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DEVELOPMENT OF CRYOGENIC POSITIVE EXPULSION BLADDERS

BY

D. H. POPE AND J. E. PENNER

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-6288

BEECH AIRCRAFT CORPORATION
BOULDER DIVISION

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FINAL REPORT

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by

D. H. Pope and J. E. Penner

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

January 20, 1968

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Technical Management
NASA Lewis Research Center
Cleveland, Ohio
Liquid Rocket Technology Branch
R. F. Lark

BEECH AIRCRAFT CORPORATION
Boulder Division
Boulder, Colorado

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

-33364

LIST OF FIGURES

-33364
s-R-270-1)

LIST OF FIGURES

90-33364
(REV. E-270-1)

LIST OF TABLES

FORWARD AND ACKNOWLEDGEMENTS

This final report has been prepared by the Boulder Division, Beech Aircraft Corporation, to document the work accomplished under Tasks 1 and II of Contract NAS3-6288 for the development of "Cryogenic Positive Expulsion Bladders". This work was administered by the Liquid Rocket Technology Branch, Chemical Rocket Division, Lewis Research Center, National Aeronautics and Space Administration. Mr. R. F. Lark was the project manager for NASA-LeRC, and his able and active assistance to this program is gratefully acknowledged.

The following Beech-Boulder technical personnel were actively associated with this program.

D. H. Pope
J. E. Penner
C. E. Allen

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Engineering Report
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DEVELOPMENT OF CRYOGENIC

POSITIVE EXPULSION BLADDERS

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ABSTRACT

This report describes polymeric materials, composites, and various fabrication techniques which were qualification tested in Task I for evaluation of flexibility and permeability characteristics in cryogenic liquids. Ten 11.5 inch spherical bladders which were fabricated of the five best qualified material composites were comprehensively tested in Task II and eight bladders attained the test goal of 25 complete liquid hydrogen expulsion cycles, not however, without failure of material in some bladder plys. Several material composites utilizing Mylar and Kapton demonstrated excellent expulsion and permeability performance. Extensive data on liquid hydrogen expulsion was obtained and a much greater knowledge was acquired of the characteristics and behavior of bladders composed of ten or more individual plys.

DEVELOPMENT OF CRYOGENIC POSITIVE EXPULSION BLADDERS

by D. H. Pope and J. E. Penner

Beech Aircraft Corporation, Boulder Division

1.0 SUMMARY

The objective of this program was the preliminary development of a polymeric bladder capable of the efficient and reliable expulsion of liquid hydrogen under zero gravity conditions. The goal of this program was the development of a bladder capable of 25 failure-free cycles of liquid hydrogen expulsion.

This work was performed in two progressive phases, each involving the design and fabrication of test articles and the testing of the articles in liquid hydrogen. Task I provided for the comprehensive evaluation and qualification testing of promising materials, material composites, and fabrication techniques. Task II consisted of the design and fabrication of experimental bladders utilizing the best qualified material composites, followed by the expulsion testing with liquid hydrogen.

The objective of Task I was to determine the best qualified material composite combinations (each with adequate existing fabrication technology) for use in the Task II bladders. The various materials to be considered were limited to four polymeric materials because of considerable previous cryogenic material testing and evaluation. However, Task I was to determine the optimum utilization of these basic materials so as to produce the necessary cryogenic flexibility and permeability characteristics required for bladders. This required comprehensive evaluation of such factors as material combinations, number of plys, thickness of the various materials, methods of fabricating sheets of film into spherical bladders, types of seams, adhesive and other forms of joining the materials, all within the criteria for materials for liquid hydrogen (LH_2) expulsion.

The foregoing resulted in the fabrication of 557 material samples of 95 different material composites. These samples were of both flat and cylindrical configuration and were flex tested in LH_2 by means of the Beech Twist-Flex apparatus. Each flat sample was tested for permeability prior to and after flex testing. The arrangement of the successive

1.0 SUMMARY (Continued)

samples were determined by the results of the testing of previous samples. Among the samples tested were rectangular samples cut from thermo-formed hemispheres of Mylar and samples composed of Mylar having ultrasonic welded seams.

Task I provided a wealth of test data defining the cryogenic flexibility and permeability performance of numerous material composites. Reduction of the data permitted the selection of the best qualified material composites comprised of the following materials or combinations:

Mylar
Nomex/Mylar
Dacron/Mylar
Nomex/Kapton
Polyethylene (Merfab)*/Mylar

The basic objective of Task II was to determine the bladder materials capable of 25 complete liquid hydrogen (LH_2) expulsion cycles with minimal permeability. The relationship of bladder permeability to the progressive number of LH_2 expulsion cycles was another major objective. A bladder design study and detailed design culminated in the fabrication of ten bladders (two each of five material combinations) under subcontract.

An existing cryogenic flexibility test apparatus was upgraded to provide for the twist-flex parameters as described in Paragraph 3.3.3. A special fixture for determining bladder permeability or leakage (at ambient temperature) was provided and provisions were made to obtain a qualitative indication of bladder leakage between expulsion cycles. Each bladder was tested to a maximum of 25 LH_2 cycles. Permeability tests (at ambient temperature) were made at regular intervals and the bladders received a comprehensive post-test evaluation. Eight of the bladders successfully completed the 25 expulsion cycles. The best overall performance was by one of the 10-ply Mylar bladders and by the 10-ply Kapton bladders. The lowest permeability (leak rate) after the 25 cycles was 18 cc per minute for one of the polyethylene (Merfab)/Mylar bladders.

Experience was acquired concerning the characteristics and behavior of bladders composed of ten or more individual-acting plys. The phenomena of interply inflation was also investigated.

*Merfab - Sea Space Systems, Inc.

1.0 SUMMARY (continued)

Although the program goal of twenty-five failure-free liquid hydrogen expulsion cycles was not achieved with the bladder combinations tested due to permeability and inter-ply inflation problems, a close approximation to this goal was demonstrated for one bladder material combination. Additional bladder testing would permit consolidation of the technological advances under this program. A different mode of expulsion; i.e. from inward to outward expulsion, would eliminate most of the operational problems which occurred during this program.

The necessity of removing the bladder from the testing dewar to measure permeability tends to result in some damage to the bladder upon re-installation. It would be desirable to provide a method for future bladder testing which could be done without removal of the bladder from the testing dewar.

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2.0 INTRODUCTION

The need has existed since the advent of spaceflight for an efficient and reliable system for the positive expulsion of liquid hydrogen and other cryogenic propellants in a zero gravity condition.

The lack of a suitable bladder for such a system has required the use of high pressure super-critical systems to provide single-phase cryogenic fluid in zero gravity applications. A weight penalty results from the increased tank wall thickness necessary to withstand the high propellant pressures. This factor becomes even more significant as propellant tank sizes increase. This weight penalty provides a possible reason why cryogenic propellants are not more widely used in space vehicle positive expulsion applications despite significant advantages such as the high specific impulse of liquid hydrogen.

A flexible polymeric bladder capable of repeated expulsion cycles offers advantages over the "one-shot" metallic bladder or diaphragm and over metal bellows. The weight savings and expulsion efficiency, in addition to the time and effort saved in bladder replacement after each cycle, is of considerable value in the use of a light multi-cycling polymeric bladder.

Feasible space applications for cryogenic positive expulsion systems include attitude control, environmental control, restart capabilities (or liquid propellant positioning) and fuel cells. The positive expulsion system probably has its greatest potential in orbital refueling where it presents significant advantages for the transfer of large quantities of cryogens. The subcritical system provides the capability of transferring low pressure liquid to another low pressure system with almost 100% efficiency. In the super-critical concept, however, both the ferry tank system and the system(s) being refueled must be at super-critical pressure with resultant weight penalties. In addition, a super-critical fluid transfer leaves a high percentage of residual fluid in the transferring tank.

The development of a suitable bladder for the storage and expulsion of liquid hydrogen and other cryogenic propellants has been the goal of several NASA and Air Force programs. The basic problem is finding a material (or combinations of materials) with all of the characteristics necessary for the efficient and reliable expulsion of liquid hydrogen. The major criteria for such a material is the ability to survive repeated flexing while at the temperature of liquid hydrogen (-423°F). The material must also exhibit low permeability and must be supported by adequate fabrication technology.

2.0 INTRODUCTION (Continued)

Beech Aircraft Corporation, Boulder Division, has participated in a number of programs for the development of polymeric bladders for the positive expulsion of liquid hydrogen and liquid nitrogen. Early bladder development was accomplished under Air Force Contract AF33(616)-6930 (ref. 1 and 2). This was followed by more advanced work under NASA Contract NAS9-513 (ref. 3 and 4). These programs resulted in significant advances in cryogenic bladder technology and served as ground work for the program which is the subject of this report.

The lack of data and knowledge of the properties, characteristics and behavior of polymeric materials at cryogenic temperatures required extensive preliminary testing by Beech in earlier programs. Literally, hundreds of materials were screened, with the better materials being qualified in liquid nitrogen and finally tested in liquid hydrogen.

This testing experience led to a basic design for the development of cryogenic bladders. This plan provided for extensive testing upon simple, flat samples instead of costly bladders. Beech, therefore, developed the Twist-Flex apparatus for flexibility testing, in the appropriate cryogen, of flat samples of the polymeric materials. This test method closely simulates the flexing, folding and wrinkling experienced by the bladder during actual operation and expulsion. Materials which demonstrate the most promising qualities are eventually fabricated into bladders for liquid hydrogen expulsion testing.

Forty bladders were expulsion tested (the majority with liquid hydrogen) during the earlier programs at Beech. These bladders were of a great variety of materials, including Mylar, Teflon, H-film, Nomex and various Dacron substrates. Initial testing revealed that a single film thickness could not meet all of the criteria for cryogenic bladder materials. Films thin enough to provide satisfactory cryogenic flex performance could not meet permeability and strength requirements. Therefore, many of these early bladder materials were laminates, generally of a flexible barrier film and a high tensile strength substrate material such as the Mylar/Nomex combination. The failure of these bladders was due to the build-up of material and laminating adhesive resulting in a relatively rigid composite not capable of flexing at cryogenic temperatures without failure. A few of these bladders were composed of two or three nested plys which were not bonded and which acted individually except in the stem area. These multiple-ply bladders generally exhibited good expulsion performance.

2.0 INTRODUCTION (Continued)

The state of cryogenic bladder technology at the beginning of Contract NAS3-6288 can be summarized as follows: Though several bladders had demonstrated outstanding cyclic life (up to 126 liquid hydrogen cycles at high permeation rates), the number of cycles to bladder failure was not conclusively established due to the limited number of bladders tested. The bladders indicated high permeability or leakage after a varying number of bladders tested. The bladders indicated high permeability or leakage after a varying number of cycles. The multiple ply bladder appears to present an answer to many of the problems, especially with the proper arrangement of plys of materials which compliment one another. The previous programs had proven many items of design, ranging from bladder mounting to fabrication details. Material testing in liquid hydrogen had been reduced to a simple operation and now provided knowledge of the cryogenic flex characteristic of all commercially available candidate materials.

The basic purpose of this program, Contract NAS3-6288, was to consolidate the previous achievements in cryogenic bladder technology and to advance the development from that point. The program goal was a bladder capable of 25 failure-free cycles of liquid hydrogen expulsion with emphasis on the development of a flexible bladder with minimum permeability. An overall aim was to establish the reliability factor of polymeric bladders and then advance bladder reliability to the highest possible level.

The areas for materials testing and evaluation were indicated by the results of the previous Beech effort and substantial material investigation by NASA-LeRC (including Twist-Flex testing in liquid hydrogen). Therefore, the material investigation of this program was concentrated on composite materials of multiple, individual-acting plys. These composites were of two varieties: Those composed only of low-permeability barrier plys and those composed of barrier plys plus substrate plys to enhance tear resistance and extend the cryogenic flex life of the barrier plys. The program investigation was specifically directed toward the evaluation of cryogenic performance of Mylar, Kapton and elements of ultra-thin polyethylene, plus Nomex and Dacron substrates.

These were investigated in varying arrangements to determine the optimum configuration to produce the desired cryogenic flex and permeability characteristics. Emphasis was placed on attaining minimum permeability and extensive testing was performed to establish permeability characteristics of the materials. The investigation also covered the various fabrication techniques and processes to provide maximum utilization of the selected materials. This investigation included the various types of seams and adhesives employed in sealing the polymeric materials. Also included was the use of the ultrasonic welding for making seams and the use of thermoforming processes to provide contoured Mylar hemispheres.

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3.0 MATERIAL AND FABRICATION PROCESS EVALUATION (TASK I)

This task consisted of the preliminary evaluation, selection, testing and analysis of the basic materials considered potential candidates for use in the fabrication of bladders. In addition to the basic material evaluation, additional studies were performed to resolve the problems associated with the fabrication of the bladders using the materials selected.

This task was divided into specific areas of investigation which are described in the following sections:

- 3.1 Task Objectives
- 3.2 Material Selection
- 3.3 Evaluation and Testing Procedures
- 3.4 Apparatus
- 3.5 Twist-Flex Test Data
- 3.6 Permeability Studies
- 3.7 Thermoformed Mylar Investigations
- 3.8 Seaming Investigations
- 3.9 Ultrasonic Seaming Study
- 3.10 Inter-Ply Pressurization Study
- 3.11 Conclusions
- 3.12 Bladder Material Recommendations

3.1 Task Objectives

The objective of Task I was to develop the best material and fabrication procedure for joining materials for use in making bladders for positive expulsion of liquid hydrogen. This goal was sought through the use of flat and cylindrical samples which were twist-flex tested in a manner similar to that experienced by an actual bladder.

Objectives included investigation of thermally formed Mylar samples to determine the feasibility of fabricating bladders from two Mylar hemispheres. Also investigated was the effect of permeation of cryogenic liquid into a multi-ply sample which results in inter-ply inflation when the cryogenic liquid evaporates. The feasibility of ultrasonically seaming Mylar samples as a means of fabricating bladders was also a goal of the program.

The final objective was the evaluation of all materials and processes considered in this task for the selection of the most promising materials for bladder fabrication.

3.1.1 Materials

The materials were limited to the following commercial materials:

a. Mylar Film (1/2 mil or less)
b. Polyethylene Film (.10 mil)
c. Polyimide Films (1/2 mil) Kapton
d. Polyester woven substrates--Dacron Fabric
e. Polamide Fibrous Substrate--Nomex-Nylon Paper

These materials were assembled in multiple unbonded or weakly bonded plys to form a laminated composite with the desired characteristics determined through Twist-Flex testing in a special apparatus at liquid hydrogen or nitrogen temperatures.

The flat samples were 4 inches by 11 inches in size and included some specimens with seams running vertically and horizontally through the sample as well as edge seams. A smaller number of cylindrical samples were tested which were 3.5 inches in diameter and 4 inches tall.

Flat samples were tested for helium gas permeability before and after the twist-flex test to determine the number of cycles at which a specific material failed. The cylindrical samples were checked for permeability only when installed.

Mylar

Mylar Type C film had already received a considerable amount of previous testing by Beech and NASA in liquid nitrogen and hydrogen and in various combinations of materials and plys. The emphasis, therefore, in this program was upon multi-ply samples of Mylar C with various seams and seaming methods. Thin films of Mylar are highly flexible at cryogenic temperature, however, tear resistance of these fibers was generally low and occasionally resulted in gross splitting.

Polyethylene

Polyethylene films of 0.1 mil thickness and combination of polyethylene with Mylar films were evaluated for cryogenic flexibility by both Beech and NASA-Lewis Resear Center. Test results indicated that further studies were warranted.

Kapton

Kapton, a polyimide film, had received some testing in liquid nitrogen by Beech with varying results. NASA requested that this material receive additional liquid nitrogen testing followed by liquid hydrogen testing. (Ref 5)

3.1.2 Fabrication Processes

Adhesives

The following adhesives in liquid and tape form were tested in this program:

a. Polyester types, GT-100, GT-200, and GT-300 from the G. T. Schjeldahl Company.
b. Types S-110 and S-114 from the Sea Space Systems, Inc.
c. Elastromeric type Pliobond-20 from the Goodyear Tire & Rubber Company

The GT series of adhesives have been used quite successfully in the past on expulsion bladders whereas the "S" series was relatively new and experience was needed. The Pliobond adhesive had shown some possibilities from NASA test work and was included in this program since it would offer some simplicity of fabrication of bladders. (Ref 9)

Thermal Sealing

Materials which can be thermally bonded together without adhesive offer some advantages in sample and bladder fabrication by reducing seam thickness. If a sample is composed totally of polyethylene then a thermal seal is possible throughout since polyethylene can be sealed to itself. Adhesive sealing is, however, required for all Mylar or Mylar and polyethylene film combinations.

Ultrasonic Seaming

The use of ultrasonic welding offered a promising method of joining plastic films. The lack of experience in ultrasonically joining of 1/4 mil Mylar C and the advantages of such a method have established the need for consideration of this method. Development work was done in this area and resulted in fabrication of single ply flat samples with horizontal ultrasonic welded seams.

3.1.3 Permeability Measurement

The only criteria, for determining whether a material is satisfactory for use in an expulsion bladder, is to compare its cycle life performance with the failure pattern. The material which results in the greatest number of cycles without failure should prove to be the best material for the job.

Failure must be defined. If failure is considered to be the point at which gross shattering of the material occurs, then this point is more readily observed and determined. If, however, permeability is used for the determination of failure, then the amount of permeability or porosity which can be tolerated must be established. In either event, the ideal goal would be a graph in which the failure criteria is plotted against number of cycles. In practice, this goal is not easily achieved for the following reasons. The many factors which play a part in the failure of a material sample are not easily controlled nor understood. The basic material itself, fabricated under established control procedures, varies in quality within some acceptable limits according to the manufacturer. When this material is assembled into a sample in which some adhesive or bonding method is used, then it is likely that this operation affects the basic material either in its basic characteristics or physical activity.

The result of all of these variables is exhibited by the lack of real correlation between failure and number of cycles. Although permeability data is recorded, both before and after a sample is tested and cycles are recorded, the random type of failures makes analysis difficult. An attempt is made to test the first sample of a group to 200 cycles or to failure, whichever occurs first. The results of a permeability test made on the samples then determines the number of cycles that the next sample would be run.

3.1.4 Inter-Ply Inflation

In previous work at NASA-LeRC, it was observed that when multi-ply film samples were immersed in cryogens during flex-testing, inflation of the plys would occur when the samples were removed from the cryogen. In several cases, considerable quantities of liquid nitrogen was seen to be trapped between the plys. Subsequent evaporation of the cryogen resulted in destruction of the sample by over pressurization. Further study of inter-ply inflation was performed in this program, including the effect that inflation has on cycling of bladders.

3.2 Material Selection

The four basic materials: Polyesters, Polyethylene, Polyimide, and Polyamides were specified by NASA for this program. The problem of selecting the best combination of these materials is a complex one. It is necessary to ascertain an optimum thickness and number of plys. Plys must be joined with the best type of seam which is located in the ideal position on the sample and finally the material samples and bladders should be assembled by the most proficient vendor. This variety of selection parameters is illustrated in Figure 3.1.

Figure 3.2 illustrates many of the possible combinations of film seams which may be considered for joining two or more films together to form a bladder.

FIGURE 3.1
SAMPLE AND SEAM VARIATIONS
SELECTION PARAMETERS

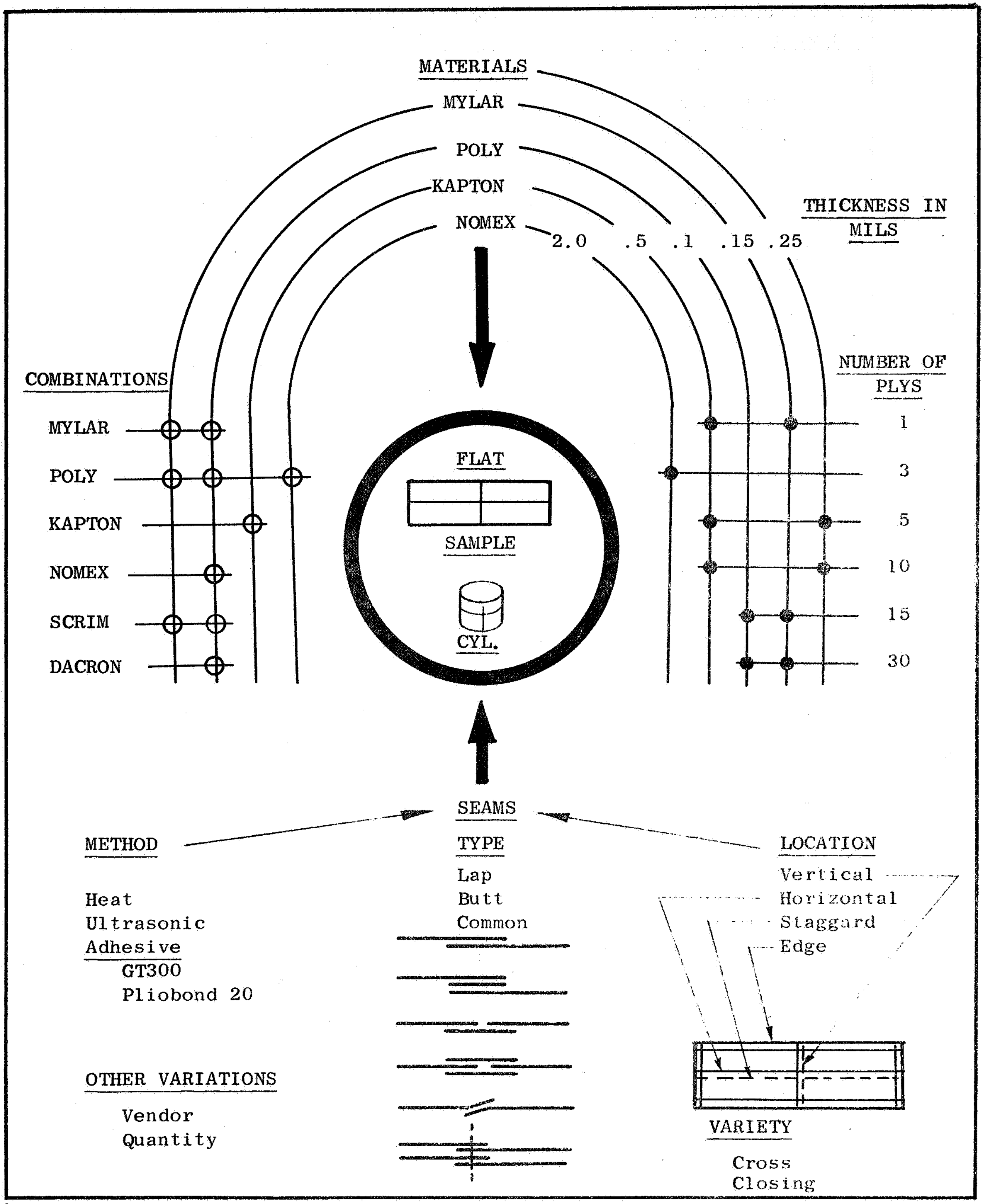
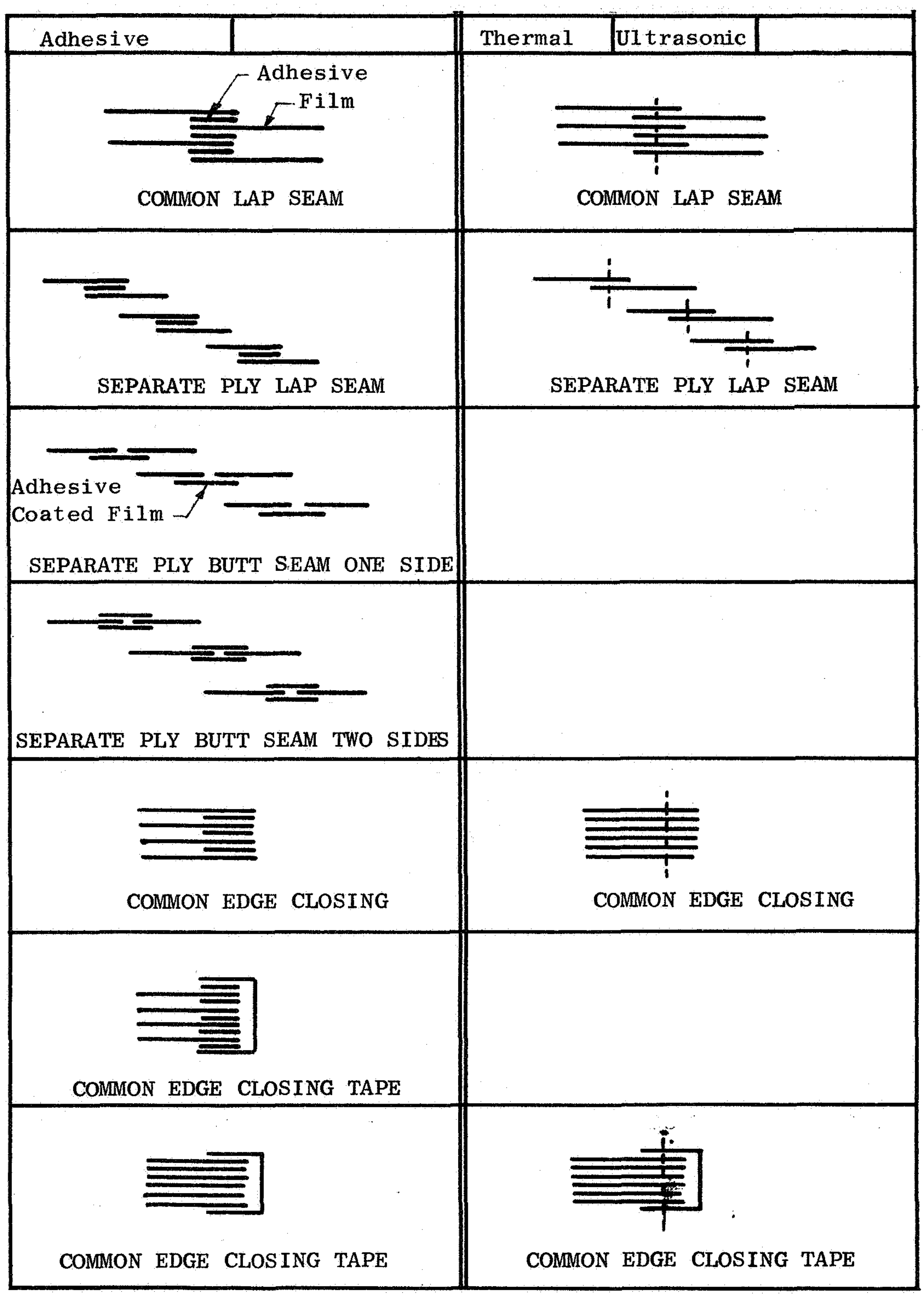


FIGURE 3.2
I PLY ASSEMBLY - SEAMING OF THIN FILMS



3.2.1 Requirements

The contract statement of work specified that the materials to be selected and evaluated shall be limited to commercial materials and composites approved by the NASA LeRC Project Manager and shall include the following:

a. Multiple-plys of 1/4 and/or 1/2 mil biaxially oriented poly (ethylene terephthalate) film used either alone (unbonded) or separated by unbonded or weakly bonded layers of fibrous or woven substrates.

   The forms of the Mylar film to be investigated shall consist of both the commercially available film in the "as received" and in the thermoformed conditions . . . .

b. Multiple, unbonded or weakly bonded, plys of 0.1 mil thick films of polyethylene reinforced with polymeric filaments.

c. Multiple plys of 1/4 and/or 1/2 mil polyimide films used alone in the unbonded condition or separated by unbonded or weakly bonded layers of fibrous or woven polyester substrates. . . . .

Within this framework and under NASA direction, the final material selection, discussed in Section 3.2.2, was made. The selection was based upon the following factors:

a. Thin films of the polymers mentioned above have proven the most flexible at cryogenic temperatures.

b. Thin films are more permeable, and it is necessary to add many plys of the film to reduce permeation.

c. Multi-ply materials offer greater reliability.

d. Mylar and other plain films lack tear resistance and so the addition of woven substrates appear necessary to strengthen the composite.

e. No tight bonding of film and substrates should be allowed because of detrimental interaction to the laminate. (Ref 6)

f. Most of these materials are not easily formed as single pieces into bladder shapes, therefore, consideration must be given to seaming techniques.

g. Seaming must not destroy the flexibility of the material to an extent which will cause a failure in the seam or material.

h. The seam shall not impair the integrity of the multi-ply film construction.

i. Thermal, ultrasonic or other methods of sealing films must not destroy the natural flexibility of a material by changing the physical characteristics.

j. Seam adhesives must remain adhesive and flexible at cryogenic temperatures.

k. Seaming techniques must be capable of being used in the fabrication of spherical bladders.

l. Small scale samples must duplicate the material and construction which would be used for bladder fabrication.

m. Commercially made films have limitations of film thickness which must be considered in a composite selection.

n. The number of plys must be optimized so as not to increase the seams beyond practical limits and difficulty of bladder fabrication.

Figures 3.3, 3.4, 3.5, 3.6, and 3.7 show requirements for fabrication of samples.

3.2.2 Initial Selection

After all parameters were considered separately and then related to each other, a list of the materials, combinations, thickness, plys, seaming methods and other factors were tabulated as the initial sample selection as shown in Table 3.1.

The initial sample selection and test program was reviewed, and it was agreed by Beech and NASA to be in the best interest of the program to eliminate all liquid nitrogen testing except for tests involving the use of Kapton film which had not previously been adequately tested. In addition, the number of samples of any one type of material to be tested was reduced and 1/2 mil Mylar films were deleted. These reductions resulted in the final list of materials which were subsequently ordered from subcontractors.

FIGURE 3.3

BASIC CONFIGURATION OF TWIST-FLEX MATERIAL SAMPLES
(All Dimensions in Inches)

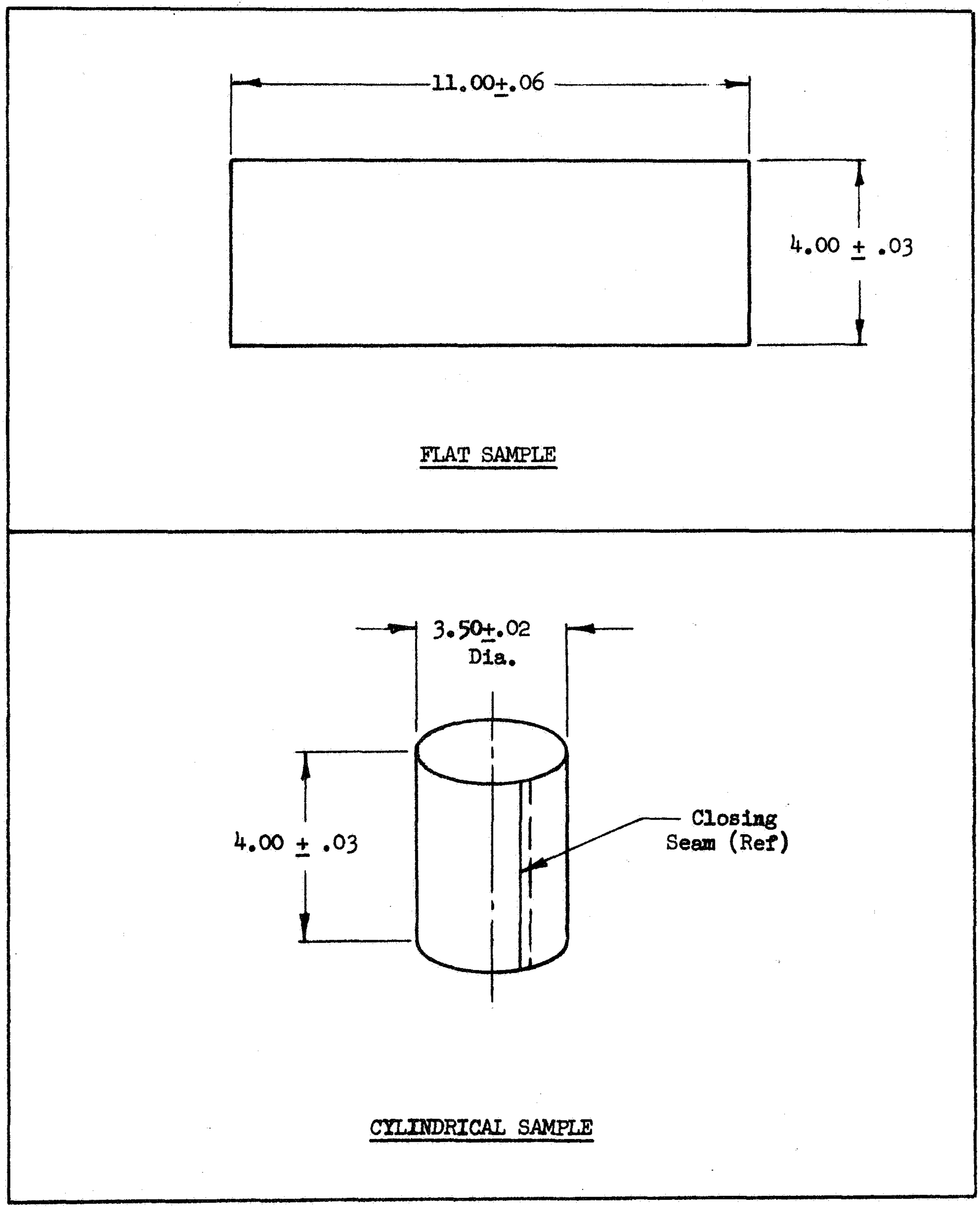


FIGURE 3.4

VARIETIES OF SEAMS IN TWIST-FLEX MATERIAL SAMPLES
(All Dimensions in Inches)

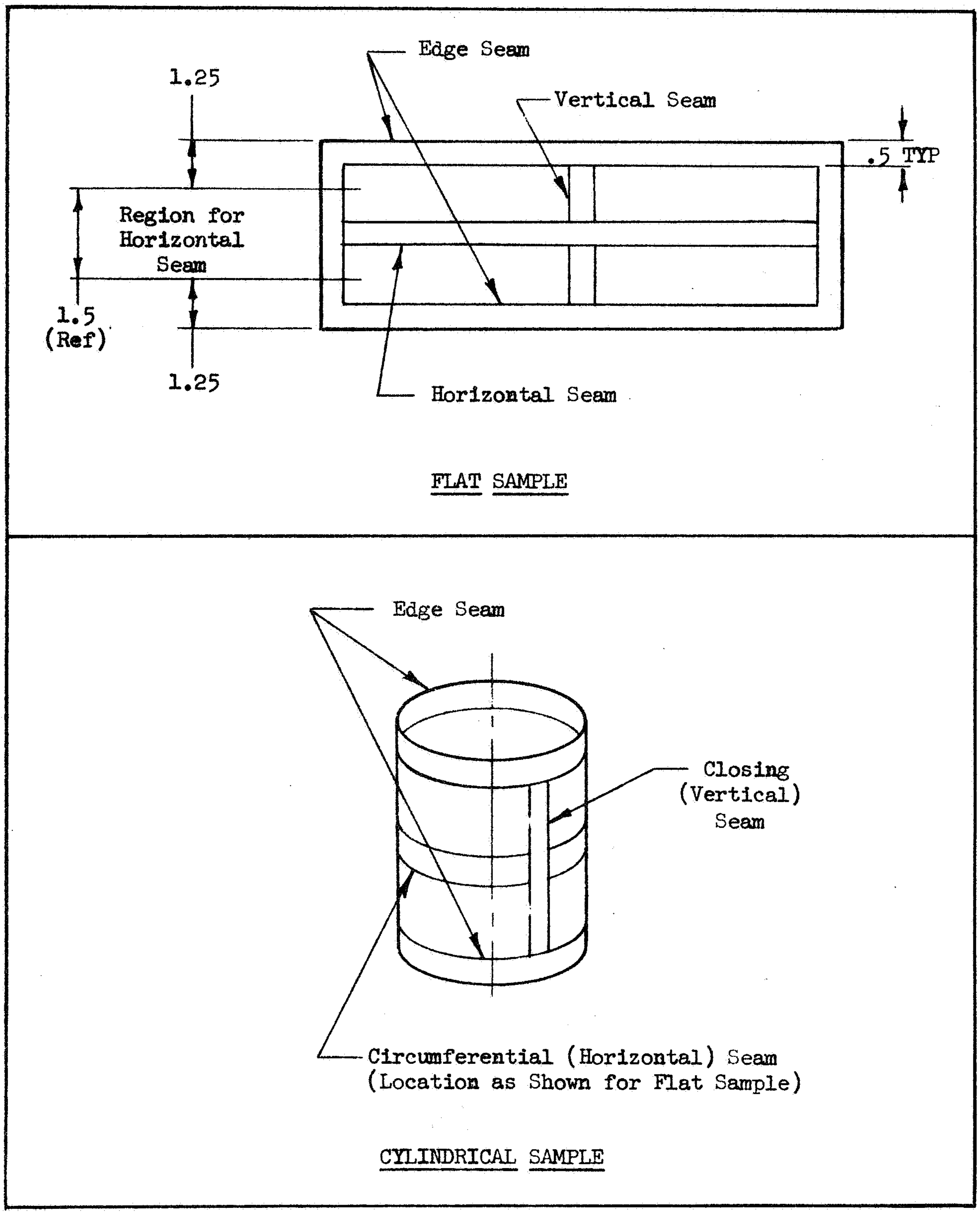
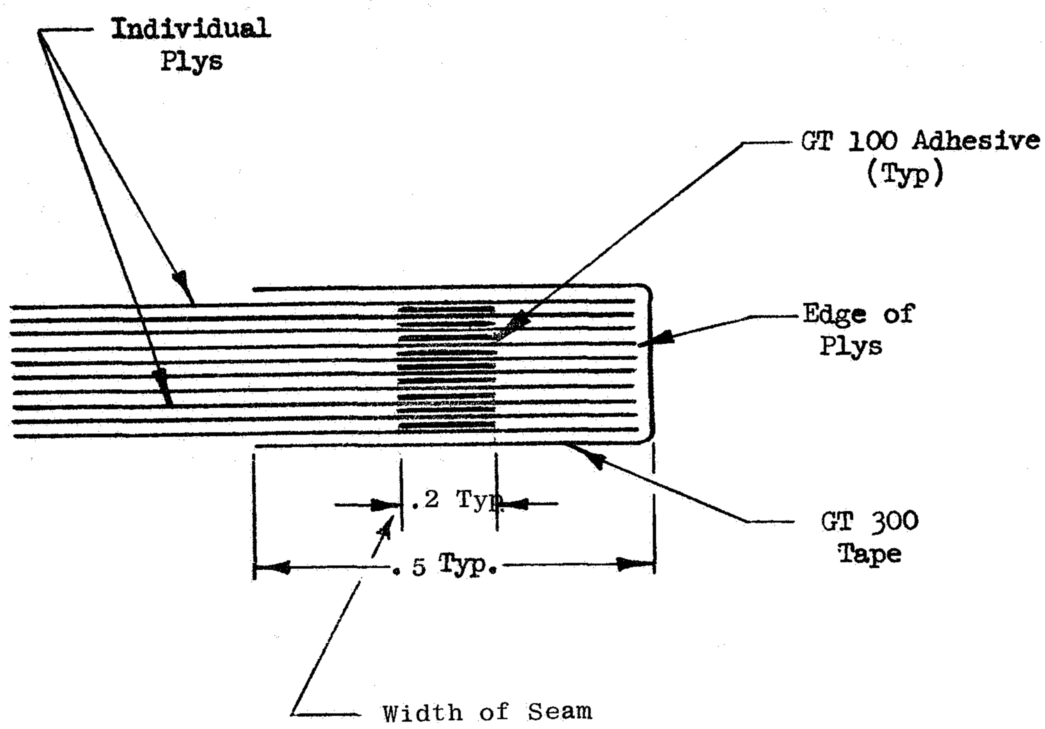


FIGURE 3.5

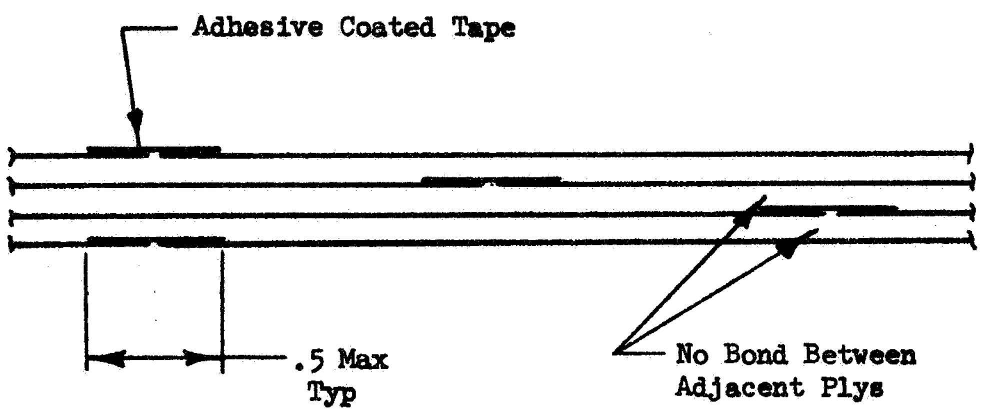
EDGE SEAM DETAILS
FLAT TWIST-FLEX SAMPLES
(All Dimensions in Inches)



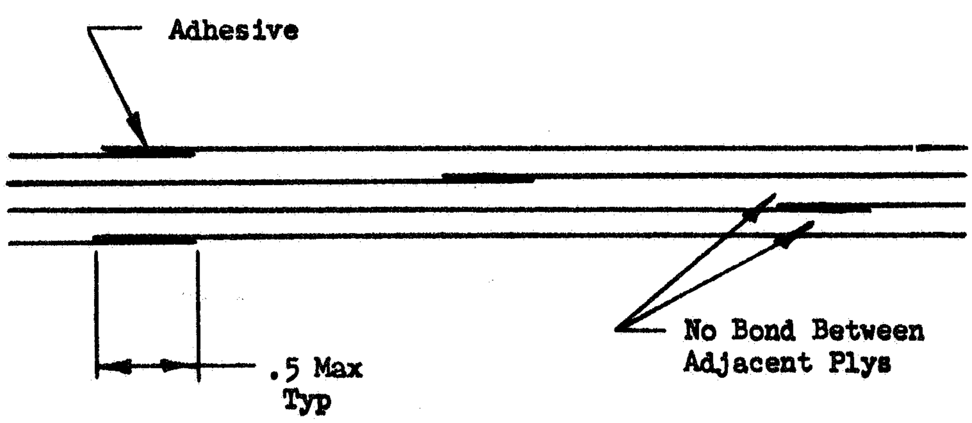
CROSS-SECTION THRU EDGE SEAM

FIGURE 3.6

SEAM DETAILS
TWIST-FLEX SAMPLES
(All Dimensions in Inches)



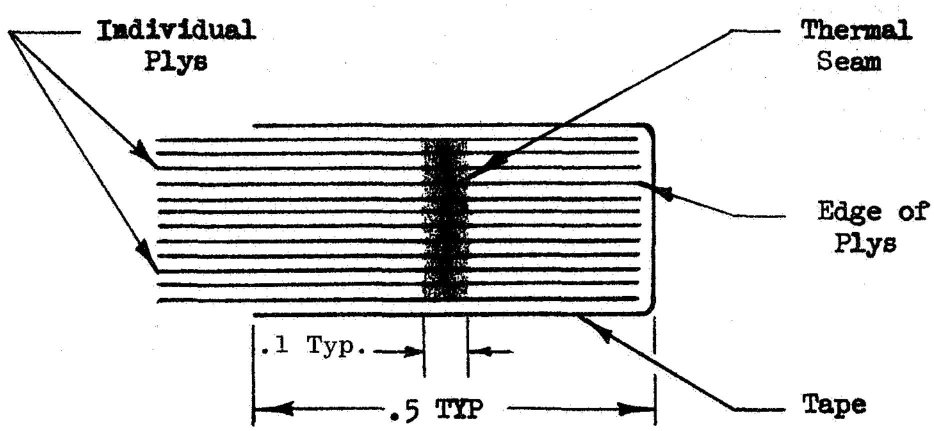
CROSS-SECTION THRU BUTT-TYPE SEAM



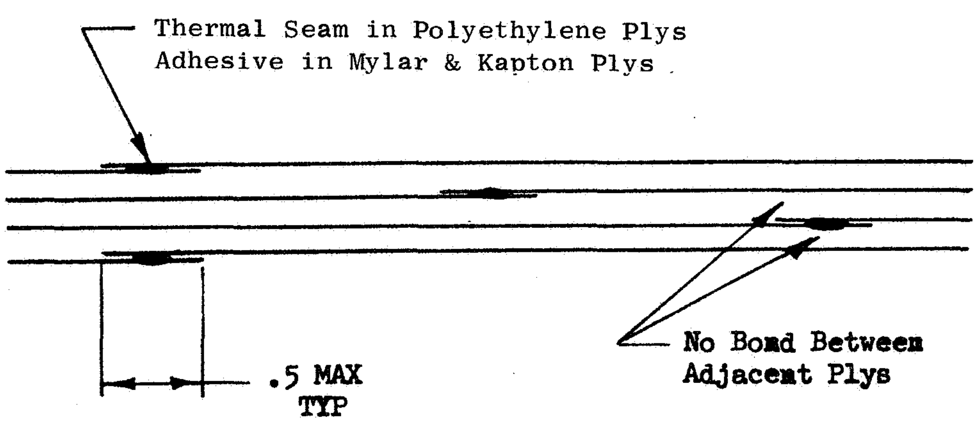
CROSS-SECTION THRU LAP-TYPE SEAM

FIGURE 3.7

SEAM DETAILS
TWIST-FLEX SAMPLES
(All Dimensions in Inches)



CROSS-SECTION THRU EDGE SEAM



PARTIAL CROSS-SECTION THRU INDIVIDUAL-ACTING,
STAGGERED, LAP-TYPE SEAM

3.2.2 Initial Selection (Continued)

The work on development of ultrasonic seaming of 1/2 mil Mylar Type C was also accomplished. The purpose of this work was to determine if it was feasible to fabricate spherical bladders in which the individual gores are joined by ultrasonic seaming. These samples were tested in the same manner as the other seamed samples in liquid hydrogen under twist-flex conditions to determine their ambient temperature permeability characteristics and cryogenic flex-life. (Ref 10)

TABLE 3.1

INITIAL TWIST-FLEX SAMPLE SELECTION

Mylar Type C - Flat 4" x 11" - Edges Sealed

Item No.	Mil Thickness	No. Plys	No. of Samples	Liq.	Seaming
1	.5	5	12	LH_2	No Seams
2	.5	10	12	LH_2	No Seams
3	.25	5	12	LH_2	No Seams
4	.25	10	12	LH_2	No Seams
5	.5	5	20	LN_2	Horizontal*
6	.5	10	20	LN_2	Horizontal*
7	.25	5	20	LN_2	Horizontal*
8	.25	10	20	LN_2	Horizontal*

9, 10, 11, 12 same as 5, 6, 7, 8 but using LH_2.

13, 14, 15, 16 same as 5, 6, 7, 8 but with Vertical Seams.

17, 18, 19, 20 same as 9, 10, 11, 12 but with Vertical Seams.

21, 22, 23, 24 same as 5, 6, 7, 8 but with Horizontal and Vertical Seams.

25, 26, 27, 28 same as 9, 10, 11, 12 but with Horizontal and Vertical Seams.

29, 30, 31, 32 same as 5, 6, 7, 8 but using Pliobond -20 Adhesive System.

33, 34, 35, 36 same as 9, 10, 11, 12 but using Pliobond -20 Adhesive System.

Item No.	Mil Thickness	No. Plys	No. of Samples	Liq.	Seaming
37	.5	5	20	LN_2	Horizontal
38	.5	10	20	LN_2	Ultrasonic
39	.25	5	20	LN_2	Ultrasonic
40	.25	10	20	LN_2	Ultrasonic

41, 42, 43, 44 same as 37, 38, 39, 40 but using LH_2.

45, 46, 47, 48 same as 37, 38, 39, 40 but with Vertical Seam.

49, 50, 51, 52 same as 41, 42, 43, 44 but with Vertical Seam.

53, 54, 55, 56 same as 37, 38, 39, 40 but with Horizontal & Vertical Seams.

57, 58, 59, 60 same as 41, 42, 43, 44 but with Horizontal & Vertical Seams.

* All seams GT-100 tape or equivalent.

TABLE 3.1 (continued)

Mylar - Type C 3.5" Diameter Cylinders

Item No.	Mil Thickness	No. Plys	No. of Samples	Liq.	Seaming
1	.25	5	5	LH_2	Vertical Seam using GT-100 Tape or equivalent
2	.25	10	5	LH_2	Vertical Seam using GT-100 Tape or equivalent
3	.25	5	5	LH_2	Vertical & Horizontal
4	.25	10	5	LH_2	Vertical & Horizontal
5	.15	5	5	LH_2	Vertical & Horizontal
6	.15	10	5	LH_2	Vertical & Horizontal

Mylar - Type C (Thermoformed) 4" x 11" (spherical surface)

Item No.	Mil Thickness	No. Plys	No. of Samples	Liq.	Seaming
1	.5	1	5	LH_2	No Seams
2	.25	1	5	LH_2	No Seams

Polyethylene and/or Mylar C Combinations Flat 4" x 11" Edged Sealed

Item No.	Mil Thickness	No. Plys	No. of Samples	Liq.	Seaming
1	.10 poly/.15 Mylar	10	12	LH_2	No Seams
2	.10 poly/.15 Mylar	15	12	LH_2	No Seams
3	.10 poly/.15 Mylar	20	12	LH_2	No Seams
4	.10 poly/.15 Mylar	10	12	LH_2	Vertical
5	.10 poly/.15 Mylar	20	12	LH_2	Vertical
6	.10 poly/.15 Mylar	10	12	LH_2	Horizontal
7	.10 poly/.15 Mylar	20	12	LH_2	Horizontal
8	.10 poly/.15 Mylar	10	12	LH_2	Horizontal & Vertical
9	.10 poly/.15 Mylar	20	12	LH_2	Horizontal & Vertical

10 through 16 same as 1 through 9 with addition of filament reinforcements between film plys.

TABLE 3.1 (continued)

Polyethylene and/or Mylar--Type C Combination   3.5" Diameter Cylinder

Item No.	Mil Thickness	No. Plys	No. of Samples	Liq.	Seaming
17	.10 poly/.15 Mylar	10	5	LH_2	Vertical
18	.10 poly/.15 Mylar	20	5	LH_2	Vertical

19 same as 17 with addition of Dacron reinforcement.

20 same as 18 with addition of Dacron reinforcement.

Kapton   Flat 4" x 11" Edges Reinforced

Item No.	Mil Thickness	No. Plys	No. of Samples	Liq.	Seaming
1	.5	1	24	LN_2	No Seams
2	.5	3	24	LN_2	No Seams
3	.5	5	24	LN_2	No Seams
4	.5	10	24	LN_2	No Seams

5, 6, 7, 8 same as 1, 2, 3, 4 but using LH_2.

Combinations

1. 5 ply (.25 mil) Mylar/1 ply (2 mil) Nomex/5 ply (.25 mil) Mylar 12 samples LH_2 no seams.

2. Nomex/Mylar/Nomex/Mylar/Nomex 12 LH_2 no seams.

3. Nomex/Mylar/Nomex/Mylar 12 LH_2 no seams.

4, 5, 6, same as 1, 2, 3 except using .10 mil poly for .25 Mylar.

7, 8, 9 same as 1, 2, 3 except using Dacron cloth for Nomex paper.

TABLE 3.2

MATERIAL SAMPLE SUMMARY
SEA SPACE SYSTEMS, INC.

(Ref. Fig. 3.8)

Ident. No.	Quan.	Configu-ration	Material (1) Gauge (Mil)	Material (1) Type	No. of Plys (2)	Seams (3) Var.	Seams (3) Type
T101	3	Flat	.10 Mil Poly		30		
102	3	"	.15 Mil Mylar		30		
103	3	"	.10 Poly/.15 Mylar		15/16		
104	3	"	Merfab/.15 Mylar		20/11		
105	3	"	Merfab		30		
106	3	"	Merfab/.10 Poly		20/9		
107	3	"	Merfab/.10 Poly/.15 Mylar		20/9		
108	3	"	Merfab/Poly/.15 Mylar		16/12		
109	3	"	.15 Mylar		30		
110	3	"	.15 Mylar		10		
111	3	"	Merfab/.15 Mylar		16/14		
112	3	"	Merfab/.15 Mylar		8/6		
113	3	"	Merfab/.15 Mylar/Nomex		4/4/3		
114	3	"	.10 Poly/.15 Myl/Nomex		8/12/3		
115	6	"	Merfab/.15 Mylar		20/12		
116	6	"	Merfab/.15 Mylar		20/12	Cross	Lap
117	3	"	.25 Mylar		30	Cross	Lap
118	3	"	.15 Mylar		10	Cross	Lap
119	3	"	.25 Mylar		30		
120	3	"	.25 Mylar		10		
121	6	"	.10 Poly/.15 Mylar/ Nomex		8/12/3		
122	6	"	Merfab/.15 Mylar		20/12		
123	5	Cyl.	.15 Mylar		30		
124	5	Flat	.15 Mylar/Nomex		12/3		
125	5	"	.15 Mylar/Nomex		12/3	Cross	Lap
126	5	"	.10 Poly/.15 Mylar/ Nomex		8/12/3	Cross	Lap
127	5	"	.5 Mil Kapton		10	Cross	Lap

NOTE (1) Kapton - .5 Mil
Mylar - .15 Mil, .25 Mil, Type C
Polyethylene - .10 Mil
Merfab - two .10 Mil Poly with Scrim between plys
Nomex - 2.0 Mil

(2) 1/2/3 same order as material listed

(3) Samples were acceptable without closing tapes on ply groups, if edges were sealed by "adhesive wetting."

TABLE 3.3

MATERIAL SAMPLE SUMMARY
G. T. SCHJELDAHL CO.

(Ref. Fig. 3.9)

Ident. No.	Quan.	Configu-ration	(1) Material Gauge (Mil)	Type	Total No. of Plys	(2) Cross Seams Variety	Type	(3) Adhesive
T201	10	Flat	.15 Mylar	"C"	5			
T202	10	Flat	.15 Mylar	"C"	10			
T203	10	Flat	.15 Mylar	"C"	5	Cross	Butt	GT 300-3
T204	10	Flat	.15 Mylar	"C"	5	Cross	Butt	GT 300-3
T205	10	Flat	.15 Mylar	"C"	5	Cross	Lap	GT 100-1
T206	10	Flat	.15 Mylar	"C"	10	Cross	Butt	GT 300-3
T207	10	Flat	.15 Mylar	"C"	10	Cross	Lap	GT 100-1
T208	10	Flat	.15 Mylar	"C"	5	Cross	Butt	Pliobond 20 w/tape
T209	10	Flat	.5 Kapton		1			
T210	10	Flat	.5 Kapton		5			
T211	10	Flat	.5 Kapton		10			
T212	10	Flat	.15 Mylar except 1st, 7th & 13th plys are 2-mil Nomex paper	"C"	13			
T213	10	Flat	.15 Mylar except 1st, 7th & 13th plys are 2.2-oz. Dacron fabric	"C"	13			
T214	3	Cyl.	.15 Mylar	"C"	5	Closing	Lap	GT 100-1
T215	3	Cyl.	.15 Mylar	"C"	10	Closing	Lap	GT 100-1
T216	3	Cyl.	.15 Mylar	"C"	5	Cross	Butt	GT 300-3
T217	3	Cyl.	.15 Mylar	"C"	5	Cross	Lap	GT 100-1
T218	3	Cyl.	.15 Mylar	"C"	10	Cross	Butt	GT 300-3
T219	3	Cyl.	.15 Mylar	"C"	10	Cross	Lap	GT 100-1
T220	3	Cyl.	.15 Mylar	"C"	5	Cross	Butt	Pliobond 20 w/tape

TABLE 3.3 (Continued)

MATERIAL SAMPLE SUMMARY
G. T. SCHJELDAHL CO.

Ident. No.	Quan.	Configu-ration	(1) Material Gauge (Mil)	(1) Material Type	Total Number of Plys	(2) Cross Seams Variety	(2) Cross Seams Type	(3) Adhesive
T221	5	Cly.	.15	Mylar "C"	10	Cross	Butt	GT 300-3
T222	5	Cyl.	.15	Mylar "C"	10	Cross	Lap	GT 100-1
T223	3	Cyl.	.5	Kapton	10	Closing	Butt	GT 300-4
T224	3	Cyl.	.5	Kapton	10	Closing	Lap	GT 100-1
T225	3	Cyl.	Same as T212		13	Cross	Butt	GT 300-3
T226	3	Cyl.	Same as T213		13	Cross	Butt	GT 300-3
T227	5	Flat	.25	Mylar "C"	1	Horiz.	"W" Butt	GT 300-3
T228	5	Flat	.25	Mylar "C"	1	Horiz.	"N" Butt	GT 300-3
T229	5	Flat	.25	Mylar "C"	1	Horiz.	"W" Lap	GT 100-1
T230	5	Flat	.25	Mylar "C"	1	Horiz.	"N" Lap	GT 100-1
T231	5	Flat	.25	Mylar "C"	1	Horiz.	"I" Butt	GT 300-3
T232	5	Flat	.25	Mylar "C"	1	Horiz.	"I" Lap	GT 100-1
T233	5	Flat	.25	Mylar "C"	1	Horiz.	1/2" Lap	GT 100-2
T234	5	Flat	.25	Mylar "C"	1	Horiz.	1/2" Lap	GT 100-2
T235	5	Flat	.25	Mylar "C"	1	Horiz.	1/2" Lap	GT 100-2
T236	10	Flat	.15	Mylar "C"	10			
T237	20	Flat	.25	Mylar "C"	10			
T238	10	Flat	.25	Mylar "C" Except 1st, 7th & 13th plys to be 2 mil Nomex Paper	13			
T239	10	Flat	.25	Mylar "C" Except 1st, 7th & 13th plys to be 2.2 oz. Dacron Fabric	13			
T240	5	Flat	2	Nomex Paper	1	Horiz.	"W" Butt	GT 300-4
T241	5	Flat	2	Nomex Paper	1	Horiz.	"N" Butt	GT 300-4

F-270 -1

TABLE 3.3 (Continued)

MATERIAL SAMPLE SUMMARY
G. T. SCHJELDAHL CO.

Ident. No.	Quan.	Configu- ration	(1) Material Gauge (Mil)	Type	Total Number of Plys	(2) Cross Seams Variety	Type	(3) Adhesive
T242	5	Flat	2	Nomex Paper	1	Horiz.	"W" Lap	GT 100-1
T243	5	Flat	2	Nomex Paper	1	Horiz.	"N" Lap	GT 100-1
T244	5	Flat	2.2 oz.	Dacron Fabric	1	Horiz.	"W" Butt	GT 300-4
T245	5	Flat	2.2 oz.	Dacron Fabric	1	Horiz.	"N" Butt	GT 300-4
T246	5	Flat	2.2 oz.	Dacron Fabric	1	Horiz.	"W" Lap	GT 100-1
T247	5	Flat	2.2 oz.	Dacron Fabric	1	Horiz.	"N" Lap	GT 100-1
T248	10	Flat	.25	Mylar "C"	10	Horiz.	"W" Butt	GT 300-3
T249	10	Flat	.5	Mylar "C"	10	Horiz.	"N" Butt	GT 300-3
T250	10	Flat	.5	Kapton	10	Horiz.	"W" Butt	GT 300-3
T251	10	Flat	.25	Mylar "C"	10	Horiz.	"W" Lap	GT 100-1
T252	10	Flat	.25	Mylar "C"	10	Horiz.	"N" Lap	GT 100-1
T253	10	Flat	.5	Kapton	10	Horiz.	"W" Lap	GT 100-1
T254	10	Flat	.25	Mylar/Nomex	5/6	Horiz.	Butt/Lap	GT300-3/100-1
T255	10	Flat	.5	Kapton/Nomex	5/6	Horiz.	Butt/Lap	GT300-4/100-1
T256	5	Flat	2	Nomex	1	Horiz.	Butt two sides	GT 300-4
T257	5	Flat	2.2 oz.	Dacron	1	Horiz.	Butt two sides	GT 300-4
T258	10	Flat	.25	Mylar/Dacron	6/5	Horiz.	Butt/Lap	GT300-3/100-1

NOTE: (1) Mylar "C" - .25 Mil
Kapton - .5 Mil
Nomex - 2 Mil
Dacron - 2.2 Oz.

(2) "W" - 1/2" Wide Hot Roller Seal
"N" - 1/8" Wide Hot Roller Seal
"I" - 1/8" Wide Impulse Seal
Butt Seames Taped on One Side Only (Except T204)

(3) GT 100-1 adhesive .5 Mil thick x .5" wide.
GT 100-2 adhesive 1 Mil thick x .5" wide.
GT 300-3 tape .25 Mil thick x adhes .25 Mil thick x .5" wide.
GT 300-4 tape .5 Mil thick x adhes .5 Mil thick x .5" wide.

FIGURE 3.8
SAMPLE DETAILS
SEA SPACE SYSTEMS INC.

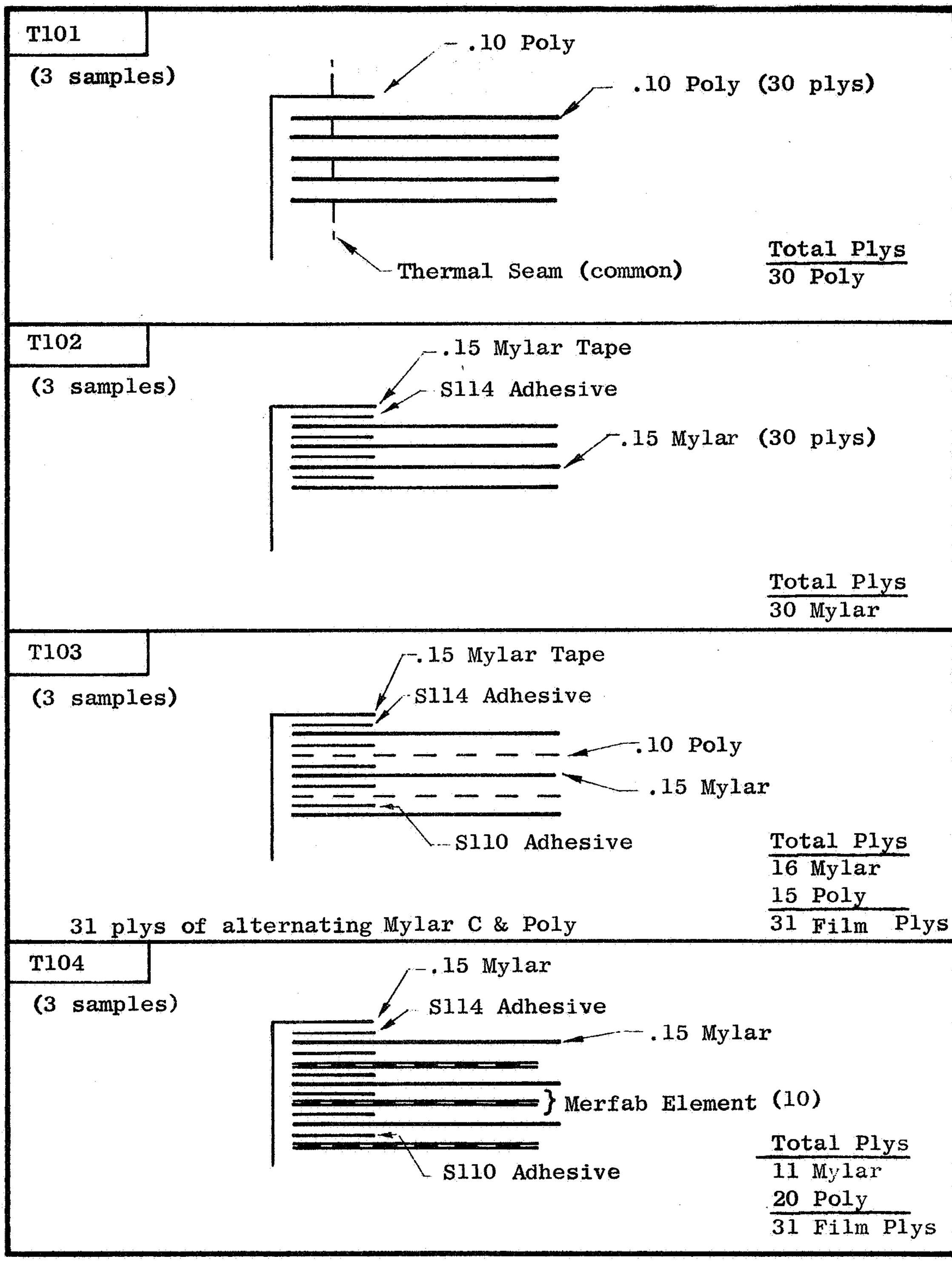
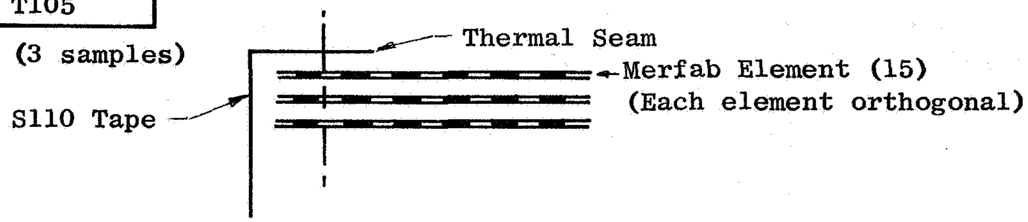


FIGURE 3.8 (Continued)
SAMPLE DETAILS
SEA SPACE SYSTEMS INC.

T105

(3 samples)

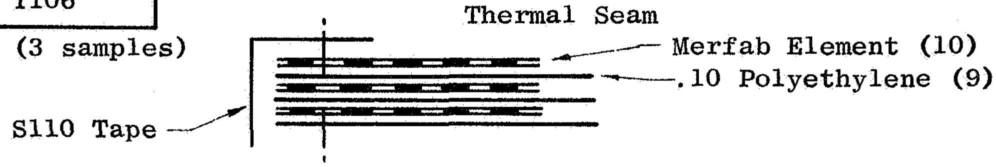


Similar to T101 plus fibers.

Total Plys
30 Poly

T106

(3 samples)

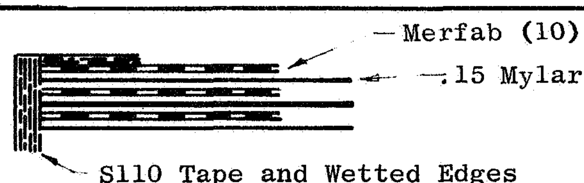


Similar to T104 except Poly in place of Mylar Film between Merfab elements. Similar to T105 plus .10 Poly Film.

Total Plys
20 Poly of Merfab
9 Poly
29 Film Plys

T107

(3 samples)

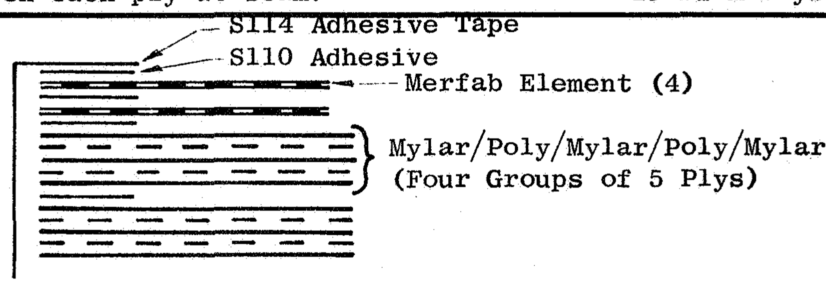


Same as T104 except only edges wetted instead of adhesive between each ply at seam.

Total Plys
20 Poly
9 Mylar
29 Film Plys

T108

(3 samples)



Double, orthogonal layers of Merfab elements as an abrasion shield on both sides.

Total Plys
16 Poly
12 Mylar
28 Film Plys

FIGURE 3.8 (Continued)
SAMPLE DETAILS
SEA SPACE SYSTEMS INC.

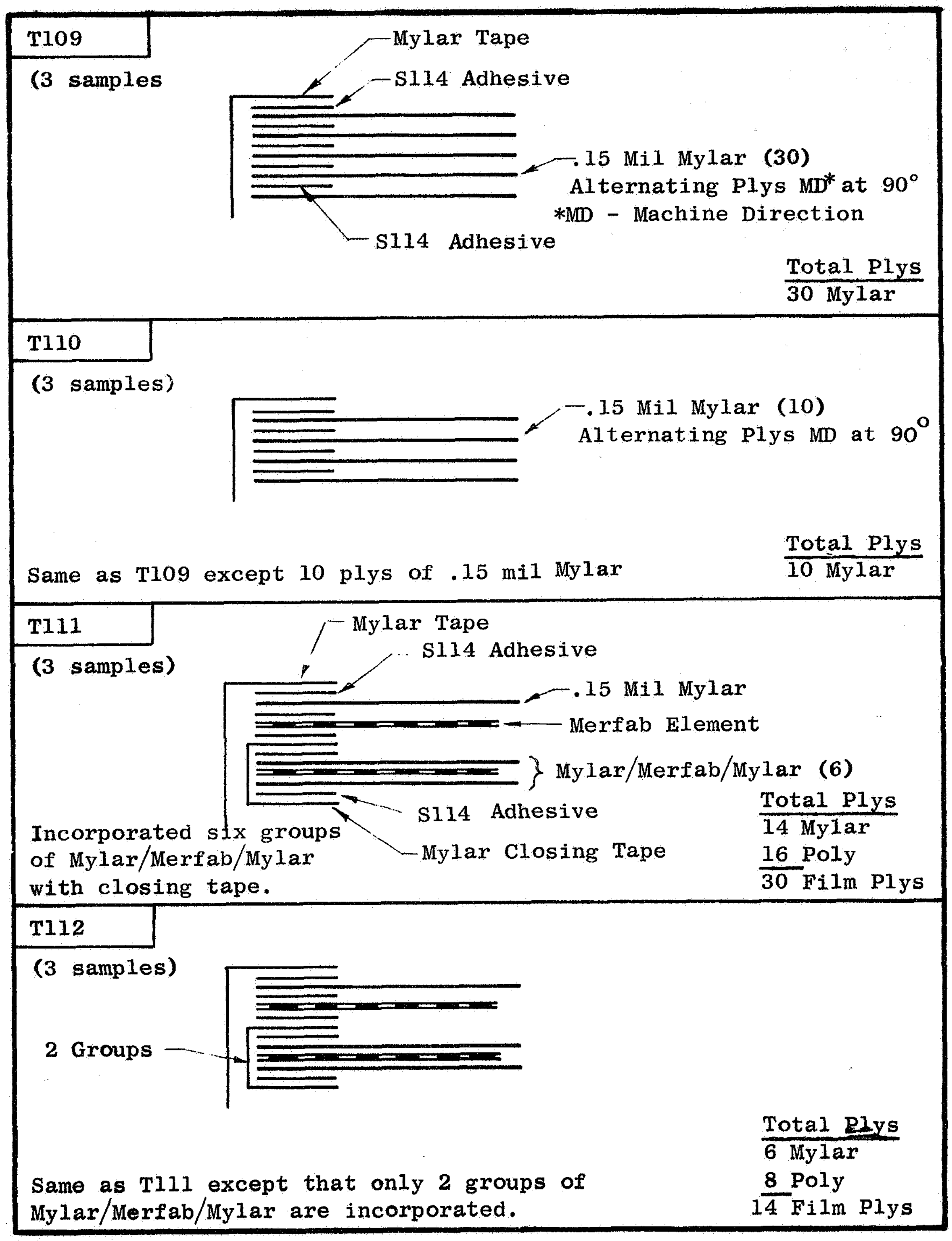


FIGURE 3.8 (Continued)
SAMPLE DETAILS
SEA SPACE SYSTEMS INC.

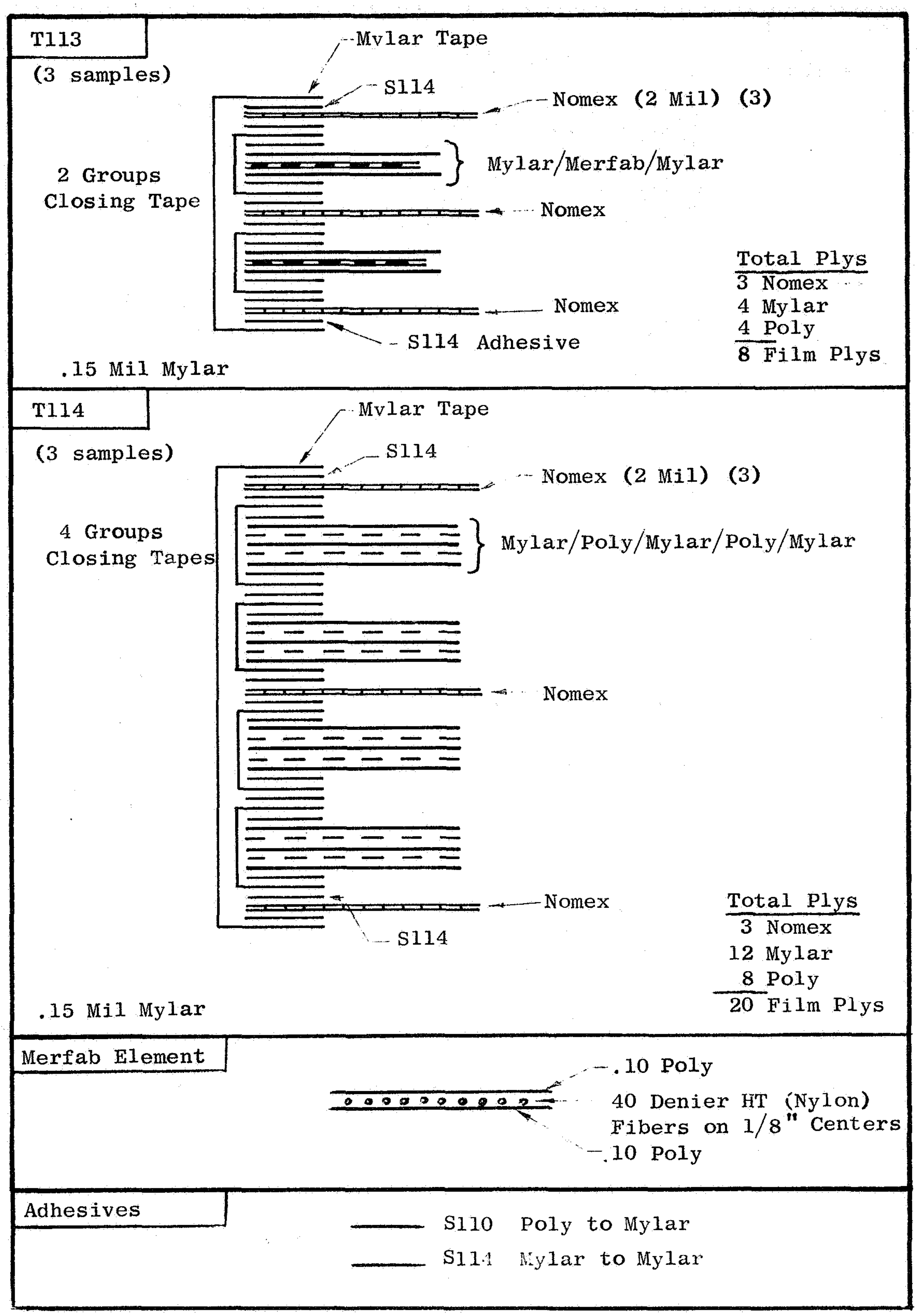
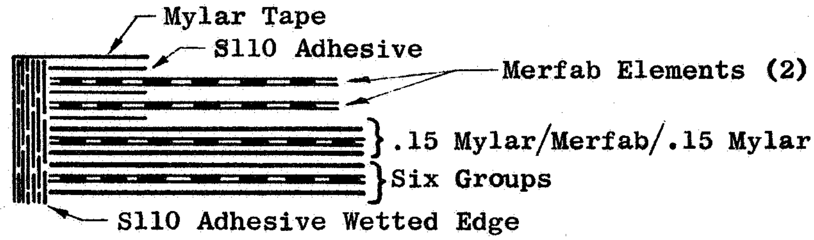


FIGURE 3.8 (Continued)
SAMPLE DETAILS
SEA SPACE SYSTEMS INC.

T115

(6 samples)



Total Plys
20 Poly
12 Mylar
32 Film Plys

Two outer Merfab Elements orthogonal.

T116

(6 samples)

Identical to T115 material with the addition of lap cross seams in sample.

T105

(6 samples) Identical to T105 as previously fabricated.

T117

(3 samples)

Identical to T109 as previously fabricated with the addition of lap cross seams. (.25 mil Mylar to be used in place of .15 mil Mylar.)

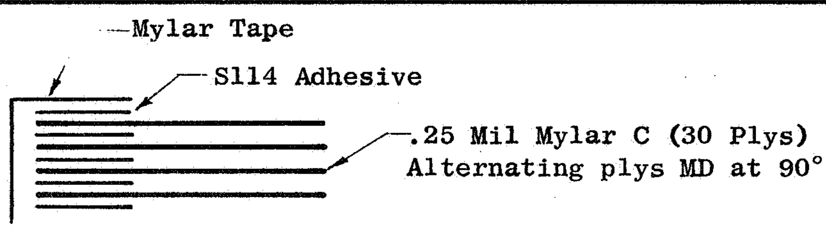
T118

(3 samples)

Identical to T110 as previously fabricated with the addition of lap cross seams. (.25 mil Mylar to be used in place of .15 mil Mylar.)

T119

(3 samples)



Total Plys
30 Mylar (.25 mil)

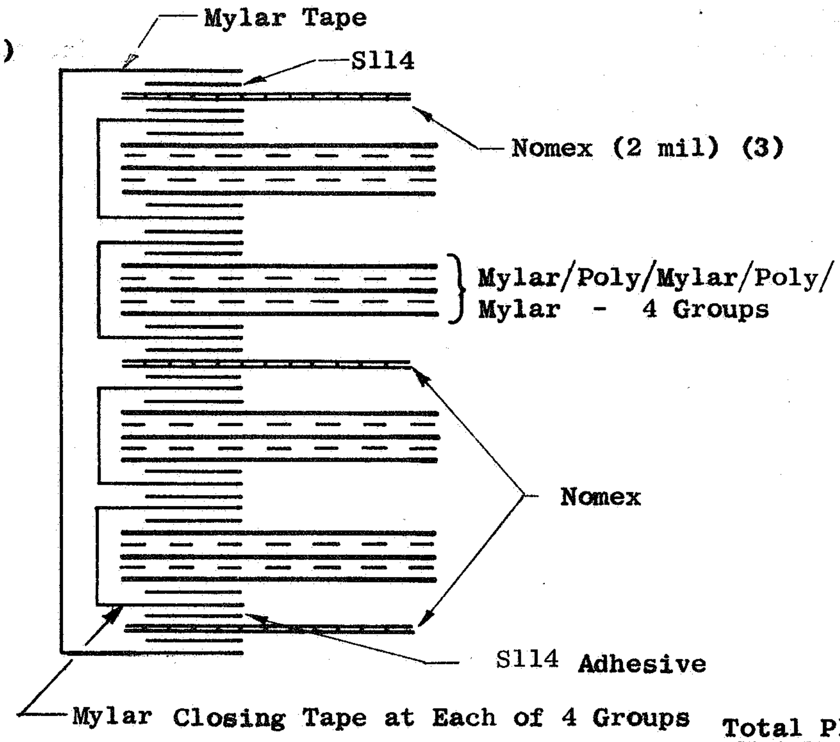
T120

(3 samples) (Same as T119 except 10 plys of .25 mil Mylar Type C)

FIGURE 3.8 (Continued)
SAMPLE DETAILS
SEA SPACE SYSTEMS, INC.

T121

(6 samples)

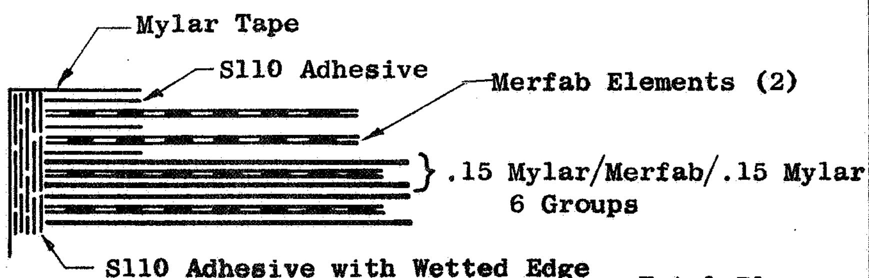


Total Plys
3 Nomex
12 Mylar
8 Poly
20 Film Plys

.15 Mil Mylar C

T122

(6 samples)



Total Plys
12 Mylar
20 Poly
32 Film Plys

Outer Merfab Elements orthogonal and edge seamed w/S110 Adhesive.
(Identical to T115)

T123

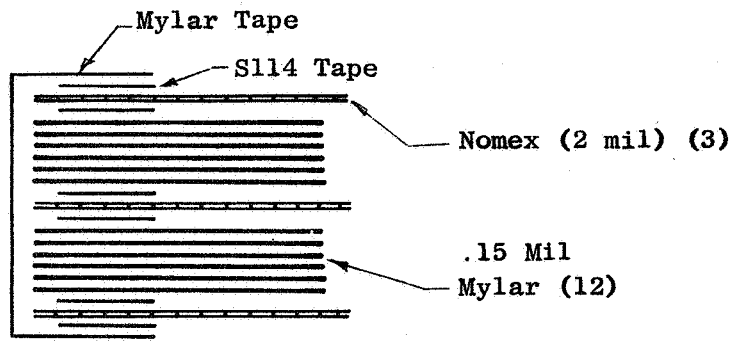
(5 CYLINDRICAL Samples)

Material and edge seams same as T119 except 30 plys of .15 mil Mylar Type C.

FIGURE 3.8 (Continued)
SAMPLE DETAILS
SEA SPACE SYSTEMS, INC.

T124

(5 samples)



Same as T121 but without polyethylene plys.

Total Plys
12 Mylar
3 Nomex

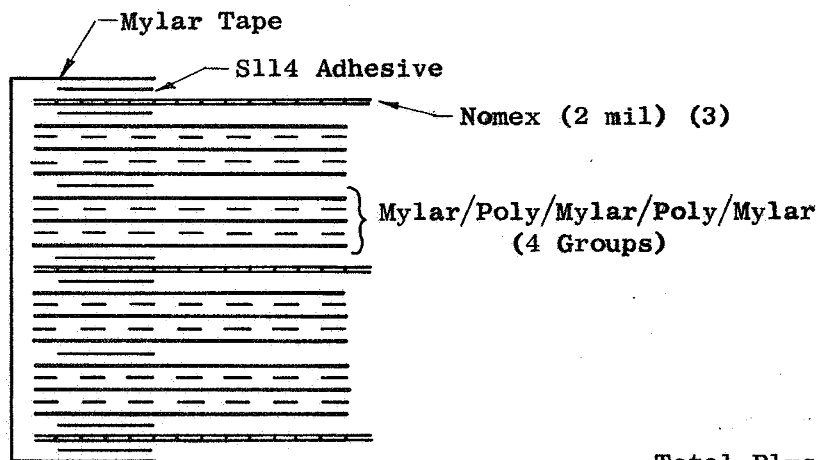
T125

(5 samples)

Identical to sample above but with cross seams.

T126

(5 samples)

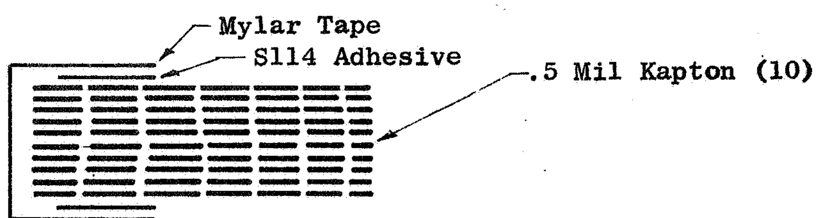


Identical to T121 but with cross seams.
.15 mil Mylar C.

Total Plys
12 Mylar
9 Poly
3 Nomex

T127

(5 samples)



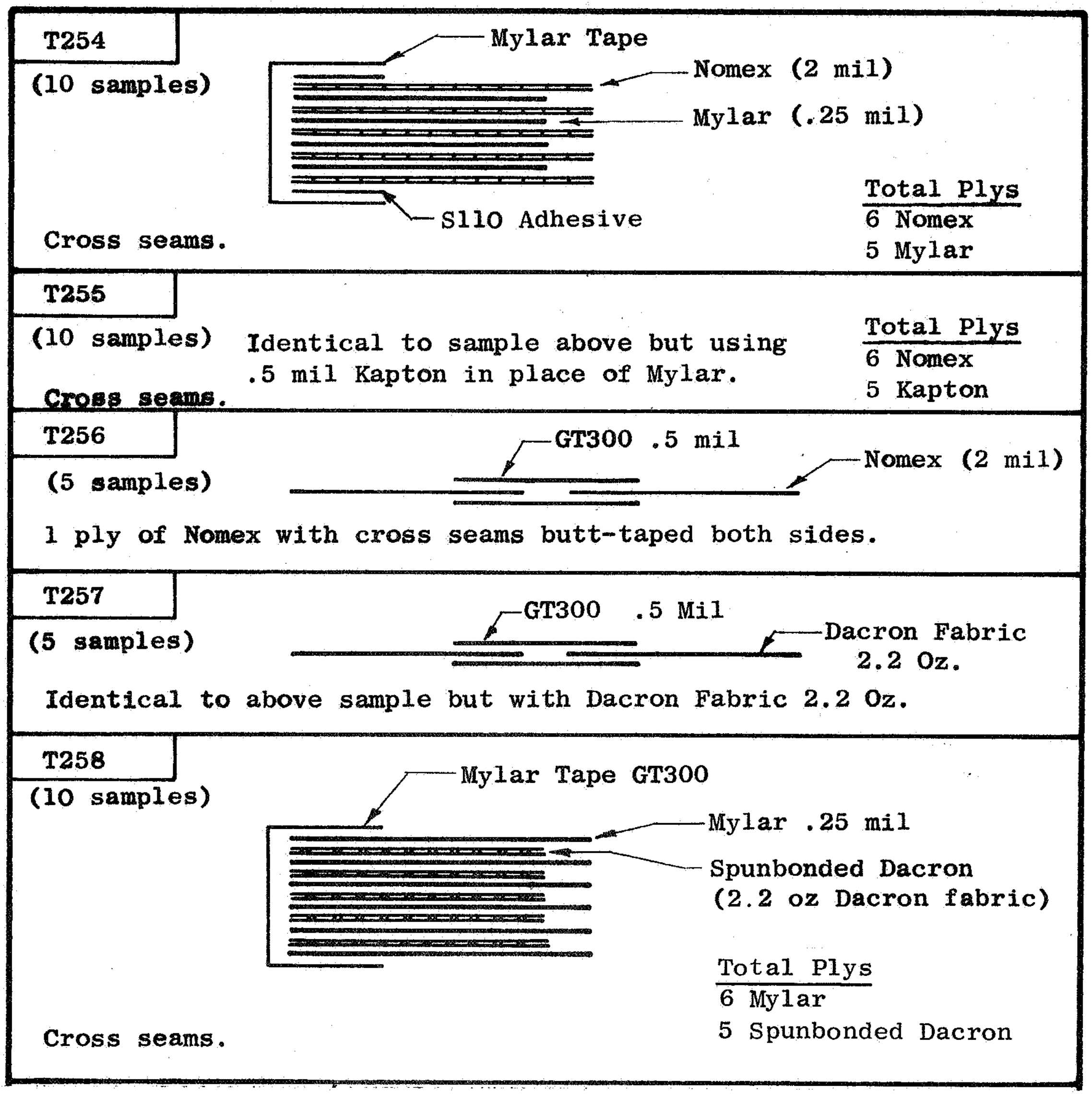
Cross seams.

Total Plys
10 Kapton

FIGURE 3.9

SAMPLE DETAILS
G. T. SCHJELDAHL

T201 through T253 samples are fully described in Table 3.3.



3.3 Evaluation and Testing Procedures

All material samples were "run" through a series of inspections and tests. The fabricator of the sample was required to provide a leak tight sample which was only accepted after having passed a permeability check at Beech. Thus, each sample received a final inspection at the time of fabrication by the vendor, a receiving and acceptance inspection by Beech followed by actual testing. The testing consisted of an initial permeability test, a cryogenic flexibility test, followed by a final permeability test and failure analysis.

The samples were fabricated in accordance with a material specification which described in detail the material, lamination, seaming, environmental conditions, inner ply gas environment, and packaging requirements. The basic specification was modified for different materials and for different fabricators. Details of materials and sample construction are described in Section 3.2.

3.3.1 Receiving Analysis

Upon receipt of the fabricated samples at Beech, they were inspected for appearance and conformity to the specification. Each specimen was individually checked for dimensional accuracy, thickness of material, seams, wrinkles or fabrication discontinuities. An appraisal was made of observable defects or discrepancies which might be judged to have an effect upon the flexibility testing to be performed.

3.3.2 Permeability Testing

After the material samples had been given a visual inspection, they were then tested for helium gas permeability at ambient temperature, in the apparatus shown in Figures 3.10, 3.11, and 3.12.

The permeability apparatus consists of an upper and lower plate between which the material samples are placed for leak testing. A pressure regulated source of helium is provided to the bottom plate and lower surface of the specimen.

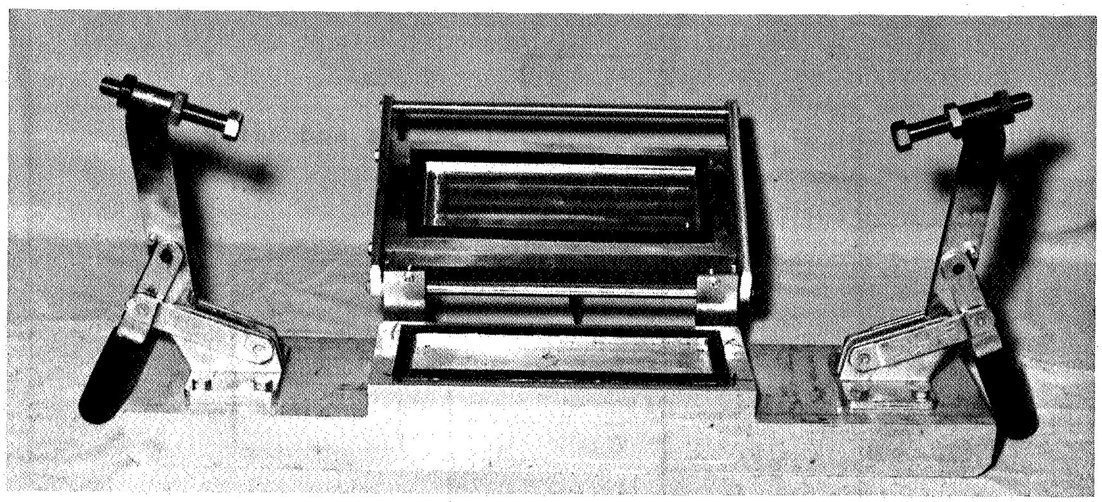
Gas permeating through the sample is collected by the upper plate. Its presence is detected and volume measured as follows:

1) Qualitative detection of extremely small volume by a mass spectrometer.

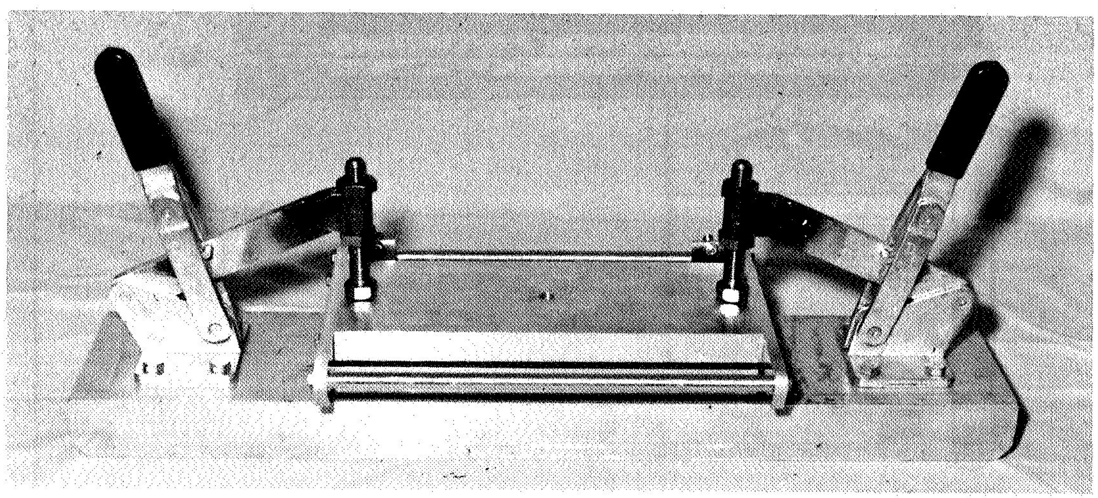
2) Passage of gas through a tube, inserted in a container of water, to show formation of bubbles.

