DESIGN AND DEVELOPMENT OF THE INTELSAT VIIA & N-STAR PROPELLANT TANKS

M. J. Debreceni, W. D. Lay, & T. K. Kuo
Pressure Systems, Inc., Commerce, CA
and
D. L. Bond, R. E. McClellan, & Dr. T. P. Yeh
Space Systems/Loral, Palo Alto, CA

ABSTRACT

Both the Intelsat VIIA and N-Star Programs required adaptations of the Intelsat VII Program Propellant Tanks to meet specific requirements. The former program, with a heavier spacecraft, greater capacity, higher power, and more capability with additional Ku-band transponders, demanded more propellant capacity to achieve the desired design life of 22.5 years minimum. It is characterized by an additional 9-inch long cylindrical section. The latter program, being extremely weight critical, required a lighter weight version of the original I-VII spherical propellant tank to achieve the desired minimum design life of 10.2 years. It includes a thinner shell and a lighter surface tension device.

The resultant tanks are fabricated in an all-welded titanium configuration with similar propellant management devices (PMD's) to store and to provide pressurized gas-free propellants to the main satellite thrusters and reaction control system thrusters in a zero g environment. Each spacecraft contains two tanks -- one for nitrogen textroxide (N_2O_4) oxidizer and the other for monomethylhydrazine (MMH) fuel. Hardware commonality is achieved by maintaining the same pressurant and propellant ports' locations and configurations, PMD mounting, isopropyl alcohol (IPA) test system, and spacecraft mounting interface of 32 tabs with nut plates located near the tank equator.

Both versions were analyzed, designed, fabricated, tested, and qualified to Space Systems/Loral's requirements. All flight units were delivered on time.

INTRODUCTION

Space Systems/Loral (SS/L) contracted with Pressure Systems, Inc. (PSI) to analyze, design, fabricate, assemble, test, qualify, and deliver propellant tanks for the Intelsat VIIA (I-VIIA) and N-Star programs. The I-VIIA program provided for two qualification units and six flight tanks while the N-Star program included one qualification unit and six flight tanks.

The Intelsat VIIA satellites are designed to serve the multi-national global communications cooperative, Intelsat, in the mid-to-late 1990's and beyond with 112,500 telephone circuits and three television channels simultaneously per spacecraft. This series include improved coverages, improved redundancy and reliability, improved signal performance, and increased capacity.

The N-Star spacecraft, ordered by Nippon Telegraph & Telephone Corporation from Space Systems/Loral, provides communication services for the Western Pacific Rim countries, particularly Japan.

Each of the satellites includes two propellant tanks -- one for the nitrogen tetroxide (N_2O_4) oxidizer and one for the monomethylhydrazine (MMH) fuel. They are mechanically mounted in tandem inside the satellite's central cylinder with 32 equally spaced tabs and welded into the propulsion fluid system. The tanks are of an all-welded titanium construction. They incorporate passive propellant management devices for propellant acquisition and to supply gas-free propellants to the system thrusters throughout the required mission life. An IPA flow and test system is also installed internally to allow testing of the critical PMD screen elements after installation of the tanks in the spacecraft.

The I-VIIA tanks include a cylindrical section to accommodate the required propellant weights while the N-Star tanks include a reduced weight tank shell and PMD components to achieve the mission's maximum weight constraint.

These tank assemblies reflect the latest in design innovation and state-of-the-art technology for improved manufacturability, performance, reliability and testing for these advanced communications satellites.

The PMD was specifically analyzed and designed to meet the Intelsat VIIA and N-Star mission profile and requirements.

DESIGN, DEVELOPMENT & ASSEMBLY

The I-VIIA and N-Star propellant tank assemblies summary of capabilities is shown in Figure 1.

FIGURE 1: I-VIIA & N-STAR SPACECRAFT PROPELLANT TANKS SUMMARY OF CAPABILITIES

	I-VIIA	N-STAR
Tank Outside Diameter Pressurized (in.)	49.35	49.30
Tank Length Pressurized (in.)	58.10	49.23
Tank Fluid Capacity, Minimum Liters in^3	 1275 77,805	 1000 61,025
Maximum Initial Propellant Load	95% of Tank Volume 3836 lbs N_2O_4 2380 lbs MMH	95% of tank volume 3027 lbs N_2O_4 1858 lbs MMH
Fluids	MMH, N_2O_4, IPA, Freon, Distilled Water, Ar, He, GN_2, LN2	MMH, N_2O_4, IPA, Freon, Distilled Water, Ar, He, GN_2, LN2
Temperature Range	19-122°F	19-122°F
Pressures (psia at 122°F) MEOP * Collapse Proof Burst	 250 3.5 312.5 375	 250 3.0 312.5 375
Minimum Expulsion Efficiency, %	99.5	99.5
Leakage	Zero liquid leakage $\leq 1 \times 10^{-6}$ scc/sec He at MEOP * Pressurant Leakage	Zero liquid leakage $\leq 1 \times 10^{-6}$ scc/sec He at MEOP * Pressurant Leakage
Maximum Weight, lb.	104.6	77.8
Minimum Design Life, Years	22.5	10.2
Stiffness Tank (95%) Propellant Fill Fraction) PMD Lateral (Immersed in Freon) PMD Axial (Immersed in Freon)	 > 50 Hz Natural Frequency > 17 Hz Natural Frequency > 100 Hz Natural Frequency	 > 50 Hz Natural Frequency > 20 Hz Natural Frequency > 100 Hz Natural Frequency
Launch Vehicle Compatibility	Atlas, Titan, & Ariane 4	Atlas 2AS & Ariane 44P

* Maximum expected operating pressure.

