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PRELIMINARY STUDIES OF LIQUID OXYGEN EXPULSION BLADDERS

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ABSTRACT

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Expulsion bladders for liquid oxygen (LOX) were fabricated from several different materials and evaluated by functional testing. The results indicated that materials considered chemically compatible with liquid oxygen generally are unsuited for fabrication of expulsion bladders because of their mechanical properties at low temperatures. Complex expulsion bladders involving reinforced films and predetermined fold patterns performed slightly better than simple unreinforced films. However, extensive improvement will be necessary before this method of LOX transfer can be utilized in zero-gravity propulsion systems.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

TECHNICAL MEMORANDUM 53005

PRELIMINARY STUDIES OF LIQUID OXYGEN EXPULSION BLADDERS

SUMMARY

Expulsion bladders for liquid oxygen (LOX) were fabricated from several different materials and evaluated by functional testing. The results indicated that materials considered chemically compatible with liquid oxygen generally are unsuited for fabrication of expulsion bladders because of their mechanical properties at low temperatures. Complex expulsion bladders involving reinforced films and predetermined fold patterns performed slightly better than simple unreinforced films. However, extensive improvement will be necessary before this method of LOX transfer can be utilized in zero-gravity propulsion systems.

INTRODUCTION

One of the promising methods of positive expulsion of liquid propellants under conditions of zero gravity is by the use of bladders. Although numerous investigators (Ref. 1, 2, and 3) have studied the use of such bladders for liquid hydrogen and storable liquid propellants, little consideration has been given to the transfer of liquid oxygen (LOX). Consequently, this investigation was initiated to determine materials suitable for the manufacture of LOX expulsion bladders. The first phase of the study, described in this report, was limited largely to materials selection, fabrication, and testing of single film hemispherical bladders. However, preliminary studies also were made to investigate the use of more complex bladder configurations with emphasis on reinforced films and bladders possessing predetermined fold patterns.

MATERIALS SELECTION CRITERIA

The primary requirement imposed on materials selected for bladder fabrication was LOX compatibility as defined by MSFC-SPEC-106A, "Testing Compatibility of Materials for Liquid Oxygen Systems." The selected design was a hemispherical diaphragm capable of undergoing complete inversion through the equatorial plane during an expulsion cycle. This configuration was adopted because the severe mechanical property requirements imposed by complete reversal suggested that material satisfactory for this configuration also should be satisfactory for other configurations of interest.

MATERIALS SELECTION AND EVALUATION

Thirty-nine samples, representing a number of different materials in various thicknesses, were tested for LOX compatibility at 72.3 ft-lbs of impact energy in accordance with MSFC-SPEC-106A. The results are summarized in Table I. Inspection of these data indicates that, in general, only fluorocarbon and chlorofluorocarbon polymers, such as Teflon, Kel-F, Armalon, and Aclar, were acceptable.

Previous investigators (Ref. 1, 2, and 3) have found that Mylar possesses excellent mechanical properties at LOX temperature. Therefore, attempts were made to desensitize this material to impact in LOX by use of insensitive metallic surface coatings. These attempts were unsuccessful (Table I). Consequently, Mylar was omitted from further consideration, as were Tedlar, H-Film and HT-1 paper because of their failure to meet requirements of MSFC-SPEC-106A.

Typical properties for LOX compatible materials are presented in Table II. Consideration of the sizes (up to 54-inch width sheets) in which these materials are available and also of some of the suggested fabrication techniques indicated that some method for bonding sheets would be necessary. Because no LOX compatible adhesive was available for such applications, all films were fusion bonded by impulse heating methods. Table III presents mechanical properties for fusion bonded specimens of the various fluorocarbon and chlorofluorocarbon films. These data indicate, as expected, that bonded films usually are weaker than the parent films. Tensile failure of the bonded specimens occurred exclusively in the heat-affected zone adjacent to the bond.

The effects of crystallinity upon mechanical properties of fluorocarbon and chlorofluorocarbon polymers were not determined experimentally. However, all diaphragm fabrication procedures were selected to minimize any increase in crystallinity of the polymeric films and spray dispersions.

DESIGN AND FABRICATION APPROACHES

To determine the commercial state-of-the-art, 11 requests for price quotations were distributed to known fabricators of plastic and elastomeric products in which the following requirements were specified: (1) LOX compatible materials must be used (based upon MSFC LOX compatibility tests); (2) the geometric configuration must consist of a reversing hemisphere with an equatorial attachment flange; (3) the diaphragm must be able to withstand a ΔP of 5 psi; and (4) a flat sample of the finished material configuration must be submitted for MSFC physical properties testing.

Five commercial fabricators subsequently furnished diaphragms for evaluation. Cross-sections of four of these are shown in FIG 1. Not shown is a plain 6-mil thick diaphragm made of Kel-F spray-dispersion submitted by Company A.

The Company B diaphragm was comprised of a 2-mil spray-dispersion layer of aluminum powder in Teflon FEP sandwiched between two 2-mil layers of Teflon FEP spray-dispersion. The Company C diaphragm featured a gradation in thickness from 11 mils at the equator to 4 mils at the apex. This diaphragm was made of a homogeneously dispersed aluminum powder in Teflon FEP spray dispersion film. The Company D diaphragm was composed of a 2-mil layer of a chemically milled aluminum foil sandwiched between two 2-mil layers of Teflon FEP spray dispersion. The Company E diaphragm was a 6-mil Teflon FEP, heat formed film bonded to two 1/16-inch nominal Teflon TFE felt layers.

