GER 13342

FLEXIBLE VACUUM JACKET DEVELOPMENT

FINAL REPORT

22 JUNE 1967



Contract No. NAS 8-11376

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for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SECTION I. INTRODUCTION

This program, sponsored by NASA-MSFC, was initiated under Contract NAS 8-11376 for the purpose of advancing the state of the art for designing and fabricating flexible envelopes for insulated vessels containing cryogenic liquids. A flexible envelope system was sought that would serve as a lightweight vacuum jacket for cryogenic tanks insulated with mutilayer insulation systems.

Two paramount design criteria for the flexible vacuum jacket development were a maximum allowable helium permeability of 3.3×10^{-8} cc/sec/ft^2 total leak and an inherent spring-back capability to relieve the jacket pressure on multilayer insulation in a space environment.

A second flexible envelope was sought that would serve to contain helium purge gas in a multilayer insulation system during ground hold and automatically open to vent the purge gas during the ascent phase.

At the beginning of this development effort, it was known that existing flexible plastic films and film-metal foil laminates could not meet the stringent leak-tight requirements and maintain the desired flexibility under the full range of operating conditions associated with cryogenic liquid propellant tanks. In addition, the spring-back requirement posed a unique characteristic that mandated the development of the vacuum jacket as a system in which the basic performance characteristics of permeability, flexibility, and spring-back capability are interdependent. It was recognized that new materials or combinations of materials would be required to realize the overall objectives. Specifically, the vacuum jacket objectives were to be accomplished by the development and application of a flexible vacuum jacket on a NASA 105-inch diameter LH_2 test tank.

The flexible helium purge jacket objectives were to be accomplished by the development and application of flexible purge jackets on a 70-inch and a 105-inch diameter NASA LH_2 test tanks.

Through a program encompassing materials and process development and flexible jacket systems analysis, selected flexible jacket configurations were designed and fabricated for testing on MSFC 105-inch and 70-inch diameter LH_2 test tanks.

SECTION II. SUMMARY

Upon completion of the program plan, which was prepared in accordance with the scope of work outlined in the contract, the MSFC test tank and insulation designs were analyzed and the flexible vacuum jacket design parameters were established.

Early in the program the greatest efforts were directed toward the development of suitable spring-back media. To reduce the interdependent variables during screening evaluation of spring-back test specimens, a 0.0015-inch Mylar-aluminum-Mylar (MAM) vacuum jacket material was utilized with the various spring-back media. This effort led to the selection of a lightweight (17.4 gram/ft^2) glass fiber mat spring-back material, which is bonded to the exterior surface of the vacuum jacket material.

Concurrent with the spring-back media development, a vacuum jacket materials development program was conducted wherein 30 jacket materials were evaluated for helium leak tightness. The materials tested were usually plastic film and metal foil laminates of existing constructions or new configurations developed for this program.

From the vacuum jacket materials screening tests, a 0.002-inch thick Mylar-aluminum-aluminum-Mylar (MAAM) laminate construction weighing 0.0187 lb/ft^2 was selected on the basis of light weight and low permeability. The helium permeability of MAAM was nearly two orders of magnitude below the maximum allowable leak established by NASA-MSFC flexible vacuum jacket specification.

The glass mat spring-back material and the MAAM vacuum jacket material were combined and successfully tested for acceptable permeability rates after eight spring-back cycles.

A vacuum jacket was designed to envelop a multilayer insulation as applied to the NASA 105-inch diameter LH_2 test tank. The design philosophy employed a hard cover approach to the treatment of the tank protrusions. Bellows-mounted metal covers surround each protrusion to provide a suitable attachment for the flexible vacuum jacket material.

The basic vacuum jacket envelope was fabricated in two halves and shipped together with the protrusion hard covers to NASA-MSFC for final trim and installation

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on a 105-inch diameter test tank. The installation of the vacuum jacket is beyond the scope of this contract and is therefore not discussed in this report.

A flexible helium purge jacket was designed to envelop a multilayer insulation as applied to a 70-inch diameter LH_2 test tank. A urethane-coated Dacron fabric, previously developed by GAC for containment of helium gas, was selected for the flexible purge jacket; therefore, no materials development was required. The development effort for this jacket was directed toward the perfection of a zipper release mechanism that would release the zipper to vent the purge jacket at a predetermined internal pressure of 0.5 psi. A full-scale purge jacket was fabricated and successfully pressure tested for zipper release before shipment to NASA-MSFC.

A flexible helium purge jacket designed to envelop a 105-inch diameter LH_2 test tank covered with multilayer insulation was designed, fabricated, and tested at GAC in a manner described above, prior to shipment to NASA-MSFC.

SECTION III. FLEXIBLE VACUUM JACKET

A. GENERAL

This section describes the development of a flexible vacuum jacket material and the fabrication of a vacuum jacket specifically designed for use on a NASA-MSFC 105-inch diameter LH_2 test tank. The flexible vacuum jacket design requirements as delineated by NASA-MSFC are as follows:

(1) Jacket Material Selection

(a) Light in weight.
(b) Low permeability (depends on total leakage).
(c) Low moisture absorption.
(d) Durable when subjected to moderate handling.
(e) Flexible throughout the required temperature range.
(f) Compatible with LH_2 and LOX (if obtainable).
(g) Having a low outgassing rate in vacuum conditions (depends on total outgassing).
(h) Low thermal conductivity (if obtainable).
(i) Can be stretch-formed or hand-formed.
(j) Does not develop pinholes.

(2) Adhesive Selection

(a) Compatible with jacket material selected.
(b) Capability of holding seal when flexed.
(c) Capability of holding seal throughout the required temperature range (depends on location).
(d) Low or minimal outgassing rate.
(e) Can be applied with minimum requirements for skilled personnel and special equipment.
(f) Can be used for repair work without unsealing original seams. This may dictate a second adhesive.
(g) Moisture must not harm.
(h) Desirable to be flexible after cured.
(i) Heat seal and weld seal (sonic) and tapes.

(3) Problems MSFC Has Encountered:

(a) Difficult to evacuate interstitial gas in superinsulation when jacket is compressing insulation.
(b) Recovery of bag not good.
(c) Pinholes in bag caused by three-cornered folds.
(d) Bag material (Al-Seal - 1/2-mil Mylar, 1-mil al, 1/2-mil Mylar) does not form (one direction only).
(e) Insulation material does not follow exact dimensions; therefore, the bag must be flexible in geometry.
(f) Cure cycle for best adhesive, Narmco 7343, is complicated and long.
(g) Bond joint does not work well without hard backup structure.
(h) Hard to patch pinholes without using a spray coat (which makes jacket stiff).
(i) Number and location of vacuum ports.

In the design discussions in this report, reference is made to the design of vacuum jackets for both a 70-inch diameter tank and a 105-inch diameter tank. Due to a technical redirection of a portion of this program, the 70-inch diameter tank vacuum jacket requirement was changed to a helium purge jacket requirement (see Section IV). The vacuum jacket material development and testing philosophies reflected considerations of the 70-inch diameter tank vacuum jacket requirements; therefore, reference will be made to the 70-inch diameter tank vacuum jacket, which was partially designed but not fabricated.

B. DESIGN

1. General

The MSFC 70-inch and 105-inch diameter test tanks and insulation drawings were comprehensively analyzed, and the program objectives were reviewed to establish design approaches for satisfying the lightweight flexible vacuum jacket requirements. The parameters, assumptions, and considerations in arriving at a design philosophy are discussed in the following paragraphs.

2. Design Philosophy

a. Operating Environment. During the functional period of the flexible vacuum jacket performance, it is assumed that the temperature of the environment surrounding the jacket will not drop appreciably below ambient conditions. In the vicinity of protrusions such as fill and vent lines, the vacuum jacket will be cooled

below ambient temperature to a degree depending on factors of cold guard lengths, temperature of air surrounding the jacket, and shielding of the jacket by the spacecraft structural shell. In these areas, the jacket was designed to function flexibly at temperatures near the cryogenic fluid range.

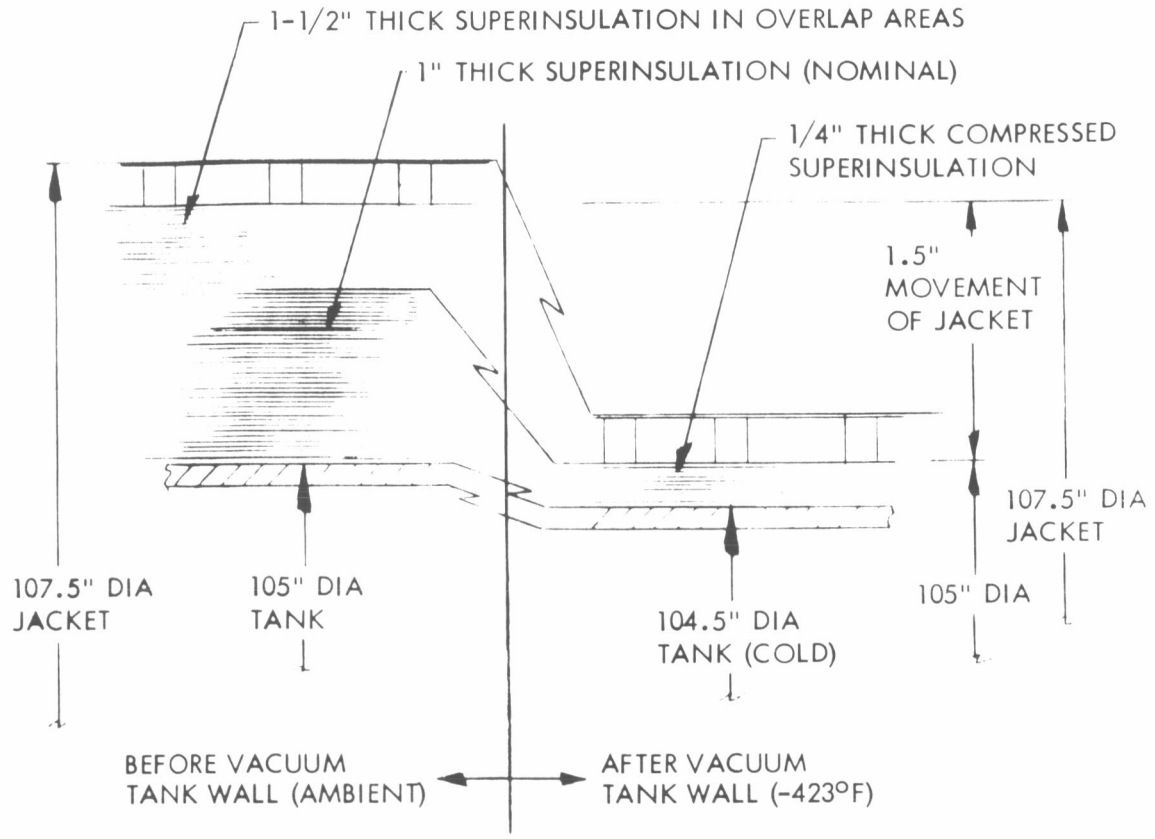
b. Vacuum Jacket Movement and Mode of Contraction. Analyses of the vacuum jacket movements are presented in Figures 1 and 2. The analyses are based on a tank shrinkage of 0.4 percent at -423°F and an installed (non-compacted) superinsulation nominal thickness of 1 inch and 1.5 inches in overlap areas. A launch (compacted) thickness of 0.25 inch is assumed.

The mode of contraction of the vacuum jacket as it closes against the insulated tank wall will naturally influence the design of the jacket itself. When evacuated, the vacuum jacket will tend to shrink, following the path of least resistance. Basically, each of the test tank vacuum jackets comprises a cylindrical portion and two nearly hemispherical end domes. The end domes, because of their compound curvatures, will have greater resistance to collapse than the cylindrical portions. It is assumed that the cylindrical portion of the vacuum jacket will contract in a hoop direction only, and therefore will not aid in the contraction of the domes. The end domes must be designed to have sufficient bidirectional contraction capabilities within themselves to allow the required contraction without strain on the jacket.

From the analyses of the vacuum jacket shrinkage presented in Figures 1 and 2, the maximum jacket shrinkage is 10 percent in the dome end of the 70-inch diameter tank vacuum jacket. It is logical to assume that the shrinkage of the jacket contributes a proportional degree of wrinkles, folding, and potential damage to the jacket. The 105-inch diameter tank vacuum jacket would experience a 6 percent shrinkage in the dome areas; however, the 10 percent shrinkage was established as design and test criteria for evaluation of vacuum jacket materials for both the 70-inch and the 105-inch diameter tanks.

c. Treatment of Protrusions. The protrusions existing on the 70-inch and 105-inch diameter test tanks will require vacuum jacket terminations of rather complex shapes. Two approaches were investigated, viz., soft vacuum jacketing and semirigid jacketing around the protrusions. The vacuum jacket terminations were designed to permit contraction of the jacket without excessive stress concentrations in jacket areas around the protrusions.

d. Arrangement of Vacuum Jacket Components. To facilitate assembly, the vacuum jacket was designed to be broken down into the largest practical components whose split lines will be located to allow portions of the jacket to be readily



Shrinkage of Jacket = Reduction of ID of Jacket to OD of Compressed SI on Cold Tank

Cylinder Wall Shrinkage (Area Shrinkage Proportional to Change in Dia):

$$\frac{(107.5 - 0.50)}{105} = 1.0245 \text{ or } 2.5\% \text{ Shrinkage}$$

Dome End Shrinkage (Area Shrinkage Proportional to Change in Radius^2):

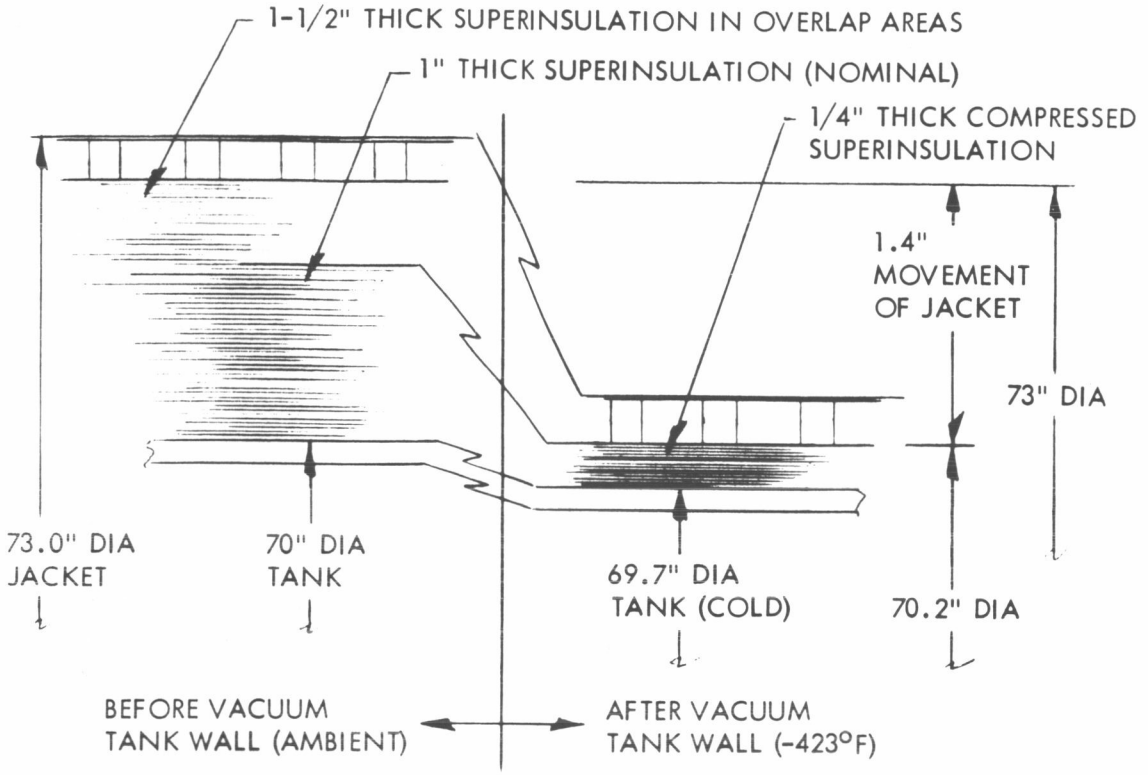
$A = 2\pi R^2$

Outside Area Compressed Insulation $= 6.283(52.5)^2 = 17,317$ In.^{2}

Area of Inside Dia of jacket $= 6.283(54.25-0.25)^2 = 18,321$ In.^{2}

$$\frac{18,321}{17,317} = 1.05804 \text{ or } 6\% \text{ Shrinkage}$$

Figure 1. 105-Inch Diameter Tank Vacuum Jacket Movement



Shrinkage of Jacket = Reduction of ID of Jacket to OD of Compressed SI on Cold Tank

Cylinder Wall Shrinkage (Area Shrinkage Proportional to Change in Dia):

$$\frac{(73.0 - 0.50)}{70.2} = 1.04 \text{ or } 4\% \text{ Shrinkage}$$

Dome End Shrinkage (Area Shrinkage Proportional to Change in Radius^2):

$A = 2\pi R^2$

Outside Area Compressed Insulation $= 6.283(35.1)^2 = 7740$ In.^{2}

Area of Inside Dia of jacket $= 6.283(36.5)^2 = 8485$ In.^{2}

$$\frac{8485}{7740} = 1.0962 \text{ or } 10\% \text{ Shrinkage}$$

Figure 2. 70-Inch Diameter Tank Vacuum Jacket Movement

fitted around protrusions with a minimum of field seams. In protrusion areas, two approaches to satisfying these local restraints were investigated - both soft and semirigid protrusion covers.

e. Recovery of Spring-Back Characteristics of Vacuum Jacket. To enable the superinsulation to recover to the as-wrapped layer density, the recovery or spring-back of the vacuum jacket should be of sufficient force to provide spring-back without restricting the recovery of the superinsulation. It is desirable that the latent spring-back force be sufficient to overcome any stiffness induced by creep and set of the jacket material during long-term hold in an evacuation condition.

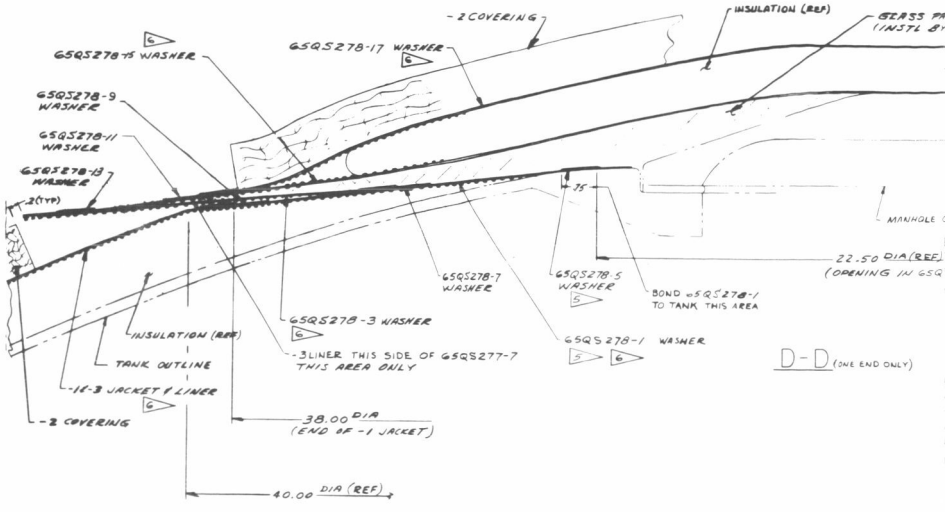
f. Adhesive Requirements. Although the major portion of the vacuum jacket will be at ambient temperature, some areas of the jacket may be cooled to the cryogenic range. These areas require the use of proven cryogenic adhesives to seal the jacket seams and terminate the jacket around protrusions. Because the temperature along the jacket seams can vary from ambient to cryogenic, the adhesive selection will be based on the most difficult capability, that of good cryogenic performance. In the present spectrum of cryogenic adhesives, ambient temperature performance is generally equal to or superior to cryogenic performance in terms of flexibility and vacuum sealing capability.

g. Leak Testing Capability. A preliminary leak-tightness test will be performed on the vacuum jacket assembly without cutouts for tank protrusions. This test will verify the integrity of the seams in the jacket by a helium mass spectrometer technique.

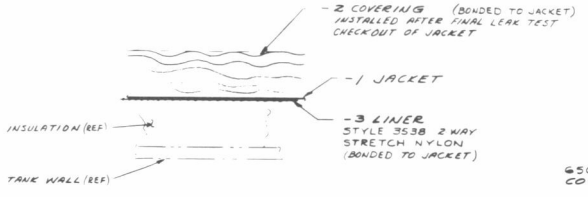
To verify the leak-tightness of the vacuum jacket after assembly on the test tank, a mass spectrometer helium leak technique will be employed, wherein a pressure tap is attached to the jacket and the insulation space pumped down to 25 microns (minimum) by the leak detector roughing and diffusion pumps. While monitoring the leak detector gage, a stream of helium gas will be directed over the jacket, with particular emphasis on bond-line seams. Essential to locating leaks by this process is the need for rapid movement of the gas from leak source to the leak detector; therefore, the vacuum jacket design must ensure this bleeding capability over the entire inner surface of the vacuum jacket.

3. 105-Inch Diameter Tank Vacuum Jacket Configuration

The 105-inch diameter tank vacuum jacket configuration, shown in Figure 3 (Sheets 1 through 4), was designed to meet the NASA-MSFC requirements of Contract NAS 8-11376. As previously noted, the vacuum jacket requirement for the 70-inch diameter tank was changed to a helium purge jacket; therefore, the vacuum jacket design discussion will be limited to the 105-inch diameter tank.



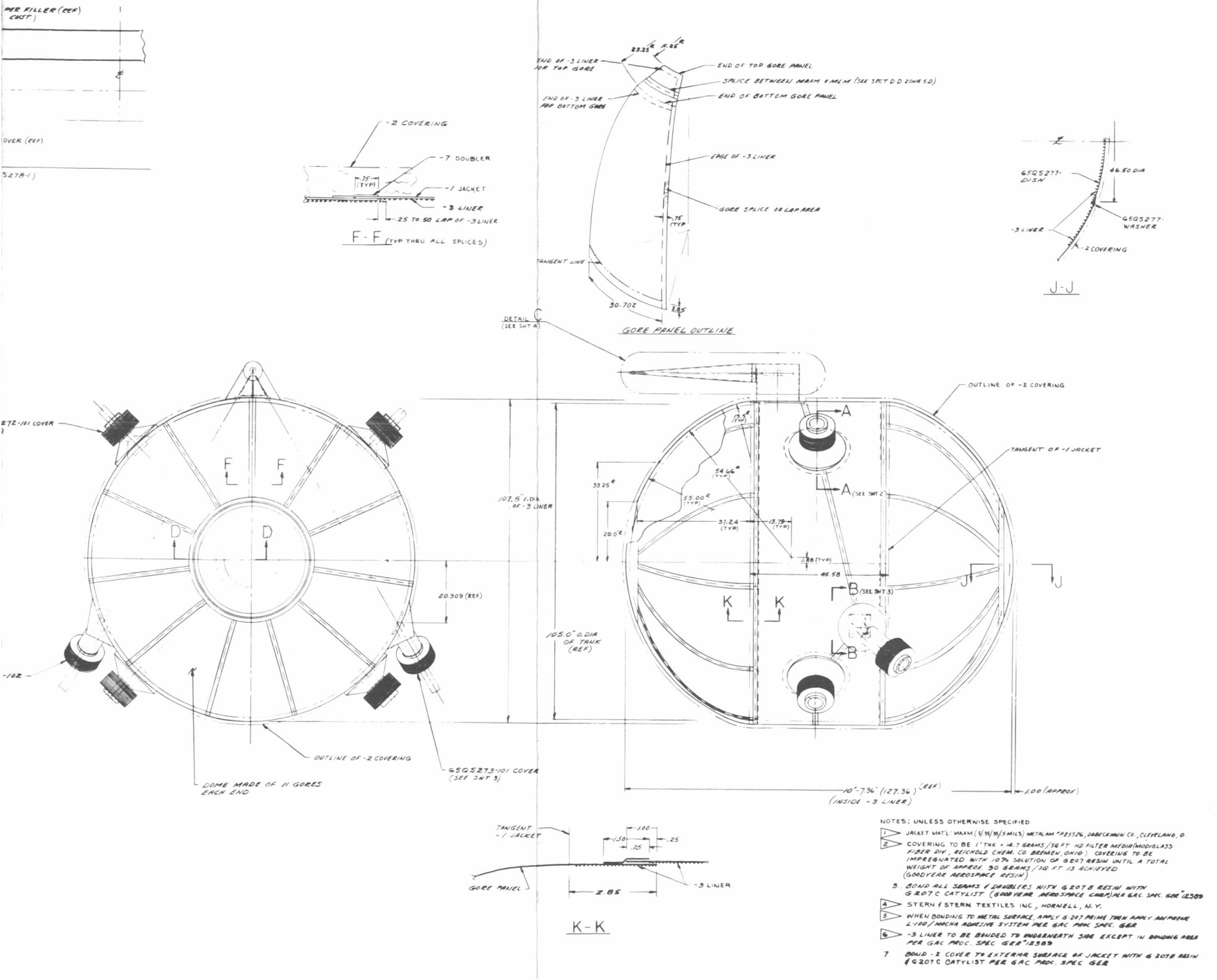
GSQS
4 REQ



TYP SECTION THRU JACKET

GSQS273
COVER

FOLDOUT FRAME 1



NOTES: UNLESS OTHERWISE SPECIFIED

1. JACKET MAT'L: MRAM (5/15/15/5 MILS) METALAM "P8552K", DABECKMUN CO., CLEVELAND, O.
2. COVERING TO BE 1" THK × 14.7 GRAMS/SQ FT HD FILTER MEDIA (MODIGLASS FIBER DIV., REICHOLD CHEM. CO. BREMEN, OHIO). COVERING TO BE IMPREGNATED WITH 10% SOLUTION OF G207 RESIN UNTIL A TOTAL WEIGHT OF APPROX. 90 GRAMS/SQ FT IS ACHIEVED. (GOODYEAR AEROSPACE RESIN)
3. BOND ALL SEAMS & DOUBLERS WITH G 207 B RESIN WITH G 207 C CATYLIST (GOODYEAR AEROSPACE CHEM.) PER GAC SPEC. GER 12389
4. STERN & STERN TEXTILES INC., HORNELL, N.Y.
5. WHEN BONDING TO METAL SURFACE, APPLY G 207 PRIME THEN APPLY ADHESIVE L-120 / MACHA ADHESIVE SYSTEM PER GAC PROC. SPEC. GER
6. -3 LINER TO BE BONDED TO UNDERNEATH SIDE EXCEPT IN BONDING AREA PER GAC PROC. SPEC. GER "12389
7. BOND -2 COVER TO EXTERNAL SURFACE OF JACKET WITH G 207 B RESIN & G 207 C CATYLIST PER GAC PROC. SPEC. GER

Figure 3. 105-Inch Diameter Tank Jacket Installation (Sheet 1 of 4)

FOLDOUT FRAME

FOLDOUT FRAME 2

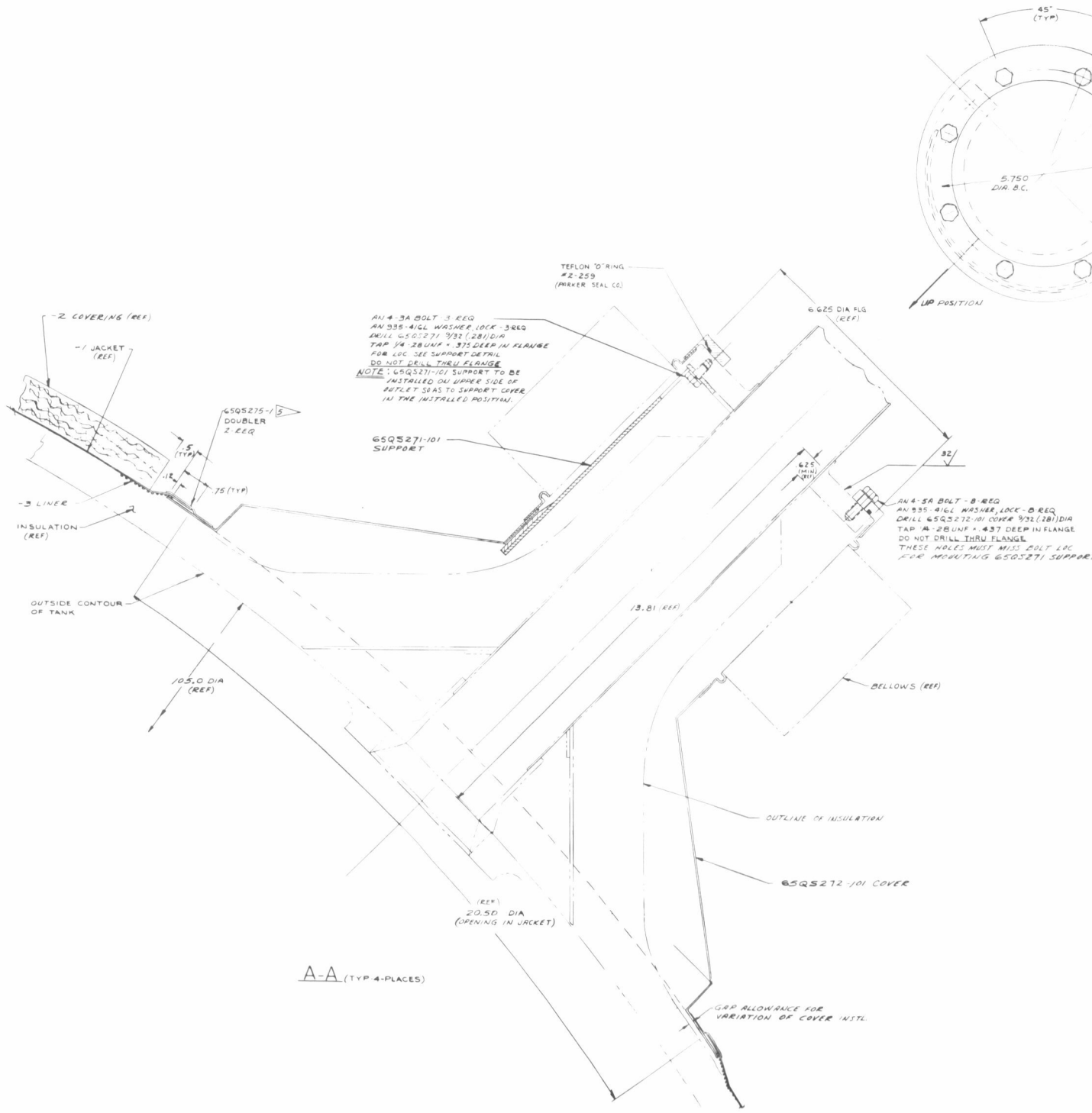
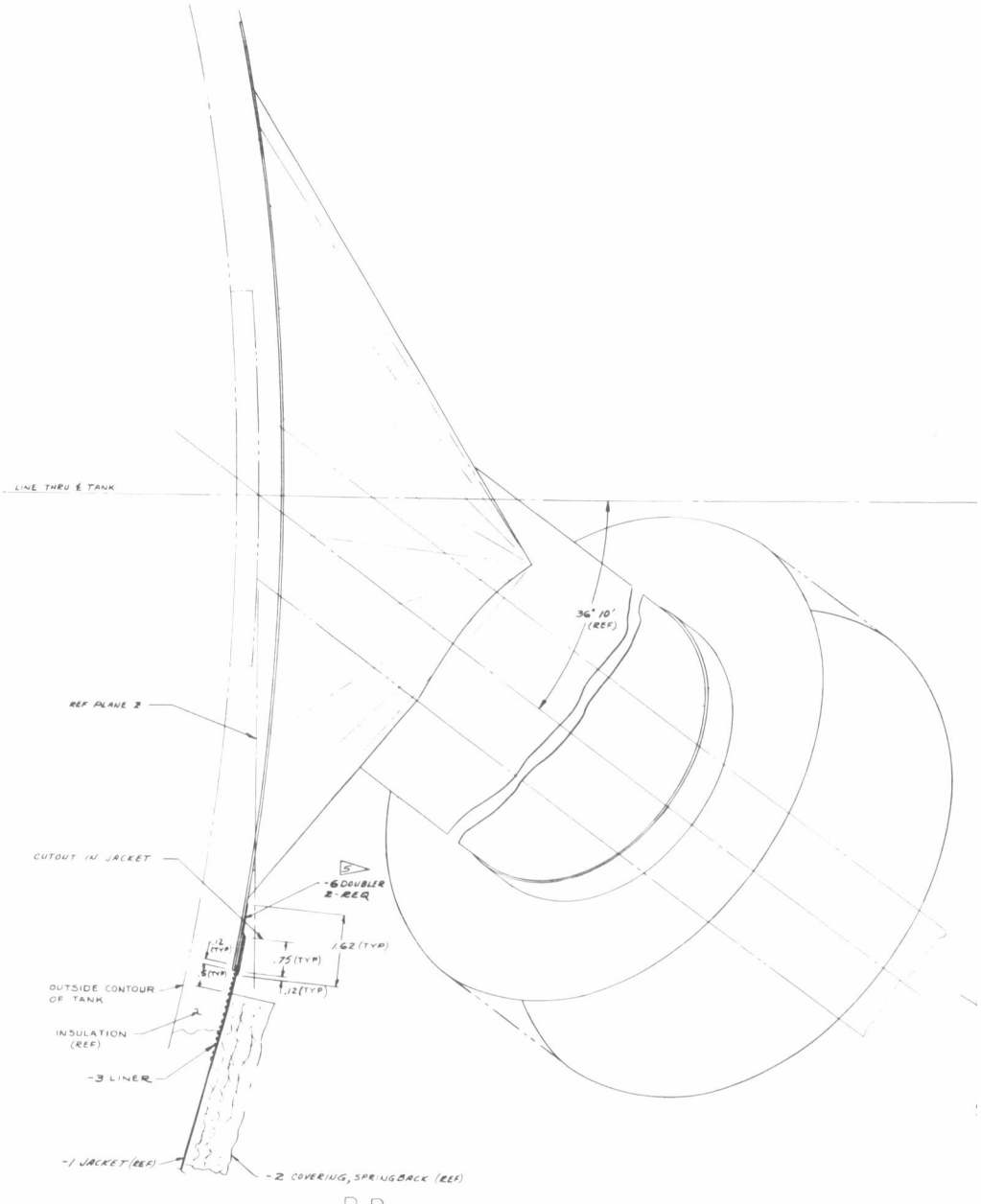


Figure 3. 105-Inch Diameter Tank Jacket Installation (Sheet 2 of 4)



B-B (ROTATED 29°32' C'CW)

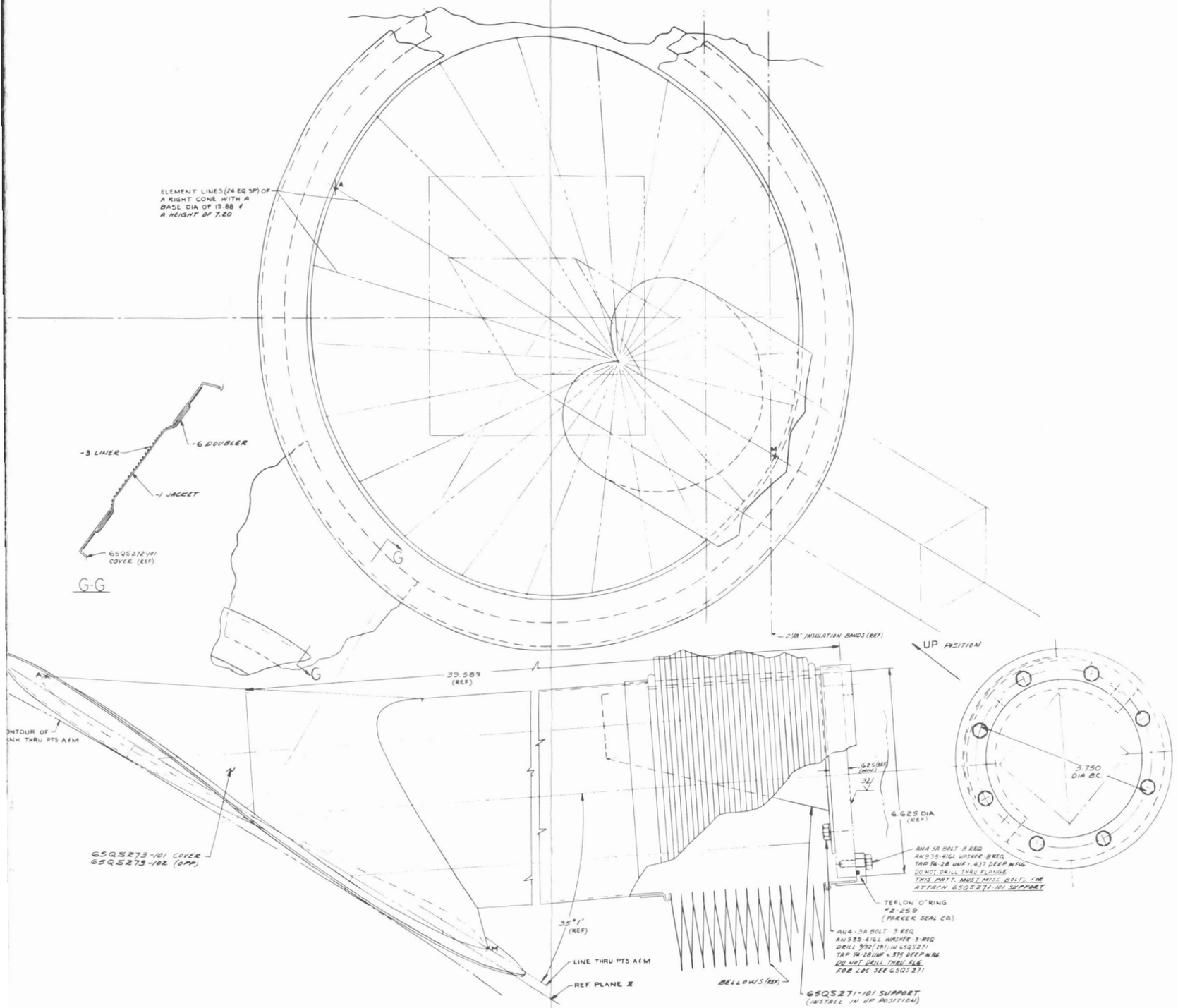


Figure 3. 105-Inch Diameter Tank Jacket Installation (Sheet 3 of 4)

FOLDOUT FRAME

FOLDOUT FRAME 2

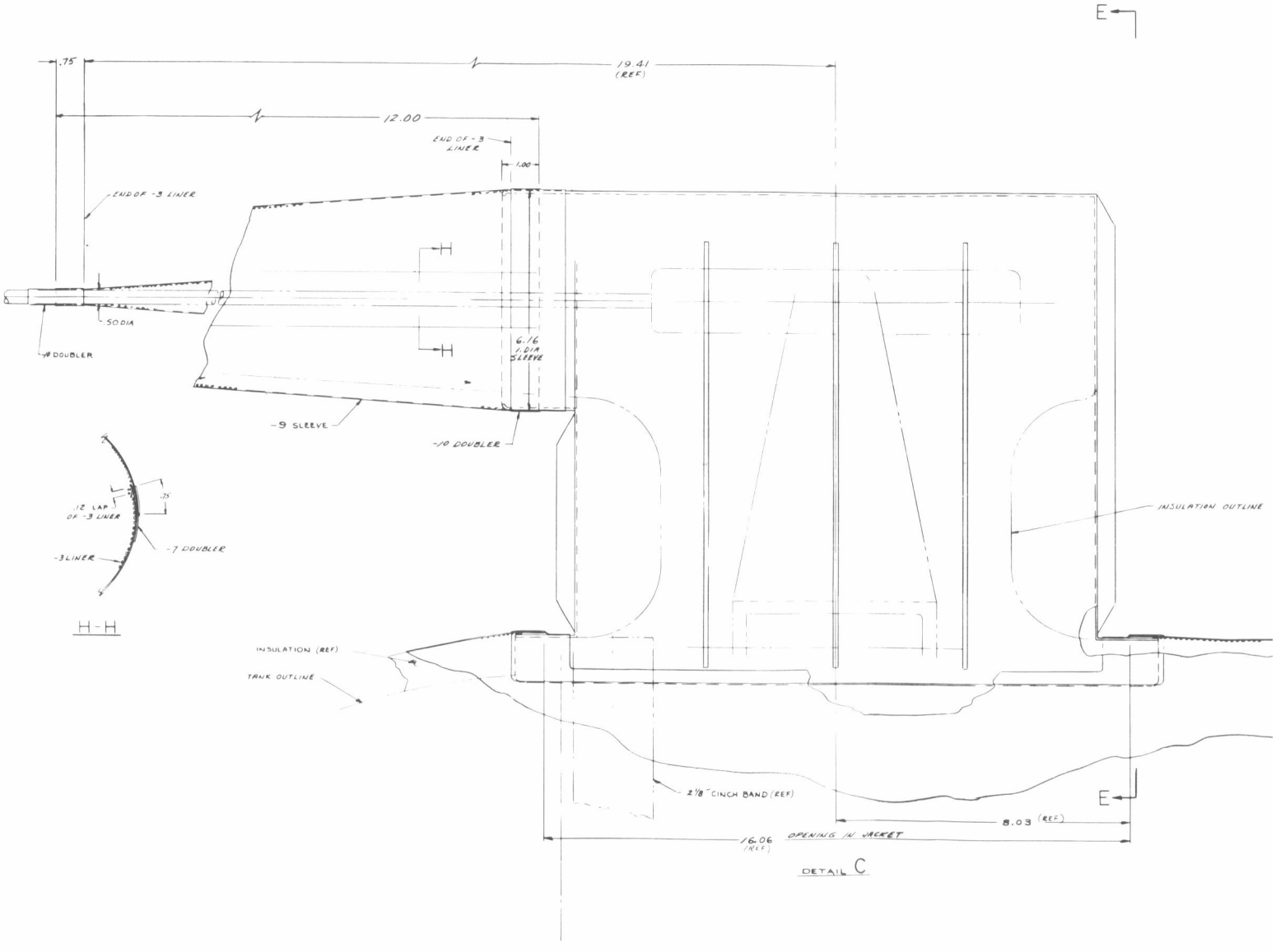
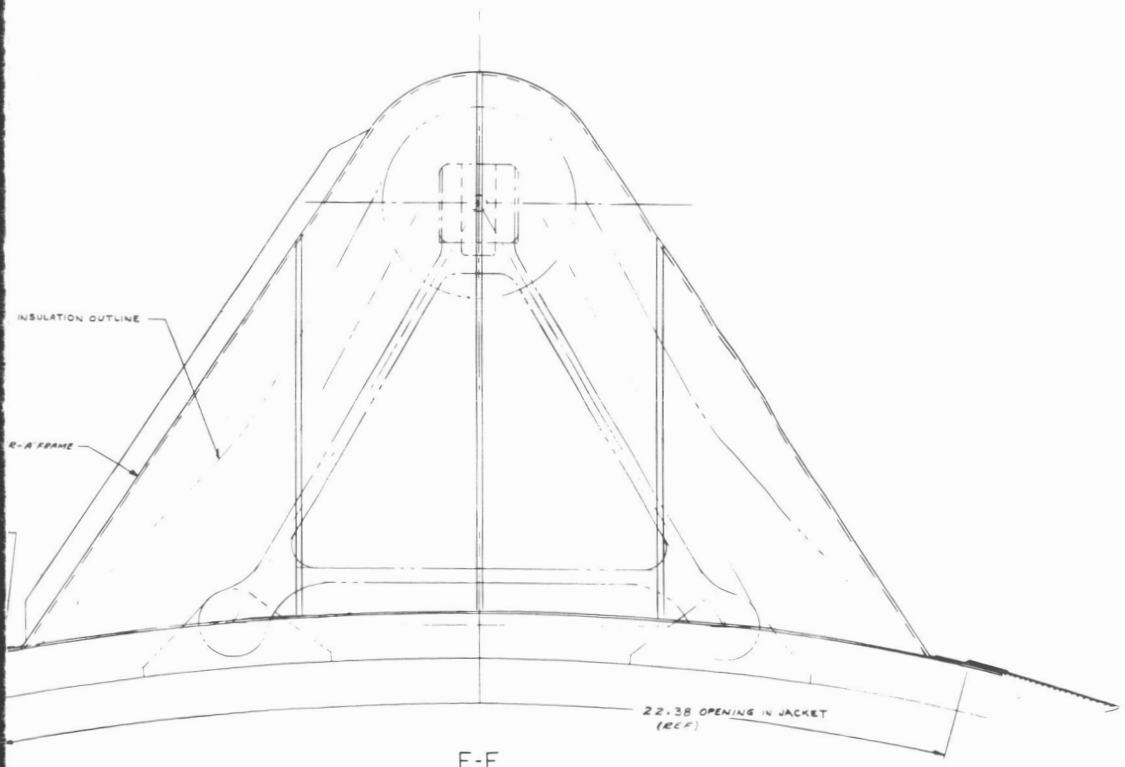


Figure 3.A 105-Inch Diameter Tank Jacket Installation (Sheet 4 of 4)



E-E

Fig. 3-B

14-B

Selection of the flexible vacuum jacket material was made on the basis of test results from a comprehensive test program (see subsection C). Evaluation of jacket materials included gaseous helium permeability and spring-back tests of various vacuum jacket and spring-back media combinations. The following combination of materials was selected for the 105-inch diameter tank flexible vacuum jacket:

(1) Spring-back media: 1-inch thick glass floss mat
(2) Vapor barrier: 0.002-inch thick MAAM
(3) Vapor barrier back-up material: Style A3583, two-way stretch, nylon fabric

The vacuum jacket configuration shown in Figure 3 is based on consideration of the following design parameters:

(1) Size and shape of the 105-inch diameter tank. NASA-MSFC drawing SK30-1834 and all related drawings formed the basis for the vacuum jacket configuration. The A-frame fitting lower suspension rod was essential to the performance of the test tank; therefore, this rod was removed to simplify the vacuum jacket termination of the A-frame hard cover.

(2) The SI62 insulation was specified by NASA-MSFC to be 1 inch normal thickness with a 1-1/2 inch thickness in certain overlap areas. The vacuum jacket is designed to have approximately 1/4-inch clearance with the insulation. It is desirable to keep this clearance to a minimum practical value to reduce the amount of jacket shrinkage during evacuation of the insulation.

(3) Location of tank penetrations. The size and location of the numerous tank penetrations and attendant hard covers dictated the cutouts in the vacuum jacket. The jacket seams were carefully routed to these cutouts to minimize the length of seams in the jacket assembly.

(4) Width of available vacuum jacket materials. The 40-inch maximum width of the MAAM material dictated the size and number of gore panels in the dome ends of the vacuum jacket. To minimize seams, each gore panel is cut from a single piece of material.

(5) Installation of the vacuum jacket with a minimum of field seams. The close-out seams of the vacuum jacket were reduced to minimum by designing the jacket to be fabricated in two half shells that would be joined in the equator region by short length seams routed between the penetration hard covers. Cutouts in the jacket for the penetration covers

provide access to the underneath side of the jacket for bonding the short close-out seams. All other seams in the vacuum jacket are made under the most desirable fabricating conditions while the jacket is off the tank.

(6) All jacket-to-jacket seams or splices are adhesive-bonded lap-joint seams with a MAM doubler strip cemented over the seam, as shown in section F-F of Figure 3 (Sheet 1).

(7) Vacuum jacket to tank penetration termination is accomplished by bonding the flexible vacuum jacket to the flange of a bellows-mounted hard cover attached to the penetration as shown on a typical hard cover detail in Section A-A of Figure 3 (Sheet 2). Two basic types of vacuum jacket treatment around protrusions were studied: flexible jacket configurations and semirigid jacket configurations. The semirigid configuration employing the flexible bellows was selected after evaluation of both types in a test described in subsection C.

(8) In the manhole area of the 105-inch diameter tank, the vacuum jacket is designed to be bonded and sealed to the tank in the area adjacent to the manhole cover, as shown in Section D-D of Figure 3 (Sheet 1). A removable vacuum jacketed insulation blanket covers the manhole plate and is sealed to the tank vacuum jacket by means of external bonding flaps. The flaps may be cut to remove the manhole cover insulation without losing the integrity of the tank vacuum jacket. The bonding flaps are designed large enough to permit cutting open and rebonding the flaps at least two times before replacement of the flap is required. To reduce heat leak to the tank, the vacuum jacket to tank close-out is achieved by bonding the MAAM jacket material to a Mylar-lead-Mylar (MLM) laminate material that is bonded to the tank. By substituting the MLM for the MAAM in a 5-inch wide band at the manhole region where the vacuum jacket is bonded to the tank, the heat leak to the tank is reduced from approximately 200 Btu/hr to 23 Btu/hr.

(9) The glass fiber mat spring-back media, shown in section F-F of Figure 3 (Sheet 1), is designed to be applied to the exterior surface of the MAAM jacket material after the jacket and seams have been tested for leak-tightness by helium mass spectrometer techniques.

To verify the 105-inch diameter tank flexible vacuum jacket spring-back characteristics and hard cover designs, a subscale mock-up test tank with a flexible vacuum jacket applied over Linde SI62 insulation was designed, fabricated, and tested for vacuum jacket spring-back performance before final design release of the 105-inch diameter tank vacuum jacket.

The test tank, shown in Figure 4, is 48 inches in diameter and 64 inches high, including a hemispherical bulkhead. The tank was fitted with two full-scale typical 105-inch diameter tank penetrations - one fill and vent line and one square tube diagonal support strut. The penetrations were designed to full scale to provide fabrication experience and testing of actual size vacuum jacket hard covers planned for the 105-inch diameter tank.

C. TESTING

1. General

The design and selection of all critical elements of the 105-inch diameter tank flexible vacuum jacket assembly is based on a materials testing program that constituted a major portion of the vacuum jacket development. Test programs were conducted to evaluate the following items:

(1) Vacuum jacket material spring-back characteristics
(2) Vacuum jacket material permeability to gaseous helium
(3) Vacuum jacket seams permeability to gaseous helium
(4) Vacuum jacket to tank penetration attachment

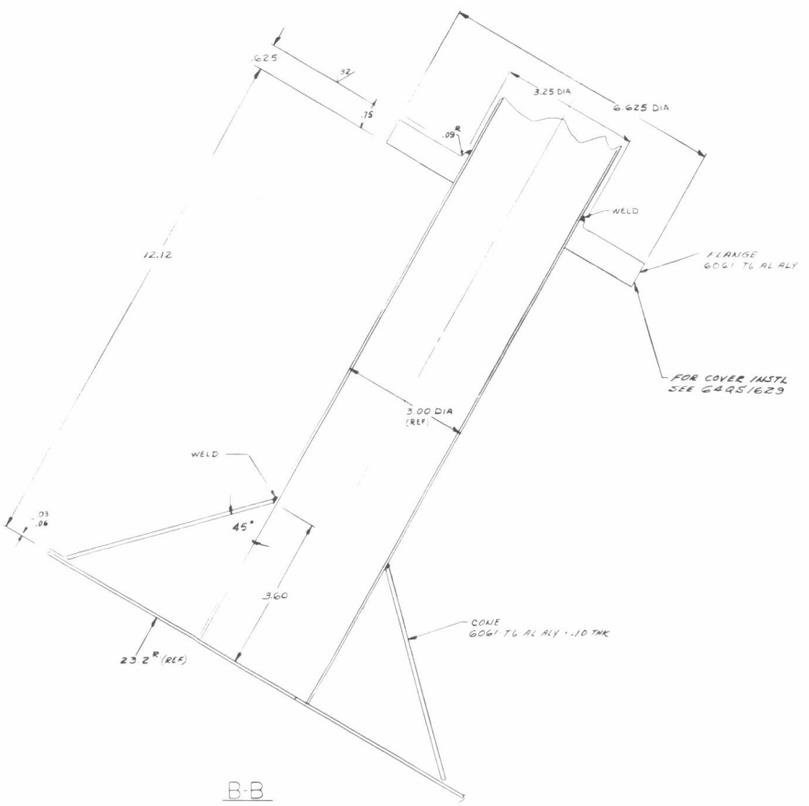
2. Vacuum Jacket Material Qualification Test Specification

To qualify a flexible vacuum jacket material meeting the spring-back and low helium permeability requirements delineated by NASA-MSFC, a Vacuum Jacket Material Qualification Test Specification was written by GAC and approved by NASA-MSFC. This specification as outlined below formed the basis of the test programs for evaluating and qualifying flexible vacuum jacket materials.

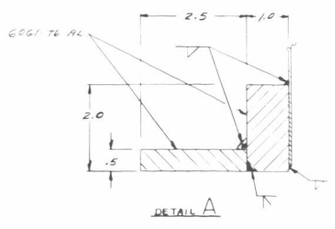
I. Spring-back Test

1. Vacuum jacket constructions in the form of 30-inch diameter curved test specimens having a spherical segment shaped 24-inch test area shall be mounted in the flex-cycle test fixture. The test specimen shall be evacuated from the back side, thereby collapsing the specimen onto a spherical segment surface having 10 percent less area than the test area of the specimen, thereby causing a 10 percent shrink and attendant wrinkling of the test specimen.

2. After a minimum of one-minute hold in the evacuated position, the vacuum is to be vented to atmosphere and the specimen observed for spring-back to its original size and shape. Acceptable spring-back is



B-B



DETAIL A

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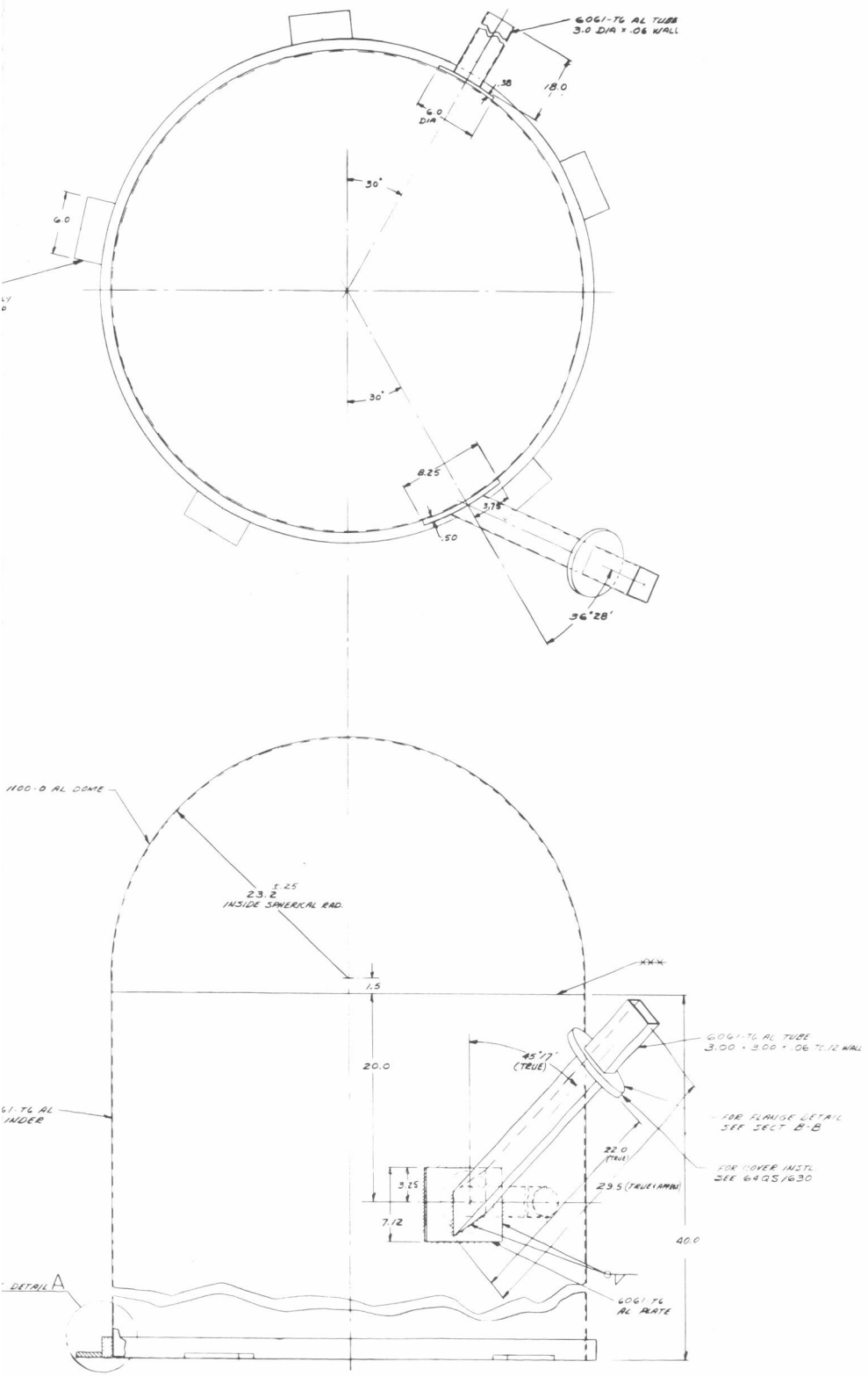


Figure 4. Vacuum Jacket Test Tank

FOLDOUT FRAME 2

considered a return to original shape, although slightly smaller due to traces of wrinkles remaining in the jacket. The time of spring-back is limited to a maximum of three minutes.

