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Elastomeric Diaphragm Tank**

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DESIGN AND MANUFACTURE OF A COMPOSITE OVERWRAPPED ELASTOMERIC DIAPHRAGM TANK

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ABSTRACT

A new diaphragm propellant tank is required for space application. This tank must be low-cost, light weight, and highly reliable. Pressure Systems, Inc. (PSI) was contracted to develop this Hydrazine Tank in 1999.

The Hydrazine Tank design is based on several titanium lined, partially wrapped propellant tanks developed by PSI in the past decade. However, several manufacturing process and product developments were conducted, including:

- Development of a Ti-6Al-4V spun dome,
- Development of a new diaphragm,
- Development of a new diaphragm seal configuration,
- Development of bonded mounting tabs,
- Development of the adhesive bond validation test,
- Development of a cure cycle that would not degrade the diaphragm seal and mechanical properties.

Stress, finite element, and fracture mechanics analyses were performed to design and validate the tank shell for the mission environment.

The Hydrazine Tank liner is constructed of annealed 6Al-4V spun domes and assembled with a single girth weld. An AF-E-332 elastomeric diaphragm is mounted to the propellant dome prior to tank closure. The liner is overwrapped with graphite-epoxy composite over the center cylinder. Two mounting tabs and an anti-rotation tab are adhesive bonded to the composite overwrap. To verify the integrity of the adhesive bond, the tabs are static load tested prior to tank acceptance testing.

A spun dome qualification program was conducted to qualify the spun domes, including examination of mechanical & chemical properties, microstructure, and grain flow. A development tank was fabricated for a series of development tests, including random vibration and pressure hold, to validate the design approach, manufacturing processes, tooling, and test methodologies. A complete qualification testing program was conducted to qualify the new tank. The qualification program was successfully completed in 2001.

The Hydrazine Tank is PSI's first composite overwrapped diaphragm tank. One tank is required for each shipset. Several tanks have been delivered to date, and two tanks have successfully flown.

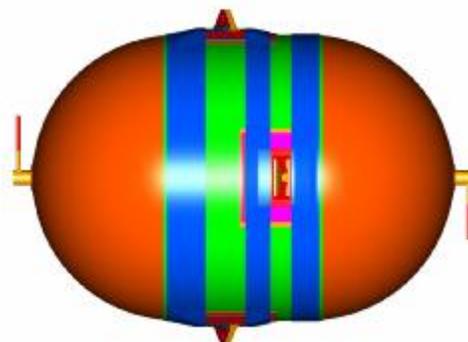
INTRODUCTION

In 1999 PSI was contracted to design, develop, and qualify a hydrazine tank containing an elastomeric diaphragm. This tank must be low-cost, light weight, and highly reliable. To achieve the primary objective of low cost, several innovative features were incorporated into the new tank design. Some development efforts were required to qualify this tank, whose design features include:

- Two spun-formed Ti-6Al-4V domes with integral cylinder section,
- Fully reversible AF-E-332 diaphragm with a cylinder extension,
- Center section overwrapped with graphite-epoxy composite, and
- Adhesive bonded mounting and anti-rotation tabs.

A model of the Hydrazine Tank is shown in Figure 1.

Figure 1, Composite Overwrapped Hydrazine Tank Assembly



The Hydrazine Tank was designed to the requirements listed in Table 1:

Table 1, Hydrazine Tank Design Requirements

Parameters	Requirements
Operating Pressure	550 psig
Proof Pressure	690 psig
Burst Pressure	825 psig @ 160 °F
Material of Construction	Liner: 6AL-4V Titanium, Annealed Heads, Annealed cylinder Inlet/outlet Ports: 6AL-4V titanium to 321 CRES transition tubes Composite: T300/T800/T1000 graphite fibers Mounting and Anti-rotation Tabs: 6AL-4V titanium Elastomeric Diaphragm: AF-E-332
Membrane Thickness	0.040" (1.01 mm) minimum on annealed titanium heads
Tank Mount(s)	Bonded and overwrapped mounting and anti-rotation tabs (3 ea.)
Expulsion Efficiency	98.25% minimum
Propellant Load	343 lbm (156 kg) Hydrazine
Tank Capacity	10,431 in ³ minimum
Internal Dimensions	22.85" ID x 33.85" long
Overall Length	36.8" maximum
Tank Weight	42 lbm (19.1 kg) maximum design weight
Propellant	Hydrazine N ₂ H ₄
Fluid Compatibility	N ₂ H ₄ , GAr, GHe, GN ₂ , D.I. water, Isopropyl alcohol
Shell Leakage	<1x10 ⁻⁶ std cc/sec He @ 550 psig
Natural Frequency	109 Hz axial, 59 Hz & 194 Hz lateral
Failure Mode	Leak Before Burst / Fracture Mechanics Safe-Life
Temperature Environment	-35°F to 160°F (-37°C to 71°C)
Storage Life	10 years maximum

DESIGN HERITAGE

The design of this Hydrazine Tank shell was based on several partially wrapped propellant tanks currently in production. PSI has developed four partially wrapped, or hybrid, propellant tanks starting in 1995. These tanks all contain Solution Treated and Aged (STA) hemispherical heads, and annealed Ti-6Al-4V cylinder overwrapped with composite¹. The term “hybrid” reflects the fact that these tanks combine the favorable characteristics of the all-titanium propellant tanks and high pressure Composite Overwrapped Pressure Vessels (COPVs). Figures 2a through 2d show several partially wrapped hybrid propellant tanks from which the Hydrazine Tank design was developed.

