Development and Qualification of the Propellant Management System for Viking 75 Orbiter

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The Viking 75 Orbiter propulsion subsystem uses Earth storable propellants, monomethylhydrazine and nitrogen tetroxide, to provide midcourse corrections, Mars orbit insertion, and Mars orbit changes for the Viking spacecraft. A surface-tension propellant management system provides propellant center-of-mass control, supplies gas-free propellant to the engine, and insures liquid-free gas venting if required. The surface tension system consists of a passive sheet metal baffle assembly, a communication channel, and a pressurization/vent tube. This paper describes the development and qualification of the surface tension system and includes results of low-*g* drop tower tests of scale models, 1-*g* simulation tests of low-*g* large ullage settling and liquid withdrawal, structural qualification tests, and propellant surface-tension/contact-angle studies. Subscale testing and analyses were used to evaluate the ability of the system to maintain or recover the desired propellant orientation following possible disturbances during the Viking mission. This effort included drop tower tests to demonstrate that valid wick paths exist for moving any displaced propellant back over the tank outlet. Variations in surface tension resulting from aging, temperature, and lubricant contamination were studied and the effects of surface finish, referee fluid exposure, aging, and lubricant contamination on contact angle were assessed. Results of movies of typical subscale drop tower tests and full scale slosh tests are discussed.

Introduction

THE Viking 75 mission includes boost, the approximately 12-month transit time to Mars with the necessary midcourse corrections, Mars Orbit Insertion (MOI), release of a lander vehicle, and periodic orbit adjustment of the Orbiter. The midcourse correction, Mars Orbit Insertion, and Mars orbit adjustment functions are performed by the Orbiter propulsion system. The propulsion system consists of a 1330N (300lbf) bipropellant engine using monomethylhydrazine (MMH) and nitrogen tetroxide (N_2O_4) propellants, tankage to accommodate approximately 1360 kg (3000 lbm) of propellant, helium pressurant tanks, and other feed system components. A comprehensive mission optimization study was conducted and a surface-tension propellant management system was chosen to be developed for the Orbiter. This selection[1] represents the first time that a complete surface-tension propellant management system has been applied to interplanetary flight. After undergoing some design changes during the development phase, the surface tension system has been successfully qualified for flight on the Orbiter.

System Requirements

The Viking 75 Orbiter propellant management system begins operation after boost into an Earth-Mars transfer orbit and must perform satisfactorily until propellant depletion. It must provide propellant upon demand for Earth-Mars interplanetary trajectory corrections, insertion into Mars orbit, and orbit trims around Mars. In addition to supplying gas-free propellant to the engine, it must also position propellant symmetrically about each tank centerline to keep the spacecraft center-of-mass within the allowable tolerance and to permit venting of the ullage gas with a minimum loss of propellant in the event of a pressure regulator failure. Close control of propellant center-of-mass is necessary to maintain acceptable pointing accuracy for velocity change maneuvers. Liquid-free venting is required to minimize propellant loss, to avoid vehicle torques, and to prevent contamination of critical equipment. As a result of the propellant tank design, the propellant management device must be designed for installation and removal through a 22.9 cm (9.0 in.) diam access hole. Some of the specific environmental constraints, physical constraints, and functional requirements for the Viking Orbiter propellant management system are given in Table 1.

Hardware Description and Operation

A schematic representative of the Viking 75 Orbiter propellant management system is shown in Fig. 1. Primary elements of the surface-tension system are the central baffle assembly, the communication channel, the pressurization/vent tube, and the mounting cap assembly. The central baffle assembly consists of a hollow central tube or standpipe to which 12 sheet metal vanes are attached. The communication channel is a sheet metal element that runs along the tank wall from the top to the bottom of the tank, being attached to the tank only at each end. The mounting cap assembly forms the tank outlet closure and also serves as the attachment point for the central baffle assembly. Surface tension forces of the propellants are used to reorient any off-axis ullage bubble to the only stable location in the tank directly above the baffle assembly and symmetric about the tank centerline. Surface tension of the liquid creates a difference between the gas pressure and the liquid pressure at any curved liquid-gas interface. This pressure difference is proportional to the surface curvature, as expressed by the equation

$$P_G - P_L = \sigma\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

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Table 1 Viking propellant management requirements

Functional requirements	
Number of burns	12 to 35
Time between burns	1 to 320 days
Minimum time between maneuver and burn	128 sec
Minimum propellant quantity at start of final burn	8.52 kg (18.8 lbm) N_2O_4 5.89 kg (13.0 lbm) MMH
Minimum ullage volume (initial)	6.1% MMH, 11% N_2O_4
Minimum ullage volume (after Mars Orbit Insertion)	70% MMH
Flowrates	0.19 kg/sec (0.42 lbm/sec) MMH, 0.29 kg/sec (0.64 lbm/sec) N_2O_4
Pressurization	
Pressurant	regulated helium
Liftoff pressure	68.9 N/cm^2 (100 psia) at 294 K (70°F)
Flight pressure at first burn and after	167.5 N/cm^2 (243 psia) nominal
Time from flight pressurization to first burn	24 hr
Regulator flowrate	4000 std m^3/hr (250 scfm) He max per tank
Bulk temperature of stored propellant in flight	286–297 K (55–75°F)
Feed quality	greater than 99%
Ullage bubble eccentricity and liquid loss during venting	minimum practical
Materials and compatibility	referee fluids (Freon TF and isopropyl alcohol) and propellants
Physical constraints	
Weight	66.6 N (15 lb) per device
Tank	Cylindrical with hemispherical domes, 92.7 cm (36.5 in.) diam and 144.8 cm (57.0 in.) long, 6Al-4V Titanium alloy
Tank outlet end configuration	22.9 cm (9 in.) diam access hole
Environmental constraints	
Steady boost	5 g forward, 2 g lateral
Steady coast	$1\times10^{-7}g$ max in any direction
Spacecraft attitude maneuver (up to 360° at 0.001 rad/sec)	
Steady (due to angular acceleration)	0.0002 g for 0.6 sec
Steady Orbiter engine burn	0.04 g min, 0.15 g max
Slosh	see Fig. 16

