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Long-Life Bipropellant System Demonstration, Viking Orbiter Propulsion System

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On April 23, 1980 Viking Orbiter One (VO-1), operating in the blowdown mode, completed a 10-s Mars orbit trim maneuver to position the spacecraft for its final science sequence in May-June 1980. This brings the number of propulsive maneuvers for VO-1 to 23. Total accumulated operating time for the rocket engine is 2896 s, representing a total impulse of 3.93×10^6 N-s. The estimated propellant remaining is sufficient to operate the rocket engine for an additional 30 s. VO-1 has completed more than 1700 days in space, 1400 days in orbit around Mars, and more than 2 yr of attitude-control-system operation with helium gas transferred from the propulsion-system pressurant tank. The mass of helium remaining is expected to be sufficient for attitude control through June 1980. This paper presents the flight history of the Viking 75 Orbiter propulsion systems and summarizes the design and test philosophy that have contributed to their success.

Introduction

THE Viking missions are part of a group of missions directed toward the exploration of the planet Mars using automated spacecraft. The Viking 75 spacecraft was comprised of the Viking Lander (VL) and the Viking Orbiter (VO).

Two identical Viking 75 spacecraft, each consisting of an Orbiter and Lander, were launched late in the summer of 1975 and placed into Mars orbit in 1976, following a 10-month 750-million km cruise. Mars surface reconnaissance was conducted by both Orbiters, landing sites selected, and both Landers safely placed on the surface of Mars; VL-1 on July 20, 1976, and VL-2 on September 3, 1976. Following lander separation, the Orbiters continued their orbital science observations. Meanwhile, on the surface of Mars, the Landers conducted their primary missions until solar conjunction in November 1976 when, for a short time, communications with Earth were interrupted. The primary portion of the Viking mission which ended at that time is discussed in Ref. 1.

Following solar conjunction, both Viking spacecraft resumed orbital operations, which continued at a high level of activity until March 1978. This operational period was called the "extended mission" and was designed to obtain maximum scientific data return while both Orbiters and Landers were operating normally.

On April 1, 1978, since both Orbiters were still operating normally, orbital operations were resumed but at a reduced activity level. This "continuation" mission was designed to fill in any scientific data voids that still existed and to continue coverage of areas of interest. Viking Orbiter Two (VO-2) exhausted its attitude-control gas supply as the result of a leaking attitude-control valve and was powered down on July 24, 1978. Viking Orbiter One (VO-1) continued operations, supporting both Landers until February 1979 when operations were suspended to preclude any interference with the Voyager Jupiter encounter operations.

A propulsive maneuver was conducted in May 1979 to "walk" VO-1's orbital track over the Martian surface. Survey Mission I operations commenced in July 1979 with a series of high-resolution contiguous surface-mapping sequences which continued into November 1979. On November 6, 1979, a maneuver was conducted to raise VO-1's periapsis from 300 to 333 km and slow the orbit "walk" rate. A series of medium-resolution mapping sequences were conducted during November and December 1979. A propulsive maneuver conducted on April 23, 1980 raised VO-1's periapsis from 333 to 368 km forthe final science operations, Survey Mission II, scheduled for May and June 1980.

This paper presents the flight history of the Viking 75 Orbiter propulsion system and summarizes the design and test philosophy which have contributed to its very long and successful operation.

Spacecraft Description

The two Viking 75 spacecrafts were identical, and each consisted of two major assemblies—the Viking Lander (VL) and the Viking Orbiter (VO)—joined together by a supporting structure that was jettisoned from the Orbiter after VL separation and landing. As shown in Fig. 1 the Orbiter propulsion system was covered by a thermal blanket.

Propulsion System Description

The VO-75 propulsion subsystem is a fixed-thrust, multistart, pressure-fed, earth storable, bipropellant system designed to deliver in excess of 3.96×10^6 N-s of impulse to the Viking spacecraft. The propellants utilized were nitrogen tetroxide (N_2O_4) and monomethylhydrazine (MMH). Gaseous helium was used for pressurization. A two-axis, gimballed engine and electromechanical actuators provided thrust vector control in the pitch and yaw directions during engine operation. Roll control was provided by the attitude-control subsystem utilizing cold-gas nitrogen thrusters. The VO-75 propulsion subsystem with its structure represented a mechanically defined module, as shown in Fig. 2, capable of being fueled, pressurized, and monitored prior to being mated with the VO.