Figure 2a, Hybrid Propellant Tank, PSI P/N 80391, with Bonded Mounting Plates



Figure 2b, Hybrid Propellant Tank, PSI P/N 80432, with Composite Skirt



Figure 2c, Hybrid Propellant Tank, PSI P/N 80434, with Bonded Mounting Plates



Figure 2d, Hybrid Propellant Tank, PSI P/N 80435, with Bonded Mounting Plate



The Hydrazine Tank contains annealed spun domes, which is a deviation from these heritage hybrid propellant tank designs. However, the processes for machining, welding, wrapping, bonding the tabs, and testing all utilized the heritage approach developed for PSI P/Ns 80391, 80395, 80425, 80432, 80434, and 80435.

SPUN DOMES

One of the first challenges of this program was the development of the spun domes. The Hydrazine Tank liner requires two spun domes of different configuration. The domes are spun formed from 6Al-4V titanium plates, and both contain a hemispherical head and an integral cylindrical section. Both domes are identical except in cylinder length: the short dome contains a 3-inch cylinder, while the longer dome contains a 7-inch cylinder. The inclusion of a cylinder section simplified the tank assembly by using one girth weld only, but added significant effort to the spun dome development and fabrication.

Key spinning operations are as follow and are repeated with each breakdown operation:

- 1) Clean breakdown tool,
- 2) Pre-heat breakdown tool to required temperature,
- 3) Heat material to spin temperature,
- 4) Spin material to the tool contour using the qualified parameters of spin rate, temperature, and roller radius,
- 5) Repeat process for each breakdown.

As with any other manufacturing operation, proper tooling would best insure the quality of the end product. A set of breakdown tools was designed and manufactured to control the quality of the spun domes, facilitate the fabrication process, and assure repeatability and final dome geometry.

Pictures of typical breakdown tools used during the spinning process are shown in Figure 3. Both domes were spun using the same tooling.

Figure 3, Typical Breakdown Tools for Spun Dome Manufacturing



The goal of the spun dome development was to establish the manufacturing parameters to consistently fabricate a 6Al-4V titanium spun dome. Unlike Commercially Pure (CP) titanium which is more commonly used for spinning applications and easier to process, the 6Al-4V titanium is more difficult to spinform. The more challenging task, however, was to spinform the integral cylinder section from a piece of flat plate. Defects encountered during process development included pitting, cracking, and thin wall. These problems were overcome and a consistent manufacturing process was eventually developed.

The spun domes were successfully developed by Spincraft.

A picture of the as-spun dome (long) is shown in Figure 4.

Figure 4, A Spun Dome with Integral Cylinder Section



Following spinning operations, the domes were finish machined to achieve final dome contour and thickness, accompanied by anneal and stress relieve cycles to insure dimensional stability. A picture of the finish machined domes is shown in Figure 5.

Figure 5, Finish Machined Spun Domes



SPUN DOME QUALIFICATION

A dome qualification program was performed to qualify the spun dome. A number of test coupons were cut from a development dome to evaluate mechanical properties, chemical content, microstructure, and grain flow. The mechanical coupons were tested, per ASTM E8, for yield strength, tensile strength, elongation, and reduction of area. The chemical coupons were tested,

per MIL-T-9046, for hydrogen, oxygen, and nitrogen content. The microstructure coupons were examined, per ASTM E 112, for grain size in three different directions: planes long, long transverse, short transverse. The test results are shown in Tables 2a through 2c.

ELASTOMERIC DIAPHRAGM

PSI has pioneered the use of elastomeric diaphragm tanks in space flight². To date nearly 900 diaphragm tanks have been delivered, and a majority of them contains AF-E-332 diaphragms.

Due to its unique geometric configuration, a new AF-E-332 elastomeric diaphragm was designed and fabricated for the Hydrazine Tank. This new diaphragm contains a cylinder extension and is fully reversible, from pressurant hemisphere to propellant hemisphere and vice versa, during tank operations. PSI has previously developed four elastomeric diaphragms with cylinder extension, therefore, the design, tooling, and manufacturing approaches for this new diaphragm were based entirely on heritage.

A picture of the new diaphragm for the Hydrazine Tank is shown in Figure 6.

Figure 6, AF-E-332 Elastomeric Diaphragm for the new Hydrazine Tank

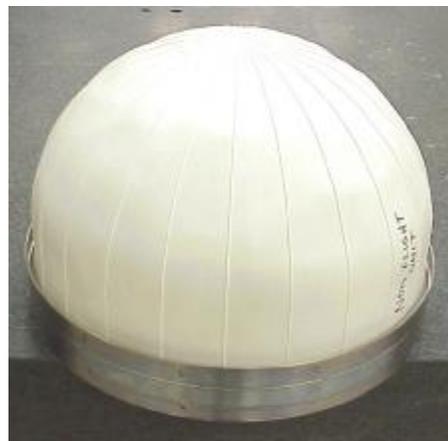


Table 2a, Tension Test Results

Sample No.	Sample Dimensions (inch)	Yield Load (lbs)	Tensile Load (lbs)	Yield Strength (psi)	Tensile Strength (psi)	Elongation (%)	Reduction of Area (%)
1	0.253 x 0.0782	2,581	2,799	130,000	141,000	15.0	46.0
2	0.252 x 0.0459	1,512	1,648	131,000	142,000	11.0	35.0
3	0.253 x 0.0811	2,676	2,898	130,000	141,000	14.0	49.0
4	0.252 x 0.0623	2,087	2,241	133,000	143,000	11.0	35.0
5	0.253 x 0.0793	2,709	2,912	135,000	145,000	12.0	45.0
6	0.252 x 0.0923	3,058	3,329	131,000	143,000	13.0	50.0
7	0.253 x 0.0650	2,223	2,393	135,000	146,000	13.0	44.0
8	0.253 x 0.0802	2,665	2,926	131,000	144,000	13.0	43.0
Minimum Requirements				120,000	130,000	10.0	25.0

