Viking Spacecraft

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Introduction

This report expands on the Viking spacecraft subsystem briefs provided in Ido Dubrawsky's "Viking Probe Systems Analysis." Particular emphasis is placed on the inputs/outputs required and produced by each subsystem. The intent is to give the reader a clear picture of the data flow (in terms of electronic commands, measured loads, etc.) across the subsystem interfaces.

For a much more detailed analysis of each subsystem and of the intricate interfaces between them, the reader is referred to NASA Reference Publication 1027, "Viking '75 Spacecraft: Design and Test Summary." In addition to an analysis of the design, the publication offers functional block diagrams of each subsystem and detailed engineering drawings of some of the equipment (landing structures, propulsion systems, aeroshells, etc.) used on the orbiter and lander. To reiterate, since an in-depth analysis by NASA is already available for the Viking spacecraft, this report will simply emphasize the subsystem organization and interfaces. For the benefit of the student designer, relevant numerical data indicating mass, volume, and power requirements of certain equipment will also be provided when available.

The Viking Orbiter

The orbiter is best described as a three-axis stabilized spacecraft whose attitude stabilizing references were the Sun and Canopus. The orbiter had two primary purposes. Firstly to survey and help choose a landing site and secondly to act as a communications relay between Earth and Mars. The major subsystems on the spacecraft included power, propulsion, thermal, attitude control, command and data processing.

Power Subsystem

The solar array was the principal electrical power source for the Viking spacecraft. The array consisted of four panels each spaced 90^{o} about the bus. The total area of the panels was 15.2 m^2 (164 ft^2) and provided 712 W of power at Mars. A graph showing the total power output of the solar panels from launch to Mars is given below (power output decreases as distance from Sun increases).

The secondary electrical power source was provided by two rechargeable Nickel-Cadmium batteries that were estimated to have a total of 2100 W-hr at launch and 1900 W-hr at Mars encounter. These batteries were kept fully charged at all times. The mission plan ensured that battery charging occurred no later than 24 hours after the Viking orbiter batteries reached a 20% depth of discharge. When illuminated by the Sun the solar panels provided the power needed and if more electrical power was required then the batteries were utilized. Also during periods of Sun occultations or partial illumination the batteries provided the reserve power.

Propulsion Subsystem

The propulsion subsystem is best described as "a fixed thrust, multistart, pressure fed, Earth-storable bipropellant system".[1] The two propellants used were Nitrogen Tetroxide and Mono-Methyl Hydrazine. The total mass of the propellant at launch was 1405 kg (3097 lb) and at Mars encounter was 1387 kg.

The propulsion subsystem was designed to deliver 3.87 MN-sec (870000 lb-sec) of propulsive impulse to the Viking spacecraft The propulsion also had to be capable of performing 2 or 3 interplanetary trajectory corrections (ITC), a Mars orbit injection (MOI) and about 20 orbital trim maneuvers.

At Mars the subsystem was capable of providing a total Δv of 1480 m/s to a 3430 kg spacecraft. In a single burn at MOI a velocity increment between 900-1325 m/s could be provided.

The firing of the rocket engine depended on the pressure in the tank and how quickly the propellant could be warmed up by the solar energy controller. Firing time depended on the required maneuver. The times varied from a minimum of 1 sec to a maximum of about 40 minutes. Also sufficient time had to be given between each of the firings. This ranged from a few minutes to several days.

Thermal Subsystem

The design of the Viking orbiter was such that it was able to maintain all its elements within safe temperature limits. Temperatures in all the other orbiter subsystems were constantly monitored. The orbiter however did not have an internal temperature control subsystem as such. Passive and active elements were incorporated in to the design to satisfy the temperature requirements.