FIGURE 3.10

PERMEABILITY FIXTURE
4" x 11" FLAT SAMPLES



OPEN FOR SAMPLE



CLOSED FOR TEST

-33364
E-270-1)

FIGURE 3.11

PERMEABILITY MEASUREMENT SYSTEM
(FLAT SAMPLES)

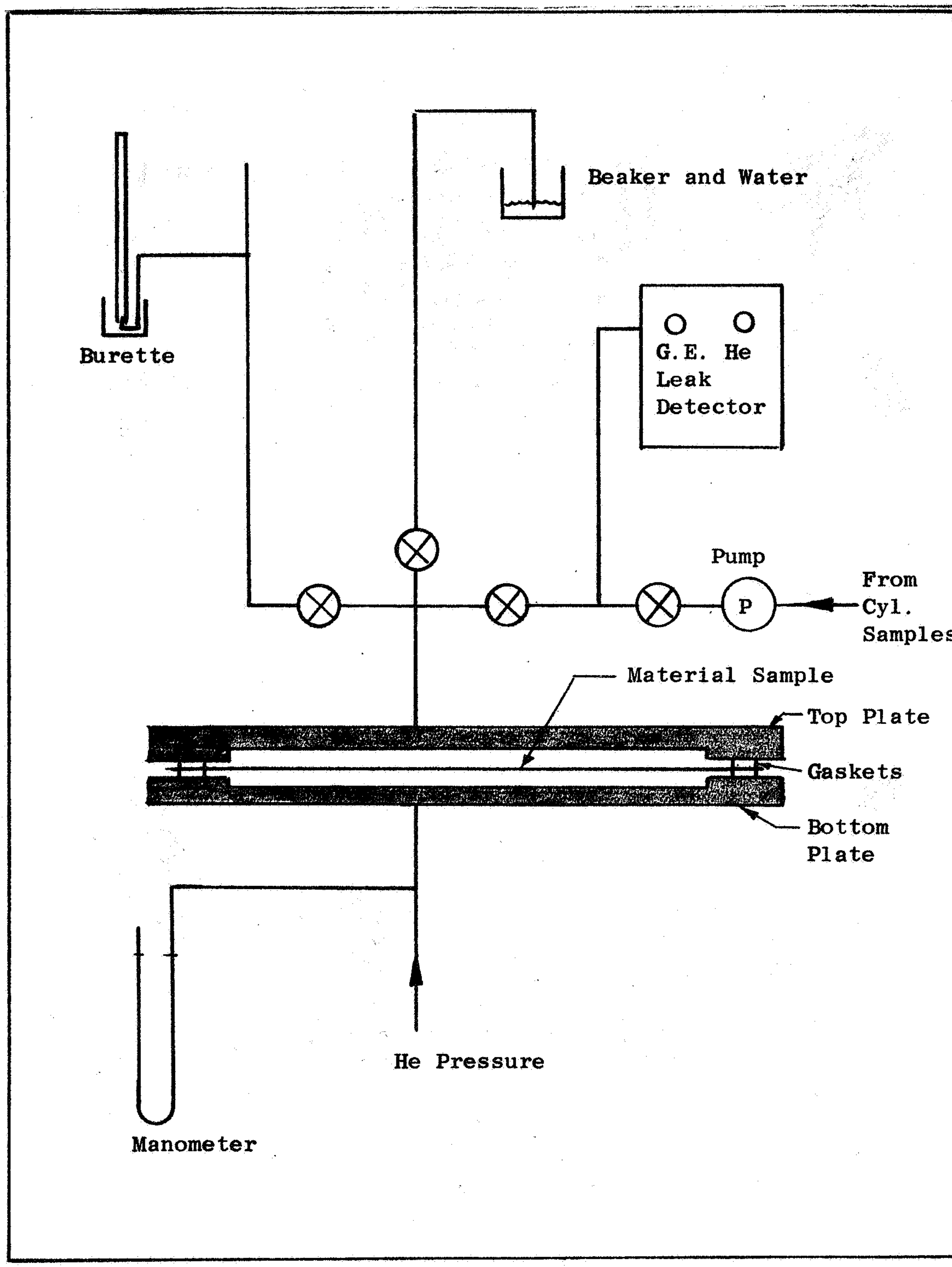
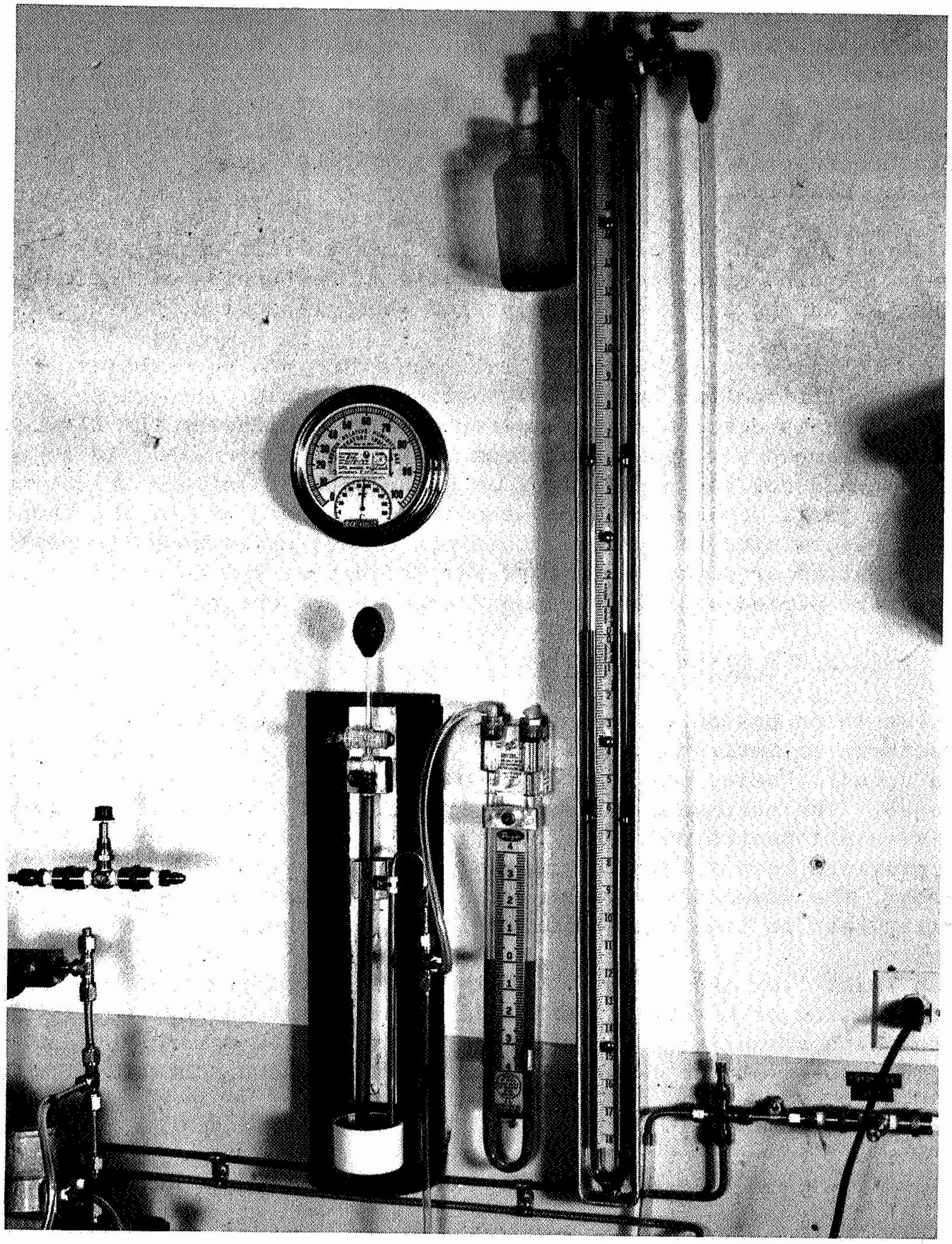


FIGURE 3.12

BURETTE & MANOMETER FOR PERMEABILITY MEASUREMENT



3) Similar to 2) above except that bubbles are collected in a burette by displacement of water. This method was used for a precise measurement of gas volume permeating through the sample per unit time.

The permeability fixture was designed to also accept a 4-inch by 9 1/2-inch sample because of the necessity of cutting off the ends of some samples to remove the heavy end seam and eliminate a source of sample failure. This was accomplished by the manufacture of a secondary pair of plates which fit the shortened samples and clamp between the original heavy plates of the permeability fixture.

Samples were required to pass a helium gas leakage test using the above equipment. Samples were declared acceptable if no bubbles of helium gas were observed during a three-minute period when pressurized to one psig.

If the sample passed all of the initial inspection and permeability testing, it was then qualified for Twist-flex testing in liquid nitrogen or liquid hydrogen, which is described in Paragraph 3.3.3. Following the flexibility testing, the sample was again subjected to a similar permeability test providing it had not had a splitting or gross type of failure which would prevent this test. This second permeability test used one of the three methods of determining a leak described above, depending upon the severity of the permeation or leak. A failure was defined as helium bubbles within a three-minute period with pressure differential of one psi.

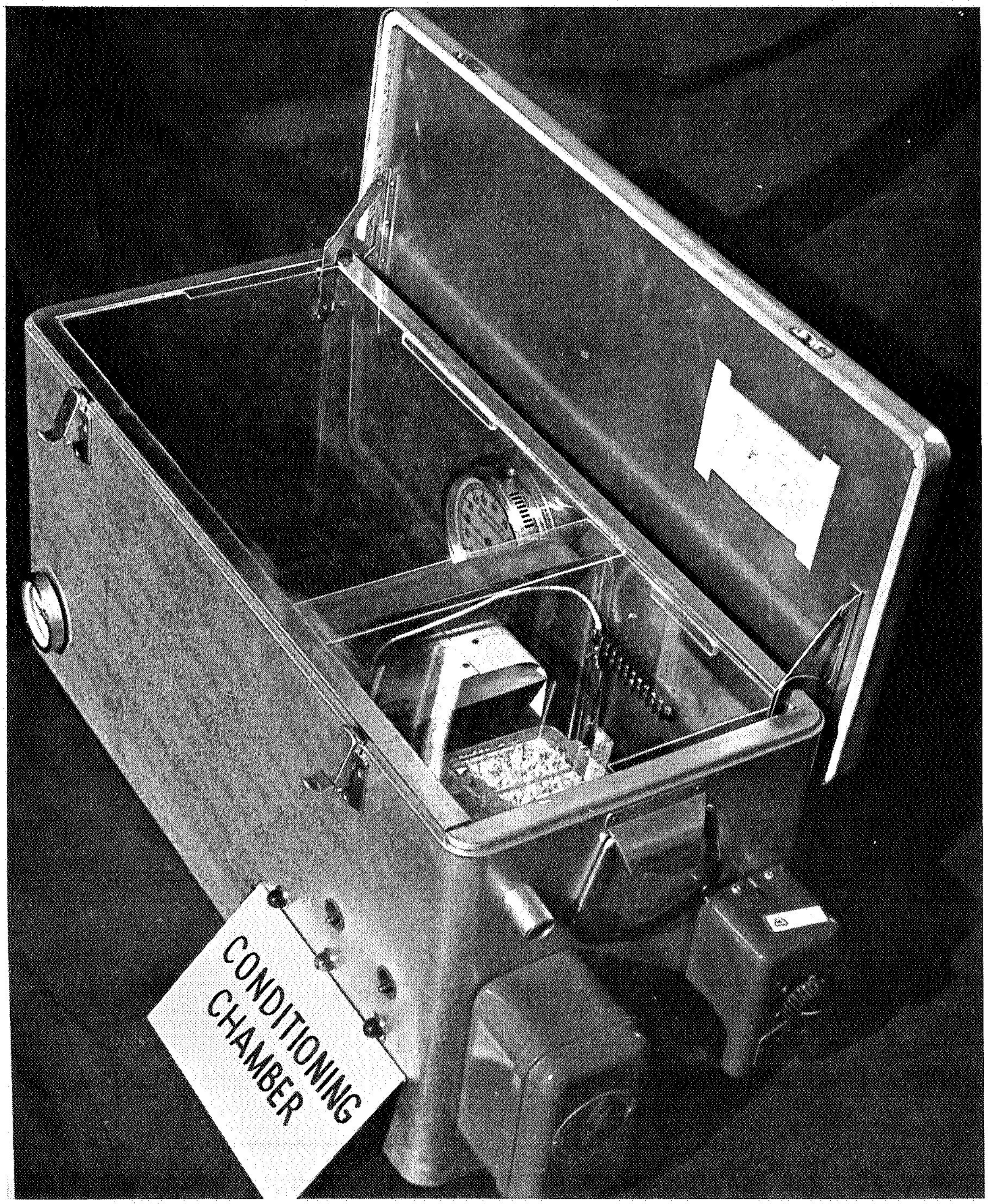
3.3.3 Flexibility Testing

The samples which passed the receiving analysis and permeability check were then placed in an environmental conditioning chamber, shown in Figure 3.13, prior to actually being subjected to the Twist-flex test in liquid nitrogen or hydrogen. The purpose of this chamber was to provide assurance that the samples were all tested under the same conditions of moisture content. The chamber provided both a temperature and humidity control. After removal from the chamber, the samples were installed in the Twist-flex apparatus for flexibility test in liquid nitrogen or liquid hydrogen.

The Beech Twist-flex Apparatus was designed and developed to permit the cryogenic testing of material samples in a manner simulating the flexing action to which actual bladder materials are subjected during an expulsion cycle. The motion of the Twist-flex Apparatus is shown schematically on Figure 3.14.

FIGURE 3.13

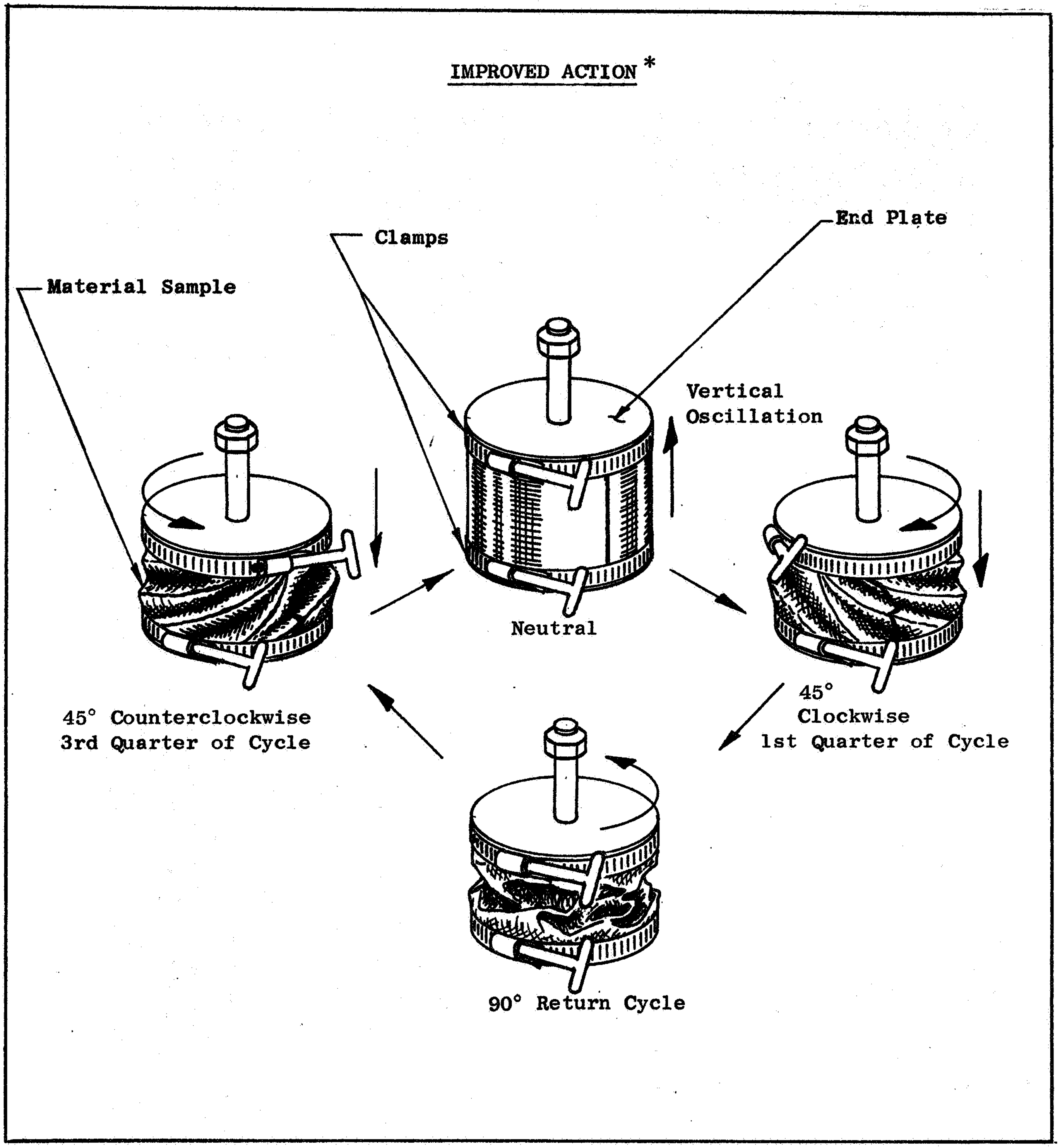
CONDITIONING CHAMBER



-33364
E-270-1)

FIGURE 3.14

TWIST-FLEX ACTION



*The "Original Action" (as described in the formal report for NASA Contract NAS9-513) did not include the 90° return cycle as shown in this illustration.

The samples used for the flexibility test were either flat, 4 inches wide by 11 inches long, or cylindrical shaped, 3-1/2 inches in diameter by 4 inches high. The flat sample is formed into a cylinder by wrapping the material around the cylindrical end plates and then clamped in place. The upper end plate rotates through 90 degrees (45^{o} each side of neutral). This rotation is accompanied by a cam-controlled vertical oscillation which tends to follow the collapsing-twisting action of the material sample during half of the cycle but permits a folding and rolling of the material during the other half cycle.

The test apparatus as shown on Figure 3.15 consists of a large plexiglass enclosed chamber which allows the operating test mechanism to perform the test cycle in a purged atmosphere. The mechanism is cycled at 9 RPM by an electric motor which drives a crank through a reduction gear box. A connecting rod from the crank pin to the oscillating shaft causes a roller on the shaft to follow a cam which is automatically cycled under the cam during one half of the cycle and withdrawn during the second half. This action is directly imposed onto the upper end plate to which the sample is attached.

After the sample was attached to the end plates, the sample was then submerged in the cryogenic liquid and the twist action started. The sample was observed during the cycling and, if necessary, the dewar could be momentarily lowered for a close inspection. During the hydrogen tests the entire test apparatus was enclosed in a helium purge chamber. The sample was flexed for a predetermined number of cycles or until failure occurred.

When some indication was given of a failure either through splitting of the film or apparent leaks through the sample, the cycling was stopped, the dewar lowered and the entire end plate assembly removed from the test apparatus. Testing was often stopped at a predetermined number of cycles, based on the experience of similar samples whose failure rates were known. The maximum number of cycles for a sample without failure or other criteria was 200 cycles.

Following the Twist-flex test, the sample was returned to the permeability fixture for another permeability test to compare with the test data prior to twist-flexing. If the sample had gross failure, a permeability test was impossible and the sample was sent to engineering for final analysis and recording.

Cylindrical samples were handled differently from flat samples only as follows:

1) The permeability test was accomplished while the sample was installed on the Twist-flex Apparatus plates. Permeability was noted by the absence of bubbles through the sample surface when 1/2 psi internal pressure of helium gas was applied. A quantitative measurement was not possible.

2) Failure caused by small pin holes was determined by observing the bubbles formed on the surface of the sample. The twist-flexing was then stopped and a determination made for continued cycling or removal of the sample.

3) After testing, the sample was returned to engineering for final analysis and recording of the data.

During the program, the twist-flex apparatus was modified to investigate the feasibility of continuous monitoring of the cylindrical samples permeation during cycling. The modification, as shown in Figures 3.16, 3.17, 3.18, 3.19, and 3.20 consisted of a new upper shaft and removable end plates. The new shaft is a hollow tube with the end plate attached and a ullage chamber is provided at the top for minimizing the pressure pulsations caused by the flexing action. An equalizing pressure was furnished from a controllable gaseous helium source. This line had a manometer installed to maintain the proper pressure and observe fluctuations, if any, and to show when and if a gross failure occurred.

Further improvements in the operation included the addition of a lower purge chamber and access opening with covers to maintain the helium purge at all times. The access opening for the installation of the sample and end plates were equipped with flexible sleeves so that the operator could reach through the openings without loss of the purge gas.

The test procedures established the requirement to determine the relationship between the permeation rate and the number of cycles. Great difficulty was experienced in observing direct correlation because of the random type of failures which prevented judgement in determining the number of cycles for succeeding samples. The flat samples required that the sample be removed after the Twist-flex test and the permeation rate determined. Because the gross failures occur at an unpredictable number of cycles without producing a trend, the accomplishment of this goal was not easily achieved.

FIGURE 3.15

TWIST-FLEX APPARATUS

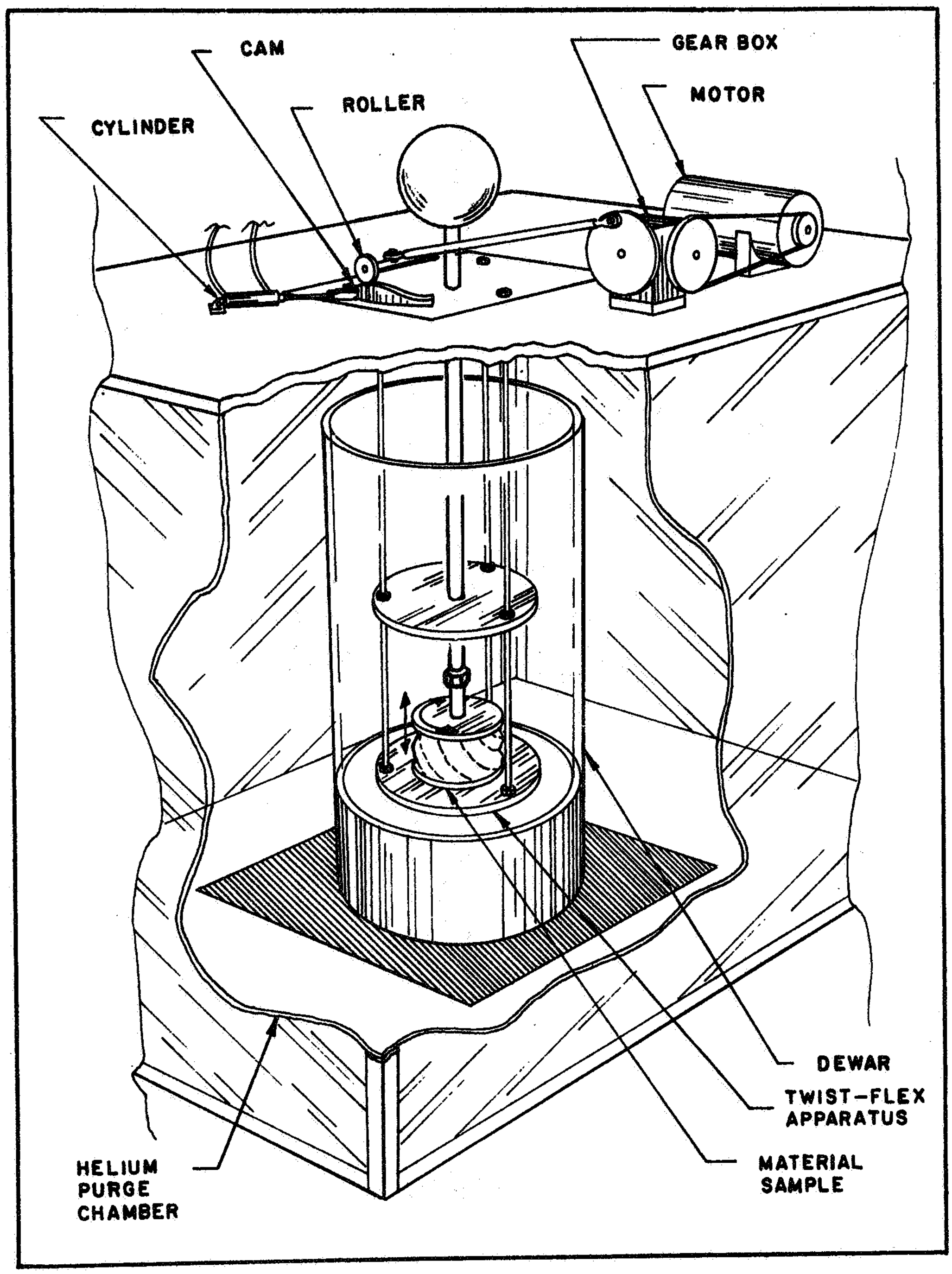


FIGURE 3.16

TWIST-FLEX MOUNT AND DRIVE SHAFT SUBASSEMBLIES

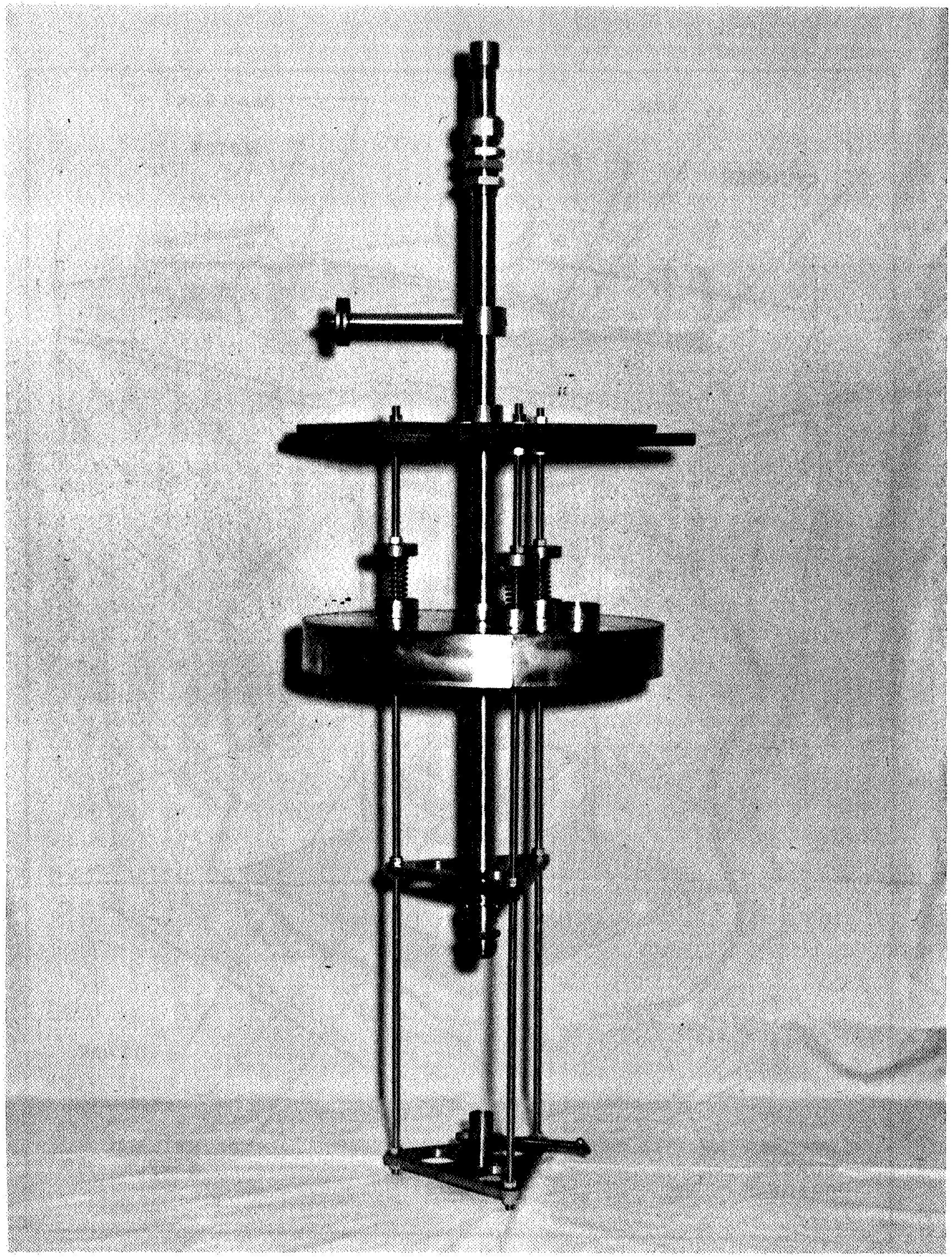


FIGURE 3.17

TWIST-FLEX APPARATUS

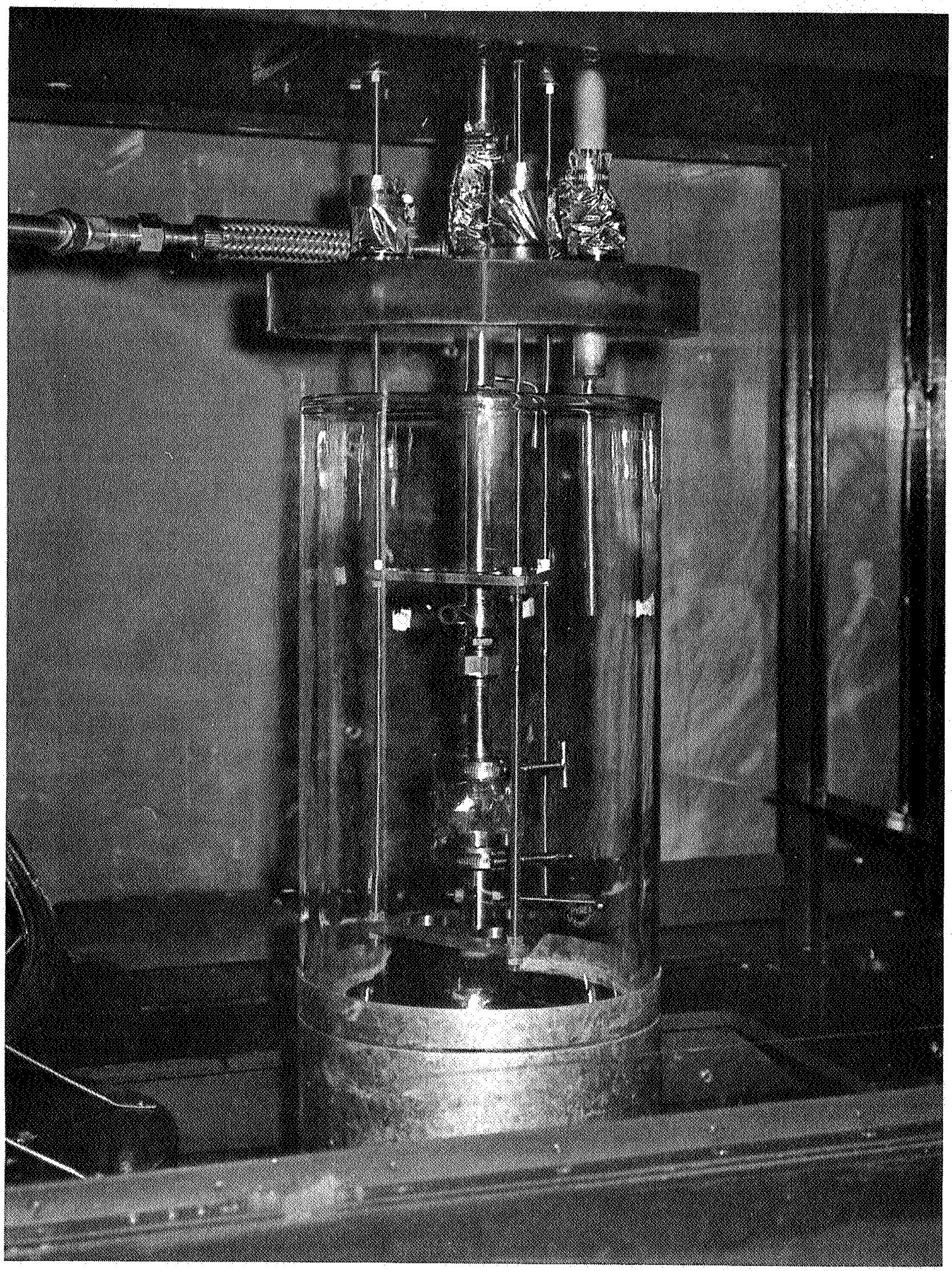


FIGURE 3.18

TWIST-FLEX SAMPLE INSTALLED

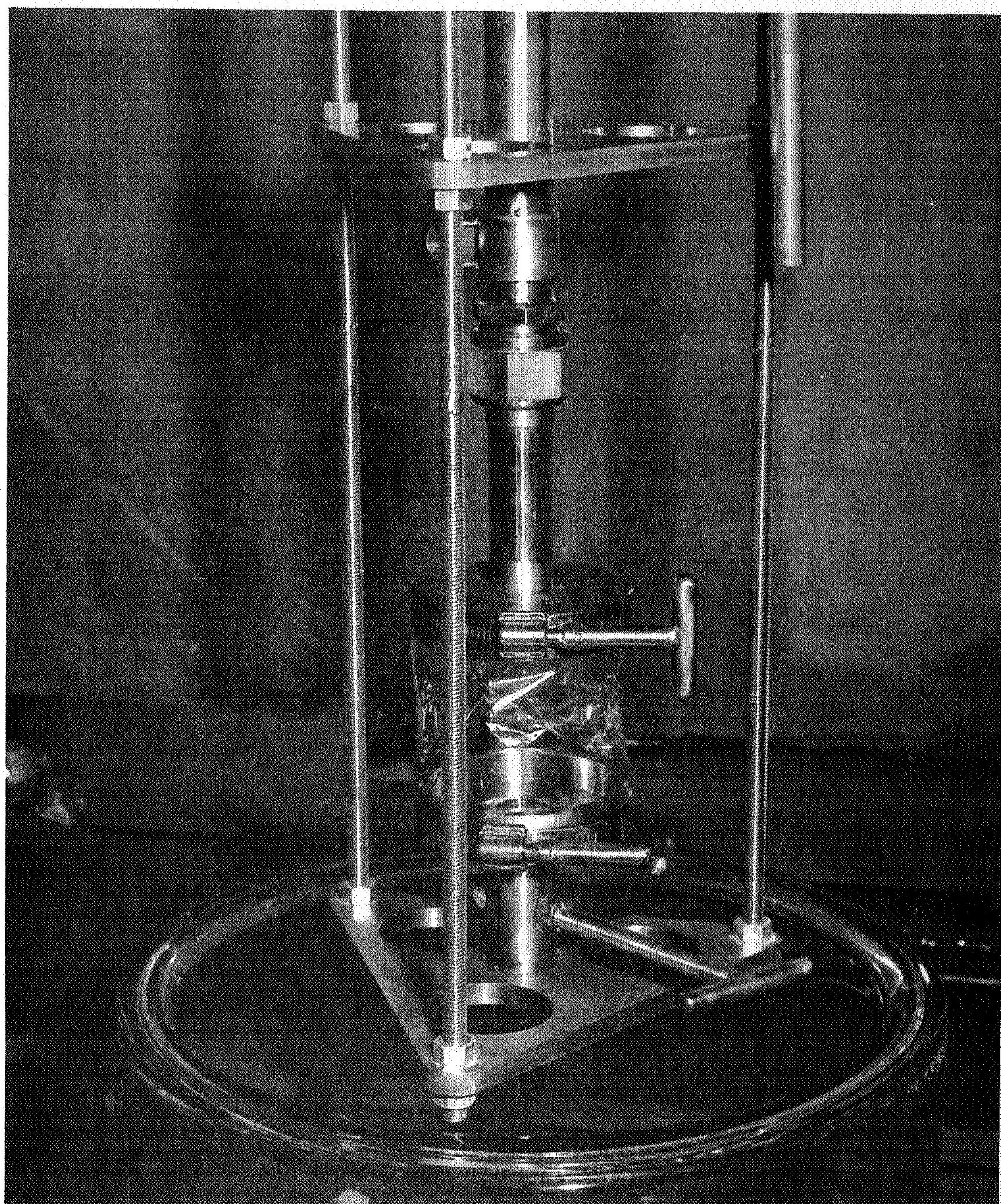


FIGURE 3.19

EKD PLATE ASSEMBLY WITH SAMPLE INSTALLED

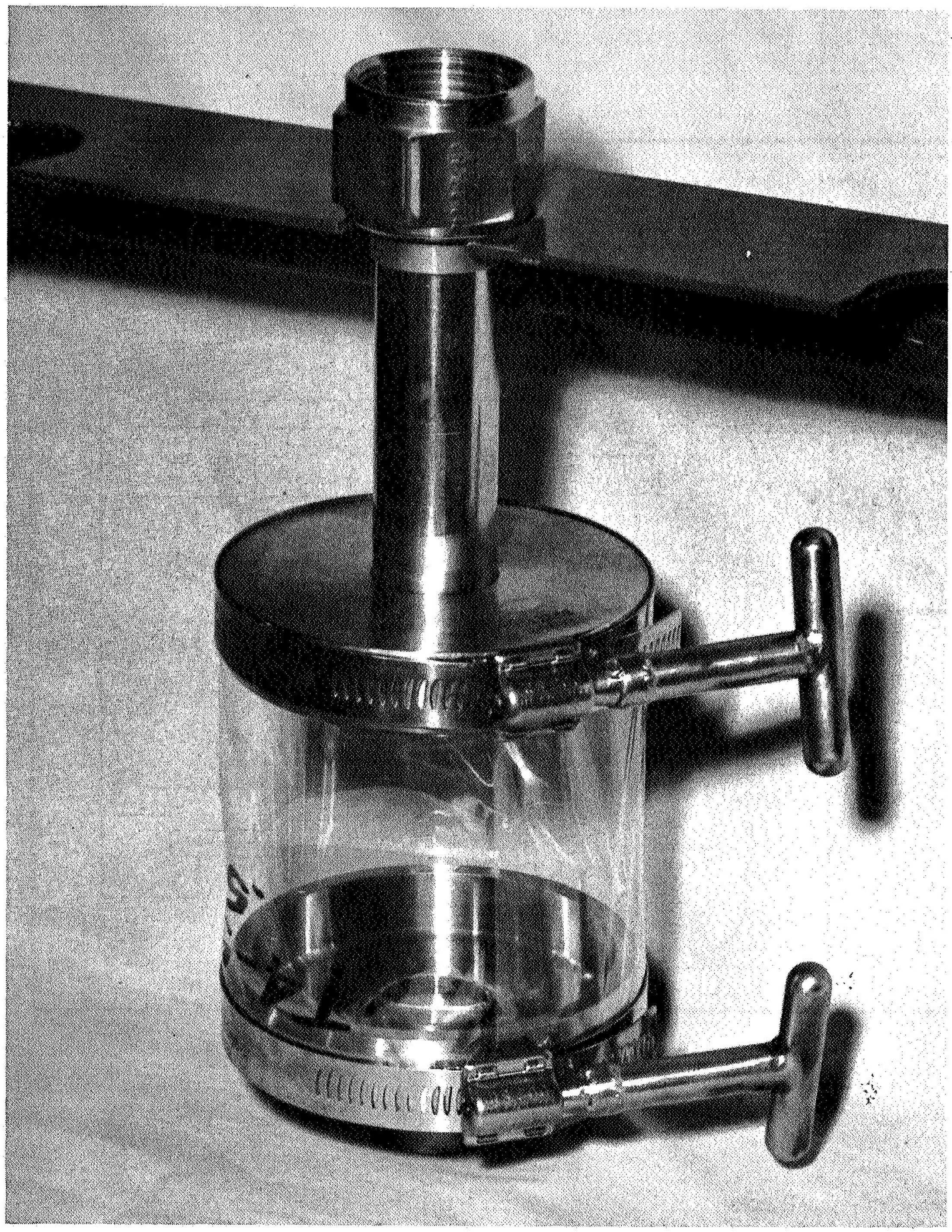
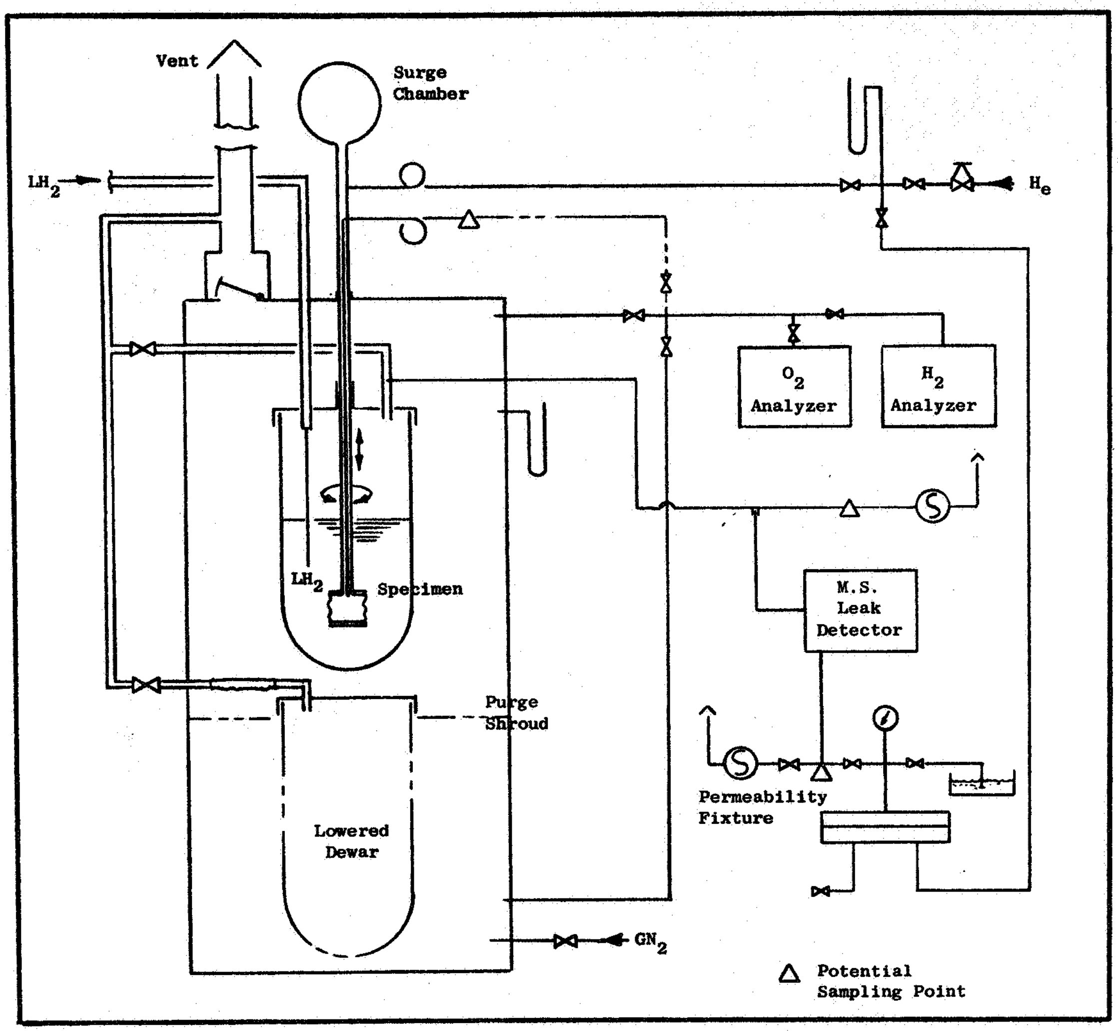


FIGURE 3.20

SCHEMATIC
TWIST-FLEX INSTALLATION
WITH PERMEABILITY MEASURING SYSTEM



3.3.4 Fluid Support System

The twist-flex test apparatus was located in a liquid hydrogen facility containing two 7000-gallon liquid hydrogen dewars and one 5000-gallon liquid nitrogen dewar. These fluids were transferred directly to the twist-flex apparatus through a system of lines and valves capable of controlling the filling of the 43-liter test dewar with either liquid. The actual operation was conducted from inside a control room through the use of remote control valves. The boil off and vented gas was conducted out of the test area through a 4-inch copper vent pipe through the roof and clear of the area.

A nitrogen gas purge was maintained during non-use of the test apparatus. During use, it was expected that the hydrogen boil-off would be vented through the dewar cover vent but actual practice showed the necessity of the helium purge to eliminate all possibility of nitrogen gas condensation and frost on and in the dewar.

The oxygen content of the purge chamber was monitored prior to each test by means of a GOW-MAC Oxygen Analyzer. A positive helium purge was maintained to prevent the entrance of air during actual testing.

3.3.5 Final Analysis

Analysis of the material test results was a continuing effort immediately following the removal of the sample from the final permeability test. Engineering judgement was required from sample to sample in order that the most efficient and effective use was made of each succeeding sample.

The samples ordered from Sea Space Systems, Inc., involved the fabrication of groups of 12 samples of four different materials to be tested before a decision was made as to the next group to be fabricated. The purpose of this arrangement made possible the improvement of samples by changing the material construction based upon the failure analysis of previous group.

Toward the end of Task I, a selection of the best material composites, fabrication processes, and seaming techniques was made, based upon a total analysis of the test results of all samples tested. The planned goal for Task I was the selection of five material composites for use in fabricating bladders.

All samples from the G. T. Schjeldahl Company were ordered at one time since the material composites could be determined in advance and the fabrication processes were considered established procedure.

The Boeing Company order consisted of 4-inch by 11-inch .25 mil Mylar C samples cut from thermally formed hemispheres. Only three samples were permitted from any one hemisphere. Following receipt of these twenty samples, they were combined into three samples of five plys each and five single ply samples with the ends sealed by NASA-LeRC.

Engineering and Development Company's work on ultrasonic seaming resulted in nineteen additional samples being made available for testing even though the primary purpose of the program was to determine if this method was practical for 1/4 mil Mylar and not to obtain samples.

Approval of Materials

Approval of the materials, composites and design concepts was obtained from NASA-Lewis program manager after consultation with fabricators and in consideration of the limitation of the cost and time as outlined in the Statement of Work. The reduction in the number of samples desired from 1600 to approximately 577 was achieved by eliminating liquid nitrogen testing, all 1/2 mil Mylar samples, except for Kapton samples and reducing the number of samples of any one composite.

3.4 Twist-Flex Test Data

This section contains all of the data obtained on each of the flat and cylindrical material samples tested in Task I, with the exception of samples tested in specific studies reported in Section 3.5, 3.6, 3.7, 3.8, and 3.9.

All samples were coded directly using an identification number defining source, composite, and sample.

3.4.1 Sample Coding

T100 Series from the Sea Space Systems, Inc.

The samples (Table 3.2) made by Sea Space consisted of .15 mil Mylar, .10 mil polyethylene, 40 denier HT (Nylon) fibers, Nomex paper, S110 and S114 adhesives in various combinations. The samples vary both in the number of plys, material, adhesive application, type of seams, use of filaments, and are fabricated within these limitations.

T200 Series from the G. T. Schjeldahl Co.

The samples (Table 3.3) made by the Schjeldahl Company consist of .25 mil Mylar, Kapton, Nomex paper, Dacron fabric, GT tapes, and Pliobond adhesive in various combinations. These samples were used to investigate horizontal and vertical; butt and lap-type seams.

T400 Series from the Engineering and Development Co.

These samples were single plys of .25 mil Mylar C in which an ultrasonic lap seam was placed down the horizontal or vertical face of the sample. The horizontal seams were placed in 4" x 11" samples and the vertical seams in 4" x 4" samples which were tested two at a time.

TN Series were furnished by NASA-Lewis Research Center

Samples furnished by NASA-LeRC are categorized in this series of letters. The TN1 samples were 10 ply .25 mil Mylar C in which GT-300 tape had been used to seal the edges. The TN2 samples were constructed of both Mylar and "spun-bonded" Dacron paper.

TC Series

The TC series were .5 mil Mylar Type C samples representing the first group of twist-flex control samples.

3.4.2 Preliminary Sample Tests

Test Results

Preliminary tests (performed in LH_2) were run on the modified twist-flex apparatus prior to installing any official program samples. The samples used in these tests were all .5 mil Mylar Type C, 4 inches by 11 inches in size and installed in the manner described in Paragraph 3.3.3. The purpose of these tests was to check out the twist-flex apparatus.

Preliminary Samples

SAMPLE NUMBER	NO. CYCLES TESTED	REMARKS
TC1-1	5	Original Action - Leakage more than 5 bubbles per second.
TC1-2	10	Leakage more than 2 bubbles per second.
TC1-3	25	Split 2/3rd the way along the 11" sample dimension. Complete break upon removal from apparatus.
TC1-4		Sample not tested.
TC1-5	10	Leakage 2 bubbles per second.
TC1-6	25	Leakage 1 bubble per second.
TC1-7		Sample not tested.
TC1-8		Sample not tested.
TC1-9	5	Original Action - Leakage 52 cc/min by burette.
TC1-10	5	Leakage in excess of measurement capability.
TC1-11	10	Leakage in excess of measurement capability.
TC1-12	25	Leakage in excess of measurement capability.

The results of these tests showed that the modified apparatus was not imposing any unusual conditions.

3.4.3 Summaries of Twist-Flex Material Sample Tests Sea Space Systems, Inc.

All samples tested and reported on in this section have been tested in liquid hydrogen except for part of the .5 mil Kapton samples T209, T210, T211, which were tested in liquid nitrogen.

T101 Description

30 plys of .10 mil polyethylene
Plain film - no seams
Thermally sealed with tape around all edges

Test Summary

This material and edge seaming method showed the most flexibility in handling since there was no build-up of thickness at the seams. Apparently a reinforcing ply of scrim materials is needed to help eliminate the tearing.

T102 Description

30 plys of .15 mil Mylar C
Plain film - no seams
Edges seamed with S114 adhesive between each ply

Test Summary

The extremely heavy edge seams, caused by the build-up of adhesive between each of the 30 plys and closing tape, was approximately 48 mils. This thickness cannot be tolerated at cryogenic temperatures.

T103 Description

30 plys of alternating films of .10 mil Poly and .15 mil Mylar C
Plain film - no seams
Edges seamed between plys with S110 adhesive
Closing tape sealed with S114 adhesive

Test Summary

The edge seam of these material samples was quite thick but not as stiff as T102. The material was very flexible and cycle life shows some promise. The edge seams must be reduced in thickness and in stiffness to improve this material.

3.4.3 Summaries of Twist-Flex Material Sample Test (continued)

T104 Description

30 plys of .10 mil polyethylene and .15 mil Mylar C
Between the .10 mil Poly film are 40 denier HT fibers on 1/8" centers
Between any two Poly films is a .15 Mylar film
Outer films are .15 Mylar
Edges seamed between Poly and Mylar with S110 adhesive
Closing tape sealed with S114 adhesive.

This material appeared to be the most satisfactory of the four materials tested of this group. Improvement in the adhesive or seaming method to reduce the stiffness and some variations of lamination order of plys may improve this material.

T105 Description

Similar to T101 with addition of fibers
30 plys of .10 mil polyethylene assembled into 15 Merfab elements with 40 denier HT (nylon) fibers 1/8" on centers
Edges seamed with S110 adhesive between each ply
Closing tape around edges of sample

Test Summary

Excellent appearing material with wrinkled but soft, smooth surface. Edge seams and material flexible. Very satisfactory except for the high permeability following testing. Splitting of film apparently on outer plys, although permeability might indicate splits in all film plys. Some of the T105 samples were also tested in Section 3.9.2, "Test Results of Inter-Ply Inflation".

T106 Description

Identical to T105 with the addition of .10 mil polyethylene film ply between each Merfab element
30 plys of polyethylene
Edges seamed with S110 adhesive and taped

Test Summary

Appearance identical to T105 and results very similar. Permeability relatively high. Addition of Mylar film ply would reduce permeability.

3.4.3 Summaries of Twist-Flex Material Sample Test Data (continued)

T107 Description

Identical to T104 except edges of plys wetted with adhesive
S110 adhesive used
Closing tape

Test Summary

Extremely soft, smooth and flexible material and edge seams. Permeability improved over other pure polyethylene samples by the addition of Mylar film.

T108 Description

30 plys of film total consisting of 12 plys of .15 mil Mylar and 16 plys of .10 polyethylene
Two outside plys of Merfab elements
Four groups of alternating Mylar/Poly/Mylar/Poly/Mylar
S114 closing tape and adhesive
S110 adhesive between selected plys

Test Summary

Extremely soft, smooth and flexible material and edge seams. Permeability extremely low.

T109 Description

30 plys of .15 mil Mylar C
Each ply 90 degree machine direction
S110 adhesive between plys at edges
S114 closing tape and adhesive

Test Summary

Typical Mylar multi-ply sample with good permeability following twist-flex testing. Seam extremely flexible.

T110 Description

Same as T109 except 10 plys of .15 mil Mylar C.

Test Summary

Typical Mylar multi-ply sample with good permeability following twist-flex testing. Seam extremely flexible.

3.4.3 Summaries of Twist-Flex Material Sample Test Data (continued)

T111 Description

A 30 ply sample composed of 14 plys of .15 mil Mylar C and 16 plys of .10 mil polyethylene
Outer plys Mylar
Inner plys alternating Merfab elements with Mylar films

Test Summary

Extremely soft, smooth and flexible material and edge seams. Permeability higher than some other pure Mylar samples, otherwise similar.

T112 Description

Same as T111 except only 6 Mylar and 8 Poly films
Inner plys grouped into two groups of Mylar/Merfab/Mylar

Test Summary

Same as T111 analysis.

T113 Description

Three Nomex plys and 8 film plys
.15 mil Mylar, Merfab element
S110 adhesive between plys at edges
S114 closing tape and adhesive

Test Summary

Excellent appearing material without any serious damage. Mylar films apparently not affected according to second permeability reading.

T114 Description

Three Nomex plys and 20 film plys consisting of 12 Mylar .15 mil and 8 polyethylene .10 mil
S110 adhesive between plys
S114 adhesive and closing tape

Test Summary

Excellent appearing material without any serious damage. Mylar films apparently not affected too seriously by flexing as shown by second permeability readings. Material more bulky than T113 because of additional film plys.

3.4.3 Summaries of Twist-Flex Material Sample Test Data (continued)

T115 Description

Two outer Merfab elements; Orthogonal, S110 adhesive between plus six groups of .15 Mylar/Merfab/.15 Mylar joined only by S110 wetted edges and closing Mylar tape.

Test Summary

A soft, flexible material in which the Orthogonal fibers are visible through all of the layers of film. Exceptionally good condition following twist-flex testing.

T116 Description

Identical to T115 material with the addition of cross seams in sample.

Test Summary

Appearance and results similar to T115 with the cross seams producing no serious changes. Splitting apparently in outer plys only.

T117 Description

30 plys of .25 mil Mylar
Cross seams
S110 between plys
S114 closing tapes

Test Summary

Very bulky sample with 30 plys of Mylar. Exhibited typical Mylar results with very good permeability and flexibility unless complete splitting failure occurs which destroys the entire sample.

T118 Description

10 plys of .25 mil Mylar
Cross seams
S110 between plys
S114 closing tapes

Test Summary

Splitting of end caps most serious problem in this sample. Permeability not measurable when all films split into field of sample.

3.4.3 Summaries of Twist-Flex Material Sample Test Data (continued)

T119 Description

30 plys of .25 mil Mylar
S110 adhesive on edge seams
S114 closing tapes

Test Summary

Excellent results with low permeability and no splitting which occurred on similar T117 samples with cross seams. Conclusion is not possible, however, that seams were the cause of the difference in results.

T120 Description

10 plys of .25 mil Mylar
S110 adhesive
S114 closing tapes

Test Summary

Typical Mylar results. Good permeability with multi-ply films unless splitting occurs which frequently affects all plys.

T121 Description

3 Nomex plys and 20 film plys (12 plys of .15 mil Mylar C and 8 plys of .10 mil polyethylene)
S110 between edge seam plys
S114 at closing tapes

Test Summary

Excellent results with flexibility and strength with low permeability following twist-flex testing with good cycle life.

T122 Description

Identical to T115 with addition of cross seams.

Test Summary

Soft, flexible, somewhat bulky material but with good characteristics. Results of permeability indicate splitting only on a few surface films.

3.4.3 Summaries of Twist-Flex Material Sample Test Data (continued)

T123 Description

30 plys of .15 mil Mylar C
Cylinder 3/14" diameter x 4"
Cross lap seam

Test Summary

The cylinder configuration shows more serious and early failure due to the restriction of the material.

T124 Description

12 plys of .15 mil Mylar C and 3 plys of Nomex (2 mil) without cross seams.

Test Summary

Very good flex and permeability performance; however, samples are without cross seams. Also see data for T125.

T125 Description

12 plys of .15 mil Mylar C and 3 plys of Nomex (2 mil) with lap type cross seams, 1/2" wide.

Test Summary

Good flex and permeability performance despite persistent seam failures in Nomex (apparently insufficient adhesive). Seams in Nomex not acceptable without additional development.

T126 Description

3 Nomex plys and 20 film plys (12 plys of .15 mil Mylar C and 8 plys of .10 mil Polyethylene)
Lap type cross seam - 1/2" wide

Test Summary

Generally very short flex life to point of advanced deterioration and incipient seam failure.

NOTE: These samples exhibit very irregular lap seams.

3.4.3 Summaries of Twist-Flex Material Sample Test Data (continued)

T127 Description

10 plys of .5 mil Kapton with closing tape of Mylar and S114 adhesive
Lap type cross seams - 1/2" wide

Test Summary

Very poor flex performance suggesting that Kapton should not be used without substrate plys.

Conclusions

Figure 3.21 shows the results of permeability testing for all Sea Space Systems, Inc., material samples. This comparison provides an indication of which materials have the lowest permeability after twist-flex testing. It is necessary, however, to relate cycle life to permeability in order to select the most satisfactory composite.

The damage to the material can only be judged by noting the condition of each sample as described after each sample in test data of Appendix A. A sample with heavy or stiff edge seams often cause a failure of an entire sample by initiating a split from the edge into the field of the sample. This is not necessarily indicative of a poor material but poor edge seam. This occurred in T101, T102, T103, T104, and was corrected in later samples.

All samples furnished by Sea Space Systems, Inc., were extremely soft and flexible except for the first group with heavy edge seams.

The polyethylene film was found to be highly permeable and therefore the need for barrier plys of Mylar or Kapton was apparent. The poly or Merfab material appeared to offer some substrate value of strength and body to improve qualities of a composite. Nomex and Dacron substrates also offered somewhat similar value but were stiffer and provided better abrasion resistance. (Ref 12,13)

The seamed samples did not perform as well as the plain samples and resulted in lower cycle life and higher permeability. The plain Mylar samples, T109 and T119, with 30 plys of .15 and .25 mil Mylar C exhibited the best all-around performance of low permeability and high cycle life. T110 with 10 plys of Mylar ran a close second in acceptability and T114 and T121 showed many good characteristics.

3.4.3 Summaries of Twist-Flex Material Sample Test Data (continued)

The addition of cross seams to samples of T126 (Poly/Mylar/Nomex) has resulted in performance far below that obtained for the samples without cross seams (T121). Seam separation in the Nomex plys is the primary failure mode but was not identified as being a problem with Mylar barrier plys.

Seam separation problems in the T125 (0.15 Mylar/Nomex) samples resulted in poor performance of those samples in comparison to other Nomex-Mylar combinations such as T238 (Schjeldahl bladder Type 1 material). The very poor performance of T127 samples further demonstrates that the flex characteristics of Kapton are such that it should not be used without substrate plys.

The selection of the various material composite from Sea Space was done to determine the best arrangement of Polyethylene, Merfab, Mylar, Kapton with Nomex and Dacron.

The final material recommendations are given in Section 3.10.7.

Detailed test data on each individual sample may be found in Appendix A.

3.4.4 Summaries of Twist-Flex Material Sample Test Data G. T. Schjeldahl Co.

T201 Description

5 plys of .25 mil Mylar C
Edges seamed together with GT 100 adhesive
GT 300 closing tape

Test Summary

The majority of these samples failed by the splitting of the film from the ends toward the center. The reduction of the width of the end seam did not appear to contribute to the success of the testing of these samples. The adhesive extruded out beyond the 1/2" seam into the field of the sample. The effect of the heat applied to the seam appeared to wrinkle the material adjacent to the seam. It is possible that the heat changed the physical characteristics of the film.

The seaming method uses heat and pressure and causes the multi-ply sample to become a single ply at the seam of approximately 8 to 9 mils. Mylar in this thickness is not capable of withstanding the flexing required at the edge seam.

3.4.4 Summaries of Twist-Flex Material Sample Test Data - G. T. Schjeldahl Co.

T202 Description

Same as T201, except 10 plys of .25 mil Mylar C
Edges seamed together with GT 100 adhesive
GT 300 closing tape

Test Summary

The majority of these samples failed by the splitting of the film from the ends toward the center. Splits were generally near the upper and lower edges at the ends. Only the samples that did not split into the field of the sample were tested for permeability after flex testing. The reduction of the width of the end seam did not necessarily indicate improvement since there was a limited number of samples tested in this manner. The seams must be improved for this material to be satisfactory.

T203 Description

5 plys of .25 mil Mylar C
Edges seamed with GT 100 adhesive
Horizontal and vertical seams in field
Butt seams taped one side
GT 300 closing tape

Test Summary

Many of these samples failed by the splitting of the film from the ends toward the center. Splits occurred near the upper and lower edges at the ends. The samples with the end seams removed showed the best results with only the outer ply splitting. Permeability data was possible on several of the samples in this group. The horizontal and vertical seams did not appear to influence the results.

T204 Description

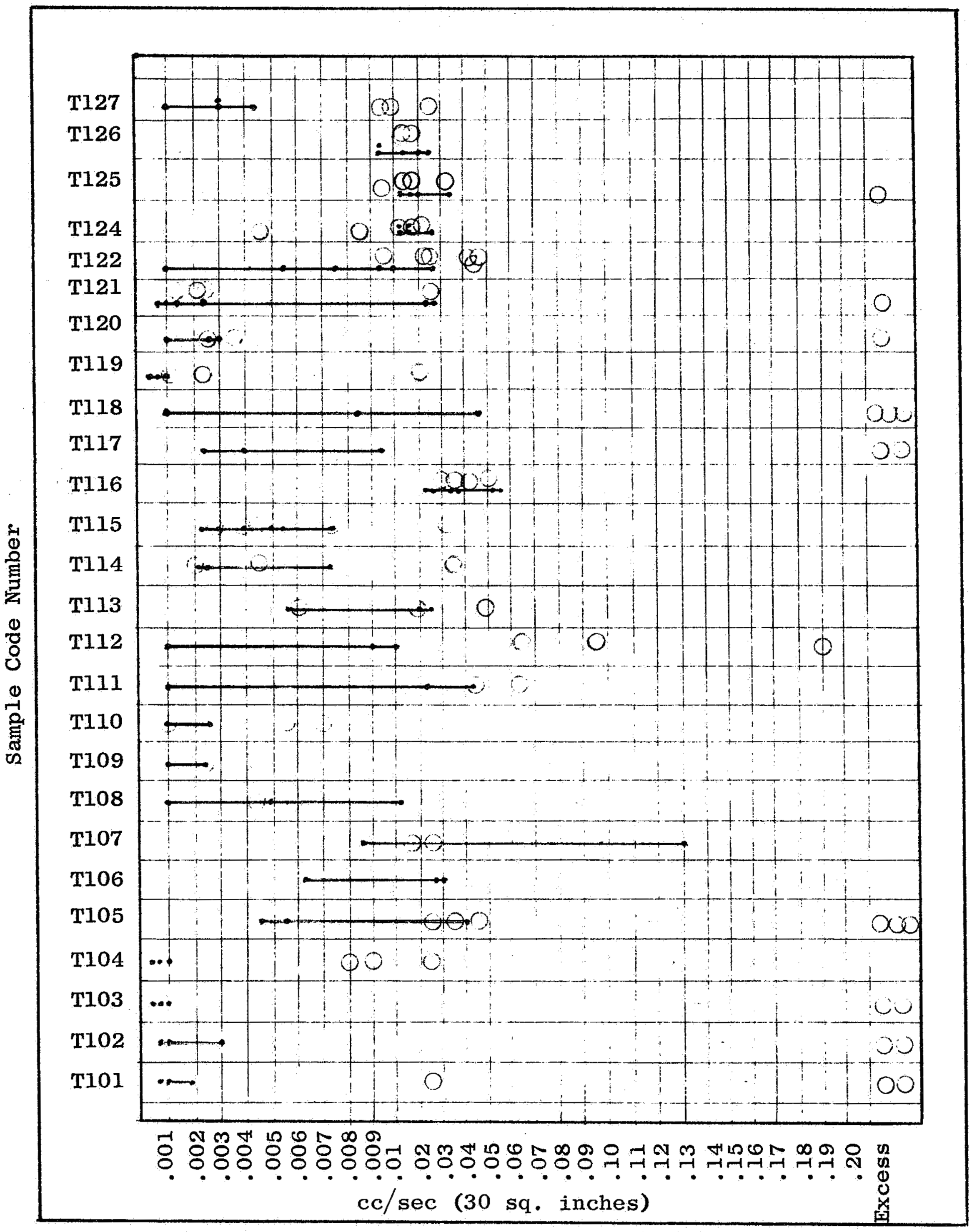
5 Plys of .25 mil Mylar C
Edges seamed with GT 300 adhesive
Horizontal and vertical seams in field
Lap seams using GT 100 tape
GT 300 closing tape
Ends seamed as noted

Test Summary

Samples, with end seams failed with the splitting of the sample from, the end into the field, preventing any permeability check. The samples with GT 300 tape end sealing did not split at the ends, but had considerable

FIGURE 3.21

SEA SPACE SAMPLES
PERMEABILITY CORRELATION



• Before T-F Test ◌ After T-F Test

3.4.4 Summaries of Twist-Flex Material Sample Test Data (continued)

film splitting in the field of the sample. The splitting was random and extended across the seams or adjacent to the seams. No conclusions can be drawn regarding the cause of these failures.

T206 Description

10 plys of .25 mil Mylar C
Edges seamed with GT 100 adhesive
Horizontal and vertical seams in field
GT 300 closing tape
Butt seams taped on one side
Ends seamed as noted

Test Summary

The failures on the samples with .06" width end seams are identical to those occurring on all other samples with seam of any width. The failures started as a splitting of the end near the top or bottom edge and extend into the field of the sample. The failures of the samples with the end seams cut off consisted of splitting of one or more plys from the edge and frequently extending many inches into the sample. Complete splitting of all plys did not occur.

T206-1 through -4 were tested as originally received from Schjeldahl with a very rigid end seam and results proved early failure through splitting of ends. The group -5 through -9 had the original end seam cut off and were then reseamed on the ends by wrapping a GT 300 tape around and heat sealing with impulse sealer. The results are better although splitting still occurred.

T207 Description

10 plys of .25 mil Mylar C
Edges seamed with GT 100 tape
Horizontal and vertical seams in field
GT 300 closing tape
Lap seams using GT 100 adhesive
Ends seamed as noted

Test Summary

Failures occurred as splitting of the film from the center or field of the sample. There did not appear to be any failures from the end with the exception of one ply of -3. The change of the point of failure from the end splitting to field originated splitting in this group of samples, is not easily explained.

90-33364
(was E-270-1)

3.4.4 Summaries of Twist-Flex Material Sample Test Data (continued)

Failures occurred as splitting of the film from the center or field of the sample. There did not appear to be any failures from the end with the exception of -7 which had a 1/2-inch split through end. The change to seal the ends with GT 300 tape did not change the type of failure as found in the first group -1 through -5.

Some of the T207 samples were also tested in Section 3. 9 .2 "Test Results of the Inter-Ply Inflation".

T208 Description

5 Plys of .25 Mylar C
Flat sample with horizontal seams
Butt seams using Pilobond 20 with tape
Ends seamed as noted

Test Summary

All samples tested produced splitting of at least the front single ply usually above the horizontal seam and not through the seam. Permeability testing was only possible in three samples, the remaining samples had excessive leakage. Pilobond seams do not appear to offer any unusual characteristics for further consideration.

Some of the T208 samples were also tested in Section 3. 9 .2 "Test Results of the Inter-ply Inflation".

T209 Description

1 ply of .5 mil Kapton
Flat sample, no seams
Ends not sealed for -1 through -5
Liquid nitrogen tested for -1 through -5
Liquid hydrogen tested for -6 through -10

T209-1 through -5 Test Summary

Only one sample, the -1, did not show any splitting of the film. All other samples had a complete splitting failure from end to end usually near the top or bottom edge of sample. A closing end seam could help eliminate the start of the split but would not help the extension of split if once started. This film is similar to Mylar in its unpredictable behavior.

3.4.4 Summaries of Twist-Flex Material Sample Test Data (continued)

T209-6 through -10 Test Summary

All samples had a complete shattering type of splitting failure across the entire field of the sample. The end seams did not change this characteristic failure.

T210 Description

5 plys of .5 mil Kapton
Edges sealed with GT 300 tape
GT 100 adhesive used between film seams
Liquid nitrogen tested for -1 through -6
Liquid hydrogen tested for -7 through -9

T210-1 through -6 Test Summary

Failure typical of Kapton are shown in the results above. The random type of splitting failure with jagged tears has been demonstrated in many previous samples tested in LN_2 in other Beech programs.

T210-7 through -9 Test Summary

The removing of the original end seams and reseaming with GT 300 tape with impulse narrow heat seal apparently helped prevent splitting from ends. The lack of consistency of this film, however, does not warrant a conclusion that this film is satisfactory if seamed in this manner.

Some of the T210 samples were also tested in Section 3.9.2 "Test Results of Inter-Ply Inflation".

T211 Description

10 plys of .5 mil Kapton
Edges sealed with GT 300 tape
GT 100 adhesive between film seams
Liquid nitrogen tested for -1 through -7
Liquid hydrogen tested for -8 through -11

T211-1 through -7 Test Summary

The increase in number of plys has helped this material. Although the outer ply splits frequently, the remaining plys are intact and do not permit permeation. Unpredictability of failure still present.

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3.4.4 Summaries of Twist-Flex Material Sample Test Data (continued)

T211-8 through -11 Test Summary

The samples with the reseamed ends with GT 300 tape appear to withstand the flexing better. Every sample, however, had a splitting of at least the outer ply in the field near the end of the sample.

T212 Description

13 alternating plys of Mylar and Nomex paper
10 plys of .25 Mylar C
3 plys of 2 mil Nomex paper (1st, 7th, 13th ply)
No seams except edge seams
GT 100 adhesive between edge seam
GT 300 closing tape

Test Summary

The only failures in this combination of Mylar and Nomex paper occurred when the heavy end seams split. The tear resistance of the Nomex paper prevented the tear from extending far into the field of the sample. The -3 and -4 samples in which the end seams were removed produced excellent results in both permeability and flexibility.

This type of material consistently appears to offer the most hope for cryogenic bladders. The combination of Nomex for reducing the stresses in the Mylar, which provides the permeability barrier, is proving to be the best arrangement of materials in the twist-flex test.

T213 Description

13 alternating plys of Mylar and Dacron fabric
10 plys of .25 mil Mylar C
3 plys of 2.2 oz Dacron fabric (1st, 7th, 13th ply)
No seams in field
GT 100 adhesive between edge seam
GT 300 closing tape

Test Summary

Results on these samples show promise for bladder material. Similar to the Nomex/Mylar samples T212, the Dacron fabric adds strength and tear resistance to the sample preventing gross splitting of the Mylar. Even the heavy ends did not split although fabricated in the same manner as other Schjeldahl samples which have had incessant end splitting.

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3.4.4 Summaries of Twist-Flex Material Sample Test Data (continued)

T214 Description

5 plys of .25 mil Mylar C
Cylindrical sample
Closing lap seams
GT 100 adhesive

Test Summary

Permeability measurement is not possible on cylindrical samples in a manner similar to the flat samples. Permeability is noted by bubbles appearing on the outside of cylinders when pressurized with helium gas. Detection of bubbles is an indication to stop test. The number of cycles are then determined either by the first formation of bubbles or visible indication of film splitting. Random splitting of film indicates the necessity of a change in sample material or fabrication method. Cylindrical shapes may impose greater stresses than flat type samples. Failures are similar to flat samples of the same material.

T215 Description

Same as T214, except 10 plys of film
10 plys of .25 mil Mylar C
Cylindrical sample
Closing lap seams for cylindrical plys
GT 100 adhesive

3.4.4 Summaries of Twist-Flex Material Test Data (continued)

Test Summary

Analysis same as that for T214.

T216 Description

5 plys of .25 mil Mylar C
Cylindrical sample
Horizontal and closing vertical seam
Butt seam taped one side
GT 100 adhesive
GT 300 closing tape

Test Summary

Analysis same as that for T214.

T217 Description

Cylindrical sample
5 plys of .25 mil Mylar C
Horizontal and closing vertical seam
Lap type of seam
GT 100 adhesive between plys on seams
GT 300 closing tape

Test Summary

Analysis same as that for T214.

T218 Description

Cylindrical sample
10 plys of .25 mil Mylar C
Horizontal and closing vertical seam
Butt type of seam
GT 100 adhesive between plys on seams
GT 300 closing tape

Test Summary

Analysis same as that for T216.

3.4.4 Summaries of Twist-Flex Material Sample Test Data (continued)

T219 Description

Cylindrical sample
10 plys of .25 mil Mylar C
Horizontal and vertical seam
Lap type of seam
GT 100 adhesive between plys on seams
GT 300 closing tape

Test Summary

Analysis same as that for T216.

T220 Description

Cylinder sample
5 plys of .25 mil Mylar C
Horizontal and closing vertical seam
Pliobond 20 with tape

Test Summary

Analysis same as T216.

T221 Description

Same as T218 except .15 mil Mylar C

Test Summary

Analysis same as that for T216.

T222 Description

Same as T219 except .15 mil Mylar C

Test Summary

Analysis same as that for T216. Some of the T222 samples were also tested in Section 3.9.3 "Test Results of Inter-ply Inflation".

3.4.4 Summaries of Twist-Flex Material Sample Test Data (continued)

T223 Description

Cylindrical sample
.5 mil Kapton
10 plys of film
Closing vertical seams only
GT 300 tape with butt seams

Test Summary

Analysis same as that for T216.

T224 Description

Same as T223 except lap vertical seam using GT 100 adhesive

Test Summary

Analysis same as that for T216.

T225 Description

Same as T212, except cylinder
Cross butt seam using GT 300 tape

Test Summary

Analysis same as T216 except that failure primarily in seams. The use of heavier tape might prevent the failure at this point. Previous experience has shown that the failures usually do not occur in the seam.

T226 Description

Same as T213 material except cylinder
Cross butt seams using GT 300 tape

Test Summary

Analysis is the same as T225. Samples T227 through T235 are tested in Section 3.7.1 "Single Ply Seamed Twist-Flex Test Data".

T236 Description

10 plys of .15 mil Mylar C

3.4.4 Summaries of Twist-Flex Material Sample Test Data (continued

Test Summary

Exceptional results without serious failure and good permeability following twist-flex testing.

Some of the T236 samples were also tested in Section 3.9.2 "Test Results of Inter-ply Inflation".

T237 Description

10 plys of .25 mil Mylar C

Test Summary

A large number of identical samples produced relatively consistent results with good flexibility and low permeability.

Some of the T237 samples were also tested in Section 3.9.2 "Test Results of Inter-ply Inflation".

T238 Description

13 plys of .25 mil Mylar C
1st, 7th and 13th plys
2 mil Nomex paper

Test Summary

All of the T238 samples had breaks on both end cap edges - creases and wrinkles on front and back plys. Only slight increase in permeability.

T239 Description

13 plys of .25 mil Mylar C
1st, 7th and 13th plys of 2.2 oz Dacron fabric

Test Summary

All of the T239 samples had breaks on both end cap edges - no wrinkles or other visible effects from twist-flexing.

Samples T240 through T247 are tested in Section 3.7.1, page 3-108 "Single Ply Seamed Twist-Flex Test Data".

Samples T248 through T253 are tested in Section 3.7.2, page 3-110 "Multi-Ply Seamed Twist-Flex Test Data".

3.4.4 Summaries of Twist-Flex Material Sample Test Data (continued)

T254 Description

Alternating plys of 2 mil Nomex and .25 mil Mylar (6 plys of Nomex and 5 plys of Mylar)
Lap seams 1/2" wide in Nomex; Butt seams 1/2" wide in Mylar

Test Summary

Increased deterioration and permeability (all plys) over configuration such as T238 where Mylar plys are used in groups of 5 between Nomex plys.

T255 Description

Alternating plys of 2 mil Nomex and .5 mil
Kapton (6 plys of Nomex and 5 plys of Kapton)
Lap Seams 1/2" wide in Nomex
Butt Seams 1/2" wide in Kapton

Test Summary

Much poorer performance and more extensive damage than T254, indicating that .5 mil Kapton is inferior to .25 mil Mylar C in this configuration.

T256 Description

1 ply 2 mil Nomex
Butt seam 1/2" wide using GT 300 on both sides

Test Summary

Good flex performance; nearly as good as 1/2-inch wide lap seam using GT 100.

T257 Description

1 ply of Dacron fabric 2.2 oz
Butt seam 1/2" side using GT 300 on both sides

Test Summary

No permeability reading because of high normal porosity. Good flex performance; equal to 1/2" wide lap seam using GT 100.

T258 Description

Alternating plys of .25 mil Mylar and Spunbonded Dacron fabric (6 Mylar - 5 Dacron)
Lap seams 1/2" wide Spunbonded
Butt seams 1/2" wide in Mylar

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3.4.4 Summaries of Twist-Flex Material Sample Test Data (continued)

Test Summary

Very poor flex life and high permeability if flexed more than 5 cycles; spunbonded substrate appears to induce high stress in the Mylar plys of this configuration, as evidenced by frequent holes in seams of Mylar plys.

Conclusions

The test results on the T254 samples show that alternating plys of Nomex and Mylar result in much higher permeability, after flex testing, than the use of groups of consecutive Mylar plys between Nomex plys such as in T238. It is believed that the intimate contact of the consecutive Mylar plys reduces permeation by restricting lateral flow between plys, whereas such restriction cannot be attained when the Nomex and Mylar plys are alternated. Also, many interior Mylar plys of the T254 samples show flex damage in the form of small holes or tears through the GT 300 seams. It is concluded from these tests that Nomex-Mylar combinations should be in a configuration per the T238 samples and not per the T254 samples.

The overall performance of the T258 samples was below that of the T254 samples, with the same type of damage to the Mylar plys. Therefore, the only remaining application for the Spunbonded polyester substrate is as the substrate ply of a sample in the configuration of T238. Any advantages of Spunbonded polyester over such substrates as Nomex or Dacron fabric was not established.

The very poor permeability performance of the T255 samples is due to serious flex damage to the Kapton plys. These tests indicate that the alternating substrate-barrier ply arrangement is even more severe upon Kapton than on Mylar.

The T256 and T257 samples with butt seams taped on both sides produced results approximately equal to those for 1/2-inch wide lap seams in Nomex or Dacron fabric. Since the double-taped butt seams are not superior to the lap seams being used on all Schjeldahl bladders, the butt seams will receive no further consideration for bladder fabrication for Nomex or Dacron.

Final material recommendations are presented in Subsection 3.10.7.

3.4.5 Material Samples Test Data - NASA

TABLE 3.4

TN1 Description

1/4 mil Mylar C
10 plys
Plain film no seams
NASA furnished
GT 100 closing tape around edges
Individual plys not bonded together

SAMPLE NUMBER	CC/SEC PERMEABILITY BEFORE	AFTER	NO. CYCLES TESTED	REMARKS
-1	0	0	200	No visible change in appearance of sample.
-2	0	0	200	No visible change in appearance of sample.
-3	0	0	190	Incipient failure tear in outer plys at center of sample. Interply inflation.
-4	0	0	125	Incipient failure in outer plys at 110 cycles. Failure expanded at 125 cycles, test stopped.

Typical Mylar sample, transparent and flexible. The lack of bonding between inner plys at the edge seams improved flexibility without encouraging splitting. Little change in appearance and no increase in permeability. Unpredictable behavior as shown by two out of four samples tested above is typical of Mylar films.

TN2 Description

NASA furnished
Alternating plys of 1/4 mil Mylar C and Style 201 "Spunbonded" Dacron paper
5 plys of Mylar and 4 plys of Dacron
Edge seamed with GT 100 closing tape

SAMPLE NUMBER	CC/SEC PERMEABILITY BEFORE	AFTER	NO. CYCLES TESTED	REMARKS
-1	0	-	60	Permanent wrinkles and creases. Breaks on both end caps.
-2	0	-	200	Permanent wrinkles and creases. Breaks on both end caps.
-3	0	1	35	Permanent wrinkles and creases. Split at right end front side 3" long. Breaks on both end caps.

Permeability data was not obtained after twist-flex testing. The low number of cycles to splitting would indicate a poor combination or assembly method. Mylar requires a reinforcing material for strength against splitting but the substrate should not cause failure of the Mylar. The failure of one or two plys in multi ply sample is not necessarily cause for rejection of the material.

Samples TN3 through TN8 are tested in Section 3.9.2, "Test Results of Inter-Ply Inflation".

Samples TN9 through TN12 and portions of TN3, TN4, TN7, and TN8 are tested in Section 3.9.3 "Rapid and Slow Warm-Up Inter-Ply Inflation Tests".

3.5 Permeability Study

This section will describe in detail the work conducted to determine the relationship of permeability to flexibility of material samples briefly described in Section 3.3.2.

3.5.1 Apparatus

As described in Section 3.3.2 and illustrated in Figures 3.10, 3.11, and 3.12, the permeability apparatus and testing procedures evolved from a series of preliminary tests made on three apparatus configurations or "methods" shown in Figure 3.23. Figure 3.2.2 shows the assembly of the permeability apparatus with the manometer, burette, and helium mass spectrometer.

FIGURE 3.22

PERMEABILITY APPARATUS

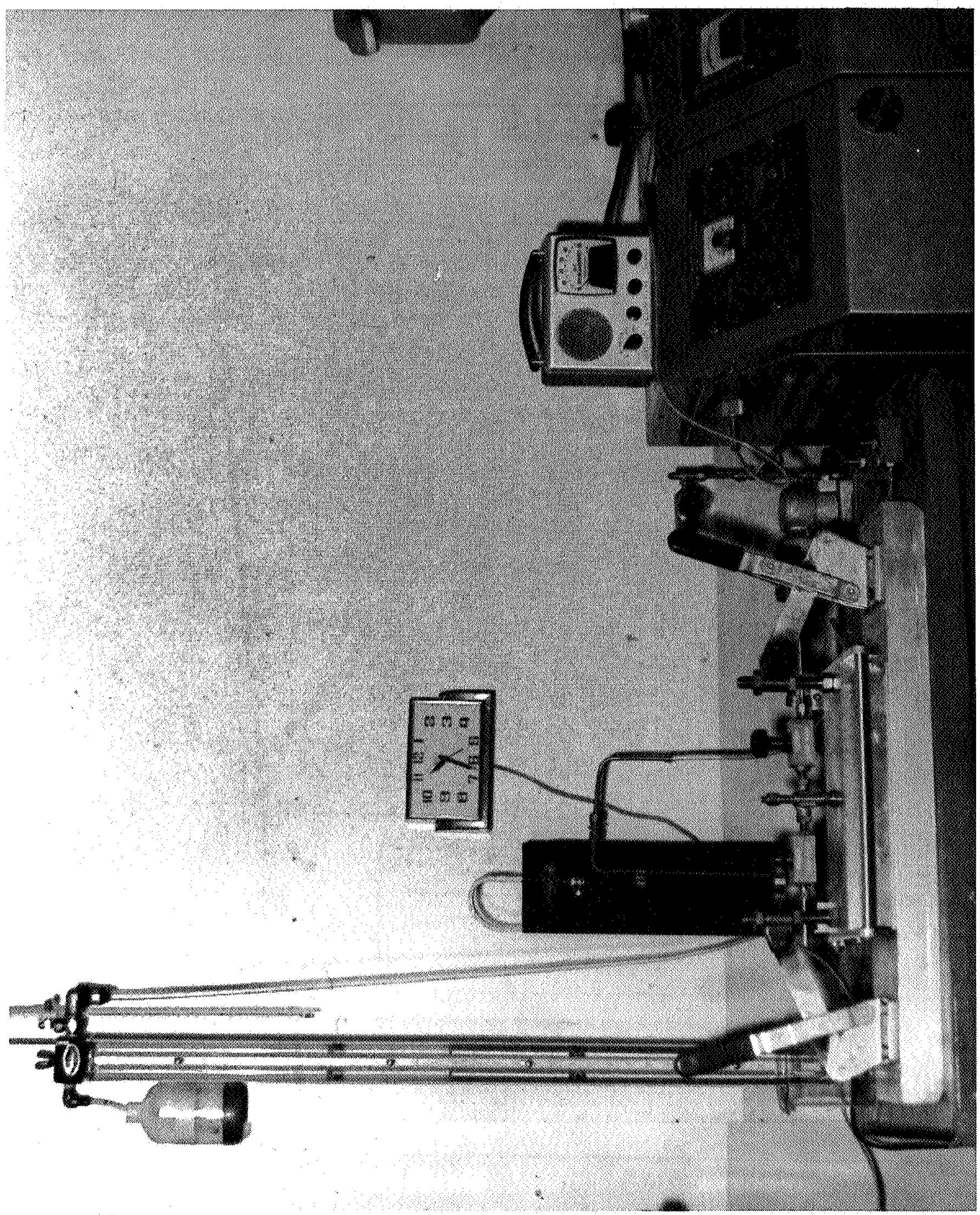

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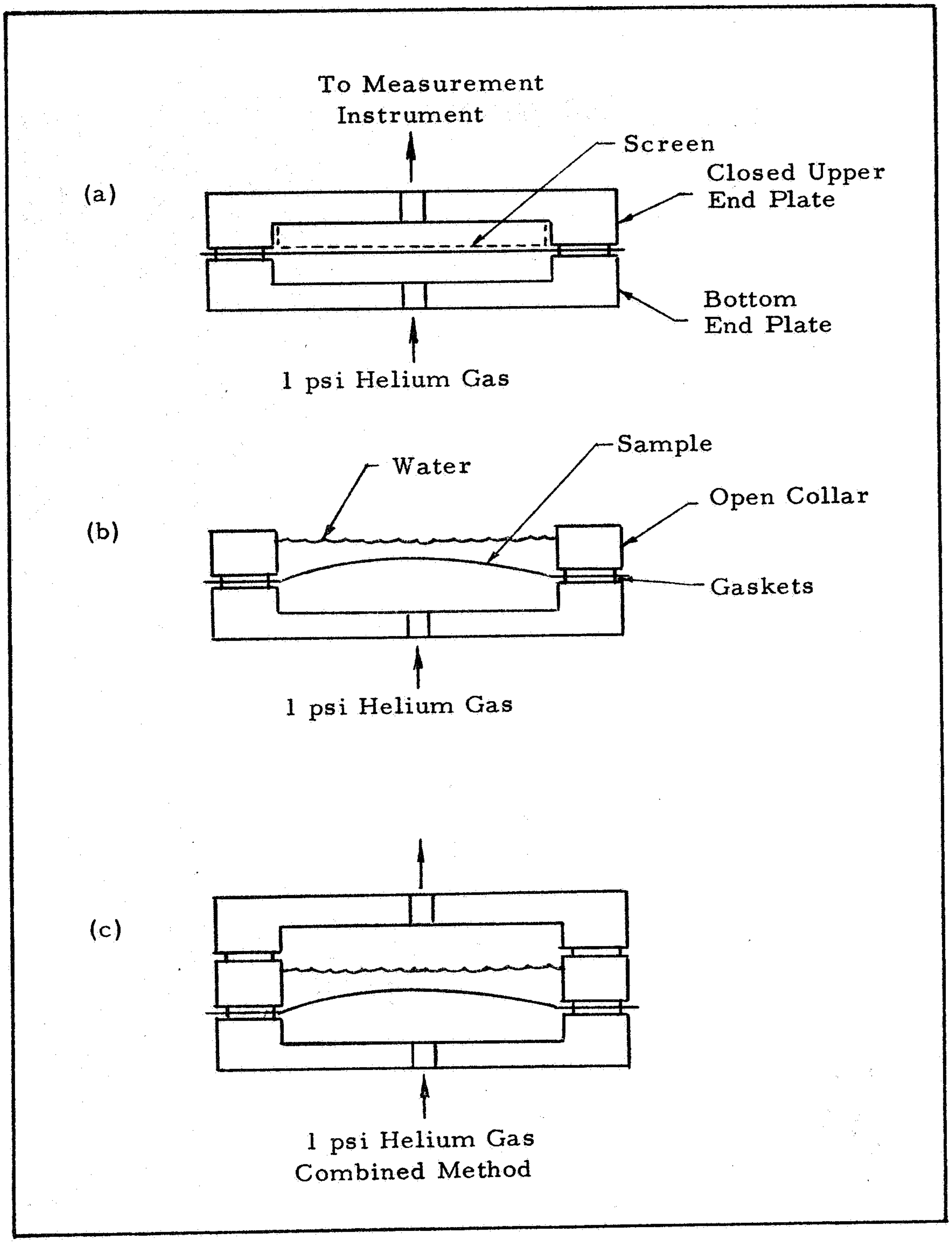
FIGURE 3.23

PERMEABILITY MEASUREMENT METHODS



3.5.2 Methods

The following five (5) methods have been used in the permeability study of samples and films in this program.

Method #1 The upper end plate of the fixture was a rectangular collar which permitted a layer of water to be added above the sample and any porosity through the film was observed by the formation of bubbles. A material failure was defined as any detectable leakage after pressurization with one psi of helium gas for three minutes.

Method #2 - A closed upper end plate was used so that any gas permeating the sample could be conducted through tubing to a beaker of water and the bubbles formed could be counted over a three-minute period of time.

Method #3 - A closed upper end plate was used so that any gas permeating the sample could be conducted through tubing to a burette for quantitative measurement of the gas.

Method #4 - A closed upper end plate was used so that gas permeating the sample could be qualitatively measured by a helium mass spectrometer by the insertion of the probe into the upper plate port.

Method #5 - In addition to the four separate permeability measurements a fifth method was used which combined Methods #1 and #3 so that permeation of helium gas through the sample and water, and which was invisible to the naked eye, could be collected above the water by the closed upper end plate and measured by the burette. Figure 3.23(c) shows this combination of fixture plates.

3.5.3 Procedures

The test sequence is started for all methods by installing a 4-inch by 11-inch sample between the lower plate, collar, and upper plate as required for each method. The fixture is then clamped tight to compress the gaskets for holding and sealing the sample. The ambient room temperature and burette water level is recorded. One psi of helium is applied to the bottom surface of the sample and the top plate is connected to the burette by means of a flexible tube. At the same time a 5-minute time period is started at the end of which the burette is disconnected and the amount of displacement recorded. The rate is then converted to cc/sec.

The second test was conducted by connecting the tube from the upper plate to a beaker of water and the number of bubbles for three minutes noted. The average number of bubbles per minute was then recorded as an indication of permeability by use of this method. A correlation was found between the burette and bubble method and is shown in Figure 3.24.

Following the bubble test the upper plate was unclamped and was purged with nitrogen gas. The plate was then reclamped and one psi of helium gas applied to the bottom surface of the sample. The upper plate was connected to the mass spectrometer by inserting the probe into a connection fitting on the plate. A three-minute reading was taken and the background count subtracted from the reading. This mass spectrometer measurement was a qualitative reading because a full vacuum was not attainable on the top surface of the sample.

If the results of the above three tests indicated the need for determining if there were actual holes in the material, the sample was clamped into the fixture using the lower plate and the rectangular collar. The sample was then covered with water to a depth of 1/4 inch and helium pressure applied to the bottom surface. Any holes found by visual observation of bubbles were marked on the film and recorded.

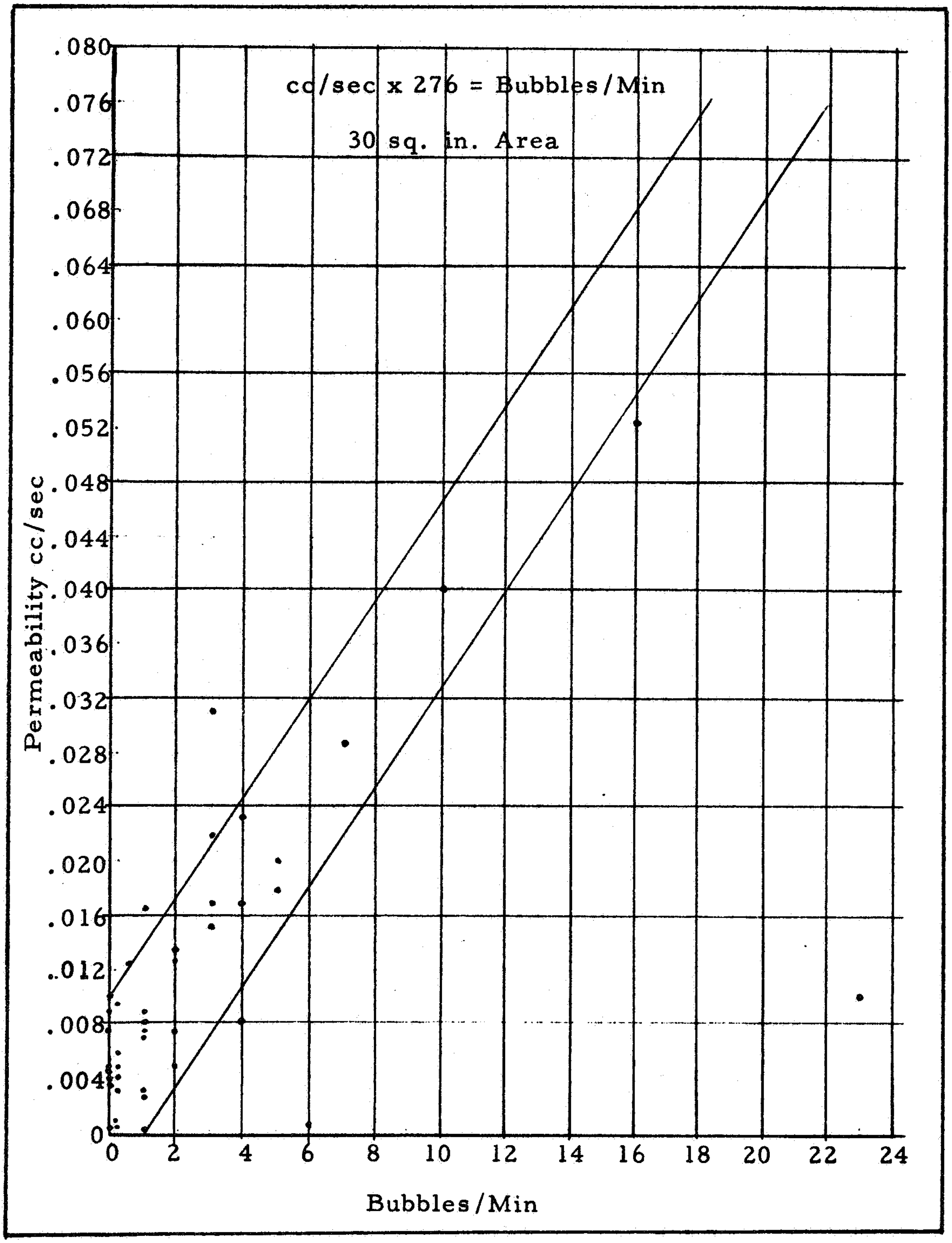
A combination of procedures was used for determining the permeability through the sample and the water. This test was made to confirm the accuracy of the apparatus and to satisfy the question of why permeability was measured by the burette but not visible through the water.

On a few samples a high leak rate was observed during the permeability tests but upon running porosity tests (Method No. 1) no holes appeared. To confirm that the helium gas was permeating through the sample, the upper closed plate was clamped on top of the collar plate while the water was still above the sample. The burette was connected to the upper plate and the leak rate was found to be nearly identical to the sample when checked without the water covering. Use of the mass spectrometer indicated that the leakage was helium. The conclusion reached from this test was that helium permeates the sample and the water without providing any visual indication of bubbles through the water.

The data showed that permeability through 0.25 mil Mylar film could reach 0.018 cc/sec over a 30 square inch sample without being visible through water as long as it was constant throughout the sample and yet a small hole

FIGURE 3.24

GRAPH OF PERMEABILITY
cc/sec vs. bubbles/min



or defect might produce bubbles visible to the eye at even as small a rate as 0.0006 cc/sec. The conclusion, therefore is that visible bubbles can not be used as the sole indication of material permeability or failure.

In addition to the regular tests conducted on all samples, the permeability study program on single ply films included special tests to confirm the accuracy of the testing and apparatus. Attempts were made to produce holes with the equivalent permeability of a typical sample. Reliability data was also obtained by repeat testing of the same sample or same film.

3.5.4 Materials

The materials used for the permeability studies was Mylar C film of 0.15 and 0.25 mil thickness obtained from Schjedldahl Company, NASA, Boeing and DuPont. This material was obtained from different rolls of Mylar C as produced by DuPont and stocked by these agencies.

The 0.25 mil Mylar from Boeing was received in two conditions: (1) plain Mylar C film and (2) thermoformed samples.

The Branson Company provided ultrasonically seamed samples of various thickness of Mylar in combination with Dacron.

The polyethylene film used for making the Sea Space Systems samples was not included in the special permeability studies because it was not available in single ply films. The permeability of samples made using this 0.10 mil polyethylene may be found under Section 3.4 - Twist-Flex Test Data.

3.5.5 Mylar Permeability Data

Many methods are used to obtain film permeability. This section reports data from several sources and gives units, gases, and correlation with sample sizes used in the program when possible. No attempt is made to correlate all methods to account for different gases, pressures or film thickness.

DuPont - Plastics Encyclopedia 1966 (Ref 7)

100 cc/100 sq. in./24 hrs/mil/atmos (hydrogen gas) = 3.48×10^{-4} cc/30 sq. in*/sec/mil/atmos

Pseudo-Conversion to 0.25 mil from 1.0 mil = $3.48 \times 10^{-4} \times 4 =$ 1.39×10^{-3} cc/30 sq. in*/sec/0.25 mil/atmos

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Schjeldahl Final Report NAS9-513 (March 1964)

(P) cc/sq. meter/24 hrs/mil/atmos (nitrogen gas)

	(P)		
Sample No. 1 (1 mil)	96	=	2.16×10^{-5} cc/30 sq. in*/sec/mil/atmos
Sample No. 2 (1 mil)	24	=	5.4×10^{-6} cc/30 sq. in*/sec/mil/atmos
Sample No. 3 (1 mil)	7.8	=	1.75×10^{-6} cc/30 sq. in*/sec/mil/atmos

Schjeldahl Memorandum Report (reference only)

5 liters/sq. meter/24 hrs/0.25 mil/3 cm H_2O (hydrogen gas) = 2.02×10^{-3} cc/30 sq. in*/sec/0.25 mil/3 cm H_2O (helium gas)

Sea Space Systems 0.15 Mylar C for NAS3-6288

2.59×10^{-7} ft^3/ft^2/sec/psi/mil = 5.1×10^{-4} cc/30 sq. in*/sec/psi/mil

*30 sq. in. is material area when installed in permeability fixture.

3.5.6 Permeability Test Data

The following tests isolate certain phases of permeability measurement in order to provide more accurate data, prove existing data, and correlate data with permeability information from other sources.