3. Repeat spring-back test for a minimum of six cycles.

4. Test specimens which have successfully passed tests 1, 2, and 3 shall be evaluated for long-term hold and spring-back as follows:

   a. Mount specimen in long-term test fixture.

   b. Evacuate specimen to effect a 10 percent shrink onto a curved surface.

   c. Hold vacuum for two weeks. Relieve vacuum and observe spring-back amount and rate. A minimum acceptable rate shall be 3 minutes. The amount of spring-back may be slightly less than the original spring-back observed in test 3.

   d. Repeat long-term hold and spring-back tests b and c for periods of four, six, and eight weeks accumulative hold time.

II. Helium Permeability Test

1. Flat samples 5 inches in diameter with a 2.95-inch diameter test area shall be mounted in a test cell connected to a mass spectrometer helium leak detector. One side of the sample shall be evacuated to 10^{-3} torr, and the opposite side pressurized with 1/2 atmosphere of pure helium. The maximum allowable helium leak will be 1.49×10^{-9} cc/second at room temperature.

   A minimum of three samples of each material or material combination shall be tested. These samples will be unwrinkled.

2. Repeat test 1 with samples creased in the test area. The creases shall simulate as near as possible the actual creases observed in vacuum jackets when evacuated onto superinsulation. The maximum acceptable helium leak will be 1.49×10^{-9} cc/second at room temperature.

   A minimum of three samples of each material or material combination shall be tested.

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3. Materials that are found acceptable in tests 1 and 2 shall be further evaluated for helium permeability with 30-inch diameter curved test specimens having 24-inch diameter test area. The test procedure is as follows:

   a. Mount test specimen in flex-cycle test fixture. Use vacuum grease on sealing ridges of fixture base plate.

   b. Place Mylar envelope over the test specimen and seal with vacuum grease to flange of test specimen in area of sealing ridges of test fixture.

   c. Place clamping ring over flanges of both the Mylar envelope and the test specimen. Bolt clamping ring securely to base plate of test fixture.

   d. Evacuate test specimen onto the 2 percent curve surface of the test fixture, thus shrinking the test specimen 10 percent with attendant wrinkles.

   e. Inflate Mylar envelope to approximately 0.5 psi with pure helium. Evacuate envelope and refill with helium. Repeat for three helium changes.

   f. Measure helium diffusion through wrinkled test specimen. The maximum allowable leak is 1.10×10^{-7} cc/second helium at room temperature.

   g. Relieve helium pressure in Mylar envelope. Back-fill test specimen with air to allow test specimen to regain its original shape before evacuation.

   h. Repeat test operations d through g for eight cycles and record helium leak rate.

3. Spring-Back Testing

a. General. To enable the multilayer superinsulation on the 105-inch diameter tank to recover to the as-wrapped layer density during the exit phases of rocket flight, the recovery or spring-back of the vacuum jacket should be of sufficient force to provide spring-back without restricting the recovery of the superinsulation. It is desirable that the latent spring-back force be sufficient to overcome

any stiffness induced by creep and set of the jacket material during long-term hold in an evacuated condition.

b. Test Setup. To evaluate the spring-back characteristics of vacuum jacket materials, a test fixture, shown in Figures 5 and 6, was designed as a flat circular plate and clamping ring for mounting a spring-back test specimen having a 24-inch diameter test area. A vacuum line will evacuate the space between the specimen and test plate, thus pressing the specimen onto the plate for visual observation of the test specimen in a shrunken or compressed condition. All test specimens are formed to a 24-inch diameter spherical segment contour which has 12 percent greater area than a 24-inch diameter flat plate. By installing foam inserts having 9, 7, 5, and 2 percent spherical segment contours in the test fixture, the specimen shrinkages of 3, 5, 7, and 10 percent, respectively, are attained by evacuating the 12 percent curved specimen onto the respective inserts.

The test fixture is mounted on a mobile stand as shown in Figure 6. Incorporated in the mobile stand are the following control valves for operation of the test fixture:

(1) Vacuum line
(2) Vent line
(3) Micromanometer
(4) Mass spectrometer connection
(5) Pressurization connection to helium or nitrogen gas

The test specimens are secured to the fixture by the circular clamping ring. Flex-cycle testing may be performed with the fixture in the horizontal position for ambient temperature tests or in the vertical position (see Figure 7) when the LN_2 chamber is filled to expose the perimeter of the specimen to cryogenic temperature.

c. Test Specimens. Twenty-seven test specimens were fabricated for spring-back evaluation tests. The construction of these specimens is given in Table I. The first 20 specimens were constructed with the same 0.0015-inch thick MAM jacket material to avoid introducing spring-back performance variables caused by different jacket materials. Later in the test program, other jacket materials such as MAAM, MAMAM, and MLM, selected from the helium permeability test program, were tested with spring-back media selected from earlier phases of the spring-back test program. The spring-back media evaluated are described in the following paragraphs.

(1) Specimens No. 1 and 2: Mylar honeycomb bonded to the inner surface of the vacuum jacket material. Previous tests at GAC have demonstrated the

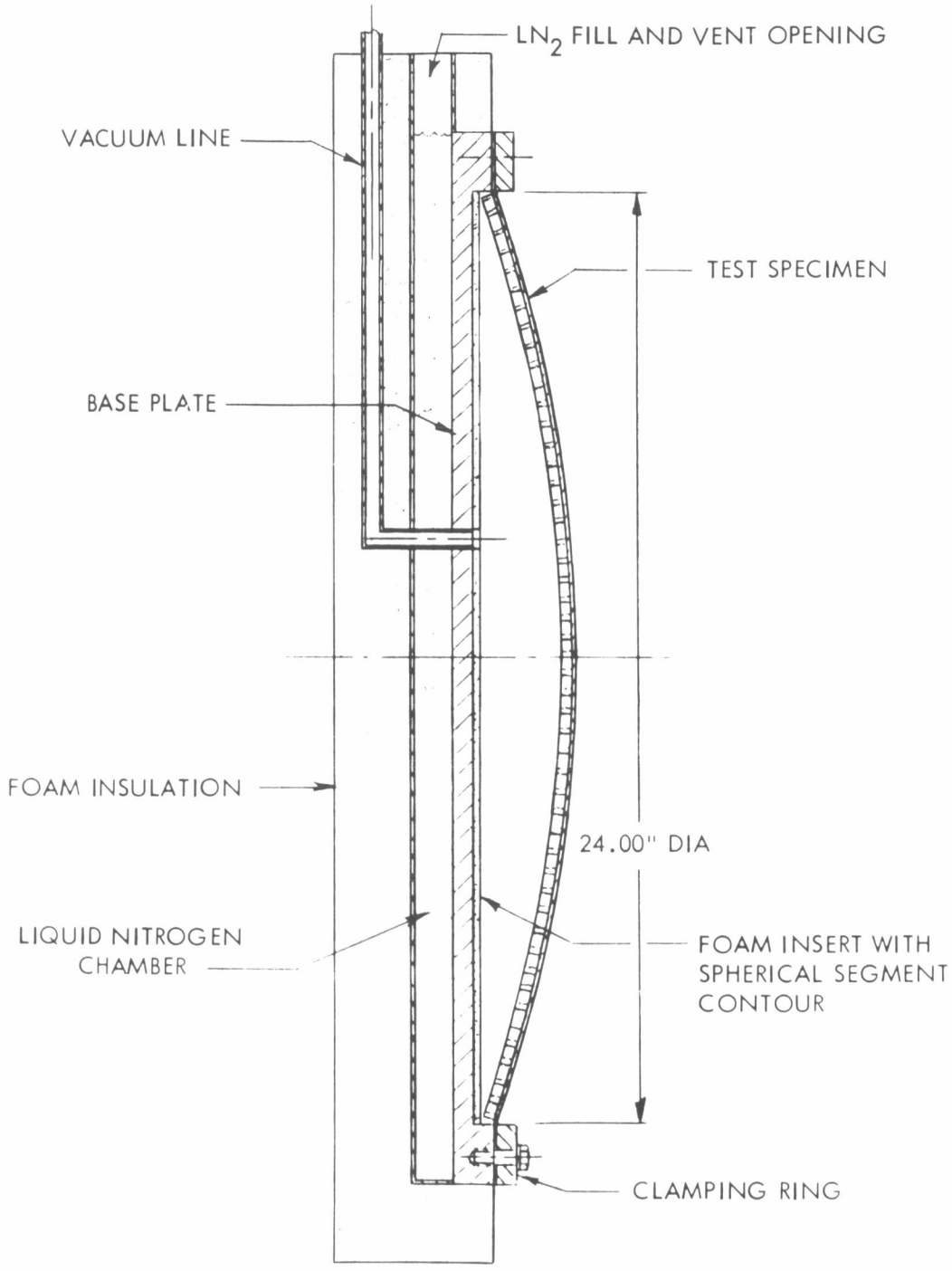


Figure 5. Sketch of Flex-Cycle Spring-Back Test Fixture

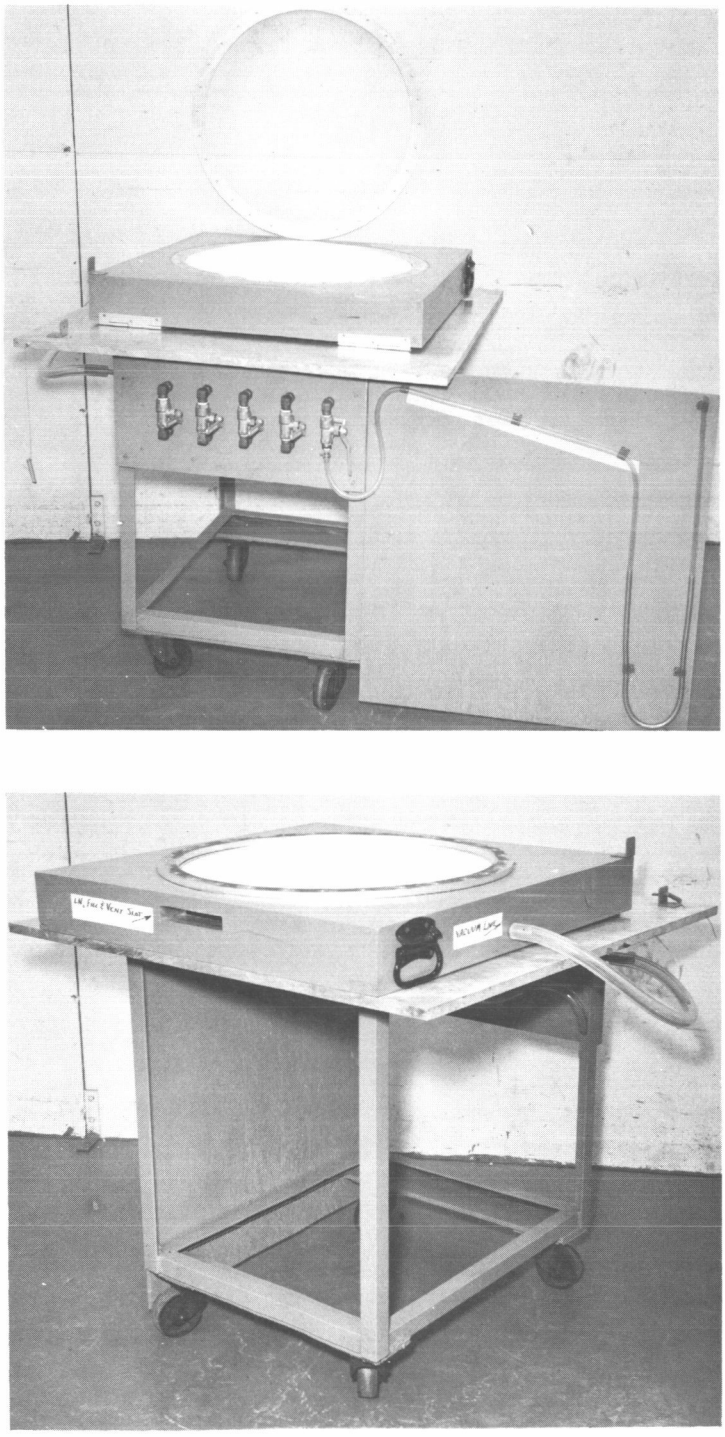


Figure 6. Flex-Cycle Test Fixture
(Front and Rear Views)

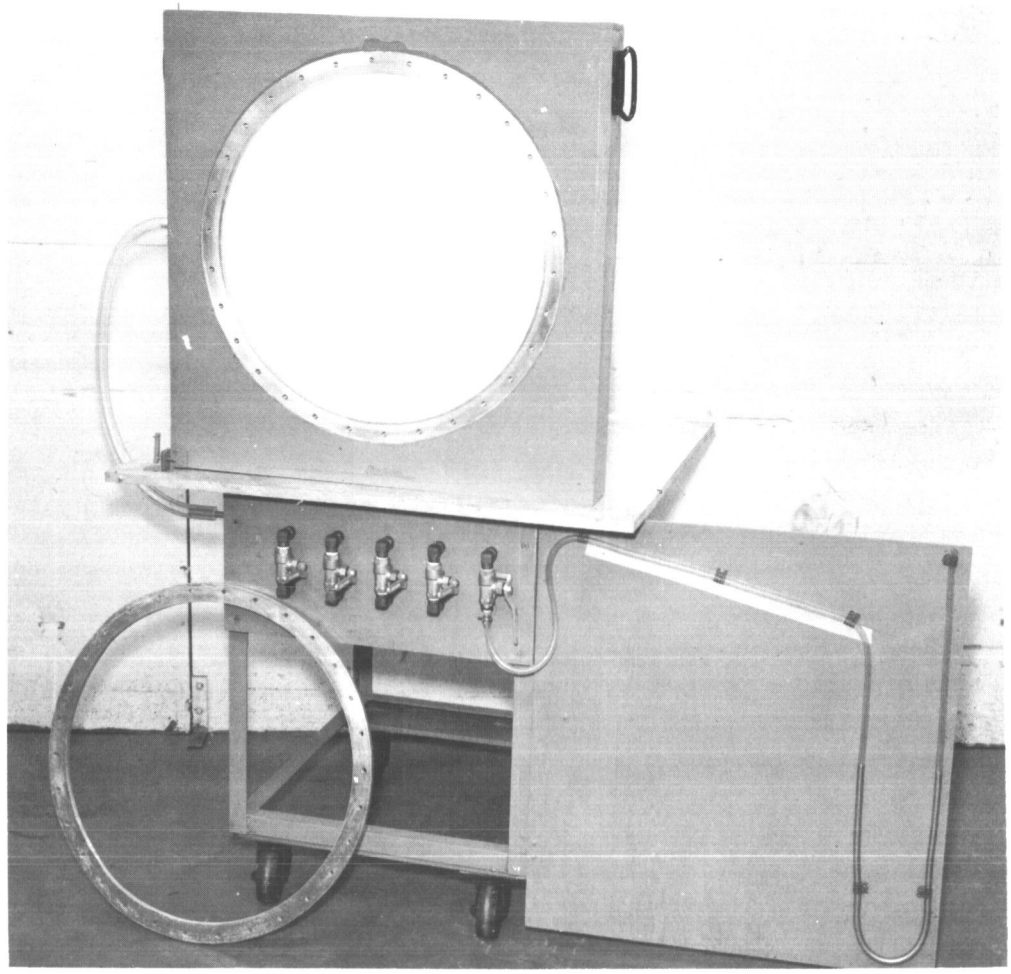


Figure 7. Flex-Cycle Test Fixture in Vertical Postion

potential advantages of Mylar honeycomb as a flexible self-quilting support for vacuum jacket barrier film materials. This arrangement effects a multiplicity of interlocking hexagonal cells that allow the jacket material to expand or contract biaxially without wrinkling which precipitates three-corner pinhole leakage in the barrier film.

(2) Specimens No. 3 and 11: Mylar honeycomb bonded to the outer surface of the vacuum jacket material. The Mylar honeycomb on the outer surface of the vacuum jacket material will not bear directly on the superinsulation, thus avoiding potential damage to the insulation. The vacuum jacket material being located adjacent to the insulation will provide a minimum size envelope which during the evacuation cycle will shrink and wrinkle less than the jacket described in (1).

Table I. Flex-Cycle Spring-Back Test Specimens - 24-Inch Diameter

Spec No.	% Shrink	Jacket Material	Back-up Media		Adhesives		Remarks
			Material	Location	Material	Location	
1	10	0.0015-inch MAM	0.25-in. x 3/4-003 HMH*	Inside surface of MAM	Narmco 7343/7139 polyurethane	HMH to MAM	
2	10	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	
			0.25-in. x 3/4-003 HMH	On nylon	7343/7139 polyurethane	HMH to nylon	
3	7	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	
			0.25-in. x 3/4-003 HMH	Outside surface of MAM	7343/7139 polyurethane	HMH to MAM	
4	10	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	
			G-207 impregnated spun glass mat (0.5 lb/ft^3)	Outside surface of MAM	G-207	Spun glass to MAM	
5	10	0.0015-inch MAM	0.4-in. flexible 2 lb/ft^3 polyurethane foam	Inside surface of MAM	G-207	Foam to MAM	
6	10	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	1/4-inch diameter pressure tap added to outside MAM skin for inflation of specimen.
			0.25-in. 2 lb/ft^3 flexible polyurethane foam	Outside surface of MAM	G-207	Foam to MAM	
			0.0015 MAM outer skin	Outside surface of foam	G-207	MAM to foam	
7	10	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	
			0.4-in. 4 lb/ft^3 flexible polyurethane foam	Outside surface of MAM	G-207	Foam to MAM	

*Hexcel Mylar honeycomb.

Table I. Flex-Cycle Spring-Back Test Specimens - 24-Inch Diameter (Continued)

Spec No.	% Shrink	Jacket Material	Back-up Media		Adhesive		Remarks
			Material	Location	Material	Location	
8	10	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	Pressure tap added after first cycle.
			0.4-in. 2 lb/ft^3 flexible polyurethane foam	Outside surface of MAM	G-207	Foam to MAM	
			0.0005-in. Mylar outer skin	Outside surface of foam	G-207	Mylar to foam	
9	10	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	Repeat of No. 8. Foam vented before test.
			0.4-in. 2 lb/ft^3 flexible polyurethane foam	Outside surface of MAM	G-207	Foam to MAM	
			0.0005-in. Mylar outer skin	Outside surface of foam	G-207	Mylar to foam	
10	12	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	
			1-in. Glassfloss mat (16 gm/ft^2)	Outside surface of MAM	G-207	Glass mat to MAM	
11	12	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	
			0.25-in. x 3/4-005 HMH	Outside surface of MAM	7343/7139 polyurethane	HMH to MAM	
12	12	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	12 percent curve. Repeat of No. 9.
			0.4-in. 2 lb/ft^3 flexible polyurethane	Outside surface of MAM	G-207	Foam to MAM	
			0.0005-in. Mylar film outer skin	Outside of foam	G-207	Mylar to foam	

Table I. Flex-Cycle Spring-Back Test Specimens - 24-Inch Diameter (Continued)

Spec No.	% Shrink	Jacket Material	Back-up Media		Adhesive		Remarks
			Material	Location	Material	Location	
13	12	0.0015-inch MAM	Style 3583 nylon 2 layers	Inside surface of MAM	G-207	Nylon to MAM and nylon to nylon.	Specimen for wrinkle control only. NASA demonstration.
14	12	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	
			1-in Glassfloss mat 14.7 gm/ft^2 (unimpregnated)	Outside surface of MAM	G-207	Glass to MAM	
15	12	Repeat of Specimen No. 14 with G-207 impregnated Glassfloss mat.					
16	12	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	
			2-in. Glassfloss mat, Style EC media (dry)	Outside surface of MAM	G-207	Glass to MAM	
17		Same as Specimen No. 16 except using G-207 impregnated glass mat.					
18	12	0.0015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	
			2-in. Glassfloss mat, Style FARR media	Outside surface of MAM	G-207	Glass to MAM	
19	12	Same as Specimen No. 18 except using G-207 impregnated glass mat.					
20	12	0.00015-inch MAM	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	
			2-in. Glassfloss mat (16.5 gm/ft2)	Outside surface of MAM	G-207	Glass to MAM	Mat sectioned into three equal parts, butt joined.

Table I. Flex-Cycle Spring-Back Test Specimens - 24-Inch Diameter (Continued)

Spec No.	% Shrink	Jacket Material	Back-up Media		Adhesive		Remarks
			Material	Location	Material	Location	
21	12	0.0015-inch MAM, 2 plies laminated together with G-207	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	
			2-in. Glassfloss mat impregnated with G-207	Outside surface of MAM	G-207	Glass to MAM	
22	12	Mylar-lead-Mylar (MLM) X283 Schjeldahl Co	Style 3583 nylon	Inside surface of MLM	G-207	Nylon to MLM	
			2-in. thick Glassfloss mat impregnated with G-207	Outside surface of MLM	G-207	Glass to MLM	
23	12	MAAM Dobeckmun Co, 34321	Style 3583 nylon	Inside surface of MAAM	G-207	Nylon to MAAM	
			2-in. thick Glassfloss mat impregnated with G-207	Outside surface of MAAM	G-207	Glass to MAAM	
24	12	MAMAM Dobeckmun Co, 34322	Style 3583 nylon	Inside surface of MAMAM	G-207	Nylon to MAMAM	
			1-in. thick Glassfloss mat impregnated with G-207	Outside surface of MAMAM	G-207	Glass to MAMAM	
25	12	MAM, Dobeckmun Co, 34320	Style 3583 nylon	Inside surface of MAM	G-207	Nylon to MAM	
			1-in. thick Glassfloss mat impregnated with G-207	Outside surface of MAM	G-207	Glass to MAM	
26	12	MAAM, Dobeckmun Co, 34321	Style 3583 nylon	Inside surface of MAAM	G-207	Nylon to MAAM	Repeat of No. 23 with 1-in. thick glass mat spring-back media.
			1-in. thick Glassfloss mat impregnated with G-207	Outside surface of MAAM	G-207	Glass to MAAM	
27	12	MAAM, Dobeckmun Co, 34321	Style 3583 nylon	Inside surface of MAAM	G-207	Nylon to MAAM	Repeat of No. 26 with new 1-in. thick glass mat as delivered to Martin Co
			1-in. thick Glassfloss mat (14.7 oz ft^2) impregnated with G-207	Outside surface of MAAM	G-207	Glass to MAAM	

(3) Specimen No. 5: Flexible polyurethane foam bonded to the inner surface of the vacuum jacket material. A 2-lb/ft^3 flexible polyurethane foam was selected for evaluation because of the inherent elastic properties, ease of application, light weight, and low cost.

(4) Specimens No. 7 and 12: Flexible polyurethane foam located on the outer surface of the vacuum jacket. Various thicknesses and densities of flexible polyurethane foams were evaluated for spring-back characteristics. These foams were placed on the outer surface of the vacuum jacket material for minimum shrinkage of the jacket, as discussed in (2).

(5) Specimens No. 6, 8, and 9: Flexible polyurethane foam with outside skins laminated to foam. Flexible polyurethane foam spring-back medium located on the outer surface of the vacuum jacket was improved by the addition of a MAM or Mylar skin to the outer surface of the foam. Specimens No. 6 and 8 represent a concept wherein the complete recovery is effected by internal pressurization of the foam space, thereby stretching the outer skin to its original as-molded shape and the vacuum jacket being laminated to the foam and outer skin is thus returned to the expanded shape. Pressurization would be accomplished by the air trapped in the foam space expanding during the boost phase. Specimen No. 9 represents an improvement over specimens 6 and 8 in that pressurization of the foam space was not required to obtain full recovery from a 10 percent shrink condition. Specimen No. 9 was made by a fabrication process that resulted in a more resilient composite than specimens No. 6 and 8.

(6) Specimens No. 4, 10, and 14 through 27: Spun glass fiber mat on the outer surface of the vacuum jacket. Various weights and thicknesses of lightweight glass fiber mats were selected for evaluation of spring-back characteristics when bonded to the outer surface of the vacuum jacket material. The glass mats were selected for evaluation because of the inherent springiness of the glass fibers, no elongation or creep, light weight, and commercial availability at low cost. Glass fiber mats were evaluated in the as-received condition and also with an additional resin dip coat of G-207 resin, which improved the stiffness and spring characteristics.

d. Test Procedure. The test procedure for evaluating the spring-back characteristics of spring-back media and vacuum jacket materials is as follows:

(1) Mount test specimen in flex-cycle test fixture and secure perimeter of specimen with test fixture circular clamping ring.

(2) Lightly pressurize the back side of the test specimen to ensure inflation of specimen to the true contour as fabricated.

(3) Set the cotton cord horizontal reference line flush with the top center area of the test specimen.

(4) Evacuate the space between the specimen and the test fixture to shrink the specimen onto the curved surface of the foam insert on the test fixture. Measure the distance between the horizontal reference line and the top of the evacuated specimen.

(5) Vent the evacuated space to atmosphere to break the vacuum and allow the spring-back media to return the test specimen as nearly as possible to the original contour. Record the length of time of spring-back.

(6) Measure the distance between the cotton cord reference line and the top of the spring-back specimen after spring-back, as shown in Figure 13.

(7) Repeat operations 2 through 6 for three to six cycles. Calculate the average percent of spring-back for all test cycles.

e. Test Results. The spring-back test results are given in Table II. Photographs of tests and specimens after testing are shown in Figures 8 through 33.

Table II. Spring-Back Test Results - 24-Inch Diameter Specimens

Spec No.	Ref Fig.	% Shrink	No. of Cycles	Test Results
2	8	8	3	Specimen collapsed onto curved surface. Wrinkles in hexagonal pattern. Nylon backing provided well rounded wrinkle ridges and prevented sharp corners at wrinkle intersections. HMH pulled loose from nylon in portions of the wrinkle areas. Node bonds broken in wrinkle areas and HMH walls buckled. Spring back complete over 80 percent of specimen area. Remaining 20 percent had reverse curve that pressed downward. By inducing vibration to specimen, the spring-back was 90 - 95 percent complete.
3	9	5	3	Seven percent curve specimen collapsed onto 2 percent curved surface. Wrinkle pattern less than specimen No. 2 due to less shrink. Wrinkles well rounded with no sharp corners. Spring-back was virtually complete with small wrinkles remaining in MAM.
		7	3	Seven percent curve specimen No. 3 was evacuated onto flat surface of test fixture to 7 percent shrink in specimen. Wrinkles were larger and followed same path previously established in 5 percent tests. Spring-back complete in 80 percent of area. The remaining 20 percent had reverse curve pressing downward. Some damage to HMH node bond noted in wrinkle areas. HMH in general was in better condition than HMH located on inside surface of MAM as on specimen No. 2. Spring-back complete over 80 percent of area, and rate of recovery was faster than specimens No. 1 and 2.
4.	Not tested - scrap part.			
5		10	2	Sharp creases indicating need for a backup material of higher density than foam. Poor spring-back - approximately 50 percent of area recovered very slowly.
6	10	10	3	Wrinkles well cushioned and rounded. No sharp corners observed. Spring-back was poor with only 50 percent of specimen area recovering. Remaining area had large reverse curve pressing downward.
		10	3	Added 1 4-inch diameter pressure tap to hole pierced in outer MAM skin. Venting the foam space improved the spring-back characteristics. Complete recovery was not achieved until 7 to 10 psi air pressure was applied to pressure tap.
7	11	10	3	Large hexagonal wrinkle pattern. Wrinkles well rounded. Poor spring-back with recovery noted in 40 to 50 percent of specimen area. Remaining areas had reverse curves pressing downward. Recovery rate was slow, and the 0.4-inch thick foam appeared too rigid to encourage spring-back.

Table II. Spring-Back Test Results - 24-Inch Diameter Specimens (Continued)

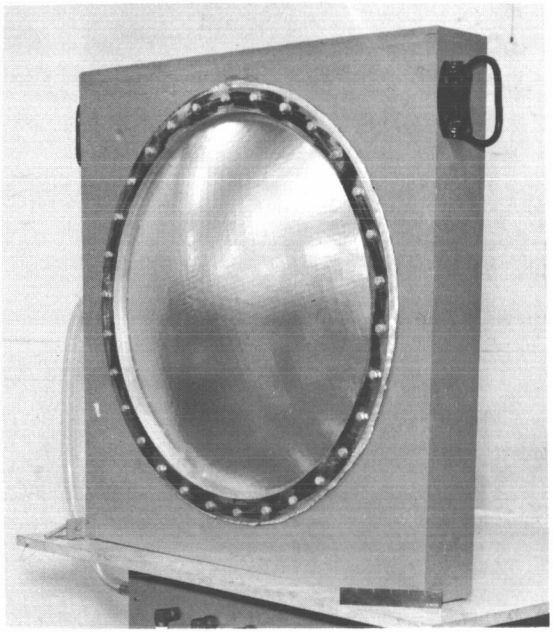
Spec No.	Ref Fig.	% Shrink	No. of Cycles	Test Results
8	12	10	6	Pressure tap added over hole pierced in outside 1/2-mil Mylar skin to vent foam space before first test. Spring-back was virtually complete except for one shallow reverse curve area which prevented complete recovery on several test cycles. Light tapping or vibration of specimen would induce complete recovery. Addition of 3 to 5 psi to pressure tap would ensure rapid and complete recovery.
9	13	10	6	Spring-back complete over entire specimen area. Spring-back recovery was within 0.10 inch °F original specimen height. No pressure introduced to foam on cycles 1 through 3.
			1	Collapsed the specimen (by vacuum) onto test fixture and held down for 90 hours. No appreciable spring-back noted. Spring-back was rapid and complete when 5 psi air was introduced at pressure tap.
10	14	10	6	Evacuated onto curved surface for 10 percent shrink. Wrinkle pattern difficult to observe due to bulk of glass mat. Appeared random and not severe. Spring-back 100 percent within 30 seconds after releasing vacuum.
11		12		Not tested.
12		10	3	Evacuated onto 2 percent curved surface for 10 percent shrink. Spring-back virtually 100 percent (within 0.06 to 0.10 inch of original height).
13		10	2	Wrinkle control test only. No appreciable spring-back. Wrinkle well cushioned by double layer of two-way stretch nylon. Samples of creased areas to be tested in Dow cell.
14	15	10	2	Evacuated onto 2 percent curve for 10 percent shrink. Spring-back slow and only about 80 percent complete. One large area had reverse curve that would not recover. Wrinkle pattern was different from impregnated glass samples (No. 10 and 15) in that there were fewer and larger wrinkles on this sample. Indications are less wrinkle control and less spring-back with unimpregnated 14.75-oz glass floss.
15	16	10	3	Evacuated onto 2 percent curve for 10 percent shrink. Spring-back 100 percent within 30 seconds after releasing vacuum. Excellent wrinkle control with many small wrinkles as compared to specimen No. 14. This sample to be tested for long-time hold under vacuum and spring-back testing.

Table II. Spring-Back Test Results - 24-Inch Diameter Specimens (Continued)

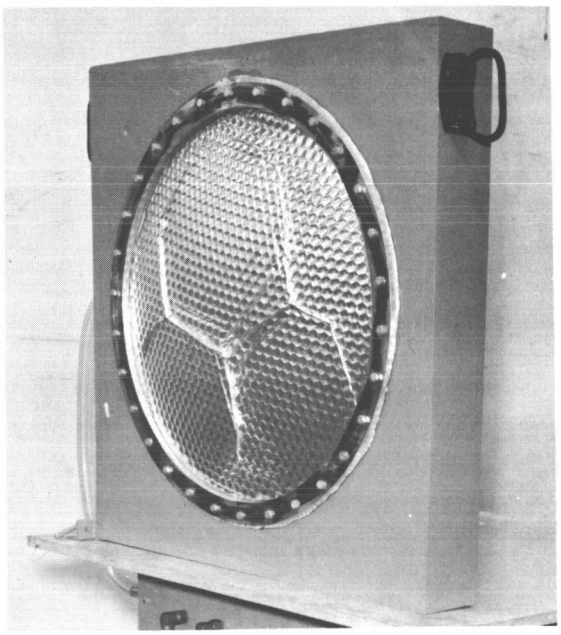
Spec No.	Ref Fig.	% Shrink	No. of Cycles	Test Results
16		10		Will not be tested.
17	17 and 18	10	3	Thickness of glass mat uneven. Three inches thick at OD edges, 2 inches thick at center. Stiffness of outer skin of mat prevents mat from following jacket 12 percent curve contour, thus causing uneven thickness of mat. Also induces shallow wrinkles to specimen before test (see Figure 18). Evacuated onto 2 percent curve for 10 percent shrink. During evacuation, wrinkle pattern was very random and seemed to follow some of the previous wrinkles (see Figure 18). Spring-back slow but complete to within 0.2 inch of original height.
18	19 and 20	10	3	Evacuated onto 2 percent curve for 10 percent shink. Spring-back very slow and reached 0.62 inch from original height. Fewer and deeper wrinkles than Specimen No. 19 (see Figure 20). Spring-back not as complete as Specimen No. 19.
19	20 and 21	10	3	Evacuated onto 2 percent curve for 10 percent shrink. Spring-back 100 percent complete. Within 0.2 inch of original height in 30 seconds after releasing vacuum. Good wrinkle control with many small wrinkles evenly distributed over surface of specimen.
20	22 and 23	10	3	Evacuated onto 2 percent curve for 10 percent shrink. Spring-back 100 percent complete. Butt joints of glass mat segments allowed jacket wrinkles to form along line of joint. These wrinkles were somewhat heavier than other wrinkles in the jacket; however, are not considered objectionable.
21	24	10	1	Evacuated onto 2 percent curve for 10 percent shrink. Spring-back incomplete and very slow. Returned to approximately 3/4 inch of original height or 62 percent spring-back at center area of the specimen. Approximately 25 percent of the specimen did not spring back more than 50 percent. Wrinkle pattern was several large creases connected by numerous small wrinkles. Less wrinkle control than specimens No. 15 and 19. This material is considered too stiff for practical vacuum jacket use.
22	25	10	3	Evacuated onto 2 percent curve for 10 percent shink. Spring-back at the center was within 0.25 inch of original height in 40 seconds after releasing vacuum. An area in the center and to one side of the specimen comprising approximately 60 percent of the total area recovered by spring-back to 90 percent of original height. The remaining 40 percent of the specimen area recovered 70 percent of original height. Wrinkle pattern was three large creases with few small interconnecting wrinkles, indicating less wrinkle control than obtained on MAM test specimens No. 15 and 19. This specimen had fewer wrinkles than specimen No. 21.

Table II. Spring-Back Test Results - 24-Inch Diameter Specimens (Continued)

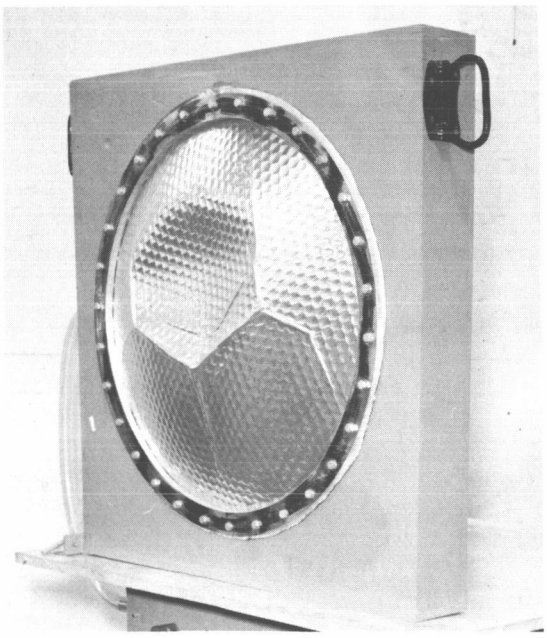
Spec No.	Ref Fig.	% Shrink	No. of Cycles	Test Results
23	26 and 27	10	3	Evacuated onto 2 percent curve for 10 percent shrink. Spring-back at center was 0.38 inch of original height in 60 seconds. Approximately 80 percent of the specimen area recovered by spring-back to 80 - 85 percent of its original height. The remaining 20 percent of the area recovered only 65 percent of original height. This area (see Figure 27 of wrinkles after test viewed from rear of specimen) having lowest recovery is bounded by a hexagonal pattern of heavy wrinkles. Other heavy wrinkles would indicate a lesser degree of wrinkle control than was experienced on earlier specimens. Contributing to this may be variations in density of the 2-inch thick Glassfloss mat.
24	28 and 29	10	3	Evacuated onto 2 percent curve for 10 percent shrink. Spring-back at center within 0.25 inch of original height. Spring-back was rapid and complete except for small area near perimeter of specimen where a flat spot existed due to an abnormal fold defect in the glass mat spring-back media. Wrinkle pattern shown in Figure 29 indicates large creases with few interconnecting small wrinkles, probably caused by the stiffness of the five-ply material.
25	29 and 30	10	3	Evacuated onto 2 percent curve for 10 percent shrink. Spring-back at center within 0.09 inch of original height. This specimen had fastest and most complete spring-back of all laminated film materials tested. The rapid spring-back and even distribution of small wrinkles, as shown in Figure 29, are attributed to the light gage (0.0017) of the laminated material.
26	29 and 31	10	3	Evacuated onto 2 percent curve for 10 percent shrink. Spring-back at center within 0.25 inch of original height. Spring-back was rapid and complete over entire area. Wrinkle pattern shown in Figure 29 was a uniform distribution of medium depth wrinkles.
27	32 and 33	10	3	Evacuated onto 2 percent curve for 10 percent shrink. Spring-back was rapid and 100 percent complete to 0.25 inch of original height at center of specimen. Wrinkle pattern (see Figure 33) shows a uniform distribution of medium to heavy creases having well rounded edges.



BEFORE EVACUATION



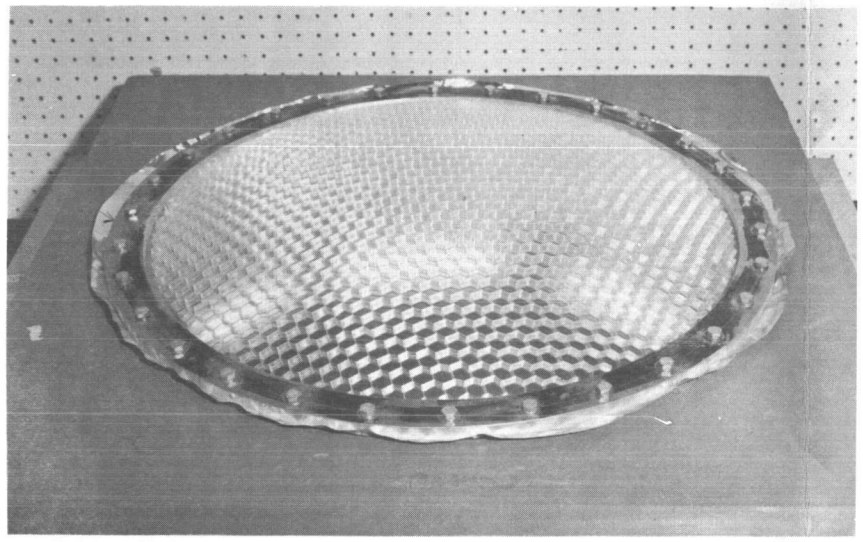
EVACUATED ONTO CURVED SURFACE



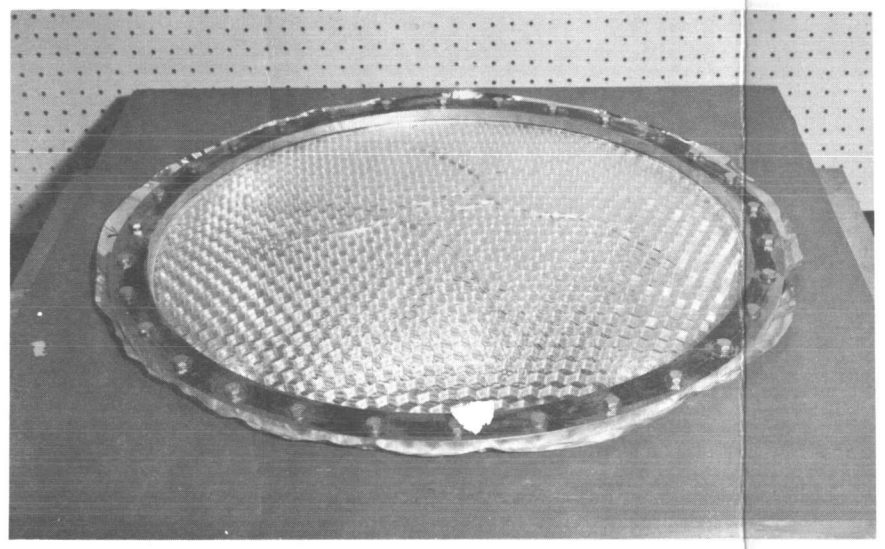
SPRING-BACK AFTER EVACUATION

Figure 8. Spring-Back Tests of Specimen No. 2

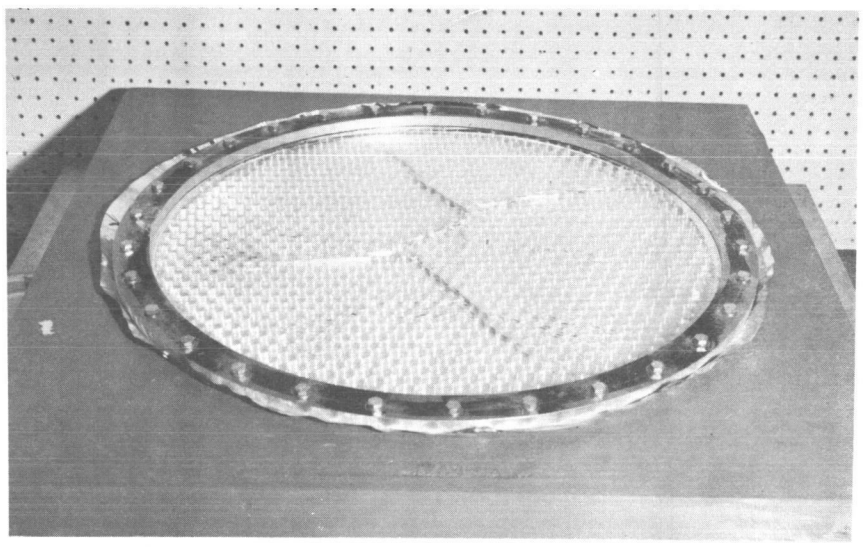
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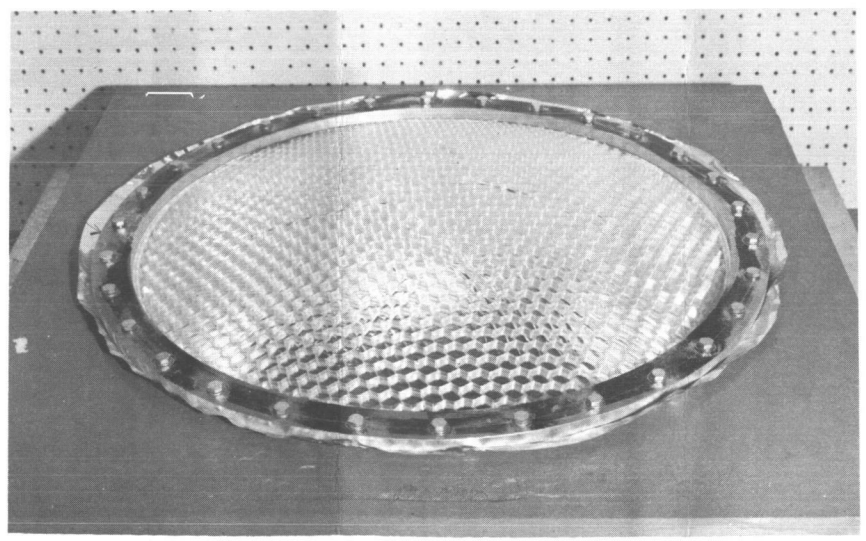
BEFORE EVACUATION



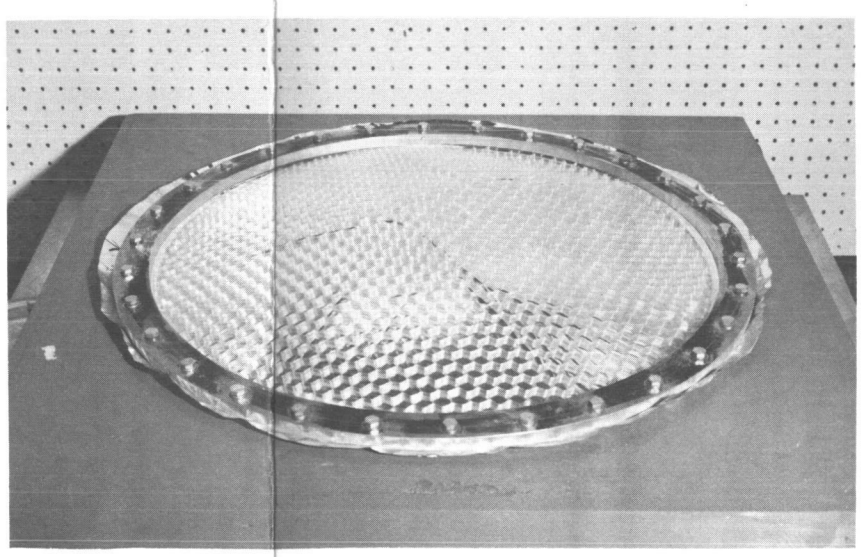
EVACUATED ONTO CURVED SURFACE



EVACUATED ONTO FLAT SURFACE



SPRING BACK AFTER EVACUATION
(FROM CURVED SURFACE)



SPRING BACK AFTER EVACUATION
(FROM FLAT SURFACE)

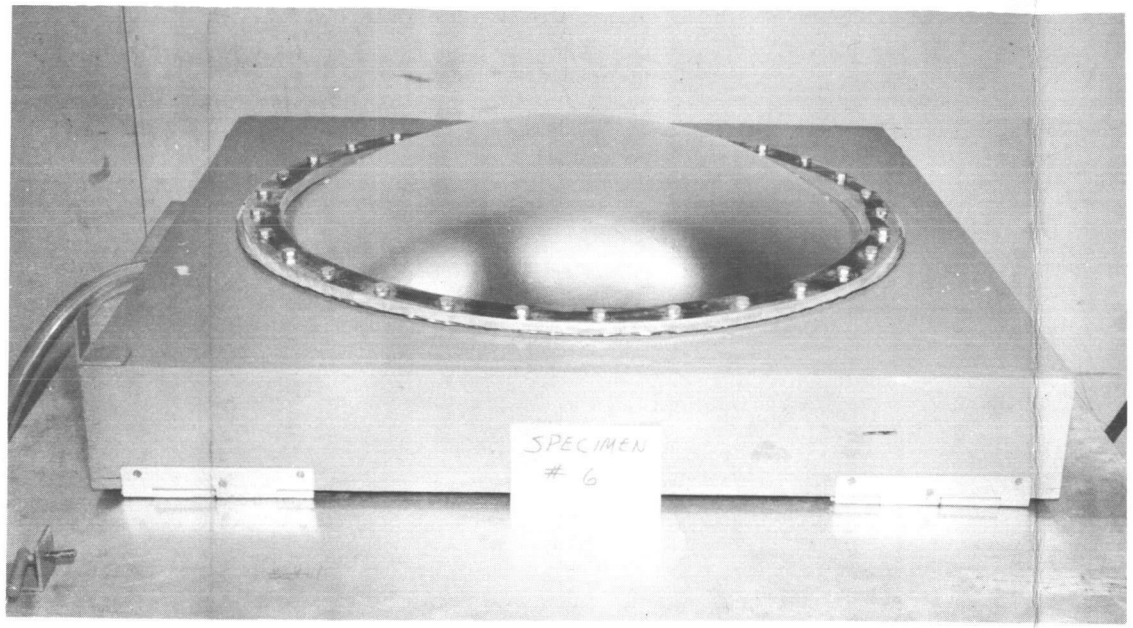
Figure 9. Spring-Back Tests of Specimen No. 3

FOLDOUT FRAME 1

FOLDOUT FRAME

FOLDOUT FRAME 2

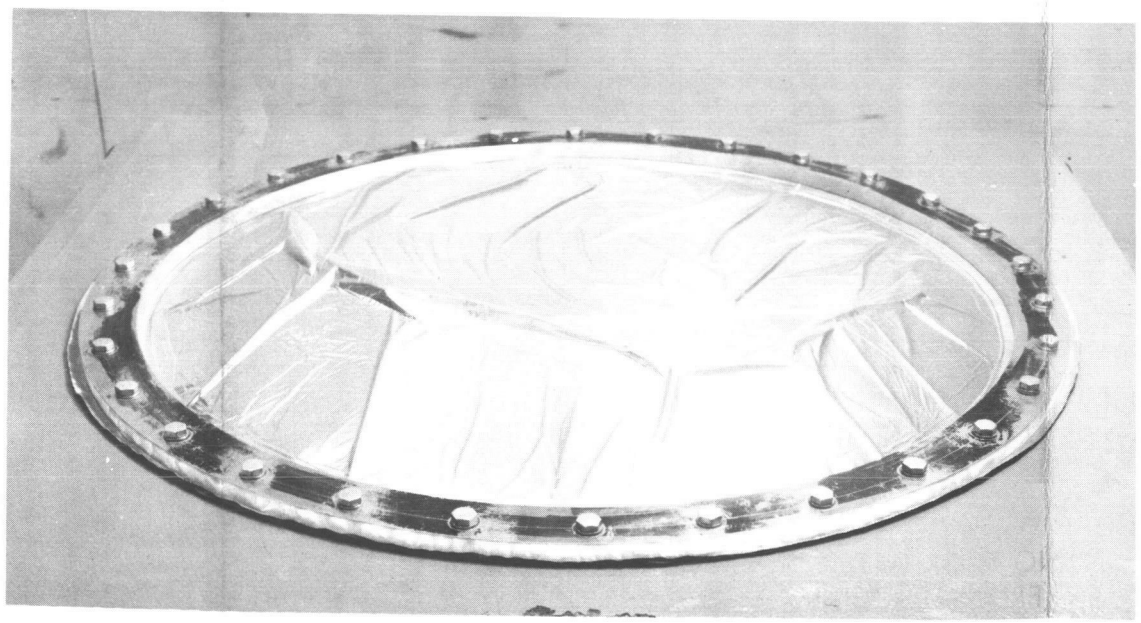
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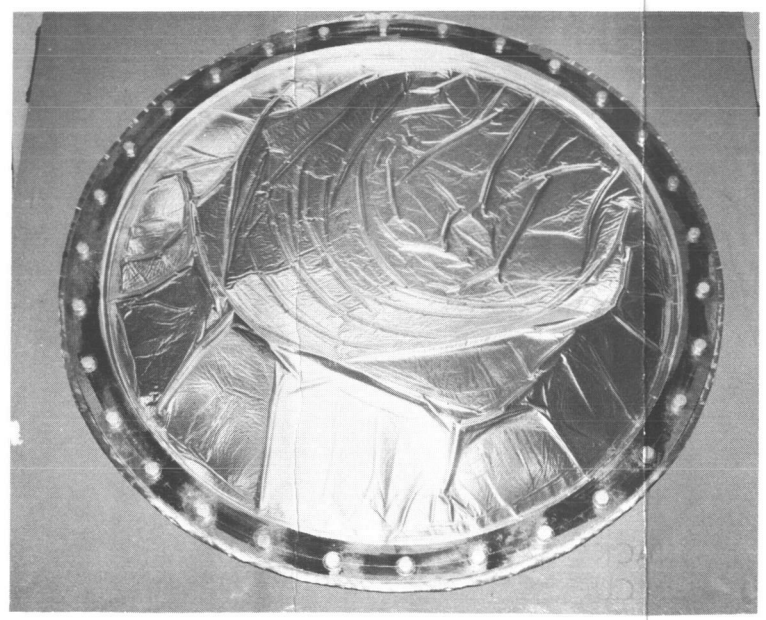
BEFORE EVACUATION



EVACUATED ONTO FLAT SURFACE

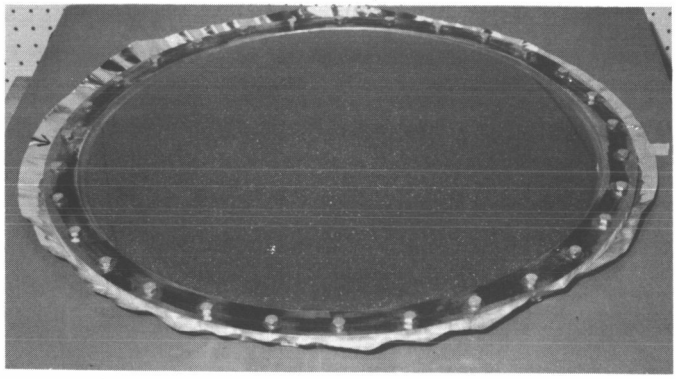


SPRING BACK AFTER EVACUATION

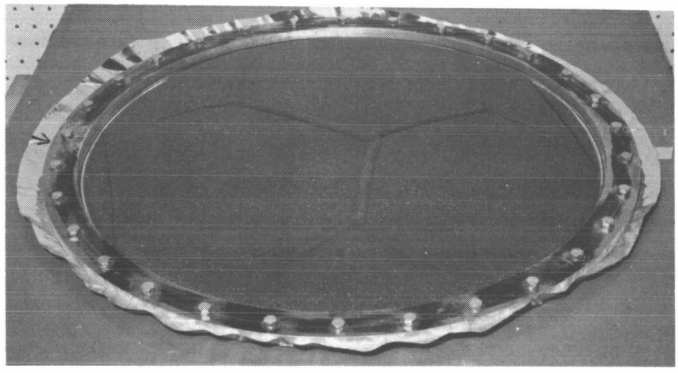


SPRING BACK AFTER EVACUATION

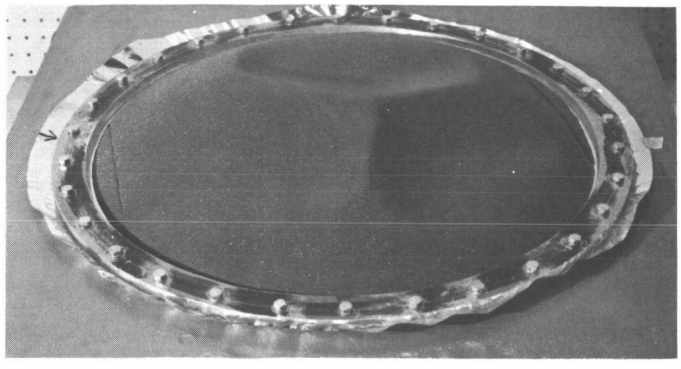
Figure 10. Spring-Back Tests of Specimen No. 6