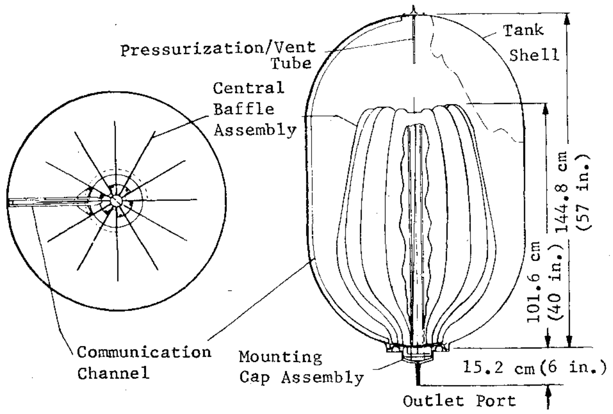

Fig. 1 Propellant management system.

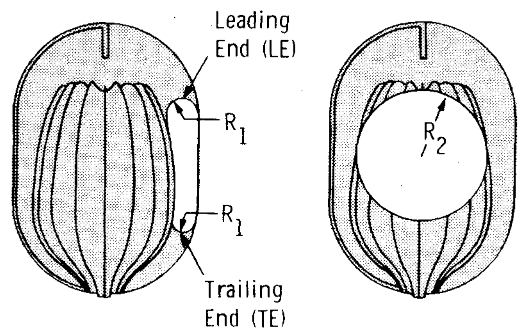

Fig. 2 Liquid surface curvature for an off-axis ullage bubble.

where

P_L = liquid pressure
P_G = ullage gas pressure
σ = liquid surface tension
R_1, R_2 = principal radii of surface curvature

Figure 2 shows two views (side and front) of an off-axis ullage bubble and defines the principal radii of curvature at the leading end (LE) and trailing end (TE) of the bubble. The pressure difference in the liquid between the leading end and trailing ends of the bubble can then be expressed as

$$(P_L)_{LE}-(P_L)_{TE}=\left[P_G-\sigma\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\right]_{LE}$$
$$-\left[P_G-\sigma\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\right]_{TE}$$

Assuming the pressure is uniform throughout the ullage bubble and differences in R_2 at the leading and trailing ends of the bubble can be neglected, this equation can be simplified to yield

$$(P_L)_{LE}-(P_L)_{TE}=\sigma\left[\left(\frac{1}{R_1}\right)_{TE}-\left(\frac{1}{R_1}\right)_{LE}\right]$$

By virtue of the shape of the baffles in relation to the tank wall, an off-axis bubble is distorted to produce higher liquid pressure at the leading end of the ullage bubble, which in turn causes the bubble to move toward a centered position on top of the baffles.

Figures 3 and 4 show some typical propellant orientations. During launch, the liquid surface is relatively flat, although some slosh will occur. Once the launch and separation disturbances are removed, the ullage bubble will be pumped to the coast position shown in Fig. 3. Under the influence of

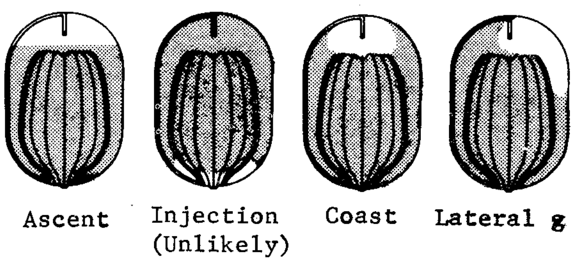

Fig. 3 Small ullage orientations.

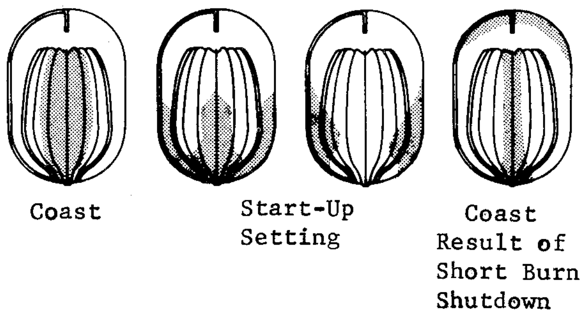

Fig. 4 Large ullage orientations.

the lateral-*g* environments expected during the flight, the device must have sufficient holding power to assure that the pressurization/vent tube remains within the ullage in the event venting is required. During coast after Mars Orbit Insertion with ullages of 70% and greater, surface-tension forces will cause the propellant to orient in column form in the baffle elements as shown in Fig. 4. At engine startup, the propellant settles down the center of the baffles and rises up the sides of the tank.