The VO-75 propulsion subsystem includes eight major assemblies, as represented on the subsystem schematic shown in Fig. 3. These include a pressurant-tank assembly; a propulsion/reaction control gas-share assembly; a pressurant-control assembly (PCA), which controlled the functions of the gaseous-helium pressurant system; two identical propellant-tank assemblies (PTA), containing surface-tension propellant-management devices (PMD); two identical

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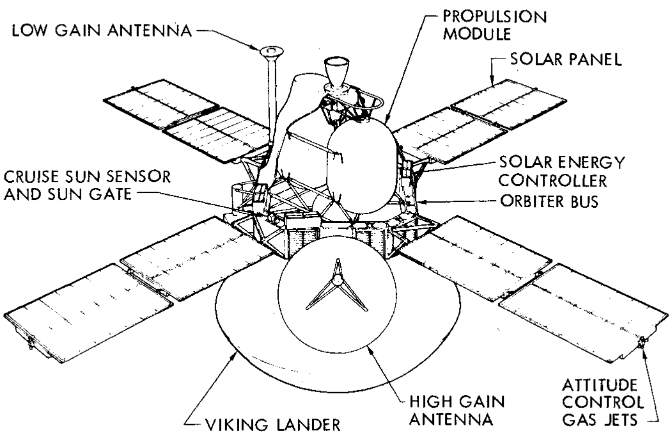

Fig. 1 Viking-75 spacecraft with thermal blanket partially removed from propulsion subsystem.

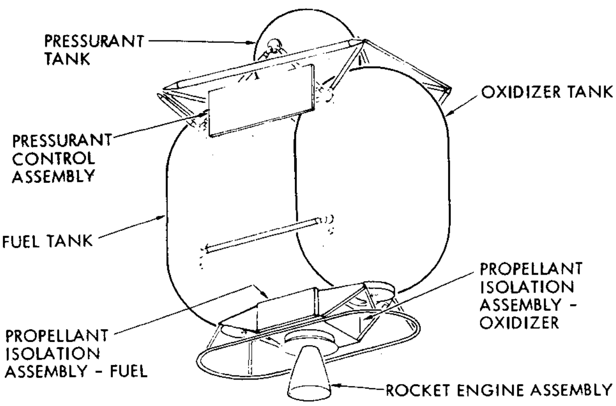

Fig. 2 Viking Orbiter propulsion module.

propellant-isolation assemblies (PIA), which provided propellant-control functions; and a rocket-engine assembly (REA), which includes a mechanically linked bipropellant valve. The rocket-engine assembly is adapted from MM'71 and employs a beryllium thrust chamber utilizing INTEREGEN (conduction) cooling to achieve continuous burn durations of up to 2730 s in thermal equilibrium (see Ref. 2).

Applications of new technology to a planetary flight system included the surface-tension propellant-management device (PMD) and acoustic cavity cooling in the rocket engine. The PMD, which was developed and qualified for VO-75, represented a new technique for utilization of propellant surface-tension forces to achieve propellant orientation and center of mass control in a low-*g* environment. The general features of the PMD, as shown in Fig. 4, include a 12-blade baffle assembly for locating the ullage bubble in a low-*g* field ($10^{-5}g$) and a capillary channel to provide communication between the bulk liquid and the tank top, thereby accommodating sizable temperature gradients within the large tank shell. Details of the design and development of the VO-75 PMD can be found in Ref. 3.

The basic design philosophy and the detailed design requirements for the Orbiter propulsion subsystem are described in Ref. 4. Propulsion-subsystem nominal design-performance parameters are presented in Table 1.