Mechanical properties data based upon MSFC tests of commercial diaphragm sample materials are presented in Table IV.

Diaphragms fabricated and tested in-house included plain single films as well as films with "spiral" and "beehive" reinforcement as illustrated in FIG 2. More complicated designs in which the bladders possessed predetermined fold patterns are shown in FIG 3. Fabrication difficulties limited the number of test diaphragms of these latter designs.

FUNCTIONAL TESTING

A schematic drawing of the functional test apparatus is shown in FIG 4. The system consisted of a gas pressurization and vacuum system manifolded with a suitable differential pressure gauge and relief valve for a bladder holding fixture which was immersed in the fluid to be expelled. For the room temperature air and water expulsion tests, LN_2 was replaced by the appropriate fluid.

Functional expulsion tests were conducted with air, water, and liquid nitrogen as the fluid. Air was used as the pressurizing gas for fluid expulsion at room temperatures, and helium was used at liquid nitrogen temperatures. Tests in air served mainly to check the bladder fit to the test fixture and to precheck the system for pressurant gas leaks before liquid expulsion testing. Tests with water were made at room temperature in plexiglass tanks through which folding patterns in the material could be easily observed and photographed during the filling and expulsion cycles.

DISCUSSION OF RESULTS

The results are summarized in Table V, and the data indicate that single film bladders made of LOX-compatible materials do not perform satisfactorily. Of the 37 bladders in this category tested, all failed after less than one-half cycle in LN_2; most failures consisted of rips or tears originating at three corner folds. However, more complex bladders involving laminated layers, reinforced structures, and/or predetermined fold patterns performed somewhat better, with one bladder surviving 3-1/2 cycles before failing.

The number of cycles and the associated confidence limit required for vehicle application have not been established. However, it is apparent that much improvement will be necessary. For this reason, future studies should emphasize the fabrication and testing of complex bladders incorporating new material and design configurations.

CONCLUSIONS

Expulsion bladders for LOX transfer were fabricated from several different materials. Results of functional tests in LN_2 indicated that materials compatible for LOX with respect to explosive hazards generally are not suited for LOX expulsion bladders with respect to mechanical properties at low temperatures. Complex bladder designs involving laminated layers, reinforced films, and/or predetermined fold patterns performed slightly better than single films. However, much improvement will be needed before this method can be considered for vehicle application. Combinations of reinforced or laminated films and predetermined fold patterns may yield bladders of acceptable durability.

