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Technical Report No. 32-865

ALPS Generant Tank and Cell Assembly

O. F. Keller
L. R. Toth

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

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CONTENTS

I. Introduction 1
A. Design Criteria 4
B. Types of Cells Considered 4
1. Balloon-Type Cell (or Bladder) 4
2. Diaphragm-Type Cell (or Bladder) 6
C. Evaluation of Characteristics 6
D. Development Approach 6

II. Development of Transparent Model Generant Tank and Initial Bladder Tests 8
A. Purpose of the Transparent Model Tank 8
B. Description of Test Tank 8
C. Tests 10
D. Determination of Expulsion Efficiency 14
E. Conclusions—Transparent Model Generant Tank 15

III. Development of Water Expulsion Test Facility 15
A. Purpose 15
B. Description of Equipment 15
C. Tests 18
D. Operational Problems 18
E. Conclusions—Water Expulsion Test Facility 18

IV. Development of Heavyweight 4130 Generant Tank 19
A. Basic Concept of the Heavyweight Tank 19
B. Design Criteria and Description of Test Specimen 19
C. Fabrication and Assembly of Tank and Bladder 20
D. Tests 20
E. Conclusions—Heavyweight Generant Tank 21

V. Development of Flight-type Titanium Generant Tank with Diaphragm-type Bladder 22
A. Basic Concept of the Flight-Type Tank 22
B. Design Criteria and Preliminary Development 22
1. Preliminary Welding Development 22
2. Diaphragm Development and Design Selection 26
3. Barrier Plate and Outlet Boss 30
4. Mounting and Handling 30

CONTENTS (Cont'd)

C. Fabrication of Flight-Type Tank 30
1. Tooling 30
2. Welding Parameters 36
3. Assembly Problems 37
4. Cleaning 38
5. Special Problems 38
D. Test Program 39
1. Proof Test 39
2. Aspiration Test 39
3. Expulsion Tests 40
4. Sterilization 40
5. Other Tests 40
E. Conclusion—Flight-Type Generant Tank 41

VI. Overall Program Conclusions 41
A. Internal Bladder Summary Evaluation 41
1. Diaphragm-Type 41
2. Balloon-Type 42
B. Alternate Design 42

References 42

TABLES

1. Component design data sheet, generant tank and cell 3
2. Tabulation of bladder characteristics for ALPS generant tank 7
3. Expulsion efficiencies of fully- and partially-ribbed diaphragm-type bladders at expulsion pressures up to 100 psig 12
4. Initial welding parameters and maximum temperatures, with water-cooled chill rings 24
5. ALPS generant tank diaphragm extrusion tests 28
6. Results of permeability and compatibility tests of polymeric materials and hydrazine 29
7. Welding parameters 33

FIGURES

1. Photographic mock-up of the advanced liquid propulsion system . . . 2
2. Cross section of the ALPS generant tank and cell assembly 4
3. Balloon-type cell (or bladder) assembled with heavyweight outlet flange 5
4. Random folding pattern of balloon-type bladder at point of propellant depletion 5

FIGURES (Cont)

5. Diaphragm-type cell (or bladder) bonded to back-up ring 6
6. Diaphragm-type bladder (fully ribbed) for use in transparent generant tank 6
7. Diaphragm-type bladder assembled in transparent model generant tank in upright position 9
8. Balloon-type bladder assembled in transparent model generant tank in upright position 10
9. Diaphragm-type bladder (no ribs) for use in transparent generant tank 10
10. Balloon-type bladder (or cell) used in transparent generant tank expulsion tests with *Ranger*-type adapter attachment 10
11. Early outlet baffle design used with transparent generant tank 11
12. Early outlet fitting design used with transparent generant tank 11
13. Small outlet baffle or barrier (center) used with transparent generant tank 11
14. Fully ribbed diaphragm-type bladder in transparent model generant tank—water droplets remaining after one aspiration cycle 12
15. Expulsion efficiencies of fully ribbed diaphragm-type and balloon-type bladders at various expulsion pressures up to 100 psig 13
16. Diaphragm-type bladder (partially ribbed) for use in transparent generant tank 14
17. Expulsion efficiency of smooth diaphragm-type bladder (no ribs) at various expulsion pressures up to 100 psig, upright position 14
18. Water expulsion test facility 15
19. Control panel and instrumentation for operating water expulsion test facility 16
20. Water expulsion test facility schematic 17
21. Heavyweight (4130 steel) generant tank with balloon-type bladder enclosed in upright position 18
22. Heavyweight (4130 steel) generant tank installed in *Mariner* 1966 prototype subsystem 19
23. Outlet fitting for heavyweight (4130 steel) generant tank, showing internal mast for use with balloon-type bladder 20
24. Failure of balloon-type bladder at the splice 21
25. Flight-type titanium generant tank with integral elastomeric diaphragm-type bladder 22
26. Theoretical stress distribution at girth weld in axial direction, psi $\times 10^3$ 23
27. Thermocouple installation in titanium weld-feasibility test tank 23

FIGURES (Cont'd)

28. Titanium weld-feasibility test tank with chill rings installed and mounted in welding rig 24
29. Maximum temperature vs distance from weld for titanium weld-feasibility test tank 24
30. Section through girth-weld area of flight-type titanium generant tank, with welding lip 25
31. Section through girth-weld area of flight-type titanium generant tank, without welding lip 25
32. Section through girth-weld area of S/N 001 flight-type titanium generant tank 26
33. Test setup for performing diaphragm lip test at Pressure Systems, Inc. 26
34. Diaphragm-lip test configurations 26
35. Diaphragm load per lineal in. vs diaphragm deflection: Pressure Systems, Inc. data 27
36. Flight-type generant tank outlet barrier 27
37. Test fixture for extrusion testing of diaphragm-type bladder samples 27
38. Silicone extrusion test sample after test with barrier having 0.040-in. D holes 27
39. LS-53 extrusion test sample after test with barrier having 0.040-in. D holes 28
40. Butyl extrusion test sample after test with barrier having 0.040-in. D holes 28
41. Flight-type titanium generant tank mounted in protective wood cradle, upright position, for water-expulsion testing 31
42. Experimental girth-weld setup of first flight-type titanium generant tank 31
43. Thermocouple leads and temperature-sensitive tape on back-up ring of S/N 001 titanium generant tank, as viewed through access hole 32
44. S/N 001 experimental flight-type titanium generant tank after completion of girth weld 32
45. Circulating-water system for water-cooled chill rings for welding flight-type generant tanks 32
46. Test setup for leak checking diaphragm-type bladder prior to assembly in generant tank 38
47. Damage to ethylene propylene diaphragm after inadvertent immersion in trichloroethylene solution 39
48. Expulsion efficiency of the ribbed-diaphragm-type ALPS generant cell 40

ABSTRACT

A development program was carried out to determine the relative advantages and disadvantages of diaphragm-type bladders as opposed to balloon-type bladders for expulsion of hydrazine to an Advanced Liquid Propulsion System (ALPS). Bladder materials used were limited to butyl and ethylene propylene elastomers. Ribs, molded integrally with the diaphragm-type bladders, were used to increase expulsion efficiencies at the higher expulsion pressures. Water expulsion tests were made at pressures up to 100 psig using a transparent Plexiglas tank as a full-scale working model to simulate the flight-type generant tank. Two heavy-weight AISI 4130 steel generant tanks were fabricated for testing as part of a *Mariner* 1966 prototype subsystem utilizing a 50-lb thrust rocket. Expulsion pressures used were generally limited to 1300 psig. One test using hydrazine was conducted to the point of propellant depletion. Three flight-type 6AL-4V titanium generant tanks were fabricated for testing in the ALPS pressurization subsystem. Expulsion pressures were again generally limited to 1300 psig. A detailed description of the fabrication procedure for the flight-type titanium generant tank includes: a discussion of the welding parameters, cooling devices used during welding, the method used to attach the elastomeric diaphragm to the generant tank wall prior to the final girth weld operation, and the procedure used in replacing the diaphragm in the tank.

I. INTRODUCTION

The basic purpose of the Advanced Liquid Propulsion System (ALPS) generant tank and cell development program has been to provide a suitable pressure vessel for long-term high-pressure space-storage (periods up to 1 yr or longer) of a liquid generant (anhydrous hydrazine) pressurized by a gaseous pressurant, e.g., nitrogen, and to provide a suitable expulsion device for expelling the hydrazine under zero g conditions. To accomplish the latter, an elastomeric diaphragm-type cell has been developed which acts as a positive expulsion device and as a barrier between the liquid hydrazine and the nitrogen gas to avoid entrainment of gas bubbles in the liquid generant.

These developments were accomplished as part of the Jet Propulsion Laboratory ALPS program (Ref. 1) which was initiated to do advanced development work on a space-storable liquid rocket system and its component parts. A photographic mock-up of the ALPS system, including the flight-type generant tank, is shown in Fig. 1.

In the ALPS system, the generant (hydrazine) which is decomposed to pressurize the propellant tank is stored in the generant tank and cell assembly. A "blowdown" mode of operation is used to expel the generant. This means that the tank is partially filled with generant and

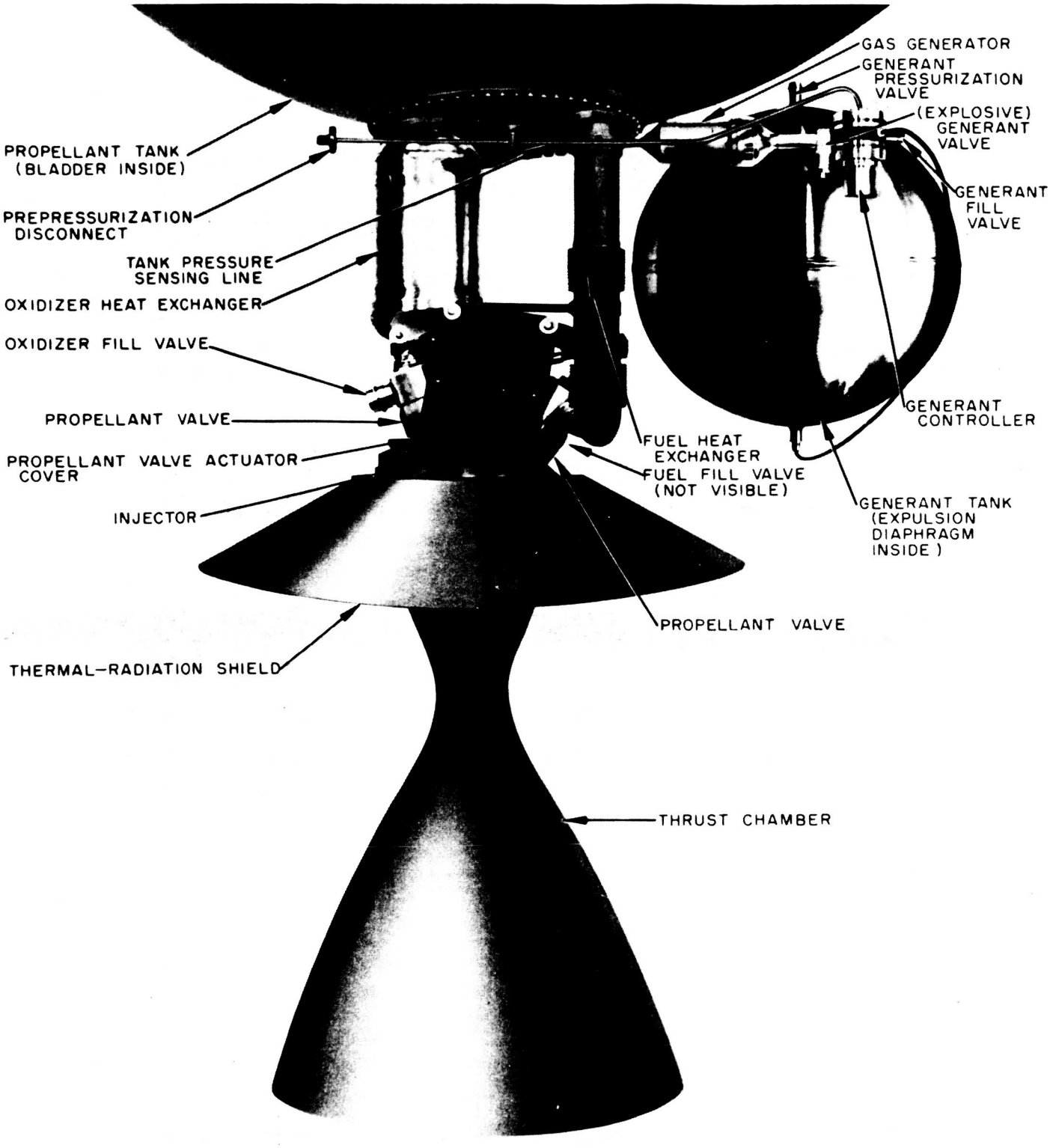


Fig. 1. Photographic mock-up of the advanced liquid propulsion system

Table 1. Component design data sheet, generant tank and cell

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California

COMPONENT DESIGN DATA SHEET

Schematic No. D9116000-16-17
Page ____ of ____ Pages
Date ____
Job No. ____
Prepared by ____
Approved by ____

Preliminary ☐ Final ☒

Revision Date OCTOBER 20, 1965
Supersedes sheet dated July 21, 1961

DESCRIPTION

Name Generant Tank and Cell Assy. No. J9116270 "H"
Manufacturer ____
Spacecraft Model ____ No. Used Per System 1 Total No. Required ____
Length 24 in. Width 17 in. Height 17 in. Weight 21 lbs.
Estimated Costs ____ Actual Cost ____

FUNCTION

Function After a specified storage time, to expel liquid generant to the gas generator regardless of tank orientation. The elastomeric diaphragm to function as a barrier between hydrazine and pressurizing gas.

GENERAL

Working Fluids hydrazine and gaseous nitrogen
Fittings Inlet Size 1/4 Type Special fitting
Outlet Size 1/4 Type Special fitting
Actuation Size ____ Type ____
____ Size ____ Type ____
____ Size ____ Type ____
Valve Position Normally ____
Corrosion Resistance Internal Water and hydrazine
External N_2O_4, N_2H_4 fumes, water and salt (NaCl)
Adjustments ____
Mounting Requirements SK 6-8-63-100
General Specifications 30265
Test Specifications Qualification 31161 Acceptance 31162

PERFORMANCE

Inlet Working Pressure Max. 1500 psig, Nominal 1300 psig, Min. 0 psig
Outlet Working Pressure Max. 1500 psig, Nominal 1300 psig, Min. 0 psig
Test Pressures INLET Proof 2250 psig, Burst 3750 psig, Leak 1500 psig
OUTLET Proof 2250 psig, Burst 3750 psig, Leak 1500 psig
____ Proof ____ psig, Burst ____ psig, Leak ____ psig
Allowable Leakage Specified Internal (4) External (3)
Rated Flow 0.1384 lbs/sec at 485 psia. Max Δ P at Rated Flow 1.5 psi
Temperature Range Amb. 35-120 °F. Working Fluid (5) °F.

ACTUATION

Open's Clos'g
☐ ☐ Actuation Time Opening ____ sec. Closing ____ sec.
☐ ☐ Manual - Stroke Nom. ____ in. Max. ____ in. Min. ____ in.
☐ ☐ Pneumatic Press. - Normal ____ psig, Max. ____ psig, Min. ____ psig
☐ ☐ Hydraulic Press. - Normal ____ psig, Max. ____ psig, Min. ____ psig
☐ ☐ Electrical
Voltage Normal ____ Maximum ____ Minimum ____
Amperage Normal ____ Maximum ____ Minimum ____
☐ ☐ Working Fluid Cracking Pressure ____ psi
Fully Open Pressure ____ psi
Fully Closed Pressure ____ psi
☐ ☐ Spring Loaded Stroke Nom. ____ in. Max. ____ in. Min. ____ in.

MATERIALS

Body 6AL-4V TITANIUM Bar Stock ☐ Casting ☐ Forging ☒
Operating Parts ETHYLENE PROPYLENE COMPOUND (8)
Seats ____ Seals EPR E 515-8
Gaskets ____ Springs ____
Lubricants ____

NOTES

(1) Internal volume of sphere 2350 cubic inches (16-1/2 ID)
(2) Volume of hydrazine 1227 cubic inches
(3) External leakage not to exceed ten standard cubic centimeters of helium gas per year at 1500 psig with 1×10^{-3} mm Hg ambient pressure
(4) Internal leakage not to exceed one standard cubic centimeter per minute of helium gas total for entire cell. Test at one (1) psig.
(5) LIQUID: 35 to 120°F GAS: -50 to 150°F
(6) Pressure will be equal within 0.5 psi on both sides of cell wall, except when a vacuum is obtained inside during filling - then 14.7 psi differential will exist.
(7) Sterilization - preliminary requirement 300°F for 36 hours duration per cycle. Total of six (6) consecutive cycles
(8) Stillman Rubber Company compound SR 722-70
Parker Seal Company compound E515-8

JPL 11-017

then pressurized with gas which expands as the liquid is withdrawn. No gas is added during the withdrawal process; therefore, the tank pressure decays from an initial maximum of 1500 psig down to a final minimum of 500 psig.

A. Design Criteria

The ALPS generant tank is spherical in shape, approximately 17 in. D, and contains an elastomeric diaphragm-type cell for expelling generant to the ALPS system regardless of generant tank orientation.

A component design data sheet, Table 1, specifies the pertinent design criteria for the ALPS generant tank and cell assembly. Figure 2, a cross-sectional view of the final ALPS generant tank and cell assembly design, illustrates some of the major features such as the inlet and outlet boss configurations.

B. Types of Cells Considered

Basically, two types of generant cells have been given detailed consideration: the balloon-type cell (or bladder) and the diaphragm-type cell (or bladder). In both cases, it was anticipated that an elastomeric material would be suitable for this requirement as specified in the component design data sheet. No attempt was made to utilize teflon or metallic bladders; however, these may be used later since they are being developed for the main propellant tank in another part of the ALPS program.

1. Balloon-Type Cell (or Bladder)

The balloon-type bladder, Fig. 3, consists of two hemispheres of elastomeric material which have been bonded, or spliced, together at the girth. A metallic flange, used for mounting the balloon-type bladder to the generant

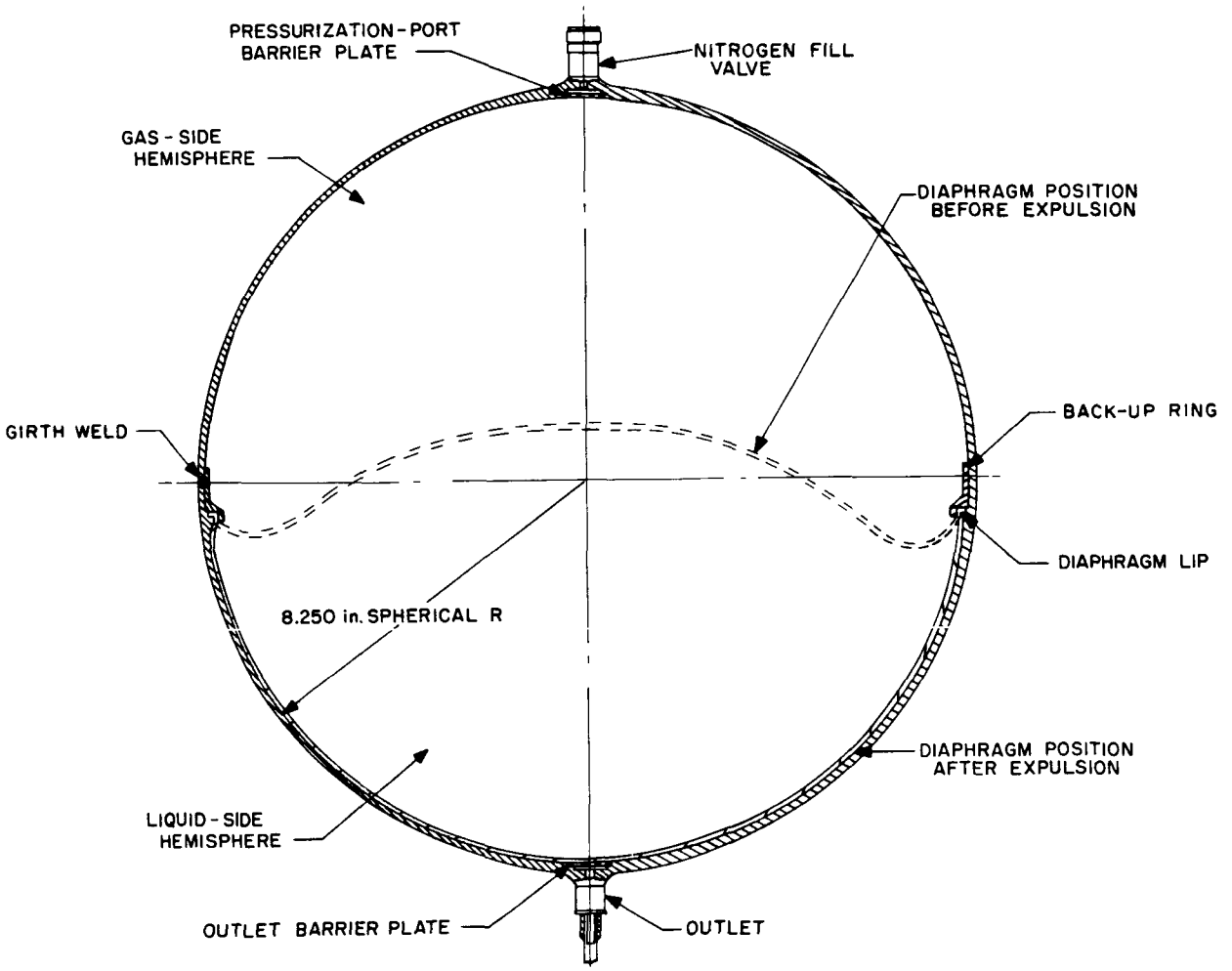


Fig. 2. Cross section of the ALPS generant tank and cell assembly

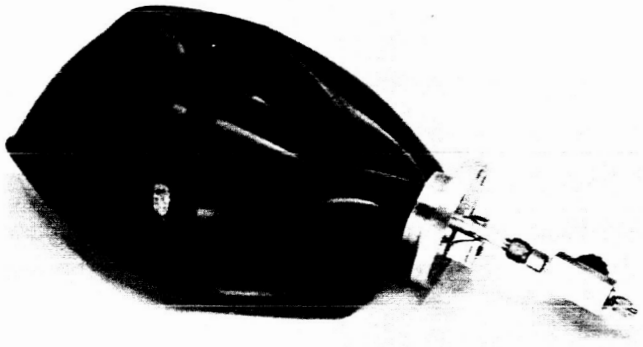


Fig. 3. Balloon-type cell (or bladder) assembled with heavyweight outlet flange

tank outlet, is attached to one of the hemispheres by means of a clamping ring.

One of the major disadvantages of the balloon-type bladder is the questionable reliability of the bonded, or spliced, girth joint because of incompatibility of the bonding material with hydrazine. Also, during the expulsion cycle the balloon-type bladder tends to fold in a random manner, as shown in Fig. 4, depending somewhat on the generant tank orientation, and has at times caused discontinuities of propellant flow near the point of propellant depletion. Such flow discontinuities could cause adverse effects in gas generator operation and could contribute to a system malfunction.

