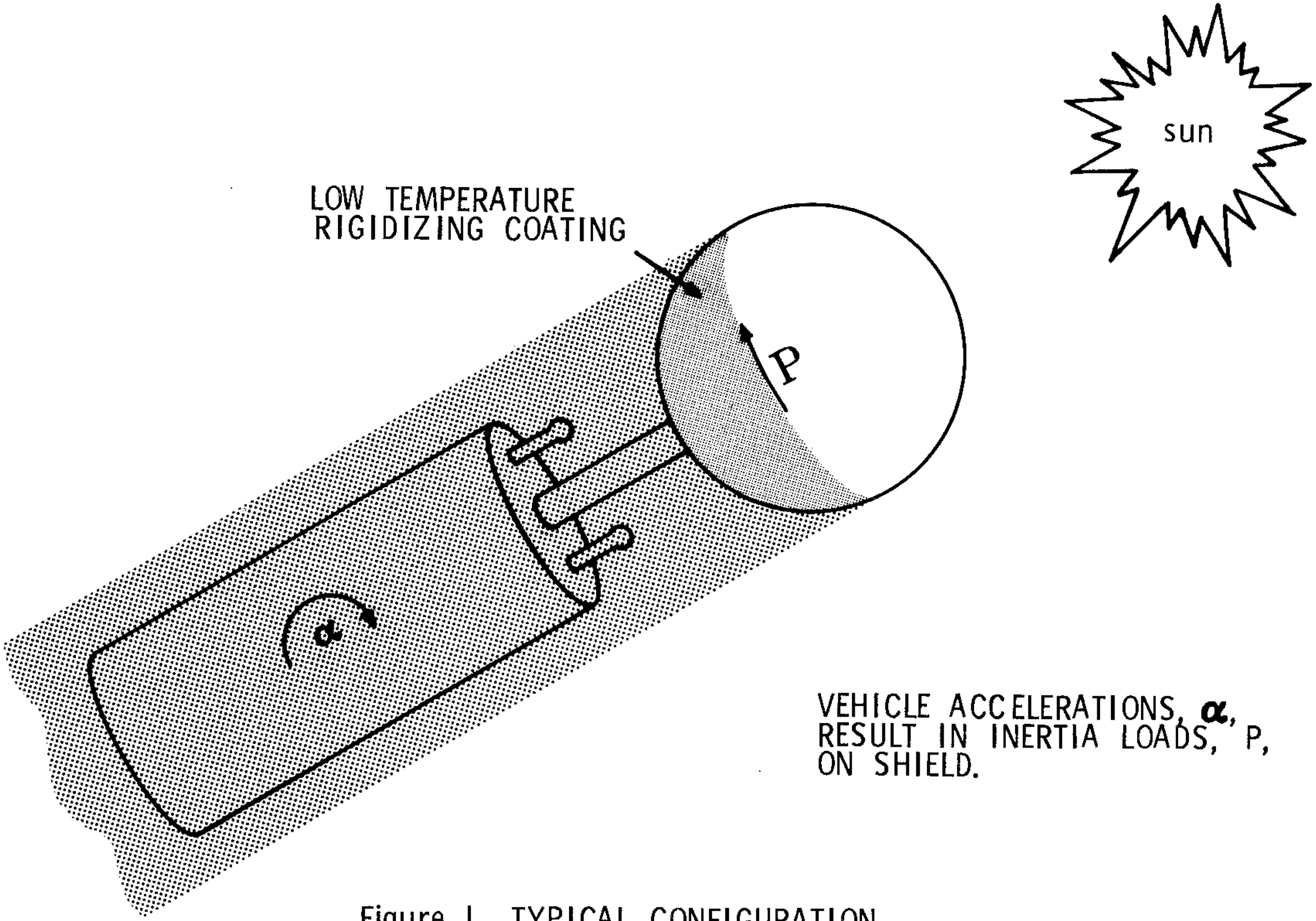


Figure I TYPICAL CONFIGURATION

DESCRIPTION OF TEST PROGRAM, PROCEDURE, AND RESULTS

The test program was conducted in three parts:

(1) Determination of structural properties of possible reinforcing materials.
(2) Evaluation of the relative abilities of these materials to rigidize the spherical shield configuration.
(3) Determination of the degree and extent of rigidization required to maintain shape and position of the shield under predicted loading conditions.

The rigidizing materials included in the test program were:

(1) Polyurethane Foam
(2) Neoprene
(3) Natural Rubber
(4) Latex
(5) Silicone Rubber (Dow Corning X-3-0902 RTV)
(6) Viton "A" (DuPont Fluorocarbon)
(7) EC776 (Minnesota Mining and Manufacturing)
(8) Polysulfide Rubber (Thiokol)
(9) Vinyl Base Lacquer (Brolite DC-25)

DETERMINATION OF STRUCTURAL PROPERTIES OF ELASTOMERS

Test specimens were prepared by applying a coating of the candidate materials to six-inch squares of the X-15 material. These nine squares were then cured completely and cut into strips, one inch by six inches. Two strips of each material were set aside as controls. The remaining four strips of each material were exposed to an environment of 4×10^{-7} mmHg, and -124°F for a period of 48 hours. Typical test specimens are shown in Figure 2. The environmental exposure test equipment is shown in Figure 3. Following this exposure, the specimens were examined for changes in weight and appearance. No significant changes were detected in any of the specimens. Three specimens of each material were then tested in tension and three in bending as shown in Figures 4 through 6. All tests were run at -124°F. Figures 7 and 8 show typical data recorded from these tension and bending tests. With the limited number of specimens tested and the short exposure time, there was no definite indication of structural degradation or improvement due to exposure. Table 1 is a summary of some significant structural properties from these tests. An attempt has been made to evaluate the strength per unit weight and stiffness per unit weight or efficiency of the materials. The strength-weight relationship has been represented by a simple ratio of maximum measured tensile stress divided by the unit weight of the composite material in pounds per square foot. The stiffness parameter shown combines the maximum calculated bending stress, an effective modulus of elasticity, and the moment of inertia of the specimen; all divided by the unit weight of the composite material in pounds per square foot. All specimens were 1.0 inch

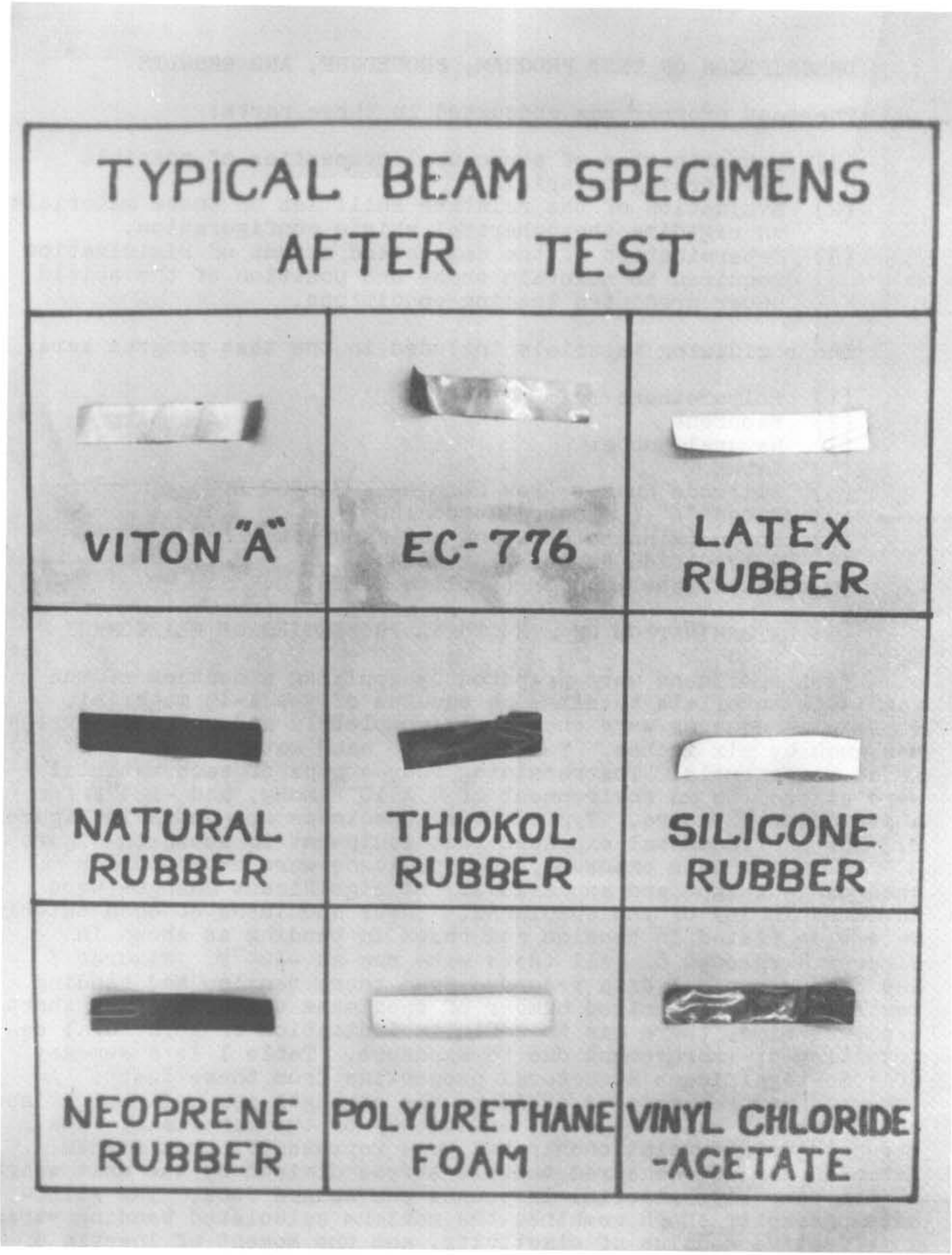


Figure 2 RIGIDIZING MATERIAL TEST SPECIMENS (STRIPS)