When the propellant is away from the outlet, the standpipe at the center of the baffles performs its function as a fluid reservoir from which the engine is fed until the sloshing propellant returns to cover the tank outlet. At termination of a short burn, settling inertia could result in propellant continuing up the tank wall (carry-over) and lodging in the upper dome as shown in Fig. 4. The difference in surface curvature between the liquid in the dome and that in the baffle assembly causes liquid to flow along the wetted communication channel to the baffle assembly during spacecraft coast.

During large ullage settling, when the standpipe is partially drained, propellant carry-over could result in sealing a bubble inside the standpipe as shown in the left view of Fig. 5. A tapered fin was incorporated inside the standpipe to distort the bubble to cause it to move to the upper open end of the standpipe. The fin was designed to pump bubbles of approximate standpipe diameter and larger. During pumping, the column of propellant above the bubble will be reduced to a thin membrane that will burst allowing the standpipe to totally fill with propellant.

A schematic representation of the base area of the surface-tension propellant management system is given in Fig. 6. Several design features were incorporated in the base area to assure the existence of valid wick paths from the communication channel to the baffle assembly and sump areas.

Propellant wicking proceeds along the communication channel until it is in close proximity to the baffle elements. Surface discontinuities between the tank outlet flange and the mounting cap assembly and the baffle assembly support could act as barriers to liquid from the channel to the center of the baffle assembly. To provide proper wicking, a thin extension was incorporated as an integral part of the communication channel to bridge these discontinuities and assure proper communication of propellants.

As propellant reaches the center of the baffles, the baffle elements begin to fill. The propellant contacts the wicking key

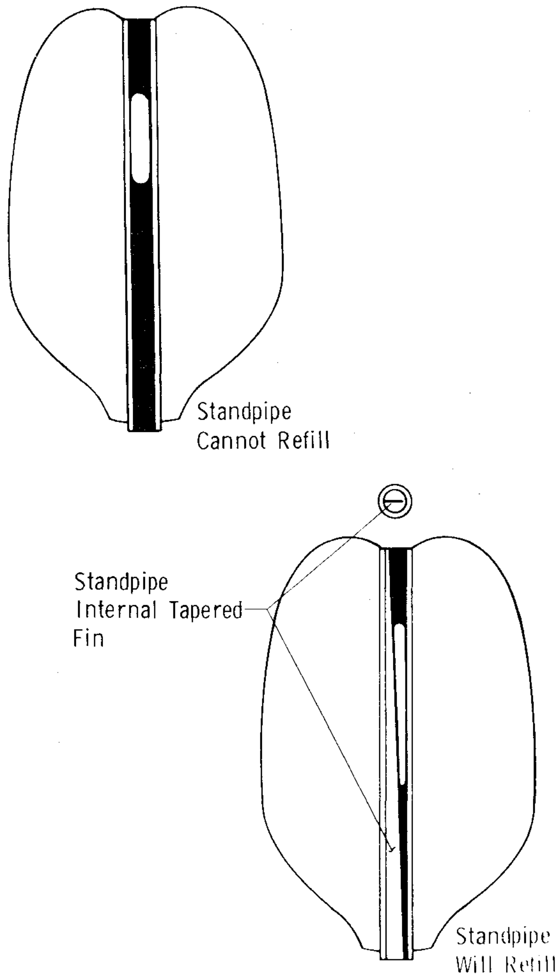

Fig. 5 Standpipe filling.

and wicks through the upper flange of the baffle assembly support and begins to fill the sump. Wicking continues along the key until the propellant contacts the standpipe fin, and the standpipe begins filling.

Normally, at the start of communication the sump would be full, and there would be some propellant within the baffles over the tank outlet. Under these conditions communicated propellant would replenish propellant at the base of the baffles and in the sump. The column of liquid in the baffle elements would grow radially between each pair of baffles and the standpipe would be replenished from propellant in the sump.

As indicated by the flow arrows, propellant flows from the tank into the sump passing through three equally spaced openings at the outside of the baffle assembly support upper flange. Propellant flowing from the standpipe enters the sump through 12 equally spaced holes below the standpipe fin.

All propellant flows through the bubble filter and through 10 holes in the bottom of the baffle assembly support before leaving the propellant tank assembly. The bubble filter consists of 478 2.5 mm (0.1 in.) diam holes that were sized to a) allow gas trapped below the filter to be transferred to the tank ullage by buoyancy during launch, and b) prevent large quantities of gas from being ingested into the spacecraft engine during start-up settling under large ullage conditions.

Qualification Program

Qualification of a sheet metal baffle surface-tension propellant management system is significantly different from the qualification of other types of systems since the performance of the surface-tension system cannot be verified by

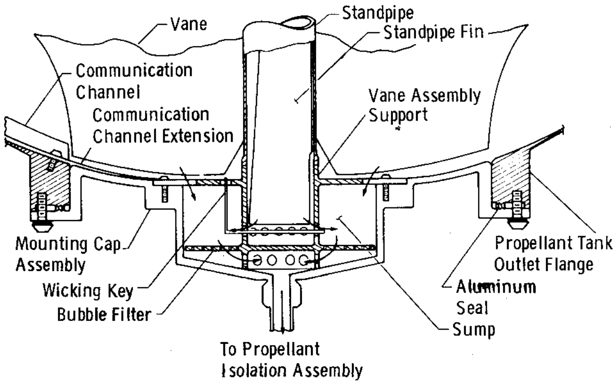

Fig. 6 PMD base area.