Each test is described in detail in Paragraph 3.5.3 to explain the purpose of the test and is documented in Appendix C. In all cases assumptions required in the beginning of the permeability test program were substantiated and assured that a correlation was possible between sample test results.

INDEX OF PERMEABILITY TESTS PERFORMANCE

PERMEABILITY TEST SAMPLE CODING

SAMPLE NUMBER		MATERIAL	SOURCE
PC15	-1 through -5	0.15 mil Mylar	Schjeldahl
PC25	-1 through -6	0.25 mil Mylar	
PS25	-1 through -5	0.25 mil Mylar	
PN15	-1 through -5	0.15 mil Mylar	NASA - Lewis Research Center
PN25	-1 through -10	0.25 mil Mylar	
PB25	-1 through -5	0.25 mil Mylar	Boeing
PUB	-1 through -6	miscellaneous	Branson Industries
PD15		0.15 mil Mylar	DuPont
PD25		0.25 mil Mylar	
PVP15	-1 through -3	0.15 mil Mylar	DuPont (Permeability Variable Pressure Test)
PVP25	-1 through -3	0.25 mil Mylar	
PH15	-1 through -3	0.15 mil Mylar	DuPont (Permeability vs Hole Size Test)
PH25	-1 through -3	0.25 mil Mylar	

3.5.6.1 Control Test - Film Permeability

Samples of many of the materials were tested for permeability without being first twist-flexed tested. This information was used as a basis of comparison and provided control data. Appendix C enumerates the results.

3.5.6.2 Multiple Ply Tests

In these tests 0.15 mil Mylar C received from DuPont was used by starting with 5 plys of film in which the edges were loosely bonded together during the cutting operation. After the 5 plys were tested then one ply was peeled off and the remaining 4-ply sample was tested. This procedure was continued until the last single ply was tested.

Test No. 1 - PN15-1 - Conclusion

During this test there was no indication of gas transmission until the single ply was tested. From a permeability viewpoint the use of two plys would satisfy the condition of zero permeability in a 5-minute period. The condition of zero permeability is explained in Paragraph 3.5.6.8, "Extended Time Test.

Test No. 2 - PN25-1 - Conclusion

There was no measurable leakage during a 5-minute period in any of the tests on 0.25 mil Mylar material from DuPont. This would indicate that the 0.25 mil material is less porous than the 0.15 mil material and this result should be expected.

In Test No. 3 and Test No. 4, 0.15 mil and 0.25 mil Mylar C was used which was obtained from rolls of film used to make test samples. These film samples were added together to produce the multiple-ply test which differed from Test No. 1 and Test No. 2 in which plys were removed.

In these tests -1 ply had an excessive leak reduced only by the addition of the second ply.

Test No. 3 - PC15 - Conclusion

The permeation is not reduced significantly after the third ply is added. It is believed that points of porosity in a particular film might be blocked by an adjacent film on occasions thus randomizing the results.

Test No. 4 - PC15 - Conclusion

The permeation is not reduced significantly after the third ply is added. It is believed that points of porosity in a particular film might be blocked by an adjacent film on occasions thus randomizing the results.

3.5.6.3 Increasing Pressure Test

This test was performed to provide a better understanding of the effect of pressure upon the gas transmission rate through a film. Three 0.25 mil Mylar C and three 0.15 mil Mylar C films from DuPont were used for these tests.

Each sample was placed into the permeability fixture and the pressure was increased in increments of 5 inches of water from zero to 35 inches of water pressure. Each pressure was held for a period of 5 minutes during which time a burette measured the volume of helium gas passing through the film. The test data is shown on Figure 3.25.

CONCLUSIONS

The rate of gas transmission through Mylar films increases with increase in pressure differential across the film. Although one sample in these tests showed no permeability it is presumed that if a longer period of time had been allowed at each pressure setting, the results would follow the other samples, but at a lower gas transmission rate.

It is important to note that although all permeability tests for this program have been conducted at one psi or 28 inches of water pressure, it is not anticipated that the bladder will receive more than a few inches of differential pressure during cycling. This lower operating pressure will therefore be advantageous in reducing the permeability through the bladder. The permeability of some materials of low permeability stays relatively constant even when the pressure is increased. Pressure increase though, can cause increased permeability in certain materials and even cause some materials to become permeable when they were not at lower pressure.

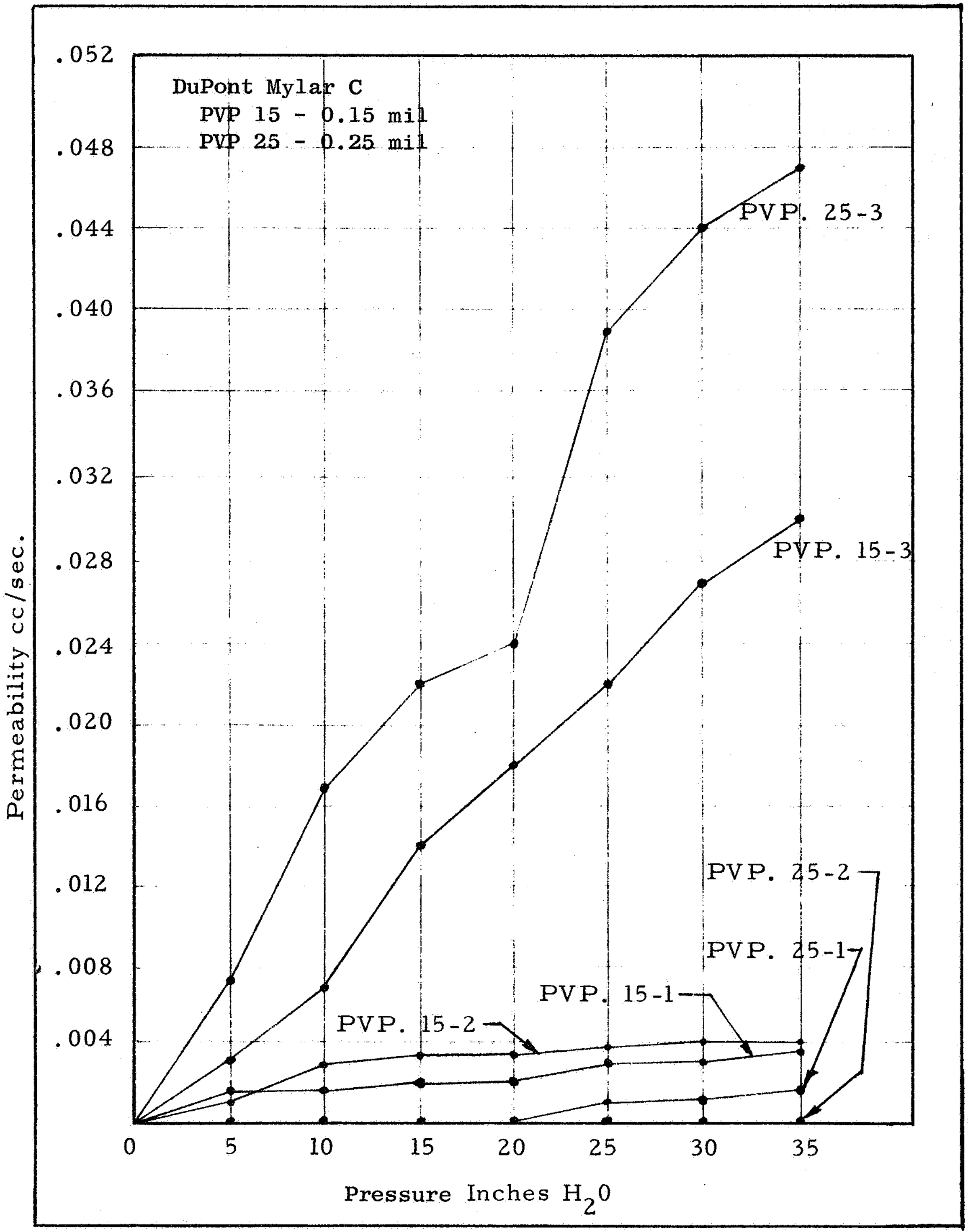
3.5.6.4 Combination Test (Water and Burette)

The Combination Tests involved four separate tests on each material for the purpose of comparing the different test methods and to verify that permeation is possible through water without visible bubbles.

The first test was performed in the regular manner in which the sample was installed in the permeability fixture and one psi of helium gas was placed on the underside of the film. The gas passing through the film was collected and measured on a burette over a 5-minute period.

FIGURE 3.25

INCREASING PRESSURE TESTS



Ref: Paragraph 3.5.6.3

The second test involved the use of an open plate in which a layer of water was placed over the sample and the helium gas at one psi was under the the film sample. The appearance of bubbles was noted. In many cases, however, no bubbles were observed even though the first permeability test indicated gas transmission.

The third test combined the first two by leaving the water on top of the sample and then the burette was attached so that the gas which passed through the sample and the water could be collected and measured.

The fourth test was a repeat of the first test after the sample was thoroughly dry to see if moisture affected the gas transmission through the sample. The following data shows the results of these tests.

CONCLUSIONS

An important conclusion that can be made by this data is that it is possible to have considerable permeation through a sample and water without any visible indication by the formation of bubbles. The difference in permeability readings before and after the water test is within the normal range of repeatable readings proven by tests in Paragraph 3.5.6.6, Repeatability Tests. Tests have shown that it is possible to have up to 0.018 cc/sec permeation over a 30 square inch sample of 0.25 Mylar without bubble formation.

Using bubbles in water as an indication of gas transmission is, therefore, not a satisfactory method for precise measurement of gas leakage.

3.5.6.5 Consecutive Reading Tests

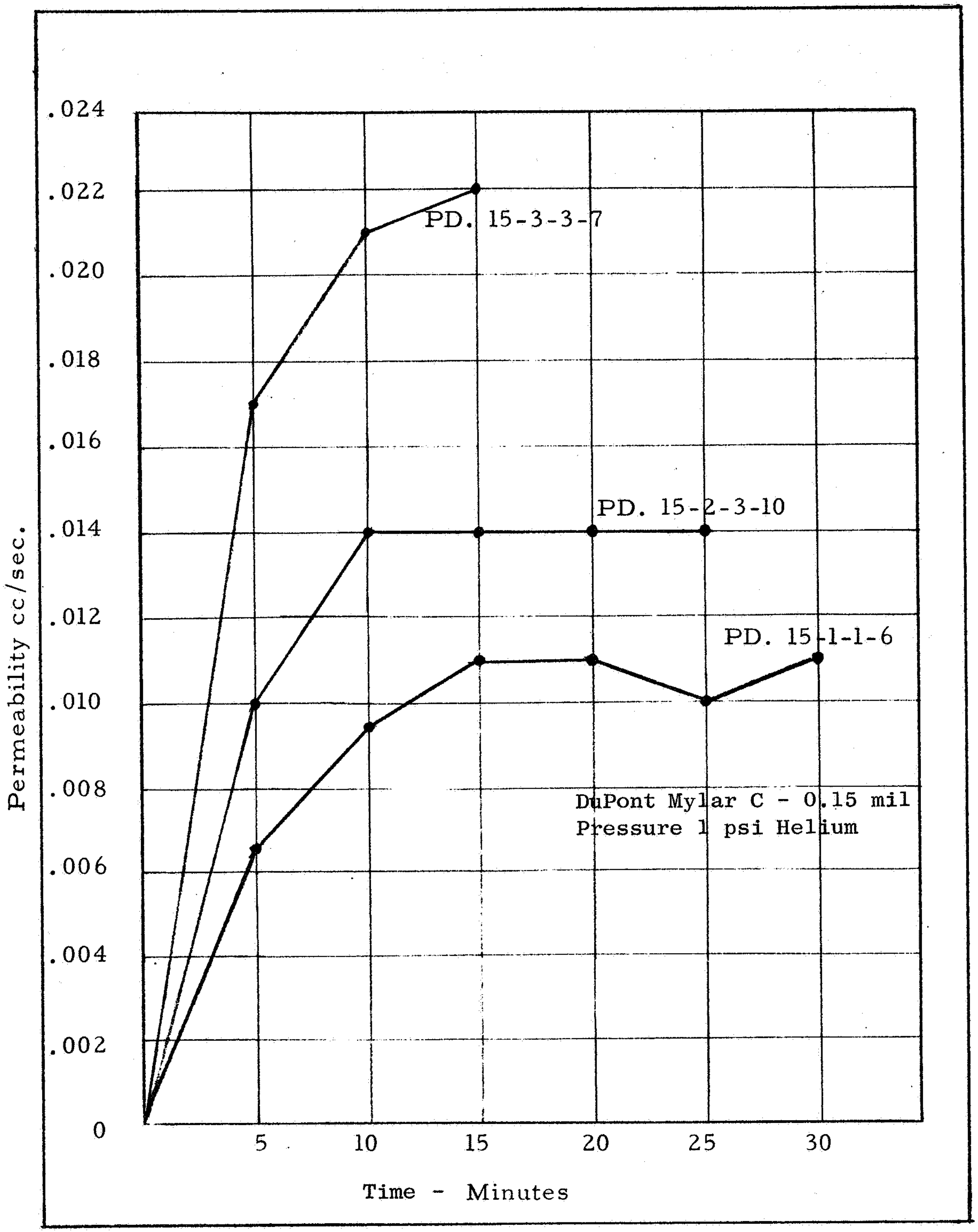
The purpose of this series of tests was to determine if there was a length of time of pressurizing the sample in which the rate of gas transmission would stabilize and remain constant. Three different samples of 0.15 mil Mylar C obtained from DuPont were used in which they were pressurized to one psi of helium and held constant for a period of up to 30 minutes. The permeability was measured during each 5-minute consecutive period and the results were plotted in Figure 3.26.

CONCLUSIONS

The data indicates that after approximately 15 minutes the permeability rate stabilizes and will stay uniform thereafter. The rate of permeability increases for 10 to 15 minutes and then becomes steady. This would indicate

FIGURE 3.26

CONSECUTIVE READING TESTS (CONSTANT PRESSURE)



Ref: Paragraph 3.5.6.5

that it would be desirable to wait for at least 15 minutes before taking a permeability reading for utmost accuracy. The procedure followed in this program was to take readings at exactly five minutes thereby providing a consistency which should result in a constant relationship between each sample's permeability at a specified time. The difference in each sample's permeability for each time stayed relative to the other samples.

3.5.6.6 Repeatability Tests

In order to determine if there was a significant difference in permeability readings when made on the same sample at different times, or due to repeat pressurization, as well as to determine the accuracy of operator technique, tests were run on three different samples. It should be noted that each sample was given a typical handling and permeability test identical to that performed on a sample prior to a twist-flex test. After each test the sample was removed and then reinstalled as if for the first time. This introduced the factor of installation, random wrinkling and gasket sealing not previously investigated in the previous test; Paragraph 3.6.6.5, Consecutive Reading Tests.

CONCLUSIONS

The first two samples indicated that a $\pm$15% variation can be expected in reading of permeability data. The third sample would show that in some rare cases a difference can amount to seven times the lowest reading. Figure 3.27 illustrates this variation.

3.5.6.7 DuPont Mylar Correlation Tests

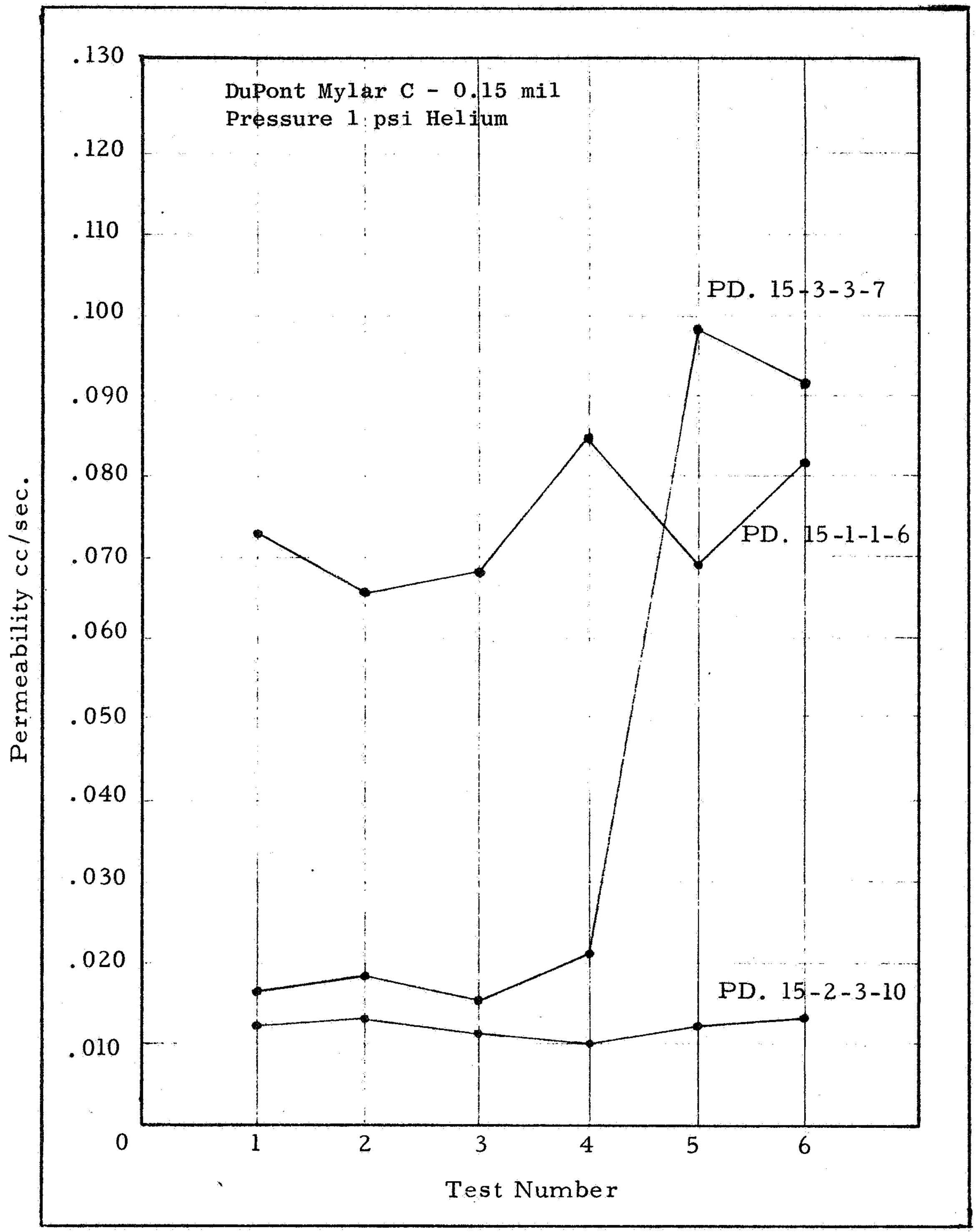
Tests were performed to find a correlation between methods of quality control used by DuPont in the production of Mylar and the permeability measurement methods described in Paragraph 3.5.3.

The DuPont Mylar C samples were provided by NASA-Lewis together with the quality control data and coded for later comparison.

Three 0.25 mil Mylar groups were tested totaling 30 separate film samples. Nine 0.15 mil Mylar groups were tested totaling 90 samples. The results of these tests are shown below and shown on Figure 3.28. The relationship of the observed permeation values with the DuPont dielectric strength data is shown on Figure 3.29.

FIGURE 3.27

REPEATABILITY TESTS



Ref: Paragraph 3.5.6.6

Each sample was subjected to the normal permeability test of one psi of helium gas. The gas transmission was measured on a burette in cc/sec.

DuPont Dielectric Strength Test Data (DuPont Mylar Film Samples)

DuPont uses a dielectric strength test as a quality control method in the production on Mylar. The film to be tested is subjected to increasing voltage and the number of breakdown determines the acceptance of the film.

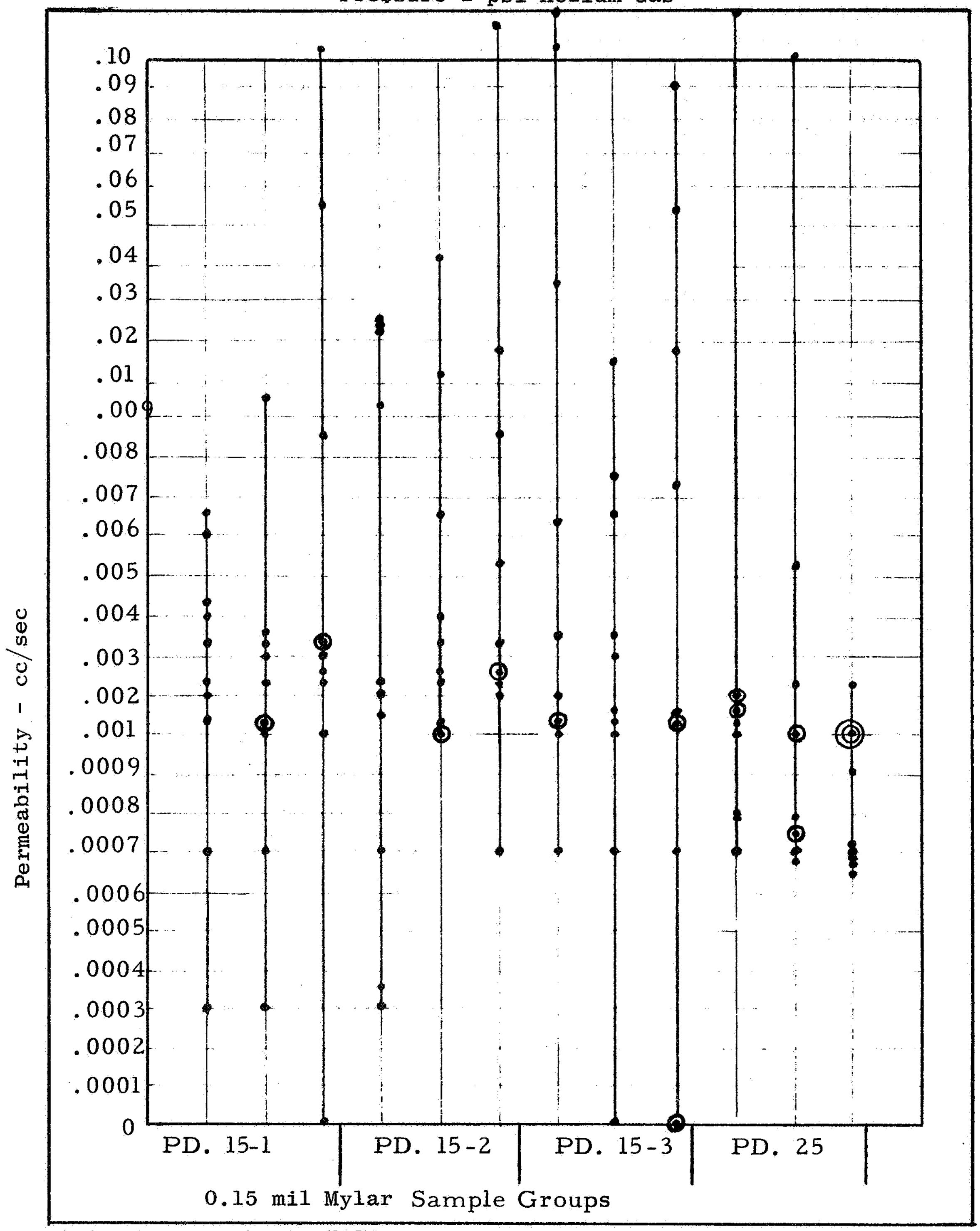
0.15 mil Mylar	(at 200 volts 17 survivals out of 20 is acceptable (at 500 volts 10 survivals out of 20 is acceptable
0.25 mil Mylar	(at 400 volts 19 survivals out of 20 is acceptable (at 1000 volts 17 survivals out of 20 is acceptable

CONCLUSIONS

The dielectric strength data supplied by DuPont and the permeability obtained on the same samples in this program did not show a good correlation. There is a trend indicated for three of the sample groups but an inverse relationship for the PD15-1 group.

FIGURE 3.28

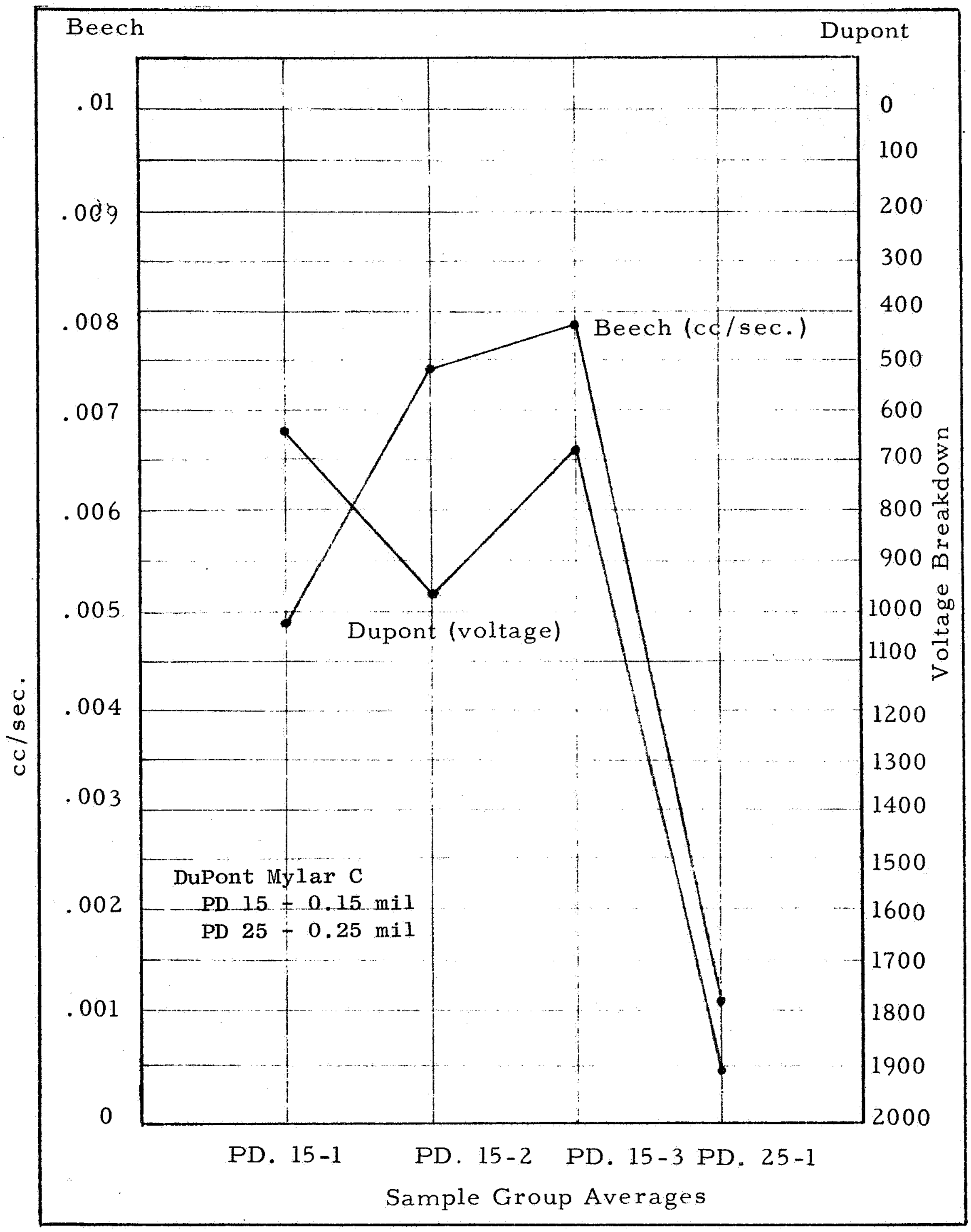
DUPONT MYLAR SAMPLES
PERMEABILITY TESTS
Pressure 1 psi Helium Gas



Ref: Paragraph 3.5.6.7

FIGURE 3.29

DUPONT/BEECH
PERMEABILITY CORRELATION



Ref: Paragraph 3.5.6.7

3.5.6.8 Extended Time Test

The Extended Time Test was conducted to demonstrate that samples which show zero permeability in a 5-minute period actually have some permeability which was not measurable in this period of time. The following tests were therefore conducted for a time period which permitted at least two groups of bubbles to enter the burette or to five minutes whichever occured last.

The use of a burette as a means of measuring permeability depends upon the accumulation of bubbles. It is normal to find that the bubbles enter the burette in groups of two or three and therefore if sufficient time is allowed it is always possible to obtain a finite rate.

Three different pressures were used and are noted at the top of the columns. Some of the data was substituted for the zero readings previously obtained for the DuPont Correlation Tests, Paragraph 3.5.6.7.

The samples used for this test were 0.25 mil and 0.15 mil Mylar C received from DuPont. These samples gave outstandingly low permeability readings as compared with some other Mylar samples tested in the program.

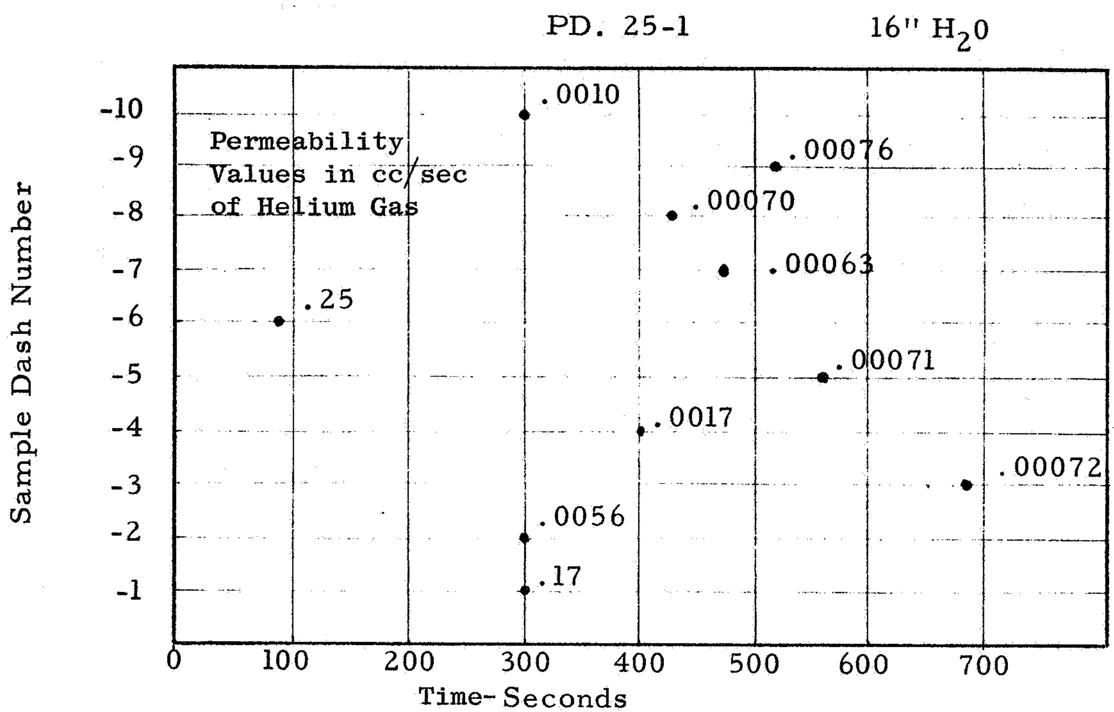
CONCLUSIONS

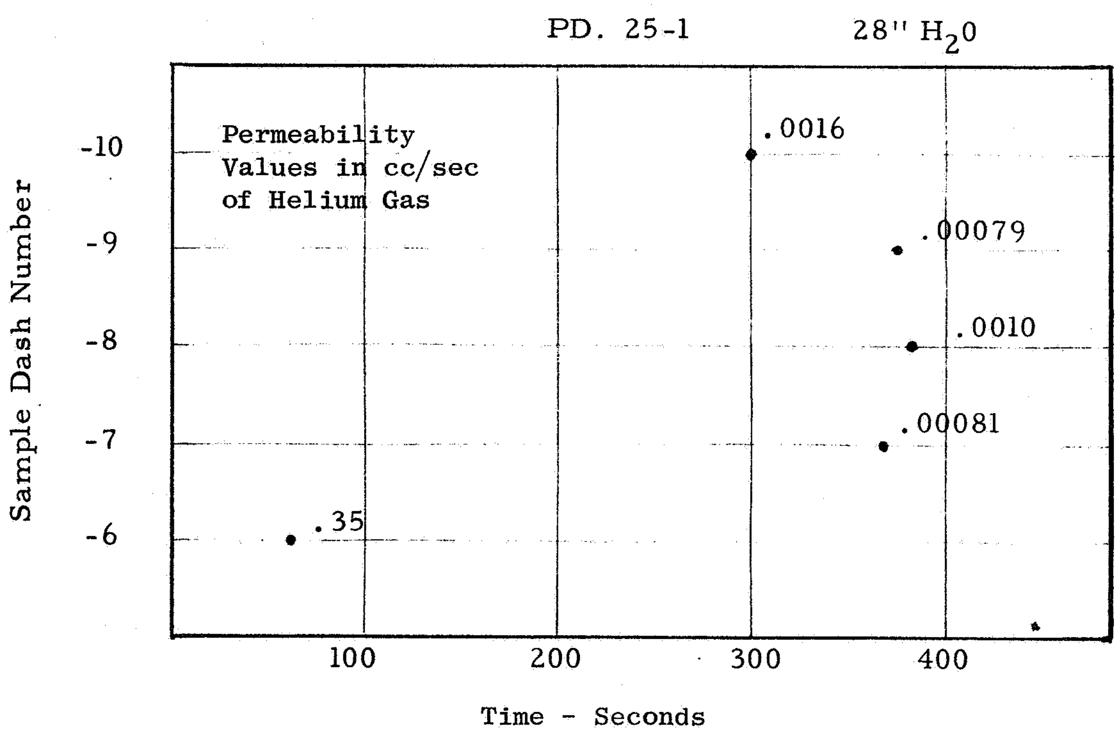
The results of the Extended Time Tests show that many samples which have zero leakage at the end of five minutes will indicate permeation if the time is extended. The doubling of the time period showed that permeation could be as small as 0.00016 cc/sec. As has been noted in previous reports on permeability, the smallest permeability reading which can be obtained in a 5-minute period is 0.00066 cc/sec. Anything less than that is considered zero for this program. The selection of five minutes was made, fully recognizing this fact for the reason that it was not feasible to spend excessive time on each sample. The Extended Time Test has shown that zero permeation in five minutes means only that it is less than 0.00066 cc/sec (Ref. Figure 3.30).

The test data shows that a definite relationship exists between the permeation of a sample under 16 inches of water as compared with 28 inches of water. The higher the pressure the greater the gas transmission.

FIGURE 3.30.1

EXTENDED TIME TESTS *

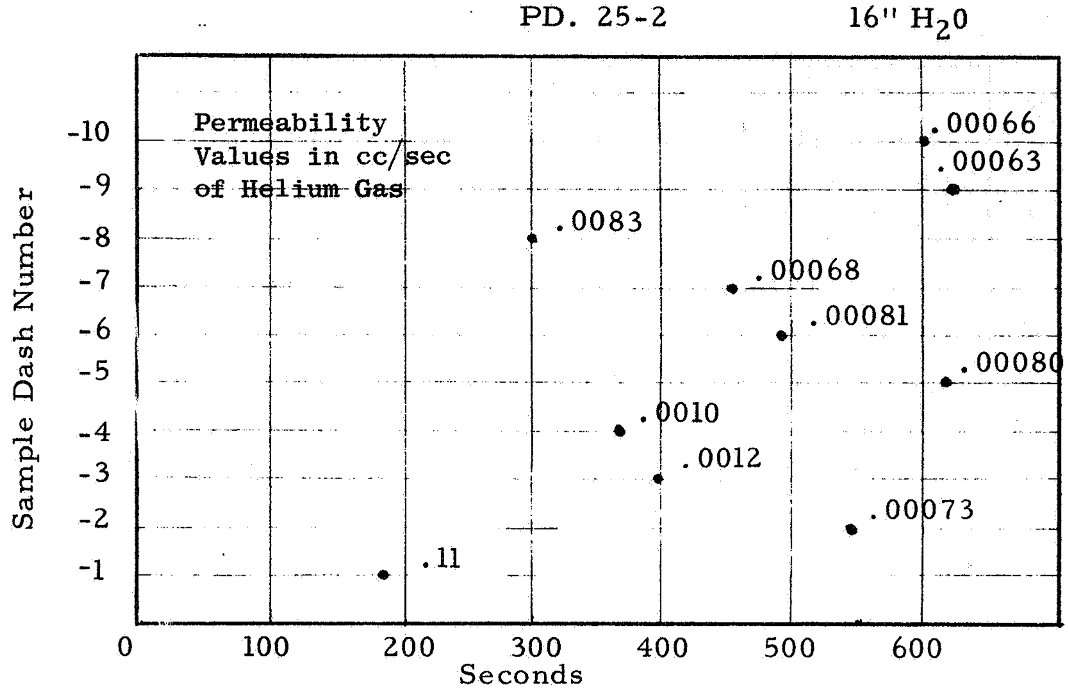




* Ref: Paragraph 3.5.6.8

FIGURE 3.30.2

EXTENDED TIME TESTS



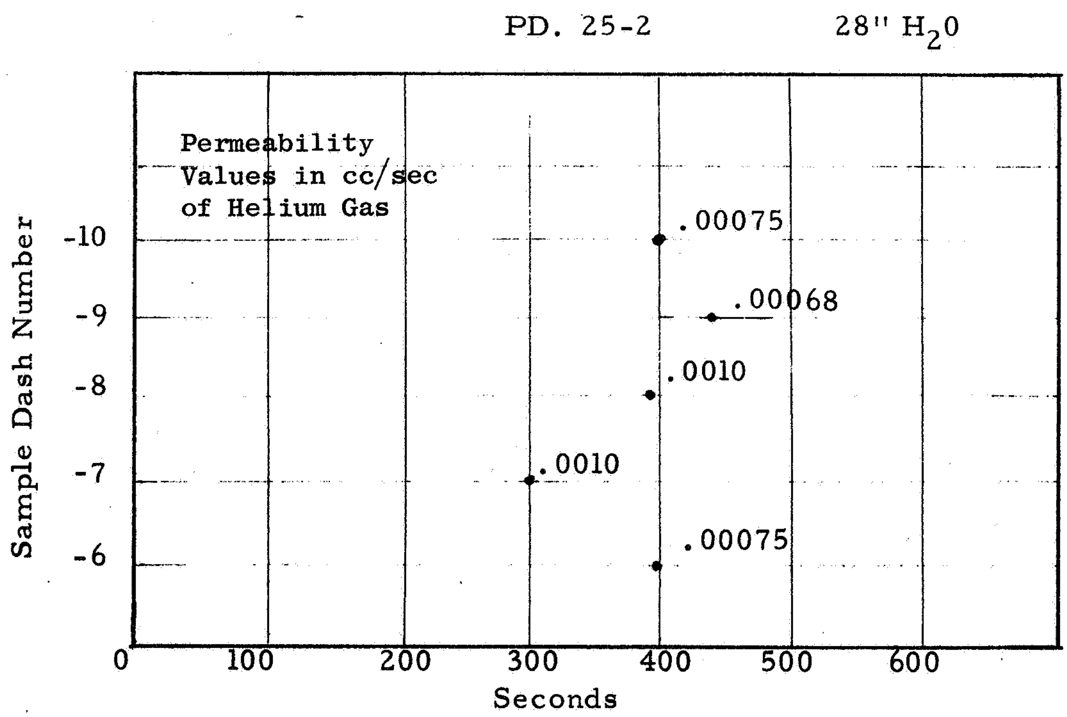
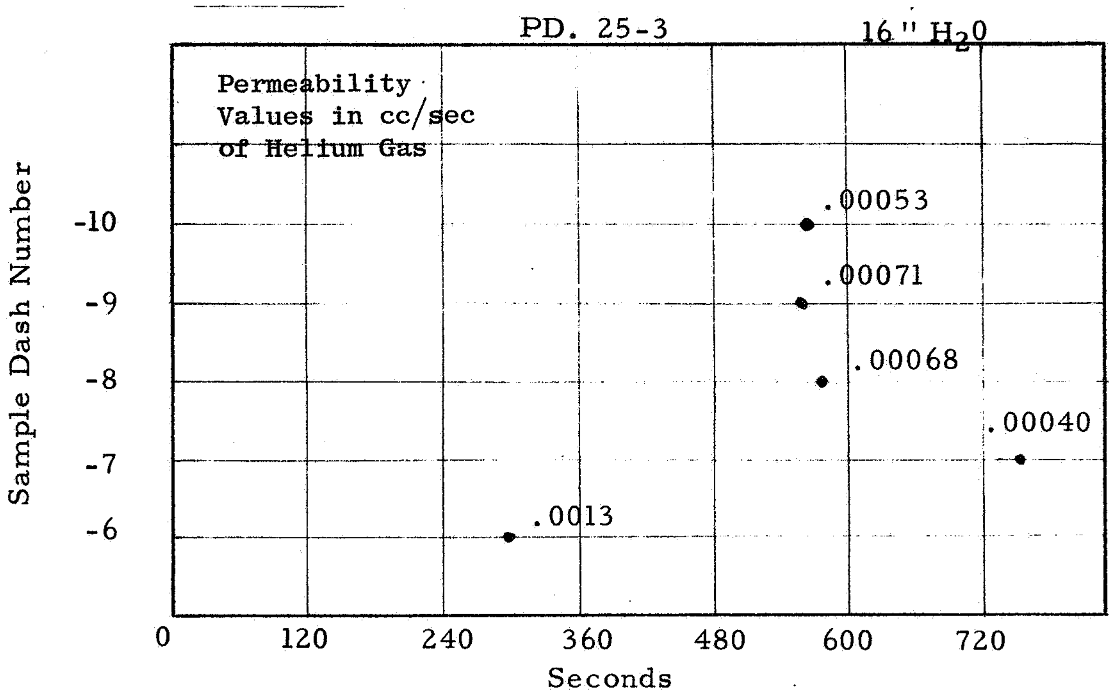


FIGURE 3.30.3

EXTENDED TIME TESTS



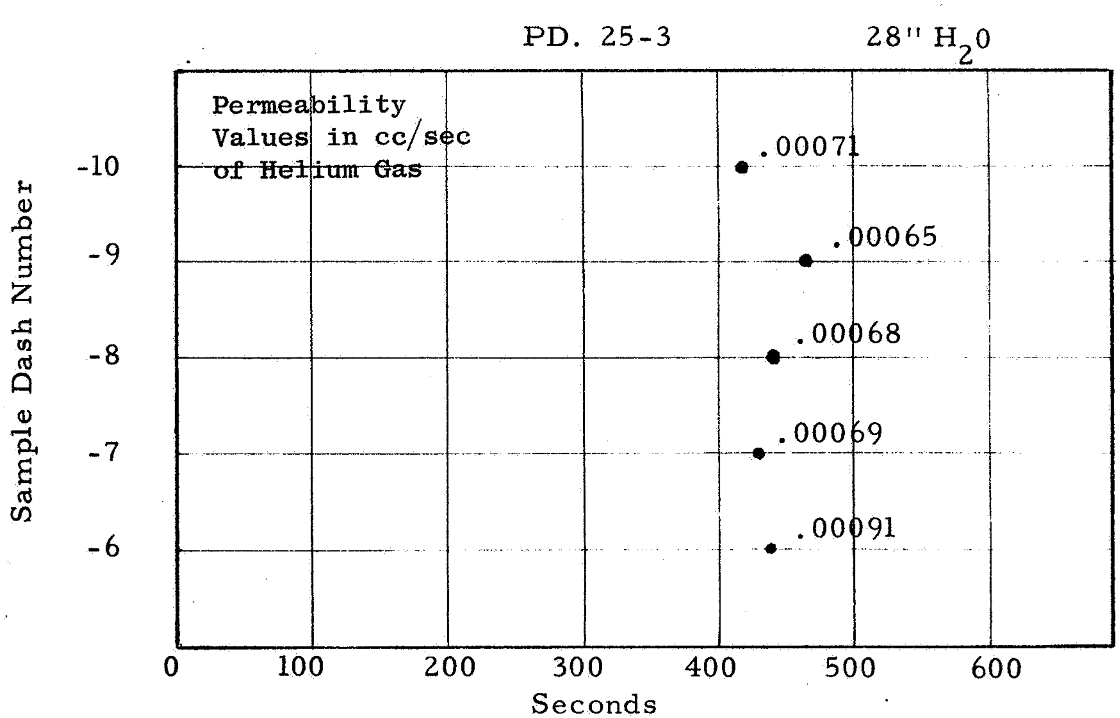
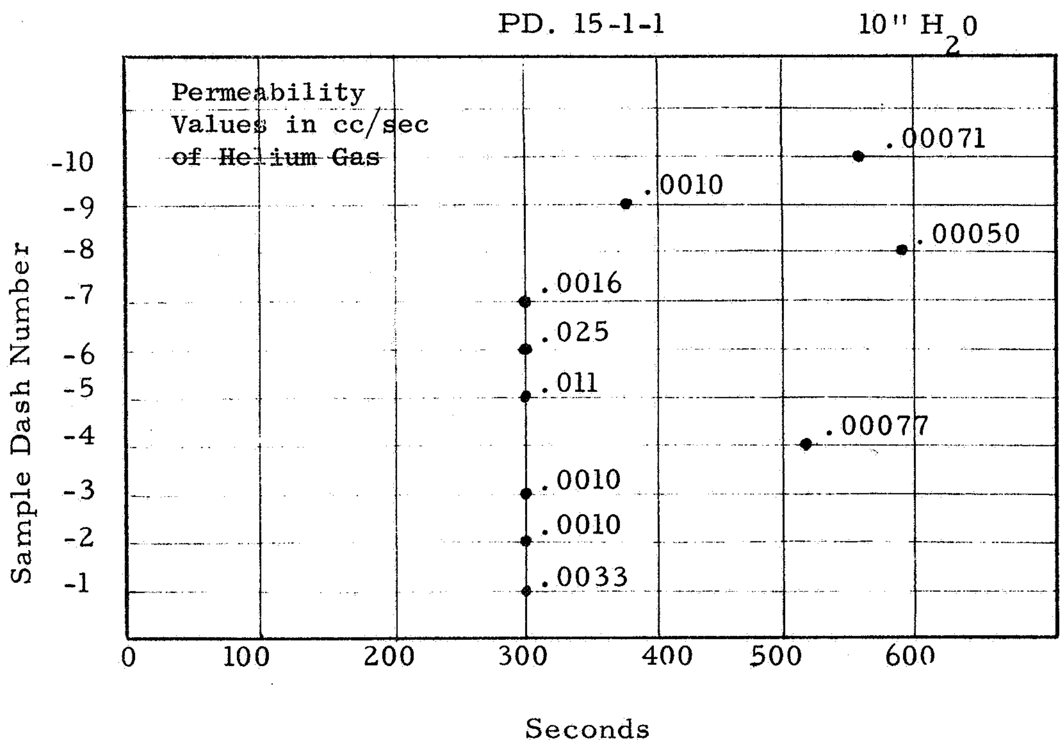


FIGURE 3.30.4

EXTENDED TIME TESTS



3.5.6.9 Pressure and Time Variation Test

This test was conducted on two different samples of 0.5 mil Kapton at two different pressures and for two different periods of time. The purpose was similar to the Extended Time Test, Paragraph 3.5.6.8, but combined the two parameters and for a different material. These samples were regular program samples received from the G. T. Schjeldahl Company.

CONCLUSION

The conclusions are identical to previous tests of a similar nature in that extending the time of permeation measurement will provide a figure for permeability which otherwise would be termed zero in a 5-minute period.

3.5.6.10 Burst Tests

These tests provided a maximum pressure allowable for conducting permeability flat sample tests and also an indication of film strengths useful for bladder fabrication.

3.5.7 Summary of Permeability Studies

(1) Permeability of Mylar film varies considerably from one roll batch to another and is affected by handling and storage.

(2) The permeation of helium gas through multiply Mylar films is reduced by the addition of two or three plys but does not significantly improve by additional plys.

(3) The rate of helium gas transmission through Mylar films increases with increase in pressure differential across the film.

(4) Helium gas at one psi pressure will permeate through a 30 square inch 0.25 mil Mylar film at a rate up to 0.018 cc/sec without visible bubbles if covered with water to a depth of 1/4 inch.

(5) The permeability rate of helium gas through 0.15 mil Mylar film stabilizes after approximately 15 minutes.

(6) A ± 15% variation is possible in permeability data recorded in this report for flat samples as well as bladders. This is indicated by the repeatability test and the utilization of the same equipment for bladder tests.

(7) A hole of 0.007-inch diameter permits more gas transmission through a film than that attributed to actual permeability of any 30 square inch samples tested.

(8) This program did not observe a good correlation between the DuPont electrical strength data and gas permeability rates.

(9) Zero permeation as measured for a period of five minutes in this program means that the rate is less than 0.00066 cc/sec for Helium gas at one psi over 30 square inches of 0.15 or 0.25 mil Mylar film area.

(10) There is no sharp or distinct increase in gas transmission through a film to clearly define the terms permeability and porosity.

3.6 Thermo-Formed Mylar Film Investigation

In addition to testing of flat commercially available films, the program required that an evaluation of thermally-formed Mylar "C" be performed. Although permeability, flexibility, and other specific material characteristics are important in the selection of a material for a bladder, the capability of a material to be fabricated into a bladder shape is of equal importance.

If a bladder could be fabricated from a material with a minimum amount of seaming, it would be assumed to be a more satisfactory bladder. This thermo-formed investigation was to determine if Mylar could be formed into hemispherical shapes and still retain the properties of flat film of the same thickness.

The Boeing Company was given an order for twenty-one 4" x 11" samples from .25 mil Mylar "C" film which had been thermally-formed into 12" diameter hemispheres. The following detailed description was provided Boeing for this order.

1. 4.00 ± .03" wide by 11.00 ± .06 long.

2. Made from formed 12" (nominal) hemispheres of 1/4 mil Mylar "C". Specimens to be cut from truly spherical surfaces with no more than three pieces obtained from one hemisphere. Longitudinal centerline of each specimen shall, prior to removal, describe a great circle upon the spherical surface.

3. Each specimen shall undergo careful examination to preclude defective specimen.

4. All specimens to be coded to identify those obtained from the same hemisphere with "high" side marked on all specimens, except those centered on polar area.

Figure 3.31 shows the manner in which the samples were cut to provide three samples from a hemisphere providing characteristics of the thermally-formed film from different portions of the hemisphere. Tabs were left on each sample as shown to identify the sample and were used for a point of location in measuring the film thickness. (See Table 3.6).

The samples were inspected and found to be satisfactory, having the expected curvature and with a minimum of film thickness variation across the sample. Each sample was measured at three or more points across the surface for film thickness. Table 3.6 lists the thickness measured at the corner from the tab. Other measurements were taken on many samples to confirm the consistency of the sample film thickness. The samples were then tested for permeability and flexibility by the same procedure as used on flat samples previously. Also, a flat sample from the same Boeing material was tested for permeability only and then a comparison was made. Table 3.5 shows the test results for T301 and T302 thermally-formed samples and the PB25 flat samples supplied by Boeing.

3.6.1 Twist-Flex Test Data

The figures listed in columns under each sample description are as follows:

TABLE 3.5

Sample No.	Permeability Before Testing	Permeability After Testing	(LH_2) No. of Cycles	Comments
BOEING SAMPLES				
T301 Description	Single Ply 0.25 Mil Mylar C 4" x 11" Thermo-form samples Cut from hemispheres			
-1	0.97	-	18	Splitting of film across entire face of sample
-2	4.7	-		Sample torn upon removal from apparatus
-3	6.5	-	200	Sample split when removed from fixture
-4	4.5	-	45	Splitting of film from left end across sample
-5	4.4	-	49	Splitting of film from left end across sample
-6	2.3			

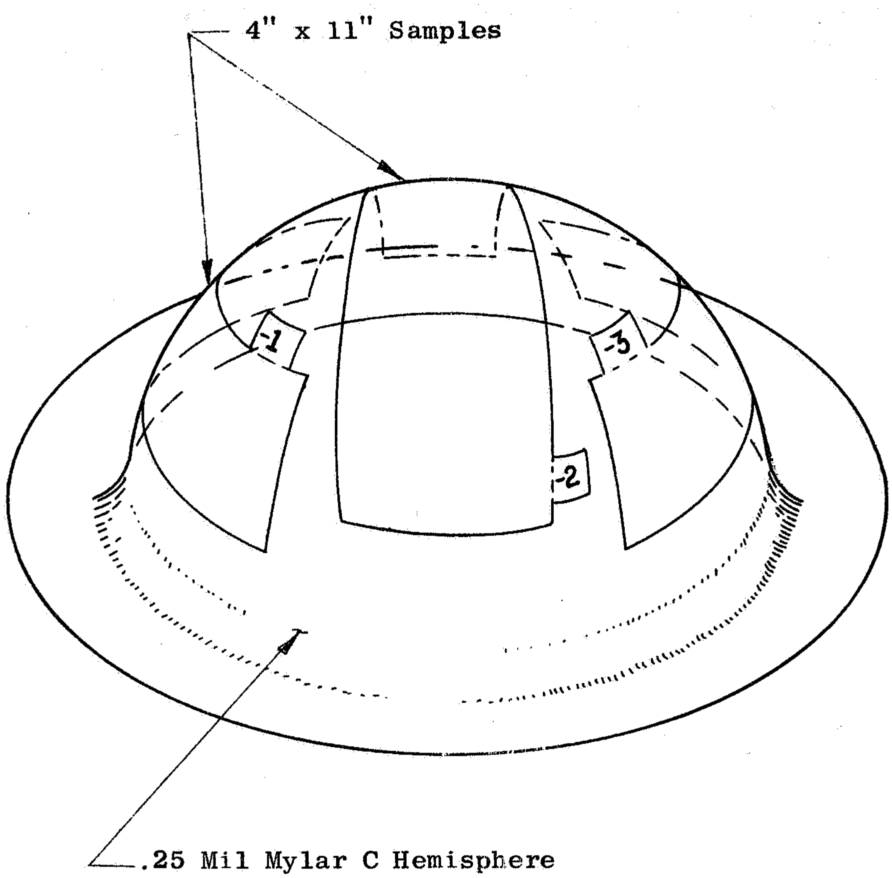
90-33364
(was E-270-1)

3.6.1 Twist-Flex Test Data (Continued)

All of these samples showed severe effects of twist-flexing. Every sample split across the face of the sample with the exception of two which split when being removed from twist-flex fixture. The high porosity of film prior to testing indicated the influence of thermo-forming of Mylar. The fabrication of these samples was highly satisfactory.

FIGURE 3.31

THERMO-FORMED SAMPLES
(THE BOEING COMPANY)



Twelve inch hemisphere showing cutting pattern
for thermo-formed samples of 0.25 Mil Mylar C

TABLE 3.5 (Continued)

T302	Description		5 Plys 0.25 Mil Mylar C 4" x 11" Thermo-Formed samples cut from hemispheres	
-1	.013	-	100	Bubbles detected during flexing - 1/2" split
-2	.047	-	200	Split from right end into field of sample 2" long
-3	.015	-	200	Split from end 2" long and split in field

Results similar to single ply film. Porosity relatively high for five plys of Mylar and flexibility effects severe on material.

PB25	Description		.25 mil Mylar Single ply Unformed film	
-1	.018	-	-	No twist-flex test - only initial permeability
-2	.066	-	-	No twist-flex test - only initial permeability
-3	.053	-	-	No twist-flex test - only initial permeability
-4	4.6	-	-	No twist-flex test - only initial permeability
-5	.16	-	-	No twist-flex test - only initial permeability

3.6.2 Conclusions

It should be noted that the thermally formed samples before twist-flex testing had a high permeability measurement as compared to the flat samples which were not thermally formed.

It appears from this study that there is a degradation of the Mylar caused by the heat and stretching of the film during the thermal forming which adversely affects the normally good physical characteristics of the film. It is therefore not recommended that Mylar be thermally formed for the fabrication of bladders unless the process can be improved to prevent this change in film characteristics.

The fact that bladders can be formed from gores seamed with adhesive type tape, without adversely affecting the expulsion performance, minimizes the need for seeking one or two-piece type of construction. Seaming was not found to be the source of material failure during cycling of cryogenic expulsion bladders.

TABLE 3.6

THERMO-FORMED SAMPLE THICKNESS
.25 MIL MYLAR C

Hemi. No.	Dash No.	Ident. Corner	Center	Opp. Corner from Ident.
1	-2	.24	.24	.28
1	-3	.22	.21	.21
2	-1	.21	.20	.22
2	-2	.20	.20	.20
3	-1	.22	.22	.22
	-2	.22	.20	.20
	-3	.22	.26	.29
4	-1	.28	.22	.28
	-2	.29	.23	.28
5	-1	.27	.21	.22
	-2	.30	.27	.26
	-3	.26	.21	.30
6	-1	.20	.21	.22
	-3	.22	.21	.23
7	-1	.20	.20	.21
	-2	.21	.25	.20
	-3	.22	.21	.22
8	-2	.20	.25	.23
	-3	.24	.26	.20
9	-1	.25	.23	.26
	-3	.24	.23	.29

NOTE: All thicknesses in mils. These samples were cut from nine hemispheres and the "Dash No." shows where they were cut from in relation to Figure 3.31 indentification.

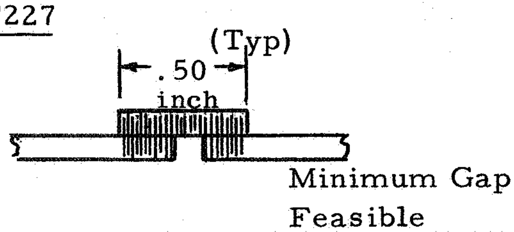
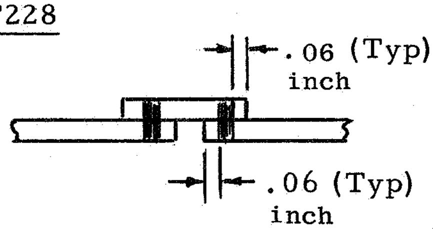
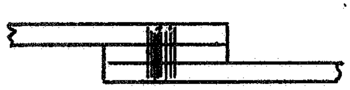
3.7 Seaming Investigation

From the previous test it was decided that bladder fabrication using a taped and gored method of construction would be the better way. This decision, therefore, made the seaming of materials together of prime importance. Seaming had not caused any great difficulty in bladders fabricated by this method in previous programs; however, the optimum method of joining two pieces of thin film or substrate material had not been previously investigated in depth.

Samples for the seaming investigation were made from Mylar, Nomex, and Dacron fabric and fabricated by the G. T. Schjeldahl Company. The various types of seams tested are shown and coded in Figure 3.32 and 3.33. Single-ply films were tested first, followed by multi-ply samples in various multi-ply combinations which appeared to have potential application in bladders.

The Twist-Flex apparatus was used for testing all samples. The difficulty in obtaining useful results was in being able to separate the failures of the basic material from the failures caused by the seam. The same procedures were followed in the seaming investigation as had been previously used for cycling other flat or cylindrical samples. Permeation and cycle life was evaluated by recording data of these parameters for each sample.

FIGURE 3.32

SEAM VARIATION & SAMPLE NO.		BUTT & LAP SEAM VARIATION G. T. SCHJELDAHL CO. SEAM DETAILS
(1) T227		Butt Seam 1/2" Wide Hot Roller Sealing Iron Seal GT 300 Tape and Adhesive (.25 Mil Tape Thickness X .25 Mil Adhesive Thickness X 1/2 inch wide)
(2) T228		Butt Seam Two 1/8" Wide Hot Roller Sealing Iron Seal GT 300 Tape and Adhesive (Same Dimensions as Above)
(3) T229		Lap Seam 1/2" Wide Hot Roller Sealing Iron Seal GT 100 Adhesive (.5 Mil Thickness X 1/2" Wide)
(4) T230		Lap Seam 1/8" Wide Hot Roller Sealing Iron Seal GT 100 Adhesive (Same Dimension as Above)
(5) T231		Butt Seam Two 1/8" Wide Impulse Seals GT 300 Tape and Adhesive (Same Dimensions as Above).
(6) T232		Lap Seam 1/8" Wide Impulse Seal GT 100 Adhesive (Same Dimensions as Above).

GT 100 (.5 mil ± 10% x 1/2")   GT 300 (.25 x .25 x 1/2")

3.7.1 Single-Ply Seamed Twist-Flex Test Data

The single ply seamed twist-flex test data is summarized as follows and detailed in Appendix D.

T227 Description	1 ply of .25 mil Mylar "C" Butt Seam, 1/2" Wide (See Figure 3.32, No. 1) GT300 Tape and Adhesive

Conclusions

Complete random type of splitting across samples not related to seam. Seam type comparison test.

T228 Description	1 ply of .25 mil Mylar "C" Butt Seam, 1/8" wide hot roller (See Figure 3.32, No. 2) GT300 Tape and Adhesive

Conclusions

Complete random type of splitting failure across entire sample not related to type of seam. Seam type comparison tests.

T229 Description	1 ply of .25 Mylar "C" Lap Seam, 1/2" wide (See Figure 3.32, No. 3) GT100 Adhesive

Conclusions

Complete random splitting of film influenced to some degree by seam which deterred a split from propagating across seam in most cases. Seam type comparison tests.

T230 Description	1 ply .25 mil Mylar "C" Lap Seam 1/8" wide Hot Roller (See Figure 3.32, No. 4) GT100 Adhesive

Conclusions

Complete random type splitting failures in which the seams deterred a split from propagating across a seam. Splits not initiated by seams. Seam type comparison tests.

T231 Description	1 ply .25 Mylar "C" Butt Seam, 1/8" wide impulse seal (See Figure 3.32, No. 5) GT300 Tape and Adhesive

3.7.1 Single-Ply Seamed Twist-Flex Test Data (Continued)

T232 Description

1 ply .25 mil Mylar "C"
Lap seam 1/8" wide Impulse Seal (See Figure 3.32, No. 6)
GT100 Adhesive

Conclusions

Random splitting of film within a relatively few number of twist flex cycles not influenced to a great degree by the seam. Seam type comparison tests.

T233, T234, T235 Description

1 ply of .25 mil Mylar "C"
Lap Seam 1/2" wide (See Figure 3.32, No.3)
GT100 Adhesive

Conclusions

Complete random type of splitting across sample not related to seam. Seam type comparison test.

The results shown for T233, T234, and T235 indicate that the failures apparently were not due to the seams but to the basic material. The failures were of a gross nature in which the splits originated in the material and extended through the seams in a random manner. The samples, when received, had a wrinkled appearance which caused some concern as to the quality of the Mylar as compared to other samples which had been received wrinkle-free. The permeability data in the tables also indicates a wide variety between samples, possibly due to this wrinkled condition.

T240 Description

1 ply of 2 mil Nomex-Nylon Paper
Butt Seam, 1/2" wide (See Figure 3.32, No. 1)
GT300 Tape and Adhesive One Side

Conclusions

Severe splitting of the Mylar tape between the butt ends of the Nomex material.

T241 Description

1 ply of 2 mil Nomex-Nylon Paper
Butt Seam, 1/8" Wide (See Figure 3.32, No. 2)
GT300 Tape and Adhesive One Side

Conclusions

Severe splitting of the Mylar tape between the butt ends of the Nomex material.

3.7.1 Single-Ply Seamed Twist-Flex Test Data (Continued)

T242 Description

1 ply of 2 mil Nomex-Nylon Paper
Lap Seam, 1/2" wide (See Figure 3.32, No. 3)
GT 100 Adhesive

Conclusions

The lap wide seams appeared to be more satisfactory than the butt seams tested as T240 and T241.

T243 Description

1 ply of 2 mil Nomex-Nylon Paper
Lap Seams, 1/8" wide (See Figure 3.32, No. 4)
GT100 Adhesive

Conclusions

Serious separation of lap seams indicate that the narrow seal is not sufficiently strong in this application.

T244 Description

1 ply of 2.2 oz. Dacron Fabric
Butt Seam, 1/2" wide (See Figure 3.32, No. 1)
Tape one side
GT300 Tape and Adhesive

Conclusions

Severe splitting of horizontal and vertical seams. This material is too heavy to be seamed with .25 mil Mylar tape.

T245 Description

1 ply of 2.2 oz. Dacron Fabric
Butt Seam, 1/8" wide (See Figure 3.32, No.2)
GT300 Tape and Adhesive One Side

Conclusions

Complete splitting of horizontal and vertical seams. This material is too heavy to be seamed with .25 mil Mylar tape.

T246 Description

1 ply of 2.2 oz. Dacron Fabric
Lap Seam, 1/2" wide (See Figure 3.32, No.3)
GT100 Adhesive

Conclusions

A superior seam for use in joining this 2.2 oz. Dacron Fabric together.

3.7.1 Single-Ply Seamed Twist-Flex Test Data (Continued)

T247 Description

1 ply of 2.2 oz. Dacron Fabric
Lap Seam, 1/8" wide (See Figure 3.32, No. 4)
GT100 Adhesive

Conclusions

A superior seam for use in joining 2.2 oz. Dacron Fabric together. Appears to be equally as good as the wide seam.

3.7.2 Multi-Ply Seamed Twist-Flex Test Data

The following Twist-Flex samples consist of six different sample groups. These groups (T248 through T253, inclusive) were procured and tested to provide for the comprehensive evaluation, of multi-ply Mylar and Kapton samples, of the types and styles of seams illustrated in Figure 3.33.

Each sample (except as noted) was tested to the complete Twist-Flex test procedure: Permeability test, T-F in LH_2 and second permeability test. Samples T250-10 and T253-10 were disassembled and permeability tested in the form of single plys to provide additional permeability data deemed necessary for the bladder specifications.

The multi-ply seamed twist-flex test data is summarized as follows and detailed in Appendix D.

T248 Description

10 ply of .25 mil Mylar "C"
Butt Seam, Style "W"
GT300 Tape and Adhesive

Conclusions

Random failures of Mylar film; failures generally not attributed to type of cross seam.

T249 Description

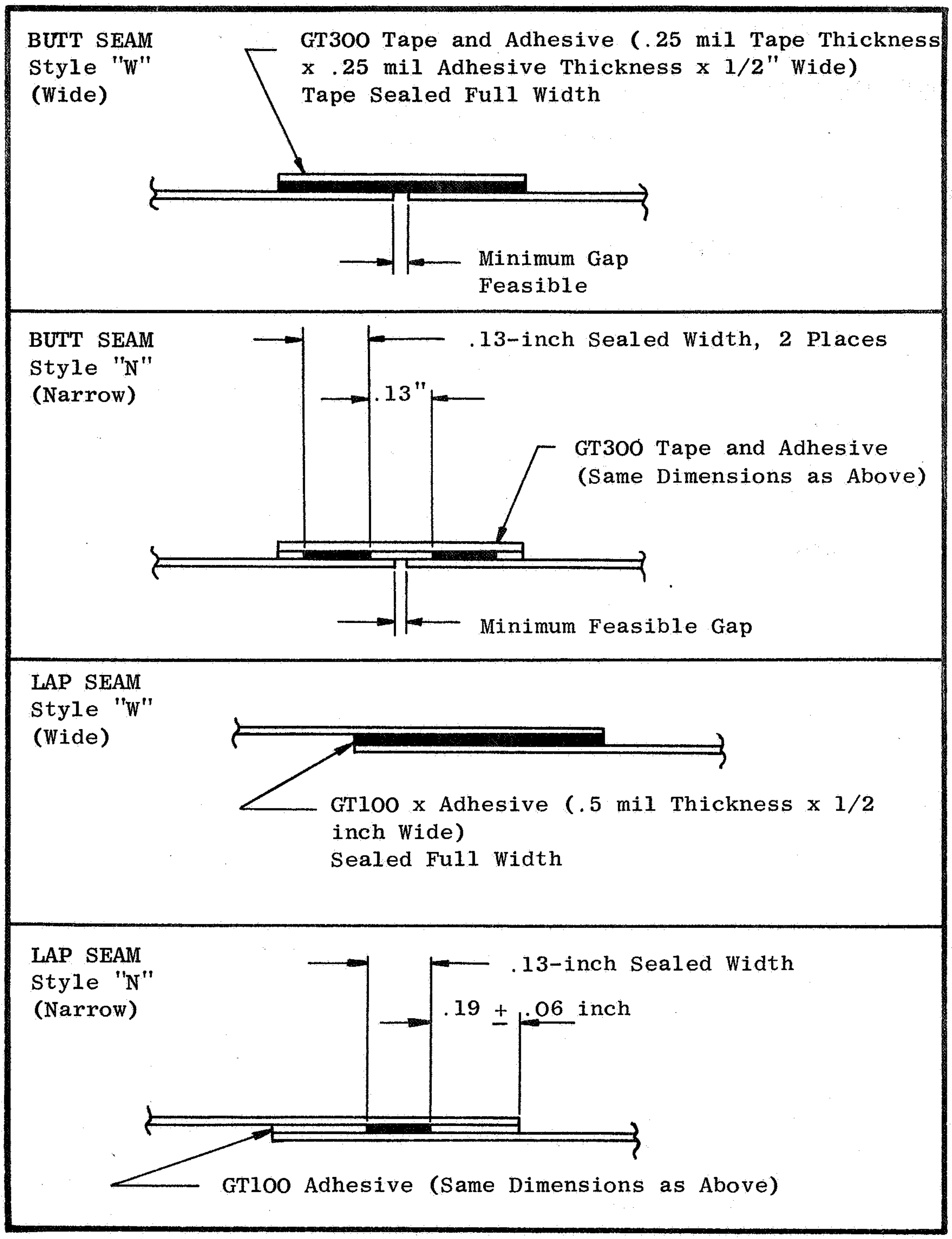
10 plys .25 mil Mylar "C"
Butt seam, Style "N"
GT300 Tape and Adhesive

Conclusions

Good flex performance; increased permeability after Twist Flex.

FIGURE 3.33

BUTT AND LAP SEAM VARIATIONS



3.7.2 Multi-Ply Seamed Twist-Flex Test Data (Continued)

T250 Description — 10 plys of .5 mil Kapton
Butt Seam, Style "W"
GT300 Tape and Adhesive

Conclusions

Seam failures: Light tape being cut at center of cross seams.

T251 Description — 10 plys of .25 mil Mylar
Lap seam, Style "W"
GT100 Adhesive

Conclusions

Generally good flex performance with some random material failure not directly attributable to cross seams.

T252 Description — 10 plys of .25 mil Mylar
Lap seam, Style "N"
GT100 Adhesive

Conclusions

Very random flex performance ranging from good to poor, with failures not directly attributable to type of cross seams.

T253 Description — 10 plys of .5 mil Kapton
Lap seam, Style "W"
GT100 Adhesive

Conclusions

Poor flex performance with considerable seam failure; other random failures appear to be induced by the cross seams.

3.7.3 Overall Conclusions for Seaming Testing

The T248 samples (butt seam, Style "W") exhibited the lowest permeability after T-F tests, although exhibiting low flex performance, it must be considered that the purpose of this test series was to evaluate seams, and the failures were basically other than seam failures. It is believed that the addition of cross seams to a 4 x 11 inch sample contributes to material failures of the type encountered, due to reduced area for stress dissipation. However, there is no reason to believe that one type of seam would induce greater stress than another type.

3.7.3 Overall Conclusions for Seaming Testing (Continued)

The tests upon the T250 and T253 samples were to select the optimum type of seam for .5 mil Kapton bladder plys. The flex performance of the T250 samples (butt seam, Style "W") was somewhat inferior because the heavier (.5 mil) material produced a cutting effect upon the lighter (.25 mil) film of the tape. The overall T-F damage to the T253 samples (lap seam, Style "W") was more extensive than that suffered by the T250 samples.

The butt type seam offers the apparent fabrication advantage of easy and positive gore lay-up. Therefore, the butt seam, Style "W" with GT300 X .5 mil X .5 X 1/2 wide tape, was recommended for seaming all .5 mil Kapton bladder plys. The heavier tape should eliminate the condition of tape shear encountered in the T250 tests.

The samples fabricated with and without seams provide a broad experience on both materials and fabrication procedures which were used in the bladders for Task II. The seams were fabricated either under heat and pressure, thermally bonded, ultrasonically, or using a room temperature adhesive which provided opportunity for comparing the effect of different fabrication methods upon a material. The basic material may be affected by the seaming to an extent which destroys good characteristic which the material might demonstrate when tested without seams.

Samples tested have shown that the seams have influenced the results in several ways. Seams which required adhesive, heat and pressure, sometimes produced heavy, rigid seams, and some apparent shrinkage near the edges. Thermally bonded and ultrasonic seams had the least effect upon the flexibility of the sample.

Mylar Films - Table 3.7 shows the relationship of the Mylar film seam types to performance by classifying the seams by Narrow Impulse (NI), Wide Hot Roller (W), and Narrow Hot Roller (N) and also whether Butt or Lap Seam. The sample code numbers are also noted and Figure 3.32 provides a picture of the various seam configurations.

The seams, when categorized by best performance, produce somewhat random relationships and make a selection of the best seam difficult. It appears that the 1/2" wide hot roller seam shows a better over-all performance than the other two types. In consideration of performance and other factors of fabrication, the butt seam becomes the most satisfactory.

The selection, therefore, for future samples and bladder fabrication, is the "W" wide butt seams, using GT300 X .25 mil X .25 mil X 1/2" wide tape.

3.7.3 Overall Conclusions for Seaming Testing (Continued)

Nomex-Nylon Paper and Dacron Substrates - The correlation tests of seaming Nomex-Nylon Paper and Dacron Fabric with lap, butt and narrow and wide seams resulted in specific conclusions. The wide lap seam is superior in the case of the Nomex material which had produced extended life of 200 cycles or more, whereas the butt seam failed in relatively few cycles. The Dacron Fabric showed good cycle life with either the wide or narrow lap seam and poor results with the butt joint.

The conclusion is that for future samples and bladder fabrication, the wide lap seam should be used for both Nomex-Nylon Paper and Dacron Fabric.

Final Seam Recommendation

The Final Seam recommendations are summarized in Table 3.8.

TABLE 3.7

SCHJELDAHL TWIST FLEX MYLAR SEAMED SAMPLES

TEST RESULTS COMPARISON

	Seam Type					
	Butt			Lap		
BY LH_2 T-F CYCLES	Sample No.	Seam	Cycles	Sample No.	Seam	Cycles
Best	T228	N	(68) 42*	T229	W	(34)
2nd	T227	W	(39)	T232	NI	(33)
3rd	T231	NI	(26)	T230	N	(28)
BY SEAM PERFORMANCE						
Best	T228 T227	N & W		T229	W**	
2nd				T230	N or NI	(232)
3rd	T231	NI				
BY PERMEABILITY			Perm. cc/sec			Perm. cc/sec
Best	T231	NI	(0.018)	T232	NI	(0.012)
2nd	T227	W	(0.019)*	T229	W	(0.054)*
3rd	T228	N	(0.026)*	T230	N	(0.680)*

*Highest reading not considered

**Probably better than Butt N or W.

TABLE 3.8

Final Seam Recommendations

Material	Type	Style	Tape
.25 mil Mylar C	Butt	1/2" Wide	GT300 x .25 x .25 x 1/2" Wide
.5 mil Kapton	Butt	1/2" Wide	GT300 x .5 x .5 x 1/2" Wide
Nomex-Nylon Paper	Lap	1/2" Wide	GT100 x 1 mil x 1/2" Wide
Dacron Fabric	Lap	1/2" Wide	GT100 x 1 Mil x 1/2" Wide

3.8 Ultrasonic Seaming Program

Among the seam bonding techniques which were evaluated under Task I was the ultrasonic welding process. The feasibility of the ultrasonic welding of .25 mil Mylar "C" film was studied in the course of two subcontracts with the Engineering and Development Company of Colorado (EDC). This company had significant experience in the ultrasonic welding of plastics and other materials, having developed a variety of production processes for ultrasonic sealing.

The first of these feasibility studies resulted in ultrasonic welds which were structurally sound but exhibited excessive porosity.

3.8.1 First Ultrasonic Study

All welds produced under the first ultrasonic study were compression-type welds of single-lapped material (see T401 configuration in Figure 3.34. The laboratory setup included (1) a Branson SA-250 sonifier on a pivoting support assembly, (2) a transport table upon which the film is mounted and moved at a fixed rate under the welding tip, and (3) a variable frequency generator used as a power supply to the sonifier.

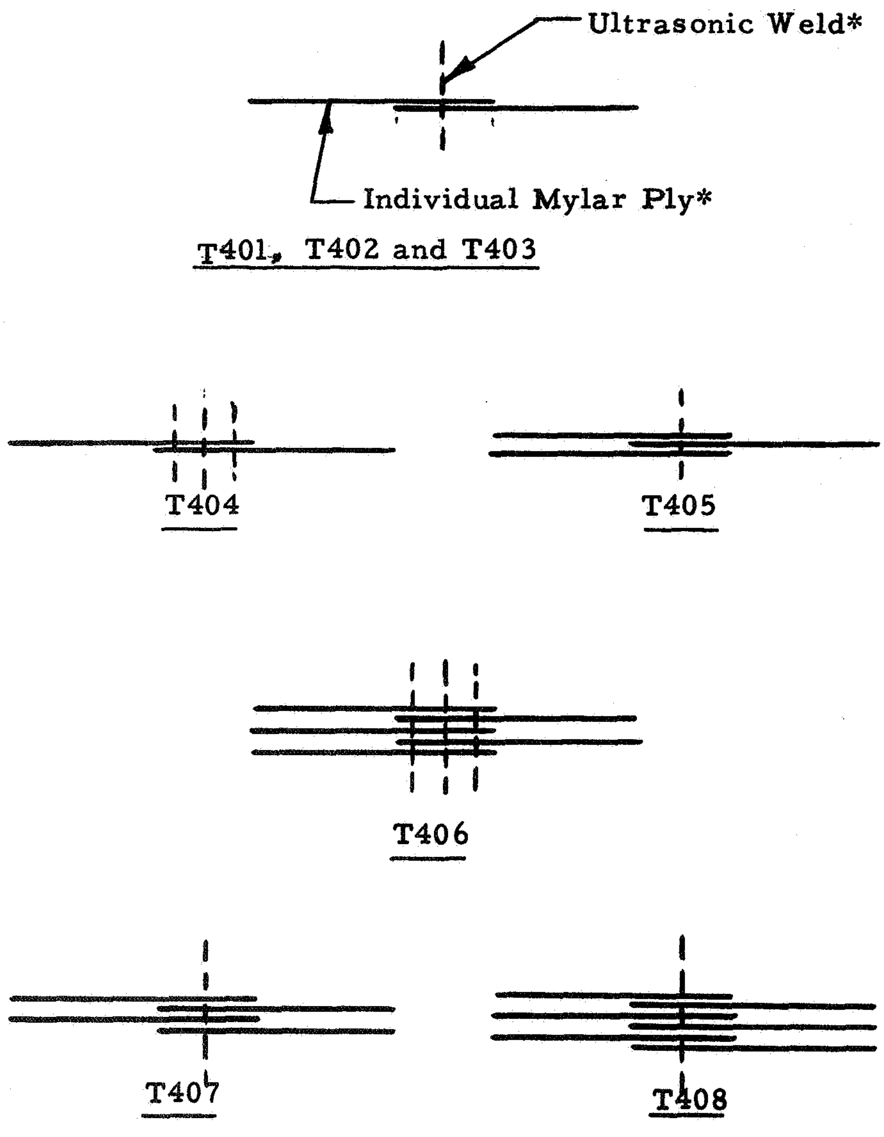
Following the necessary experimentation, the weld samples were produced using the following parameters:

(a)	Feed Speed	4.15 inches per minute
(b)	Head Weight	15.25 pounds (actual pressure applied to welding tip)
(c)	Weld Tip	Detachable tip, rectangular (.125 x .365 inches) in cross section, with edges rounded to prevent material snagging
(d)	Frequency	19.6 KC
(e)	Back-up Material	1 mil Teflon on 1/4 inch safety glass on standard aluminum transport table

The welds exhibited a higher tensile strength than the parent material and presented a good appearance except for weld tip marks and some pitting. The welds were approximately .080 inch wide and approximately centered on the 1/2 inch overlap of the .25 mil Mylar "C" film.

FIGURE 3.34

ULTRASONIC SEAM CONFIGURATIONS



*Typical for all views

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Considerable "lead-in" difficulty was initially encountered, but was reduced by pre-tuning the frequency prior to beginning material travel. However, it remained necessary to make the weld approximately 1 inch over-length so that the faulty lead-in portion could be trimmed off. Two pieces of film were welded by EDC to form an over-size sample, which was then trimmed to 4 x 11 inches by Beech, with the ultrasonic weld located on the long (11 inch) centerline of the sample. Six such samples were obtained.

The 4 x 11 inch samples were designated T401-1 through -6 inclusive. All of these samples were tested for permeability except -1, which had a .03 inch diameter hole in the weld. The remaining five samples all exhibited excessive leakage and -3 was tested under water to verify that the leaks were emanating from the ultrasonic weld. All of the samples except -3 were then Twist-Flex tested in LH_2 to 200 cycles. There was no evidence of weld damage or deterioration due to T-F cycling in LH_2. Eight smaller samples (too small for the permeability fixture) were also T-F tested in LH_2 with their ultrasonic seams in a vertical position. These samples (T402) were also cycled to 200 cycles with no indication of weld deterioration or damage. See Table 3.9.

Thus, the first ultrasonic bonding study resulted in the conclusion that the welds were entirely acceptable except for porosity. This suggested that additional effort should be undertaken in an attempt to eliminate this problem.

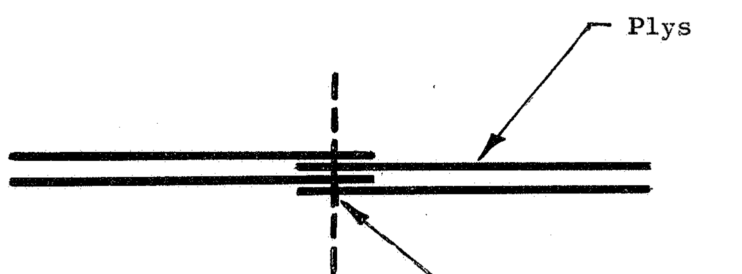

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TABLE 3.9

ULTRASONIC SEAMING TWIST-FLEX TEST DATA

The figures listed in columns under each sample description are as follows:

Sample No.	Permeability Before Test	Permeability After Test	No. of Cycles	Comment
T401 Description	1/4 mil Mylar C 4 x 11" sample size Horizontal seam Ultrasonically seamed Single plys			
-1	--	--	200	Appears satisfactory after flexing. Permeability check impossible because of excessive leak through seam.
-2	12*	--	200	Numerious wrinkles but no visible change on welded seam.
-3	--	--	--	No flexibility test only water permeability test. Nine holes apparent from bubbles of helium gas.
-4	24*	--	200	Numerous wrinkles. No visible change in seam.
-5	60*	--	200	Numerous wrinkles. No visible change in seam.
-6	19*	--	200	Numerous wrinkles. No visible change in seam.
T402 Description	1/4 mil Mylar C Ultrasonic seamed Single plys 4 x 4 inch size Vertical seam			
-1 (a) (b)	--	--	200	Split on T402-1b upper edge down across to center of end. No change in T402-1a.
-2 (a) (b)	--	--	25	Tear at upper and lower left end near edge on T402-21b. Upper split 1" long, lower split almost full length. No change in T402-2a.
-3 (a) (b)	--	--	200	No visible change in either a or b sample.
-4 (a)	--	--	165	Split in T402-4b off center to left and down. No change in T402-4a.

*cc/sec of helium gas.

3.8.2 Second Ultrasonic Study

The second feasibility development study performed by EDC was of a magnitude approximately three times that of the first effort. The objective of the second study was to improve the permeability characteristics of the ultrasonic seam while retaining all of the favorable attributes of the first study. To begin at the point where the first study left off, the second study was concentrated on the following variables:

(a) Feed Speed

(b) Pressure

(c) Amplitude

(d) Backup Materials

(e) Weld Tip Configuration

More than 35 experiments, each with an objective variation in one or more of the above parameters, were conducted. The results of these experiments ranged from no weld to a cut through the lapped material and into the backup film. Pressure was the most widely varied parameter, being adjusted to obtain different results and to compensate for changes in other parameters. Amplitude was also the subject of wide experimentation. Weld tips investigated included the tip described in 3.8.1, modifications thereof, a bar tip .25 x 3.5 inches, various ball bearing tips and modifications thereof. The use of a backup film was discarded quite early in this study when it became apparent that such film was adding to the problem of concentrating the energy in the material being bonded.

The difficulty of achieving good ultrasonic welds in single-lapped .25 mil Mylar C became increasingly apparent as the above experiments were conducted. Weld results ranged from insufficient energy (poor tensile strength or no weld) to excessive energy (increased porosity of the weld or fracture of material at the weld). In some cases, a weld varied from poor strength to high porosity in an 11-inch length, even though the parameters had not been varied.

The problem has been analyzed as one of spacing control. The optimum energy must be applied at a point .00025 (plus or minus approximately .00010) inches above the surface of the backup plate. Such precise spacing is considered to be beyond the capability of the equipment commonly used for the ultrasonic bonding of plastic film. Any slight deflection of the transport table or horn support assembly can result in loss of the precision spacing necessary for a high strength, zero porosity weld in .25 mil film.

The first group of samples provided for evaluation included a number of single-lapped, single-seamed samples designated T403 (see Figure 3.34). In an attempt to improve the weld strength and/or porosity characteristics, multiple-seamed and multiple-lapped samples as depicted by T404, T405 and T406, Figure 3.34, were also included in this group. These samples were tested for permeability as shown in Table 3.10. No attempt was made to Twist-Flex test these samples because they lacked the seam strength necessary to prevent tearing during installation into the T-F apparatus. Lead-in continued to present some problem and several samples were too short to permit the desired amount of trim. In general, the samples were seriously lacking in weld strength: Some welds literally "fell apart" during careful handling. The welds were quite narrow (approximately .03 wide) and quite rough, as if the weld tip had "dug-in" at approximately .05 intervals.

The test results and observations for these samples are as follows:

TABLE 3.10

Sample Number	Permeability (cc/sec)	Comments
T403-1	6.6	Holes through weld (due to welding) in one area .5 long.
T403-2	.081	Weld separated for 3 inches at center of sample during subsequent examination.
T403-3	--	Seam ripped at one end during trimming to size.
T403-4-1	6.7	Seam ripped at end during subsequent examination.
T403-4-2	.086	Intact
T403-5	1.2	Subsequently tested under water - unsupported seam parted at 6" H_2O pressure.
T404-1	6.6	Series of pinholes in welds near one end of tri-seam.

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TABLE 3.10 (Cont'd.)

Sample Number	Permeability (cc/sec)	Comments
T404-2	3.1	Underwater test revealed leakage at edge of weld
T405-1	7.0	Weld questionable at ends of sample.
T406-1	-	(Sample too small for permeability fixture) Weld tore at very low tensile loading.

The preceding tests further substantiated that the type of equipment being used was incapable of simultaneously producing both a high strength and a low permeability weld in two thicknesses of .25 mil Mylar C. The "weld zone" in which the energy had to be concentrated was so narrow that it was scarcely attainable, even for a very short length of weld. Since more sophisticated equipment was entirely beyond the scope of this program, the only solution was to use thicker total material to increase the "weld zone" depth. Since this entire program had been concentrated on .25 mil Mylar, approval was given EDC to increase the number of plys for the remaining effort, rather than to investigate the welding of heavier gauges of Mylar. The funds remaining were insufficient to permit additional experimentation by varying parameters, so the previously determined values were used, except for pressure. The production of welds for three T407 and two T408 samples (see Figure 3.34) concluded the EDC effort.

These samples were welded using the following parameters:

(a) Feed Speed — 6.85 inches per minute

(b) Head Weight — 8 pounds (actual pressure applied to welding tips)

(c) Weld Tip — 1/4 inch diameter steel ball with 1/16 inch diameter flat.

(d) Back-up — 1/4 inch automotive safety plate glass on 1/16 inch lead sheet on standard transport table

(e) Frequency — 19.75 KC

The resultant welds were approximately .05 inch wide in the T407 samples; .08 inch in the T408 sample. The edges of the welds presented a definite "step-down" rather than a smooth transition to the unaltered material. The welds exhibited some longitudinal marks but were quite devoid of pits. Preliminary laboratory tests had exhibited an improvement in tensile strength.

Evaluation of these samples consisted of a permeability test, Twist-Flex in LH_2 and a second permeability test; however, both of the T408 samples tore at the weld while being installed in the Twist-Flex apparatus. The test results were depicted in Table 3.11.

TABLE 3.11

Sample No.	Permeability Before Test	Permeability After Test	No. of Cycles	Comments
T407-1	.25	-	73	3" tear near seam in front ply; 5" tear from end and along upper clamp area.
T407-2	.014	-	38	8" tear from end along upper clamp area.
T407-3	.019	6.3	120	1" tear near seam in front ply - probably influences permeability.
T408-1	3.0	-	-	
T408-2	.2	-	-	

The test results for the T407 samples showed these to be the best welds evaluated under the ultrasonic bonding program. These welds show a good general reduction in permeability while exhibiting strength which approaches that of the original material. It is considered that additional experimentation for optimum values for the various parameters for four .25 mil thicknesses could result in yet further improved welds. It is concluded that the settings used for the various parameters in welding the T407 samples are no longer the correct settings when the number of thicknesses is increased to six.

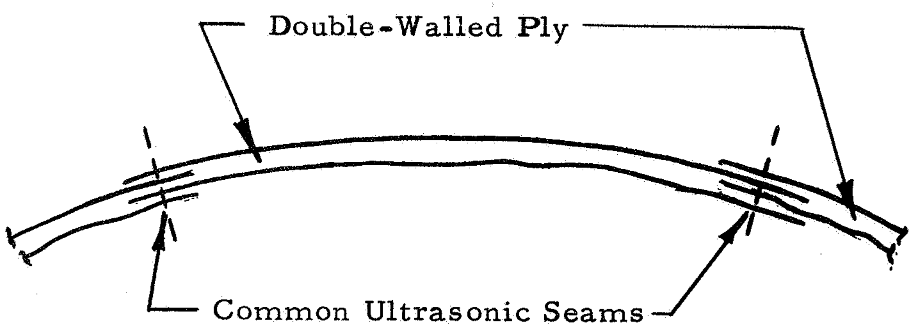
3.8.3 Conclusions

It is concluded that ultrasonic welds of satisfactory permeability and strength are attainable in .25 mil Mylar C by using a total of four thicknesses of the film per T407, Figure 3.34. This configuration could be utilized in bladders in the form of individual plys comprised of double-walled gores joined by common seams as shown in Figure 3.35. Another application of the T407 weld configuration is in the form of doublers as shown in Figure 3.35. If desired, the doublers could be trimmed down to a final width after welding.

The feasibility of ultrasonic welding of three thicknesses of .25 mil Mylar C has not been eliminated by these studies. Additional investigation of the variables would have to be directed specifically to three thickness welds to establish such feasibility. A three-thickness weld could be utilized in the form of a seam with a single doubler.

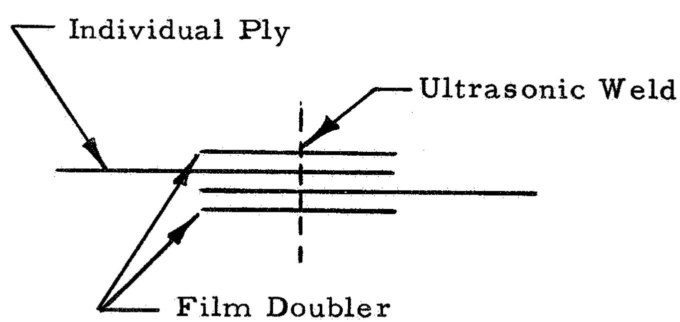
FIGURE 3.35

UTILIZATION OF FOUR-THICKNESS ULTRASONIC WELDS



Partial Cross Section through Equator of Bladder

DOUBLE-WALLED BLADDER PLY



Cross Section through

SEAM WITH DOUBLERS

It is concluded that special ultrasonic welding equipment, providing much greater rigidity for precise spacing control, is required for the development of high strength, low permeability welding of two thicknesses of .25 Mylar C.

Such equipment would probably be quite massive, employing milling machine type ways for supporting the transport table. However, there is no assurance that such rigid equipment would eliminate all problems of concentrating the optimum welding energy at the very precise point required for satisfactory welds.

It is not recommended that any additional ultrasonic welding development be undertaken for LH_2 expulsion bladders. Additional effort would be warranted only if ultrasonic welds were shown to be equal or superior to adhesive (or thermal) type seams in all of the following characteristics:

Seam Strength
Low Seam Permeability
Ease of making seams in bladder configuration

3.9 Inter-Ply Inflation Study

The inter-ply inflation study was added to this program because of the earlier observation that an inflation phenomenon occurred occasionally in multi-ply material samples when they were removed from a cryogenic liquid. Experience with some tightly bonded laminates, which were twist-flexed in liquid nitrogen or hydrogen and then warmed to room temperatures, showed the development of small bubbles on the surface. These bubbles appeared to be highly pressurized with gas and could only be attributed to the vaporization of some liquid which permeated the film during submersion.

The apparent phenomenon is that the cryogenic liquid is capable of passing through the film at these low temperatures but cannot escape back out through the film when the film is warmed to room temperatures.

This has also been previously confirmed in loosely bonded samples where a 4" x 11" sample was sealed around the circumference and submerged into a cryogenic liquid and then removed. The resulting pressurization caused the sample to expand for an extended period of time. (Figures 3.36 and 3.37).

Based on the observation of this phenomenon, all samples tested in this program have been observed for indication of similar inflation. Many samples have shown various amounts of inflation but only a few cases have resulted in severe inflation and material failure. The most serious case occurred following the twist-flexing of a 5 ply Kapton sample T210-5 in liquid nitrogen. Upon removal, the sample literally blew up. Examination, however, showed that only the outer ply was fractured and a permeation measurement was possible because of the integrity of the remaining plys, indicating permeation was limited to the outer plys in this case.

Tests to examine this phenomena were conducted on various Twist-Flex samples from Schjeldahl and Sea Space Systems, Inc. (SSS). The data from these tests was of a random nature even after the number of samples used for such testing was doubled. Additional emphasis was applied to this area and a more complete study was undertaken.