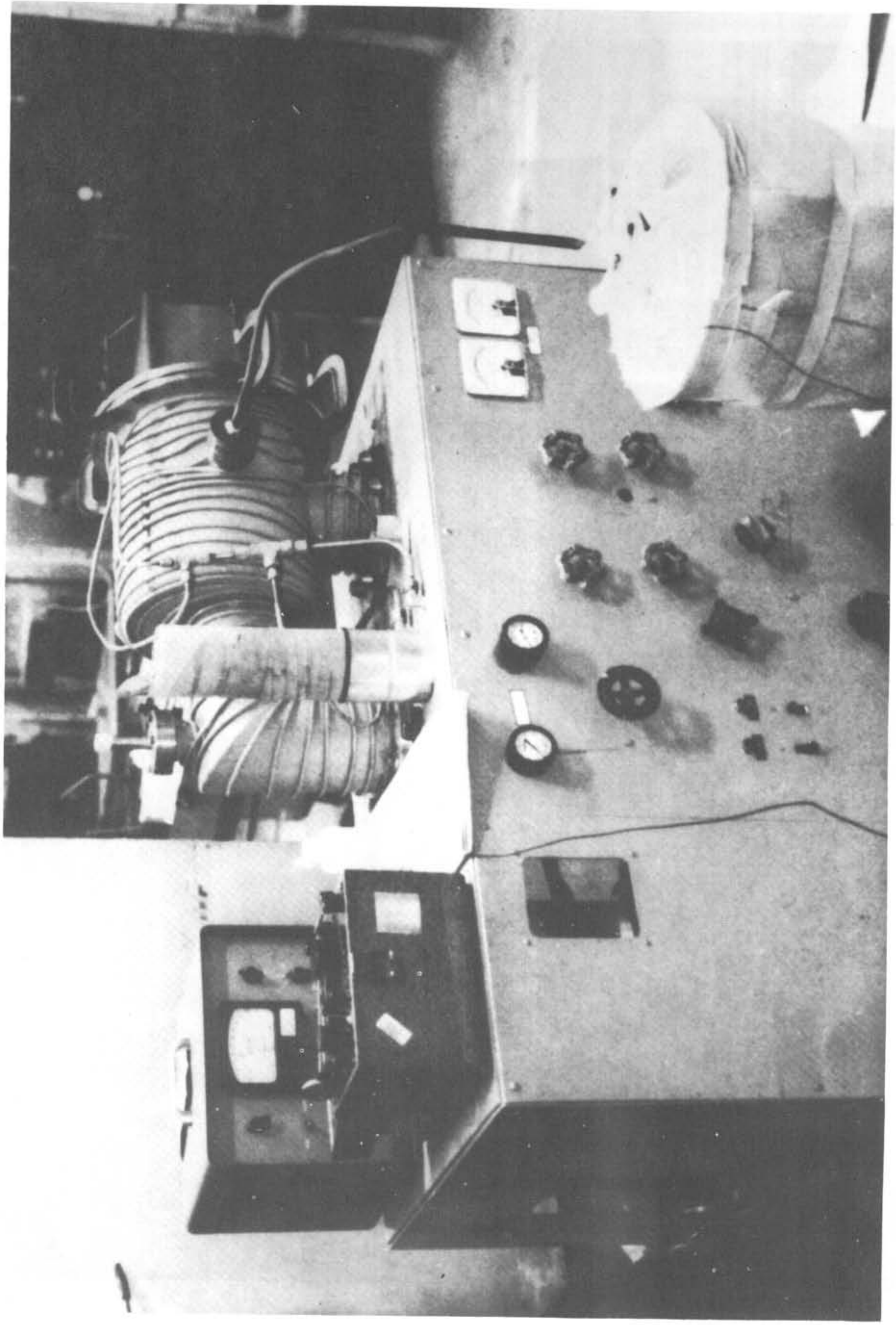


Figure 3 LOW-TEMPERATURE VACUUM EXPOSURE TEST

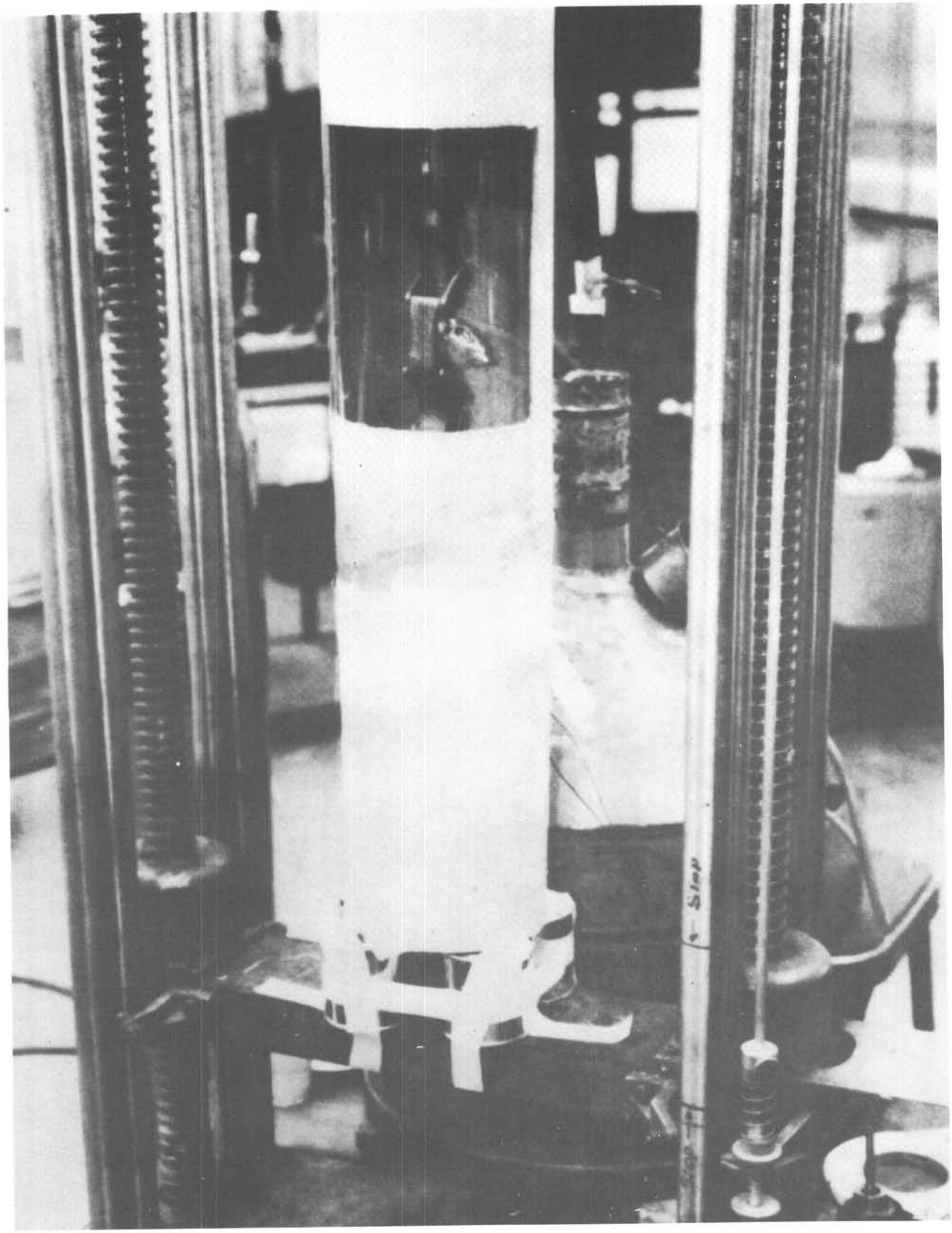


Figure 4 TENSILE TEST

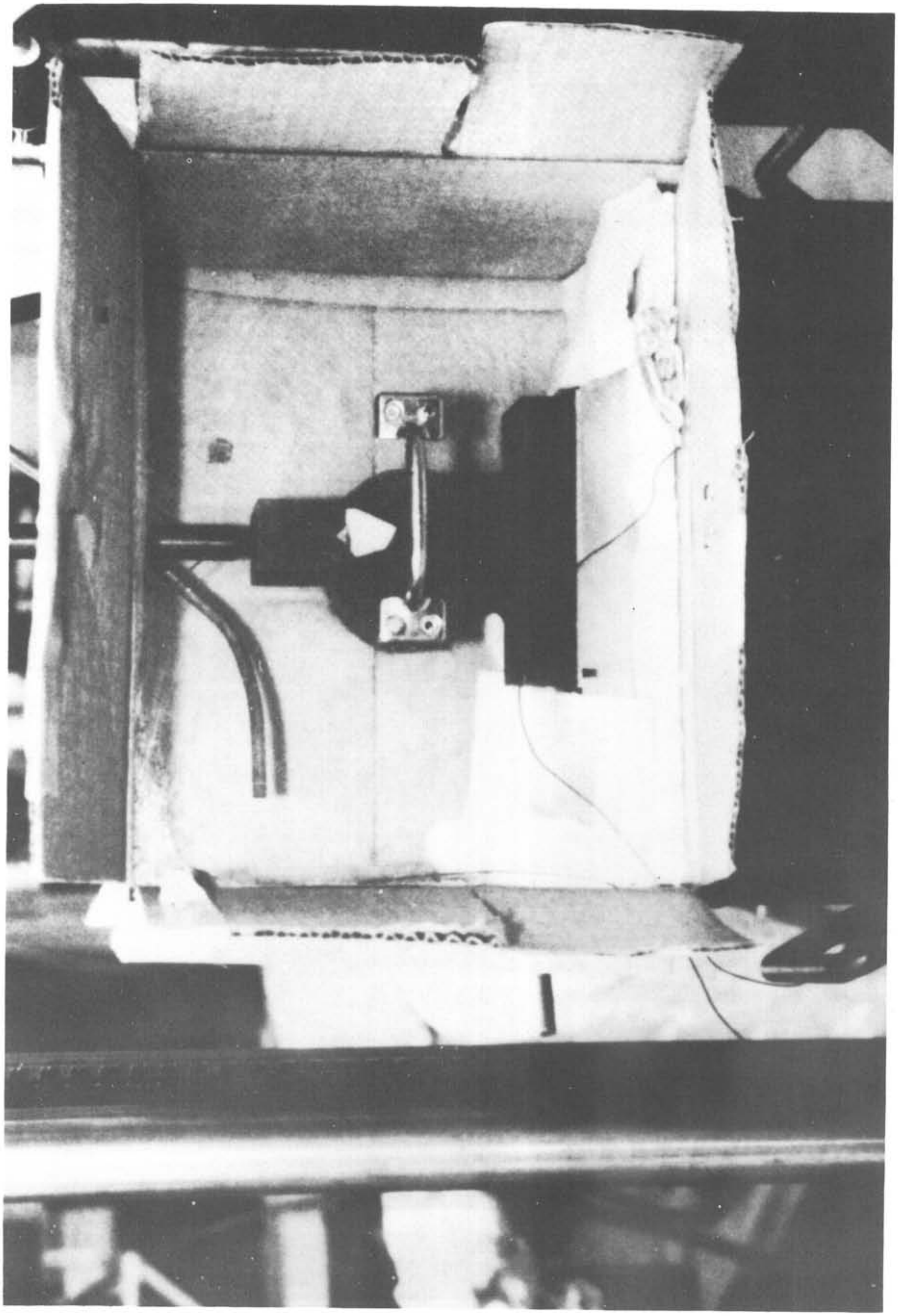


Figure 5 BENDING TEST

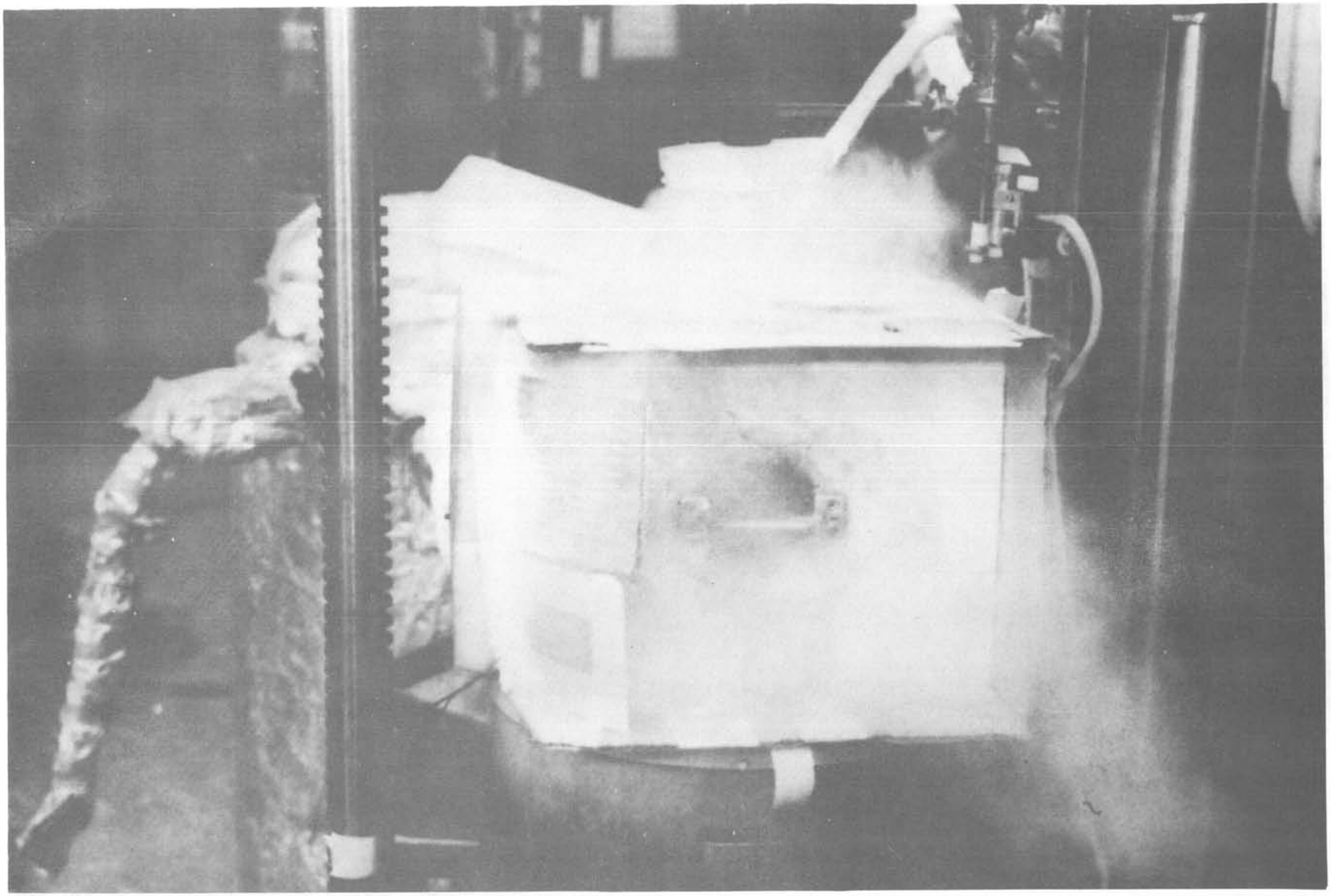


Figure 6 BENDING TEST IN OPERATION

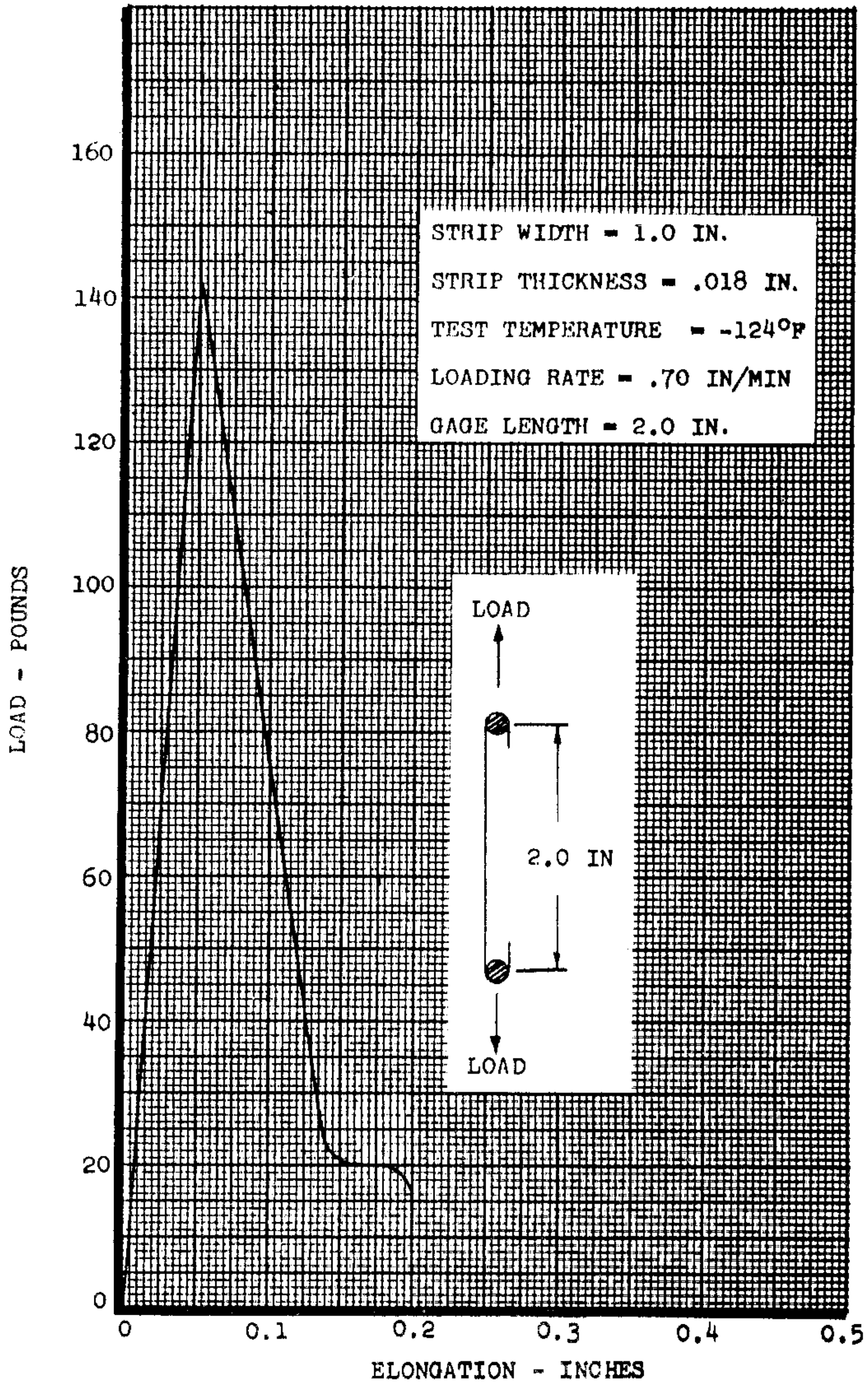


Figure 7 TENSILE TEST DATA FOR VINYL-BASE LACQUER COATING

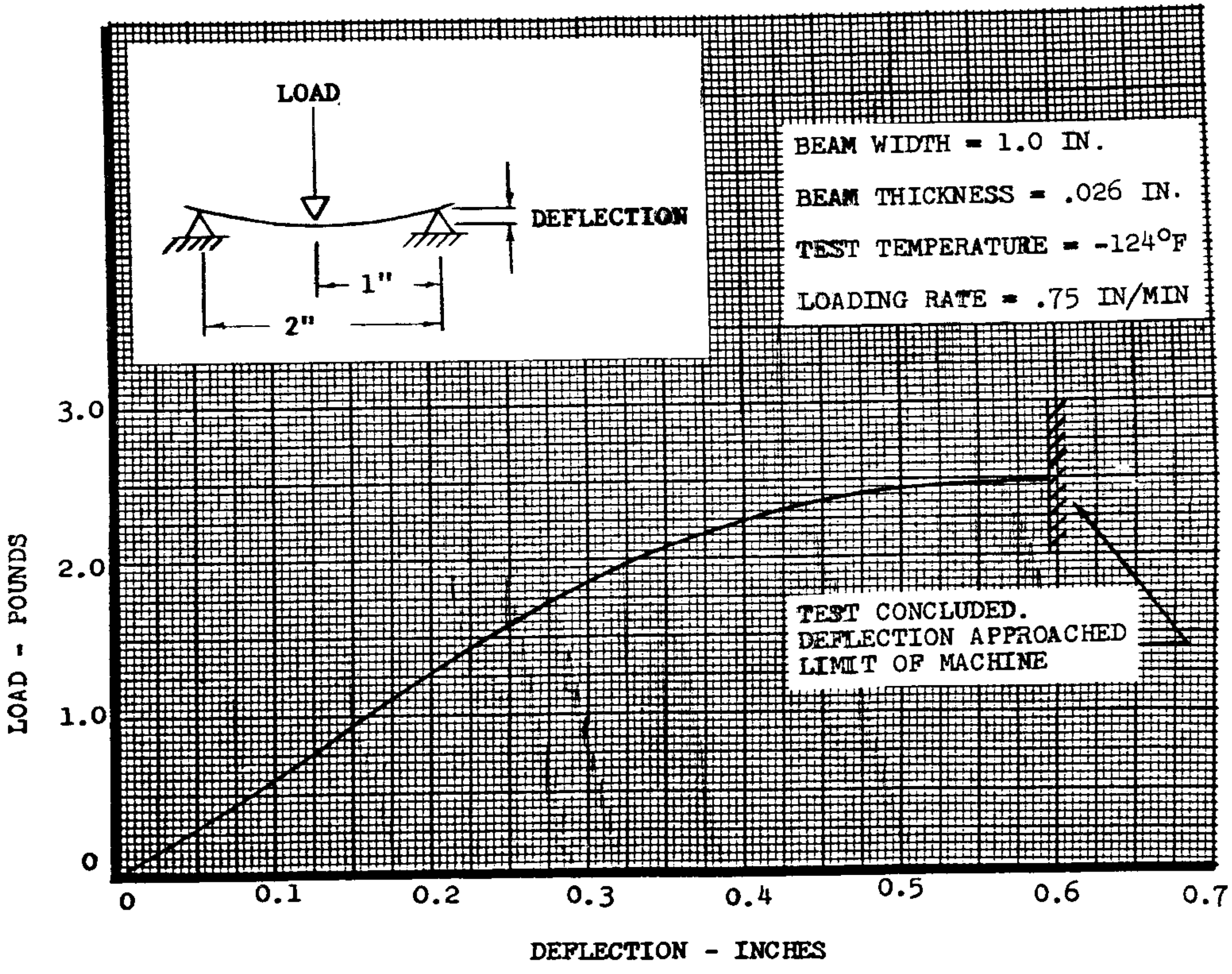


Figure 8 BENDING TEST DATA FOR VINYL-BASE LACQUER COATING

Table 1 EVALUATION OF POTENTIAL RIGIDIZING MATERIALS

SPECIMEN NO.	MATERIAL	WEIGHT (LB/FT^2)	THICKNESS (IN.)	MAXIMUM TENSILE STRESS, FT. (PSI)	ELONGATION AT MAX. LOAD (%)	STRENGTH PARAMETER $\frac{F_t}{\text{UNIT WT.}}$	MAXIMUM BENDING STRESS, F_B (PSI)	MAXIMUM BEAM DEFLECTION (IN.)	EFFECTIVE MODULUS E_{EFF} (PSI x 10^6)	STIFFNESS PARAMETER $\frac{E_{EFF} F_b I}{\text{UNIT WT.}}$
1	Polyurethane Foam	.06564	.25	100	16	1520				
2		.06787	.25	112	22	1650				
3		.07244	.25				111	.275	.00108	2125
4		.05156	.25				74	.275	.00072	1340
5 (c)*		.07523	.25				101	.275	.00098	1690
6 (c)		.07427	.25	90	12	1210				
7	Neoprene	.19195	.029				5700	.120	1.09	66000
8		.21445	.032	645	4	3000				
9		.19355	.030	564	4	2910				
10		.21998	.033				6500	.110	1.20	106400
11 (c)		.21166	.028	1275	3	6030				
12 (c)		.19670	.030				7300	.110	1.48	123700
13	Natural Rubber	.15492	.030				3200	.400	.18	8350
14		.15587	.025	1800	27	11550				
15		.16049	.025				8100	.490	.44	29000
16		.16557	.030	1660	23	10000				
17 (c)		.14993	.035				4900	.56	.17	19700
18 (c)		.14902	.027	648	21	4350				
19	Latex	.15671	.022	1229	9	7840				
20		.19857	.037				11800	.32	.67	169000
21		.21669	.044	455	16	2100				
22		.21117	.041				11200	.26	.70	212000
23 (c)		.18926	.033	515	11	2720				
24 (c)		.20563	.030	667	19	3250				
25	Silicone Rubber	.26728	.041				3500	.24	.24	18000
26		.29760	.048	509	7	1710				