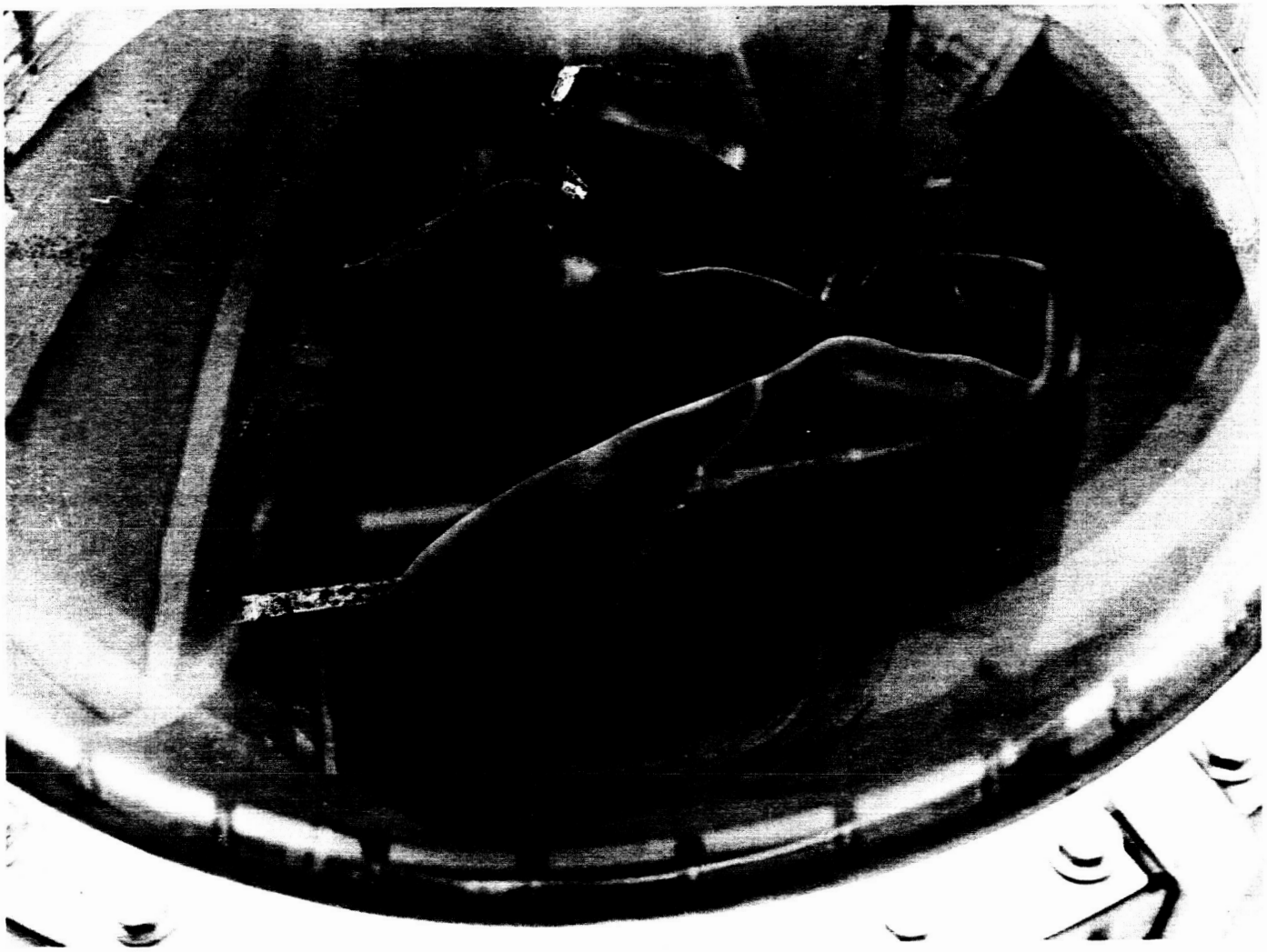


Fig. 4. Random folding pattern of balloon-type bladder at point of propellant depletion

In addition, the severe folding of the balloon-type bladder at the point of propellant depletion causes excessive stretch in the external portions of the bladder wall on the outer surface of the fold. If this stretch exceeds more than 200%, according to the vendor, failure of the bladder could occur.

2. Diaphragm-Type Cell (or Bladder)

The diaphragm-type bladder, Fig. 5 and 6, is hemispherical in shape and, in the final design, has an interrupted rib pattern molded integrally with the wall. These ribs improve expulsion efficiency at the higher expulsion pressures and tend to maintain uniform propellant flow up to the point of propellant depletion.

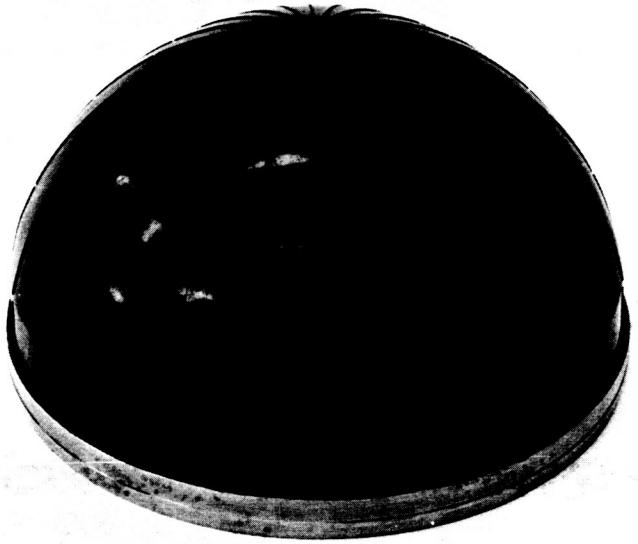


Fig. 5. Diaphragm-type cell (or bladder) bonded to back-up ring

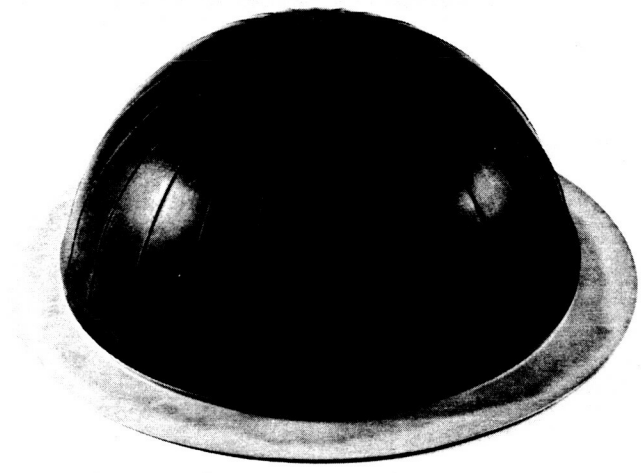


Fig. 6. Diaphragm-type bladder (fully ribbed) for use in transparent generant tank

The diaphragm terminates at its periphery with an O ring-type lip which is used as a seal between the gas-side and liquid-side hemispheres of the generant tank. The diaphragm bonded to the back-up ring, as shown in Fig. 5, aids assembly of the generant tank hemispheres.

C. Evaluation of Characteristics

In order to judge advantages and disadvantages of the diaphragm-type bladder as opposed to the balloon-type bladder, a tabulation of estimated characteristics of these two types of generant tank bladders has been compiled in Table 2.

Advantages of the diaphragm-type bladder include: smoothness of propellant flow; good repeatability of operation regardless of generant tank orientation; no severe diaphragm folds, particularly at the point of propellant depletion; good scalability, up or down by an order of magnitude; and relative ease of fabrication.

Advantages of the balloon-type bladder include the ability to replace a defective bladder using a bolted connection; however, fabrication of large one-piece balloon-type bladders is extremely difficult during the molding operation because of the complicated coring requirements.

D. Development Approach

In order to establish the basic tank assembly configuration, the generant tank development program was divided into the following major phases:

1. Transparent model tank
2. Heavyweight tank
3. Flight-type tank

To evaluate the advantages and disadvantages of the diaphragm-type bladder versus the balloon-type bladder, a transparent working-model of the generant tank was employed so that various experimental bladder expulsion characteristics could be demonstrated. The liquid generant was simulated using distilled water and expulsion pressures were limited to 100 psig.

During the next phase a heavyweight tank was utilized so that expulsion pressures could be increased to the

Table 2. Tabulation of bladder characteristics for ALPS generant tank[a]

Criterion	Type A diaphragm-type		Type B balloon-type		Type C other-type[b]	
	Metallic	Non-metallic	Metallic	Non-metallic	Metallic	Non-metallic
Component reliability	2	4	1.5	3	2	2
Functional simplicity	2	3	1	3	0	0
Number of parts	3	3	2	2	2	2
Number of moving parts	4	4	4	4	3	3
Number of non-moving parts	3	3	2	2	2	2
Number of seals	0	4	0	3	2	2
Number of static seals	0	4	0	3	0	0
Number of dynamic seals	4	4	4	4	0	0
Inherent friction	2.5	4	2.5	4	2	3
Inherent wear	1	3	1	3	2	3
Lubrication requirements	0	0	0	3	0	0
Filtration requirements	3	3	3	3	0	0
Fabricational simplicity	2	3	2	3	2	2
Weldability of final assembly	3	2	3	2	3	2
Heat treatment requirements	2	3	2	3	2	2
Adjustments	2	4	2	3	2	3
Lubrication servicing	2	4	2	3	2	3
Special tooling	2	3	2	3	2	2
Replacement of parts and/or seals	2	3	2	3	3	3
Comparative size and weight	3	3	3	2	1	1
Comparative cost	2	3	2	3	3	3
Scheduling	2	3	2	3	3	3
Performance capability	2	4	2	3	2	3
Expulsion efficiency (ribbed bladder)	3	4	2	4	2	2
Expulsion efficiency (non-ribbed bladder)	0	3	0	3	0	0
Repeatability	3	4	2	2	3	3
Internal leakage	2	3	2	3	2	3
External leakage	4	4	3	3	3	3
Uniformity of flow	3	4	2	2	3	3
Space environment operation	4	3	4	3	4	3
High temperature performance	4	3	4	3	4	3
Low temperature performance	4	3	4	3	4	3
High pressure performance	3	3	3	3	2	2
Low pressure performance	2	4	2	4	2	3
Static acceleration testing	0	0	0	0	0	0
Vibration testing	0	0	0	0	0	0
Shock testing	0	0	0	0	0	0
System compatibility	4	4	3	3	3	3
Interfacial connections	4	4	4	4	4	4
Functional response	3	4	3	4	3	3
Smoothness of flow	3	4	2	3	2	3
Generant tank orientation	4	4	3	3	3	3
Sterilization requirements	4	3	4	3	4	3
Materials compatibility	4	3	4	3	4	3
Generant cell and hydrazine	4	3	4	3	4	3
Generant cell permeation by hydrazine	4	2	4	2	4	2

[a] Scoring characteristics—(0) not considered, (1) poor, (2) fair or not clearly defined, (3) good, (4) excellent. Total possible score = 54 × 4 = 216.
[b] Bellows and pistons included.

Table 2. Tabulation of bladder characteristics for ALPS generant tank[a] (cont'd)

Criterion	Type A diaphragm-type		Type B balloon-type		Type C other-type[b]	
	Metallic	Non-metallic	Metallic	Non-metallic	Metallic	Non-metallic
Bonded joints and splices with hydrazine	0	1	0	1	0	1
Generant tank and hydrazine	3	3	3	3	3	3
Generant tank and nitrogen tetroxide	0	0	0	0	0	0
Cleaning procedure	2	3	2	3	2	3
Growth potential	4	4	2	3	2	3
Scalability	4	4	2	2	2	2
Performance improvement	3	3	2	2	2	2
Severity of folding	4	4	2	2	2	2
Total	134.5	165	117	145	113	115
Rating, %	62.2	76.3	54.1	67.1	52.4	53.2

[a] Scoring characteristics—(0) not considered, (1) poor, (2) fair or not clearly defined, (3) good, (4) excellent. Total possible score = 54 × 4 = 216.
[b] Bellows and pistons included.

working range of 1500 psig. This tank was also used for hot firing tests of a *Mariner* 1966 prototype subsystem utilizing a 50-lb thrust rocket.

Prior to fabricating a flight-type tank, preliminary fabricational development was carried out to gain experience with the titanium welding process as related to temperature control of the titanium pressure vessel during the welding operation. This information was required in order to devise a suitable method for attaching the diaphragm-type bladder to the generant tank wall (Fig. 2 and Ref. 2). After assimilating information generated during the above development program, the best features were then incorporated into a flight-type titanium tank. Three tank assemblies were completed and tested.

II. DEVELOPMENT OF TRANSPARENT MODEL GENERANT TANK AND INITIAL BLADDER TESTS

A. Purpose of the Transparent Model Tank

A transparent model generant tank was constructed of Plexiglas, to permit visual observation and evaluation of the expulsion characteristics of diaphragm-type bladders as opposed to balloon-type bladders.

The basic function was to serve as a full-scale working model of the flight-type generant tank. The inside diameters of both the model tank and the flight-type tank were essentially identical. The model tank was of polished Plexiglas to allow a high degree of transparency. Maximum working pressure was limited to 100 psig and proof pressure was specified as 200 psig. In addition, the transparent generant tank was constructed so as to be adaptable to testing with both balloon-type and diaphragm-type bladders. The expulsion test fluid was limited to distilled water, methylene blue chloride being added on occasion to aid visual observation.

Expulsion tests at pressures up to 100 psig were carried out with the transparent generant tank in an attempt to evaluate trends that might point the way to achieving improved expulsion characteristics at higher expulsion pressures.

Figure 7 illustrates a smooth diaphragm-type bladder assembled in the transparent model tank and Fig. 8 a balloon-type bladder assembled in the same tank.

B. Description of Test Tank

Because of the uncertain structural properties of Plexiglas, the transparent generant tank was designed some-

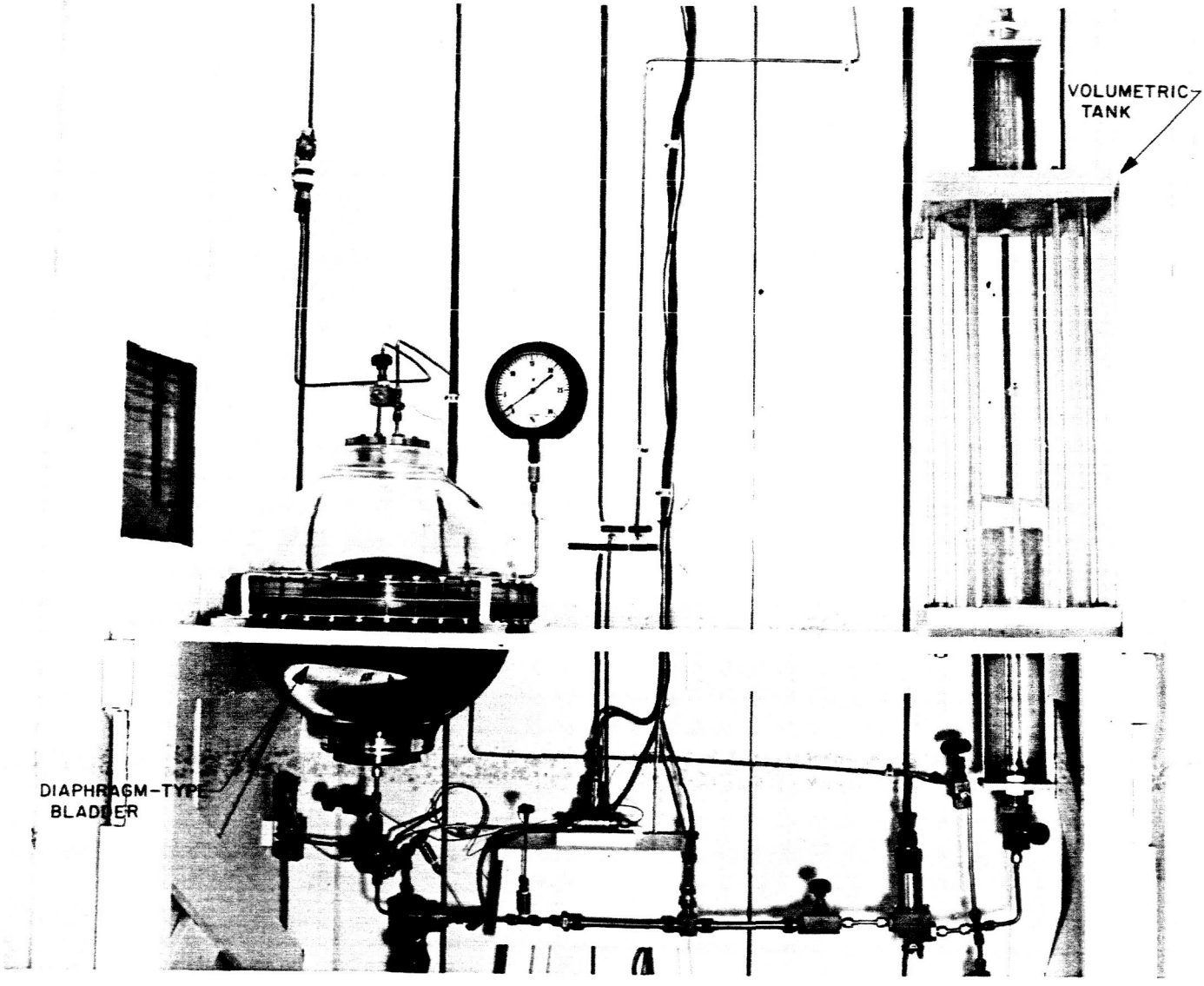


Fig. 7. Diaphragm-type bladder assembled in transparent model generant tank in upright position

what conservatively. The tank wall thickness at the minimum point was approximately ½ in. Wherever possible, large radii were used to avoid forming regions of stress concentration. The original transparent generant tank failed (Ref. 3) at a proof pressure of 200 psig. This failure was primarily attributed to local stress concentrations that occurred at the bolt circle of threaded inserts located in the Plexiglas portion of the transparent generant tank outlet. Also, residual stresses contributed to the failure, due to inadequate annealing of the Plexiglas after fabrication.

Design changes were made to eliminate the threaded inserts and thorough annealing procedures were specified to be used during the fabrication of the second tank. The annealing procedure used consisted of heating the tank to 175 ±5°F for a minimum of 12 hr, then cooling it at a rate not exceeding 13°F/hr. In the second tank, special connections were designed for the inlet and outlet ports to avoid tapping threads into the Plexiglas material. Special precautions were taken to avoid scratching the polished surface of the Plexiglas which could also result in regions of local stress concentration.

The vessel consisted of two flanged hemispherical sections bolted together as shown in Fig. 7. The smooth diaphragm-type bladder was bonded to a light-gage metallic flange as shown in Fig. 9. This metallic flange was then mounted between the two Plexiglas flanges. O-rings were used to effect a seal at the flanged connection.

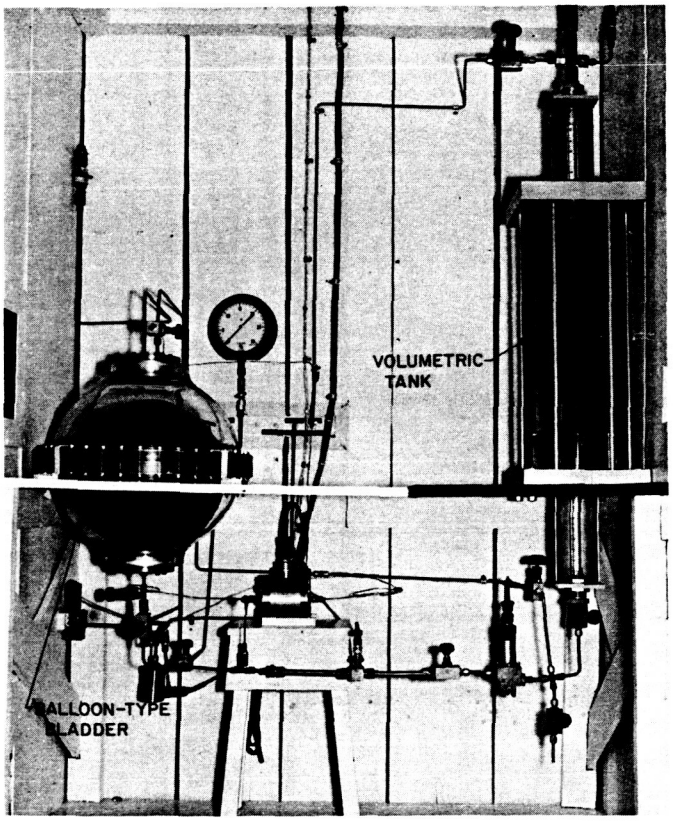


Fig. 8. Balloon-type bladder assembled in transparent model generant tank in upright position

The balloon-type bladder, shown in Fig. 10, was mounted to the outlet flange of the transparent generant tank with a special wire-wrapped clamp; this clamp design was first used in the midcourse propulsion system in the Ranger spacecraft.

The original tank design featured a curved baffle over the outlet, Fig. 11 and 12. Early tests indicated that a loss in expulsion efficiency was being caused by an entrapped volume of liquid which remained around the outlet baffle in the tank at the time of propellant depletion. A smaller baffle or barrier was therefore designed and fabricated as shown in Fig. 13. The small baffle reduced the entrapped volume of liquid and increased expulsion efficiency. Most of the expulsion testing with the transparent tank was carried out using this smaller outlet design.

C. *Tests*

The transparent model generant tank, modified as described in Section IIB above, was successfully proof tested at 200 psig for 5 min duration for a total of 3 cycles.

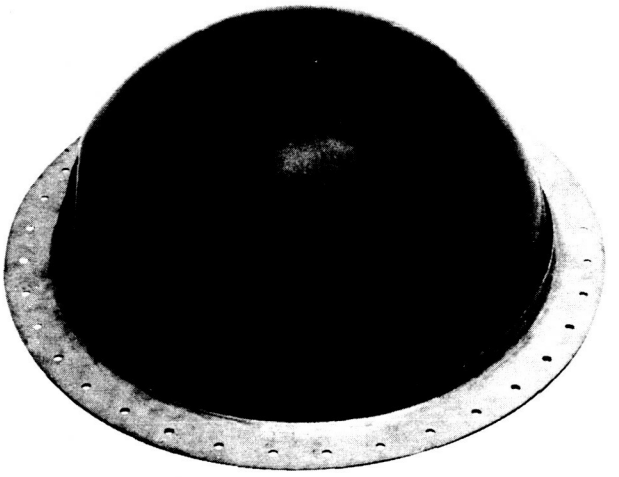


Fig. 9. Diaphragm-type bladder (no ribs) for use in transparent generant tank

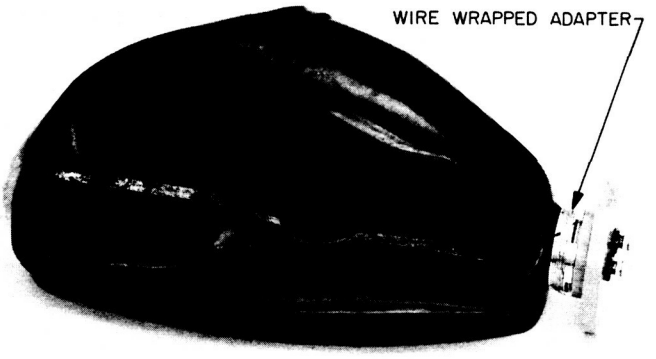


Fig. 10. Balloon-type bladder (or cell) used in transparent generant tank expulsion tests with *Ranger*-type adapter attachment

Prior to filling the bladder with distilled water, it was necessary to empty it completely. This was accomplished using an aspirator capable of providing a vacuum of 25-in. Hg. After the first aspiration cycle, a small quantity of nitrogen gas was introduced into the bladder, as shown in Fig. 14, as an aid in aspirating the last few droplets of water. Note how the water droplets tend to adhere to the surface of the diaphragm-type bladder. The above aspiration cycle was then repeated. After 3 aspiration cycles, the bladder was filled with 1227 $in.^3$ of distilled water, the standard generant volume for the ALPS system.