Flight Sequence/History

The in-flight sequence of events, relating to the VO-1 and VO-2 propulsion subsystems, are fully covered in Ref. 5 and will not be repeated here. However, the in-flight sequences differ only slightly from the prelaunch nominal sequence. One notable exception, and a good example of the "adaptive

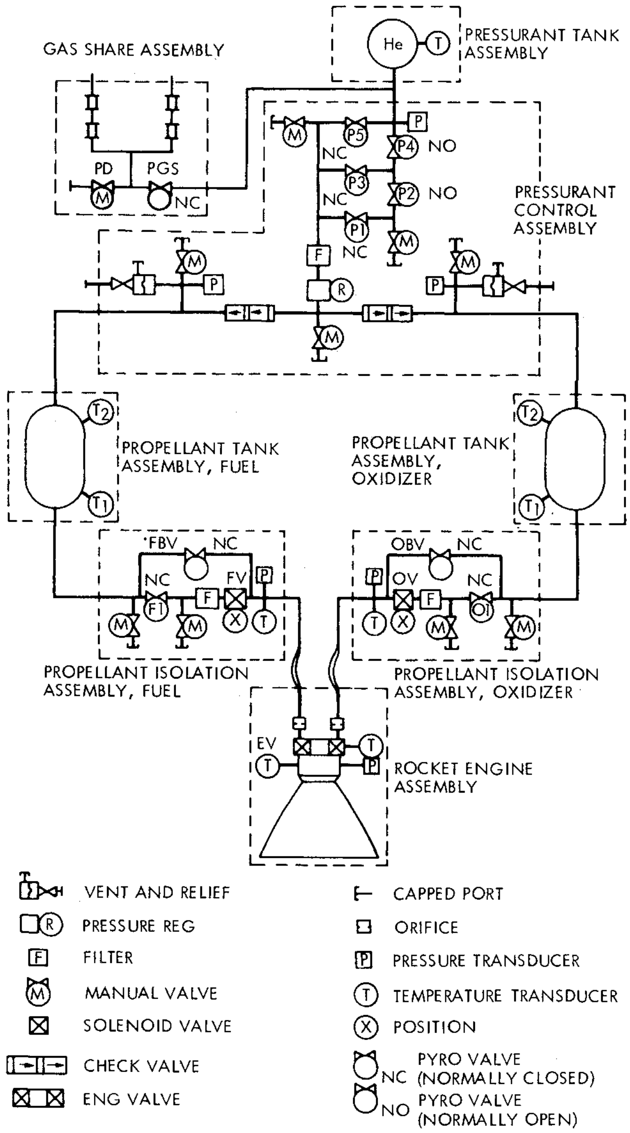

Fig. 3 VO-75 propulsion-subsystem schematic.

capability" of the Viking Mission, was the change on VO-1 necessitated by the discovery of a pressurant-regulator leak. This portion of the mission is discussed in the flight-problems section and in detail in Ref. 1.

Mars orbit insertion (MOI) was accomplished on June 19, 1976 without further difficulty as was the first orbit trim on June 21. The pressurant system was isolated with the closure of pyro valve P4 on July 7, terminating helium flow into the propellant tanks. Lander separation on VO-1 occurred on July 20 followed by separation of the Lander aft bioshield and adaptor 1 day later. The remainder of the orbit-trim maneuvers for VO-1 were conducted in the blowdown mode in accordance with the nominal mission plan.

Table 2 is a summary of the propulsive maneuvers for VO-1. VO-1 has expended 1411 kg of propellant during 2896 s of operation, representing a total impulse of 3.93×10^6 N-s. The VO-1 attitude control system has been operating on helium from the propulsion pressurant tank since January 1978. The attitude-control gas supply is expected, based on current usage rates, to be depleted in late June 1980. A propulsive maneuver, the 23rd since launch for VO-1, was performed on April 23, 1980 to trim VO-1's orbit for the final science sequence in May and June 1980.