27		.30192	.044	564	7	1870				
28		.27411	.041				4000	.24	.27	22300
29 (c)		.31501	.041	552	8	1752				
30 (c)		.29124	.044	414	8	1420				
31	Viton A	.24364	.035	3125	8	12850				
32		.22782	.031				9000	.51	.38	37200
33		.20435	.026	3910	21	19100				
34		.23082	.038				8600	.40	.27	46100
35 (c)		.24138	.034	4650	36	19300				
36 (c)		.24811	.037				11500	.48	.43	84400
37	EC #776	.11047	.020	740	11	6700				
38		.11677	.021				10900	.41	.85	61000
39		.11387	.022				10100	.37	.83	64600
40		.10082	.021	562	6	5580				

*CONTROL SPECIMEN

Table 1 (Continued)

SPECIMEN NO.	MATERIAL	WEIGHT (LB/FT^2)	THICKNESS (IN.)	MAXIMUM TENSILE STRESS, F_T (PSI)	ELONGATION AT MAX. LOAD (%)	STRENGTH PARAMETER F_T / UNIT WT.	MAXIMUM BENDING STRESS, F_B (PSI)	MAXIMUM BEAM DEFLECTION (IN.)	EFFECTIVE MODULUS E_{EFF} ($PSI \times 10^6$)	STIFFNESS PARAMETER $E_{EFF} F_b I$ / UNIT WT.
41 (c)	Vinyl-Base Lacquer	.09551	.018				7900	.41	.71	28600
42 (c)		.10153	.018	655	1	6450				
43		.13189	.018	7850	3	59500				
44		.14724	.026				11000	.52	.54	58800
45		.13472	.024				10900	.52	.58	53800
46		.12832	.022	5020	15	39100				
47 (c)		.13027	.020	4000	20	30700				
48 (c)		.12661	.020				11900	.50	.80	50300
49	Polysulfide Rubber	.13675	.017				21100	.35	2.37	150000
50		.07845	.012	1715	2	21900				
51		.09336	.011				11700	.37	1.92	26500
52		.19349	.024	4180	8	21600				
53 (c)		.21950	.030	965	6	4400				
54 (c)		.25426	.035	1450	5	5700				
55 (c)		.28007	.016	3120	14	11100				

wide. Thicknesses were as shown in Table 1. All bending test specimens were tested as center-loaded simple beams with a 2.0 inch span. Tension strips were 2.0 inches long. The equations defining the parameters in Table 1 are:

$$F_T = \text{Maximum Tensile Stress} = \frac{\text{Maximum Measured Tensile Load}}{(\text{Width, 1.0 in.})(\text{Specimen Thickness}, t)}$$