The tank shells are machined from annealed titanium alloy Ti-6AL-4V hemispherical forgings with the I-VIIA's cylindrical section made from an annealed Ti-6AL-4V ring forging. The N-Star configuration does not have a cylindrical section. During processing the hemispheres are rough machined, solution heat treated and partial aged, skim machined, final aged and then final machined.

The tank is mounted into the spacecraft structure by 32 equally spaced circumferential tabs with nut plates located on one of the hemispheres near the girth weld. The mounting tabs are machined from a ring forging that is Electron Beam (EB) welded to one of the hemispheres in the partial machined state. Individual tabs are finish machined from the ring when the hemisphere is completed. The propellant and pressurant ports are 1/2 inch diameter 6AL-4V titanium-to-304L CRES transition tubes with a flow control venturi in the propellant line.

Figures 2 and 3 depict outlines of the N-Star and Intelsat VIIA propellant tank assemblies.

FIGURE 2: OUTLINE OF N-STAR TANK ASSEMBLY

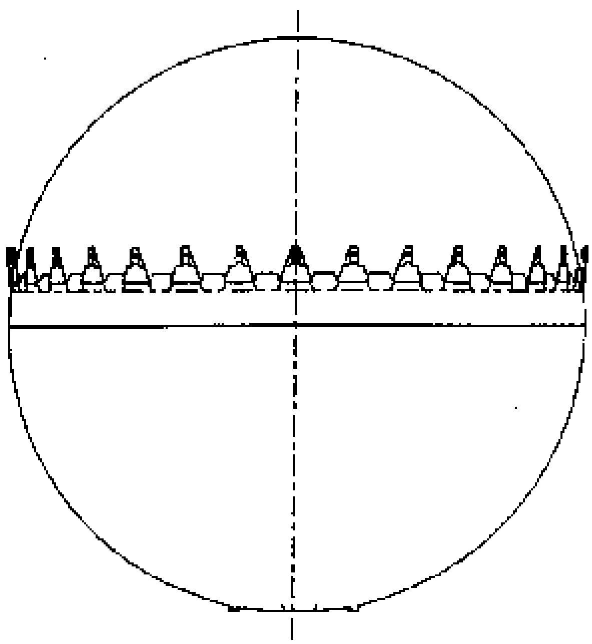
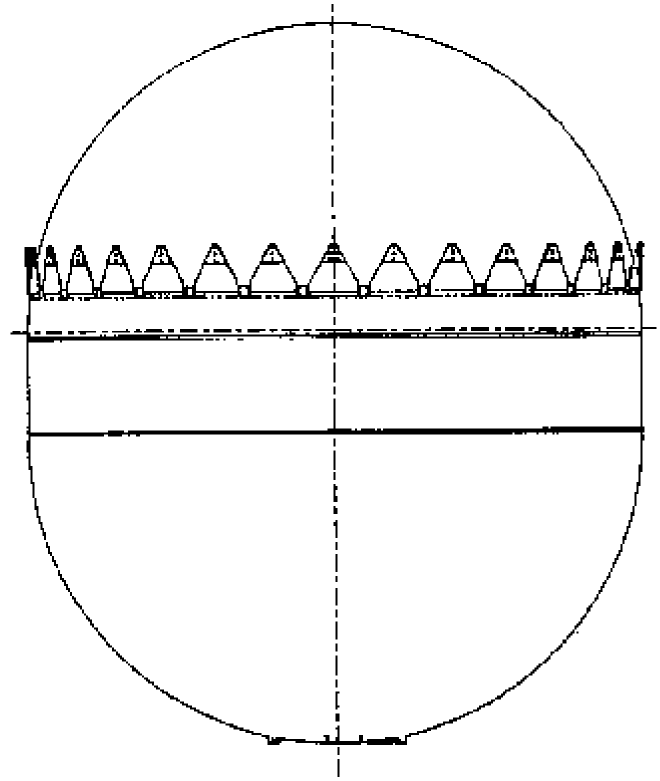


FIGURE 3: OUTLINE OF I-VIIA TANK ASSEMBLY



A shell structural analysis and fracture mechanics analysis, utilizing the NASA FLAGRO program, were used to design the tank shell thicknesses and reinforcements while a stress analysis was used to analyze the PMD details, subassemblies, and assemblies including its installation into the tank. An initial fracture mechanics plan with the tanks' histogram governed the former analysis while the imposed design and environmental test conditions, as listed in Figures 1, 10, and 13, dictated the structural and stress analyses parameters and boundary conditions.