Passive elements:

1. Material coatings or finishes (these varied for each subsystem as required)
2. Multilayer blankets

Active elements:

1. Bimetallic actuated switches
2. Solar energy collectors
3. Controllable electrical heaters

The spacecraft was maintained at an acceptable equilibrium temperature throughout its mission. The only times this was not true was during prolonged engine firings (i.e. Mars orbit injection) and Sun occultations. However for transient off-Sun periods the design of the orbiter was such that it had a large thermal capacitance so it could maintain the vehicle at an acceptable temperature for about three or four hours.

The solar energy controllers (SECs) were primarily in charge of keeping the propellant at a temperature of about 16°-18° C. The warming-up period for the propellants using the SECs was about five days for an off-loaded mission and about thirteen days for a mission with fully loaded propellant tanks.

Scan platform had an electrical heater located on it. Each of the instruments on the platform had a thermal replacement heater. This was sufficient for maintaining an acceptable temperature for the instruments to work.

Attitude Control Subsystems

The attitude control subsystem (ACS) provided the spacecraft with stabilization and orientation from the time of separation from the Titan-Centaur launch vehicle throughout the mission. The ACS itself consisted of two star sensors and a set of compressed nitrogen jets.

The Sun and Canopus were used as star references. The Sun provided pitch and yaw information and Canopus provided roll information. The ACS received coded commands from the computer command subsystem (CCS) and executed roll, pitch and yaw maneuvers to put the orbiter in the desired attitude.

The gas jets were capable of providing 0.133 N of thrust and thus maintained the Sun and Canopus in the view of the star sensors. In the event of loss of view of the Sun the ACS had an internal logic system that chose a roll mode and then awaited coded commands from the CCS.

There were eight primary operating modes: launch mode, Sun acquisition mode, Canopus acquisition mode, celestial cruise mode, roll inertial mode, all axes inertial mode, commanded turn mode and thrust vector mode.

Computer Command Subsystem

The CCS issued commands to the Viking orbiter from either ground control or pre-programmed commands in its memory. The CCS consisted of two identical and independent data processors and two output units. Each processor consisted of a 4096-word memory: for data acquisition purposes only one processor was used. The memory was divided such that a maximum of 1500 words were available for each load of ground command to operate the orbiter.The command words specified how, when and for how long the science platform operated. These processors could be operated individually, in tandem, or even together in individual mode (as was the case for the MOI).

Flight Data Subsystem

This subsystem handled all the data for the orbiter and also was a source of central timing. It controlled the visual imaging subsystem, the Mars atmospheric water detector, and the infrared thermal mapper. All three of these subsystems' main objective was to provide information to help choose a landing site for the lander. From these instruments the flight data system converted the data from analog to digital, combined data from one instrument with that of another with proper format and routed data either to data storage subsystem or for immediate transmission.

Radio Frequency Subsystem

This consisted of dual two-way radio frequency communication to transmit all data including lander relay data to Earth and to receive coded commands from ground control to command the spacecraft. It also provided navigational tracking data. Only one transmitter and receiver were used at any one time while the other was on standby in case of malfunction.

Orbiter Design Strengths and Weaknesses

The use of two processors aboard the orbiter was one strength of the design. This allowed one processor to be active in receiving commands from earth while the other was concerned with handling the incoming data from the lander as well as the science package onboard the orbiter itself. Furthermore had one of the processors failed the other could be used to handle both tasks although not simultaneously. One weakness of the orbiter design was the limitation of the computer. The computer had to be constantly reprogrammed from earth in order to change experiments. Unlike some of the current unmanned probes like Magellan and Galileo, Viking was essentially dumb. It only knew what it had been recently programmed to do. It could make no decisions by itself.

Viking Lander

The Viking lander was very similar in some respects to the Viking orbiter. The lander had an onboard computer which would receive commands as well as handle the incoming data from the scientific instruments. The lander also used a liquid fueled propulsion system. This is where the similarities end.

Electrical Power and Power Distribution

Four sub-assemblies formed the power subsystem. These were:

1) Radioisotope Thermoelectric Generators,
2) Batteries,
3) Bioshield Power Assembly, and
4) Power Conditioning and Distribution Assembly.