Table 2b, Chemical Content Test Results

Sample No.	Hydrogen (%)	Oxygen (%)	Nitrogen (%)
1	0.007	0.13	0.01
2	0.009	0.13	0.01
3	0.007	0.15	0.01
Maximum	0.015	0.20	0.05

Table 2c, Grain Size

Sample No.	LT-ST	L-ST	L-LT
1	10	10	9
2	10	10	9
3	10	10	9
4	10	10	9
5	10	10	9
6	10	10	9
7	10	10	9
Grain Size Requirement is 6 or finer			

DIAPHRAGM RETENTION

A new challenge faced by PSI tank designers was the incorporation of the heritage diaphragm retaining scheme. Prior to this Hydrazine Tank, all the diaphragm tank shells were made from forgings, where the diaphragm retaining features were integrally machined. However, the thin walled spun domes do not provide extra material to accommodate these features. The diaphragm retaining rings are therefore individually machined, and the new method of affixing the diaphragm retaining rings was developed using weldments.

A picture of the welded diaphragm retaining ring is shown in Figure 7.

Figure 7, Welded Diaphragm Retaining Ring



DESIGN ANALYSES

The tank shell analyses included stress analysis and fracture mechanic analysis. All the analyses used assumptions, computer tools, test data and experimental data utilized on a majority of the pressure vessels successfully designed, fabricated, tested and qualified during the past four decades. Conservatism was used throughout the analysis process, and the worst case scenarios were analyzed.

TANK SHELL STRESS ANALYSIS

A stress analysis was performed to establish that the Hydrazine Tank meets the specification requirements. The analysis took into consideration the requirements such as:

- Temperature environment;
- Material properties, annealed titanium;
- Material properties, fiber material;
- Material properties, adhesive;
- Volumetric requirements;
- Mass properties of tank shell material;
- Mass properties of fluid;
- Fluids used by the tank;
- Tank pressurization history;
- External loads;
- Girth weld offset and weld suck-in;
- Resonant frequency;
- Tank boundary conditions;
- Residual stress in girth weld;
- Load reaction points; and
- Design safety factors.

This stress analysis established the tank shell and the mounting designs for the mission requirements. Some elements of the analysis are presented below:

MATERIAL SELECTION

The selection of 6Al-4V titanium was based on several favorable factors:

- Its superior strength-to-weight ratio which is ideal for thin wall pressure vessels,
- Its excellent machinability and dimensional stability,
- Its weldability and superior weld properties,
- Its excellent compatibility with hydrazine,
- Its excellent fatigue performance characteristics,
- Its excellent corrosion and erosion resistance capabilities,

- Its long-term heritage in the application of AF-E-332 diaphragm tanks,
- Its excellent galvanic compatibility with graphite, and
- It is less susceptible to pitting and stress corrosion,

However, quantitative analyses were also conducted to verify the metallurgical properties of these spun domes through spun dome qualification.

FINITE ELEMENT MODELS

Finite element models (FEMs) were generated for axisymmetric analysis, dynamic analysis, and localized detail analysis of several critical regions such as welds, mounting tabs, and diaphragm retaining rings. Figures 8 through 11 show some of the typical outputs of the FEM.

Figure 8, Axisymmetric FEM.



Figure 9, Dynamic FEM.

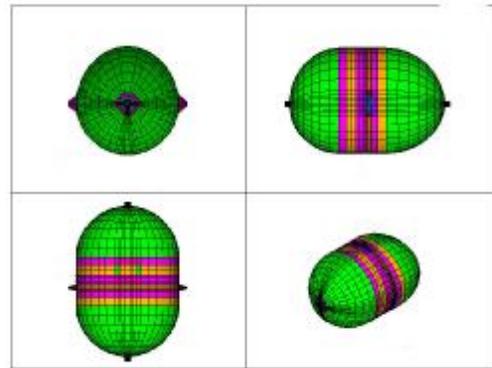


Figure 10, Detailed Support Tab FEM.