Weight savings of up to 6 lbs. were effected on the N-Star tank assembly by accomplishing the following modifications:

a. Reducing the shell membrane thickness by 0.001 inch.

b. Reducing the shell reinforcement in the PMD mounting area.

c. Reducing the shell reinforcement in the upper PMD support boss area.

d. Re-contouring and reducing the size of the mounting tabs and surrounding tank shell reinforcement

e. Reducing the PMD channel wall thicknesses and length of the channel stiffening leg.

The propellant management device is a screened galleries and trap design. The PMD's for both programs are the same except for the N-STAR weight saving changes and the additional length in the I-VIIA unit necessary to accommodate the cylindrical tank shell. The PMD will supply bubble-free propellants to the thrusters under all mission maneuver environments until propellant depletion.

The PMD will perform with bubble point margins of greater than 2.0 times the design criteria under all conditions. With no moving parts, the PMD will provide totally passive control of the propellant during all acceleration phases of the mission.

The screened gallery-type PMD is used for higher flow rates, unlimited durations, and larger accelerations as compared to the vane-type PMD. The galleries are V-shaped structures with rows of screened windows on the side adjacent to the tank wall. The screened galleries are used to retain the propellant under adverse acceleration conditions, to transport gas-free propellant from one location within the tank to the outlet trap and to provide gas-free propellant to all the thrusters with no limit on North-South stationkeeping or East-West maneuver firing durations. In addition, this PMD is designed to provide capabilities for spin-up and recovery from a flat spin.

The trap is cylindrically shaped with an internal screen assembly and screened vent window. The trap is designed to retain propellant at the tank outlet during spin-mode and adverse acceleration conditions, and to provide propellant for contingency operation.

The contingency trap volume was selected to provide nominally 6 months of normal operation after the bulk of the propellant in the tank is emptied. This pre-depletion is detected by a patented detection technique which can discern when liquid is no longer held against the tank wall by the capillary forces in gaps between the PMD channel arms and the tank wall.

The PMD contains four galleries which are spaced at 90^{0} to each other. They are joined at the top of the tank, follow the inside contour of the tank, and interlace into the trap at the bottom of the tank. The PMD design incorporates a test system with an Isopropyl Alcohol (IPA) wetting line and a pressurization line to the interior of the trap. External ports for this system are 1/8 inch diameter lines located near the propellant outlet port. This system can be used to bubble point test the trap vent screen and gallery arm screens after tank closure through final spacecraft integration tests. The two test ports are then welded close before launch.

The PMD is fabricated from 6AL-4V and 3AL-2.5V titanium alloys and commercially pure (CP) titanium sheet and bar stock. All details are tungsten inert gas (TIG) or Electron Beam (EB) welded into next assemblies. The PMD screen configurations are listed in Figure 4. The screens are twilled dutch weave cloth. EB drilled perforated sheet is also used in the trap at the gallery arms' interfaces.

FIGURE 4: PMD SCREEN REQUIREMENTS

	I-VIIA FUEL TANK	I-VIIA OXIDIZER TANK	N-STAR
Trap Vent Window	200 x 1400 304L CRES	200 x 1400 304L CRES	200 x 1400 304L CRES
Center Body Cylinder & Cone	200 x 1400 304L CRES	165 x 800 CP Titanium	200 x 1400 304L CRES
Gallery Arms	200 x 1400 304L CRES	165 x 800 CP Titanium	200 x 1400 304L CRES

After assembly, the PMD is mounted and welded into the outlet hemisphere while the gallery arm-to-tank wall gaps are maintained. The expulsion assembly is bubble point tested and accepted before the tank assembly is closed. For the N-Star configuration there is one automatic TIG girth weld to assemble the final tank assembly. For the I-VIIA configuration there are two automatic TIG girth welds -- the first joins the cylindrical center section to the pressurant or mounting hemisphere and the second joins this subassembly to the expulsion assembly to finally close the tank.

The girth welds are radiographic and dye penetrant inspected and the final assembly is stress relieved in a vacuum heat treat furnace. The mounting tabs are then final machined and the nut plates are installed. The tank is then ready for final inspection testing, cleaning, and delivery.

PMD ANALYSIS & DESIGN

The operational parameters used in the design of the I-VIIA and N-Star PMD are listed in Figure 5. The I-VIIA and N-Star PMD(s) are shown in Figures 6 and 7, respectively. A portion of the IPA test system has been omitted for clarity.

FIGURE 5: INTELSAT VIIA & N-STAR PROPELLANT MANAGEMENT DEVICE PERFORMANCE REQUIREMENTS SUMMARY

NOTE : Unless specified noted parameters are for the I-VIIA and N-Star missions.

Definitions & Assumptions

- Z axis passes through the tank centerline and is perpendicular to the plane of the circumferential mounting points.
- X & Y axes are perpendicular to the Z axis and each other and pass through the tank center.
- Tank volume is 1015 liters (N-Star) or 1290 liters (I-VIIA) when pressurized to MEOP (250 psia). Nominal satellite dry mass is 1225-1575 kg (N-Star) or 1895 kg (I-VIIA).