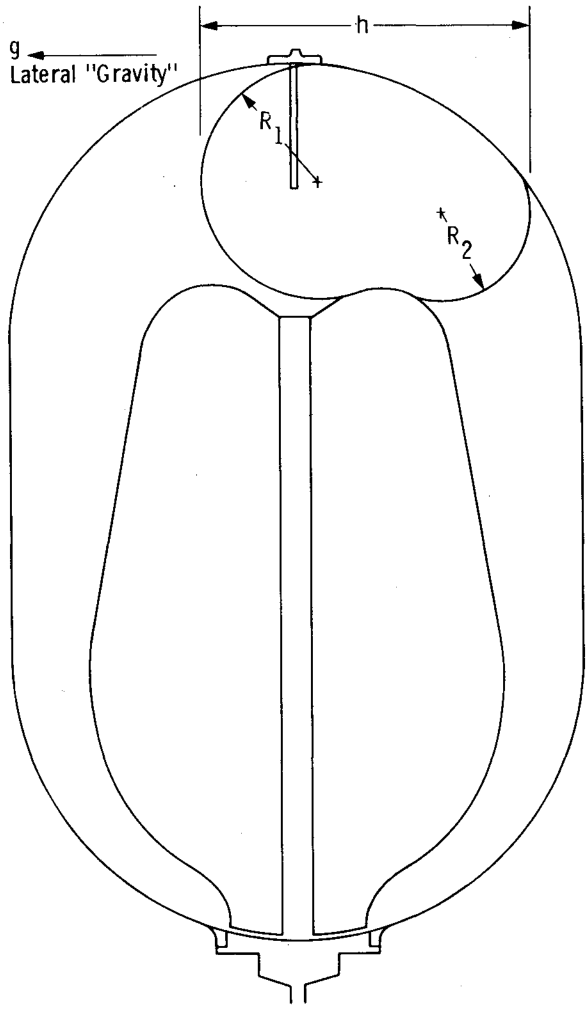

Fig. 7 Six percent bubble offset by a lateral "gravity."

testing a full-scale unit because of the low-g environment required for its proper operation. Test facilities do not exist for testing a full-scale unit. To assure satisfactory performance of a passive propellant management system, its operation must be completely evaluated, and the associated phenomena, requirements, and design element functions identified.

The qualification program for the propellant management system for Viking 75 Orbiter included the three broad categories of performance verification, structural qualification, and propellant capillary properties. In many of the areas, a combination of analysis and test methods was used. Performance qualification was based upon properly scaled 1-g tests, zero-g tests of small-scale models, and analysis. Performance areas covered were selected to include all of the performance requirements of the Viking 75 Orbiter mission. Details of some of the qualification tests and analyses will be discussed in the following sections.

Performance Verification

Ullage Positioning

Bubble Breakup

Characteristically, in establishing the baffle profiles, it is important that they be far enough away from the tank wall such that the centers of the smallest ullage bubbles do not fall radially inward from the baffle chord lines. Improperly designed baffle elements can cause undesirable ullage bubble breakup while attempting to pump an ullage bubble from the tank bottom. Ullage bubble breakup results when the distance from the tip of the baffle to the tank wall gets too small, causing the ullage to be pumped into the baffle elements rather than toward the tank top. A bubble breakup criterion was established analytically, and the dimensions and tolerances of the baffles were set to prevent this problem.

A test series was conducted in the Martin Marietta drop tower facility to verify that the bubble breakup would not occur in the Orbiter design. The drop tower facility provides 2.16 sec of a near zero-g environment (less than $10^{-5}g$). A 1/32-scale plastic model of the propellant tank, baffle assembly, communication channel, and the pressurization/vent tube was fabricated and assembled. Considerable attention was given to the control of dimensional tolerances to provide confidence that the fluid behavior in the model would be a true representation of the full-scale system.

Tests were made using 6 to 20% ullages with the bubble initially located at the tank bottom and at 20 and 30° from the tank bottom. The test fluid was reagent grade methanol, which was dyed light blue to enhance the high-speed motion picture coverage of the tests. No bubble breakup was observed during these tests. Similar results were obtained using a 1/12-scale model at the Lewis Research Center (LeRC) Zero Gravity Research Facility which provides approximately 5 sec of near zero-g test time.

Lateral-g Centering Capability

It is essential that the propellant management system design hold the minimum size ullage bubble centered so the pressurization/vent tube is inside the bubble to prevent propellant loss should venting become necessary. Figure 7 shows a 6% ullage bubble balanced against a lateral "gravity" or vehicle acceleration. An approximate model of this condition equates hydrostatic head with the capillary pressure difference across the bubble

$$\rho g h \simeq \sigma(1/R_2 - 1/R_1)$$

The worst-case propellant is N_2O_4, since its ratio of surface tension to density is approximately twice that of MMH. The worst-case ullage is the minimum ullage volume, which is 6% for MMH and 11% for N_2O_4. The particular configuration shown is calculated to be stable against a $1.5 \times 10^{-5}g$ lateral acceleration for MMH with a 6% ullage. The 11% ullage bubble has been similarly configured and calculated to be stable against $1.5 \times 10^{-5}g$ lateral acceleration for N_2O_4. Analytically, there is substantial margin in the design since the Orbiter requires ullage centering against a $10^{-7}g$ acceleration. A drop test series using a 1/32-scale plastic model was conducted to verify the ullage centering margin. Three drops were made with the tank longitudinal axis in a horizontal position. A constant force spring was used to exert an upward force on the specimen during the first drop, then a downward force during the second two drops. The spring forces were selected to produce a lateral gravity field of $5 \times 10^{-6}g$ during each drop. High-speed motion picture films were made of each drop. In each test, the ullage centered and the pressurization/vent tube remained within the ullage for the remainder of the test as the bubble oscillations dampened.