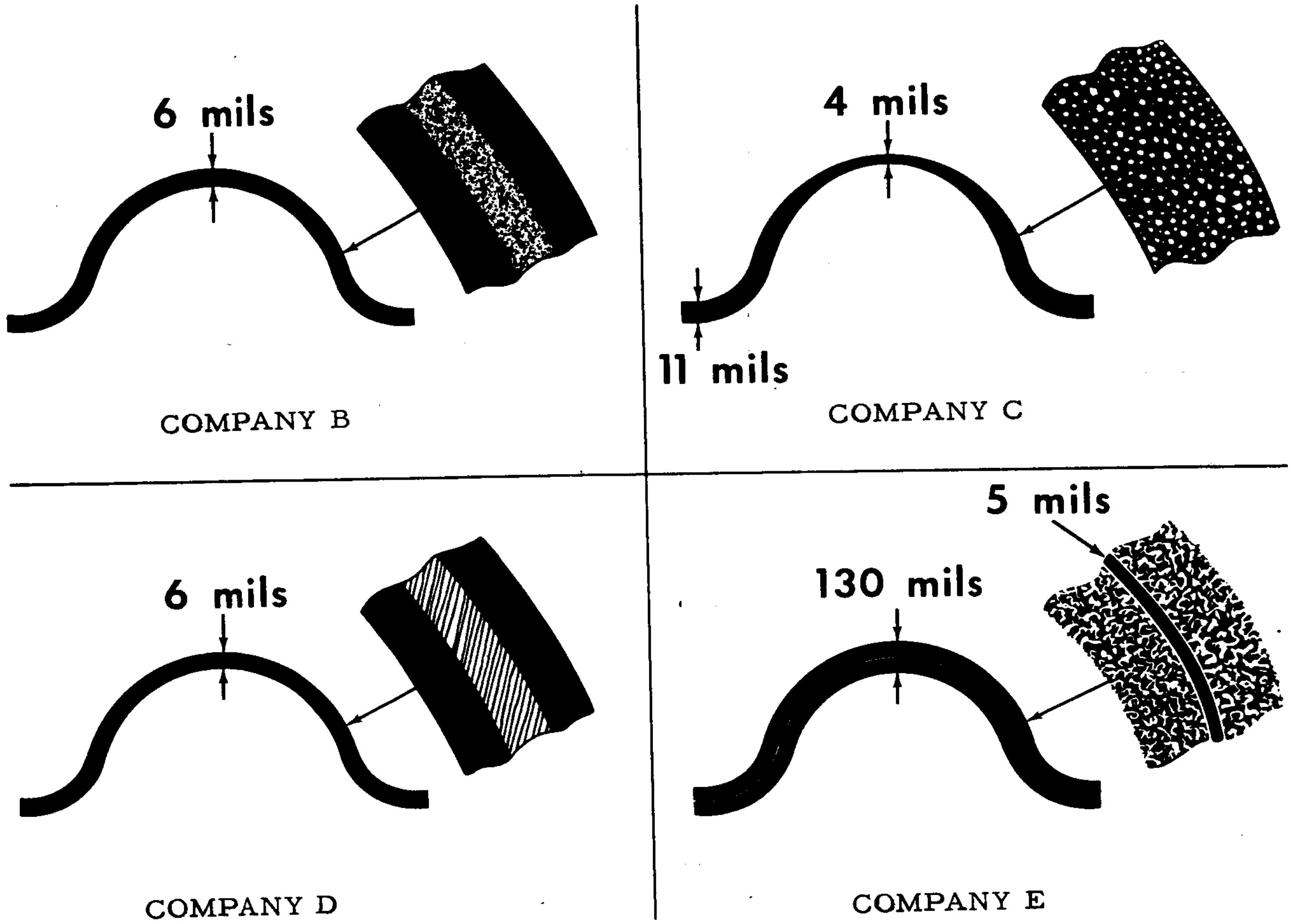


FIGURE 1. COMMERCIAL CONFIGURATIONS