FIGURE 3.36

ILLUSTRATION OF FLAT AND CYLINDRICAL
SAMPLES BEFORE AND AFTER INFLATION

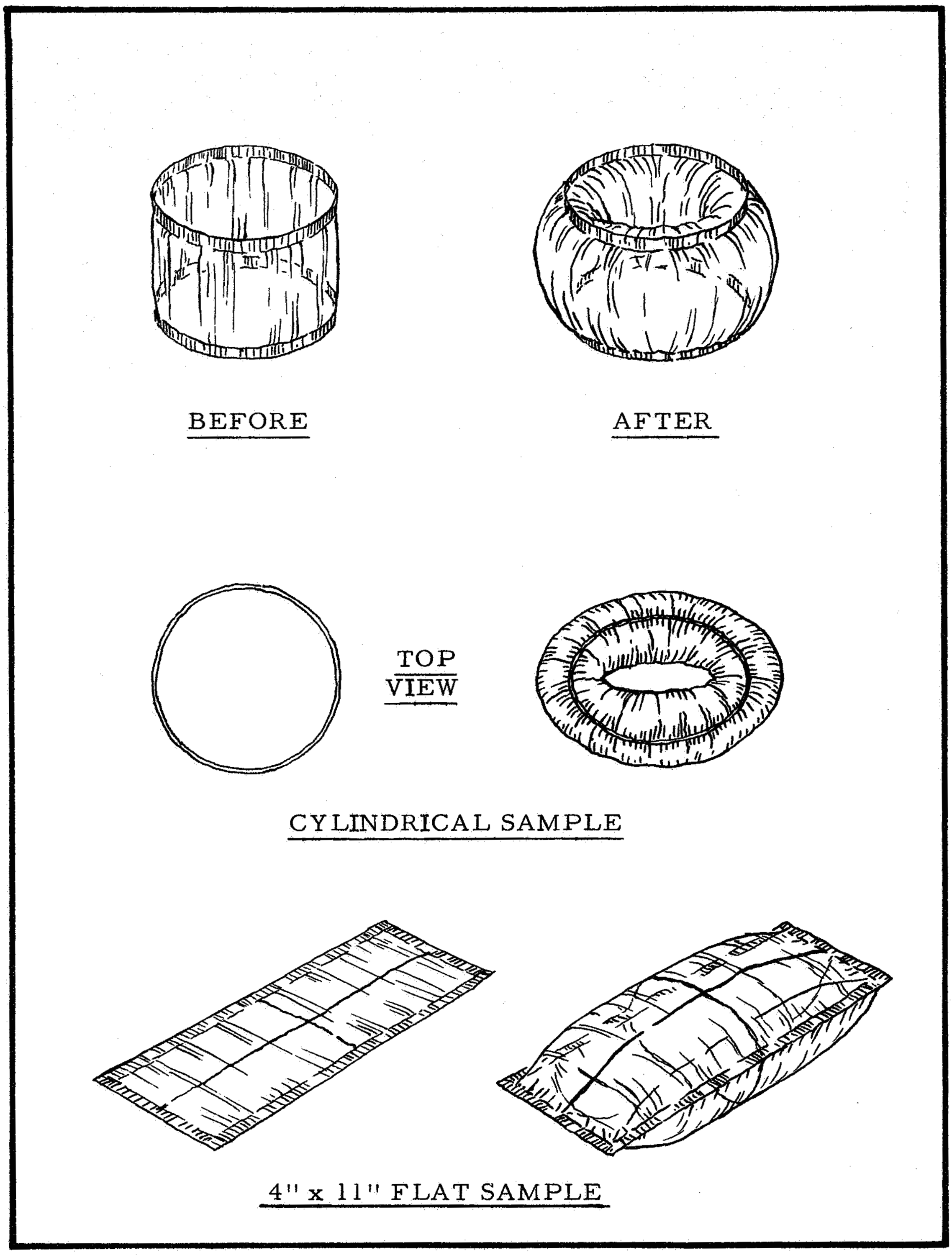
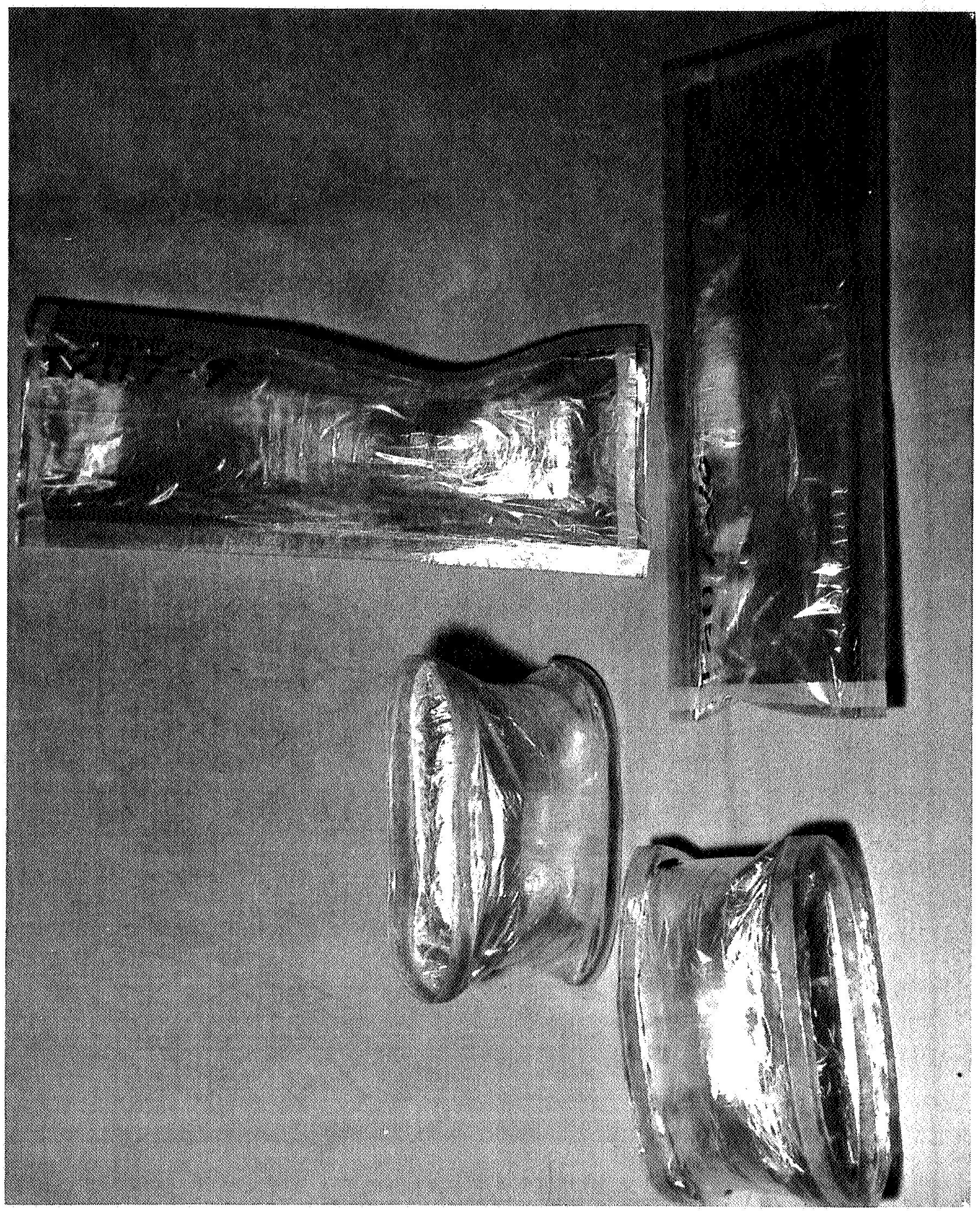


FIGURE 3.37

INTER-PLY PRESSURIZATION SAMPLES



3.9.1 Testing Procedure

Tests were conducted in this program on ten samples with varying material characteristics, such as number of plys, type of material and various seams and gauge thickness. The procedure used is as follows:

1. Each sample was placed on a flat surface and normal inflation observed.

2. Each sample received a permeation test to provide an indication of basic material porosity.

3. The sample was then submerged in liquid hydrogen without any twist-flexing for a period of five minutes.

4. The sample was then removed rapidly from the liquid and from the apparatus and returned to room temperature within 15 seconds.

5. The sample was then placed on a flat surface and again noted for amount of inflation by measuring the height of the center of the sample above the surface.

6. These samples were then given the regular twist-flex test and inflation noted after test and upon warming to room temperature.

3.9.2 Test Results of Inter-Ply Inflation Samples

The following tests were conducted on samples selected from regular twist-flex sample groups.

Figures 3.38, 3.39 and Table 3.12 record the results of these tests. There appears to be little correlation of time the sample is submerged to expansion of the sample in these tests.

TABLE 3.12

INTER-PLY INFLATION SAMPLE TEST DATA

T-105 Description	Similar to T-101 with addition of fibers 30 plys of .10 mil polyethylene assembled into 15 merfab elements with 40 denier HY (nylon) fibers 1/8" on centers. Edges seamed with S110 adhesive between each ply. Closing tape around edges of sample.

TABLE 3.12 (contd.)

	Permeation cc/sec	Inflation Before	Inflation After
-4	.0013	3/16" high cylinder when gas forced to one end of sample	1" high at center of sample
-5	.0086	3/16" high cylinder when gas forced to one end of sample	1" high at center of sample

After Twist-Flex Test -4 .07 cc/sec and no inflation noted.
-5 .033 cc/sec and no inflation noted.

T207 Description

10 plys of .25 mil Mylar C
Edges seamed with GT 100 tape
Horizontal and vertical seams in field
GT 300 closing tape
Lap seams using GT 100 adhesive
End seams of following samples cut off and reseamed by NASA

	Permeation cc/sec	Inflation Before	Inflation After
-9	0	1/16" high cylinder when gas forced to one end of sample	1.8" high at center of sample
-10	0	1/16" high cylinder when gas forced to one end of sample	1.8" high at center of sample

After Twist-Flex Test -9 split prevented permeation test - no pressure noted.
-10 .028 cc/sec and no inflation noted.

TABLE 3.12 (contd.)

T208 Description

5 plys of .25 mil Mylar C
Flat sample with horizontal seams
Butt seams using Pliobond 20 with tape
Ends seamed as noted

	Permeation cc/sec	Inflation Before	Inflation After
-9	.01	1/16" high cylinder when gas forced to one end of sample	.75" high at center of sample
-10	.001	1/16" high cylinder when gas forced to one end of sample	1.25" high at center of sample

After Twist-Flex Test -9 .0033 cc/sec and no inflation noted.
-10 split prevented permeation test - no inflation noted.

T210 Description

5 plys of .5 mil Kapton
Edges sealed with GT 300 tape
GT 100 adhesive used between film seams
Ends seamed

	Permeation cc/sec		Inflation Before	Inflation After
-5	.0016	LN_2	None	Outer plys blew up
-8	.0023	LH_2	None	None
-9	.002	LH_2	None	None

TABLE 3.12 (contd.)

T222 Description

Cylindrical samples
10 ply of .15 mil Mylar C
Horizontal and vertical seam
Lap type of seam
GT 100 adhesive between plys on seams
GT 300 closing tape

	Permeation cc/sec	Inflation Before	Inflation After
-4	-	Moderate	1.3" thick, center closed tight
-5	-	Slight	1.3" thick, center closed tight

Splitting of outer plys prevented any permeation or inflation analysis.

TABLE 3.12 (contd)

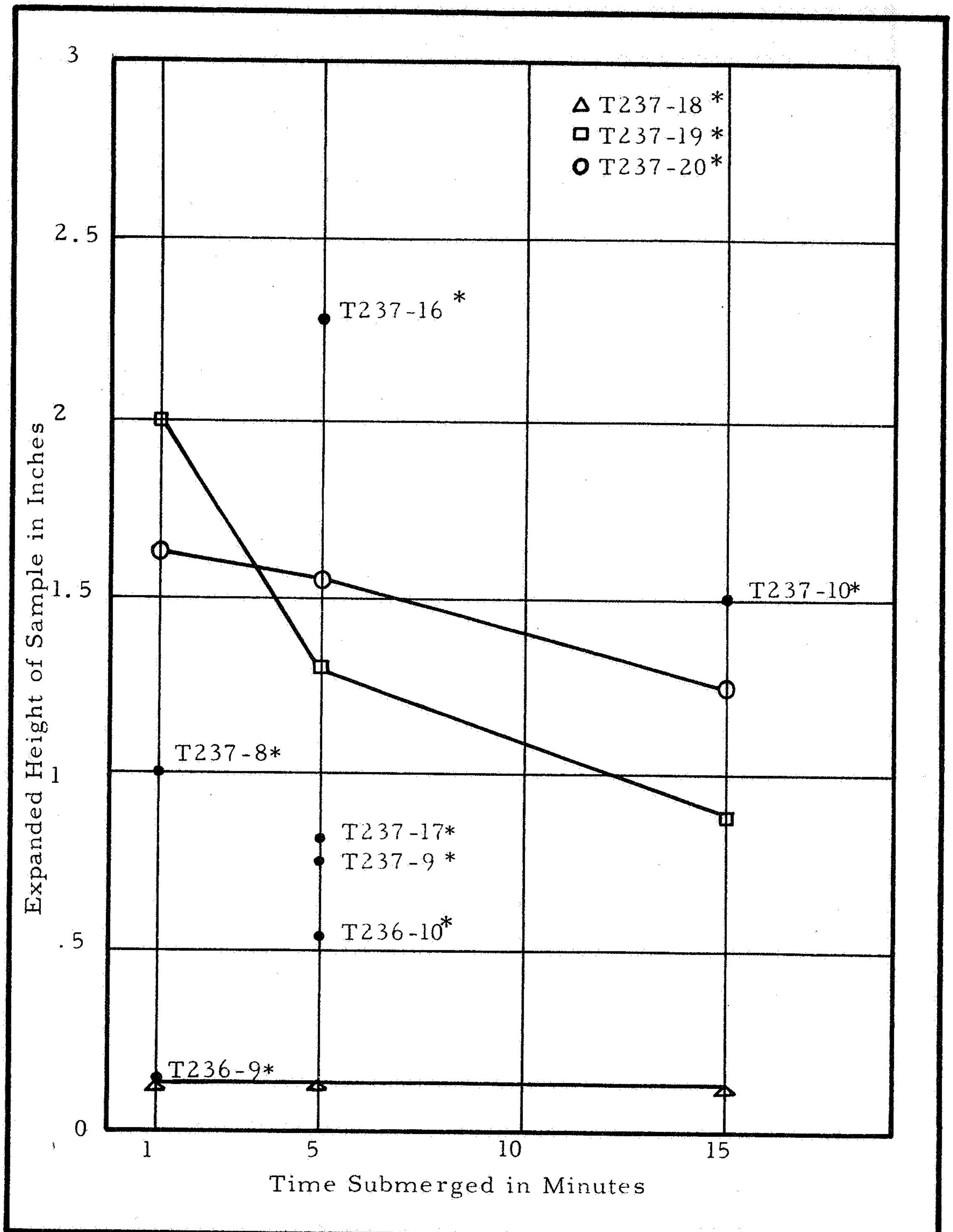
Sample No.		Permeability Before Test	Permeability After Test	Time Submerged	Inflation Height After Test
T236	10 plys of .15 mil Mylar C				
-9		0	.0020	1 min.	1/8"
-10		0	.013	5 min.	9/16"
T237	10 plys of .25 mil Mylar C				
-8		.0020	.0093	1 min.	1"
-9		0	.00066	5 min.	3/4"
-10		0	.0010	15 min.	1-1/2"
-16		.0070	.0056	5 min.	2-5/16"
-17		0	0	5 min.	1-3/16"
-18	(1)	0	0	1 min.	1/8"
	(2)	0	0	5 min.	1/8"
	(3)	0	0	15 min.	1/8"
-19	(1)	0	0	1 min.	2"
	(2)	0	0	5 min.	1-5/16"
	(3)	0	0	15 min.	7/8"
-20	(1)	0	0	1 min.	1-5/8"
	(2)	0	0	5 min.	1-9/16"
	(3)	0	0	15 min.	1-1/4"
TN3 Description			2 plys of .25 mil Mylar C		
-1	(1)	0	.037	15 sec.	0
	(2)		.013	1 min.	0
	(3)		.0020	5 min.	1/8"
-2	(1)	.0010	.025	15 sec.	0
	(2)		.023	1 min.	0
	(3)		.0096	5 min.	1/8"
-3	(1)	0	.0013	30 sec.	0
	(2)		.051	1 min.	1/4"
	(3)		.090	5 min.	2-1/8"
-4	(1)	0	.010	30 sec.	0
	(2)		.031	1 min.	1/8"
	(3)		.031	5 min.	7/16"

TABLE 3.12 (contd.)

Sample No.		Permeability Before Test	Permeability After Test	Time Submerged	Inflation Height After Test
TN3, Continued . . .					
-5	(1)	0	0	30 sec.	0
	(2)		.0016	1 min.	0
	(3)		.0093	5 min.	1/8"
TN4 Description			2 plys .25 Mylar C 1 ply spun-bonded Dacron		
-1	(1)	0	0	15 sec.	0
	(2)	0	0	1 min.	0
	(3)		0	5 min.	5/16"
-2	(1)	0	0	15 sec.	0
	(2)		0	1 min.	0
	(3)		0	5 min.	1/8"
-3	(1)	0	0	30 sec.	7/16"
	(2)		0	1 min.	1/2"
-4	(1)	0	0	30 sec.	0
	(2)			1 min.	0
	(3)		0	5 min.	0
-5	(1)	0	0	30 sec.	0
	(2)		0	1 min.	0
	(3)		0	5 min.	1/4"

FIGURE 3.38

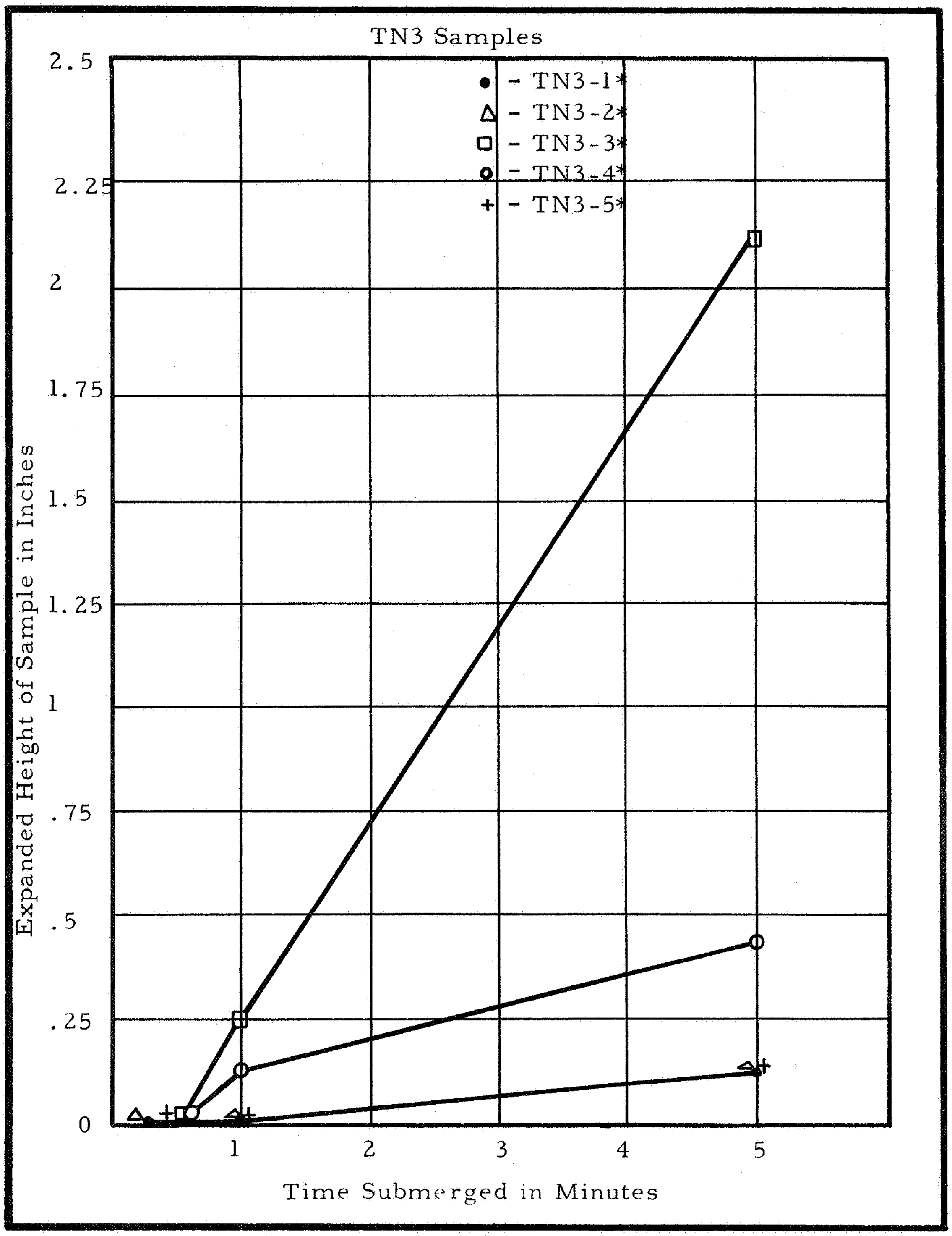
INTER-PLY INFLATION



* Reference Table 3.12 for Description of Samples and Test

FIGURE 3.39.1

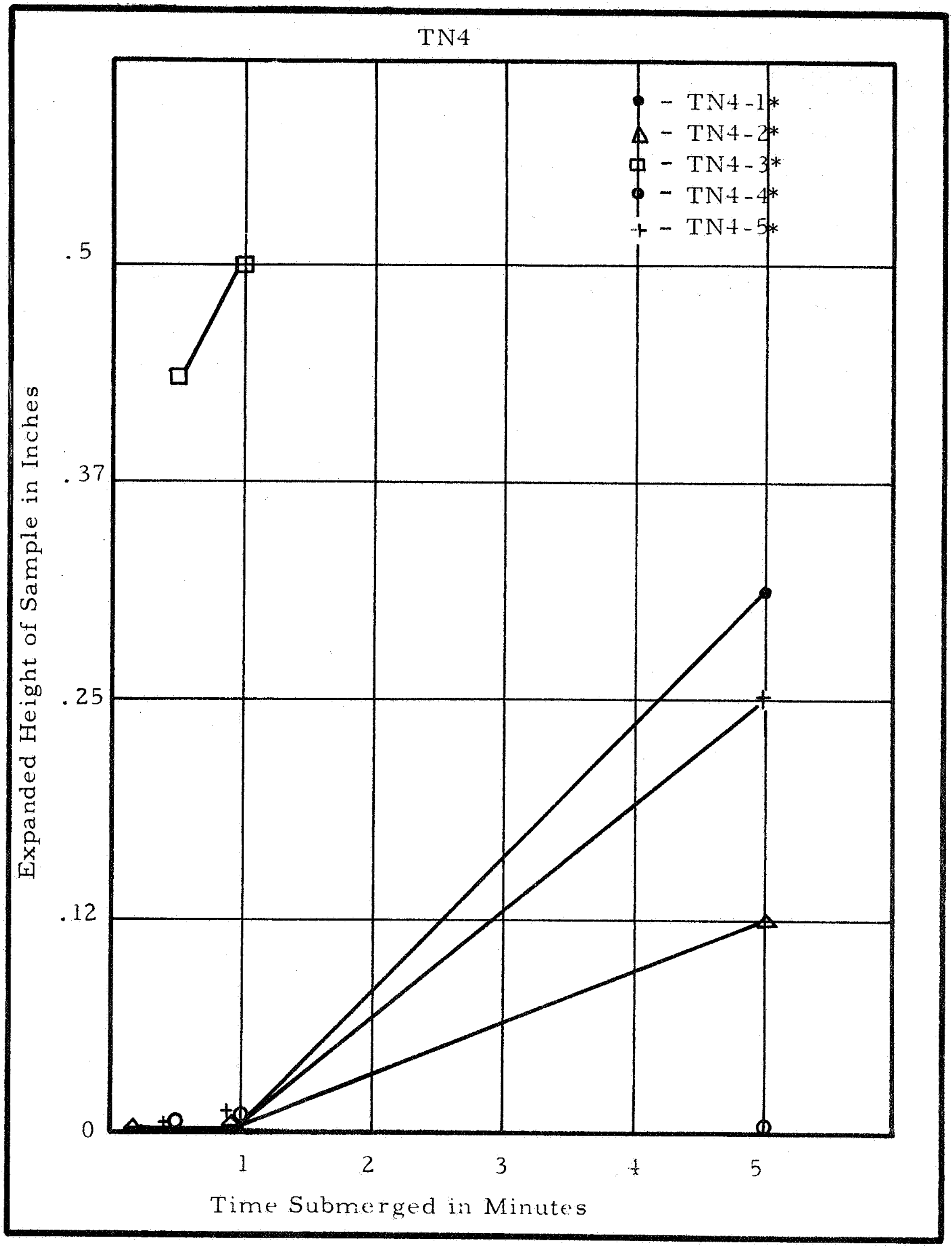
INTER-PLY INFLATION



* Reference Table 3.12 for Description of Samples and Test

FIGURE 3.39.2

INTER-PLY INFLATION



* Reference Table 3.12 for Description of Samples and Test

3.9.2 Test Results (Continued)

INTER-PLY INFLATION TESTS

The following table shows the results of testing 15 inter-ply inflation samples fabricated by NASA-Lewis with varying numbers of spun-bonded layers between the .25 Mylar.

TABLE 3.13

Inter-Ply Inflation Sample Tests (Spun-Bonded) Data

Sample No.		Permeability Before Test	Permeability After Test	Time Submerged	*Inflation Height After Test
NASA-Lewis					
TN5 Description			2 plys .5 mil Mylar "C" 1 ply spun-bonded Dacron		
-1	(1)	0	0	1 min.	0
	(2)	0	0	15 min.	0
-2	(1)	0	0	1 min.	0
	(2)	0	0	15 min.	0
-3	(1)	0	0	5 min.	0
	(2)	0	0	15 min.	0
-4	(1)	0	0	5 min.	0
	(2)	0	0	15 min.	0
-5	(1)	0	0	5 min.	0
	(2)	0	0	15 min.	0
TN6 Description			3 plys .5 Mylar "C" 2 plys spun-bonded		
-1	(1)	0	0	1 min.	0
	(2)	0	0	15 min.	0

* After removal from test apparatus.

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TABLE 3.13 (contd.)

Sample No.		Permeability Before Test	Permeability After Test	Time Submerged	*Inflation Height After Test
TN7 Description			5 plys .5 Mylar "C" 4 plys spun-bonded		
-1	(1)	0	0	1 min.	.25
	(2)	0	0	15 min.	Ruptured Ply
	(3)	0	0	**	0
-2	(1)	0	0	1 min.	Ruptured Ply
	(2)	0	0	**	.5
-3	(1)	0	0	30 sec.	Ruptured Ply
	(2)	0	0	**	.5
-4	(1)	0		5 min.	2.0
	(2)			15 min.	Ruptured Ply
-5	(1)	0		5 min.	Ruptured Ply
TN8 Description			10 plys .5 Mylar "C" 9 plys spun-bonded		
-1	(1)	0		1 min.	Ruptured Ply
-2	(1)	0		1 min.	Ruptured Ply
-3	(1)		.002	30 sec.	Ruptured Ply
	(2)		0	**	0
-4	(1)	0	0	30 sec.	Ruptured Ply
	(2)		0	**	.7
-5	(1)	0	0	30 sec.	Ruptured Ply
	(2)		0	**	.1

*After removal from test apparatus.
**Submerged overnight with slow warm-up.

3.9.3 Rapid & Slow Warm-up Inter-Ply Inflation Tests

Very little additional data would be derived from continued testing of each sample to a variety of submerged times ranging from 15 seconds to 15 minutes. The previous data, plus the 15-minute LH_2 submergence data, indicates for the TN3 and TN4 series (see tabulation on following pages for description) that the degree of inter-ply inflation is not necessarily a function of time submerged. The data for TN5, TN6, TN7 and TN8 demonstrates that the degree of inflation for these samples was generally the same, whether they were submerged for 30 seconds or for 15 minutes. Therefore, it was considered that a 1 minute submerging in LH_2 would provide adequate rapid warm-up data for the remaining NASA-Lewis samples.

[illegible] Since previous study had failed to eliminate or fully explain the phenomena, effort was expended to establish whether this condition might be expected to occur on the bladders for Task II LH_2 expulsion testing. A total of 24 NASA-LeRC samples were subjected to a "slow warm-up" test. These samples were kept in the dewar overnight until the LH_2 had boiled away and they gradually returned to ambient temperature - the exact conditions usually imposed on a bladder in LH_2 expulsion testing. The sample was removed from the dewar the next morning, at which time the inflation was measured.

The tabulation which follows provides a direct comparison of inflation occurring from the rapid warm-up (immediate return to ambient temperature) and the slow warm-up (overnight return to ambient temperature). It should be noted that the test results (slow or rapid warm-ups) are shown in the order in which the tests were conducted. The time submerged in LH_2 was 1 minute for the rapid warm-up tests, unless otherwise indicated. The description following each sample group destination shows the numbers of plys of Mylar or Spun-bonded polyester (8 to 10 mils thick) comprising each sample. The Mylar and Spun-bonded are alternated, ply for ply, in all bi-material samples.

TABLE 3.14

Inter-Ply Inflation Sample Tests (Rapid Slow Warm-up) Data

Sample No.	Permeability Before (cc/sec.)	Permeability After (cc/sec.)	Warm-up Rate
TN12 Description:	10-ply	.5 Mylar "C"	
-1	0	0	Slow
	0	0	Rapid
-2	0	0	Slow
	0	0	Rapid
-3	0.0	0.001	Slow
	0.001	0.0	Rapid

Inflation Inches

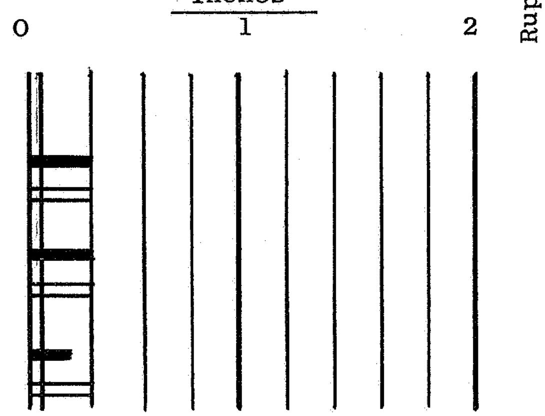

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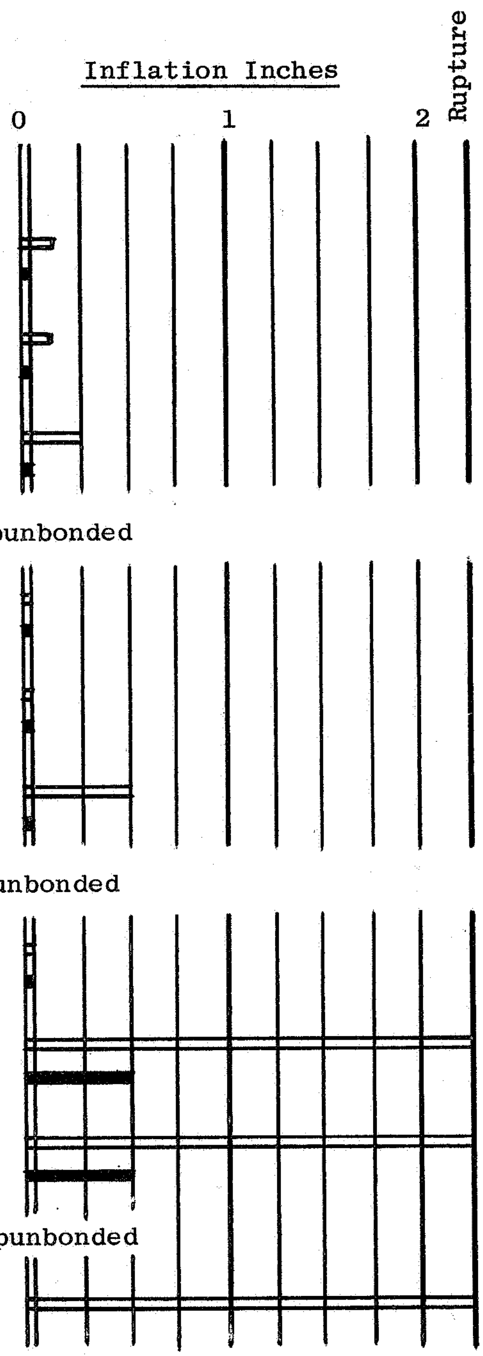
TABLE 3.14 (contd.)

Sample No.	Permeability Before (cc/sec.)	Permeability After (cc/sec.)	Warm-up Rate
TN3	Description: 2-ply .25 Mylar "C"		
-1	.037	.013	Rapid
	.006	.034	Slow
-2	.025	.023	Rapid
	.009	.012	Slow
-3	.001	.051	Rapid
	.066	.054	Slow
TN4	Description: 2-ply .25 Mylar "C"; (1) Spunbonded		
-1	0	0	Rapid
	0	0	Slow
-2	0	0	Rapid
	0	0	Slow
-3	0	0	Rapid
	0	0	Slow
TN7	Description: 5-ply .5 Mylar "C"; (4) Spunbonded		
-1	0	0	Rapid
	0	0	Slow
-2	0	0	Rapid
	0	0	Slow
-3	0	0	Rapid*
	0	0	Slow
TN8	Description: 10-ply .5 Mylar "C"; (9) Spunbonded		
-3	0	.002	Rapid*
	.002	0	Slow

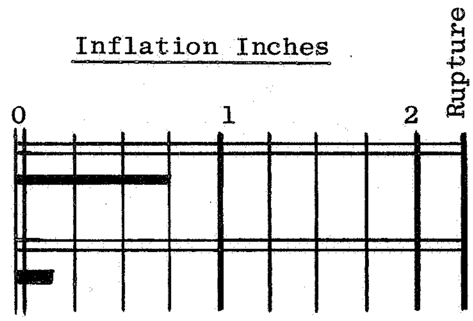


*30 seconds submerged

TABLE 3.14 (contd.)

Sample No.	Permeability Before (cc/sec.)	Permeability After (cc/sec.)	Warm-up Rate
-5	0	0	Rapid*
	0	0	Slow
-5	0	0	Rapid*
	0	0	Slow

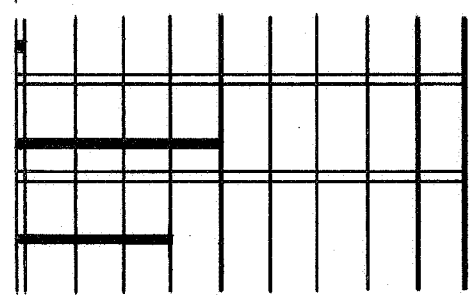
Inflation Inches



*30 second test

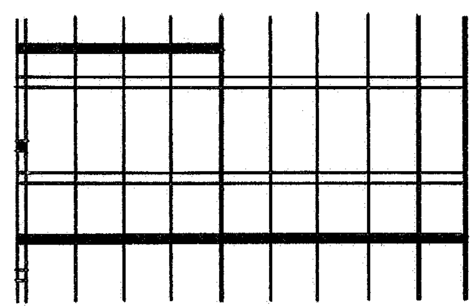
TN9 Description: 5-ply .25 Mylar "C"; (4) Spunbonded

Sample No.	Before	After	Warm-up Rate
-1	.005	.008	Slow
	.008	0	Rapid
-2	0	0	Slow
	0	.005	Rapid
-3	0	0	Slow
	0	0	Rapid



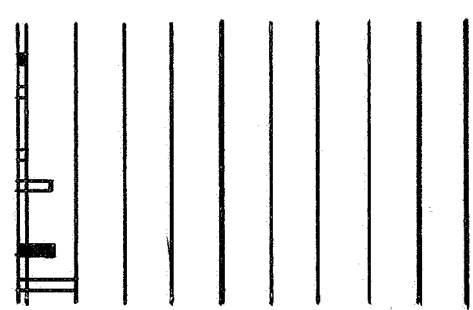
TN10 Description: 10-ply .25 Mylar "C"; (8) Spunbonded

Sample No.	Before	After	Warm-up Rate
-1	.009	0	Slow
	0	.001	Rapid
-2	0	0	Slow
	0	0	Rapid
-3	.008	.010	Slow
	.010	0	Rapid**



TN11 Description: 5-ply .5 Mylar "C"

Sample No.	Before	After	Warm-up Rate
-1	0	0	Slow
	0	0	Rapid
-2	0	0	Slow
	0	0	Rapid
-3	0	0	Slow
	0	0	Rapid



**Tested with hole (through edge seam) into one interstice.

270 -1

TABLE 3.14 (contd.)

The following conclusions are derived from the preceding tabulation:

1. In all cases except one, the slow warm-up of a sample produced less inflation than the rapid warm-up.

2. In general, the inclusion of four or more Spun-bonded plys (very porous and 10 mils thick) substantially increased the inflation encountered in multi-ply Mylar samples as was predicted.

3. In general, the amount of inflation increased as the number of plys were increased.

4. Thickness is not a substantial factor for Mylar in the range of .25 mil to .5 mil.

5. Little or no correlation can be established between permeability of the characteristics of the sample and its inter-ply inflation behavior.

3.9.4 General Conclusions

The LH_2 inter-ply inflation study has resulted in the following general conclusions and observations:

1. Liquid hydrogen and nitrogen permeate through a plastic film when it is submerged in the liquid.

2. When two films are joined together around the circumference as in the case of the 4" x 11" flat samples, the cryogen which permeates through the films into the interior of the sample is trapped when the sample is removed and warmed up to room temperatures.

3. The cryogen which permeates into the sample expands when warmed and pressurizes the tightly closed sample. The expansion ratio for hydrogen is 784 and for nitrogen, 646.

4. The ability for the cryogen to permeate through the sample when it is cold, and yet not be able to escape from the sample when it is warmed, is the phenomenon which is not fully understood.

5. "Cryo-pumping" has been partially substantiated as a cause by the increased inflation of TN7, TN8, TN9, and TN10 samples over straight Mylar samples. The residual gas within the porous spun-bonded plys cools down and causes a vacuum, drawing in LH_2 through the film under a differential pressure of approximately one atmosphere. Upon warm-up, the fluid turns to gas, expands and inflates the sample. The differential pressure, during warm-up, is relatively low since the sample would burst above 1 or 2 psi.

6. Cryo-pumping of straight Mylar samples would result in the collapsing of the sample until the voids causing the vacuum were eliminated, unless such condition resulted entirely from microscopic voids. Therefore, and in view of some inflation of various multi-ply Mylar samples, the theory of physical "microscopic opening" of the film at cryogenic temperatures to admit LH_2 cannot be discarded.

7. The permeability of hydrogen gas through Kapton film is 2.5 times that of Mylar film and 6 times the permeability with nitrogen gas. This would indicate that the cryogen would permeate the Kapton sample more readily but should also escape equally as easy. The transition point in which the gas is allowed to permeate into the film, but not escape, is not known or considered of critical importance.

3.9.4 General Conclusions (continued)

8. A greater interstitial volume caused by wrinkling or seaming would permit a greater volume of liquid to be forced into a sample.

9. The faster the warm-up of the sample, the greater the inflation effect due primarily to the leakage of expanded gas by normal permeation at ambient temperature. The length of time that the sample was submerged is not a critical parameter in the amount of blow-up providing the initial time is sufficient to permit the internal and external pressure to approximately equalize.

10. The correlation of information obtained from flat samples and spherical bladders must be made with some qualifications. The inflation of the gas between the plys of a loosely laminated multi-ply bladder will result in the inner plys being expanded inwardly and thus not tend to overpressurize the bladder until the inner bladder has become fully collapsed. This is a real possibility since the area of the bladder is approximately 26 times that of a 4" x 11" flat sample and, therefore, a greater transmission occurs. The other problem which is inherent in a multi-ply bladder in which each ply is separated from the adjacent plys is that the various plys will receive varying amount of gas transmission and will, therefore, expand at different rates.

3.10 Task I - General Conclusions

3.10.1 Permeability Studies

The permeability studies described in Section 3.5 and the data obtained on the twist-flex samples produced a mass of information useful, not only for bladder material selection but also yielded better material permeability data.

Permeability varies not only from material-to-material, but from one batch of the same material to another. The variation in permeability data apparently is caused by handling, re-rolling, etc. and should be minimized by special control in acceptance and fabrication techniques to maintain low initial permeability.

The value of several plys of thin film rather than a single film of greater, thickness was established from the flexibility standpoint as well as efficient reduction of gas transmission.

Helium permeates through a film of 0.25 mil Mylar and a layer of water without visible bubbles up to a rate of 0.0006 cc/sec/sq. inch. Defects in the film indicate visible bubbles at a lesser gas transmission rate.

A correlation between the DuPont dielectric quality control procedure for Mylar and gas transmission should be investigated by further testing under special control conditions. The selection of uniform bladder material by the DuPont procedure would be valuable if this additional investigation proved the consistency of results.

It is necessary in selecting a material for bladders to determine in advance the permeability rate acceptable and to find a material which will not permit any more than this rate during the cycles of operation anticipated during its normal use. It is obvious there is no such thing as zero permeability when dealing with 0.15 and 0.25 mil Mylar.

3.10.2 Thermo-Formed Mylar

Tests conducted in this program show that Mylar, when thermally formed under heat and pressure, loses its relatively good characteristics of low permeability and high cycle flexibility in liquid hydrogen. The fact that bladders are successfully fabricated by seaming gore shaped sections together, minimizes the urgent need for thermo-forming. A one- or two-piece bladder, so formed, however, should add to the total reliability of a bladder if the film characteristics are not seriously altered.

3.10.3 Seaming

The seaming studies showed that all materials considered in this program can be seamed satisfactorily for cryogenic expulsion bladder service by use of conventional lap or butt type joints. The use of Schjeldahl GT tapes and adhesives or Sea Space S-110 or S-114 adhesive can be used for seaming specific materials as demonstrated in samples tested in Section 3.5. Details for specific seams can be found in Section 3.8.

3.10.4 Ultrasonic Seaming

Among seam-bonding techniques which were evaluated under Task I was the ultrasonic welding process. This was accomplished in the form of feasibility/development studies for the ultrasonic welding of 0.25 mil Mylar C. It was ultimately established that ultrasonic welds of satisfactory permeability and strength in two thicknesses of 0.25 mil Mylar C are not readily attainable, though such welds were accomplished in four thicknesses of the Mylar film. It was concluded that ultrasonic welding of plastic film presented no advantages over other fully-developed seaming methods and would not be employed in the fabrication of bladders for Task II.

3.10.5 Interply Inflation

The phenomena of a liquid (such as hydrogen) penetrating a plastic film, and then being unable to escape as a gas following warm-up, received extensive study under Task I. Regular twist-flex samples and a large number of special samples from NASA-LeRC were submerged in liquid hydrogen for varying lengths of time and then were subjected to rapid or overnight warm-up. Though the phenomena is not fully understood, considerable data was obtained from this study, and it was concluded that interply inflation would not present any serious problems in the bladders being procured for Task II. Bladder testing, however, did reveal difficulty in installation and removal as well as in the filling and expulsion cycling when using an "inward" expulsion technique.

3.10.6 Twist-Flex Test Results

The individual materials and composites were analyzed in detail in Section 3.4. An evaluation was made following the test data of materials from each supplier. The eleven best material samples from all sources as based upon the parameter of cycle life, permeability, and general appearance are:

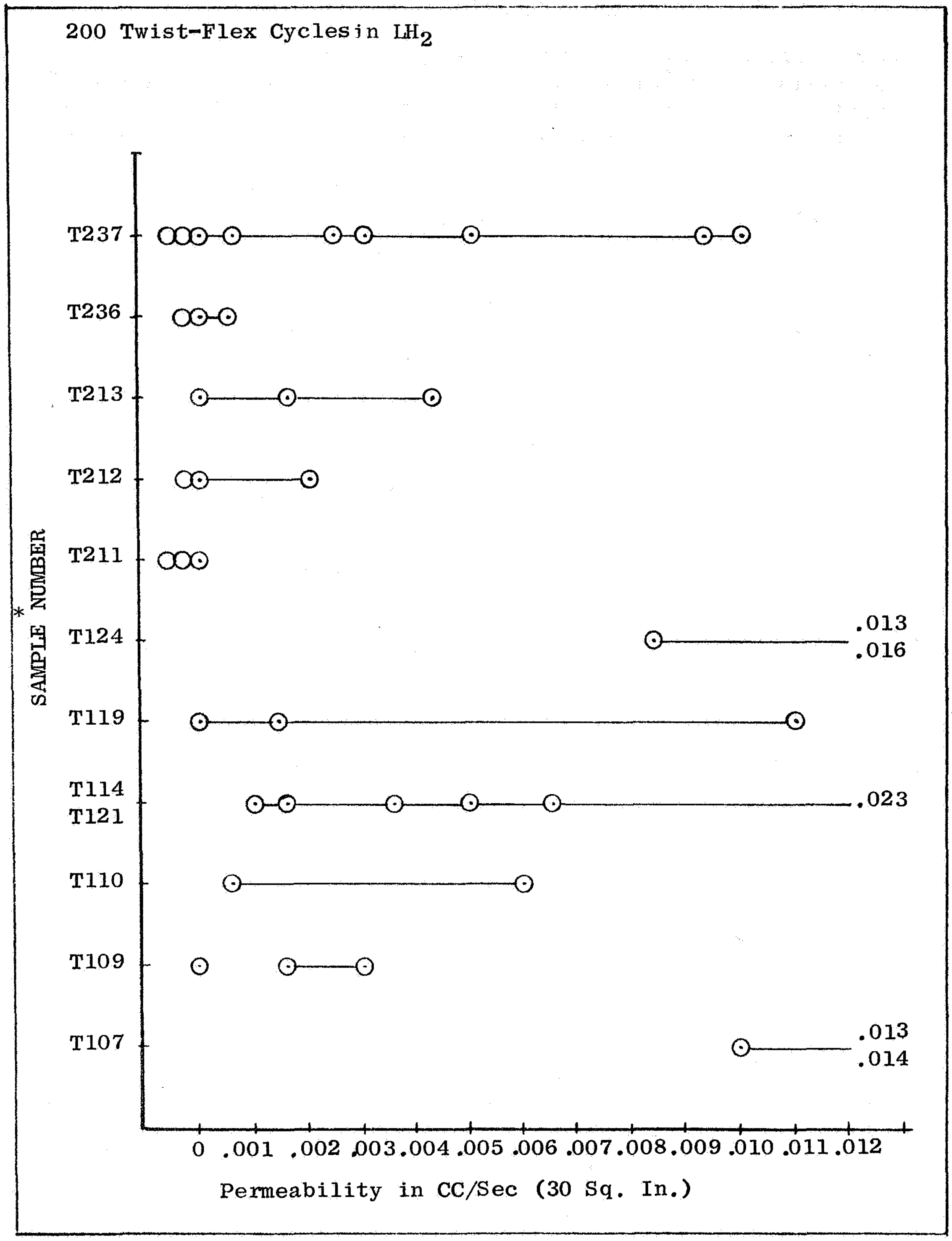
T-107	0.15 mil Mylar(9-ply)/Merfab (10-ply)
T-109	0.15 mil Mylar (30-ply)
T-110	0.15 mil Mylar (10-ply)
T-114) ----------	(Nomex (3-ply)/0.15 mil Mylar (12-ply)/
T-121)	(0.10 mil Poly (8-ply)
T-119	0.25 mil Mylar (30-ply)
T-124	Nomex (3-ply)/0.15 mil Mylar (10-ply)
T-211	0.15 mil Kapton (10-ply)
T-213	Dacron (3-ply)/0.25 mil Mylar (10-ply)
T-212	Nomex (3-ply)/0.25 mil Mylar (10-ply)
T-236	0.15 mil Mylar (10-ply)
T-237	0.25 mil Mylar (10-ply)

Figure 3.40 shows the permeability of these samples after 200 LH_2 twist-flex cycles. All other samples tested on this program had a lower cycle life or higher permeability, or both, and therefore are not compared in this figure. It should be noted that T-114 and T-121 are identical in construction and would normally carry the same code number except that they were obtained at different times. T-110 and T-236 are the same material but were obtained from different manufacturers.

Bladder material selection was based upon this data and upon other subjective considerations gathered from the appearance and action of each sample during testing.

FIGURE 3.40

TWIST-FLEX AND PERMEABILITY COMPARISON
OF BEST MATERIAL COMPOSITES



* Samples and Test Conditions are Described in Section 3.5.

3.10.7 Bladder Material and Fabrication Recommendations

The original materials selected for the program are still considered to be the best for cryogenic expulsion bladders. These have included Mylar C, Kapton, .10 mil polyethylene, Nomex, Dacron in various combinations. Results have generally shown that the thin film Mylar exceeds all other materials for ability to maintain flexibility at cryogenic temperatures. It further has a relatively low permeability value for its thinness. Kapton has also shown excellent qualifications as 0.5 mil film and should be even better if manufactured in 0.25 mil thickness.

Comments regarding promising bladder material combinations are as follows:

MERFAB - .15 MIL MYLAR C COMBINATION

T107 represents a typical composite using Merfab and Mylar. Although an infinite number of lamination alternatives are possible, this particular combination of alternating plys gave the lowest permeability after 200 cycles of T-F testing. It is included in Figure 3.40 which compares the twelve best material samples. Other similar configurations are those found in T104, T111, T112, T115, T116, and T122.

This combination was selected for bladders because of its good T-F performance in LH_2 and low permeability before and after Twist-Flex. The material was designated BS 15108, Type 1, for bladder fabrication by SSS. See Figure 3.41.

The composite with two Mylar plys adjacent and alternated with one Merfab was considered superior for permeability blockage of microscopic holes in the Mylar barrier plys.

NOMEX-POLYETHYLENE - MYLAR C COMBINATION

This combination of materials from SSS was tested as T113, T114, and T121 samples. All samples were above average of those tested to 200 T-F cycles. T114 and T121 were the identical composite but were obtained at different times. This material is recommended for consideration but was not selected for bladders because it is more complex than the Merfab-Mylar composite and presented no special advantage in permeability or flexibility.

POLYETHYLENE-MERFAB COMBINATION

.10 mil polyethylene was tested as T101 samples: Merfab as T105 and a combination of the two as T106. Despite 30 plys, these samples displayed excessive permeability after Twist-Flex testing. Polyethylene is, therefore, not recommended for a bladder material by itself. All other samples in which polyethylene was used also included a permeability barrier plys such as Mylar. Polyethylene, in thicknesses greater than .10 mil, is not flexible enough at cryogenic temperatures to be valuable in construction of expulsion bladders.

MYLAR

Straight Mylar samples in .15 and .25 gauges and of 10 and 30 plys were tested as T109, T110, T119, and T120 from SSS. All samples exhibited good T-F performance and low permeability excepting T120 which had end splitting problems preventing permeability readings.

.25 mil Mylar "C" exhibited the best performance of samples composed of barrier plys only. Its permeability was good and showed good flex performance. It is probably unsurpassed for ease of fabrication and repeatability. It should be noted that this gauge is considered to be representative of all gauges below .5 mil with better permeability characteristics than the .15 gauge material.

Figure 3.40 shows the comparison of the 12 best materials. Six of the 12 materials are plain multiply Mylar. The Schjeldahl code numbers are T236, T237.

A 10-ply bladder of .25 mil Mylar was recommended. The material was recommended. The material was designated BS 15753, Type 5, from the Schjeldahl Co. (Figure 3.42).

MYLAR-NOMEX COMBINATION

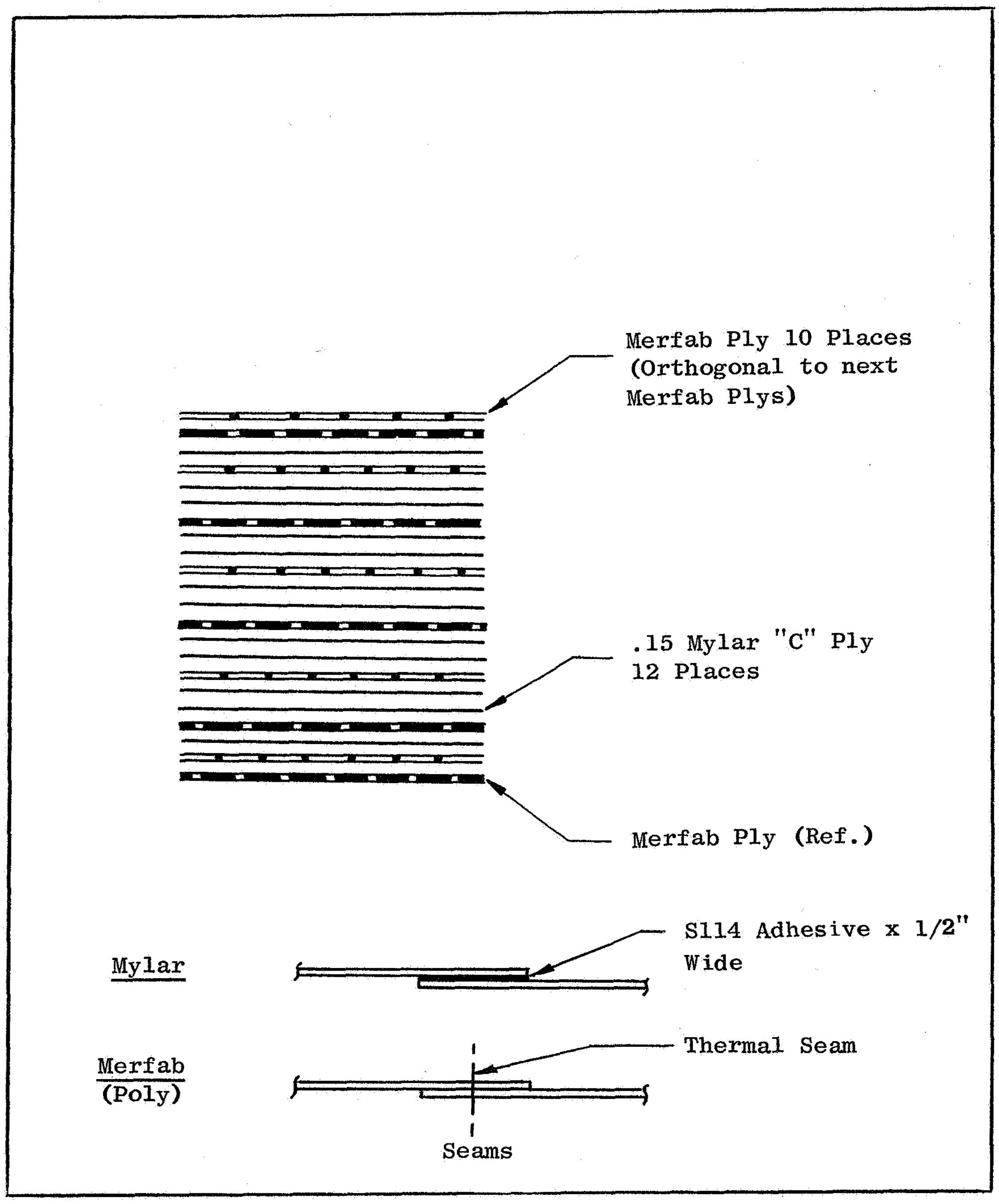
The composite T124 from Sea Space, containing 10 plys of .15 mil Mylar and three plys of Nomex, showed good flexibility and low permeability and was judged to be a candidate for a bladder. The composite from Schjeldahl was T212 and T238, using .25 mil Mylar and Nomex. The bladder material was designated BS 15753, Type 1. See Figure 3.43. This material combination was obtained from the G. T. Schjeldahl Company for reasons of cost and their previous experience with Nomex fabrication.

MYLAR-DACRON COMBINATION

This material from the G. T. Schjeldahl Company consisted of 10 plys of .25 Mylar and three plys of Dacron Sailcloth assembled as shown in Figure 3.44.

FIGURE 3.41

BS15108 TYPE 1 BLADDER MATERIAL



BS15753 BLADDER MATERIALS

FIGURE 3.42

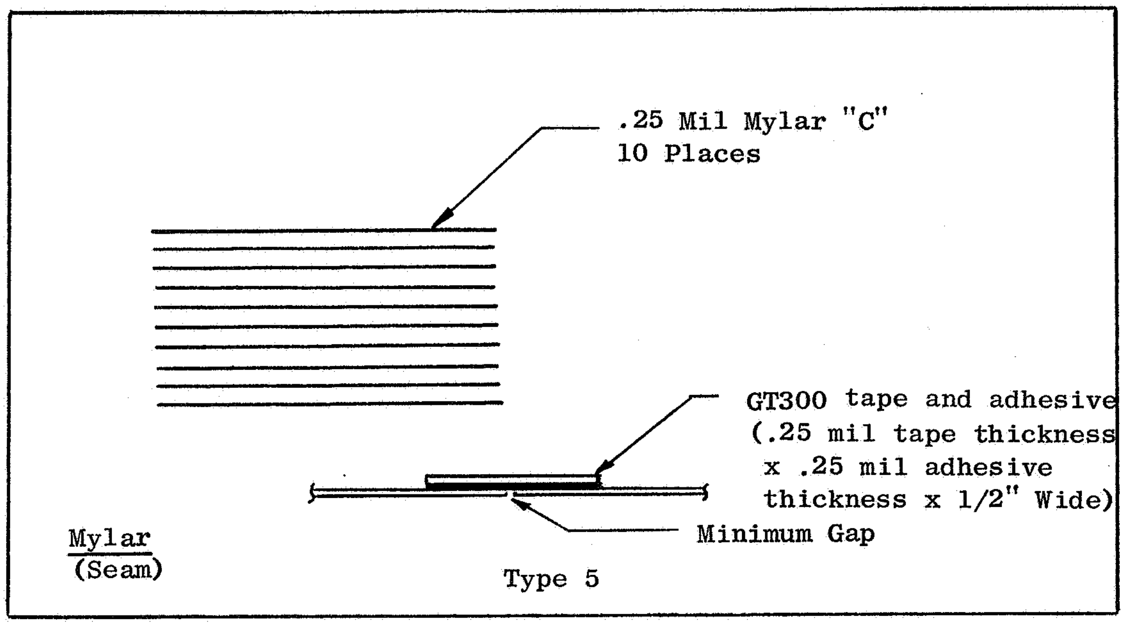
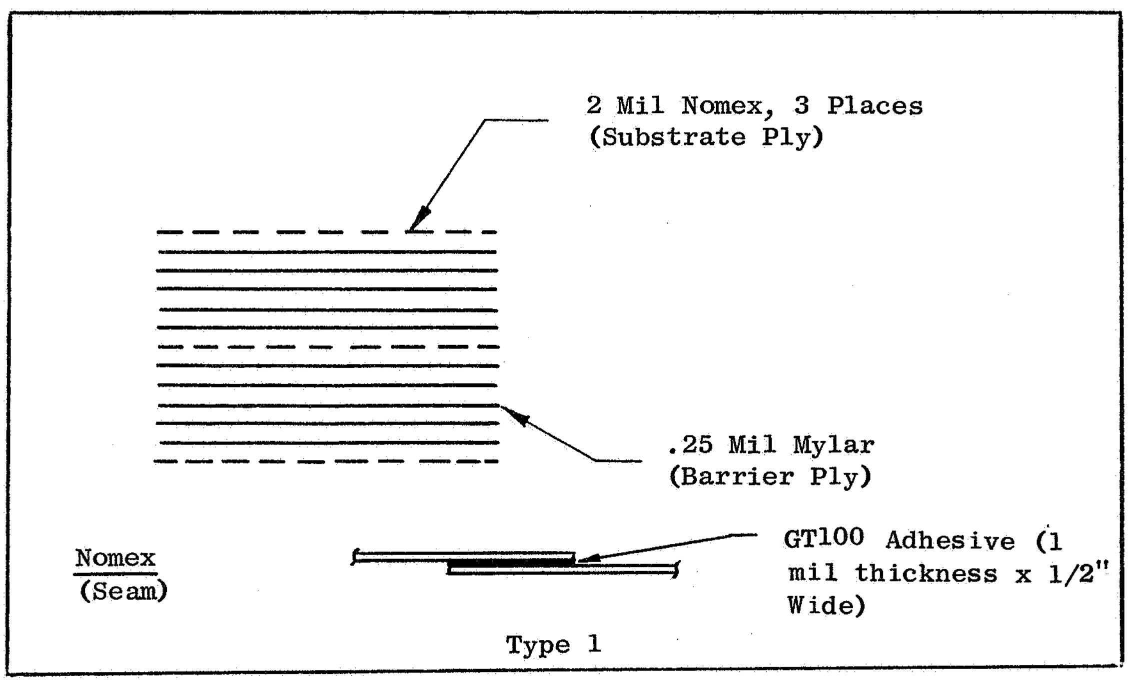


FIGURE 3.43



BS15753 BLADDER MATERIALS

FIGURE 3.44

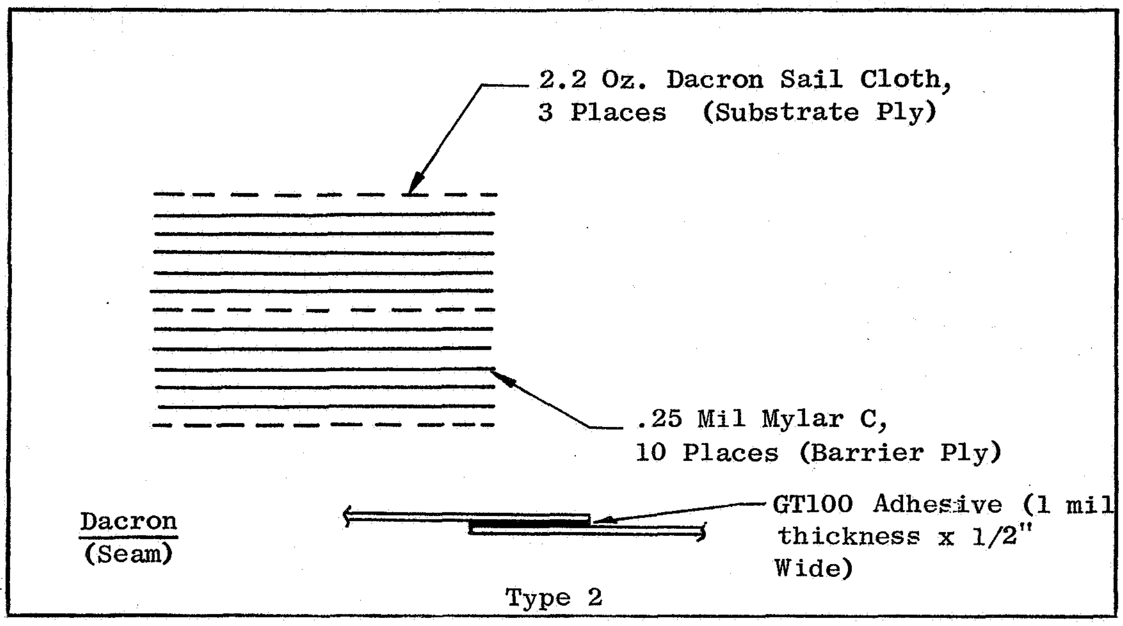
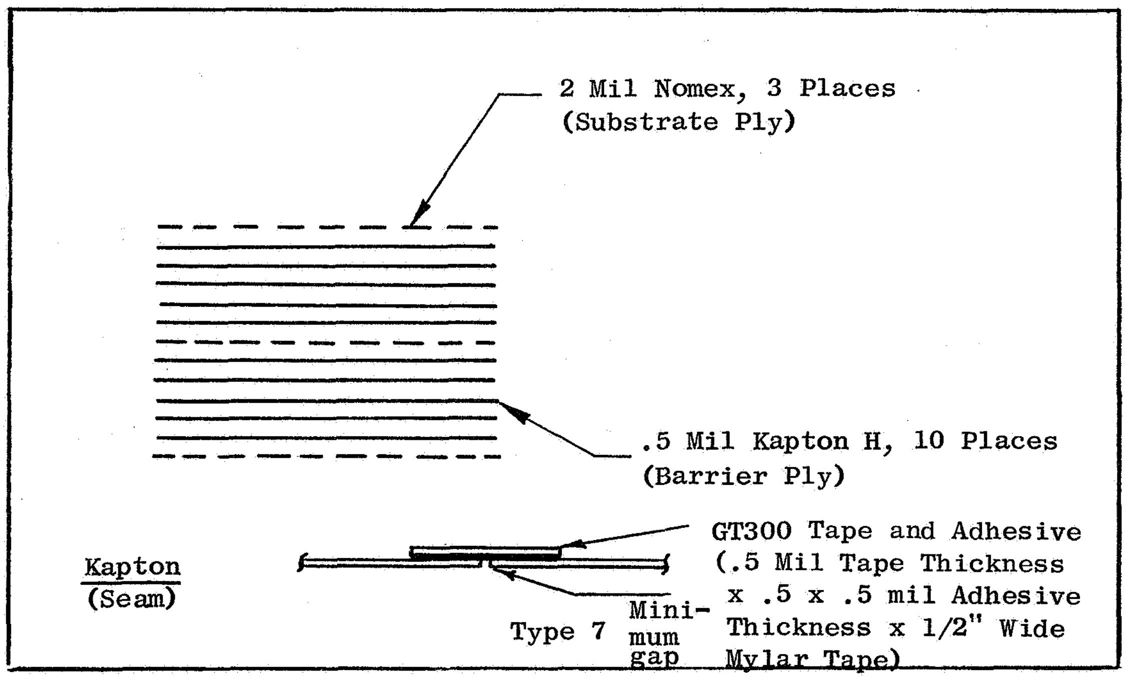


FIGURE 3.45



This material configuration was tested in the form of such samples as T213 and T239. T213 exhibited the best performance in T-F with low permeability. This is the same material configuration as the Mylar-Nomex considered by both Sea Space and Schjeldahl. Bladder material was designated BS 15753, Type 2.

NOMEX/KAPTON

.5 mil Kapton samples of 10 plys, with the code number T127 from Sea Space, did not have a high cycle life although the permeability was low. This material requires substrate plys to resist the splitting of the film. The splitting, which usually starts at the edge of flat samples as was shown in the Twist-Flex tests, should not be a problem in an actual bladder. Seams are satisfactory and do not cause sample failure.

Kapton was tested as plain 10 ply samples in the form of T211 and seamed as T250 and T253 from the Schjeldahl Company. This material exhibited very good permeability, but its flex performance was more subject to random failures than Mylar "C". It was recommended that Kapton be tested in the form of multi-ply bladders with Nomex material as substrate plys. The bladder material is designated BS 15753, Type 7 (see Figure 3.45).

RECOMMENDED SEAMING AND FABRICATION PROCESSES

Lap type seams sealed approximately 1/2 inch wide are standard on all SSS samples and bladders. These seams are made thermally for polyethylene and Merfab elements, but employ Sea Space S110 and S114 adhesives for all other materials. These seams have proven highly satisfactory and are recommended for Sea Space bladder fabrication.

Seam recommendations for Schjeldahl materials are as follows:

.25 Mylar "C"	Butt seam using GT 300 x .25 mil x .25 mil x 1/2" wide sealed full width
.5 Kapton "H"	Butt seam using GT 300 x .5 mil x .5 mil x 1/2" wide sealed full width
Substrate Plys	Lap seam using GT 100 x 1 mil x 1/2" wide sealed full width

BLADDER MATERIAL RECOMMENDATIONS - SUMMARY

The final recommendations for bladder materials derived from the Task I material test program are summarized as follows: (Figure 3.46).

G. T. SCHJELDAHL CO. MATERIALS (BS15753 Bladders)

a. Nomex-Mylar Combination

BS15753 Type 1
T-F tested at T212

b. Dacron Fabric-Mylar Combination

BS15753 Type 2
T-F tested as T213

c. Mylar without substrates.

BS15753 Type 5
T-F tested as T237

d. Nomex-Kapton Combination

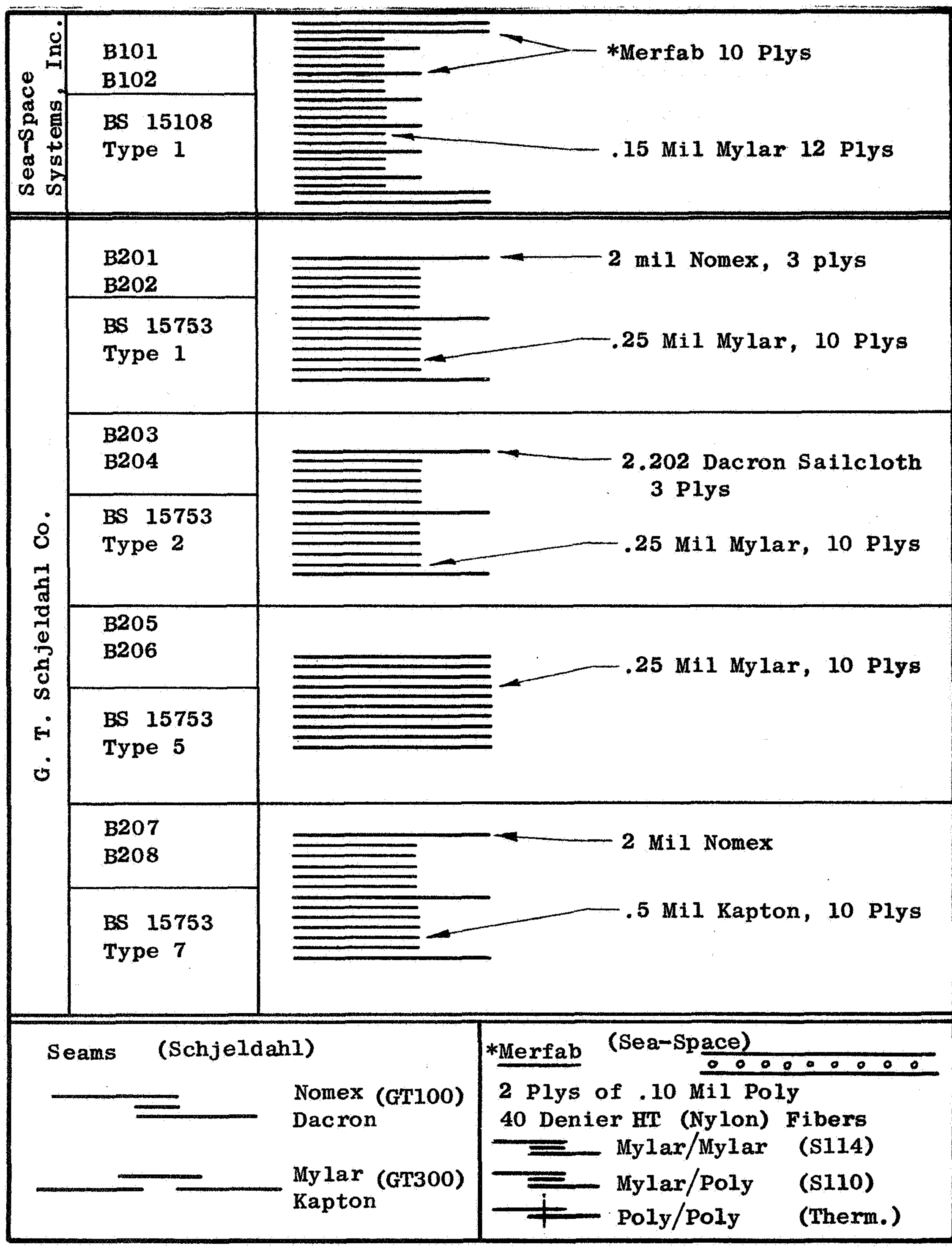
BS15753 Type 7
Kapton plys tested as T250 and T253
Nomex plys tested in (a) above

SEA-SPACE SYSTEMS MATERIALS (BS15108 Bladders)

Merfab-Mylar Combination
BS15108 Type 1
T-F tested as T122

FIGURE 3.46

BLADDER MATERIALS SELECTED FOR TASK II



4.0 EXPULSION TEST PROGRAM (TASK II)

This task was the second phase of the program and provided for the fabrication of polymeric expulsion bladders and the expulsion testing of the bladders with liquid hydrogen. The bladders utilized those material composites and fabrication processes indicated by Task I testing to be the most promising for liquid hydrogen service. The results of the expulsion testing were analyzed using all applicable parameters. The recommendations resulting from this testing and analysis are presented in Section 5.0.

4.1 Bladder Design

Selection of the proper bladder material is the paramount task in the overall design of an expulsion bladder. Almost all of the elements of bladder design must be fulfilled by the material comprising the bladder. The initial selection of materials for Task I evaluation was guided by certain basic requirements, which were followed throughout the development and qualification testing of Task I. This insured that the materials finally selected would exhibit the necessary characteristics to the greatest degree possible. The requisites for bladder materials are discussed in the following paragraphs.

4.1.1 Criteria for Bladder Materials

The characteristics which were considered to be most important in selecting materials for use in these expulsion bladders are as follows:

Flex performance at $-423^{\circ}F$
Permeability
Fabrication characteristics

These criteria are initially discussed as they apply to single thickness bladders. Utilization of these characteristics in multiple ply and in composite materials is discussed in Paragraph 4.1.2.

4.1.1.1 Flex Requirements

The primary requirement of a material for liquid hydrogen expulsion bladders is the ability to withstand repeated flexing, folding and wrinkling while subjected to temperatures as low as $-423^{\circ}F$. All other criteria are secondary to this requirement: if a material will fail under flexure at the operating temperature of the system, any other good characteristics of the material are of no benefit. (Ref 8)

The flexing of the bladder during a typical expulsion cycle occurs at random and in a variety of forms. The forms of flexing vary from the simple "oil-canning" of a segment of a spherical surface and common folding and creasing to a more severe three-corner fold. Three-corner folding can be described as a fold upon a fold and is illustrated in Figure 4.1. Any one segment of the bladder may be subjected at one time to an infinite number and variety of folds, wrinkles and creases, most of them being dynamic. The severity of the folding and wrinkling is further magnified by the increased rigidity of the polymeric material at cryogenic temperature. Similar forms of flexing may also occur at ambient temperature during handling of the bladder.

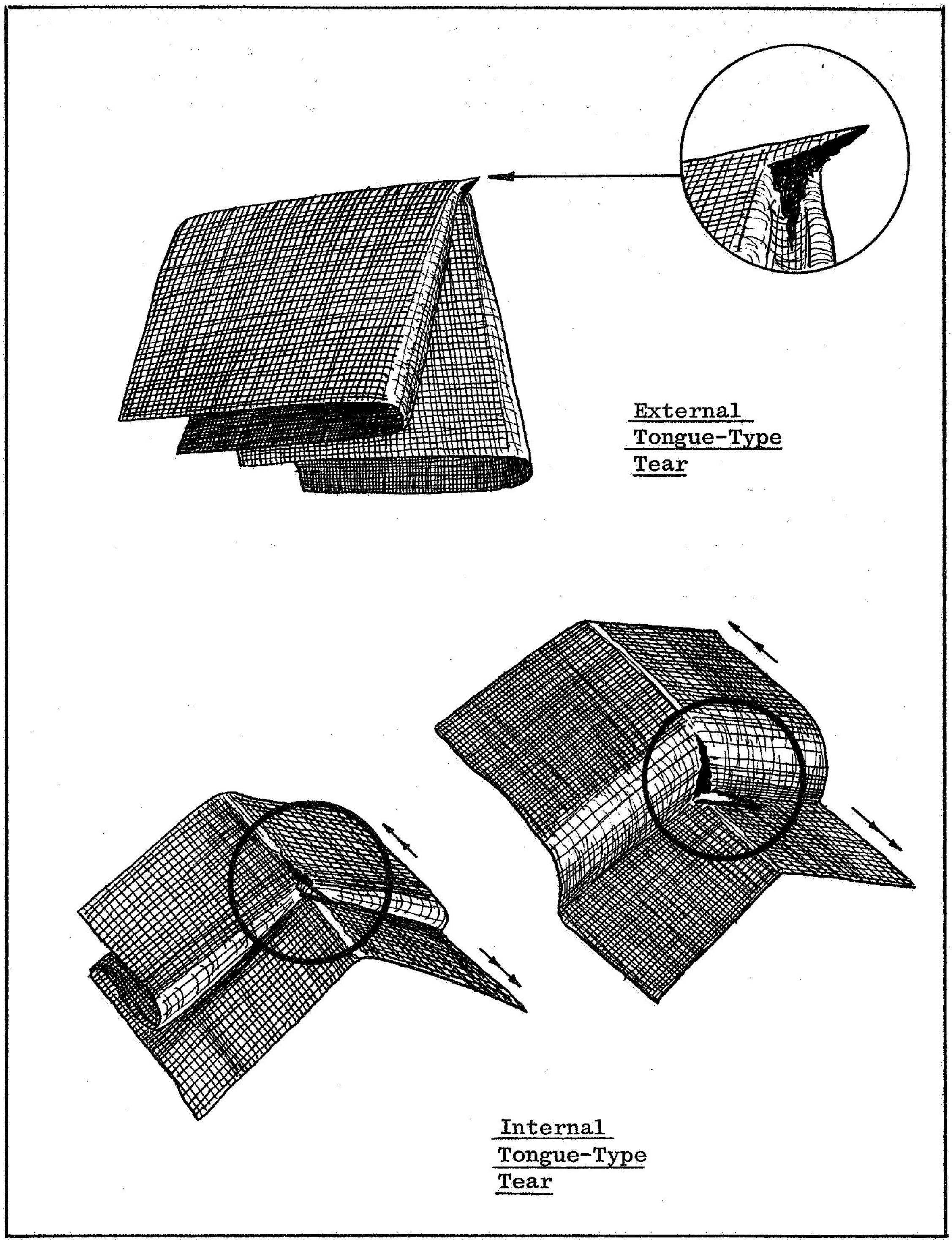
Considerable experience with cryogenic expulsion bladders in previous programs has demonstrated that only the very thin (1/2 mil or less) materials show any promise in polymeric films suitable for cryogenic bladders. It is considered that highly reduced bending stresses result from the folding of the very thin films. However, ultra-thin film is not a solution within itself. The thin film must have "integrity": it must possess adequate strength and tear resistance, and must have low permeability. It is extremely difficult to establish the precise requirements for each of the various mechanical properties of a film. A rationalization of design factors shows that the ideal film can not be solely determined from mechanical properties.

As previously stated, the ability to survive repeated flexing at cryogenic temperatures has been established as the primary requisite for the bladder material. The flexing and folding action upon the bladder arises not only during filling and expelling, but also during handling and flight conditions. Analysis indicates that the sloshing of propellants due to vibration and inertial loads is transmitted to the bladder in the manner of additional deflection. Even if the bladder is in a state of partial expulsion, the stresses produced upon the bladder by movement of the propellant mass is one of flexing as the bladder deflects and permits the propellant to seek a new attitude within the tank. (Ref 14)

Extensive expulsion bladder testing has shown that severe folding and crushing is imposed upon the bladder as it collapses about the mount-fitting and the (liquid) withdrawal tube upon completion of expulsion. The pressurant forces the bladder to drape tightly about these surfaces and opposing sections of the bladder are pressed tightly together. This results in very tight folds of a random nature, many of which are the three-corner fold variety. Careful designing of the bladder mount and the withdrawal tube is essential, but the folds cannot be entirely eliminated.

FIGURE 4.1

THREE-CORNER FOLDS IN MATERIAL



Expulsion efficiency (the percentage of the stored propellant expelled) is determined by the flexibility of a material and its ability to collapse tightly about the withdrawal tube and itself. Flexibility is essentially a function of material thicknesses and stiffness and is influenced greatly by temperature.

4.1.1.2 Strength Requirements

High expulsion system operating pressures by themselves do not necessarily impose high tensile strength requirements on bladder materials. Analysis shows that a differential pressure (ΔP) across the bladder does not occur under ideal conditions of propellant expulsion (and storage). The bladder merely provides a flexible interface between the propellant and the pressurant gas. The bladder adjusts its position as necessary to preclude any ΔP which may be initiated by an increase in pressure on one side of the bladder. Such factors as tensile and tear strength, however, cannot be disregarded because of wrinkling during expulsion and indeterminate stresses that may be transmitted to the bladder due to vibration and slosh. The material must also have sufficient strength to "span" any small gaps (such as the vent orifice) when fully expanded or collapsed under pressure. Adequate tensile strength is necessary to permit operating test pressures and provide increased resistance to damage due to handling.

4.1.1.3 Permeability

The permeation characteristics of a material present a major item for consideration. Helium is the only pressurant being considered for the expulsion of liquid hydrogen (all other gases would liquefy upon contact with a bladder at -423^{o}F). Unfortunately, helium permeates readily through polymeric materials, even when a driving force is absent. The helium, being inert, could seriously contaminate the propellant if there were any significant permeation through the bladder. An operational mission profile would be necessary to determine the permissible helium permeation rate. It is anticipated that such a rate would be very low, but within the permeability range of such materials, as Mylar and Kapton. The goal of this program was to attain the lowest possible permeation for all bladders.

4.1.1.4 Fabrication Characteristics

Fabrication characteristics warrant substantial consideration in the selection of bladder material. The material (and especially, the composite material) must be entirely adaptable to the bladder configuration with no loss of characteristics or performance. Adhesives or other seaming techniques must be available which will permit fabrication of a bladder with all of the cryogenic potential of the selected material.

4.1.2 Composite Materials and Multiple Plys

Problems in finding suitable materials for cryogenic bladders led to extensive investigation of composite materials in earlier expulsion bladder programs. These earlier efforts included such measures as adding various fabrics (with a high tensile strength) to low strength films to relieve the film of any tensile strength loading. Also, comparatively thick and bulky fibrous materials were employed to impart a more liberal bend radius to the plastic film. These earlier composite materials were usually laminated into a single tightly bonded material. Such laminates, however, proved unsatisfactory in cryogenic testing due to excessive hardness of the laminating adhesive at cryogenic temperatures and due to severe bending stresses arising from the thick material.

The advantages of a laminated composite material can often be gained by utilizing the same material arrangement in the form of multiple, unbonded, individual-acting plys. The high strength fabric materials and materials supporting the bend capability need not be laminated to the plastic films to work effectively. This has led to the barrier ply - substrate ply arrangements used extensively in this program. The barrier plys are of a film such as Mylar and Kapton; their basic function is to reduce the permeability of the composite material to acceptable levels. The barrier plys must have excellent flex characteristics to maintain the acceptable levels of permeability throughout the cycle life of the bladder. The substrate plys may be one of a variety of woven or fibrous materials located outside or inside of the bladder composite, or at intermediate points between the barrier plys. The purpose of the substrate plys is to enhance the performance of the barrier ply. The substrate plys provide one or more of the following:

Tensile and tear strength
Abrasion shielding
Radius-producing and cushioning effect
Slip-action between barrier plys

The substrate plys must also have good flex characteristics. They may be quite porous and pervious to gases, without adversely affecting the composites' qualities.

The use of multiple numbers of individual-acting barrier plys without substrate plys also offers a means to improve the total permeability and tensile strength with no significant loss of flex performance. The necessary cryogenic flex characteristics have been found only in films 1/2 mil thick or less. Single ply bladders lack sufficient permeability and tensile strength requirements so that additional plys of the material may be added as necessary to obtain the required permeability and tensile strength performance. The multilayer configuration presents problems in calculating the exact permeation rate and this value is most readily determined by testing material samples. Also, the effectiveness of the plys (due to dimensional tolerance) when under internal pressure may have a slight effect upon pressure calculations.

4.2 Detailed Design

Following the selection of material composites for Task II bladders, the various tentative design details of the bladder were completed.

4.2.0.1 Mounting and Sealing

Bladder mounting and sealing is considered to be a critical design area. A stem assembly had been previously developed which performed both mounting and sealing functions in a satisfactory manner. This stem is of a configuration similar to the stem used in the inner tube of an automobile tire. As shown in Figure 4.2, the stem assembly consists of a flanged stem, a matching washer, and a round nut. The 2 3/8-inch diameter stem flange can be passed through a 1 3/4-inch diameter hole in the bladder, providing ample bladder to flange contact area. The bore through the stem accommodates the withdrawal tube when the bladder is installed in the expulsion apparatus. The stem assemblies used on this contract are identical to the pictured stem assembly, except that the upper end terminates in a flare-fitting end for easy and trouble-free mounting.

4.2.0.2 Typical Ply Design

The material composites and appropriate fabrication processes selected for these bladders resulted in all plys of all bladders being comprised of 12 equal gores (orange-peel segments) running from a lower polar cap to the hole (for the stem assembly) at the top of the bladder. All material was cut from flat sheet. Extra considerations pertaining to the number of gores are discussed in the following paragraphs. The types of seams utilized in the bladders are described in Paragraph 4.2.1. Reinforcement of the polar caps was not done to avoid a material buildup and circumferential seam in the area adjacent to the stem.

4.2.1 Bladder Specifications

The bladders produced and tested in this program were fully defined by formal specifications. Because some sole-source materials were involved, separate specifications were prepared for each of the bladder subcontractors. The subcontractors and the respective specifications are as follows:

Sea-Space Systems, Inc.	Beech Specification BS 15108
G. T. Schjeldahl Company	Beech Specification BS 15753

The bladders under this contract were sized to fit a 12-liter spherical glass dewar with an ID varying from 11.30 inches to 11.36 inches. Consultation with the bladder fabricators selected in Task I indicated that a diametric tolerance of ± 0.13 inch could be held on a spherical bladder

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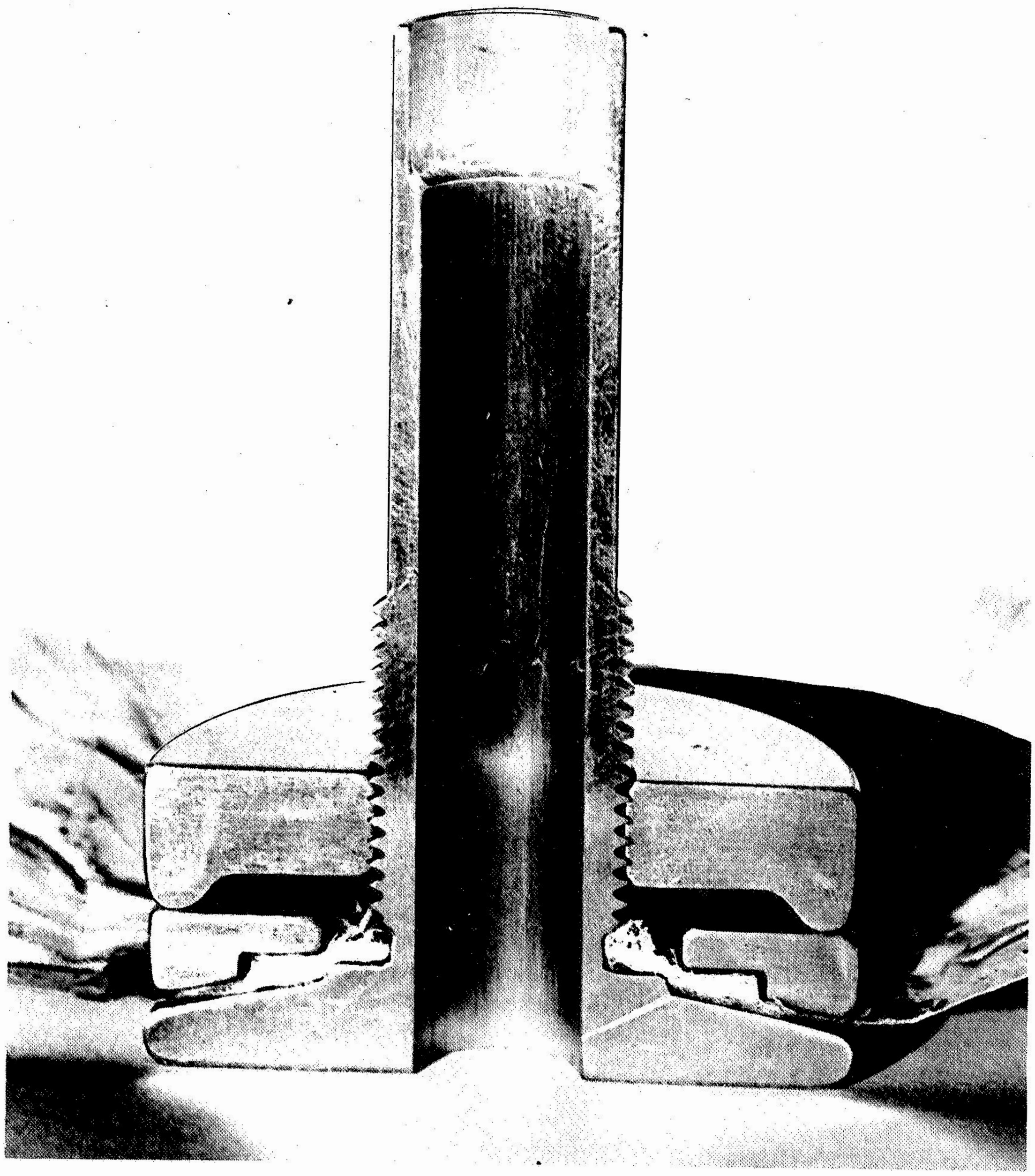
FIGURE 4.2

SECTIONAL VIEW OF STEM ASSEMBLY



of this size. The diameter of the bladders, therefore, was dimensioned at 11.50 $\pm$ 0.13 inches at 12 inches of H_2O gauge pressure to insure that the expanded bladder would be supported by the dewar, even if all tolerances were adverse.

The elongation of the material resulting from bladder expansion (under high internal pressure) from a series of chords to a circumference equal to the ID of the dewar is a consideration in determining the number of gores for the bladders. Such elongation is very minimal for a 12-gore bladder.

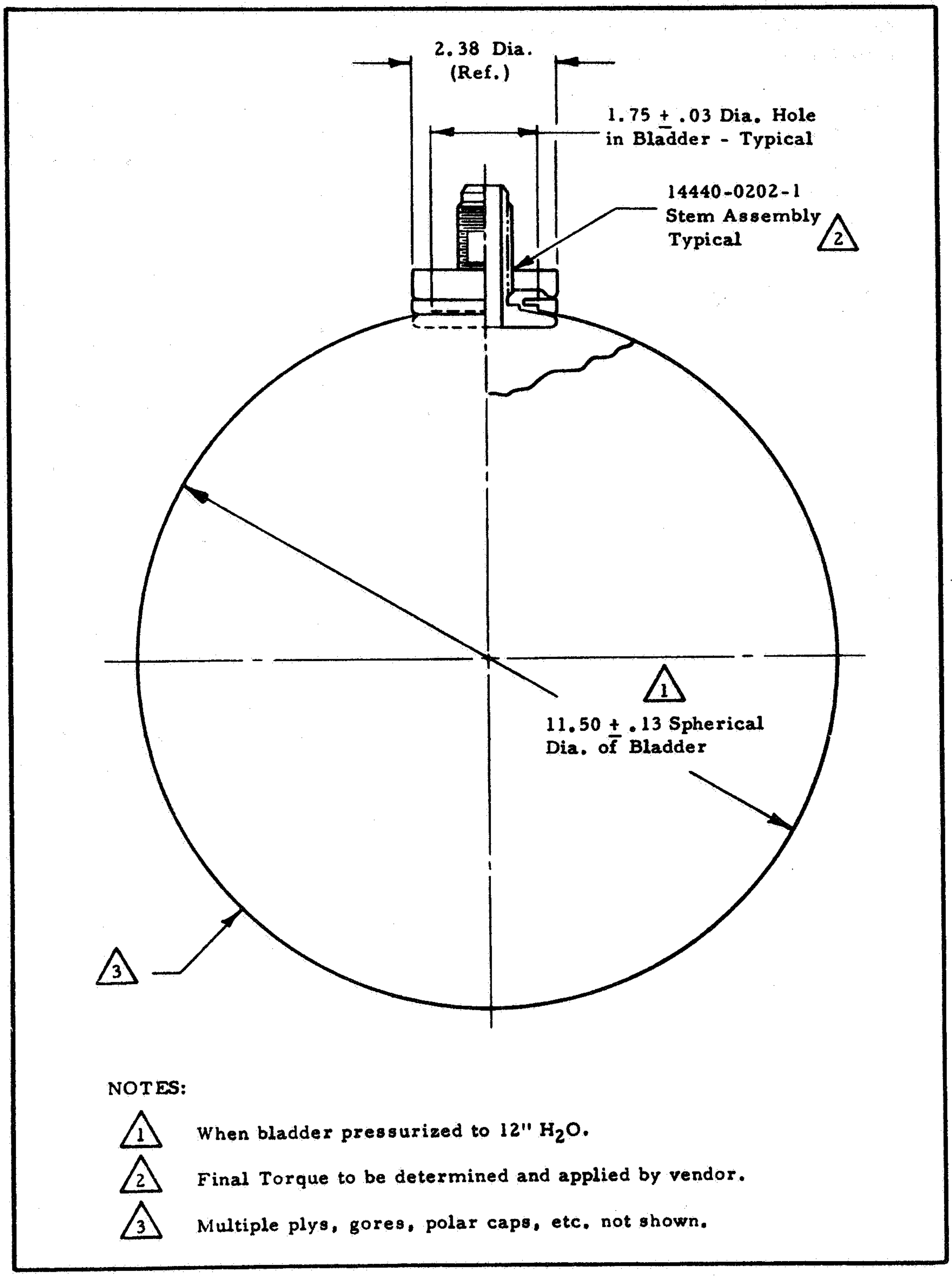
The specifications fully defined the basic configuration of the bladder, complete with dimensions, as shown in Figure 4.3. The stem assembly was furnished by Beech for installation and sealing into the bladder by the subcontractor. As previously stated, all bladders were comprised of multiple, individual plys, all free to act independently of each other (except for the area clamped in the stem assembly). All plys were nested so as to produce one multiwalled bladder. All plys were numbered for identification, beginning with one for the outer ply and progressing consecutively to the innermost ply. A ply consisted of a single layer of material or it was composed of several layers of material tightly bonded together to produce a single thickness as in the case of the merfab plys. The types of plys were defined as follows:

Barrier Ply	A ply consisting of a low permeability film such as Mylar or Kapton
Substrate Ply	A ply such as a polyethylene composite, Nomex or Dacron fabric which enhances the flex life of barrier plys

Each ply consisted of 12 equal gores and a 4-inch diameter cap centered upon the lower pole. The subcontractor was required to leak check each ply immediately prior to assembly into the bladder. This leak check was performed in a special test fixture, and the test apparatus and its operation will be described in subsequent paragraphs. The test pressures and maximum allowable individual ply leak rates for the various materials and thickness are as follows:

FIGURE 4.3

BLADDER ASSEMBLY DRAWING



MATERIAL	HELIUM PRESSURE INCHES OF WATER	MAXIMUM LEAK RATE cc/min.
0.15 mil Mylar "C"	10	32
0.25 mil Mylar "C"	16	18
0.5 mil Kapton "H"	16	10

The above test pressures were selected to produce a stress on the ply equal to 50 per cent of the material's allowable tensile yield strength at ambient temperature. The permissible leak rates were derived from permeability tests upon samples of the materials.

During assembly, the plys of the bladder were oriented so as to provide maximum seam clearance from seams in the adjacent plys and to avoid any bunching of seams. A helium purge was employed to remove the air from all spaces between plys. It was specified that the bladders be free of any foreign particles, fibers and hydrocarbons.

4.2.2 Bladder Procurement, Fabrication, and Inspection

Purchase orders were placed for bladders as follows:

Sea-Space Systems, Inc.

2 each	BS15108	Type 1

G. T. Schjeldahl Company

2 each	BS15753	Type 1
2 each	BS15753	Type 2
2 each	BS15753	Type 5
2 each	BS15753	Type 7

These bladder types are illustrated in figures in Section 3.10.7.

Considerable preparation was necessary for each bladder subcontractor prior to fabrication. Some of this prior effort was necessary to meet the requirements of NASA Quality Document NPC 200-3. Other requirements resulted from the Beech specification, which reflected a level of quality assurance consistent with NPC 200-3. Each subcontractor was required to submit an inspection plan conforming to the requirements of NPC 200-3. The subcontractor was also required to submit, for approval, plans for such items as cleanliness, safe handling and packing, and procedures for individual ply and bladder leak checks.

The leak check of the individual barrier plys and the acceptance leak test of the bladder required a permeability test fixture at each of the subcontractors. One was provided to each subcontractor, who made the setup of the test apparatus. A similar fixture was retained at Beech for use in receiving inspection and throughout the expulsion testing.

In order to construct the bladder and leak test each ply as fabrication was under way, the following procedure was used:

a. Make the final closing seam of each ply (except the innermost) with the partial bladder assembly (consisting of the preceding plys in place on the stem assembly) contained inside the ply.

b. Use extra stem assembly with rubber gasket to perform barrier ply leak check with partial bladder assembly inside ply being checked.

c. Removed test stem, position ply on stem flange and seal in place with adhesive.

Appearing early in the fabrication of the first bladder was the problem of excessive gas transmission through the barrier plys. Investigation revealed this excessive leak rate to be due to pinholes in the 0.25 mil Mylar "C". The possibility of obtaining pinhole-free material appeared very remote and exceedingly expensive, therefore, it was decided to repair each pinhole with a small (approximately 3/8-inch diameter) patch of the same adhesive-coated tape used in making the seams.

No more than five patches were allowed on any one ply. This procedure resulted in barrier plys with practically zero leak, all without any identifiable loss of flex performance.

The gores were cut by means of precision templates. Seaming was accomplished with the use of seaming machines which feed and seal the appropriate sealing tape. Sealing temperatures and pressures used were those normally used at Schjeldahl for the particular tape specified. The rather rigid dimensional control of the spherical bladder was obtained by precision manual alignment of the adjacent gores.

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The bladders from Schjeldahl exhibited very fine workmanship, and showed great precision in seams and all other features. More than 90 per cent of the barrier plys exhibited zero leak (for 5 minutes) during the barrier ply leak check. None of the completed bladders showed any leakage detectable by the burette method over a period of 10 minutes, except for B202, which was returned to Schjeldahl for rework. All of the bladders were within the ± 0.13-inch tolerance on the spherical diameter.