Expulsion tests were carried out with diaphragm and balloon-type bladders to study changes that occur ir

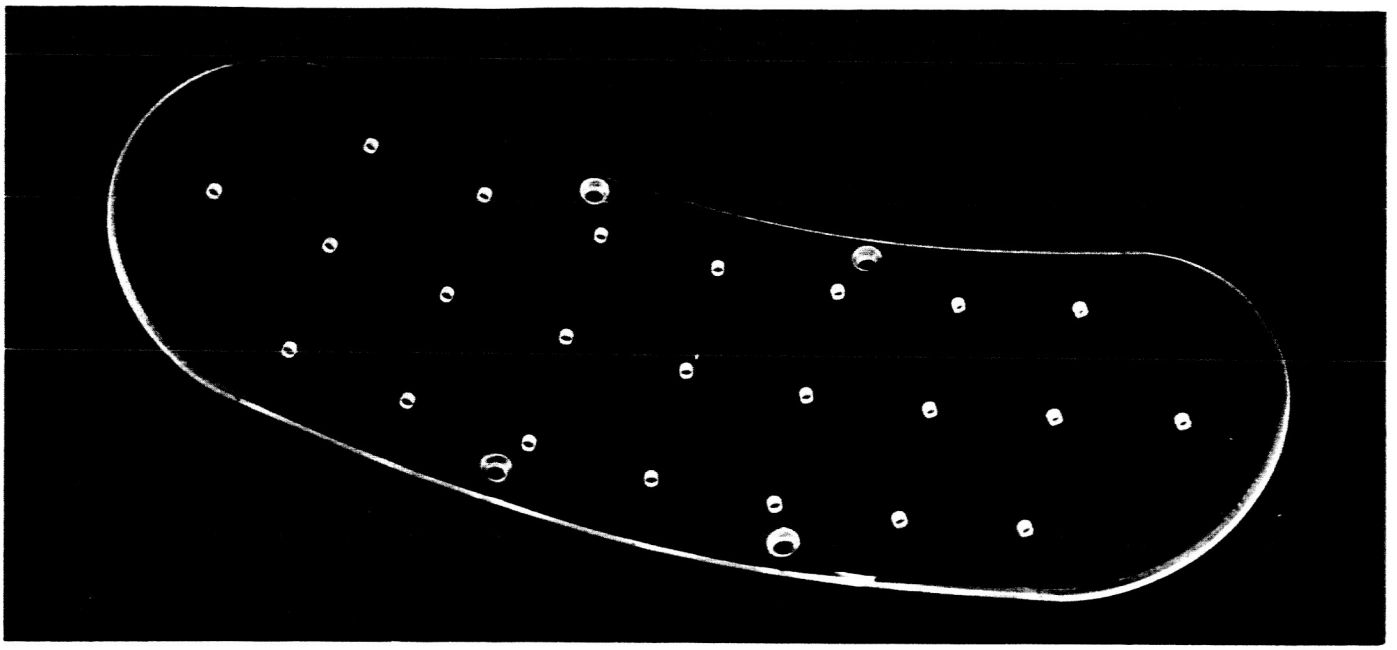


Fig. 11. Early outlet baffle design used with transparent generant tank

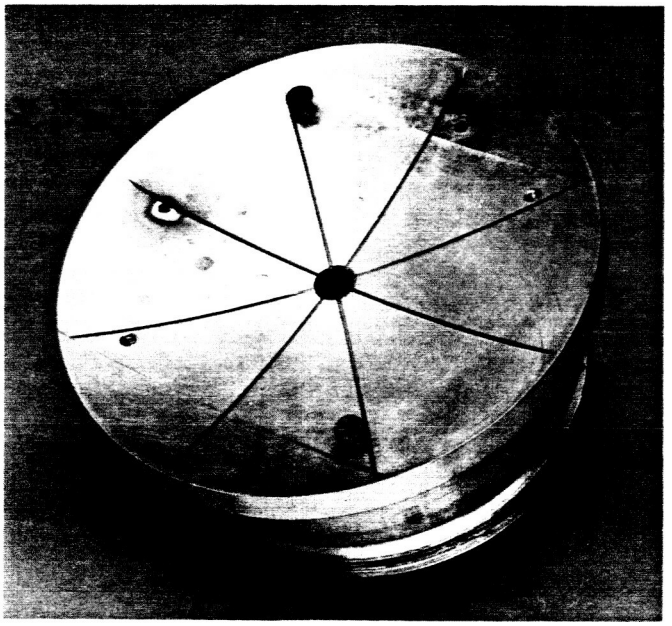


Fig. 12. Early outlet fitting design used with transparent generant tank

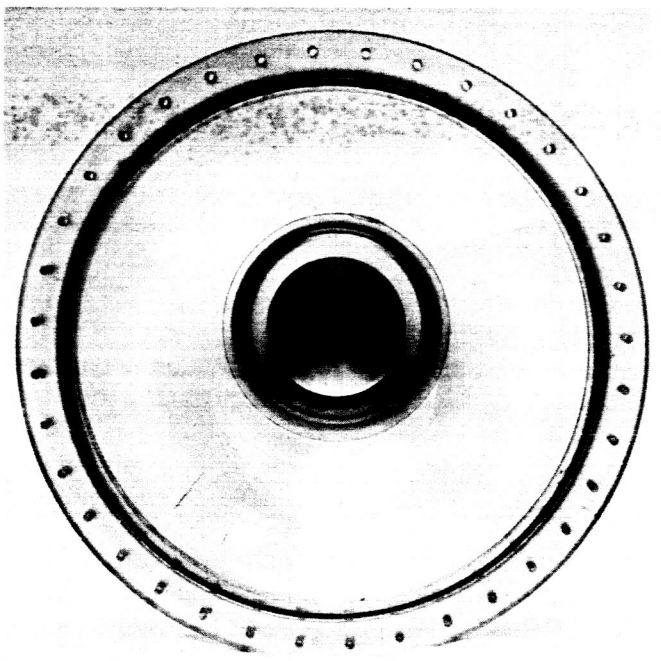


Fig. 13. Small outlet baffle or barrier (center) used with transparent generant tank

expulsion efficiency as a result of changing generant tank orientation. Using a fully-ribbed diaphragm-type bladder, Fig. 6, expulsion tests were carried out in upright, side, and inverted positions. These typical positions, graphically presented in Fig. 15, are as follows: upright —flow outlet is straight down; side—flow outlet is along the equatorial plane; inverted—flow outlet is straight up. These tests were performed with the diaphragm-type bladder installed in the transparent model generant tank shown in Fig. 7, and expulsion tests were carried out at

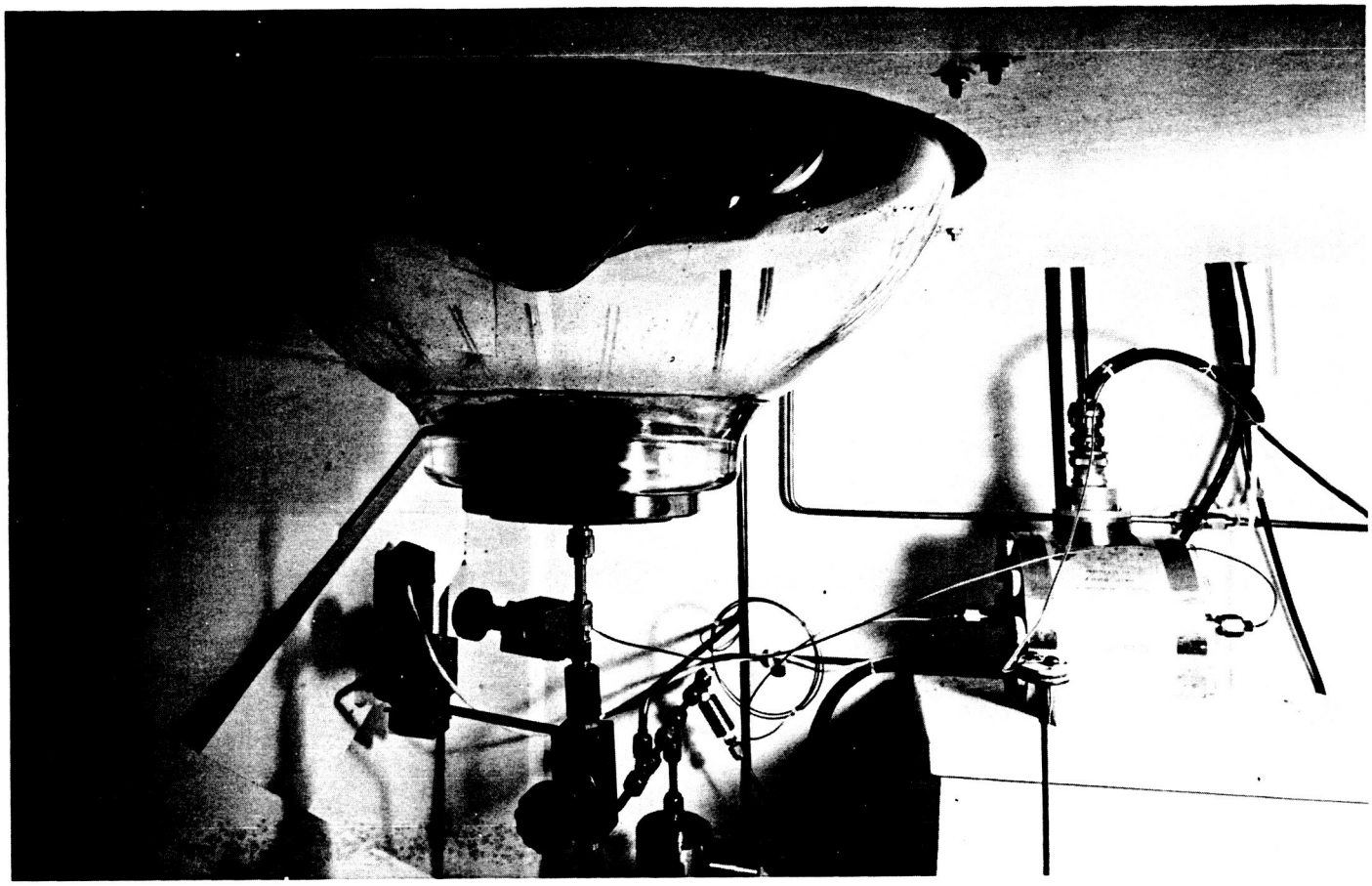


Fig. 14. Fully ribbed diaphragm-type bladder in transparent model generant tank—water droplets remaining after one aspiration cycle

pressures up to 100 psig. In a similar manner, using a balloon-type bladder, Fig. 10, expulsion tests were carried out in upright and inverted positions, the results of which are also graphically presented in Fig. 15.

Apparent expulsion efficiencies in the side and inverted positions were generally higher than in the upright position. This was attributed to the fact that it was more difficult to aspirate the last few drops of distilled water from the generant tank when the tank was in the side or inverted positions than when the tank was in the upright position. When the generant tank was in the upright position, gravity caused the last few drops of water to collect in the vicinity of the generant tank outlet, resulting in more efficient aspiration. During the normal expulsion cycle, particularly at the higher expulsion pressures, this residual water was expelled resulting in an apparent increase of expulsion efficiency.

A test program was carried out to determine the optimum rib configuration for the diaphragm-type bladder. A fully-ribbed diaphragm of seven rib segments was used as shown in Fig. 6. The ribs were then successively removed from the diaphragm and expulsion tests were made with four, three, two, one, and finally no rib segments. Figure 16 illustrates a diaphragm of two rib segments (five rib segments have been removed). Table 3

Table 3. Expulsion efficiencies of fully- and partially-ribbed diaphragm-type bladders at expulsion pressures up to 100 psig

Number of rib segments	Expulsion pressures, psig				
	5	10	20	50	100
7	99.82%	99.86%	99.85%	No data	No data
4	99.74%	99.78%	99.76%	99.67%	99.61%
3	99.79%	99.77%	99.66%	99.64%	99.56%
2	No data	No data	99.75%	99.67%	99.61%
1	99.90%	99.83%	99.74%	99.68%	99.57%
0	99.88%	99.80%	99.73%	99.58%	99.36%

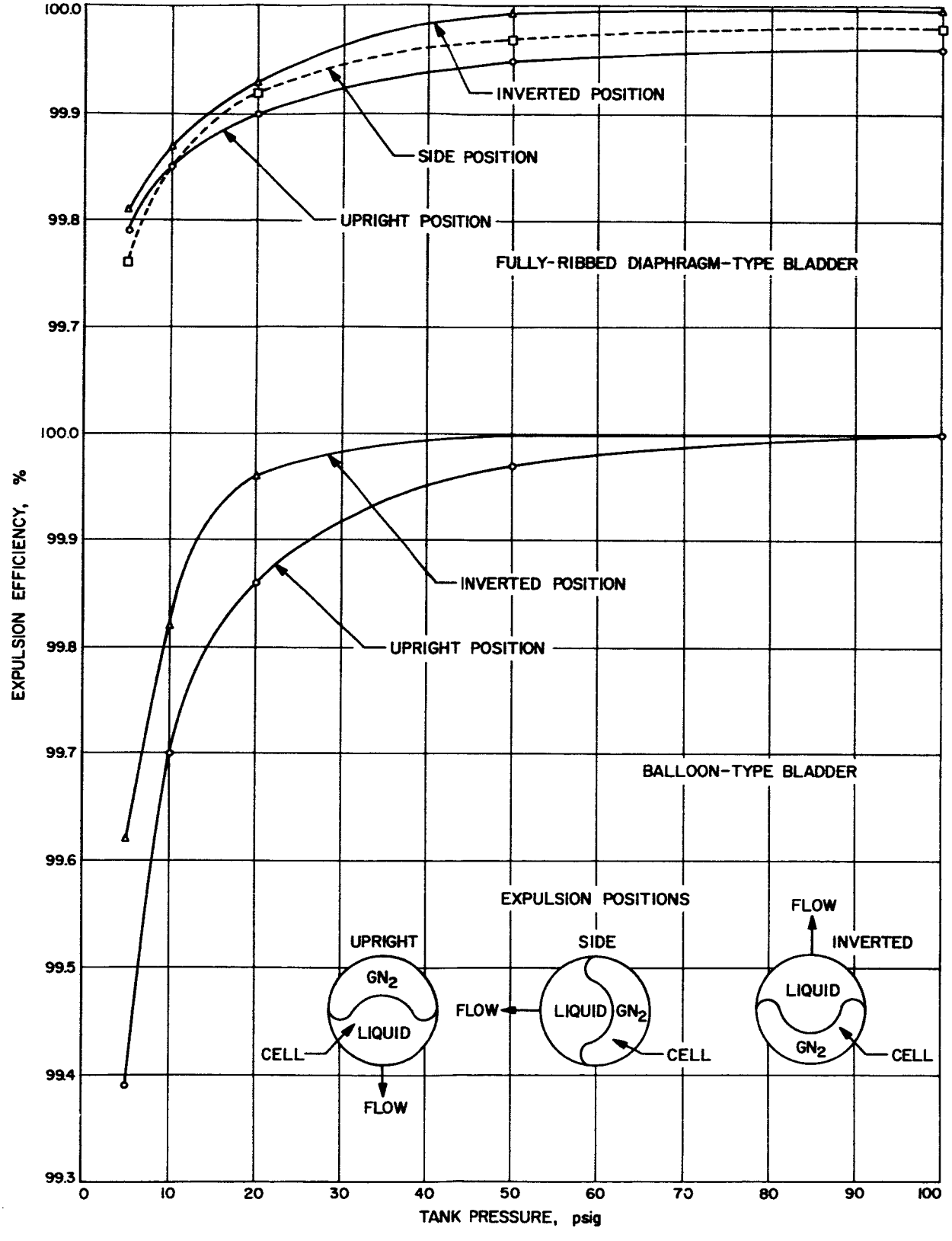


Fig. 15. Expulsion efficiencies of fully ribbed diaphragm- type and balloon-type bladders at various expulsion pressures up to 100 psig

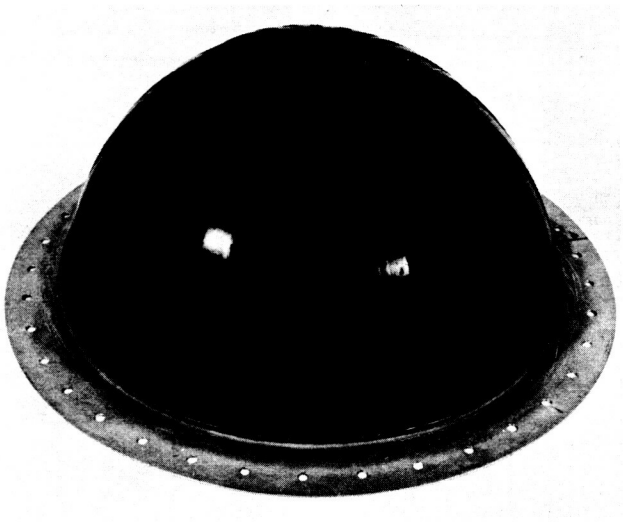


Fig. 16. Diaphragm-type bladder (partially ribbed) for use in transparent generant tank

and Fig. 17 indicate that with no rib segments, expulsion efficiency decreases with increasing expulsion pressure. This was attributed to the tendency for a seal to form between the relatively smooth tank wall and the elastomeric diaphragm. The same trend is apparent but to a lesser degree, for diaphragms with one, two, three, and four rib segments as shown in Table 3. On the basis of this test program, it was decided that the fully-ribbed diaphragm, Fig. 6, offered the best possibility for achieving the highest expulsion efficiencies at the higher expulsion pressures. The fully-ribbed diaphragm also tends to fold more uniformly and repeatably.

D. Determination of Expulsion Efficiency

Initial attempts to determine expulsion efficiency involved weighing the water expelled from the tank and comparing this with the weight of water initially transferred to the tank. With the weighing equipment then

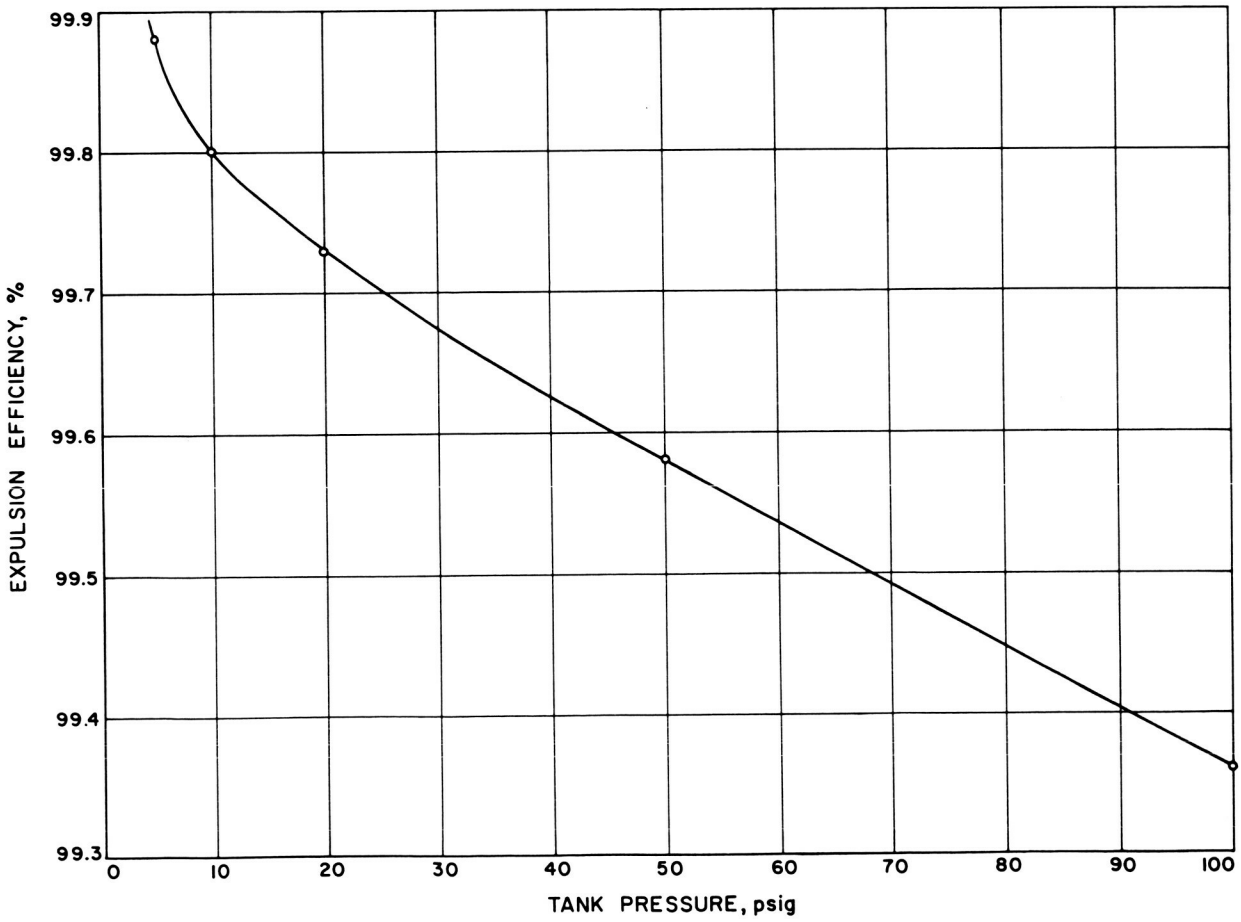


Fig. 17. Expulsion efficiency of smooth diaphragm-type bladder (no ribs) at various expulsion pressures up to 100 psig, upright position

currently available, however, the weight of the water could at best be determined only to an accuracy of $\pm\frac{1}{4}$ pound (or $\pm 0.6\%$). This degree of accuracy was not sufficient for determining differences in expulsion efficiency trends at low expulsion pressures that could be readily extrapolated for estimating efficiency trends at higher pressures. A special transparent volumetric tank, Fig. 7, was designed and fabricated therefore for determining expulsion efficiencies on a volumetric basis. This development is described in the next section.

E. Conclusions—Transparent Model Generant Tank

Expulsion efficiency trends obtained at low expulsion pressures with the transparent generant tank have proven very useful in pointing the way toward the use of the fully-ribbed diaphragm-type bladders in the flight-type version of the generant tank. The transparent generant tank has proven valuable in gaining operational experience with the balloon-type and diaphragm-type expulsion devices, and it has been an aid in visualizing various aspects of the expulsion process, such as the folding patterns, etc. Also it has served as a tool in trouble-shooting malfunctions of the expulsion system.

It is also noted that, for safety reasons, no personnel were allowed near the transparent generant tank when the expulsion pressures were higher than 20 psig. All expulsion tests with the transparent generant tank were carried out in a protective barricade as shown in Fig. 7 and 8.

III. DEVELOPMENT OF WATER EXPULSION TEST FACILITY

A. Purpose

The water expulsion test facility was developed to provide a means of determining expulsion efficiencies to a greater degree of accuracy than could be determined by using the method of weighing the test fluid.

The facility and instrumentation is shown in Fig. 18 and 19; Fig. 20 is a schematic of the system.

The portion of this equipment considered to be of prime importance is the volumetric device described in the next Section.