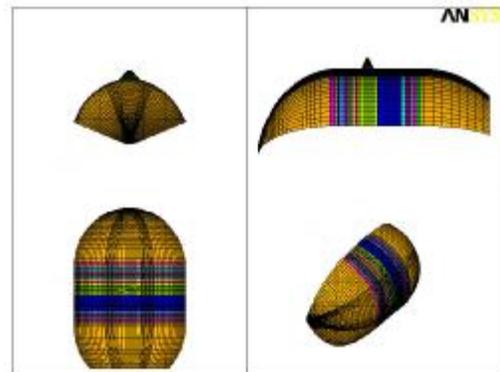
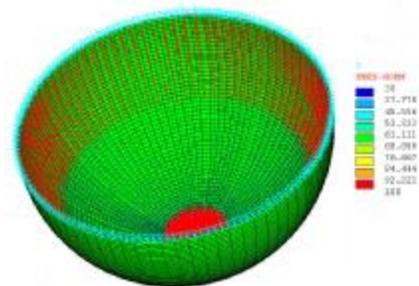


Figure 11, Dome FEM



MODAL ANALYSIS

The modal analysis was conducted to determine the tank frequencies during launch. Table 3 lists the analytical critical resonance frequencies of this Hydrazine Tank. Figures 12a through 12d show the various tank modes and their effective masses.

Table 3, Effective Modal Masses and Frequencies, 100% Fill at 475 psi.

Direction	Mode Number	Frequency (Hz)	Effective Mass (lbm)
X (Lateral)	1	57.5	90.5
	2	59.1	261.4
Y (Axial)	3	108.6	334.1
	6	193.7	13.5
Z (Lateral)	6	193.7	228.7
	8	245.4	74.9

AXIS IDENTIFICATION

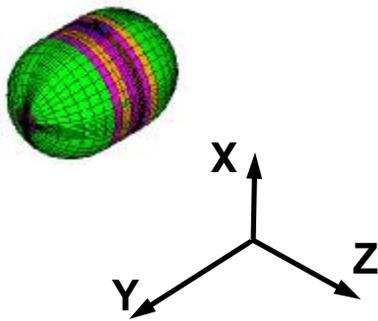


Figure 12a, Mode 1, 57.5 Hz, Effective Mass 90.5 lbm

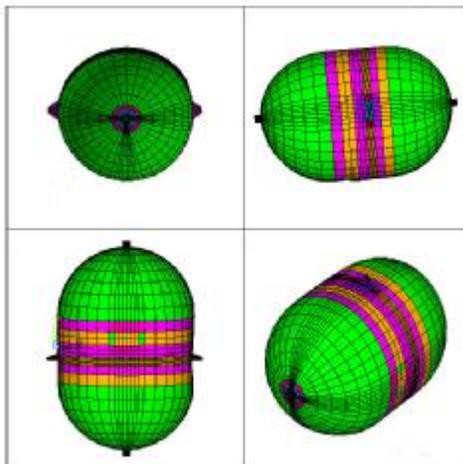


Figure 12b, Mode 2, 59.1 Hz, Effective Mass 261.4 lbm

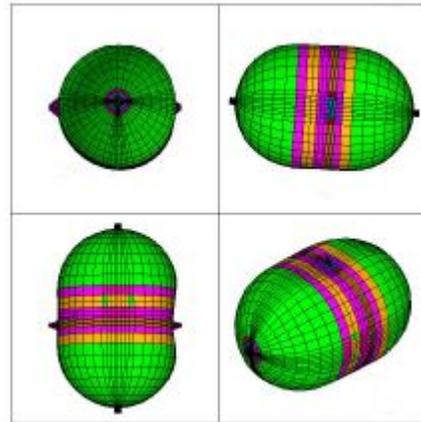


Figure 12c, Mode 3, 108.6 Hz, Effective Mass 334.1 lbm

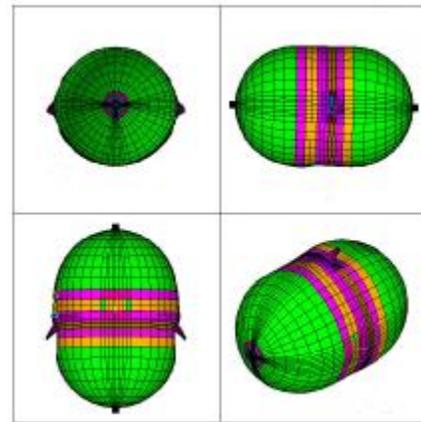
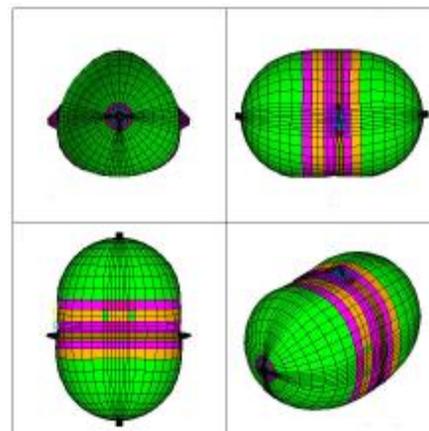


Figure 12d, Mode 6, 193.7 Hz, Effective Mass 228.7 lbm (Z axis)



RANDOM VIBRATION ANALYSIS

The random vibration analysis examined the effect of vibration loads and resulting deflections. Several fill levels were analyzed, from 20% to 100%. The analysis had determined that worst-case loading is 100% fill at 475 psi launch pressure. The tank design was based on this worst-case fill level.

LINER ANALYSIS

A liner analysis was conducted to examine two critical areas:

- the combined pressure stresses with dynamic loads, and
- residual stress on the girth weld, since a diaphragm tank cannot be stress relieved.

The worst case area was found to be in the girth weld under the support tabs. The final tank design includes sufficient material to insure positive margin of safety.