BEFORE EVACUATION

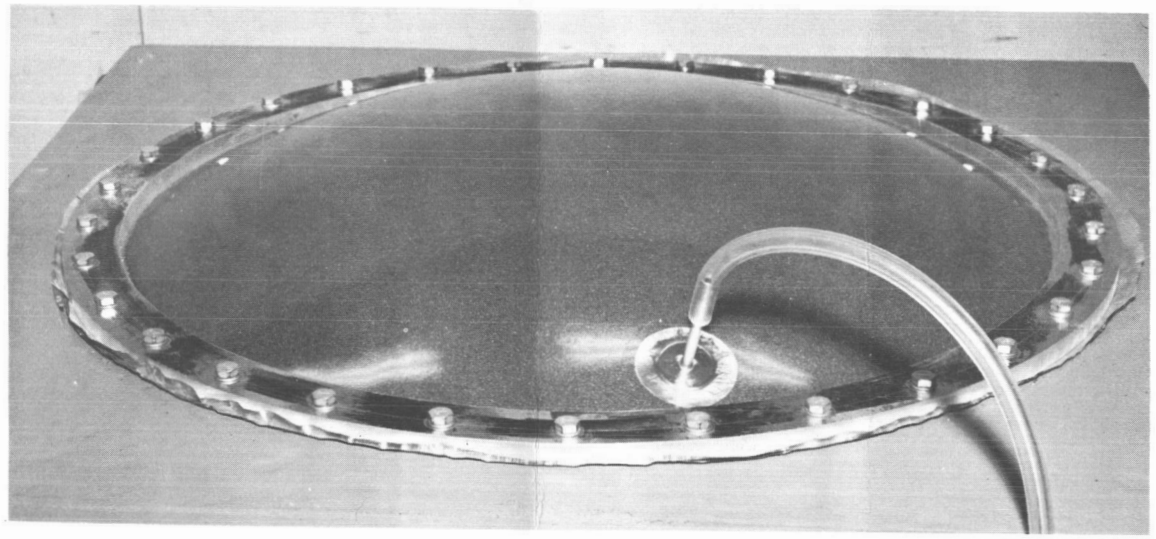


EVACUATED ONTO FLAT SURFACE

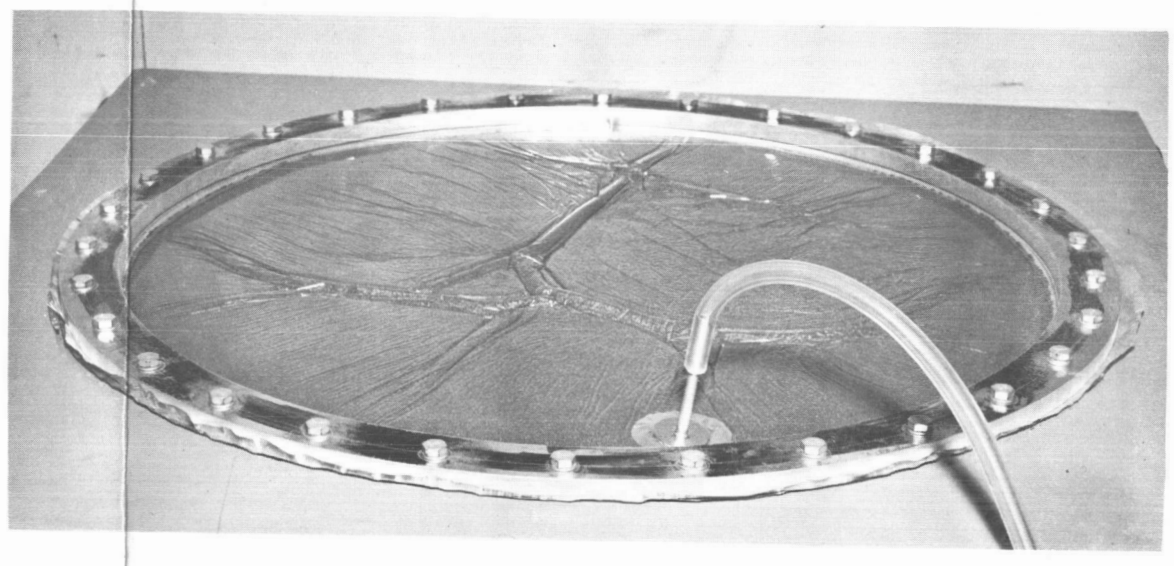


SPRING BACK AFTER EVACUATION

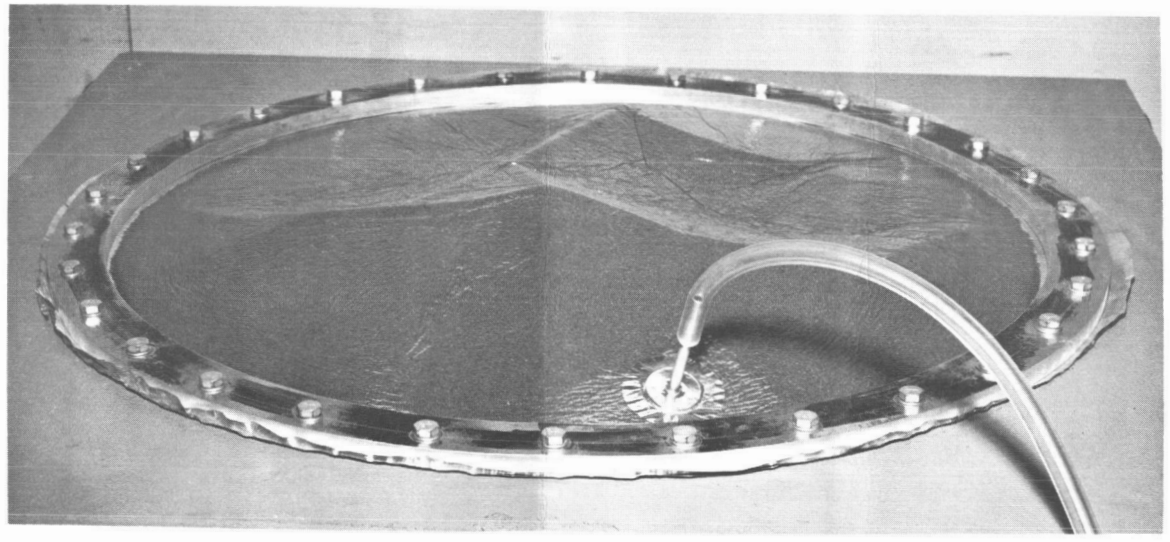
Figure 11. Spring-Back Tests of Specimen No. 7



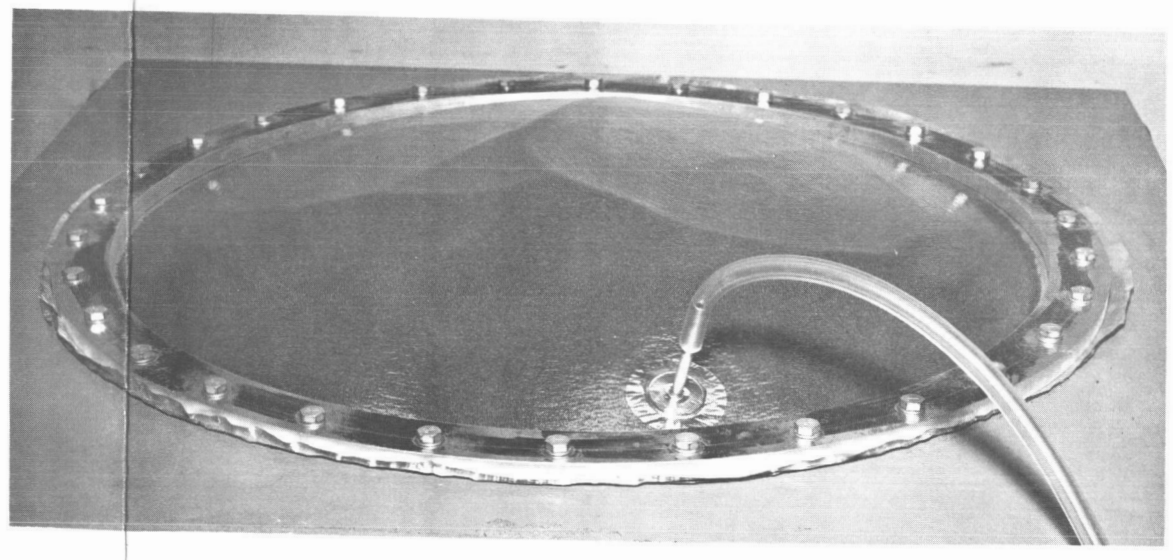
BEFORE EVACUATION



EVACUATED ONTO FLAT SURFACE



SPRING BACK AFTER EVACUATION
(WITHOUT INFLATION OF FOAM SPACE)



SPRING BACK AFTER EVACUATION
(FOAM SPACE INFLATED)

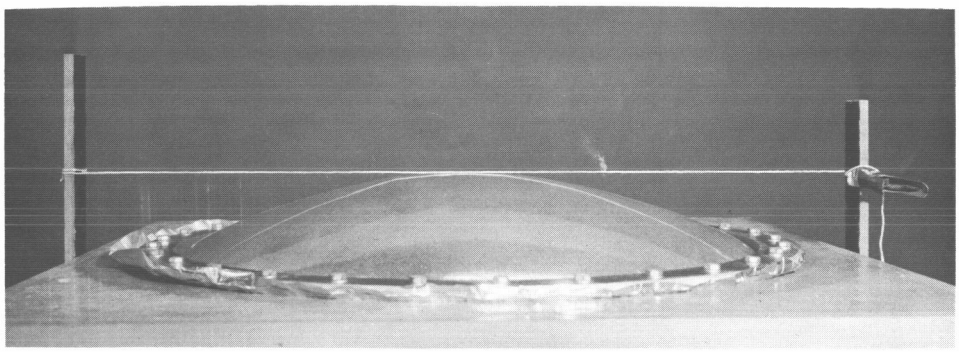
Figure 12. Spring-Back Tests of Specimen No. 8

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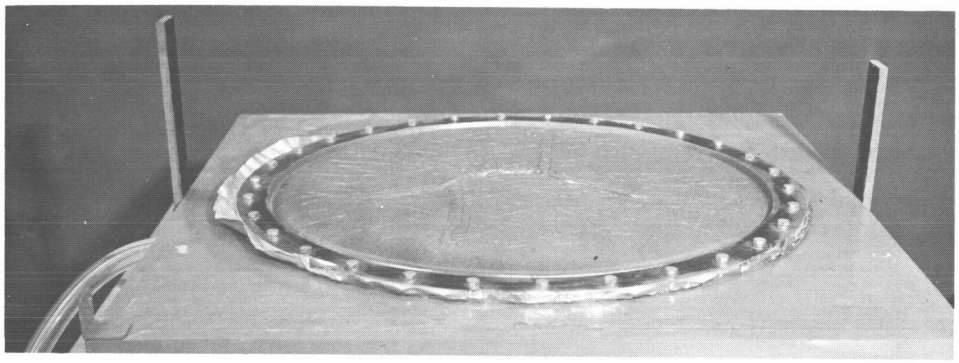
FOLDOUT FRAME 1

FOLDOUT FRAME

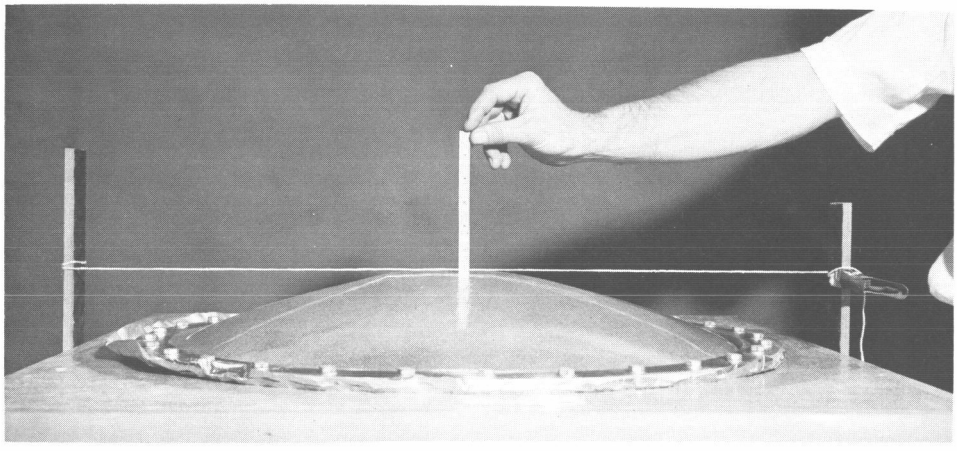
FOLDOUT FRAME 2



BEFORE EVACUATION



EVACUATED ONTO FLAT SURFACE



SPRING BACK AFTER EVACUATION

Figure 13. Spring Back Tests of Specimen No. 9

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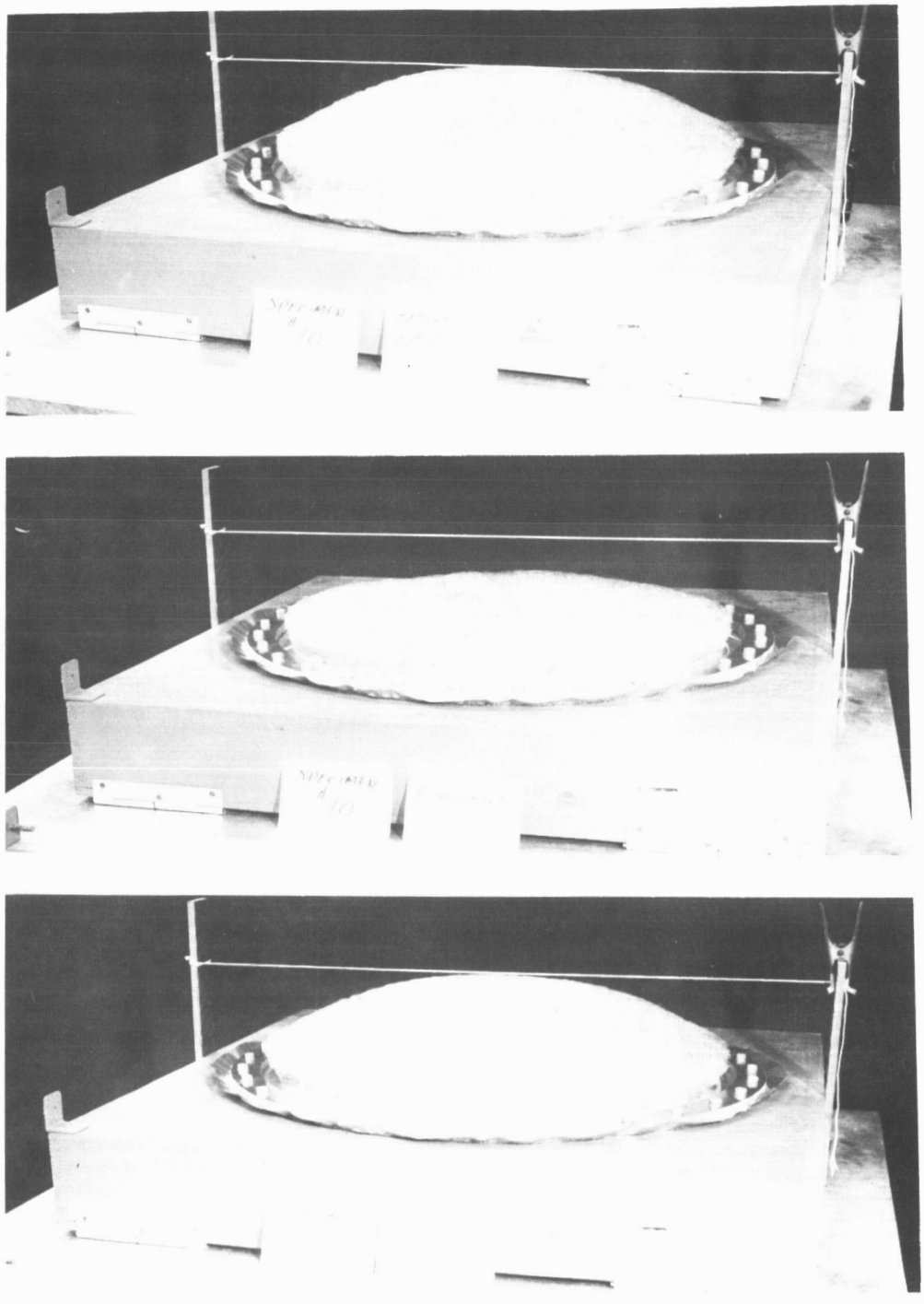


Figure 14. Spring-Back Tests of Specimen No. 10

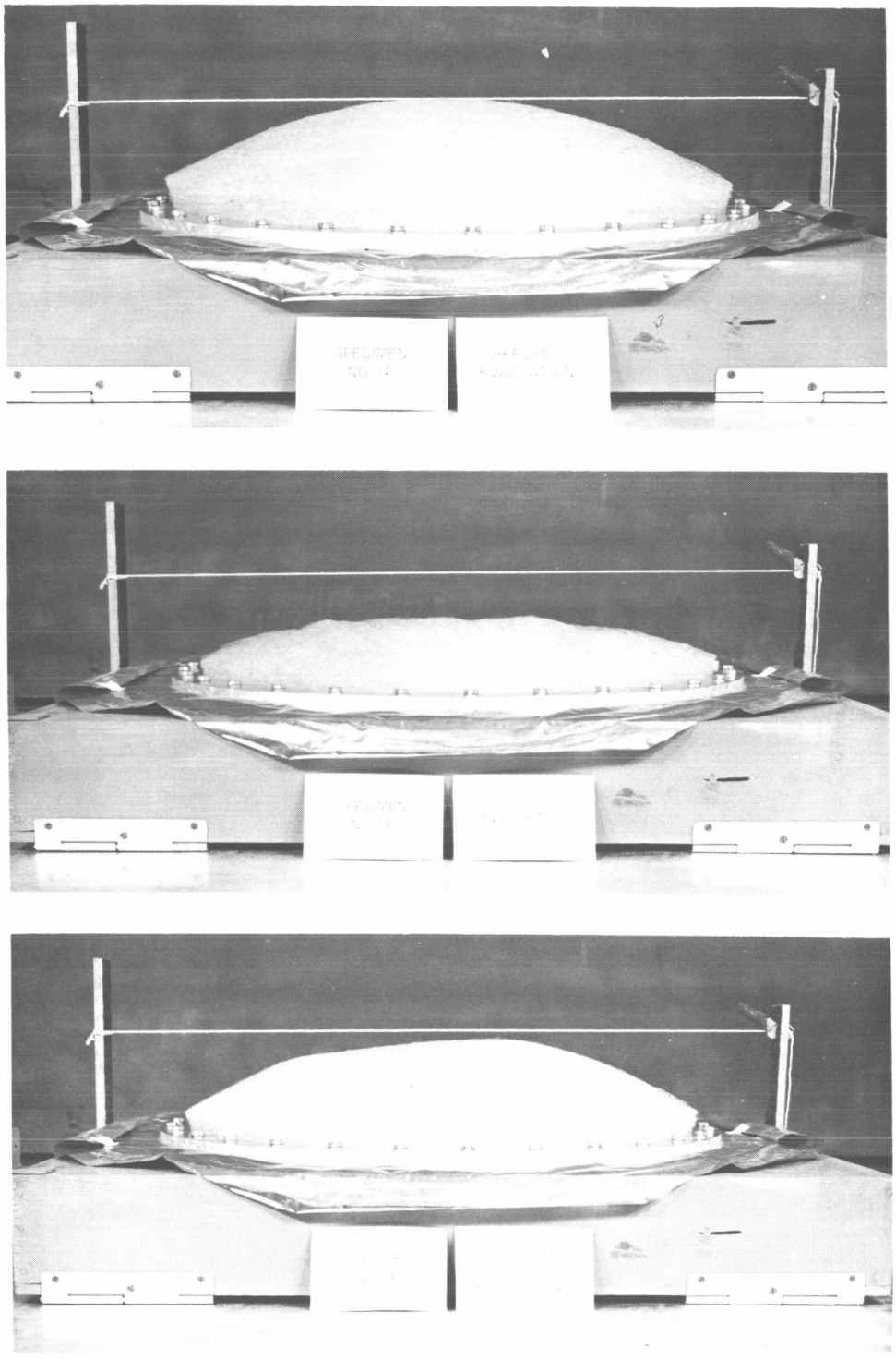


Figure 15. Spring-Back Tests of Specimen No. 14

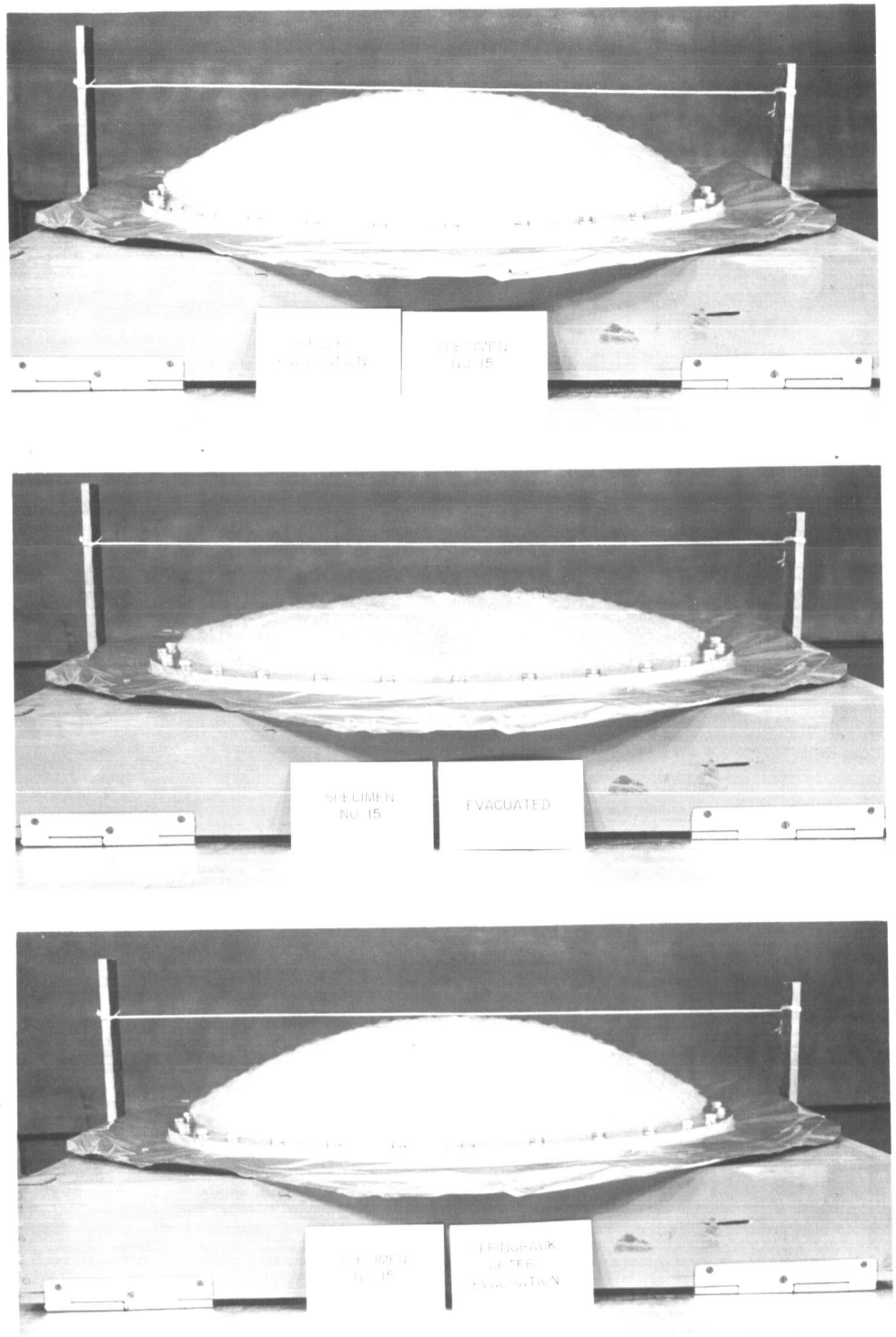


Figure 16. Spring-Back Tests of Specimen No. 15

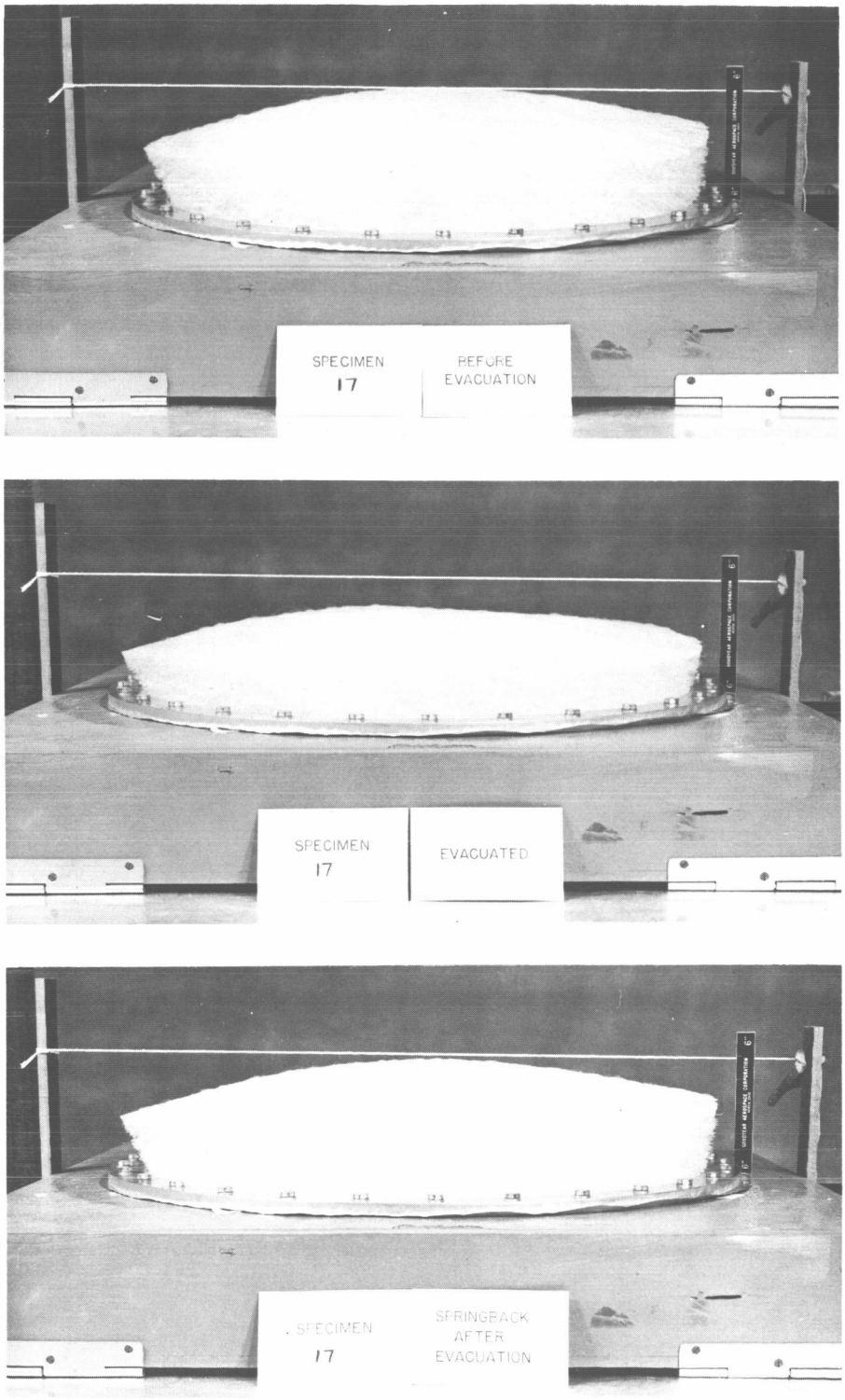


Figure 17. Spring-Back Tests of Specimen No. 17

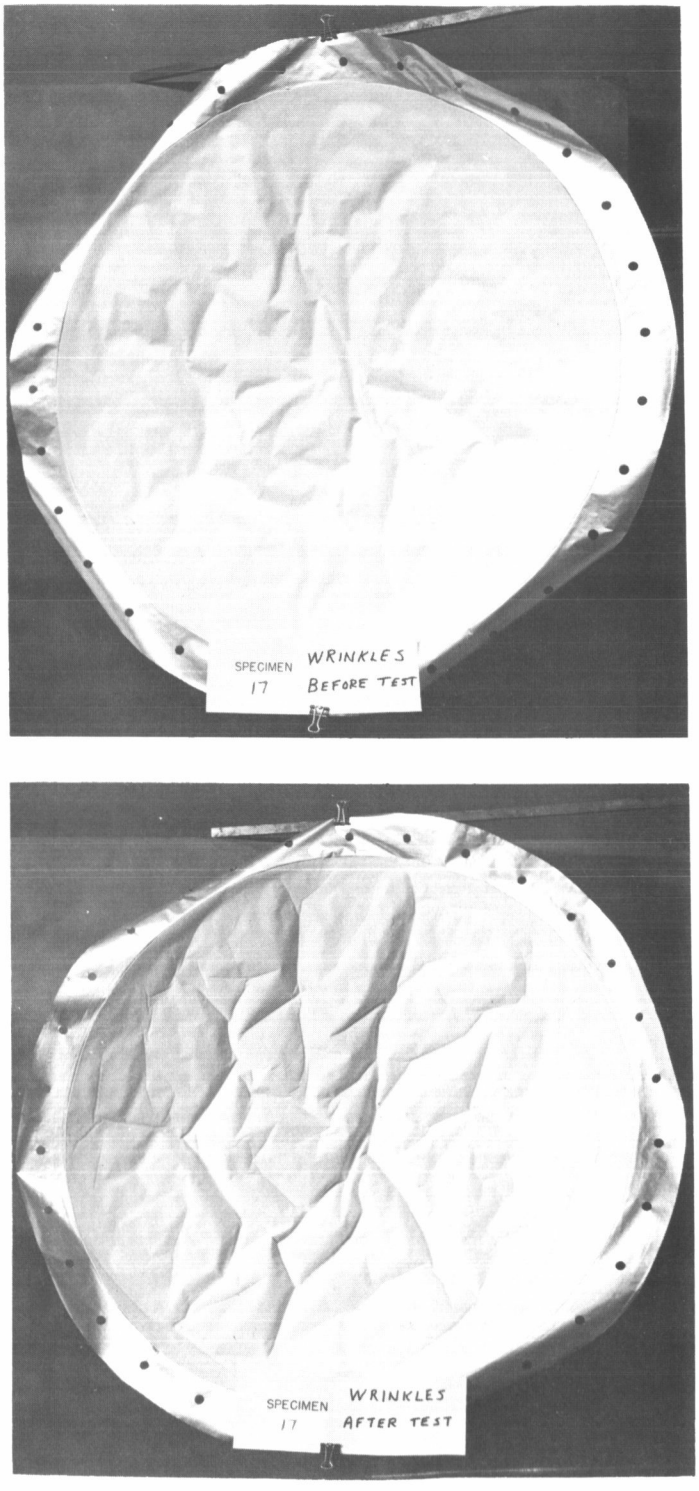


Figure 18. Wrinkles in Specimen No. 17

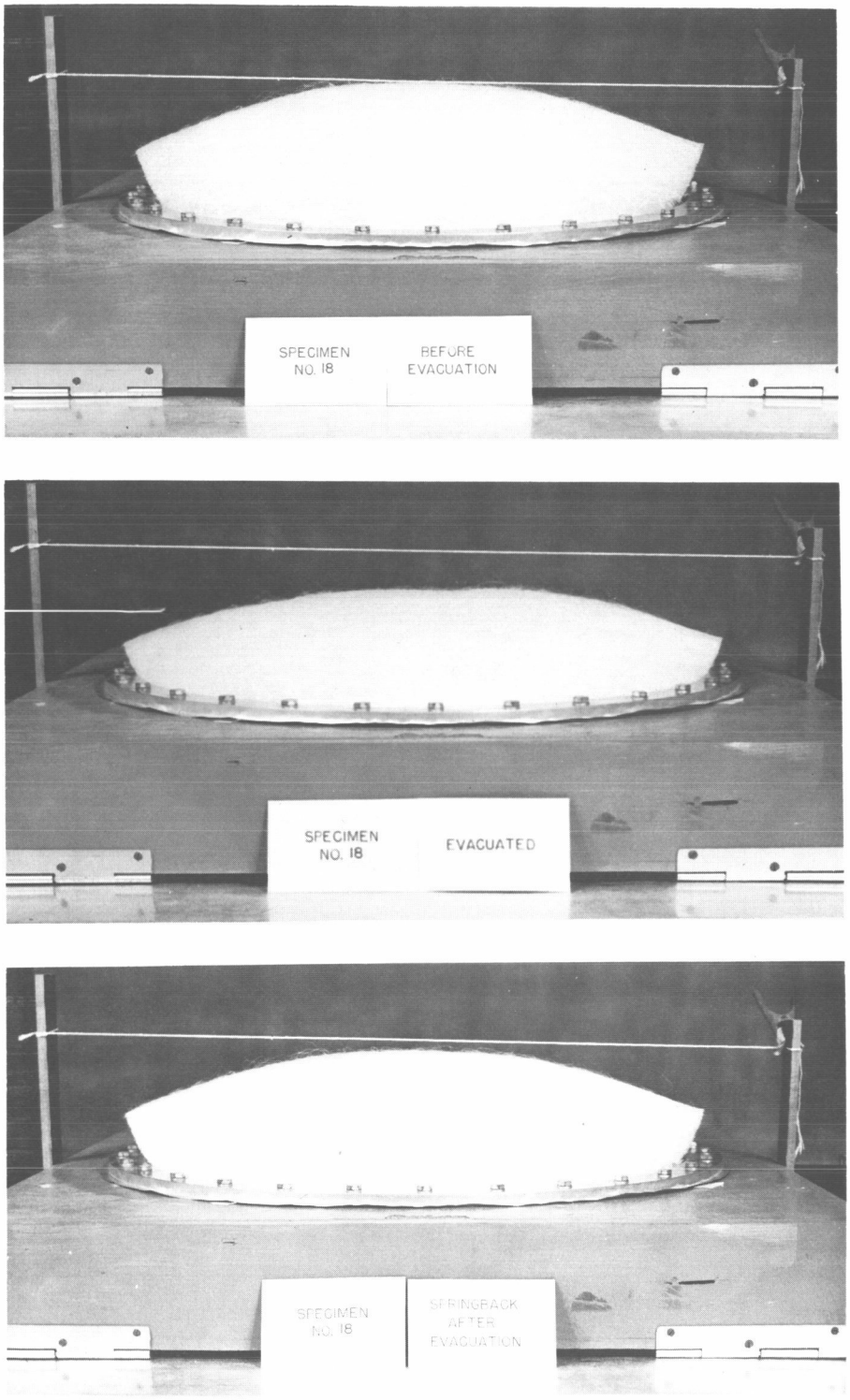


Figure 19. Spring-Back Tests of Specimen No. 18

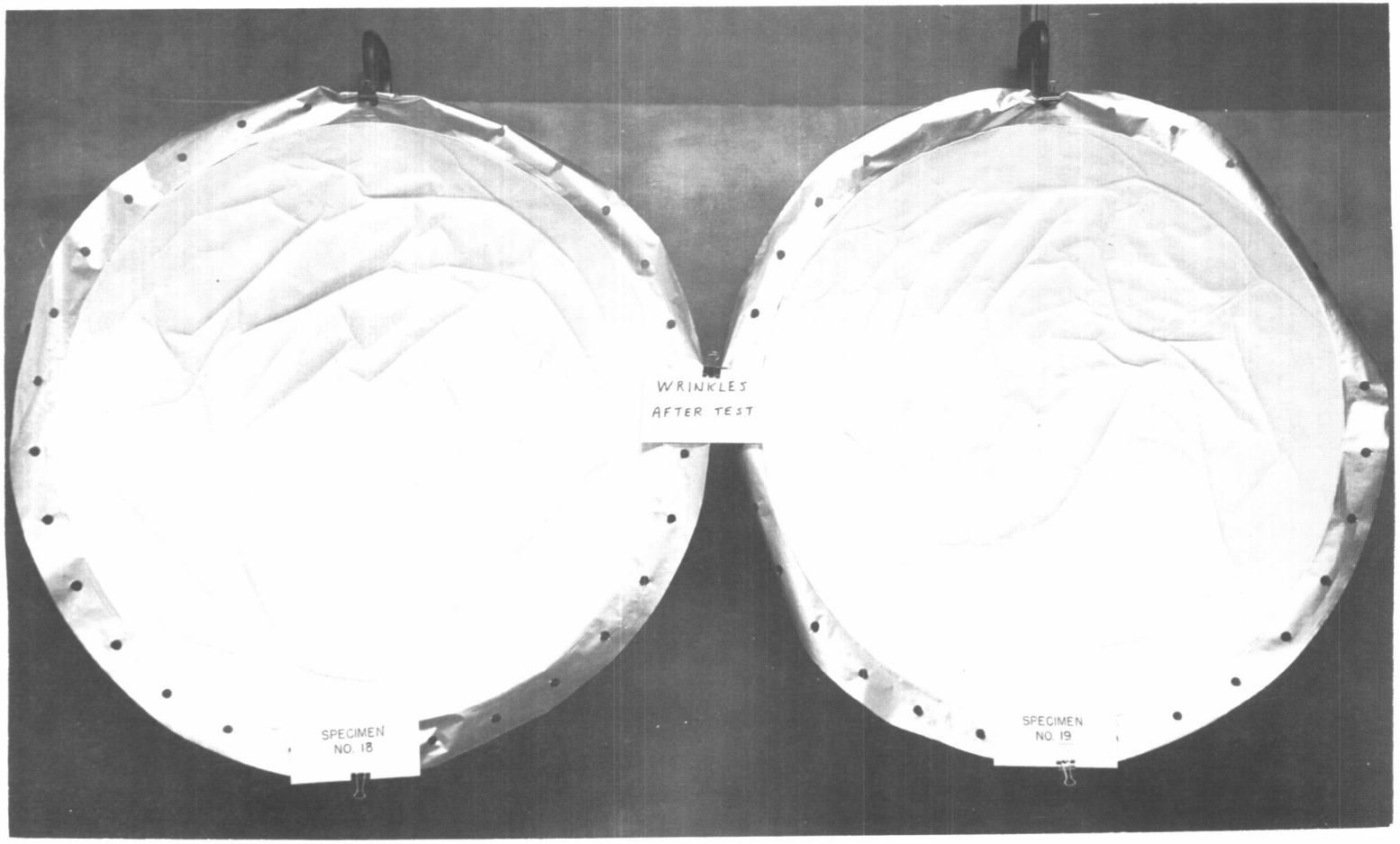


Figure 20. Wrinkles after Test (Specimens No. 18 and 19)

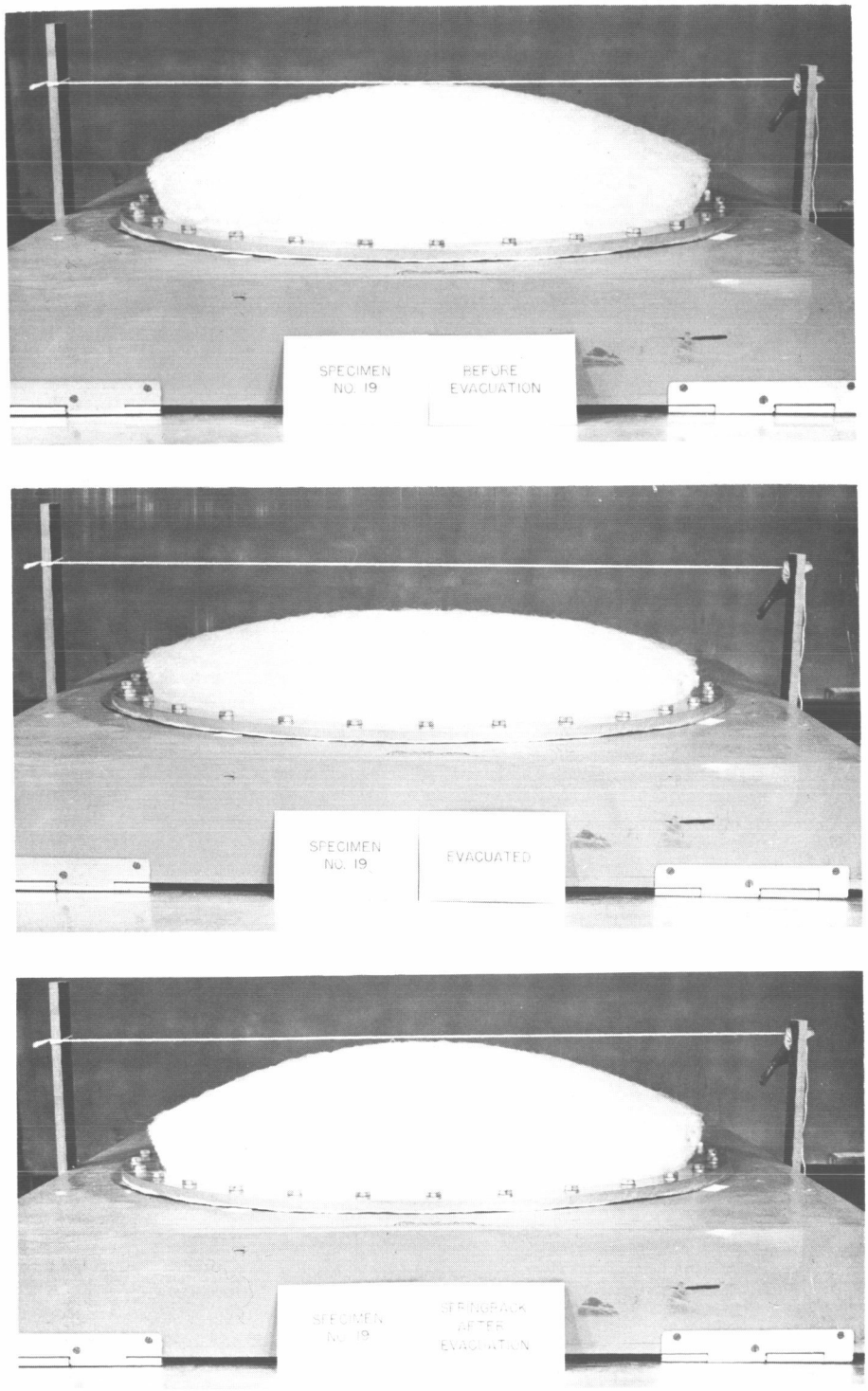


Figure 21. Spring-Back Tests of Specimen No. 19



Figure 22. Spring-Back Tests of Specimen No. 20



Figure 23. Wrinkles after Test (Specimen No. 20)

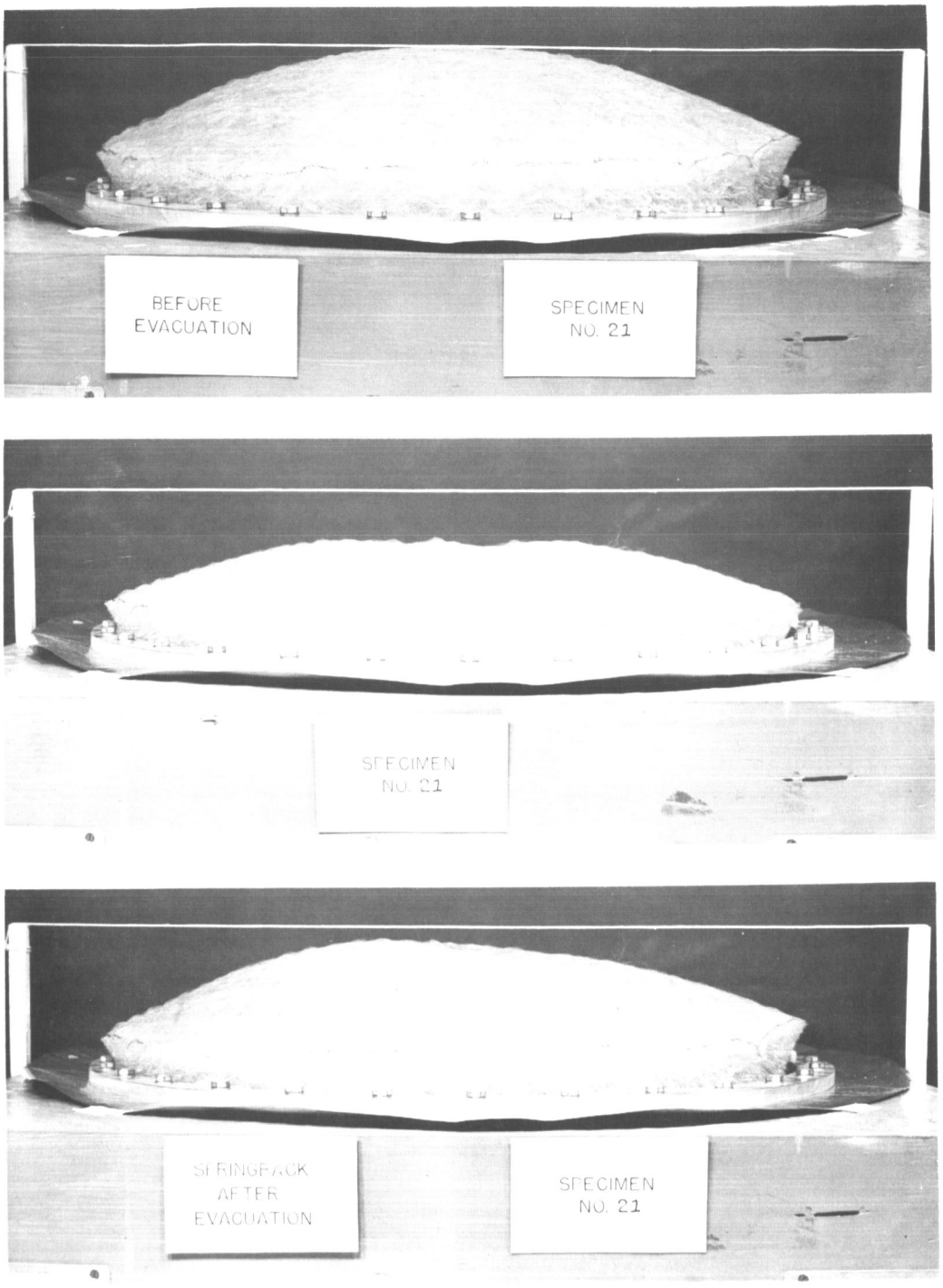


Figure 24. Spring-Back Tests of Specimen No. 21

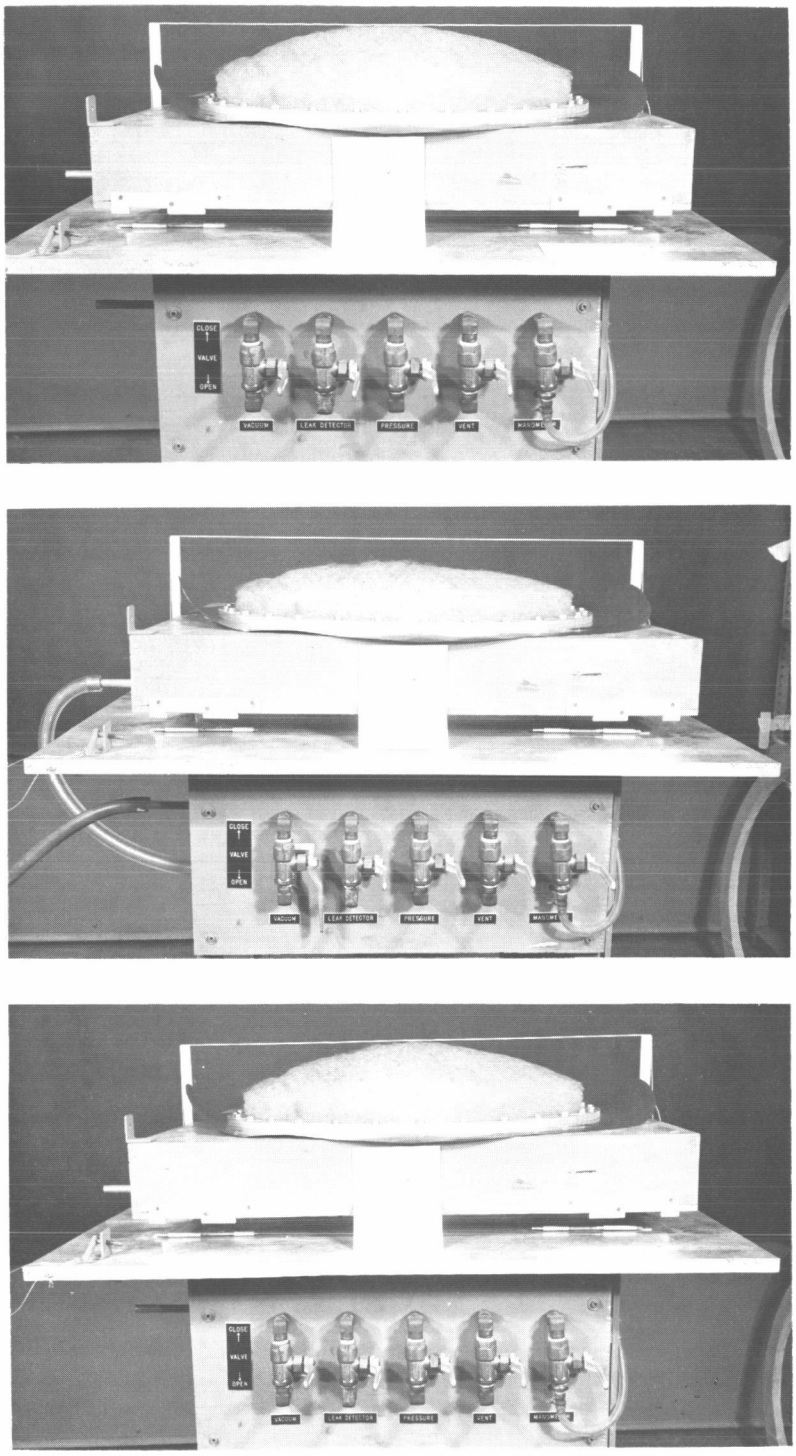


Figure 25. Spring-Back Tests of Specimen No. 22

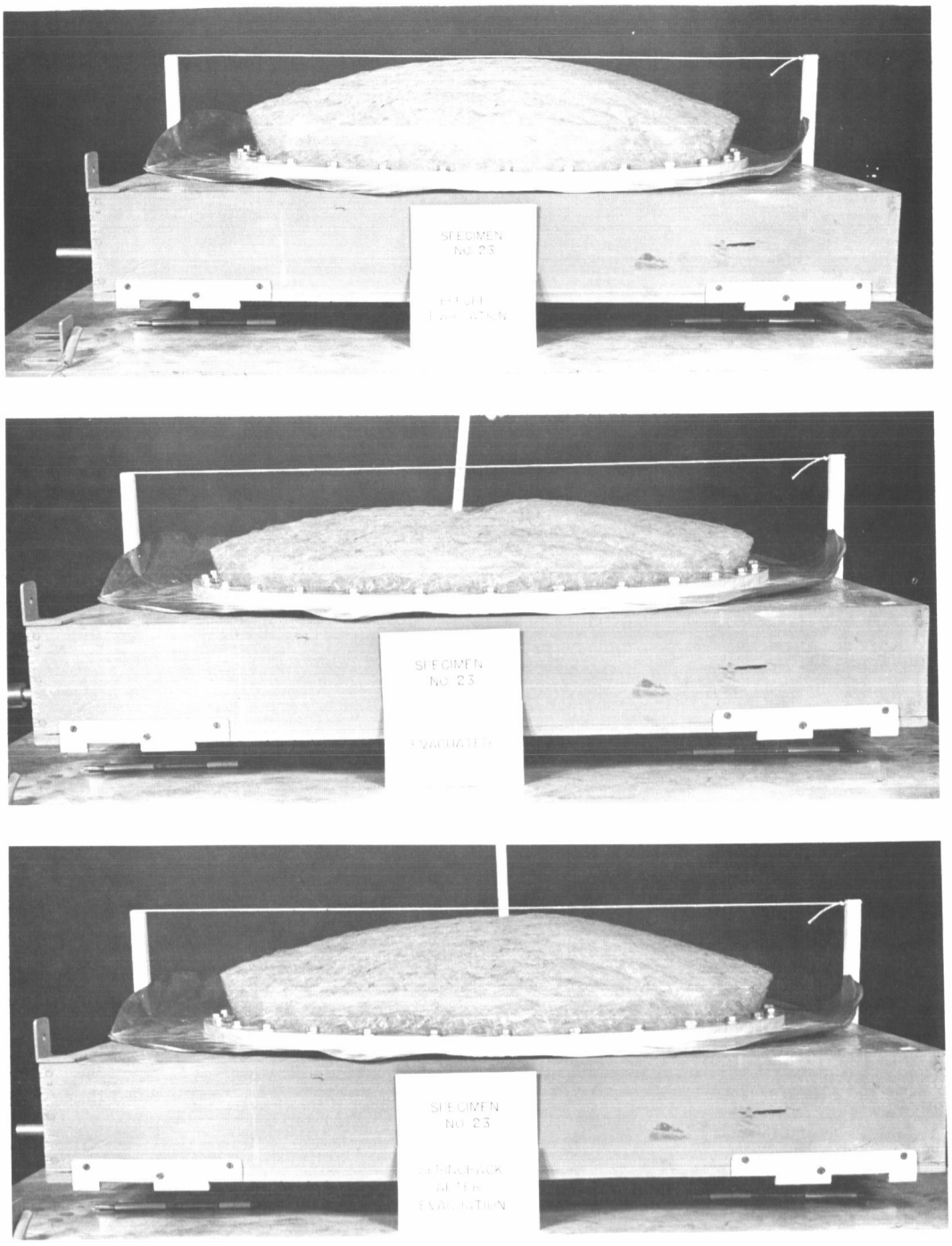


Figure 26. Spring-Back Tests of Specimen No. 23



Figure 27. Wrinkles after Test (Specimen No. 23)