$$F_B = \text{Maximum Bending Stress} = \frac{Mc}{I} = \frac{3P}{t^2}$$

Where P = Maximum Beam Load From Bending Test
t = Specimen Thickness
$c = t/2$

$$E_{EFF} = \text{Effective Modulus of Elasticity} = \frac{P\ell^3}{48I\delta} = \frac{P}{6I\delta}$$

Where P = Maximum Beam Load From Bending Test
I = Specimen Moment of Inertia $= \frac{bt^3}{12}$
ℓ = Beam Length = 2 inches
δ = Beam Deflection at Maximum Load
b = Specimen Width = 1 inch

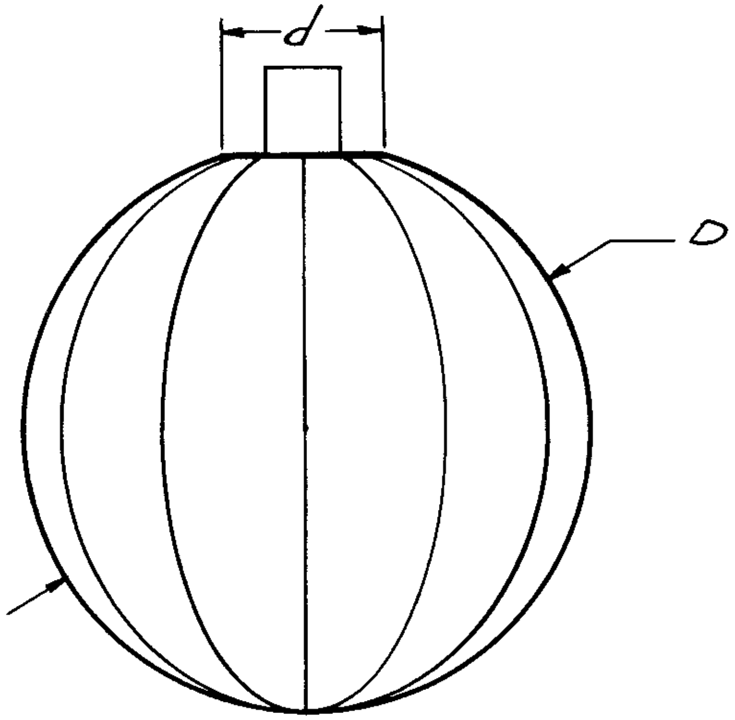
ASSESSMENT OF RELATIVE RIGIDIZATION VALUES

The results of this first phase of testing indicated which materials might be suitable rigidizers. These indications, with other considerations of ease of handling and application, determined which materials would be applied to 30-inch diameter spheres for actual rigidization tests. These materials were:

(1) Vinyl Base Lacquer
(2) Viton A
(3) Latex
(4) Neoprene
(5) EC776

These spheres were fabricated from twelve gores of X-15 material and attached to a flanged support cylinder as shown in Figure 9. To facilitate fabrication and testing, the support cylinder was represented by a rigid metal cylinder with a rigid flange supporting the sphere. An investigation of the rigidity of the actual support cylinder was not part of this study, interest being in the stability of the "neck" of the sphere near the sphere-cylinder intersection.

Each of the selected materials was applied to one of the spheres as shown in Figures 10 and 11, covering what would be its supported or shaded hemisphere. These coatings were applied by spraying to a thickness of between .010 and .020 inch. Specimens were weighed before and after coating to determine the weight of the coating. Thicknesses were measured using a Tinsley Thickness Gage. Tabulated thicknesses are the average of several measure-



Sphere Diameter, D	Flange Diameter, d
15 in.	3.5 in.
24 in.	5.0 in.
30 in.	7.0 in.