Following acceptance of bladder B201 (BS15753, Type 1), additional permeability testing was performed for longer periods of time to determine the exact influence of system back pressure on the burette readings. This testing verified that back pressure was such that bubbles flowed into the burette only after a period of pressure build-up, which may exceed 10 minutes in the case of very low heat rates. It was thus established that the leak in B201 was less than 1 cc/minute. Though this leak rate was not considered to be prohibitive for expulsion test purposes, a failure analysis was initiated.

Leak detection and consultation with Schjeldahl suggested that the leak was a result of gas leaking through or under the innermost substrate ply in the area where it is sealed to the flange of the stem. The adhesive being used to seal the plys to the flange of the stem was the same polyester adhesive (Schjeldahl GT200) which had been used very successfully on cryogenic bladders throughout two previous programs, however, the Nomex of Ply 13 had presented some problems in securing a good seal to the stem flange and did provide a porous channel for possible leakage. The initial stem seal configuration is shown in Figure 4.4, with arrows showing the suspected leak paths.

Though the leakage of B201 was of tolerable levels, it was decided to attempt to reduce to the leakage at Beech. The nut and washer were removed from the stem and a build-up of Schjeldahl GT200 polyester adhesive was applied to the stem seal area. After considerable experimenting, it was learned that best results were obtained when light applications of GT200 were "ironed" down with a hot sealing iron. The leak rate was thus reduced to 0.2 cc per minute.

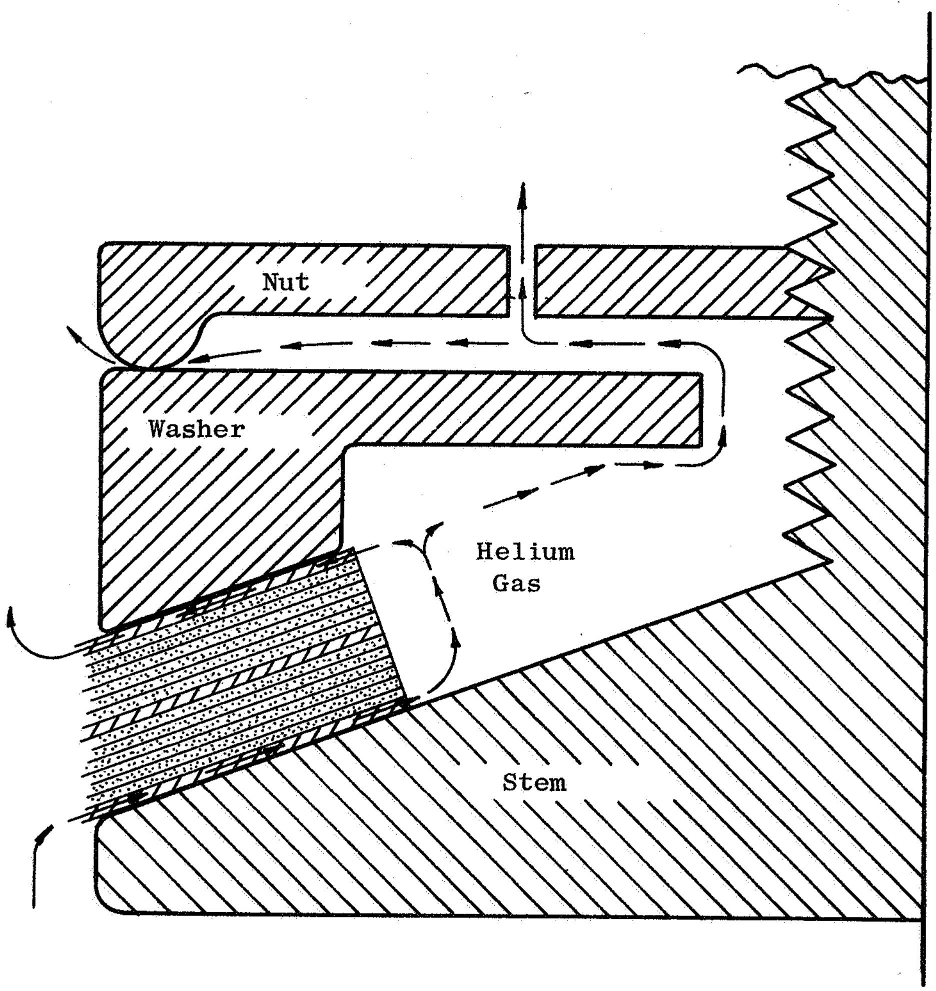
B201 showed an excessive leak rate of approximately 500 cc per minute after five cycles of liquid hydrogen expulsion. Examination showed five major cracks (basically radial) completely through the adhesive thickness and the bladder was loose on the stem flange in two places. This damage was judged to be definitely due to cold shock from being cycled to liquid hydrogen temperature.

Bladder B202 (BS15753, Type 1) showed no detectable leak during acceptance testing by Schjeldahl but had a leak rate of 2.6 cc per minute at the acceptance test at Beech. It was concluded that the polyester adhesive being applied inside the hole diameter was not sealing effectively. Because of the relief in the washer (see Figure 4.4) a mechanical back up was not provided for the adhesive inside the hole diameter. The washer design was satisfactory except in cases where the innermost ply was a pervious material such as Nomex or Dacron. The gas leaked through the fibrous substrate ply and then out through the nut, unless the adhesive build up was pushed down and held down by a mechanical backup.

Bladder B203 (BS15753, Type 2) was accepted with no detectable leak. One liquid hydrogen expulsion cycle resulted in three major cracks through the adhesive in the stem seal area, verifying that excessive thicknesses of the adhesive would crack upon cold shock.

FIGURE 4.4

SCHEMATIC OF STEM SEAL LEAKAGE



The answer to the preceding problems was to rework the stem seals of bladders B202, B203, and B204 as shown in Figure 4.5. The discs overlapping the hole in the bladder screen off any passages at the edge of the hole. The smaller discs alternated with the larger discs provide for a uniform thickness of the total buildup, which was from 25 to 50 mils thick. The discs were cut from Schjeldahl GT300 tape. Light applications of GT200 liquid adhesive were also used. The purpose of the Mylar in the discs was to provide reinforcement to avoid cracking of the buildup at cryogenic temperatures. The buildup was of sufficient thickness that some compression of the seal could be attained. The packing in the relief of the washer was also composed of adhesive with Mylar reinforcement. Its purpose was to bear on the buildup on the stem flange.

A change order to BS15753 was issued to incorporate this change on bladders B202, B203, and B204 (the latter being Type 2). The rework was performed by Schjeldahl and bladders B202 and B203 were returned to them for that purpose. Provisions were also made for incorporation of these improved features into bladders B207 and B208 (BS15753, Type 7), which also had a Nomex inner ply. The reworked stem seals presented a very satisfactory solution to the problem. There was no subsequent leakage that could be attributed to the stem seal, and even prolonged liquid hydrogen cycling did not result in any cracks in the buildup. The original stem seal configuration performed very satisfactorily on the BS15753, Type 5 bladders (B205 and B206), which presented a Mylar inner ply.

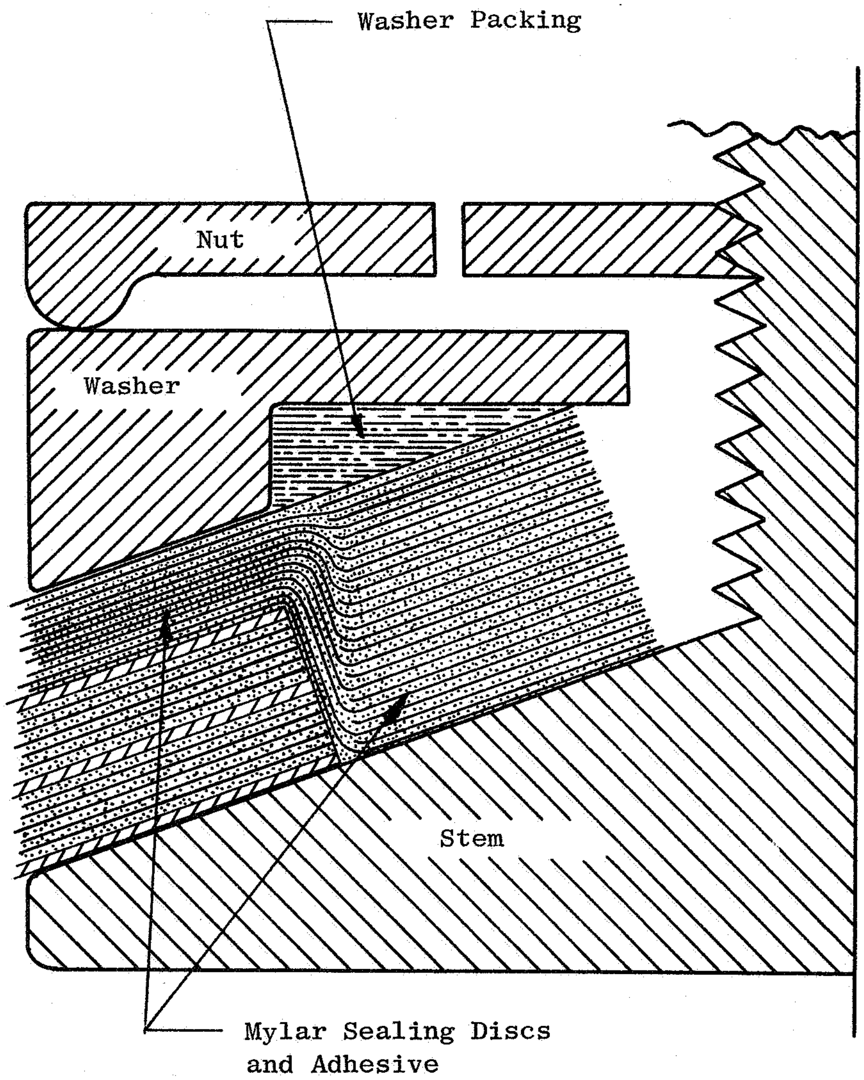
Fabrication by Sea-Space Systems, Inc.

Sea-Space Systems (SSS) had developed a good capability in related areas of fabrication, but had never fabricated expulsion bladders. The bladders to be fabricated by SSS were the most complex bladders of this program, being comprised of 22 individual plys, 10 of which were each a laminate of three separate materials. Other problems included producing, testing, and handling ultrathin 0.10 mil film.

Considerable effort was required for preparation of the various plans and procedures required by the Beech specification, which reflected the minimum requirements consistent with NASA Quality Document NPC 200-3. Meanwhile, SSS produced the Merfab laminate and developed their tooling and jigs for bladder fabrication. SSS was confident that the extremely thin materials used by them would circumvent the need for the concurrent individual ply leak check/bladder assembly procedures required of Schjeldahl.

FIGURE 4.5

REWORK OF STEM SEAL



SSS planned to complete one bladder before beginning assembly of the second bladder. The problem of pin holes in the 0.15 mil Mylar "C" barrier plys was encountered by SSS throughout the fabrication. The disposition of this problem was to accept barrier plys with no more than five patches of a prescribed nature. In this manner it was possible to obtain barrier plys of ultrathin film with an average total leak rate of 15.33 cc per minute.

Other than the pin holes, no fabrication problems were reported by SSS. All plys exhibited orange colored dots at the center of the lapped seams joining the adjacent gores which were tooling "match" marks. The seams in the Merfab plys were thermally bonded and those in the Mylar barrier plys utilized a liquid adhesive specially formulated for cryogenic applications. The various plys were joined at the stem hole with a minimum of adhesive and the seal of the bladder to the stem was achieved without the use of additional adhesive.

Both of the SSS bladders presented an excellent appearance. The finished seams exhibited excellent workmanship. During acceptance testing at SSS, no leakage was detectable by burette over periods in excess of 10 minutes. Both the bladders were within the $\pm$ 0.13-inch tolerance on the spherical diameter. The first SSS bladder (B101) produced an overtolerance reading at one time which was caused by interply inflation between the first two plys. This inflation evidently permeated out through Ply No. 1 (Merfab) over a period of time, and the diameter was again within tolerance. B101 also showed a leak during acceptance testing at Beech, which was totally eliminated by tightening the nut on the stem assembly. This discrepancy was attributed to low torque application at SSS and to cold flow of the bladder material.

A slight change was incorporated into the second bladder (B102) following liquid hydrogen expulsion testing of B101. The two outer and two inner Merfab plys had been expected to perform as abrasion shields, but were failing early on B101. These plys suffered extensive shredding to a degree where major tears (in the direction of the reinforcing filaments running from pole to pole) were spaced at intervals of less than one inch. Such failure was not apparent during the material testing of Task I; it was attributed to the high friction coefficient of the polyethylene and lack of tear resistance at cryogenic temperatures. It was judged that the 0.15 mil Mylar barrier plys performed significantly better (than the Merfab) when they were exposed following failure of the Merfab plys, therefore, it was believed that better performance would be achieved by rearranging the plys of bladder B102. The fabrication of B102, however, had progressed to a point where it was feasible to add only a single Mylar ply to the outside of the bladder.

4.3 Test Requirements and Apparatus

The objectives of Task II expulsion testing required the following capabilities of the expulsion test apparatus:

Liquid hydrogen expulsion via inward expulsion (cryogen inside bladder).

Transparent dewar to permit visual observation.

Spherical configuration, approximately 12 inches in diameter.

Up to 25 rapid cycles (fill and expel) per bladder.

Provisions for detecting incipient bladder failure during expulsion test run.

Means for flowing liquid hydrogen into bladder and venting same.

Provisions for positive purge.

System versatility for reversing flow paths, etc.

System pressures up to 20 psia.

Fine and positive control over both inside bladder and outside bladder pressure.

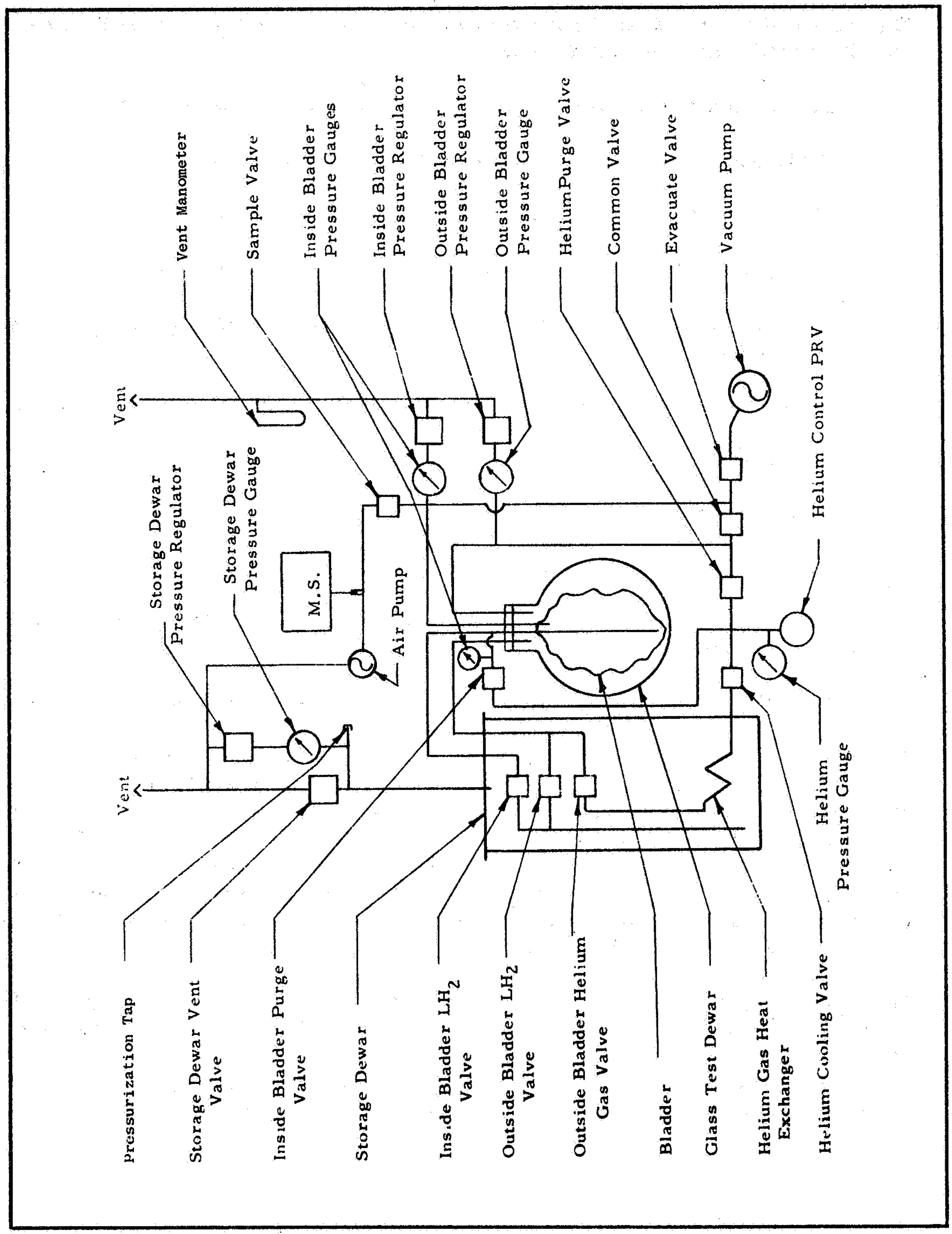
Variable flow rates from 0.1 gpm to a maximum approaching 10 gpm.

The expulsion test apparatus, together with all other test apparatus utilized in this program, was located in a remote test area. The expulsion and Twist-Flex apparatus were located in one room, separated from the control room by a 12-inch concrete blast wall with two blast-proof observation windows. A foam-insulated line supplied liquid hydrogen to the expulsion and Twist-Flex apparatus; another line supplied liquid nitrogen to the Twist-Flex apparatus. Helium gas was supplied from a tube trailer or from a bank of "K" bottles.

The control panel for the expulsion test apparatus, Twist-Flex controls, permeability test fixture, and the helium MS leak detector were located in the control room. The area was equipped with a permanent system for detecting hydrogen contamination in the test and storage areas. The test area was also equipped with a liquid nitrogen deluge system.

FIGURE 4.6

EXPULSION TEST SYSTEM SCHEMATIC



4.3.1 Expulsion Test Apparatus

A flow schematic and general view of the expulsion test apparatus are shown on Figures 4.6 and 4.7 respectively. The upright cylindrical object to the right of the figure is a 70-gallon storage dewar. The test dewar is filled from the storage dewar and the helium pressurant is precooled by the liquid hydrogen in the storage dewar. The storage dewar is filled by a foam-insulated line from a hydrogen dewar in the storage wing. Two small vacuum-jacketed lines carry liquid hydrogen from the storage dewar to the glass test dewar. One of these lines also carries the cold pressurant to the test dewar. The glass test dewar is at the lower center of the photo, and is shown in the test position. It can be lowered by means of a jack for installation or removal of the test bladder. The vacuum/purge gas manifold valves and the pressure control vent valves are located along the top of the test stand. The vent line extends upward from the two diaphram-type vent valves. The vacuum pump is to the left and out of the photo. All lines and wires to the control room are routed in instrumentation tunnels under the floor.

Figure 4.7 is viewed looking toward the control room and one of the rectangular observation windows can be seen behind the vent valves at the left of the photo. A remote control panel is located in the control room and adjacent to the window so that the operator can observe the test from his position at the control panel.

The major components of this system and the control panel are further described in the following paragraphs.

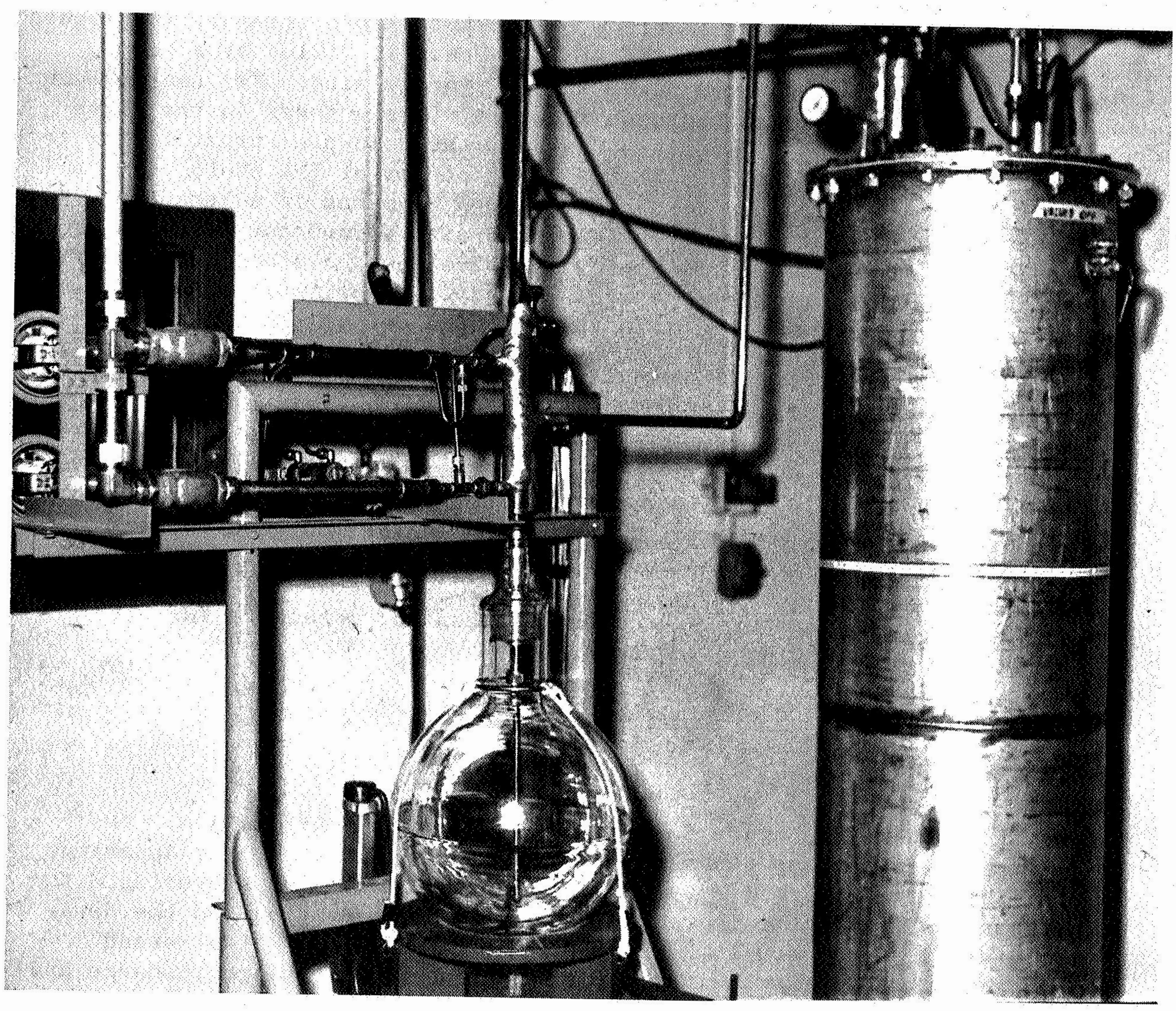
4.3.1.1 Description of Major Components

4.3.1.1.1 Glass Test Dewar

The dewar is shown in Figure 4.7 and is also shown in Figure 4.8. The 12-liter spherical glass dewar is a product of Scientific Glass Apparatus Company, Bloomfield, New Jersey, and was purchased without silvering. The metal base was removed to increase the field of observation and the dewar was mounted by shock cord to a plywood base located on the test stand "elevator". The dewar exhibited surprisingly good thermal performance and has successfully withstood internal pressure as high as 7 psig.

FIGURE 4.7

EXPULSION TEST APPARATUS



4.3.1.1.2 Plumbing Riser

The special glass stopper terminates in a plumbing riser as shown in Figure 4.9. This plumbing riser was developed to provide a capability for both inward and outward expulsion. The vacuum-jacketed lines from the storage dewar connect to the plumbing riser at the top and at a point on the side. Twin connection points on the other side of the plumbing riser lead to the evacuation/gas purge/vent manifolds (non-jacketed).

The plumbing riser is stationary and the glass test dewar is lowered to permit installation of the bladder. The flare-fitting end on the stem assembly of the bladder connects to the B-nut shown in Figure 4.9. The figure also shows how the withdrawal tube passes through the stem assembly of the bladder. The withdrawal tube extends to a point near the inside bottom of the dewar, as shown in Figure 4.8. The weight of the plumbing is sufficient to maintain the stopper-to-dewar seal at internal pressures up to approximately 5 psi.

4.3.1.1.3 Storage Dewar

The schematic of Figure 4.6 shows the arrangement of the plumbing inside the 70-gallon LH_2 storage dewar. The solenoid valves were located inside the dewar to avoid encumbering the vacuum-jacketed transfer lines and to minimize heat input. The dewar plumbing included four solenoid valves prior to this program to provide a full capacity for inward and outward expulsion. The coil for cooling the helium pressurant was located near the bottom of this dewar. A pressure controller and pneumatic-operated valve provide for the desired pressure (generally 12 psi) for filling the test dewar. A pressure tap was incorporated to raise the pressure within the storage dewar at a rate much more rapid than that realized from normal boil off.

4.3.1.1.4 Remote Control Panel

The remote control panel presents a comprehensive flow diagram of the expulsion system as shown in Figure 4.10. The system schematic (Figure 4.6) is graphically arranged so as to generally duplicate the control panel. In general, the items identified as valves in the schematic are indicator switches on the panel and control the respective valves. These switches are illuminated green when the valve is open and red when the valve is closed. The flow lines on the panel are color coded. The three pressure controllers provide variable pressure control on the outside of the bladder, on the inside of the bladder, and in the storage dewar, respectively. This control is achieved by means of respective diaphragm

FIGURE 4.8

TEST DEWAR AND PLUMBING RISER

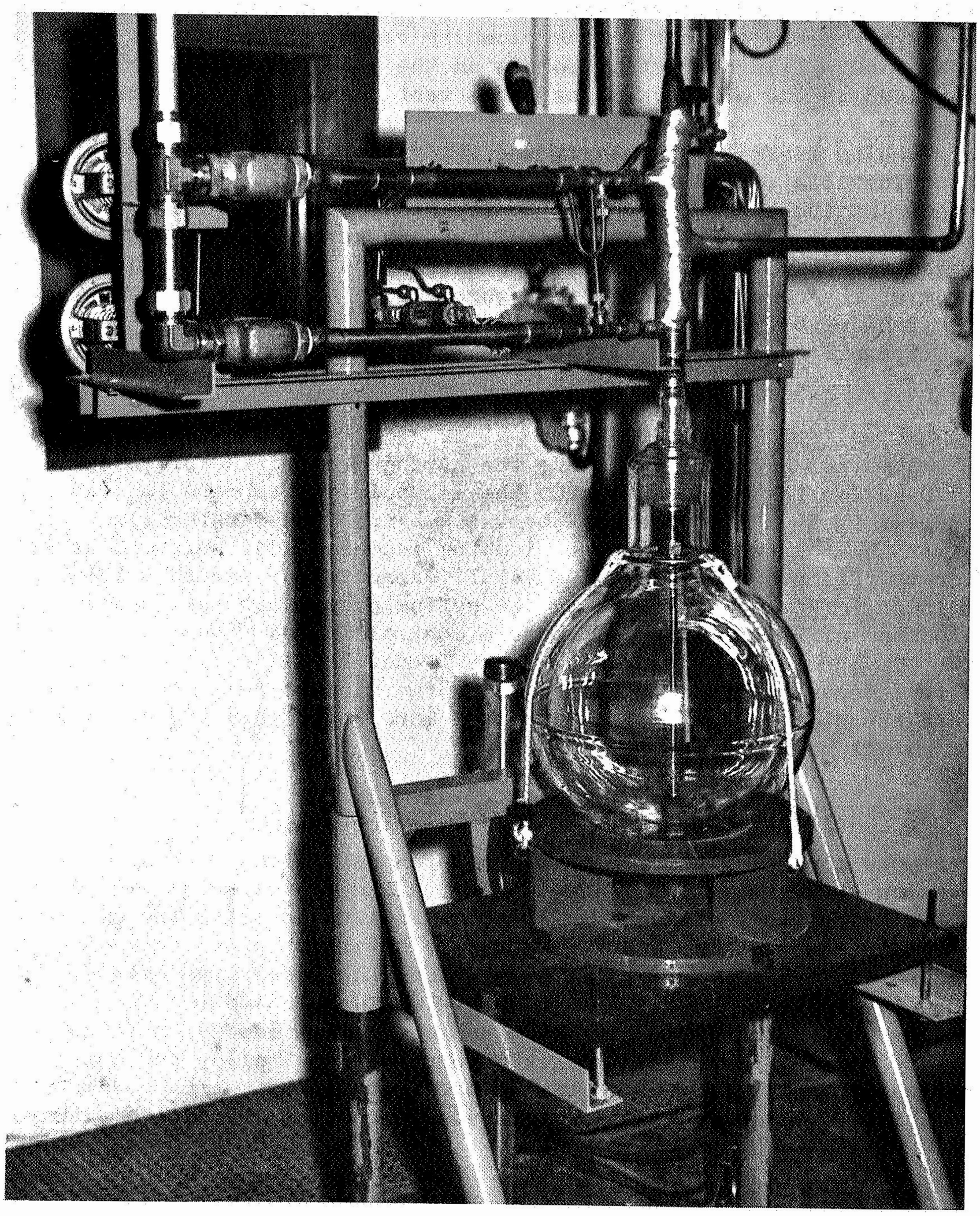
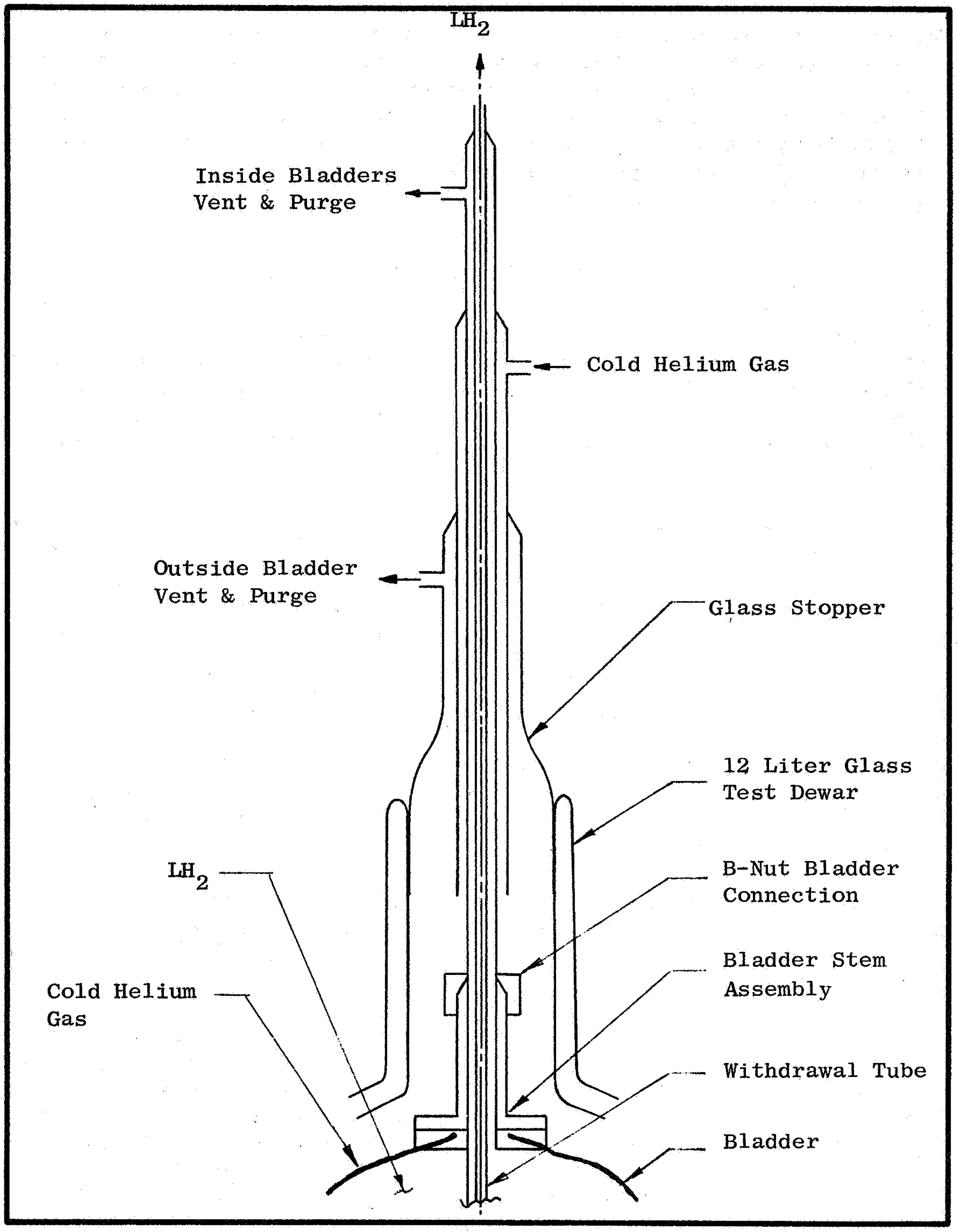


FIGURE 4.9

TEST DEWAR PLUMBING RISER (SECTIONAL VIEW)



valves in the various vent lines. The gauge with the black dial is a duplex compound gauge reading from 30 inches Hg vacuum to 30 psig and indicates the respective pressures inside and outside the bladder. Another duplex gauge (0 to 15 psi) was added (immediately above the duplex compound gauge) to provide more precise readings of pressures inside and outside the bladder during the fill and expulsion cycles. The duplex gauges provided an indication of the pressure differential across the bladder.

4.3.1.1.5 Miscellaneous Features

Several items which appear on the system schematic (Figure 4.6) and are not portrayed on the control panel were added during the course of the expulsion testing. A pressure gauge was added in the liquid hydrogen fill line (at the plumbing riser) to indicate the inside bladder pressure during certain test runs when the duplex gauges were partially inoperable due to vent orifice blockage. This gauge also indicated the pressure drop through the bladder during fill.

A manometer was connected into the common vent line to provide an indication of vent back pressure during liquid hydrogen expulsion. This proved to be a valuable addition to the system because it provided positive indication of liquid expulsion. Readings ranging from 3 to 4 inches (total) water, produced a significant pressure indication of the liquid hydrogen expulsion.

4.3.2 Permeability Test Apparatus

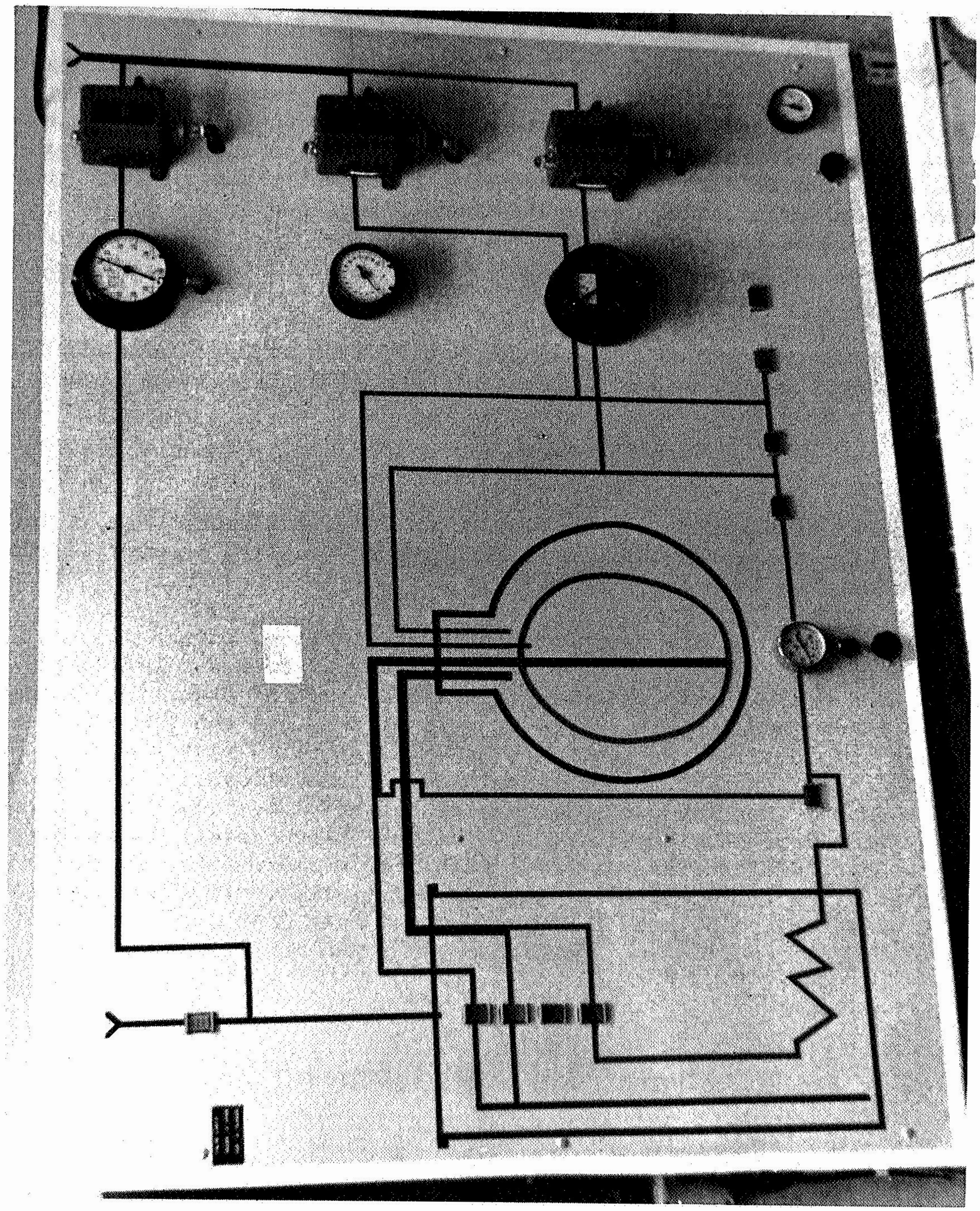
The secondary objective of this test program was to determine the effects of progressive liquid hydrogen expulsion cycling upon the permeability of each bladder. This required quantitative permeability measurement at regular intervals in the test procedure for each bladder.

The apparatus is shown in Figure 4.11. The permeability fixture is seen at the bottom of the photo, while the burette tube appears on the wall to the left. The piping schematic of the permeability apparatus is shown in Figure 4.12.

The basic components of the bladder permeability test fixture were a bell jar and a plate to close off the bell jar. The glass bell jar was 14 1/4 inches OD, 3/8 inch thick, and 18 inches high and was procured with a matching rubber gasket. The bell jar was held upright by a wood and plywood stand. The circular 1/2-inch stainless steel cover plate provided a bladder-mount fitting mating with the bladder stem assembly. The cover plate also included an air-bleed probe and the necessary connections for bleeding off the air from inside the bladder and for pressurizing the

FIGURE 4.10

EXPULSION TEST CONTROL PANEL



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bladder. Provision was also made for connection of a line to carry to the burette that volume of gas which had permeated out through the pressurized bladder.

The large manometer in Figure 4.11 indicated the pressure on the inside of the bladder. The smaller manometer was incorporated to indicate the back pressure caused by the burette and to assure that it was within acceptable levels for acceptance leak tests. Helium supply and vent lines and the necessary valves were semi-permanently installed in the control room. The larger leak rates were determined by a wet test meter instead of the burette.

4.4 Expulsion Bladder Testing

All of the procedures and bladder tests performed at Beech are described in the following paragraphs. The nature and form of the data to be acquired is also discussed.

4.4.1 Receiving Inspection

A procedure was developed to provide for a receiving inspection of Task II bladders at Beech which was consistent with the quality provisions imposed upon bladder fabrication.

The receiving inspection procedure was quite routine, except for the acceptance leak test. The shipping container was examined for damage and then opened, checking for compliance with the packing plan. The condition of the bladder and the stem assembly were checked and the bladder identification was verified. A check was made to establish that all of the required documentation had been submitted for the bladder. The bladder dimensions were then measured by means of a flat plate, angle blocks and calipers to determine the spherical diameter. The official diameter was obtained by taking the average of a number of measurements, across both the "flats" and the "points" of the bladder (inflated to a pressure of 12 inches of water).

FIGURE 4.11

BLADDER PERMEABILITY TEST SETUP

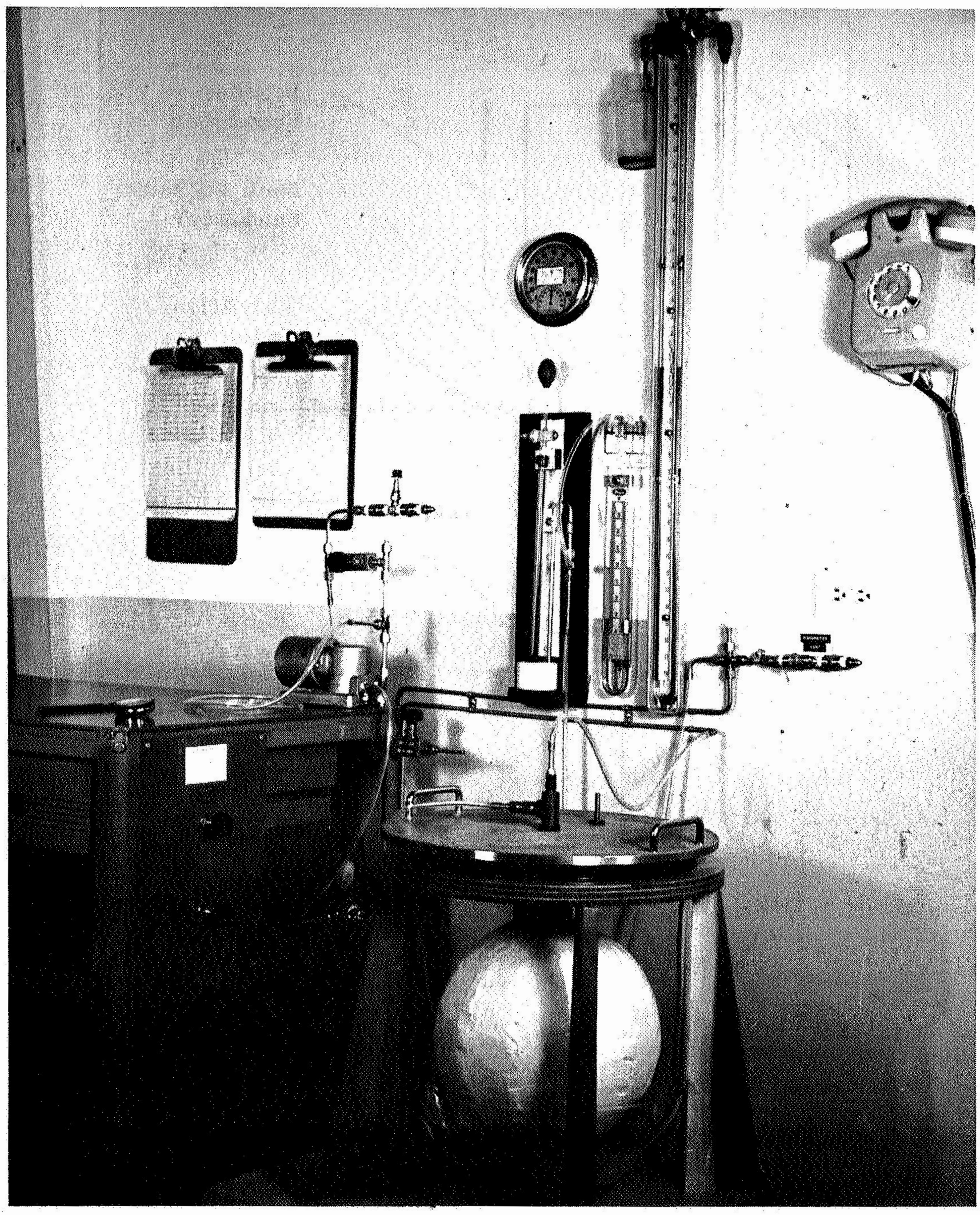

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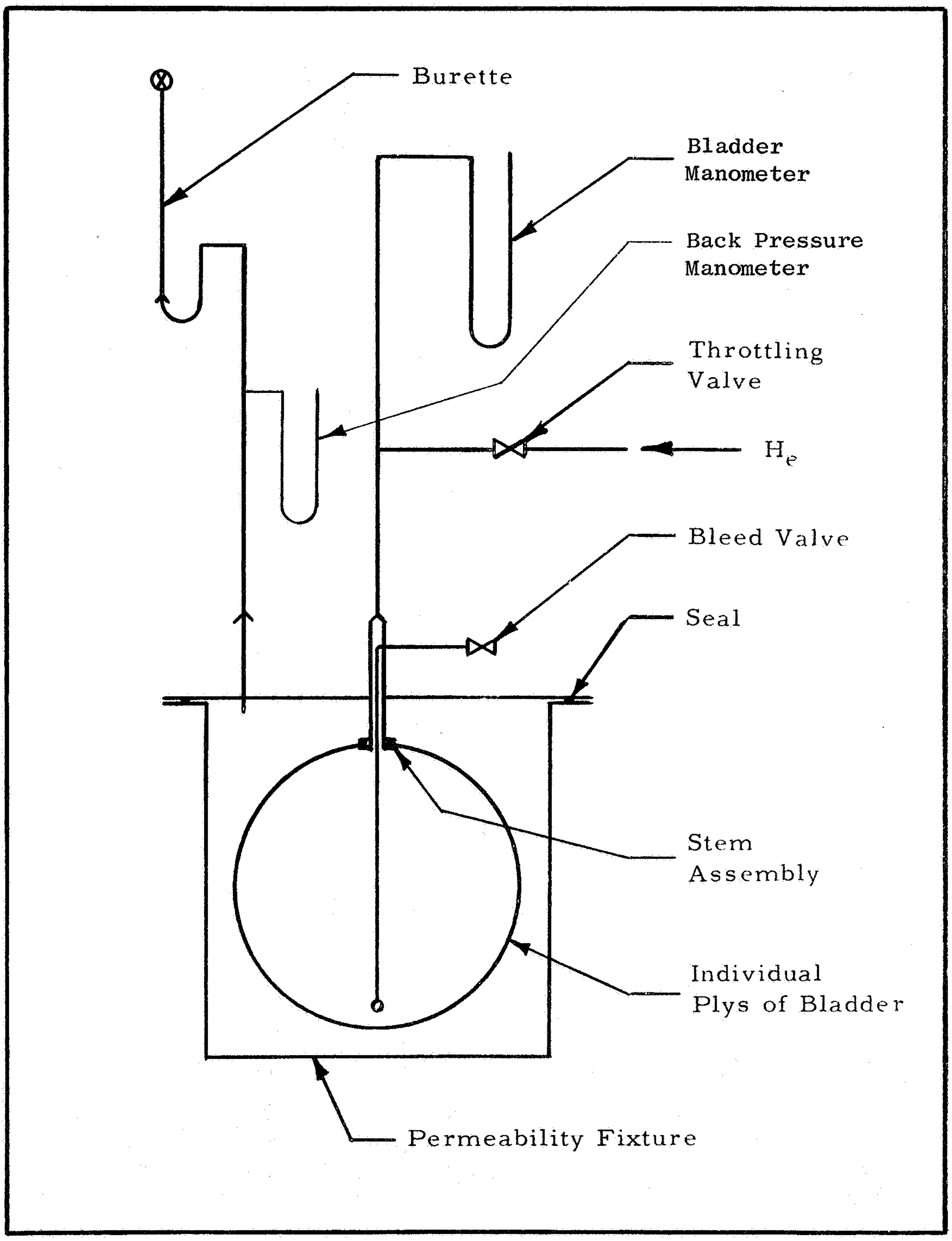
FIGURE 4-12

SCHEMATIC OF BLADDER PERMEABILITY TEST SYSTEM



The acceptance leak test was made per the detailed procedure previously described. It was specified that the bladder could not have any burette indication of leakage in 10 minutes when inflated with helium to a pressure of 28 inches of water (1 psi). As previously stated, the back pressure caused by the burette delays the appearance of bubbles in the burette until the gas which has permeated through the bladder builds up sufficient pressure to overcome the back pressure. This condition was acceptable within certain limits and it was utilized to provide a plus tolerance for the specified zero leak rate. Several bladders exhibited no detectable leakage over periods of time exceeding 30 minutes, but the other bladder showed a trace of leakage. The burettes at Beech and at the subcontractors were adjusted so as to limit the back pressure to 0.75 inch of water and an additional manometer was added to provide assurance that the back pressure was within these limits. With this provision, the leak rate could range from 0 to approximately 0.5 cc per minute, even though no bubbles appeared within 10 minutes of the time the burette line was connected.

Following acceptance, the bladder was placed in a conditioning chamber for at least 24 hours. The conditioning chamber had been developed to provide a low humidity environment of nitrogen gas at a controlled temperature.

The chamber was maintained at a temperature between 90°F and 110°F and at a humidity ranging from 2% to 5% during all times of bladder conditioning.

4.4.2 Bladder Permeability Testing

The procedures for determining bladder permeability (leakage) during expulsion testing were basically the same as for the individual ply leak check (by the bladder subcontractor) and the acceptance leak test. Any deviation between the various permeability tests are described in the following paragraphs.

The basic bladder permeability test procedure was as follows. The first six steps provided a system integrity check to insure that the system was leak free.

1. Install bladder on fitting on cover plate of permeability fixture, using copper Del-Seal.

2. Position cover plate on bell jar and clamp leak tight.

3. Open bleed valve making inside of bladder common to space outside of bladder by proper tube connection.

4. Pressurize with helium until reading on bladder manometer is 12 inches (water).

5. Monitor bladder manometer for 5 minutes. If pressure drop occurs, repair leak and repeat this step.

6. Remove burette line/bleed line loop, reducing internal pressure gradually.

7. Flow helium for three minutes (or until all air is bled off from interior of bladder) through the throttling valve, the bladder, and the bleed valve.

8. Pressurize interior of bladder with helium to test pressure of 28 $\pm$ 0.5 inches of water and maintain pressure through Step 10.

9. Bring oil in burette to proper level for initiation of permeability test.

10. Connect line from cover plate to burette. Start test timing and take first burette reading immediately after first bubbles have ascended. Stop test timing and take second burette reading immediately after a bubble or a group of bubbles. Record all times and readings.

    (For acceptance tests, the test timing was started and first burette reading was taken at time burette line was connected. Time was stopped and second burette reading was taken at end of 10 minutes.)

11. Close throttling valve and open bleed valve to secure system after test. Remove "C" clamps.

The preceding procedure was applicable to all bladder permeability tests employing the permeability fixture and the burette, except for the burette back pressure check for acceptance leak tests. It was specified that the acceptance leak test procedure include a flow of gas (from an external source) through the line to the burette to verify that the back pressure (as read on the burette manometer) did not exceed 0.75 inch (water). The manner of taking burette readings in Step 10 above eliminated any concern for burette back pressure during expulsion test permeability checks.

A major effort was expended during the Task II test program to establish a permeability profile for each bladder as it progressed through the 25 cycles of liquid hydrogen expulsion. Though quantitative permeability could not be expected, it was hoped that the mass spectrometer (MS) helium detector would provide some indication of change in permeability after each expulsion cycle. Such indications could be correlated to frequent permeability readings at ambient temperature in the permeability fixture for initial bladders. Relative permeability rates could then be determined for subsequent bladders by means of MS readings only and without resorting to permeability tests at ambient temperature. Permeability testing at ambient temperature was very time consuming because more than 12 hours elapsed during warm up from liquid hydrogen temperature to ambient temperature, therefore, the frequency of ambient temperature permeability testing established the number of expulsion cycles which could be accomplished in a work day.

The Task II test plan specified that ambient temperature permeability be performed at intervals of five expulsion cycles. It was hoped that a satisfactory correlation between the ambient temperature test and the MS indication could be acquired during the 25 cycles of expulsion testing on no more than two bladders. The MS method of indicating inter-cycle leak rates however proved inadequate. Frequent permeability tests at ambient temperature, therefore, provided the only means for determining a bladder's permeability profile for the 25 liquid hydrogen expulsion cycles.

Difficulties were encountered in the installation into the test dewar (and removal) of the first bladders. The bladders incurred additional handling due to the repeated installation and removal operations for permeability testing. This situation led to the development of a procedure for performing the permeability test while the bladder was still in the glass test dewar (with the dewar at ambient temperature). This method utilized a rubber stopper and an adapter as shown in Figure 4.17. The long tube through the stopper terminated in an adapter for connecting the bladder stem assembly and provided a means for pressurizing the inside of the bladder with helium. The short tube opened into the neck portion of the dewar; its upper end provided for connection of a line to the burette. This arrangement utilized the same helium supply, manometers, and burettes which were used with the bell jar arrangement.

The test dewar permeability arrangement was used for all bladders, even though procedures were developed which decidedly facilitated bladder installation and removal. Some of the permeability tests were repeated by using the bell jar method, especially for those bladders which were comparatively easy to install in (and remove from) the glass test dewar.

These duplicate tests were to provide a correlation between the two methods. Complete correlation was not attained, but the duplicate readings did serve to verify the test dewar permeability readings. The burette provided a precise method of measurement for low leak rates, especially for those approaching zero. A Precision wet test meter was ideal for reading the higher leak rates from 100 cc per minute on up to its maximum rate of approximately 30,000 cc (30 liters) per minute. Both the burette and the wet test meter produced precision readings in the leak range between the extremes described above.

4.4.3 Expulsion Testing

The following paragraphs reflect the procedures presented by the Task II test plan. The procedures are for the installation of the bladder in the dewar and expulsion apparatus, the purging of the dewar for liquid hydrogen operation and a typical inward expulsion cycle.

4.4.3.1 Bladder Installation

The test plan originally provided for bladder attachment to the plumbing riser, followed by installation of the bladder into the glass test dewar as the dewar was raised around the collapsed bladder. Difficulties were encountered in inserting the first bladder through the comparatively narrow neck of the dewar. The problem originated from excessive inter-ply

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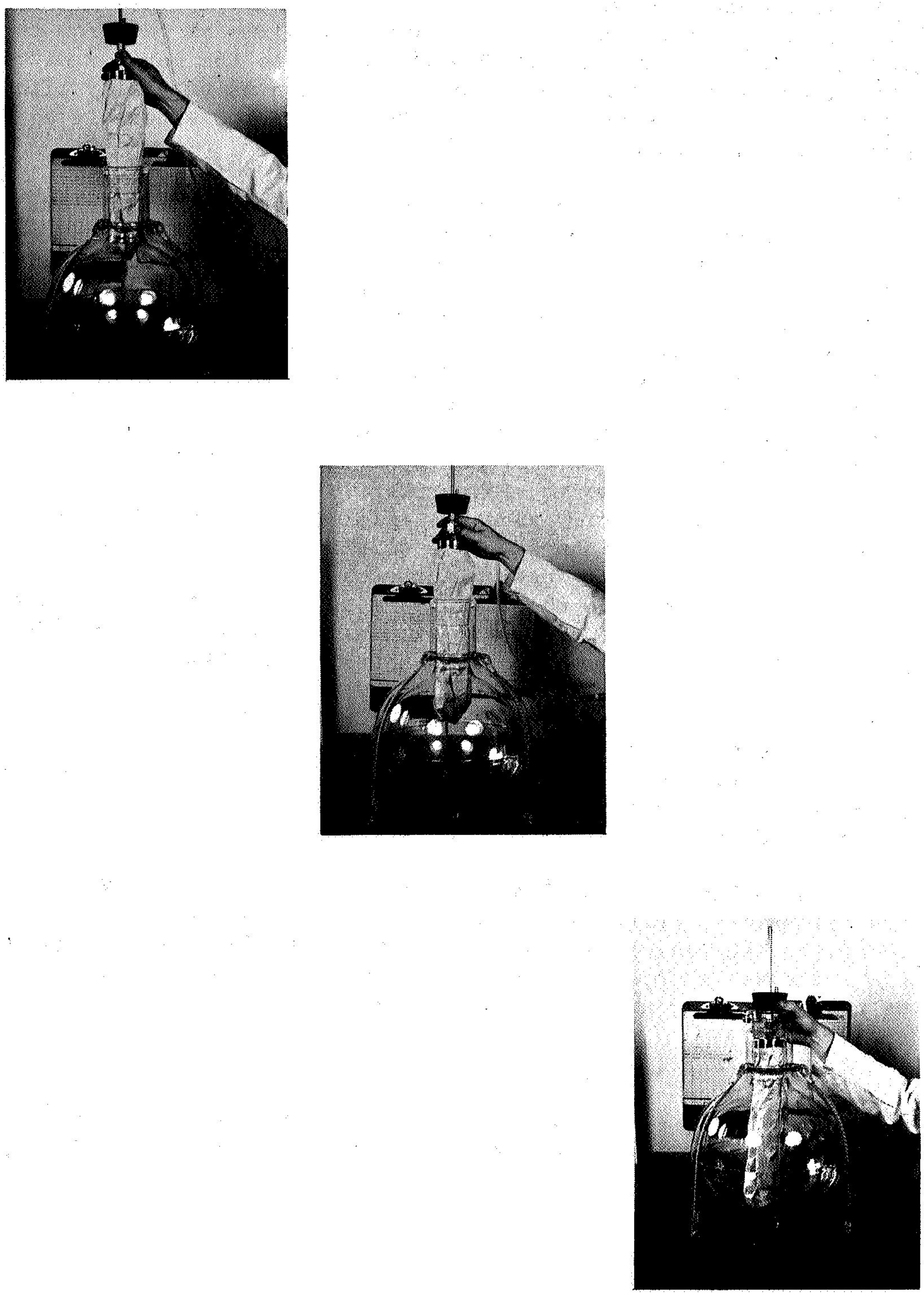
FIGURE 4.13

INSTALLING BLADDER IN DEWAR



inflation. The inherent bulkiness of various bladders was also a factor. The interstial gas was forced to the top of the bladder as the lower portion of the bladder was squeezed down by entry into the dewar neck. Difficulty arose in "transferring" the contained volume of gas from the upper portion, through the restricted portion, and to the portion of the bladder below the neck of the dewar. This situation is partially illustrated by Figure 4.13, though the early inflation was considerably more pronounced than that shown in the figure.

A procedure was developed to facilitate the insertion of the problem bladders into the dewar. The test bladder was installed in the permeability test fixture and a vacuum pump was used to pump on both the inside and outside of the bladder. A pumping time of from 1/3 hour to one hour was generally required to produce a significant reduction in inter-ply inflation, though considerably more pumping was employed in isolated cases. The partial vacuum was then gradually and simultaneously "broken" on both the inside and the outside of the bladder. The cover plate (with bladder attached) was then transferred to a work stand. The bladder was folded by hand as it was again collapsed by means of the air pump. If the plys were not correctly nested for proper folding, the inside of the bladder was inflated momentarily and then refolded. A properly folded bladder would present a star-shaped cross section in the equatorial plane. The bladder could then be quite easily inserted into the dewar. The bladder was held in a position where the stem assembly protruded from the neck of the dewar so that the connection to the plumbing riser could be made during installation into the expulsion test apparatus.

A similar procedure was employed when inter-ply inflation presented problems in removing the bladder from the dewar. A partial vacuum was pumped on both the inside and outside of the bladder (while in the dewar) using the stopper arrangement shown in Figure 4.13. The final phase of this procedure was to pump on the inside of the bladder only to collapse the bladder.

The last steps in bladder installation were to position the dewar on the test stand "elevator", partially raise the elevator and connect the bladder stem assembly to the plumbing riser by means of the "B" nut, using a copper Del-Seal. The glass stopper was lightly coated with vacuum grease and the dewar was raised further until the dewar-stopper seal was affected.

4.4.3.2 Purge

The following procedure was used to purge the newly installed bladder, the test dewar and associated plumbing to a condition safe for operation with liquid hydrogen (LH_2).

1. Set inside and outside bladder pressure regulators at 2 psi. Raise H_2 pressure in storage dewar to 3 psi.

2. Start vacuum pump and open common valve.

3. Open evacuate valve and evacuate both sides of bladder to approximately 25 inches Hg vacuum. Close evacuate valve and pressurize both inside and outside of bladder to approximately 2 psi of helium.

   NOTE: The differential pressure across the bladder shall not exceed 1 psia.

4. Repeat Step 3 two times.

5. Set bladder pressure regulators so that inside regulator is open at 0 pressure. Open inside bladder LH_2 valve and flow H_2 gas through bladder for five minutes (flow of liquid H_2 into bladder is permissible). Close inside bladder pressure regulator.

6. Open common valve. Open sample valve. Flow H_2 gas through bladder, avoiding any pressure in excess of 2 psi inside glass dewar. Continue H_2 flow until mass spectrometer (MS) reads only low helium background. Close common valve. Close inside bladder LH_2 valve and close sample valve.

Bladder is now purged and ready for LH_2 fill. Avoid addition of helium to inside of bladder to avoid helium contamination of sample line.

4.4.3.3 Expulsion Testing

The following step by step procedure describes a typical liquid hydrogen (LH_2) inward expulsion cycle.

Several simulated expulsion cycles were made after installation (or re-installation) of the bladder, using cold H_2 gas inside the bladder and cold helium gas outside the bladder.

Fill

1. Set storage dewar pressure regulator at 12 $\pm$ 3 psi. Do not proceed until this pressure has been attained.
2. Set inside and outside bladder pressure regulator at 0.
3. Open inside bladder LH_2 valve to fill bladder with LH_2.

Reduce storage dewar pressure if pressure inside bladder exceeds one psi. Continue fill until liquid level is inside the bladder stem assembly. Close inside bladder LH_2 valve. Promptly perform following expulsion procedures.

Expulsion

4. Set inside bladder pressure regulator at 2 psi and outside bladder pressure regulator at 3 psi.

   NOTE: Do not exceed ΔP of one psi across bladder at any time during expulsion.

5. Open helium cooling valve and check that helium control PRV is closed (0 psi).

6. Open outside bladder helium gas valve and increase setting of helium control PRV as necessary to approach ΔP of one psi across bladder. Helium gas on outside of bladder will force LH_2 from bladder, through bladder stem assembly and through the open inside bladder pressure regulator (valve) to vent.

   NOTE: Increase pressure momentarily as permissible and as necessary to suppress boiling of LH_2 to enhance observation or photography.

7. Decrease setting of helium control PRV as end of expulsion cycle is approached and close same when expulsion is completed.

8. Make inter-cycle leak check as described in Paragraph 4.4.4.

9. Set inside and outside bladder pressure regulators at 0 psi to secure system until subsequent operation. Place storage dewar in standby mode.

It should be noted that the various pressures and settings given above are median values and were intentionally exceeded at times to satisfy particular test parameters or conditions.

Operational Parameters

The Task II test plan directed that complete liquid hydrogen (LH_2) expulsion cycles per the above procedures be repeated until 25 cycles had been completed except as follows:

1. Interrupt expulsion testing at the end of every five complete cycles and perform bladder leak test in the permeability fixture until a correlation between inter-cycle leak check and actual ambient bladder permeation rates was established.

2. Observe the degree of inter-ply LH_2 permeation during all periods of overnight (or comparable) warm up.

3. Vary expulsion parameters at times directed by the Beech project engineer as follows:

   a) Expel at flow rates from 0.1 gpm to 0.5 gpm for one cycle.

   b) Expel at maximum flow rates (but not to exceed 10 gpm) for one cycle.

   c) Impose high fill rates, sudden depressurization and high venting rates upon the bladder in the course of two cycles.

The correlation described in Step 1 was never fully attained, so ambient temperature permeability tests were performed at regular intervals on all of the bladders.

Post Test

Upon completion of the LH_2 expulsion cycles, the bladder was removed from the expulsion test apparatus and given the final permeability testing. Each bladder was finally given a thorough examination which included a ply-by-ply dissection. The post test examinations are fully described in Subsection 4.5.

4.4.4 Inter-Cycle Leak Check

It was anticipated that an inter-cycle leak check by means of a mass spectrometer (MS) helium leak detector would provide positive indication of bladder permeability and incipient failure.

The MS helium detector was calibrated prior to each daily series of expulsion cycles. The air pump was operated during the test series to pull the sample of the expelled gas through the sampling line and past the point where it was "sniffed" by the MS helium detector. The sample valve was opened immediately prior to the daily test series to provide MS indication throughout the time that liquid hydrogen was being expelled from the bladder.

The MS readings generally followed a set pattern for the various bladders as follows. There was essentially no helium indication when expulsion was first initiated because the boil off from LH_2 fill and the air pump combined to clear the sample line of residual helium from the preceding expulsion cycle. This no-indication condition continued through the first portion of the expulsion cycle. Helium was first indicated in the last portion of the expulsion cycle with indication continuing then in an increasing amount. The reading showed a sharp increase within 10 seconds after completion of liquid expulsion, going off scale in the majority of cases before expulsion was completed.

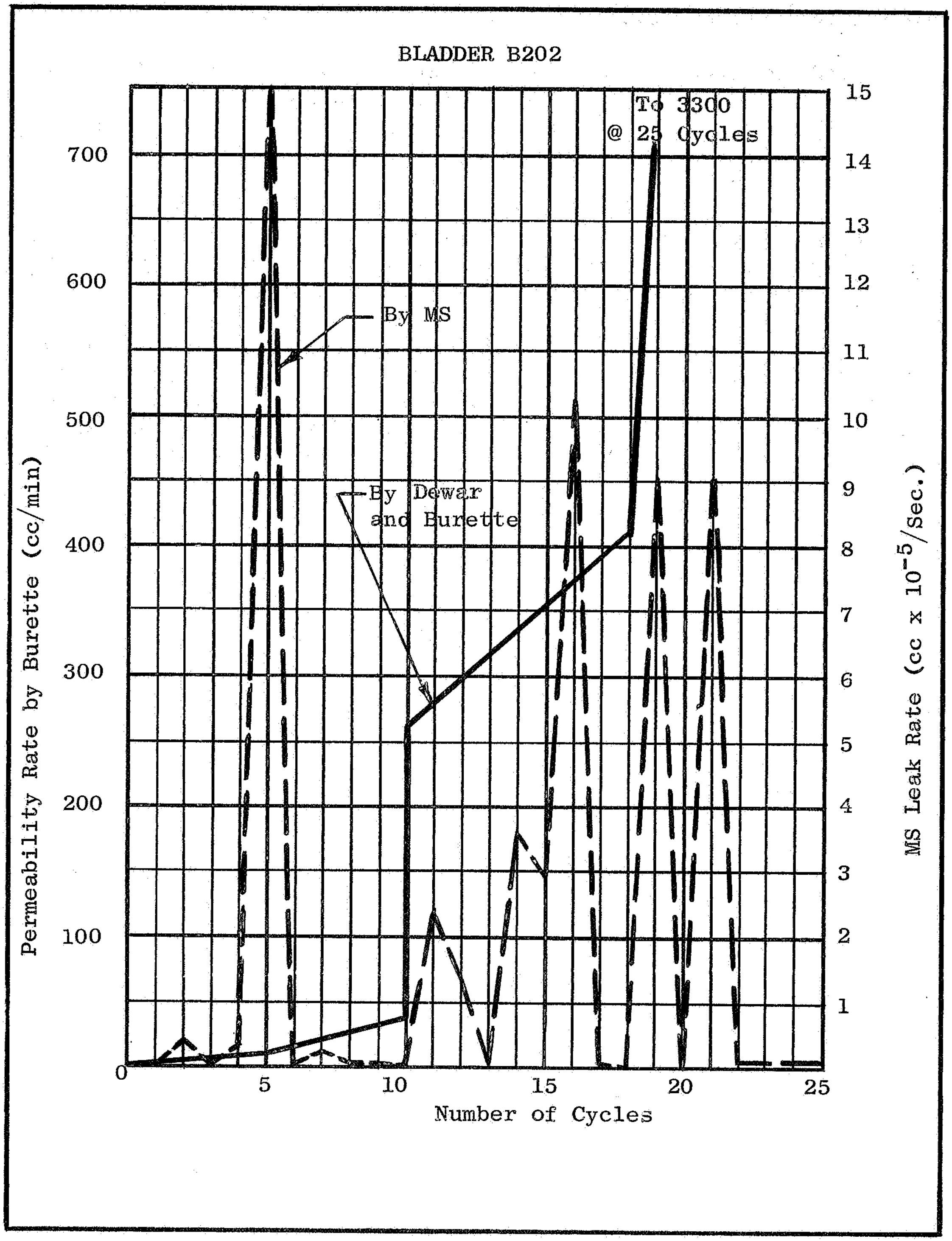
MS readings were taken at regular intervals during the period of liquid expulsion. The multiple readings generally showed an orderly increase in helium indication for each cycle of liquid expulsion. These readings had to be converted into a single, representative value to permit comparison of helium leak rates for successive expulsion cycles. Following careful study of the MS reading profiles for numerous individual expulsion cycles, the reading taken at 75% to 85% of the total time for actual liquid expulsion was selected to be used as the one permeability reading representative of that cycle.

The inter-cycle leak check produced erratic results which could not be realistically correlated to the results of other methods of permeability (leak) testing. Figure 4.14 presents, as a typical example, the permeability profile of bladder B202 as determined by the inter-cycle leak check and a leak test at ambient temperature in the dewar. In view of such inter-cycle leak check results, the ambient temperature permeability test at regular intervals was used to determine the permeability profile for each bladder. The inter-cycle leak check was continued for all bladders to insure that potential data was not overlooked.

Analysis has failed to establish the exact cause for the erratic results of the inter-cycle leak check. The MS method probably was not able to provide adequate indication of the helium leakage through the bladder at cryogenic temperatures. Though the reading was taken at a fixed time during each cycle, the erratic readings presented the appearance that successive expulsion cycles had been sampled at different times relative to some significant point in the cycle. The variations could conceivably result from changing fluid concentrations within the interstial spaces of the bladder plys, which might change rapidly (at cryogenic temperatures) from pure hydrogen to a hydrogen-helium mixture.

FIGURE 4.14

BLADDER PERMEABILITY PROFILES BY VARIOUS METHODS



4.4.5 Expulsion Data

The data of each expulsion cycle upon one bladder was recorded on a special form which provided for entries as follows:

> Bladder number, cycle number, date, inside and outside bladder pressure controller settings (also ΔP across bladder), fill pressure (of storage dewar), fill time, helium pressure regulator setting, expulsion time, per cent of expulsion, and remarks.

The vent back pressure during expulsion was noted after installation of the vent manometer. Except for the earlier bladders, the per cent of liquid fill was also noted if the fill was less than 95 per cent.

Cycle-by-cycle observations of each bladder were also recorded, noting the general expulsion characteristics of the bladder, together with any unusual or unique behavior. A complete history was also maintained for each bladder. The bladders were photographed before testing, and additional photos were also made of several bladders during and after expulsion testing.

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4.5 Expulsion Test Results

This section will provide a detailed account of the liquid hydrogen expulsion testing of the ten bladders. A brief summary of the results of LH_2 expulsion testing is presented in Table 4.1 providing a comprehensive insight of the overall results of the program.

SUMMARY OF BLADDER EXPULSION TESTS

TABLE 4.1

Bladder	L H_2 Cycles	Final Perm. (cc/min.)	Performance and Remarks
Merfab/Mylar - 22 Plys (See Figure 3.41) Sea-Space Systems, Inc.			
B101	25	5800	Excellent expulsion performance; severe fill problem eliminated by deletion of nine failed plys; early and extensive failure of Merfab substrate plys.
B102	25	18	Lowest permeability rate of all bladders; severe interply inflation; flow restriction resulted in poor fill and expulsion behavior; severe damage to Merfab plys only; nine plys deleted because of failure.

TABLE 4.1 (contd.)

Nomex/Mylar - 13 Plys (See Figure 3.43); G. T. Schjeldahl Company

B201	5	500	Failure of bladder-to-stem seal; field repair was not successful.
B202	25	3300	Fair expulsion performance; serious LH_2 fill problems; substantial leak rate.

Dacron/Mylar - 13 Plys (See Figure 3.44); G. T. Schjeldahl Company

B203	15	28,000	Fairly good expulsion performance; fair fill behavior; six plys deleted (because of failure) after Cycle 9; unable to expel due to high leak rate during Cycle 15.
B204	25	17,000	Sub-normal expulsion performance, improved considerably by deletion of six plys; poor fill behavior; difficult unified bladder action due to easy penetration of Dacron by LH_2 and helium gas.

Mylar - 10 Plys (See Figure 3.42); G. T. Schjeldahl Company

B205	25	28,000	Excellent fill performance; excellent expulsion, especially in view of poor bladder condition and excessive leak rates after Cycle 10.
B206	25	180*	The most trouble-free operation of all 10 bladders; excellent LH_2 fill; good expulsion performance; third best (lowest) permeability.

*After stem seal leakage eliminated.

Nomex/Kapton - 13 Plys (See Figure 3.45); G. T. Schjeldahl Company

B207	25	80	Second best (lowest) permeability rate; extreme problems in filling inside of bladder with LH_2; very good inward expulsion; four near-perfect outward expulsion cycles (99% fill and 99% expulsion).

TABLE 4.1 (contd.)

B208	25	240	Good expulsion behavior; comparatively low permeability rates; very poor LH_2 fill and excessive interply inflation for inward expulsion; excellent and problem-free outward expulsion performance.

4.5.1 Format for Detailed Reports on Expulsion Tests

The following paragraphs provide a comprehensive report of the LH_2 expulsion testing of the experimental bladders. This information is presented by means of a standard format. Each of the five material composites is defined and described. Detailed information concerning the testing of each individual bladder is then presented in the following categories and order:

a. Initial condition
b. Expulsion testing described by the individual cycle or by series of cycles
c. Post-test condition
d. Summary of test

This is followed by test conclusions for each of the material composites which were tested in the form of bladders.

4.5.1.1 Terminology

Expulsion test procedures and operations are described in detail in Subsection 4.4. However, several terms which will be employed in the following paragraphs deserve explanation at this point.

Expulsion Percentages

The degree of LH_2 fill into the bladder and the degree of expulsion from the bladder are expressed in percentages of the nominal capacity of the bladder or dewar (12 liters). Thus, a 50% fill would result in the bladder being one-half full (6 liters) of LH_2 (assuming that the internal volume of the bladder has not been reduced by interply inflation). Expulsion of 75% indicates that the bladder has collapsed to a point where it has expelled 75% (9 liters) of its internal capacity and that 25% (3 liters) of its capacity remains unexpelled (again assuming that the internal volume is equal to the volume of the outer or observed ply). As another example, 40% expulsion would indicate that 60% of the bladder's volume (as determined by the observed ply) remains unexpelled.

Apparent incongruities of expelling a larger volume than had been filled or contained are readily explained by noting that the expelled volume may be either liquid or gas, while the fill percentage involves only liquid. A 50% fill followed by a 90% expulsion indicates that expulsion included at least 40% gas (assuming that the internal volume is equal to the volume of the outer or observed ply). It is anticipated that such a case would probably produce 6 liters of gaseous expulsion, followed by 4.8 liters of liquid expulsion, with a residual in the bladder of 1.2 liters liquid.

Reverse Expulsion

All expulsion was to the vent, except for several cycles which were expelled back to the storage dewar (after its gauge pressure had been reduced to zero). This expulsion back to the storage dewar is called "reverse expulsion."

Inward and Outward Expulsion

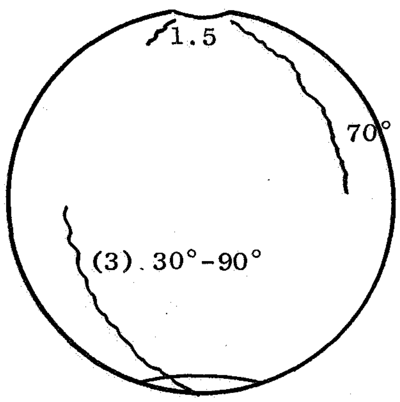
As previously stated, all but a few of the cycles were inward expulsion (the propellant inside the bladder and the pressurant on the outside of the bladder). Several cycles of outward expulsion were performed by collapsing the bladder tightly about the withdrawal tube and filling with LH_2 on the outside of the bladder. The pressurant is then introduced on the inside of the bladder and the bladder is expanded to obtain outward expulsion.

4.5.1.2 Ply Condition Data

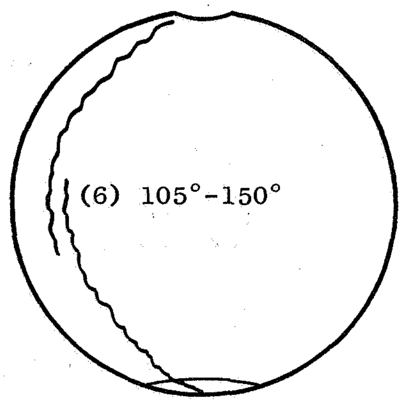
The visible damage suffered by the various plys of the different bladders is portrayed by a series of figures of a special format. Each page of these figures provides a number of sketches, each representing a single ply which is identified as to ply number and material. Any tears (and holes) are so marked on each ply as to reflect the total damage incurred by the ply.

The predominate damage to the various plys was in the form of tears which were basically on a vertical, great circle path. Such tears are indicated in the figures in the following manner:

4.5.1.2 Ply Condition Data (contd.)



Example A

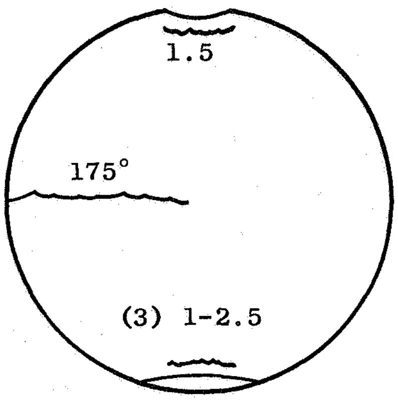


Example B

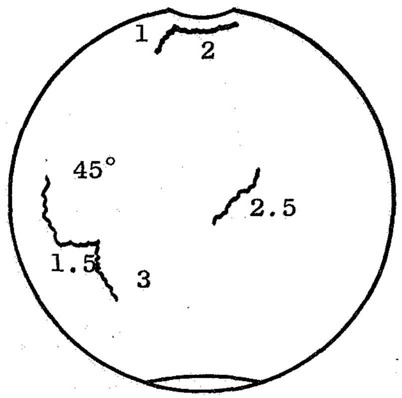
The upper portion of Example A above represents two vertical great circle tears of varying length. The length of the shorter tears are dimensioned in inches as shown for the 1.5 inch tear. Tears longer than 3 inches are shown in degrees representing the central angle of the tear (10° of central angle equals 1 inch of arc length). The lower portion of Example A indicates that three vertical great circle tears with central angles ranging from 30° to 90° originated from the lower pole of the bladder ply. In all cases, a numeral inside parentheses indicates the total number of a particular type of tear found upon the ply. Example B indicates that a total of six vertical great circle tears, each with central angles of from 105° to 150°, appeared on the bladder ply and originated from the stem area and from the (lower) polar area in more or less equal numbers.

Other damage encountered included tears which were basically in a horizontal plane, being a circumferential arc such as on the equator or parallel to the diameter of the stem assembly or the polar cap. These tears are indicated on the figures in the manner illustrated in Example C below. Diagonal tears and combination tears are indicated as appears in Example D.

4.5.1.2 <u>Ply Condition Data</u> (contd.)



Example C



Example D

Example C indicates a horizontal circumferential tear 1.5 inches long adjacent to the stem assembly, an equatorial tear with an included angle of 175° and three horizontal circumferential tears from 1 inch to 2.5 inches long parallel to and adjacent to the polar cap. The methods of indicating quantities and lengths of all tears are identical to those explained for the vertical great circle tears. Example D portrays two combination great circle-circumferential tears and one diagonal tear, with combination lengths indicated by elaboration of the method already described. Several additional markings are also improvised in the figures accompanying the individual test description.

4.5.2 BS15108 Type 1 Bladders (Figure 4.15)

Units: B101 and B102
Material category: Merfab/Mylar
Material composite: See Figure 3.41
Subcontractor: Sea Space Systems, Inc. (SSS)

Appearance:

These two bladders were identical in appearance. They were silvery in color, with small orange-colored dots (tooling match marks) centered on the lap seams. The mono-directional filaments of successive Merfab plys resulted in a diamond pattern due to their alternating angles. The diminshing transparancy of the multi-ply material produced an appearance of considerable "depth" to the composite. It was impossible to distinguish the liquid level within the bladders. The bladders produced a "feel" which was softer and more flexible than any tested under all programs at Beech.

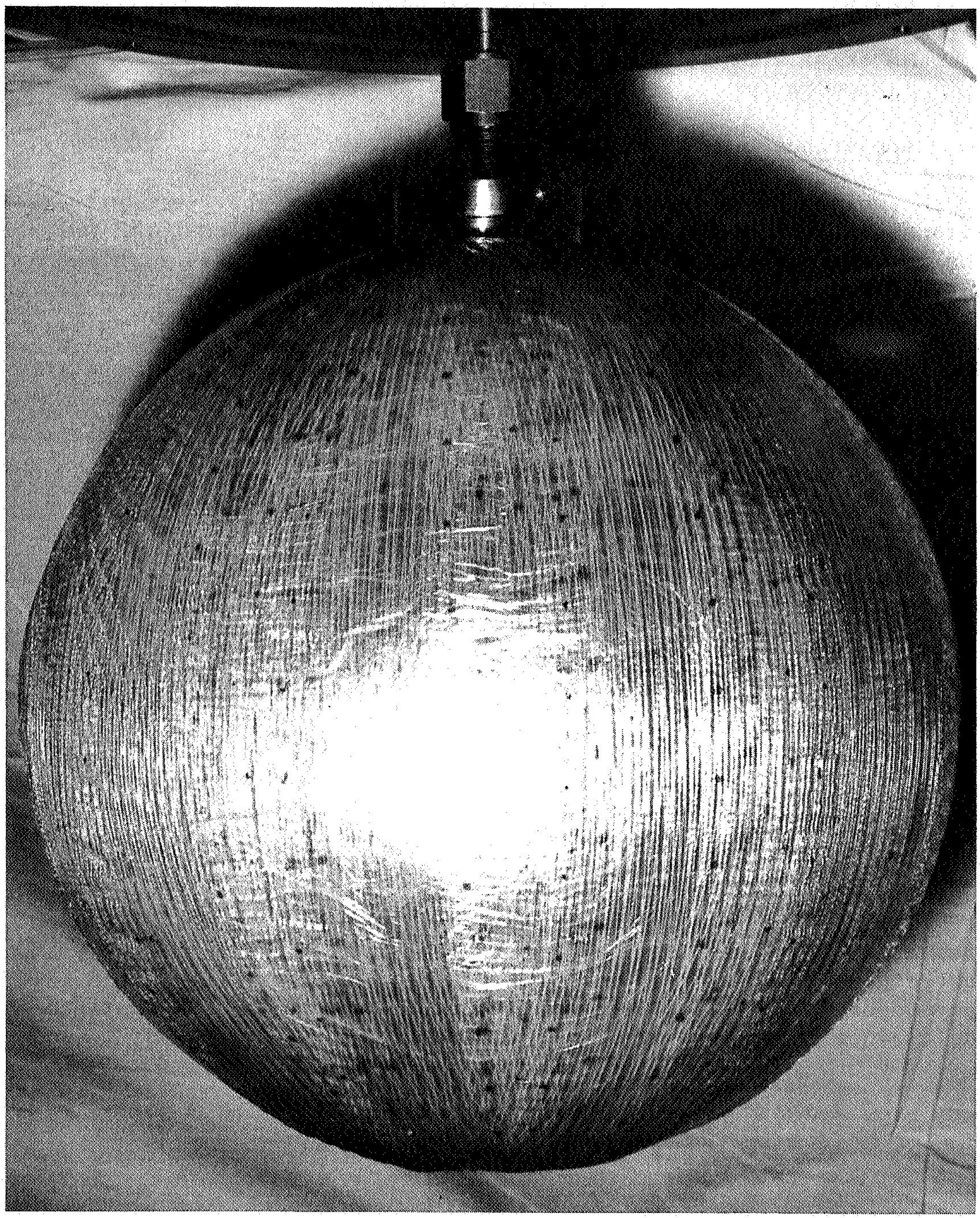
4.5.2.1 Bladder B101

a. Initial Condition

Bladder B101 exhibited no detectable leakage (by burette) in 30 minutes and measured 11.56 inches (11.50 $\pm$ .13 was specified) in diameter during the acceptance test at SSS. The bladder was out-of-tolerance in both of these items upon acceptance testing at Beech even though the bladder was hand-carried from SSS by Beech personnel and had received no damage in any manner. The bladder diameter was measured at 11.72 inches and it was noted that the outer ply was under pressure and stood out approximately .13 inch from the second ply. However, this pressure evidently permeated out through the outer Merfab ply overnight, and the bladder diameter was 11.59 inches when receiving inspection was resumed on the second day. The leak rate during the acceptance leak test at Beech was .43 cc per minute. Helium leak detection and a failure investigation suggested that this leak might be due to insufficient torque on the nut of the stem assembly and due to cold-flow of the bladder material "clamped" in the stem assembly. The torque on the nut was subsequently increased and the leakage was reduced to less than .1 cc per minute, which was within the tolerance for acceptance leak tests. Beech was then able to complete acceptance of the bladder. The bladder exhibited excellent workmanship.

FIGURE 4.15

BS15108 TYPE 1 BLADDER



MERFAB MYLAR

Bladder B101 (Merfab/Mylar)

b. LH_2 Expulsion Testing

Bladder B101 was one of five bladders which presented serious difficulties of installation into the dewar. Talcum powder was used in addition to the bladder collapsing and folding techniques described in Paragraph 4.4.3. In addition, a piece of Tygon tubing was positioned to lead into the dewar to provide a path for "venting" the air trapped at the bottom of the dewar by the introduction of the bladder. These measures were sufficient to enable bladder installation, though with considerable difficulty.

The following factors contributed to these additional installation problems. The Merfab outer ply exhibited a very high friction coefficient, especially against the glass of the dewar. This bladder also exhibited more "bulk" than any bladder previously installed in the dewar, due to the 22 plys and slight but unavoidable interply inflation.

Cycles 1 through 5:

Fill: 80%, 85%, 97%, 93% and 97% respectively
Expulsion: 97 to 98%
Permeability after Cycle 5: 14 cc per minute (also see Figure 4.16)

This bladder exhibited the best expulsion action of any bladder tested in all programs at Beech, except that the outer plys (Merfab) acted independently of other bladder plys. Considerable difficulty was experienced in removing the bladder from the dewar for permeability tests. The bottoms of Plys No. 1 and 2 (outer Merfab plys) were found to be ripped. The bladder was re-installed with Plys 1 and 2 in place in hope that they would continue to be effective as abrasion shields.

Cycle 6:

First attempt: The glass stopper lifted and then froze open shortly after LH_2 fill was begun. A part of Ply 1 was distended up into the neck of the test dewar, possibly blocking the outer vent orifice. After overnight warmup, the bladder was removed sufficiently to delete Plys 1 and 2. (Note: outer plys were usually deleted by cutting them off at the OD of the stem assembly as shown in Figure 4.17).
Permeability: 25 cc per minute.

70 - 1

FIGURE 4.16

PERMEABILITY PROFILE OF BLADDER B101
(MERFAB/MYLAR)

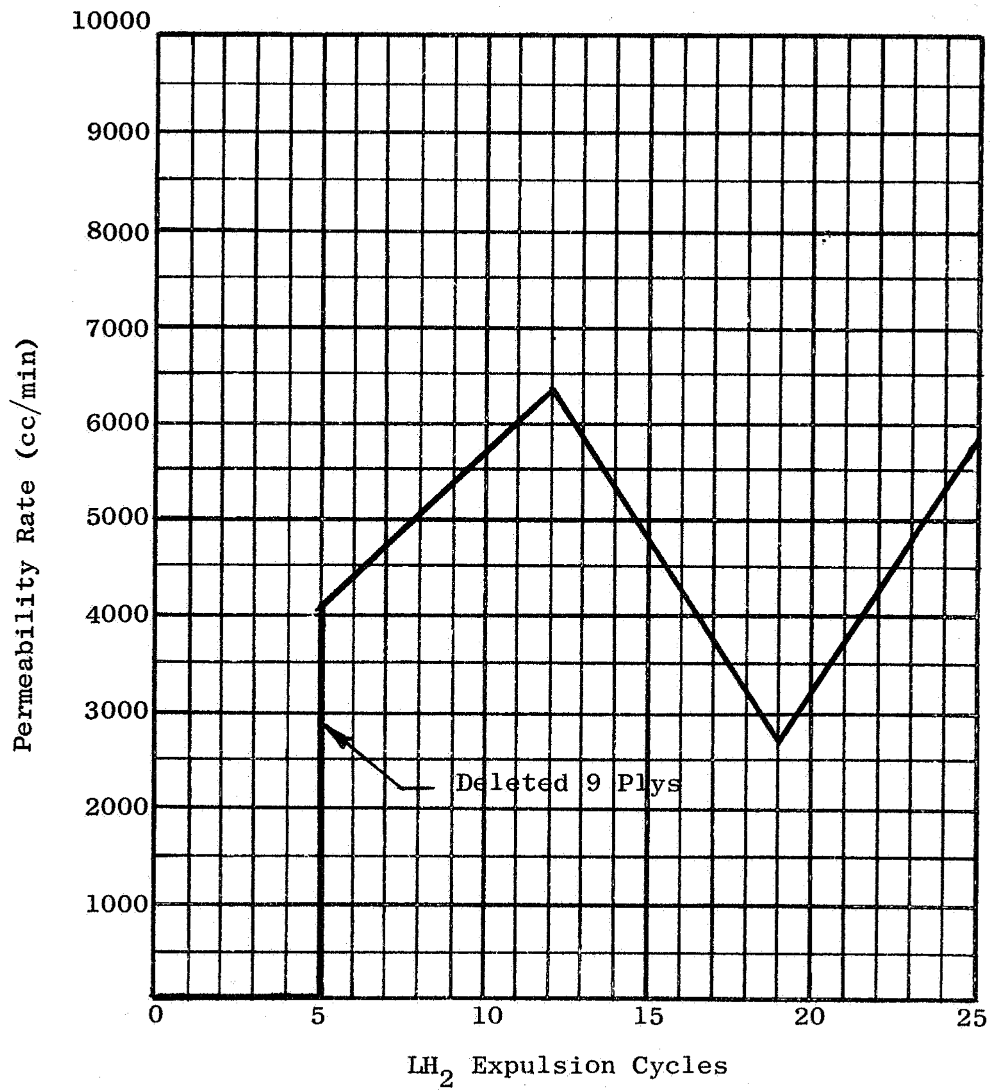
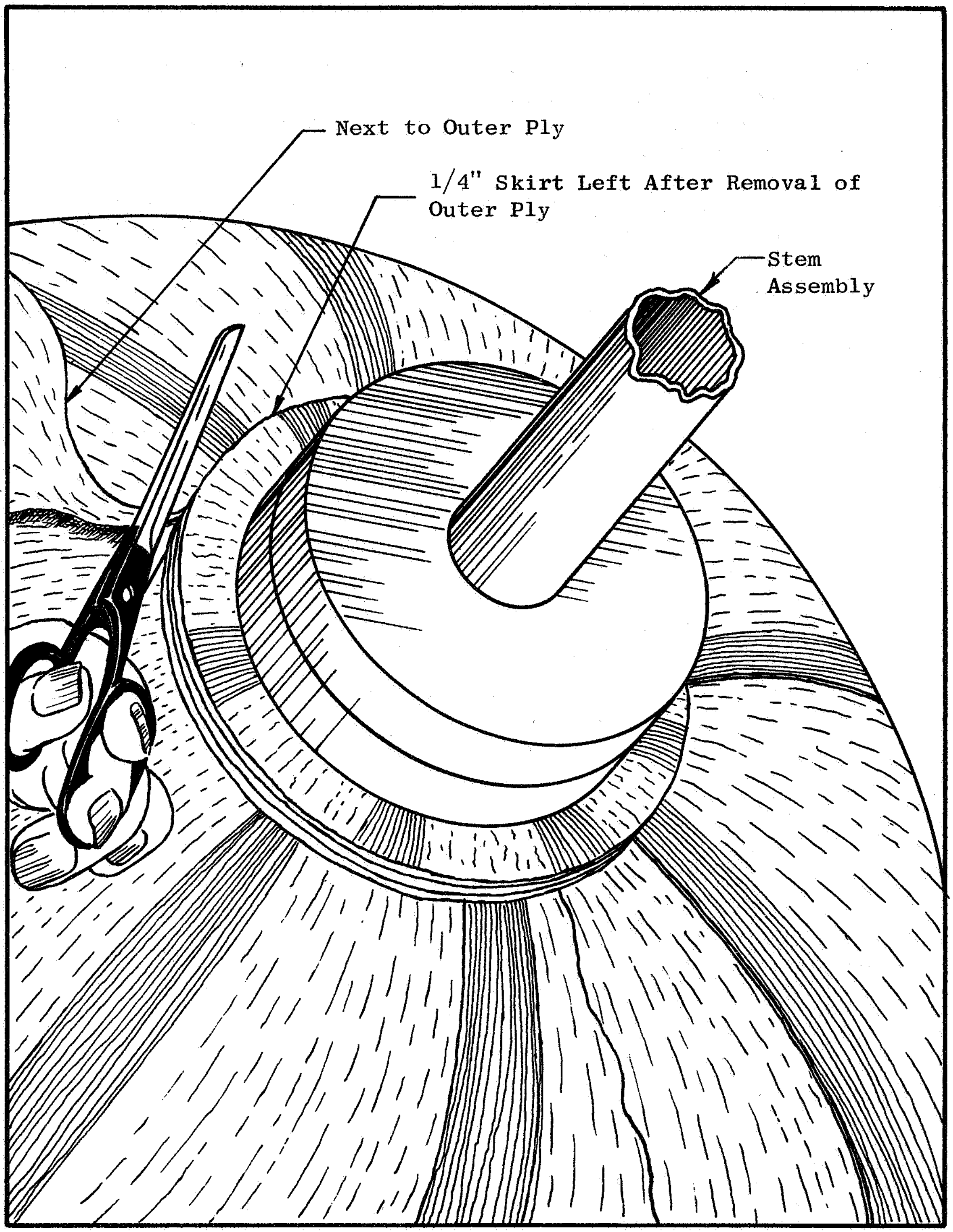


FIGURE 4.17

REMOVAL OF OUTER PLYS



Bladder B101 (Merfab/Mylar)

Second attempt: Unable to flow fluid through bladder; inside bladder pressure gauge (tapped off at vent line) read zero. Checked and determined that LH_2 flow was supplied to bladder and that vent line was open.

It was concluded that the inner Merfab plys (Plys 21 and 22) were jammed into vent orifice, prohibiting any flow through bladder.

Following warmup, bladder was removed and stem was loosened. Plys 21 and 22 were completely shredded so they were removed. Reassembled bladder and reinstalled in dewar.

Permeability: 37 cc per minute.

Third attempt: Every possible manner of fill was attempted for 1.5 hours but fluid flow through bladder was not possible.

Following warmup, the bladder was removed: - inner Mylar ply was protruding through bore of stem assembly, further indicating that inner plys were blocking vent orifice.

The following failed plys were deleted: 3, 4, 18, 19, and 20. Bladder was reassembled and reinstalled in dewar.

Permeability: 4100 cc per minute. This high leak rate was believed to be due to poor "lay" of inner plys on stem flange during reassembly but efforts to improve same were of no avail.

Cycles 6 through 12:

Fill: 99%
Expulsion: 98% (except 80% for Cycle 6)
Permeability after Cycle 12: 6350 cc per minute

Action and behavior was excellent during these cycles. Deletions of nine (of 22) plys appeared to correct fill problems.
Failed outer Ply 5 (Mylar) was removed.

Cycles 13 through 19:

Fill: 99%
Expulsion: 99%
Permeability after Cycle 19: 2750 cc per minute
(Lower leak rate could be attributed to better seating of plys on stem flange.)

Action and behavior continued to be excellent during these cycles.

Bladder B101 (Merfab/Mylar)

Cycles 20 through 25:

Fill: 99%
Expulsion: 98 - 99%
Final permeability after 25 cycles: 5800 cc per minute

Action and behavior continued excellent.

c. Post-Test Condition

Individual plys which were removed from bladder B101 during the course of expulsion testing were Plys 1, 2, 3, 4, and 5 from the outside of the bladder and Plys 22, 21, 20, 19, and 18 from the inside of the bladder. The remainder of the plys were carefully removed for examination after all expulsion testing had been completed. The condition at time of removal of the various plys is portrayed by Figure 4.18 (five pages) in the manner described in Paragraph 4.5.1.2.