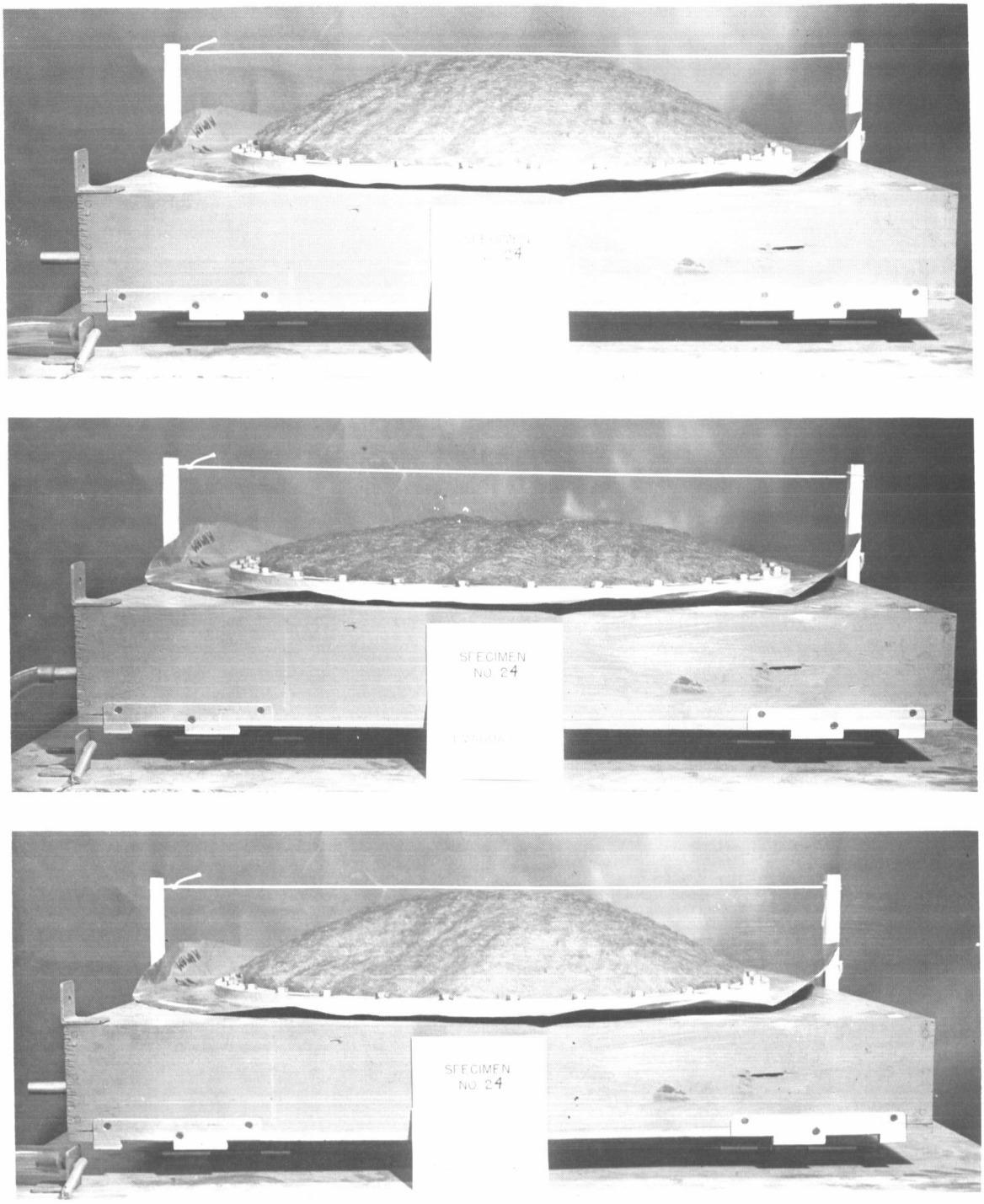


Figure 28. Spring-Back Tests of Specimen No. 24

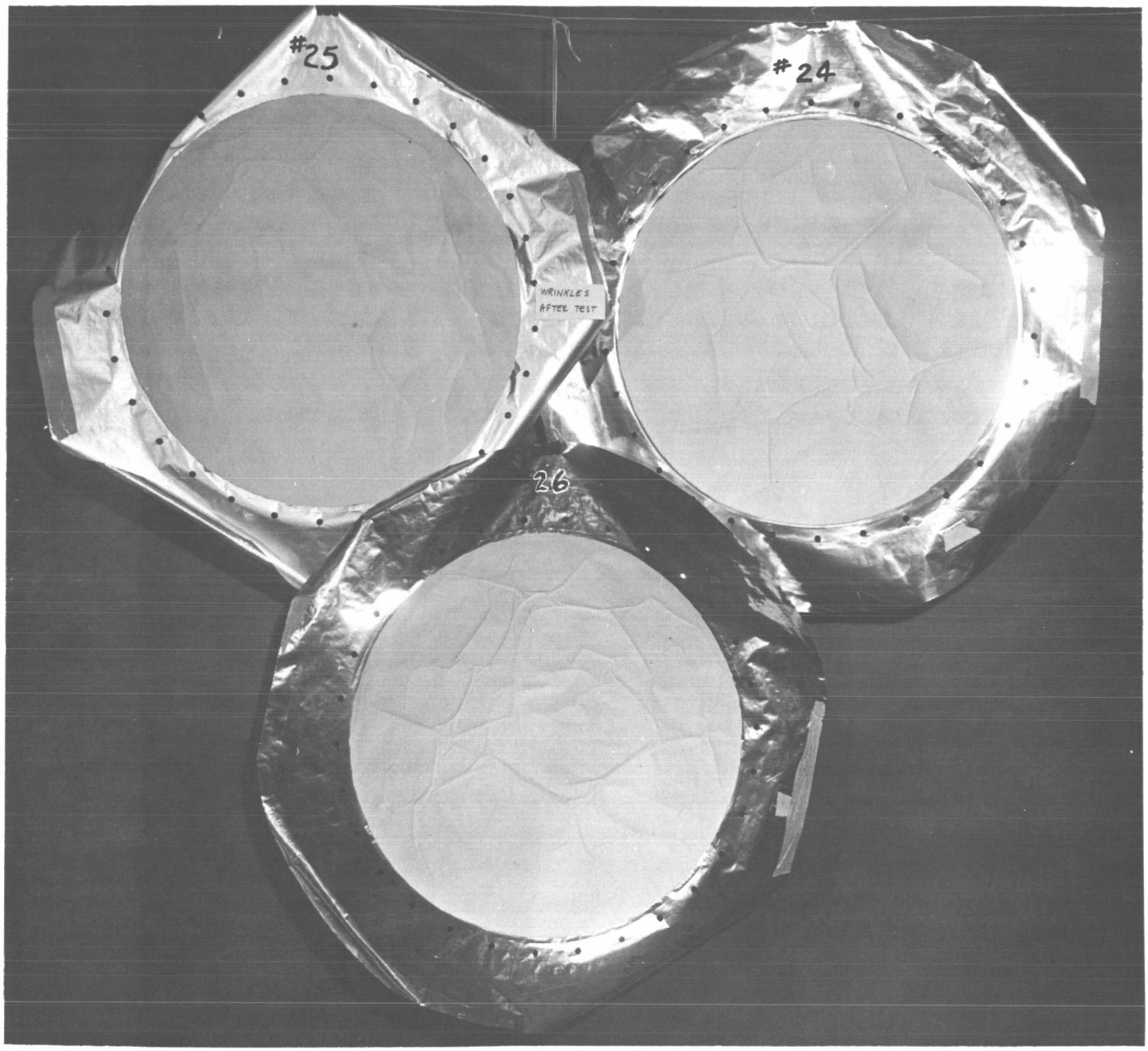


Figure 29. Wrinkles after Test (Specimens No. 24, 25, and 26)

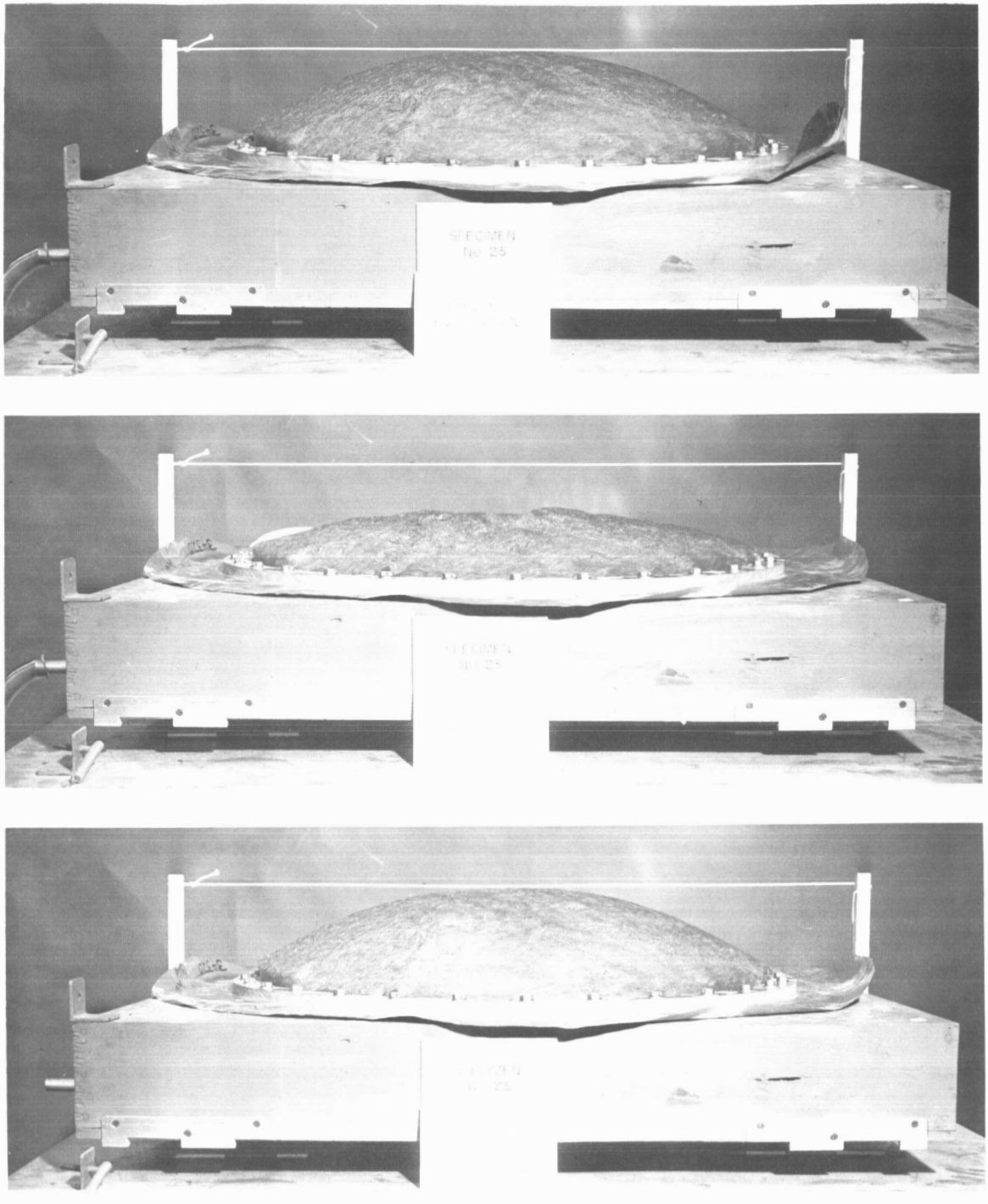


Figure 30. Spring-Back Tests of Specimen No. 25

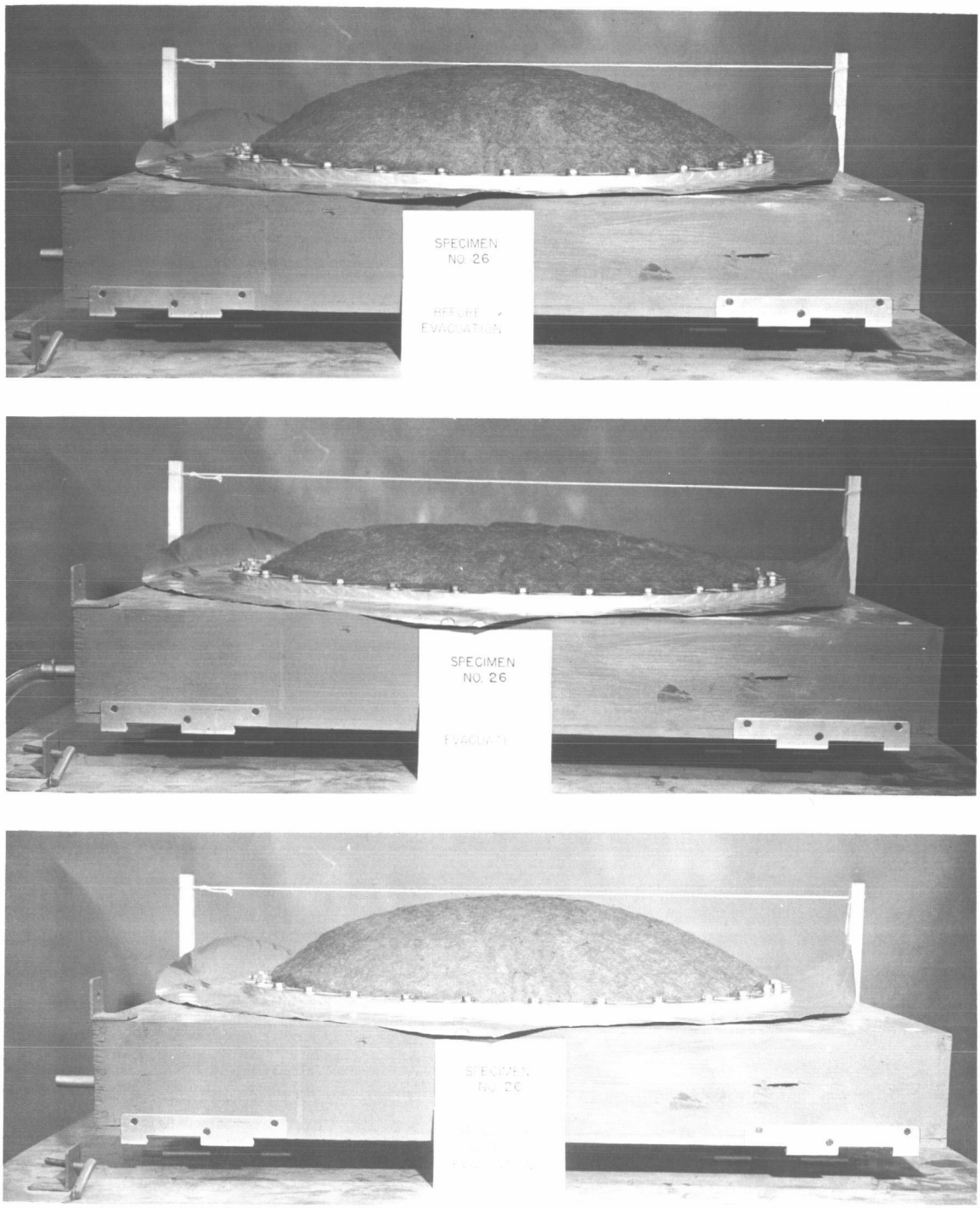


Figure 31. Spring-Back Tests of Specimen No. 26

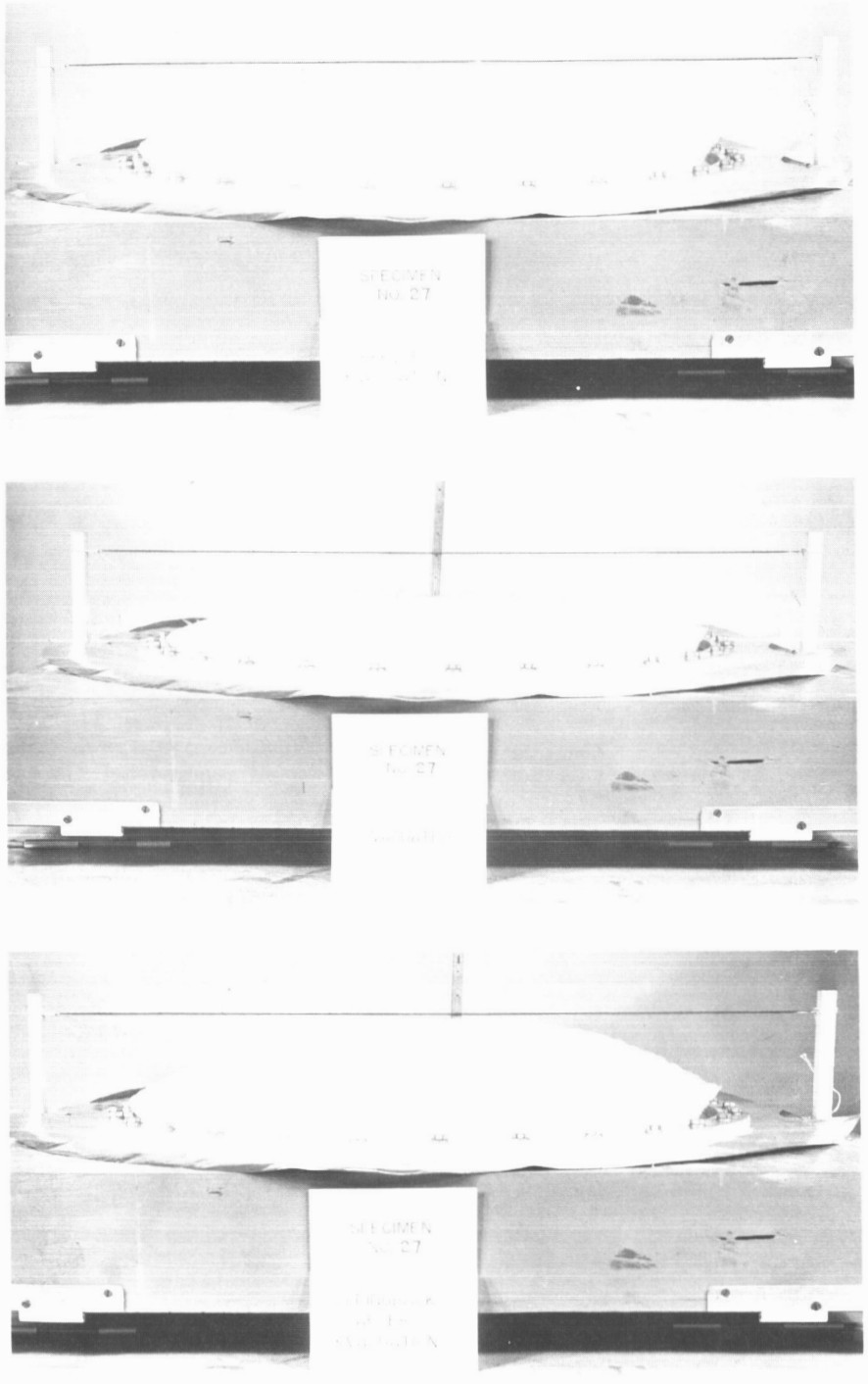


Figure 32. Spring-Back Tests of Specimen No. 27

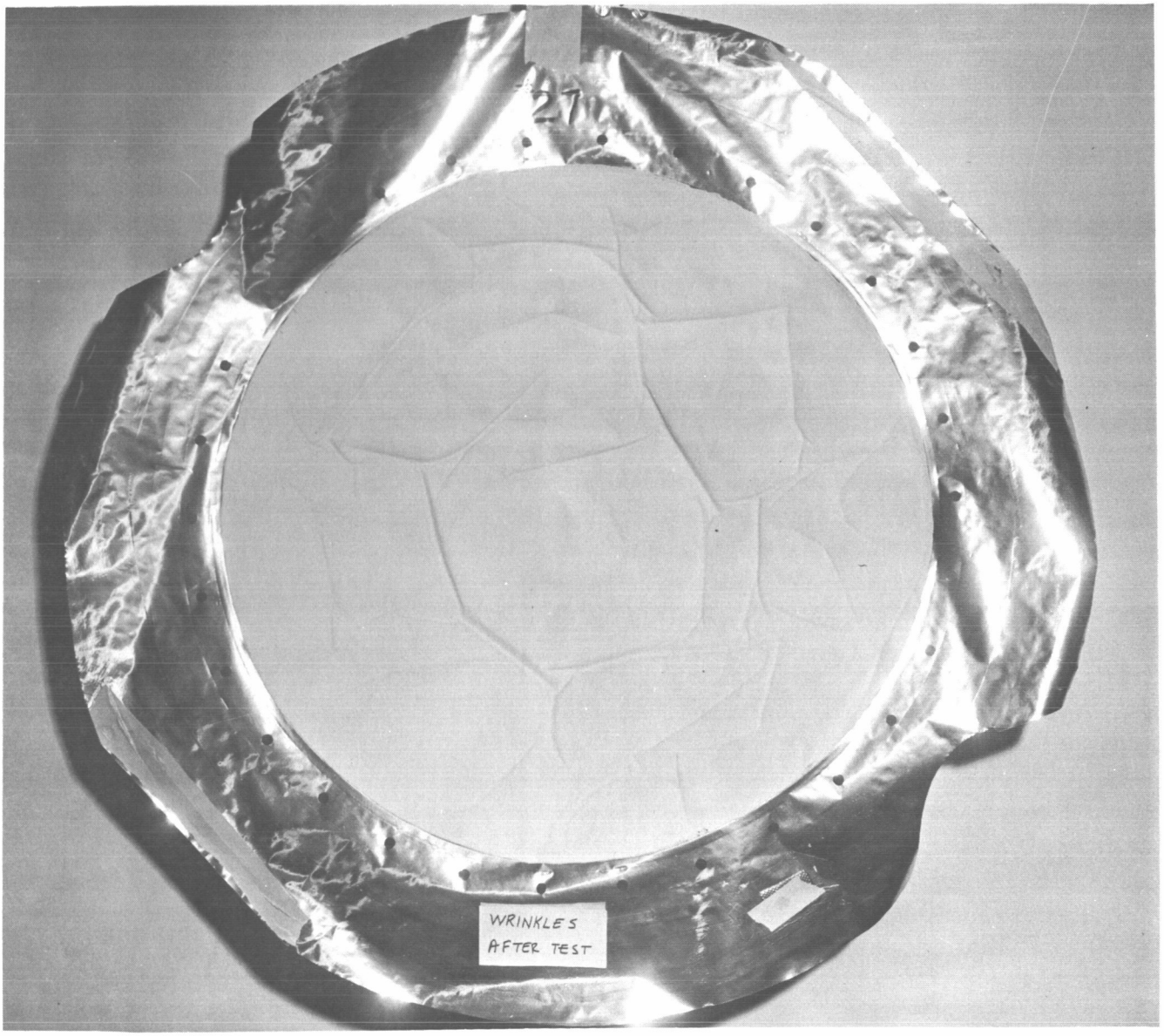


Figure 33. Wrinkles after Test (Specimen No. 27)

Conclusions derived from the spring-back tests are summarized as follows:

(1) The 0.003-inch wall Mylar honeycomb spring-back medium is not effective enough for vacuum jacket shrinkage greater than 5 percent.

(2) The 5-mil thick, 3/4-inch cell Mylar honeycomb is too stiff as a spring-back medium.

(3) Flexible foam rubber in the 2 to 4 lb/ft^3 density range does not have sufficient spring-back force to recover jackets over 5 percent shrinkage. The addition of a lightweight outer skin over the foam will greatly improve the spring-back characteristics of the foam.

(4) The two-way stretch nylon fabric laminated to the inside surface of the vacuum jacket increases the bend radius of the wrinkles, thereby reducing the probability of pinhole leaks.

(5) Application of the spring-back media to the outside surface rather than the inside of the vacuum jacket has the following advantages:

   (a) Elimination of vacuum pressure damage to the spring-back media.

   (b) Less liklihood of damage to vacuum jacket caused by spring-back materials piercing the jacket.

   (c) The vacuum jacket may be fitted closer to the insulation, thereby reducing the shrinkage of the jacket when the insulation is evacuated.

   (d) No out-gassing problems associated with spring-back materials located within the evacuated insulation.

   (e) Makes possible the addition of spring-back media to the vacuum jacket after the jacket has been installed and checked for leak-tightness.

(6) A 2 lb/ft^3 density polyurethane foam rubber having a 1/2-mil Mylar skin bonded to the outside surface of the foam will provide sufficient spring-back to recover a nylon-backed 1-1/2 mil MAM jacket from a 10 percent shrink condition.

(7) A 15 $gram/ft^2$ continuous-filament fiberglass mat impregnated with a thin polyester resin coat will provide sufficient spring-back to recover a nylon-backed 1-1/2 mil MAM jacket from a 10 percent shrink condition.

(8) The 15 gram/ft^2 continuous-filament fiberglass mat not impregnated with polyester resin cannot effect complete recovery of the jacket from a 10 percent shrink condition.

(9) The 2-inch thick, 24 gram/ft^2 Glassfloss mat (EC media) having a built-in "skin" of glass fibers is not sufficiently pliable to permit application to compound curved surfaces. The lack of pliability induced wrinkles in the specimen before test, and these wrinkles were magnified by the spring-back test, as shown in Figure 17.

(10) The 2-inch thick, 22 gram/ft^2 Glassfloss mat (FARR media) impregnated with a thin polyester resin will provide sufficient spring-back to recover a nylon-backed 1-1/2 mil MAM jacket from a 10 percent shrink condition.

(11) Polyester resin impregnation of the continuous-filament glass mat (specimen No. 19) imparts a stiffness to the spring-back media which affords a degree of wrinle control that creates a vacuum jacket wrinkle pattern having a greater number of creases of small size, as shown by comparing specimens No. 18 and 19 in Figure 20. The smaller wrinkles will induce less strain on the vacuum jacket than would the larger creases (specimen No. 18), which fold over and flatten on themselves. This observation was also noted in earlier tests on specimens No. 14 and 15.

(12) The two-ply MAM material in specimen No. 21 is too stiff for practical vacuum jacket use where spring-back is required.

(13) The MLM material in specimen No. 23, while being heavy and seemingly stiff, does spring back reasonably well. The material has a tendency to wrinkle in fewer large wrinkles than the Mylar-aluminum foil laminates. In test specimen No. 22, it was noted that one area bounded by the large wrinkles did not attain the desired amount of spring-back.

(14) The Dobeckmun Company laminated aluminum foil and Mylar materials, MAAM (34321), MAMAM (34322), and MAM (34320), are flexible enough to provide acceptable spring-back when bonded to the glass net spring-back media. MAM (34320), MAAM (34321), and MAMAM (34322) are in decreasing order of flexibility. Since MAM cannot be guaranteed to meet permeability requirements, the MAAM material is the logical selection for the most flexible vacuum jacket material.

(15) The Modiglass Fibers, 14.7 gram/ft^2, 1-inch thick glass mat impregnated with G-207 resin to a 75 to 80 percent weight pick-up will provide an excellent spring-back medium for the MAAM vacuum jacket material.

A weight analysis of the vacuum jacket spring-back test specimens is given in Table III. The vacuum jacket construction of specimen No. 26, which weighs 0.1047 psf, was selected to be further tested in long-term spring-back tests and a helium permeability test after shrink and spring-back cycling.

Long-term spring-back tests were conducted on specimen No. 15. The specimen was mounted on a test plate and evacuated to 10 percent shrink condition. Periodically, the vacuum was relieved and the spring-back rate and percent recovery were noted. After 11 days of vacuum hold-down, the vacuum was released and the specimen spring-back was observed to be nearly identical with the original test reported in Table II. Additional spring-back observations were made at approximately two-week intervals during a three-month period. After a three-month vacuum hold-down, the spring-back was demonstrated 100 percent complete at a rate nearly as rapid as the first spring-back cycle.

It can be concluded from the vacuum jacket spring-back program that the 1-inch thick, 14.7 grams/ft^2 Glassfloss mat impregnated with G-207 resin will provide excellent spring-back of the MAAM vacuum jacket material after long-term evacuation of the jacket.

Additional vacuum jacket spring-back testing was performed on the 48-inch diameter subscale mock-up tank. The objective of the test was to validate the spring-back performance of the 105-inch diameter tank vacuum jacket design, using materials selected from the vacuum jacket materials test program. The vacuum jacket assembly on the 48-inch diameter mock-up tank, shown in Figure 34, incorporated the 0.0015-inch thick MAAM flexible vacuum jacket material in lieu of the MAM jacket material, because the latter material was not available in sufficient size or quantity at the time the jacket was fabricated. The mechanical properties of the MAM and MAAM are similar; therefore, the materials may be used interchangeably for spring-back testing. One gore panel of the dome was constructed from MAAM for comparison with MAM during the test. The vacuum jacket without spring-back media is shown in Figure 35.

To test the spring-back of the vacuum jacket, the jacket was evacuated with shop vacuum lines to approximately 26-inch Hg vacuum. When backfilled with air, the spring-back of all parts of the jacket was 100 percent complete. With the exception of a minor leak in the jacket around one hard cover, the test was a successful demonstration of the spring-back characteristics of the vacuum jacket materials selected for the 105-inch diameter tank. The leak was later located and repaired.

Table III. Weight Analysis of Vacuum Jacket Spring-Back Test Specimens

Spec No.	Element	Element Wt (psf)	Total Wt (psf)
1	0.0015 MAM HMH	0.014 0.027	0.041
2	0.0015 MAM Nylon HMH	0.014 0.045 0.027	0.086
3	0.0015 MAM Nylon HMH	0.014 0.045 0.027	0.086
4	0.0015 MAM Nylon 1-in. glass mat	0.014 0.045 0.041	0.100
5	0.0015 MAM Nylon Flexible foam	0.014 0.045 0.166	0.225
6	0.0015 MAM Nylon Flexible foam 1/2-mil Mylar	0.014 0.045 0.166 0.0036	0.2286
7	0.0015 MAM Nylon Flexible foam	0.014 0.045 0.332	0.391
8	0.0015 MAM Nylon Flexible foam 1/2-mil Mylar	0.014 0.045 0.166 0.0036	0.2286
9	0.0015 MAM Nylon Flexible foam 1/2-mil Mylar	0.014 0.045 0.166 0.0036	0.2286
10	0.0015 MAM Nylon 1-in. glass mat	0.014 0.045 0.041	0.100
11	0.0015 MAM Nylon HMH	0.014 0.045 0.040	0.099
12	0.0015 MAM Nylon Flexible foam 0.0005 Mylar	0.014 0.045 0.166 0.0036	0.2286
14	0.0015 MAM Nylon 1-in. glass mat	0.014 0.045 0.041	0.100
15	0.0015 MAM Nylon 1-in. glass mat	0.014 0.045 0.041	0.100

Table III. Weight Analysis of Vacuum Jacket Spring-Back Test Specimens (Cont)

Spec No.	Element	Element Wt (psf)	Total Wt (psf)
16	0.0015 MAM Nylon 2-in. glass mat EC media	0.014 0.045 0.064	0.123
17	0.0015 MAM Nylon 2-in. glass mat EC media	0.014 0.045 0.084	0.143
18	0.0015 MAM Nylon 2-in. glass mat FARR media	0.014 0.045 0.059	0.118
19	0.0015 MAM Nylon 2-in. glass mat FARR media	0.014 0.045 0.073	0.132
20	0.0015 MAM Nylon 2-in. glass mat	0.014 0.045 0.041	0.100
21	0.0015 MAM (2 plies) Nylon 2-in. glass mat	0.029 0.045 0.041	0.115
22	X283 MLM Nylon 2-in. glass mat	0.0703 0.045 0.041	0.1563
23	34321 MAAM Nylon 2-in. glass mat	0.0187 0.045 0.041	0.0947
24	34322 MAMAM Nylon 1-in. glass mat	0.023 0.045 0.041	0.109
25	34320 MAM Nylon 1-in. glass mat	0.0017 0.045 0.041	0.0877
26	34321 MAAM Nylon 1-in. glass mat	0.0187 0.045 0.041	0.1047
27	34321 MAAM Nylon 1-in. glass mat (white)	0.0187 0.045 0.0524	0.1161

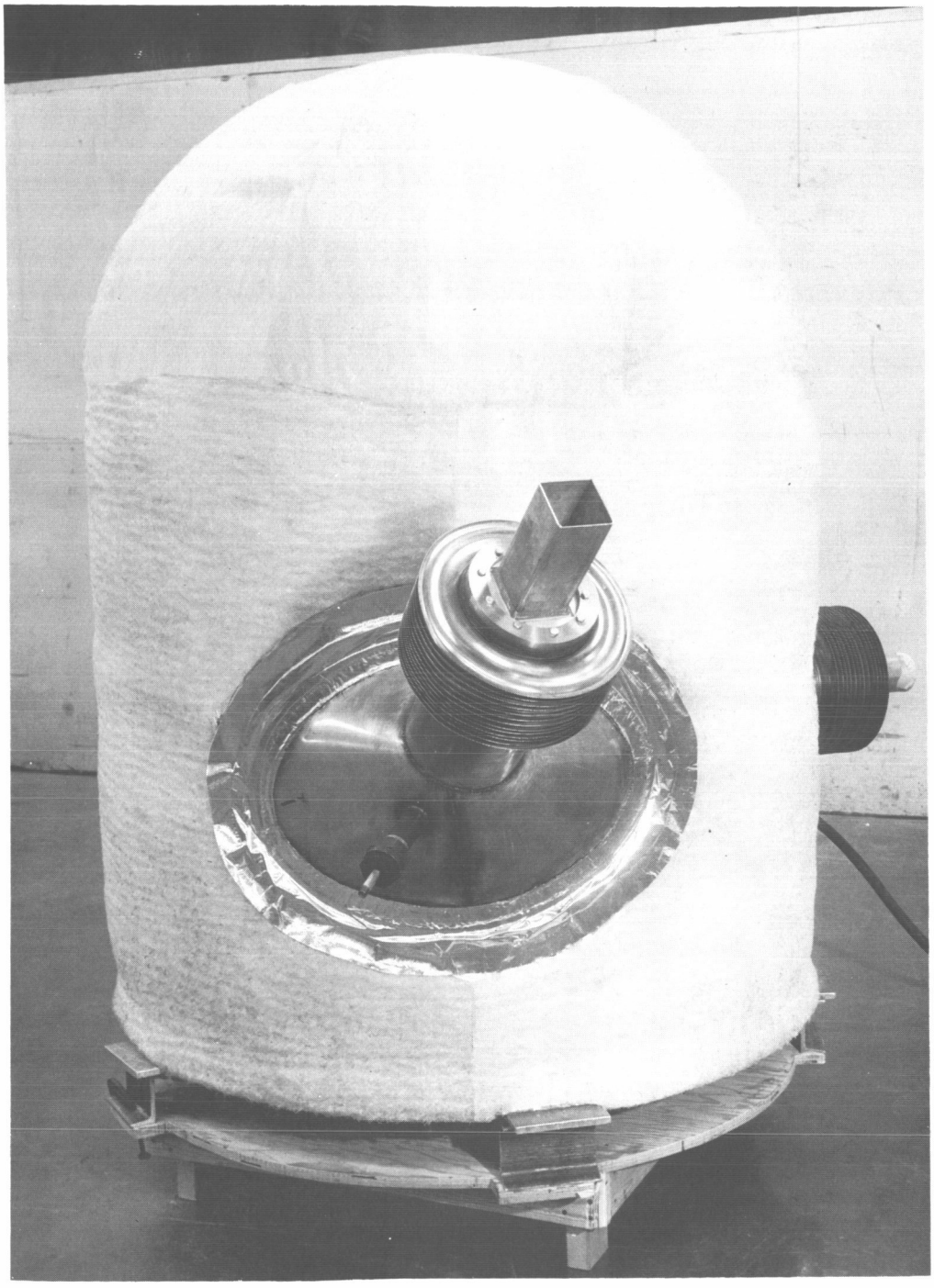


Figure 34. Flexible Vacuum Jacket Assembly on 48-Inch Diameter Subscale Test Tank

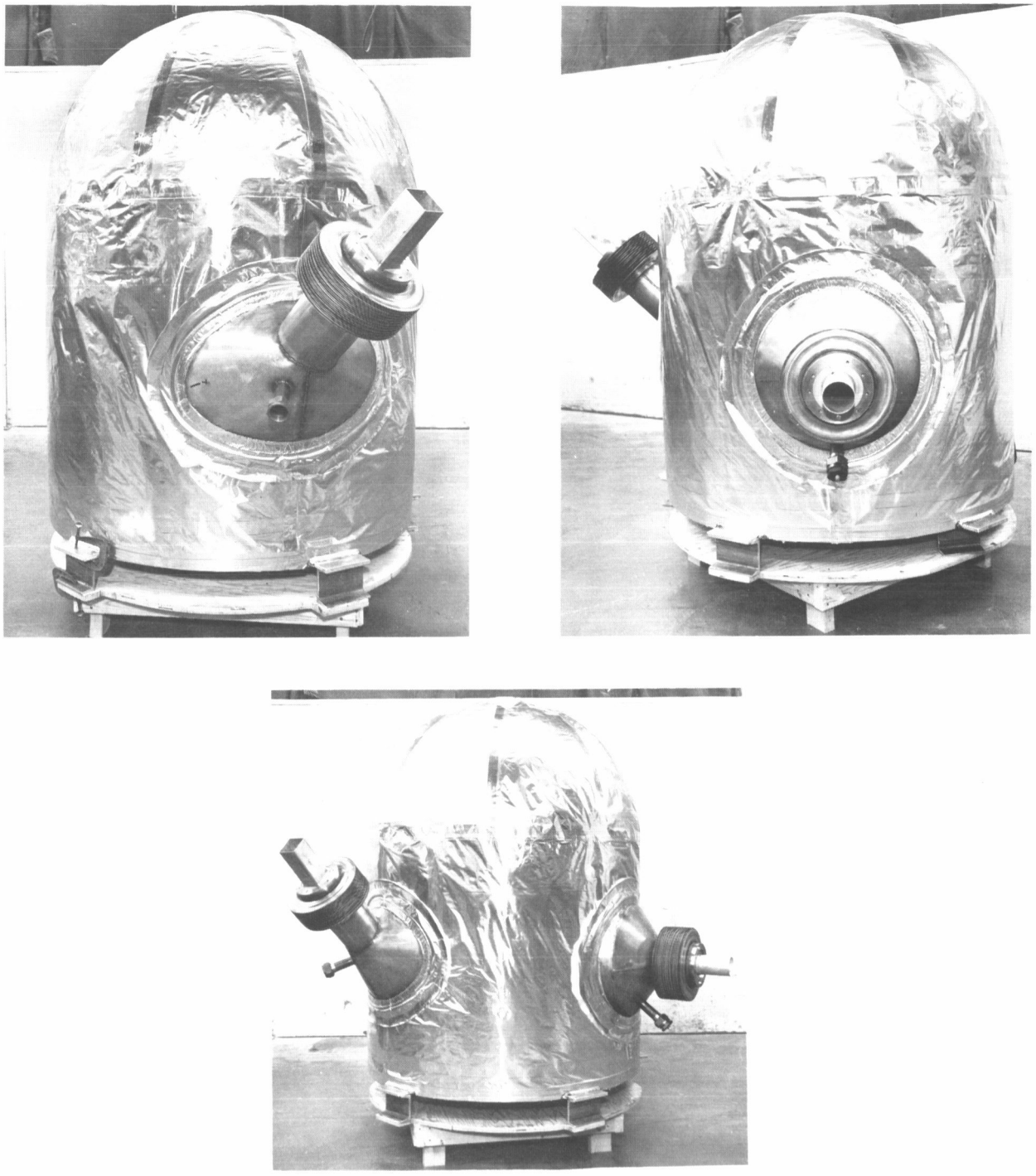


Figure 35. Vacuum Jacket without Spring-Back Media as Installed on 48-Inch Diameter Subscale Test Tank

4. Permeability Testing

To select an optimum vacuum jacket material, helium permeability tests were conducted on 30 vacuum jacket materials. The materials included existing vapor barrier materials and new materials developed to meet the low helium permeability requirements of the NASA-MSFC vacuum jacket specification.

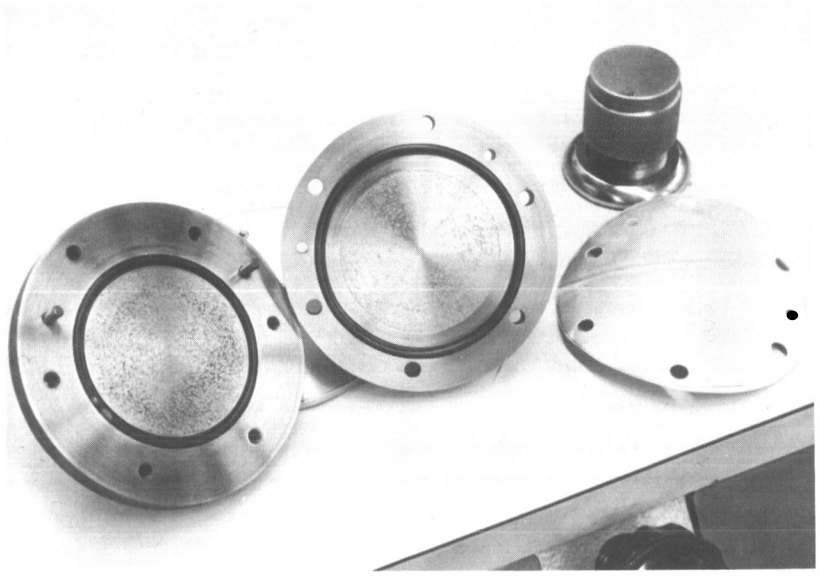
A Veeco MS-9 helium mass spectrometer was used to measure helium permeability of the test specimens. Permeability tests were initiated on test specimens having a 2.9-inch diameter test area. The maximum acceptable leak was calculated from the contract specification of total leakage of 10^{-5} cc/second over the total vacuum jacket area. For the 105-inch diameter tank vacuum jacket having a surface area of approximately 45,056 $in.^2$, the test specimen maximum helium leak rate is 1.49×10^{-9} cc/second at a test condition of 10^{-3} torr vacuum applied to the mass spectrometer side of the specimen and 0.5-psi helium gas pressure applied to the opposite side of the specimen. All testing was conducted at room temperature.

An existing test fixture was utilized at the start of this permeability test program. During the early portion of the test program, it became apparent that a new test fixture would be desirable. The old test fixture was heavy and cumbersome due to the need for a multiplicity of adapter plates and plumbing. The adapter plates lacked provisions for keeping the test specimens flat during all phases of the test. On certain test specimens, mark-off was observed from the effects of stretching the specimen over the center hole in the adapter plates. To relieve this condition, a fine-mesh screen with padded edges was placed over the center hole; however, some mark-off from the screen was also observed. The effects of mark-off on the specimens cannot be stated, but the test results could be questionable due to possible increase in helium permeation due to mark-off. All permeability testing was withheld pending availability of a new and improved test fixture. The new test fixture, shown in Figure 36, has the following advantages:

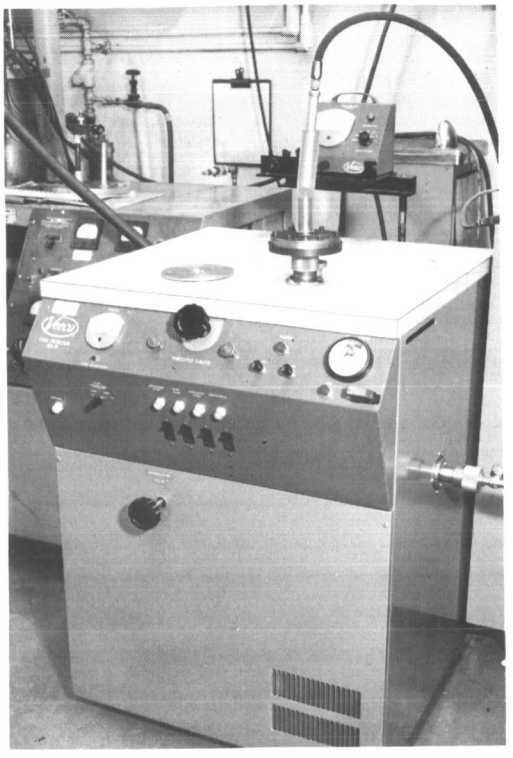
(1) Mounts directly on the inlet connection to the Veeco MS-9 mass spectrometer, thus eliminating any tie-in plumbing.

(2) Simple construction comprising two basic elements, a fixed base flange and a removable clamping plate for mounting the test specimens.

(3) A sintered stainless steel disc is incorporated in the base flange and in the clamping plate to provide a smooth porous surface adjacent to each side of the test specimen in the test area.



TEST FIXTURE - OPEN



TEST FIXTURE INSTALLED IN LEAK DETECTOR

PERMEABILITY TEST SETUP - OVERALL VIEW

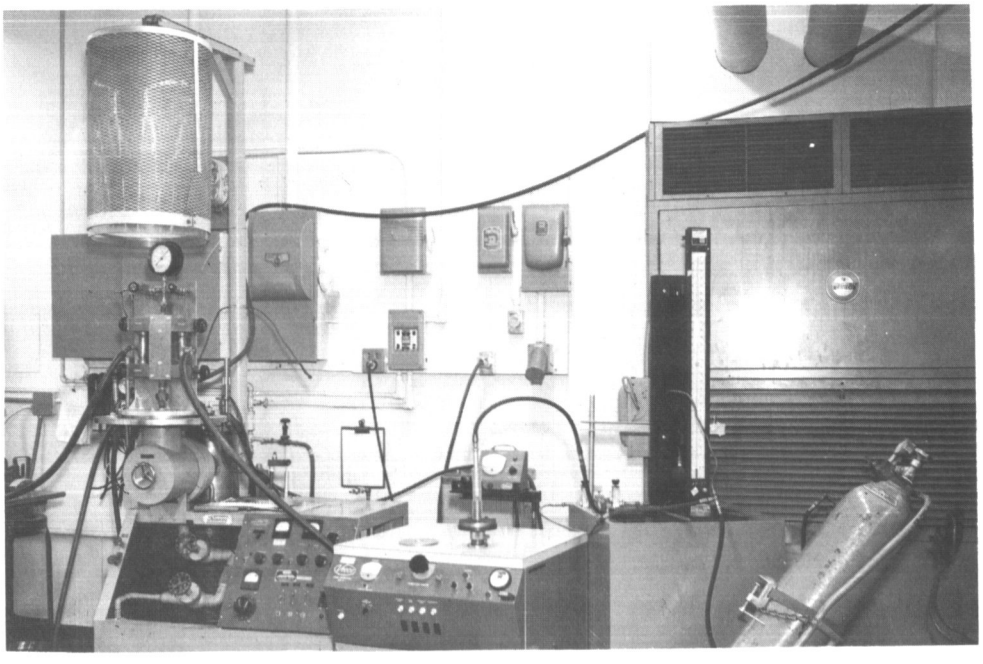


Figure 36. Permeability Test Fixture

The vacuum jacket materials tested for helium permeability are listed in Table IV. Permeability rates for the specimens are given in Table V. Three specimens of each material were tested to establish an average leak rate for the specimens in four conditions designated as follows:

Type	Description
P	Material in the as-received condition.
PW	Material as-received with wrinkles in the test area.
N	Material in the as-received condition with one ply of two-way stretch nylon fabric bonded to test area.
NW	Material in the as-received condition with one ply of two-way stretch nylon bonded to test area and wrinkled.

Permeability tests were conducted on the materials starting with material in the as-received condition, followed by tests on as-received and wrinkled condition. If the maximum helium leak rate was 1.49×10^{-9} cc/second or less, tests were not conducted on the material with nylon backing to avoid redundancy of testing because the nylon backing lowers the leak rate. If the leak tests exceeded the maximum leak rate, additional testing was performed on nylon-backed material to evaluate the cushion effect of the nylon on the wrinkles in the test specimen.

The observations and conclusions derived from the permeability test results are presented in the following paragraphs.

Test results on materials 1 through 17 indicate, with few exceptions, that the candidate vacuum jacket materials chosen from commercially available vapor barrier materials exceed the 1.49×10^{-9} cc/second maximum helium permeability rate. Material 2 (MAM type 32899) was considered acceptable on the basis of tests run on a sample roll of material. A quantity of this material was purchased from Dobeckmun Company and tested (test material 16) and found unacceptable. These tests pointed out difficulties in obtaining consistently good material that can meet the acceptable helium leak rate.

Permeability test materials 18, 19, and 21 represent attempts by GAC to laminate combinations of MAM to produce vacuum jacket materials having helium permeability rates substantially below the 1.49×10^{-9} cc/second maximum rate. Test material 20 was laminated by Dobeckmun Company for an earlier GAC contract. In the most severe permeability test (plain material, wrinkled), these composite

Table IV. List of Jacket Materials for Permeability Tests

Material No.	Description
1	MAM, 1/2 mil each layer, Type 12-1169, Continental Can Co
2	MAM, 1/2 mil each layer, Type 32899 Dobeckmun Co
3	MAM, 1/4 mil each layer, Alumi-Seal Co
4	MAM, 1/2-mil Mylar, 1-mil Alum, Alumi-Seal Co
5	Aclar-Aluminum-Aclar, 1/2-mil Aclar, 1/4-mil Alum, Scheldahl Co
6	Tedlar-Aluminum-Tedlar, 1/2-mil Tedlar, 1/4-mil Alum, Scheldahl Co
7	Conolam 5 AL30, Polyethylene-Fluorohalocarbon Film, Continental Can Co
8	Conofilm 1134, Polyolefin Film, Continental Can Co
9	2-mil Mylar
10	1-mil Mylar Bilaminate, G-207 Adhesive, GAC
11	1/2-mil Mylar Trilaminate, G-207 Adhesive, GAC
12	1/2-mil aluminized Mylar Bilaminate, G-207 Adhesive, GAC
13	1/4-mil aluminized Mylar, 4-ply Laminate, G-207 Adhesive, GAC
14	1-mil aluminzed Mylar
15	1-mil Mylar and 1/4-mil aluminized Mylar laminate, G-207 adhesive, GAC
16	MAM, 1/2-mil each layer, No. 40478, Dobeckmun Co (Type 32897)
17	MAM, 3/4-mil Mylar, 1-mil aluminum, Dobeckmun Co (Type 32898)

Table IV. List of Jacket Materials for Permeability Tests (Continued)

Material No.	Description
18	MAM, 1/2 mil each layer, Type 32899, two plies laminated with G-207, Dobeckmun Co
19	MAM, 1/2 mil each layer, Type 40478, two plies laminated with G-207, Dobeckmun Co
20	AMA, 0.35-mil aluminum, 1-1/2 mil Mylar, Dobeckmun Co
21	MAMAM, 1/2-mil Mylar, 0.35-mil aluminum, 1-1/2 mil Mylar, 0.35-mil aluminum, 1/2-mil Mylar
22	MLM, 1-mil Mylar, 0.8-mil lead, selected from good quality areas of roll, Schjeldahl Co
22_a	MLM, selected from poor quality areas of roll
22_b	MLM, selected from narrow smooth lead seam areas of roll
22_c	MLM, selected from wide wrinkled lead seam areas of roll
23	MAM, 1/2-mil Mylar, 0.35-mil aluminum, Type 34320, Dobeckmun Co
24	MAAM, 1/2-mil Mylar, 0.35-mil aluminum 2 plies each, Type 34321, Dobeckmun Co
25	MAMAM, 1/2-mil Mylar, 0.35-mil Mylar, Type 34322, Dobeckmun Co
26	S-81000-1, metalized Saran to metalized Saran, Continental Can Co
27	S-81000-2, metalized Saran to metalized Saran to metalized Saran, Continental Can Co
28	S-81000-3, metalized Mylar to metalized Mylar, Continental Can Co
29	S-81000-4, metalized Mylar to metalized Mylar to metalized Mylar, Continental Can Co
30	S-81000-5, metalized Mylar to metalized Saran to metalized Mylar, Continental Can Co

Notes: Metalized Mylar is 0.0005 inch in gauge and is metalized on one side. The metalized side is laminated in all cases. Metalized Saran is 0.001 inch in gauge and is metalized on two sides.

Table V. Permeability Test Results (2.9-Inch Diameter Test Area Samples)

Sample No.	Leak Rate	Sample No.	Leak Rate	Sample No.	Leak Rate	Sample No.	Leak Rate
1P-1	8.6×10^{-9}	1PW-1		1N-1		1NW-1	
1P-2	9.86×10^{-9}	1PW-2		1N-2		1NW-2	
1P-3	7.17×10^{-10}	1PW-3		1N-3		1NW-3	
2P-1	7.74×10^{-10}	2PW-1	1.07×10^{-9}	2N-1	6.02×10^{-10}	2NW-1	5.16×10^{-10}
2P-2	8.17×10^{-10}	2PW-2	7.74×10^{-10}	2N-2	6.88×10^{-10}	2NW-2	1.11×10^{-9}
2P-3	7.09×10^{-10}	2PW-3	1.11×10^{-9}	2N-3	3.44×10^{-10}	2NW-3	3.44×10^{-8}*
3P-1	1.72×10^{-8}	3PW-1	$>10^{-5}$	3N-1	2.58×10^{-10}	3NW-1	3.8×10^{-8}
3P-2	6.8×10^{-10}	3PW-2	9.46×10^{-9}	3N-2	1.7×10^{-10}	3NW-2	6.5×10^{-8}
3P-3	2.4×10^{-10}	3PW-3	6.4×10^{-8}	3N-3	9×10^{-5}	3NW-3	5.1×10^{-8}
4P-1	8.0×10^{-9}	4PW-1	1.2×10^{-9}	4N-1	6.8×10^{-9}	4NW-1	7.7×10^{-9}
4P-2	1.0×10^{-10}	4PW-2	2.6×10^{-9}	4N-2	1.5×10^{-9}	4NW-2	3.4×10^{-9}
4P-3	9.0×10^{-9}	4PW-3	2.4×10^{-9}	4N-3	2.5×10^{-9}	4NW-3	4.3×10^{-9}
5P-1	1.6×10^{-9}	5PW-1	5.2×10^{-6}	5N-1	Could not pump down	5NW-1	Could not pump down
5P-2	6.3×10^{-7}	5PW-2	1.8×10^{-8}	5N-2		5NW-2	
5P-3	Could not pump down	5PW-3	2.4×10^{-9}	5N-3	Could not pump down	5NW-3	
6P-1	4.3×10^{-9}	6PW-1	4.7×10^{-8}	6N-1	3.4×10^{-10}	6NW-1	6.0×10^{-10}
6P-2	5.93×10^{-9}	6PW-2	5.3×10^{-8}	6N-2	2.8×10^{-8}	6NW-2	1.3×10^{-8}
6P-3	2.75×10^{-10}	6PW-3	1.0×10^{-5}	6N-3	4.2×10^{-8}	6NW-3	1.7×10^{-8}

*Wrinkle extended beyond O-ring seal.

NOTES: (1) Blank spaces denote specimens not tested to date.

(2) Code of sample types (5-inch dia with 2.9-inch test area):

P = plain material as received

PW = plain material as received with wrinkles in test area

N = plain material as received with one ply of two-way stretch nylon bonded to test area

NW = plain material as received with one ply of two-way stretch nylon bonded to test area and wrinkled

Adding the material No. prefix, a typical sample designation is as follows:

2PW-1 = MAM Type 3289 Dobeckmun Co plain material as received with wrinkles in test area.