B. Description of Equipment

The volumetric tank shown in Fig. 18 has a 9 in. OD, is 26 in. long and encloses a specified volume of 1227 in^3. Sight gages, provided at top and bottom of the volumetric tank, enable determination of the enclosed volume to a high degree of accuracy (on the order of $\pm 0.02\%$). A Plexiglas vernier plate, or filler block, was used inside the volumetric tank to adjust the volume during the calibration process. The top and bottom edges of the Plexiglas vernier plate were tapered to facilitate the venting of any air bubbles entrapped in the distilled water. The volumetric tank was found to be sensitive

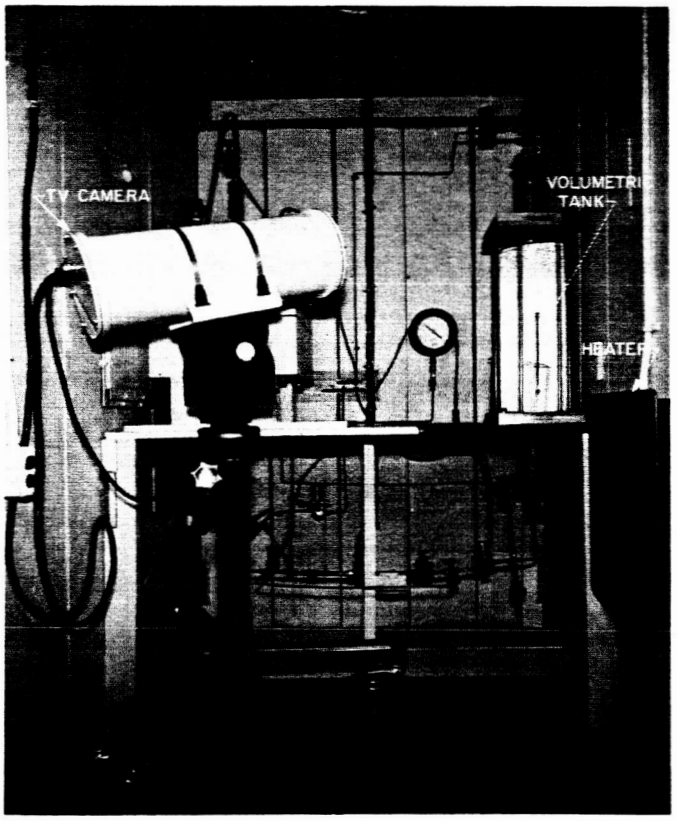


Fig. 18. Water expulsion test facility

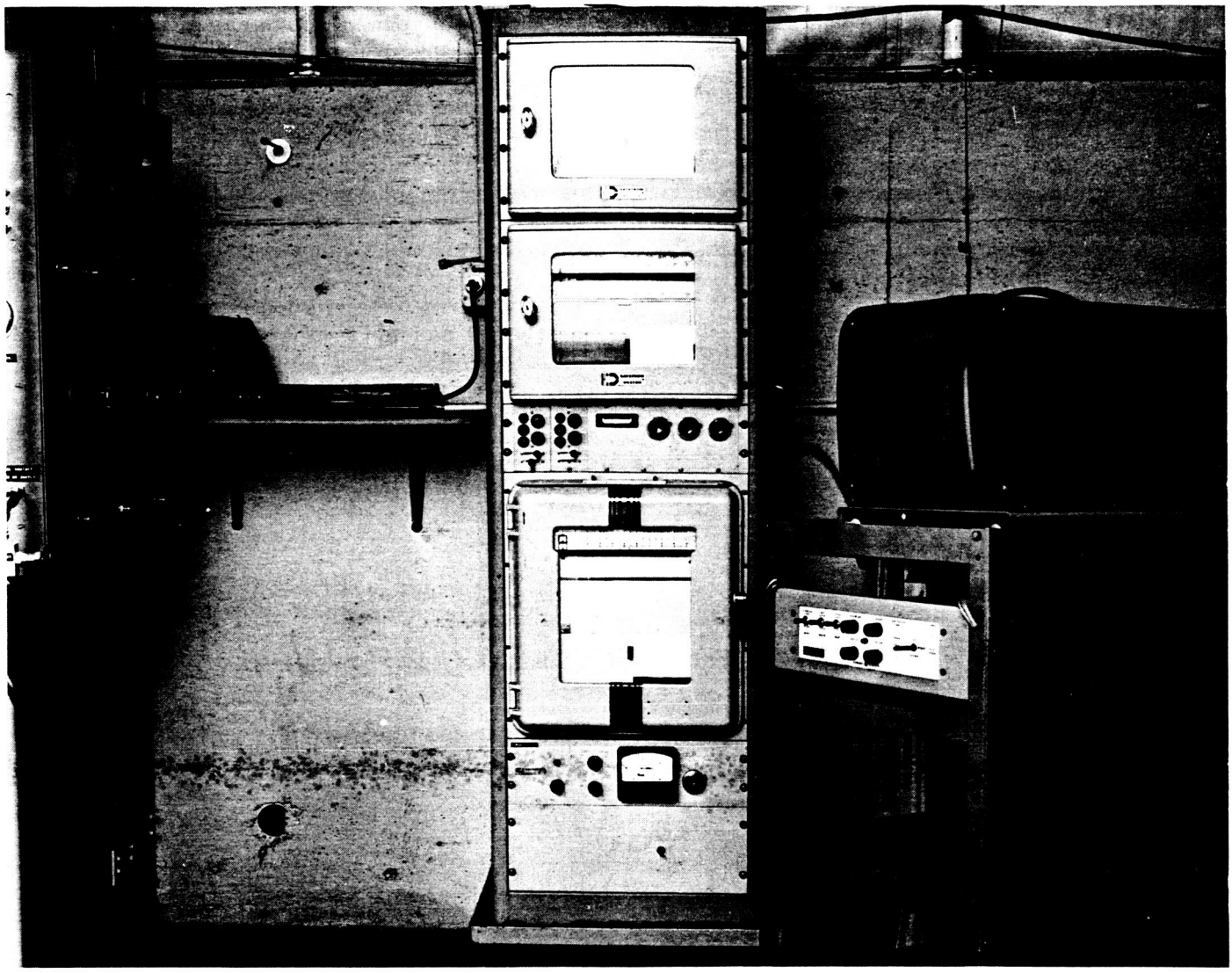


Fig. 19. Control panel and instrumentation for operating water expulsion test facility

to temperature changes of the enclosed distilled water; therefore, water temperature corrections were made in the calculations of the expulsion efficiencies.

A burette was used to measure precisely the volume of distilled water required to bring the water level in the volumetric tank to the reference line in the upper sight glass.

Inside the aluminum flanges which make up the ends of the volumetric tank, a conical-shaped contour had been machined to facilitate venting of any air bubbles entrapped in the distilled water.

During early developmental stages of the ALPS generant tank, ordinary tap water was used in the volumetric tank. It was soon discovered, however, that dissolved air had a tendency to come out of solution inside the volumetric tank in the form of air bubbles, making volumetric determinations unsatisfactory. When distilled water was used in place of tap water, the quantity of dissolved air was substantially reduced to the point where there were virtually no air bubbles.

The Plexiglas walls of the volumetric tank were polished to a high degree of transparency for ease in visually observing the various water levels. Special precautions were taken to prevent scratching the tank which

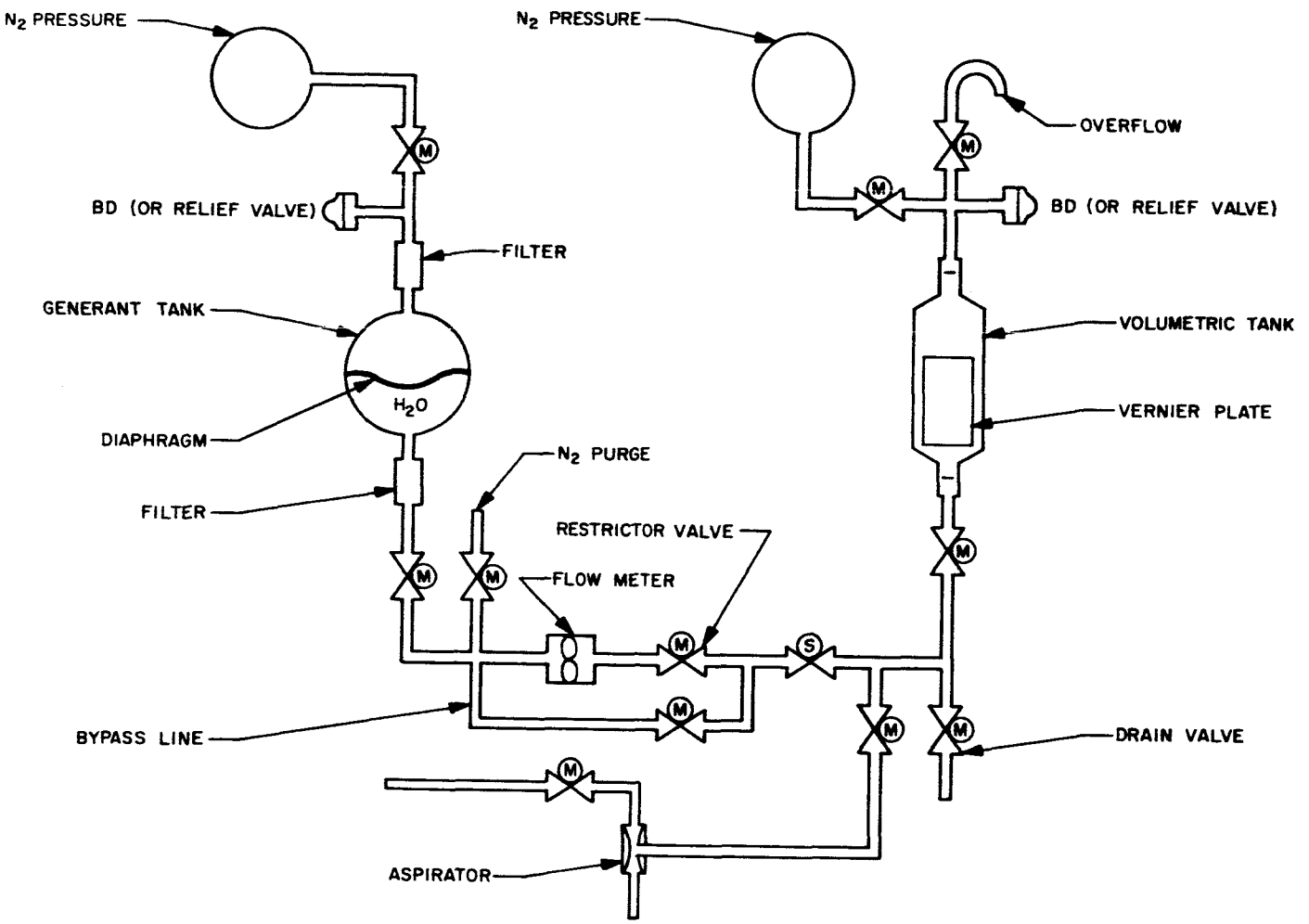


Fig. 20. Water expulsion test facility schematic

could result in regions of stress concentration. All other features of the design were such as to avoid regions of stress concentration. The annealing procedure used was similar to that used during the fabrication of the transparent generant tank. (See Section IIB above.)

The volumetric tank was designed to withstand a proof pressure of 150 psig. Normally, operating pressures up to 50 psig were used for pressurizing during the process of transferring distilled water from the volumetric tank to the generant tank. In the early stages of the ALPS generant tank development program, a gravity feed system was used for filling the generant tank. This process was very slow, however, resulting in a fill time on the order of 40 min. By pressurizing the volumetric tank during the distilled water transferring operation, the generant tank fill time was reduced to approximately 20 min. The volumetric tank and system were protected with a relief valve to prevent inadvertent over-pressurization during the distilled water transferring operation.

All generant test tanks were protected with burst diaphragms or relief valves to prevent inadvertent over-pressurization during the water expulsion test operation.

The volumetric tank was installed in the vertical position with a shut-off valve at the bottom of the tank in addition to an auxiliary valve used for draining distilled water from the system; see Fig. 21. A pressurization valve was provided at the top of the tank in addition to an overflow line and a relief valve.

No special problems were encountered with the volumetric tank. Only one tank was fabricated and this was used throughout the generant tank development program.

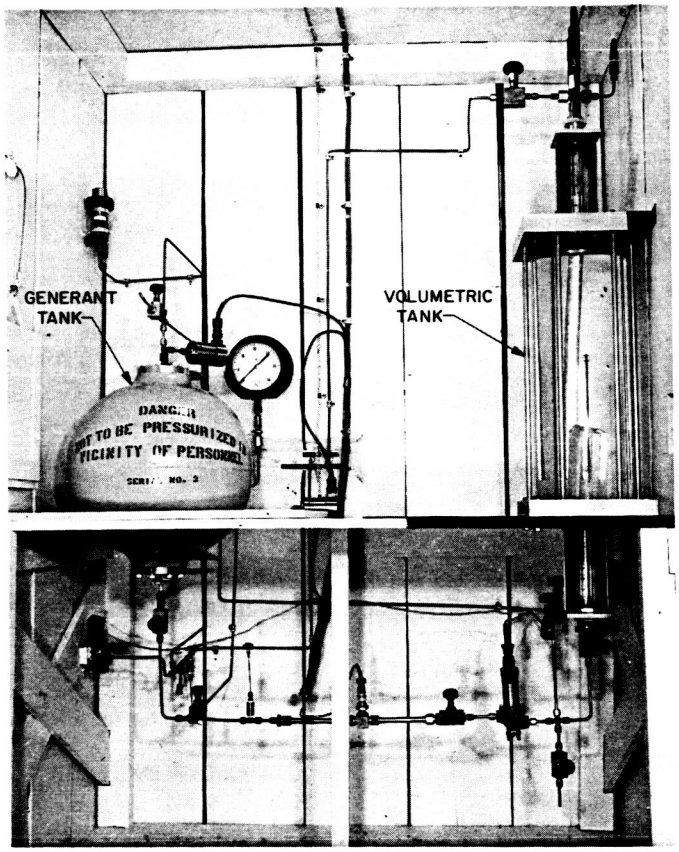


Fig. 21. Heavyweight (4130 steel) generant tank with balloon-type bladder enclosed in upright position

C. Tests

Prior to its use in the water expulsion test facility, the volumetric tank was successfully proof tested by subjecting it to 3 cycles of pressurization to 150 psig for 5 min.

The unit was carefully calibrated, prior to its use in the determination of expulsion efficiencies, in order to determine temperature effects resulting from variations in the distilled water temperature. The edges of the Plexiglas vernier plate were machined slightly until the volume between specified reference marks on the upper and lower sight gages measured precisely 1227 in.^{3} at a distilled water temperature of 62°F. During expulsion testing, a correction factor of 2.31 ml/°F was used to take into account any variations in the distilled water temperature from the reference temperature of 62°F.

D. Operational Problems

One of the problems with the volumetric tank has been its sensitivity to changes in temperature. Although corrections were made for the gross changes due to variations in distilled water temperature, no specific corrections were made for changes in the tank dimensions due to variations in ambient temperature. The experimental data could therefore be improved slightly by making all expulsion runs under controlled ambient conditions.

E. Conclusions—Water Expulsion Test Facility

It has been demonstrated that a volumetric tank could be used successfully for determining expulsion efficiencies to a greater degree of accuracy than could be determined by using the currently available weighing equipment.

As stated previously, it is believed that the accuracy of the volumetric tank is on the order of ±0.02%.

IV. DEVELOPMENT OF HEAVYWEIGHT 4130 GENERANT TANK

A. Basic Concept of the Heavyweight Tank

A heavyweight generant test tank assembly with a balloon-type bladder was designed and fabricated in order to provide expeditiously a tank for a series of hot-firing feasibility tests of a *Mariner* 1966 prototype mid-course propulsion system. The original design specified 17-4 PH stainless steel; however, this tank was not fabricated because of delivery and cost. Instead, an AISI 4130 steel test tank was built using off-the-shelf hardware wherever possible in order to save time.

B. Design Criteria and Description of Test Specimen

Several off-the-shelf hydroformed hemispherical shells were purchased from Tavco Inc., Santa Monica, California. These shells were 17.30 in. ID and had a wall thickness of 0.218 in.

In all other respects, the design criteria for the heavyweight tank were essentially the same as those for the flight-type titanium tank as shown in Table 1. Maximum working pressure specified was 1500 psig; proof pressure, 2250 psig; and minimum burst pressure, 3750 psig.

Since the heavyweight hemispheres offered a greater margin of safety than the titanium hemispheres, the heavyweight bosses and flanges were designed to offer the same extra margin of safety. It was felt that the extra margin of safety would be worthwhile, particularly during the early test phase of the generant tank development program. The 4130 steel tank was heat treated, per MIL-H-6875, to 160,000–180,000 psi ultimate tensile strength after welding.

Suitable precautions were taken to insure that the interior of the heavyweight tank was very smooth to avoid any damage to the bladder during the expulsion cycle.

The heavyweight generant tank was mounted in a circular opening in the work surface of the water expulsion test facility as shown in Fig. 21. All water expulsion testing was carried out with the heavyweight generant tank mounted in the upright position. A similar mounting arrangement was used during the (*Mariner* 1966) hot-test feasibility firings as shown in Fig. 22.

The interior surface of the heavyweight generant tank was protected from rusting by a protective coating consisting of Trail Chemical Corporation EPON No. X 7546, applied 0.001 in. thick. The interior surface of the tank was cleaned and Parkerized per MIL-P-16232 prior to the application of the EPON coating. This coating was felt to be necessary because any contact between hydrazine and particles of rust could result in a catalytic reaction. And, if enough heat were generated in such a reaction, the hydrazine could eventually react spontaneously as a monopropellant, resulting in a possible detonation.

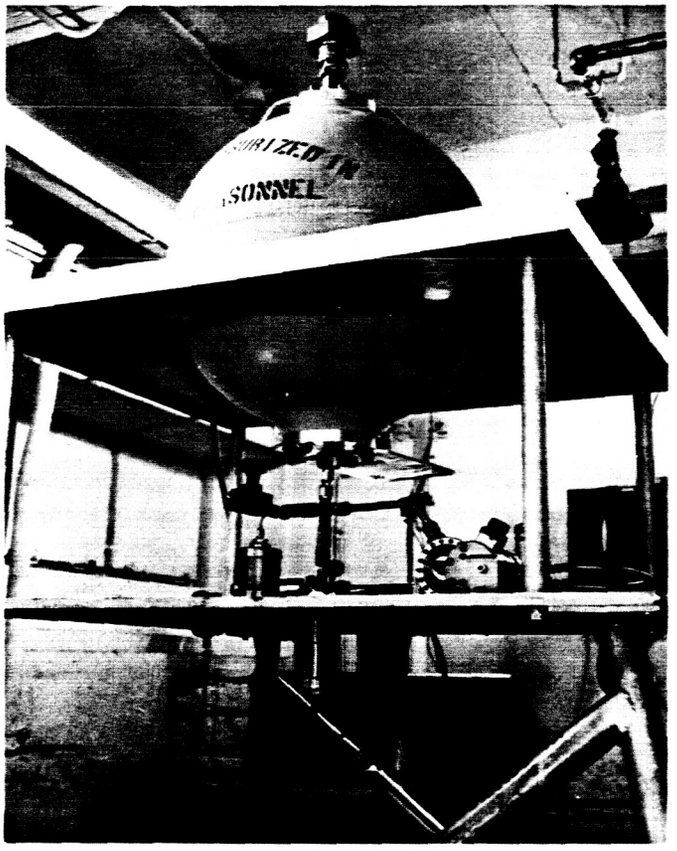


Fig. 22. Heavyweight (4130 steel) generant tank installed in *Mariner* 1966 prototype subsystem

One of the balloon-type bladders leaked during the hot firing portion of the development program; this allowed hydrazine to come in contact with the 4130 steel wall of the heavyweight generant tank. The hydrazine dissolved the EPON coating, exposing the parent 4130 steel to hydrazine corrosion; however, since no rust particles were present, a catalytic reaction did not occur.

The heavyweight generant tank bosses were made large in order to afford easy access to the generant tank interior for the purpose of inspecting the condition of the protective EPON coating. In addition, both bosses were made interchangeable so that the bladder could be mounted from either end.

C. Fabrication and Assembly of Tank and Bladder

The heavyweight generant tank was fabricated by Missile Welding and Engineering Co., El Monte, California. Standard welding procedures for 4130 steel were used during the fabrication process. These welding procedures have been well established for this type of tank material and configuration. No. 502, 4130 steel wire was used for welding the heavyweight generant tank per MIL-R-5632, Class II. Special precautions were taken by the vendor to prevent weld drop-through where the inlet and outlet bosses were welded into the tank hemispheres.

Prior to assembly, the bladder neck was thoroughly cleaned with toluene reagent ACS Code 2398. The bladder neck and ring collar were then coated with a cement consisting of a 20% solution of Stillman Rubber Company Compound SR 613-75 in toluene as furnished by the bladder vendor. The balloon-type subassembly including the internal mast shown in Fig. 23 was then assembled within the generant tank. Fig. 20 is a schematic of the heavyweight generant tank and bladder assembly installed in the water expulsion test facility. Proof testing of the tank (shell only) was accomplished hydrostatically at pressures up to 2250 psig prior to assembly with the bladder subassembly. The proof pressure was maintained for 5 min duration and the test was repeated for a total of 3 cycles.

At this point in the development of the heavyweight generant tank, experience with the balloon-type bladders indicated mechanical and quality control problems in the splice area and in the area immediately adjacent to the splice, Fig. 24, which resulted in leaks at both high and low expulsion pressures. Of six bladders purchased from the vendor, only two were satisfactory at expulsion pressures up to 1350 psig.

D. Tests

Expulsion testing of the heavyweight generant tank and bladder was carried out in the upright position at generant tank pressures up to 1500 psig; final expulsion pressures were as high as 700 psig; however, no expulsion efficiencies were determined. Distilled water was used as the test fluid; nitrogen gas as the pressurant.

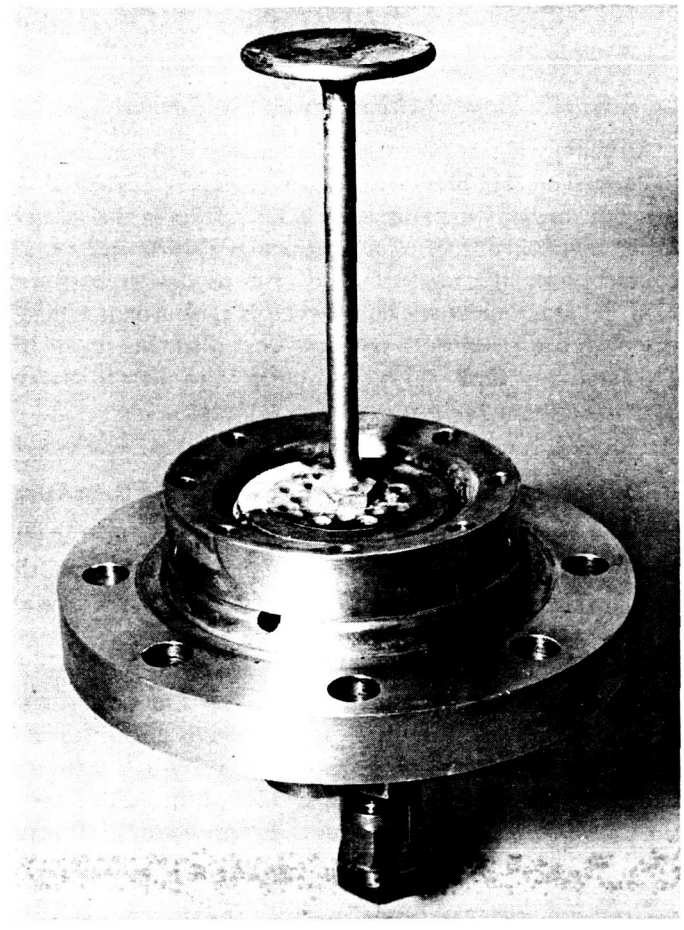


Fig. 23. Outlet fitting for heavyweight (4130 steel) generant tank, showing internal mast for use with balloon-type bladder

Following expulsion testing, the heavyweight generant tank with the bladder assembled within it, was pneumatically proof tested at 2250 psig for 5 min. duration, for a total of 3 cycles. Prior to pneumatic proof testing, the bladder was filled with 1227 $in.^3$ of distilled water to prevent a differential pressure from developing across the outlet filter.

In order to determine the leak tightness of the bladder, all the distilled water and/or air was aspirated from it. The vacuum obtained during the aspiration process was 25-in. Hg, or greater. At this point the vacuum system was locked up for a test period of 15 min. It was arbitrarily specified that a vacuum reading falling below 23-in. Hg during the 15 min test interval would indicate an unacceptable leak in the bladder. The aspiration test was completed successfully three times.