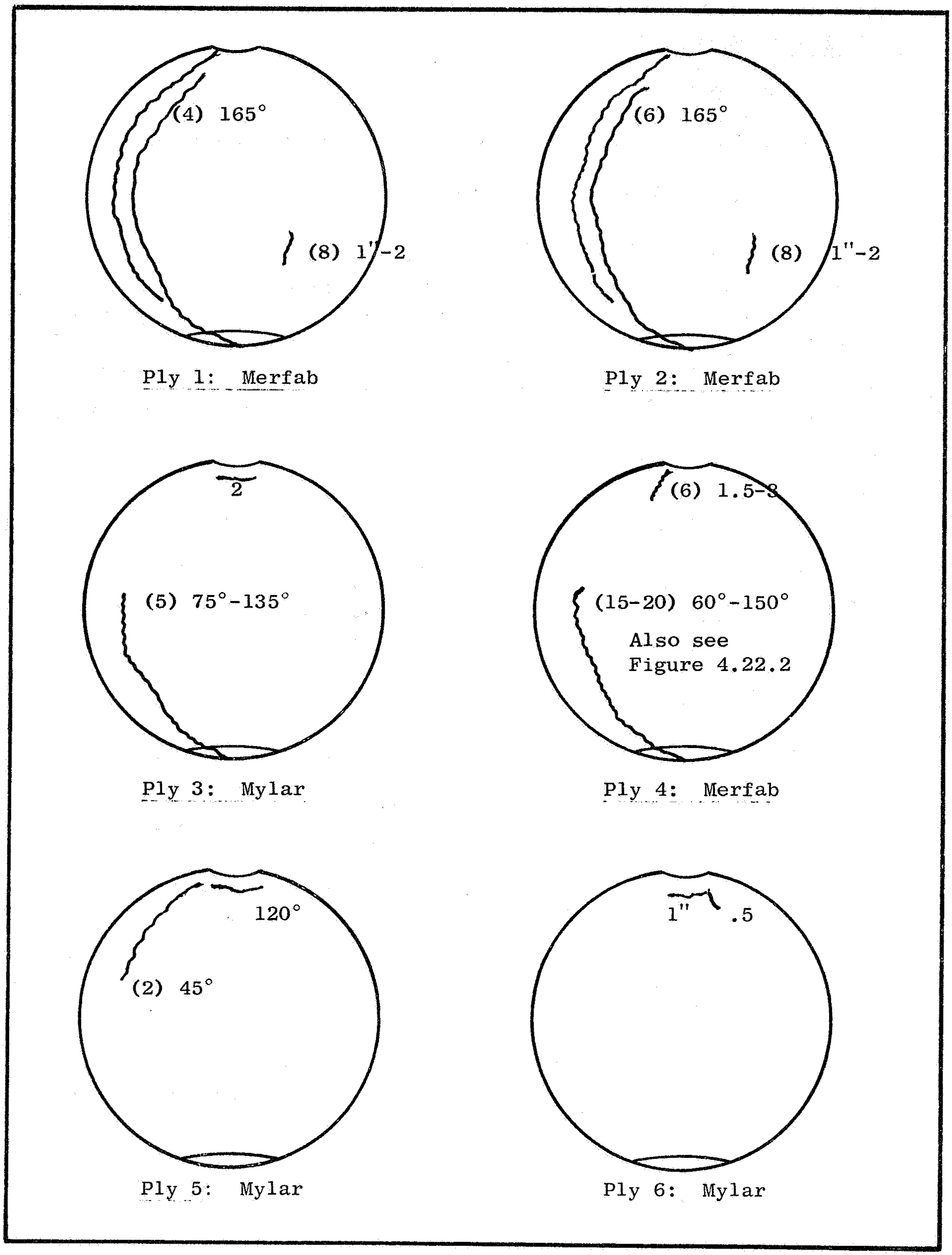
As shown in Figure 4.18 all plys suffered some amount of damage, with the most severe damage occurring to the outer plys. The plys midway through the material composite suffered the least damage. The Merfab plys incurred much more damage than the adjacent Mylar plys. Most of the Merfab plys exhibited very advanced failure, with long, mono-directional tears parallel to the filaments. Ply 10 exhibited the only tears in the Merfab which were normal to the filaments.

d. Summary

1. This bladder was restored to an operational status by the removal of nine of 22 original plys (41% deleted).
2. The fill characteristics of this bladder were considerably better with only 13 (or 12) plys in place than with the original 22.
3. The expulsion characteristics of this bladder remained very good in spite of some damage to each ply.
4. The LH_2 flex performance of this material composite was not as good as indicated by the testing of flat material samples in Task I.
5. The Merfab plys exhibited early failure and a high degree of damage. It is not possible to establish that the Merfab plys performed their intended function to enhance the operation of the Mylar plys.

FIGURE 4.18.1

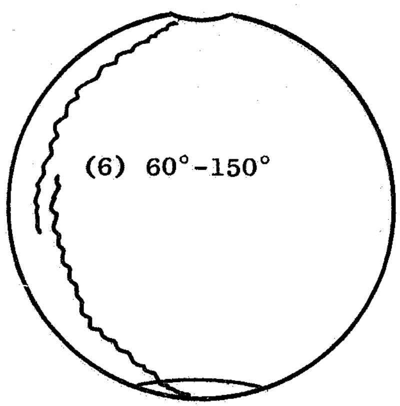
CONDITION OF PLYS: BLADDER B101



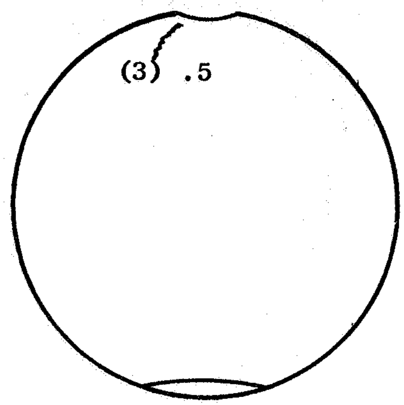
(contd.)

FIGURE 4.18.1 (contd.)

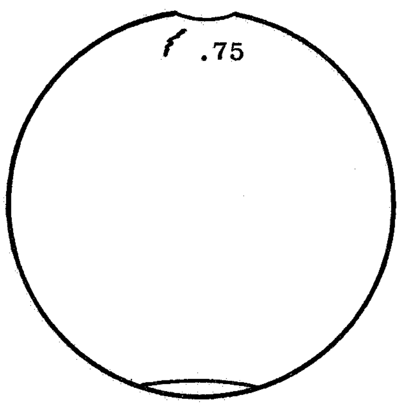
CONDITION OF PLYS: BLADDER B101



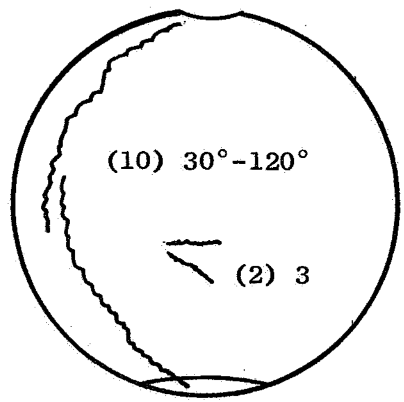
Ply 7: Merfab



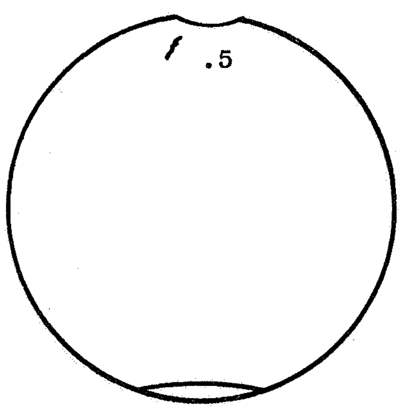
Ply 8: Mylar



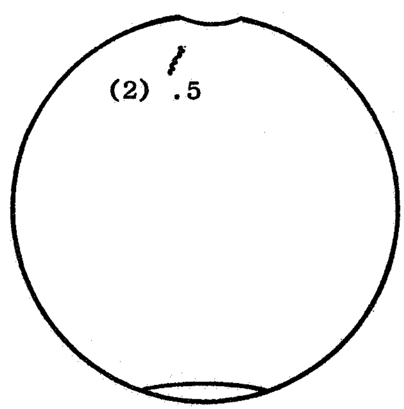
Ply 9: Mylar



Ply 10: Merfab



Ply 11: Mylar

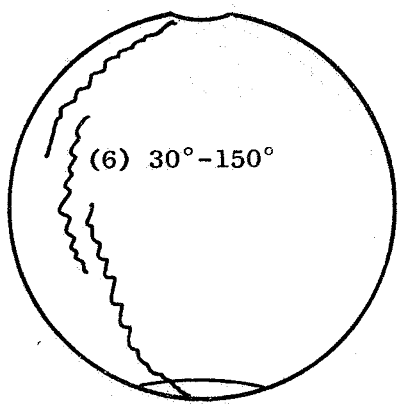


Ply 12: Mylar

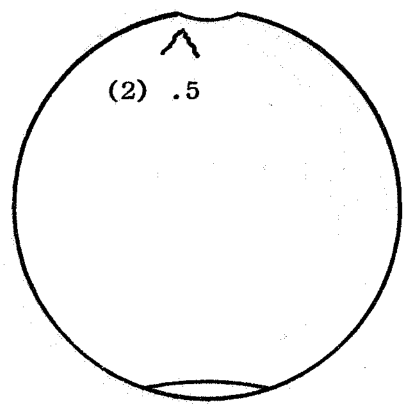
(contd.)

FIGURE 4.18.1 (contd)

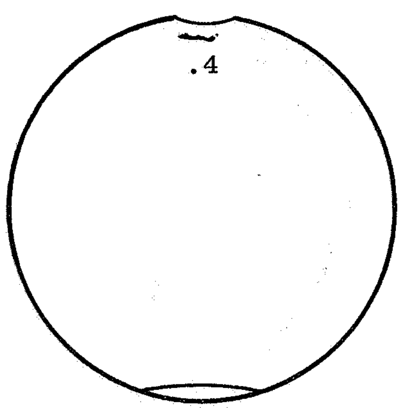
CONDITION OF PLYS: BLADDER B101



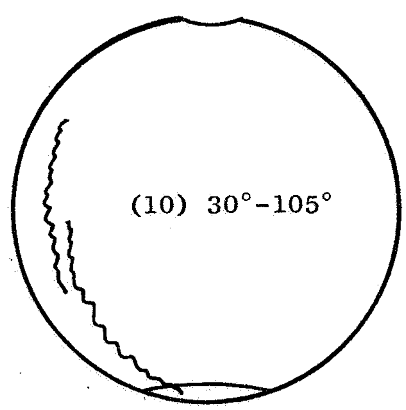
Ply 13: Merfab



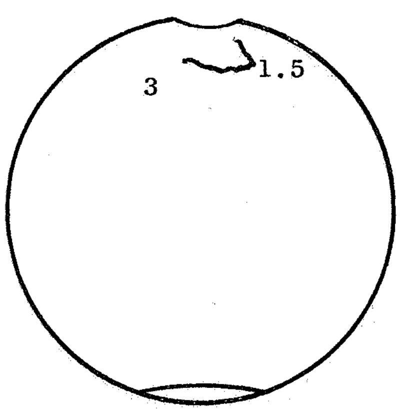
Ply 14: Mylar



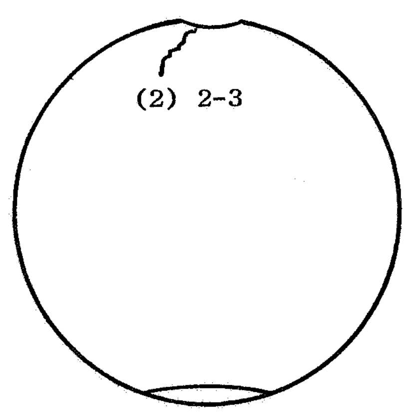
Ply 15: Mylar



Ply 16: Merfab



Ply 17: Mylar

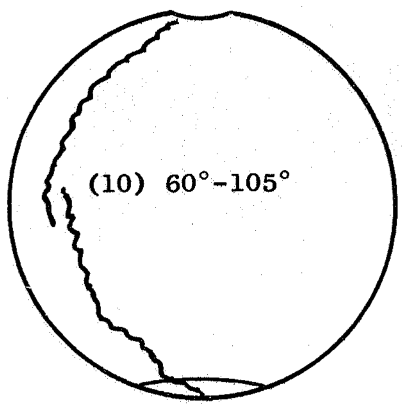


Ply 18: Mylar

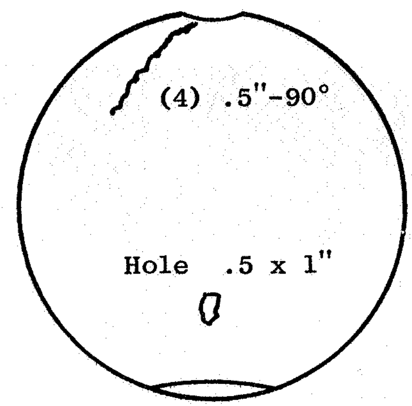
(contd.)

FIGURE 4.18.1 (contd)

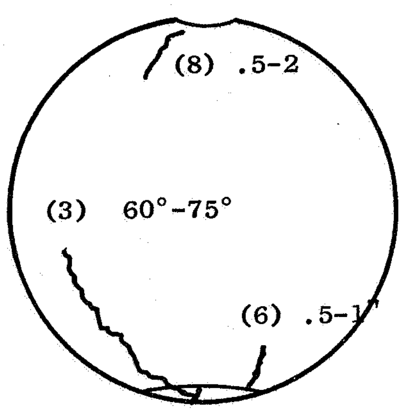
CONDITION OF PLYS: BLADDER B101



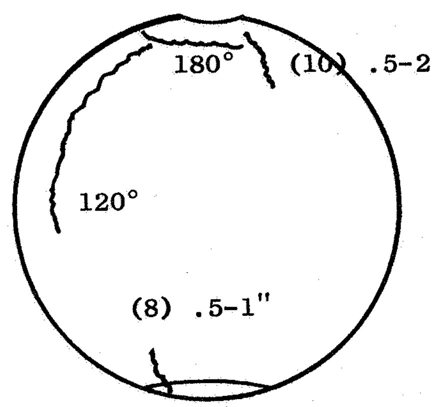
Ply 19: Merfab



Ply 20: Mylar



Ply 21: Merfab



Ply 22: Merfab

FIGURE 4.18.2

CONDITION OF PLYS: BLADDER B101

MERFAB/MYLAR

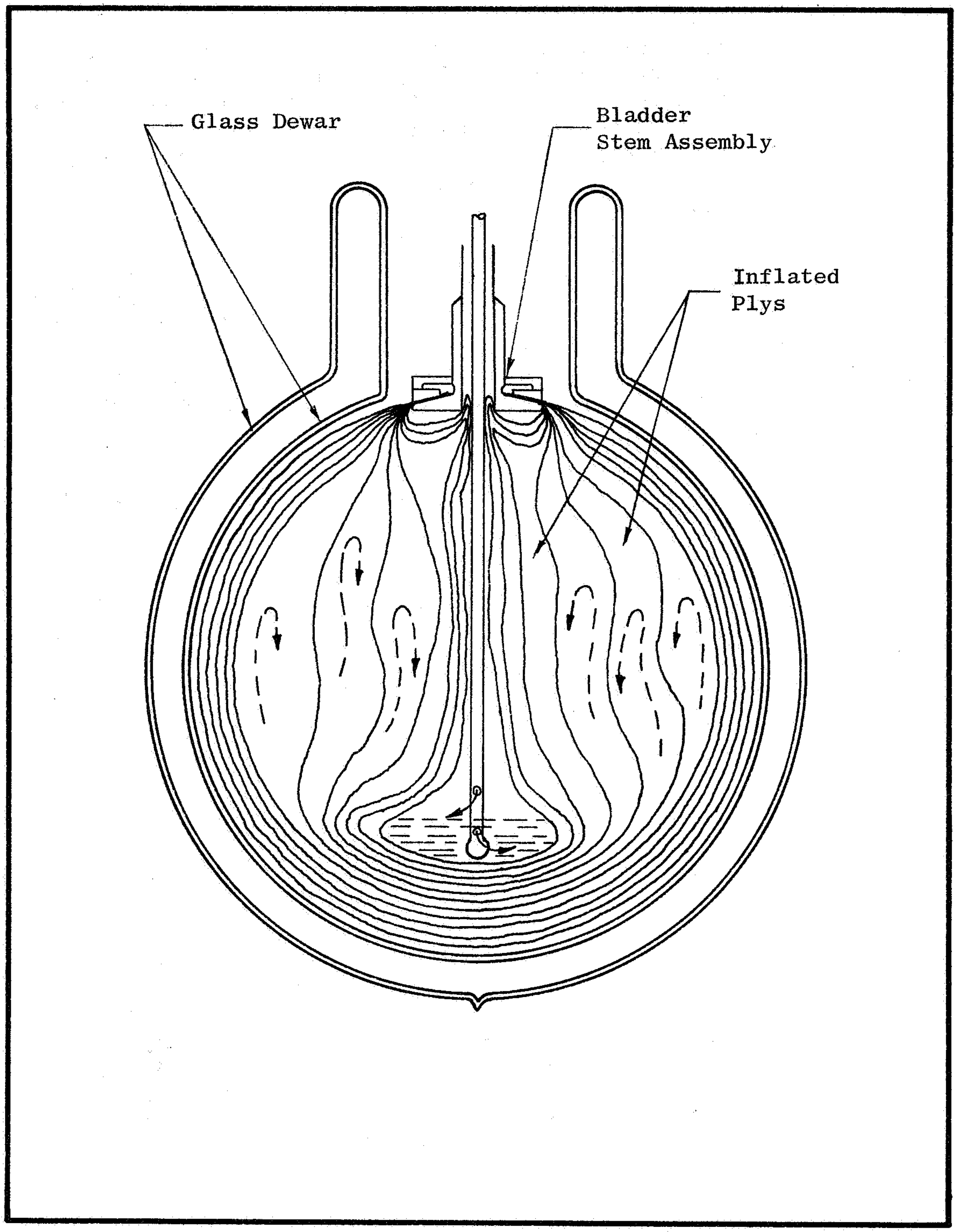
6. The inability to flow H_2 (as gas or liquid) through a bladder had never been encountered before in testing more than 50 bladders. It was first believed that the Merfab inner plys were fluttering up (due to tears or the extremely thin gauge) and blocking the vent orifice. This was further indicated when Plys 22 and 21 were found to be severely damaged. This could not be attributed solely to the Merfab, however, because when the next Mylar ply (No. 20) was exposed, the same fill problem still persisted. It was only after Plys 20, 19, and 18 were removed (again leaving a Mylar ply exposed) that the fill problem was eliminated and did not reoccur. Ply 17 did not incur the damage in the remaining 20 cycles that Plys 22, 21, 20, 19, and 18 did in only five cycles, suggesting that the vent blockage may have been due to causes other than a loose or displaced inner ply being carried into the vent orifice by the comparatively high velocity vent flow.

7. The problem mentioned in Item 6 could have been due to LH_2 permeation and the excellent insulation qualities of the 22-ply bladder. If interply inflation of .26 inch occurred within all interstial spaces of the 22 ply bladder, the dewar would have been entirely filled by the bladder alone. The insulative effects of a bladder expanded in such a manner would make it extremely difficult to cool all plys to LH_2 temperature (which would essentially eliminate all interply inflation as long as the cryogenic temperature were maintained).

   Interply inflation was undoubtedly present during the first five cycles to an extent sufficient to reduce the internal volume of the bladder, resulting in a fill of less than 12 liters. Interply inflation may have been sufficient, after re-installation of B101 for Cycle 6, to bring about the phenomena shown in Figure 4.19. Such a condition could develop in the following manner. The inner plys are expanded sufficiently to allow an initial flow of fluid from the holes near the bottom of the withdrawal tube, through the inside of the bladder and to the vent orifice between the stem bore and the withdrawal tube. It is believed that fluid (gas or liquid) permeation through the bladder plys increases as the plys are cooled by the fluid flow. An ever increasing mass of H_2 (first as cold gas, and eventually as liquid) penetrates into the inner series of interstial spaces. As the fluid penetrates deeper (or moves laterally between plys) it encounters warmer interstial gas and flashes to gas, which rises to the upper regions of the particular interstial spaces. This permeation/vaporization process continues until it results in the ply attitude shown in Figure 4.19.

FIGURE 4.19

BLADDER INTERPLY INFLATION PHENOMENA



Bladder B101 (Merfab/Mylar)

The successive interstial spaces contain more comparatively warm gas than can be cooled by the limited liquid mass. The gas inflating (inwardly) the top of the bladder is insulated from the cold vent gas by the inner-most plys of the bladder. The pressure inside of the bladder increases and the flow of cold fluid is arrested. The pressure finally forces the inner-most plys into the vent orifice, and it is blocked off. An increase in fill pressure only serves to perpetuate the cycle; excessive fill pressure results in raising of the glass stopper or, if the stopper is frozen into position, the pressure upon the dewar becomes prohibitive. Pressure inside the bladder can then be relieved only through the withdrawal tube. The pressure within the various interstial spaces can be reduced only by gas permeation through the successive plys.

The preceding phenomena was attributed to the excellent insulative qualities of 22 plys in a state of thermal isolation due to interply inflation. The mass of the cool H_2 was insufficient to penetrate the thermal barrier and cooldown (or condense) the large interstial volume. However, the insulative quality and interstial volume of the 13 ply bladder were reduced to a level where the cold fluid could achieve a cooldown to LH_2 temperature.

8. This bladder was very difficult to install into (and remove from) the test dewar.

4.5.2.2 Bladder B102 (Merfab/Mylar)

a. Initial Condition

Bladder B102 did not exhibit any leakage detectable by burette in more than 10 minutes during acceptance testing at SSS and at Beech. The spherical diameter of the bladder (11.45 inches) was well within tolerance. The bladder exhibited excellent workmanship.

As previously stated, an extra Mylar ply was added to the outside of the bladder to minimize the friction with the glass test dewar. The additional ply was considered to be a substrate ply and will be referred to as Ply A in the following description.

b. LH_2 Expulsion Testing

Bladder B102 presented problems of installation into the glass test dewar approaching those experienced with B101. The Mylar outer ply presented an improvement over the Merfab outer ply of B101. Repetition and practice also served to facilitate the installation of B102 into the dewar.

Cycles 1 through 5:

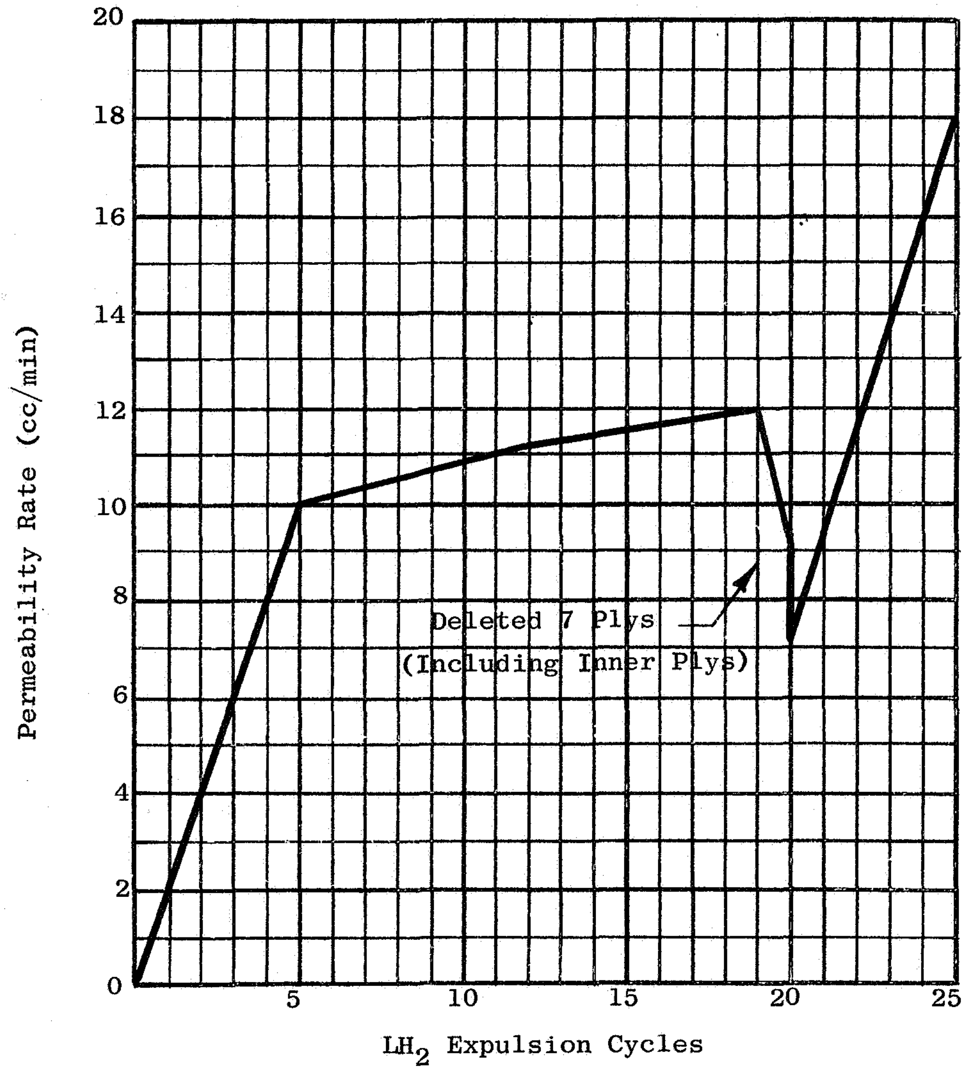
Fill: 70 to 90% and very slow
Expulsion: 99%
Permeability after Cycle 5: 10 cc per minute (also see Figure 4.20)

The bladder was very slow to fill, as if a normal flow rate was not achieved. On several cycles, LH_2 fill was facilitated by cooling the outside of the bladder with LH_2 to condense the gases causing the interply inflation. Expulsion performance was very good.

Advanced interply inflation was noticed when bladder was pulled up in dewar so as to permit disconnection for ambient temperature permeability test.

FIGURE 4.20

PERMEABILITY PROFILE OF BLADDER B102
(MERFAB/MYLAR)



Bladder B102 (Merfab/Mylar)

Cycle 6:

Fill: Stopper lifted at standard storage dewar pressure of 12 psi, though inside bladder pressure gauge indicated zero. This indicated that vent orifice was being restricted. It was possible to reseal stopper and 90% fill was achieved in approximately 1/2 hour at reduced pressure.

Expulsion: Rapid expulsion to 30% bladder collapse, then unable to expell further. Inside bladder pressure indication taken at vent line was zero, indicating vent orifice restriction by inner ply of bladder. All attempts to expel in normal manner were of no avail. Accomplished reverse expulsion cycle (back to storage dewar at 0 psi) of 99% expulsion, indicating that holes at bottom of withdrawal tube were not then closed off by bladder.

Cycle 7:

Fill: 90% in normal manner

Expulsion: Attempted normal (to vent) expulsion: slow expulsion rate of 50%, then unable to expel further. This suggested vent orifice blockage or interply inflation reduced the internal volume of the bladder.

Cycles 8 and 9:

Fill: 90% and 80% in normal manner

Expulsion: Initial attempts to expel in either direction (to vent or to storage dewar) were unsuccessful for both cycles. All possible measures were without success. Additional LH_2 fill was attempted as last resort to break fluid "lock up". Flow into bladder was finally achieved and reverse expulsion of 95% was then possible. The additional fill had evidently moved the bladder plys away from the holes in the withdrawal tube and further closure did not occur during the reverse expulsion.

Cycle 10:

Fill: 80%

Expulsion: 30% expulsion on initial try at reverse expulsion, then unable to expel any further. Made additional fill of LH_2 and was then able to slowly expel in reverse direction to 95% expulsion.

Bladder B102 (Merfab/Mylar)

Cycles 11 and 12:

Fill: 50 and 80%
Expulsion: 98% in normal (to vent) direction
Permeability after Cycle 12: 11.2 cc per minute

Poor fill was attributed to restricted flow through bladder. There was no change in expulsion procedures from previous cycles to produce such drastically different expulsion performance. Vent orifice blockage was evidently eliminated by unknown reduction in interply inflation, by self-removal of the restricting plys or by rupture of the restricting plys. Verification of any of these was not possible, but visual examination through the bore of the stem assembly after Cycle 12 did not reveal any discernible damage to the inner plys.

Cycle 13:

Fill: 95% - very slow fill preceded by tendency of stopper to relieve pressure in dewar
Expulsion: 45% expulsion in normal (to vent) direction, then to 98% by reverse expulsion back to storage dewar.

Cycles 14, 15, and 16:

Fill: 95% - very slow fill
Expulsion: 98% expulsion at varying flow rates. Cycle 14 was expelled in both directions (to vent and back to storage dewar) simultaneously at a flow rate of 4.5 liters per minute. The vent manometer indicated that expulsion to the vent was up to 40% of the total. Cycle 15 was expelled in the reverse direction and Cycle 16 was expelled to vent with decreasing flow rates.

Cycle 17:

Fill: 95% at good fill rate
Expulsion: 30% maximum expulsion in normal manner. Unable to expel additional amount by reverse expulsion. New pressure gage tapped into fill line at plumbing riser read zero, indicating that holes in withdrawal tubes could be closed over by inner plys.

Bladder B102 (Merfab/Mylar)

Cycle 18:

Fill: 95%
Expulsion: Initially unable to achieve any expulsion by normal or reverse manner or combination of the two. Prolonged application of pressurant resulted in 5% expulsion, but further expulsion was impossible. Examination under a strong light showed that outer plys were only 5% collapsed, while inner plys were collapsed to 95%. Therefore, 95% expulsion had been attained over a prolonged period of time. The observed condition could result from extraordinary interply inlation in one (or several) interstial space or from failure of those outer plys which were operating independent of the rest of the bladder. No tears were observed in the outer plys.

Cycle 19:

Fill: 95%
Expulsion: 93% (by inner plys)
Permeability after Cycle 19: 12 cc per minute

Three of the outer plys acted independently of the rest of the bladder during this cycle. Ply A (Mylar) exhibited major failure.

Plys 1 through 5 also were found to be failed when the bladder was removed for ambient temperature leak check. These plys were removed. Visual examination through the base of the stem assembly revealed that the inner ply had suffered serious damage. Plys 22 and 21 were subsequently removed from the inside of the bladder.

Cycle 20:

Fill: Only partial fill (approximately 50%) in one hour.
Expulsion: 95%
Permeability after Cycle 20: 9.1 cc per minute

Ply 6 (Mylar) was severely damaged after Cycle 20 and was deleted. Permeability after reinstallation into dewar was 7.2 cc per minute.

Cycles 21 through 25:

Fill: 80 to 90%
Expulsion: 50%, 60%, 40%, 45%, and 60%
Final permeability after 25 cycles: 18 cc per minute.

Bladder B102 (Merfab/Mylar)

The outside of the bladder was precooled with LH_2 for these five cycles, resulting in more rapid fills. All of the expulsion was in the normal manner (to vent) and was generally decreasing in expulsion percentage and overall performance. Ply 7 exhibited very advanced damage upon removal from the dewar and was deleted.

c. Post-Test Condition

Bladder B102 was comprised of Plys 8 through 20 only following completion of expulsion testing. A variety of subsequent tests were performed on this portion of the bladder to fully determine and analyze its post-test condition. The first of these tests was to attempt to reduce leakage through the stem, if any. This resulted in a total leak rate of 60 cc per minute, which was acceptable for the following comparative tests.

The bladder was permeability tested in the bell jar after each succeeding outer Mylar ply was removed (a Merfab ply was removed together with the succeeding Mylar ply). This resulted in a curve presenting the increase in permeability for the decrease in the number of plys as shown in Figure 4.21. The increase in permeability was quite orderly until the permeability of Ply 18 (the last intact ply) increased sharply to 16,800 cc per minute. It should be noted that Ply 18 is shown in Figure 4.21 as the fifth ply (of the original 22 plys) remaining on the bladder. Due to the transparency of the plys, it was possible to tell in advance when the last intact ply was being approached. The bladder was pressurized with helium to 28 inches of water (1 psi) except that the pressure was reduced for Plys 17 and 18 to produce consistent results. Plys 17 and 18 were tested at 24 inches and 16 inches of water respectively, with the result that Ply 18 was stressed to 11,000 psi, or approximately 85% of a tensile yield value of 13,00 psi. Ply 18 was later pressurized to 28 inches of water (resulting in a unit stress of approximately 19,000 psi) without failure, though the leak rate was beyond the capacity of the wet test meter.

The condition of all plys with visible damage was carefully diagramed upon removal as reflected by Figure 4.22 (3 pages). Many of the Mylar plys (Plys 8, 9, 11, 12, 14, 17 and 18) were without any detectable tears or holes and are not shown in the figure. This condition of the Mylar plys is consistent with the very low permeability of the bladder. The Merfab plys were in a state of very advanced failure, being practically in "ribbons." As in the case of B101, the tears in the Merfab were parallel to the filaments (see Figure 4.18.2).

The state of disarray of the inner Merfab plys is demonstrated by the following item of interest. The disection revealed that Ply 19 had been inadvertently removed after Cycle 19, instead of 21, as thought. Ply 21 was found in three loose pieces inside Ply 20.

FIGURE 4.21

PERMEABILITY VS. NUMBER OF PLYS: BLADDER B102
(MERFAB/MYLAR)

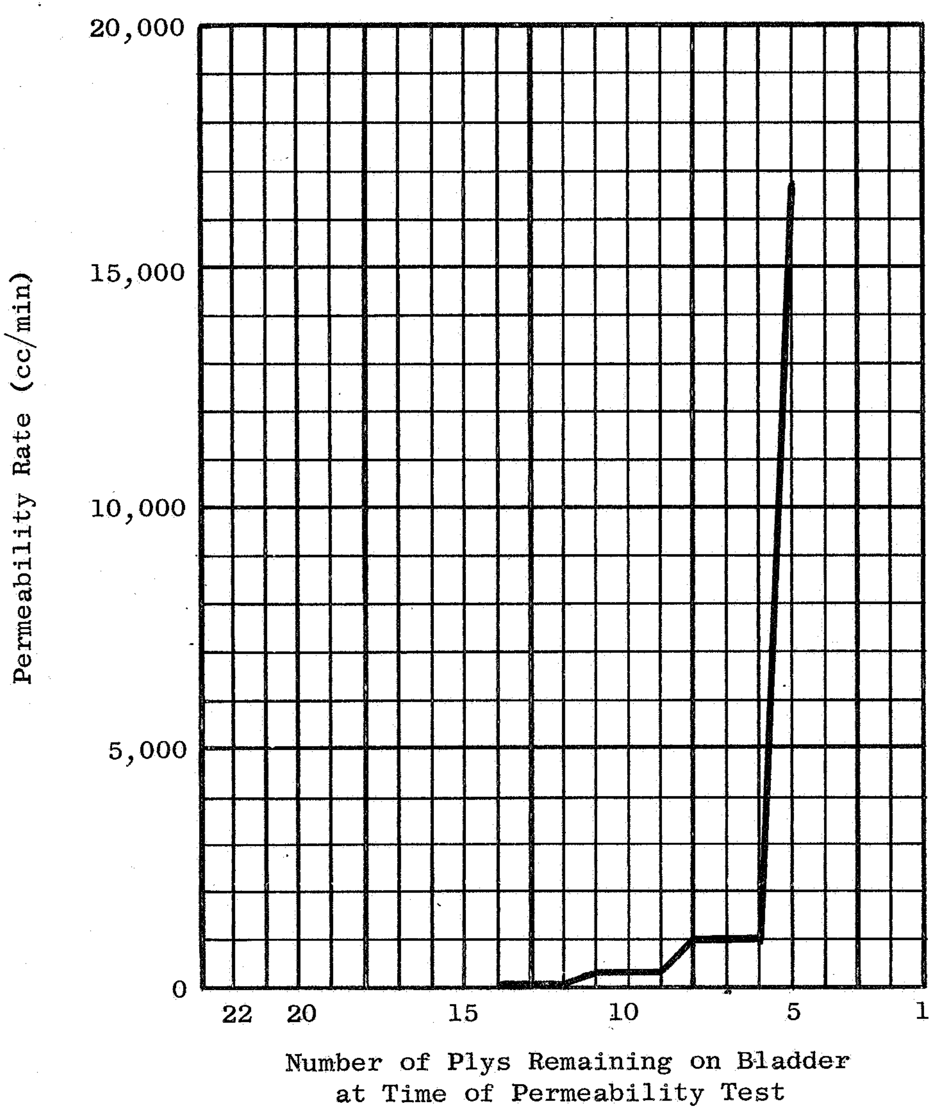


FIGURE 4.22

CONDITION OF PLYS: BLADDER B102

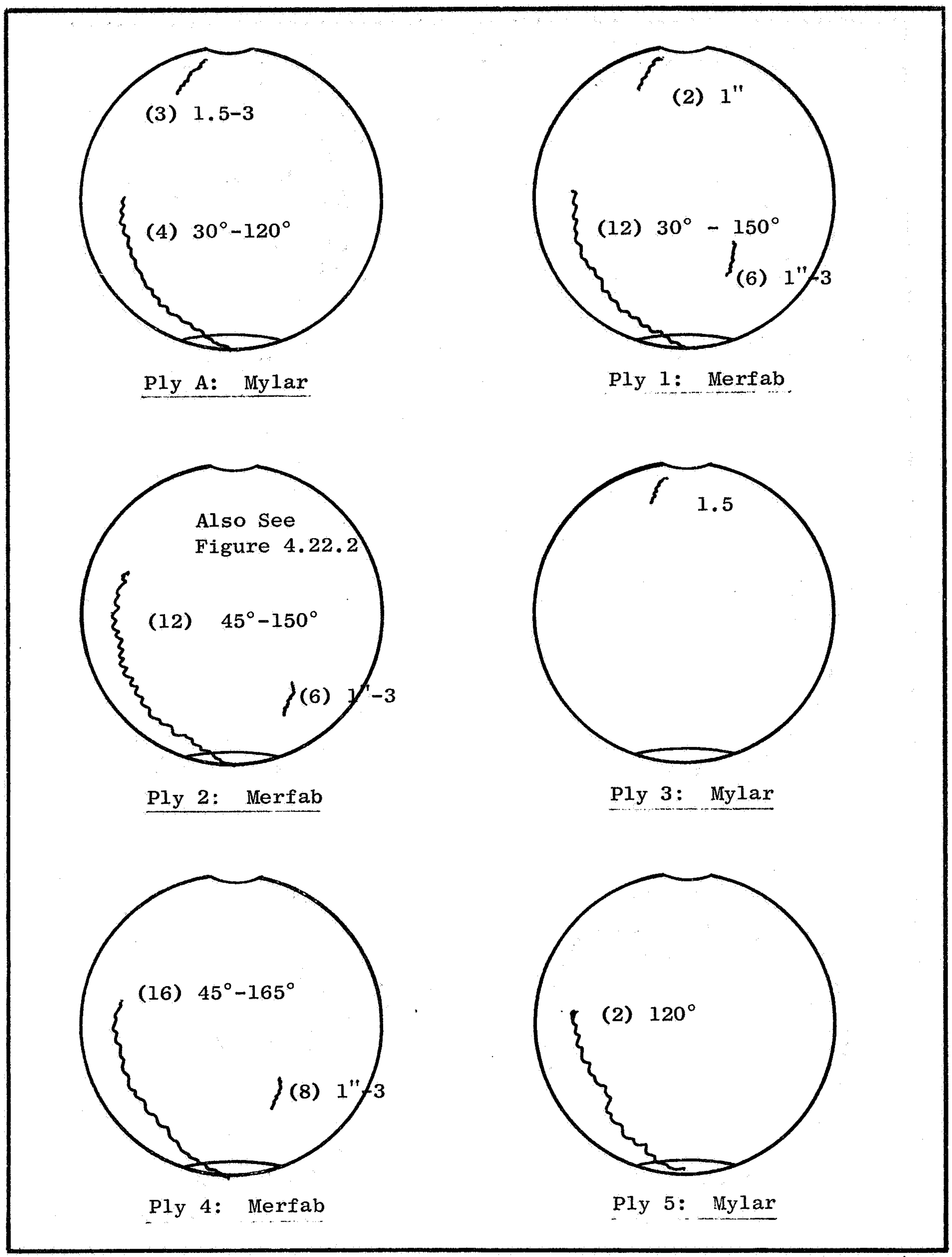


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FIGURE 4.22 (contd.)

CONDITION OF PLYS: BLADDER B102

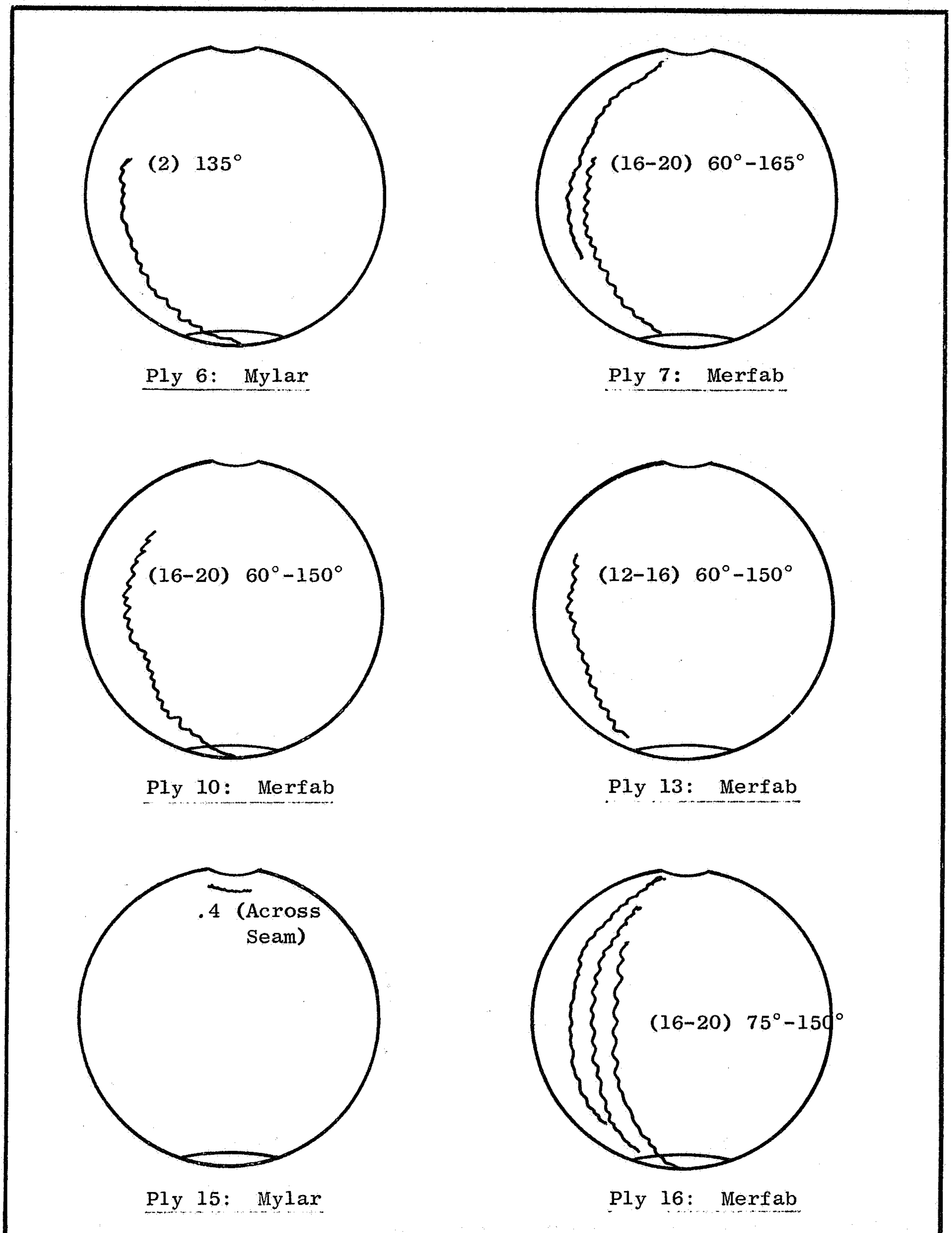

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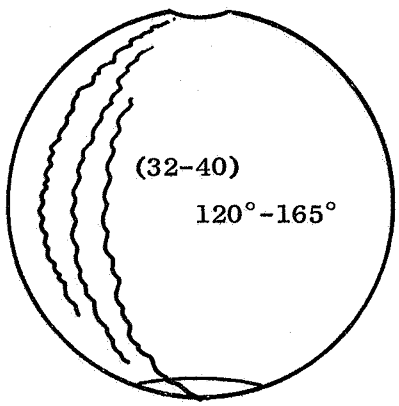
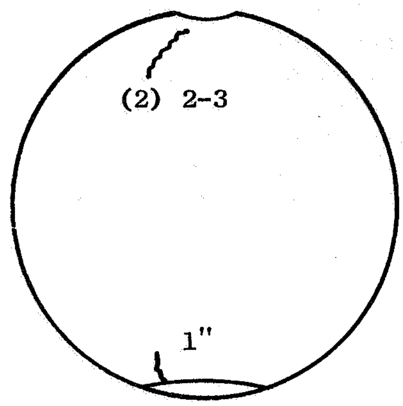
FIGURE 4.22 (contd.)

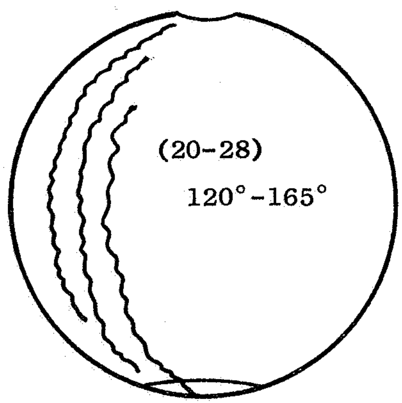
CONDITION OF PLYS: BLADDER B102



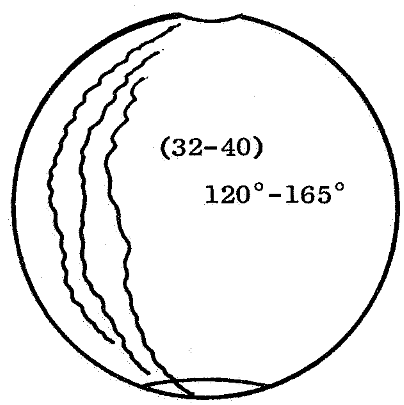
Ply 19: Merfab



Ply 20: Mylar



Ply 21: Merfab



Ply 22: Merfab

Bladder B102 (Merfab/Mylar)

A last test was performed to determine which of two areas had suffered the greatest wear: the area at the stem seal, or that at the (lower) polar cap. 4 x 11 inch samples were cut from barrier plys as shown in Figure 4.23, and identified as "stem area" or "polar area" samples. These were tested under helium pressure at 28 inches of water in the flat sample permeability test apparatus described in Section 3.0. The test results from three plys of Bladder B102 were as follows:

	Leakage in cc per Minute	
Ply No.	Stem Area	Polar Area
8	60	.2
12	50	6.2
17	2.4	.24

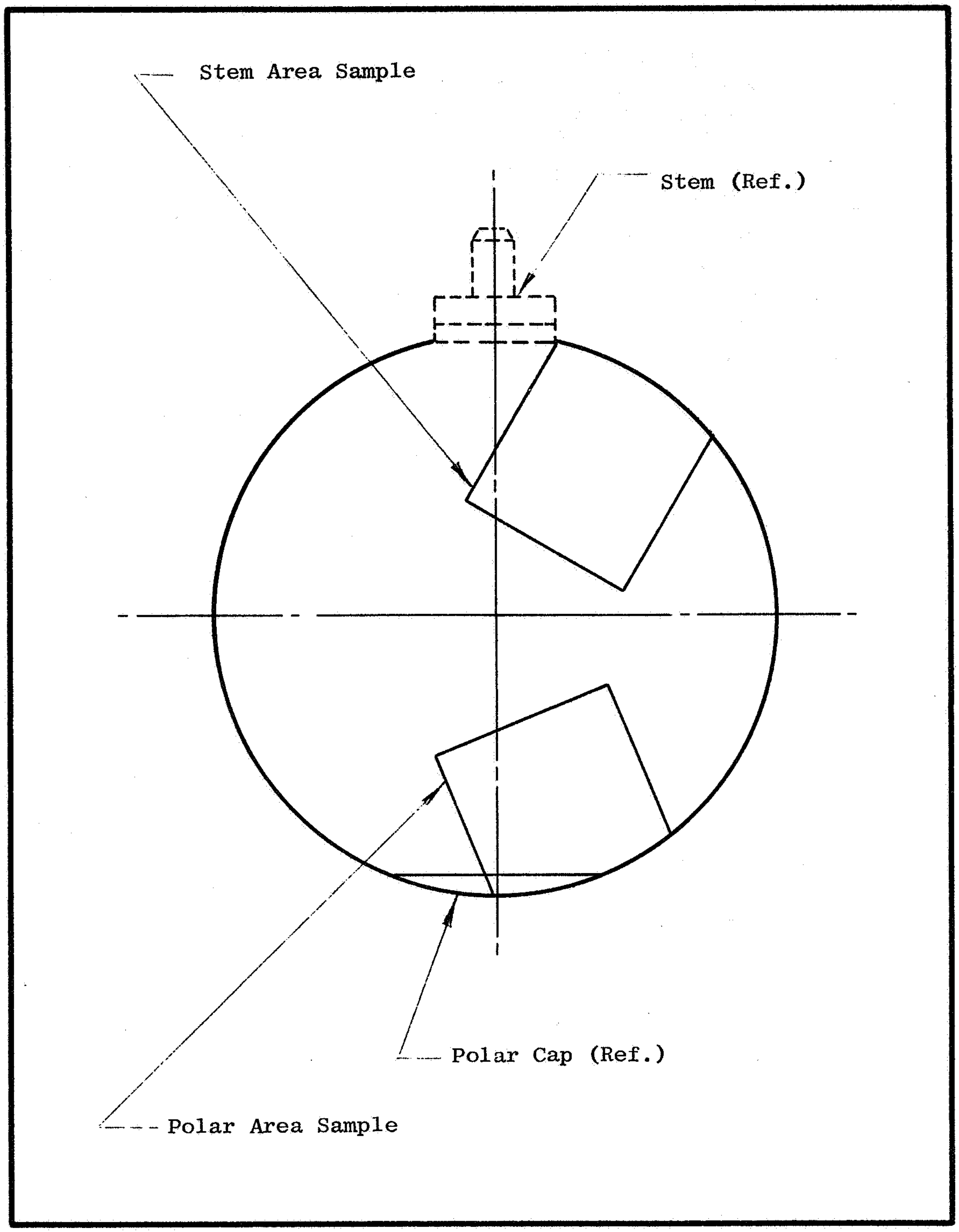
The above data indicates that the stem area encountered greater wear than the cap area.

d. Summary

1. Bladder B102 had the lowest permeability rate, by a significant margin, of all the bladders tested in this program.
2. This bladder showed only a small increase in permeability in the course of 25 LH_2 expulsion cycles.
3. The Merfab plys suffered even more gross damage than those of B101, while the intermediate Mylar plys remained in very good condition.
4. The fill and expulsion characteristics of this bladder deteriorated during the course of 25 LH_2 expulsion cycles, and were not appreciably improved by the deletion of eight plys.
5. Bladder B102 showed a basic fill characteristic of restricted fluid flow through the bladder, resulting in very low fill rates. The flow was never totally interrupted as for Bladder B101. Bladder B102 was often very difficult to fill to 90% of its capacity, or better. Precool of the outside of the bladder with LH_2 did not appear to increase the per cent of fill, but did result in a higher fill rate after eight plys had been removed.

FIGURE 4.23

RECTANGULAR PERMEABILITY SAMPLES FROM BLADDER PLYS



Bladder B102 (Merfab/Mylar)

The above fill behavior can be attributed to vent orifice restriction due to loose pieces of the thin film or due to interply inflation and also to internal volume reduction due to interply inflation. The fill problems are believed to arise from a combination (or varying combination) of the preceeding factors.

6. The predominate expulsion problem with Bladder B102 was the variable inability to expell in one or the other or both directions (to vent or back to the storage dewar). This behavior is partially attributed to vent orifice blockage and fill tube blockage due to loose pieces of the inner plys and due to interply inflation. This factor probably worked in combination with the excessive interply inflation phenomena described in Paragraph 4.5.1.1, d, 7. However, total immobility of the bladder was only temporary, since it was finally possible to overcome the operational deadlock by flowing additional fluid into the bladder. The blockage of the vent orifice or the "fill holes" in the withdrawal tube is partially attributed to loose plys rather than solely to interply inflation because one or the other blockage could eventually be cleared. It is believed that even a partial expulsion in one direction served to clear the blockage in the other direction.

4.5.2.3 Test Conclusions, BS15108 Type 1 Bladders

The comprehensive testing of Bladder B101 and B102 led to the following conclusions:

a. The overall expulsion characteristics of this 22 ply Merfab/Mylar material composite were substantially less than anticipated following the testing of Task I flat samples. The material composite did demonstrate a potential for low permeability.

b. The Merfab substrate plys failed to withstand LH_2 cycling and sustained damage ranging from advanced failure to massive failure. It is not established that the Merfab plys performed their intended function of enhancing the operation of the barrier plys.

Bladder B102 (Merfab/Mylar)

c. Bladder B101 had predominate fill problems while B102 demonstrated both fill and expulsion problems, even though the problems are attributed to the same factors (or combination thereof). These factors are vent and/or fill line blockage due to loose plys or due to interply inflation. Advanced cases of interply inflation can be induced by multi-ply polymeric bladders which present good thermal insulation but permit some fluid permeation at cryogenic temperatures.

d. Bladder B101 exhibited good operating characteristics as a 13 (or 12) ply bladder, suggesting that the optimum number of plys is nearer to 13 or 12 than 22. The deletion of 8 plys did not facilitate the operation of B102.

e. The problems presented by these bladders were not due to workmanship or bladder design, but due to the 22 ply material composite involved.

4.5.3 BS15753 Type 1 Bladders (Figure 4.24)

Units: B201 and B202
Material category: Nomex/Mylar
Material composite: See Figure 3.43
Subcontractor: G. T. Schjeldahl Company

Appearance:

These two bladders presented an identical appearance. The exterior Nomex plys presented an off-white, slightly fiberous appearance and were opaque. The comparatively heavy material resulted in a chordal effect, rather than a true sphere. The three Nomex plys gave the bladder a feel of considerable rigidity.

4.5.3.1 Bladder B201

Bladder B201 was the first bladder received and tested under this program.

a. Initial Condition

Bladder B201 was entirely within specification when received at Beech and exhibited no leakage detectable by the burette method within 10 minutes. The bladder reflected excellent workmanship.

Following acceptance, additional permeability testing was performed on Bladder B201 for longer periods of time to determine the exact influence of back pressure on the burette readings. This test established that the leak in B201 was less than 1 cc per minute, but stem seal repair was undertaken as described in Paragraph 4.2.2, Fabrication by G. T. Schjeldahl Company. The leakage of the bladder was reduced to .2 cc per minute in the course of the repair.

b. LH_2 Expulsion Testing

Bladder B201 presented some difficulties of installation into the test dewar, due to the bulk and rigidity of the three Nomex plys and due to considerable interply inflation which had accumulated during permeability testing. The development of installation procedures was initiated to minimize these problems.

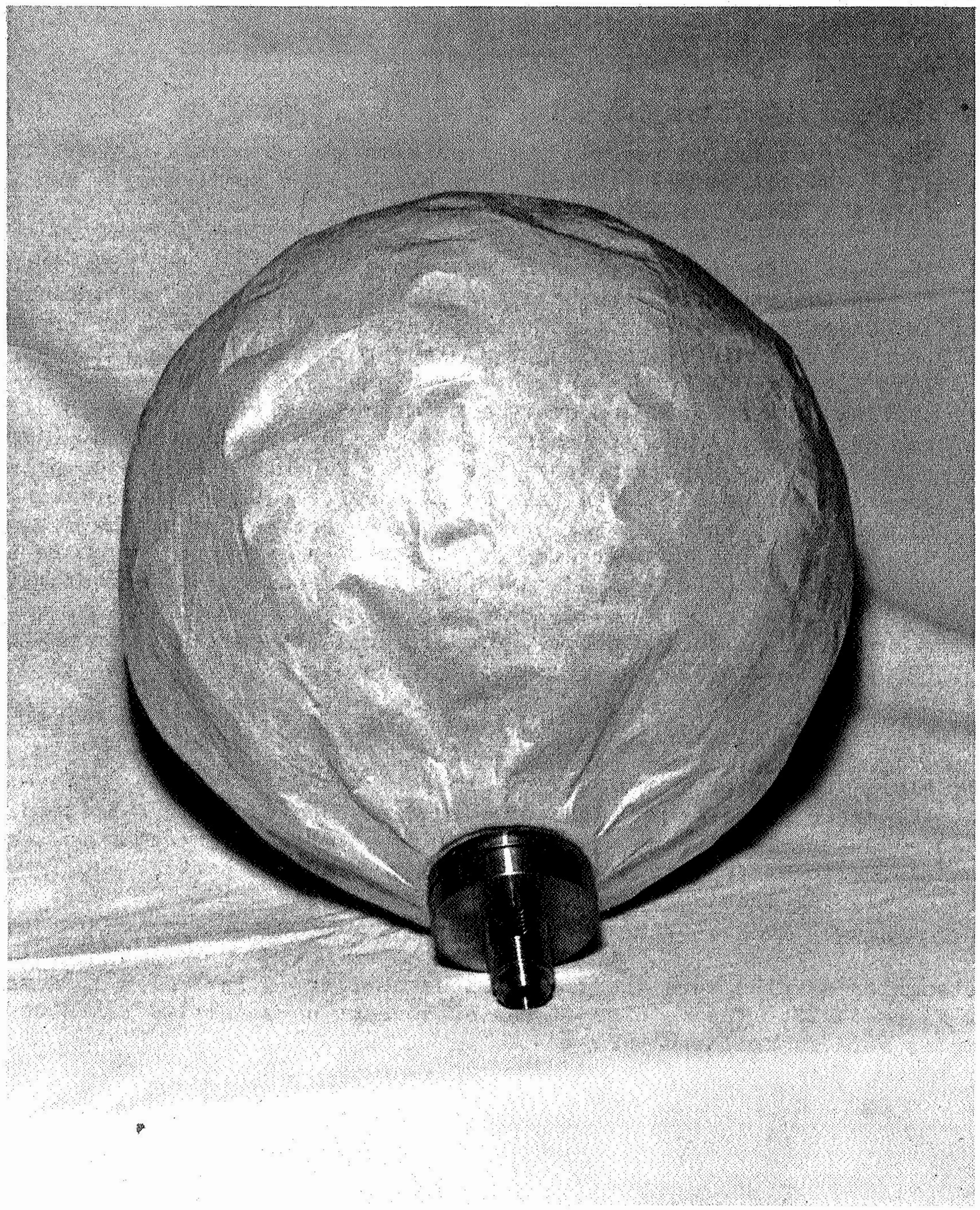
Cycle 1:

Fill: 95%
Expulsion: 95%

This bladder exhibited very good fill and expulsion behavior. The MS helium detector went off-scale at the completion of expulsion. Additional expulsion cycles later showed this to be a normal occurrence and not necessarily an indication of sudden bladder failure.

FIGURE 4.24

BS15753 TYPE 1 BLADDER



NOMEX/MYLAR

Bladder B201 (Merfab/Mylar)

Cycles 2 through 5:

Fill: 95 to 98%
Expulsion: 95%
Permeability after Cycle 5: 500 cc per minute

The bladder filled readily and expulsion was comparatively effortless (13 to 20 liters per minute). The bladder was quite easily removed from the dewar for permeability testing.

The leak rate of 500 cc per minute was considered quite high, even though the expulsion capabilities of the bladder were not impaired. Investigation revealed that the leakage was from five major cracks through the adhesive sealing the bladder to the flange of the stem. This adhesive failure resulted from thermal shock encountered in cycling from ambient temperature to -423°F. Past problems in affecting an adequate seal and this thermal failure removed any hopes of satisfactorily repairing this bladder at Beech by the use of polyester adhesives. Attempts were then made to salvage this bladder for additional cryogenic testing by using a suitable epoxy at the stem seal. However, adequate repair was not achieved and the bladder could not be restored to a condition adequate for additional expulsion testing.

A method of producing polyester adhesive seals suitable for use at LH_2 temperature was subsequently developed.

c. Post-Test Condition

Only Ply 1 (the outer Nomex ply) of bladder B201 exhibited any damage (other than the expected wear) when the bladder was disected for examination. Ply 1 had a .3 inch long tear (on a vertical great circle) adjacent to the stem assembly. Two of the lap seams in the Nomex revealed partial peeling (approximately .25 inch deep, or halfway through the seam) for a short distance adjacent to the stem assembly.

Rectangular samples were cut from various barrier (Mylar) plys in a manner per Figure 4.23. The results of the subsequent permeability tests on these samples were as follows:

Bladder B102 (Merfab/Mylar)

Ply No.	Leakage in cc per Minute Stem Area	Polar Area
2	.08	0
6	.08	.6
10	426	468
11	0	4.8

The preceding tabulation indicates that the polar cap area of the various Mylar plys suffered slightly more wear than the stem area due to installation of the bladder into the dewar.

d. Summary

The five LH_2 expulsion cycles on bladder B201 revealed good fill and expulsion characteristics. The sharp increase in leak rates was attributed to stem seal failure and not to permeation through the bladder material.

4.5.3.2 Bladder B202

a. Initial Condition

Bladder B202 was within specification for all requirements, except leak rate, during receiving inspection at Beech and leak rate was 2.6 cc per minute. This was attributed to ineffective sealing of the polyester adhesive in the stem seal area. This was one of the factors included in the stem evaluation described in Paragraph 4.4.2, Fabrication by G. T. Schjeldahl Company, which resulted in the rework of the stem seals on bladders B202, B203, and B204. Therefore, Bladder B202 was returned to Schjeldahl for rework prior to any expulsion testing.

The reworked Bladder B202 was entirely within specification and was accepted upon its second receipt at Beech. This bladder exhibited very good workmanship.

b. LH_2 Expulsion Testing

It was quite difficult to install this bladder in the test dewar, due to its bulk and ridigity. The impression was gained that the Nomex plys might not be nested in the most orderly manner.

Cycles 1 through 5:

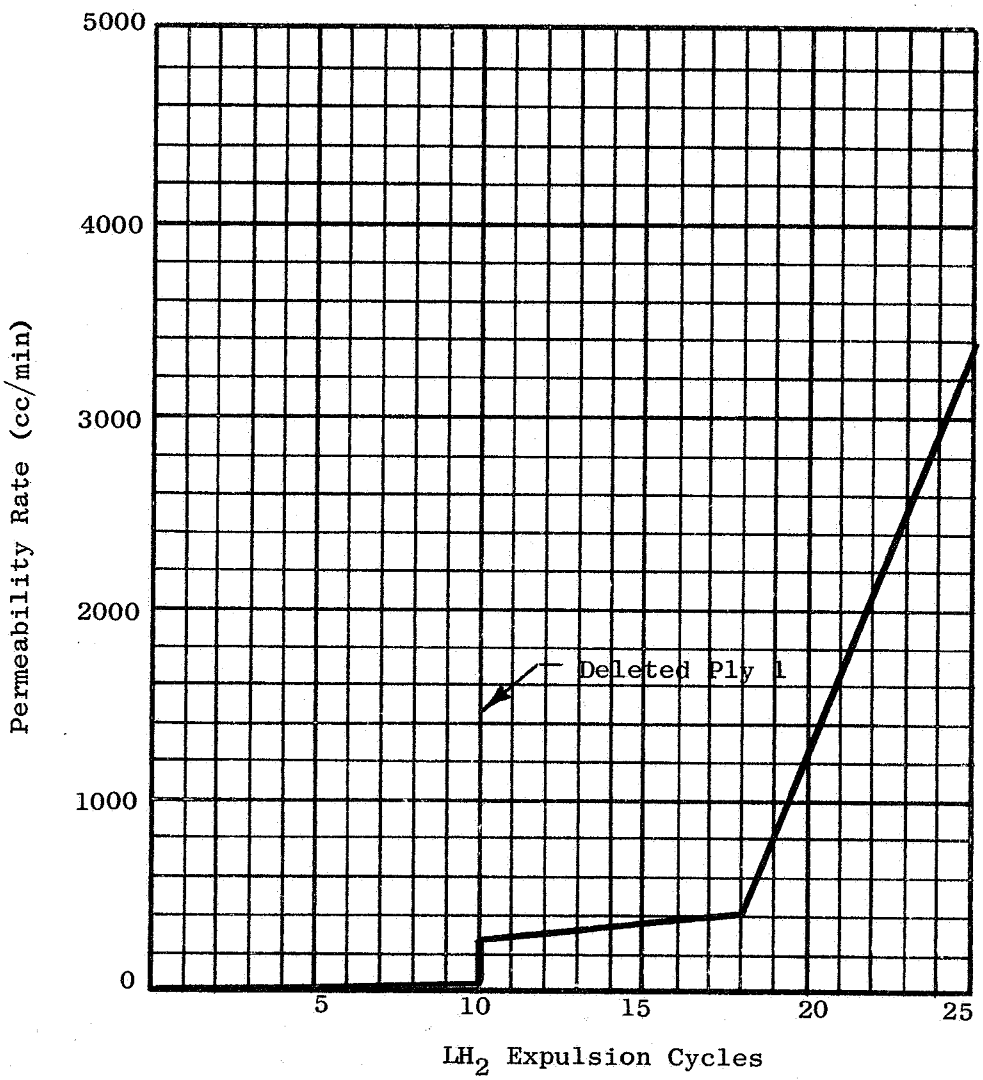
Fill: No more than 50%
Expulsion: 98%, except 80% for Cycle 5
Permeability after Cycle 5: 10 cc per minute (also see Figure 4.25)

It was soon apparent that this bladder was accepting only a partial fill. Indications by the vent manometer and vent line wetting also correlated to a 50% fill. The inside of the bladder was intermittently or continually kept under a back pressure during fill to expand the inner plys of the bladder. This procedure did not result in any appreciable increase in fill volume. This fill problem was attributed to a reduction in internal volume due to interply inflation or due to improper nesting of the plys.

Ply 1 (outer Nomex ply) had 5 parallel tears (on vertical great circles) from .25 to .6 inch long adjacent to the stem assembly after the 5 cycles. Bladder removal for permeability testing revealed that Ply 1 was operating independently of the other plys. The other plys could be felt partially "knotted up" within Ply 1.

FIGURE 4.25

PERMEABILITY PROFILE OF BLADDER B202
(NOMEX/MYLAR)



Bladder B202 (Nomex/Mylar)

The bladder was quite difficult to remove from the dewar and was very difficult to re-install. The installation procedure described in Paragraph 4.4.3 was developed to facilitate the installation of this bladder.

Cycles 6 through 10:

Fill: 30 to 40%
Expulsion: 85%, 55%, 15%, 35%, and 15%
Permeability after Cycle 10: 38 cc per minute

Fill characteristics and behavior were as described for Cycle 1 through 5, except that a lesser fill was realized. The expulsion percentage fell off drastically after Cycle 6, though the same expulsion pressure and controller settings were employed. The expulsion percents given represent the percents of collapse of the opaque outer ply which was most likely acting independently of the rest of the bladder. The inner plys were probably collapsing further, which would present the true but unknown percent of expulsion. This condition made it essential that Ply 1, though still effective as an abrasion shield, be removed at the time of the next permeability test.

Ply 1 had eight tears (of the nature previously described) from .3 to .6 inch long when the bladder was removed for permeability testing. Ply 1 was then deleted, and all of the remaining plys appeared to be more closely nested. A permeability test after re-installation in the dewar produced a reading of 264 cc per minute. The increase in permeability could not be explained.

Cycles 11 through 18:

Fill: 70%, 60%, 50%, 35%, 40%, 10%, 20%, and 40%
Expulsion: 85 to 95%, except 80% for Cycle 14
Permeability after Cycle 18: 414 cc per minute

The fill performance of this bladder continued to deteriorate, despite precooling on the outside of the bladder with LH_2. This measure failed to reduce the interply inflation (if any) by condensing the interstial gases. This again suggested that the bladder plys were not properly nested. Another possibility was that the Nomex plys were too stiff to expand fully; though they were sufficiently flexible at cryogenic temperatures to collapse to 85 to 95% on the expulsion cycle. However, the pressure applied at expulsion was twice that which could be applied to the inside of the bladder during fill.

Bladder B202 (Nomex/Mylar)

Cycles 19 through 25:

Fill: 15%, 25%, 25%, 45%, 65%, 60%, and 65%
Expulsion: 95% except 90% for Cycle 20
Final permeability after 25 cycles: 3300 cc per minute

The bladder continued to show very poor fill behavior through Cycle 22, despite precooling (on the outside) with LH_2. For the last cycle, this precooling was combined with a steady back pressure inside the bladder, resulting in better, but still inadequate, fill performance. This indicated that the partial fill characteristic was due to both interply inflation and due to bladder rigidity or poor nesting of the plys. The expulsion action remained very satisfactory.

c. Post-Test Condition

Bladder B202 was permeability tested in the bell jar after each succeeding outer ply was removed. This provided a curve presenting the increase in permeability for the reduction in number of plys as shown in Figure 4.26. The curve begins with the permeability after Ply 1 was removed (leaving 12 plys on the bladder) and ends with the permeability after Ply 12 was removed (leaving only one ply).

Each ply was carefully examined upon its removal from the bladder. Figure 4.27 (two pages) shows the condition of those plys which exhibited visible damage. Plys 2, 3, 5, 6, 8 and 9 (all Mylar) had no visible damage and are not shown in the figure.

It is believed at various times during expulsion testing that the plys of this bladder were not nesting properly. Disection of the bladder failed to produce any faulty or unsymmetrical plys which would contribute to such a condition.

d. Summary

1. Bladder B202 exhibited a very serious and presistent problem in filling with LH_2. This deficiency was attributed to a major reduction in the internal volume of the bladder due to any or all of the following:

   a) Interply inflation
   b) Improper nesting of the plys
   c) Rigidity of the bladder material; especially at LH_2 temperature

   The average per cent of fill was 40%.

FIGURE 4.26

PERMEABILITY VS. NUMBER OF PLYS: BLADDER B202
(NOMEX/MYLAR)

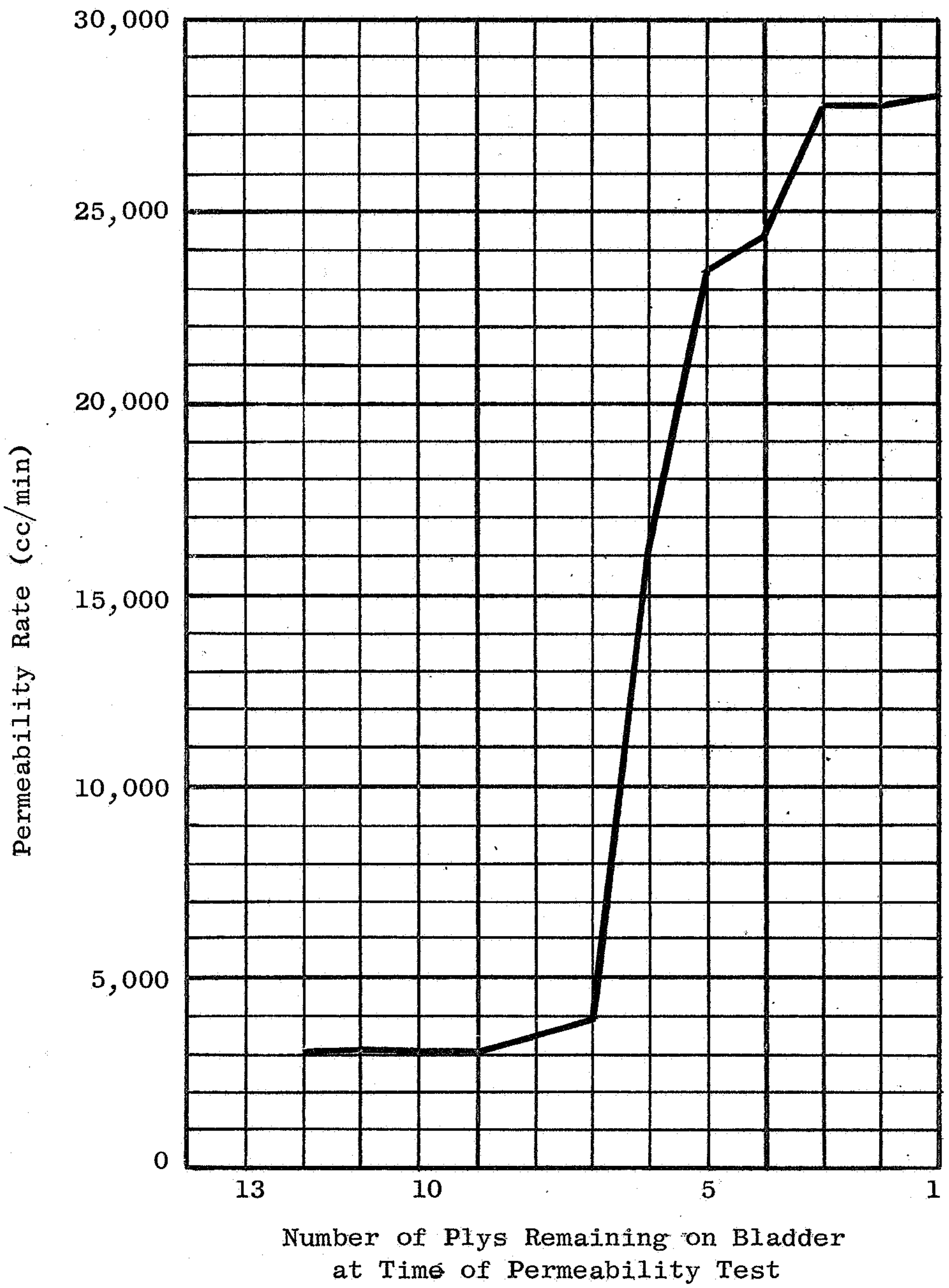
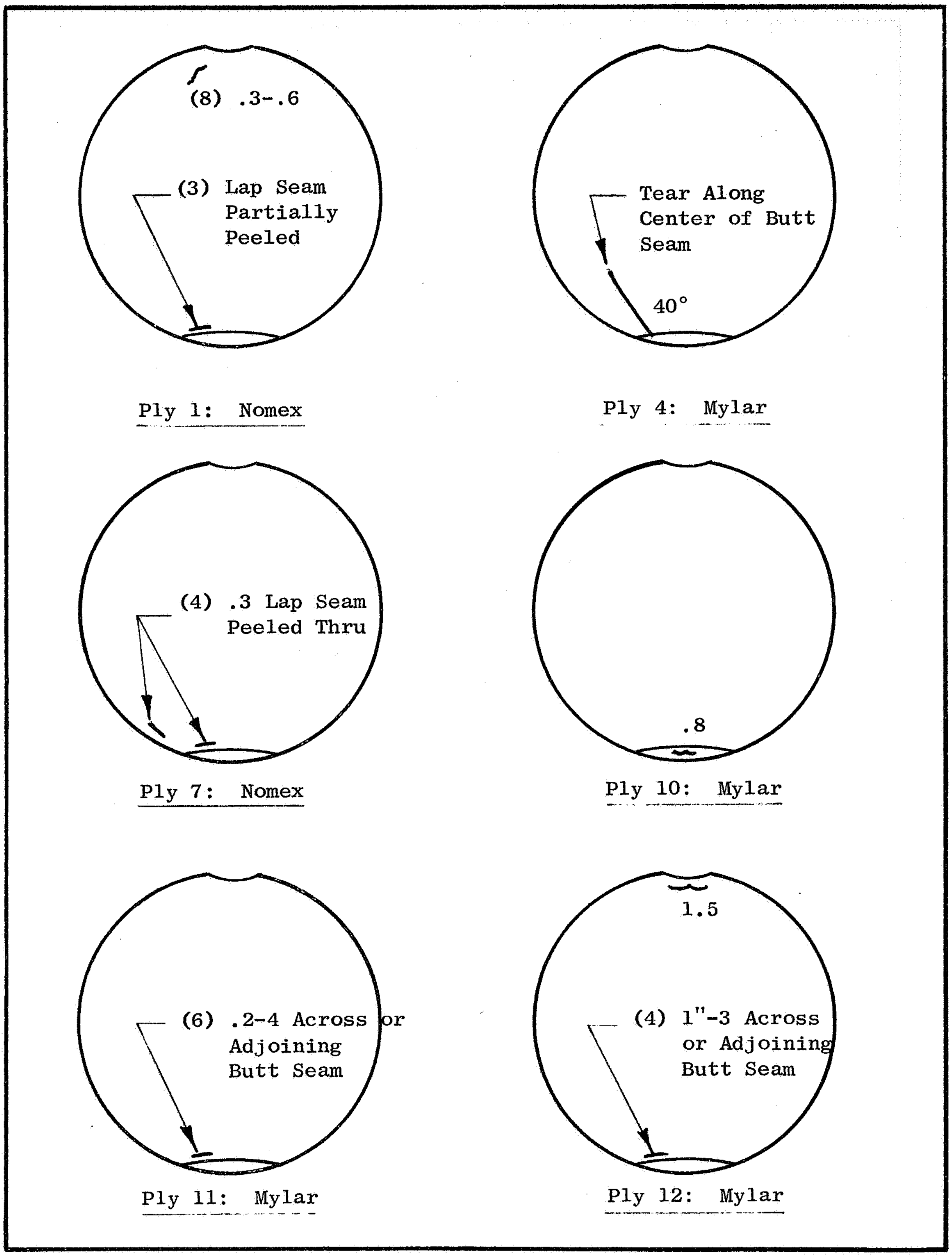


FIGURE 4.27

CONDITION OF PLYS: BLADDER B202



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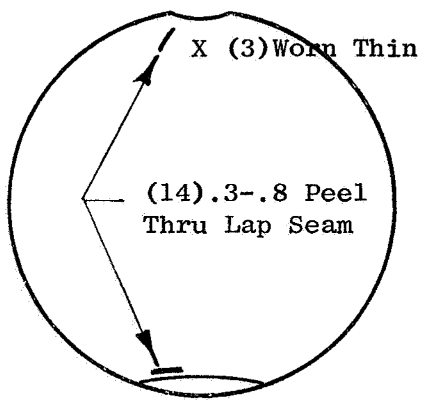
70 -1

FIGURE 4.27 (contd.)

CONDITION OF PLYS: BLADDER B202



Ply 13: Nomex

Bladder B202 (Nomex/Mylar)

2. The expulsion behavior of this bladder was fair. The average expulsion per cent was 81% despite the apparent rigidity of the Nomex plys.
3. This bladder exhibited a higher leak rate (3300 cc per minute) than five of the bladders tested.
4. Interply inflation or similar conditions were the predominate cause for the problems of performance (other than permeability) associated with this bladder.

4.5.3.3 Test Conclusions, BS15753 Type 1 Bladders

The following conclusions were based largely upon the 25 LH_2 expulsion cycles by Bladder B202. The lesser number of cycles on B201 tended to corroborate these conclusions.

a. The Nomex/Mylar material composite produced satisfactory expulsion action.

b. This material composite exhibited serious fill problems in small bladders. These problems could not be eliminated, despite use of all possible counter measures.

c. It was not established that the Nomex substrate plys performed their intended function.

d. It is believed that the Nomex substrate plys contributed heavily to such suspected problems as interply inflation, poor nesting of plys and excessive rigidity.

e. The problem areas were due to the material composite involved, and cannot be attributed to bladder design or workmanship.

4.5.4 BS15753 Type 2 Bladders (Figure 4.28)

Units: B203 and B204
Material category: Dacron/Mylar
Material composite: See Figure 3.44
Subcontractor: G. T. Schjeldahl Company

Appearance:

The appearance of these two bladders was essentially identical. The bladders exhibited a very white color, due to the Dacron sail cloth outer ply. The Dacron had a slick, closely woven texture and was opaque. These bladders presented a slightly chordal effect, due to gores of comparatively heavy material.

4.5.4.1 Bladder B203

a. Initial Condition

Bladder B203 was entirely within specification upon receipt from the subcontractor. It exhibited excellent workmanship.

b. LH_2 Expulsion Testing

The bladder was installed in the dewar with little difficulty, using the established procedure for collapsing and folding the bladder.

Cycle 1:

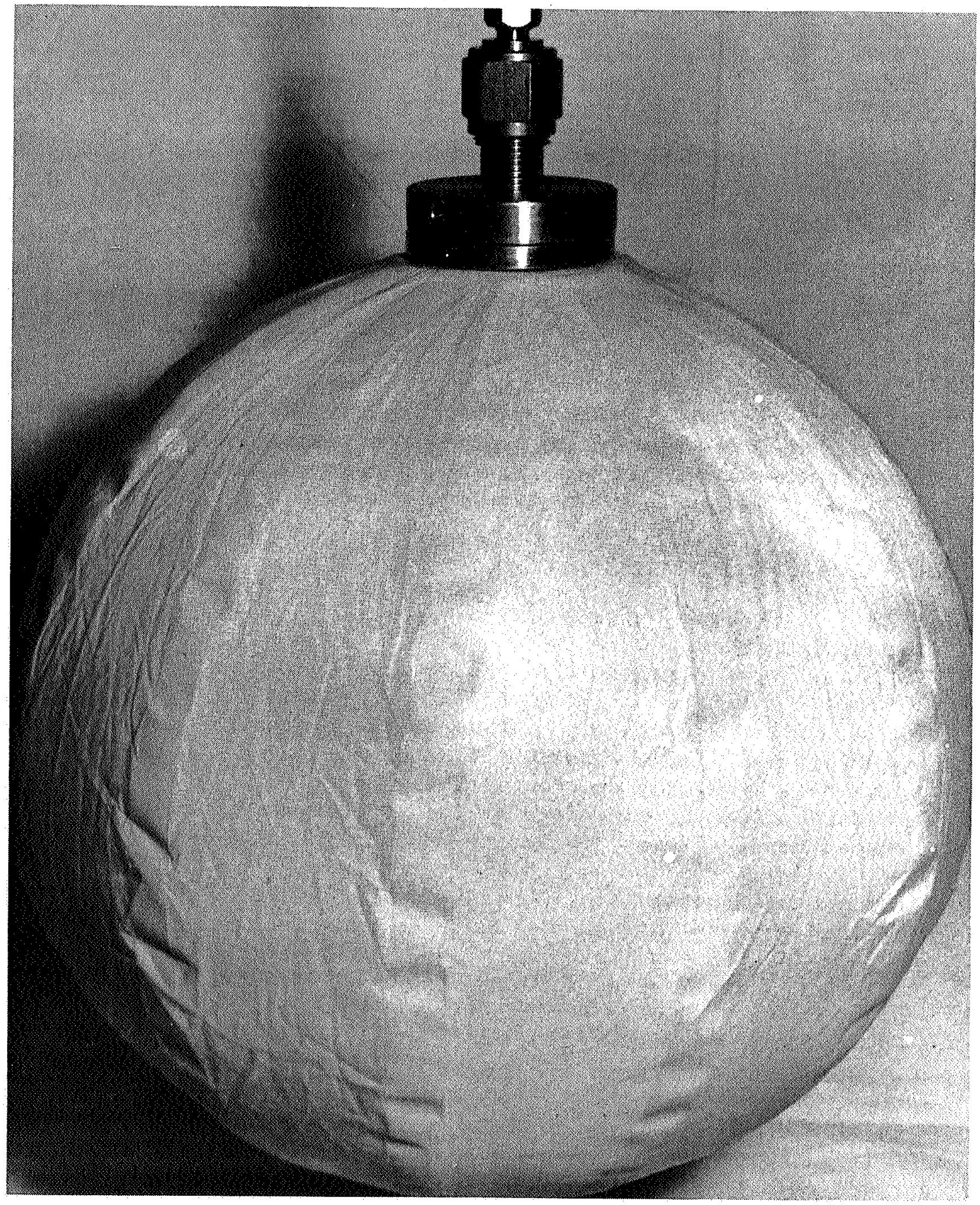
Fill: 75%
Expulsion: 45%
Permeability after Cycle 1: 300 cc per minute

The fill was quite normal, even though full fill was evidently not achieved. The failure to attain a higher degree of expulsion was thought to be due to early bladder failure. The permeability test revealed a leak rate of 300 cc per minute and examination of the stem seal showed that it had failed due to thermal shock. The bladder was then returned to Schjeldahl for rework of the stem seal as previously described.

The bladder continued to show a leak rate of 10 cc per minute after several rework operations by Schjeldahl. It was finally concluded that this leak was through the polymeric bladder material and not through the reworked stem seal. The bladder was then returned to Beech for additional expulsion testing.

FIGURE 4.28

BS15753 TYPE 2 BLADDER



DACRON/MYLAR

Bladder B203 (Dacron/Mylar)

Cycles 2 through 9:

Fill: 75 to 80%
Expulsion: 75 to 80%
Permeability after Cycle 9: 14,000 cc per minute (also see Figure 4.29)

The lack of complete fill was attributed to a reduced internal volume due to interply inflation or excessive bladder rigidity (at LH_2 temperature). Due to its porosity, the helium pressurant could flow through the outer (Dacron) ply and it did not collapse entirely. Therefore, this ply acted independendently of the rest of the bladder and prevented visual observation of the actual degree of expulsion. However, other indications enabled the per cent of expulsion to be established as 75 to 80%.

Following bladder removal for the permeability test after Cycle 9, the intact Ply 1 was removed to provide for visual observation of exact bladder operation. It was then found that the next five Mylar plys had split near the neck and were also removed.

Cycles 10 through 15:

Fill: 75 to 80%
Expulsion: 85 to 95%
Permeability after Cycle 15: 28,000 cc per minute

Fill behavior was similar to that of the preceding eight cycles. The outer ply was again Nomex (Ply 7) and was inactive because of its porosity. Expulsion was now established to be 85 to 95%. The improved expulsion might be explained by the reduced number of plys resulting in reduced total interply inflation or in reduced bladder rigidity.

At the end of Cycle 15, the pressurant pressure dropped to zero and remained there. This showed that the pressurant was flowing through the bladder, indicating gross bladder failure. Therefore, expulsion testing was interrupted for an ambient temperature leak test. The leak rate of 28,000 cc per minute verified gross bladder failure.

c. Post-Test Condition

All plys of Bladder 203 were carefully examined for damage after their removal from the bladder. Figure 4.30 (two pages) reflects the damage to the various plys in the manner described in the early paragraphs of Subsection 4.5. The three Dacron substrate plys (Plys 1, 7, and 13) showed no visible damage and are not included in the figure.

FIGURE 4.29

PERMEABILITY PROFILE OF BLADDER B203
(DACRON/MYLAR)

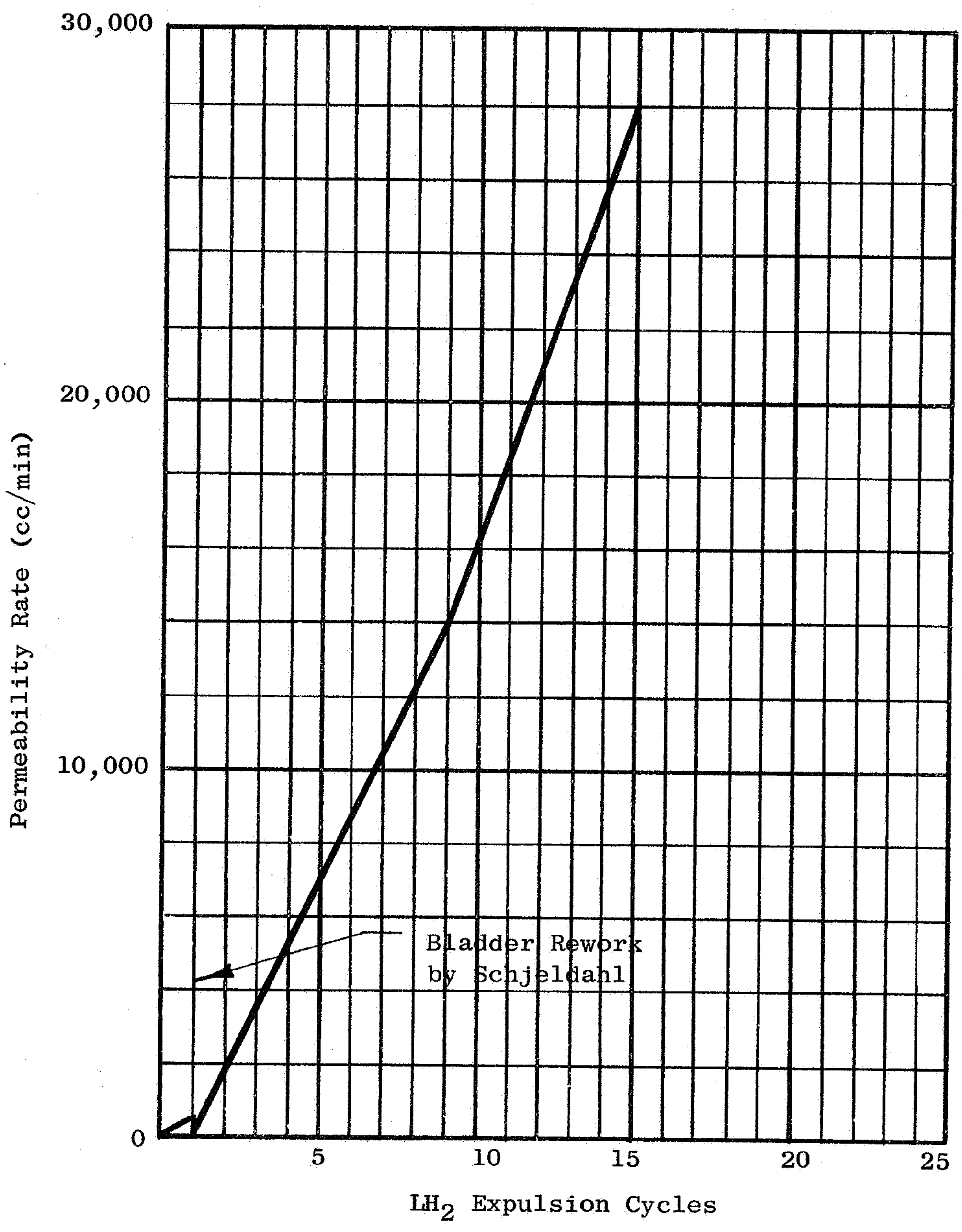


FIGURE 4.30

CONDITION OF PLYS: BLADDER B203

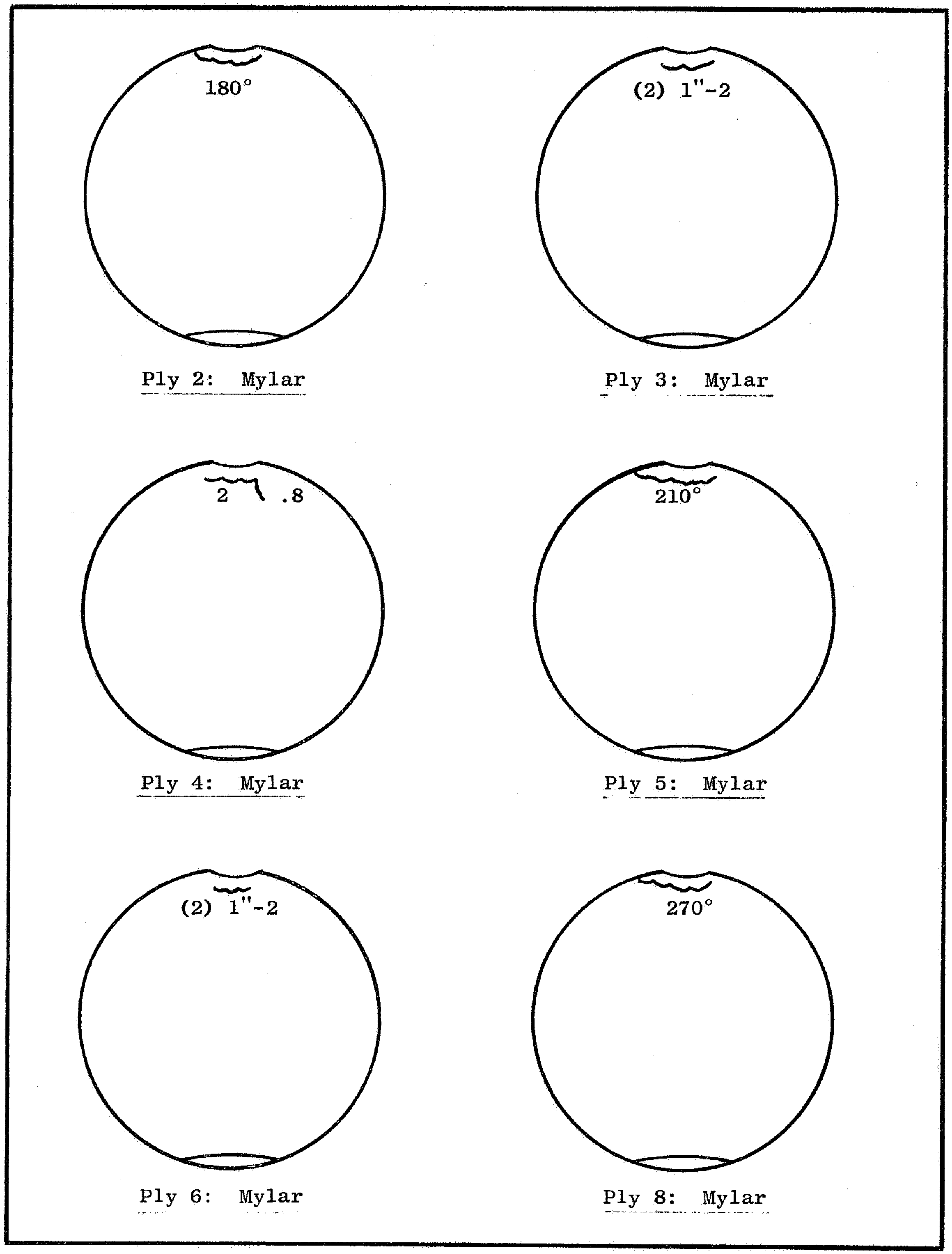


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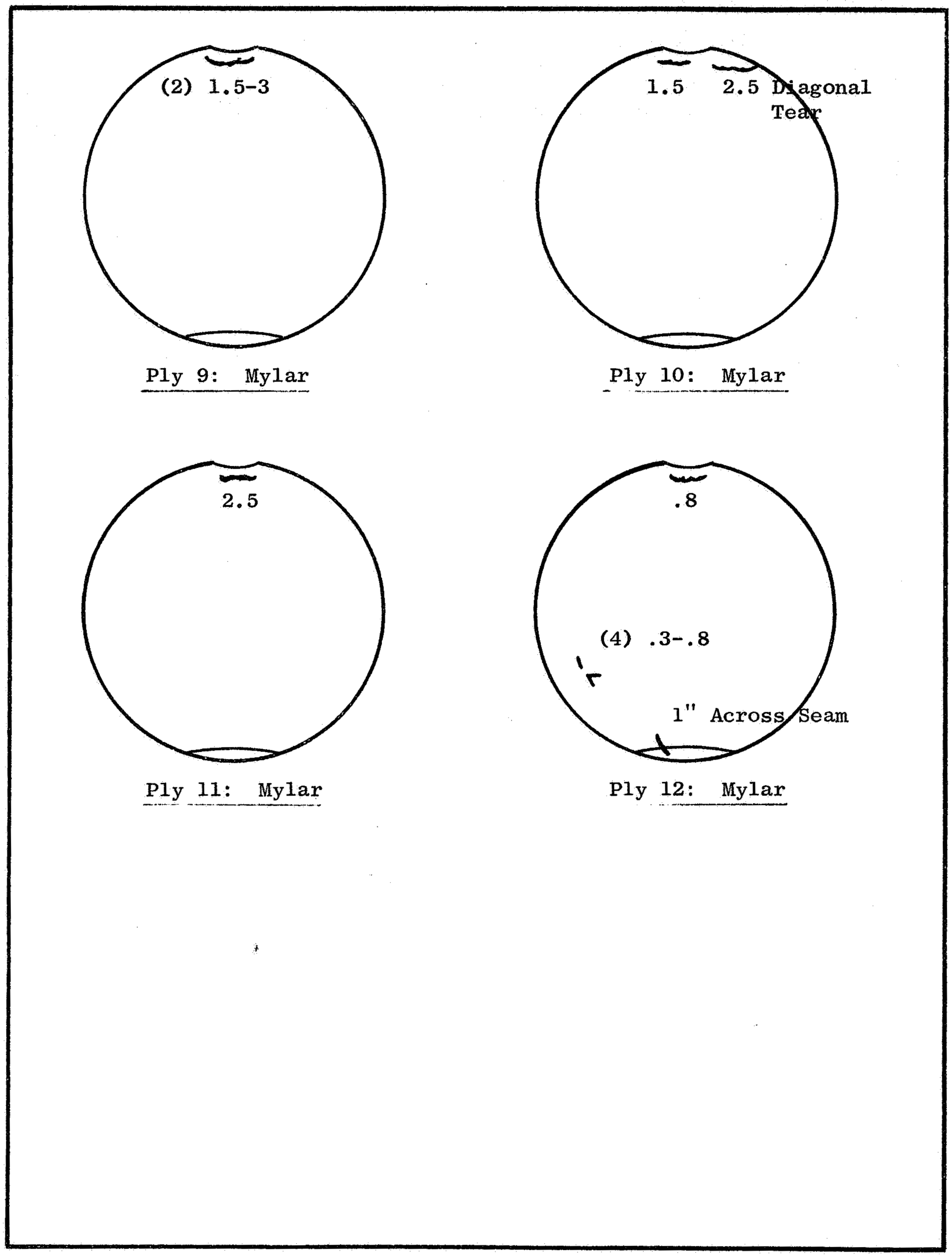
FIGURE 4.30 (contd.)