VO-2 performed 15 propulsive maneuvers during its operational lifetime of 1049 days. Maneuver durations ranged from a 3-s Mars orbit trim to the 39.6-min Mars orbit in-

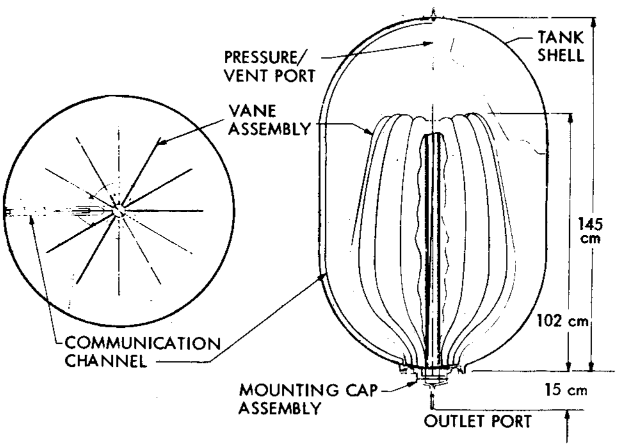

Fig. 4 Propellant management system.

Table 1 Propulsion subsystem design performance characteristics

Parameter	Nominal value
Vacuum thrust	1334 N
Vacuum specific impulse	2857.6 N-s/kg
Thrust chamber expansion ratio	60:1
Thrust chamber pressure	792.9 kN/m^2 (7.9 bar)
Propellant mixture ratio, oxidizer/fuel by weight	1.5 ± 0.06
Nominal N_2O_4 flow rate	0.280 kg/s
Nominal MMH flow rate	0.186 kg/s
Propellant load capacity	1423 kg
Usable propellant load	1405 kg
Minimum burn duration	0.4 s
Shutdown impulse, 3σ	9 to 53 N-s
Pressurant	helium
Propulsion module mass[a]	224 kg

[a] Includes structure, gimbal actuators, thermal control, cabling, and unusable propellant.

sertion (MOI). A summary of these propulsive maneuvers is given in Table 3.

The gas-share valves on VO-2 were actuated in January 1978 and 1.3 kg (2.9 lb) of helium were transferred to the attitude-control system. A leaking attitude-control jet valve ultimately depleted the gas supply and VO-2 was shut down on July 24, 1978.

Design and Development Test Philosophy for Long Life

The long life requirement for Viking was recognized early in the propulsion-system-design phase as one of the more critical design parameters. The design and development program designed to demonstrate compliance with the Viking propulsion-system requirements is discussed in detail in Ref. 4.

The basic design philosophy behind the VO-75 propulsive system was based on the maximum possible use of technology from the highly successful Mariner-Mars 1971 (MM-71) propulsion subsystem, with changes limited to those dictated by Viking-mission requirements. Applications of this philosophy placed reduced emphasis on technical optimization, in keeping with minimum cost and least technical risk. Identical-component hardware was employed wherever such use did not compromise technical quality, or have a pronounced adverse effect on mission requirements.

Special emphasis was given to critical, nonredundant components such as the pressurant regulator and rocket engine. Qualified flight hardware from several previous programs was used to the greatest possible degree, and the final design reflects the results of several failure modes analyses by eliminating or providing protection against single-point failures to the greatest possible degree.

To minimize leakage, brazed-tubing fittings were utilized in all propulsion-system joints, with the exception of the gas-share interconnect lines between the attitude-control nitrogen tanks and the propulsion helium pressurant tank. B-nut fittings were used (4 places) only to facilitate spacecraft assembly at the launch site. Normally closed explosive valves were used on each side of this interconnect to eliminate leakage prior to gas-share utilization. Special flared tubing and fittings were designed for these joints and extensive leak testing was conducted prior to launch to assure leak-free joints.

The test philosophy applied to the propulsion system followed standard JPL and industry practices, with acceptance tests performed on manufactured components prior to their use in major assemblies. To reduce program costs, only new components, or those which required major redesign to meet new requirements, were subjected to development tests and/or formal qualification tests at the component level.

The general objectives of the propulsion-system test program were to verify basic operating characteristics and performance, evaluate the influence of various mission environments, verify assembly operations in a subsystem, and, finally, to formally qualify the propulsion system for flight. Three VO-75 propulsion systems were utilized to meet these objectives, a Breadboard System (BB), an Engineering Test Model (ETM), and a Type Approval (TA) system. The test program was integrated to permit evaluation of most of the mission modes at least once during trhe overall plan, which included all three systems. The basis purpose was to "wring out" the propulsion system and identify any problems that could preclude or compromise mission success, and to characterize the system well enough to permit timely evaluation of flight performance. To accomplish this the propulsion system test plans were designed to overtest the systems in the areas of 1) duty cycle (by a factor of four), 2) propellant temperature (low of 4.5°C, high of 35°C), 3) propellant-tank pressure (high of 2158 kN/m^2, low of 1365 kN/m^2), and 4) propellant helium solubility (none to 100%).