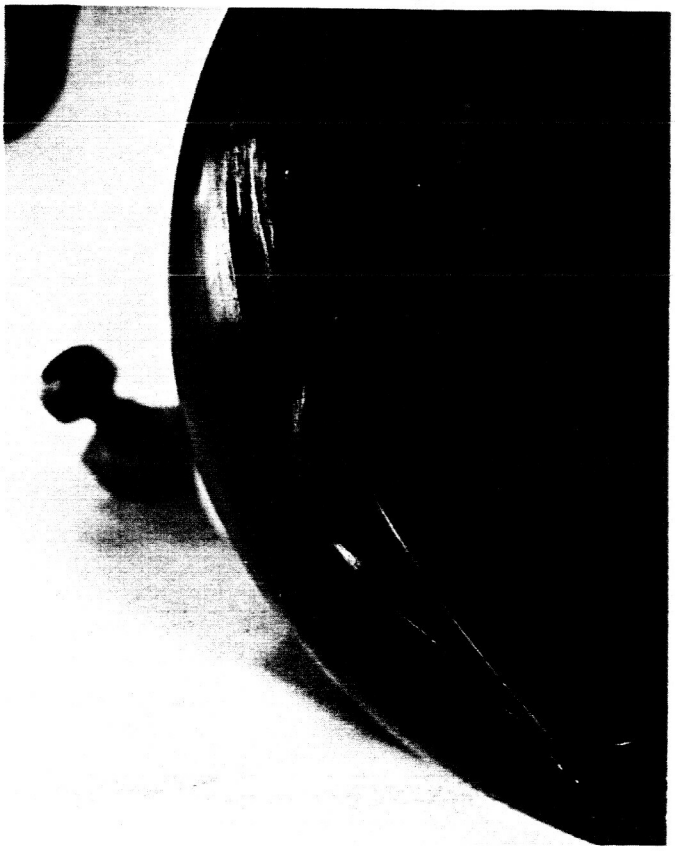


Fig. 24. Failure of balloon-type bladder at the splice

The heavyweight generant tank (with bladder installed) was used as part of the *Mariner* 1966 feasibility demonstration system which included a 50-lb thrust rocket motor and the ALPS generant controller as shown in Fig. 22. Several firings were successfully carried out at durations up to 120 sec; generant tank expulsion was terminated prior to the point of propellant depletion. One test, which lasted 180 sec, was made to the point of propellant depletion. The shutdown transient which occurred at the termination of this test was reported as being normal in all respects.

E. Conclusions—Heavyweight Generant Tank

The following conclusions were reached:

1. The use of the balloon-type bladder at high initial expulsion pressures up to 1500 psig, and final expulsion pressures up to 700 psig, offered an opportunity for evaluation of high pressure expulsion devices.
2. Operation of the balloon-type expulsion bladder-up to the point of propellant depletion, it was discovered, could result in a transient condition probably caused by the balloon-type bladder sealing off the outlet filter holes momentarily. Such a flow disturbance could be reflected adversely by a corresponding disturbance in engine or gas generator combustion.
3. It was found that the reliability of the balloon-type bladder was seriously impaired because of an incompatibility between the bonding agent used at the bladder splice and the hydrazine. A suitable bonding agent was not found with the same compatibility characteristics as the parent elastomer.
4. It was further concluded that if the balloon-type bladder were to be used as an expulsion device with hydrazine, the splice should be eliminated, i.e., only one-piece bladders should be used.
5. Some difficulty was experienced in attempting to maintain a seal at the bladder neck; however, there is no reason to believe that this sealing problem could not be resolved through a redesign of the bladder neck seal configuration.

V. DEVELOPMENT OF FLIGHT-TYPE TITANIUM GENERANT TANK WITH DIAPHRAGM-TYPE BLADDER

A. Basic Concept of the Flight-type Tank

The flight-type titanium generant tank incorporated as many principles as possible that evolved during the transparent model generant tank and the 4130 steel heavyweight generant tank development and test programs. By so doing, it was hoped that the state-of-the-art of designing, fabricating, testing, and operating zero g expulsion devices was advanced. This will tend to shorten the development lead time of future liquid propulsion systems using this device.

Figure 25 illustrates the flight-type titanium generant tank with an integral elastomeric diaphragm-type bladder. The generant tank plus the generant cell weight as shown is 20.8 lb.

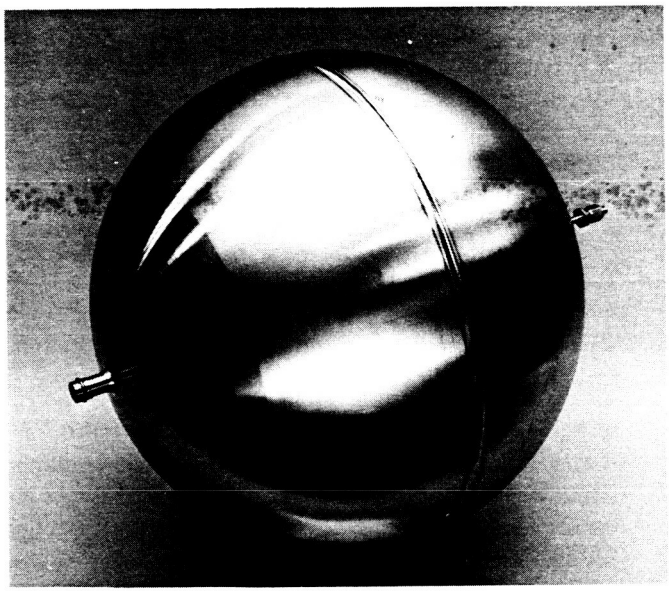


Fig. 25. Flight-type titanium generant tank with integral elastomeric diaphragm-type bladder

B. Design Criteria and Preliminary Development

The design criteria for the titanium generant tank have been described in Section I. The component design data sheet, as shown in Table 1, gives a summary of these criteria. The tank material was chosen to be 6AL-4V titanium because of lightweight, high strength and compatibility with hydrazine, and was based on previous experience at JPL with this material in the fabrication of high-pressure tanks.

In addition, the integration of the flight-type titanium generant tank and cell assembly into the overall ALPS propulsion system has been considered. From an expulsion viewpoint, it was decided that the generant tank axis should be parallel with the longitudinal axis of the thrust chamber and that the generant tank outlet should face aft. In this way, acceleration acts as an aid to the expulsion process.

The titanium generant tank was designed basically as a flight-type tank in accordance with JPL requirements for spacecraft flight-equipment; however, since this was the first tank of this type, it was designed conservatively.

Some weight probably could be saved through a careful redesign using information obtained from an instrumented burst test.

A preliminary stress analysis of the titanium generant tank was completed by the vendor, Electrada Corporation. This analysis was based on the stress formula: hoop stress = internal pressure $\times$ rad/2 $\times$ thickness. The transition areas, adjoining the generant tank girth weld and the generant tank bosses were then proportioned on an empirical basis according to the vendor's previous experience.

Subsequently, a 7090 Computer Program was set up by the JPL stress group and a point-by-point stress analysis of the titanium generant tank was made. For example, Fig. 26 is a pictorial representation of the generant tank girth weld and diaphragm attachment indicating the computed inner and outer wall stress distribution in the vicinity of the girth weld and in an axial direction; i.e., in a direction parallel to the generant tank axis.

The design proof pressure for the flight-type titanium generant tank was 2250 psig; maximum working pressure, 1500 psig; nominal working pressure, 1300 psig.

1. Preliminary Welding Development

Prior to fabrication of the flight-type titanium generant tank a preliminary fabrication development program was carried out to determine the feasibility of completing a girth weld of a titanium tank with an integral elastomeric diaphragm. The problem essentially was to complete the weld without heating the adjacent edge of the diaphragm

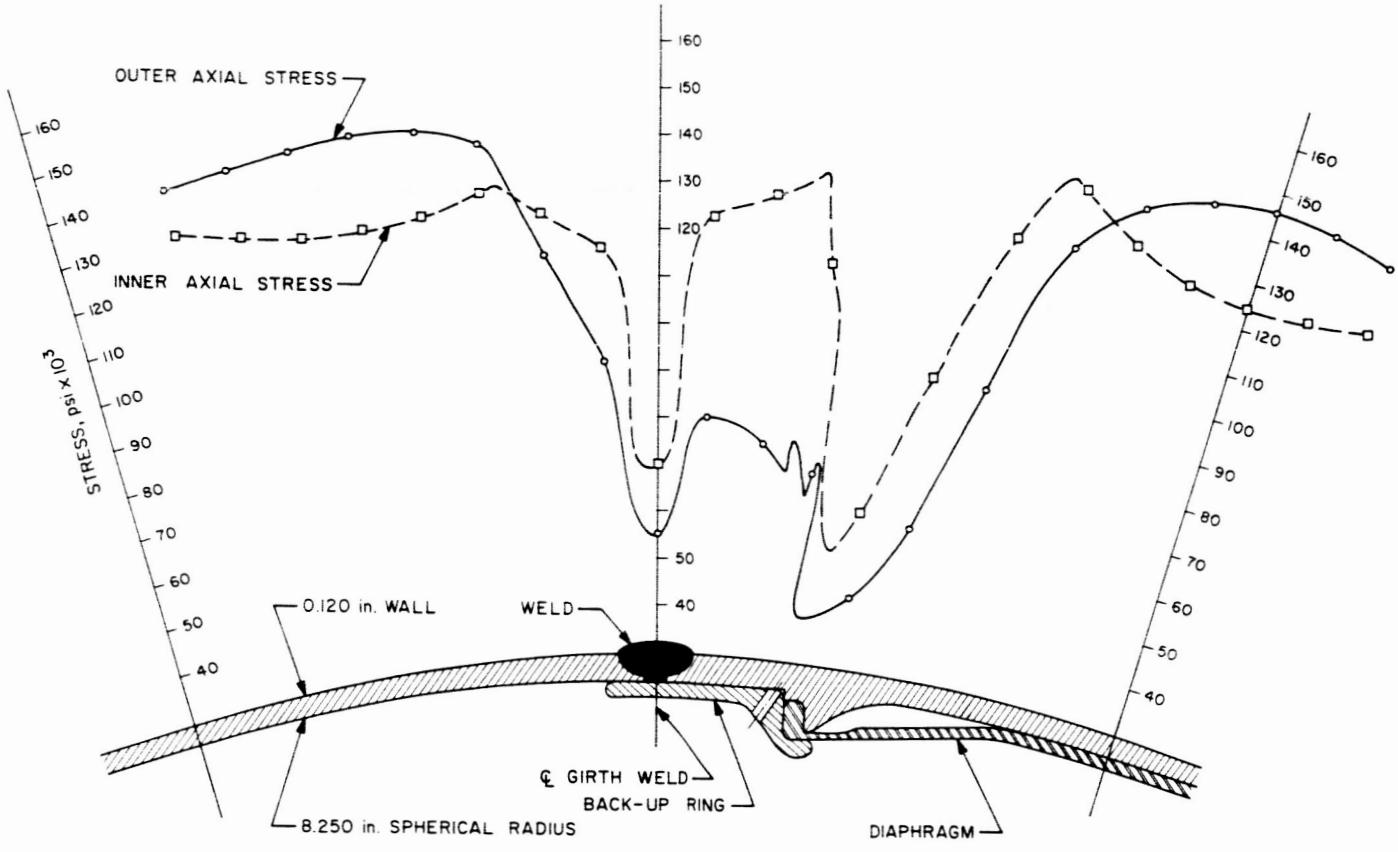


Fig. 26. Theoretical stress distribution at girth weld in axial direction, psi × 10^3

above a specified safe temperature for the elastomer. A more detailed description of this work appears in Ref. 3. This preliminary development work was completed by the Electrada Corporation, Airite Division, Los Angeles, California. Two welding processes were considered for use in joining the generant tank hemispheres: 1, Tungsten Inert Gas (TIG) welding; and 2, Electron Beam (E/B) welding. At this time, a broad background existed in the TIG welding process, but the E/B welding process was still considered in the developmental stage. For this reason, TIG welding was selected as the welding process for the first four flight-type generant tanks. Thermocouples were installed in the titanium weld-feasibility test tank, Fig. 27, to study the temperature profile in the vicinity of the girth weld during the welding operation. The tank was divided into four quadrants and the welding parameters were varied for each quadrant.

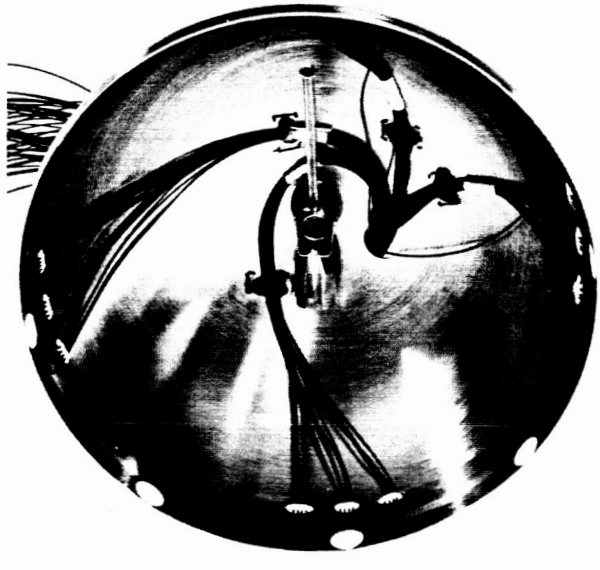


Fig. 27. Thermocouple installation in titanium weld-feasibility test tank

Figure 28 illustrates the titanium weld-feasibility test tank with two water-cooled chill rings made of copper (installed adjacent to the girth weld). Shrinkage of the

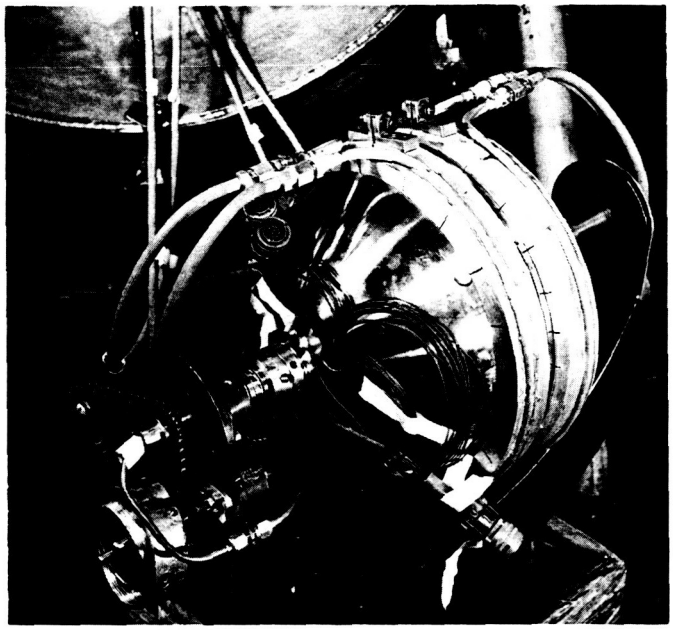


Fig. 28. Titanium weld-feasibility test tank with chill rings installed and mounted in welding rig

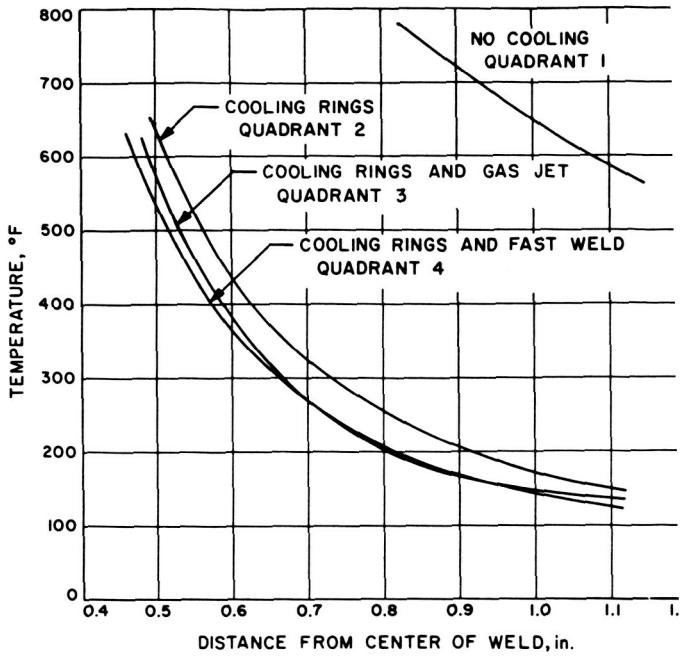


Fig. 29. Maximum temperature vs distance from weld for titanium weld-feasibility test tank

titanium tank at the girth weld during the welding operation resulted in a loosening of the chill ring fit. The loose fit resulted in poorer heat transfer between the chill rings and the titanium tank walls resulting in higher diaphragm temperatures for a given energy input. The chill ring fit was later improved by using soft metal shim-stock between the chill rings and the titanium tank walls and by using adjustable chill rings.

Using the thermocouple data as described above, the maximum temperatures for each quadrant were plotted against the corresponding distances from the weld. Assuming a critical temperature for the elastomeric diaphragm of 350°F and a critical distance of the elastomer from the center of the weld of 0.65 in., it was apparent from the data, plotted in Fig. 29, that cooling with chill rings only would be marginal. It was also apparent that the best possibility for a cool (satisfactory) weld involved the use of chill rings combined with a fast welding speed. The use of an internal auxiliary gas jet for cooling presented the added complication of an entrance tube passing through the pressurization port; therefore, the gas jet was not used.

X-rays of these early experimental welds indicated a lack of penetration at the root of the weld. This condition was later corrected on flight-type tanks by removal of the welding lip on the backup ring to allow greater weld penetration for a given weld setting.

The flight-type titanium generant tank is constructed of two hemispheres held in register by a back-up ring as shown in Fig. 30. An integral part of this back-up ring is a welding lip which protrudes from the back-up ring and separates the two hemispheres. The welding lip also functioned as a thrust ring for applying the necessary squeeze to the diaphragm lip to effect a diaphragm seal. In the process of making the girth weld, it is necessary to melt this 0.090 in. welding lip in order to achieve complete weld penetration. The necessary heat to melt the welding lip resulted in temperatures at the diaphragm lip in excess of 400°F. Table 4 indicates the welding speeds, welding currents, and welding voltages used during this preliminary phase with S/N 001 flight-

Table 4. Initial welding parameters and maximum temperatures, with water-cooled chill rings

Segment number	Lineal welding speed, in./min.	Welding current, amps	Welding voltage, v	Maximum temperature, °F
I	13.2	140.0	10.7	350
II	13.2	119.0	10.0	350
III	4.5	84.0	9.2	375+
IV	4.5	66.5	8.5	375+

Note: Initial weld results on flight-type test tank S/N 001 performed at Electrada Corp., Airite Division, Los Angeles, Calif.

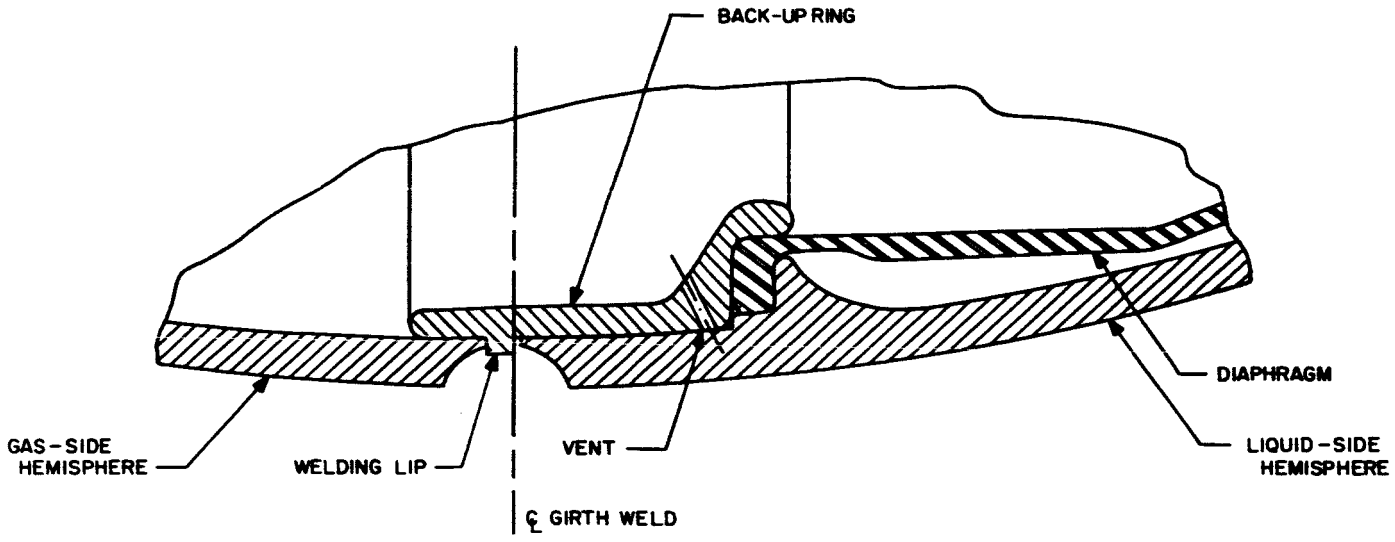


Fig. 30. Section through girth-weld area of flight-type titanium generant tank, with welding lip

type tank. It should be noted that the lower temperatures occurred at the higher welding speeds but, as mentioned above, the X-rays of these welds indicated a lack of penetration at the generant welding projection. On the basis of this information, the vendor recommended that the welding lip be removed and that its functions be performed by twelve tack welds to be located as shown in Fig. 31.

Complete weld penetration at the girth weld was successfully achieved after this modification was made. Figure 32 is a section through the girth weld area of the S/N 001 flight-type titanium generant tank. Note the grain growth in the weld area and that the grains are uninterrupted as they pass from the back-up ring to the generant tank hemispheres. Note also the abrupt termination of the heat affected zone adjacent to the weld area. The diaphragm lip shows no ill effects from the close proximity of the high temperature weld area. Some weld shrinkage and distortion of the back-up ring are also apparent. This critical portion of the generant tank program, considered to be a follow-on development to the work described heretofore, was accomplished by Pressure Systems Incorporated, City of Commerce, California.