Pressurization

The pressurization/vent tube design was selected from several proposed candidate concepts. The number of candidates was narrowed to two by applying the following constraints: 1) capable of being installed through a 19 mm (0.75-in.) diam port in the top dome of the tank; 2) provide for "slip-over" attachment of the communication channel; 3) provide for venting from the center of the minimum volume ullage; and 4) permit ullage centering around the pressurization/vent tube.

The two concepts chosen for evaluation were identified as the "Vortex-Generator" concept and the "Direct Impingement" concept, both of which are shown in Fig. 8. The Direct Impingement concept consisted of a closed-end, 9.5 mm (3/8 in.) OD tube extending 17.8 cm (7 in.) down from the tank top with a diffuser section located along the last few centimeters of the tube. The diffuser section would uniformly spray the pressurant flow directly toward the zero-*g* ullage bubble surface. The Vortex Generator concept was similar to the Direct Impingement concept, except that it would uniformly direct the pressurant flow forward within the tank, against the upper dome. The choice of concepts was based on analyses of the feasibility of pressurization in a zero-*g* environment from launch pressure [68.9 N/cm^2 (100 psia)] to flight pressure [172 N/cm^2 (250 psia)] prior to the first engine burn without breaking up the ullage bubble. Direct impingement was rejected because the velocity head of the incoming flow was two orders of magnitude greater than the critical value for surface breakup. Also, the amount of dissipation by jet mixing was unpredictable in the complex circulation flowfield induced inside the ullage by pressurant flow. Analyses of critical aspects of vortex flow associated with the Vortex-Generator concept showed that a practical diffuser could be designed that would not break up the ullage bubble during initial pressurization. The Vortex-Generator concept was selected for flight and was incorporated into the propellant tanks.

Propellant Settling

Following Mars Orbit Insertion (MOI), the quantity of propellant remaining in the propellant tanks is 30% or less of the tank volume with the propellant in zero-*g* being located in an approximately cylindrical column over the tank outlet because of baffle geometry. During an engine burn, the propellant settles toward the tank outlet and continues to rise up the tank wall due to slosh carry-over until the slosh energy is dissipated by the action of viscosity. During this slosh carry-over, it is necessary to prevent ullage gas ingestion to the engine.

A series of 1-*g* Gate Release Tests using a 0.83-scale model was performed to simulate large ullage propellant settling during a thrusting maneuver. A schematic representation of the test setup is shown in Fig. 9. Withdrawal flow rates were based on Froude-Number scaling, and high-speed movies were used to determine the amount of gas ingestion. Tests were made with a 5% liquid volume to simulate withdrawal before Viking Lander Capsule (pre-VLC) separation and with 2 and 0.8% liquid volumes to simulate post-VLC separation engine firings. A transient analysis of standpipe draining during propellant settling was made to support the evaluation of this propellant management system function. Although some changes in outlet configuration resulted from this analysis and the Gate Release Tests, the final design was tested and found to have acceptable gas-ingestion characteristics [less than 33 cm^3 (2.0 in.^{3}) per engine burn].

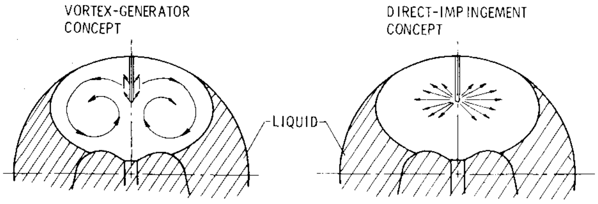

Fig. 8 Candidate pressurization concepts.

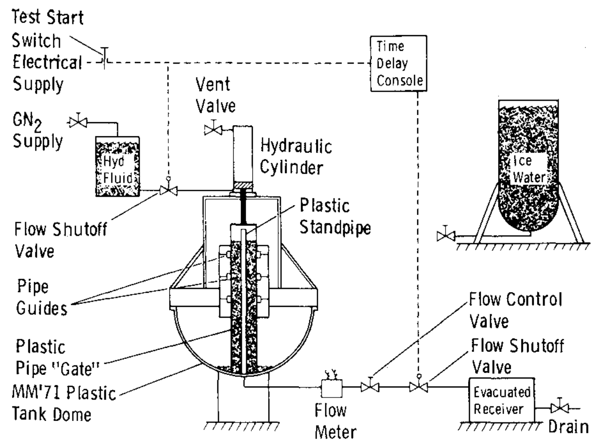

Fig. 9 Gate-release test setup.