In addition, engine valve and feed-system latch valves were cycled under the adverse conditions of temperature, pressure, and actuation voltage. One system test was also conducted with the nitrogen tetroxide (N_2O_4) saturated with iron in order to simulate maximum ferric-nitrate concentration in the propellant. No significant effect on system operation was noted for this test.

The Viking Orbiter propulsion systems completed the design mission in spite of the regulator leakage problems at orbit insertion and continued to support the Viking-mission operations, which have been extended in time well beyond any prelaunch expectations.

The attitude-control system for VO-1 has operated since January 1978 on the helium supplied via the gas-share system for the propulsion pressurant tank. At the current usage rate, the remaining gas mass of less than 0.5 lb is expected to be depleted by the end of June 1980. Prior to VO-1 shutdown it is planned to expend the remaining propellants to verify system propellant utilization. Also, the capacitor banks in the pyro system will be activated and recharged as a final test of their present condition and to document their long history of flawless operation.

Propellant-Management Device

The surface-tension propellant-management device utilized for Viking (Ref. 3) represents an area of new technology to a flight system. The primary purpose of the PMD was to position the propellant within the tanks for center-of-mass control. The PMD also provided for propellant slosh damping and maintained liquid propellant over the tank outlet to

Table 2 Viking Orbiter propulsive maneuver summary VO-1

Maneuver number	Date	Event	Engine on-time, s	Velocity change, m/s	S/C maneuver weight, kg	Expended propellant, kg	
						Oxide	Fuel
	8/20/75	Launch	–	–	3534	–	–
1	8/28/75	M/C-1	12.07	4.634	3470	3.4	2.3
2	6/10/76	AMC-1	122.39	50.540	3464	36.8	23.5
3	6/15/76	AMC-2	143.09	60.000	3404	42.8	27.4
4	6/19/76	MOI	2256.3	1097.270	3333	633.4	423.7
5	6/21/76	MOT-1	130.63	80.050	2276	37.7	24.7
6	7/08/76	MOT-5	41.11	25.713	2213	11.8	7.9
7	7/14/76	MOT-6	4.38	2.736	2193	1.3	0.9
8	8/02/76	SK-2	1.73	2.228	1048	0.5	0.3
9	9/11/76	MOT-7	16.26	21.327	1047	4.6	3.1
10	9/20/76	MOT-8	2.84	3.708	1039	0.8	0.7
11	9/24/76	MOT-9	17.40	22.926	1037	4.9	3.3
Extended mission							
12	1/22/77	MOT-10	35.09	47.002	1026	10.0	6.7
13	2/04/77	MOT-11	4.04	5.393	1010	1.1	0.8
14	2/11/77	MOT-12	1.95	2.563	1008	0.6	0.4
15	3/11/77	MOT-13	51.86	69.998	1007	14.6	9.7
16	3/24/77	MOT-14	8.28	11.24	982	2.3	1.5
17	5/15/77	MOT-15	1.095	1.48	977	0.3	0.2
18	7/01/77	MOT-16	3.23	4.34	976	0.9	0.6
19	12/02/78	MOT-17	11.54	15.78	968	3.2	2.1
20	5/19/79	MOT-18	4.442	5.49	962	1.2	0.8
21	7/19/79	MOT-19	3.28	4.49	959	0.9	0.6
22	11/06/79	MOT-20	13.16	18.19	957	3.6	2.4
23	4/23/80	MOT-21	10.56	14.67	951	2.9	2.0