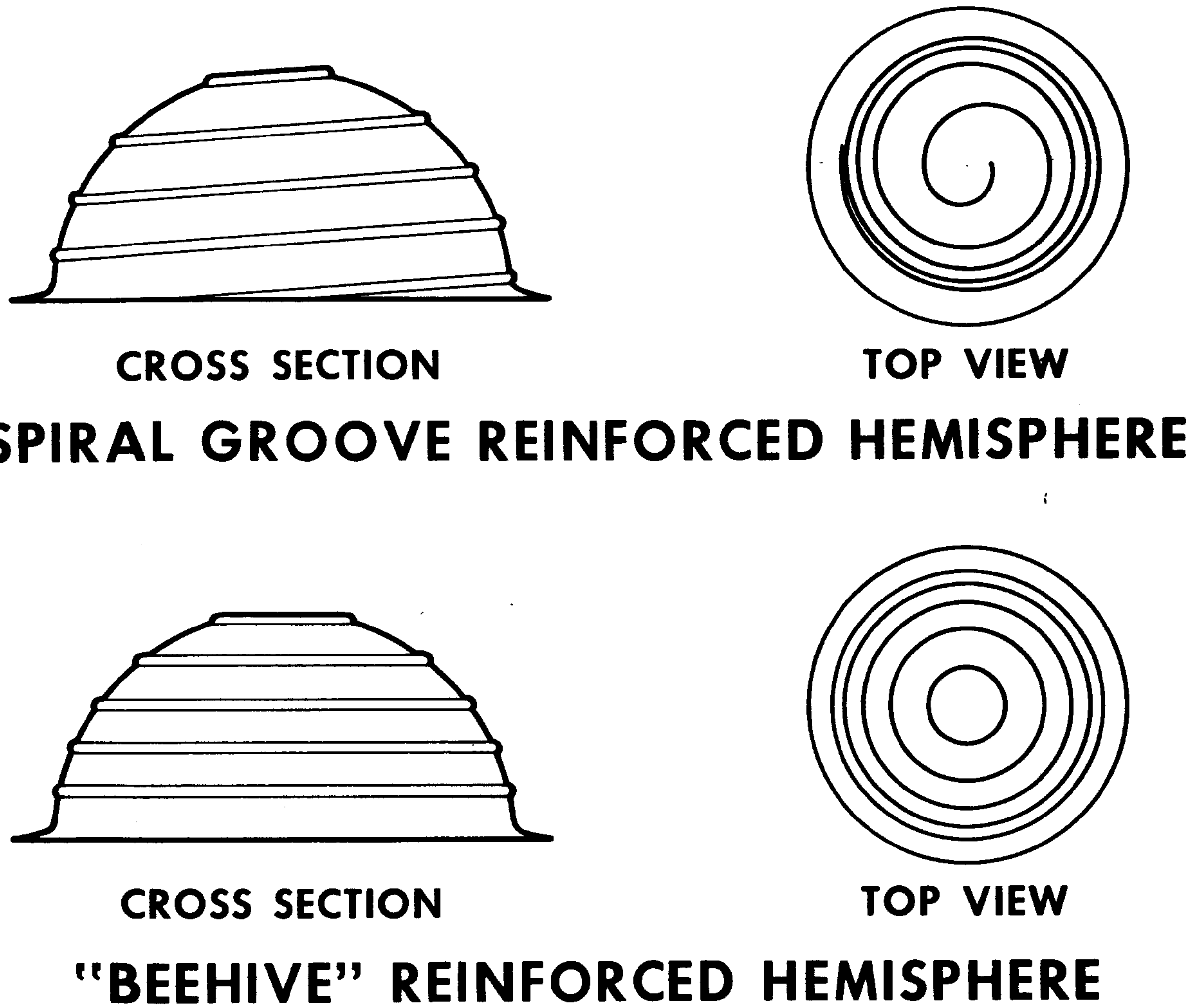
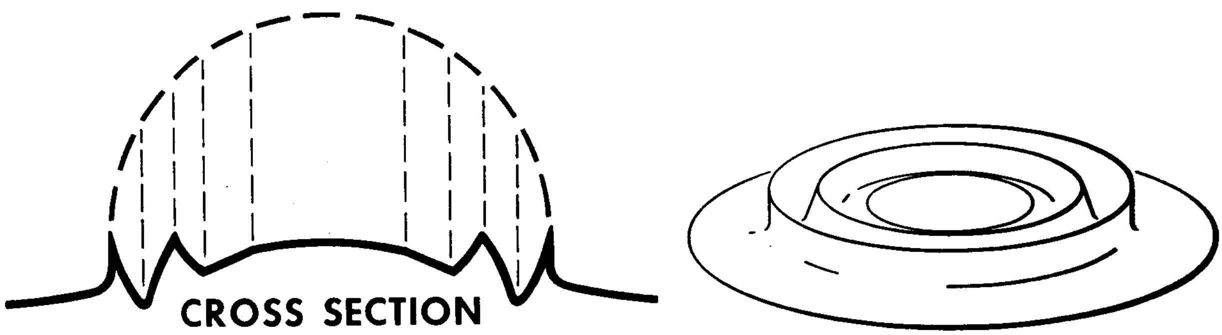