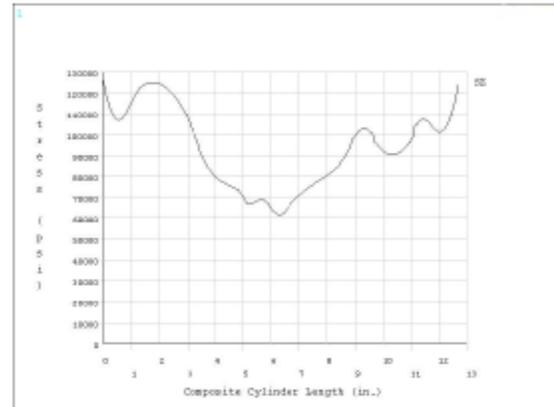
GIRTH WELD ANALYSIS

Girth weld analysis was conducted to examine the combined stresses from the 475 psi internal pressure, residual weld stresses, and the stress due to reaction load exerted on the mounting tab. Positive margin of safety was shown by the fracture mechanics analysis.

WRAP ANALYSIS

An examination of composite stresses at burst pressure was conducted as part of the tank design analysis. Figure 13 shows the composite stresses as a function of the composite cylinder length. The margin of safety, as determined by the stress analysis, is +2.66.

Figure 13, Composite Stresses



SUPPORT TAB ANALYSIS

The Hydrazine Tank requires two mounting tabs and one anti-rotation tab. The analysis examined fatigue, bond line, and loads required to break off the bonded tabs. The analysis results were used to size the tabs, determine their configuration, and calculate the analytical safety margin. The analysis also yielded the magnitude of the loads that must be applied to each flight tank during acceptance static load testing.

The final tab designs are shown in Figures 14a and 14b. It was determined that the loads on anti-rotation tab were significantly less than the loads on the two mounting tabs, resulting in a high margin of safety for the bonded anti-rotation tab.

Figure 14a, A Mounting Tab

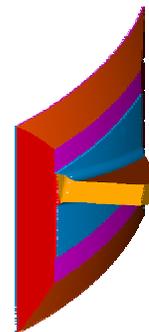
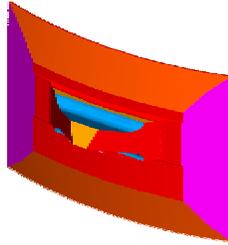


Figure 14b, An Anti-Rotation Tab



FRACTURE MECHANICS ANALYSIS

A fracture mechanics analysis was conducted to establish whether the growth of an initial flaw, in the anticipated cyclic and sustained pressure environment, may cause a failure in the tank shell. The analysis was performed using external and internal stresses from the stress analysis, and using NASA/FLAGRO with minimum thicknesses as parameters. Special fracture critical dye-penetrant and radiographic inspections were used as the primary flaw screening techniques for the fracture mechanics safe-life analysis. The analysis was performed at critical locations including:

- Girth welds and heat affected zones;
- Several regions on the metallic hemisphere;
- The boundary where the composite and the metal shell intersects;
- The intersection between the retaining ring and cylinder;
- The mounting tab at its base; and
- The intersection between the metallic mounting tab and the composite.

The conclusion of the fracture mechanics analysis indicates the tank design meets both safe-life and Leak Before Burst (LBB) requirements.

The special NDE requirements established by this fracture mechanics analysis include:

- Special fracture critical dye-penetrant on all surfaces; and
- Special fracture critical radiograph on welds.

These requirements were instituted as part of the tank fabrication requirements. The components parts as well as welded liners were NDE inspected to the established PSI NDE inspection procedures.

SAFETY MARGINS

Some minimum safety margins, as predicted by stress analysis, are summarized in Table 4.

Table 4: Propellant Tank Safety Margins

Characteristics	M.S.
Girth weld, proof pressure, yield	+0.000
Girth weld, burst pressure, ultimate	+0.053
Girth weld, internal pressure combined with random vibration, yield	+0.084
Girth weld, internal pressure combined with random vibration, ultimate	+0.127
Liner, launch loads, yield	+0.181
Liner, launch loads, ultimate	+0.273
Liner, proof pressure, yield	+0.016
Liner, burst pressure, ultimate	+0.003
Bonded area, axial excitation, shear	+0.819
Bonded area, axial excitation, pull-off	+0.085
Bonded area, lateral excitation, pull-off	+8.170
Bond line, shear	+0.303
Bond line, peel	+2.275
Bonded joint, resin	+0.068
Tab overwrap	+1.086

DEVELOPMENT LOAD TEST OF BONDED TABS

A development load test was conducted to verify the proposed bonded tab design. The test methodology was derived from a similar test conducted on a previous wrapped tank development program. The test article was a composite overwrapped cylinder that simulates the wrapped tank configuration in the cylinder section. The mounting tabs were bonded to the test cylinder, and the cylinder was mounted into a load test fixture, filled with test fluid, and pressurized. Various loads were applied to the test specimen, including 20,000 lbf on each side mount in the vertical and lateral direction. A second case applied a combined load of 14,000 lbf on each sidemount in the lateral and vertical direction. See Figure 15. The cylinder remains intact after the load tests. Post test inspection revealed no catastrophic failure. Test data registered lateral deflections of 0.75". Strain gauges recorded strain levels within expected ranges. This successful test provided sufficient data to incorporate the bonding techniques into the tank design.