Table 3 Viking Orbiter propulsive maneuver summary VO-2

Maneuver number	Date	Event	Engine on-time, s	Velocity change, m/s	S/C maneuver weight, kg	Expended propellant, kg	
						Oxide	Fuel
	9/09/75	Launch	–	–	3523	–	–
1	9/19/75	M/C-1	21.30	8.11	3468	5.9	3.9
2	7/27/76	AMC	25.01	9.223	3458	6.8	4.3
3	8/07/76	MOI	2362.7	1100.8	3447	657.0	437.9
4	8/09/76	MOT-1	7.08	4.077	2352	2.0	1.3
5	8/14/76	MOT-2	3.06	1.776	2349	0.9	0.6
6	8/25/76	MOT-3	72.74	42.728	2347	21.0	13.6
7	8/27/76	MOT-4	19.19	11.292	2313	5.5	3.6
8	9/28/76	MOT-5A	4.58	5.0	1247	1.3	0.9
9	9/30/76	MOT-5B	298.82	342.551	1245	83.9	55.9
Extended mission							
10	12/20/76	MOT-8	71.56	89.83	1104	20.4	13.5
11	3/02/77	MOT-9	9.92	12.532	1069	2.8	1.8
12	4/18/77	MOT-10	12.18	15.456	1064	3.4	2.3
13	9/25/77	MOT-11	9.08	11.55	1055	2.5	1.7
14	10/09/77	MOT-12	5.73	7.254	1049	1.6	1.0
15	10/23/77	MOT-13	13.783	17.608	1046	3.9	2.5

prevent feed-system gas ingestion. To date there has been no indication on any of the propulsive maneuvers that the propellants were not properly positioned within the tank. The largest ullage volume start, 96.5%, occurred on the final VO-2 maneuver. The PMD is designed to operate with ullage volumes as large as 99%.

Performance Predictability

A digital computer program called PSOP (Propulsion Subsystem Operation and Performance) similar to that developed during the MM'71 Mission, was used to support Viking-mission analysis. PSOP is a low-frequency simulation model of the complete propulsion subsystem. The program was used to predict flight parameters, generate thrust and spacecraft-mass time functions for flight maneuver analyses, perform malfunction analyses, and investigate effects of variations in system initial conditions.

The propulsion model was formulated by first describing the significant physical processes in each of the propulsion components and then organizing these descriptions into a large equation set. Like the physical hardware, component identity is retained and interactions between components (equations) are required to achieve a system solution. Figure 5 is a simplified block diagram of the propulsion model.

In general, the significant physical processes include heat transfer, gaseous compression and expansion, gaseous release from saturated propellants, pressure regulation, fluid flow, distributed hydraulic resistance, and chemical combustion. External radiation heating is considered for the helium pressurant tank, pressure regulator, and propellant tanks.

The gas in the pressurant tank and the gas in the propellant tanks may compress or expand according to real-gas thermodynamic functions. Energy and mass balance are maintained in each tank in order to determine the state of the gas and the mass of both gas and liquid in each container.

PSOP was available early in the program and, as a result, was used extensively during the subsystem developmental testing. This early use provided invaluable real-time operational experience and the opportunity to fine tune the analytical model to the Viking propulsion system. This was particularly true in regard to the system-performance effects of helium-saturated propellants and regulator/feed system operation in both the regulated and blowdown modes.

The extensive propulsion-system-level testing produced a well-defined set of system-performance characteristics over a wide range of operating conditions. This resulted in the ability to predict in-flight performance with a high degree of accuracy. The accuracy of the performance is best illustrated by comparing the predicted engine operation time to impart a given velocity change to the spacecraft to the actual duration as determined by the onboard accelerometers. The 3σ difference between the predicted and actual engine durations for all propulsive maneuvers for both Viking propulsion systems is 0.5%.

Flight Problems

The only propulsion-subsystem problem encountered during the Viking mission was the regulator gas leak that occurred during Mars encounter. In preparation for the final Viking 1 course-correction maneuver on June 9 (10 days before MOI), the propellant latch valves were opened on June 4 and the pressurant system (pyro valve P3) actuated on June 7 to pressurize the propellant tanks. Shortly after the pyro valve firing, telemetered data revealed a problem. A small leak was detected in the helium-gas pressure regulator. While the situation did not represent an operational emergency, it did require action and careful consideration of various alternatives and their risks. At the observed pressure-rise rate, the propellant-tank pressures would have reached the pressure-relief-system burst-diaphragm rupture pressure of 2206 kN/m^2 within 4 days. The potential helium loss during the interval between burst-diaphragm rupture and the start of MOI was estimated at 0.22 kg. An even greater concern, however, was the opening of a potential overboard gas-leak path.