Figure 9 TEST SPHERE GEOMETRY

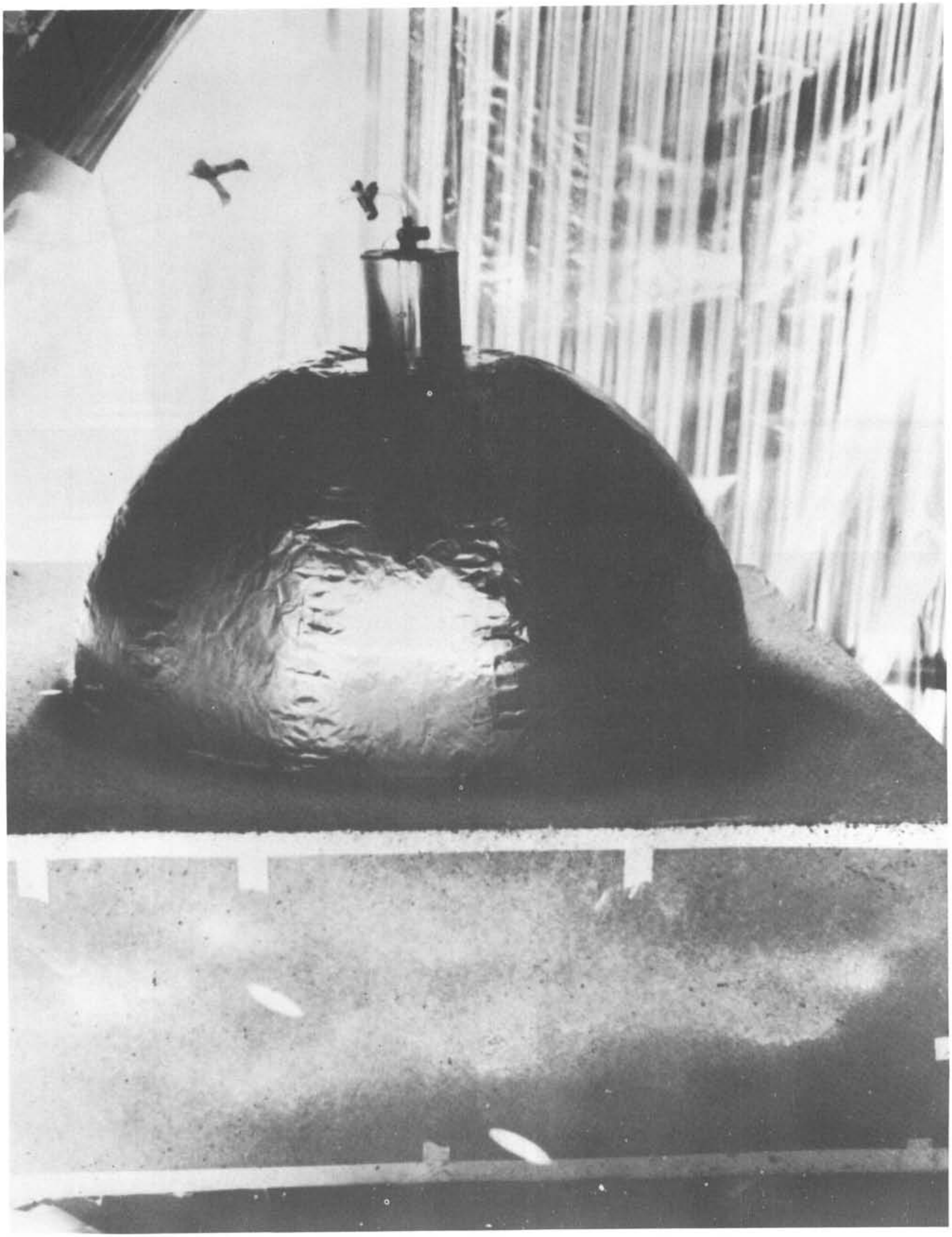


Figure 10 30-INCH-DIAMETER SPHERE COATING FIXTURE

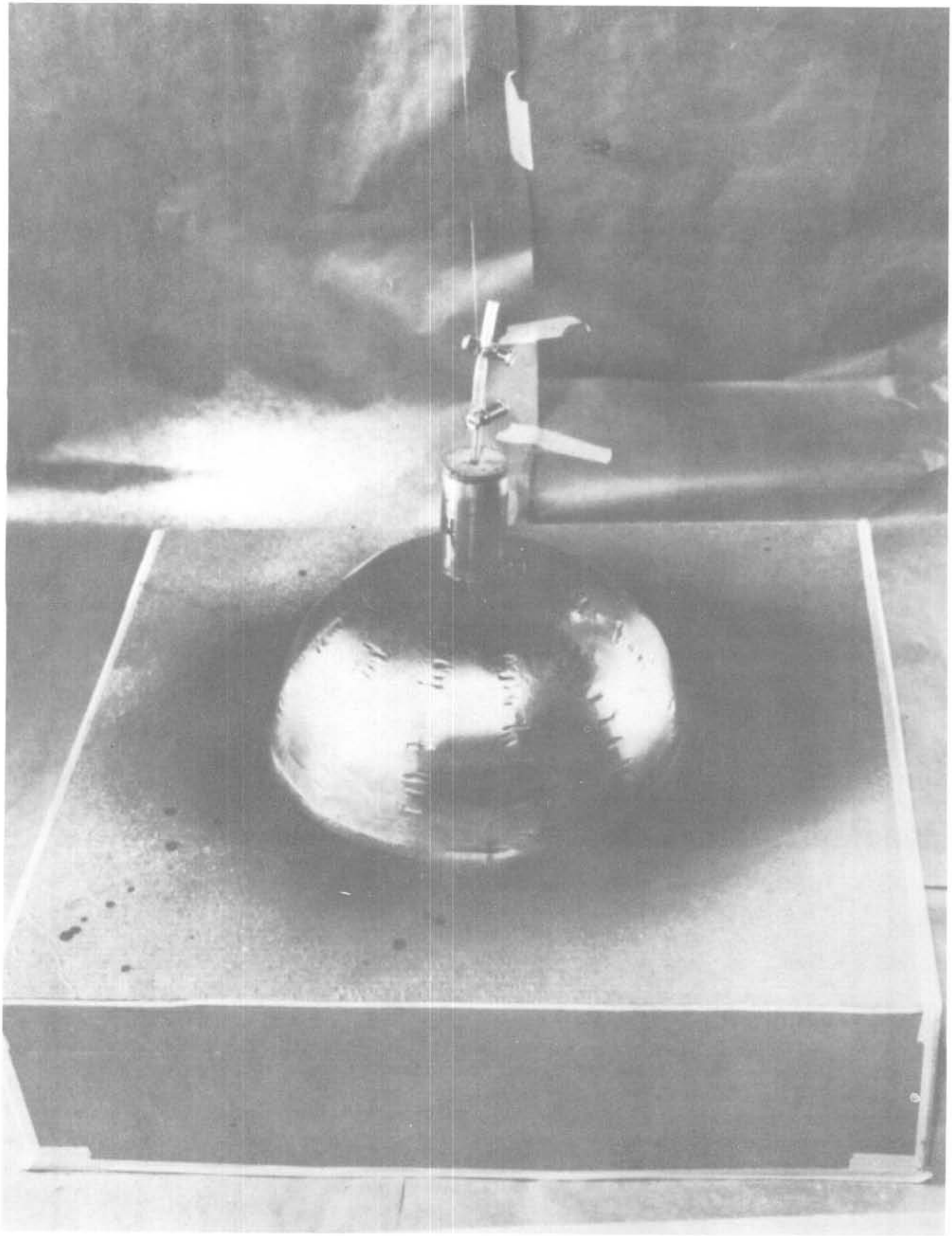


Figure 11 15-INCH-DIAMETER SPHERE COATING FIXTURE ments taken around the critical "neck" of the sphere (see Table 2).

These spheres were tested by applying inertial loads normal to the sphere support axis using a centrifuge. To provide the desired loading, an extension arm was fitted to a Genisco Model 50159 Accelerator, giving a maximum radius of rotation of about 12 feet. A lightweight 42-inch cubic container was mounted on the end of the boom. This container was a reinforced, foam-insulated, corrugated cardboard box which protected the specimen from airloads and, after being cooled with liquid nitrogen, maintained the proper reduced temperature during testing. Wedge fairings were added to the forward and aft faces of the box for drag reduction. This test equipment is shown in Figures 12 and 13. Test spheres were suspended in the box as shown in Figures 14 and 15. A sphere surface temperature of approximately -130°F was maintained throughout the test. As the rate of rotation of the centrifuge was increased, corresponding sphere deflections were noted and points of failure were determined. Using these measured rotational rates, the specimen radius of rotation, and the specimen mass, the sphere loading could be calculated.

Sphere surface temperature near the "neck" was monitored using thermocouples taped to the surface. These thermocouple voltages were amplified by precision amplifiers mounted directly on the rotating boom. The amplified signals were then fed through slip rings on the centrifuge shaft for remote reading. Sphere deflections and failure were indicated by a wireless system to avoid noise problems inherent with the slip rings. This consisted of a battery powered electronic oscillator mounted on the specimen box. As the conducting surface of the deflecting sphere approached a coil in the oscillator circuit, a corresponding decrease in signal strength was detected by a field strength meter at the console and converted to sphere position. The components of this instrumentation are shown in Figures 16 and 17.

After installation of the test specimen in the box as shown in Figure 15, an initial pressure of about ten inches of water was held in the sphere by inflation with gaseous nitrogen. With this pressure holding the shape and position of the sphere, liquid nitrogen was pumped into the box. When the sphere had cooled sufficiently to become rigid (below about -50°F), the internal pressure was released and the box covered. The addition of liquid nitrogen was continued until the temperature of the rigidized surface reached -150°F. At this point the liquid nitrogen was shut off and the centrifuge started. For the time required for one test run, approximately two minutes, an essentially constant temperature was maintained by boiling of residual liquid nitrogen in the bottom of the box. In the event of a delayed or prolonged run, the maximum temperature rise was only 20 or 30 degrees. Such a rise had no noticeable effect on the specimen rigidity. Some runs were purposely prolonged to observe specimen behavior under constant load and increasing temperature.

Table 2 shows the results of these tests of the relative rigidizing abilities of the five elastomers. Due to the power limit of the centrifuge, maximum radial acceleration attainable

Table 2 RIGIDIZING MATERIAL EVALUATION 30-INCH SPHERES

Coating Material	Sphere Uncoated Weight (gms)	Sphere Coated Weight (gms)	Weight Of Coating (gm)	Coating Thickness (in)	Ultimate Load (g's)
Latex	257	487	230	.012	3.43
Vinyl Base Lacquer	266	540	274	.010	3.67
Neoprene	253	440	187	.015	2.76
Viton A	254	782	528	.020	>4.13
EC776	260	542	282	.020	>4.13
None			0	0	.59