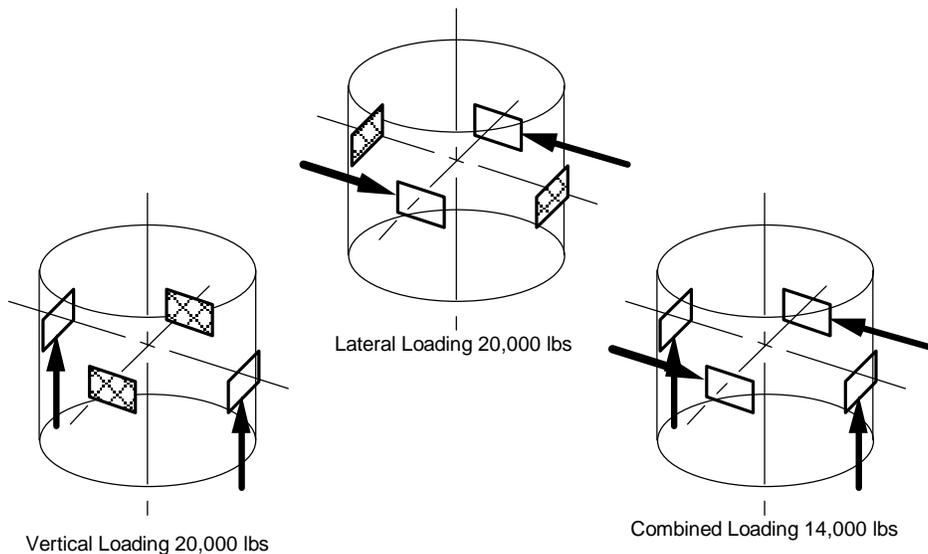
TANK DEVELOPMENT

A development tank was fabricated as a pathfinder to validate the design approach, tooling, manufacturing processes, and test methodologies. Key areas of concern were the spun domes and the bonded mounting tabs.

The development tank underwent development testing per the following test sequence:

- Handling shock
- Volumetric capacity
- Proof pressure
- Expulsion efficiency
- Diaphragm leak
- Tank leak (helium leak)
- Vibration
- Pressure hold
- X-ray inspection

Figure 15, Load Testing of The Bonded-On Tabs



Vibration Test: The Pathfinder development tank was vibration tested to the following vibration levels:

Table 5: Vibration Test Levels

Frequency (Hz)	Qualification PSD (g ² /Hz)
20	0.05
40	0.24
200	0.24
400	0.036
1200	0.036
2000	0.002
Overall	9.9 Grms
Duration	180 sec/axis

The random vibration test was conducted on all three axes. The vibration test verified some analytical predictions, such as the resonant frequencies.

The vibration test setup is shown in Figures 16a and 16b.

Figure 16a, Vibration Test Setup



Figure 16b, Vibration Test Setup



Pressure Hold Test: The pressure hold test on the Pathfinder development tank was conducted for approximately 165 hours. The tank was pressurized between 475 (MEOP) psig and 690 psig (proof).

After the development testing, the development tank was delivered to the customer for acoustic testing.

HYDRAZINE TANK FABRICATION

The Hydrazine Tank liner consists of two spun and finish machined domes. A machined diaphragm retaining ring and propellant port elbow are welded to the propellant dome, followed by the installation of the elastomeric diaphragm with a welded diaphragm retaining ring, to complete the expulsion assembly. A similar elbow is welded to the pressurant dome to make the pressurant dome assembly. The two dome assemblies are joined together with a final girth weld to complete the liner assembly.

Figure 17 shows a completed Expulsion Assembly. Figure 18 shows a completed Hydrazine Tank liner assembly.

Figure 17, Hydrazine Tank Expulsion Assembly



Figure 18: Hydrazine Tank Liner Assembly



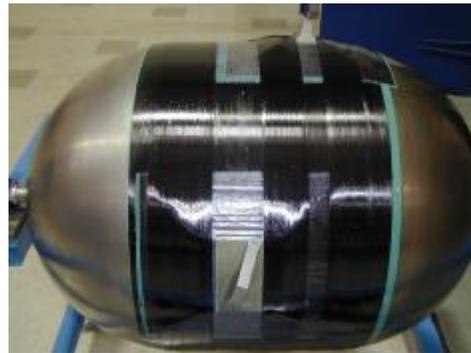
The liner assembly is overwrapped with T-1000 graphite/epoxy composite, over the center cylinder only, as shown in Figure 19.

Figure 19: Hydrazine Tank Liner Overwrapped with Composite



The mounting tabs and anti-rotation tab are bonded to the composite overwrap, followed by a tie-down hoop wrap. The composite is cured. The completed tank is shown in Figure 20.

Figure 20: Hydrazine Tank with Bonded Mounting and Anti-Rotation Tabs



The completed flight tank is acceptance tested and precision cleaned prior to final tank delivery.

The manufacturing flow diagram of the Hydrazine Tank Assembly is presented in Figure 21.