Several options were explored to prevent the rupture of the burst diaphragms without actuating the last remaining normally open helium-isolation valve. The most direct action would have been to simply fire P4 to isolate the helium tank from the regulator; this action would, however, have left only one valve (P5) to open the flow circuit again for the MOI. In the event that P5 failed, there could be no insertion into orbit about Mars and no landing. While pyro valves are extremely reliable, it was felt that this action (closing P4) would be taking an unnecessary chance as long as other corrective actions could be made.

In the workaround selected, the planned June 9 approach course-correction maneuver was delayed so that planning for a longer total burn could take place. This provided a chance of flushing out any small particle that might have been allowing the helium leak.

A series of emergency ground tests were conducted using the Engineering Test Model (ETM) propulsion subsystem to verify system capability to successfully enter a long-duration maneuver from a start at elevated tank pressure. These tests, discussed in Ref. 1, were successful and the delayed maneuver was reprogrammed to a 50-m/s change in velocity lasting 125 s on June 10. The pressurant leak continued, and a second maneuver of 60 m/s was conducted on June 15 to reduce the pressure in the tanks to an acceptable level.

The propellant-tank-pressure excursions during the encounter-phase operations are shown in Fig. 6. Note that the

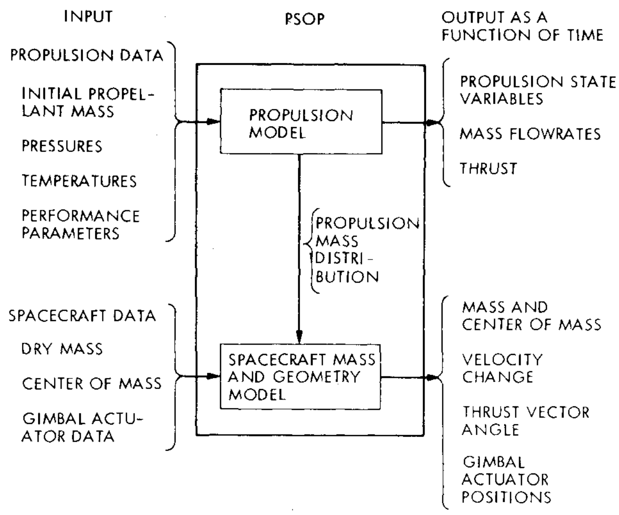

Fig. 5 Propulsion-subsystem block diagram.

initial regulator leak rate of 8700 scc/h after the P-3 event is indeed large compared to the component-specification leak rate of 20 scc/h. It is also apparent that the leakage rate was not constant and was significantly reduced after the first approach maneuver. Although the precise cause of the problem could not be determined, it is believed to be the result of vapor reaction and deposition on the regulator seat during the 10-month cruise period.

The two approach maneuvers reduced the tank pressures to an acceptable level for the MOI on June 19. The initial propellant tank pressures for the MOI were 1951 kN/m^2. Regulator performance during the MOI was normal in all respects. Regulator leakage continued following MOI, however, the propellant-tank pressure-rise rates were acceptably small due to the large post-MOI ullage volumes. The first Mars orbit trim maneuver, 80 m/s, was conducted on June 21. On July 7, the helium system was isolated by closing pyro valve P4 in accordance with the nominal mission plan. The six subsequent maneuvers in the primary mission were conducted in the blowdown mode.

Since the cause for the regulator leakage on VO-1 could not be uniquely determined, it was assumed that a reasonable probability existed for a similar occurrence when pyro valve P3 was opened on VO-2. To accommodate this possibility, the sequence of events was rearranged so that the approach course correction was done in the blowdown pressure mode. The actual course-correction maneuver occurred on July 27, with starting oxidizer and fuel-tank pressures of 1665 and 1627 kN/m^2, respectively. Maneuver duration was 25 s; delivered ΔV was 9.2 m/s. The final tank pressures were 1572 kN/m^2 for oxidizer and 1469 kN/m^2 for fuel. The rocket-engine chamber pressure started at 772 kN/m^2 and ended at 731 kN/m^2.