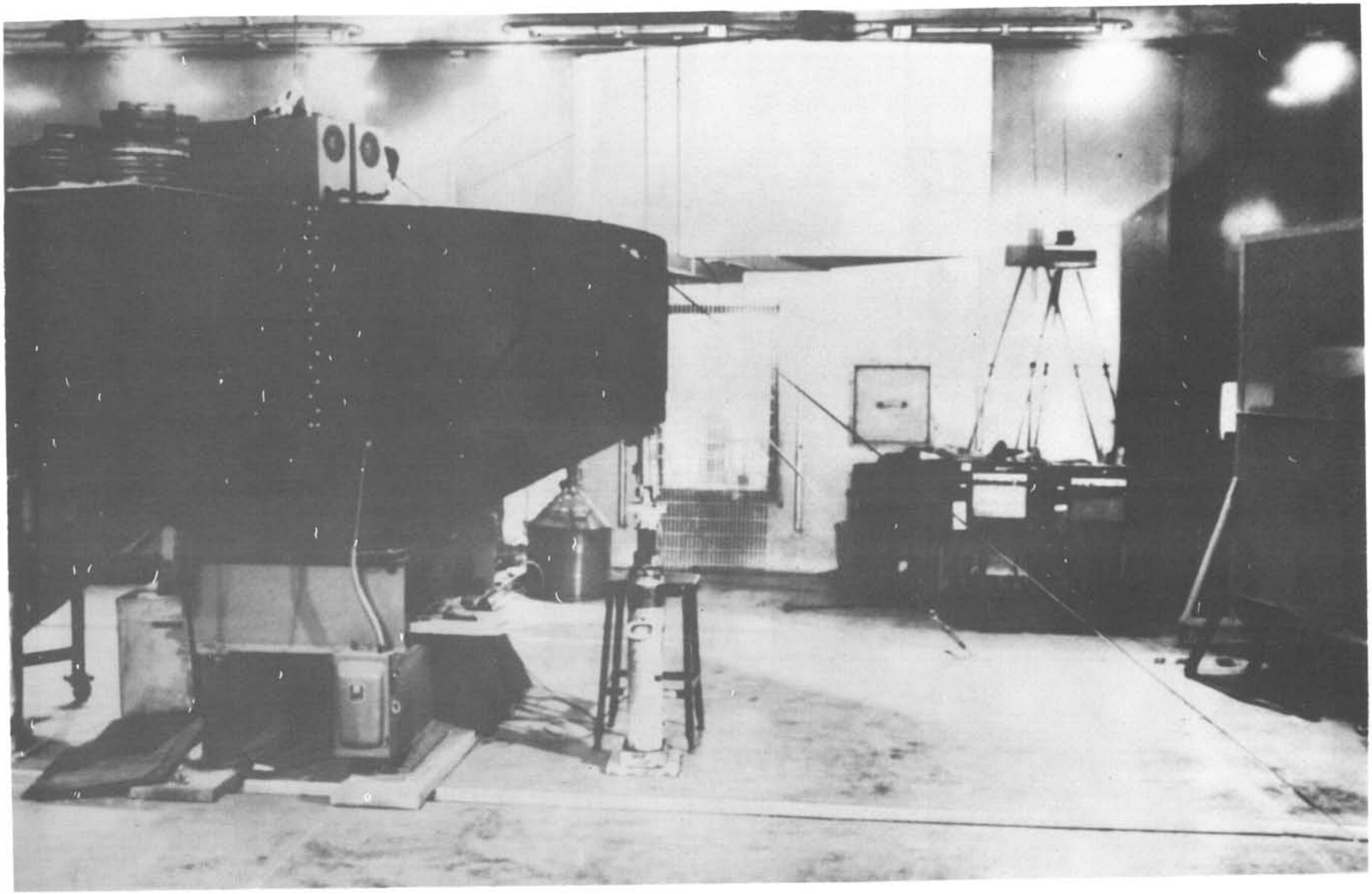


Figure 12 SPHERE LOADING TEST

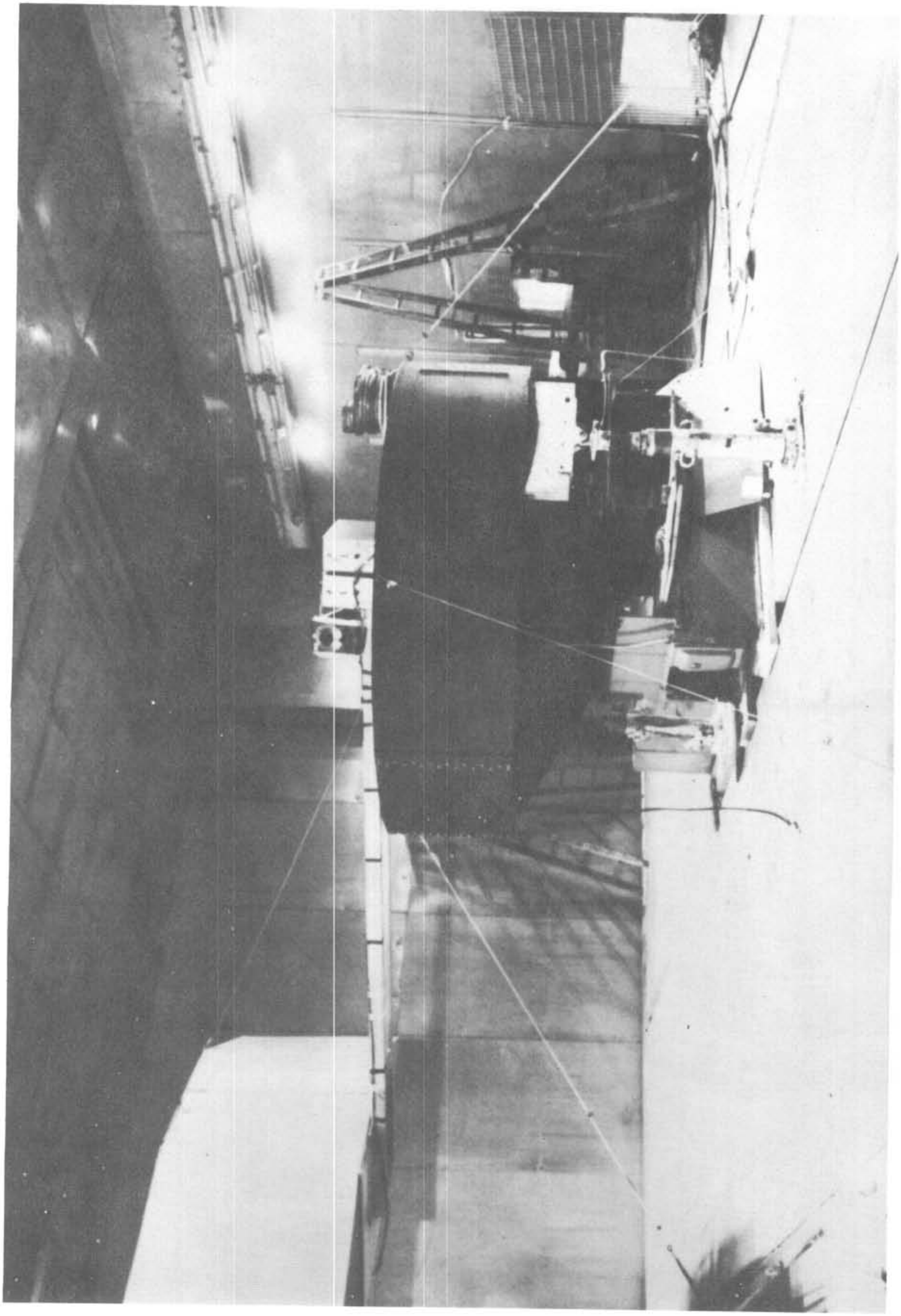


Figure 13 SPHERE LOADING TEST

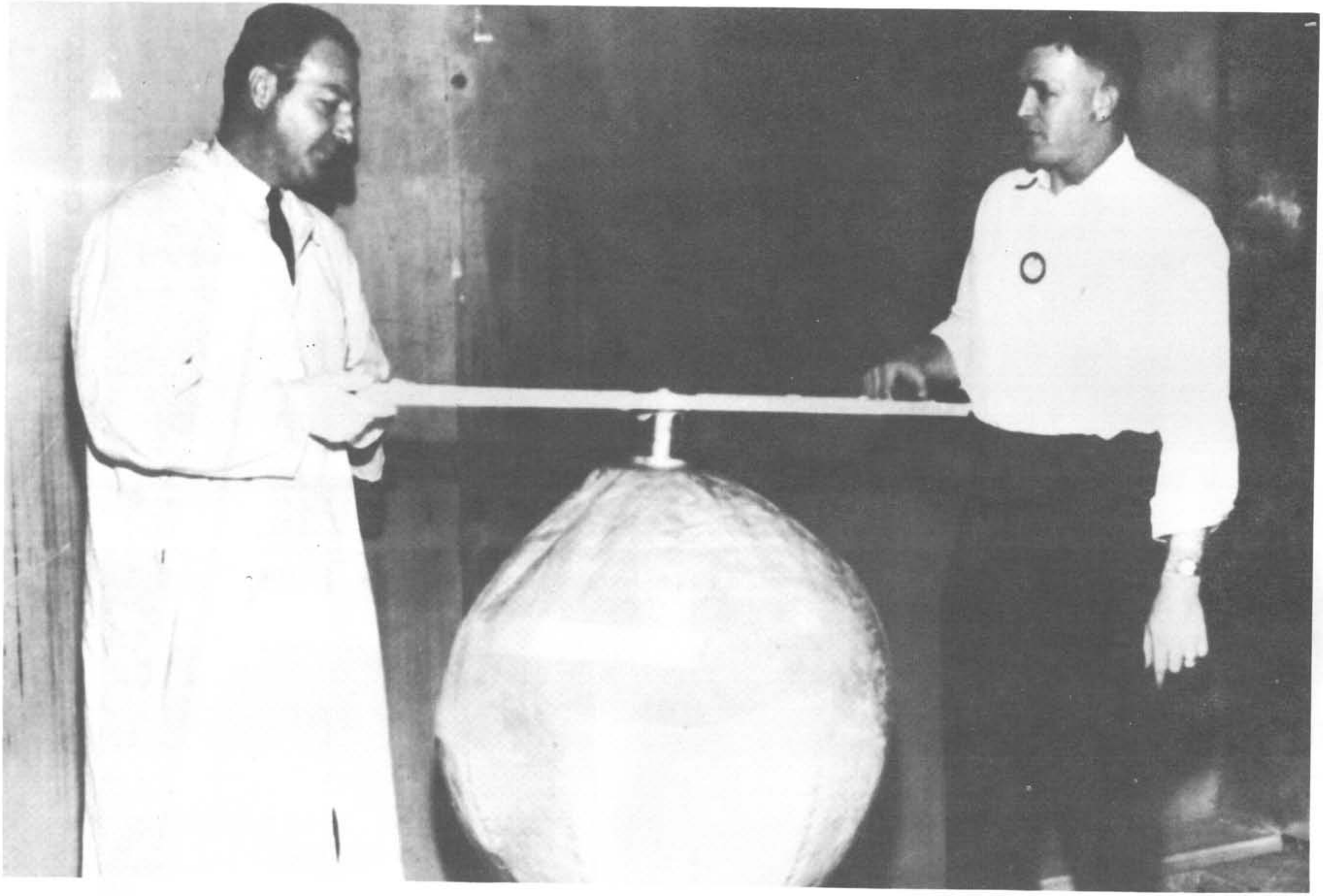


Figure 14 30-INCH-DIAMETER SPECIMEN READY FOR INSTALLATION IN CENTRIFUGE BOX

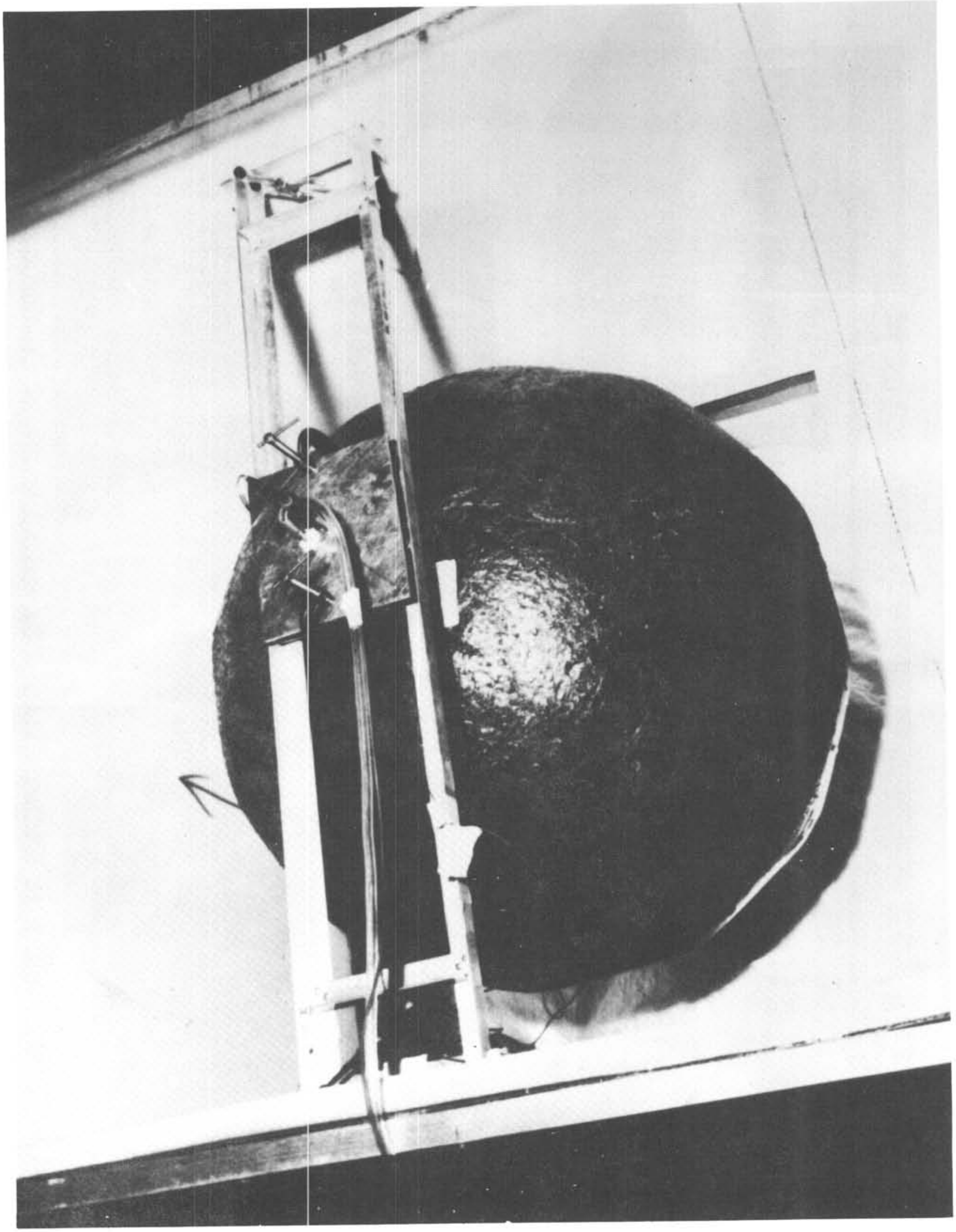


Figure 15 30-INCH-DIAMETER SPECIMEN INSTALLED IN CENTRIFUGE BOX (TEMPORARY PRESSURE ATTACHED)