Figure 21: Hydrazine Tank Manufacturing Flow Diagram

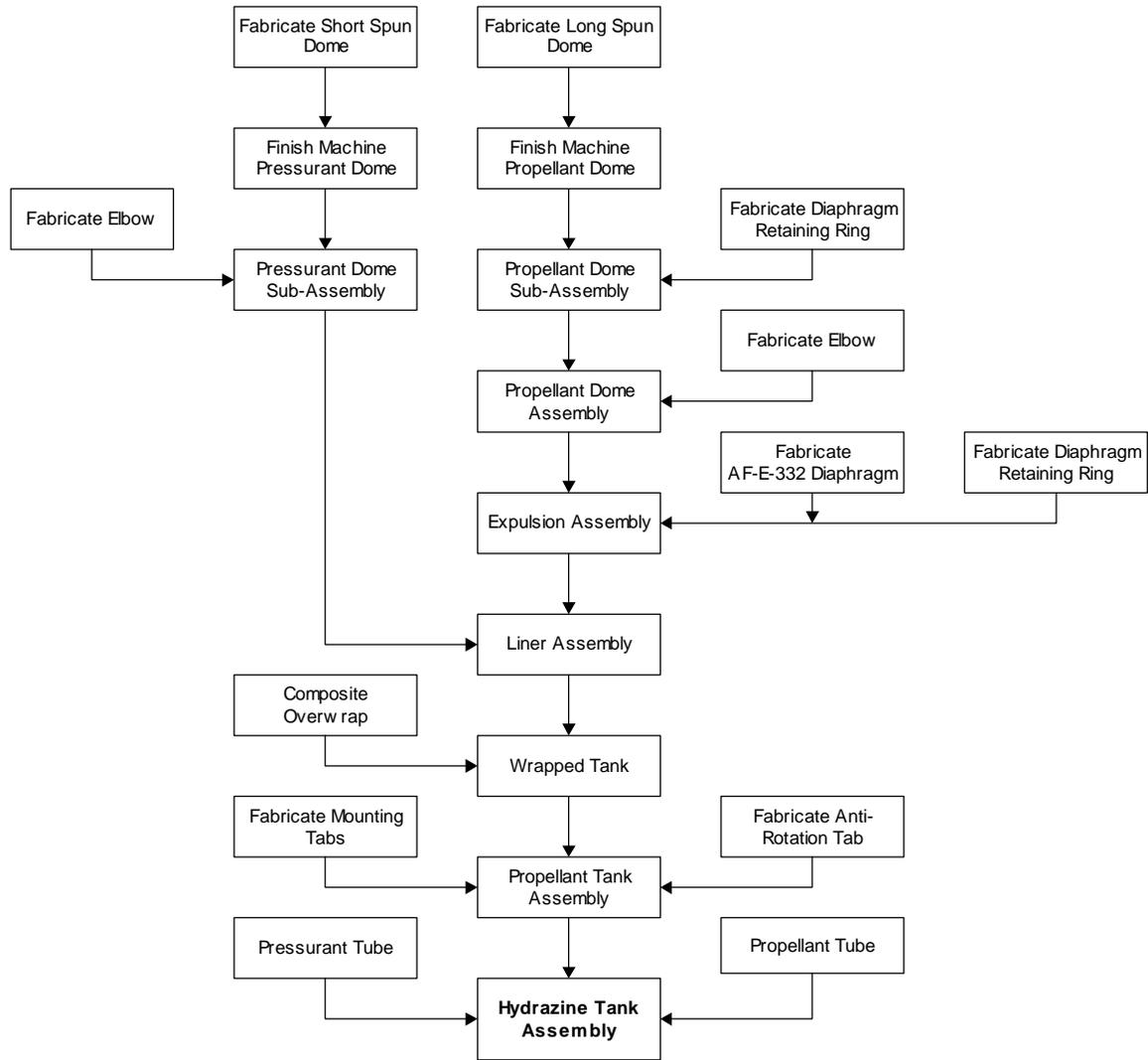


Table 6: Static Load Test Matrix

Test No.	Tab Tested	Tank Pressure (psig)	Applied Test Load (lbf)		
			Anti-Rotation Tab	End Load	Side Load
1	Anti-rotation Tab	200	2,100	N/A	N/A
2	Support Tabs	200	N/A	10,000	1,200
3	Support Tabs (Reverse Loading)	200	N/A	10,000	1,200

Note: Hold time 30 seconds, 5 cycles for each test

STATIC LOAD TESTING

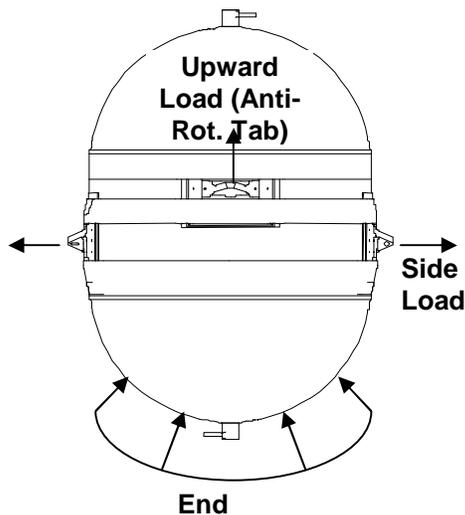
Static load testing is conducted on each tank to verify the integrity of the bonded tabs. The test is performed with the Hydrazine Tank mounted in the static load test fixture, as shown in Figure 22.

Figure 22: Static Load Test Setup



Each tank is subjected to 3 cases of static load testing. Two of the cases test the support tabs and one tests the anti-rotation tab. The test matrix is shown in Table 6. Load Definition is shown below in Figure 23.

Figure 23: Static Load Test Load Definition



The static load test is considered a part of the manufacturing validation, therefore, it is not included in the tank acceptance test sequence.