CONDITION OF PLYS: BLADDER B203



Bladder B203 (Dacron/Mylar)

d. Summary

1. LH_2 and helium gas penetrated the Dacron plys more readily than anticipated, reducing their function as inner and outer substrate plys to only that of floating abrasion shields. There is no indication that the substrate plys were of benefit to the barrier plys.

2. Bladder B203 exhibited only fair fill behavior, which was probably influenced by interply inflation or substrate ply rigidity.

3. This bladder produced fairly good expulsion, which was improved somewhat by removal of six of the 13 plys

4. The high leak rate after Cycle 9 was attributed to incipient failure of the Mylar plys.

5. The bladder became incapable of expulsion as a leak rate of 28,000 cc per minute was approached.

6. This bladder was installed in the test dewar (using established procedure) without much difficulty.

4.5.4.2 Bladder B204

a. Initial Condition

This bladder had been reworked to incorporate the improved stem seal, prior to shipment by Schjeldahl. The bladder was entirely within specification and exhibited excellent workmanship.

b. LH_2 Expulsion Testing

Bladder B204 presented greater difficulty of installation than any other bladder under this program, despite full utilization of the established installation procedures. An added problem was the apparent bunching or knotting of the inner plys, which were very unyielding to the touch. The bladder showed a slight increase of permeability (to 1 cc per minute) after installation.

Cycle 1:

Fill: A two stage fill was observed, with additional fill (to 80%) after inside of bladder had been pressurized to expand same.
Expulsion: Unable to expell more than 35%, in spite of increased expulsion pressure.

Cycle 2:

Fill: Probably 80%
Expulsion: Only 5% at increased pressure. Use of warm pressurant did not increase expulsion, but 50% expulsion was attained after warm helium was flowed into bladder for approximately 2 minutes. The warm helium evidently warmed the bladder to some degree (also boiled off some LH_2).

Cycle 3:

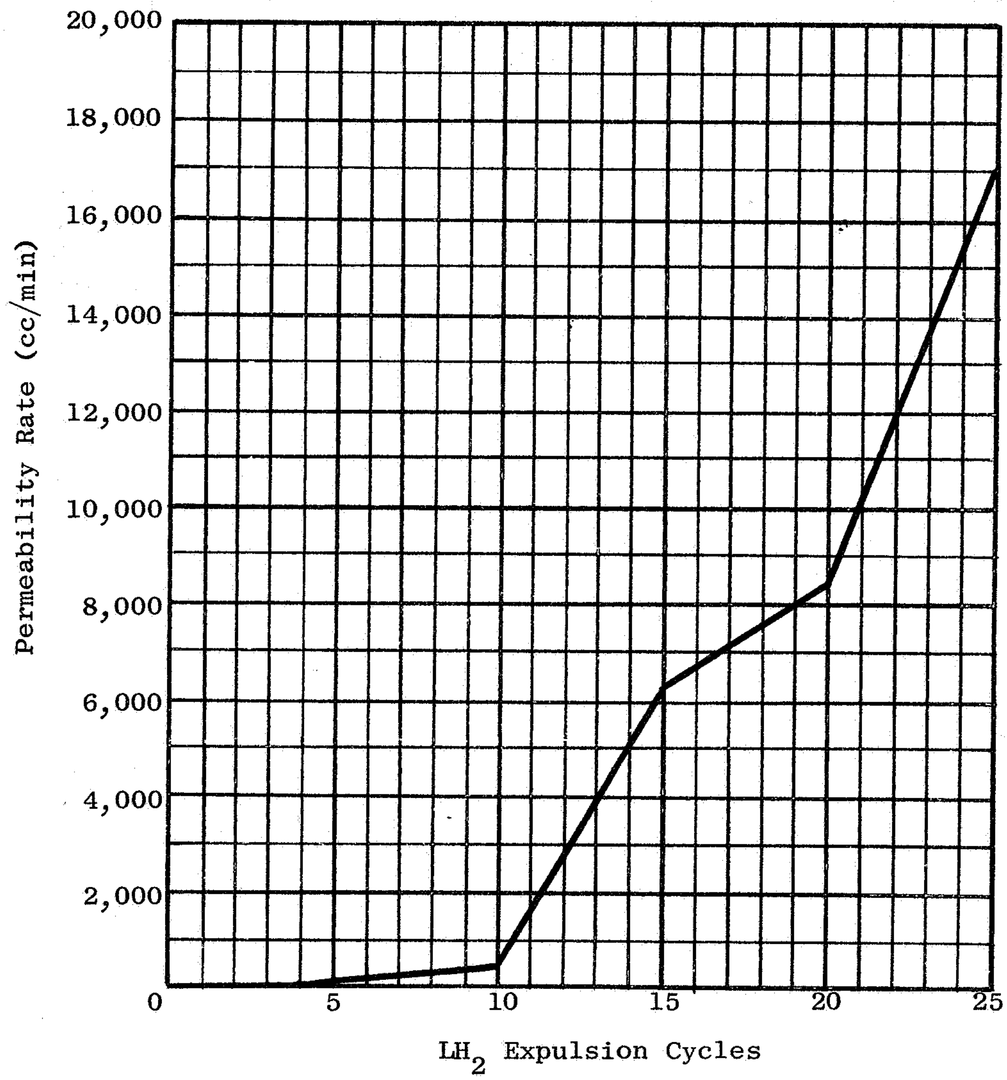
Fill: Probably 80%
Expulsion: 15%

Cycle 4:

Fill: Probably 80%
Expulsion: 0; then 30% after flow of warm H_e, then 70% after additional warm gas flow.
Permeability after Cycle 4: 39 cc per minute (also see Figure 4.31)

FIGURE 4.31

PERMEABILITY PROFILE OF BLADDER B204
(DACRON/MYLAR)



Bladder B204 (Dacron/Mylar)

All indications were that the test system was fully operable during the preceding cycle, but the bladder could be only partially collapsed. This could have resulted from a serious leak in the bladder, but an ambient temperature permeability test after Cycle 4 failed to indicate such a leak. This then suggested that the pressure of the pressurant was not sufficient to collapse the cold bladder because of bladder rigidity or poor nesting of plys. It was believed that the flow of warm helium made the bladder less rigid, thus resulting in additional bladder collapse. Interply inflation was not suspected because the addition of warm helium should aggravate that condition, not improve it. It was comparatively easy to remove and install the bladder, further indicating that interply inflation was not excessive.

Cycles 5 through 10:

Cycle No.	Fill %	Expulsion %
5	95	60
6	75	35
7	85	20, then 60
8	50	70
9	65	40
10	50	55

Permeability after Cycle 10: 382 cc per minute

Expulsion percentages declined through Cycles 5, 6, and 7, so warm helium gas was flowed into the bladder during Cycle 7, resulting in additional collapsing to a total of 60%. A five minute period of warm up before Cycle 9 expulsion had little effect on the bladder and did not improve the percent of expulsion. The pressure of the pressurant was increased to excessive levels for Cycle 10, but additional expulsion could not be produced. Pressure lock-ups on the outside of the bladder revealed that the bladder would not hold external pressure when at LH_2 temperature. Such leak was much less apparent when the bladder was in a warmer condition, suggesting that a leak existed which was amplified by the LH_2 temperature. Excess bladder rigidity (when cold) was not discarded as a contributing factor.

Following removal for permeability testing after Cycle 10, Ply 1 (undamaged) was removed to enable observation of the rest of the bladder. It was then found that the next five Mylar barrier plys were failed, with a tear in each ranging from 8 inches to 2 inches long. Therefore, all plys through Ply 6 were removed, again leaving a Dacron ply (Ply 7) exposed.

Bladder B204 (Dacron/Mylar)

Cycle 11:

Fill: 25%
Expulsion: 65%

Cycle 12:

Fill: 90 to 95% (with LH_2 precool)
Expulsion: 90 to 95%; Ply 7 was inactive and collapsed to only 20%

Cycle 13 (Outward Expulsion):

The expulsion cycle was in the outward manner (see Paragraph 4.5.1.3) in an attempt to learn more of the behavior of this bladder.

Fill: 90 to 95% (outer ply collapsed only 25%, with LH_2 penetrating Dacron fabric)
Expulsion: 95%

Bladder showed good performance in outward expulsion.

Cycles 14 and 15 (Inward Expulsion):

Fill: 75% (no precool) and 70% (with precool)
Expulsion: 95%
Permeability after 15 cycles: 6300 cc per minute

Reduction of bladder mass (33% reduction in Dacron substrate plys and 50% reduction in Mylar barrier plys) appeared to result in significantly better performance, especially in percent of expulsion, for Cycles 11 through 15. This was believed due to a reduction in bladder rigidity, since interply inflation was not a prime suspect in this case. Precooling with LH_2 produced variable benefits for filling, also failing to establish the possible significance of interply inflation. The leak rate of 6300 cc per minute indicated substantial bladder deterioration to a degree not readily correlated to the excellent performance in Cycle 13 (outward expulsion).

Bladder B204 (Dacron/Mylar)

Cycles 16 through 19 (Inward Expulsion):

Fill: 10%, 85%, 80% and 85%,
Expulsion: 95%

The fill for Cycle 16 was without LH_2 precool and was very poor. However, the fill for Cycle 18 (also without precool) was almost as good as the LH_2 precooled fills for Cycles 17 and 19. The outer ply (Dacron) was acting independent of the rest of the bladder and was collapsing only from 10 to 25% on expulsion. This was due to porosity and not due to tears or holes.

Cycle 20 (Outward Expulsion):

Fill: 98%
Expulsion: 98%
Permeability after Cycle 20: 8400 cc per minute

The bladder continued to exhibit excellent performance in outward expulsion.

Cycles 21 through 24 (Inward Expulsion):

Fill: 90%, 80%, 90% and 80%
Expulsion: 95%

Precooling with LH_2 resulted in two fills of 90% while only 80% fill was attained without precooling. This indicated that interply inflation was still of some significance. The outer (Dacron) ply collapsed only 10% on expulsion.

Cycle 25 (Outward Expulsion):

Fill: 65%
Expulsion: 95%
Final permeability after 25 cycles: 17,000 cc per minute

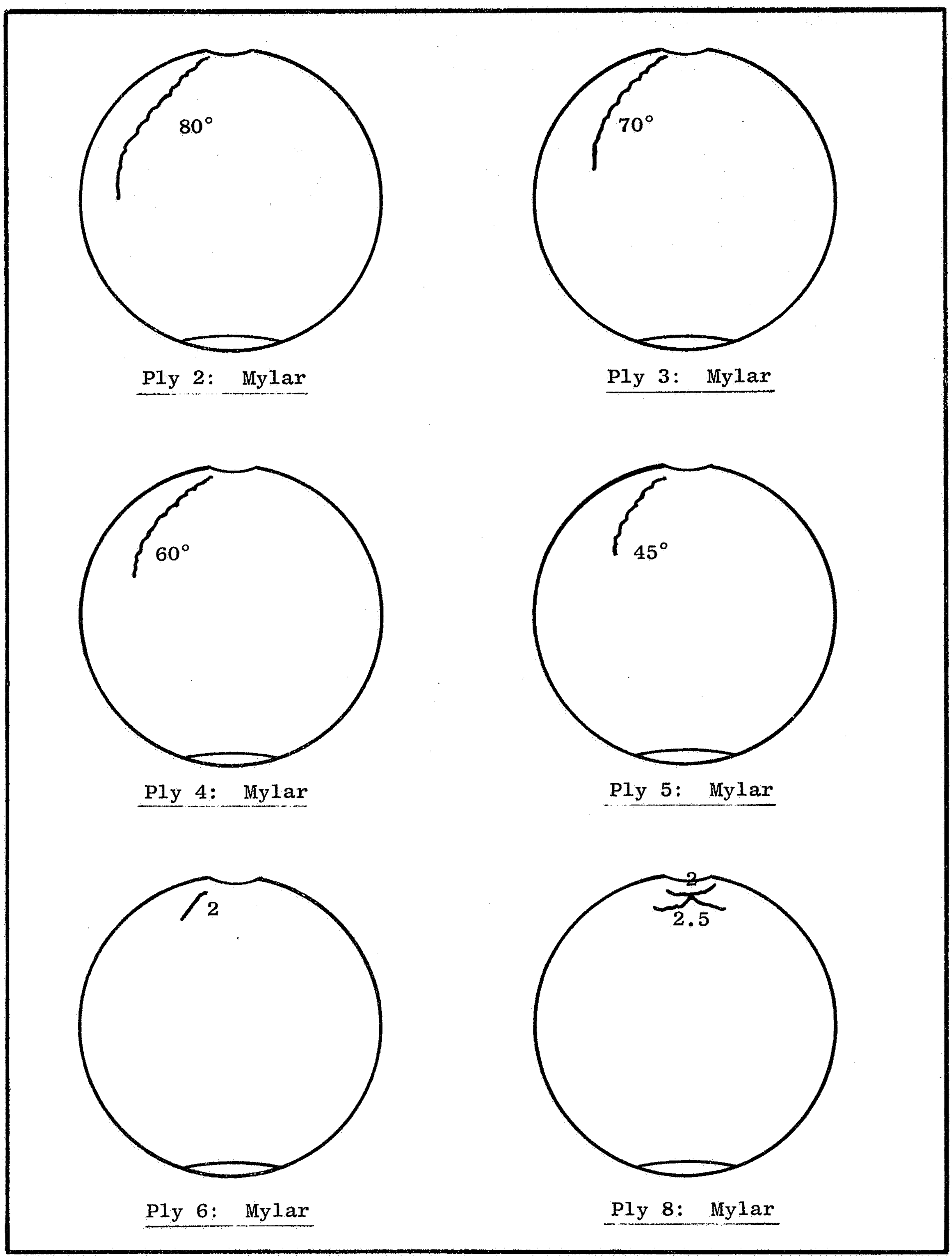
The comparatively low amount of fill could not be explained.

c. Post-Test Condition

Each individual ply of Bladder B204 was examined as it was removed from the bladder. Figure 4.32 (two pages) shows the condition of plys suffering visible damage. The three Dacron substrate ply (Plys 1, 7, and 13) were in excellent condition and are not included in the figure.

FIGURE 4.32

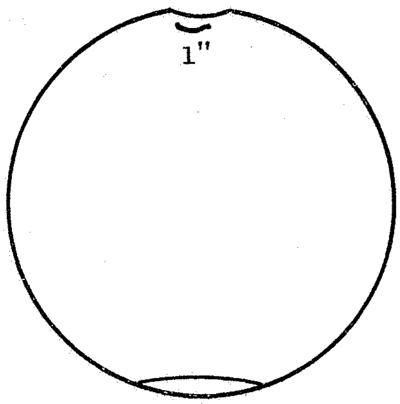
CONDITION OF PLYS: BLADDER B204



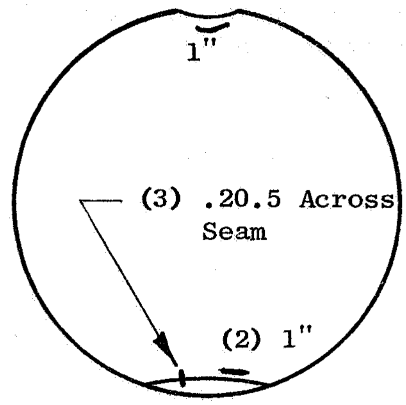
(contd.)

FIGURE 4.32 (contd.)

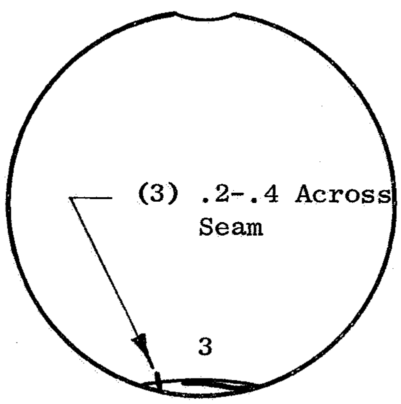
CONDITION OF PLYS: BLADDER B204



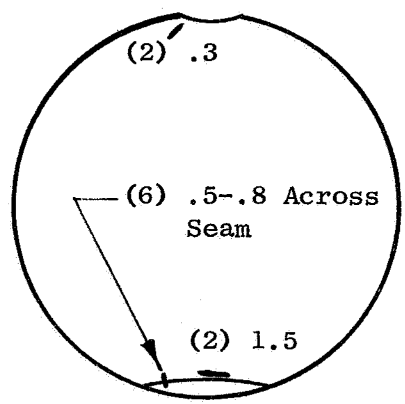
Ply 9: Mylar



Ply 10: Mylar



Ply 11: Mylar



Ply 12: Mylar

Bladder B204 (Dacron/Mylar)

Rectangular samples were cut from the various barrier plys (Mylar) in the location shown in Figure 4.23. Permeability testing upon these samples produced results as follows:

Ply No.	Leakage in cc per Minute: Stem Area	Polar Area
3	0	0
5	0	.13
9	0	580

The above data indicates that these plys received more wear at or near the polar cap than at the stem area. Plys 10, 11, and 12 also suffered considerable visible damage at or near the polar cap, as shown in Figure 4.32.

d. Summary

1. Bladder B204 exhibited fairly poor expulsion performance in its original (13 ply) configuration. Expulsion characteristics improved decidedly by the deletion of the six outer plys. Expulsion problems were attributed to excessive bladder rigidity at cold temperature, rather than to interply inflation. Average expulsion for the 22 inward expulsion cycles was 67%.

2. The fill characteristics of this bladder were quite poor, averaging 73% for the 22 inward expulsion cycles. Fill behavior was not improved by deletion of the six outer plys. Fill problems were attributed to bladder rigidity, with some suggestion of interply inflation.

3. The five outer Mylar plys suffered early failure in the stem area, despite the presence of the substrate plys (which were undamaged). The five inner Mylar plys suffered considerable damage in the lower polar area, while the adjoining Dacron plys were in a condition like new.

4. Helium gas or LH_2 penetrated the Dacron plys quite readily.

5. This bladder presented the greatest problems, of all bladders of installation into and removal from the test dewar.

6. The bladder exhibited high leak rates consistent with the damage to the barrier plys.

4.5.4.3 Test Conclusions, BS15753 Type 2 Bladders

a. It was concluded that the Dacron substrate plys did not perform their intended function of enhancing the operation of the barrier plys. The Mylar plys incurred considerable damage, while the Dacron plys remained in excellent condition.

b. The Dacron substrate plys presented problems in unified bladder action, due to the ready penetration of the material by LH_2 and by helium gas.

c. These bladders exhibited generally poor fill and expulsion characteristics. Their expulsion behavior was improved by the deletion of approximately half of the plys.

d. Poor operational characteristics were basically attributed to excessive rigidity of the Dacron plys at LH_2 temperature. The Dacron showed higher rigidity than any other material expulsion tested in this program.

e. Both bladders suffered early partial failure, followed by early total failure of B203. Both bladders exhibited excessive leak rates.

f. Bladder problems could not be attributed to workmanship.

4.5.5 BS15753 Type 5 Bladders (Figure 4.33)

Units: B205 and B206
Material category: Mylar
Material composite: See Figure 3.42
Subcontractor: G. T. Schjeldahl Company

Appearance

These two bladders were identical in appearance. They were semi-transparent, with the outer plys clear and transparent while the inner plys appeared silvery in color. It was possible to distinguish the liquid level within the bladders. These bladders became essentially spherical when inflated to 1 psi. They exhibited meticulous workmanship and were very flexible to the touch.

4.5.5.1 Bladder B205

a. Initial Condition

Bladder B205 was entirely within specification upon receipt at Beech. It had a zero leak rate and exhibited excellent workmanship. The Mylar showed considerable wrinkling, but the seams were very smooth and clear.

b. LH_2 Expulsion Testing

Bladder B205 was installed in the test dewar with very little difficulty. All of the expulsion cycles on this bladder were inward expulsion.

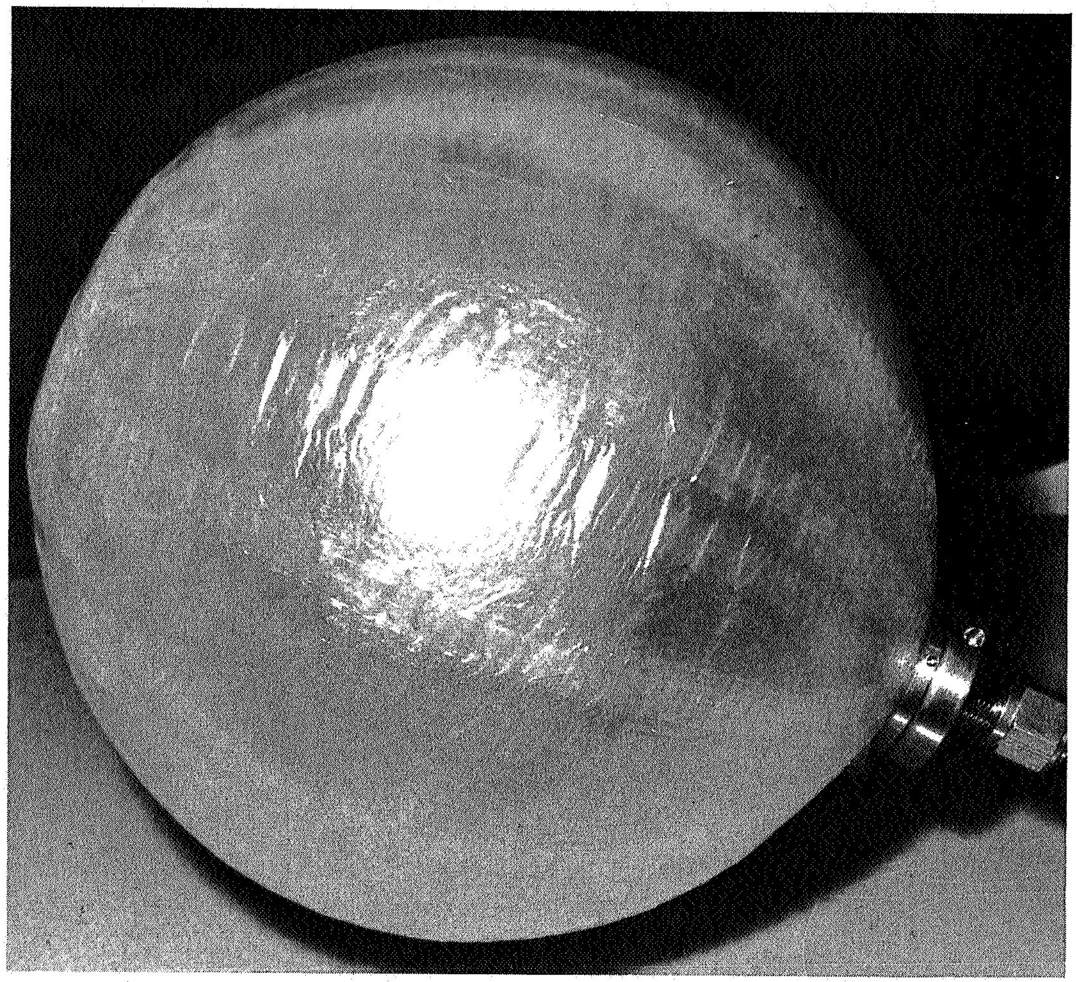
Cycles 1 through 5:

Fill: 99%
Expulsion: 70%, 50%, 45%, 65%, and 75%
Permeability after Cycle 5: 700 cc per minute (also see Figure 4.34)

The fill performance of this bladder was excellent. The noted percents of expulsion may be low, because it was not discovered until later cycles that the outer ply(s) was acting independent of the other plys and not collapsing as far as the rest of the bladder.

FIGURE 4.33

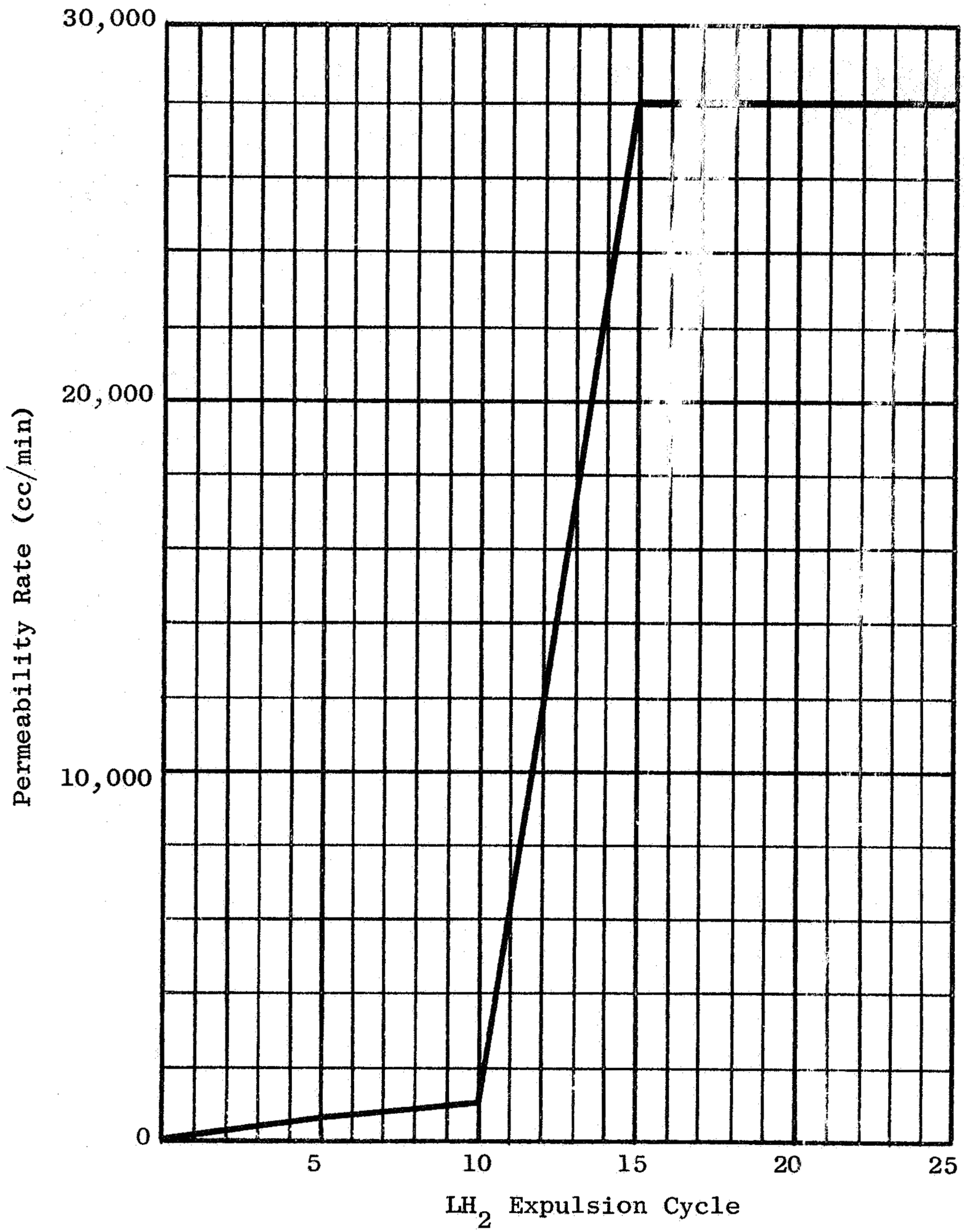
BS15753 TYPE 5 BLADDER



MYLAR

FIGURE 4.34

PERMEABILITY PROFILE OF BLADDER B205
(MYLAR)



Bladder B205 (Mylar)

A tear in each of the five outer plys was noted when the bladder was removed for permeability testing. These tears were adjacent to the stem assembly and were nearly aligned with one another. Each was approximately 1.5 inches long. These tears were definitely not due to malpractice or mishandling. The poor expulsion performance of the first five cycles was attributed to the tears in the bladder which were also correlated to the increased leak rate.

Cycles 6 through 10:

Fill: 99%
Expulsion: 80%, except 85% for Cycle 7
Permeability after Cycle 10: 1000 cc per minute

The expulsion behavior was thought to be quite good, considering the damage to the bladder. (This was one of the first bladders tested, and such leak rates had not been previously encountered). Removal from the dewar for permeability testing was extremely difficult. After removal, Ply 1 was nearly separated from the bladder (at the stem assembly) and was removed.

Cycles 11 through 15:

Fill: 99%
Expulsion: 95%, 90%, 95%, 75% and 95%
Permeability after Cycle 15: 28,000 cc per minute

The expulsion behavior improved over that for previous cycles, despite the sharp increase in leakage. Expulsion was comparatively slow (averaging approximately 70 seconds) and the three outer plys were inactive. The bladder was leak checked in the test dewar. The wet test meter being used to measure the leak had a capacity of approximately 30 liters (30,000 cc) per minute, but it was believed to become inaccurate at a flow rate of approximately 28 liters per minute.

Cycles 16 through 20:

Fill: 99%
Expulsion: 98%, 96%, 95%, 93% and 95%
Permeability after Cycle 20: 28,000 cc per minute

The performance of this bladder was amazing, in view of its excessive leak rate and considerable damage. Expulsion continued to be comparatively slow. Problems of installation into (and removal from) the test dewar were reduced by use of the air pump to reduce interply inflation.

Bladder B205 (Mylar)

Cycles 21 through 25:

Fill: 99%
Expulsion: 95%, 93%, 97%, 90% and 90%
Final permeability after 25 cycles: 28,000 cc per minute

c. Post-Test Condition

Bladder B205 was dissected following expulsion testing to permit a detailed visual examination of each ply. Figure 4.35 (two pages) portrays the condition of each ply in the manner described in the initial paragraphs of Subsection 4.5. The figure shows that essentially the same type of damage occurred on a diminishing scale (from outside to inside) on all of the plys.

d. Summary

1. Bladder B205 exhibited excellent fill performance of 99% fill for each cycle.

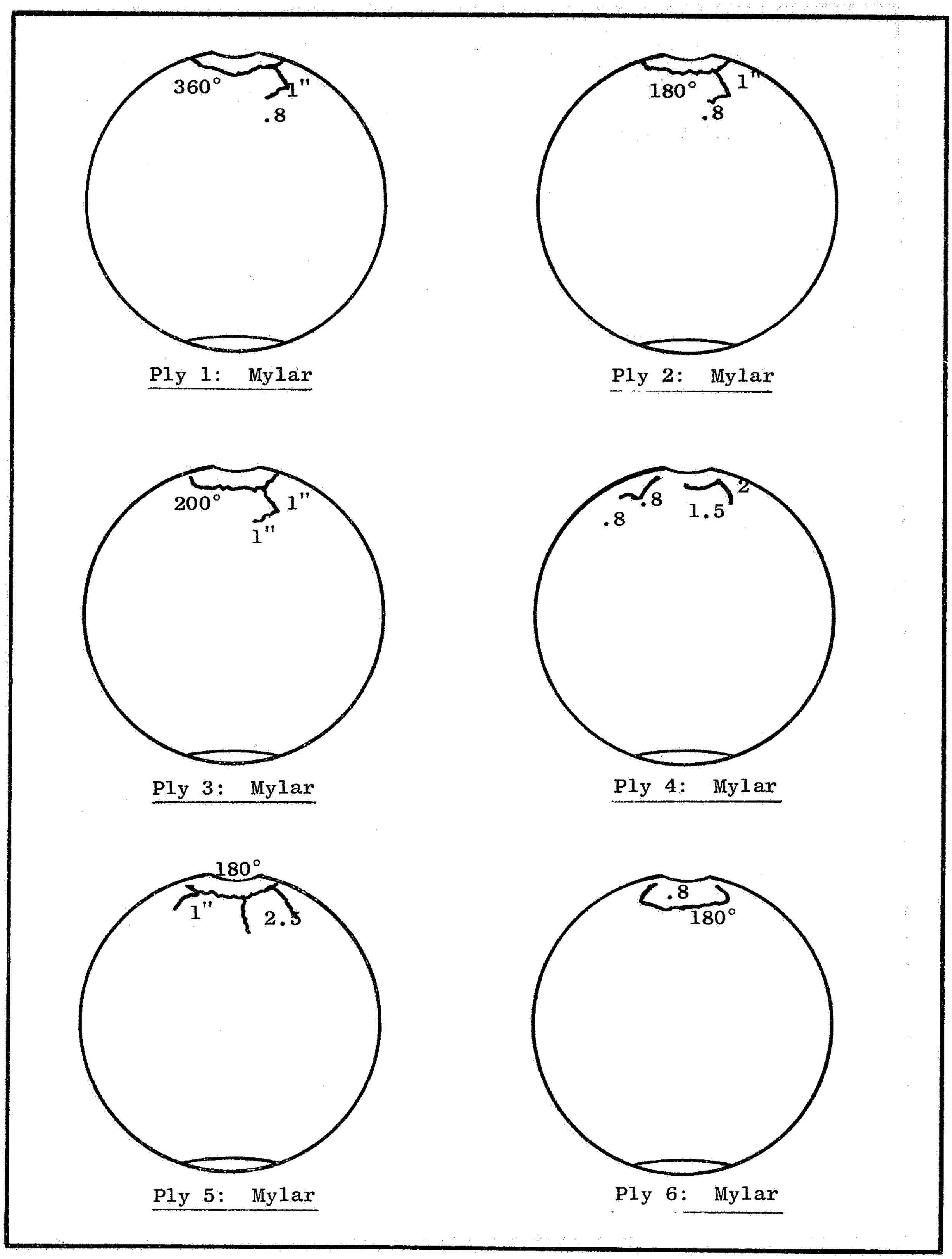
2. The expulsion performance of this bladder was exceptionally good. The bladder was still capable of 90% and higher expulsion when damage was of a magnitude resulting in a leak rate of 28,000 cc per minute. Expulsion behavior improved after the first 10 cycles and averaged 86% for all 25 cycles.

3. The very high leak rate (28,000 cc per minute) resulted from the progressive failure of plys.

4. The only apparent problem areas were failure of all plys in the stem area and installation problems resulting from inter-ply inflation.

FIGURE 4.35

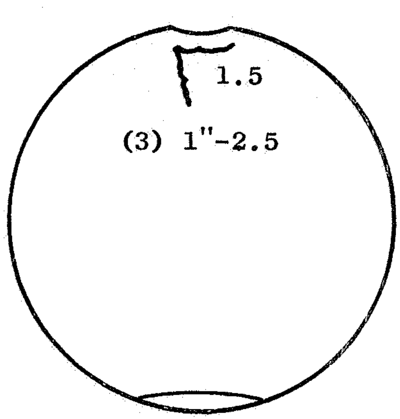
CONDITION OF PLYS: BLADDER B205



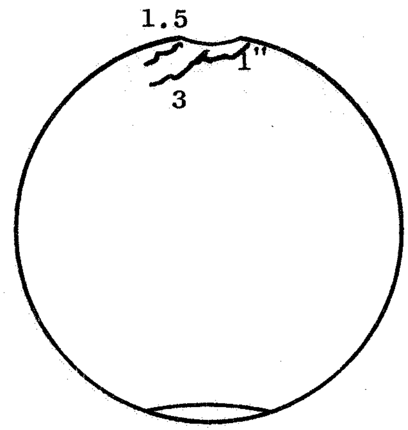
(contd.)

FIGURE 4.35 (contd.)

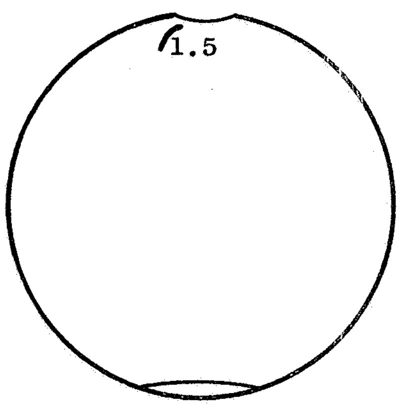
CONDITION OF PLYS: BLADDER B205



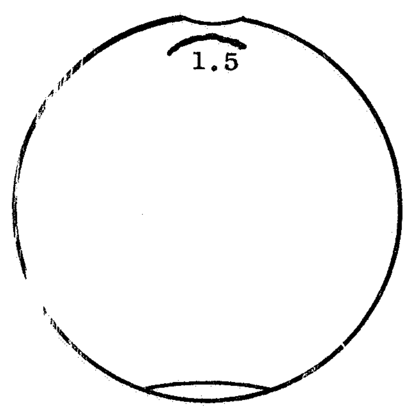
Ply 7: Mylar



Ply 8: Mylar



Ply 9: Mylar

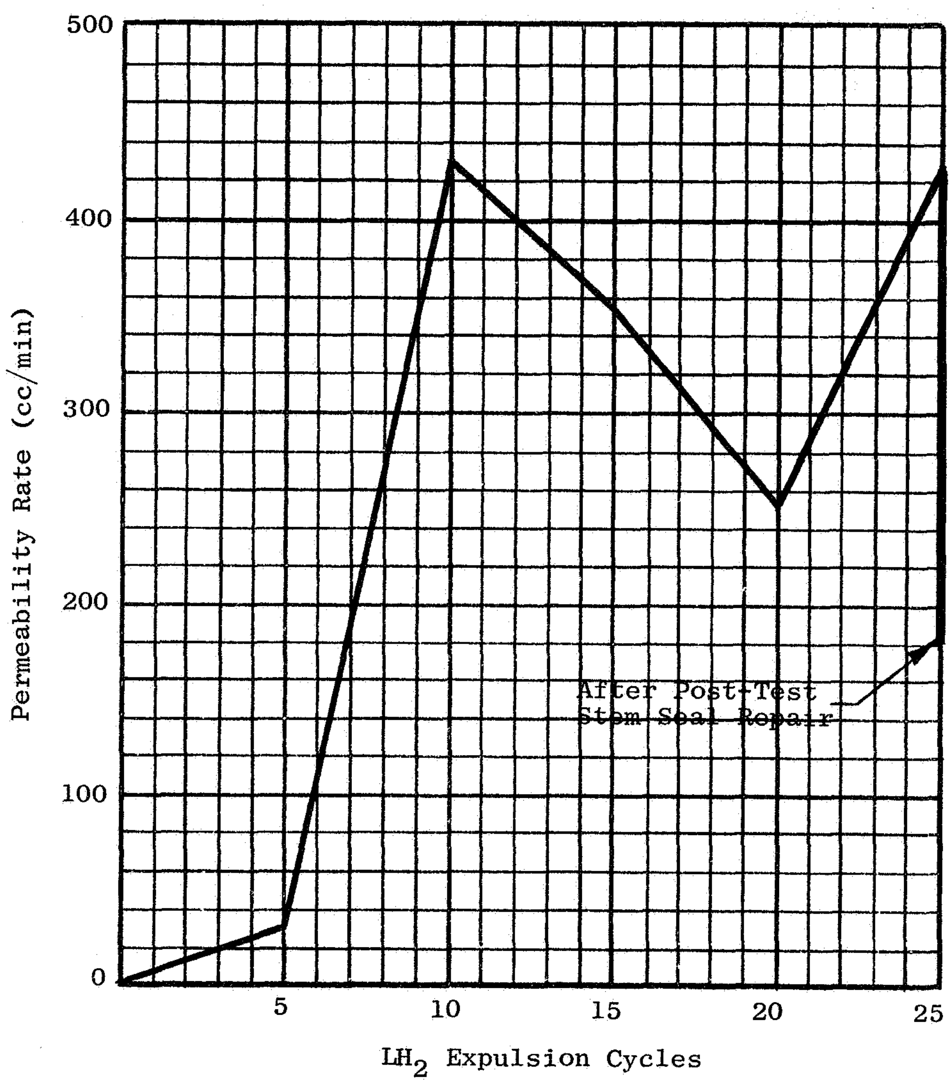


Ply 10: Mylar

FIGURE 4.36

PERMEABILITY PROFILE OF BLADDER B206

(MYLAR)



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4.5.5.2 Bladder B206

a. Initial Condition

Bladder B206 was in full compliance with the specification. The bladder exhibited excellent workmanship. The Mylar appeared quite wrinkled but the seams presented an excellent appearance.

b. LH_2 Expulsion Testing

No particular problems were encountered in installing Bladder B206 into the test dewar. All of the cycles for this bladder were inward expulsion.

Cycles 1 through 5:

Fill: 99%
Expulsion: 99%
Permeability after Cycle 5: 31 cc per minute (also see Figure 4.36)

The bladder exhibited excellent operational characteristics. Only one small problem appeared: the outer ply had a tendency to pull up into the neck approximately .6 inch when vacuum was first pulled during system purge.

Cycles 6 through 10:

Fill: 99%
Expulsion: 85%, 99%, 97%, 99% and 98%
Permeability after Cycle 10: 431 cc per minute

Operational characteristics remained excellent, even though expulsion percentage deteriorated on several cycles. Ply 1 was observed to act independent of the rest of the bladder. It was found to have considerable damage when the bladder was removed for permeability testing and was removed from the bladder. The leak rate took a rather sudden increase to 431 cc per minute.

Cycles 11 through 15:

Fill: 99%
Expulsion: 90%, 85%, 87%, 87% and 85%
Permeability after Cycle 15: 355 cc per minute

Bladder B206 (Mylar)

The bladder still exhibited smooth and positive action. The reduction in expulsion percentages and the decrease in leak rates could not be explained. The outer ply (Ply 2) was now partially inactive.

Cycles 16 through 20:

Fill: 99%
Expulsion: 90%, except 95% for Cycle 19
Permeability after Cycle 20: 253 cc per minute

The performance during these cycles was very similar to the proceding five cycles. The outer ply (Ply 2) condinued to be partially inactive. It was found to have considerable damage and was removed. There was no explanation for the decline in leak rate.

Cycles 21 through 25:

Fill: 99%
Expulsion: 98%, 99%, 98%, 97% and 99%
Final permeability after 25 cycles: 428 cc per minute

Excellent operating characteristics.

c. Post-Test Condition

Upon completion of expulsion testing, the stem seal area of Bladder B206 was examined in an attempt to locate the leakage. This examination revealed five radial cracks through the polyester adhesive which were due to thermal shock (this bladder did not include the improved stem seal because of the absence of Nomex plys). The stem seal was repaired at Beech and leaks were eliminated, resulting in a permeability through the bladder of 180 cc per minute. (Note: This was the only BS15753 bladder in which a significant stem seal leak was detected after expulsion testing.)

Bladder B206 was permeability tested in the bell jar after each succeeding outer ply was removed. This provided the profile shown in Figure 4.37 representing the increase in permeability for the reduction in number of plys. The curve begins with the permeability rate after Ply 2 was removed (leaving 8 plys on the bladder) and ends with the permeability rate after Ply 9 was removed (leaving only 1 ply).

Each ply was carefully examined upon its removal from the bladder. Only Plys 1 and 2 showed any visible damage (other than crazing of the Mylar) and this damage is portrayed in Figure 4.38. All of the plys showed considerable crazing of the Mylar, but this was not considered to be deleterious.

FIGURE 4.37

PERMEABILITY VS. NUMBER OF PLYS: BLADDER B206
(MYLAR)

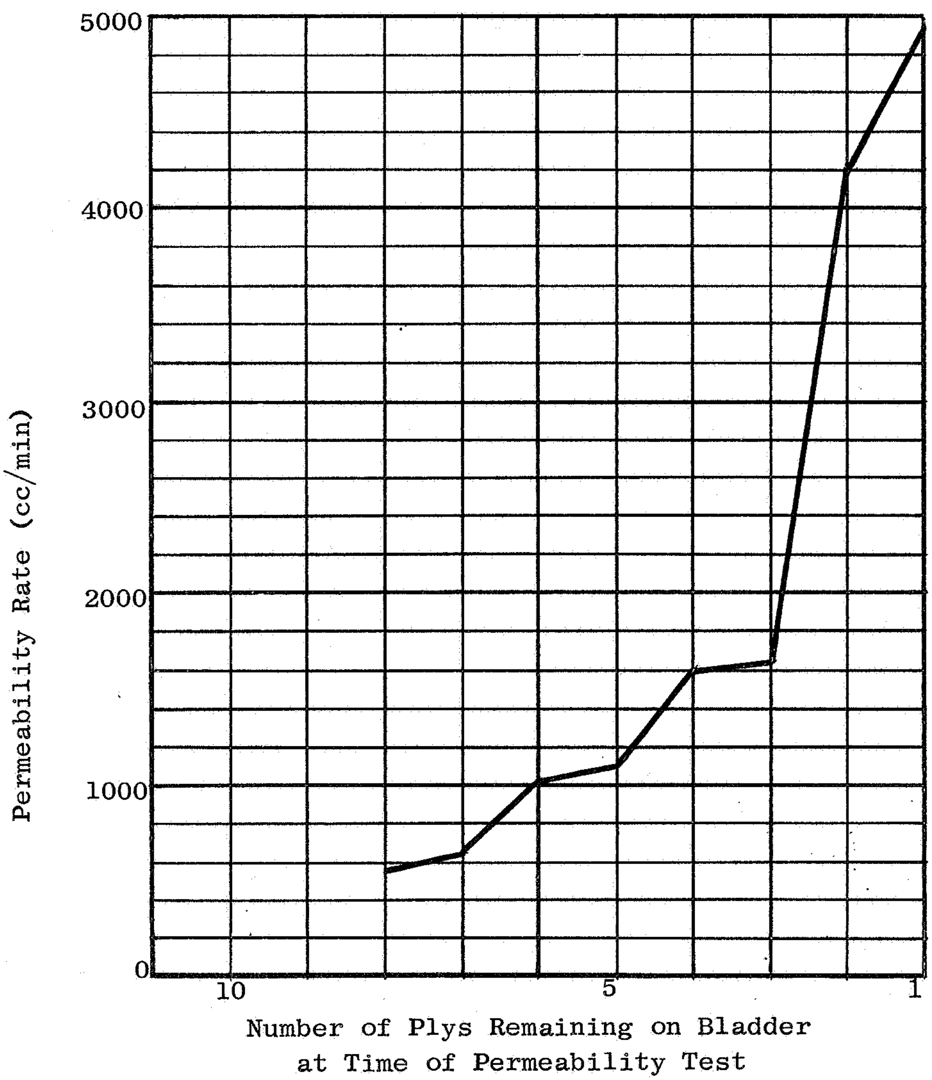
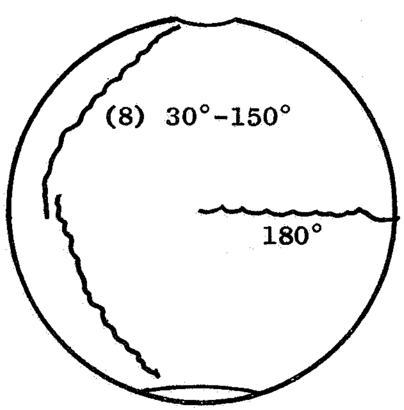
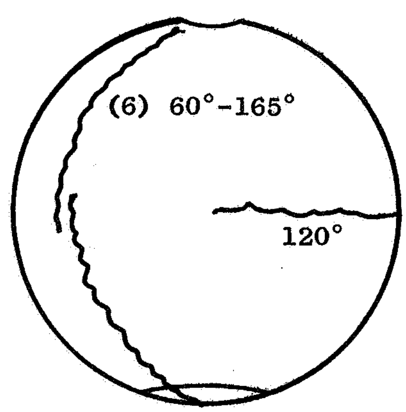


FIGURE 4.38

CONDITION OF PLYS: BLADDER B206



Ply 1: Mylar



Ply 2: Mylar

Bladder B206 (Mylar)

Rectangular samples were cut from various plys in the locations shown in Figure 4.23. Permeability tests upon these samples produced the following results:

	Leakage in cc per Minute	
Ply No.	Stem Area	Polar Area
4	0	29.4
6	.21	.31
10	0	.68

The above indicates that these plys incurred greater wear at or near the polar cap than in the stem area.

d. Summary

1. Bladder B206 produced the most trouble-free operation of all the bladders.

2. This bladder exhibited excellent fill performance (99%) and very good expulsion performance (95%).

3. Only two bladders had a lower leak rate after 25 LH_2 expulsion cycles than this bladder.

4. This bladder gave no evidence of any undesirable characteristics (except for interply inflation at ambient temperature).

4.5.5.3 Test Conclusions, BS15753 Type 5 Bladders

The LH_2 expulsion testing of Bladders B205 and B206 resulted in the following conclusions:

a. This material composite provided operational performance which was entirely free of the various undesirable characteristics exhibited by the other material composites tested.

b. These bladders exhibited excellent fill performance (99%). One bladder (B206) produced very good expulsion performance (95%), while B205 exhibited fair expulsion (86%).

c. Bladder B205 suffered early damage of considerable proportions (28,000 cc per minute leak rate), but was still capable of expulsion of up to 90% of its volume.

d. Good permeability characteristics can be expected of this material composite if serious damage to the plys does not occur.

4.5.6 BS15753 Type 7 Bladders (Figure 4.39)

Units: B207 and B208
Material category: Nomex/Kapton
Material composite: See Figure 3.45
Subcontractor: G. T. Schjeldahl Company

Appearance

These two bladders were very identical in appearance. The exterior Nomex plys were opaque and presented an off-white fibrous appearance which had a slight tinge of amber due to the underlying Kapton plys. These bladders were quite rigid and presented a chordal effect (rather than a true sphere) due to the heavy Nomex material.

4.5.6.1 Bladder B207

a. Initial Condition

The bladder was within specification when received at Beech. It had been fabricated with the improved type of stem seal. The bladder reflected excellent workmanship.

b. LH_2 Expulsion Testing

Bladder B207 presented serious difficulties of installation into the test dewar, despite use of all measures to facilitate the installation. This difficulty was attributed to the bulk and rigidity of the three Nomex plys and due to interply inflation. A permeability test after installation revealed a leak rate of 6.4 cc per minute. All cycles were inward expulsion, except as noted.

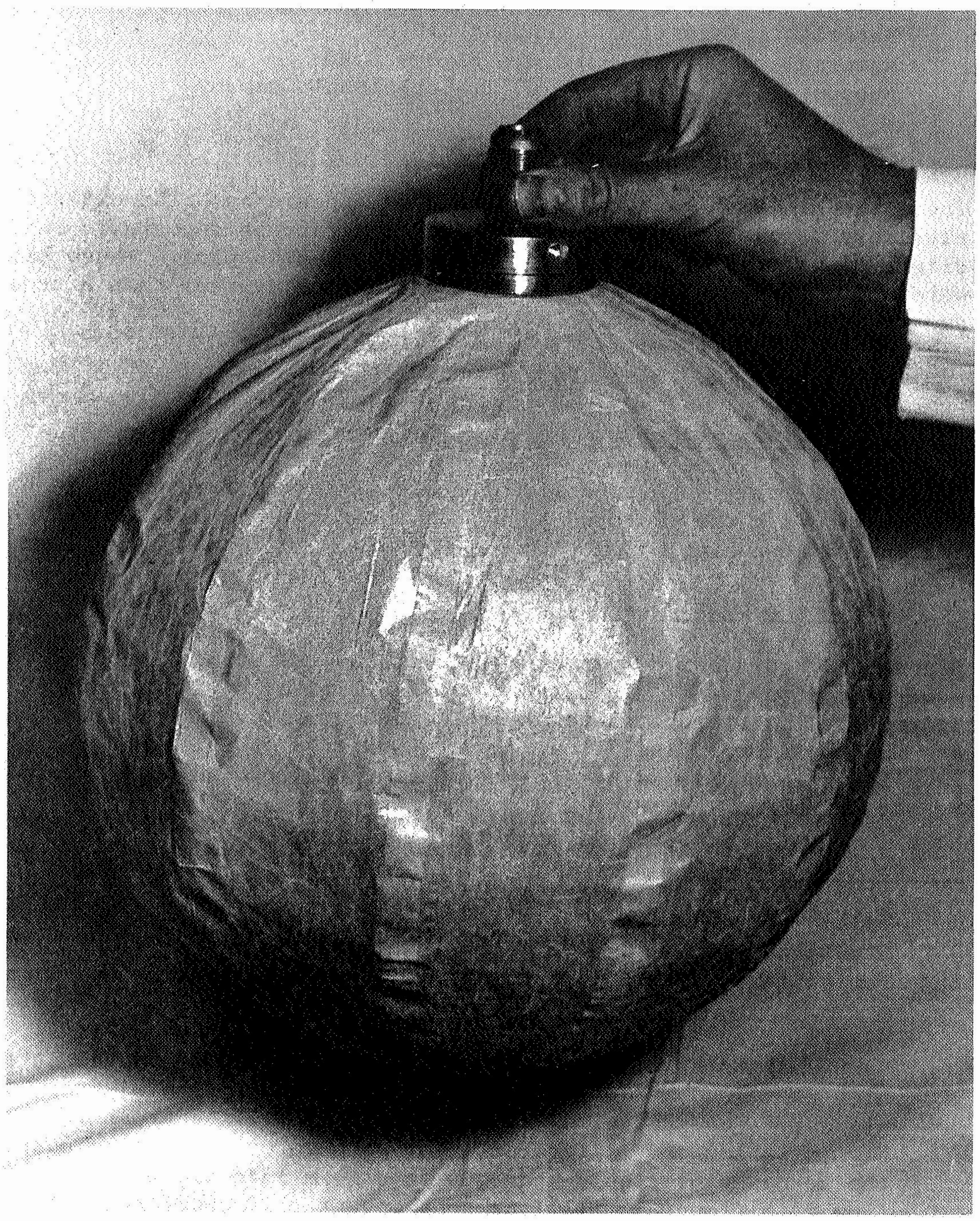
Cycles 1 through 5:

Fill: No more than 15%
Expulsion: 95%
Permeability after Cycle 5: 13.4 cc per minute (also see Figure 4.40)

A significant percentage of fill could not be attained in spite of such assists as a back pressure in the bladder (steady or intermittent), high storage dewar pressure, and LH_2 precool on the exterior of the bladder. The initial explanation to this fill behavior involved interply inflation and failure of inner plys to expand. Also suspected was the tendency of liquid hydrogen to stream into the vent line if the flow path from the fill line to the vent orifice is reduced and not of the proper configuration.

FIGURE 4.39

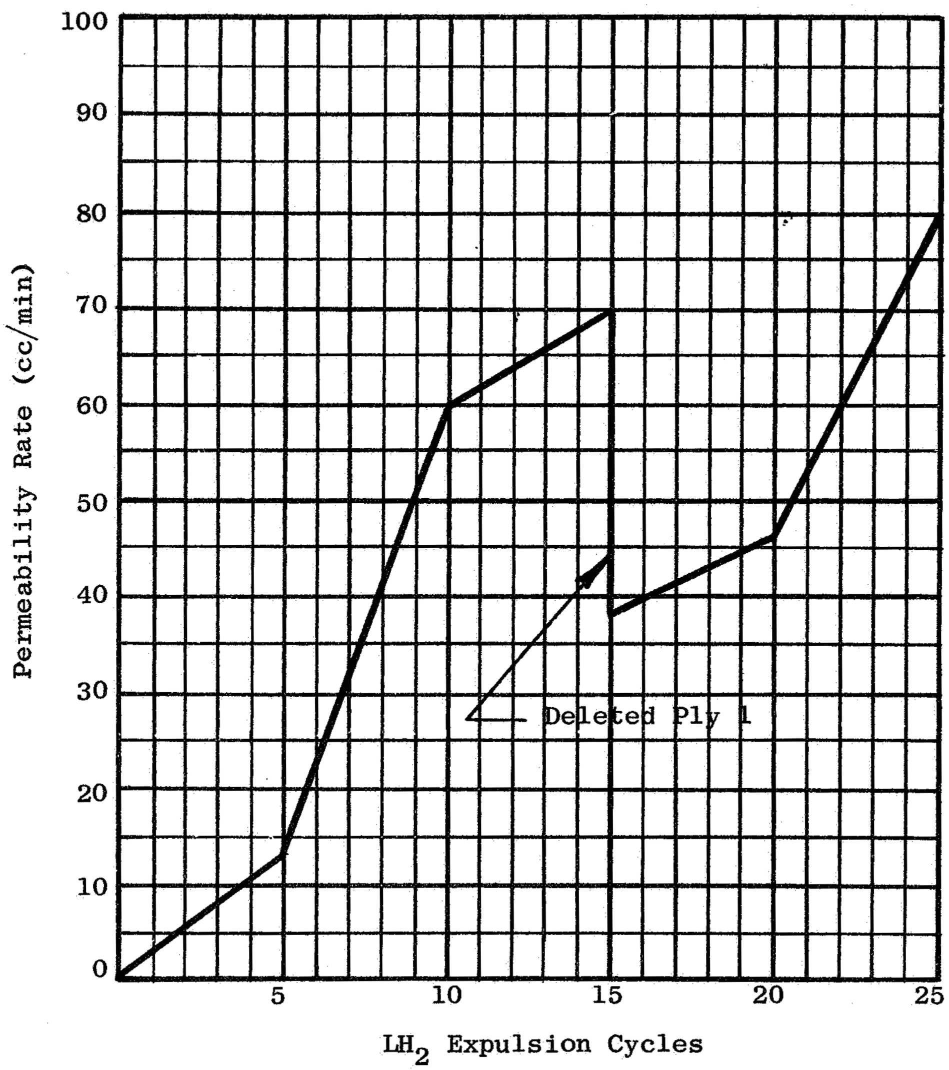
BS15753 TYPE 7 BLADDER



NOMEX/KAPTON

FIGURE 4.40

PERMEABILITY PROFILE OF BLADDER B207
(NOMEX/KAPTON)



Bladder B207 (Nomex/Kapton)

The bladder readily collapsed to 95% of total collapse, but mostly gas was expelled. The bladder was removed from the dewar (for permeability testing) with great difficulty. The collapsed and folded bladder was very rigid and posed a considerable problem on re-installation into the test dewar.

Cycles 6 through 10:

Fill: No more than 15%
Expulsion: 95%
Permeability after Cycle 10: 60 cc per minute

Bladder behavior during these five cycles very closely duplicated the preceding cycles. All efforts to increase the percent of fill were unsuccessful.

Cycles 11 through 15:

Fill: No more than 15%
Expulsion: 95%
Permeability after Cycle 15: 70 cc per minute

These cycles produced behavior very much like the preceding cycles. The poor fill behavior was still attributed to reduction of the internal bladder volume to a "flue" along the withdrawal tube, due to interply inflation and/or bladder rigidity. The LH_2 would have a tendency to stream from the fill line opening to the vent orifice.

Removal of the bladder for permeability testing revealed a .2 inch long tear adjacent to the stem assembly. Ply 1 was removed and a subsequent permeability test indicated a reduction in the leak rate to 38 cc per minute.

Cycle 16:

Fill: 5%, using LH_2 precool
Expulsion: 98% (nothing but gas)

Bladder B207 (Nomex/Kapton)

Cycle 17:

Fill: 10% using LH_2 precool and back pressure inside of bladder.
Expulsion: Bladder began to collapse itself after 6 minutes of fill time: interply inflation between Plys 2 (now outer ply) and 3 reached a degree where Ply 3 collapsed to 8% in 4 minutes. An expulsion cycle was then initiated by the operator, and 95% expulsion was attained (mostly gas).

Cycle 18:

Fill: No more than 10%
Expulsion: 98% (mostly gas)

Cycles 19 and 20 (Outward Expulsion):

Fill: 99%
Expulsion: 99%
Permeability after Cycle 20: 46 cc per minute

Outward expulsion was undertaken to overcome the fill problem. The bladder was capable of a very high degree of collapse, so a 99% fill on the outside of the bladder was readily achieved. The outward expulsion action was 99% effective. Even if the inner plys did not expand fully, the outer plys expanded fully and provided excellent expulsion.

The maximum possible interply inflation was observed after the test series and as the dewar began to warm up. The outer ply (Kapton) was out against the dewar, while all other plys were totally collapsed.

Cycle 21 (Inward Expulsion):

Fill: 10%
Expulsion: 98%

Cycle 22 (Inward Expulsion):

Fill: 0 to 5%, using LH_2 precool
Expulsion: Bladder began to collapse itself after 3 minutes of fill time; interply inflation between Plys 2 (now outer ply) and 3 reached a level where Ply 3 collapsed to 15% in 2 minutes. Upon operator activation, 97% expulsion (all gas) was then achieved.

Bladder B207 (Nomex/Kapton)

This presented a question: where did the 15% (of total volume) between Plys 2 and 3 go when bladder collapse attained 97% of total collapse? No satisfactory explanation to this phenomena can be presented.

Cycle 23 (Inward Expulsion):

Fill: 10%, using LH_2 precool and internal back pressure
Expulsion: 93%

Cycles 24 and 25 (Outward Expulsion):

Fill: 99%
Expulsion: 99%
Final permeability after 25 cycles: 80 cc per minute

c. Post-Test Condition

So as to preserve one bladder in an intact condition, bladder B207 was not dissected following expulsion testing. Therefore, this bladder did not undergo a ply by ply examination.

d. Summary

1. It was impossible to fill B207 to more than 15% of its total volume, in spite of use of all practical measures to improve fill behavior. This could have resulted from failure of the inner plys to expand satisfactorily, due to rigidity or inter-ply inflation. This could also have resulted from a partial condition of the phenomena described for Bladder B102 in Paragraph 4.5.2.2.

2. Bladder B207 partially expelled itself during fill in two different cycles. Inflation between the outer plys collapsed all other plys, resulting in partial expulsion. Such expulsion followed after LH_2 precool, suggesting that some LH_2 may have penetrated the outer ply and then "flashed" into gas.

3. This bladder performed four near-perfect outward expulsion cycles (99% fill and 99% expulsion), eliminating the grossly prohibitive fill problem associated with filling LH_2 on the interior of the bladder.

Bladder B207 (Nomex/Kapton)

4. This bladder exhibited good inward expulsion performance (95%).

5. Bladder B207 had the second lowest permeability rate (80 cc per minute) after 25 LH_2 expulsion cycles.

6. Any unique behaviors of this bladder resulted from the material composite and were not due to bladder design and fabrication.

4.5.6.2 Bladder B208

a. Initial Condition

This bladder was within specification and exhibited excellent workmanship.

b. LH_2 Expulsion Testing

Bladder B208 incorporated the improved stem seal. It was installed in test dewar with little difficulty, using all measures to assist bladder installation. All cycles were inward expulsion, except as noted.

Cycles 1 through 5:

Fill: 20%, 30%, 50%, 40%, and 50%
Expulsion: 98% to 99%
Permeability after Cycle 5: 1.7 cc per minute (also see Figure 4.41)

This bladder immediately gave evidence of a serious fill problem, despite the use of steady and intermittent back pressure in the bladder to help expand the inner plys of the same.

Cycles 6 through 10:

Fill: 25%, except 35% for Cycle 9
Expulsion: 98%
Permeability after Cycle 10: 3.4 cc per minute

Fill behavior remained very poor, despite use of back pressure in bladder. Permeability continued at a very low level.

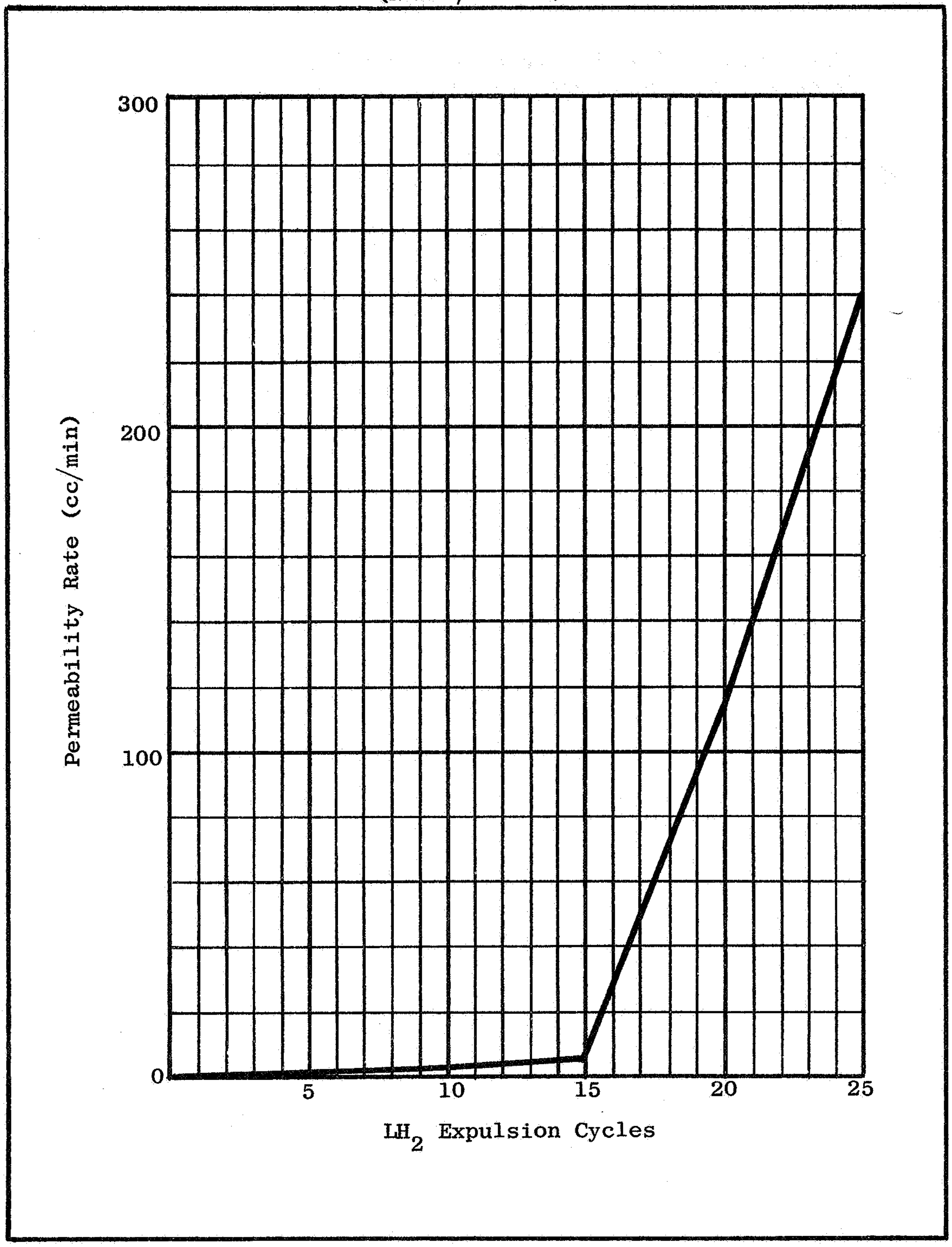
Cycles 11 through 15:

Fill: 60%, 65%, 75%, 70%, and 80%
Expulsion: 98%, 98%, 98%, 95%, and 93%
Permeability after Cycle 15: 5.8 cc per minute

The use of LH_2 precool on the exterior of the bladder (in addition to the interior back pressure) provided for some additional fill for Cycles 13 and 15. The general increase in liquid fill percentages was not readily explained. It appeared that the fill problem was due to a reduced internal volume, resulting from interply inflation or from bladder rigidity. The percentage of fill was too great to suspect the fill phenomena indicated by B207.

FIGURE 4.41

PERMEABILITY PROFILE OF BLADDER B208
(NOMEX/KAPTON)



Bladder B208 (Nomex/Kapton)

Ply 1 had a .3 inch long tear adjacent to the stem assembly. It was removed to enhance observation and because it was feared that it would become inactive.

Cycles 16 through 20:

Fill: 5%, 25%, 5%, 5%, and 0
Expulsion: 95%, 80%, 85%, 85%, and 85%
Permeability after Cycle 20: 115 cc per minute

The fill performance again deteriorated, in spite of the use of LH_2 precool and a back pressure on the interior of the bladder. Now that the opaque outer ply had been deleted, it was possible to observe interply inflation. Interply inflation did not occur while there was LH_2 on the outside of the bladder. However, interply inflation began as soon as the LH_2 boiled away. Since the outer ply was expanded out against the dewar, the interply inflation caused the inner plys to (partially) collapse, reducing the internal usable volume of the bladder.

Cycle 21 (Outward Expulsion):

Fill: 98%
Expulsion: 98%

Outward expulsion action eliminated the interply inflation which degraded the fill percentage for inward expulsion.

Ply 2 (now the outer ply) had a .4 inch long tear near the stem assembly and was removed.

Cycle 22 (Inward Expulsion):

Fill: 20-25% in 12 minutes (with LH_2 precool)
Expulsion: Bladder began to expel itself when LH_2 had boiled away after 12 minutes of fill. This action continued until the inner plys were totally collapsed.

This expulsion further demonstrated the extent of interply inflation which followed the presence of LH_2. Considerable difficulty was experienced in reducing this inflation so that testing could be resumed. Cold H_2 was applied to the outside of the bladder at pressures up to 6 psi before a reduction in interply inflation was achieved.

In view of the problems encountered in this cycle, it was decided to utilize outward expulsion for all remaining cycles.

Bladder B208 (Nomex/Kapton)

Cycles 23, 24, and 25 (Outward Expulsion):

Fill: 98%
Expulsion: 98%, 98%, and 97%
Final permeability after 25 cycles: 240 cc per minute

These cycles again demonstrated that the serious problems of inward expulsion action did not exist for outward expulsion.

c. Post-Test Condition

Bladder B208 was permeability tested in the bell jar after each succeeding outer ply was removed. The results of this testing are shown in Figure 4.43, representing the increase in permeability for the reduction in number of plys. The profile begins with the permeability rate after Ply 2 had been removed (leaving 11 plys on the bladder) and terminates with the permeability rate after Ply 9 was removed (leaving 4 plys on the bladder). Plys 11, 12, and 13 had sufficient damage to prevent acquisition of permeability rates.

All plys were carefully examined upon removal from the bladder. Figure 4.43 shows the damage to the various plys which exhibited visual damage. Kapton Plys 3, 4, 5, 6, 8, 9, and 10 showed no signs of damage or undue wear. Nomex Plys 7 and 13 showed considerable partial peeling of the lap seam, averaging approximately .4 inch long and extending approximately one half (.25 inch) through the seam, in addition to the damage shown in Figure 4.43.

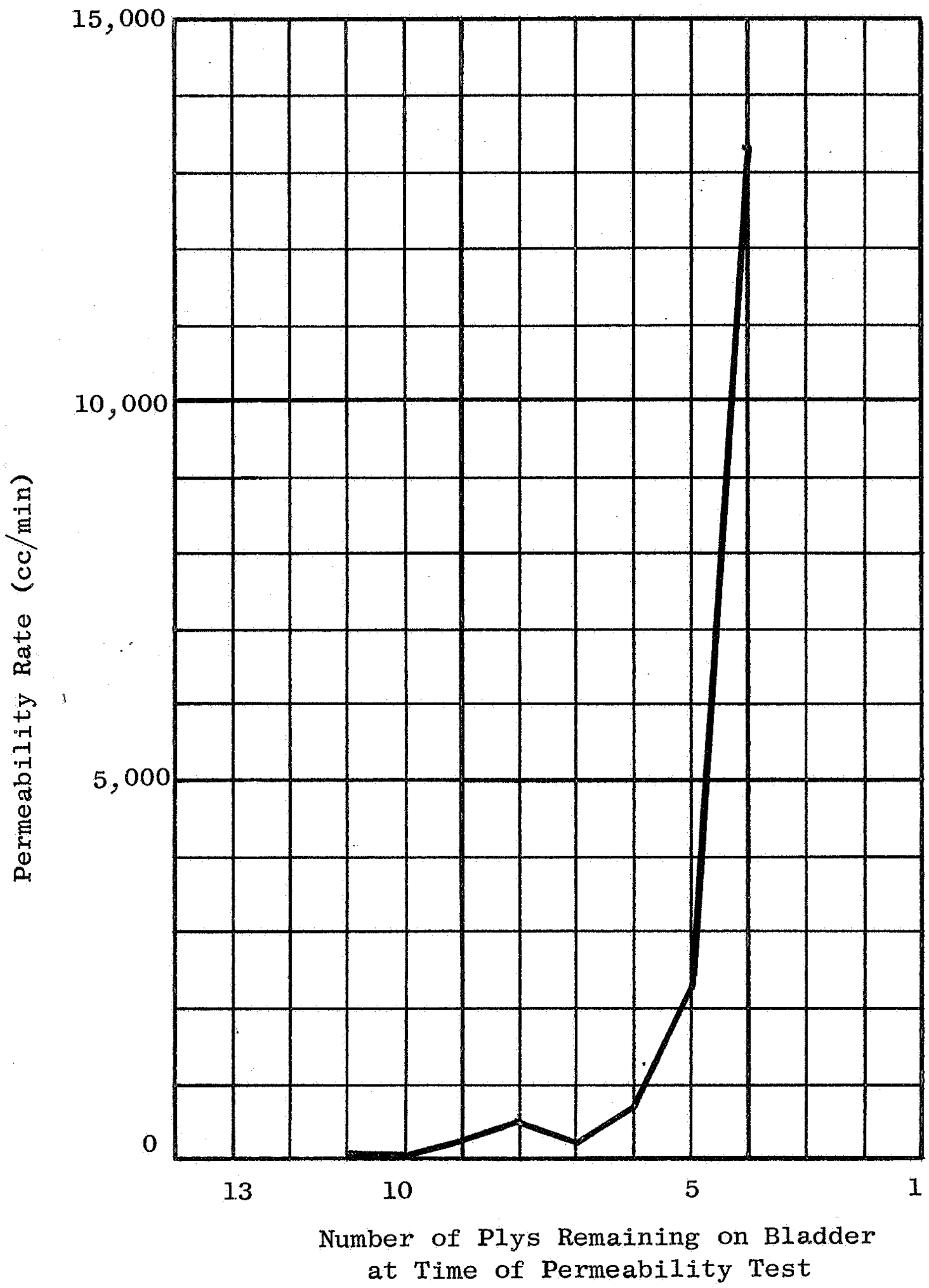
Rectangular samples were cut from various Kapton plys in the locations shown in Figure 4.27. Permeability tests upon these samples produced the following results:

	Leakage in cc per Minute	
Ply No.	Stem Area	Polar Area
2	1750	.12
6	92	.28
10	1600	330

The above indicates that these plys experienced more wear in the stem area than they did in the area at or near the polar cap.

FIGURE 4.42

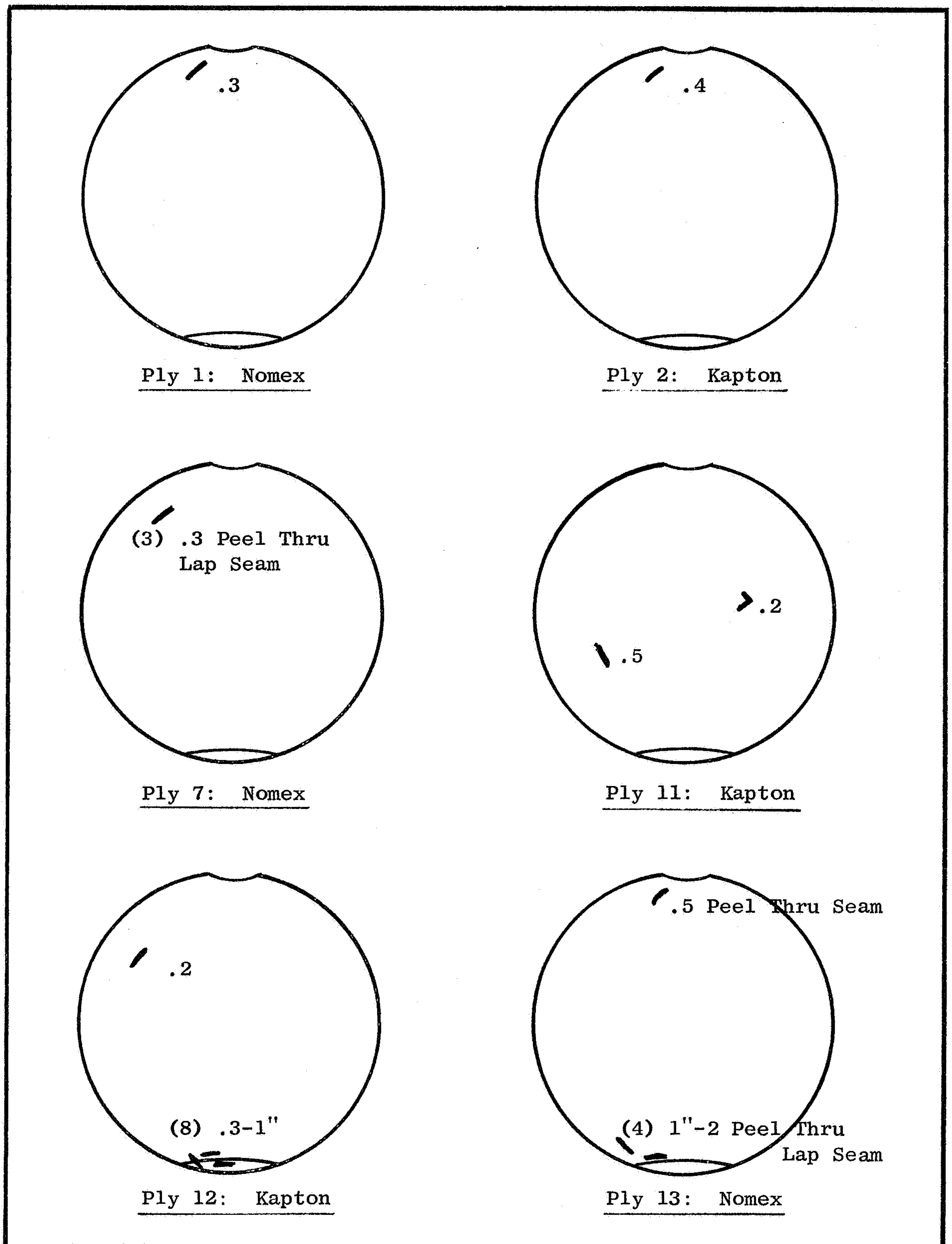
PERMEABILITY VS. NUMBER OF PLYS: BLADDER B208
(NOMEX/KAPTON)



E-270 -1

FIGURE 4.43

CONDITION OF PLYS: BLADDER B208



Bladder B208 (Nomex/Kapton)

d. Summary

1. Bladder B208 exhibit very poor characteristics (average of 36%) for LH_2 fill on the inside of the bladder. This was attributed to a reduction in the internal volume of the bladder due to extensive interply inflation.

2. Nearly total expulsion occurred during fill (following exterior LH_2 cool down) in Cycle 22. This was due to massive interply inflation, believed to result from LH_2 permeation during the precool phase.

3. This bladder exhibited excellent performance in four outward expulsion cycles. None of the preceding problems appeared during outward expulsion.

4. This bladder exhibited good inward expulsion performance (95%).

The testing of Bladders B207 and B208 produced the following results:

a. This Nomex/Kapton material composite produced very good inward expulsion action (96%).

b. This material composite exhibited very poor characteristics for LH_2 fill on the inside of the bladder.

c. The fill problem of Item b above was attributed to massive interply inflation, which was believed to result from LH_2 permeation through the plys, followed by vaporization and resultant inflation.

d. Excellent fill and expulsion performance was exhibited in outward expulsion (liquid outside the bladder and pressurant applied inside bladder).

Many of the problems experienced on inward expulsion did not exist during outward expulsion.

e. It was not established that the Nomex substrate plys performed their intended function of enhancing the operation of the Mylar plys.

f. This material composite reflected good permeability characteristics, exhibiting the second and fourth lowest permeability rate (after 25 LH_2 expulsion cycles) of the 10 bladders.

g. These bladders yielded the lowest average values of porosity up to 25 LH_2 cycles and also the most consistent and relatively uniform porosity values after 25 LH_2 cycles.

4.6 Analysis of Bladder Tests

4.6.1 Evaluation of Test Results

This subsection presents a detailed analysis of the results and data of the LH_2 expulsion testing of the bladders. This analysis shown in Table 4.2 represents essentially all of the primary test data. Values corresponding to the various parameters and characteristics are shown in adjoining columns for each of the bladders.

Table 4.2 presents both statistical information and evaluation based on judgement. Test data is presented in units such as permeability (leak) rates or percentages. Items of a judgement nature are graded as to excellent, very good, good, fair, and poor, as noted at the bottom of the table. These judgements are predicated upon all pertinent test observations and data. The various values were established for each bladder individually, and were not derived by comparison with other bladders. The data pertains primarily to inward expulsion cycles. The cycle-by-cycle permeability pattern correlates to the various permeability profile figures of Subsection 4.5, while the ply-by-ply permeability pattern correlates to the permeability versus number of ply figures.

4.6.2 Conclusions

Analysis of the LH_2 expulsion testing of the bladders has led to the following conclusions. These conclusions are grouped in various categories which are pertinent to evaluation of these bladder tests. The material composites are identified by their material category and bladders are referred to by their identification number.

a. Overall Performance

1. Bladder B206 (10 plys of .25 mil Mylar C) produced the best all-around and most trouble-free performance. This bladder exhibited excellent fill and expulsion behavior and presented the third lowest helium permeation rate (180 cc per minute after repair of a stem seal leak).

2. Bladder B205 (Mylar) produced good all-around performance except for an excessive leak rate (28 liters per minute) arising from partial failure of five of the 10 plys.

3. Bladders B207 and B208 (Kapton) yielded the lowest average values of porosity up to 25 LH_2 cycles and also the most consistent and uniform porosity values after 25 LH_2 cycles. Filling and expelling operations were completely trouble-free during outward expulsion cycling.

b. Operational Behavior

1. Bladders exhibiting the best expulsion percentages and excellent expulsion behavior were:

   B101 (Merfab/Mylar)

   B206 (Mylar)

2. The Nomex/Kapton material composite (Bladders B207 and B208 produced excellent percentages of expulsion, but was very susceptible to serious interply inflation when in the inward expulsion mode.

3. Satisfactory expulsion performance was not as difficult to attain as satisfactory LH_2 fill performance. The average expulsion percentage for all bladders was 85%, while the average fill percentage was 71%.

4. The 10 ply .25 mil Mylar C material composite (Bladders B205 and B206) produced the best liquid fill behavior. 99% LH_2 fill was readily achieved without the various undersirable characteristics exhibited by other material composites tested.

5. Some of the multiple ply material composites presented serious fill problems as follows:

Merfab/Mylar:	Inability to flow LH_2 through bladder in 22-ply configuration due to highly advanced interply inflation.

TABLE 4.2

TABULATION OF EXPULSION TEST RESULTS
(Based on inward expulsion testing observations)

PARAMETERS	BLADDERS									
	B101	B102	B201	B202	B203	B204	B205	B206	B207	B208
1. LH_2 CYCLES										
Number Completed	25	25	5	25	15	25	25	25	25	25
% Expulsion	98	82	95	81	80	67	86	95	95	95
% Expulsion - Last 10 Cycles	99	68	--	93	85	91	94	95	96	90
Expulsion Behavior	Excel	Poor	Good	Fair	Good	Fair	VyGd	Excel	Poor	Fair
% Fill	97	76	96	40	77	73	99	99	13	36
Fill Behavior	Poor	Poor	Good	Poor	Fair	Fair	Excel	Excel	Poor	Poor
Flow Characteristics	Poor	Poor	Excel	Good	VyGd	Good	Excel	Excel	Good	Good
2. PERMEABILITY										
Post-Test Rate (cc/min)	5800	18	500	3300	28000	17000	28000	180*	80	240
Cycle-by-Cycle Pattern	Fair	Good	--	Good	Poor	VyGd	VyGd	Good	VyGd	Good
Ply-by-Ply Pattern	--	Fair	--	Poor	--	--	--	Good	--**	Fair
3. INTERPLY INFLATION										
Installation & Removal	Poor	Poor	Good	Fair	VyGd	Poor	Poor	Good	Poor	Fair
Operational	Poor	Poor	Excel	Fair	VyGd	Fair	Excel	Excel	Poor	Poor
4. PLY CONDITION AFTER TEST										
Barrier Plys										
Near Stem	Poor	Good	Excel	Good	Poor	Poor	Poor	Good	--**	Fair
At Polar Cap	Good	Good	Excel	Good	VyGd	Fair	Excel	Good	--	Excel
Other Areas	Excel	VyGd	Excel	Good	Good	Excel	Excel	Good	--	Fair
Substrate Plys										
Near Stem	Poor	Poor	Good	Good	Excel	Excel	--	--	--	Good
At Polar Cap	Poor	Poor	Excel	Good	Excel	Excel	--	--	--	Good
Other Areas	Poor	Poor	Excel	Good	Excel	Excel	--	--	--	Fair
Comparative Perm.										
At Stem	--	Poor	Fair^{+}	--	--	Excel	--	Excel	--	Poor
At Polar Cap	--	Excel	Fair^{-}	--	--	Poor	--	Poor	--	Excel
% Plys Retained & Effective	55	61	(100)	92	54	54	50	80	92	85

Code for bladder ratings:
Excel (excellent); VyGd (very good); Good; Fair; and Poor

*After repair of stem seal leak, leakage immediately after LH_2 cycling was 428 cc/min.
**Dissection of bladder after testing not performed.

Nomex/Mylar: Average LH_2 fill percentage of 49% due to reduced internal volume caused by interply inflation, improper nesting of plys or rigidity of material composite at LH_2 temperature.

Dacron/Mylar: Generally poor fill performance suspected to be due to material rigidity at LH_2 temperature.

Nomex/Kapton: Very poor fill behavior attributed to reduction of internal volume due to massive interply inflation.

All of the above tendencies occurred only during LH_2 fill for inward expulsion.

6. The degree of liquid fill for bladders of the above materials was often increased by precooling the outside of the bladder with LH_2. This resulted in a reduction (or elimination) of interply inflation due to the condensing of the interstial gases.

c. Permeability

1. The best (lowest) permeability was exhibited by Bladder B102 (merfab/Mylar) followed by B207 (Nomex/Kapton).

2. A leakage level at which further expulsion is impossible was not established for all bladders. Bladder B203 (Dacron/Mylar) was incapable of expulsion at a leak rate of 28 liters per minute, while B205 (Mylar) expelled up to 98% with an identical leak rate. This might be explained by the much greater rigidity (at LH_2 temperature) of the Dacron.

d. Interply Inflation

1. Interply inflation is a problem of considerable magnitude which requires special consideration in the selection of material composites and expulsion methods for cryogenic expulsion bladders.

2. Almost all of the operational problems of these multi-ply bladders can be attributed partly or entirely to interply inflation.

3. Interply inflation was indicated to be a function of the number of plys: The 22-ply Merfab/Mylar composite experienced very advanced operational interply inflation, while the 10-ply Mylar material composite exhibited the least inflation.

4. Interply inflation was more prevelant in the bladders with Nomex substrate plys than in the bladders without substrate plys.

5. Increased interply inflation occurred between Kapton plys (of Bladders B207 and B208) immediately following the boil-off of any LH_2 in contact with the bladder. This suggested that the LH_2 permeation rate through Kapton is significant or that film damage after cycling was not as severe for Mylar and hence Kapton would be able to retain trapped inter-ply gases a longer period of time.

e. Substrate Plys

1. It was not possible to establish to what degree the substrate plys (Merfab, Nomex, or Dacron) performed their intended function of enhancing the flex performance of the barrier plys.

2. Though the Merfab substrate plys suffered massive damage under LH_2 cycling, the bladders utilizing this material demonstrated some characteristics superior to Mylar plys only. Therefore, the investigation of Merfab as a substrate ply should not be terminated because of a lack of evidence as to its merit.

3. The Nomex substrate plys were believed to contribute to interply inflation in the inward expulsion mode. However, utilization of the outward expulsion mode eliminated this problem, while still taking advantage of their abrasion shielding potential.

4. The Dacron substrate plys were readily penetrated by LH_2 and helium gas, and thus presented problems of unified bladder action. The weight of the Dacron fabric tested resulted in considerable material rigidity at LH_2 temperature.

f. <u>General</u>

1. Many of the test problems associated with these bladders must be attributed directly to the use of the inward mode of expulsion. Sufficient outward expulsion cycles were performed to indicate virtual elimination of flow, fill, and expulsion problems due to interply inflation.

2. The restoration of Bladder B101 (Merfab/Mylar) to excellent performance was accomplished by the removal of nine of 22 original plys after Cycle 5. This suggested that the optimum number of plys for the Merfab/Mylar composite is nearer to 14 than to 22.

3. The small size of these bladders may have contributed to poor LH_2 fill behavior of the Nomex/Mylar and Dacron/Mylar bladders. The improper nesting of plys and excess substrate ply rigidity should be less significant in larger bladders. The "tacking" of all bladder plys at selected points might be of benefit in controlling these behaviors.

4. The performance of all seams was outstanding, except for a number of short peels through the lap seams of the Nomex plys of several bladders. These Nomex plys also exhibited considerable peeling partially through the lap seams.

5. The predominate area for ply wear and damage was not fully established. The various plys of Bladders B102 and B207 exhibited the most damage in the area adjacent to the stem assembly, while Bladders B201, B204, and B206 exhibited more damage in or near the polar cap. Damage in the stem area must be partially attributed, in varying degrees, to problems of repeated installation into and removal from the test dewar for permeability testing.

5.0 RECOMMENDATIONS

The following general and specific recommendations are made with respect to future cryogenic expulsion bladder development programs.

5.1 General Recommendations

a. Additional bladders of identical or similar materials selected in this program should be tested to provide data on repeatability and reliability. At least five bladders of one type are necessary to assure that expulsion characteristics and data can be correlated and the best bladder selected.

b. The following bladders are recommended to augment the bladders tested in this program and to further investigate minor improvements in material composites suggested by test results.

(1) .25 mil Mylar C, 10 plys (identical to B205 and B206).

(2) .5 mil Kapton H, 10 plys.

Because of the excellent performance of this material in the Nomex/Kapton bladders, it should be tested alone to provide visibility of film action and to compare cycle life with the Nomex/Kapton material. When Kapton can be obtained in .25 mil thickness, it should also be evaluated.

(3) Nomex/Kapton (identical to B207, B208). This material needs to be tested in a bladder in which outward expulsion cycling is the primary mode of operation. Bladders B207 and B208 in this program received especially harsh treatment in the course of overcoming interply inflation resulting from the conditions required by inward expulsion. The test results indicated a potentially good bladder material.

(4) Merfab/Mylar, 14 plys

Additional bladders of this material composite should be tested using a variation in ply arrangement to eliminate the poor characteristics and improve the

5.1 General Recommendations (continued)

good qualities shown in the test results of Bladders B101 and B102. The number of plys should be reduced to no more than 14 and the outer plys should be Mylar with alternating Mylar and Merfab inner plys.

c. The outward expulsion mode of operation should be specified for future multiply ply bladders unless improved dewar design essentially eliminates all heat input. Many of the problems associated with cycling the bladders in this program were attributed to interply inflation which is exaggerated by a fully expanded bladder during inward expulsion. Although a fully expanded bladder is desirable for long term storage with regard to wrinkle-free material, the heat transfer through the container wall and resultant interply inflation may negate this advantage. Tests have shown that a collapsed bladder in a dewar full of liquid using outward expulsion will eliminate the problem of interply inflation. (Ref. 11).

d. A clear glass dewar should continue to be used for all cryogenic expulsion bladder testing. Observation of the bladders and individual plys is necessary for the understanding of the expulsion cycling action. Conclusions and recommendations are based not only upon specific test data but also from observations of bladder performance.

e. Any new polymeric materials which appear to have promise for cryogenic expulsion bladders should be evaluated by use of the Twist-Flex test and correlated with permeability measurements similar to methods used in this program. At the present time, all known potential materials commercially available have been evaluated as flat samples and many of the best have been tested as bladders.

5.2 Specific Program Recommendations

It is recommended that the following programs be undertaken to take advantage of the advances in cryogenic technology achieved by the past program.

5.2.1 Bladder Testing Program

A bladder testing program is recommended to consolidate the experience and understanding of multiple-ply cryogenic bladders acquired in this program. It is necessary to test a sufficient number of identical or similar bladders of the type tested in this program to confirm the results with statistical data for repeatability and/or reliability.

The test program should conform to the present test plan of Section 4.0 with the following exceptions.

a. The primary mode of expulsion should be outward.

b. The bladders should be ambient temperature leak checked in the glass dewar at intervals of approximately eight expulsion cycles, eliminating the need for excessive handling by total removal from the dewar.

c. The mass spectrometer lacks the quantitative measurement achieved by the burette method in Paragraph (b) above, and therefore is not recommended.

d. Increase motion picture coverage by a permanent explosion-proof camera and lighting installation would provide better visual documentation of bladder cycling action.

5.2.2 Future Programs

Subsequent to the proposed program of Paragraph 5.2.1, the following programs are recommended which will logically lead to the ultimate goal of spaceflight expulsion bladder systems.

a. A study should be conducted to establish operational parameters and mission profiles for present and future space vehicles in which cryogenic expulsion bladders could be utilized. Acceptable permeability values, cycle life requirements, bladder size, environmental conditions, etc. are essential parameters required in determining whether the present state-of-the-art could justify using presently developed materials and bladders.

b. A self-contained cryogenic expulsion bladder system should be designed, fabricated and tested as a prototype unit for a specific space vehicle application. Testing should include not only flexibility and permeability measurements but also slosh and vibration data.

c. A flight test program should be initiated using the prototype unit developed in Paragraph (b) above, or a specially designed flight-weight system. The flight testing could be accomplished in a KC135 jet aircraft flying a parabolic flight path in which an expulsion cycle could be accomplished during the time element of zero gravity.

d. Concurrently with the development of flightweight systems, all new materials should continue to be evaluated together with bladder fabrication processes. Although present materials are probably satisfactory for certain applications, the improvement in permeability and the proof of reliability will expand the potential applications.

e. Qualification testing of materials, bladders and fabrication techniques should be accomplished through regular testing procedures using standard size materials and bladders for reasons of correlation. The 4 x 11 inch flat samples and 11.5 inch diameter bladders are recommended because of the presently available data.

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TABLE OF CONTENTS

7.0 APPENDICES

APPENDIX A

INDIVIDUAL SAMPLE DETAIL TEST DATA - SEA SPACE SYSTEMS, INC.

All samples tested and reported on in this section have been tested in liquid hydrogen except as noted. The only liquid nitrogen tested samples are the .5 mil Kapton samples T209, T210, T211.

Following the detail data, a general summation of the results for that particular group is provided except where each sample is described in detail. The characteristic failure of all samples of a type made it feasible to summarize the test results for the entire group.

* An asterisk after permeability data indicates excessive leakage measured as the number of seconds to reduce H_e pressure of one psi to zero on one side of sample.