Tank Load Conditions

	N-Star	I-VIIA
Total Propellant, kg	1650-2216	2060-2820
Oxidizer, kg	1018-1373	1263-1740
Fuel, kg	632-843	797-1080
Tank Pressure,psia	18-250	180-215

Ground Operations and Launch

- Tanks are filled, drained, and launched outlet down.
- Tank fill fraction is between 70 and 95%. The first 40 liters are filled at a flow rate of 2.3 1/min maximum and the remaining propellant at 11 1/min maximum.
- Tanks are upright $\pm 15^{o}$ during handling.
- Launch vehicle attitude control and deployment produce accelerations of up to 0.02 g laterally and up to 0.01 g in any direction. No propellant is required.,
- System line priming occurs during zero g or during a <0.35 rpm spin about the lateral, X axis,
  - The priming flow rate is 20 in^3/sec for 61in^3.
  - The X axis is 400 mm below the fuel outlet maximum.
- Spinning perigee at up to 30 rpm about the Z axis may follow system priming.
  - Tank fill fraction is 60% or above.
  - Spin up requires 5.2 liters maximum at up to 10 cc/sec.
  - Active Nutation Control requires 1.8 liters maximum. Axial accelerations of up to 1.0 g may be encountered.
  - Despin requires 1.3 liters at up to 14 cc/sec.
    - Z axis spin of up to 30 rpm or
    - X axis spin of up to 14.3 rpm.

Ascent Operations

- Post system priming, the propellant is required for attitude control at any time during mission,
  - 20 ms pulse width at up to 1000 pulses per hour.
  - Flow rates of up to 10 cc/sec.
- Post system priming, the propellant is required for safe mode at any time during mission.
  - Spin about the X axis at up to 0.3 rpm.
  - 300 cc (I-VIIA) or 215 cc (N-Star) is required at flow rates of up to 10 cc/sec.

- Apogee and Orbit Augmentation requires long duration settling burns at any fill fraction.
  - Tank pressure is regulated to 225-235 psia.
  - Unlimited burn duration is required.
  - The flow rate is 85 cc/sec maximum.
  - The settling acceleration is between 0.013 and 0.071 g.
- Apogee and Orbit Augmentation failure mode requires long duration - Y axis lateral burns
  - Fill fractions above 10%.
  - 90 minute duration is required.
  - The flow rate is 10 cc/sec maximum.
  - The lateral acceleration is 0.008 g maximum.
- Once on orbit, stationkeeping maneuvers and repositioning require up to 4.3 liters (I-VIIA) and 2.58 liters (N-STAR) in any of four lateral axes.
  - Tank pressure is reducing to 170 psia minimum.
  - Tank fill fraction is between 20 and 0.5%
  - The flow rate is 20 cc/sec maximum.
  - The lateral acceleration is 0.008 g maximum.
- Deorbit requires up to 2.58 liters in any of the four lateral axes.
  - Tank fill fraction is between 0.25 and 0.15%.
  - The flow rate is 16 cc/sec maximum.
  - The lateral acceleration is 0.004 g maximum.
- Gas free propellant delivery is required throughout mission.
- Residuals shall be limited to 0.5% of the tank volume maximum.
- Propellant temperature is between 59 and 86°F.

FIGURE 6: OUTLINE OF I-VIIA PMD

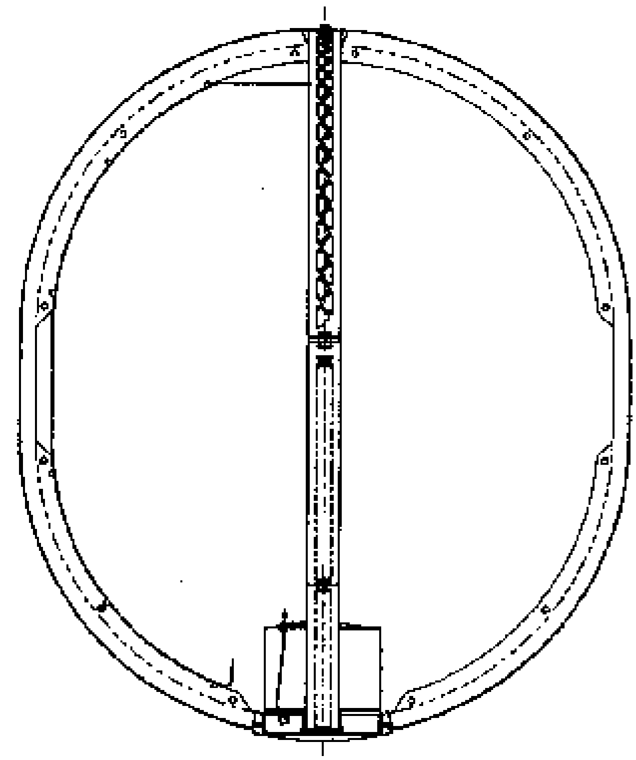
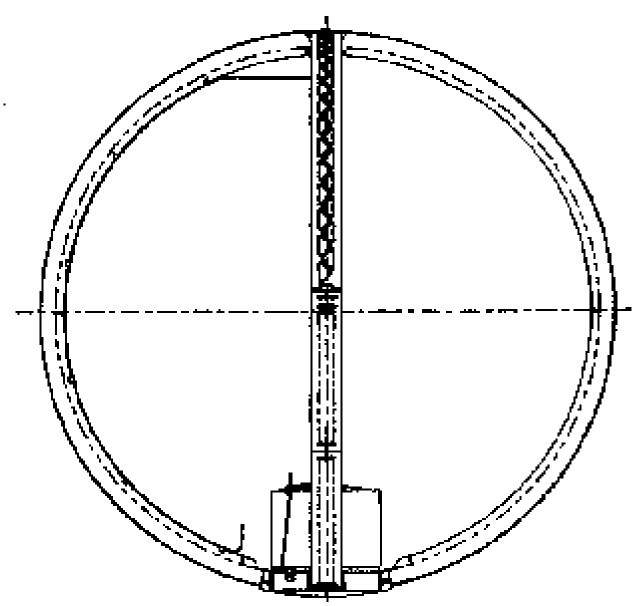