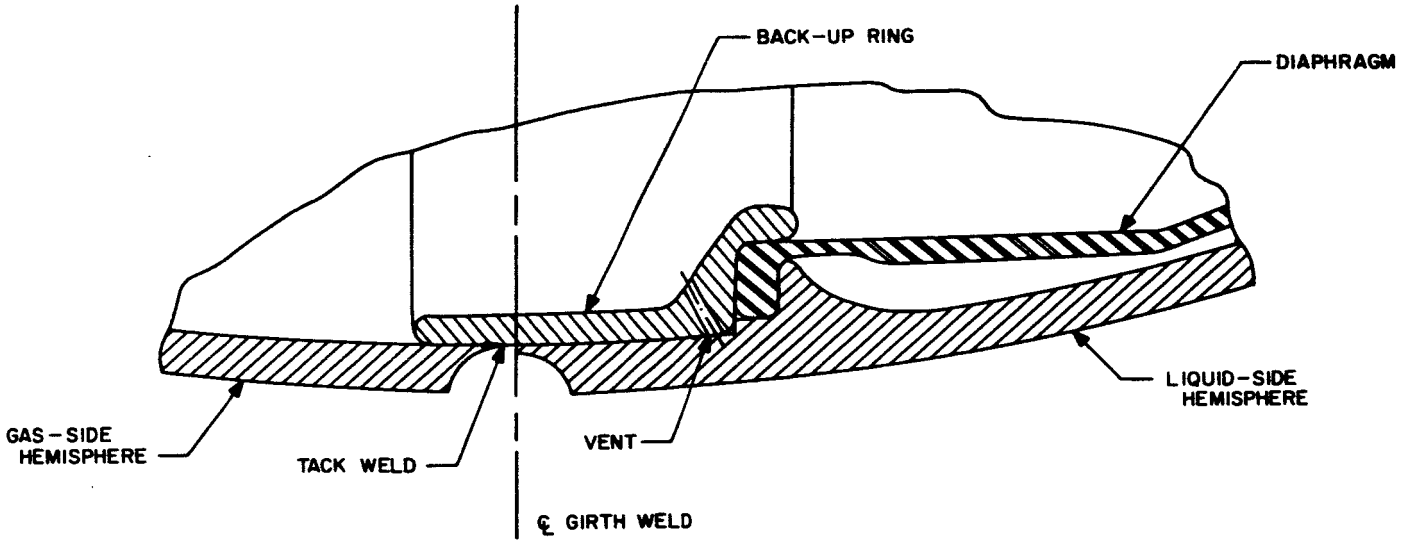


Fig. 31. Section through girth-weld area of flight-type titanium generant tank, without welding lip

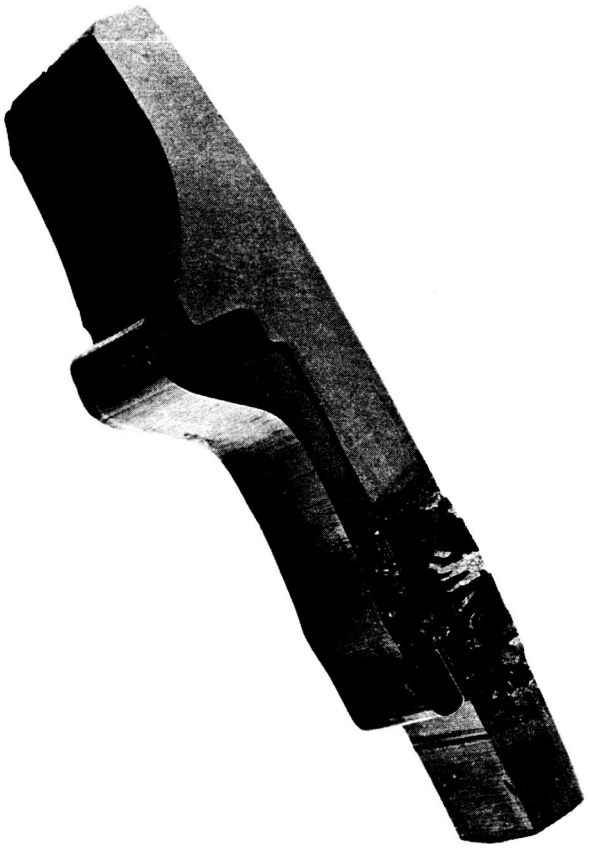


Fig. 32. Section through girth-weld area of S/N 001 flight-type titanium generant tank

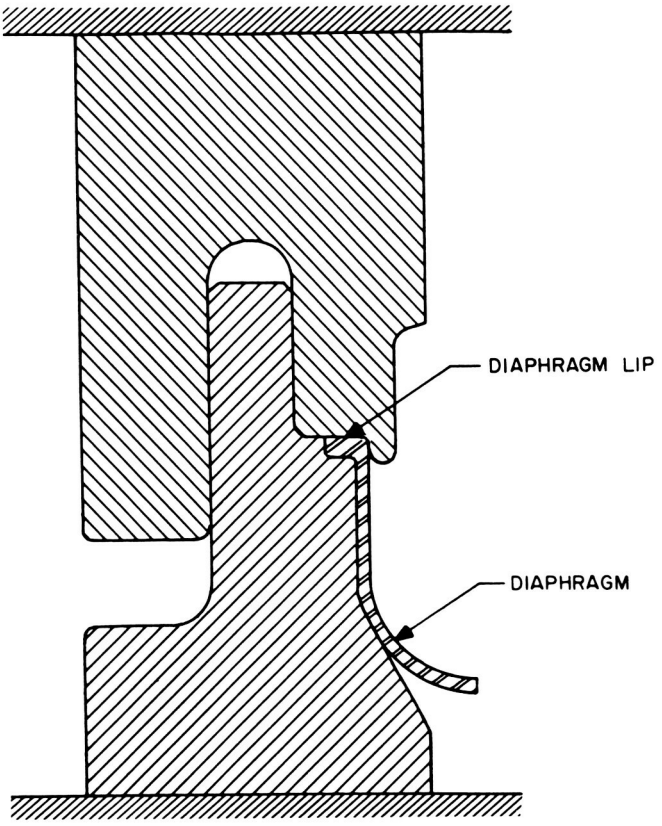


Fig. 33. Test setup for performing diaphragm lip test at Pressure Systems, Inc.

2. Diaphragm Development and Design Selection

A series of tests was carried out by Pressure Systems Incorporated to determine the necessary axial loads on the titanium generant tank hemispheres for effecting a seal at the diaphragm lip. Fig. 33 is a section through the test device which is capable of testing a 6-in. portion of the diaphragm lip.

The two lip configurations shown in Fig. 34 were tested. Resulting data, in the form of unit loads/lin. in. of diaphragm lip vs diaphragm deflection, are shown in Fig. 35. The lip configuration shown in Fig. 34a was chosen for use in the generant tank because of simplicity of fabrication. Even though the axial load required was slightly higher, one less machining operation was required because of the elimination of the 15 deg angle. It was determined that a load of 50 lb/lin. in. was required to effect a seal at the diaphragm lip for the chosen configuration.

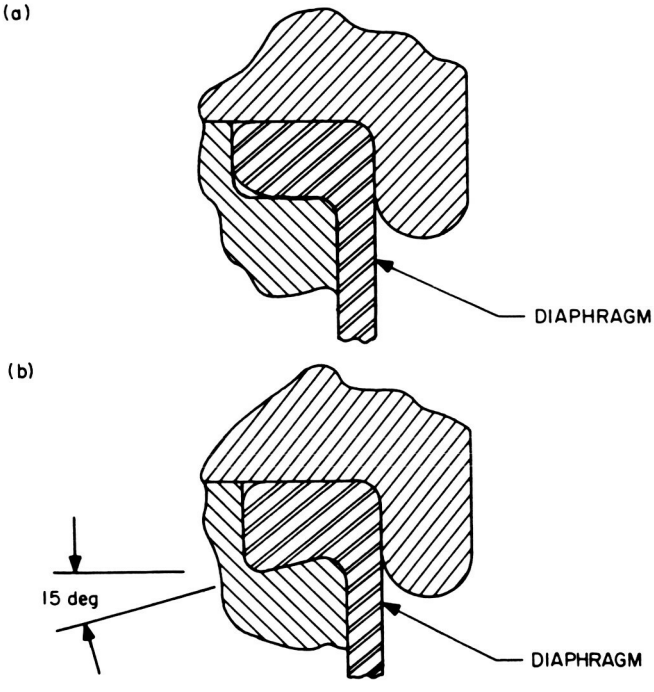


Fig. 34. Diaphragm-lip test configurations

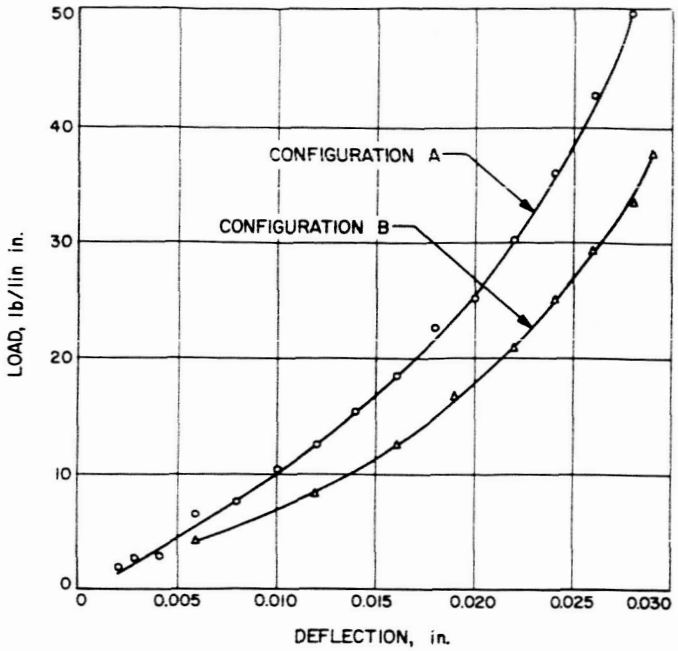


Fig. 35. Diaphragm load per lineal in. vs diaphragm deflection: Pressure Systems, Inc. data

To prevent extrusion of the diaphragm-type bladder at the point of propellant depletion, a sievelike barrier plate, such as in Fig. 36, was incorporated in the generant tank outlet port. A test program was carried out to determine the optimum ratio of diaphragm thickness to barrier hole diameter (t/d) as a function of the final generant tank pressure. Table 5 is a tabulation of the various diaphragm materials and hole sizes tested. The tests were performed in a test fixture such as shown in Fig. 37. With the exceptions of test items 18 and 19 (Table 5) all diaphragm failures occurred at t/d ratios < 1.

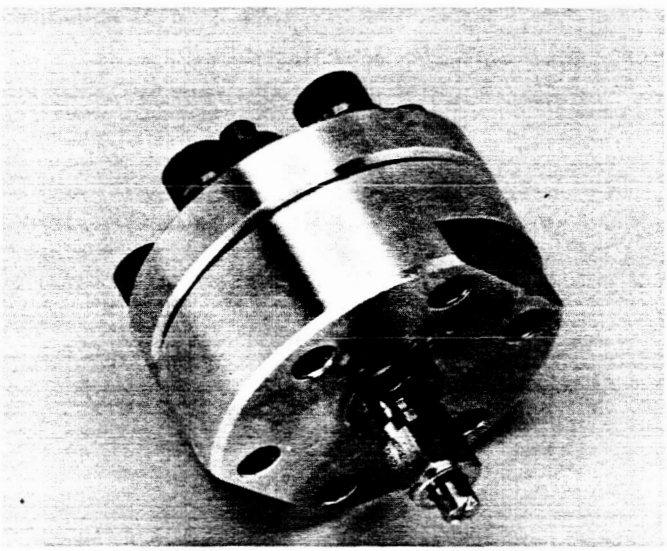


Fig. 37. Test fixture for extrusion testing of diaphragm-type bladder samples

The failures that occurred in Items 18 and 19 in Table 5 were attributed to the low shore hardness of the test material; see Fig. 38. For comparison Fig. 39 shows a test sample of LS-53 which failed after being tested at 1500 psig pressure for 3 min. Fig. 40 shows the appearance of a butyl test sample after it had been successfully tested for 22¼ hr at a pressure of 1500 psig using a barrier plate having 0.040 in. D holes. From this series of tests, using only gaseous nitrogen or water, it

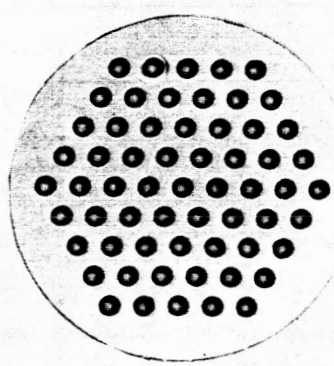


Fig. 36. Flight-type generant tank outlet barrier

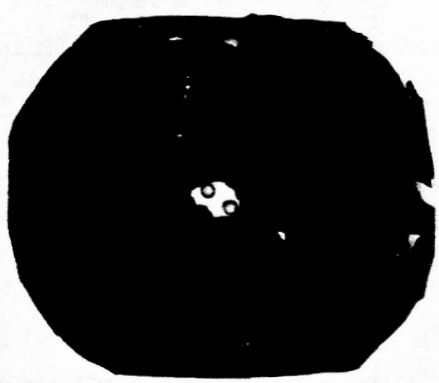


Fig. 38. Silicone extrusion test sample after test with barrier having 0.040-in. D holes

Table 5. ALPS generant tank diaphragm extrusion tests

Item	Test pressure, psig	Test fluid	Test duration, hr	Cycles	Material thickness, in., t	Plate hole, in., d	t/d	Test material	Shore hardness, A	Remarks
1	1500	H_2O	0.25	1	0.047	0.062	0.758	E 515-8 (EPR)	81	Very slight marks
2	2000	H_2O	0.25	1	0.047	0.062	0.758	E 515-8 (EPR)	81	Very slight marks
3	1500	H_2O	0.08	10	0.047	0.062	0.758	E 515-8 (EPR)	82	Slight marks
4	1500	H_2O	0.08	50	0.068	0.062	1.098	SR 722-70 (EPR)	65	Heavy marks
5	1500	GN_2	65.0	1	0.078	0.062	1.259	SR 722-70 (EPR)	65	Substantial marks
6	1500	GN_2	0.08	1	0.035	0.062	0.565	SR 634-70 (butyl)	81	Failed after 5 min
7	800	GN_2	22.0	1	0.041	0.062	0.661	E 515-8 (EPR)	82	Slight marks
8	1500	GN_2	24.0	1	0.062	0.040	1.550	Neoprene	61	Slight marks
9	1500	GN_2	24.0	1	0.080	0.062	1.290	SR 634-70 (butyl)	68	Slight marks
10	1500	GN_2	24.0	1	0.043	0.040	1.075	FR 6-60-26 (butyl)	65	Substantial marks
11	1500	GN_2	0.11	1	0.043	0.062	0.693	FR 6-60-26 (butyl)	67	Failed after 7 min
12	1500	GN_2	24.0	1	0.062	0.062	1.0	Neoprene	61	Slight marks
13	1500	GN_2	22.25	1	0.035	0.040	0.875	SR 634-70 (butyl)	80	Substantial marks
14	800	GN_2	24.0	1	0.041	0.040	1.025	E 515-8 (EPR)	83	Very slight marks
15	1500	GN_2	24.25	1	0.080	0.040	2.0	SR 634-70 (butyl)	71	Slight marks
16	1500	GN_2	—	—	0.033	0.040	0.825	GE-RTV-60—teflon	90	Failed at 1200 psig
17	1500	GN_2	—	—	0.033	0.062	0.532	GE-RTV-60—teflon	90	Failed at 1180 psig
18	1500	GN_2	0.11	1	0.102	0.040	2.55	Raybestos-Manhattan fluoray	45	Failed after 7 min
19	1500	GN_2	—	—	0.102	0.062	1.645	Raybestos-Manhattan fluoray	45	Failed at 860 psig
20	1500	GN_2	42.5	1	0.037	0.062	0.596	Styrene butadyene	80	Substantial marks
21	1500	GN_2	25.0	1	0.037	0.040	0.925	Styrene butadyene	81	Substantial marks
22	1500	GN_2	—	—	0.033	0.062	0.532	LS-53	79	Failed at 1280 psig
23	1500	GN_2	—	—	0.033	0.062	0.532	LS-53	80	Failed at 20 psig
24	1500	GN_2	0.05	1	0.033	0.040	0.825	LS-53	80	Failed after 3 min
Long term tests										
1-1	800	GN_2	7,427	1	0.035	0.040	0.875	SR 634-70 (butyl)	—	Test still in progress

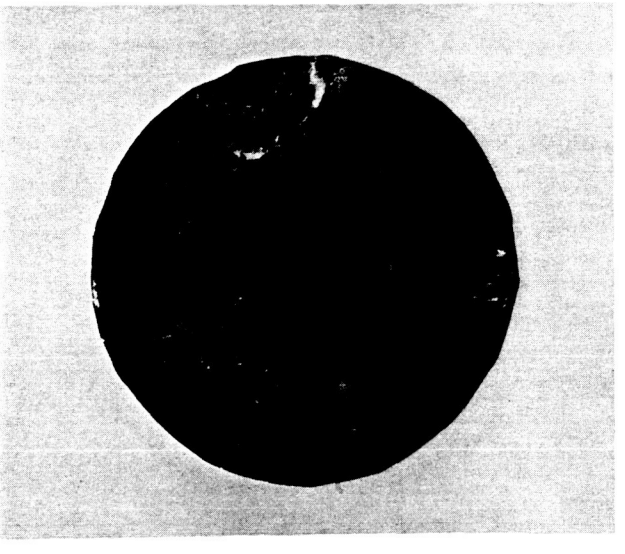


Fig. 39. LS-53 extrusion test sample after test with barrier having 0.040-in. D holes

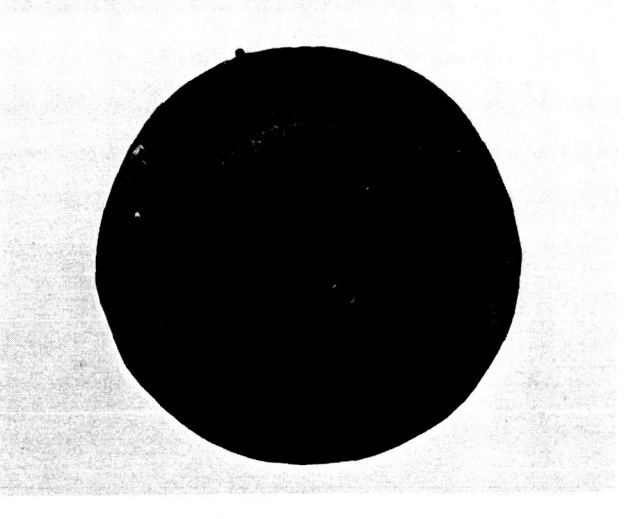


Fig. 40. Butyl extrusion test sample after test with barrier having 0.040-in. D holes

appeared that butyl and ethylene propylene compounds were the most satisfactory elastomers for this application. No tests using samples exposed to hydrazine have been performed to date.

Also the thickness of the diaphragm-type bladder was increased by a factor of 2 in the vicinity of the outlet barrier plate, resulting in local t/d ratios of 1½ to 3. In general it was found that a relatively small increase in thickness of the elastomeric diaphragm had little or no effect on expulsion efficiency.

For a number of years compatibility studies and tests have been under way at the Jet Propulsion Laboratory in order to identify the best materials for use in hydrazine. It seems that the most promising elastomeric materials are butyl and ethylene propylene. As can be seen from the data in Table 6, the butyls are very good from a permeability resistance point of view while the ethylene propylene compounds are better from an overall compatibility point of view. Ref. 4 is a more detailed discussion of preliminary compatibility testing.

The results of permeability tests show that the permeability of a good butyl compound, Stillman Rubber Company Compound SR 634-70 is approximately 0.0005 mg/in.^{2}/hr for a 0.040 in. thick sample after a test duration of 95.7 hr. By comparison, the permeability of an ethylene propylene compound, Parker Seal Company compound E 515-8 is indicated as 0.029 mg/in.^{2}/hr for a

Table 6. Results of permeability and compatibility tests of polymeric materials and hydrazine

Source	Compound number	Polymer	Permeability at 72°F		Effect on hydrazine			
			Average rate; mg/in.^{2}-hr	Test duration, hr	Change in composition		Pressure rise in 10 days, psi	Number of days to reach 30 psia
					%	No. of days		
The Connecticut Hard Rubber Company, New Haven, Connecticut	3609	Butyl	0.001	95.7	0.72	71	5	55
	3818	SBR[a]	0.15	95.7	—	—	3	153
	3906	SBR	0.13	95.6	—	—	3	148
	3954	SBR	0.21	116.75	—	—	4	97
	4131	Butyl	0.0004	116.75	0.92	77	5	58
	4706	PBR[b]	0.204	116.75	1.38	71	9	34
	4610	SBR	0.131	96.5	—	—	5	121
	4762	Synpol	0.229	100.5	1.42	98	6	55
E. I. Dupont de Nemours, Inc., Wilmington, Delaware	5109D-590	EPR[c]	—	—	2.4	10	42.5	9
Fargo Rubber Corporation, Los Angeles, California	FR 6-50-3	Butyl	—	—	1.0	61	8	30
	FR 6-60-26	Butyl	—	—	0.72	105	1	87
	FR 6-60-26	Butyl	—	—	—	—	37	1
	FR 6-60-26	Butyl	—	—	0.4	73	5	48
	FR 6-60-27	EPR	0.013	95.7	0.59	71	10	34
Hadbar, Inc., Alhambra, California	XB-800-71	Butyl	0.0004	96.5	1.12	98	2	65
	G.E. RTV-60	Silicone	—	—	—	—	2	—
Parker Seal Company, Culver City, California	E 515-8	EPR	0.029	99.0	—	—	—	—
	E 515-8	EPR	—	—	—	—	0	—
	E 515-8	EPR	0.018	96.2	—	—	—	—
	E 515-8	EPR	0.036	168.8	—	—	—	—
	E 515-8	EPR	0.033	168.8	—	—	—	—
Stillman Rubber Div., Electrada Corporation, Culver City, California	SR 613-75	Butyl	—	—	1.0	35	14	20
	SR 634-70	Butyl	0.0005	95.7	0.71	78	2	64
	SR 634-70	Butyl	—	—	—	—	40	5
	SR 634-70	Butyl	—	—	0.4	69	8	39
	SR 722-70	EPR	—	—	—	—	3	—
	SR 722-70	EPR	—	—	—	—	2	—
	SR 722-70	EPR	Nil	97	—	—	—	—
	SR 722-70	EPR	0.001	97	—	—	—	—
	SR 722-70	EPR	0.001	97	—	—	—	—
	SR 722-70	EPR	0.045	70	—	—	—	—
	EX 1004-70	EPR	0.03	116.7	0.97	35	10	24
	EX 9835-75	EPR	—	—	—	—	6	—
	EX 9835-75	EPR	—	—	—	—	2	—

[a]SBR — Styrene-Butadiene Rubber
[b]PBR — Polybutadiene Rubber
[c]EPR — Ethylene-Propylene Rubber

0.030 in. thick sample after a test duration of 99.0 hr. It is felt that the resistance to permeability of the ethylene propylene compound can be improved substantially by increasing the diaphragm thickness by a factor of 2 or possibly 3, without drastically affecting expulsion efficiency. Of these two classes, the ethylene proplyenes are generally considered as the first choice for diaphragm materials; the butyls, the second choice. The titanium generant tank was designed in such a manner that either of the above elastomers would be satisfactory for effecting a seal at the diaphragm lip.

For the flight-type version of the generant tank, the ethylene propylene compound was chosen because of its greater compatibility with hydrazine. The chosen configuration was fully ribbed as shown in Fig. 5; this latter choice was based upon the expulsion efficiency determined in previous tests.

3. Barrier Plate and Outlet Boss

The outlet barrier plate was established as follows: As described above, it was determined experimentally that a t/d ratio > 1 is desirable to prevent extrusion of the elastomeric diaphragm through the outlet holes at the point of propellant depletion. In the above expression, t is the diaphragm thickness; d, the diameter of the holes. To increase this ratio, it is desirable to maintain the hole diameter at a minimum consistent with the state-of-the-art fabricational limitations for machining titanium. The final hole diameter was chosen as 0.040 in. The entrances to each hole were rounded with a 0.020 in. rad. This barrier plate contains 61 holes located in a hexagonal pattern for a total area of 0.0765 $in.^2$ as shown in Fig. 36. This provides a flow area 3.29 times greater than the area of the generant tank outlet tube.

A similar barrier containing nineteen 0.040 in. D holes arranged in a hexagonal pattern, has been provided at the pressurization port to prevent extrusion of the diaphragm in the event that the diaphragm is inadvertently reversed as during the generant tank venting operation, for example.

The outlet boss configuration evolved as changes were made to the outlet anti-extrusion element. In review, the first design used consisted of a saddle-like perforated plate as shown in Fig. 11. This was used in conjunction with the outlet fitting as shown in Fig. 12. The design was then changed to a smaller one as shown in the center of Fig. 13; and finally to its present configuration as shown in Fig. 36. Externally, both the outlet boss and the pressurization boss were designed to function as points of generant tank support.

4. Mounting and Handling

The integration of the flight-type titanium generant tank with the overall ALPS system will require incorporation of suitable mounting provisions. No mounting provisions have been made to date, particularly in the area adjacent to the generant tank girth weld. The outlet and pressurization bosses have been machined, however, for possible use as support points. Mounting bosses located in the vicinity of the girth weld could interfere with the water-cooled chill rings required for making the generant tank girth weld. If mounting bosses are required in the girth weld area, they should be located away from the diaphragm lip on the gas-side hemisphere. The forging dies for manufacturing the titanium hemispheres have been designed with adequate wall thickness for accommodating integral structural mounting bosses, should such bosses be required in the future.

For convenience in transporting and handling, special handles were mounted at the pressurization and outlet ports. Wooden boxes were made for purposes of protective storage and transportation.

During water expulsion testing, the flight-type generant tank was mounted in a protective wood cradle as shown in Fig. 41. The assembled titanium tank and protective wood cradle were then installed in the water expulsion test facility.