FIGURE 2. IN-HOUSE CONFIGURATIONS

CONCENTRIC CONVOLUTIONS



GRAPHICALLY COMPRESSED

FIGURE 3. IN-HOUSE CONFIGURATIONS

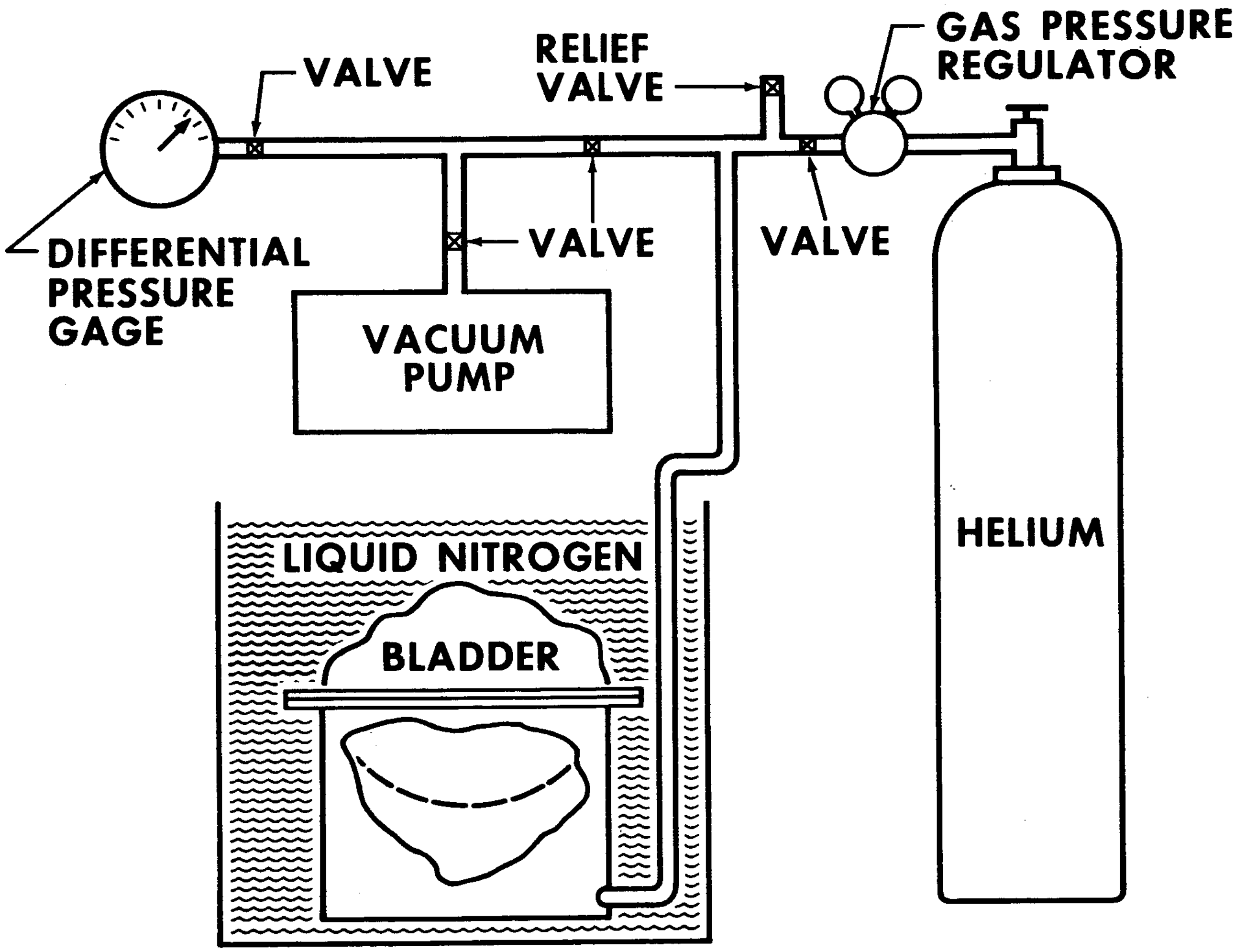


FIGURE 4. EXPULSION TEST APPARATUS

TABLE I

LIQUID OXYGEN IMPACT SENSITIVITY TEST DATA

NO.	MATERIAL	SOURCE	THICKNESS (INCHES)	RATING
1.	Aclar 22A, Poly-fluorochloroethylene	Allied Chemical Co.	.002	Satisfactory
2.	Aclar 22A, Poly-fluorochloroethylene	Allied Chemical Co.	.005	Satisfactory
3.	Aclar 22A, Poly-fluorochloroethylene	Allied Chemical Co.	.010	Satisfactory
4.	Aclar 22A, Poly-fluorochloroethylene	Allied Chemical Co.	.015	Satisfactory
5.	Aclar 22A, Poly-fluorochloroethylene	Allied Chemical Co.	.030	Satisfactory
6.	Armalon 97-001, Bleached	Du Pont	.011	Satisfactory
7.	Armalon 97-001A, Bleached	Du Pont	.011	Satisfactory
8.	Armalon 506A-112, FEP Teflon impregnated on Fiberglass	Du Pont	.006	Satisfactory
9.	Armalon PDX 7550 TFE Felt and FEP Film	Du Pont	.125	Satisfactory
10.	Monolamic Film, GT-903 FEP-Aluminum Composite	G. T. Schjeldahl Co.	.006	Satisfactory
11.	Tedlar, #100530, Polyvinyl Fluoride	Du Pont	.001	Unsatisfactory
12.	Tedlar, #200540, Polyvinyl Fluoride	Du Pont	.002	Unsatisfactory
13.	Tedlar, #200530WH white pigmented, Polyvinyl Fluoride	Du Pont	.002	Unsatisfactory
14.	H Film	Du Pont	.005	Unsatisfactory

TABLE I (CONTINUED)

LIQUID OXYGEN IMPACT SENSITIVITY TEST DATA

NO.	MATERIAL	SOURCE	THICKNESS (INCHES)	RATING
15.	HT-1, paper, #67011	Du Pont	.002	Unsatisfactory
16.	HT-1, paper, #67014	Du Pont	.010	Unsatisfactory
17.	HT-1, paper, #380369-3701	Du Pont	.030	Incomplete
18.	HT-1, Non-Woven Bat, 8 oz/yd^2	Du Pont	.125	Unsatisfactory
19.	ML Film	Du Pont	.002	Satisfactory
20.	ML Film	Du Pont	.004	Satisfactory
21.	ML Film	Du Pont	.008	Satisfactory
22.	Teflon, FEP, Spray Dispersion Film 856-200	Du Pont	.005	Satisfactory
23.	Kel-F, #8105 Film, Poly-fluoroethylene	Minnesota, Mining, & Manufacturing Co.	.005	Satisfactory
24.	Kel-F #8110 Film, Polyfluorochloro-ethylene	Minnesota, Mining, & Manufacturing Co.	.010	Satisfactory
25.	Kel-F #8202 Film, Polyfluorochloro-ethylene	Minnesota, Mining & Manufacturing Co.	.002	Satisfactory
26.	Kel-F #8205 Film, Polyfluorochloro-ethylene	Minnesota, Mining, & Manufacturing Co.	.005	Satisfactory
27.	Kel-F #2810 Film, Polyfluoroethylene	Minnesota, Mining, & Manufacturing Co.	.010	Satisfactory
28.	Kel-F, KX-633 Spray Dispersion Film, Polyfluoro-chloroethylene	Minnesota, Mining, & Manufacturing Co.	.003	Satisfactory

TABLE I (CONCLUDED)

LIQUID OXYGEN IMPACT SENSITIVITY TEST DATA

NO.	MATERIAL	SOURCE	THICKNESS (INCHES)	RATING
29.	Kel-F, #1380 Film, Polyfluoro-chloroethylene	Minnesota, Mining, & Manufacturing Co.	.005	Satisfactory
30.	Mylar	Du Pont	.002	Unsatisfactory
31.	Mylar, 400A°, aluminum vapor deposited one side	MSFC	.002	Unsatisfactory
32.	Mylar, 400A°, aluminum vapor deposited two sides	MSFC	.002	Unsatisfactory
33.	Mylar	Du Pont	.006	Unsatisfactory
34.	Mylar 400A°, aluminum vapor deposited one side	MSFC	.006	Unsatisfactory
35.	Mylar 400A°, aluminum vapor deposited two sides	MSFC	.006	Unsatisfactory
36.	Kynar, #6210-9E	Fluorocarbon Co.	.016	Unsatisfactory
37.	Kynar, #6210-9E	Fluorocarbon Co.	.025	Unsatisfactory
38.	Kynar	Connecticut Hard Rubber Co.	.002	Unsatisfactory
39.	Kynar	Connecticut Hard Rubber Co.	.025	Unsatisfactory