FIGURE 7: OUTLINE OF N-STAR PMD



The propellant management device (PMD) design for the I-VIIA and N-STAR propellant tanks is based on the SS/L design used for the GOES, I-VII and Superbird programs. The design requirements were quite stringent based on a necessity to be compatible with any launch vehicle using either a spinning or 3 axis stabilized injection system. Further, it was necessary to be compatible with either the standard SS/L 3 axis stabilized liquid propulsion transfer orbit system or a spin stabilized solid perigee or apogee motor. The on-orbit requirements are for unlimited operation for any lateral or axial attitude control thruster.

The PMD design has been verified by tests in the drop towers at the University of Santa Clara and at NASA-Lewis Research Center. Additional zero g testing was also conducted on the NASA KC-135 aircraft. Data from some of these tests are presented in References 1 and 2.

Figure 8 presents PMD requirements and predicted performance for the major requirements.

FIGURE 8: PMD HOLDING REQUIREMENTS AND RETENTION CAPABILITY FOR KEY REQUIREMENTS

OPERATIONAL PHASE	REQUIREMENT (g-inches)	CAPABILITY (g-inches)	SAFETY FACTOR
Launch	No Gas Injestion	Screens immersed	Infinite
Orbit Raising	1.33 (oxidizer)	4.97 (oxidizer)	3.7
N/S Stationkeeping (2 thrusters firing)	0.25 (oxidizer)	4.97 (oxidizer)	20.0
E/W Maneuvers (2 thrusters firing)	0.25 (oxidizer)	4.97 (oxidizer)	20.0
Spin-up/de-spin	2.40 (oxidizer)	4.97 (oxidizer)	2.0
Flat spin recovery	4.3 (fuel)	11.1 (fuel)	2.5

Based on worst case screen holding requirement.

QUALIFICATION TESTS

Three test specimens -- one I-VIIA Fuel Tank, one I-VIIA Oxidizer Tank, and one N-Star tank were subjected to qualification testing as listed in Figure 9.

FIGURE 9: QUALIFICATION TESTS FOR THE LORAL SPACECRAFT PROPELLANT TANKS

- Preliminary Inspection of Product
- Mass Measurement
- Pre-Proof Volumetric Capacity
- Ambient Proof Pressure Test
- Post-Proof Volumetric Capacity
- Cryogenic Proof Pressure Test
- Post-Cryo Proof Volumetric Capacity
- Bubble Point Test
- Cleanliness Check
- Sine & Random Vibration Test
- Cleanliness Check
- Bubble Point Test
- Acceleration *
- Pressure Cycles
- Expulsion Test
- Bubble Point Test
- External Leakage Test
- Radiographic Inspection
- Dye Penetrant Inspection
- Visual Inspection
- Cleanliness Check
- Burst Pressure
- Data Review

* This test was not performed on the N-Star qualification tank since it had been accomplished successfully on the I-VII tank assemblies.

The qualification test starts with an inspection for dimensions, verification of previous inspections and tests, identification, successful completion of all manufacturing planning, damage, and material certifications. The dry tank assembly is weighed on a precision scale. Actual weights of 102.46 and 102.64 lbs. for I-VIIA and 76.79 lbs. for N-Star were within specification limits. The tank is subjected to an ambient hydrostatic proof pressure of 322.5 psig for 66 seconds maximum and the mass of water required to fill the tank is measured to determine the actual tank volume before and after the application of the proof pressure.

A cryogenic proof pressure test, utilizing liquid nitrogen at 440 psig for three seconds maximum, is then performed followed by an ambient hydrostatic volumetric capacity check to determine if there is any change from the original tank volume. The permanent set shall not exceed 0.2% Maximum permanent set for the three test specimens was 0.04%. An external leakage test is run at 240 psig with helium gas for 15 minutes minimum in a chamber evacuated to 0.2 microns of mercury or less. Leakage shall not exceed 1×10^{-6} scc/sec of helium gas. Maximum measured leakage was 1 x 10^{-8} scc/sec which is essentially the background reading.