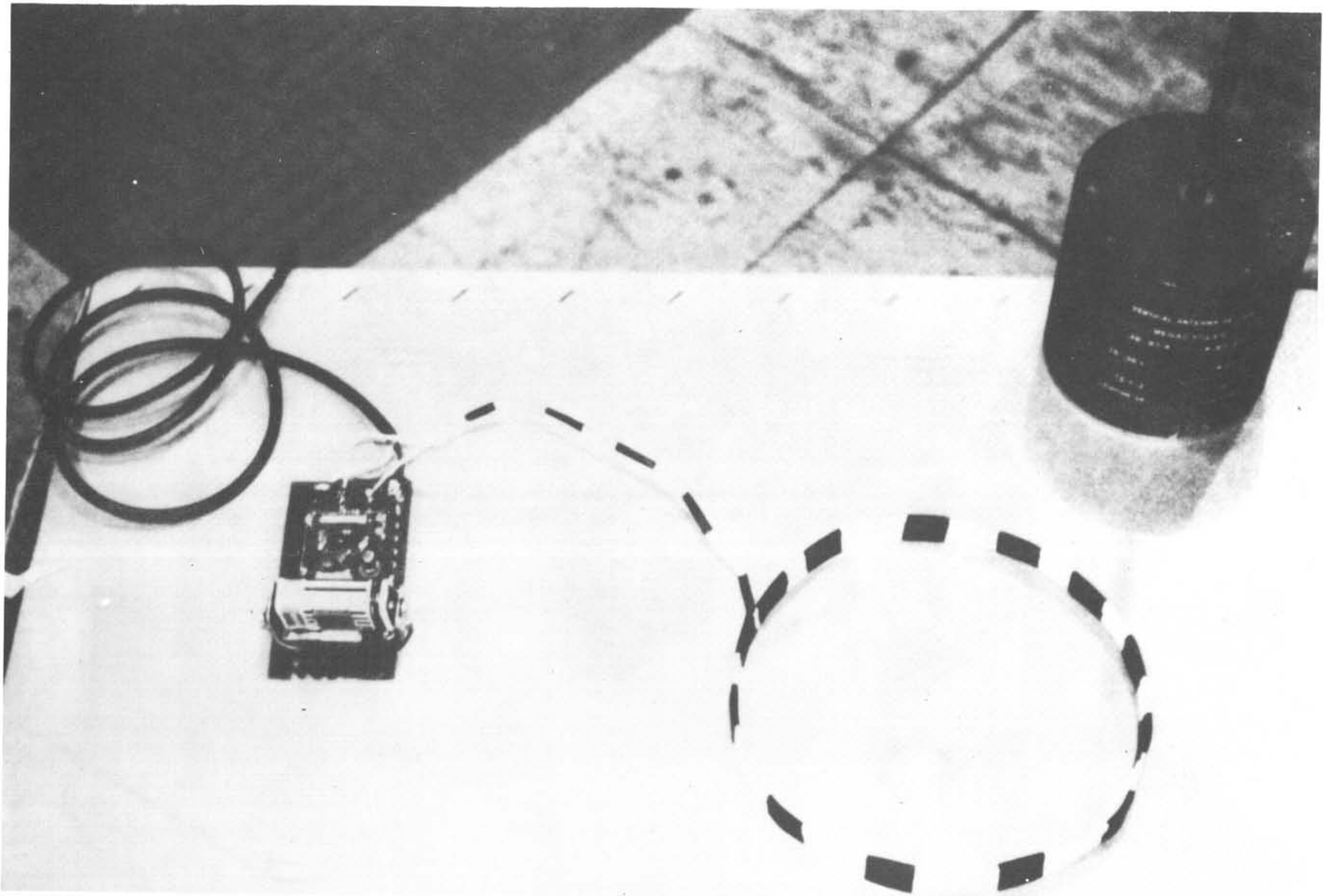


Figure 16 SPHERE POSITION SENSING SYSTEM

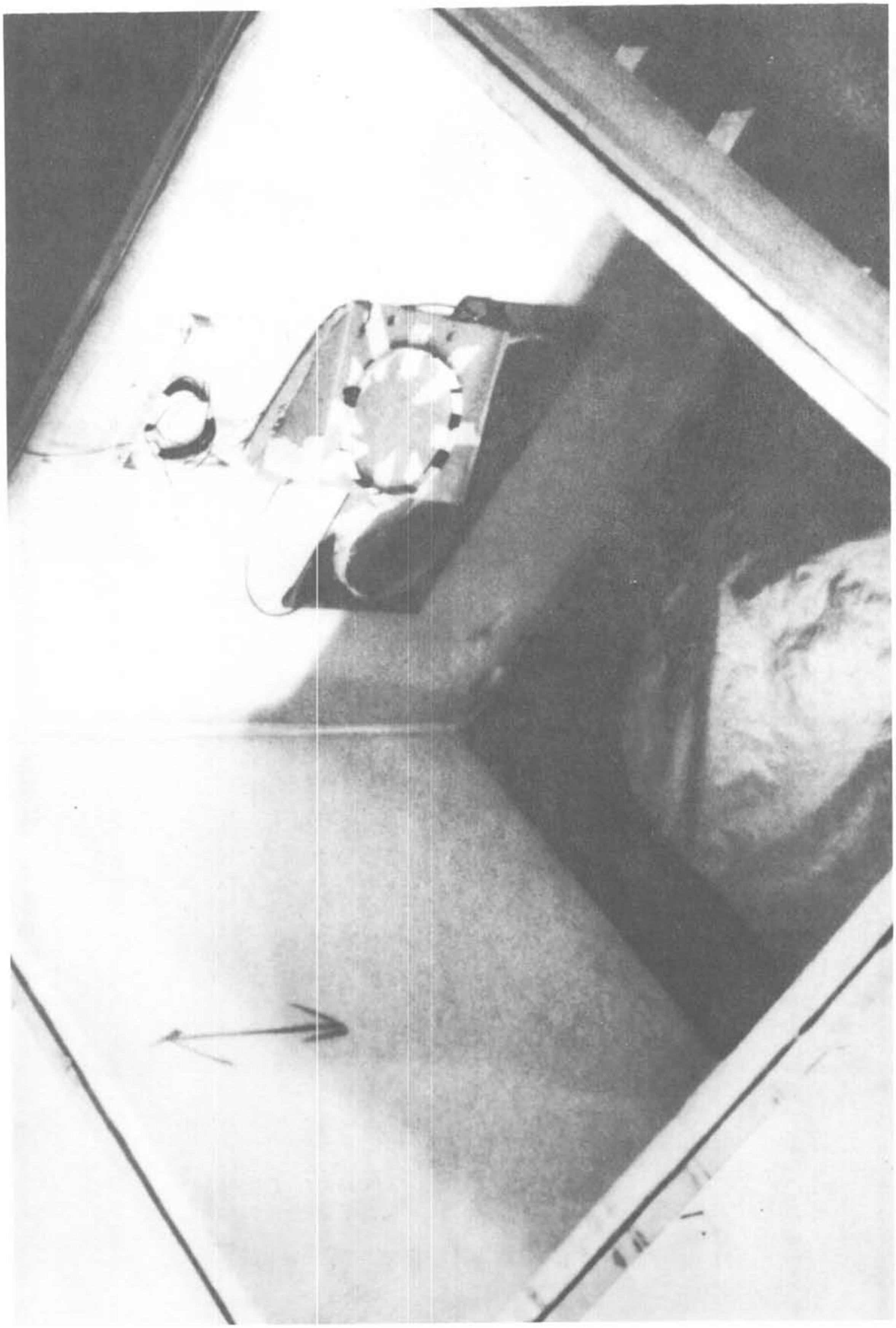


Figure 17 SPHERE POSITION SENSING SYSTEM INSTALLED

was 4.13 g's. At this point the "Viton A" and EC776 coated spheres had not failed. Subsequent modifications have raised this centrifuge limitation.

All sphere failures were, as expected, buckling of the material near the neck as shown in Figure 18. Most of the materials were not permanently damaged by this buckling. Only the neoprene cracked. The previous material tests had shown the neoprene to be a brittle material. The remaining materials were evaluated as follows:

Viton A - Heavy, expensive, and relatively difficult to handle. These disadvantages may ultimately be outweighed by its apparent rigidizing properties, as yet not completely evaluated.

EC776 - Apparently a good rigidizing material, but the low-density coating obtained in these tests may not be reproducible. Bubbles in this coating are thought to be responsible for its efficiency.

Latex - Latex has marginal flexibility for proper storage after an extended cure at room conditions.

Vinyl Base Lacquer - This material is inexpensive, easy to handle and apply, and rigidizes satisfactorily. This and the Viton were the only materials which did not fail in the bending tests.

DETERMINATION OF RIGIDIZING COATING REQUIREMENTS

On the basis of test data and other considerations, vinyl base lacquer was selected for the coating material for the remaining sphere tests. Fifteen, twenty-four, and thirty-inch diameter spheres were fabricated, coated, and tested as described previously. Both the coating thickness and extent of coverage were varied for these tests. Indications were that a coating covering the complete hemisphere is no better than an equal thickness covering one-half of the hemisphere in the polar cap area. The range of coating thicknesses was from 1.5 to 10 mils. Data from these tests are shown in Table 3. Figure 19 shows the relationship between sphere deflection and lateral load in g's obtained from the centrifuge tests. The sudden increase in slope of some of the curves is characteristic of thin shell buckling, as is the initial deflection as stiffening wrinkles are established.