Table V. Permeability Test Results (2.9-Inch Diameter Test Area Samples) (Continued)

Sample No.	Leak Rate	Sample No.	Leak Rate	Sample No.	Leak Rate	Sample No.	Leak Rate
7P-1	Excess leak	7PW-1	Excess leak	7N-1	Did	7NW-1	Did
7P-2	Excess leak	7PW-2	Excess leak	7N-2	not	7NW-2	not
7P-3	Excess leak	7PW-3	Excess leak	7N-3	test	7NW-3	test
8P-1	Did	8PW-1	Did	8N-1	Did	8NW-1	Did
8P-2	not	8PW-2	not	8N-2	not	8NW-2	not
8P-3	test	8PW-3	test	8N-3	test	8NW-3	test
9P-1	3.6×10^{-8}	9PW-1	Did	9N-1	2.2×10^{-6}	9NW-1	Did
9P-2	2.5×10^{-6}	9PW-2	not	9N-2	1.6×10^{-6}	9NW-2	not
9P-3	2.5×10^{-6}	9PW-3	test	9N-3	6.5×10^{-7}	9NW-3	test
10P-1	8.6×10^{-7}	10PW-1	Did	10N-1	5.8×10^{-7}	10NW-1	Did
10P-2	1.5×10^{-8}	10PW-2	not	10N-2	7.2×10^{-7}	10NW-2	not
10P-3	7.2×10^{-9}	10PW-3	test	10N-3	5.0×10^{-7}	10NW-3	test
11P-1	2.8×10^{-8}	11PW-1	1.3×10^{-8}	11N-1	2.1×10^{-7}	11NW-1	2.6×10^{-6}
11P-2	3.3×10^{-6}	11PW-2	4×10^{-6}	11N-2	3.0×10^{-7}	11NW-2	3.4×10^{-6}
11P-3	1.2×10^{-8}	11PW-3	2.2×10^{-8}	11N-3	2.3×10^{-8}	11NW-3	5.2×10^{-6}
12P-1	4.1×10^{-8}	12PW-1	Did	12N-1	1.2×10^{-8}	12NW-1	Did
12P-2	4.2×10^{-8}	12PW-2	not	12N-2	1.0×10^{-8}	12NW-2	not
12P-3	2.2×10^{-8}	12PW-3	test	12N-3	1.0×10^{-8}	12NW-3	test
13P-1	Did	13PW-1	Did	13N-1	Did	13NW-1	Did
13P-2	not	13PW-2	not	13N-2	not	13NW-2	not
13P-3	test	13PW-3	test	13N-3	test	13NW-3	test
14P-1	1.1×10^{-6}	14PW-1	4.6×10^{-6}	14N-1	4.2×10^{-6}	14NW-1	5.8×10^{-6}
14P-2		14PW-2		14N-2	3.8×10^{-6}	14NW-2	7.2×10^{-7}
14P-3	3.2×10^{-6}	14PW-3		14N-3	4.3×10^{-6}	14NW-3	5.5×10^{-6}
15P-1	Excess leak	15PW-1	Did	15N-1	1.3×10^{-8}	15NW-1	Did
15P-2	Excess leak	15PW-2	not	15N-2	1.2×10^{-8}	15NW-2	not
15P-3	Excess leak	15PW-3	test	15N-3	1.2×10^{-8}	15NW-3	test
16P-1	1.0×10^{-8}	16PW-1	Did	16N-1	2.1×10^{-8}	16NW-1	Did
16P-2	3.6×10^{-9}	16PW-2	not	16N-2	2.1×10^{-8}	16NW-2	not
16P-3	3.6×10^{-8}	16PW-3	test	16N-3	4.3×10^{-8}	16NW-3	test
17P-1	4.5×10^{-8}	17PW-1	4.5×10^{-8}	17N-1	2.7×10^{-8}	17NW-1	1.2×10^{-7}
17P-2	7.2×10^{-9}	17PW-2	9.8×10^{-9}	17N-2	2.4×10^{-8}	17NW-2	3.2×10^{-8}
17P-3	1.4×10^{-8}	17PW-3	2.2×10^{-8}	17N-3	1.4×10^{-8}	17NW-3	4.3×10^{-8}

Table V. Permeability Test Results (2.9-Inch Diameter Test Area Samples) (Continued)

Sample No.	Leak Rate	Sample No.	Leak Rate	Sample No.	Leak Rate	Sample No.	Leak Rate
18P-1	$<1 \times 10^{-10}$	18PW-1	$<1 \times 10^{-10}$	18N-1	Did	18NW-1	Did
18P-2	$<1 \times 10^{-10}$	18PW-2	$<1 \times 10^{-10}$	18N-2	not	18NW-2	not
18P-3	$<1 \times 10^{-10}$	18PW-3	$<1 \times 10^{-10}$	18N-3	test	18NW-3	test
19P-1	$<1 \times 10^{-10}$	19PW-1	$<1 \times 10^{-10}$	19N-1	Did	19NW-1	Did
19P-2	$<1 \times 10^{-10}$	19PW-2	$<1 \times 10^{-10}$	19N-2	not	19NW-2	not
19P-3	$<1 \times 10^{-10}$	19PW-3	$<1 \times 10^{-10}$	19N-3	test	19NW-3	test
20P-1	$<1 \times 10^{-10}$	20PW-1	2×10^{-10}	20N-1	Did	20NW-1	Did
20P-2	$<1 \times 10^{-10}$	20PW-2	3×10^{-10}	20N-2	not	20NW-2	not
20P-3	$<1 \times 10^{-10}$	20PW-3	5×10^{-10}	20N-3	test	20NW-3	test
21P-1	$<1 \times 10^{-10}$	21PW-1	$<1 \times 10^{-10}$	21N-1	Did	21NW-1	Did
21P-2	$<1 \times 10^{-10}$	21PW-2	$<1 \times 10^{-10}$	21N-2	not	21NW-2	not
21P-3	$<1 \times 10^{-10}$	21PW-3	5×10^{-10}	21N-3	test	21NW-3	test
22P-1	$<1 \times 10^{-10}$	22PW-1	$<1 \times 10^{-10}$	22N-1	Did	22NW-1	Did
22P-2	$<1 \times 10^{-10}$	22PW-2	$<1 \times 10^{-10}$	22N-2	not	22NW-2	not
22P-3	$<1 \times 10^{-10}$	22PW-3	$<1 \times 10^{-10}$	22N-3	test	22NW-3	test
22_aP-1	1.5×10^{-10}	22_aPW-1	4.5×10^{-10}		Did		Did
22_aP-2	$<1 \times 10^{-10}$	22_aPW-2	2.5×10^{-10}		not		not
22_aP-3	7.0×10^{-9}	22_aPW-3	9.0×10^{-9}		test		test
22_bP-1	8.0×10^{-10}	22_bPW-1	9.0×10^{-10}		Did		Did
22_bP-2	2.0×10^{-10}	22_bPW-2	5.0×10^{-10}		not		not
22_bP-3	6.0×10^{-10}	22_bPW-3	8.0×10^{-10}		test		test
22_cP-1	4.0×10^{-10}	22_cPW-1	4.4×10^{-9}		Did		Did
22_cP-2	3.0×10^{-10}	22_cPW-2	6.7×10^{-9}		not		not
22_cP-3	1.2×10^{-9}	22_cPW-3	7.0×10^{-8}		test		test
23P-1	$<1 \times 10^{-10}$	23PW-1	$<1 \times 10^{-10}$	23N-1	Did	23NW-1	Did
23P-2	$<1 \times 10^{-10}$	23PW-2	$<1 \times 10^{-10}$	23N-2	not	23NW-2	not
23P-3	$<1 \times 10^{-10}$	23PW-3	$<1 \times 10^{-10}$	23N-3	test	23NW-3	test
24P-1	$<1 \times 10^{-10}$	24PW-1	$<1 \times 10^{-10}$	24N-1	Did	24NW-1	Did
24P-2	$<1 \times 10^{-10}$	24PW-2	$<1 \times 10^{-10}$	24N-2	not	24NW-2	not
24P-3	$<1 \times 10^{-10}$	24PW-3	$<1 \times 10^{-10}$	24N-3	test	24NW-3	test
25P-1	$<1 \times 10^{-10}$	25PW-1	5.0×10^{-9}	25N-1	Did	25NW-1	Did
25P-2	$<1 \times 10^{-10}$	25PW-2	1.0×10^{-9}	25N-2	not	25NW-2	not
25P-3	$<1 \times 10^{-10}$	25PW-3	1.0×10^{-10}	25N-3	test	25NW-3	test

Table V. Permeability Test Results (2.9-Inch Diameter Test Area Samples) (Continued)

Sample No.	Leak Rate	Sample No.	Leak Rate	Sample No.	Leak Rate	Sample No.	Leak Rate
26P-1	2.3×10^{-6}	26PW-1	1×10^{-5}	26N-1	Did	26NW-1	Did
26P-2	3.3×10^{-6}	26PW-2	1×10^{-5}	26N-2	not	26NW-2	not
26P-3	2.6×10^{-6}	26PW-3	1×10^{-5}	26N-3	test	26NW-3	test
27P-1	1.4×10^{-6}	27PW-1	1.9×10^{-6}	27N-1	Did	27NW-1	Did
27P-2	1.7×10^{-6}	27PW-2	1.7×10^{-6}	27N-2	not	27NW-2	not
27P-3	1.4×10^{-6}	27PW-3	1.2×10^{-6}	27N-3	test	27NW-3	test
28P-1	1.2×10^{-7}	28PW-1	1.2×10^{-7}	28N-1	Did	28NW-1	Did
28P-2	1.0×10^{-7}	28PW-2	1×10^{-5}	28N-2	not	28NW-2	not
28P-3	5.2×10^{-8}	28PW-3	5.2×10^{-8}	28N-3	test	28NW-3	test
29P-1	5.0×10^{-9}	29PW-1	5.0×10^{-9}	29N-1	Did	29NW-1	Did
29P-2	2.7×10^{-9}	29PW-2	2.1×10^{-8}	29N-2	not	29NW-2	not
29P-3	3.5×10^{-8}	29PW-3	1.2×10^{-7}	29N-3	test	29NW-3	test
30P-1	3.0×10^{-8}	30PW-1	2.2×10^{-8}	30N-1	Did	30NW-1	Did
30P-2	6.6×10^{-8}	30PW-2	2.1×10^{-8}	30N-2	not	30NW-2	not
30P-3	2.8×10^{-8}	30PW-3	2.2×10^{-8}	30N-3	test	30NW-3	test

materials exhibited permeability rates approximately one order of magnitude lower than the maximum acceptable rate of 1.49×10^{-9} cc/second. The most significant contribution to the low permeability is the double layer of aluminum in each composite material.

To reduce thickness and improve flexibility of composite jacket materials having two aluminum layers, Dobeckmun Company laminated the following experimental materials for GAC evaluation:

(1) MAAM

Mylar	0.0005"
Aluminum	0.00035"
Aluminum	0.00035"
Mylar	0.0005"

(2) MAMAM

Mylar	0.0005"
Aluminum	0.00035"
Mylar	0.0005"
Aluminum	0.00035"
Mylar	0.0005"

Test material 22, MLM laminated film, was tested in samples taken from three visually discernible areas of the stock having the following characteristics:

(1) Areas of good quality in the laminate.
(2) Areas of poor quality in laminate.
(3) Areas of seams in lead foil element.

As noted in Table V, the permeability rate of MLM film is approximately one order of magnitude below the maximum acceptable rate of 1.49×10^{-9} cc/second. However, in the poor quality areas (sample 22_a) and in the areas of smooth narrow lead foil seams (sample 22_b) the leak rates are somewhat greater, but within the maximum acceptable permeability value before and after wrinkling the specimen. In the areas of wide wrinkled lead foil seams (sample 22_c), the prewrinkled permeability is greater than narrow seam areas, and after wrinkling, all permeability values fell below the maximum acceptable value of 1.49×10^{-9} cc/second. The wrinkles in sample 22_c were judged to be more severe than average wrinkles for other samples. This may account for the higher permeability rates.

Test materials 23 through 25 were received from Dobeckmun Company and the test results indicated. As expected, materials 24 and 25, each having two layers of aluminum foil, tested less than 1×10^{-10} cc/second helium leak. Based on earlier permeability measurements of MAM laminates, the excellent test results on MAM material 23 were unexpected. Tests of materials 23 through 25 were run several times to verify their accuracy.

The exceptional performance of the MAM (material 23) is attributed to a below average pinhole count in the aluminum foil layers. Dobeckmun Company would not guarantee reproducibility of MAM of this quality utilizing the 0.35-mil aluminum foil, inasmuch as the aluminum foil manufacturers will not guarantee pinhole-free foil in this gage.

Samples 26 through 30 were received from Continental Can Co in response to GAC requests for vacuum jacket material samples. These samples represented a metalized polymer film multilayer concept of vacuum jacket material. In general, the samples did not meet the 1.49×10^{-9} cc/second helium permeability rate. Two of

these specimens of the S-81000-4, three-ply, metalized Mylar came close to meeting the leakage specification in the plain unwrinkled condition. From previous experience, it is assumed that wrinkling will degrade the material beyond the acceptable leakage rate.

The vacuum jacket material qualification test program was concluded with the successful demonstration of the Dobecknum Type 34321 MAAM laminate, which met all the helium permeability test requirements of the Vacuum Jacket Material Qualification Test Specification. In accordance with section 1.3 of the test specification, the 30-inch diameter MAAM test specimen (with 24-inch diameter test area) was cycle-tested as shown in Figures 37 and 38. Eight evacuation and back-fill cycles were made with helium permeability measurements taken during each evacuation cycle. Test results are given in Table VI.

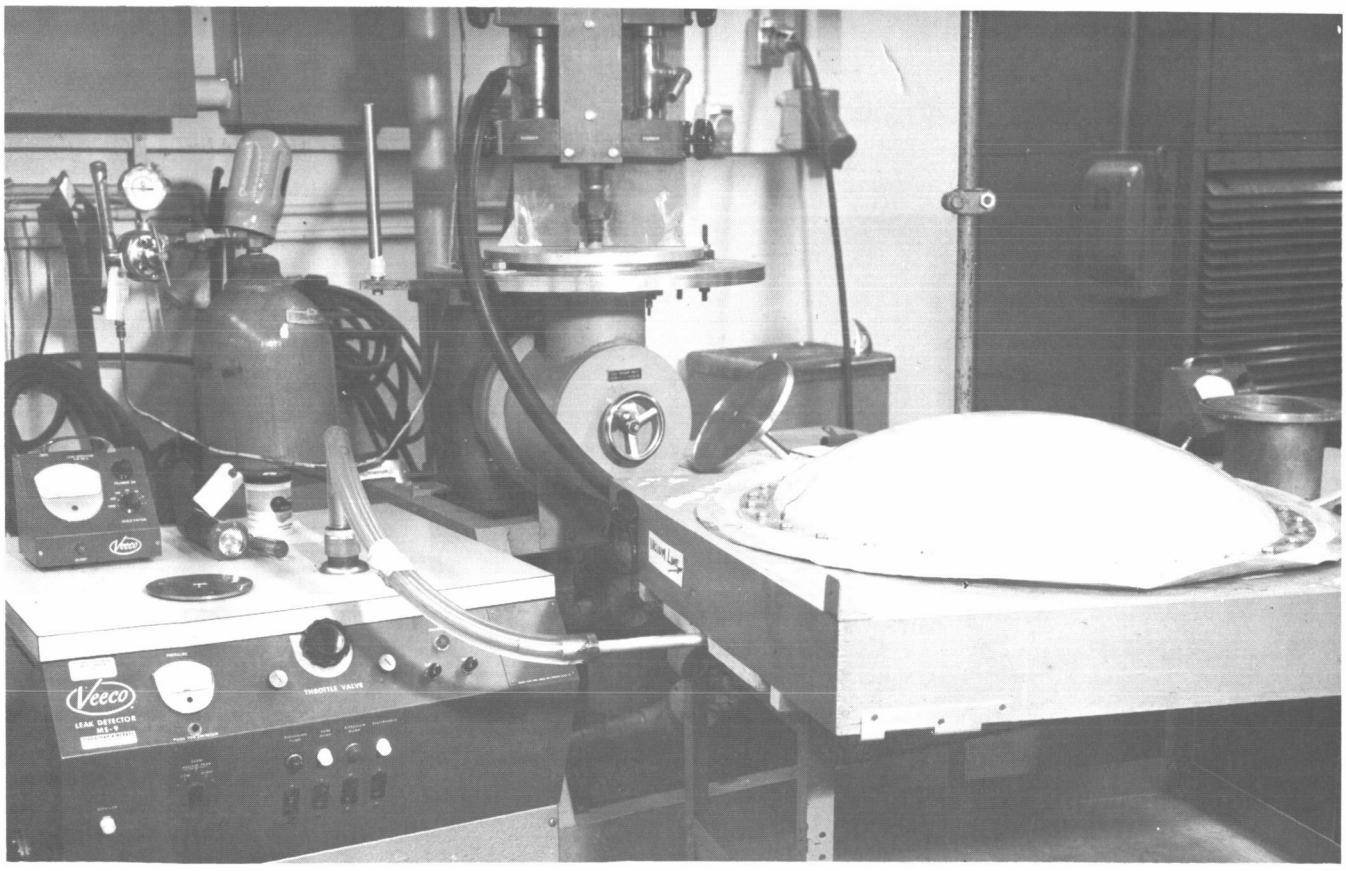


Figure 37. Helium Permeability Test Setup for 24-Inch Diameter MAAM Test Specimen

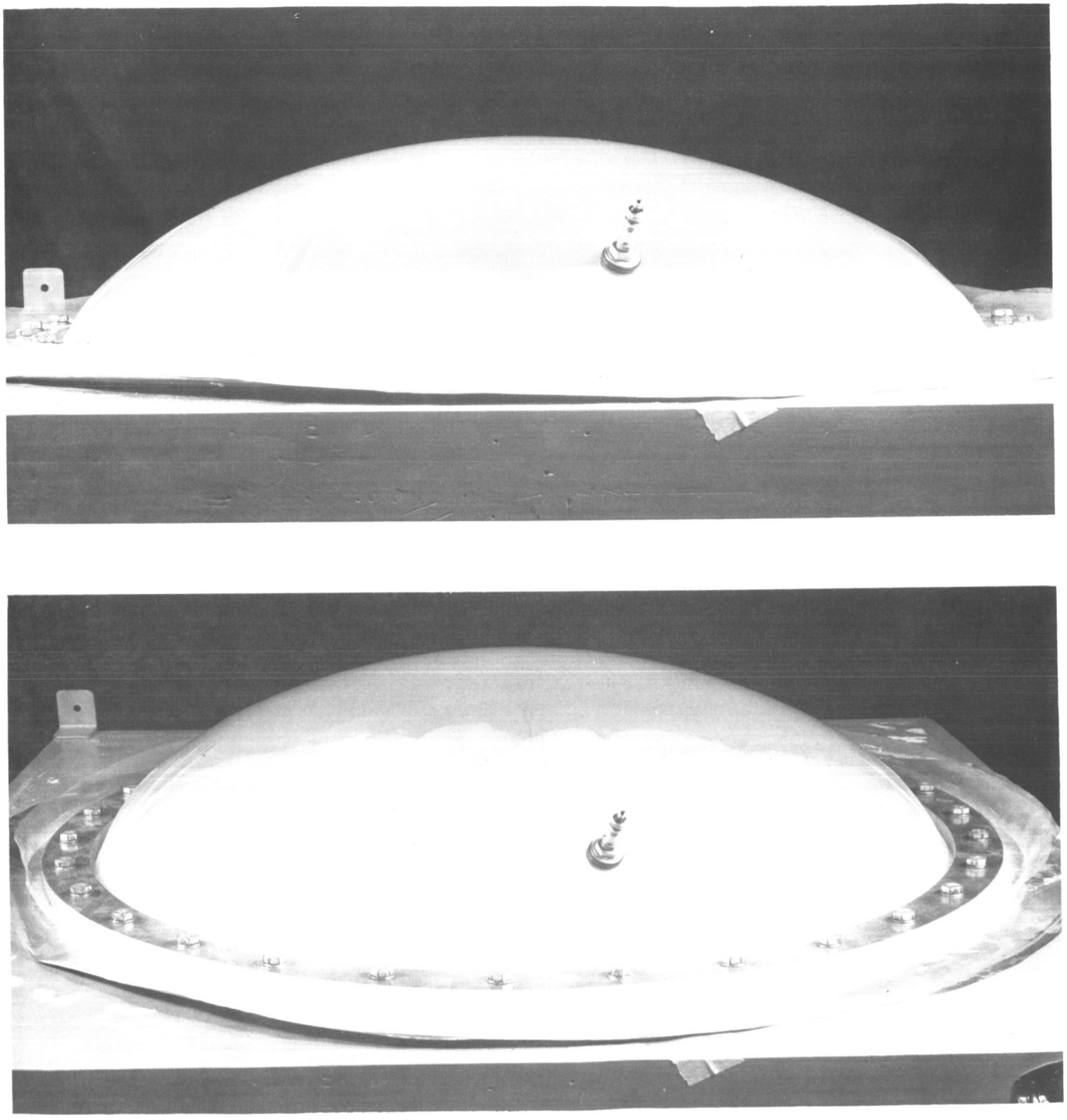


Figure 38. 24-Inch Diameter MAAM Test Specimens during a Typical Evacuation and Helium Permeability Measurement Cycle

Table VI. Helium Permeability Test Values on 24-Inch Diameter MAAM Test Specimen

Cycle No.	Helium Leak Rate (cc/sec)
1	1.1×10^{-9}
2	1.4×10^{-9}
3	1.4×10^{-9}
4	1.45×10^{-9}
5	2.0×10^{-9}
6	2.0×10^{-9}
7	2.2×10^{-9}
8	2.2×10^{-9}

Test Conditions:

(1) Room temperature
(2) 10^{-4} torr vacuum on evacuated side of sample
(3) 1 psi helium on pressure envelope side of sample
(4) 10 percent shrinkage of test specimen when evacuated
(5) Cycle time - 1 hour per cycle

The leak rate on all cycles was less than the maximum allowable leak rate of 1.1×10^{-7} cc/second at room temperature, thus qualifying the MAAM for vacuum jacket use.

A post-test disassembly of the test specimen is shown in Figure 39. The assembly sequence viewed from top to bottom is metal clamping ring and bolts, Mylar dome for helium, MAAM test specimen, and base plate of test fixture covered with glass cloth bleeder ply. The test specimen is constructed identically with spring-back test specimen No. 27, described in Table I. The wrinkle pattern after testing is shown in Figure 40. The pattern is comparable to spring-back specimen No. 27, having a uniform distribution of medium to heavy creases with well-rounded edges.

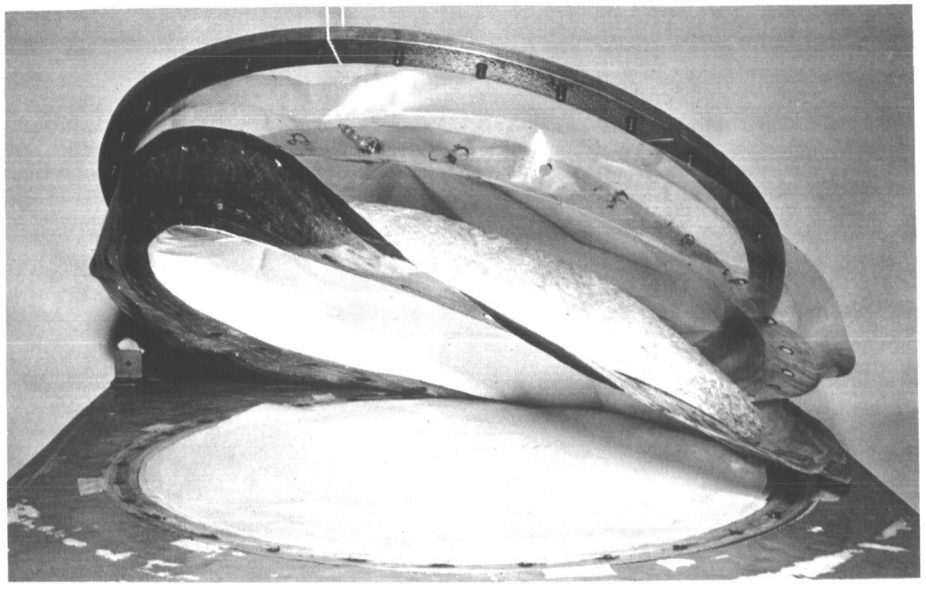


Figure 39. 24-Inch Diameter MAAM Test Specimen and Test Fixture Assembly Sequence Shown after Test

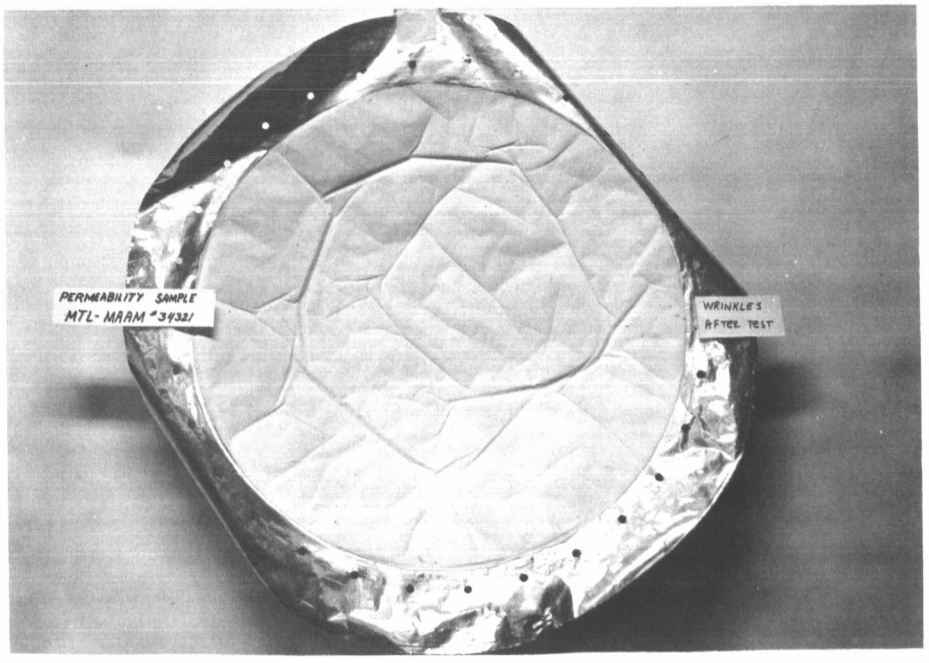


Figure 40. Wrinkles after Test on MAAM 24-Inch Diameter Helium Permeability Test Specimen

5. Vacuum Jacket Seam Testing

The vacuum jacket seam test program was initiated with the fabrication and testing of 12-inch diameter vacuum jacket test specimens containing the following seam designs:

(1) A 1/2-inch lap joint
(2) A 1/2-inch lap joint with a 1-1/4 inch wide overlapping doubler of vacuum jacket material
(3) A butt joint with a single overlapping doubler of vacuum jacket material
(4) A butt joint with two overlapping doublers of different widths of vacuum jacket material

The design philosophy of the above seam configurations is that the vacuum jacket seams, in general, are not completely leak-tight in a single lap joint. Experience with film-type vacuum jackets over foam insulation has shown that the addition of a doubler strip will greatly improve the leak-tightness and reliability of adhesive-bonded seams. An additional benefit of doubler strips is derived from the distribution of stress concentrations likely to occur along the edges of seams in areas of vacuum jacket protrusion terminations. In these locations, the vacuum jacket may be simultaneously stretched and cooled to cryogenic temperature during evacuation.

Testing of the seam designs was conducted to evaluate the structural integrity of the seams when stressed to 3 percent strain at room temperature and -320°F. In these tests, 12-inch diameter flat samples with seams (see Figures 41 and 42) are mounted in a test fixture and evacuated one side to draw the sample down to a curved plate representing a 3 percent stretch in the sample. Figures 43 and 44 show the test fixture and the room temperature tests. To chill the seam to -320°F, liquid nitrogen is poured on top of the sample before drawing the test sample down on the curved plate. Test results are given in Table VII.

Leakage tests were conducted on 30-inch diameter test specimens of seam types selected from preliminary tests on 12-inch diameter specimens. The 30-inch diameter diaphragm seam samples listed in Table VIII were prepared for leak testing. The seams were bonded under conditions representative of methods that may be used to join pieces of vacuum jacket material making up a subassembly. The subassemblies were joined by field seams, which were evaluated on 30-inch diameter samples seamed together over a SI-62 insulation blanket, shown in Figure 45. The test specimen comprises four gore panels lap-seamed and heat-sealed over a 12 percent curve mold and covered with an SI-62 insulation blanket.

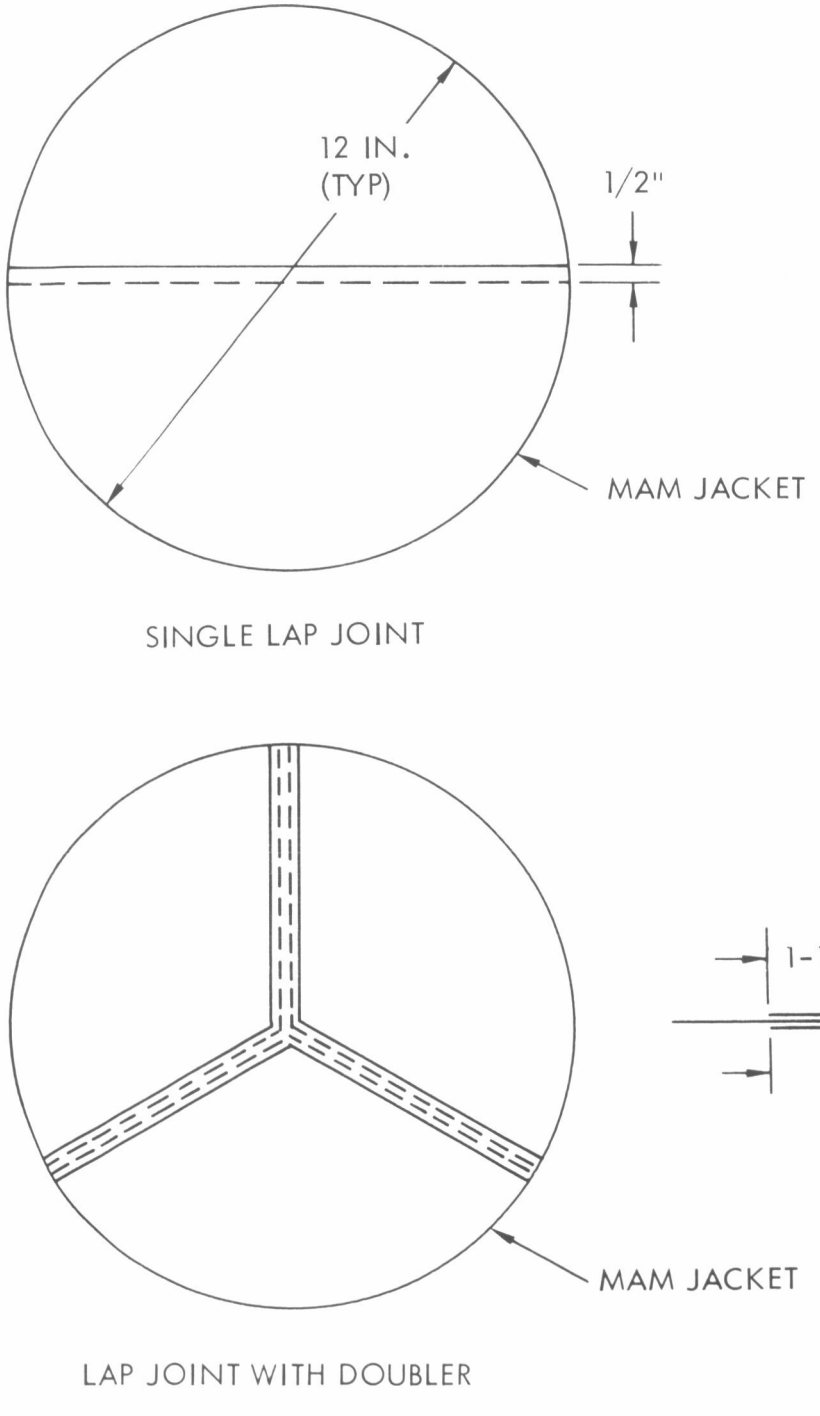
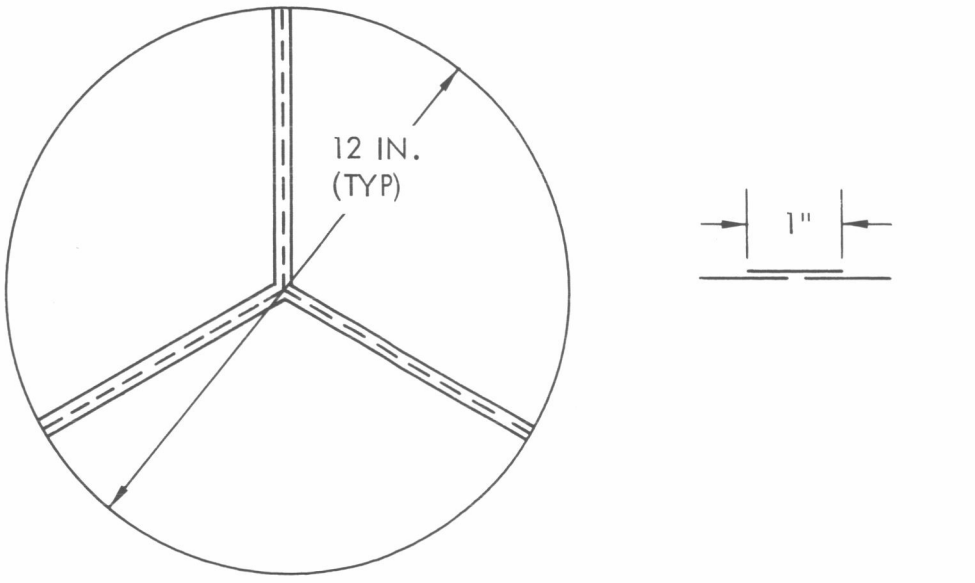
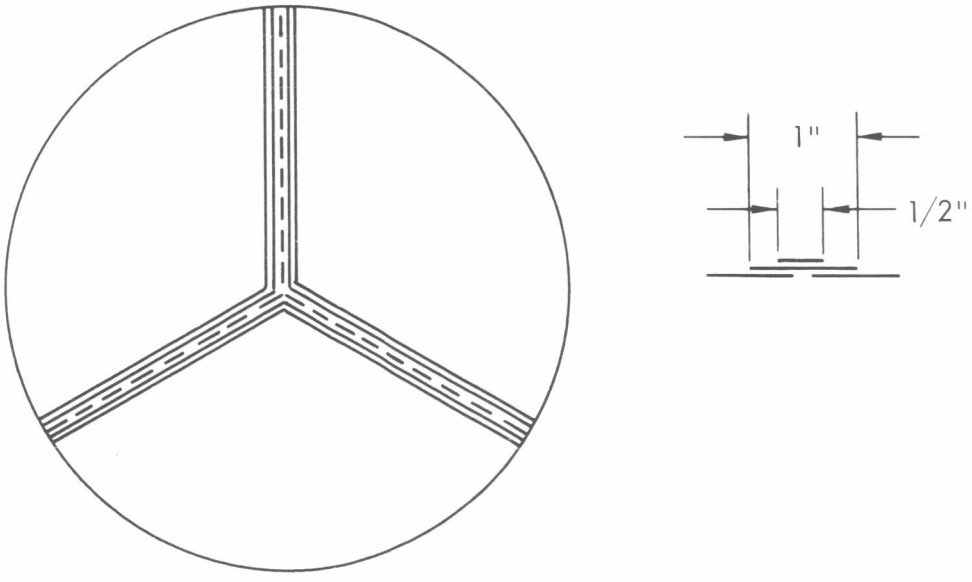


Figure 41. Vacuum Jacket Lap Joint Seam Test Specimens



BUTT JOINT - ONE-INCH DOUBLER



BUTT JOINT - TWO DOUBLERS

Figure 42. Vacuum Jacket Butt Joint Seam Test Specimens

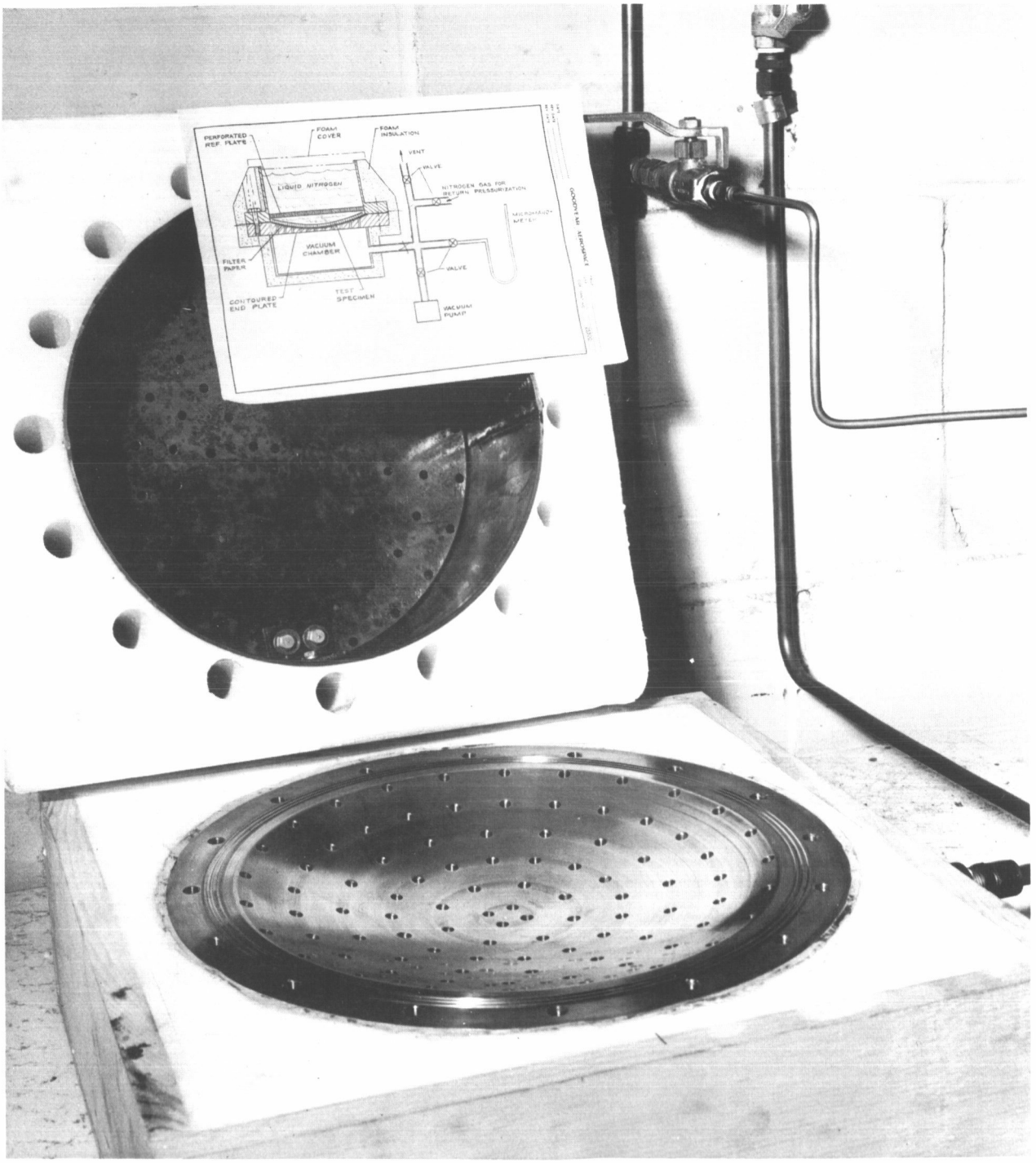
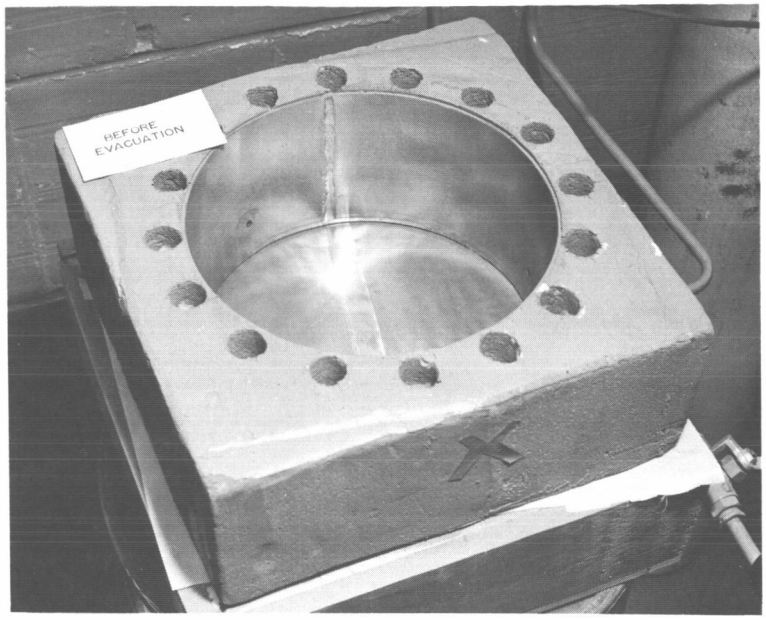
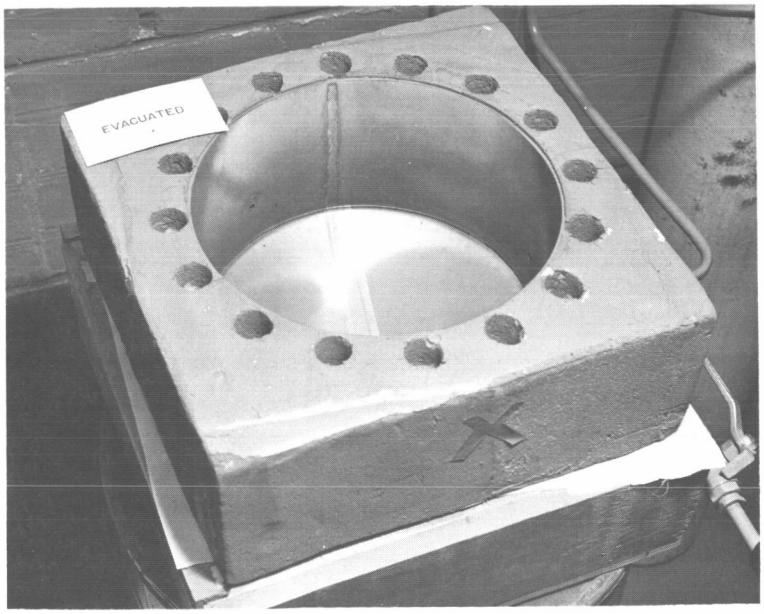


Figure 43. Twelve-Inch Diameter Seam Test Fixture



SEAM SPECIMEN FLAT (BEFORE EVACUATION)



SEAM SPECIMEN STRAINED 3% (EVACUATED)

Figure 44. Twelve-Inch Diameter Seam Test (Three Percent Strain at Room Temperature)

Table VII. Test Results - 12-Inch Diameter Seam Specimens

Type of Seam	No. of Specimens Tested	Temperature (°F)	No. of Cycles	Test Results
1/2-In. Single Lap	3	RT	20	No failures.
	3	-320	10 to 40	No failures.
	1	-320	1	Split in jacket adjacent to edge of lap.
1/2-In. Lap with 1-1/4 In. Doubler	3	RT	20	No failures.
	4	-320	6 to 20	No failures.
	1	-320	1	Split in jacket adjacent to doubler over seam.
Butt Joint with 1-In. Doubler	3	RT	20	No failures.
	2	-320	1	Split along butt seam.
Butt Joint with Two Doublers	3	RT	20	No failures.
	7	-320	5 to 20	No failures.
	1	-320	1	Split in jacket adjacent to widest doubler over seam.

Table VIII. 30-Inch Diameter Helium Permeability Seam Test Specimens and Test Results

Material: Doebeckmun No. 32-899 (1/2-Mil Mylar, 1/2-Mil Aluminum, 1/2-Mil Mylar)

Samples are representative of seams and repaired areas.

Sample	Leak Rate	Sample	Leak Rate
1-in. lap joint, G-207 adhesive	1.3×10^{-9}	Butt joint, 1-in. doubler, G-207 adhesive	4.3×10^{-8}
1-in. lap joint, G-207 adhesive	1.0×10^{-9}	Butt joint, 1-in. doubler, G-207 adhesive	1.0×10^{-9}
1-in. lap joint, G-207 adhesive	Excess leak, unable to check.	Butt joint, 1-in. doubler, G-207 adhesive.	1.0×10^{-8}
1-in. lap joint with 1-1/2 in. doubler, G-207 adhesive	Excess leak, overlapping material extended beyond O-ring seal.	1-in. dia hole, 2-5/8 in. dia patch, G-207 adhesive	1.0×10^{-10}
1-in. lap joint with 1-1/2 in. doubler, G-207 adhesive	Excess leak, same as above.	Replace 1/4-in. section, 1/2-in. lap joint, G-207 adhesive*	Excess leak, unable to check.
1-in. lap joint with 1-1/2 in. doubler, G-207 adhesive	Excess leak, same as above.	Triangular tear 3/4 x 3/4 in., rectangular patch 1-3/4 x 2-1/2 in., G-207 adhesive*	1.0×10^{-10}

*Repair made over glass fiber mat to simulate field repair.

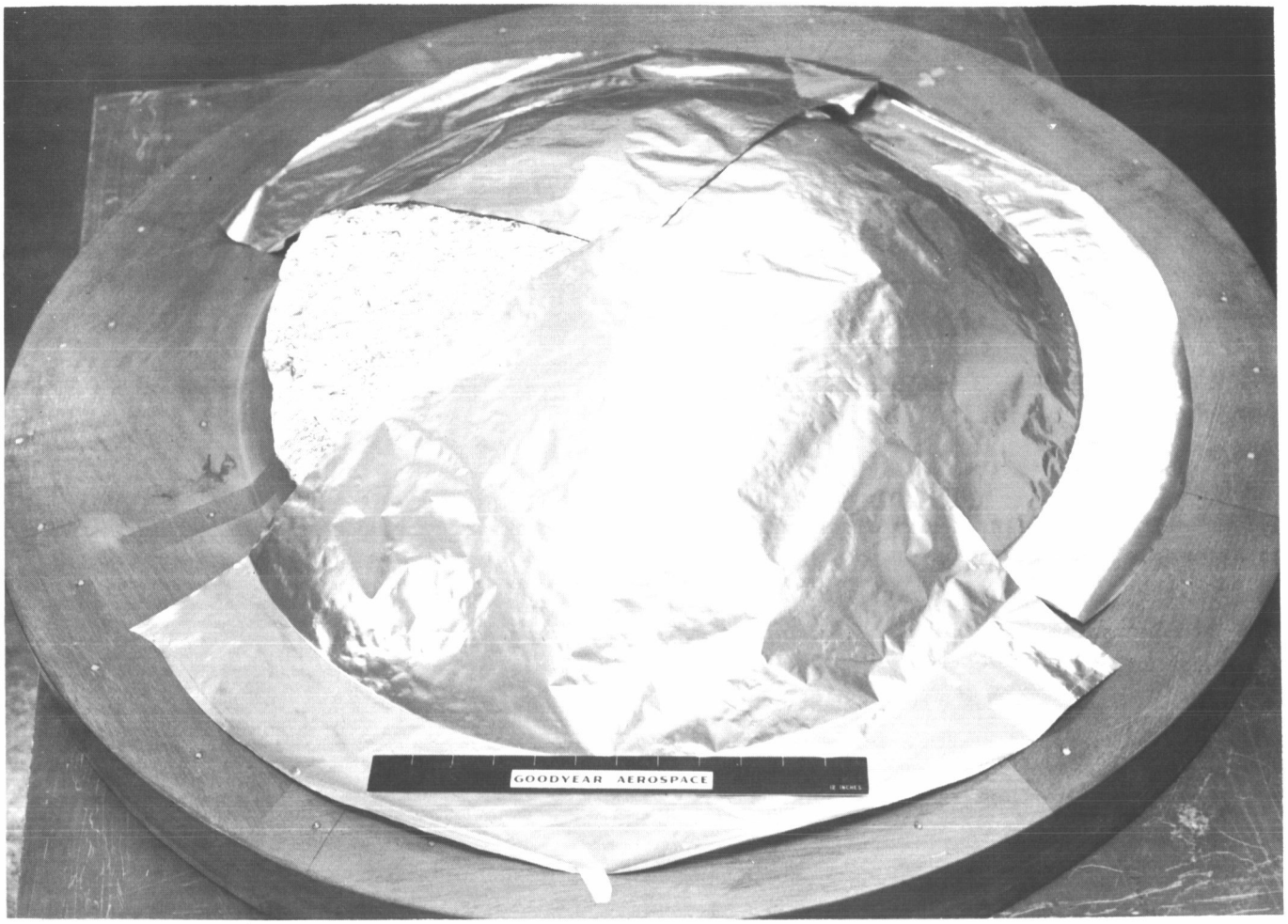


Figure 45. 30-Inch Diameter Seam Permeability Test Sample under Construction

It may be concluded from the seam test program that 1-inch wide lap joints with 1-1/2 inch wide MAM double strips will provide an adequate structural seam that will exhibit a helium leakage value within the 1.1×10^{-7} cc/second allowable leak for 30-inch diameter test specimen.

6. Vacuum Jacket to Tank Penetration Attachment Testing

The selection of the design of the vacuum jacket around tank penetrations was based on spring-back tests conducted on two types of jackets: (1) a flexible jacket configuration and (2) a semirigid jacket assembly. To evaluate the spring-back

performance of both types of protrusion jackets, a mock-up of each type was designed and fabricated.

The flexible design comprises a MAM envelope configured in the form of a truncated cone joined to a base flange of MAM, as shown in Figure 46. The small end of the cone is clamped and sealed to a flange on the tank penetration tubing. The base flange bears on the tank superinsulation.

The spring-back test fixture is a 36-inch diameter metal base plate having a 3-inch diameter tube extending upward approximately 15 inches from the center of the plate. The tubing and base plate are covered with SI-62 insulation to simulate insulation around a tube type tank penetration similar to the fill and vent lines on the 105-inch diameter NASA-MSFC test tank.

Excess material is provided in the cone to allow for axial movement of the jacket during evacuation. As shown in Figure 46, the flexible jacket exhibited heavy wrinkling when evacuated and incomplete recovery after vacuum was released. The lack of recovery caused a residual compressive force on the insulation, thereby reducing the thermal effectiveness of the insulation surrounding the penetration.

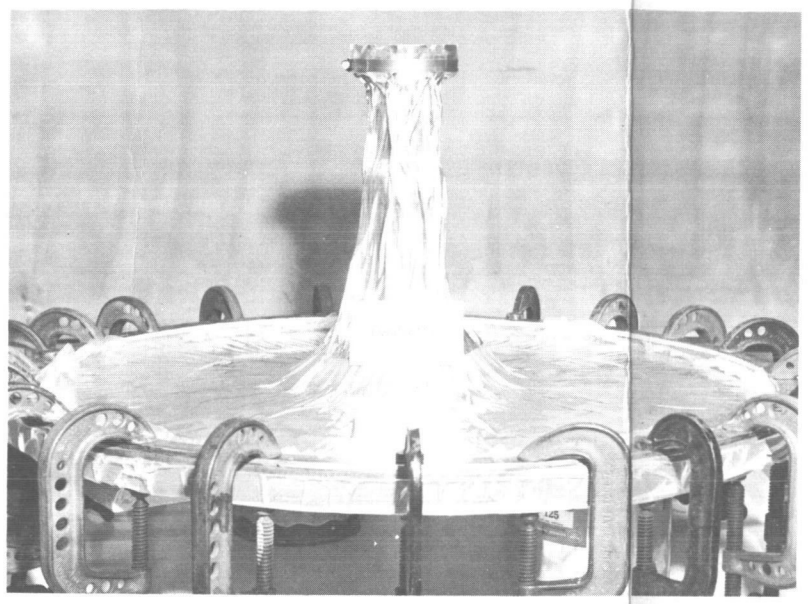
The semirigid jacket assembly design shown in Figure 47 comprises a metal hard cover configured as a truncated cone joined to a bellows-mounted tubular sleeve. The metal bellows was selected after consultation with Robertshaw-Fulton Controls Co, Knoxville, Tennessee. The hard cover surrounds the SI-62 insulation applied over the tube on the spring-back test fixture. A disk of MAM flexible vacuum jacket material with glass mat spring-back media is bonded to the base flange of the metal cone to simulate the vacuum jacket material in the area of the hard cover assembly. Spring-back testing, as shown on Figure 47, was performed by evacuating the bellows-mounted cover and flexible jacket. When the vacuum was released, the hard cover and flexible vacuum jacket spring-back was rapid and complete, with no residual pressure on the insulation. Conclusions from these tests are summarized as follows:

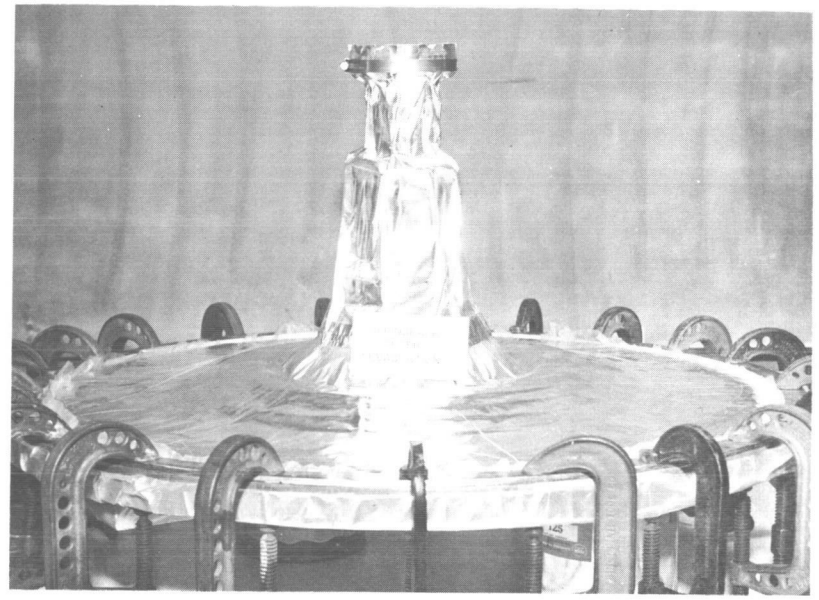
(1) The semirigid protrusion jacket design offers the most practical method of vacuum jacketing the superinsulation around protrusions. The semirigid jacket will not compress large areas of the insulation around protrusions, thereby minimizing heat transfer and boil-off.

(2) The flexible vacuum jacket design is extremely difficult to fit and seal. The excursion of the flexible jacket creates many large wrinkles having insignificant spring-back, thereby inducing pressure on the insulation, with attendant loss of thermal efficiency.

Based on the spring-back testing discussed above, the 105-inch diameter tank flexible vacuum jacket assembly incorporated the semirigid hard cover design of vacuum jacket termination around tank penetrations.