Bubble point tests with Isopropyl Alcohol (IPA) as the test medium are accomplished on the channel arms and trap vent window screens as a unit and on the cone and cylinder screen assemblies inside the trap as a unit. The former screens are tested using the IPA flow and test system built into the tank assembly. Bubble points are verified for 60 seconds minimum to verify PMD screen integrity then the capillary breakdown value is measured. The tanks are cleaned to the levels specified in Figure 14 and all fluids entering the tank are filtered to the 10 micron absolute level.

Vibration tests are performed on the tanks in each of three orthogonal axes. The test fixture simulates the tank-to-spacecraft installation interface but is also sufficiently stiff to be considered a rigid mass and not introduce spurious inputs to or responses from the tank assembly. Figure 10 presents the vibration test parameters.

FIGURE 10: QUALIFICATION VIBRATION TEST REQUIREMENTS

		I-VIIA	N-Star
Test Fluid		Freon	
Fluid Weight, lb.		3837-3842	3030-3035
Test Pressure, psig		240-250	
Sine Vibration (Dry)	Axis	Frequency (Hz)	Acceleration (g) (0-PEAK)
	All	5-10.8	.25 in S.A.
		10.8-20	3
		20-100	1.5
		100-400	1
Sine Vibration (Wet)	Axis	Frequency (Hz)	Acceleration (g) (0-PEAK)
	Lateral (X & Y)	5-10.8	.25 in S.A.
		10.8-45	3
		45-100	2
	Axial (Z)	5-18.2	.20 in S.A.
		18.2-20	6.8
		20-22	Ramp Down
		22-50	2.6
		50-52	Ramp Down
		52-100	1.3
Sine Vibration Sweep Rate, Octaves/Minute		2	
Random Vibration (Wet)		Frequency (Hz)	Levels
		90-100	+30dB/Octave
		100-800	$.054g^2/Hz$
		800-2000	-3dB/Octave
		Overall g-rms	8.7
Random Vibration Duration, Minutes (Each Axis)		2	

FIGURE 11: TANK NATURAL FREQUENCIES, 95% FILL FRACTION (HZ)

	AXIS	CALCULATED	MEASURED
N-Star	X	70	70-80
	Y	70	70
	Z	80	70-80
I-VIIA	X	60	60-70
	Y	60	60-70
	Z	70	70

The Freon load simulates the worst case oxidizer load condition. Up to 13 accelerometers are installed on the tank to measure the response levels and to characterize the response spectrum. Up to four control accelerometers are mounted on the test fixture to provide a closed loop control system with the vibration driver equipment to insure that specification requirements are met. The wet sine vibration spectrum input is notched to limit the acceleration loads on the tank. Natural frequency results are presented in Figure 11. They are consistent and meet the specification limit of >50 Hz for all axes.

Using IPA or Freon, the tank is flushed through the pressurant and propellant ports after vibration testing and the effluent analyzed for cleanliness level. This check determines if contamination is self-generating in the tank during testing, the quantity and size of contaminants, the non-volatile residue, and the type of particles.

Post-vibration bubble point tests are performed to verify that the screens have not been damaged by the vibration tests. One representative configuration of the I-VIIA tank was subjected to steady acceleration loads while filled with 3839 lbs. of Freon and pressurized to 250 psig. The tank was installed in a test fixture simulating the spacecraft interface and rotated in a centrifuge in three different orientations to apply the net ultimate acceleration vectors of 3.35g, 5.40g, and 7.84g for one minute each.

Pressure cycling tests, using distilled deionized water, consist of 10 cycles from Zero to 322.5 psig (proof pressure), 96 cycles from Zero to 255 psig (MEOP), and five external pressure (collapse) cycles from ambient pressure to 3.0 psid (N-Star) or 3.5 psid (I-VIIA). The internal pressure tests were run for five seconds maximum while the external pressure test was held for 36 second maximum. Following these tests an expulsion test was performed. The initial flow is discharged into an evacuated surge tank to simulate orbital operations. The tank is drained in the vertical attitude using a 230 psig ullage pressure and a flow rate of 1.35 gpm. Pressure drop and residual water volume are measured. The qualification units demonstrated residuals well within the requirements of 389 in^3 (I-VIIA) and 305 in^3 (N-Star). A final set of verification tests, including bubble point tests, external leakage test, dye penetrant inspection of the complete external surface, radiographic inspection of the girth weld and internal PMD views, visual inspection, and cleanliness check (NVR and particle count) are performed before the burst test.

Finally, a burst pressure test was performed on the water-filled test specimen to 387 psig. No leakage or rupture was allowed. The I-VIIA tank assembly with the CRES PMD screens and the N-Star assembly were then pressurized to actual rupture. The I-VIIA qualification tank with the titanium and CRES PMD screens was taken to burst but not ruptured since the tank shell was scheduled for use as a test specimen on another LORAL program. Actual burst pressures were 479 psig and 478.8 psig, respectively.