Drop tower tests at the LeRC facility of a 1/12-scale model with a 20% liquid volume verified that the zero-*g* propellant shape used for the Gate Release Tests was correct. An analysis study was made to define the mechanisms of bubble formation and their subsequent ingestion into the engine. The study concluded that the Gate Release Tests were conservative and that there should be less gas ingested during flight than in the simulated tests.

Propellant Communication

Should propellant become displaced from the baffle assembly and/or outlet area of the tank during the flight, it is necessary that a valid liquid communication path be available to reorient the propellant to the desired zero-*g* shape over the tank outlet. A side-wall communication channel was designed to perform this function. Drop tests of a 1/12-scale model with 10% liquid initially located at the tank top, out of communication with the baffle assembly, demonstrated that the communication channel provides this valid zero-*g* flow path.

The flow capacity of the communication channel was designed to permit moving a 30% liquid volume from the tank top to the baffle assembly within the minimum time between engine burns. An analytical model of the pumping rate was used to show that the worst-case condition could be met in less than 28 hrs, meeting the design requirement. A heat-soakback analysis indicated that the communication channel easily has the capability to return any possible condensate to the tank outlet.

The full-scale assembly has several other potentially troublesome communication links. A continuous wick path must exist from the end of the communication channel to the baffle assembly, sump, and standpipe to refill these areas in the event they should become dry. To demonstrate fluid wicking from the communication channel to a baffle element, across the baffle assembly base plate, and to the base of the standpipe, a ¼-scale model of the outlet was tested in the drop tower. A second ¼-scale model was tested to demonstrate that the wicking key provides a valid communication path for refilling the sump and standpipe.

Propellant Capillary Properties

The Viking 75 Orbiter propellant management system is designed to function properly by utilizing the capillary properties of the propellants, monomethylhydrazine (MMH) and nitrogen tetroxide (N_2O_4), in contact with the 6Al-4V titanium surfaces of the propellant tank assembly. The properties of surface tension and contact angle determine the propellant behavior in zero-*g* environment.

An acceptable method of cleaning the propellant management system and propellant tank assembly had to be established. The selected cleaning method,[2] which is the alkaline cleaning procedure normally employed for titanium, was qualified through contact-angle evaluation of test coupons over a 10-week period.

Contact-angle measurements, using a goniometer, were made to assess the effects of surface cleanliness, surface finish, referee-fluid exposure, aging, and lubricants on the propellant wetting characteristics. Data were obtained for 6Al-4V titanium coupons having surface-machined, chem-milled, and EB-welded finishes that are representative of the surfaces in the propellant tank assembly. Measurements included data on samples that had been immersed in propellants for up to 33 months. The effect of Krytox 143AB lubricant was evaluated, since this lubricant is used in some propulsion subsystem components and could reach the propellant tanks in small quantities. All contact-angle measurements were 5° or less, which is adequate for the proper performance of all required functions of the propellant management system.

Surface-tension measurements were made using Sugden's method of differential maximum bubble pressure,[3] to assess the effects of aging, temperature, and lubricants. There was no noticeable degradation in surface tension for storage times of up to 33 months. Surface tension data for MMH and N_2O_4 at various temperatures are shown in Figs. 10 and 11. Theoretically, the surface tension decreases with increasing temperature, approaching zero at the critical temperature of the propellant. For the thermal environment of the Viking 75 Orbiter mission, propellant surface-tension values are adequate to assure normal performance.

Additional measurements of surface tension were made to determine the effect of Krytox 143AB on propellant surface tension. The surface tension of MMH was unaffected by the lubricant; however, reductions in N_2O_4 surface tensions of up

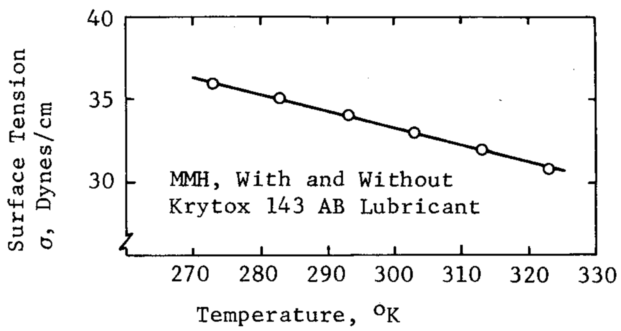

Fig. 10 Surface tension of MMH.

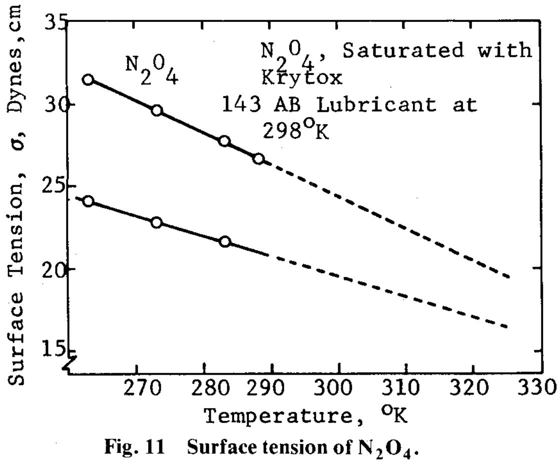

Fig. 11 Surface tension of N_2O_4.