The bending moment at the neck of a cylinder-supported sphere loaded by inertia normal to its support axis may be expressed as

$$M = r^3 n(\omega_2 + 3\omega_1)$$

Figure 18 TYPICAL SPHERE FAILURE

Table 3 SPHERE DATA

VINYL BASE LACQUER COATING

Specimen No	Uncoated Weight (gm)	Coated Weight (gm)	Weight Of Coating (gm)	Coating Thickness (in)	Extent Of Coverage*	Ultimate Load (g's)
1 -15 in.	106	120	14	.0045	1/4	3.55
2 -15 in.	107	124	17	.0040	1/4	4.25
3 -15 in.	106	124	18	.0055	1/2	9.15
4 -15 in.	107	125	18	.0040	1/2	4.75
II-1-15 in.	95	100	5	.0014	1/4	4.0
II-2-15 in.	95	104	9	.0027	1/4	3.8
II-3-15 in.	95	100	5	.0015	1/4	2.9
1 -24 in.	168	192	24	.0033	1/4	3.5
2 -24 in.	166	203	37	.0055	1/4	5.0
3 -24 in.	168	222	54	.0070	1/4	6.15
1 -30 in.	264	328	64	.0040	1/2	1.56
2 -30 in.	256	313	57	.0040	1/4	1.12
3 -30 in.	261	328	67	.0040	1/2	1.12
4 -30 in.	257	298	41	.0040	1/4	1.12
X -30 in.	266	540	274	.0100	1/2	3.67

* Portion of complete sphere

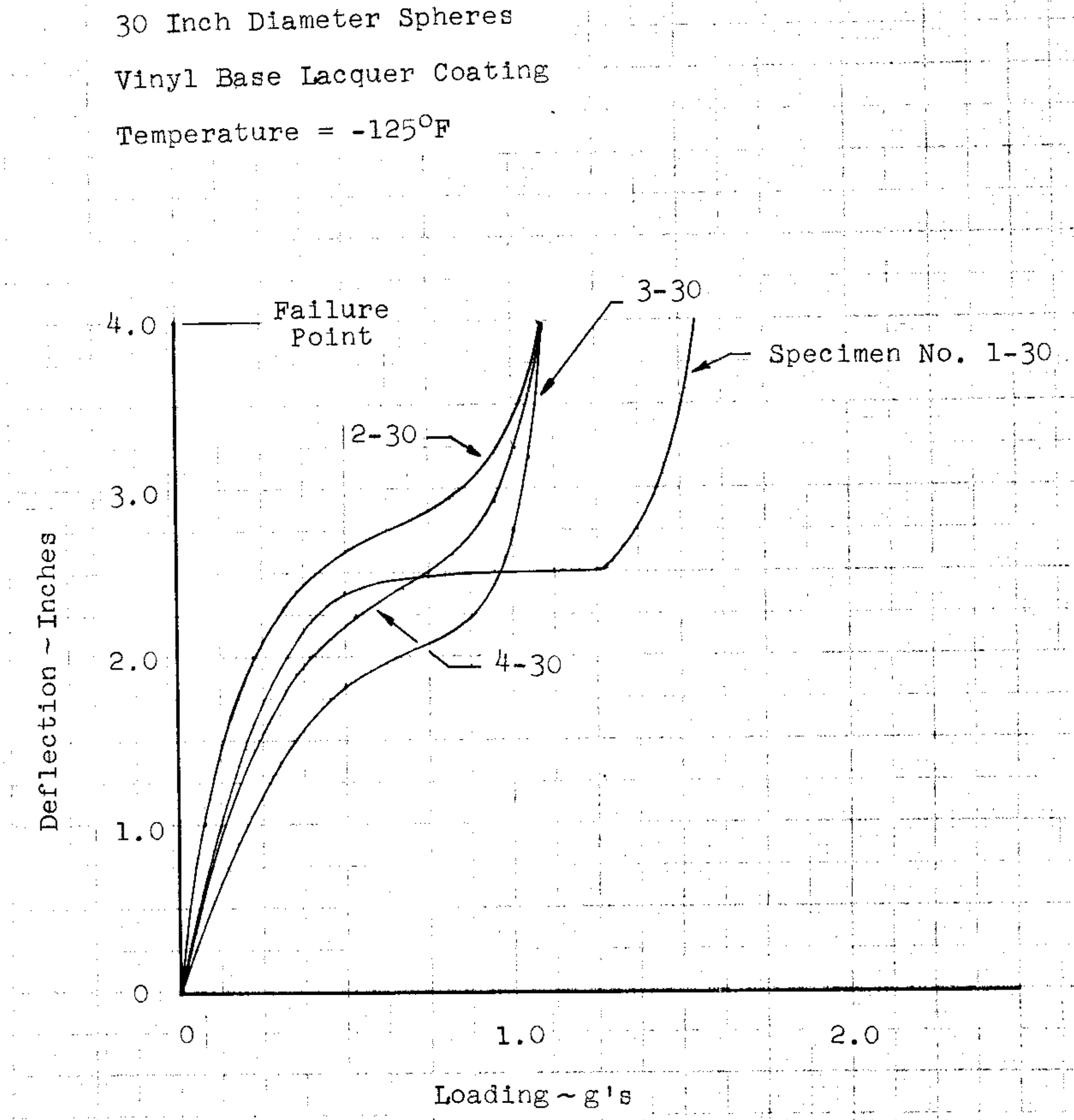


Figure 19 SPHERE DEFLECTION FOR VINYL BASE LACQUER COATED SPHERES

Where r = radius of sphere (in.)

n = inertial loading (g's)

ω_2 = unit weight in pounds per square inch of sphere surface on support side of sphere equator (coated hemisphere)

ω_1 = unit weight in pounds per square inch of sphere surface on far (uncoated) hemisphere

M = bending moment (in-lbs)

Therefore, for spheres of similar unit weights (i.e., the same thickness of coating, t_c), the loading at the critical area can be seen to be proportional to r^3n. The critical buckling load on a thin shell elastic structure is assumed to be a function of the ratio of shell radius to thickness, r/t. Table 4 summarizes these loading and geometric parameters for the test specimens.

EXTRAPOLATION OF TEST DATA TO FULL SCALE SHIELD GEOMETRY

The results of the sphere rigidization tests were extrapolated to estimate the suitability of the low temperature rigidizing concept for application to a proposed Mars Mission Vehicle. Figure 20 shows data from Table 4 with extrapolation to a 330-inch diameter sphere with vinyl base lacquer coating thicknesses of 4 and 10 mils (total thicknesses of .00475 and .01075 inches, respectively). The estimated masses and load carrying capabilities from this extrapolation are shown in Table 5. For the 330-inch diameter shield with a 10 mil coating the allowable lateral load is estimated to be .0356 g's. For a hypothetical vehicle whose center of gravity is 50 feet from the shield center, this allowable shield load corresponds to an attitude control angular acceleration of 1.31 $^\circ/\mathrm{sec}^2$.

Table 4 SPHERE TEST SUMMARY

VINYL BASE LACQUER COATING

Specimen	Radius "r" (in)	Coating Thickness "t_c" (in)	Total Thickness "t" (in)	r/t	Loading At Failure "n" (g's)	r^3n
1 -15 in.	7.5	.0045	.00525	1430	3.55	1490
2 -15 in.	7.5	.0040	.00475	1580	4.25	1780
3 -15 in.	7.5	.0055	.00625	1200	9.15	3840
4 -15 in.	7.5	.0040	.00475	1580	4.75	1995
II-1-15 in.	7.5	.0014	.00215	3480	4.0	1680
II-2-15 in.	7.5	.0027	.00345	2170	3.8	1595
II-3-15 in.	7.5	.0015	.00225	3330	2.9	1220
1 -24 in.	12	.0033	.00405	2960	3.5	6040
2 -24 in.	12	.0055	.00625	1920	5.0	8620
3 -24 in.	12	.0070	.00775	1550	6.15	10600
1 -30 in.	15	.0040	.00475	3160	1.56	5290
2 -30 in.	15	.0040	.00475	3160	1.12	3800
3 -30 in.	15	.0040	.00475	3160	1.12	3800
4 -30 in.	15	.0040	.00475	3160	1.12	3800
X -30 in.	15	.0100	.01075	1394	3.67	12420

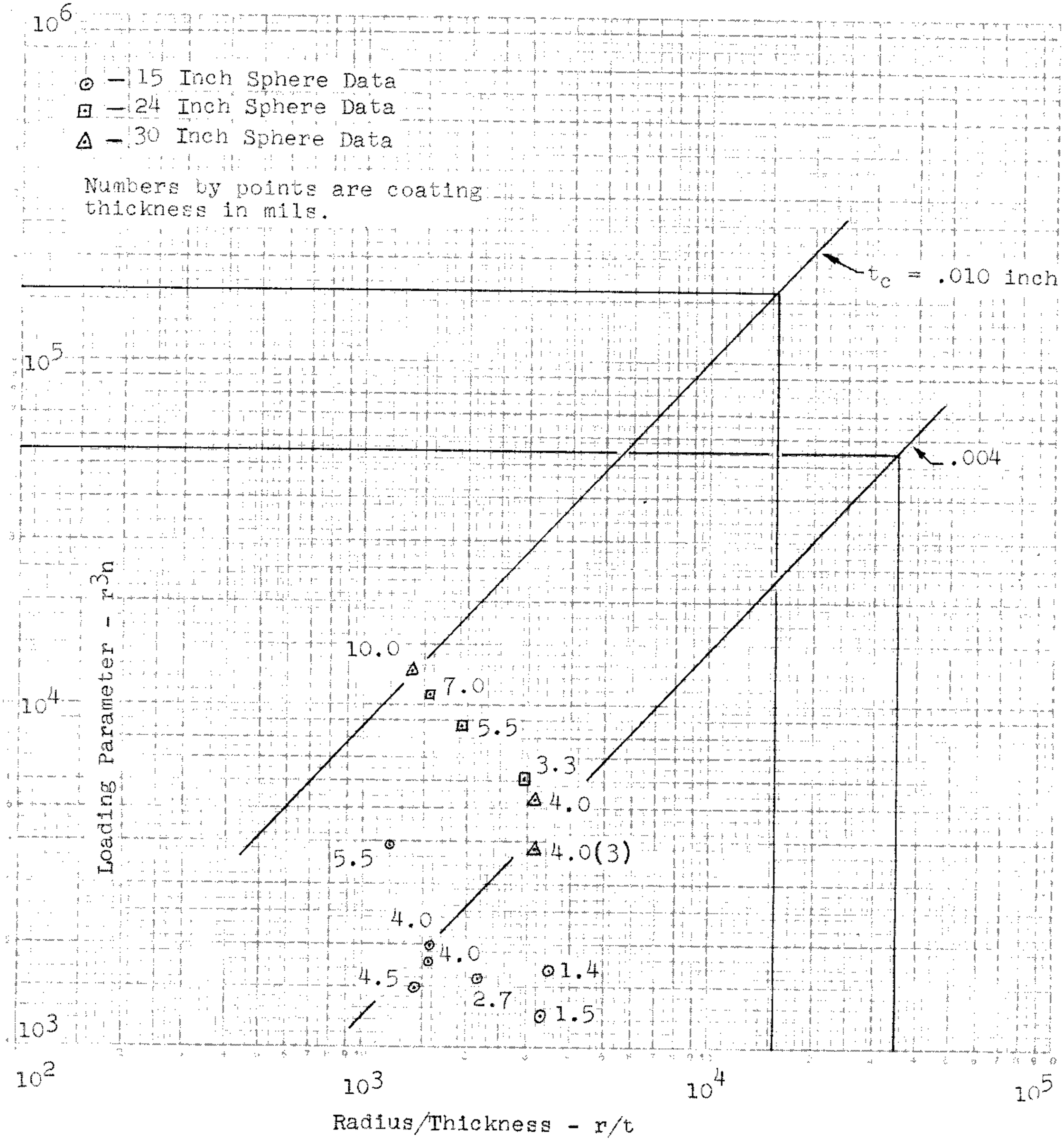


Figure 20 EXTRAPOLATION OF TEST DATA FOR VINYL BASE LACQUER COATING

Table 5 MASS ESTIMATION - FULL SCALE SPHERICAL SHIELD

Diameter (Inches)	Basic Sphere Mass (LBM)	Coating Thickness (in)	Coating Mass -25% Of Surface Coated (LBM)	Total Sphere Mass (LBM)	Ultimate Lateral Load (g's)
330	23	0.004	9	32	0.0123
330	23	0.010	22	45	0.0356