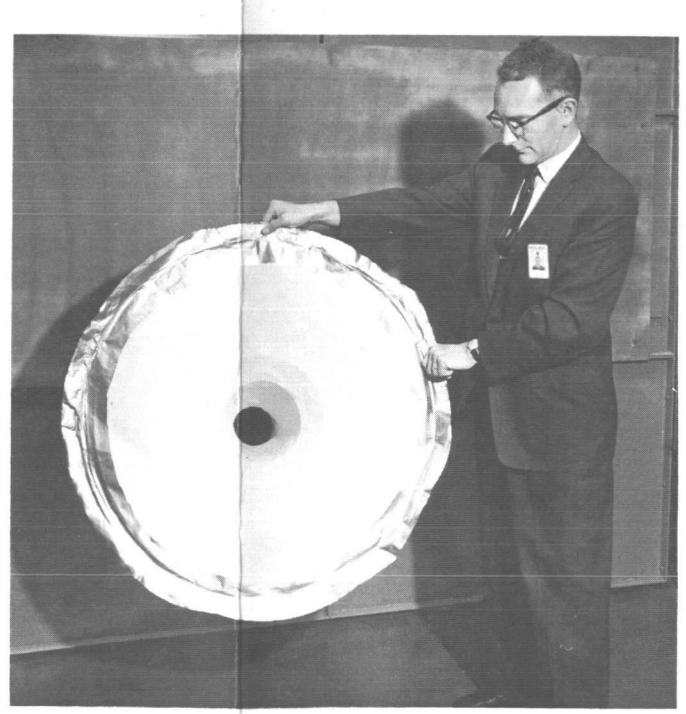




Spring Back Test



Top View (Exterior)



Bottom View (Interior)

Jacket after Test

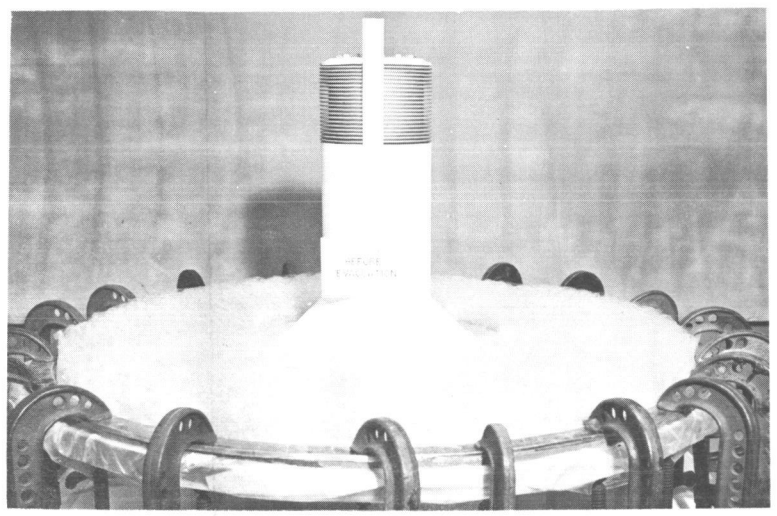
Figure 46. Protrusion Flexible Vacuum Jacket

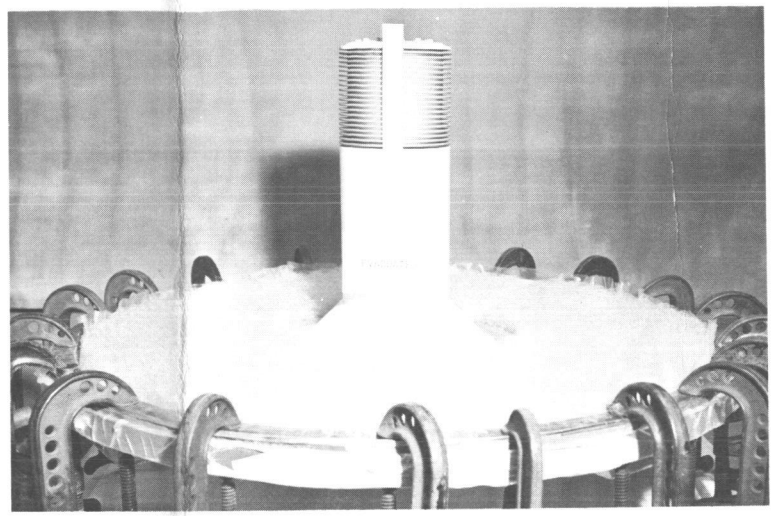
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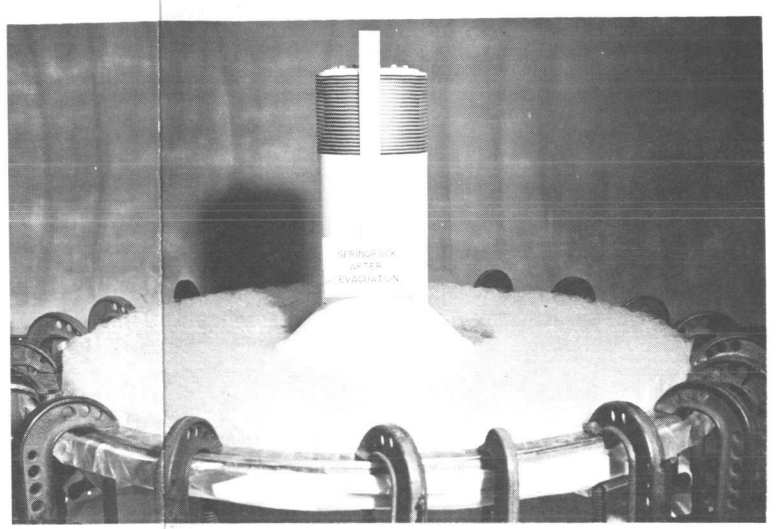
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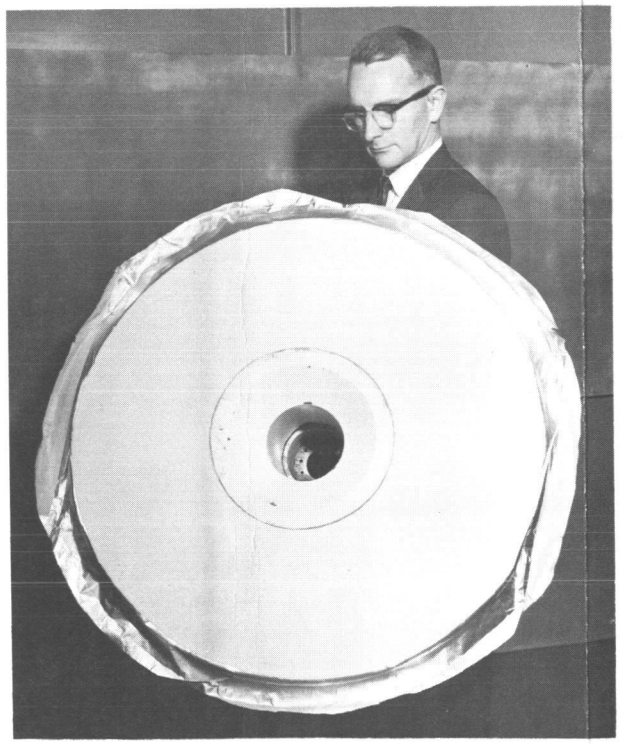






Spring Back Test





Top View (Exterior)

Bottom View (Interior)

Jacket after Test

Figure 47. Protrusion Semirigid Vacuum Jacket

98 - A

98 - B
Fig. 47.B

D. FABRICATION

1. 48-Inch Diameter Mock-Up Tank and Vacuum Jacket

a. General. The vacuum jacket for the 48-inch diameter mock-up test tank was fabricated with tooling and processing techniques planned for the 105-inch diameter tank vacuum jacket. All design details such as type of materials, seams, hard cover to flexible jacket connections, and spring-back media attachment were identical with the 105-inch diameter tank vacuum jacket design shown in Figure 3 (Sheets 1 through 4). The bellows-mounted metal hard covers were fabricated to full scale of the 105-inch diameter tank hard covers. Therefore, the fabrication processing and, to some extent, the tooling was directly applicable to 105-inch diameter tank hard cover fabrication. The half-scale flexible vacuum jacket was fabricated with forming and joining techniques that were applicable to the full-size 105-inch diameter tank vacuum jacket. The fabrication techniques are discussed in the following paragraphs.

b. Mock-up Tank and Insulation. The 48-inch diameter, 64-inch high mock-up test tank design shown in Figure 4 was fabricated from a 0.090-inch thick spin-formed hemispherical aluminum bulkhead and roll-formed 0.090-inch aluminum cylinder section welded to the bulkhead and an aluminum base flange. The mock-up protrusions were welded to the outside of the tank to simulate typical penetrations on the 105-inch diameter test tank. The welded tank assembly was checked for leak-tightness by helium mass spectrometer techniques, whereby the open end was sealed off and the tank cavity purged with gaseous helium. The weld seams were then probed with a Veeco MS-9 helium mass spectrometer probe. The tank was leak-tight, rendering it satisfactory for use in evacuation tests of potential vacuum jacket materials.

Linde SI-62 superinsulation supplied by NASA was applied to the tank. The insulation, comprising 70 layers each of aluminum foil and fiberglass paper, was applied one layer at a time to keep it in place, and required approximately two weeks to complete. This effort took considerably longer than the original plan, which called for application of 10-layer thick blankets at a time. The 10-layer blanket technique was attempted and abandoned as impractical because of uncontrolled slippage of underlying layers during application of the blanket to the tank. Application of the SI-62 insulation to the subscale tank is shown in Figures 48, 49, and 50. A mock-up of the SI-62 insulation cinching bands was applied to an appropriate area of the tank, as shown in Figure 50, by the use of glass fabric tape convolutely wrapped around the tank after every 10 layers of insulation were applied.

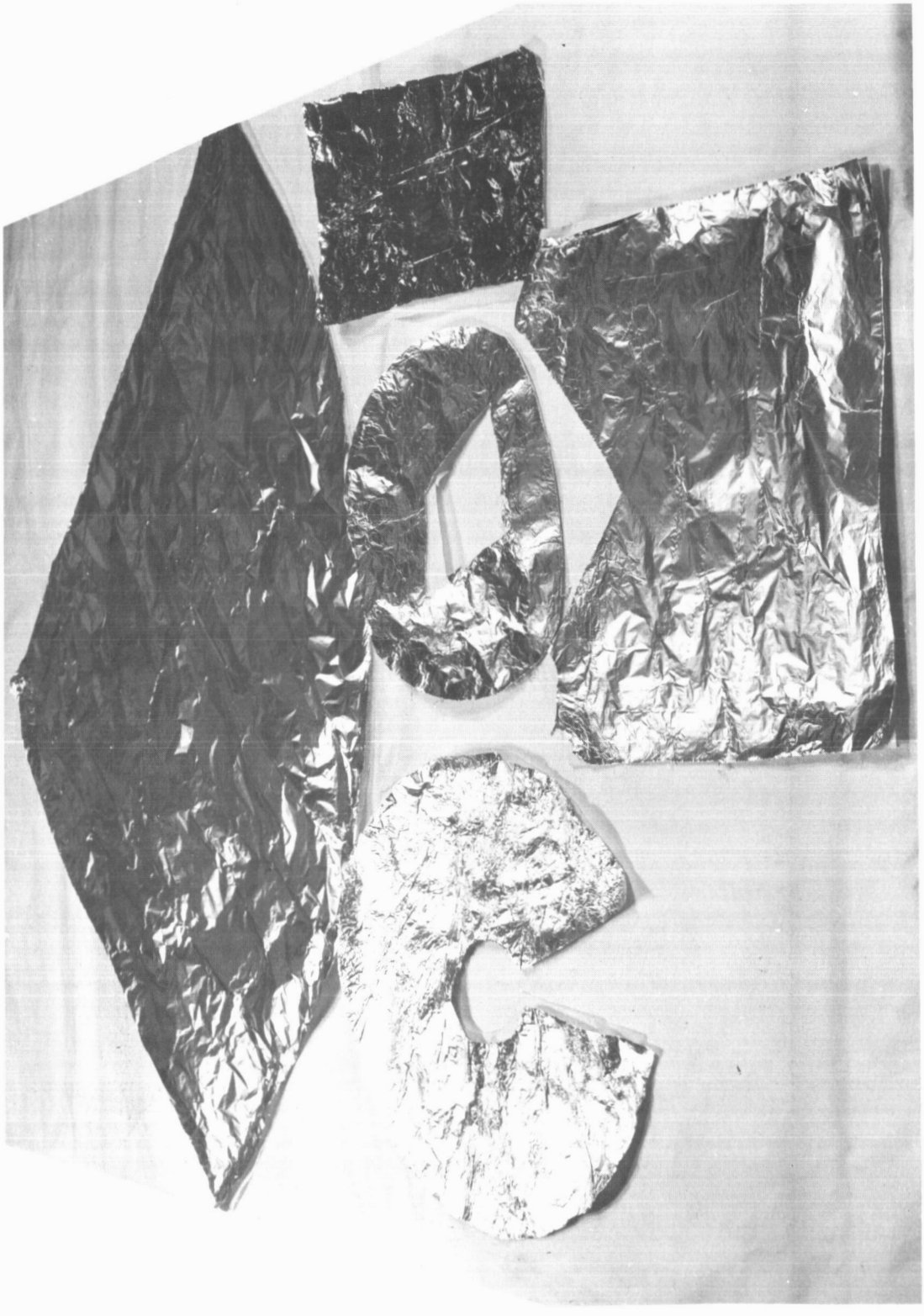
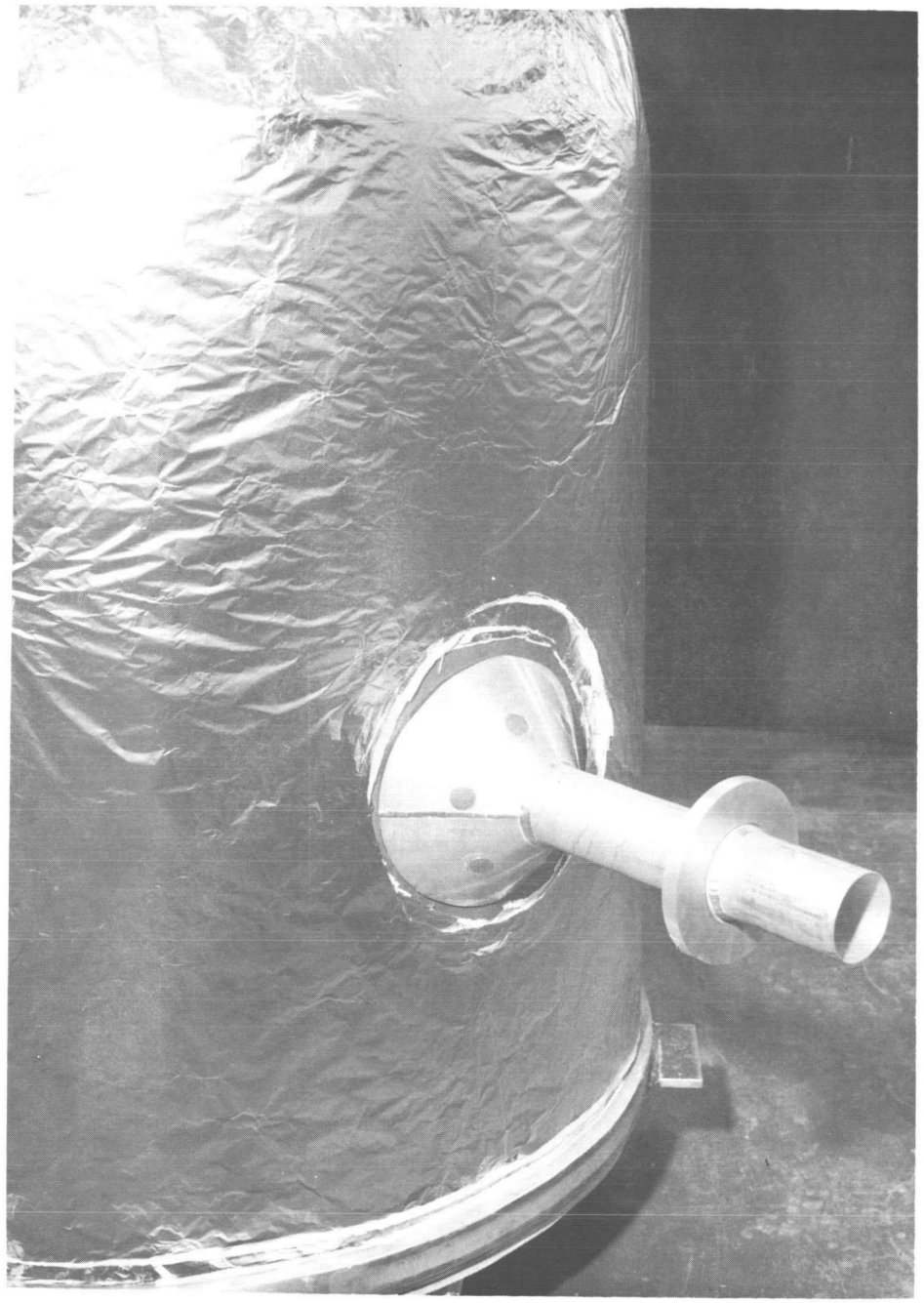


Figure 48. Typical SI-62 Insulation Patterns for Subscale Test Tank



PROTRUSION WITHOUT INSULATION



APPLICATION OF INSULATION PATTERN



INSULATION 50 PERCENT COMPLETE

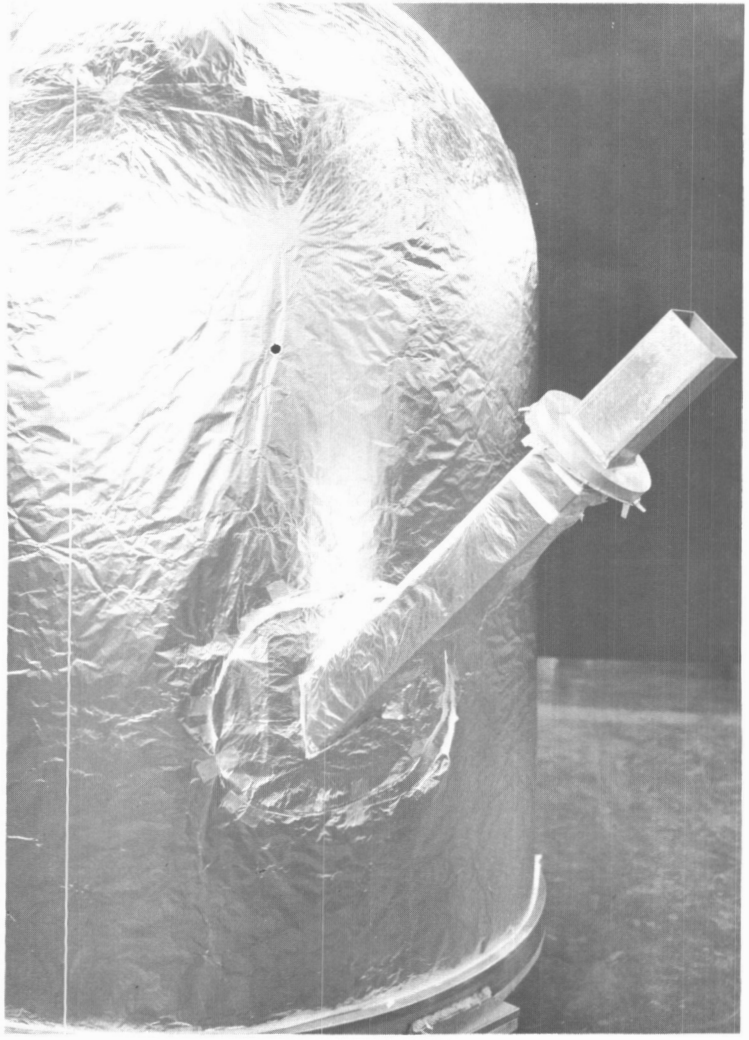
Figure 49. SI-62 Insulation as Applied to 3-Inch Diameter Protrusion on Subscale Test Tank

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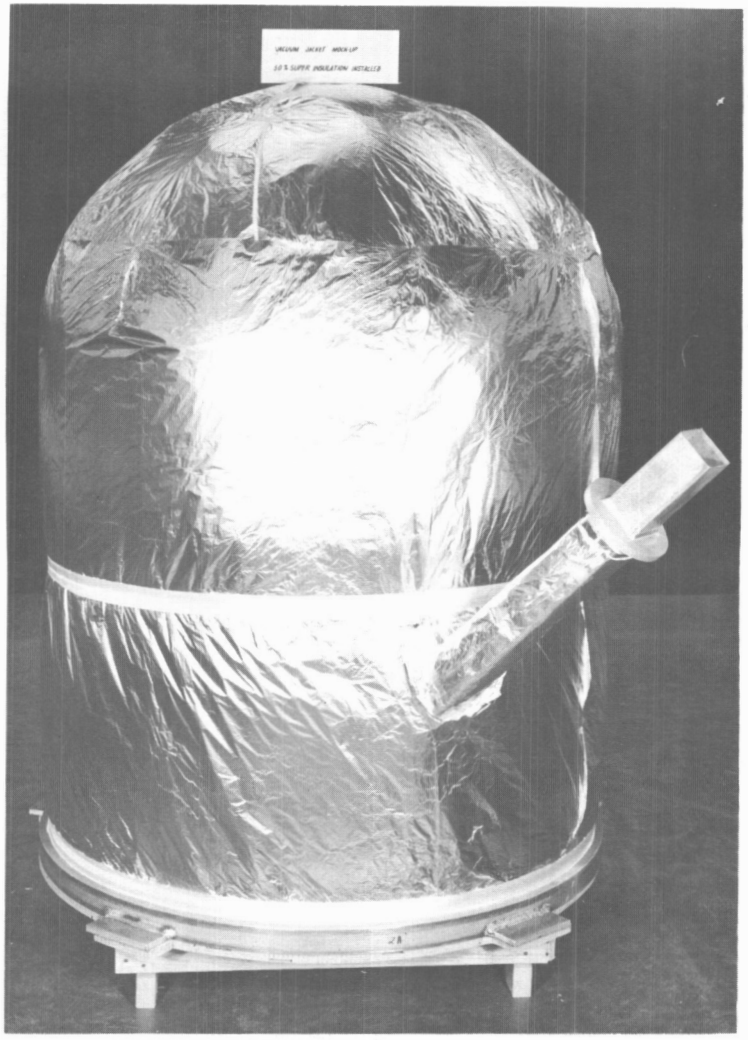
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INITIAL LAYER OF INSULATION



INSULATION 50% COMPLETE
(CINCH BAND IN PLACE)

Figure 50. SI-62 Insulation as Applied to Square Strut Protrusion on Subscale Test Tank

The insulated tank was covered with a polyethylene dust shield and placed in a 120°F warm room for two weeks to dry out the insulation while awaiting completion of a flexible vacuum jacket and protrusion hard covers.

c. Hard Cover Assembly Fabrication. Two hard cover assemblies were fabricated for the 48-inch diameter tank vacuum jacket: a 3-inch square tube strut cover, as shown in Figure 51, and a 3-inch diameter tube cover, as shown in Figure 52. Both covers are designed to be identical with covers on the 105-inch diameter tank, except for the radius of the cover to jacket flange, which is smaller on the 48-inch diameter tank. The sheet-metal portion of the covers was fabricated from Type 403 stainless steel sheets that were hand-formed and welded together. The stainless steel bellows assemblies were purchased from the Robertshaw-Fulton Controls Company, Knoxville, Tennessee. The complete weldment of cover and bellows was tested for leak-tightness by attaching sealing cover plates to the ends of the bellows and introducing approximately 5-psi gaseous helium to the inside of the cover while probing the outer surfaces with a helium mass spectrometer probe. Any leaks were welded and retested before accepting the cover assembly for use.

d. Flexible Vacuum Jacket Assembly. The top dome was fabricated as an assembly of eight gore panels and a 6-inch diameter close-out disk at the apex of the gores. Each MAM gore panel was vacuum-formed in a female forming mold and heat-set at approximately 200° F by a hand-held heat gun. Experimental gore panels were heat-set by both oven heating and hand heating with a heat gun. Satisfactory heat-setting of the MAM was obtained with both heating methods; however, the hand-held heat gun technique was quicker and did not involve mold heat-up and cool-down. Therefore, this technique was selected for heat-setting the gores. Seven gore panels were formed from MAM stock, and one gore panel was formed from MAAM. To vacuum-form a gore panel, an oversize flat pattern of MAM was draped into a fiberglass laminate female forming mold and clamped around the edges. The space between the mold surface and MAM was evacuated at room temperature, using shop vacuum lines. The forming mold was approximately 6 inches oversize along all edges to provide space for wrinkles in clamped edges of the MAM to smooth out before reaching the gore panel trim lines. When the MAM was completely formed against the mold, the heat-setting was accomplished by passing the hand-held heat gun over the surface of the panel. The 20-ampere heat gun, Master Appliance Co Model 12750, was held 3 to 6 inches from the surface of the panel and moved slowly to avoid overheating the MAM. The surface temperatures were periodically checked with a surface temperature pyrometer.

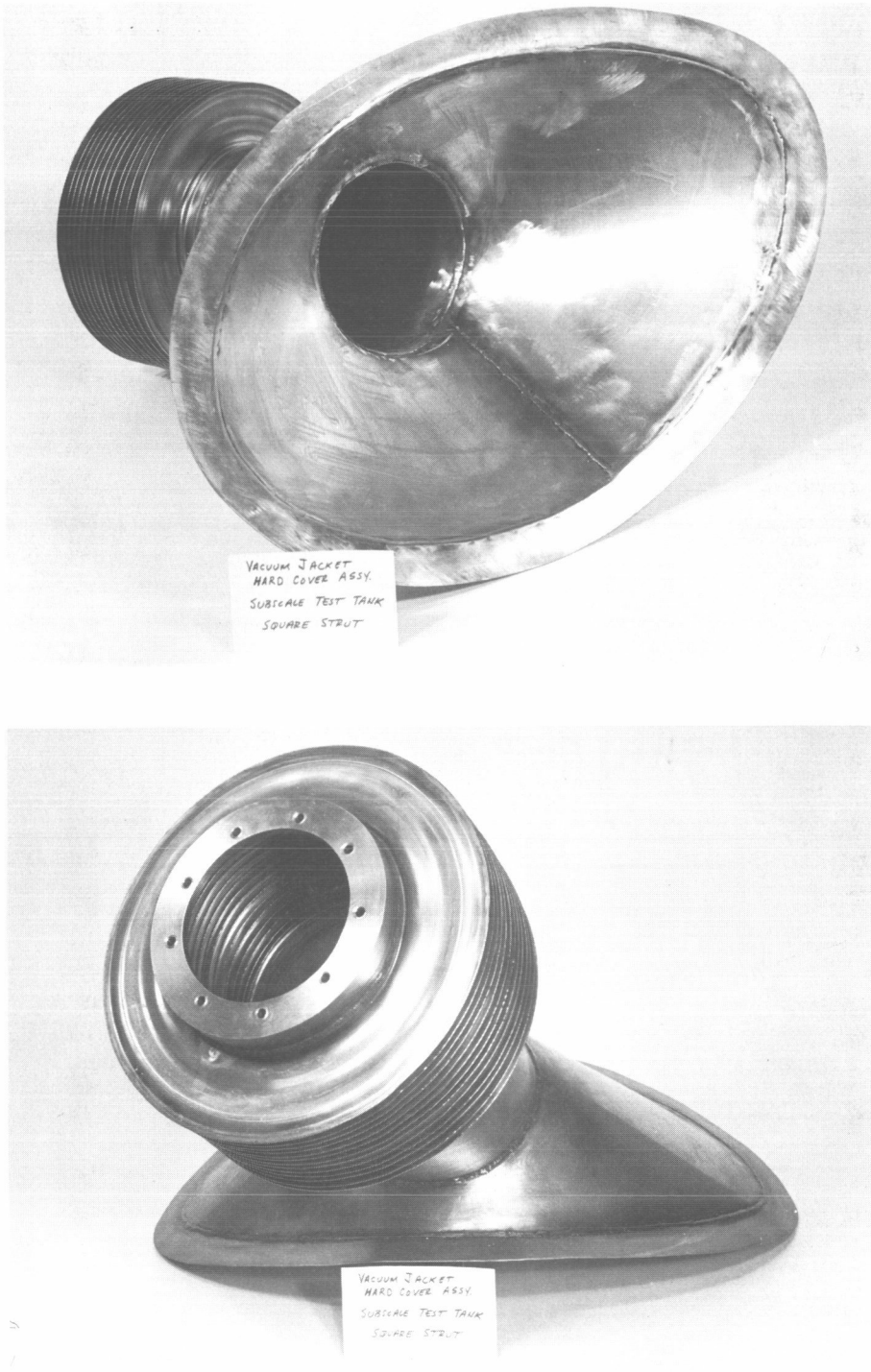


Figure 51. Bellows-Type Hard Cover Assembly for Diagonal 3-Inch Square Strut on Subscale Test Tank

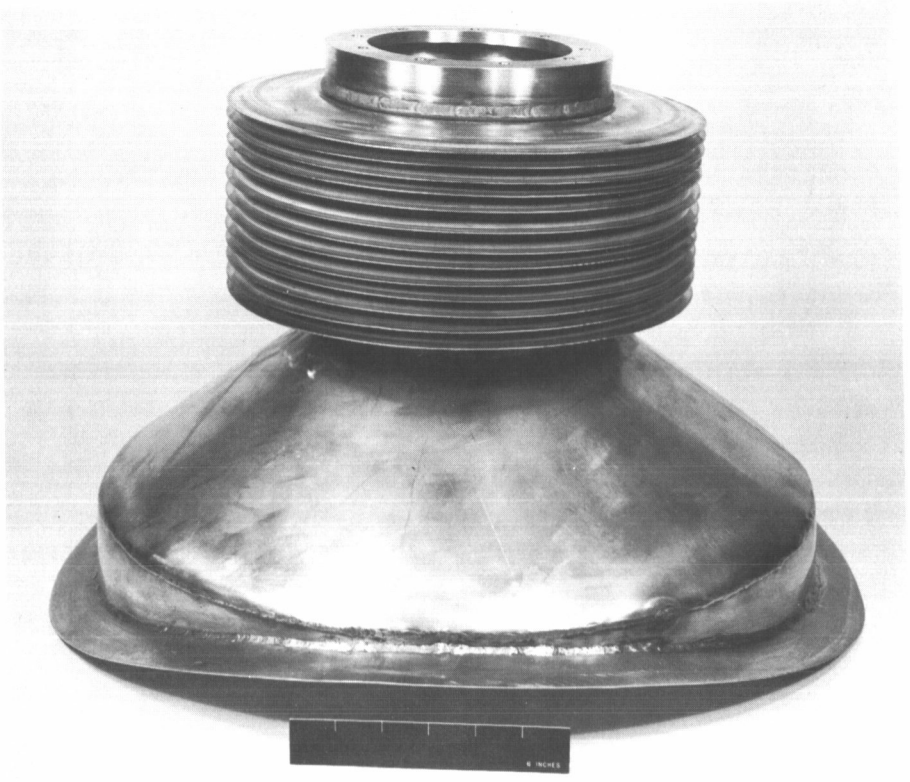


Figure 52. Bellows-Type Hard Cover Assembly for 3-Inch Diameter Protrusion on Subscale Test Tank

Before removing the vacuum-formed gore panel from the mold, a layer of Style 3583 stretch nylon was bonded with Goodyear G-207 adhesive to the concave surface of the MAM material per the following procedure:

(1) Prime the bonding surface of the MAM with a brush coat of G-207 resin mixed as follows:

G-207B Resin	100 pbw
Methylethyl ketone	27 pbw
Toluene	63 pbw
G-207C Catalyst	4 pbw

See Table IX for additional information on G-207 adhesive.

(2) Allow the resin to dry to a light-tack condition at room temperature for 10 minutes.

(3) Prime the bonding surface of the nylon by applying a spray coat of G-207 resin prepared per step 1. Allow the spray coat to dry at room temperature for 2 hours.

(4) Place the resin-coated side of the nylon over the primed surface of the MAM and smooth out any wrinkles in the nylon.

(5) Clamp a 3-mil PVA film vacuum bag nylon and MAM panel and evacuate to 25 in. Hg minimum vacuum.

(6) Activate the MAM to nylon bond line by heating to approximately 200° F with the hand-held heat gun technique previously described in forming the MAM.

(7) Allow the MAM and nylon gore panel to cool to room temperature under vacuum before removal from the forming mold.

Goodyear G-207 adhesive, a linear polyester solution resin, was developed for heat-sealing polyester films. G-207 adhesive is described in Table IX. Mylar-to-Mylar bonds made with this resin demonstrate excellent adhesion and toughness at cryogenic temperatures. It has been developed to be applied as a brush coat, roller coat, or spray coat. G-207 is a two-part adhesive system with good solution stability. The adhesive resin (G-207B) is prepared as a 28 percent solids solution that can be reduced to thinner solutions by simply adding a dual solvent such as a 70/30 ratio of toluene and methylethyl ketone. Uncatalyzed G-207B will remain permanently tacky as a coating after solvent evaporation and could be used similar to a contact adhesive. When properly catalyzed with G-207C, the adhesive coating will polymerize to a tack-free state having moderate temperature capabilities.

Each nylon-backed MAM gore panel was placed on the male mold assembly fixture and trimmed to size from trim lines marked on the mold, as shown in Figure 53. Along one meridional edge, the nylon is trimmed back one inch from the edge of the MAM to provide a bonding surface for the lap joint seams between gore panels. On the opposite meridional edge, the nylon extended approximately one-half inch beyond the edge of the MAM.

Assembly of gore panels was accomplished on the assembly fixture shown in Figure 53. Each panel-to-panel seam was bonded while the panels were supported by

Table IX. Goodyear G-207 Adhesive Physical Properties and Recommended Formulations

Physical properties

Color	Light straw colored
Odor	Odorless
Specific gravity (100 % solids)	1.215
Melting point	250 - 325°F
Bonding temperature	200 - 300°F
Thermal stability	Excellent
Moisture absorption	0.4% at 100°F at 100% relative humidity
Hydroxyl number	2.5 - 3.0

Recommended formulations:

Spray solution (10% solids)

G-207B	100 g (pbw)
Toluene	126 g (pbw)
Methylethyl ketone	54 g (pbw)
G-207C	4 g (pbw)

Brush solution (14.7% solids)

G-207B	100 g (pbw)
Toluene	63 g (pbw)
Methylethyl ketone	27 g (pbw)
G-207C	4 g (pbw)

Roller-coat solution (28% solids)

G-207B	100 g (pbw)
G-207C	4 g (pbw)



Figure 53. Vacuum Jacket Trim and Assembly Fixture for Subscale Test Tank

the full mold contour area. The seams were bonded with G-207 resin mixed as follows:

G-207B Resin	100 pbw
Methylethyl ketone	54 pbw
Toluene	126 pbw
G-207C Catalyst	4 pbw

The bonding surfaces of adjacent gore panels were wiped clean with methylethyl ketone. One brush coat of G-207 resin was applied to each seam surface and allowed to dry tack-free at room temperature for 15 minutes. The panels were carefully placed together and aligned on the mold before pressing the seam together. The seams were heat-sealed with a 265° to 275° F hand-heating iron.

After all gore panels and the center cap were seamed in place, 1-1/2 inch wide MAM doubler strips were bonded over the lap seams, using the seam-bonding technique described above. The completed dome assembly was then trimmed to length around the base end as shown in Figure 54. The dome assembly was removed from the mold, and the loose nylon edge along each seam was bonded to the underlying nylon skin. The interior of the completed dome is shown in Figure 55.



Figure 54. Completed Dome Assembly on Assembly Fixture Subscale Test Tank



Figure 55. Interior View of Vacuum Jacket Dome Assembly Subscale Test Tank

The cylinder section of the vacuum jacket was made from a single sheet of 3583 nylon-backed MAM rolled into a cylinder and joined with a single longitudinal seam. The nylon was bonded to the MAM by the same procedure described for the dome gore panels. The cylinder section and dome assembly were joined together by the seam-bonding procedure used on the dome gore panels. The cylinder-to-dome seaming operation is shown in Figure 56.

e. Installation of Vacuum Jacket on 48-Inch Diameter Tank. Rough cutouts were made in the vacuum jacket in two areas of tank protrusions, and the jacket was slit between the cutouts and the bottom of the jacket to facilitate installation over the protrusion struts. The base end of the jacket was trimmed to fit the tank base flange and bonded to the tank flange with a polyurethane resin system mixed as follows:

Resin - Narmco 7343	100 pbw
Curing Agent - Narmco 7139	12 pbw

Clamping pressure for the bond line was obtained by tightly wrapping several layers of stretch nylon tape over the bonding area. The bond was cured 24 hours at room temperature before removing tape.

The cover assemblies were placed on the struts, and the outline of the hard cover base flange was marked on the jacket to establish a reference for the final trim of the jacket cutout around each protrusion. The cutouts were made in the jacket, and the jacket to protrusion cover MAM sealing flaps were added to the jacket and protrusion hard cover base flange as shown in Figure 57. In the area of each hard cover, a 1-1/2 inch hole was cut through all the layers of SI-62 insulation to facilitate evacuation of the insulation during spring-back tests of the vacuum jacket assembly. This hole is shown to the left of the insulated strut in Figure 57.

The hard cover is shown in place in Figure 57 prior to bonding the sealing flaps. In Figure 57 it may be noted that the longitudinal seam in the cylinder section of the jacket is shortened in length by the cutout for the 3-inch square tube protrusion cover. The hard cover to vacuum jacket sealing flaps were bonded at the perimeter of the flaps with G-207 resin system and heat-sealed with the hand-heating iron technique used on the jacket seams. MAM doubler strips were applied over the seams by the same bonding techniques. The completed sealing flaps are shown in Figure 35. The 1-1/2 inch diameter tubes and coupling nuts extending from the conical portion of both hard covers were used to hook up vacuum lines for spring-back tests on the jacket and hard cover assemblies.



Figure 56. Joining Dome and Cylinder Section - 48-Inch-Diameter Tank Vacuum Jacket



View showing back side of hard cover with flexible flap bonded to cover. Vacuum jacket cut-out flexible flap bonded to jacket. 1.5-inch hole through insulation.



View showing hard cover in place. Hard cover and vacuum jacket flaps rolled back to show construction.

Figure 57. Typical Jacket to Hard Cover Connection for 48-Inch Diameter Subscale Test Tank

f. Installation of Spring-back Media. The flexible vacuum jacket was completed with the installation of the 1-inch thick Glassfloss mat spring-back media. Lengths of glass mat were impregnated with G-207 resin solution mixed as follows:

G-207B resin	100 pbw
Methylethyl ketone	54 pbw
Toluene	126 pbw
G-207C Catalyst	4 pbw

The glass mat was dipped in resin, hung up to drip dry for 2 hours at room temperature, and oven-cured at 120° F for 4 hours.

The impregnated glass mat was cut into patterns to fit the outer surfaces of the vacuum jacket. After all mat was fitted, the exterior surfaces of the vacuum jacket were painted with a brush coat of G-207 resin, and the mat pieces were pressed onto the jacket and held in place until the resin film dried and bonded the mat to the jacket. A final trim of the glass mat was made around protrusion covers to complete the installation of the vacuum jacket spring-back media (see Figure 34).

The subscale tank jacket was a valuable aid in checking out vacuum jacket fabrication and installation techniques that will be employed on the 105-inch diameter tank vacuum jacket assembly.

2. 105-Inch Diameter Tank Vacuum Jacket Assembly

a. General. The 105-inch diameter tank vacuum jacket design, shown in Figure 3, was partially fabricated at GAC and shipped to NASA-MSFC for completion and installation on the NASA 105-inch diameter test tank. The completion and installation of the jacket is beyond the scope of contract NAS 8-11376 and therefore will not be covered in this report.

The tooling and fabrication experience obtained from fabrication of the 48-inch diameter tank vacuum jacket formed the basis for final selection of tools and fabrication technique for the 105-inch diameter tank vacuum jacket.

b. Tooling.

(1) Gore Panel Vacuum-Forming Mold. A fiberglass-reinforced plastic female mold was laid up over a male plaster model of the contour of the dome of the vacuum jacket. A metal clamping ring was fitted to the edges of the mold to secure the MAAM stock during vacuum-forming the gore panels of the vacuum jacket domes.

(2) Manhole Cover Vacuum-Forming Mold. A spherical segment fiberglass reinforced-plastic female mold was laid up over a male plaster model. A metal clamping ring was fitted to the edge of the female mold to secure the MAAM stock while vacuum-forming the manhole cover insulation skins and the vacuum jacket bottom dome cap.

(3) Dome and Cylinder Section Assembly Fixture. This fixture is a male form comprising a plywood bulkhead framework covered with thin fiberglass laminate skins. The fiberglass skins were laid up in the gore panel vacuum-forming mold. Assembly of the fiberglass skins on the wood framework provided a full-size male mold to the contour of the vacuum jacket dome ends. At the top center of the fixture, removable fiberglass laminate skins were provided of contours to match either the manhole cover jacket or the bottom dome cap.

c. Hard Cover Assembly Fabrication. Six bellows-mounted hard cover assemblies were fabricated for the 105-inch diameter tank vacuum jacket assembly. Four covers were of the design shown in Figure 58 and were fabricated in the same manner as the 3-inch diameter tube cover shown in Figure 52. Two covers were of the design shown in Figure 59 and were fabricated in the same manner as the 3-inch square tube strut cover shown in Figure 51. The A-frame fitting hard cover assembly was of the design shown in Figure 60 and was fabricated from aluminum sheets hand-formed and welded together.

All hard covers were leak-tested using the helium leak detector techniques described in the fabrication of the hard covers for the 48-inch diameter mock-up tank. The bellows assemblies purchased as leak-tight units from The Robertshaw Fulton Controls Company were retested during the leak testing of the hard cover assemblies.

d. Flexible Vacuum Jacket Fabrication. The flexible vacuum jacket was fabricated in two halves, each comprising an assembly of a dome and a cylinder section. The cylinder section of each assembly was made long to allow for final trim when the jacket halves are fitted on the 105-inch diameter tank. By fabricating the jacket in half shells, the jacket can be fitted to the tank without disconnecting the tank supports.

The dome portion of each half shell was fabricated from 11 gore panels, which was the minimum number of gore panels that could be fabricated from the 40-inch MAAM stock width. Each nylon-backed gore panel was fabricated by the vacuum-forming technique used for the 48-inch diameter tank vacuum jacket fabrication (see subsection D-1). A typical gore panel and the forming mold are shown in Figure 61.

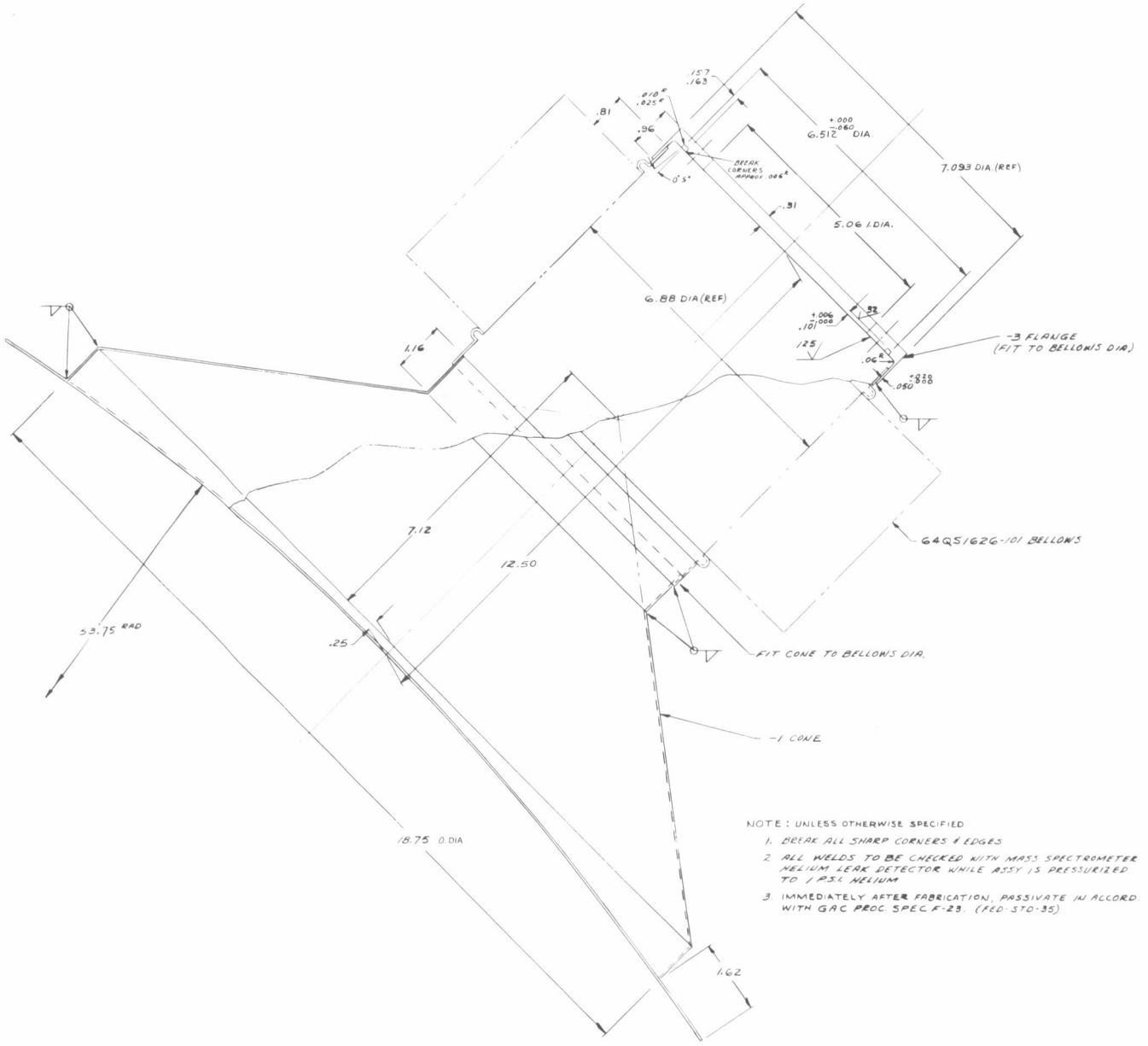
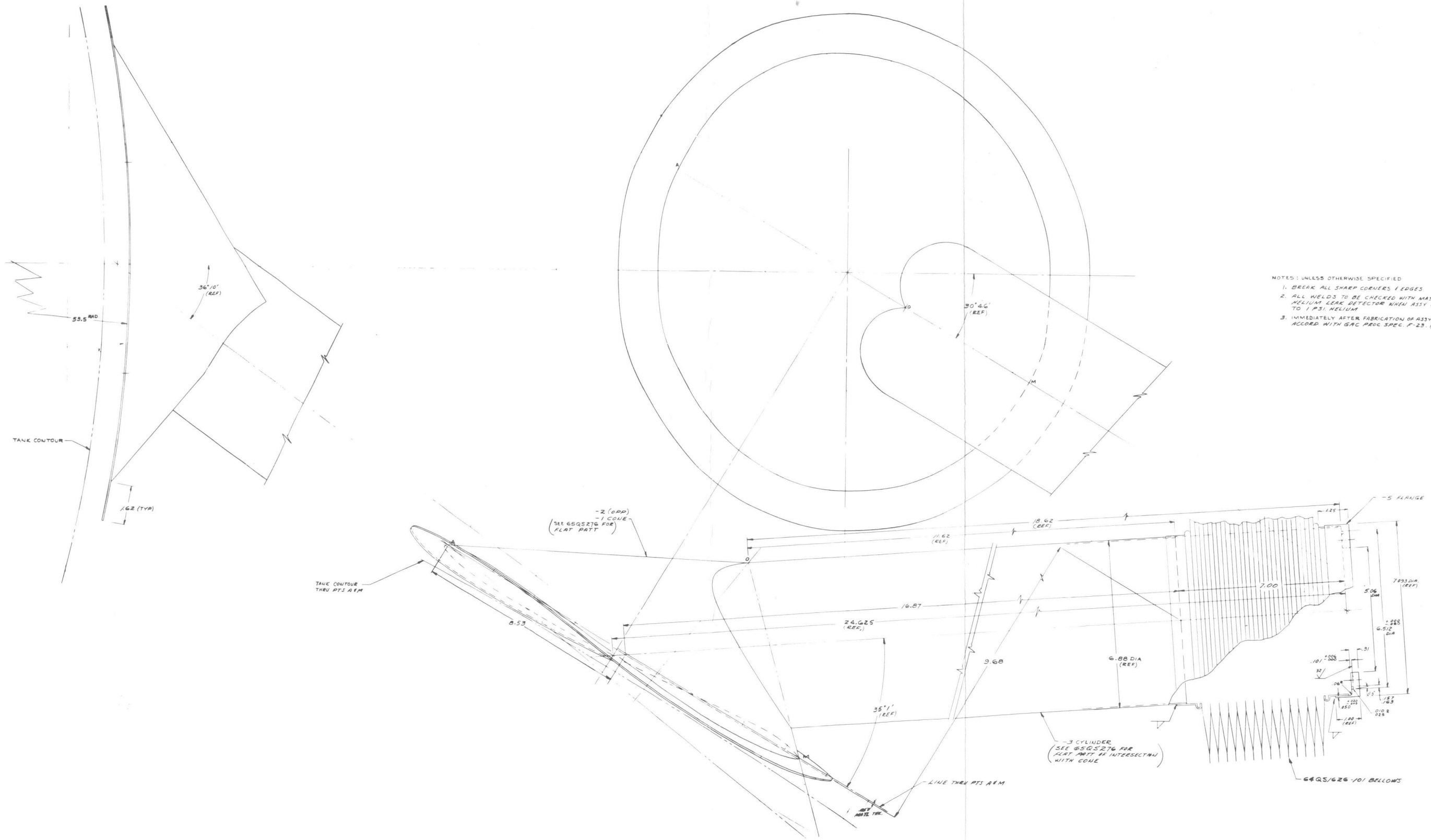


Figure 58. Hard Cover Assembly (3-Inch Diameter Opening) for 105-Inch Diameter Tank Flexible Vacuum Jacket



NOTES: UNLESS OTHERWISE SPECIFIED

1. BREAK ALL SHARP CORNERS & EDGES
2. ALL WELDS TO BE CHECKED WITH MASS SPECTROMETER HELIUM LEAK DETECTOR WHEN ASSY IS PRESSURIZED TO 1 PSI HELIUM
3. IMMEDIATELY AFTER FABRICATION OF ASSY, PASSIVATE IN ACCORD WITH GAC PROC SPEC. P-23. (PRO-STD-GC-P 35)

Figure 59. Hard Cover Assembly (3-Inch Square Tube Strut) for 105-Inch Diameter Tank Flexible Vacuum Jacket

FOLDOUT FRAME - 1

FOLDOUT FRAME

FOLDOUT FRAME 2

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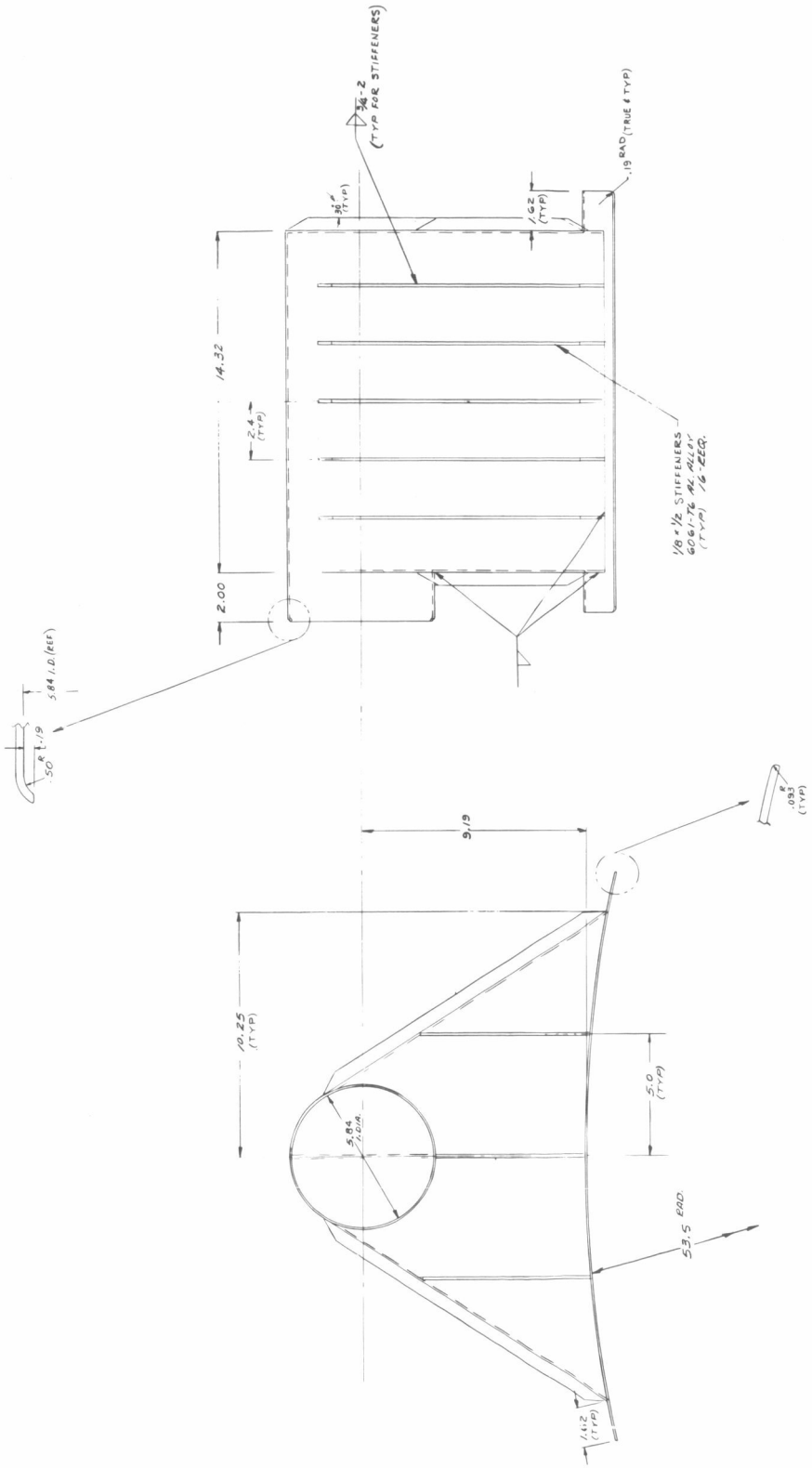


Figure 60. Hard Cover Assembly (A-Frame Fitting) for 105-Inch Diameter Tank Flexible Vacuum Jacket

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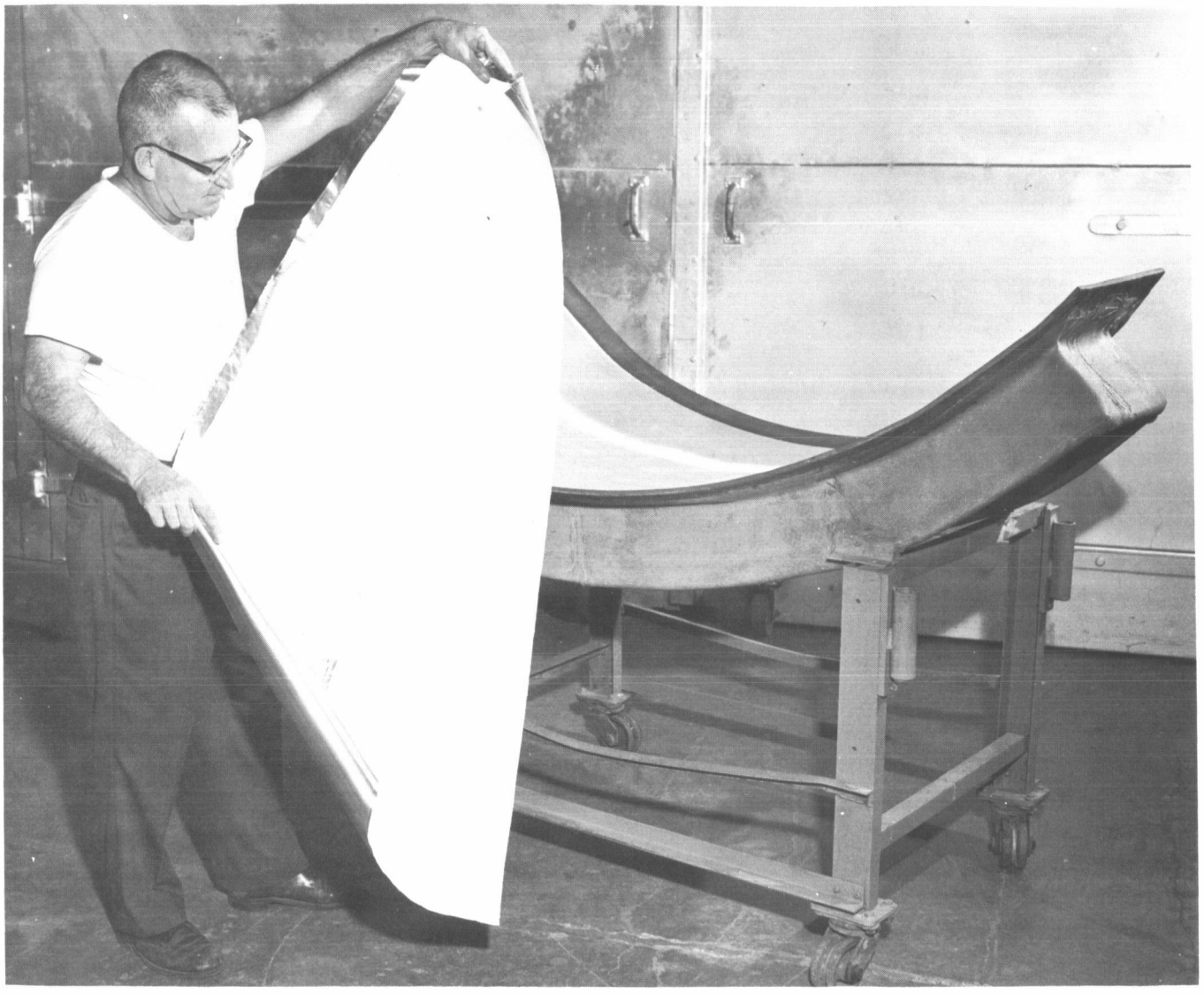


Figure 61. Nylon-Backed MAAM Gore Panel and Forming Mold for 105-Inch Diameter Tank Vacuum Jacket

The gore panels were assembled on the dome assembly fixture with the seam-bonding techniques described for the 48-inch diameter tank jacket. Because of the long length of the seams, a slip sheet of starched cheese cloth was placed between the gores at the seam area to allow the gore panels to be aligned without sticking together. When the gores were properly aligned, the slip sheet was removed as the seam was ironed down, as shown on Figure 62. When all gore panels were bonded together on the bottom dome assembly, a hemispherical close-out disk of nylon-backed MAAM was bonded to the apex of the gore panels. On the top dome assembly, a similar close-out disk was bonded to the gore panels, and in addition, a circular flap of MLM laminate material was bonded to the disk at the edge of the manhole cover cutout. The MLM circular flap will serve as the attachment for the manhole cover insulation. A temporary patch of MAM material was bonded to the jacket to seal off the manhole cover cutout during leak-testing of the jacket.