The figures listed in columns under each sample description are as follows:

Sample No.	1st Permeability (before cycling)	2nd Permeability (after cycling)	Number of Cycles	Comments

T101 Description

30 plys of .10 mil polyethylene
Plain film - no seams
Thermally sealed with tape around all edges
Tested in liquid hydrogen

-3	--	--	200	Stopped for visual check at 25 and 100 cycles. One inch split from top edge occurred prior to 200 cycles. Corner torn off and small tear in surface by code number. Sticky area by tear. Permeability check impossible after testing.
-7	--	--	200	Stopped at 25 and 100 cycles. Outer ply torn after 100 cycles in a long tear from top center to left end and back to bottom center. Tear also on back outer two plys above lower clamp. Permeability test shows five bubbles per minute.
-8	--	--	50	Checked at 25 cycles. Six tears present. One tear from top seam 1-1/2 inches long in back three or more plys extending diagonally from top. Two tears through bottom seam. One tear from right edge about one inch long.

This material and edge seaming method showed the most flexibility in handling since there was no build up of thickness at the seams. Apparently a reinforcing ply of scrim materials is needed to help eliminate the tearing.

APPENDIX A (CONT)

T102 Description

30 plys of .15 mil Mylar C
Plain film - no seams
Edges seamed with S114 adhesive between each ply
Tested in liquid hydrogen

-2	--	--	0	Break in end seam which propagated and tore through seam approximately one inch during mounting of sample in twist-flex apparatus. Sample not tested.
-3	--	--	0	Edge seams too stiff for twist-flex testing. Sample not tested because of inevitable failure. Saved for later consideration and possible removal of end seams.
-4	--	--	2	The very stiff end seams tore in two places on each end stopping test in two cycles. Permeability check after test impossible.

The extremely heavy edge seams caused by the build-up of adhesive between each of the 30 plys and closing tape was approximately 48 mils. This thickness cannot be tolerated at cryogenic temperatures and this seaming method cannot be used for future samples.

T103 Description

30 plys of alternating films of .10 mil Poly and .15 mil Mylar C
Plain film - no seams
Edges seamed between plys with S110 adhesive
Closing tape sealed with S114 adhesive
Tested in liquid hydrogen

-1	--	--	200	Stopped sample at 5, 10, 25, 100 and 200 cycles. Two splits in end seam failed the sample. Adhesive apparent at every break and along seam areas. Permeability test showed no detectable leak through area of sample.
-2	--	--	100	Checked at 25 cycles. Failure of ply noticed at 90 cycles. End split one inch long discovered when sample removed. Four small tears into seam. Two particle breaks in seam from right edge. One long break in back plys about six inches from left end. No permeability check possible.
-3	--	--	35	Five tears through edge seam. One tear 1.5 inches long from right end. One tear through left end .9 inches long. Three partial breaks through seam.

APPENDIX A (CONT)

The edge seam of these material samples was quite thick but not as stiff as T102. The material was very flexible and cycle life shows some promise. The edge seams must be reduced in thickness and in stiffness to improve this material.

T104 Description

30 plys of .10 mil polyethylene and .15 mil Mylar C
Between the .10 mil Poly film are 40 denier HT fibers on 1/8" centers
Between any two poly films is a .15 Mylar film
Outer films are .15 Mylar
Edges seamed between poly and Mylar with S110 adhesive
Closing tape sealed with S114 adhesive
Tested in liquid hydrogen

-1	--	--	200	Checked at 10 cycles and observed continuously. No serious failures noticed except for minor creases in edge seam at many points. Permeability check showed four bubbles per minute rate.
-2	--	--	200	Checked at 25 and 100 cycles and during entire run. Outer ply pealing back near code number at 90 cycles. Run continued since other plys appeared to be OK. Three end breaks in left edge and one in right end. Seam delamination apparent at many points. Tear in outer ply on back side. Permeability test indicated 1.5 bubbles per minute.
-3	--	--	200	Stopped for visual check at 25, 50, and 100 cycles. Partial breaks in end seams. Permeability rate two to three bubbles per minute.

This material appeared to be the most satisfactory of the four materials tested of this group. Improvement in the adhesive or seaming method to reduce the stiffness and some variations of lamination order of plys may improve this material.

APPENDIX A (CONT)

T105 Description — Similar to T101 with addition of fibers
30 plys of .10 mil polyethylene assembled into 15 Merfab elements with 40 denier HT (nylon) fibers 1/8" on centers
Edges seamed with S110 adhesive between each ply
Closing tape around edges of sample

-1	.0036	65*	200	Split from upper clamp to lower clamp area 3" from right end front side.
-2	.0043	35*	200	Split across upper clamp area to edge 3" from right end. Split across both ends at lower clamp area.
-3	.029	33*	200	Split across right end cap. Split across front side from upper to lower edge 4" from right end.
-4	.0013	.29	100	Split at right and left end edges also 1" split at lower right corner front side 1/2" up from edge.
-5	.0086	.056	100	Split at right and left end edges - no other visible damage.
-6	.003	.93	100	Split at right and left end caps.
-7	.011	.026	50	No visible change.
-8	.0015	.012	50	No visible change.
-9	.0043	.034	50	Split at lower right end front side 2" long also split on right and left end caps - slight inflation.

Excellent appearing material with wrinkled but soft, smooth surface. Edge seams and material flexible. Very satisfactory except for the high permeability following testing. Splitting of film apparently on outer plys, although permeability might indicate splits in all film plys.

APPENDIX A (CONT)

T106 Description — Identical to T105 with the addition of .10 mil polyethylene film ply between each Merfab element
30 plys of polyethylene
Edges seamed with S110 adhesive and taped

-1	.0053	102*	200	Split across upper edge 2" from right end. Various breaks on front side 2.5" from right end in center area. Breaks across right end cap upper and lower edge area.
-2	.017	92*	200	Split across left end cap upper and lower edge area.
-3	.020	5*	200	Split along lower edge 3" from left end. Split vertical and horizontal at lower left end 1/2" in from corner.

Appearance identical to T105 and results very similar. Permeability relatively high. Addition of Mylar film ply would reduce permeability.

T107 Description — Identical to T104 except edges of plys wetted with adhesive
S110 adhesive used
Closing tape

-1	.012	.013	200	Split 3" long on front side starting at lower edge 4" from left end and running up toward identification number. Split 1.5" long on back face about 1" from lower edge at center of strip. Also split on back side below identification number.
-2	.0076	.014	200	Split on back side starting at upper right end 1" in from end running down across strip 5" long.
-3	.0076	.010	200	Three splits on front side at left end cap across face at center area, at lower edge in center and at lower edge right end. Same on back side.

Extremely soft, smooth and flexible material and edge seams. Permeability improved over other pure polyethylene samples by the addition of Mylar film.

APPENDIX A (CONT)

T108 Description

30 plys of film total consisting of 12 plys of .15 mil Mylar and 16 plys of .10 polyethylene
Two outside plys of Merfab elements
Four groups of alternating Mylar/Poly/Mylar/Poly/Mylar
S114 closing tape and adhesive
S110 adhesive between selected plys

-1	.0093	.005	200	No visible change after cycling
-2	.004	.0036	200	Split at upper edge 2" from right end
-3	.00066	.013	200	Split on forward side at upper edge 4" from right end and lower edge 2" from left end. Back side has split almost full length at upper edge.

Extremely soft, smooth and flexible material and edge seams. Permeability extremely low.

T109 Description

30 plys of .15 mil Mylar C
Each ply 90 degree machine direction
S110 adhesive between plys at edges
S114 closing tape and adhesive

-1	0	.003	200	Numerous wrinkles - no visible damage
-2	.0013	.0016	200	Numerous wrinkles - no visible damage
-3	.0013	0	200	Numerous wrinkles - no visible damage

Typical Mylar multi-ply sample with good permeability following twist-flex testing. Seam extremely flexible.

T110 Description

Same as T109 except 10 plys of .15 mil Mylar C

-1	0	.006	200	Numerous wrinkles - no visible damage
-2	.039	---	---	This sample not tested - to be replaced
-3	0	.00066	200	Numerous wrinkles - no visible damage

Typical Mylar multi-ply sample with good permeability following twist-flex testing. Seams extremely flexible.

APPENDIX A (CONT)

T111 Description — A 30 ply sample composed of 14 plys of .15 mil Mylar C and 16 plys of .10 mil polyethylene
Outer plys Mylar
Inner plys alternating Merfab elements with Mylar films

-1	0	.005	200	Numerous wrinkles - no visible damage
-2	.013	.037	200	Numerous wrinkles - no visible damage
-3	.031	.052	200	Numerous wrinkles - no visible damage

Extremely soft, smooth and flexible material and edge seams. Permeability higher than some other pure Mylar samples otherwise similar.

T112 Description — Same as T111 except only 6 Mylar and 8 poly films
Inner plys grouped into two groups of Mylar/Merfab/Mylar

-1	.009	.085	200	Split of 1st, 2nd and 3rd ply at lower left corner
-2	.008	.056	200	Numerous wrinkles - no visible damage
-3	0	.18	200	Split full length except end seams on back ply. Split across end seam at upper right end.

Same as T111 analysis

T113 Description — Three Nomex plys and 8 Film plys
.15 mil Mylar, Merfab element
S110 Adhesive between plys at edges
S114 closing tape and adhesive

-1	.0046	.005	200	End caps split - numerous wrinkles
-2	.013	.04	200	End caps split - numerous wrinkles
-3	.01	.011	200	End caps split - numerous wrinkles

Excellent appearing material without any serious damage. Mylar films apparently not affected according to 2nd permeability reading.

APPENDIX A (CONT)

T114 Description — Three Nomex plys and 20 Film plys consisting of 12 Mylar .15 mil and 8 polyethylene .10 mil S110 Adhesive between plys S114 Adhesive and closing tape.

-1	.0016	.0036	200	End caps split - numerous wrinkles
-2	.0063	.023	200	End caps split - numerous wrinkles
-3	.0013	.001	200	End caps split - numerous wrinkles

Excellent appearing material without any serious damage. Mylar films apparently not affected too seriously by flexing as shown by 2nd permeability readings. Material more bulky than T113 because of additional film plys.

T115 Description — Two outer Merfab elements; Orthogonal, S110 adhesive between plus six groups of .15 Mylar/Merfab/.15 Mylar joined only by S110 wetted edges and closing Mylar tape.

-1	.0066	.0036	200	No visible change
-2	.003	.002	200	Split on back side 1" from upper edge 8.5" long - left end cap split 1/8"
-3	.004	.023	100	1/2" split at right end cap - no other visible damage
-4	.0046	0	100	1.5" split on left end cap - no other visible damage
-5	.0013	.003	50	No visible change
-6	.002	.0066	50	No visible change

A soft, flexible material in which the Orthogonal fibers are visible through all of the layers of film. Exceptionally good condtion following twist-flex testing.

APPENDIX A (CONT)

T116 Description				Identical to T115 material with the addition of cross seams in sample.
-1	.017	.027	200	Split on back side 1" above lower edge 8" long - 3" split in 2nd ply at center area.
-2	.026	.045	200	Split on front side from -2 I.D. no. down 2" - split on back 1/2" above lower edge three places 1" each. Split 1" long 1/2" from lower edge and 1" from right end on back side.
-3	.022	.023	100	Very uneven split across front side centerline a total of 7" split on back side 1" long at center area 1" up from lower edge.
-4	.016	.035	200	Split 1" long at center of front side. Split 2" long at center of back side.
-5	.044	.022	100	Split on front side upper left corner 1.5" long - split on left end cap edge 1.5" long.
-6	.045	.02	100	Split on front side 2" long - split on back side 5.5" long from left end.

Appearance and results similar to T115 with the cross seams producing no serious changes. Splitting apparently in outer plys only.

T117 Description				30 plys of .25 mil Mylar Cross seams S110 between plys S114 closing tapes
-1	.003	.0033	200	Split 5" long below I.D. no.
-2	.0086	.24	200	Split 2" long above I.D. no. 3" split down across center front side - 2" split 2" from right end.
-3	.0016	--	10	Split 6.5" through all plys from left end 3/4" from lower edge.

Very bulky sample with 30 plys of Mylar. Exhibited typical Mylar results with very good permeability and flexibility unless complete splitting failure occurs which destroys the entire sample.

APPENDIX A (CONT)

T118 Description				10 plys of .25 mil Mylar Cross seams S110 between plys S114 closing tapes
-1	.038	-	150	Split across left end cap 2.5" on front side - 1" split above I.D. no. 3" split on back side at right end.
-2	.076	-	15	3.5" split across right end cap 1/2" from top edge.
-3	0	.27	50	Split 2.5" below I.D. no. Split 3.5" at upper right end front side.

Splitting of end caps most serious problem in this sample. Permeability not measurable when all films split into field of sample.

T119 Description				30 plys of .25 mil Mylar S110 adhesive on edge seams S114 closing tapes
-1	0	.0013	200	Numerous wrinkles and moderate inflation.
-2	0	0	200	Numerous wrinkles and slight inflation.
-3	0	.011	200	Numerious wrinkles and moderate inflation.

Excellent results with low permeability and no splitting which occurred on similar T117 samples with cross seams. Conclusion is not possible, however, that seams were the cause of the difference in results.

T120 Description				10 plys of .25 mil Mylar S110 adhesive S114 closing tapes
-1	0	-	65	Split 6" from right end across end cap 1/2" down from top edge.
-2	.002	.0026	160	Split 4.5" long on front ply from right end - slight inflation.
-3	.0016	.0016	200	Split 2.5" long on front ply 2.5" in front left end - slight inflation.

Typical Mylar results. Good permeability with multi-ply films unless splitting occurs which frequently affects all plys.

APPENDIX A (CONT)

T121 Description — 3 Nomex plys and 20 film plys (12 plys of .15 mil Mylar C and 8 plys of .10 mil polyethylene).
S110 between edge seam plys
S114 at closing tapes

-1	0	.0013	200	Permanent creases - both end cap edges split.
-2	.012	-	200	Permanent creases - both end cap edges split.
-3	0	.0066	200	Permanent creases - both end cap edges split.
-4	.004	.005	200	Permanent creases - both end cap edges split.
-5	.0013	.0013	100	Permanent creases - both end cap edges split.
-6	.014	.01	50	Permanent creases - both end cap edges.

Excellent results with flexibility and strength with low permeability following twist-flex testing with good cycle life.

<u>T122 Description</u> — Identical to T115 with addition of cross seams.

-1	.016	.033	200	Split at left end by I.D. no. Also split (2) places approximately 3" and 4" from right end on front. Split on back side approximately center area.
-2	.0046	.031	200	Split (3) places on front.
-3	.0083	.039	100	Split on front side below I.D. no. Sticky adhesive on back side of left end.
-4	.0090	.0086	100	Split on front and right end edge - sticky adhesive on right end front side - slight inflation.
-5	.0066	.018	50	Split on front and back - sticky adhesive at left front edge.
-6	0	.017	50	Split 3 places on front and 1 place on back - sticky adhesive on back side at left end.

Soft, flexible, somewhat bulky material but with good characteristics. Results of permeability indicate splitting only on a few surface films.

APPENDIX A (CONT)

T123 Description			30 plys of .15 mil Mylar C Cylinder 3-1/4" dia. x 4" Cross lap seams	
-1	-	-	45	Vertical split on outer ply 3" long - left of I.D. no.
-2	-	-	12	Split 2" long on outer ply 2" down and to right of I.D. no.
-3	-	-	64	Multiple directional split on outer ply 180° from I.D. no.
-4	-	-	34	1" split on outer ply, 1.5" to left of I.D. no. and .75" down from edge.
-5	-	-	43	1" split just below I.D. no. on outer ply.

The cylinder configuration shows more serious and early failure due to the restriction of the material.

T124 Description			12 Plys of .15 mil Mylar C and 3 plys of Nomex (2 mil) without Cross Seams	
-1	.016	.016	200	Several small holes and areas worn thin.
-2	.026	.0083	200	Several small holes and areas worn thin.
-3	.012	.013	200	Several small holes and areas worn thin.
-4	.012	.005	100	Wrinkles and creases on front and back plys.
-5	.015	.022	36	.25" split on upper right end edge.

Very good flex and permeability performance; however, samples are without cross seams. Also see data for T125.

APPENDIX A (CONT)

T125 Description				12 Plys of .15 mil Mylar C and 3 plys of Nomex (2 mil) with Lap type cross seams, 1/2" wide
-1	.019	.02	200	Split on horizontal seam on back ply 1.5" long - several holes and areas worn thin on front and back plys - split on left end edge 1/4" long.
-2	.02	-	200	Some seam separation on front ply horizontal seam - 2" of horizontal seam separation on back ply - split 1" long at upper right end.
-3	.021	.033	200	3" seam separation on back ply horizontal seam; other incipient seam failure.
-4	.014	.017	200	Separation of horizontal seam (2) places on front ply and (1) place on back ply.
-5	.035	.0096	100	Separation of horizontal seam on back ply (2) places, 4.25" and 1" long.

Good flex and permeability performance despite persistent seam failures in Nomex (apparently insufficient adhesive). Seams in Nomex not acceptable without additional development.

T126 Description				3 Nomex Plys and 20 Film Plys (12 plys of .15 mil Mylar C and 8 plys of .10 mil Polyethylene). Lap type cross seams - 1/2" wide
-1	.0093	.016	200	Several holes and area worn thin on front and back plys; incipient seam failure, several places.
-2	.02	.013	12	1" seam separation on front ply, .75" split on upper right end edge.
-3	.0096	.016	10	5/16" split on lower right end edge, creases and wrinkles on front and back plys.
-4	.023	.012	13	Wrinkles and creases with areas worn thin on front and back plys; incipient seam failure on front.
-5	.012	.016	15	Separation (2) places 4" and 3" along horizontal seam on front ply.

Generally very short flex life to point of advanced deterioration and incipient seam failure.

NOTE: These samples exhibit very irregular lap seams.

APPENDIX A (CONT)

T127 Description — 10 Plys of .5 mil Kapton with closing tape of Mylar and S114 Adhesive
Lap type cross seams - 1/2" wide

-1	.0043	-	7	Split 3" long through all plys at lower left end - split .75" long through all plys at upper left end.
-2	.003	.026	54	Split 1" long on front ply at upper right end.
-3	.001	.0093	31	Split 3" long on front ply across horizontal seam.
-4	.003	-	7	Split 2.5" in from lower left edge through all plys - split 1" in from lower right edge through all plys.
-5	0	.01	51	Split on front ply .5" long - slight inflation.

Very poor flex performance suggesting that Kapton should not be used without substrate plys.

90-33364

APPENDIX B

INDIVIDUAL SAMPLE DETAIL TEST DATA - G. T. SCHJELDAHL COMPANY

Following the detail data, a general summation of the results for the particular group is provided except where each sample is described in detail. The characteristic failure of all samples of a particular type made it feasible to summarize the test results for the entire group.

*An asterisk after permeability data indicates excessive leakage, measured as the number of seconds to reduce He pressure of 1 psi to zero on one side of sample. The figure listed in columns under each sample description are as follows:

Sample No.	1st Permeability (Before Cycling)	2nd Permeability (After Cycling)	Number of Cycles	Comments

T201 Description — 5 plys of .25 mil Mylar C
Edges seamed together with GT 100 adhesive
GT 300 closing tape
End seamed as noted

-1	-	-	50	One split from each end 2" long
-2	.008	-	25	Full 1/2" edge seam
-3	.00067	-	5	Full 1/2" edge seam
-4	0	.03	200	Full 1/2" edge seam
-5	0	-	53	.13 edge seam
-6	0	.0055	200	.13 edge seam
-7	0	-	200	.13 edge seam
-8	0	0	200	Seam cut off - no seam
-9	-	-	50	Full 1/2" end seam (NASA tested)
-10	-	-	15	Full 1/2" end seam (NASA tested)

The majority of these samples failed by the splitting of the film from the ends toward the center. Only the samples which have permeability data after flexing did not split into the field of the sample. The reduction in the width of the end seam did not appear to contribute to the success of the testing of these samples. The adhesive extruded out beyond the 1/2" seam into the field of the sample. The effect of the heat applied to the seam appeared to wrinkle the material adjacent to the seam. It is possible that the heat changed the physical characteristics of the film.

Appendix B (Cont'd.)

The seaming method uses heat and pressure and has caused the multi-ply sample to assume a monolithic structure at the seam of approximately 8 to 9 mils. Mylar in this thickness is not capable of withstanding the flexing required at the edge seam.

T202 Description — Same as T201, except 10 plys of .25 mil Mylar C.
Edges seamed together with GT 100 adhesive
GT 300 closing tape
End seamed as noted

-1	0	-	3	Full 1/2" end seam
-2	0	-	5	Full 1/2" end seam
-3	0	-	-	Full 1/2" end seam
-4	0	-	5	Full 1/2" end seam
-5	0	-	13	.13 edge seam
-6	0	-	14	.13 edge seam
-7	0	0	13	.13 edge seam
-8	0	0	37	Seam cut-off - no seam
-9	-	-	1	Full 1/2" end seam (NASA tested)
-10	-	-	2	Full 1/2" end seam (NASA tested)

The majority of these samples failed by the splitting of the film from the ends toward the center. Splits were generally near the upper and lower edges at the ends. Only the samples that did not split into the field of the sample were tested for permeability after flux testing. The reduction of width of the end seam did not necessarily indicate improvement since there was a limited number of samples tested in this manner. The seams must be improved for this material to be satisfactory.

T203 Description — 5 plys of .25 mil Mylar C
Edges seamed with GT 100 adhesive
Horizontal and vertical seams in field
Butt seams taped one side
GT 300 closing tape
End seamed as noted

Appendix B (Cont'd.)

T203 Description (Continued)

-1	0	-	5	Full 1/2" end seam
-2	0	-	5	Full 1/2" end seam
-3	0	.4(2)	10	.13 end seam
-4	0	95*	200	.13 end seam
-5	2.7(1)	-	5	.13 end seam
-6	0	.013	50	End seam cut off - no seam
-7	0	.19	200	End seam cut off - no seam
-8	0	.0023	100	End seam cut off - no seam
-9	0	.32	50	Fill 1/2" end seam (NASA tested)

Many of these samples failed by the splitting of the film from the ends toward the center. Splits occurred near the upper and lower edges at the ends. The samples with the end seams removed showed the best results with only the outer ply splitting. Permeability data was possible on several of the samples in this group. The horizontal and vertical seams did not appear to influence the results.

T204 Description

5 plys of .25 mil Mylar C
Edges seamed with GT 300 adhesive
Horizontal and vertical seams in field
Butt seams taped on both sides
GT 300 closing tape
End seamed as noted

-1	0	-	50	End seam cut off
-2	.0066	.087	25	End seam cut off
-3	0	86*	200	End seam cut off
-4	0	-	37	End seam cut off
-5	0	-	20	.13 end seam
-6	0	-	8	.13 end seam
-7	.004	-	7	.13 end seam
-8	.0013	-	5	End seam cut off
-9	0	-	22	End seam cut off
-10	0	-	20	End seam cut off

Appendix B (Cont'd.)

T204 Description (Continued)

Failure of these samples occurred most regularly with a split originating at the end near the upper or lower edge of sample and extending at least through the seam. The samples without seams received tears on the outer plys but not necessarily through all plys. The ability to be able to record permeability after flexing indicates that the splits did not extend into the field of the sample nor through the entire sample.

T205 Description — 5 Plys of .25 mil Mylar C
Edges seamed with GT 100 adhesive
Horizontal and vertical seams in field
Lap seams using GT 100 tape
GT 300 closing tape
Ends seamed as noted

-1	.0		-	5	.06 end seam
-2		.02	-	5	.06 end seam
-3		.0016	-	3	.06 end seam
-4		.004	-	10	.06 end seam
-5	0		19*	100	NASA seamed GT 300 tape on end
-6		.0026	26*	25	NASA seamed GT 300 tape on end
-7	0		155*	15	NASA seamed GT 300 tape on end
-8	0		47*	55	NASA seamed GT 300 tape on end
-9	0		-	30	NASA seamed GT 300 tape on end
-10		.0046	88*	35	NASA seamed GT 300 tape on end

Samples with end seams failed with the splitting of the sample from the end into the field preventing any permeability check. The samples with GT 300 tape sealing the ends did not split at the ends, but had considerable film splitting in the field of the sample. The splitting was random and extended across the seams or adjacent to the seams. No conclusions can be drawn regarding the cause of these failures.

T206 Description — 10 Plys of .25 mil Mylar C
Edges seamed with GT 100 adhesive
Horizontal and vertical seams in field
GT 300 closing tape
Butt seams taped on one side
Ends seamed as noted

Appendix B (Cont'd.)

T206 Description (Continued)

-1	.006	-	8	.06 end seam
-2	0	-	2	.06 end seam
-3	0	0	77	End seam cut off
-4	0	.002	25	End seam cut off
-10	-	-	1	Full 1/2" end seam (NASA tested)

The failures on the samples with .06 end seams are identical to those occurring on all other samples with seam of any width. The failures started as a splitting of the end near the top or bottom edge and extend into the field of the sample. The failures of the samples with the end seams cut off consisted of splitting of one or more plys from the edge and frequently extending many inches into the sample. Complete splitting of all plys did not occur as proven by the ability to obtain permeability data on -3 and -4.

End seams on following samples cut off and re-seamed by NASA using GT 300 tape:

-5	0	.004	150	
-6	0	.0053	75	
-7	0	-	200	Excessive leak
-8	0	-	17	2 inch tear from right end
-9	0	-	30	2 splits on left end, split on front side .75"

T206-1 through -4 were tested as originally received from Schjeldahl with a very rigid end seam and results proved early failure through splitting of ends. The above group -5 through -9 had the original end seam cut off and were then reseamed on the ends by wrapping a GT 300 tape around and heat sealing with impulse sealer. The results are better although splitting still occurred.

T207 Description

10 Plys of .25 mil Mylar C
Edges seamed with GT 100 tape
Horizontal and vertical seams in field
GT 300 closing tape
Lap seams using GT 100 adhesive
Ends seamed as noted

-1	0	-	19	End seams cut off

Appendix B (Cont'd.)

T207 Description (Continued)

-2	.0033	-	11	End seams cut off
-3	.0033	-	57	End seams cut off
-4	0	-	23	End seams cut off
-5	0	.022	25	End seams cut off

Failures occurred as splitting of the film from the center or field of the sample. There did not appear to be any failures from the end with the exception of one ply of -3. The change of the point of failure from the end splitting to field originated splitting in this group of samples is not easily explained.

End seams of following samples cut off and re-seamed by NASA using GT 300 tape:

-6	0	-	10	Splits in face of outer film through seams
-7	0	-	6	Splits in face of outer film through seams
-8	0	-	30	Splits in face of outer film through seams
-9	0	-	200	Splits in face of outer film through seams
-10	0	.028	40	Splits in face of outer film through seams

Failures occurred as splitting of the film from the center or field of the sample. There did not appear to be any failures from the end with the exception of -7 which had a 1/2 inch split through end. The change to seal the ends with GT 300 tape did not change the type of failure as found in the first group -1 through -5.

T208 Description
5 Plys of .25 mil Mylar C
Flat sample with horizontal seams
Butt seams using Pliobond 20 with tape
Ends seamed as noted

-1	.015	-	12	Original rigid end seam - complete horizontal split
-2	.017	-	8	Original rigid end seam - end splits
-3	.0053	.8	4	End seam cut off - split on right end one ply
-4	.017	.0016	50	End seam cut off - split on right end one ply
-5	.009	-	140	End seam cut off - split on right end one ply

Appendix B (Cont'd.)

T208 Description (Continued)

-6	.022	-	80	End seam cut off and resealed with GT 300 tape by NASA.
-7	.0076	-	75	End seam cut off and resealed with GT 300 tape by NASA.
-8	.001	-	90	End seam cut off and resealed with GT 300 tape by NASA.
-9	.01	.0033	45	End seam cut off and resealed with GT 300 tape by NASA.
-10	.001	-	49	End seam cut off and resealed with GT 300 tape by NASA.

All samples tested produced splitting of at least the front single ply usually above the horizontal seam and not through the seam. Permeability testing was only possible in three samples; the remaining samples had excessive leakage. Pliobond seams do not appear to offer any unusual characteristics for further consideration.

T209 Description — 1 Ply of .5 mil Kapton
Flat sample, no seams
Ends not sealed
Liquid nitrogen tested only

-1	.003	.1	200	No visible change
-2	.001	-	15	Longitudinal split full length of sample
-3	.003	-	65	Longitudinal split full length of sample
-4	.0013	-	14	Longitudinal split full length of sample
-5	.003	-	9	Longitudinal split full length of sample

Only one sample, the -1, did not show any splitting of the film. All other samples had a complete splitting failure from end to end usually near the top or bottom edge of sample. A closing end seam could help eliminate the start of the split but would not help the extension of split if once started. This film is similar to Mylar in its unpredictable behavior.

Ends sealed as noted
Liquid hydrogen tested

-6	.001	-	25	No end seam
-7	.003	-	40	No end seam

Appendix B (Cont'd.)

T209 Description (Continued)

-8	.00066	-	10	Ends seamed with GT 300 tape by NASA
-9	.00066	-	40	Ends seamed with GT 300 tape by NASA
-10	.001	-	7	Ends seamed with GT 300 tape by NASA

All samples had a complete shattering type of splitting failure across the entire field of the sample. The end seams did not change this characteristic failure.

T210 Description 5 Plys of .5 mil Kapton
Edges sealed with GT 300 tape
GT 100 adhesive used between film seams
Liquid nitrogen tested only

-1	.0033	0	180	Split on back outer ply left end
-2	.0066	0	11	Tear along lower edge 9" long all plys
-3	.0033	0	98	3" long split on outer ply front face
-4	.002	0	160	Tongue-type tear 1/2" long on outer ply
-5	.0016	.00033	60	Pin holes. Exploded from inner ply pressurization when removed.
-6	0		180	Jagged tear outer ply 4" long

Failure typical of Kapton are shown in the results above. The random type of splitting failure with jagged tears has been demonstrated in many previous samples tested in LN_2 in other Beech programs.

Ends seamed as noted
Liquid hydrogen tested

-7	.013	-	12	Original rigid end seam - split from both ends
-8	.0023	0	200	Ends seamed with GT 300 tape by NASA - no failure
-9	.002	.0033	200	Ends seamed with GT 300 tape by NASA - no failure

The removing of the original end seams and reseaming with GT 300 tape with impulse narrow heat seal apparently helped prevent splitting from ends. The lack of consistence of this film, however, does not warrant a conclusion that this film is satisfactory if seamed in this manner.

Appendix B (Cont'd.)

T211 Description				10 Plys of .5 mil Kapton Edges sealed with GT 300 tape GT 100 adhesive between film seams Liquid nitrogen tested only
-1	.0013	0	200	Small split of outer ply front face of sample
-2	.001	0	80	Pin holes observed during flexing only
-3	.0016	.0026	90	Split outer ply. Severe inner ply inflation
-4	.0033	.0163	150	Small jagged tear front face outer ply
-5	.0066	-	5	Complete splitting all plys 3" long left end
-6	.001	.0066	200	Small crack in outer ply left end
-7	0	.0303	180	9" long split in outer plys

The increase in number of plys has helped this material. Although the outer ply splits frequently, the remaining plys are intact and do not permit permeation. Unpredictability of failure still present.

				Liquid hydrogen tested
-8	.003	-	10	Original rigid end seam - major split from end
-9	.0013	0	200	Ends cut off and resealed by NASA with GT 300 tape
-10	0	0	200	Ends cut off and resealed by NASA with GT 300 tape
-11	.0026	0	100	Ends cut off and resealed by NASA with GT 300 tape

The samples with the resealed ends with GT 300 tape appear to withstand the flexing better. Every sample, however, had a splitting of at least the outer ply in the field near the end of the sample.

Appendix B (Cont'd.)

T212 Description

13 Alternating plys of Mylar and Nomex Paper
10 Plys of .25 Mylar C
3 Plys of 2 mil Nomex Paper (1st, 7th, 13th ply)
No seams except edge seams
GT 100 adhesive between edge seam
GT 300 closing tape

-1	.9953	76*	14	Short end splits through end seam 1/2" long
-2	.0096	-	17	Short end splits through end seam 1/2" long
-3	0	0	200	End seam cut off - excellent condition
-4	.0076	.002	200	End seam cut off - excellent condition
-5	.002	0	200	End seam cut off - excellent condition
-6	.0026	.11	150	End seam cut off - leakage indicates Mylar film failure
-7	0	0	100	End seam cut off - excellent condition
-8	.0046	0	50	End seam cut off - excellent condition
-9	0	0	150	End seam cut off - excellent condition
-10	0	0	100	End seam cut off - excellent condition

The only failure shown in this combination of Mylar and Nomex paper was when the heavy end seams imposed splitting of the ends. The tear resistance of the Nomex paper prevented the tear from extending far into the field of the sample. The -3 and -4 samples in which the end seams were removed produced excellent results in both permeability and flexibility.

This type of material consistently appears to offer the most hope for cryogenic bladders. The combination of Nomex for reducing the stresses in the Mylar, which provides the permeability barrier, is proving to be the best arrangement of materials in the twist-flex test.

Appendix B (Cont'd.)

T213 Description			13 Alternating plys of Mylar and Dacron Fabric 10 Plys of .25 mil Mylar C 3 Plys of 2.2 oz. Dacron Fabric (1st, 7th, 13th ply) No seams in field GT 100 adhesive between edge seam GT 300 closing tape	
-1	0	.0042	200	No visible change other than abrasion and separation of plys on end edge
-2	0	0	200	No visible change other than abrasion and separation of plys on end edge
-3	0	.0016	200	No visible change other than abrasion and separation of plys on end edge
-4	.0066	.062	200	No visible change except for slight abrasion and end ply separation
-5	.004	.0076	200	No. visible change except for slight abrasion and end ply separation
-6	.004	.038	200	No visible change except for slight abrasion and end ply separation
-7	.002	.28	200	No visible change except for slight abrasion and end ply separation
-8	.0083	.039	200	No visible change except for slight abrasion and end ply separation
-9	.083	.022	200	No visible change except for slight abrasion and end ply separation
-10	.025	.054	200	No visible change except for slight abrasion and end ply separation

Results on these samples show promise for bladder material. Similar to the Nomex/Mylar samples T212, the Dacron Fabric adds strength and tear resistance to the sample preventing gross splitting of the Mylar. Even the heavy ends did not split although fabricated in the same manner as other Schjeldahl samples which have had incessant end splitting.

Appendix B (Cont'd.)

T214 Description			5 Plys of .25 mil Mylar C Cylindrical sample Closing lap seams GT 100 adhesive	
-1	-	-	50	Major splitting of several outside plys
-2	-	-	100	Major splitting of several outside plys
-3	-	-	25	Major splitting of several outside plys

Permeability measurement is not possible on cylindrical samples in a manner similar to the flat samples. Permeability is noted by bubbles appearing on the outside of cylinders when pressurized with helium gas. Detection of bubbles is an indication to stop test. The number of cycles was then determined either by the first formation of bubbles or visible indication of film splitting Random splitting of film indicates the necessity of a change in sample material or fabrication method. Cylindrical shapes may impose greater stresses than flat type samples. Failures are similar to flat samples of the same material.

T215 Description			Same as T214, except 10 plys of film 10 plys of .25 mil Mylar C Cylindrical sample Closing lap seams for cylindrical plys GT 100 adhesive	
-1	-	-	25	Split on inside ply of film
-2	-	-	100	Major splits on outside ply
-3	-	-	30	Major splits on outside ply

Analysis same as that for T214.

Appendix B (Cont'd.)

T216 Description			5 Plys of .25 mil Mylar C Cylindrical sample Horizontal and closing vertical seam Butt seam taped one side GT 100 adhesive GT 300 closing tape
-1	-	-	50 Splitting of four plys on inside of cylinder.
-2	-	-	25 Splitting of outer ply
-3	-	-	15 Major splitting of inside and outside plys

Analysis same as that for T214.

T217 Description			Cylindrical sample 5 plys of .25 mil Mylar C Horizontal and closing vertical seam Lap type of seam GT 100 adhesive between plys on seams GT 300 closing tape
-1	-	-	4 Splitting of inner and outer plys of cylinder
-2	-	-	7 Splitting of inner and outer plys of cylinder
-3	-	-	4 Splitting of inner and outer plys of cylinder

Analysis same as that for T214.

T218 Description			Cylindrical sample 10 plys of .25 mil Mylar C Horizontal and closing vertical seam Butt type of seam GT 100 adhesive between plys on seams GT 300 closing tape
-1	-	-	70 Severe splitting of inside and outer plys around cylinder
-2	-	-	30 Severe splitting of inside and outer plys around cylinder
-3	-	-	20 Severe splitting of inside and outer plys around cylinder

Analysis same as that for T216.

Appendix B (Cont'd.)

T219	Description		Cylindrical sample 10 plys of .25 mil Mylar C Horizontal and vertical seam Lap type of seam GT 100 adhesive between plys on seams GT 300 closing tape	
-1	-	-	8	Severe splitting on inner and outer plys all the way around cylinder
-2	-	-	15	Severe splitting on inner and outer plys all the way around cylinder
-3	-	-	10	Severe splitting on inner and outer plys all the way around cylinder

Analysis same as that for T216.

T220	Description		Cylinder sample 5 plys of .25 mil Mylar C Horizontal and closing vertical seam Pliobond 20 with tape	
-1	-	-	35	Inner ply splitting 180 degrees around cylinder
-2	-	-	50	Inner ply splitting 180 degrees around cylinder
-3	-	-	80	No splitting but two holes observed during testir

Analysis same as T216.

T221	Description		Same as T218 except .15 mil Mylar C	
-1	-	-	80	No splits but 5 bubble leaks during testing
-2	-	-	70	Severe splitting through all plys
-3	-	-	50	Splitting on inner plys and 2 holes
-4	-	-	20	Outer ply split and three holes
-5	-	-	55	Splitting of outer ply and two holes

Analysis same as that for T216.

Appendix B (Cont'd.)

T222 Description			Same as T219 except .15 mil Mylar C
-1	-	-	7 Complete splitting of inner and outer plys
-2	-	-	2 Splitting of outer plys
-3	-	-	4 Splitting of outer plys
-4	-	-	12 Splitting of inner and outer plys
-5	-	-	15 Severe splitting of entire sample from top edge

Analysis same as that for T216.

T223 Description			Cylindrical sample .5 mil Kapton 10 plys of film Closing vertical seams only GT 300 tape with butt seams
-1	-	-	150 Splitting of inner and outer plys all the way around
-2	-	-	50 Splitting of outer ply
-3	-	-	25 Splitting of outer ply

Analysis same as that for T216.

T224 Description			Same as T223 except lap vertical seam using GT 100 adhesive
-1	-	-	20 Split on outer ply
-2	-	-	15 Splitting across seam on both inner and outer plys
-3	-	-	20 Splitting of outer ply

Appendix B (Cont'd.)

T225 Description			Same as T212, except cylinder Cross butt seam using GT 300 tape	
-1	-	-	4	Splitting on all seams inside and outside
-2	-	-	17	Splitting on all seams inside and outside
-3	-	-	10	Splitting on all seams inside and outside

Analysis same as T216 except that failure primarily in seams. The use of heavier tape might prevent the failure at this point. Previous experience has shown that the failures usually do not occur in the seam.

T226 Description			Same as T213 material except cylinder Cross butt seams using GT 300 tape	
-1	-	-	18	Seam splitting on inside and outside
-2	-	-	8	Seam splitting on inside and outside
-3	-	-	6	Seam splitting on inside and outside

- Samples T227 through T235 are tested in Section 3.8.2, page 3-149 "Single Ply Seamed Twist-Flex Test Data."

Appendix B (Cont'd.)

T236	Description		10 Plys of .15 mil Mylar C	
-1	0	0	200	Small breaks on right end cap edge
-2	0	0	200	Split across end cap at upper left end - small breaks on both end cap edges 1st ply tear above I.D. no.
-3	.00033	.00050	200	Split across end cap at upper right end - small breaks on both end cap edges
-4	0	0	200	Split across end cap at lower left end - small breaks on both end cap edges
-5	.0080	.54	100	Split in 1st ply at lower right end close to end cap - small breaks on both end cap edges
-6	.00044	.00033	100	Split across end cap at upper and lower left end - split on 1st and 2nd ply at lower left end just above lower edge cap. Small breaks on both end cap edges
-7	0	.00066	50	Small breaks on both end cap edges
-8	.0020	.0033	60	Split across end cap at lower right end
-9	0	.0043	100	Split on front ply at upper right corner across end cap small breaks on both end cap edges
-10	0	.00066	50	Small breaks on both end cap edges

Exception results without serious failure and good permeability following twist-flex testing.

Appendix B (Cont'd.)

T237	Description		10 Plys of .25 mil Mylar C	
-1	9	0	200	Split on front ply at left end and at right end area - small breaks on both end cap edges
-2	.00050	.0030	200	Small breaks on both end cap edges
-3	0	.0050	200	Small breaks on both end cap edges
-4	.00033	.00033	100	Split on front ply from upper left corner down approximately 4" in from end just above lower edge cap. Small breaks on both end cap edges
-5	0	0	100	Split at upper left end across end cap on front ply - breaks on both end cap edges
-6	.0013	.0033	50	Small breaks on both end cap edges
-7	.00066	.0046	50	Small breaks on both end cap edges
-8	.0020	.038	100	Small breaks on both end cap edges
-9	0	.00033	50	Small breaks on both end cap edges
-10	0	.0016	50	Small breaks on both end cap edges
-11	0	.0093	200	Breaks on both end cap edges - numerous wrinkles
-12	0	.0023	200	Breaks on both end cap edges - numerous wrinkles
-13	0	.0076	150	Breaks on both end cap edges - numerous wrinkles
-14	.0010	.0010	150	Breaks on both end cap edges - numerous wrinkles
-15	0	.0016	150	Breaks on both end cap edges - numerous wrinkles
-16	.0070	.010	200	Breaks on both end cap edges - numerous wrinkles
-17	0	.0023	200	Breaks on both end cap edges - numerous wrinkles
-18	0	.00066	200	Breaks on both end cap edges - numerous wrinkles
-19	0	0	200	Breaks on both end cap edges - numerous wrinkles
-20	0	0	200	Breaks on both end cap edges - numerous wrinkles

A large number of identical samples produced relatively consistent results with good flexibility and low permeability.

Appendix B (Cont'd.)

T238 Description			13 Plys of .25 mil Mylar C 1st, 7th and 13th plys 2 mil Nomex paper	
-1	.047	.042	200	Breaks on both end cap edges - creases and wrinkles on front and back plys
-2	.024	.036	200	Breaks on both end cap edges - creases and wrinkles on front and back plys
-3	.055	.052	200	Breaks on both end cap edges - creases and wrinkles on front and back plys
-4	.049	.053	200	Breaks on both end cap edges - creases and wrinkles on front and back plys
-5	.054	.052	100	Breaks on both end cap edges - creases and wrinkles on front and back plys
-6	.053	.055	100	Breaks on both end cap edges - creases and wrinkles on front and back plys
-7	.053	.049	100	Breaks on both end cap edges - creases and wrinkles on front and back plys
-8	.045	.052	100	Breaks on both end cap edges - creases and wrinkles on front and back plys
-9	.056	.060	50	Breaks on both end cap edges - creases and wrinkles on front and back plys
-10	.045	.045	50	Breaks on both end cap edges - creases and wrinkles on front and back plys

All of the T238 samples had breaks on both end cap edges - creases and wrinkles on front and back plys. Only slight increase in permeability.

'0 -1

Appendix B (Cont'd.)

T239 Description			13 Plys of .25 mil Mylar C 1st, 7th and 13th plys of 2.2 oz. Dacron fabric	
-1	.19	.17	200	Breaks on both end cap edges - no other visible damage
-2	.15	.17	200	Breaks on both end cap edges - no other visible damage
-3-	.16	.15	200	Breaks on both end cap edges - no other visible damage
-4	.26	.24	200	Breaks on both end cap edges - no other visible damage
-5	.15	.14	150	Breaks on both end cap edges - no other visible damage
-6	.11	.12	150	Breaks on both end cap edges - no other visible damage
-7	.12	.11	100	Breaks on both end cap edges - no other visible damage
-8	.19	.15	100	Breaks on both end cap edges - no other visible damage
-9	.22	.21	50	Breaks on both end cap edges - no other visible damage
-10	.23	.22	50	Breaks on both end cap edges - no other visible damage

All of the T239 samples had breaks on both end cap edges - no wrinkles or other visible effects from twist-flexing.

- Samples T240 through T247 are tested in Section 3.8.2, page 3-149 "Single Ply Seamed Twist-Flex Test Data."

- Samples T248 through T253 are tested in Section 3.8.3, page 3-159 "Multi-Ply Seamed Twist-Flex Test Data."

Appendix B (Cont'd.)

T254 Description — Alternating plys of 2 mil Nomex and .25 mil Mylar (6 plys of Nomex and 5 plys of Mylar) Lap Seams 1/2" wide in Nomex; Butt Seams 1/2" wide in Mylar

-1	.008	.33	200	Several holes and areas worn thin on front and back plys
-2	.007	.21	200	Several holes and areas worn thin on front and back plys
-3	.0096	.71	200	Several holes and areas worn thin in most plys
-4	.01	1.3	200	Several holes and areas worn thin in most plys
-5	.0076	.28	150	Several areas worn thin on front and back plys
-6	.0073	1.7	150	Several holes and areas worn thin in most plys
-7	.008	.52	100	One hole on front ply - several places worn very thin on front and back plys
-8	.006	.68	100	Several places worn very thin on front and back plys
-9	.0066	.46	50	Several slightly worn places on front and back plys
-10	.0086	.07	50	Several slightly worn places on front and back plys

Increased deterioration and permeability (all plys) over configuration such as T238 where Mylar plys are used in groups of 5 between Nomex plys.

0 -1

Appendix B (Cont'd.)

T255 Description				Alternating plys of 2 mil Nomex and .5 mil Kapton (6 plys of Nomex and 5 plys of Kapton) Lap Seams 1/2" wide in Nomex Butt Seams 1/2" wide in Kapton
-1	.0063	7.1	200	Several holes and areas worn thin on each ply
-2	.0083	6.6	200	Several holes and areas worn thin on each ply
-3	.0096	6.4	200	Several holes and areas worn thin on each ply
-4	.011	6.5	200	Seam separation .25" long on front ply-holes and areas worn thin on each ply
-5	.017	4.9	150	Several holes and areas worn thin on each ply
-6	.013	7.2	150	Several holes and areas worn thin on each ply
-7	.0096	4.9	100	Several holes and areas worn thin
-8	011	1.7	100	Several holes and areas worn thin
-9	.009	.31	50	Several holes and areas worn thin
-10	.008	1.3	50	Several holes and areas worn thin

Much poorer performance and more extensive damage than T254, indicating that .5 mil Kapton is inferior to .25 mil Mylar C in this configuration.

T256 Description				1 Ply 2 mil Nomex Butt Seam 1/2" wide using GT 300 on both sides
-1	.33	7.2	200	Several pin holes and areas worn thin
-2	.25	7.0	200	Several pin holes and areas worn thin
-3	.27	6.8	200	Several pin holes and areas worn thin
-4	.66	7.2	200	Several pin holes and areas worn thin
-5	.51	6.5	200	Several pin holes and areas worn thin

Good flex performance; nearly as good as 1/2 inch wide lap seam using GT 100.

Appendix B (Cont'd.)

T257 Description			1 Ply of Dacron Fabric 2.2 oz. Butt Seam 1/2" wide using GT 300 on both sides	
-1	*	*	200	Permanent creases - no other visible damage
-2	*	*	200	Permanent creases - no other visible damage

* No permeability reading because of high normal porosity.

-3	*	*	200	Permanent creases - no other visible damage
-4	*	*	200	Permanent creases - no other visible damage
-5	*	*	150	Permanent creases - no other visible damage

* No permeability reading because of high normal porosity. Good flex performance; equal to 1/2" wide lap seam using GT 100.

T258 Description			Alternating plys of .25 mil Mylar and Spunbonded Dacron Fabric (6 Mylar - 5 Dacron) Lap Seams 1/2" wide Spunbonded Butt Seams 1/2" wide in Mylar	
-1	0	6.3	60	Vertical split 3" long on front ply at right end; small holes in all Mylar plys
-2	0	0	4	Split on front ply across horizontal seam
-3	0	7.1	85	3-corner split on front ply across horizontal seam (2) places and across vertical seam (1) place; small hole in one interior Mylar ply
-4	0	4.8	3	Split across vertical and horizontal seam on front ply; hole in interior Mylar ply
-5	.0013	0	4	Split across horizontal seam on front ply
-6	0	0	3	Split across horizontal seam on front ply
-7	0	5.3	50	Hole(s) in seam of 5 Mylar plys
-8	0	3.6	3	Split across horizontal seam on front ply; holes in several interior or Mylar plys
-9	0	0	5	Split across vertical and horizontal seam on front ply
-10	0	0	18	Incipient failure of front ply at end seam (2) places

Very poor flex life and high permeability if flexed more than 5 cycles; spun-bonded substrate appears to induce high stress in the Mylar plys of this configuration, as evidenced by frequent holes in seams of Mylar plys.

Appendix C

DETAIL PERMEABILITY TEST DATA

TABLE C-1

Control Test - Film Permeability

TEST	SAMPLE NO.	BURETTE CC/SEC	BEAKER BUBBLES/MIN
(a) 0.5 mil Mylar	TC1-1	0.0015	5
	-2	0.00083	2
	-3	0.00067	Samples Split
	-4	--	--
	-5	0.00117	2
	-6	0.0013	1
	-7	--	--
	-8	--	--
	-9	0.00033	2
	-10	0.0027	5
	-11	0.0005	5
	-12	--	--
	-13	0.0010	5
	-14	--	--
(b) Schjeldahl Group I 0.15 mil Mylar	PC15-1	3.4	
	-2	4.0	
	-3	3.3	
	-4	3.7	
	-5	2.0	
Group II 0.25 mil Mylar	PC25-1	0.20	
	-2	--	Hole
	-3	0.13	
	-4	2.6	
	-5	3.5	
	-6	0.018	
Group II 0.25 mil Mylar	PS25-1	0.06	
	-2	--	
	-3	0.13	
	-4	0.003	
	-5	0.017	

Appendix C (cont'd)

TABLE C-1 (cont'd)

TEST	SAMPLE NO.	BURETTE CC/SEC	BEAKER BUBBLES/MIN
(c) NASA-LeRC	PN15-1	1.5	
0.15 mil Mylar	-2	7.6	
	-3	7.6	
	-4	0.60	
	-5	0.83	
0.25 mil Mylar	PN25-1	0.010	
	-2	0.470	1 Hole
	-3	0.0056	1.5
	-4	0.0026	0.0
	-5	0.001	0.0
	-6	0.0083	3.0
	-7	0.0026	1.0
	-8	3.5	1 Hole
	-9	0.0083	3.0
	-10	0.006	1.0
(d) Boeing	PB25-1	0.018	5.0
0.25 mil Mylar	-2	0.066	1.0
(Plain Film)	-3	0.053	16.0
	-4	4.6	--
	-5	0.16	43.0
0.25 mil Mylar	T301-1	0.97	
(Thermoformed)	-2	4.7	
	-3	6.5	
	-4	4.5	
	-5	4.4	
	-6	2.3	
(e) Engineering & Development Co.	T401-1	Excessive	
0.25 mil Mylar	-2	"	
Ultrasonic Seamed	-3	"	
	-4	"	
	-5	"	
	-6	"	

Appendix C (cont'd)

TABLE C-1 (cont'd)

TEST	SAMPLE NO.	BURETTE CC/SEC	BEAKER BUBBLES/MIN
(f) Branson Industries (As Noted) Mylar			
0.5 mil	PUB-1	0.25	64
0.5 mil	-2	6.1	3 Holes (1)
0.5 mil	-3	2.4	4 Holes (1)
2.0 mil	-4	0.0	0
*1.0 mil	-5	0.023	4
*1.0 mil	-6	0.032	3

* Plus two Dacron plys of 3.0 mil

(1) Holes adjacent to seam area

TABLE C-2

Multiple Ply Tests

In these tests 0.15 mil Mylar C received from DuPont was used by starting with 5 plys of film in which the edges were loosely bonded together during the cutting operation. After the 5 plys were tested then one ply was peeled off and the remaining 4 ply sample was tested. This procedure was continued until the last single ply was tested.

Test Number 1 PN15-1

Number of Plys	Permeability in cc/sec.
5	0.0
4	0.0
3	0.0
2	0.0
1	0.0010

Appendix C (cont'd)

TABLE C-2 (cont'd)

During this test there was no indication of gas transmission until the single ply was tested. From a permeability viewpoint the use of two plys would satisfy the condition of zero permeability in a five-minute period.

Test Number 2 PN25-1

Number of Plys	Permeability in cc/sec.
5	0.0
4	0.0
3	0.0
2	0.0
1	0.0

There was no measurable leakage during a five-minute period in any of the tests on 0.25 mil Mylar material from DuPont. This would indicate that the 0.25 mil material is less porous than the 0.15 mil material and this result should be expected.

In Tests Number 3 and Number 4 .15 mil and .25 mil Mylar C was used which was obtained from rolls of film used to make test samples. These film samples were added together to produce the multiple ply test which differed from Test Number 1 and Number 2 in which plys were removed.

In these tests -1 ply had an excessive leak reduced only by the addition of the second ply.

TEST	SAMPLE NO.	BURETTE CC/SEC	BEAKER BUBBLES/MIN
Test Number 3 PC15			
Ply Additions	-1	3.4	1 Hole
0.15 mil Mylar	-1, -2	0.16	40.0
	-1,-2,-3	0.027	6.0
	-1,-2,-3,-4	0.60	38.0
	-1,-2,-3,-4,-5	0.10	5.0

Appendix C (cont'd)

TABLE C-2 (cont'd)

TEST	SAMPLE NO.	BURETTE CC/SEC	BEAKER BUBBLES/MIN
Test Number 4 PC25			
0.25 mil Mylar	-1	3.6	2.0
	-1, -2	0.0053	0.0
	-1,-2,-3	0.004	0.0
	-1,-2,-3,-4	0.0043	0.0
	-1,-2,-3,-4,-5	0.0016	0.0

CONCLUSION

The permeation is not reduced significantly after the third ply is added. It is believed that points of porosity in a particular film might be blocked by an adjacent film on occasions thus randomizing the results.

TABLE C-3

Increasing Pressure Test

This test was performed to provide a better understanding of the effect of pressure upon the gas transmission rate through a film. Three 0.25 mil Mylar C and three 0.15 mil Mylar C films from DuPont were used for these tests.

Each sample was placed into the permeability fixture and the pressure was increased in increments of 5 inches of water from zero to 35 inches of water pressure. Each pressure was held for a period of 5 minutes during which time a burette measured the volume of helium gas passing through the film. The following data is graphed on Figure 3.25.

Sample No.	Pressure	Permeability in cc/sec
PVP25-1	5" H_2O	0.0
	10" H_2O	0.0
	15" H_2O	0.0
	20" H_2O	0.0
	25" H_2O	0.0010
	30" H_2O	0.0010
	35" H_2O	0.0016

Appendix C (cont'd)

TABLE C-3 (cont'd)

Sample No.	Pressure	Permeability in cc/sec.
PVP25-2	15" H_2O	0.0
	20" H_2O	0.0
	25" H_2O	0.0
	30" H_2O	0.0
	35" H_2O	0.0

PVP25-3	Pressure	Permeability in cc/sec.
	5" H_2O	0.0073
	10" H_2O	0.017
	15" H_2O	0.022
	20" H_2O	0.024
	25" H_2O	0.039
	30" H_2O	0.044
	35" H_2O	0.047

PVP15-1	Pressure	Permeability in cc/sec.
	5" H_2O	0.0016
	10" H_2O	0.0016
	15" H_2O	0.0020
	20" H_2O	0.0020
	25" H_2O	0.0030
	30" H_2O	0.0030
	35" H_2O	0.0033

PVP15-2	Pressure	Permeability in cc/sec.
	5" H_2O	0.0010
	10" H_2O	0.0026
	15" H_2O	0.0033
	20" H_2O	0.0033
	25" H_2O	0.0036
	30" H_2O	0.0040
	35" H_2O	0.0040

PVP15-3	Pressure	Burette cc/sec.
	5" H_2O	0.0030
	10" H_2O	0.0070
	15" H_2O	0.014

Appendix C (cont'd)

TABLE C-3 (cont'd)

PVP15-3 (cont'd)	Pressure	Burrette cc/sec.
	20" H_2O	0.018
	25" H_2O	0.022
	30" H_2O	0.027
	35" H_2O	0.030

CONCLUSIONS

The rate of gas transmission through Mylar films increases with increase in pressure differential across the film. Although one sample in these tests showed no permeability it is presumed that if a longer period of time had been allowed at each pressure setting, the results would follow the other samples, but at a lower gas transmission rate.

It is important to note that although all permeability tests for this program have been conducted at 1 psi or 28 inches of water pressure, it is not anticipated that the bladder will receive more than a few inches of differential pressure during cycling. This lower operating pressure will therefore be advantageous in reducing the permeability through the bladder. The permeability of some materials of low permeability stays relatively constant even when the pressure is increased. Pressure increase, though, can cause increased permeability in certain materials and even cause some material to become permeable when they are not at lower pressure.

TABLE C-4

Combination Test (Water and Burette)

The Combination Tests involved four separate tests on each material for the purpose of comparing the different test methods and to verify that permeation is possible through water without visible bubbles.

The first test was performed in the regular manner in which the sample was installed in the permeability fixture and 1 psi of helium gas was placed on the underside of the film. The gas passing through the film was collected and measured on a burette over a five-minute period.

The second test involved the use of an open top plate in which a layer of water was placed over the sample, the helium gas at 1 psi was under the film sample. The appearance of bubbles was noted. In many cases, however, no bubbles were observed even though the first permeability test indicated gas transmission.

Appendix C (cont'd)

TABLE C-4 (cont'd)

The third test combined the first two by leaving the water on top of the sample and then the burette was attached so that the gas which passed through the sample and the water could be collected and measured.

The fourth test was a repeat of the first test after the sample was thoroughly dry to see if moisture affected the gas transmission through the sample. The following data shows the results of these tests.

Sample No.	1st Test (Burette Only)	2nd Test (Water Only)	3rd Test (Water & Burette)	4th Test (Burette Only)
PC25-1	0.0076	No Bubbles	0.0076	0.0070
PC25-2	0.019	One Hole	0.24	0.025
PC25-3	0.064	No Bubbles	0.0036	0.074
PS25-1	---	No Bubbles	0.018	---
PS25-2	---	No Bubbles	0.006	---
PS15-2	---	No Bubbles	0.013	---

CONCLUSIONS

An important conclusion that can be made by this data is that it is possible to have considerable permeation through a sample and water without any visible indication by the formation of bubbles. The difference in permeability readings before and after the water test is within the normal range of repeatable readings proven by tests in Table C-6, Repeatability Tests. Tests have shown that it is possible to have up to 0.018 cc/sec permeation over a 30 square inch sample of 0.25 Mylar without bubble formation.

Using bubbles in water as an indication of gas transmission is, therefore not a satisfactory method.

TABLE C-5

Consecutive Reading Tests

The purpose of this series of tests was to determine if there was a length of time of pressurizing the sample in which the rate of gas transmission would stabilize and remain constant. Three different samples of 0.15 mil Mylar C obtained from DuPont were used in which they were pressurized to one psi of helium and held constant for a period of up to 30 minutes. The permeability was measured during each five-minute consecutive period and the results were plotted in Figure 3.26.

Appendix C (cont'd)

TABLE C-5 (cont'd)

CONSECUTIVE READING TEST DATA

Sample No.	Time	Permeability cc/sec.
PD15-1-1-6	5 minutes	0.0066
	10 minutes	0.0096
	15 minutes	0.011
	20 minutes	0.011
	25 minutes	0.010
	30 minutes	0.011
PD15-2-3-10	Time	Permeability cc/sec.
	5 minutes	0.010
	10 minutes	0.014
	15 minutes	0.014
	20 minutes	0.014
	25 minutes	0.014
PD15-3-3-7	Time	Permeability cc/sec.
	5 minutes	0.017
	10 minutes	0.021
	15 minutes	0.022

CONCLUSIONS

The data indicates that after approximately 15 minutes the permeability rate stabilizes and will stay uniform thereafter. The rate of permeability increases for 10 to 15 minutes and then becomes steady. This would indicate that it would be desirable to wait for at least 15 minutes before taking a permeability reading for utmost accuracy. The procedure followed in this program was to take readings at exactly five minutes thereby providing a consistency which should result in a constant relationship between each sample's permeability at a specified time. The difference in each sample's permeability for each time stayed relative to the other samples.

TABLE C-6

Repeatability Tests

In order to determine if there was a significant difference in permeability readings when made on the same sample at different times, or due to repeat pressurization, as well as to observe the accuracy of operator technique, the following tests were run on three different samples. It should be noted that each sample was given a typical handling and permeability test identical to that performed on a sample prior to a twist-flex test. After each test the sample was removed and then re-installed as if for the first time. This

Appendix C (cont'd)

TABLE C-6 (cont'd)

introduced the factor of installation, random wrinkling and gasket sealing not previously investigated in the previous test.

REPEATABILITY TEST DATA

Sample No.	Test	Permeability Reading cc/sec.
PD15-1-1-6	1st	0.073
	2nd	0.066
	3rd	0.068
	4th	0.085
	5th	0.069
	6th	0.082
PD15-2-3-10	Test	Permeability Reading cc/sec.
	1st	0.012
	2nd	0.013
	3rd	0.011
	4th	0.010
	5th	0.012
	6th	0.013
PD15-3-3-7	Test	Permeability Reading cc/sec.
	1st	0.017
	2nd	0.019
	3rd	0.016
	4th	0.021
	5th	0.11
	6th	0.092
PC25-6	Test	Permeability Reading cc/sec.
	1st	0.015
	2nd	0.016
	3rd	0.013
	4th	0.016
	5th	0.017
	6th	0.015

CONCLUSIONS

The first two samples indicated that a ±15% variation can be expected in reading of permeability data. The third sample would show that in some

90-33364
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Appendix C (cont'd)

TABLE C-6 (cont'd)

rare cases a difference can amount to seven times the lowest reading. Figure 3.27 illustrates this variation.

TABLE C-7

Leak Rate versus Hole Size

There must be a correlation between the number of holes created by the flex cycle and the increase in gas transmission. An attempt was made to visualize and compare the permeability of different materials with the same size hole.

The two samples used in these tests were checked before and after the hole was added in order to isolate the gas transmission attributed to the hole alone. Helium gas was used at one psi pressure for all tests.

GAS TRANSMISSION IN CC/SECOND

PH25	Without Hole	With Hole of 0.007" Diameter
-1	0.00066	2.2
-1	0.0	1.5
-3	0.0056	1.2

PH15	Without Hole	With Hole of 0.007" Diameter
-1	0.015	0.92
-2	0.0016	1.5
-3	0.00066	7.1

CONCLUSIONS

The difficulty of accurately creating a uniform hole for the purpose of comparing gas transmission rates was greater than anticipated. The permeation comparison was affected by this difficulty but a correlation of uniformity between samples was possible.

Appendix C (cont'd)

TABLE C-8

DuPont Mylar Correlation Tests

The following tests were performed to find a correlation between methods of quality control used by DuPont in the production of Mylar and the permeability measurement methods described in Paragraph 3.6.4.

The DuPont Mylar C samples were provided NASA-Lewis together with the quality control data and coded for later comparison. This material was then forwarded to Beech fully coded but without the actual quality control figures.

Three 0.25 mil Mylar groups were tested totaling 30 separate film samples. None 0.15 mil Mylar groups were tested totaling 90 samples. The results of these tests are shown below and graphed on Figure 3.28. The relationship of the observed permeation values with the DuPont dielectric strength data is shown on Figure 3.29.

Each sample was subjected to the normal permeability test at Beech of one psi of helium gas. The gas transmission was measured on a burette in cc/sec.

BEECH PERMEABILITY DATA (DUPONT SAMPLES)

Sample Identification	Sample Dash No.	Permeability cc/sec.
PD15-1-1 / #557321 (C)	-1	0.006
	-2	0.0043
	-3	0.0033
	-4	0.004
	-5	0.0013
	-6	0.0066
	-7	0.0023
	-8	0.002
	-9	0.0007
	-10	0.0003
	Average	0.0031

Appendix C (cont'd)

TABLE C-8 (cont'd)

Sample Identification	Sample Dash No.	Permeability cc/sec.
PD15-1-2 #557321 (TE)	-1	0.0013
	-2	0.0033
	-3	0.0036
	-4	0.0096
	-5	0.003
	-6	0.0007
	-7	0.0023
	-8	0.0003
	-9	0.0013
	-10	0.001
	Average	0.0026
PD15-1-3 #557321 (NTE)	-1	0.003
	-2	0.0033
	-3	0.0023
	-4	0.056
	-5	0.0033
	-6	*0.11
	-7	0.001
	-8	0.0026
	-9	0.0
	-10	0.0086
	Average	0.019
	Corrected Average	*0.009
PD15-2-1 #557339 (C)	-1	0.022
	-2	0.002
	-3	0.025
	-4	0.024
	-5	0.0093
	-6	0.0003
	-7	0.0023
	-8	0.0007
	-9	0.0016
	-10	0.0036
	Average	0.0091

Appendix C (cont'd)

TABLE C-8 (cont'd)

Sample Identification	Sample Dash No.	Permeability cc/sec.
PD15-2-2 #557339 (TE)	-1	0.012
	-2	0.0023
	-3	0.042
	-4	0.0026
	-5	0.0033
	-6	0.0013
	-7	0.001
	-8	0.001
	-9	0.004
	-10	0.0066
	Average	0.0076
PD15-2-3 #557339 (NTE)	-1	0.0026
	-2	0.018
	-3	*0.18
	-4	0.0053
	-5	0.0033
	-6	0.002
	-7	0.0023
	-8	0.0007
	-9	0.0026
	-10	0.0086
	Average	0.0225
	Corrected Average	*0.0050
PD15-3-1 #557345 (C)	-1	*0.34
	-2	0.0036
	-3	0.035
	-4	0.0013
	-5	*0.13
	-6	0.001
	-7	0.0013
	-8	0.0007
	-9	0.0063
	-10	0.002
	Average	0.0521
	Corrected Average	*0.0064

Appendix C (cont'd)

TABLE C-8 (cont'd)

Sample Identification	Sample Dash No.	Permeability cc/sec.
PD15-3-2 #557345 (TE)	-1	0.0013
	-2	0.0036
	-3	0.003
	-4	0.0156
	-5	0.0076
	-6	0.0066
	-7	0.0007
	-8	0.001
	-9	0.0016
	-10	0.0
	Average	0.0041
PD15-3-3 #557345 (NTE)	-1	0.0016
	-2	0.09
	-3	0.054
	-4	0.0013
	-5	0.0073
	-6	0.0013
	-7	0.018
	-8	0.0007
	-9	0.0
	-10	0.0
	Average	0.0126
PD25-1 #500341 (C)	-1	0.0013
	-2	0.002
	-3	0.002
	-4	0.0007
	-5	0.0016
	-6	*0.35
	-7	0.00081
	-8	0.0010
	-9	0.00079
	-10	0.0016
	Average	0.0361
	Corrected Average	*0.0012

Appendix C (cont'd)

TABLE C-8 (cont'd)

Sample Identification	Sample Dash No.	Permeability cc/sec.
PD25-2 #500341 (TE)	-1	*0.11
	-2	0.0007
	-3	0.0053
	-4	0.00079
	-5	0.0023
	-6	0.00075
	-7	0.0010
	-8	0.0010
	-9	0.00068
	-10	0.00075
	Average	0.0123
	Corrected Average	*0.0013
PD25-3 #500341 (NTE)	-1	0.001
	-2	0.0023
	-3	0.001
	-4	0.0007
	-5	0.001
	-6	0.00091
	-7	0.00069
	-8	0.00068
	-9	0.00065
	-10	0.00071
	Average	0.0009

* This data was discarded in obtaining an average since it appeared to be isolated data and not contributing to total accuracy. The inclusion of these excessive permeability figures, however, did not permit any better correlation with the electrical strength data from DuPont.

DUPONT DIELECTRIC STRENGTH TEST DATA (DuPont Mylar Film Samples

DuPont uses a dielectric strength test as a quality control method in the production of Mylar. The film to be tested is subjected to increasing voltage and the number of breakdowns determine the acceptance of the film.

0.15 mil Mylar at 200 volts 17 survivals out of 20 is acceptable
0.15 mil Mylar at 500 volts 10 survivals out of 20 is acceptable

0.25 mil Mylar at 400 volts 19 survivals out of 20 is acceptable
0.25 mil Mylar at 1000 volts 17 survivals out of 20 is acceptable

The material supplied for the correlation tests had the following electrical test results:

Appendix C (cont'd)

TABLE C-8 (cont'd)

DUPONT DIELECTRIC STRENGTH DATA

Gauge	Sample No. (DuPont)	Sample No. (Beech)	No. Samples/40 Failing at Voltage Indicated			Average Breakdown Voltage
			500	200	1000	
15	557321	PD15-1	11	3	-	638
15	557339	PD15-2	0	0	-	970
15	557345	PD15-3	0	0	-	688
25	500341	PD25-1	-	-	0	1905

Sample No.	Permeability (cc/hour)
PD15-1	0.0049
PD15-2	0.0074
PD15-3	0.0078
PD25-1	0.0011

DuPont Mylar Sample Groups

Gauge	Sample Number and Designation (DuPont)		Sample No. (Beech)
15	557321	C	PD15-1-1
15	557321	TE	PD15-1-2
15	557321	NTE	PD15-1-3
15	557339	C	PD15-2-1
15	557339	TE	PD15-2-2
15	557339	NTE	PD15-2-3
15	557345	C	PD15-3-1
15	557345	TE	PD15-3-2
15	557345	NTE	PD15-3-3
25	500341	C	PD25-1
25	500341	TE	PD25-2
25	500341	NTE	PD25-3

Appendix C (cont'd)

TABLE C-8 (cont'd)

CONCLUSIONS

The electrical strength data supplied by DuPont and the permeability obtained on the same samples in this program did not show a good correlation. There is a trend indicated for three of the sample groups but an inverse relationship for the PD15-1 group.

It will be necessary to evaluate in more detail the manner in which the DuPont tests are conducted before final conclusions can be drawn with regard to a definite correlation. It appears that there is no exacting relationship at this time.

TABLE C-9

Extended Time Test

The Extended Time Test was conducted to demonstrate that samples which show zero permeability in a five-minute period actually have some permeability which was not measurable in this period of time. The following tests were therefore conducted for a time period which permitted these two groups of bubbles to enter the burette or to five minutes whichever occurred last.

The use of a burette as a means of measuring permeability depends upon the accumulation of bubbles. It is normal to find that the bubbles enter the burette in groups of two or three and therefore if sufficient time is allowed it is always possible to obtain a finite rate.

Three different pressures were used and are noted at the top of the columns. Some of the data was substituted for the zero readings previously obtained for the DuPont Correlation Tests, Table C-8.

The samples used for this test were 0.25 mil and 0.15 mil Mylar C received from DuPont. These samples gave outstandingly low permeability readings as compared with some other Mylar samples tested in the program.

Appendix C (cont'd)
TABLE C-9 (cont'd)

EXTENDED TIME TEST DATA

Test #4.8-1 Sample No. PD25-1

	16" H_2O		28" H_2O	
Dash Number	Time - sec.	cc/sec.	Time - sec.	cc/sec.
-1	300	0.017		
-2	300	0.0056		
-3	686	0.00072		
-4	400	0.0017		
-5	560	0.00071		
-6	90	0.25	60	0.35
-7	474	0.00063	368	0.00081
-8	425	0.00070	380	0.0070
-9	522	0.00076	376	0.00079
-10	300	0.0010	300	0.0016

Test #4.8-2 Sample No. PD25-2

	16" H_2O		28" H_2O	
Dash Number	Time - sec.	cc/sec.	Time - sec.	cc/sec.
-1	180	0.11		
-2	543	0.00073		
-3	398	0.0012		
-4	376	0.0010		
-5	620	0.00080		
-6	493	0.00081	399	0.00075
-7	437	0.00068	300	0.0010
-8	300	0.0083	394	0.0010
-9	628	0.00063	435	0.00068
-10	602	0.00066	400	0.00075

Test #4.8-3 Sample No. PD25-3

	16" H_2O		28" H_2O	
Dash Number	Time - sec.	cc/sec.	Time - sec.	cc/sec.
-6	300	0.0013	435	0.00091
-7	737	0.00040	431	0.00069
-8	588	0.00068	438	0.00068
-9	558	0.00071	460	0.00065
-10	560	0.00053	420	0.00071

Appendix C (cont'd)

TABLE C-9 (cont'd)

Test #4.8-4 10" H_2O

Sample Number	Time	Burette cc/sec.
PD15-1-1-1	5 minutes	0.0033
PD15-1-1-2	5 minutes	0.0010
PD15-1-1-3	5 minutes	0.0010
PD15-1-1-4	513 seconds	0.00077
PD15-1-1-5	5 minutes	0.011
PD15-1-1-6	5 minutes	0.025
PD15-1-1-7	5 minutes	0.0016
PD15-1-1-8	595 seconds	0.00050
PD15-1-1-9	374 seconds	0.0010
PD15-1-1-10	556 seconds	0.00071

Test #4.8-5 10" H_2O

PD15-1-2-1	5 minutes	0.0020
PD15-1-2-2	5 minutes	0.0053
PD15-1-2-3	5 minutes	0.0013
PD15-1-2-4	5 minutes	0.0093
PD15-1-2-5	5 minutes	0.0030
PD15-1-2-6	5 minutes	0.022
PD15-1-2-7	5 minutes	0.0020
PD15-1-2-8	518 seconds	0.00096
PD15-1-2-9	537 seconds	0.0011
PD15-1-2-10	5 minutes	0.0013

Test #4.8-6

PD15-2-1-1	5 minutes	0.017
PD15-2-1-2	5 minutes	0.0043
PD15-2-1-3	5 minutes	0.048
PD15-2-1-4	5 minutes	0.032
PD15-2-1-5	5 minutes	0.043
PD15-2-1-6	5 minutes	0.0050
PD15-2-1-7	5 minutes	0.0070
PD15-2-1-8	5 minutes	0.0010
PD15-2-1-9	5 minutes	0.0030
PD15-2-1-10	5 minutes	0.0033

Appendix C (cont'd)

TABLE C-9 (cont'd)

Test #4.8-7

Sample Number	Time	Burette cc/sec.
PD15-2-3-1	5 minutes	0.0090
PD15-2-3-2	5 minutes	0.033
PD15-2-3-3	3 minutes	0.10
PD15-2-3-4	1 minute	0.32
PD15-2-3-5	5 minutes	0.030
PD15-2-3-6	5 minutes	0.075
PD15-2-3-7	5 minutes	0.028
PD15-2-3-8	5 minutes	0.0050
PD15-2-3-9	5 minutes	0.0020
PD15-2-3-10	5 minutes	0.012

The PD25 samples have approximately the same leak rate at 16" of H_2O as they did at 28" of H_2O. This indicates that there is not enough difference in pressure to make the leak rate change a large amount.

CONCLUSIONS

The results of the Extended Time Tests show that many samples which have zero leakage at the end of five minutes will indicate permeation if the time is extended. The doubling of the time period showed that permeation could be as small as 0.00016 cc/sec. As has been noted in previous reports on permeability, the smallest permeability reading which can be obtained in a five-minute period is 0.00066 cc/sec. Anything less than that is considered zero for this program. The selection of five minutes was made, fully recognizing this fact for the reason that it was not feasible to spend excessive time on each sample. The Extended Time Test has proven that zero permeation in five minutes means only that it is less than 0.00066 cc/sec. (Ref. Figure 3.30)

The test data shows that a definite relationship exists between the permeation of a sample under 16 inches of water as compared with 28 inches of water. The higher the pressure the greater the gas transmission.

Appendix C (cont'd)

TABLE C-10

Pressure and Time Variation Test

This test was conducted on two different samples of 0.5 mil Kapton film at two different pressures and for two different periods of time. The purpose was similar to the Extended Time Test, Table C-9, but combined the two parameters and for a different material. These samples were regular program samples received from the G. T. Schjeldahl Company.

Sample Description 0.5 Mil Kapton

Sample Number	Pressure	Permeation in cc/sec. in 5 minutes
T209-11	28" H_2O	0.0
	24" H_2O	0.0
T209-12	28" H_2O	0.0
	24" H_2O	0.0
T209-11	28" H_2O	0.00076 in 525 seconds
T209-12	28" H_2O	0.00047 in 626 seconds

CONCLUSION

The conclusions are identical to previous tests of a similar nature in that extending the time of permeation measurement will provide a figure for permeability which otherwise would be termed zero in a five-minute period.

TABLE C-11

Burst Tests

These tests provided a maximum pressure allowable for conducting permeability flat sample tests and also in indication of film strengths useful for bladder fabrication.

90-33364

Appendix C (cont'd)

TABLE C-11 (cont'd)

Burst Test

Sample No.	Pressure	Comments
PC15-4	1.2 psi	0.09 dia. hole developed
	1.5 psi	0.05 dia. hole developed
	1.75 psi	Burst
PC25-5	2.6 psi	0.05 dia. hole developed
	3.2 psi	0.05 dia. hole developed
	3.7 psi	Burst

Summary of Permeability Studies

(1) Permeability of Mylar film varies considerably from one batch to another and is affected by handling and storage.

(2) The permeation of He gas through multiply Mylar films is reduced by addition of two or three plys but does not significantly improve by additional plys.

(3) The rate of helium gas transmission through Mylar films increases with increase in pressure differential across the film.

(4) Helium gas at one psi pressure will permeate through a 30 square inch 0.25 mil Mylar film at a rate up to 0.018 cc/sec without visible bubbles if covered with water to depth of 1/4 inch.

(5) The permeability rate of helium gas through 0.15 mil Mylar film stabilizes after approximately 15 minutes.

(6) A ± 15% variation is possible in permeability data recorded in this report for flat samples as well as bladders. This is indicated by the repeatability test and the utilization of the same equipment for bladder tests.

(7) A hole of 0.007" diameter permits more gas transmission through a film than that attributed to actual permeability of any 30 square inch samples tested.

(8) This program did not observe a good correlation between the DuPont electrical strength data and gas permeability rates.

Appendix C (cont'd)

(9) Zero permeation as measured for a period of five minutes in this program means that the rate is less than 0.00066 cc/sec for He gas at one psi over 30 square inches of .15 and .25 mil Mylar film area.

(10) There is no sharp or distinct increase in gas transmission through a film to clearly define the terms permeability and porosity.

APPENDIX D

SEAMED TWIST-FLEX DATA

Sample Dash No.	Permeability Before Test	Permeability After Test	No. of Cycles	Comments
G. T. Schjeldahl Company Samples				
T227 Description				1 ply of .25 mil Mylar "C". Butt Seam, 1/2" Wide (see Figure 3.32, No. 1). GT300 Tape and Adhesive
-1	.095	-	60	Split from cap end to cap end along horizontal seam and across vertical seam.
-2	.0050	-	30	Split from end to end along lower side of horizontal seam and across vertical seam. Left end cap split and delaminated from material along edge.
-3	.022	-	65	Split from end to end across vertical seam below horizontal seam.
-4	.0020	-	20	Split between left end cap and vertical seam below horizontal seam.
-5	.038	-	20	Split from left to right end cap across vertical and through approximately 3" of horizontal seam.

Complete random type of splitting across samples not related to seam. Seam type comparison test.

Sample Dash No.	Permeability Before Test	Permeability After Test	No. of Cycles	Comments
T228 Description				1 ply of .25 mil Mylar "C". Butt seam, 1/8" wide hot roller (see Figure 3.32, No. 2). GT300 tape and adhesive.
-1	.0066	-	40	Split from end cap to end cap across both center seams.
-2	.29	-	40	Split from right end cap across vertical seam above horizontal seam. Split across left end cap to vertical seam below horizontal seam.
-3	.027	-	10	Split between vertical seam and right end cap just above horizontal seam also halfway across horizontal seam at right end approximately 1" from edge.
-4	0	-	170	Split in upper left section and upper right section. Two scratches result of end plate removal.
-5	.068	-	80	Split from left to right end cap across vertical seam below horizontal seam. Split between left end cap and vertical seam above horizontal seam.

APPENDIX D (cont)

Complete random type of splitting failure across entire sample not related to type of seam. Seam type comparison tests.

T229 Description				1 ply of .25 Mylar "C" Lap Seam, 1/2" wide (see Figure 3.32, No. 3) GT100 Adhesive
-1	.016	10.0 cc/sec.	10	Split approximately 1" in lower left section just right of left end cap.
-2	.012	-	20	Split across horizontal seam just left of vertical seam.
-3	.17	-	11	Split between horizontal and vertical seam on upper and lower right end section.
-4	.76	-	60	Split between left end cap and vertical seam in upper left section.
-5	.017	-	45	Split across horizontal seam at left end section.

Complete random splitting of film influenced to some degree by seam which deterred a split from propagating across seam in most cases. Seam type comparison tests.

T230 Description				1 ply .25 mil Mylar "C" Lap Seam 1/8" wide Hot Roller (see Figure 3.32, No. GT100 Adhesive
-1	1.4	-	25	Split in upper left section and lower right section; also small area became unbonded along lower seam in lower right section.
-2	1.3	-	45	Split across vertical seam and between left end cap and vertical seam; also some bond separation along horizontal seam.
-3	6.6	-	30	Split across horizontal seam at left end section; also (2) splits in lower right section.
-4	0	-	14	Split across horizontal seam (2) places at left of vertical and (2) places at right of vertical seam. Split across vertical seam just below upper clamp area.
-5	.019	-	24	Split across horizontal seam just left of vertical seam.

APPENDIX D (cont)

Complete random type splitting failures in which the seams deterred a split from propagating across a seam. Splits not initiated by seams. Seam type comparison tests.

T231 Description				1 ply .25 Mylar "C" Butt Seam, 1/8" wide impulse seal GT300 Tape and adhesive (see Figure 3.32, No. 5)
-1	.0050	-	15	Split between vertical seam and left end cap. Vertical seam bond came loose on left hole of seam.
-2	.046	-	30	Split across vertical seam.
-3	.0026	-	28	Split from left end cap to vertical seam in lower section. Small area of vertical seam came unbonded.
-4	.026	-	16	Split from left end cap to vertical seam in lower section. Small area of vertical seam came unbonded.
-5	.0080	-	42	Split in upper right and left section and lower left section.

T232 Description				1 ply .25 mil Mylar "C" Lap seam 1/8" wide Impulse Seal GT100 Adhesive (see Figure 3.32, No. 6)
-1	.0066	-	27	Split across vertical and horizontal seam and from left to right end cap.
-2	.012	-	36	Split in upper left and upper right sections. Also separation of material at seam bond in right end section.
-3	.0060	-	32	Split in lower right and left sections. Separation of seam bond at top of vertical seam.
-4	.0023	-	42	Split in upper right section with separation of seam bond.
-5	.034	-	18	Split from right to left end cap across vertical and horizontal seam.

Random splitting of film within a relatively few number of twist flex cycles not influenced to a great degree by the seam. Seam type comparison tests.

APPENDIX D (cont)

T233 Description				1 ply of .25 mil Mylar "C" Lap Seam 1/2" wide (see Figure 3.32, No. 3) GT100 Adhesive
-1	.64	-	12	Split from left end cap to 1.5" from right end cap across vertical seam.
-2	.19	-	2	Split from right end cap across vertical and horizontal seam to 1.25" from left end cap at top edge of sample.
-3	.0016	-	6	Split from left end cap across vertical and horizontal seam to lower edge 2" from right end.
-4	.056	-	25	Split from left end cap across vertical and horizontal seam to right end cap.
-5	.0033	-	6	Split from right end cap across vertical seam to upper edge at center of sample.

T234 Description				1 ply .25 mil Mylar Lap seam 1/2" wide (see Figure 3.32, No. 3) GT100 Adhesive
-1	6.6	-	28	Split in lower left and upper and lower right sections - numerous wrinkles.
-2	1.4	-	7	Split in lower left section from end cap to vertical seam - numerous wrinkles.
-3	.01	-	5	Split from left to right end cap across vertical and horizontal seams - numerous wrinkles.
-4	.016	-	23	Split between vertical seam and right end cap in lower section.
-5	.071	-	7	Split across vertical seam in upper section.

Complete random type of splitting across samples not related to seam. Seam type comparison test.

APPENDIX D (cont)

T235 Description				1 ply .25 mil Mylar Lap seam 1/2" wide (see Figure 3.32, No. 3) GT100 Adhesive
-1	.0073	-	5	Split between left end cap and vertical seam in lower section.
-2	.2	-	14	Split from left to right end cap across vertical seam.
-3	6.3	-	3	Split between vertical seam and right end cap and down across horizontal seam.
-4	.79	-	13	Split between left end cap and vertical seam.
-5	7.0	-	11	Split across vertical and horizontal seam.

Complete random type of splitting across sample not related to seam. Seam type comparison test.

The results shown for T233, T234, and T235 indicate that the failures apparently were not due to the seams but to the basic material. The failures were of a gross nature in which the splits originated in the material and extended through the seams in a random manner. The samples, when received, had a wrinkled appearance which caused some concern as to the quality of the Mylar as compared to other samples which had been received wrinkle-free. The permeability data in the tables also indicates a wide variety between samples, possibly due to this wrinkle condition.

T240 Description				1 ply of 2 mil Nomex - Nylon Paper Butt Seam, 1/2" wide (see Figure 3.32, No. 1) GT300 Tape and adhesive one side
-1	.24	-	45	Split along horizontal seam across vertical seam - numerous wrinkles.
-2	.20	-	17	Split on vertical seam across horizontal seam - numerous wrinkles.
-3	.18	-	57	Split on vertical and horizontal seams - numerous wrinkles.
-4	.37	-	200	Numerous wrinkles - no other visible damage.

APPENDIX D (cont)

-5	.23	-	27	Split across vertical and horizontal seam - split at upper right end occurred while removing sample from apparatus.

Severe splitting of the Mylar tape between the butt ends of the Nomex material.

T241 Description

1 ply of 2 mil Nomex - Nylon Paper
Butt Seam, 1/8" wide (see Figure 3.32, No. 2)
GT300 Tape and adhesive one side

-1	.35	-	6	Split full length of horizontal seam - partial split of vertical seam.
-2	.31	-	4	Split full length of horizontal seam - partial split of vertical seam.
-3	.33	-	5	Split full length of horizontal seam - partial split of vertical seam.
-4	.25	-	4	Partial split of horizontal seam on both sides of vertical seam.
-5	.28	-	4	Split on horizontal and vertical seams.

Severe splitting of the Mylar tape between the butt ends of the Nomex material.

T242 Description

1 ply of 2 mil Nomex - Nylon Paper
Lap Seam, 1/2" wide (see Figure 3.32, No. 3)
GT100 Adhesive

-1	.24	-	200	Numerous wrinkles - several pin holes.
-2	.26	-	200	Numerous wrinkles - 2" long seam separation.
-3	.11	-	200	Numerous wrinkles - several pin holes.
-4	.44	-	200	Numerous wrinkles - several pin holes.
-5	.25	-	200	Numerous wrinkles 1/2" long seam separation.

The lap wide seams appeared to be more satisfactory than the butt seams tested as T240 and T241.

APPENDIX D (cont)

T243 Description				1 ply of 2 mil Nomex - Nylon Paper Lap Seams, 1/8" wide (see Figure 3.32, No. 4) GT100 Adhesive
-1	.37	-	4	Split along horizontal seam - numerous wrinkles.
-2	.34	-	8	Split along horizontal seam on right section - numerous wrinkles.
-3	.20	-	16	Split along horizontal seam - numerous wrinkles.
-4	.22	-	7	Split along horizontal seam - numerous wrinkles.
-5	.24	-	6	Split along horizontal seam - numerous wrinkles.

Serious separation of lap seams indicate that the narrow seal is not sufficiently strong in this application.

T244 Description				1 ply of 2.2 oz. Dacron fabric Butt Seam, 1/2" wide (see Figure 3.32, No. 1) Tape one side GT300 Tape and Adhesive
-1	*	*	1	Severe splitting of horizontal and vertical seams.
-2	*	*	1	Severe splitting of horizontal and vertical seams.
-3	*	*	1	Severe splitting of horizontal and vertical seams.
-4	*	*	1	Severe splitting of horizontal and vertical seams.
-5	*	*	2	Severe splitting of horizontal and vertical seams.

*No permeability measurement possible because of normal porosity. This material is too heavy to be seamed with .5 mil Mylar tape.

T245 Description				1 ply of 2.2 oz. Dacron Fabric Butt Seam, 1/8" wide (see Figure 3.32, No. 2) GT300 Tape and adhesive one side
-1	*	*	3	Complete splitting of horizontal and vertical seams.

APPENDIX D (cont)

-2	*	*	2	Complete splitting of horizontal and vertical seams.
-3	*	*	3	Complete splitting of horizontal and vertical seams.
-4	*	*	3	Complete splitting of horizontal and vertical seams.
-5	*	*	2	Complete splitting of horizontal and vertical seams.

*No permeability measurement possible because of normal porosity.

This material is too heavy to be seamed with .25 mil Mylar tape.

T246 Description

1 ply of 2.2 oz. Dacron Fabric
Lap Seam, 1/2" wide (see Figure 3.32, No. 3)
GT100 Adhesive

-1	*	*	200	Wrinkles but no damage.
-2	*	*	200	Wrinkles but no damage.
-3	*	*	200	Wrinkles but no damage.
-4	*	*	200	Wrinkles but no damage.
-5	*	*	200	Wrinkles but no damage.

A superior seam for use in joining this 2.2 oz. Dacron Fabric together.

*No permeability measurement possible because of normal porosity.

T247 Description

1 ply of 2.2 oz. Dacron Fabric
Lap Seam, 1/8" wide (see Figure 3.32, No. 4)
GT100 Adhesive

-1	*	*	200	Wrinkles but no damage.
-2	*	*	200	Wrinkles but no damage.
-3	*	*	200	Wrinkles but no damage.
-4	*	*	200	Wrinkles but no damage.
-5	*	*	200	Wrinkles but no damage.

*No permeability measurements possible because of normal porosity.

A superior seam for use in joining 2.2 oz. Dacron Fabric together. Appears to be equally as good as the wide seam.

APPENDIX D (cont)

T248 Description				10 ply of .25 mil Mylar "C" Butt Seam, Style "W" GT300 Tape and Adhesive
-1	0	.059	70	Split 3.5" in upper left end section on front ply - breaks on both end cap edtes.
-2	.017	.041	67	Split on back side from vertical seam to .25" from right end along horizontal seam.
-3	.00066	.016	48	Split in front ply 3" long from horizontal seam down to lower end of vertical seam.
-4	.001	.026	12	Split 1.5" along horizontal seam and 1.75 along vertical seam, then across seam on front.
-5	0	.022	200	Split 3.5" on back side at right end section.
-6	0	.065	24	Split 4.25" on back side near left end - split 3.5" on front side at left end section.
-7	0	.013	90	(2) splits on front side, 1" long at left end section and 1.25" long at left end section.
-8	0	.10	24	(2) splits on front side 1.5" long across horizontal seam and 2.5" long across horizontal seam.

APPENDIX D (cont)

-9	.00066	.036	26	Split 3" long on front side at center section.
-10	.0063	.52	200	2" x 2" right angle split at left end across horizontal seam on front side.

Random failures of Mylar film; failures generally not attributed to type of cross seam.

T249 Description — 10 plys .25 mil Mylar "C"
Butt seam, Style "N"
GT300 Tape and adhesive

-1	.00066	.41	200	Split .75" long at vertical and horizontal seam intersection on front side.
-2	.0023	.34	200	Numerous wrinkles - no visible damage.
-3	.02	.21	200	Numerous wrinkles - no visible damage.
-4	0	.26	200	Numerous wrinkles - no visible damage.
-5	0	.11	25	Split on front ply 1.5" down along vertical seam then 1" along lower clamp area.
-6	.005	.085	150	Numerous wrinkles - no visible damage.
-7	.021	.11	18	Split on front ply 1.5" down along vertical seam to 1" along lower clamp area.
-8	.024	.19	100	Numerous wrinkles - no visible damage.
-9	.0023	.28	50	Numerous wrinkles - no visible damage.
-10	0	.057	26	Split on front ply 1.5" along vertical seam and 1.5" along lower clamp area.

Good flex performance; increased permeability after Twist-Flex.

APPENDIX D (cont)

T250 Description — 10 plys of .5 mil Kapton; Butt seam, Style "W"; GT300 Tape and Adhesive

-1	0	.035	45	Split on front ply 2.5" along center of horizontal seam.
-2	0	.0033	47	Split 1" along center of horizontal seam on front ply - split on back ply 4.5" along center of horizontal seam.
-3	0	.0016	12	Split on front ply 3" along center of vertical seam.
-4	0	.024	18	Split on front ply 3.5" along center of horizontal seam.
-5	0	.0063	10	Split on front ply 2.5" along center of horizontal seam.
-6	0	.012	23	Splits .75" and 2.5" along center of horizontal seam on back ply.
-7	0	.01	36	Split 2.5" long on front ply along center of horizontal seam.
-8	0	.015	34	Split on front ply 1" and 5" along center of horizontal seam.
-9	0	.015	19	Split on front ply 4" along center of horizontal seam.

Seam failures: Light tape being cut at center of cross seams.

T251 Description — 10 plys of .25 mil Mylar; Lap seam, Style "W"; GT100 Adhesive

-1	.00066	.12	200	Split on back ply 3.5" along horizontal seam at left end section.
-2	.0063	.13	200	Numerous wrinkles - no visible damage.
-3	0	0	20	Split 1" long upper right end section on front ply.
-4	.0026	.18	200	Numerous wrinkles - no visible damage.

APPENDIX D (cont)

T251 Description (Continued)

-5	0	.15	106	Split on front side across vertical and horizontal seam.
-6	.003	.024	18	Split on front side across horizontal seam.
-7	0	.17	100	Split on back ply 2.5" along horizontal seam at right end and split 1.5" long on front ply at upper left section.
-8	.00066	.29	100	Split 1" long on front ply at lower center area - split on back ply 2" long at right end section.
-9	.0026	.001	50	Split on front ply 5" long across horizontal seam.
-10	0	.085	50	Split 1" long on front ply at left end section.

Generally good flex performance with some random material failure not directly attributable to cross seams.

T252 Description

10 plys of .25 mil Mylar
Lap seam, Style "N"
GT100 Adhesive

-1	0	.023	200	Numerous wrinkles - no visible damage.
-2	.00066	.079	200	Numerous wrinkles - no visible damage.
-3	.014	.10	200	Numerous wrinkles - no visible damage.
-4	.013	.077	200	Numerous wrinkles - no visible damage.
-5	.00066	.057	150	Split on front ply 4" long and across horizontal seam.
-6	.0023	.10	28	Split 4" long on front ply at right end section and split 4" long on back ply at right end section.

APPENDIX D (cont)

T252 Description (Continued)

-7	0	.041	100	Split 2" long on back ply at right end section and split 1" long on front side at right end section.
-8	.0036	.045	100	Split 2" long on front ply at left end.
-9	0	.093	8	Split on front ply 4.5" long and across vertical seam.
-10	.01	.1	50	Numerous wrinkles - no visible damage.

Very random flex performance ranging from good to poor, with failures not directly attributable to type of cross seams.

T253 Description

10 plys of .5 mil Kapton
Lap seam, Style "W"
GT100 Adhesive

-1	0	.02	17	Split 3.5" on front ply at upper left section - also 5.5" at upper right section along horizontal seam.
-2	0	.004	22	Split 4.5" on front ply across vertical seam at left section.
-3	0	.0066	15	Split 5.5" along horizontal seam on back ply at left end area - split 4.0" on front ply at upper left end.
-4	.019	.025	25	Split 3" on front ply at right end section - split on back ply (3) places along horizontal seam for total of 10".
-5	0	-	64	Split on front ply 3" long at right end section also 2" at upper right end - split 1.5" on back ply at right end.
-6	0	0	44	Split on back ply (2) places each 2" long.

APPENDIX D (cont)

T253 Description (continued)

-7	0	.0026	6)	Split on back ply 2.5" near left end-split on front ply 3" near right end.
-8	0	.0056	54	Split 2.5" on front ply at right end.
-9	0	0	50	Split 3.5" on front ply near left end section.

Poor flex performance with considerable seam failure; other random failures appear to be induced by the cross seams.