TABLE II

TYPICAL PROPERTIES OF PLASTIC FILMS

Material	Physical Properties		Mechanical Properties				
	Melting Point (°C)	Density @ 25°C (gms/cc)	Temperature	Thickness (mils)	Test Direction[1]	Tensile Strength (psi)	Elongation (Percent)
Aclar 22A	190	2.084	Room	2.0	Transverse	2,720	270
			LN_2	2.0	Transverse	12,137	4.4
			Room	2.0	Longitudinal	3,725	87
			LN_2	2.0	Longitudinal	18,745	5.2
Aclar 22 (Type A)	190	2.084	Room	5.0	Transverse	2,625	225
			LN_2	5.0	Transverse	13,300	5.6
			Room	5.0	Longitudinal	3,860	152
			LN_2	5.0	Longitudinal	—	6.0
Teflon FEP (Type A)	273	2.152	Room	5.0	Transverse	2,489	527
			LN_2	5.0	Transverse	12,377	6.7
			Room	5.0	Longitudinal	2,204	474
			LN_2	5.0	Longitudinal	12,404	7.0
Teflon TFE Felt (PDX 7550)	—[2]	1.50	Room	130	Transverse	1,596	190
			LN_2	130	Transverse	5,035	49
			Room	130	Longitudinal	1,128	210
			LN_2	130	Longitudinal	3,470	51.5
Teflon TFE Dispersion (No. 30)	—[2]	2.205	Room	3.5	Transverse	1,042	129
			LN_2	2.6	Transverse	3,577	2.8
			Room	3.1	Longitudinal	935	131
			LN_2	3.9	Longitudinal	5,128	3.5
Teflon FEP Dispersion (No. 856-200)	290	2.12	Room	2.8	Transverse	1,739	98
			LN_2	1.7	Transverse	10,941	6.5
			Room	2.5	Longitudinal	2,040	41
			LN_2	0.9	Longitudinal	6,500	4.0
Kel-F 82 (KX-8205) Dispersion	205	2.098	Room	6.0	Transverse	3,950	366
			LN_2	6.1	Transverse	14,045	6.0
			Room	5.7	Longitudinal	4,655	308
			LN_2	6.0	Longitudinal	15,070	10.3
Kel-F (KX-633) Dispersion	185	2.131	Room	4.7	Transverse	3,500	245
			LN_2	3.9	Transverse	10,115	7.5
			Room	3.3	Longitudinal	3,895	240
			LN_2	3.3	Longitudinal	12,275	9.0
Armalon[3] 97-001A (Unbleached)	290	2.15	Room	11.0	Transverse	5,218	80
			LN_2	11.0	Transverse	11,364	21
			Room	11.0	Longitudinal	5,218	80
			LN_2	11.0	Longitudinal	11,364	21

TABLE II (Concluded)

TYPICAL PROPERTIES OF PLASTIC FILMS

Material	Physical Properties		Mechanical Properties				
	Melting Point (°C)	Density @ 25°C (gms/cc)	Temperature	Thickness (mils)	Test Direction[1]	Tensile Strength (psi)	Elongation (Percent)
Armalon[3] (Unbleached) (No. 97-001)	275	2.14	Room	10.0	Transverse	5,040	61
			LN_2	10.0	Transverse	15,725	22
			Room	10.0	Longitudinal	5,040	61
			LN_2	10.0	Longitudinal	15,725	22
Armalon[3] (Bleached) (No. 97-001)	290	2.18	Room	10.0	Transverse	3,100	141
			LN_2	10.0	Transverse	14,200	25
			Room	10.0	Longitudinal	3,100	141
			LN_2	10.0	Longitudinal	14,200	25
Armalon[4] (No. 506A-112)	270	2.20	Room	5.8	Transverse	10,482	7
			LN_2	5.8	Transverse	19,375	10
			Room	5.8	Longitudinal	10,483	7
			LN_2	5.8	Longitudinal	19,375	10
Monolamic (GT-903)	265	2.09	Room	6.0	Transverse	3,183	7.5
			LN_2	8.0	Transverse	10,860	6.3
			Room	5.5	Longitudinal	3,990	42
			LN_2	6.3	Longitudinal	15,500	4.3
Teflon FEP Dispersion (Type XF-506)	260	2.141	Room	5.0	Transverse	3,600	451
			LN_2	5.0	Transverse	13,780	16.7
			Room	5.0	Longitudinal	4,120	440
			LN_2	5.0	Longitudinal	14,200	20.5
Teflon TFE[2] (#852-201)	—	2.21	Room	3.5	Random[5]	1,042	129
			LN_2	3.5	Random	10,841	2.8
Teflon FEP (#856-200)	>300	2.06	Room	2.6	Random[5]	1,561	197
			LN_2	2.6	Random	3,577	6.5
Kel-F (KX-8103)	248	2.156	Room	5.4	Transverse	4,040	345
			LN_2	5.4	Transverse	13,040	5.6
			Room	5.6	Longitudinal	4,860	248
			LN_2	5.1	Longitudinal	16,180	8.5

[1] Film test direction is defined relative to the direction of striations visible in the film.

[2] Sublimes/decomposes without melting.

[3] Armalon 97-001 A and Armalon 97-001 both consist of Teflon TFE fabric sandwiched between Teflon FEP film, however, Armalon 97-001A has a 1 mil, vapor-deposited aluminum film on surface.

[4] Armalon 506A-112 consists of fiberglass fabric sandwiched between Teflon FEP film.

[5] Material had no visible striations.