The cylinder section of each dome assembly is a single sheet of nylon-backed MAAM material prepared as described for the 48-inch diameter jacket (see subsection D-1). The cylinder section was bonded to the dome assembly, using the dome assembly fixture as shown in Figure 63 and the seam-bonding procedure used on the gore panels. After the cylinder section was bonded to the dome, the ends of the cylinder section were joined with a single longitudinal seam to complete the cylinder. The 1-1/2 inch wide MAM doubler strips were bonded to all gore and cylinder seams before removing the dome assembly from the assembly fixture.

e. Leak-Testing Dome Assembly. A leak check of the integrity of vacuum jacket seams prior to installation of the jacket on the 105-inch diameter tank is feasible and desirable. With leak testing of both jacket halves, any leaks found in the majority of the seams would be relatively easy to repair and test.

To accomplish the leak test of both jacket halves, the open ends of the cylinders were taped together and the jacket assembly inflated with helium gas to approximately 0.2 psig. All seams were probed with a Veeco MS-9 helium mass spectrometer probe, as shown in Figure 64. Several minor leaks were repaired and retested as satisfactory before terminating the leak test.

E. PACKING AND SHIPPING

The hard covers were packaged in a separate shipping box in accordance with commercial boxing practice.

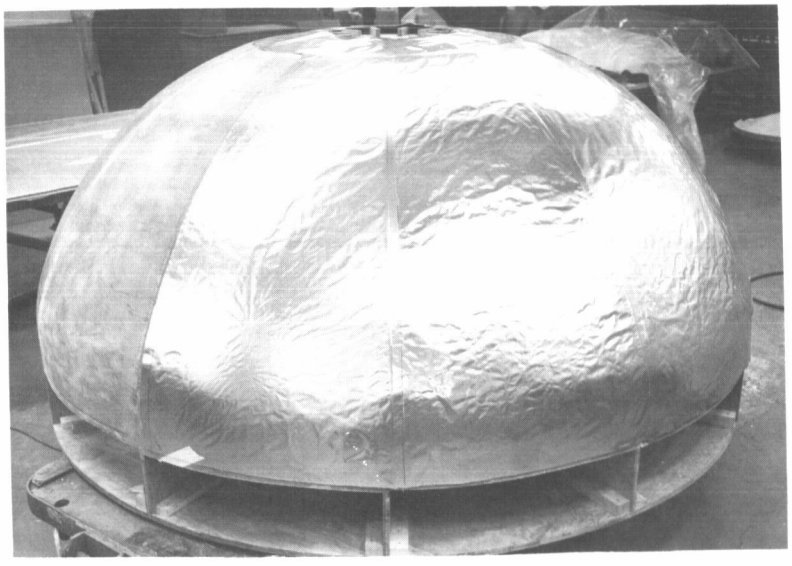
The flexible vacuum jacket halves were separated and carefully folded with folds running lengthwise of the jacket. Many of the folds were padded with shipping paper to prevent formation of sharp creases. The jacket halves were laid full length in



INITIAL PLACEMENT OF SEAM



HEAT SEALING THE SEAM



BONDED GORE PANELS ON ASSEMBLY FIXTURE

Figure 62. Assembly of Vacuum Jacket Top Dome Gore Panels for 105-Inch Diameter Tank Vacuum Jacket



COATING DOME SEAM WITH
G-207 ADHESIVE



COATING SKIRT SEAM WITH
G-207 ADHESIVE



POSITIONING SEAM



IRONING SEAM

Figure 63. Assembly Operations for Joining Skirt to Dome on 105-Inch Diameter Tank Vacuum Jacket Top Dome Assembly

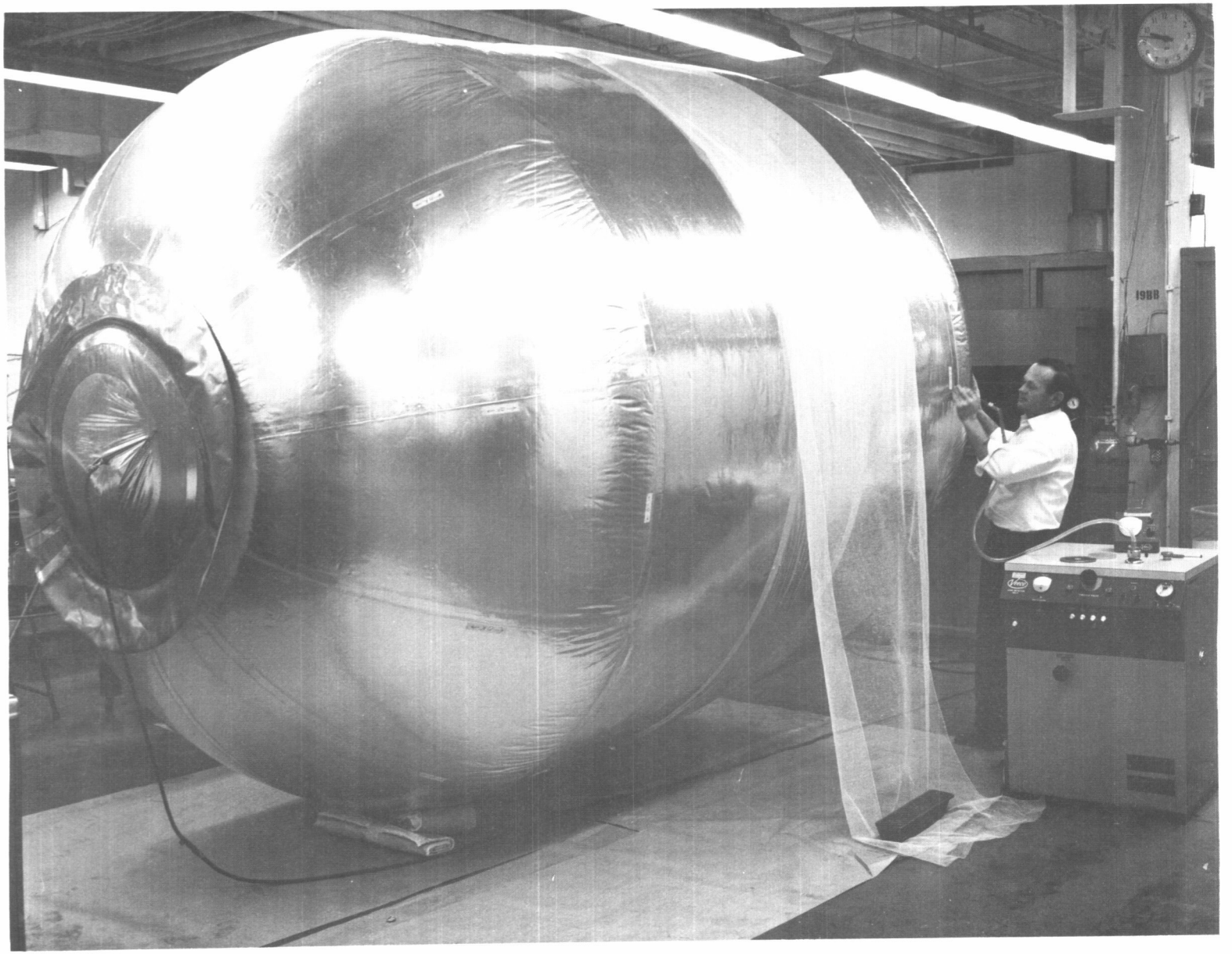


Figure 64. Leak-Testing Seams of 105-Inch Diameter Tank Vacuum Jacket Domes and Cylinder Sections

a shipping box. The unimpregnated Glassfloss mat was laid in the shipping box on top of the vacuum jacket halves. The glass mat served as a filler to prevent movement in the box during shipment.

SECTION IV. FLEXIBLE PURGE JACKET FOR 70-INCH DIAMETER LH_2 TEST TANK

A. GENERAL

This section describes the development, fabrication, and testing of a flexible helium purge jacket for a NASA-MSFC 70-inch diameter LH_2 test tank. The specified design requirements were as follows:

(1) The jacket must have a minimum of 3-inch clearance with the tank, which is shown in NASA-MSFC drawing 16-A-X-104.

(2) The jacket must be easily assembled to and removed from the insulated 70-inch diameter tank when the tank is mounted by four suspension struts in a test fixture.

(3) The purge jacket must be capable of withstanding 0.5-psi internal pressure.

(4) The purge jacket must have provisions for automatically opening at 0.5-psi pressure differential and provide approximately 4 square inches of vent area.

(5) The jacket material must have low helium permeability.

(6) The outer surface of the jacket shall be painted an aluminum color.

B. DESIGN

1. General

The NASA-MSFC 70-inch diameter tank drawing and the NASA-MSFC 70-inch diameter purge jacket specification control drawing 16-A-X-104 were analyzed and the purge jacket operational objectives were reviewed to establish the design approach. The parameters, assumptions, considerations, and test results in arriving at the design philosophy are discussed in the following paragraphs.

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2. Design Philosophy

a. Operating Environment. During the functional period of the purge jacket performance, it is assumed that the temperature of the environment surrounding the jacket will not drop appreciably below ambient conditions. In the vicinity of protrusions such as fill and vent lines, the vacuum jacket will be cooled below ambient temperature to a degree depending on factors of cold guard lengths, temperature of air surrounding the jacket, and shielding of the jacket by the space craft structural shell. In these areas, the jacket was designed to function flexibly at temperatures near the cryogenic fluid range. Simple tests were performed as shown in Figure 65 to verify the flexibility of the jacket material when cooled by contacts with metal plumbing containing liquid nitrogen.

b. Purge Jacket Movement. During the functional period, the purge jacket will be inflated with gaseous helium to a shape having a minimum of 3-inch clearance with the 70-inch diameter test tank. To inflate the jacket, several evacuation and helium purge cycles will be required to ensure the desired helium concentration in the insulation. The purging cycles will involve shrinkage of approximately 7 percent on the side wall and 15 percent on the dome ends of the jacket. The shrinkage will contribute to a proportional degree of wrinkling and folding of the jacket. Therefore, a pliable jacket material is required which can withstand repeated flexing without degradation of physical and leak-tight properties.

c. Treatment of Protrusions. The protrusions existing on the 70-inch diameter test tank will involve purge jacket terminations of complex shapes around the four support rods. Due to the jacket shrinkage requirement discussed earlier, the purge jacket terminations were designed as flexible jacket material sleeves of sufficient length to permit contraction of the jacket without stretching the sleeves.

d. Arrangement of Components. To facilitate assembly and removal of the purge jacket on the insulated 70-inch diameter test tank, the jacket was split into two half shells, with the split line aligned with the longitudinal axis of the tank. The split lines are joined with gas-tight zipper fasteners that start and terminate in two diametrically opposite protrusion cover sleeves and in the fill and vent line protrusion cover sleeve. To install the purge jacket, the tank support rod that penetrates half of the jacket would be loosened at the attachment to the test fixture, the jacket slipped over the rod, and the rod refastened. The opposite half of the jacket could be installed in the same manner; therefore, the design permits jacket installation with the tank supported by three of four support rods at all times.

e. Venting Characteristics. To enable the helium purge gas to escape from the jacket and insulation during the ascent phase, a vent must be designed in the

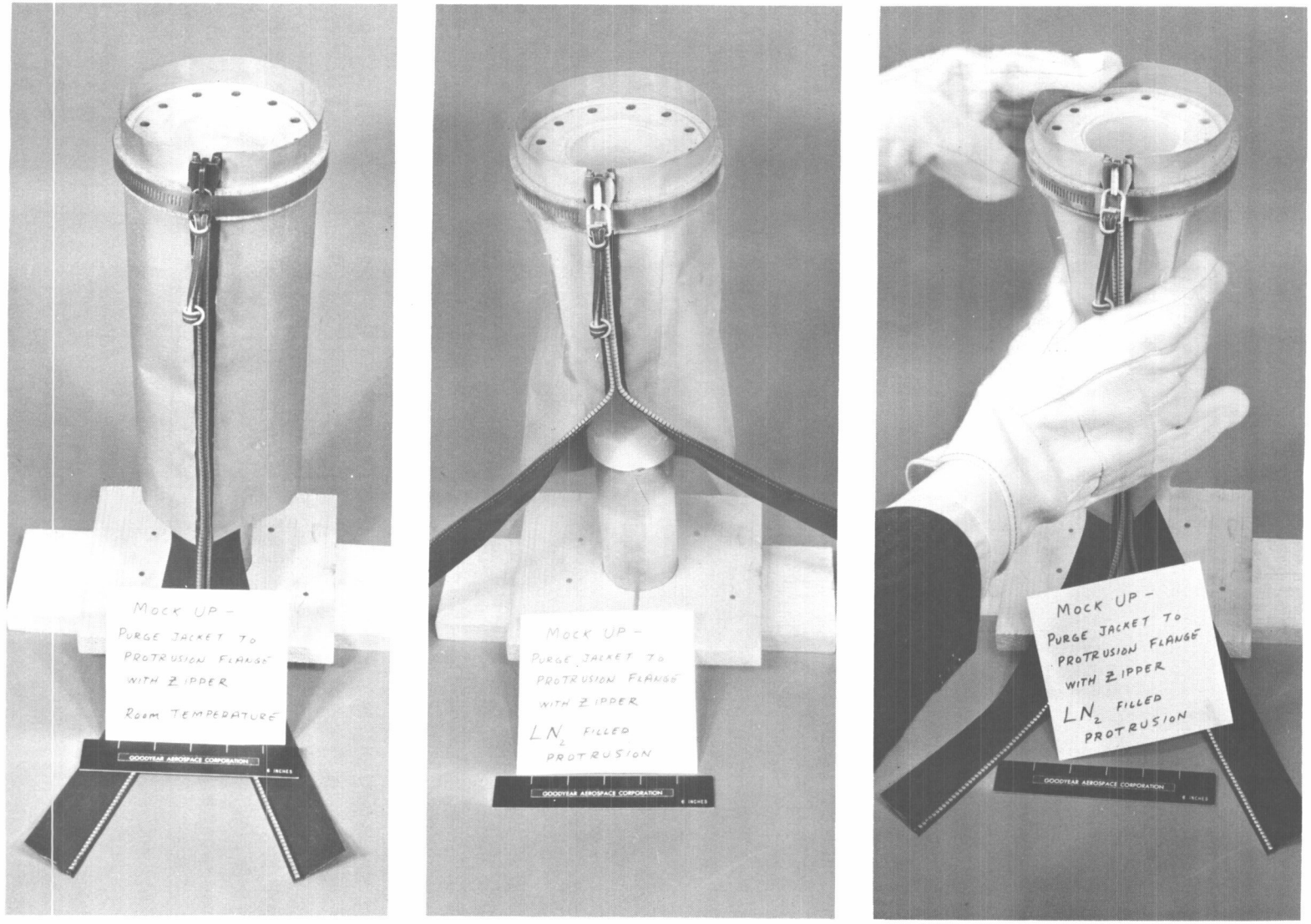


Figure 65. Flexibility Tests of Purge Jacket in Area of Attachment to Cryogenic Pipe

purge jacket that will be simple, lightweight, and reliable in operation. Two approaches were investigated: (1) pressure relief valves that could be in the jacket wall and (2) a zipper release design that would open a length of zipper at a predetermined pressure. The latter approach was selected because of desirable weight, cost, and reliability factors.

f. Adhesive Requirements. Although the major portion of the purge jacket will be at ambient temperature, some areas of the jacket may be cooled to the cryogenic range. These areas require the use of cryogenically compatible adhesive to bond the jacket seams and the zippers. Because the temperature along the jacket seams can vary from ambient to cryogenic, the adhesive selection will be based on the most efficient room temperature curing adhesive which will demonstrate suitable flexibility and adhesion at cryogenic temperatures. As noted in paragraph a, the simple tests shown in Figure 65 will verify the adhesive selection.

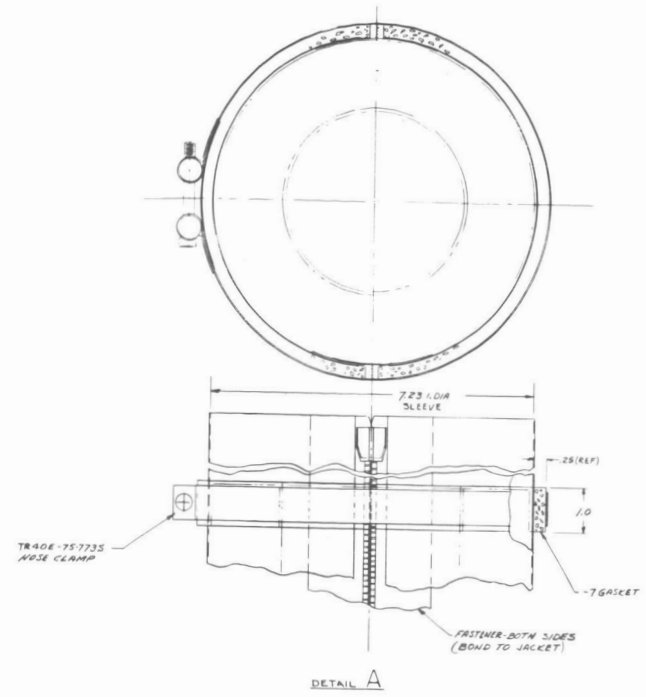
3. Flexible Purge Jacket Final Configuration

The final design drawing is shown in Figure 66 (Sheets 1 and 2). The basic configuration was obtained using NASA-MSFC drawing 16-A-X-104 of the 70-inch diameter tank. To facilitate installation and removal of the jacket, zippers were incorporated into the design. The design of the zipper release for automatically opening the jacket at 0.5-psi differential pressure was developed by tests discussed in subsection D.

The material chosen for the jacket was a polyurethane-coated Dacron fabric purchased from The Goodyear Tire & Rubber Co, Akron, Ohio. This material (stock No. XA28-A367) had been investigated and used for a similar helium purge jacket application which had a low helium permeability requirement. The coated material weighs 8.10 ($\pm$0.5) oz/yd^2. The average tensile breaking loads of the fabric are 133 lb/in. in warp direction and 110 lb/in. in fill direction. This will allow a safety factor in excess of 4.

The dome gores and side panels are bonded together with a neoprene adhesive, The Goodyear Tire & Rubber Co system 1497-C and 1473-C. All penetration cutouts in the envelope are reinforced with doubler plies to transfer discontinuity stresses. Tension tie patches are used to reduce the tension loads across the zippers at the points of high stresses.

Talon size 84 O. E. B. zipper fastener was chosen for this application. The crosswise strength of the fastener is 90 lb/in. minimum. The leak-tightness of the fastener is rated at 0.015 grams/24 hr/ft moisture vapor transmission at 100°F and 95 percent humidity.



NOTES : UNLESS OTHERWISE SPECIFIED

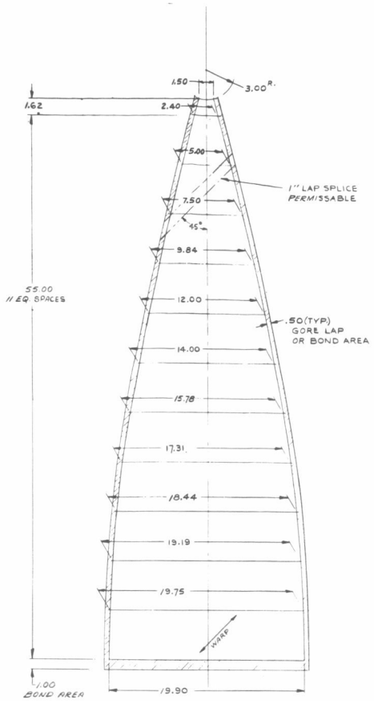
1. ALL BONDS TO BE MADE WITH 1437 C & 1473 C ADHESIVE SYSTEM (GOODYEAR TIRE & RUBBER CO.)
2. THE JACKET ASSY (MASK OFF TEETH OF FASTENERS) SHALL BE SPRAY PAINTED WITH THE FOLLOWING MIXTURE. THE BASIC COATING SHALL BE MIXED IN THE RATIO OF 51149 F837 RESIN, 13 P.B.W. & 01569 F836 ACCELERATOR (1 P.B.W. THIS MIXTURE EQUALS AS 01569 F838 (GOODYEAR TIRE & RUBBER CO). THIS MIXTURE SHALL BE THOROUGHLY MIXED PRIOR TO ADDING REMAINING INGREDIENTS TO EACH GALLON OF THE ABOVE MIXTURE ADD :
   (A) 1 GALLON MEK
   (B) 2.75 GALLON XYLOC
   (C) 1 QUART CAB-O-SEAL (SAMUEL CABOT INC. BOSTON MASS. THOROUGHLY MIX ABOVE INGREDIENTS & THEN ADD 10 PARTS OF 7468 ALCOA ALUMINUM POWDER TO 100 PARTS OF FLUID MIXTURE BY WEIGHT THE ABOVE MIXTURE MUST BE THOROUGHLY MIXED PRIOR TO SPRAYING COATING
   THE FINISH COATING SHALL BE SPRAY COATED. CURE 24 HRS AT ROOM TEMPERATURE
3. IDENTIFY BY STENCILING PART NO. WITH 3/8 CHARACTERS USING BLACK PAINT

Figure 66. Flexible Purge Jacket for 70-Inch Diameter LH_2 Test Tank (Sheet 1 of 2)

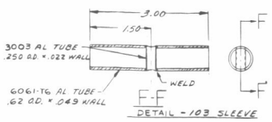
FOLDOUT FRAME

FOLDOUT FRAME 1

FOLDOUT FRAME 2

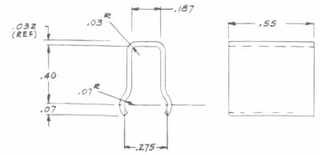


DETAIL GORE PANEL

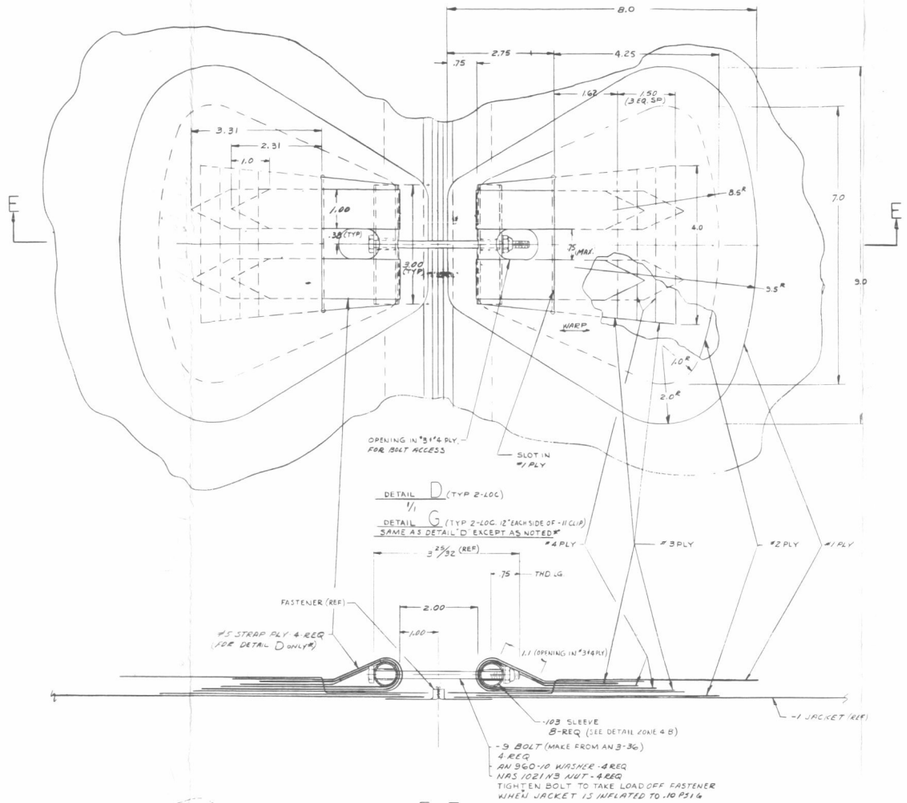


E-F

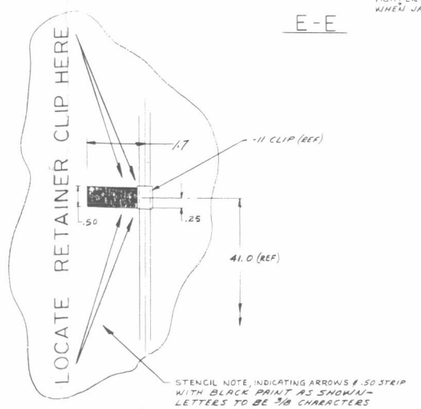
DETAIL -103 SLEEVE



DETAIL -11 CLIP



E-E



DETAIL J

Figure 66. Flexible Purge Jacket for 70-Inch Diameter LH_2 Test Tank (Sheet 2 of 2)

132-B
Fig. 66

The zipper release was designed as a simple and reliable device - a retainer clip snapped over the zipper in an area having a calculated number of teeth removed from the fastener. Crosswise loads on the zipper in this area are carried by the retainer clip that is designed to yield and snap off at the strain level imposed by 0.5-psi internal pressure in the jacket. The installation and function of the zipper release device on the 70-inch diameter tank purge jacket was developed to final configuration as described in the following subsection.

C. FABRICATION

The purge jacket was fabricated as shown in Figure 66. The basic construction was a cylinder section secured to top and bottom dome assemblies made up of gore segments. The cylinder section comprised two cylinder segments of fabric joined together to obtain sufficient cylinder section length. The support struts and neck tube protrusion covers were flexible fabric cone and tube sections joined to cutouts in the basic envelope. All bonds of fabric seams were made with The Goodyear Tire & Rubber Company 1473-C adhesive system.

Prior to installation of protrusion covers and the zippers, the basic envelope was inflated to 0.5 psi for dimensional check. The protrusion covers were then added and a second dimension check was made. The zipper location was marked on the envelope and covers prior to deflation. The zippers were added, and the envelope was reinflated for a dimension check and addition of the zipper release retainer clip. The zippers were bonded to the envelope with the 1473-C adhesive system used on envelope seams.

D. ZIPPER RELEASE DESIGN TESTS

1. Preliminary Design Tests

Preliminary designs of the retainer clip on the jacket zipper were fabricated for qualification on the zipper pressure-release test set-up shown in Figure 67. The test set-up was designed to pressurize a 7.5-inch diameter sleeve of jacket material which is closed with a Talon size 84 O.E.B. zipper. At 5 psig, the hoop tension load on the zipper is equivalent to the 19 lb/in. hoop load in the full-scale jacket at 0.5 psi. The operation sequence of a temporary clamp is shown in Figure 68. Tests of the retainer clip designs were conducted, arriving at a final design as shown in Figure 69. The operation sequence of this retainer clip is shown in Figure 70. The clip consistently withstood zipper release up to 4.75 psig, representing a 17.8 lb/in. hoop load, which is equivalent to 0.47 psig in the 70-inch diameter jacket.

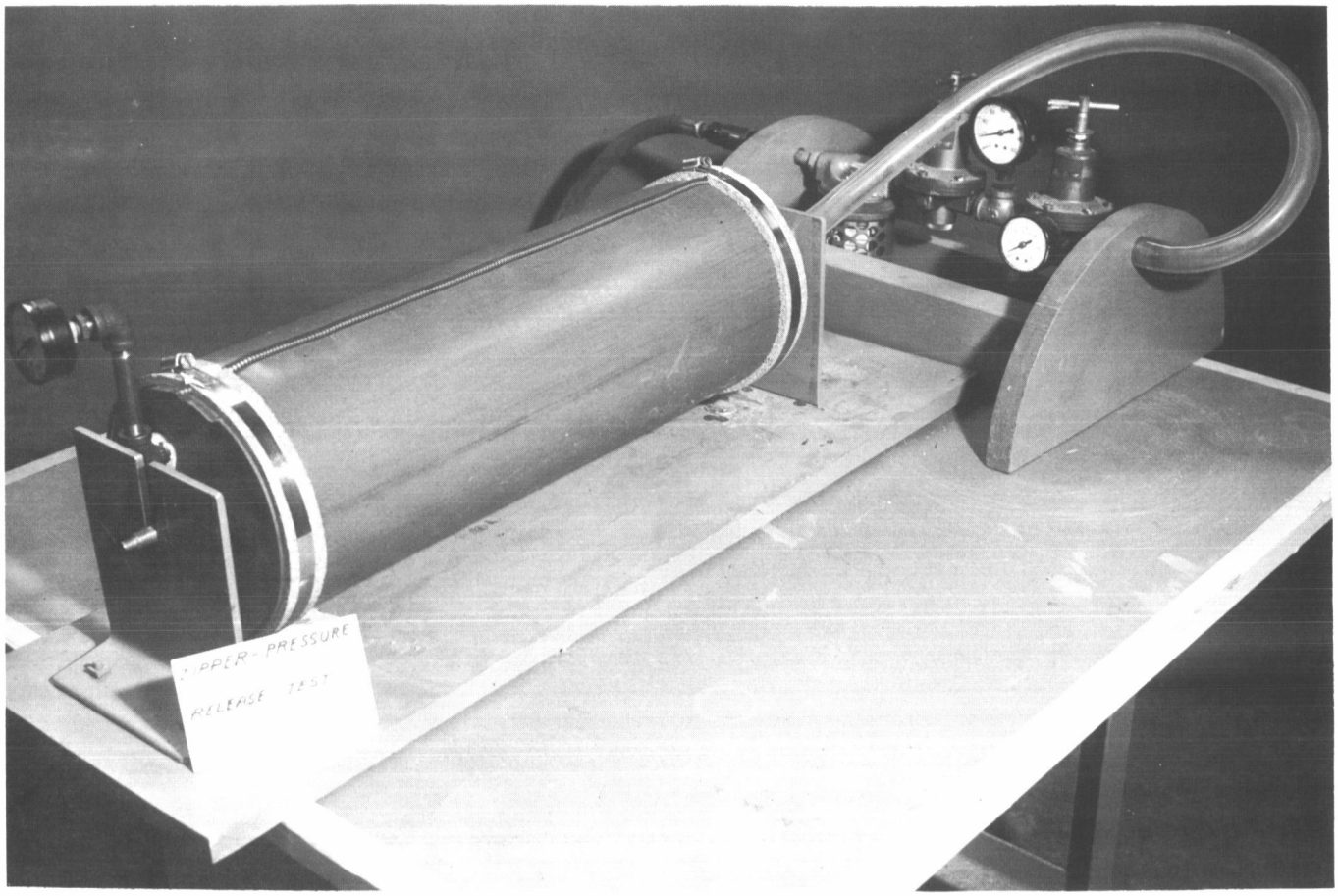
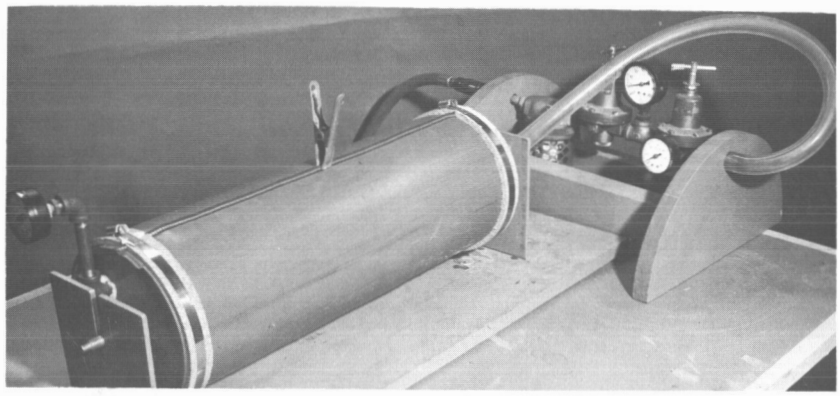
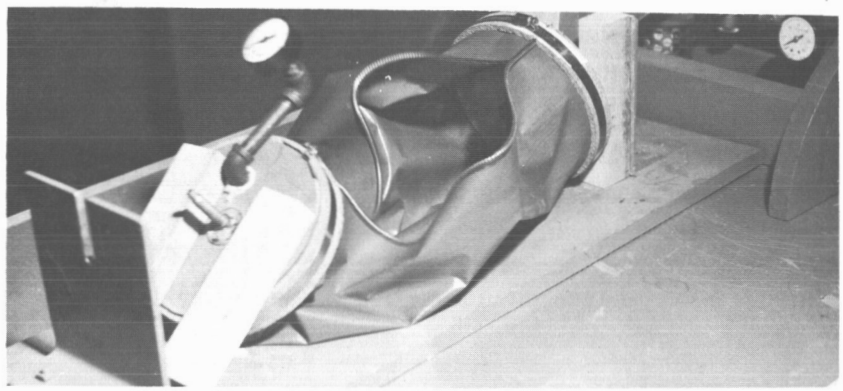


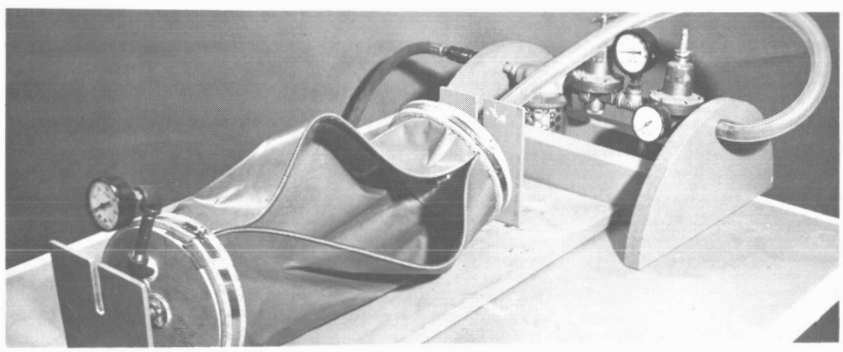
Figure 67. Zipper Pressure-Release Test Set-Up



BEFORE RELEASE OF ZIPPER - TEMPORARY CLIP IN PLACE



DURING RELEASE



AFTER RELEASE

Figure 68. Zipper Pressure-Release Sequence with Temporary Retaining Clamp

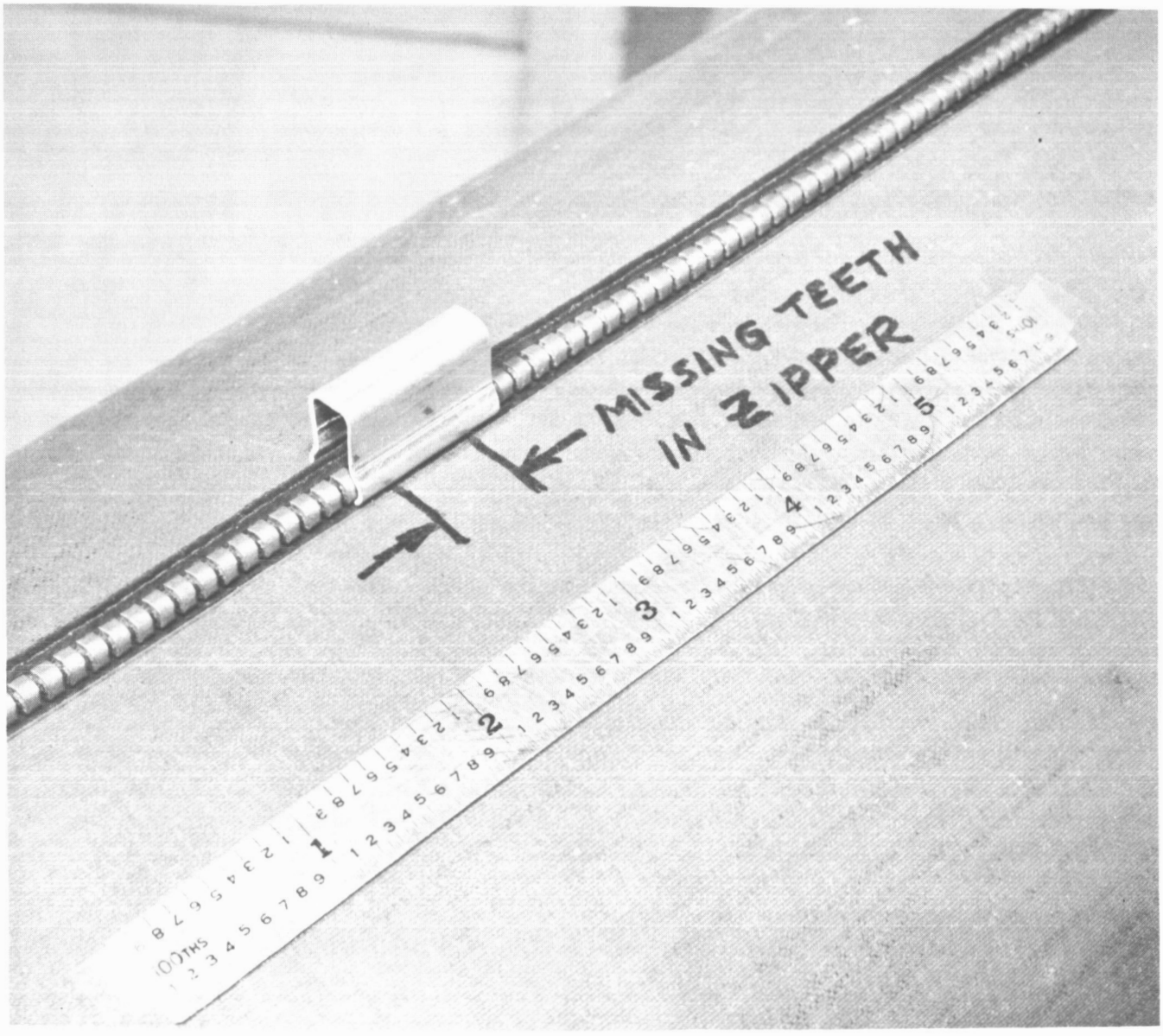
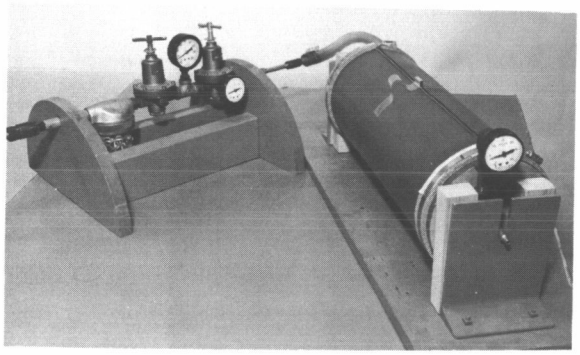
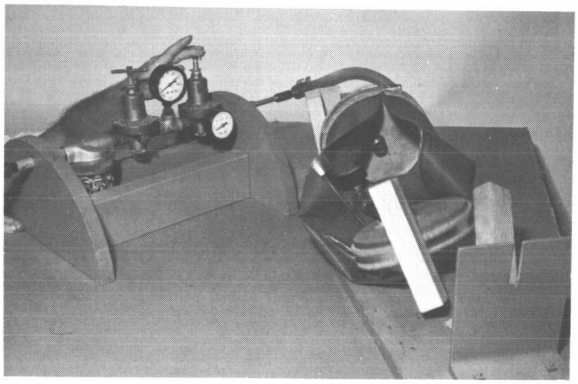


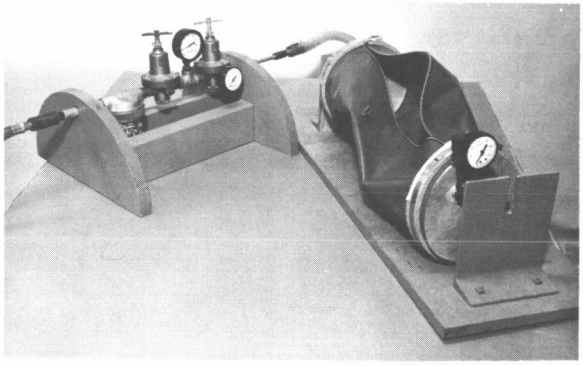
Figure 69. Retainer Clip on Zipper in 7.5-Inch Diameter Sleeve Test Cylinder



BEFORE RELEASE OF ZIPPER -
CLIP IN PLACE



DURING RELEASE



AFTER RELEASE

Figure 70. Zipper Release Sequence with Retaining Clip on 7.5-Inch Diameter Test Sleeve

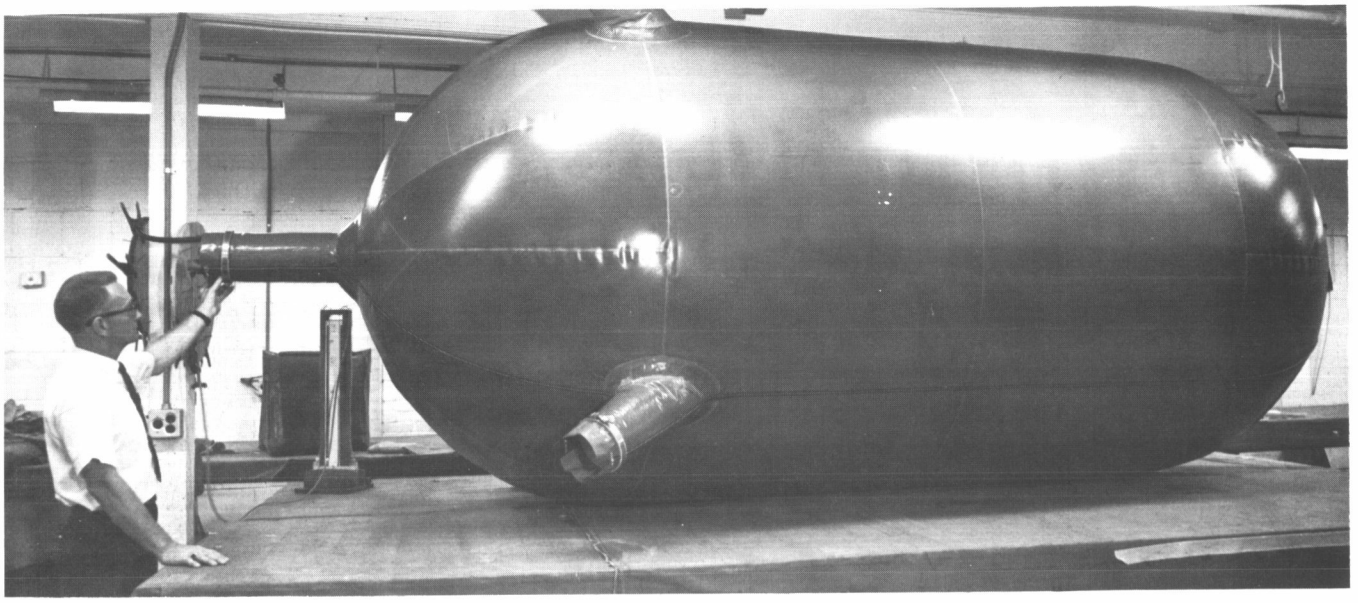


Figure 71. Inflated 70-Inch Diameter Tank Jacket

2. Final Design Tests

An inflation test of the zipper release device was run on the completed jacket (see Figure 71). The retainer clip on the jacket zipper release was located on one side of the jacket, one half the distance between the load rod sleeve and the tangent point of the bottom dome of the jacket. To test the zipper release and clip operation, the jacket was pressurized to 0.55 psi on the first cycle without experiencing release of the clip and zipper. The pressure was relieved and clip removed to shorten the length 0.12 inch. During the second pressure cycle, the jacket could not be pressurized above 0.4 psi, although the retainer clip was still in place. An investigation revealed a 3-inch long split in the zipper at the base of one load rod sleeve (see Figure 72).

The split involved tear-out of the teeth from the zipper fabric tape on one-half of the zipper. An analysis of the failure revealed that the zipper was overloaded in a critical hoop stress area due to the combined hoop loads and axial loads induced in the sleeves by the internal pressure acting on the blanking plugs clamped in the sleeves. During normal operation of the jacket on the 70-inch diameter tank, the sleeves will be secured to disks on the support struts and therefore will not be axially loaded.

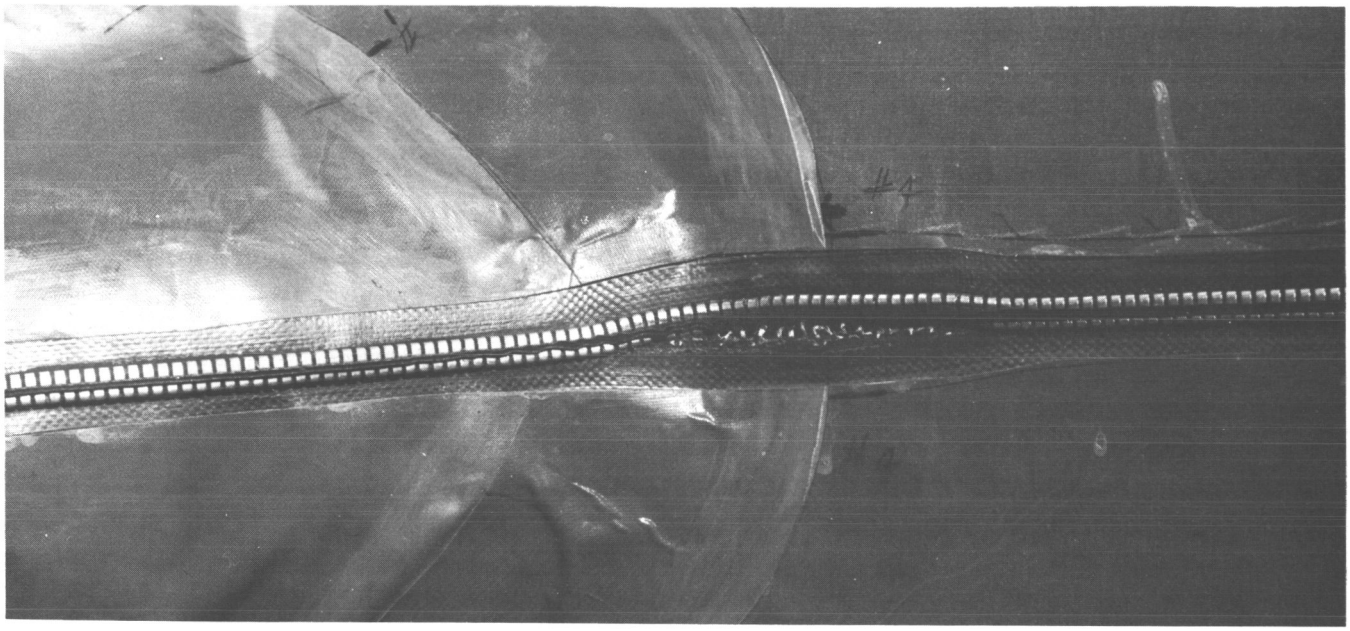


Figure 72. Split in Zipper at Base of Load Rod Sleeve on 70-Inch Diameter Tank Jacket

The zipper failure area is a critical stress region due to cutouts for the load rod sleeves. To improve the margin of safety in these areas, the jacket design was revised to install load-carrying patches on opposite sides of the zipper in the region of zipper failure. The patches were connected by a tie-bolt that can be adjusted to carry the hoop strain and thereby relieve the load on the zipper. On sleeves without zippers, an additional ply of fabric was added in the region of high stress. The damaged zipper half was removed from the jacket and sent to Talon Inc for manufacture of a matching replacement part.

The jacket was reworked by adding four load-carrying patches and a replacement zipper half. The load-carrying patches, connected by a tie-bolt between each pair, were adjusted to relieve the hoop load on the zipper at the base of the load rod sleeves when the jacket is inflated to 0.5 psig. Visual inspection during the initial inflation of the jacket indicated that operation of the load-carrying patches was satisfactory.

The retainer clip on the zipper release was located on one side of the jacket approximately 40 inches from the tangent point of the bottom of the jacket. Four consecutive teeth were removed from half of the zipper in the area of the retainer clip. To test the zipper release and clip operation, the jacket was pressurized to 0.5 psig.

At this point in the test, the clip was still firmly in place on the zipper and would not release even when struck several sharp blows with a wooden stick. To observe the zipper opening at 0.5-psi pressure, the clip was pulled off by means of a tether. The zipper did not open upon removal of the retainer clip. To cause the zipper to open, the opening started by the removal of four teeth was manually increased to approximately 3 inches, at which point the zipper split open very rapidly for a total distance of approximately 12 feet. With relation to the location of the retainer clip, the zipper opening extended in one direction to the center of the bottom dome, or 100 inches; and in the opposite direction to the tension tie patches at the base of the load rod sleeve, or 41 inches. It was noted that the tension tie-patches stopped the progress of the zipper opening by relieving the hoop tension load on the zipper.

Examination of the zipper revealed that the teeth in the old half of the zipper had completely pulled out and were retained in the new half for a length of 28 inches each in two areas, starting at an average of 12 inches on either side of the retainer clip location. A typical tear-out area is shown in Figure 73.

Technical representatives from Talon, Inc visited GAC to examine the zipper failure. The following conclusions and recommendations were reached:

(1) Zipper failure was attributed to two factors:

(a) The individual zipper teeth were on the high side of a length tolerance, which would require a higher load to unlock the zipper.

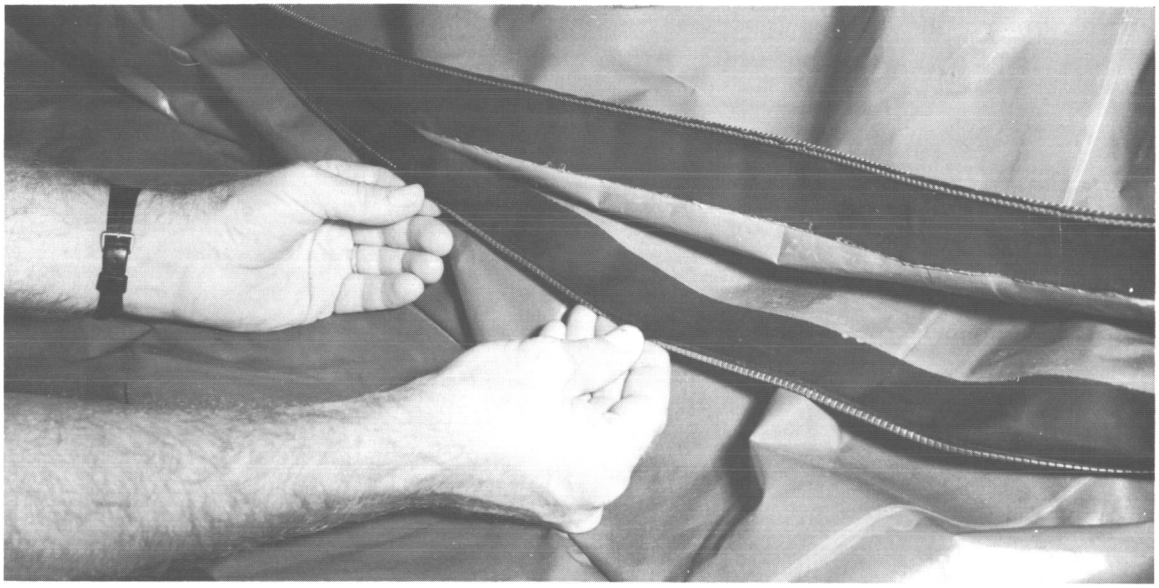
(b) In the areas of tooth tear-out, the zipper had opened at an angle below the minimum critical angle. This occurred because of the length of the zipper opening.