WEIGHT DISTRIBUTION

The Hydrazine Tank weight distribution is summarized in Table 7:

Table 7: Hydrazine Tank Weight Distribution

ITEM DESCRIPTION	Nominal Weight (lbm)
Propellant Dome Assembly	12.0
Pressurant Dome Assembly	9.0
Mounting & Anti-rotation Tabs	6.1
Composite & Adhesive	4.4
Diaphragm & Retaining Ring	6.5
TOTAL	38.0

The specification mass requirement is 42.0 lbm maximum.

ACCEPTANCE TESTS

After the flight tank is assembled, it is subjected to the following acceptance tests prior to delivery:

- Preliminary examination
- Pre-proof volume determination
- Proof pressure
- Post-proof volume determination
- Water expulsion & pressure hold test
- Internal leakage
- External leakage
- Weight determination & final inspection
- Precision clean
- Final examination

Volumetric Capacity Examination: The capacity of the Hydrazine Tank is measured utilizing the weight of water method, using clean, filtered deionized water as the test medium. This test is conducted before and after the proof pressure test to verify that the proof pressure testing does not significantly alter the tank capacity. A successful validation indicates that the tank shell is manufactured properly and that the tank can operate in the pressure environment under which it was designed for. Typically, the volumetric growth after proof pressure test is zero.

The post-proof test capacity examination also serves to verify that the tank meets the designed volume requirement.

Proof Pressure Test: The proof pressure test is typically the first pressurization cycle applied to the tank after fabrication. It is intended to validate the workmanship by verifying the strength and integrity of the tank shell. The test must be conducted in a “safe” environment to minimize hazards to test technicians. The test is conducted hydrostatically at proof pressure for a pressure hold period of 5 minutes minimum.

Pressure Hold and Water Expulsion Test: The Hydrazine Tank is loaded with 343 lbm of water and pressurized to 550 psig (MEOP) for a 24-hour pressure hold test. After the pressure hold test, the test pressure in the pressurant compartment is reduced to 475 psig and the compartment port sealed. The test fluid is expelled from the Hydrazine Tank through blow down, and the pressure drop across the tank must meet the pressure drop requirement of not-to-exceed 5.0 psid at a maximum flow rate of 3.0 GPM. The test is conducted by measuring the pressure differential between ullage and the tank outlet.

Internal Leak Test: The internal leak test is a low pressure diaphragm leak test conducted with gaseous nitrogen to validate the integrity of the diaphragm seal. The nitrogen across the elastomeric diaphragm must not exceed 12 scc per the 16-minute period.

External Leak Test: The external leak test verifies the integrity of the tank shell and also serves to validate the previous series of pressure testing. The tank is placed in a vacuum chamber, which is evacuated to under 0.2 microns of mercury, and helium pressurized to MEOP for 30 minutes. The helium leak rate cannot exceed 1×10^{-6} std cc per second after a 5-minute stabilization period.

Cleanliness Verification: After the non-destructive examination, both propellant and pressurant compartments of the tank interior must be cleaned to the cleanliness level specified in Table 8:

Table 8: Tank Cleanliness Level

Particle Size Range (Microns)	Maximum Allowed per 100 ml
0 to 5	No silting
6 to 15	265
16 to 25	78
26 to 50	11
51 to 100	1
101 and over	0

QUALIFICATION TEST PROGRAM

The hydrazine Tank is a new design and therefore must be qualified by test. Conservatism was exercised throughout the qualification test program, and all pressure tests were temperature adjusted for the worst case operating temperature. Pass/Fail criteria consisted of acceptance type internal and external leak tests conducted at intervals throughout the test program.

The qualification program was conducted to the following test sequence:

- Acceptance test (functional)
- Pressure life cycle test
- Static acceleration
- Internal leakage
- External leakage
- Operating vibration test
- Internal leakage
- External leakage
- Diaphragm thermal life cycle test
- Internal leakage
- Diaphragm integrity test
- Internal leakage
- External leakage
- Pressure life cycle test
- Internal leakage
- External leakage
- Water expulsion test
- Internal leakage
- External leakage
- Burst test

Static Acceleration Test: The static acceleration test was conducted on a loaded (343 lbm) and pressurized tank such that the test fluid is forced in the -Z axis. There were two pressurization cases: 15 psig and 475 psig. Test duration was 5 minutes for each case. The static load acceleration test setup and tank orientation are shown in Figures 24a and 24b.

Figure 24a: Static Load Acceleration Test Setup



Figure 24b: Static Load Acceleration Tank Orientation



Burst Pressure Test: Following NDE and a final visual examination, the Qualification Tank was burst pressure tested to determine the burst margin. The tank burst at 1,292 psig @ 147 °F. The adjusted burst pressure is 1,283 psig at 160 °F, which is 458 psig above the 825 psig requirement. This represents a burst margin of 56%. A picture of the Qualification Tank after burst is shown in Figure 25.

Figure 25: Burst Tank



CONCLUSION

The Hydrazine Tank assembly has successfully concluded qualification testing without failure. The production program is in progress and several flight tanks have been delivered. To date two flight tanks have flown.

This Hydrazine Tank is PSI's first composite overwrapped tank containing an elastomeric diaphragm. The tank design is based on heritage, but it also incorporates new and innovative internal and external design features.

The Hydrazine Tank assembly is low cost, lightweight, high performance, and simple to manufacture. The tank assembly is accomplished using standard processes and procedures. Special materials and processes are not required.

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