ACCEPTANCE TESTS

The acceptance tests for the I-VIIA and N-Star propellant tanks are listed in Figure 12.

FIGURE 12: ACCEPTANCE TESTS FOR THE LORAL SPACECRAFT PROPELLANT TANKS

Preliminary Inspection of Product
Mass Measurement
Pre-Proof Volumetric Capacity
Ambient Proof Pressure Test
Post-Proof Volumetric Capacity
Cryogenic Proof Pressure Test
Post-Cryo Proof Volumetric Capacity
External Leakage Test
Bubble Point Test
Sine & Random Vibration Test
Ambient Proof Pressure *
Expulsion Test
Bubble Point Test
External Leakage Test
Radiographic Inspection
Dye Penetrant Inspection
Visual Inspection
Cleanliness Check
Data Review

* This test is not performed on the N-Star tanks.

Figure 13: Acceptance Vibration Test Requirements

		I-VIIA	N-Star
Test Fluid		Freon	Distilled, Deionized Water
Fluid Weight, lb.		3837-3842	2094-2099
Test Pressure, psig		190-200	240-250
Sine Vibration (Wet)	Axis	Frequency (Hz)	Acceleration (g) (0-PEAK)
	N-Star		
	Lateral	5-13	.19 in S.A.
	(X &Y)	13-17	3.3
		17-45	2.31
		45-100	1.54
	N-Star		
	Axial	5-22.3	.15 in S.A.
	(Z)	22.3-24	7.6
		24-26	Ramp Down
		26-50	2
		50-52	Ramp Down
		52-100	1
	I-VIIA		
	Lateral	5-10.8	.19 in S.A.
	(X &Y)	10.8-45	2.31
		45-100	1.54
	I-VIIA		
	Axial	5-18.2	.15 in S.A.
	(Z).	18.2-20	5
		20-22	Ramp Down
		22-50	2
		50-52	Ramp Down
		52-100	1
Sine Vibration Sweep Rate, Octaves/Minute		4	
Random Vibration, (Wet)		Frequency (Hz)	Levels
		90-100	+30dB/Octave
		100-800	.027G^2/Hz
		800-2000	-3dB/Octave
		Overall g-rms	6.2
Random Vibration Duration, Minutes (Each Axis)		1	

The acceptance test starts with an inspection for dimensions, verification of previous inspections and tests, identification, successful completion of all manufacturing planning, damage, and material certifications. The dry tank assembly is weighed on a precision scale. The tank is subjected to an ambient hydrostatic proof pressure of 322.5 psig for a maximum of 66 seconds. The mass of water required to fill the tank is measured to determine the actual tank volume before and after the application of the proof pressure. Permanent set must not exceed 0.2%. The drained and dried tank is then exposed to a cryogenic proof pressure test at 440 psig for five seconds maximum. The tank is filled with liquid nitrogen and totally submerged in a stainless steel lined pit filled with liquid nitrogen. The tank is vented, drained, and allowed to reach ambient conditions without heating. Another volumetric capacity test is performed with water to insure that the test specimen has not experienced a permanent set greater than 0.2%. An external leakage test is run at 240 psig with helium gas for 15 minutes minimum in a vacuum chamber evacuated to 0.2 microns of mercury or less. Leakage must not exceed 1×10^{-6} scc/sec of helium gas.

To verify the integrity of the PMD screened elements after the proof pressure tests, bubble point tests with IPA as the test fluid are performed in two phases. The first phase tests the channel arms and trap vent window and the second phase checks the trap assembly internal screens. The bubble point is held for a minimum of 60 seconds and then the capillary breakdown is measured.

Vibration tests, configured as described in Figure 13, are performed on the tanks in each of three orthogonal axes.

Sufficient response accelerometers are installed on the test specimen to characterize the tank responses and control accelerometers are placed on the test fixture to insure compliance with the specification requirements. The sine vibration spectrum input is notched to limit the acceleration loads on the tank. The ambient hydrostatic proof pressure test is then repeated for the inteleal units.

Next, an expulsion test, using distilled, deionized water, is completed. Water is flowed at 1.35 gpm (worst case mission flow rate) with a 220-240 psig ullage pressure while the tank pressure drop and residuals are measured and compared to the specification requirements. The bubble point tests, external leakage test, radiographic inspection of the girth weld and internal PMD views, dye penetrant inspection of the external surface, and visual inspection are performed to verify the tank has no damage as a result of the environmental tests.

Finally, the units are cleaned to Figure 14 levels, purged to a -65°F dew point, pressurized to 15 psig with dry GN_2, the ports capped, and packaged in two sealed plastic bags for shipment.

Figures 15 and 16 depict outlines of the I-VIIA and N-Star propellant tanks showing the port orientations. In both cases the top view illustrates the pressurant port while the bottom view shows the larger diameter propellant outlet port with the two flanking IPA system test ports.