(2) Recommended corrective action:

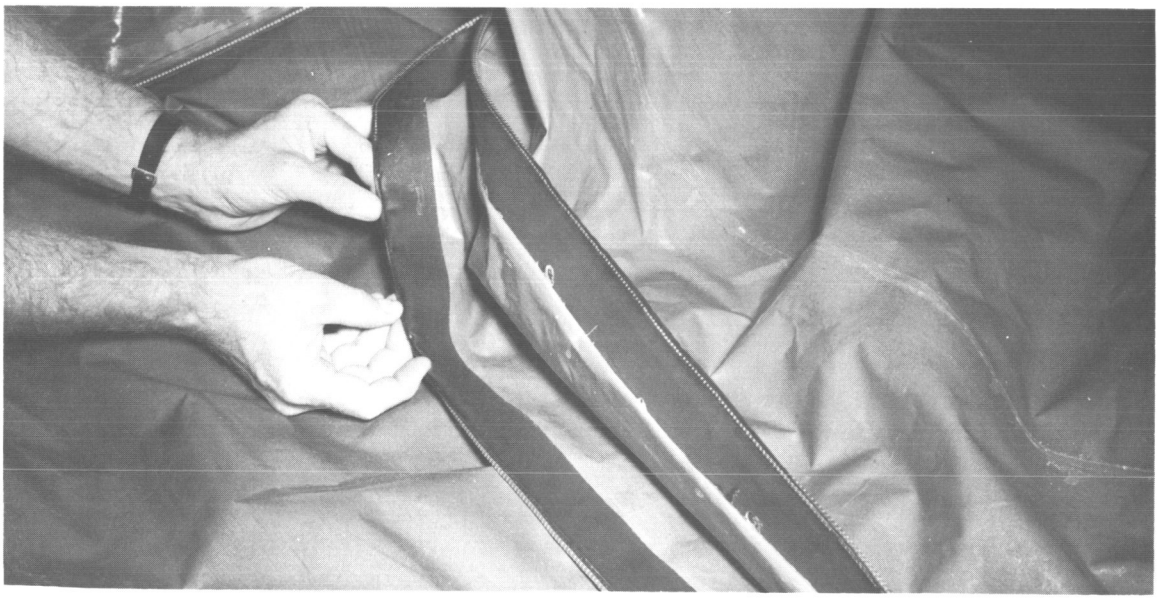
(a) The replacement zipper will have tooth lengths of the nominal size.

(b) A light lubricant will be applied in the area of the zipper opening to reduce opening friction.

(c) The length of zipper opening will be limited to 24 inches. This will be accomplished by addition of load-carrying patches and tension tie-bolts spaced a distance of 12 inches on each side of the retainer clip. The ability of these devices to stop the zipper opening has been demonstrated.



ZIPPER TOOTH TEAR-OUT NEAR BOTTOM DOME
(Note that teeth from bottom half
are retained in upper half.)



ZIPPER TOOTH TEAR-OUT NEAR LOAD ROD SLEEVE

Figure 73. Zipper Failure in 70-Inch Diameter Tank Jacket

A replacement zipper was received and installed, and the jacket was reassembled, incorporating the following corrective action:

(1) The replacement zipper had tooth lengths of nominal size.

(2) A molybdenum-disulfide dry lubricant was applied in the zipper opening area to reduce opening friction.

(3) Load-carrying patches and tension tie-bolts were added at a distance of 12 inches on each side of the retainer clip location as shown in Figure 74. The effectiveness of these devices to limit the zipper opening to 24 inches is shown in Figure 75, wherein the zipper opening is shown after ejection of the retainer clip at 0.5-psig envelope pressure.

Eight pressure tests were conducted to adjust the zipper retainer clip to release at an envelope pressure of 0.5 psig. These tests consisted of unsnapping or unlocking various numbers of zipper teeth in the area of the retainer clip until the clip ejected and the zipper opened at 0.5 psig. Repeated zipper openings at this pressure were achieved with a total of 10 teeth unlocked for an effective unlocked length of 1.25 inches retained by a 0.40-inch length of retainer clip. At the conclusion of these tests, the 10 unlocked teeth were permanently unlocked by cutting them off one-half of the zipper assembly in the clip location shown in Figure 76.

After final check-out the jacket assembly was spray-painted with aluminum coating and then stenciled per Detail J of Figure 66 (Sheet 2). The completed jacket assembly as shown in Figure 77 was packaged and shipped to NASA-MSFC, Huntsville, Alabama.

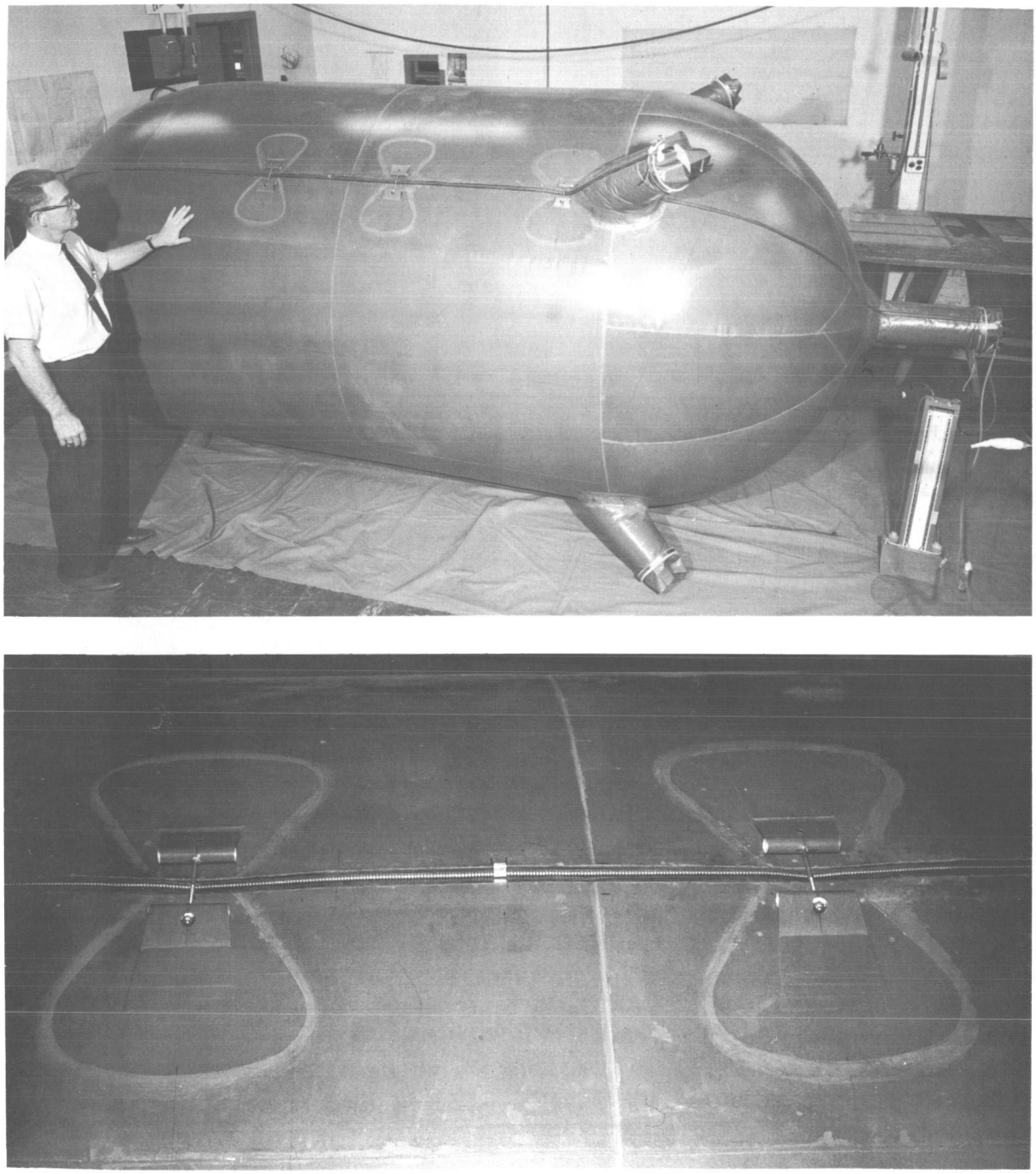


Figure 74. Patches and Tension Tie-Bolts for Limiting Zipper Opening to 24 Inches

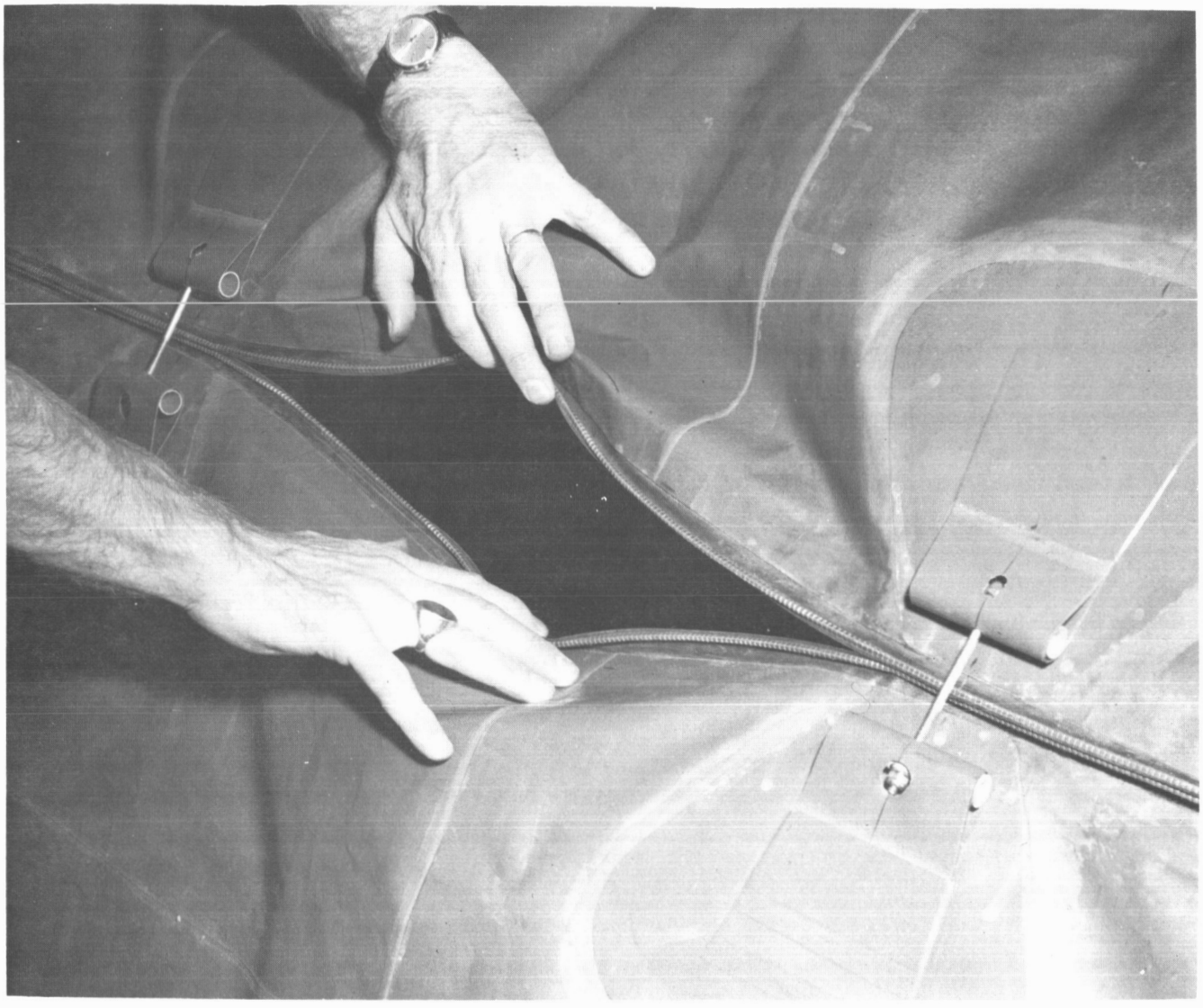


Figure 75. Zipper Opening after 0.5-PSI Pressurization of Jacket

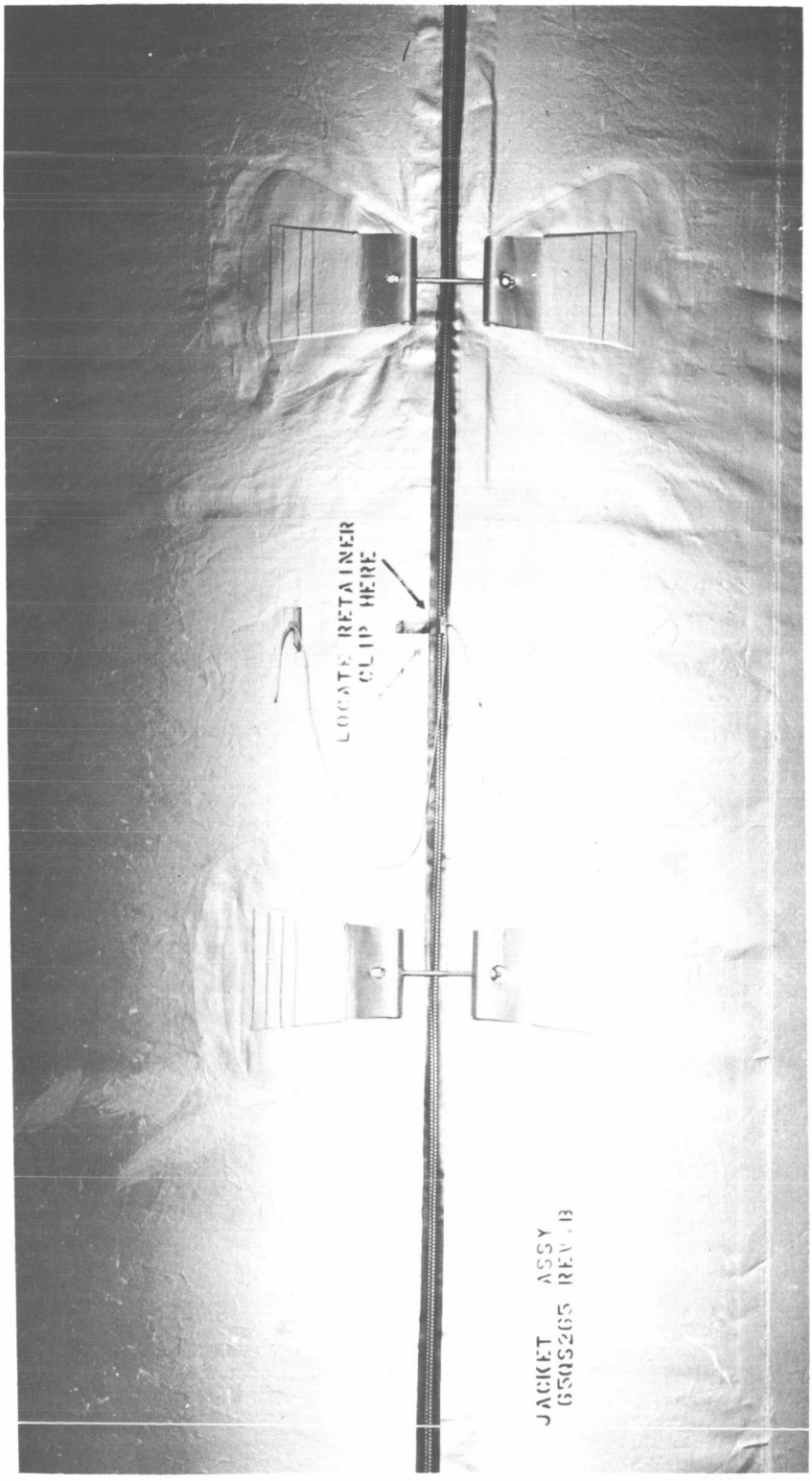


Figure 76. Zipper Retainer Clip Installation



Figure 77. Completed Purge Jacket Assembly for 70-Inch Diameter Tank

SECTION V. FLEXIBLE PURGE JACKET FOR 105-INCH DIAMETER LH_2 TEST TANK

A. GENERAL

This section describes the development, fabrication, and testing of a flexible purge jacket for a NASA-MSFC 105-inch diameter LH_2 test tank. The specified design requirements were as follows:

(1) The jacket shall be flexible.

(2) The jacket shall satisfactorily withstand an internal pressure of 0.5 psig.

(3) Reinforcement shall be applied at the protrusions to transfer discontinuity stresses.

(4) Leak-tight zippers shall be used for final assembly and closeout.

(5) One zipper shall be capable of opening automatically at 0.5 (±0.05) psig internal pressure.

(6) The materials used in the jacket fabrication shall have satisfactory off-gassing characteristics and thermal emissivity.

(7) The purge jacket shall maintain a minimum clearance of the tank and protrusions as specified in NASA-MSFC Drawing 16-A-X-247, dated 20 July 1966.

The purge jacket was designed as shown in Figure 78, based on the experience obtained during the development program on the 70-inch diameter tank purge jacket. The jacket was fabricated and tested, and shipped to NASA-MSFC.

B. DESIGN

The design as shown in Figure 78 (Sheets 1 and 2) utilized the experience gained on the development of the 70-inch diameter tank purge jacket.

The NASA-MSFC 105-inch diameter tank drawing and the NASA-MSFC 105-inch

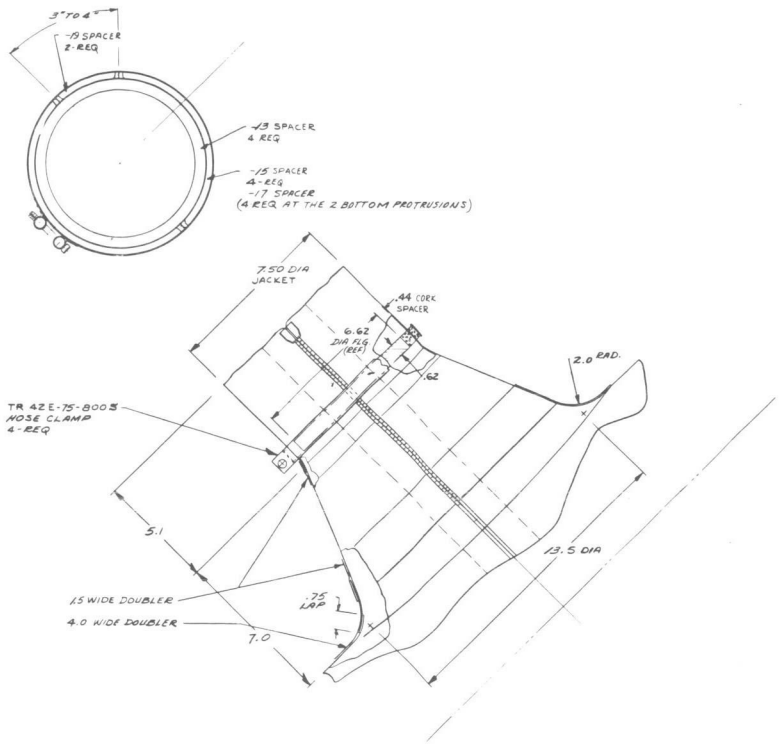
diameter tank purge jacket specification control drawing 16-A-X-247 were analyzed and the purge jacket operational objectives were reviewed to establish the design approach. The design philosophy was based on same parameters, assumptions, considerations, and test results that were applicable to the 70-inch diameter tank purge jacket (see Section IV). The jacket was designed to meet the minimum jacket-to-tank clearance specified on NASA-MSFC drawing 16-A-X-247. Due to a jacket-to-test fixture clearance problem in the area of the A-frame fitting, the design differs from the NASA-MSFC drawing in that the radius of the jacket over the A-frame fitting was reduced from 6.50 to 3.50 inches, as shown in Figure 78. In addition to solving the clearance problem, the design of the jacket in the A-frame area is also more practical for fabrication by simplifying the connection of the tubular sleeves to the jacket over the A-frame fitting area. It should be noted that while this design provides clearance between the jacket and the support structure, the proximity of the support structure to the 7-inch diameter jacket sleeves may cause some inconvenience when actuating the zippers on the sleeves.

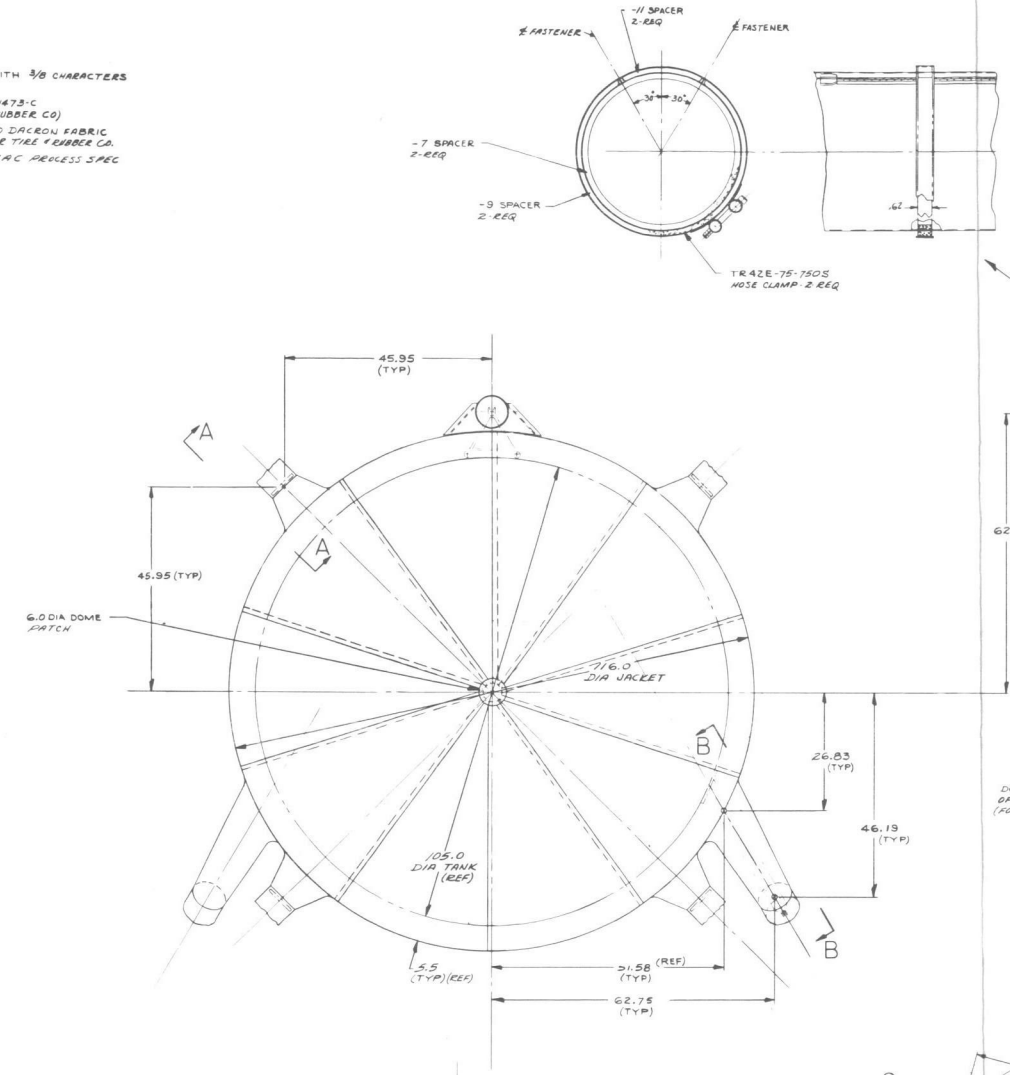
To provide the necessary clearance between the purge jacket and the 105-inch diameter tank support structure in the A-frame support area, an aluminum hard cover was designed as shown in Figure 79 to restrain the purge jacket to the "pup-tent" shape required to provide clearance. For simplicity of fabrication and installation, the hard cover was designed as a three-piece assembly constructed from 0.125-inch thick aluminum sheet as shown in Figure 79. Four clevis rods are provided, one in each corner, to secure the cover to the purge jacket assembly.

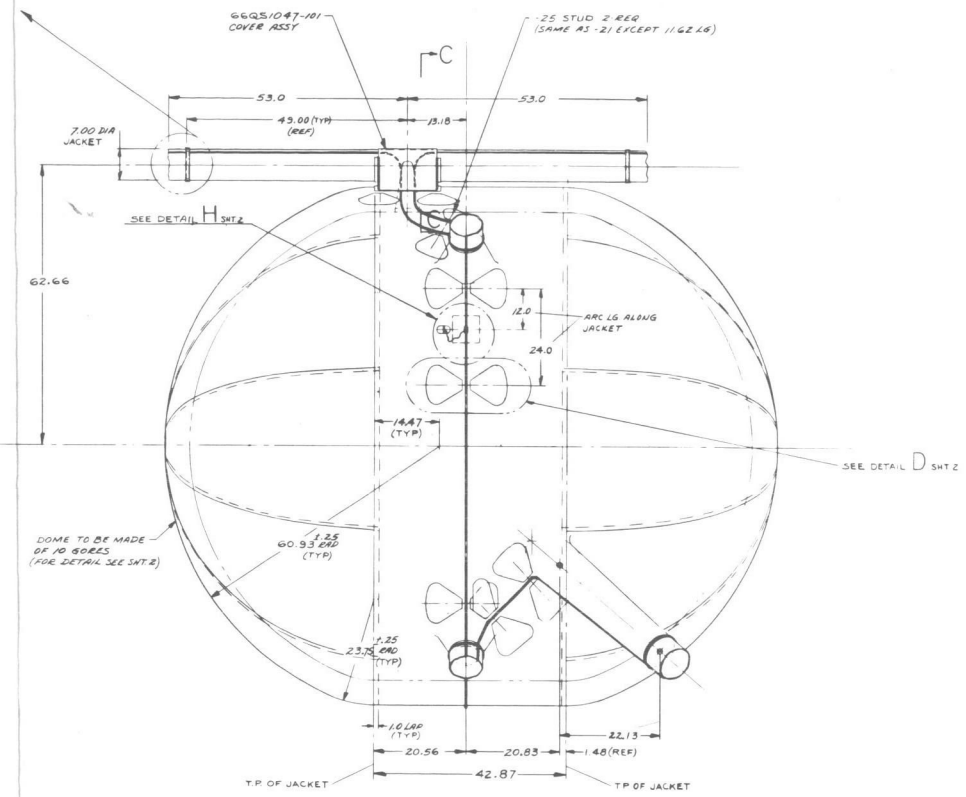
During the design development of the purge jacket for the 70-inch diameter tank, it was determined that the length of zipper openings at rapid depressurization must be restricted to prevent damage to the zipper. The manufacturer (Talon, Inc) set a maximum opening of 24 inches. During the design of the 105-inch diameter tank purge jacket, it was felt that increasing the opening length of the zipper would be desirable from the standpoint of increasing the vent area. Accordingly, a meeting was held at Talon, Inc, Meadville, Pennsylvania, to explore ways and means of increasing the length of the zipper opening. The suggestion offered by Talon was to incorporate a pair of spring-loaded retractor devices at a point along the zipper 12 inches from the retainer clip location. After release of the retainer clip and during the opening of the zipper, the purpose of the retractors is to pull the jacket open wider at this point, thus increasing the included angle between the zipper halves to an angle above the minimum critical angle at which the zipper will peel open without damage to teeth. With the retractor device, it is anticipated that the length of the zipper opening could be at least double the present 24-inch length. The Talon engineering personnel have had little previous experience with such devices and agreed that testing would have to be performed to establish the validity

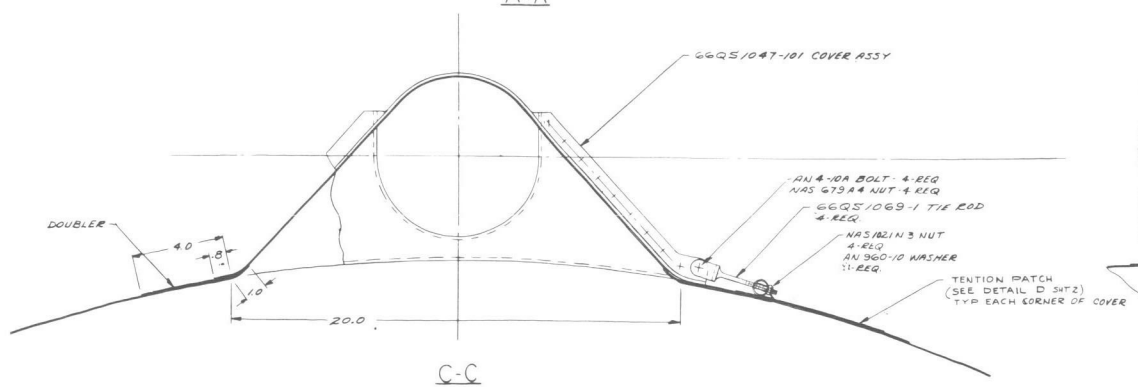
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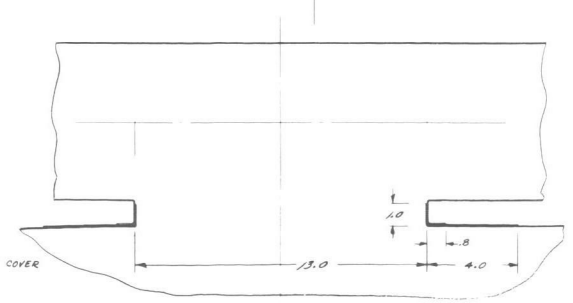
1. IDENTIFY BY STENCILING PART NO. WITH 3/8 CHARACTERS USING BLACK PAINT
2. ALL BONDS TO BE MADE WITH 1497-C & 1473-C ADHESIVE SYSTEM (GOODYEAR TIRE & RUBBER CO)
3. MATERIAL TO BE POLYURETHANE COATED DACRON FABRIC PER MIL-C-83367-1 (ALUMINUM), GOODYEAR TIRE & RUBBER CO.
4. CADMIUM PLATE IN ACCORDANCE WITH GAC PROCESS SPEC F-5100 TYPE I, CLASS 1.

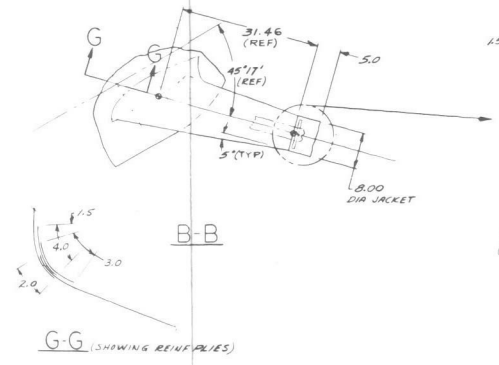












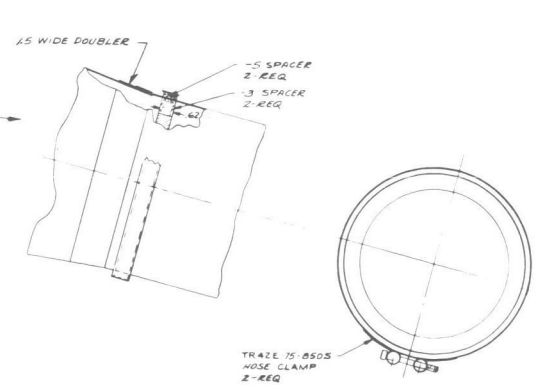
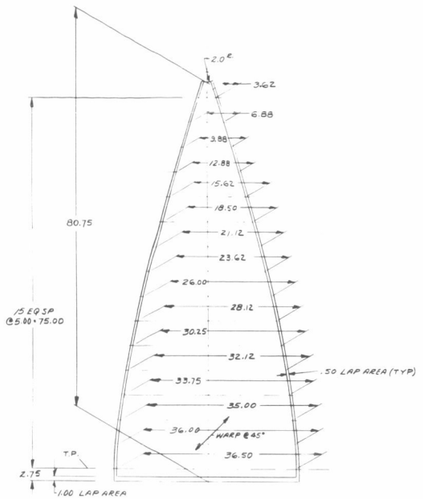


Figure 78. Flexible Purge Jacket for 105-Inch Diameter LH_2 Test Tank (Sheet 1 of 2)

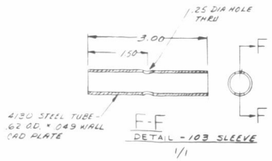
FOLDOUT FRAME 1

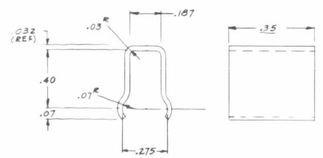
FOLDOUT FRAME

FOLDOUT FRAME 2

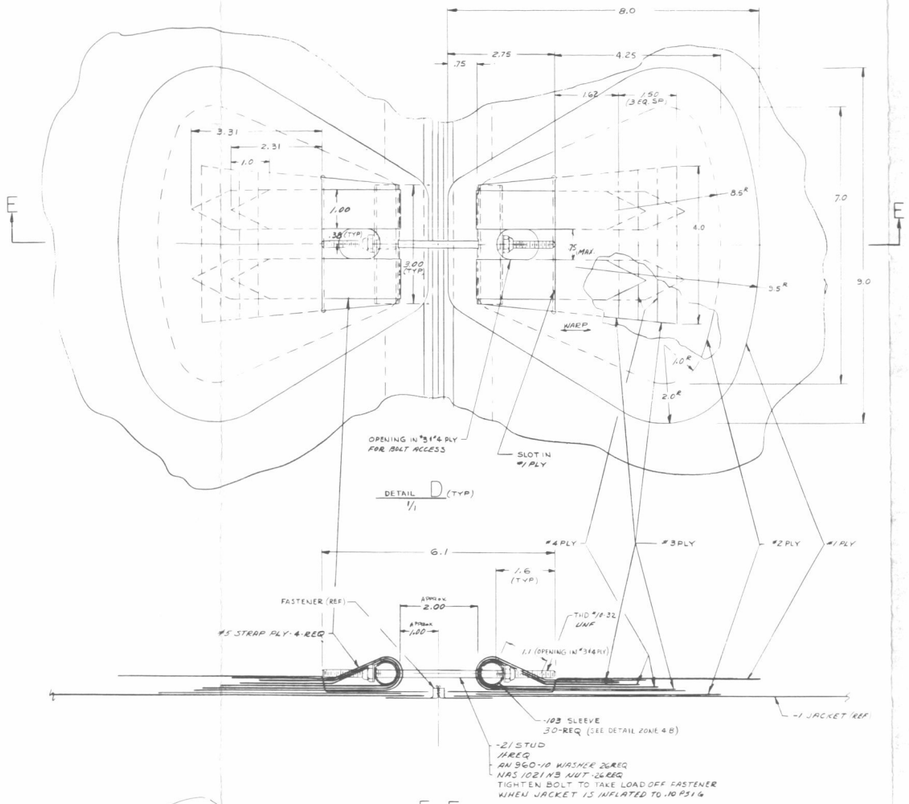


DETAIL GORE PANEL
(MATL MAY BE SPLICED BY USING 1" LAP SPLICE)





DETAIL -11 CLIP



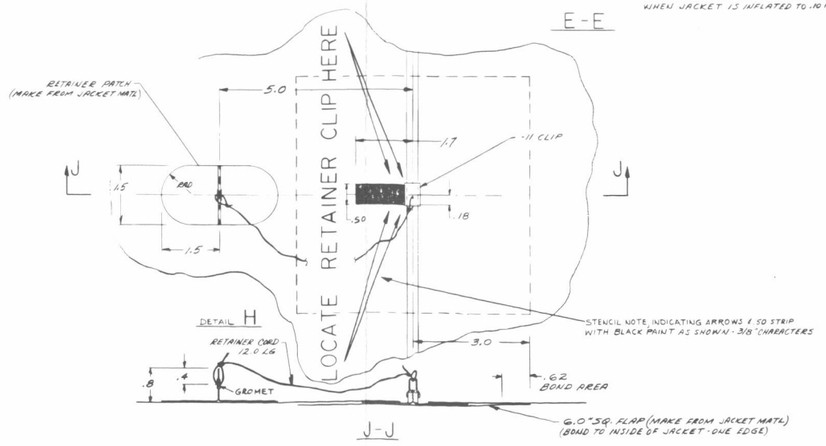


Figure 78.A Flexible Purge Jacket for 105-Inch Diameter LH_2 Test Tank (Sheet 2 of 2)

Fig 78.A
150 - A

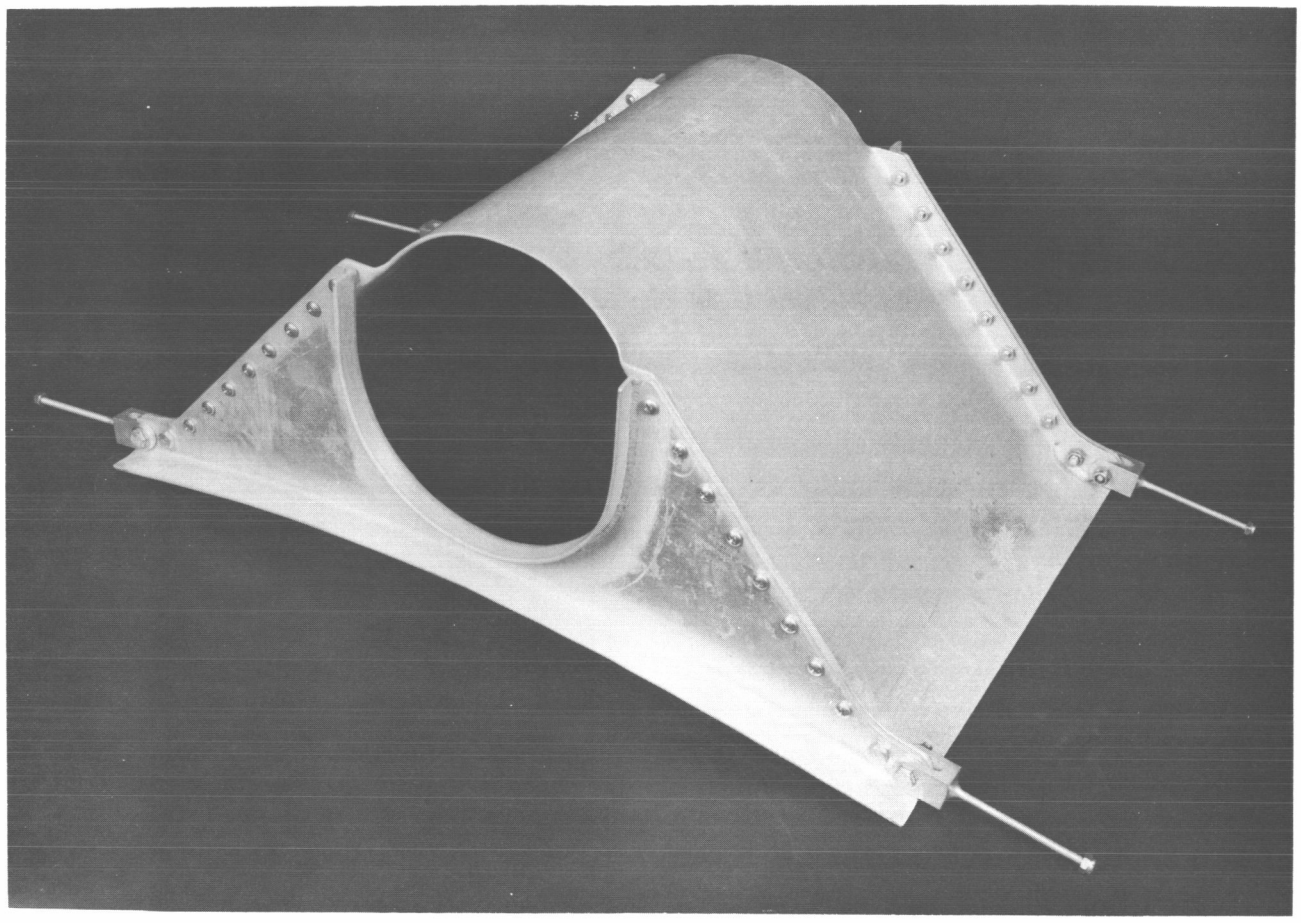


Figure 79. Hard Cover Assembly for A-Frame Area

and reliability of the device. After considering a test plan, it was decided that GAC could not build and test this device within the present funding and delivery schedule requirements for the 105-inch diameter tank jacket. If an increased vent area is desired by NASA, the design could be modified to incorporate the retractors.

C. FABRICATION

The purge jacket was fabricated as shown in Figure 78 (Sheets 1 and 2). The basic fabric construction was a cylinder section secured to top and bottom dome assemblies, made up of gore segments. All protrusion covers were flexible fabric conical sections joined to cutouts in the basic envelope.

A purge jacket assembly and test fixture was designed and fabricated. The fixture (Figure 80) duplicates the location of 105-inch diameter tank protrusion clamp-off flanges. The purge jacket was assembled on the fixture to locate the clamp-off areas of the protrusion covers. All bonds of fabric seams and zipper attachment were made using The Goodyear Tire & Rubber Co 1473-C adhesive system.

Prior to installation of the protrusion covers and zippers, the basic envelope was assembled and inflated to 0.5 psi pressure for dimensional check. The basic design dimension of 116 inches outside diameter was 0.8 inch larger at the center of the jacket and 0.6 inch larger at the dome to cylinder transition area. The overall

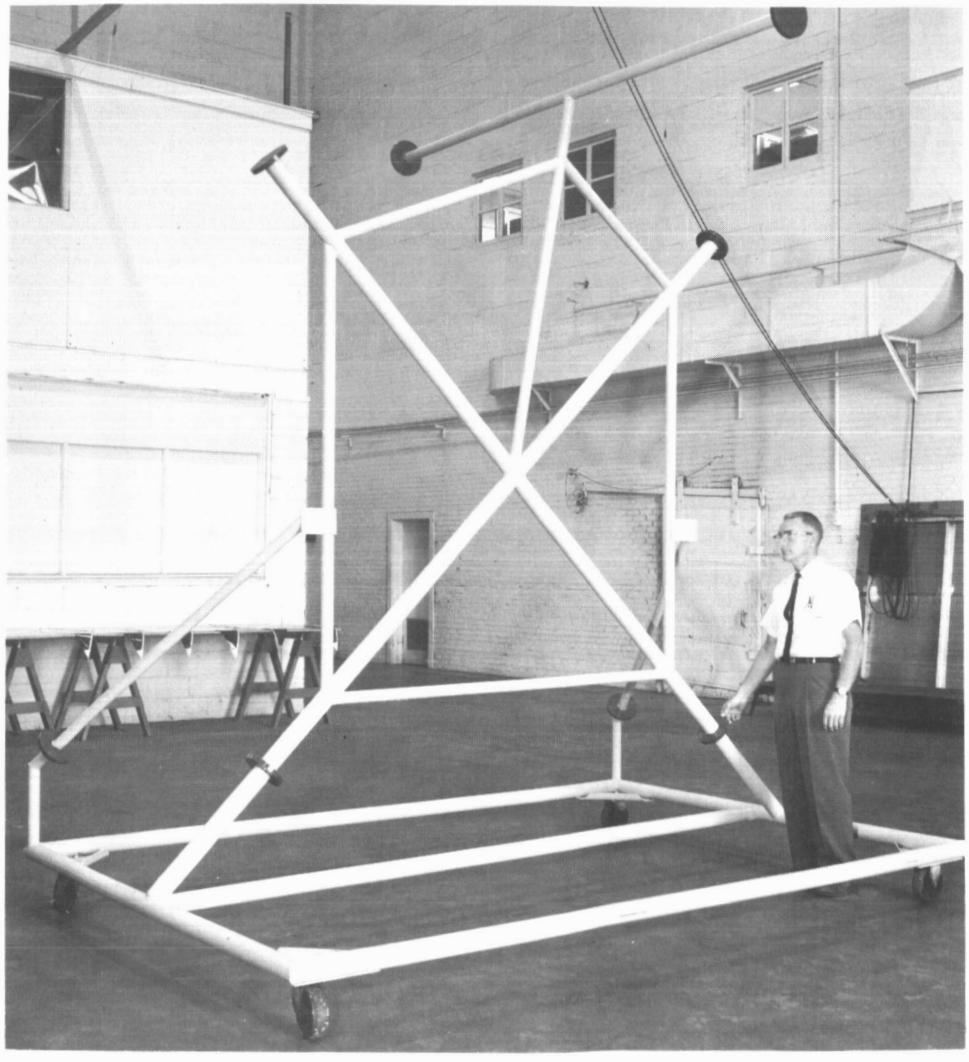


Figure 80. Purge Jacket Assembly and Test Fixture

length of 135.8 inches was 5.8 inches longer, or an average of 2.9 inches on each end. The diameter and length increases were largely attributed to stretching of the envelope from internal pressure loads. The dome ends, constructed from bias-cut fabric gore panels, would exhibit greater elongation than the cylindrical section of the jacket in which the fabric warp and weave were oriented in the direction of principal stresses. This dimensional variation was reviewed and approved by NASA-MSFC prior to continuation of subsequent fabrication operations.

The protrusion cover and zippers for the four radially oriented fill and vent lines and the A-frame fitting assembly were installed on the basic envelope. To facilitate accurate installation of the protrusion covers and zippers for the complexly oriented titanium support struts at this stage of fabrication, the jacket was assembled onto the assembly and test fixture (see Figure 80). With the jacket inflated and positioned on the fixture, the load rod-strut covers and zippers were assembled to the jacket.

The load-carrying patches with tie-rod assemblies were located and secured to the jacket in the zipper areas at the base of all protrusion covers. Installation of the aluminum hard cover assembly over the A-frame fitting area completed the assembly of the purge jacket (see Figure 81). The jacket assembly was inflated to approximately 0.3 psig, and the tie-rods of all load-carrying patches were adjusted to relieve the tension on the zippers in tie-rod areas.

D. TESTING

1. Off-Gassing and Emissivity

The purge jacket materials are fully cured, coated fabrics that exhibit low off-gassing in a vacuum environment. On current insulation development programs, GAC has employed envelopes of similar materials in vacuum chamber tests without deleterious off-gassing effects.

The aluminum pigmented exterior surface of the purge jacket has thermal emissivity value of 0.4 to 0.5. Emissivity measurements were conducted in the wavelength range of 1 to 20 microns on several samples of purge bag fabric. These tests were conducted by Minneapolis-Honeywell Company, at the Honeywell Systems and Research Division, Hopkins, Minnesota. The infrared reflectance measurements as shown in Table X were made using the integrating hemisphere apparatus described in NASA-SP-31[1] . Total hemispherical emittance measurements

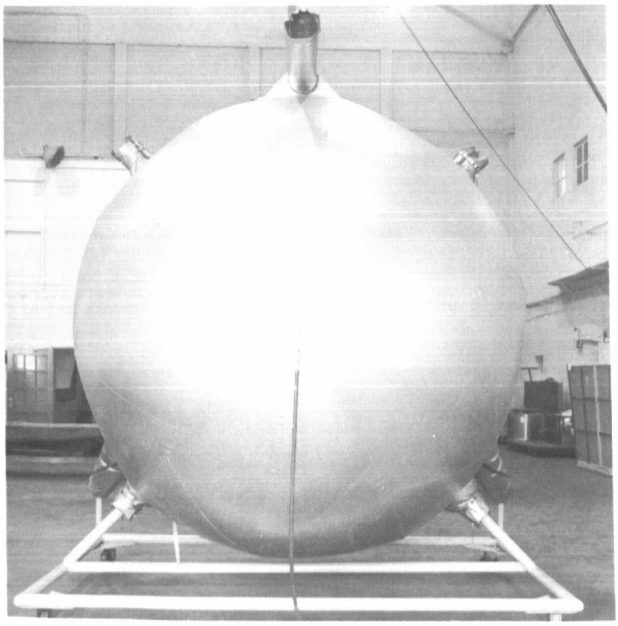
[1] Janssen, J.E., and Torborg, Measurement of Spectral Reflectance Using an Integrating Hemisphere. NASA SP-31, 1963, pp 169 - 182.



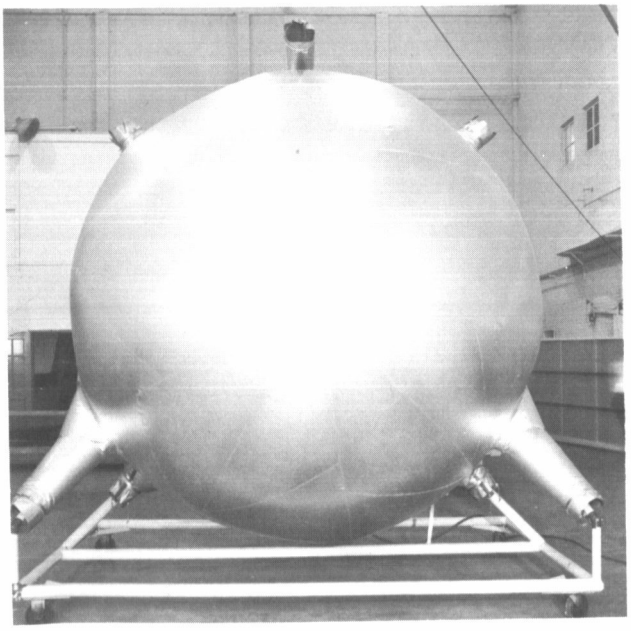
3/4 View from Top Dome End



3/4 View from Bottom Dome End



End View - Top Dome



End View - Bottom Dome

Figure 81. Purge Jacket Assembly for 105-Inch Diameter Tank

Table X. Infrared Spectral Reflectance Measurements on Purge Jacket Fabric

Wavelength (μ)	Sample Number		
	1	2	3
1	0.492	0.544	0.520
2	0.536	0.537	0.552
3	0.535	0.526	0.535
4	0.498	0.490	0.497
5	0.481	0.468	0.488
6	0.398	0.367	0.437
7	0.396	0.392	0.410
8	0.368	0.373	0.395
9	0.329	0.381	0.417
10	0.409	0.430	0.444
11	0.425	0.433	0.492
12	0.451	0.473	0.480
13	0.457	0.502	0.475
14	0.494	0.490	0.490
15	0.474	0.460	0.520
16	0.510	0.505	0.495
17	0.492	0.525	0.512
18	0.492	0.503	0.510
19	0.540	0.538	0.475
20	0.621	0.532	0.558

NOTES: 1. The above measurements were in a vacuum of 1×10^{-6} mm Hg.

2. This reflectance is the near normal reflectance for hemispherical incidence energy, which equals the hemispherical reflectance for near normal incident energy. Therefore, it can be converted to near normal directional spectral emittance.

were also made on one sample using the apparatus described in NASA SP-31[2] .

The total hemispherical emittance (E_h) of sample No. 2 is as follows:

E_h = 0.56 at 81°F

E_h = 0.56 at 86°F.

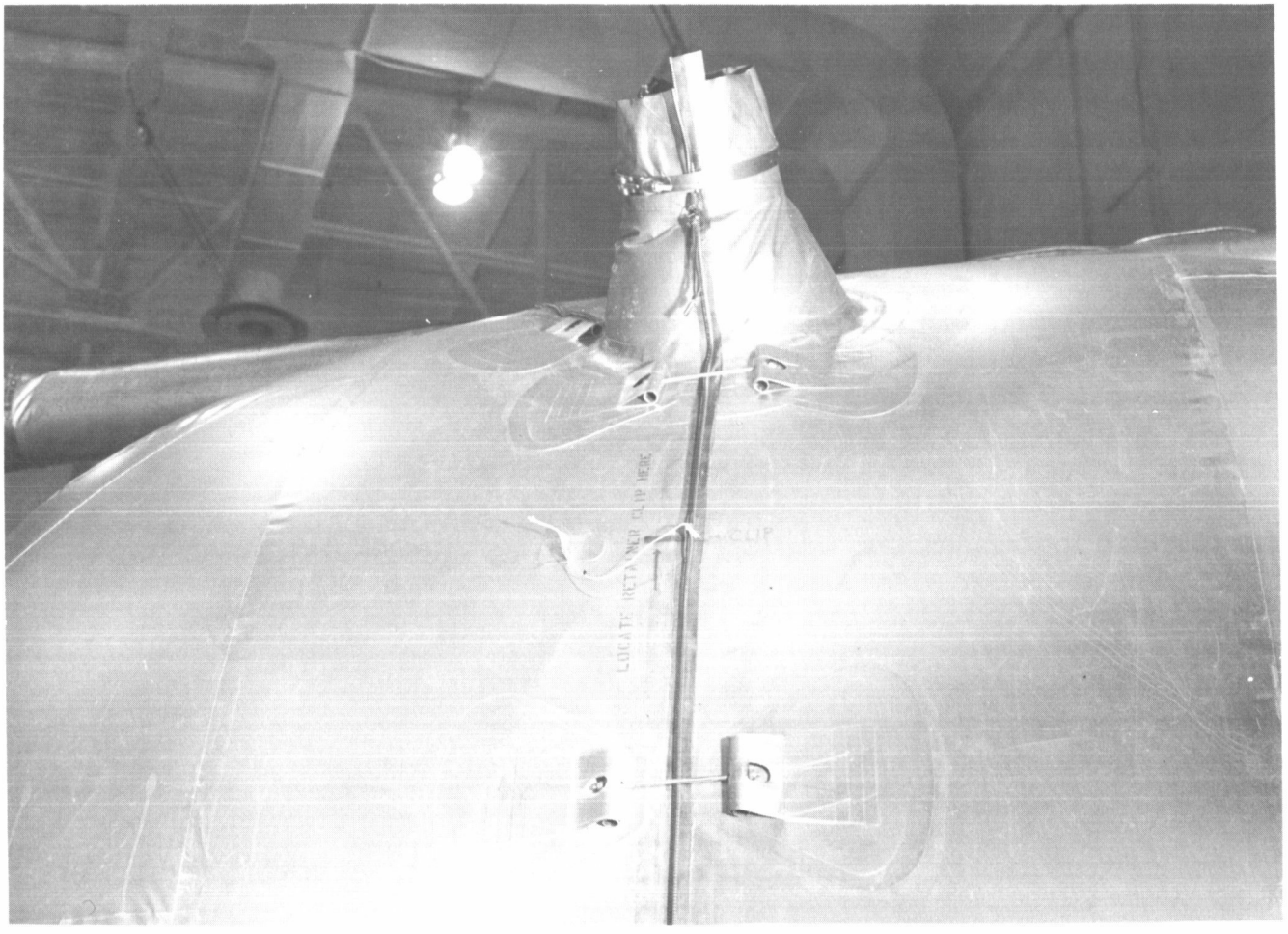


Figure 82. Zipper Retainer Clip Installation on 105-Inch Diameter Tank Purge Jacket

[2]Schmidt, R.N., and Janssen, J.E., Low Temperature Total Emittance Calorimeter. NASA SP-31, 1963, pp 225 - 230.

2. Jacket Depressurization Tests

The integrity of the purge jacket and the automatic opening of one zipper at 0.5 (±0.05) psig was demonstrated by inflating the jacket with air while the jacket assembly was mounted in the test fixture (see Figure 80). The one zipper was adjusted to open automatically at 0.5 (±0.05) psig by manually loosening the zipper teeth in the area of the retainer clip as shown in Figure 82. Sufficient teeth were loosened to permit the clip to release and the zipper to open at the required pressure level. After several repeated successful zipper opening cycles with loosened teeth, the loosened teeth were permanently cut away on half of the zipper assembly. Subsequently, four additional zipper opening pressure cycles were performed in which the zipper opened at 0.46 to 0.5 psig.

After completion of the successful test cycles, the purge bag was disassembled, packed, and shipped to NASA-MSFC, Huntsville, Alabama.