The P3 opening was delayed until just 13½ h before the MOI in order to minimize the probability of tank overpressure in the event of a leak. Regulator lockup following the P3 event appeared near normal, although 3 of the 4 system pressure measurements increased 22 kN/m^2 above the predicted lockup pressure before the start of the MOI. The estimated maximum helium leak rate for VO-2 was still significant at 3200 scc/h. The starting propellant tank pressures were 1758 kN/m^2 for the MOI on August 7, 1976. The Viking 2 MOI was flawlessly completed, and orbit was successfully achieved on August 7. The helium system was not isolated (P4 closed) until October 5, following the sixth orbital trim maneuver. Regulator performance during this period was normal with no apparent leakage, although the large post-MOI ullage volumes would make it difficult to detect anything less than a gross leak.

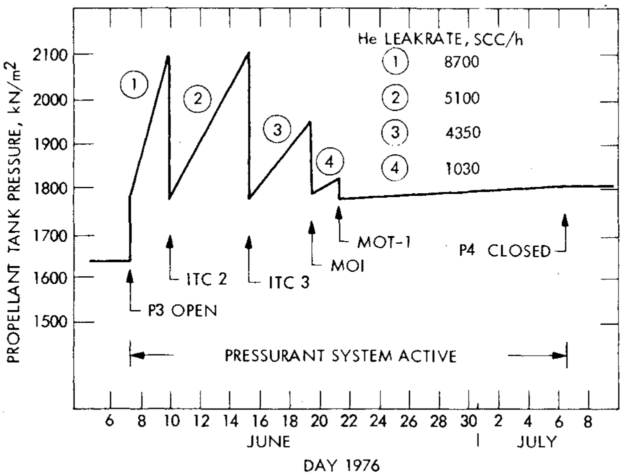

Fig. 6 VO-1 average tank pressure, second-pressurant-system activation.

Summary

The in-flight performance of the Orbiter propulsion subsystem on Vikings 1 and 2 has been nearly perfect. The only significant problem, a potentially degrading regulator-leakage situation, was successfully controlled by using the adaptive-mode mission-planning strategy and the flexibility built into the propulsion subsystem.

The Orbiter propulsion subsystems have supported the Viking spacecraft well beyond the 510-day nominal mission plan. Viking 2, even though it was shut down after 1049 days due to attitude-control gas depletion, more than doubled its design life span. Viking 1 continues operation after more than 1700 days and is expected to continue operation into June 1980.

The gas-share capability, interconnection of the attitude-control high-pressure tanks and the propulsion pressurant gas tank, has allowed Viking 1 to continue operation since January 1978—an extension of over 2 yr.

The ability of the Viking spacecraft to successfully operate over these extended periods of time is a validation of the basic design philosophy and the extensive component/system testing conducted during development.

Postscript

Note Added in Proof: Viking Orbiter One continued its formal science data gathering mission through the month of June 1980. It was estimated that the attitude control gas would be depleted by the end of July. Rather than risk loss of attitude control while the transmitter was still operating it was decided that VO-1 would be shut down while stability and communications were certain. The month of July was therefore devoted to spacecraft system tests and preparation for shutdown.

During July 1980, a series of four propulsive maneuvers was conducted to systematically deplete the remaining propellant while restarting the engine with increasing higher ullage volumes. The final propulsive maneuver duration was 7.9 s and resulted in depletion of the oxidizer. Engine shutdown was accomplished by the spacecraft on-board Central Computing Ssytem when the measured spacecraft acceleration fell below 90% of normal. The ullage volume at the start of the final maneuver (calculated from the oxidizer mass expended) was 99.8% and demonstrated the effectiveness of the surface tension propellant management device.

A total of 27 propulsive maneuvers were performed by VO-1, representing a total engine operating time of 3004 s, spread over a period of four years and eleven months.

On August 7, 1980 at 14:45 p.m. (PDT), ground commands were sent to shut down all major Viking Orbiter One spacecraft systems, thereby offically ending the Viking Mission.

Acknowledgment

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