FIGURE 14: TANK CLEANLINESS LEVEL

Particle Size (Microns)	Maximum Amount of Particles
> 100 Microns	None
76-100 Microns	8
51-75 Microns	20
10-50 Microns	500
< 10 Microns	No Silting

NOTES:

1. No metallics > 50 microns
2. Non-volative residue (NVR) less than 1mg/100 ml.

FIGURE 15: OUTLINE OF I-VIIA TANK WITH PORTS

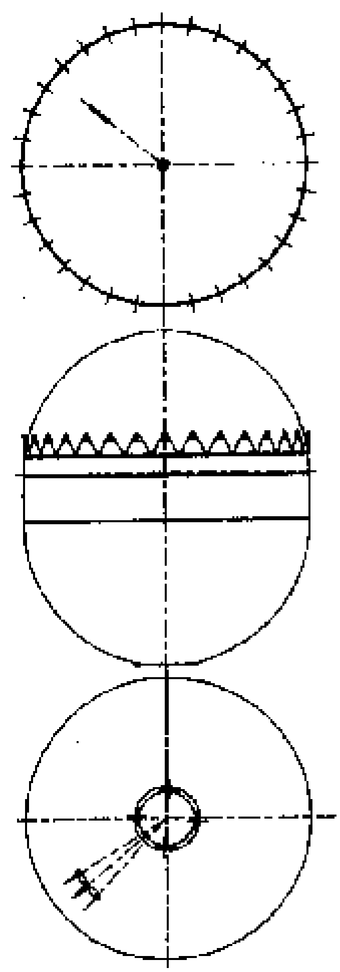
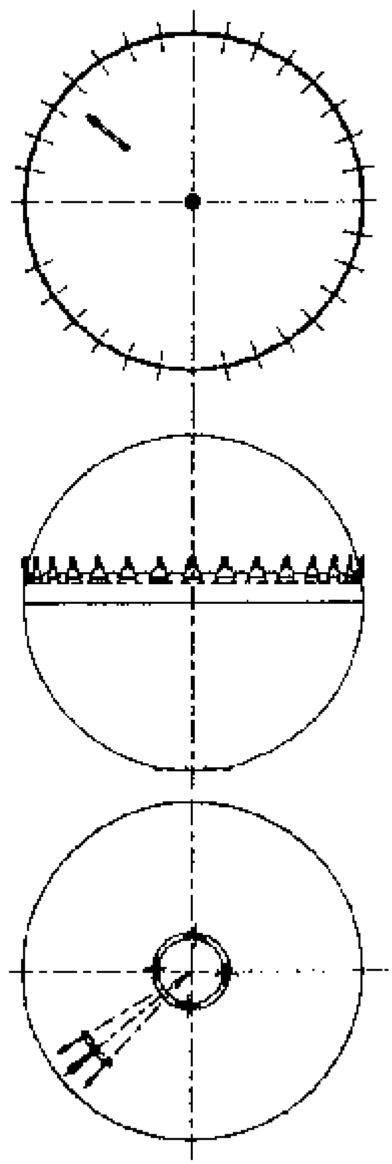


FIGURE 16: OUTLINE OF N-STAR TANK WITH PORTS



CONCLUSIONS

The I-VIIA and N-Star propellant tanks have met all design objectives that can be verified by analysis and the qualification test specimens have successfully passed all tests.

The PMD design has been successfully used on six Intelsat VII missions and two GOES missions. No anomalous operation has been encountered during transfer orbit or on-orbit operations.

Eight I-VIIA propellant tanks have been delivered to Space Systems/Loral. They include two qualification units and six flight units. Of these tank assemblies four contained titanium mesh screens in the PMD for use in the oxidizer system and four were fabricated with CRES mesh screens in the PMD for use in the fuel system. Seven N-Star tanks, all with CRES mesh PMD screens, have been delivered to Space Systems/Loral. These include one qualification unit and six flight units. All units were delivered on time.

The I-VIIA satellites are scheduled for launch in 1995 using the Ariane 4 series launch vehicle. Two N-Star spacecraft are also slated for launch in 1995 on the Ariane 4 booster with the first scheduled on August 1. The first I-VIIA satellite was launched successfully from Kourou, French Guiana on May 17, 1995 at 10 pm PDT.

ACKNOWLEDGMENTS

The authors wish to thank the following individuals for their assistance on the successful completion of the I-VIIA and N-Star Propellant Tank Programs: Don Jaekle of PMD Technology, Andover, MA who provided much PMD test support and consultation and Bruce Nehls and Denny Jakubec of Brunswick Corp., Costa Mesa, CA who contributed to the development, fabrication, and delivery of the PMD screened elements.

In addition, thanks are expressed to Harold Braun and Larry Hicks of Foster Engineering, Woodland Hills, CA who performed the Stress & Fracture Mechanics Analyses & supported the customer design reviews. Finally, thanks are expressed to all of PSI's subcontractors who provided materials, detail parts, manhours, and services to make the programs a success.

REFERENCES

1. Yeh, T. and Orton, G.F., "Analytical and Experimental Modeling of Zero/Low Gravity Fluid Behavior", AIAA 87-1865, 1987.

2. Yeh, T. and Bond, D.L., "Testing of Propellant Management Device for 3-axis Geosynchronous Spacecraft", 10th Aerospace Testing Seminar, March 1987.