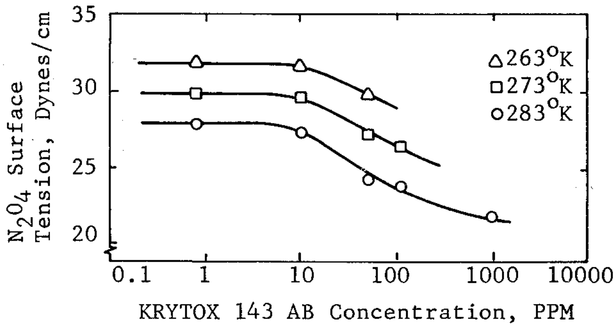

Fig. 12 Effects of lubricant on N_2O_4.

to 20% were observed. Curves for N_2O_4 are given in Fig. 12 for three temperatures, each curve being terminated at the solubility limit. To prevent this property degradation, lubricant usage in the propulsion subsystem was limited to prevent concentrations larger than 1 ppm.

In addition to decreasing the surface tension, the presence of Krytox 143AB lubricant in N_2O_4 increases the lifetime of subsurface bubbles by forming a thin surfactant layer on the propellant surface. Any increase in the time required for subsystem bubbles to coalesce with the main ullage reduces confidence in the ability to make a successful, large-ullage, engine burn. To evaluate this effect, five identical capsules of N_2O_4 were prepared with lubricant concentrations of 0, 1, 10, 100, and 2800 ppm, respectively. The capsules were vibrated simultaneously, brought to rest, and bubble lifetimes observed from high-speed movies of the test. The capsules with the larger concentrations of lubricant had an order-of-magnitude-longer bubble lifetimes, making the 1-ppm limit on Krytox 143AB lubricant desirable.

Structural Qualification

Structural qualification of the propellant management system was accomplished with three test series: installation and removal through the 22.9 cm (9.0 in.) diam propellant tank opening, dry transportation tests, and slosh tests for the range of loaded ullages. Pretest and post-test inspections of the test hardware were made to verify its structural integrity and to check dimensions critical to its proper functioning.

To accomplish its design function, the propellant management system must be installed through the 22.9 cm (9.0 in.) diam opening in the propellant tank. Using information gained during prototype development, a flight installation/removal tool was designed and built. The tool, shown in Fig. 13, provides 12 rods mounted on roller bearings that furl the baffle elements when the baffle assembly is rotated within the tool. The furled baffle assembly can then be installed or removed through the propellant tank access hole. During installation, the tool provides a means for the controlled unfurling of the baffle assembly within the propellant tank.

The qualification test was set up to verify that a flight unit would not be damaged by the installation process and would maintain satisfactory angular spacing between the baffle elements. The 30° nominal vane-spacing requirement was established to prevent undesirable ullage-bubble breakup by the baffles and also to provide approximately equal bubble-driving capability between any adjacent baffle elements. Before furlilng, measurements were made of the distance between each pair of baffle elements. The baffle assembly was then mounted on the installation tool and furled for installation. After about a 5-min wait, the baffle assembly was unfurled without difficulty. Baffle-spacing measurements revealed no significant changes due to furling with all measurement being within drawing tolerance. Close visual inspection of weld joints revealed no apparent damage.

As a part of the Viking spacecraft, the propellant management system is transported from the Jet Propulsion

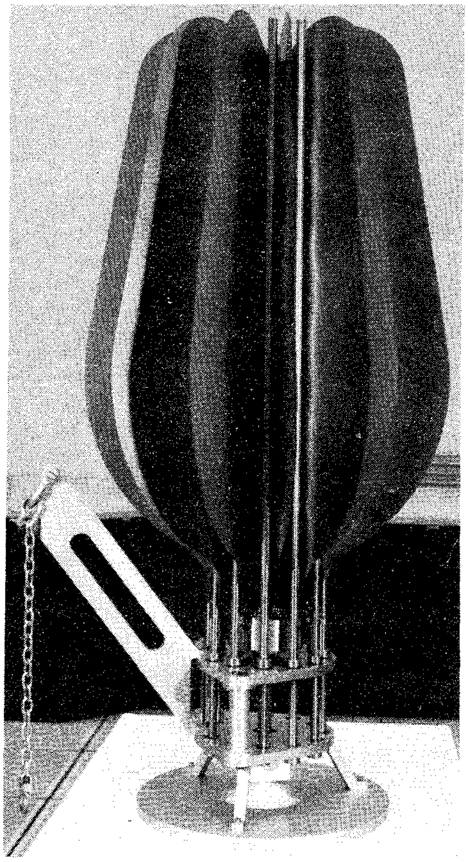

Fig. 13 Baffle assembly in installation/removal tool.

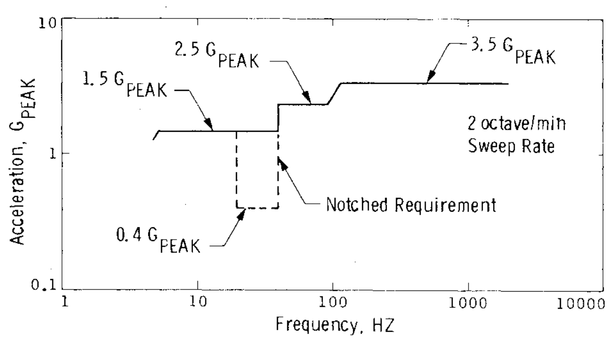

Fig. 14 Transportation vibration environment (lateral).