C. Fabrication of Flight-Type Tank

The initial program, including procurement of hardware and some machining, was carried out at the Electrada Corporation, Airite Division, Los Angeles, California. The fabrication of the flight-type titanium generant tanks was later continued and completed by Pressure Systems Incorporated, City of Commerce, California.

Three flight-type generant tanks have been successfully fabricated to date in addition to the first flight-type development tank which was used for determining the final welding settings. Pertinent information covering this phase is presented in further detail below.

1. Tooling

Special machining templates were utilized to perform the contour machining of the titanium hemispheres. The

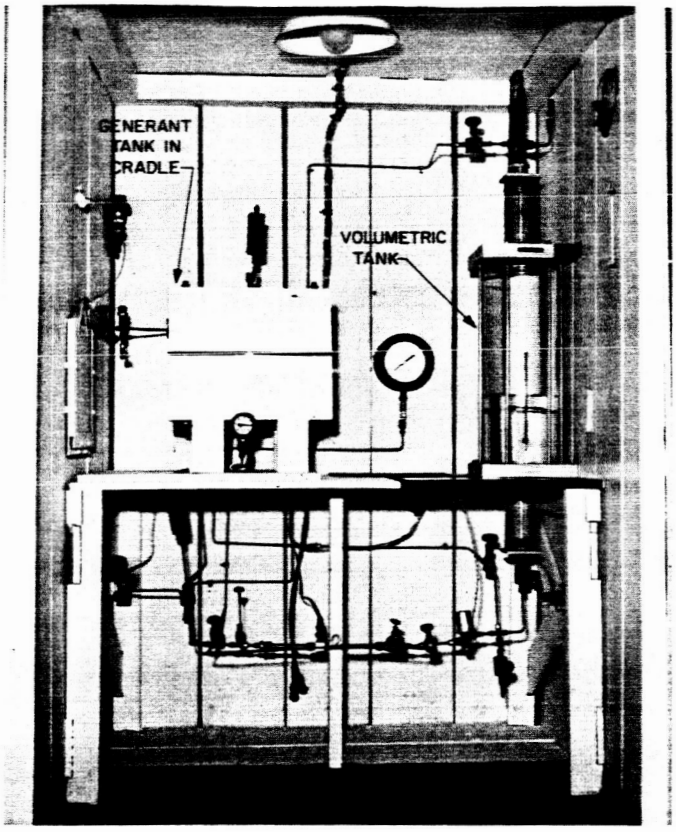


Fig. 41. Flight-type titanium generant tank mounted in protective wood cradle, upright position, for water-expulsion testing

majority of the generant tank fabrication time was consumed during this very critical operation. The difficulty of machining titanium can be compared with that of machining 347 stainless steel. This inherent difficulty of machining, plus required close wall thickness tolerances and a constantly changing contour added to the fabrication complexity.

A critical tooling component used in the generant tank fabrication process was the holding fixture for supporting the titanium hemispheres during the contour machining operation. During the machining of S/N 004 flight-type generant tank, the above holding fixture loosened, which caused a machining gouge to occur on the external surface of the liquid-side hemisphere. Fabrication of this tank was completed and the tank was used at slightly reduced operating pressures. However, no changes were made since the tooling was considered adequate.

a. Forging dies. The dies for forging the titanium generant tank hemispheres were designed with adequate wall thickness for accommodating the integral structural support bosses in the girth weld area if these are required at some future date. Presumably the structural support bosses would be located on the gas-side hemisphere only. The gas-side forging and liquid-side forging were made identical so that only one set of forging dies was required.

b. Molding dies. The dies for molding the elastomeric diaphragms were of necessity rather large. This mass of metal proved to be troublesome to one of the diaphragm vendors during the curing operation. Provisions have been made on the interior of the dies for forming the integral rib pattern as described in Secton IIC.

c. Chill rings. During the fabrication of the titanium weld feasibility test tank, as described in Section VB above, water-cooled copper chill rings were used (Fig. 28) to cool the titanium tank in the vicinity of the generant tank girth weld. No provisions were taken at this time, however, for applying an axial load to the generant tank hemispheres.

During the fabrication of the flight-type titanium tanks, aluminum water-cooled chill rings were used as shown in Fig. 42. Push rods, as shown, were used to provide the required axial load on the titanium tank hemispheres for effecting a seal at the diaphragm lip. Thermocouple leads are shown entering the gas-side hemisphere (left side of Fig. 42) for the purpose of monitoring back-up ring temperatures during the welding

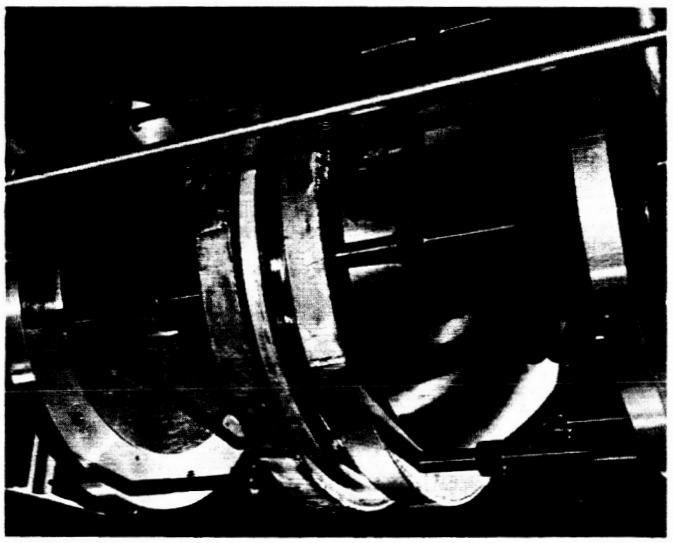


Fig. 42. Experimental girth-weld setup of first flight-type titanium generant tank

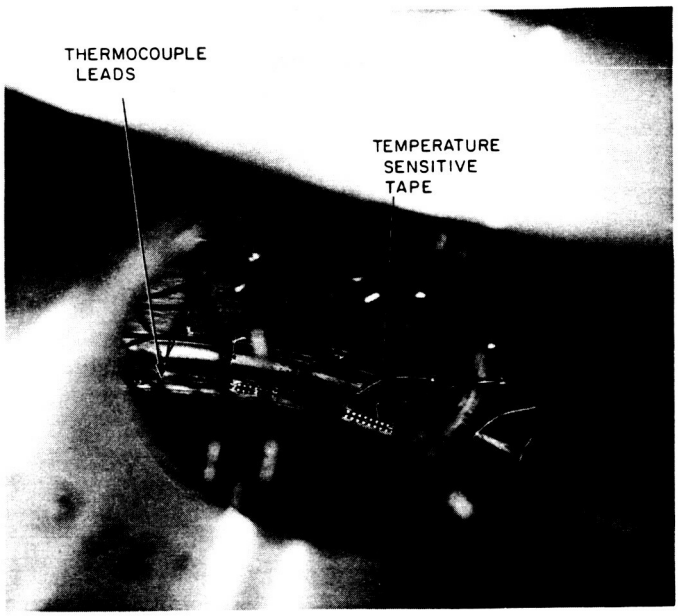


Fig. 43. Thermocouple leads and temperature-sensitive tape on back-up ring of S/N 001 titanium generant tank, as viewed through access hole

operation. Fig. 43 illustrates the interior of S/N 001 experimental flight-type tank viewed through an access port, showing the thermocouple lead attachment points. Between the thermocouple leads can also be seen, Fig. 43, strips of temperature sensitive tape attached to the back-up ring for further monitoring of the back-up ring temperatures.

The temperature sensitive tape has two rows of white dots. The lower row of dots, adjacent to the diaphragm (dark area) has been calibrated to discolor at 375°F, the upper row, at 350°F.

Figure 44 illustrates S/N 001 experimental flight-type titanium generant tank after completion of the girth weld. Thermocouple leads can be seen entering the gas-side hemisphere through one of the generant tank access openings.

Each of the chill rings as shown in Fig. 42 has four machined grooves for channeling the flow of the circulating water, the channel nearest the girth weld containing the coldest water. The circulating water was pumped through the chill rings at an optimum rate of approximately 1.45 gal/min to a recirculation tank as shown in Fig. 45. The various welding settings and circulating water flow rates for the experimental flight-type titanium gererant tank are shown in Table 7.

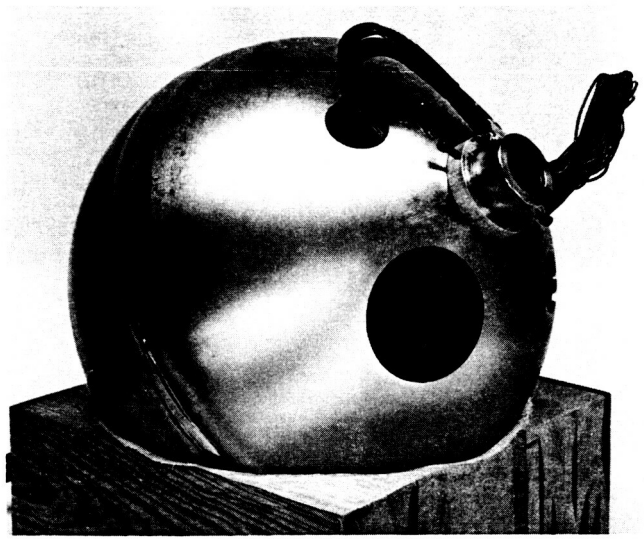


Fig. 44. S/N 001 experimental flight-type titanium generant tank after completion of girth weld

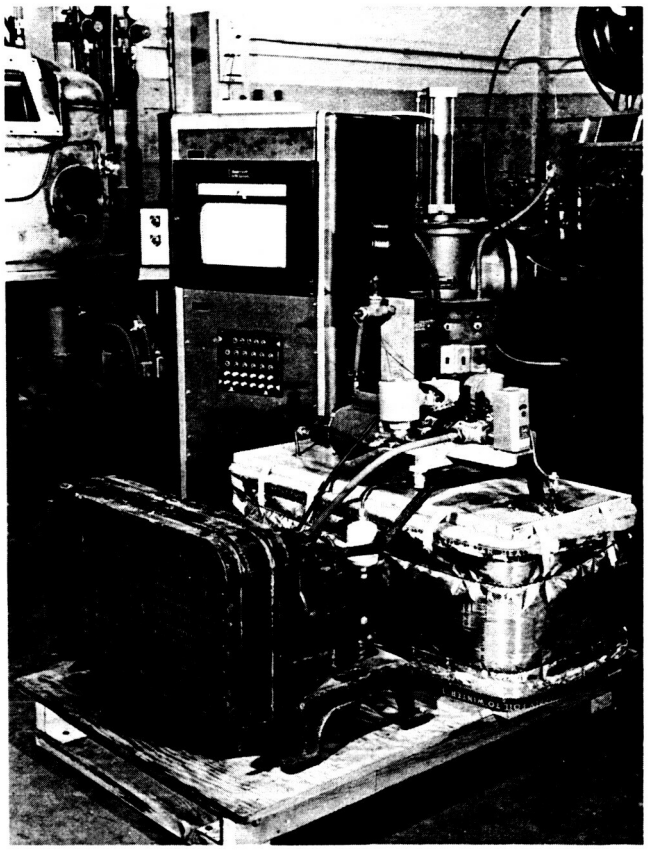


Fig. 45. Circulating-water system for water-cooled chill rings for welding flight-type generant tanks

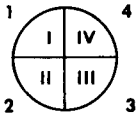
Table 7. Welding parameters

Item	Segment no.	Sta. no.	Lineal speed, in./min	Welding		Wire feed, in./min	Water temp. at start	Temp. rise	Water flow gal/min	Back-up ring Max. temp. °F			Remarks
				Amps	Volts, dc					Direct reading thermo-couple	Thermo-couple	Temperature tapes	
1 2 3 4	II I IV III	3-2 2-1 1-4 4-3	5.55 ↓	55/60 ↓	8.0 ↓	None ↓	None ↓	None ↓	None ↓	None ↓	None ↓	None ↓	Eight tacks equally spaced prior to welding. Shrinkage 0.025–0.030. Weld hot. Bladder not mounted to ring at this stage.
(Fusion pass: back-up strip to gas side hemisphere)													
5	I	2-1	2.96/4.93	70.0	8.0	None	65°F	3°	1.27	None	340	$T > 350$	All 350°F dots discolored.
6	IV	1-4	4.93	70.0	8.0		62°F	6°	1.34		340	$T > 350$	
7	III	4-3	6.16	75.0	8.0		62°F	6°	1.32		320	$T > 350$	350°F dots discolored, one place.
8	II	3-2	7.40	80.0	8.0		52°F	4°	1.27	312	301	$T < 350$	Dot reading TC #5, max. temp. 312°F.
(Fusion pass: back-up strip to fuel side hemisphere)													Bladder installed.
9	I	1-2	4.93/6.16	100.0	8.0	14/18/20	52°F	3°	1.32	326	350	$T < 375$	Setting charged at 1 min 10 sec.
10	II	2-3	10.5	150.0	9.5/10.0	20.0	52°F	4°	1.32	376	370	$T > 350$	Run time 1 min 30 sec. All 350°F dots discolored.
11	III	3-4	14.8	165/150	10.0	40/35	53°F	3°	1.32	323	330	$T < 350$	Run time 1 min 15 sec. No discoloration 350°F dots.
12	IV	4-1	7.4	110.0	9.0	16/20	52°F	3°	1.27	312	350	$T < 375$	Run time 1 min 35 sec. No discoloration 375°F dots.
(First wire pass)													
13 14 15 16	IV III II I	1-4 4-3 3-2 2-1	7.40 ↓	65.0 ↓	8.0 ↓	None ↓	50°F ↓	4° ↓	1.27 ↓	256 ↓	280 ↓	$T < 350$ ↓	Max. torch angle continuous weld 360° without stop. No discoloration of 350°F dots.
(Wash pass to fuel side hemisphere)													
17 18 19 20	IV III II I	1-4 4-3 3-2 2-1	7.40 ↓	65.0 ↓	8.0 ↓	None ↓	50°F ↓	3° ↓	1.34 ↓	205 ↓	240 ↓	$T < 350$ ↓	Max. torch angle continuous weld 360° without stop. No discoloration of 350°F dots.
(Wash pass to gas side hemisphere)													
21	I	1-2	7.40	110.0	8.0	20.0	48°F	4°	1.34	327	350	$T > 350$	Replaced temp sensitive tape. All 350°F dots discolored.
22	II	2-3	14.80	162.0	10.0	36.0	49°F	4°	1.34	322	310	$T < 350$	No discoloration of 350°F dots, groove configuration after machining (approx.) same as previous wash pass.
(Second wire pass—machined out)													

Remarks: 1 I, 4 IV, 2 II, 3 III — Quadrant orient

Table 7. Welding parameters (cont'd)

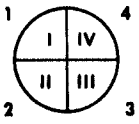
Item	Segment no.	Sta. no.	Lineal speed, in./min	Welding		Wire feed, in./min	Water temp. at start	Temp. rise	Water flow gal/min	Back-up ring Max. temp °F			Remarks
				Amps	Volts, dc					Direct reading thermo-couple	Thermo-couple	Temperature tapes	
23	I	1-2	12.33	150.0	10.0	20.0	48°F	4°	1.37	277	310	$T < 350$	No discoloration of 350°F dots except during starting transient before part was up to proper speed. Weld slightly cold.
24	II	2-3	12.33	158.0	10.0	20.0	48°F	4°	1.37	337	350	$T < 350$	No discoloration of 350°F dots, first two strips of tape. All 350°F dots discolored last four strips of tapes.
25	III	3-4	14.8	160.0	9.0	24.0	50°F	4°	1.42	277	310	$T < 350$	No discoloration of 350°F dots, slight crown can be washed out.
26	IV	4-1	13.56	160.0	9.0	23/25	50°F	4°	1.37	296	350	$T > 350$	Some discoloration of 350°F dots at start. All 350°F dots discolored at end of run, weld flat, no crown. Could be washed out. Weld acceptable. Visual only.
						(Second wire pass)							
27 28 29 30	I IV III II	2-1 1-4 4-3 3-2	14.8 ↓	65.0 ↓	8.0 ↓	None ↓	47°F ↓	3° ↓	1.42 ↓	270 ↓	280 ↓	$T < 350$ ↓	Max. torch angle continuous weld 360° without stop. No discoloration of 350°F dots. Start at station 2.5.
						(Wash pass to fuel side hemisphere)							
31 32 33 34	I IV III II	2-1 1-4 4-3 3-2	14.8 ↓	65.0 ↓	8.0 ↓	None ↓	47°F ↓	3° ↓	1.42 ↓	225 ↓	220 ↓	$T < 350$ ↓	Max. torch angle continuous weld 360° without stop. No discoloration of 350°F dots. Start at station 2.5.
						(Wash pass to gas side hemisphere)							
35	I	1-2	13.56	160.0	9.5	24.5	50°F	4°	1.42	—	310	$T > 350$	350°F dots discolored one place.
36	II	2-3	14.18	160.0	9.5/10.0	25.0	50°F	5°	1.42	324	332	$T > 350$	All 350°F dots discolored. Weld good, flat with fillets at edges.
37	III	3-4	14.8	162/161	10.0/9.0	25.0/24.0	50°F	4°	1.42	341/297	291	$T < 350$	No discoloration of 350°F dots. Weld good. Had slight crown. Can be washed. One strip 350°F discolored on edge. Potentiometer was 341°F at start and 297°F at stop.
						(Third wire pass)							
38	IV	4-1	14.8	163/162	10.0/9.0 /8.7	24.0	50°F	4°	1.40	292	290	$T > 350$	Smooth flat weld. Close overlap of weld bead. 350°F dots discolored first tape only.



Quadrant orient

Table 7. Welding parameters (cont'd)

Item	Segment no.	Sta. no.	Lineal speed, in./min	Welding		Wire feed, in./min	Water Temp. at start	Temp. rise	Water flow gal/min	Back-up ring (Max.) temp. °F			Remarks
				Amps	Volts, dc					Direct reading thermo-couple	Thermo-couple	Temperature tapes	
39	I	2-1	7.4	70.0	7.5	None	50°F	4°	1.42/1.48	272	310	No data	Max. torch angle continuous weld 360° without stop.
40	IV	1-4	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	
41	III	4-3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	
42	II	3-2	↓	↓	(Wash pass to fuel side hemisphere)	↓	↓	↓	↓	↓	↓	↓	
43	I	2-1	7.4	65.0	7.5	None	50°F	4°	1.42/1.48	279	254		Max. torch angle continuous weld 360° without stop.
44	IV	1-4	↓	↓	↓	↓	↓	↓	↓	↓	↓		
45	III	4-3	↓	↓	↓	↓	↓	↓	↓	↓	↓		
46	II	3-2	↓	↓	(Wash pass to gas side hemisphere)	↓	↓	↓	↓	↓	↓		
47	II	2-3	14.8	150	9.0	25.0	50°F	4°	1.42/1.48	238	279		Weld has slight crown. Start at station 2.3. Weld beads slightly coarse.
48	III	3-4	↓	↓	↓	↓	↓	↓	↓	↓	↓		
49	IV	4-1	↓	↓	↓	↓	↓	↓	↓	↓	↓		
50	I	1-2	↓	↓	(Fourth wire pass—angle to gas side hemisphere)	↓	↓	↓	↓	↓	↓		
51	II	2-3	14.8	160.0	10.5	28.0	50°F	4°	1.42/1.48	292	321		Weld has slight crown. Weld bead very smooth.
52	III	3-4	↓	160.0	9.75	↓	↓	↓	↓	↓	↓		
53	IV	4-1	↓	152.0	9.50	↓	↓	↓	↓	↓	↓		
54	I	1-2	↓	152.0	9.00	↓	↓	↓	↓	↓	↓		
				(Fifth wire pass—angle to fuel side hemisphere)									
55	II	2-3	14.8	158.0	10.0	25.0	50°F	4°	1.42/1.48	275	310		Weld has slight crown. Weld beads very smooth. 10 min to cool to 50°F. Say 15 min between passes.
56	III	3-4	↓	156.0	10.0	23.0	↓	↓	↓	↓	↓		
57	IV	4-1	↓	155.0	10.0	25.0	↓	↓	↓	↓	↓		
58	I	1-2	↓	155.0	9.75	25.0	↓	↓	↓	↓	↓		
				(Sixth wire pass—angle to gas side hemisphere)									
59	I	2-1	14.8	150/152	10/9.7	None	50°F	4°	1.42/1.48	292/304	314		
60	IV	1-4	↓	↓	↓	↓	↓	↓	↓	↓	↓		
61	III	4-3	↓	↓	↓	↓	↓	↓	↓	↓	↓		
62	II	3-2	↓	↓	(Wash pass to fuel side hemisphere)	↓	↓	↓	↓	↓	↓		
63	I	2-1	14.8	140/139	9.5	None	50°F	4°	1.42/1.48	246/252	241	↓	Total weld shrinkage after welding 0.120 (approx.).
64	IV	1-4	↓	↓	↓	↓	↓	↓	↓	↓	↓		
65	III	4-3	↓	↓	↓	↓	↓	↓	↓	↓	↓		
66	II	3-2	↓	↓	(Wash pass to gas side hemisphere)	↓	↓	↓	↓	↓	↓		



Quadrant orient

A refrigeration unit was connected to the recirculation tank as shown in Fig. 45. The optimum temperature of the water in the recirculation tank at the start of a given welding pass was found to be approximately 50°F. A 10 min recovery period between welding passes was used to allow the water in the recirculation tank to return to its initial temperature. During a welding pass the nominal temperature rise of the water in the recirculation tank was about 4°F.

2. Welding Parameters

The total electrical power input going into the weld is a function of the welding voltage and the welding amperage. Welding voltage is also a function of the height of the welding electrode above the point of welding. Other critical factors include welding speed, wire feed rate, circulating water temperature, and water flow rate. These welding parameters have been tabulated for S/N 001 experimental flight-type titanium tank as shown in Table 7.

Prior to welding, the welding chamber pressure was reduced to about 20-μ Hg. The welding chamber was then filled with an inert gas such as argon (or a mixture of argon and helium) to a pressure of 2 to 3 psig.

a. Welding speed. In order to meet the requirements of the flight-type generant tank, it was necessary to perform the girth weld at the melting point of titanium (3270°F), or higher, while maintaining the diaphragm temperatures, only 0.65 in. from the weld, at 350°F or lower. One of the most critical parameters for performing the above operation was welding speed. Initial welding speeds were on the order of 5 in./min; in all cases, the temperature sensitive tape indicated a temperature greater than 350°F. Final welding speeds used were increased, by a factor of three, to 15 in./min. Welding temperatures as indicated by the temperature sensitive tape were below 350°F.

b. Welding current. The optimum value of welding current depends on the welding power required to achieve complete weld penetration while maintaining the diaphragm lip temperatures below 350°F. For the fusion passes (no wire added) a welding current of approximately 65 amp was used. For the wire passes, a welding current of approximately 160 amp was used, Table 7.

c. Welding voltage. For a given amperage, the welding voltage is a function of the height of the electrode above the work and the melting point of the material being welded. While the amperage can be controlled relatively accurately, using the proper instrumentation, the voltage is a function of the welding operator's judgment as to how well the molten metal is flowing. At welding voltages of 8 to 10 v, it is not uncommon to have voltage variations on the order of ± 1 v; such variations in voltage can result in large variations in the resulting localized temperatures at the diaphragm lip, and could result in localized overheating of the diaphragm.

d. Welding wire feed rate. Another critical parameter in conjunction with the welding amperage and welding voltage was welding wire feed rate. At the slower wire feed rates, the weld tends to run hotter; at the faster wire feed rates, the weld tends to run cooler. During the first wire pass, quadrant II, Table 7, a wire feed rate of 20 in./min was used. During the welding of this quadrant, all of the 350°F dots were discolored. During the welding of the next quadrant, the wire feed rate was approximately doubled to 35 to 40 in./min with the result that all back-up strip temperatures were below 350°F.

e. Back-up ring temperatures. During the welding of S/N 001 experimental flight-type titanium generant tank, back-up ring temperatures were monitored using thermocouples and temperature sensitive tape as shown in Fig. 43. One of the above thermocouple leads was attached to a potentiometer; the others, to a recorder. The temperature sensitive tape was observed visually after completion of the weld through one of the access holes machined in the tank. The above temperatures have been tabulated for various welding conditions as shown in Table 7. Since the cure temperatures for the elastomers used range from 330° to 370°F, it was felt that these temperatures should not be exceeded except for very brief periods during the welding operation. Figure 32 is a section through the girth weld of S/N 001 experimental flight-type generant tank showing no ill effects whatever from the high temperatures in the girth weld area.