TABLE III

MECHANICAL PROPERTIES OF HEAT BONDED FLUOROCARBON

Material	Seal Method	Temperature	Thickness (mils)	BONDED FILM DATA		PARENT FILM DATA	
				Tensile Strength (psi)[1]	Elongation (%)[2]	Tensile Strength (psi)	Elongation (%)[2]
Aclar 22A	Impulse	Room	2.0	6,909	110.0	7,226	212.0
		LN_2	2.0	21,136	4.7	25,181	7.2
		Room	5.0	4,125	242.0	5,667	473.0
		LN_2	5.0	12,291	3.7	18,697	6.0
Teflon FEP (Type A)	Impulse	Room	2.0	2,600	247.0	3,333	414.0
		LN_2	2.0	13,050	6.8	12,600	15.3
Kel-F 81	Impulse	Room	5.0	4,260	192.0	6,436	489.0
		LN_2	5.0	14,607	6.3	16,103	6.3
Armalon 97-001	Impulse	Room	10.0	4,755	—[3]	4,200	85.0
		LN_2	10.0	14,212	—[3]	18,425	20.7

[1] Transverse test direction used for test specimens.
[2] Elongation values determined from cross head travel.
[3] Elongation values obtained from test were not representative of the laminate construction.

TABLE IV

MECHANICAL PROPERTIES OF MATERIALS USED BY COMMERCIAL BLADDER MANUFACTURERS

Manufacturer	Material Thickness (Inches)	Average Strength Rm Temp	Tensile (psi) LN_2 Temp	Average Elongation (Percent) Rm Temp	Average Elongation (Percent) LN_2 Temp	LOX Impact Test Rating
Company A	0.006	3,500	12,100	14	4.5	Satisfactory
Company B	0.006	2,944	15,500	848	4.3	Satisfactory
Company C	0.004-0.011	2,141	9,738	523	4.5	Satisfactory
Company D	0.007	4,123	12,275	210	5.0	Satisfactory
Company E	0.130	1,354	4,252	199	5.0	Satisfactory

TABLE V

EXPULSION TEST RESULTS

Number	Fabricator	Material	Method of Fabrication	Hemispherical Design	Thickness (mils)	Hemisphere Diameter (inches)	Preliminary Test Number Cycles In Water	Preliminary Test Number Cycles In Air	LN_2 Testing No. Cycles Before Failure	Test Observations
1	MSFC	Aluminum	Rolled Flat Sheet	Simple	15	10	0	1/2	1	2
2	MSFC	Teflon TFE	Extruded Flat Sheet	Simple	5	10	0	1	<1/2	3
3	MSFC	Teflon TFE #30	Spray Formed	Simple	3	10	0	0	<1/2	4
4	MSFC	Teflon TFE #30	Spray Formed	Simple	3	10	0	0	<1/2	4
5	MSFC	Teflon TFE #30	Spray Formed	Simple	3	10	0	3	<1/2	4
6	MSFC	Teflon TFE #852-201	Spray Formed	Simple	2	10	0	1	<1/2	3
7	MSFC	Teflon TFE #852-201	Spray Formed	Simple	2	10	0	3	<1/2	4
8	MSFC	Teflon TFE #852-201	Spray Formed	Simple	2	10	0	2	1	2
9	MSFC	Teflon FEP #856-200	Spray Formed	Simple	2	10	0	1	<1/2	2
10	MSFC	Teflon FEP #856-200	Spray Formed	Simple	2	10	0	0	<1/2	3
11	MSFC	Teflon FEP #856-200	Spray Formed	Simple	3	10	0	1	<1/2	3
12	MSFC	Teflon FEP #856-200	Spray Formed	Simple	5	10	0	1	<1/2	3
13	MSFC	Aclar 22A	Thermo-Formed	Simple	2	5	0	20	1	2
14	MSFC	Aclar 22A	Thermo-Formed	Simple	2	5	0	2	<1/2	2
15	MSFC	Aclar 22A	Thermo-Formed	Simple	2	5	0	3	<1/2	3
16	MSFC	Aclar 22A	Thermo-Formed	Simple	2	5	0	2-1/2	<1/2	3

TABLE V (CONTINUED)