Laboratory to the launch site at the Kennedy Space Center in empty propellant tanks. The dry transportation environment for the qualification test was established from an evaluation of measurements taken during the transportation of previous spacecraft to the launch site. The sinusoidal excitation levels used to simulate dry transportation are shown in Figs. 14 and 15.

The mounting cap and baffle assembly were subjected to both lateral and vertical excitation. The baffle assembly was instrumented with strain gages and single-axis accelerometers. Both lateral and vertical tests were started by sweeping up and down in frequency from 5 to 2000 Hz at a sweep rate of 2 octaves/min at the qualification levels. Resonant dwells of 1000 cycles were then performed at each resonant frequency. Resonant frequencies for the vertical test were at 9 and 20 Hz, whereas for the lateral test they were at 7 and 33 Hz. Results of the evaluation of strain gage and accelerometer data from these tests indicate no structural problems with the mounting cap and baffle assembly for this environment.

The communication channel was subjected only to lateral excitation because of the experimental difficulty of per-

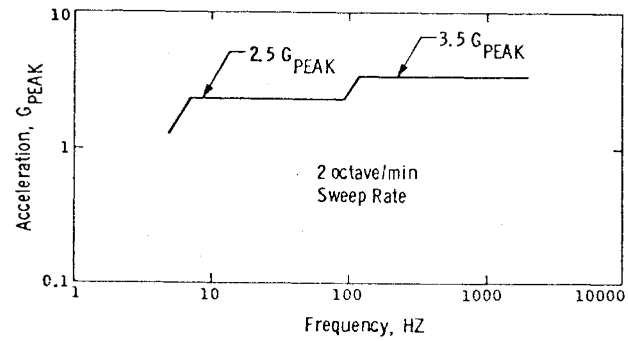

Fig. 15 Transportation vibration environment (vertical).

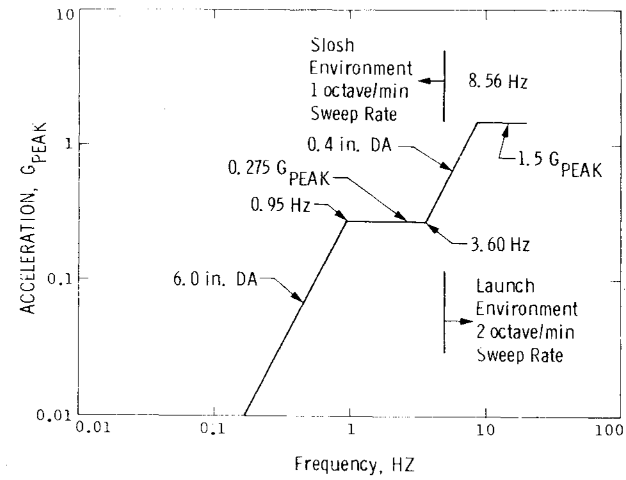

Fig. 16 Slosh and launch vibration environment.

forming the vertical test. This presents no problem, however, since the communication channel is much more sensitive to lateral excitation than to vertical excitation. The test was accomplished by mounting the communication channel in a full-scale plastic tank. The channel was instrumented with strain gages and single-axis accelerometers. Testing was started with a qualification-level sweep from 5 to 2000 Hz at 2 octaves/min. Following the sweep, a resonant dwell of 1000 cycles was performed at the resonant frequency of 29.5 Hz. Results of the evaluation of strain gage and accelerometer data from these tests indicated the channel design was structurally sound.

While on the launch pad, the Viking spacecraft will be excited by the lateral movement of the launch vehicle caused by wind loading. The slosh environment for the qualification test was established from a data analysis of the Titan/Centaur launch vehicle response to wind loads. The sinusoidal excitation levels used to simulate on-pad wind loads are shown in Fig. 16. An 18.5 min dwell was used to test for the long-period exposure time on the pad.

The mounting cap, baffle assembly, and communication channel were subjected to lateral excitation while mounted in a full-scale plastic tank. The communication channel was mounted in a plane perpendicular to the shake axis. Tests were made for 6, 10, and 20% ullages with water used as the test fluid. The ullages selected cover the range of loaded ullages for the Orbiter propellant tanks. The assembly was instrumented with strain gages and single axis accelerometers. A small amount of Rhodamine-B dye was added to the water to enhance the color motion-picture coverage of the test.

For each ullage condition, a sweep up and down in frequency from 0.17 to 20 Hz was performed at the excitation levels. Since there were no resonant frequencies in the range 0.4–0.8 Hz, the 18.5-min dwell was made for the condition of maximum fluid motion in this frequency band, which was at 0.8 Hz in each case. A 30-cycle resonant dwell was performed at the first slosh resonance, which occurred at 1.3, 1.3, and 1.1 Hz, respectively, for the 6, 10, and 20% ullages.

Although several baffle elements experienced localized yielding as a result of three-corner folds induced by the slosh motion, posttest inspection of the baffle assembly and communication channel indicated the design was structurally sound.

Conclusions

The development and qualification of a unique surface-tension propellant management system has been described. As of this writing, four of those systems continue to successfully function in the propellant tanks of the two Viking Orbiters circling Mars. The more critical events for the propellant management system, orbit insertion and the initial orbit trims, were completed with no indication of any problem. The systems should continue to function, providing propellant for orbit changes, until tank depletion.

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