During the fusion pass of the back-up ring to the fuel-side hemisphere the cooling water flow rate was set at 1.27 gal/min for quadrant I, Table 7. All of the 350°F dots were discolored. During the first wire pass, the cooling water flow rate was increased to 1.32 gal/min for quadrant I. No discoloration of 375°F dots was noted. All temperature sensitive tapes were replaced at this time. During the second wire pass, Table 7, Sheet 2 of 3, the cooling water flow rate was increased to 1.37 gal/min for quadrant I. No discoloration of the 350°F dots was noted except during the starting transient. On the third wire pass, the cooling water flow rate was increased to 1.42 gal/min for quadrant I. The 350°F dots were dis-

colored in one place only. On the fourth, fifth, and sixth wire passes, the cooling water flow rates varied from 1.42 to 1.48 gal/min. No cooling difficulties were noted on these passes. From the above data, it appears that a flow rate of 1.45 gal/min is close to optimum for the welding parameters as listed in Table 7.

During the fusion pass while welding the back-up ring to the fuel-side hemisphere, the initial cooling water temperature prior to welding of quadrant I was 65°F. Temperature rise during the welding of the first quadrant was 3°F. All 350°F dots were discolored; see Table 7. During the next two quadrants, the initial temperature of the cooling water prior to welding was reduced to 62°F. Temperature rise during the welding of each quadrant was 6°F. The 350°F dots were discolored at one place only. Prior to welding the final quadrant, cooling water temperature was reduced to 52°F. The maximum indicated temperature during the welding of the final quadrant was less than 350°F. Temperature rise during the welding of the final quadrant was 4°F.

On all subsequent welding passes, the cooling water temperature was reduced to 50°F, or lower, prior to initiation of the welding operation. A 10 min recovery period between welding passes was allowed for achieving the 50°F cooling water temperature.

f. Stress relief. Since the expulsion diaphragm has been assembled as an integral part of the titanium generant tank, no method has, as yet, been devised for stress relieving the ALPS generant tank after completion of the girth weld. Instead, the approach has been to design the generant tank for a yield stress based on the annealed strength of the 6AL-4V titanium alloy. According to JPL *Ranger* and *Mariner* Specification 30209, a material such as 6AL-4V titanium, used in the annealed condition, shall have a minimum yield strength of 125,000 psi and a maximum yield strength of 140,000 psi. The generant tanks fabricated to date have given no indication of problems resulting from elimination of the stress relieving operation.

g. Welding inspection. Welding inspection of the generant tank has been carried out primarily at the vendor's facility, including X-ray analysis, penetrant inspection, and the study of metallographic samples from the experimental tank.

X-ray analysis. X-ray analysis has proven to be very useful in determining adequate weld penetration, lack of fusion, the presence of inclusions and porosity. The vendor operates an X-ray facility in conjunction with its fabrication operation. Acceptance of all welds has been in conformance with MIL-R-11468, Std 1.

Penetrate inspection. MIL-R-11468, Std 1, states that all surfaces of machined parts and all welds and an area within 2 in. on each side of the weld shall be inspected by the fluorescent penetrant method in accordance with specification MIL-I-6866. All flight-type generant tanks welded during this program successfully passed penetrant inspection.

Metallographic samples. Metallographic samples such as shown in Fig. 32 have been used to study the grain structure in the weld area and to obtain a visual representation of the girth weld temperature effects on the diaphragm lip configuration.

3. Assembly Problems

In the assembly of the generant tank and generant cell, several problem areas developed such as bonding of the diaphragm to the back-up ring, the application of axial squeeze to the generant tank hemispheres for the purpose of effecting a seal at the diaphragm lip, and the elimination of the welding lip in order to achieve complete weld penetration at the girth.

Prior to assembly of the diaphragm and the generant tank hemispheres, it was first necessary to pressure test the diaphragm with helium gas at 1.5 psig as shown in Fig. 46. If the test indicated that no leaks were present, the diaphragm was bonded to the back-up ring as shown in Fig. 5. The bonded assembly was then pressure tested in a similar manner with helium gas at 1.5 psig. If no diaphragm leaks were found, the bonded assembly was then assembled with the generant tank hemispheres in preparation for making the generant tank girth weld.

The elimination of the back-up ring welding lip as described in Section VB above required a special sequence of tack welding to accomplish the assembly of the flight-type titanium generant tank.

First, the diaphragm-type bladder, bonded to the back-up ring, Fig. 5, was assembled into the gas-side hemisphere. The back-up ring and the gas-side hemisphere were then very lightly tack welded in three places as shown in Fig. 31. This preliminary tack welding was accomplished in the "hand" welding chamber, on the

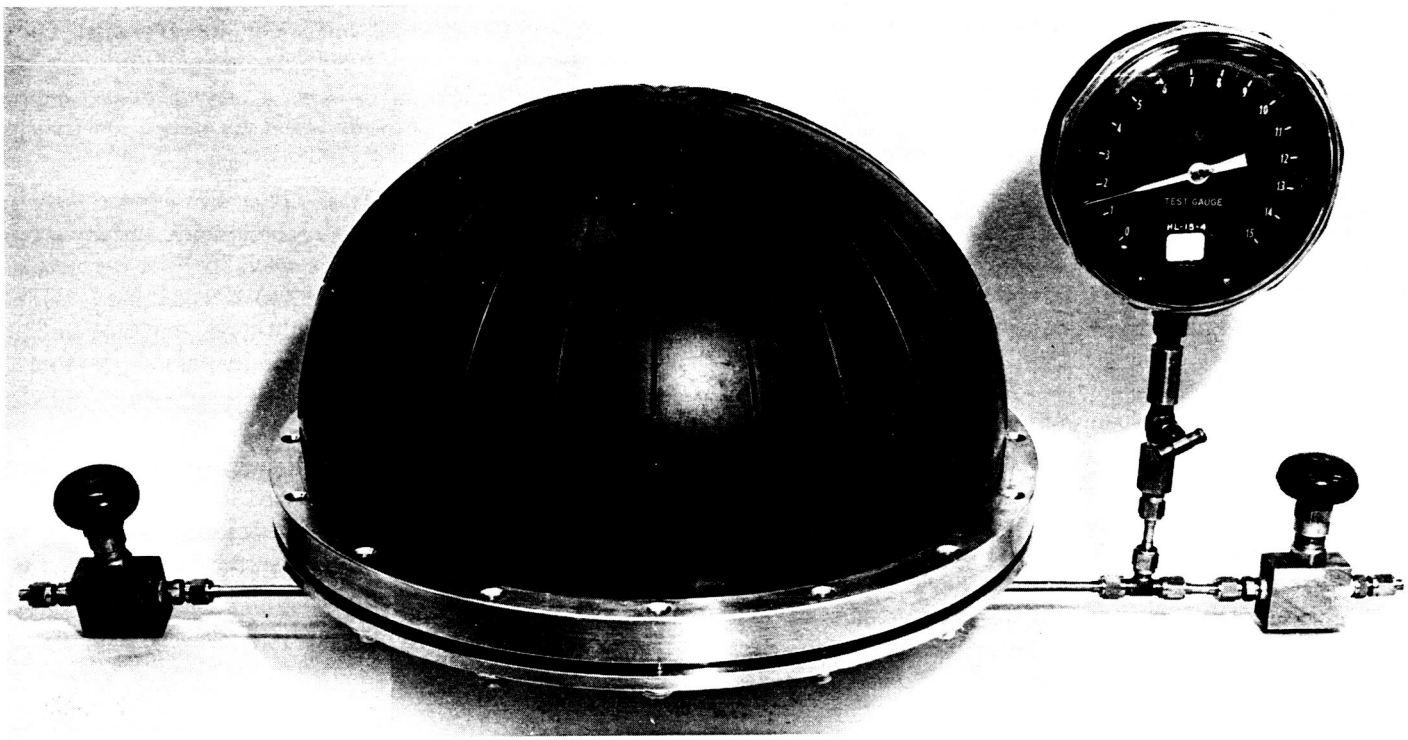


Fig. 46. Test setup for leak checking diaphragm-type bladder prior to assembly in generant tank

left-hand side of Fig. 45, without the use of chill rings or other special cooling. The weldment, now consisting of the gas-side hemisphere, the back-up ring, and the diaphragm, was then assembled with the fuel-side hemisphere using very light pressure only. During this operation, the bonding agent between the back-up ring and the diaphragm aided the assembly process. As an additional aid to the assembly process, the diaphragm-type bladder had been partially reversed, prior to assembly. Compressed air was then used to blow the diaphragm into its normal position prior to welding.

The assembled unit was then placed in the semi-automatic welding chamber, shown on the right in Fig. 45, for more substantial tack welding. Water-cooled chill rings were used for this operation as shown in Fig. 42. The back-up ring was then more substantially tack welded to the gas-side hemisphere using twelve equally spaced tacks approximately ½ in. in length. The generant tank weldment, as described above, was removed from the semi-automatic welding chamber for the purpose of tightening the jack screws. A force of 50 lb per lineal in. at the tank periphery was required to effect a seal at the diaphragm lip as described in Section VB2 above. After two preliminary fusion passes, the girth weld was ready for the first wire pass, Items 1 through 8, Table 7.

4. Cleaning

Removal of internal contamination and cleaning the flight-type titanium generant tanks involved using a detergent solution followed by thorough rinsing with distilled water.

The tank was dried by simultaneously applying a vacuum of 25-in. Hg, or greater, to the pressurization port and outlet port for a minimum duration of 30 min. The tank was then allowed to drain through the pressurization port for a minimum of 1 hr. The above steps were repeated until there was no evidence of water draining from the pressurization port.

5. Special Problems

a. Weld shrinkage. The center of the girth joint was specified to maintain its true ID within $\pm 0.2\%$ after welding except for upset or drop through. For a tank with an ID of 16.50 in., this meant a total diametral change not to exceed 0.033 in. On the ALPS generant tank, this diametral shrinkage amounted to 0.050 in., or about 50% out of the guiding specification (equivalent to $\pm 0.3\%$).

The above shrinkage at the girth weld had no ill effects whatever on the expulsion characteristics of the flight-type titanium generant tank.

b. Back-up ring venting. Eight 0.040 in. vent holes were machined into the back-up ring, Fig. 31. These vent holes were used to prevent a pressure build up from occurring between the diaphragm lip and the girth weld during the welding operation.

Also if a leak should occur on the gas-side of the diaphragm lip, pressure would build up behind the lip and cause extrusion of the lip during the generant tank venting operation.

c. Sharp edges. An attempt was made to eliminate all sharp edges from the interior of the generant tank to prevent possible damage to the elastomeric diaphragm. This includes the provision of rounded entrances to the back-up ring vent holes, the pressurization port and the outlet barrier plate holes.

d. Diaphragm replacement.

Repair serial number 003. During the proof testing of S/N 003 flight-type generant tank, the diaphragm failed at a proof pressure of 2250 psig. This failure was attributed to the overload of water which had been placed in the liquid-side hemisphere as a precautionary measure to minimize the high pressure gas volume involved in the test. In order to demonstrate the capability of replacing a damaged diaphragm, it was decided to repair S/N 003 generant tank.

The tank was therefore carefully parted at the girth weld, and the diaphragm removed by machining the edge of the back-up ring. The edges of the hemispheres were built up with weld metal and then machined to the original J-groove configuration. To compensate for shrinkage at the girth weld, a new back-up ring was custom fitted to the existing tank diameter which was now 0.050 in. smaller than the original tank diameter. After bonding a new diaphragm to the custom fitted back-up ring, the generant tank was reassembled and rewelded. Soft aluminum strips, 0.010 and 0.015 in. thick, were used to fill the annular gap between the water-cooled chill rings and the generant tank hemispheres. This tank successfully passed a proof test consisting of 3 cycles of pressurization to 2250 psig of 5 min duration each.

Repair serial number 002. Figure 47 illustrates an ethylene propylene diaphragm that had been inadvertently immersed in trichloroethylene during the cleaning process. The mode of failure is from excessive swelling of the diaphragm. The shore hardness in the vicinity of the large tear was 57 compared with a shore hardness

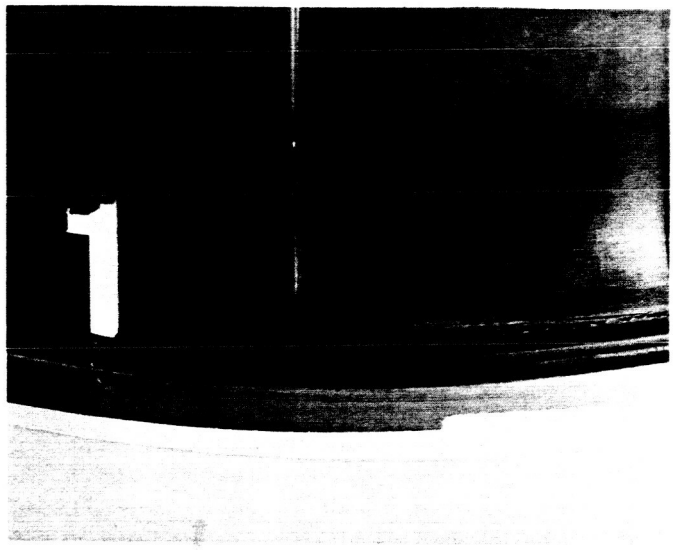


Fig. 47. Damage to ethylene propylene diaphragm after inadvertent immersion in trichloroethylene solution

reading of 65 over the remainder of the diaphragm. There was some evidence of internal shear occurring within the diaphragm material. Because this failure was inadvertent, no further consideration was given to this particular problem.

This tank was repaired using the same procedure as above, and also successfully passed the proof test noted.

D. Test Program

The initial portion of the generant tank test program included the following tests:

1. Proof Test

Proof testing of the flight-type titanium generant tanks was accomplished hydrostatically, at pressures to 2250 psig. Prior to proof testing, the air and/or gas was completely removed from the gas-side and fuel-side hemispheres and replaced with distilled water. The proof pressure was maintained for 5 min duration and the test was repeated for a total of 3 cycles. All titanium tanks passed the proof test successfully.

2. Aspiration Test

In order to determine the leak tightness of the elastomeric diaphragm, all the distilled water and/or air was aspirated from the liquid-side of the generant tank. The vacuum obtained during the aspiration process was 25-in. Hg, or greater. At this point the vacuum system

was locked up for a test period of 15 min. A vacuum reading falling below 23-in. Hg during the 15 min test interval indicated an unacceptable leak in the diaphragm. The aspiration test was completed for a total of 3 cycles.

3. Expulsion Tests

a. High pressure. Expulsion testing of the flight-type titanium generant tank and cell assembly has been successfully carried out in the upright position at generant tank pressures up to 1500 psig; and final expulsion pressures, up to 700 psig. Distilled water was used as the test fluid; nitrogen gas, the pressurant. The trend of the results indicates increasing expulsion efficiency with increasing final tank pressure as shown in Fig. 48. An expulsion efficiency of 99.85%, or higher, was achieved over a range of final expulsion pressures from 10 psig to 700 psig. (Test data below 100 psig pressure, a dashed line of the graph in Fig. 48, were obtained using diaphragms installed in a Plexiglas tank.)

b. High temperature. Three expulsion tests with S/N 003 flight-type titanium generant tank were completed after 24 hr conditioning periods during which the final generant tank temperatures ranged from 92°F to 108°F; water temperatures during these tests ranged from 96°F to 110°F. One of the above tests was made with two stops and re-starts during the expulsion. One additional test was made following a 72 hr conditioning period during which the final generant tank temperature was 102°F; the final water temperature 105°F. Expulsion during the above tests was normal. The minimum expulsion efficiency of 99.97% occurred at a final tank pressure of 560 psig; see Fig. 48.

c. Low temperature. Two expulsion tests with S/N 003 flight-type titanium generant tank were completed. The first test was completed after a 48 hr conditioning period during which the generant tank temperatures ranged from 42° to 57°F. The 42°F temperature occurred just prior to the test. During expulsion, a 3°F rise in water temperature occurred as the result of fluid friction in the valves and plumbing. The second test was essentially a repeat test, following a conditioning period of 72 hr. This test also included two stops and re-starts during the expulsion process. Expulsion during the above tests was normal except that a distilled water transfer line temporarily froze prior to the second test. The minimum expulsion efficiency of 99.90% occurred at a final tank pressure of 558 psig; Fig. 48 and Ref. 2.

4. Sterilization

The heat sterilization requirements are specified in Note 7 of Table 1. The initial phase of this investigation consisted of subjecting an ethylene propylene diaphragm bladder (Stillman Rubber Co. Compound SR 722-70) to the following preliminary evaluation test. After completing the initial leak check, Fig. 46, the diaphragm bladder was subjected to 6 consecutive heat cycles of 6 hr/cycle duration in a gaseous nitrogen atmosphere. The actual diaphragm temperature varied from 284° to 301°F during each cycle. The leak check was then repeated and the results were satisfactory. There were no apparent adverse effects as a result of this thermal test.

5. Other Tests

Of that portion of the overall test program that is still incomplete at this writing (including sterilization, induced

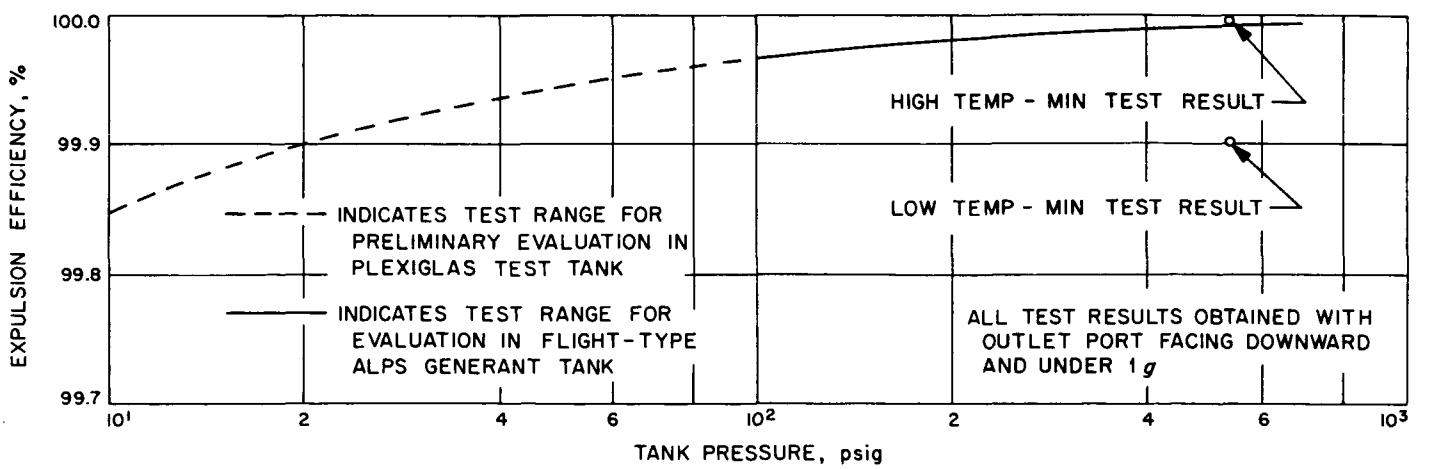


Fig. 48. Expulsion efficiency of the ribbed-diaphragm-type ALPS generant cell

and natural environmental testing such as vibration, slosh, translation, etc.) the following tests are considered the most significant for inclusion in the next testing phase:

a. Long-term storage—compatibility test. Subject S/N 002 flight-type titanium generant tank to long-term hydrazine compatibility testing at the Edwards Test Station.

b. Instrumented proof and burst test. One of the flight-type titanium generant tanks is to be subjected to an instrumented proof test and to an instrumented burst test. Strain gages will be attached to the external surface of the tank in critical stress areas such as the pressurization and outlet boss transition areas, the girth weld area, and other areas of high stress concentration. The purpose of the above tests is to correlate the actual stress distribution within the generant tank walls with the theoretical stress distribution as shown in Fig. 26.

c. Sterilization test. One of the flight-type titanium tanks with an integral elastomeric diaphragm is to be subjected to a 300°F sterilization test. The purpose of this test is to observe the effect of the heat-sterilization procedure on the completed assembly.

E. Conclusion — Flight-Type Generant Tank

A typical flight-type titanium generant tank with an integral diaphragm-type elastomeric bladder was successfully built and tested. Demonstration at the component level included water expulsion tests varying from low to high pressure; these were also combined with extreme temperature operation. Three subsystem-level-type tests utilizing one flight-type generant tank, serial number 004, have been conducted to date using hydrazine as the generant. This tank assembly performed satisfactorily during all phases.

The special problem of weld shrinkage appears to be proportional to the width of the weld bead. Therefore, it is possible that another welding process, such as E/B welding, might result in considerably less shrinkage and distortion than that resulting from the use of the tungsten inert gas technique.

VI. OVERALL PROGRAM CONCLUSIONS

On the basis of the information presented herein, it has been successfully demonstrated that a flight-type titanium generant tank, incorporating an integral diaphragm-type elastomeric bladder, is a practical configuration with respect to design, producibility, and bladder replacement after initial installation.

The scalability potential to larger configurations is excellent for at least an order of magnitude. Scalability to smaller configurations appears to be limited by the size of the diaphragm O-ring type lip and the critical distance between the lip and the girth weld of the tank.

In those instances where permeation of hydrazine would be critical, the permeation rate through the diaphragm could be reduced by increasing the thickness. Doubling the nominal thickness of the subject specimens would not affect the expulsion characteristics significantly.

A. Internal Bladder Summary Evaluation

In comparing the two types of bladders investigated, i.e., diaphragm and balloon, the following criteria were established.

1. Diaphragm-Type

The diaphragm-type was superior because of consistent and smoother performance characteristics throughout the expulsion process up to and including the point of propellant depletion. The optimum configuration is the interrupted rib pattern. This style resulted in the highest expulsion efficiencies, since a high order of uniformity was inherently achieved during propellant transfer. Finally in the zero propellant condition or storage period (for example, spacecraft flight coast) when the maximum differential pressure is experienced by the membrane, a uniform hemispherical shape is assumed

that is directly supported by the adjacent wall of the container.

2. Balloon-Type

The balloon-type bladder exhibited inconsistent and random performance near the point of propellant depletion, since the folding mechanism is variable and not amenable to precise operation during this final stage. In addition, any severe folding pattern that is maintained for an extended period at the maximum differential pressure condition seriously limits the useful service life of the creased bladder.

In the area of detail design, a one-piece bladder is preferred in order to avoid the inherent compatibility and reliability problems presented by spliced joint configurations. However, the fabrication techniques and tooling involved are both complicated and expensive. Specific disadvantages of the balloon-type bladder have been noted above. However, there is an important advantage of this type that cannot be evaluated in a distinct manner or by comparison. *This is the ease of replacement of the bladder.* The merits of this consideration without exception are wholly dependent upon the individual application. Assessments presented herein have been made according to this assumption.

B. Alternate Design

With the knowledge and experience gained in fabricating and testing titanium generant tanks, the possibility suggests itself for designing an all-metal tank including a metallic diaphragm. The metallic diaphragm could be electron-beam welded to the liquid-side hemisphere or to the back-up ring prior to making the final girth weld.

The E/B welding process has a number of significant advantages over the TIG welding process such as a smaller required heat input, and less welding distortion and shrinkage; therefore, E/B welding is recommended as the preferred process for future programs.

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