Number	Fabricator	Material	Method of Fabrication	Hemispherical Design	Thickness (mils)	Hemisphere Diameter (inches)	Preliminary Test Number Cycles In		LN_2 Testing No. Cycles Before Failure	Test Observations
							Water	Air		
17	MSFC	Aclar 22A	Thermo-Formed	Simple	2	5	0	1/2	< 1/2	4
18	MSFC	Aclar 22A	Thermo-Formed	Simple	5	5	0	2	< 1/2	4
19	MSFC	Aclar 22A	Thermo-Formed	Simple	5	5	0	1/2	< 1/2	4
20	MSFC	Aclar 22A	Thermo-Formed	Simple	5	5	0	1/2	< 1/2	4
21	MSFC	Aclar 22A	Thermo-Formed	Simple	5	5	0	90	1	2
22	MSFC	Aclar 22A	Heat Sealed Gores	Simple	5	5	<1	0	1	2
23	MSFC	Aclar 22A	Heat Sealed Gores	Simple	5	5	<1	0	1	2
24	MSFC	Kel-F 81, Disp. KX 633	Spray Formed	Simple	6	10	<1	1	1	4
25	MSFC	Kel-F 81, Disp. KX 633	Spray Formed	Simple	5	10	0	3	1	2
26	MSFC	Aclar 22A	Thermo-Formed	Beehive	5	5	1	3	1-1/2	2
27	MSFC	Aclar 22A	Thermo-Formed	Beehive	5	5	0	3	1/2	2
28	MSFC	Aclar 22A	Thermo-Formed	Beehive	5	5	3	3	1/2	2
29	MSFC	Teflon FEP	Thermo-Formed	"S" Curve	5	10	0	25	1-1/2	4
30	MSFC	Teflon FEP Disp #856-200	Spray Formed, Modulated	Simple	3-10	10	0	1/2	1/2	2
31	Company E	Teflon FEP Film & Teflon TFE Felt	Thermo-Formed Laminate	Simple	170	10	0	3	3-1/2	3
32	Company E	Teflon FEP Film & Teflon TFE Felt	Thermo-Formed Laminate	Simple	170	10	1	1/2	1	3
33	Company E	Teflon FEP Film & Teflon TFE Felt	Thermo-Formed Laminate	Simple	170	10	0	1/2	1	3

TABLE V (CONCLUDED)

Number	Fabricator	Material	Method of Fabrication	Hemispherical Design	Thickness (mils)	Hemisphere Diameter (inches)	Preliminary Test Number Cycles In Water	Preliminary Test Number Cycles In Air	LN_2 Testing No. Cycles Before Failure	Test Observations
34	Company C	Teflon FEP & Aluminum Powder	Spray Formed, Gradated	Simple	4.0-10.6	10	3	1	<1/2	[3]
35	Company C	Teflon FEP & Aluminum Powder	Spray Formed, Gradated	Simple	3.9-10.6	10	0	1/2	<1/2	[3]
36	Company C	Teflon FEP & Aluminum Powder	Spray Formed, Gradated	Simple	3.6-10.4	10	0	1/2	<1/2	[3]
37	Company D	Teflon FEP & Aluminum Sheet	Spun Formed Al & Spray Cast Teflon	Simple	6	10	0	2	<1/2	[4]
38	Company D	Teflon FEP & Aluminum Sheet	Spun Formed Al & Spray Cast Teflon	Simple	6	10	0	1	<1/2	[4]
39	Company D	Teflon FEP & Aluminum Sheet	Spun Formed Al & Spray Cast Teflon	Simple	6	10	1	1/2	<1/2	[4]
40	Company B	Teflon FEP & Aluminum	Spray Formed	Simple	6	10	0	1/2	<1/2	[4]
41	Company B	Teflon FEP & Aluminum	Spray Formed	Simple	6	10	2	1/2	<1/2	[4]
42	Company B	Teflon FEP & Aluminum	Spray Formed	Simple	6	10	1	1/2	<1/2	[3]
43	Company A	Kel-F 81 Disp. KX 633	Spray Formed	Simple	6	10	0	1/2	<1/2	[3]
44	Company A	Kel-F 81 Disp. KX 633	Spray Formed	Simple	6	10	1	1/2	<1/2	[4]
45	Company A	Kel-F 81 Disp. KX 633	Spray Formed	Simple	3	10	0	1/2	<1/2	[4]
46	MSFC	Aclar 22A	Thermo-Formed	Spiral Groove Reinforced	5	5	1	3	0	[3]
47	MSFC	Aclar 22A	Thermo-Formed	Spiral Groove Reinforced	5	5	1	3	[1]	[2]
48	MSFC	Aclar 22A	Thermo-Formed	Spiral Groove Reinforced	5	5	1	3	[1]	[3]
49	MSFC	Aclar 22A	Thermo-Formed	Spiral Groove Reinforced	5	5	1	3	[1]	[3]

Footnotes:

[1] Not tested, failed at room temperature.
[2] Multiple leaks from pinholes at three corner folds.
[3] Pinholes and small tears at three corner folds.
[4] Split and ruptured.

REFERENCES

1. Hunter, B. J., et al., "Expulsion Bladders for Cryogenic Fluids," Advances in Cryogenic Engineering, 7, 155-162 (1962).

2. Pope, D. H. and Killian, W. R., "Positive Expulsion of Cryogenic Liquids," Beech Engineering Report No. 16180, Contract NAS9-513, June 1963.

3. Krivetsky, A., et al., "Research on Zero-Gravity Expulsion Techniques," Bell Aerosystems Report No. 7129-933003, Contract NASr-44, March 1962.

CODE OF DIAPHRAGM MANUFACTURES

Company A =	Minnesota Mining and Manufacturing Company 900 Bush Avenue St. Paul, Minnesota 55106
Company B =	Joclin Manufacturing Company Lufberry Avenue Wallingford, Conneticut 06493
Company C =	Dielectric Corporation Allen Boulevard Farmingdale, Long Island, N. Y. 11735
Company D =	Swedlow Incorporated 6938 Bandini Boulevard Los Angeles, California 90022
Company E =	Boeing Company P. O. Box 3707 Seattle, Washington 98124

October 12, 1964 APPROVAL TM X-53005

PRELIMINARY STUDIES OF LIQUID OXYGEN EXPULSION BLADDERS

By V. L. Chinberg and H. Perkins

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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