Radioisotope Thermoelectric Generator (RTG)

Two RTGs provided electrical power, each roughly shaped as a cylinder (enclosing the generator components) with six radially mounted fins for heat radiation. Each generator was 41 cm (16 in.) high and 53 cm (23 in.) in diameter (fin tip to fin tip), and weighed 15.4 kg. 34 lbm. During the

90 days of Mars surface operations "each RTG produced a minimum electrical power output of 35 W."[2] The radioactive fuel source was plutonium-238.

The following is a listing of the inputs/outputs created by the RTGs and the various equipment used to monitor their operation:

Inputs

1) Signals for short-circuit mode or on-load operating mode[3] - received from the power conditioning and distribution assembly (see below)

Outputs

1) electrical power
2) thermal energy - helped maintain lander operational temperatures. A control switch could either direct the thermal energy to the lander's structure or to heat rejection systems

3) temperatures - monitored by sensors of the data acquisition and processing unit
4) internal RTG helium gas pressure (generated by fuel decay) - monitored by pressure transducers

Batteries

The lander contained "two 30-V nominal, 24-cell, nickel-cadmium batteries."[4] These rechargeable batteries stored part of the excess energy generated by the RTGs. The RTGs operated at a constant level, and during low power requirement phases their output energy was either dissipated as heat energy or stored in the batteries.

Battery Inputs

1) power to charge batteries
2) signals to switch between battery charge mode and power discharge (to equipment bus) mode - received from the power conditioning and distribution assembly

Battery Outputs

1) battery temperature - closely monitored since charging could only occur within certain temperature limits
2) power for the lander's peak loading conditions

Bioshield Power Assembly

This assembly served as the prime interface between the Viking lander and orbiter. The assembly:

1) controlled and directed Viking orbiter power for use by equipment on the lander,
2) "provided charge capability for the VLC (Viking Lander Capsule) batteries,"[5] and in general
3) provided power for the relay of signals between the orbiter and lander.

Power Conditioning and Distribution Assembly

As its name implies, this assembly was the coordinating body for the entire power subsystem of the lander. Using its available circuitry, control logic, sensors, input power source, and other control equipment, the assembly monitored loads, directed power to the appropriate equipment, and provided appropriate counter measures to protect against undue loads and improperly issued guidance and control commands.

Propulsion Subsystem

Due to the atmospheric entry requirements of the lander, the propulsion system had to compensate for two different phases of the entry procedure. The first entry phase began immediately after lander/orbiter separation and ended upon jettison of the aeroshell (to be discussed in a subsequent subsystem explanation). The propulsion system for this phase of the entry was termed the "reaction control system." The second entry phase began after jettison of the aeroshell and ended with successful landing on the Martian surface. The "terminal descent system" provided the necessary propulsion for this phase of entry. The reaction control system and terminal descent system both implemented three-axis attitude control with their respective set of engines.

Reaction Control System

The reaction control system was responsible for altering the lander trajectory for a successful Mars landing. The deorbit was accomplished with 12 engines (four roll engines and eight pitch and yaw engines) and two tanks of purified hydrazine (as previously mentioned in Ido Dubrawsky's systems analysis report). Each engine produced 36 N (8 lbf) of thrust. Total "...propellant load was 84.8 kg. (187 lbm).[6] It is worthy to note that significant attention was placed on thermal insulation of certain components of the propulsion system to prevent undesired freezing of propellant and propellant transport equipment during the mission. As such, interfacing with the thermal subsystem was necessary.

Inputs

1) control signals from the guidance and control subsystem
2) active thermal control of propellant system accomplished with the use of heaters which received signals from power and thermal subsystems

Output

1) properly directed thrust
2) interface with the "telemetry subsystem to provide engineering data"[7]

Terminal Descent System

This system immediately took control of the lander after aeroshell separation. All the engines for this phase of descent were directly mounted on the lander and remained attached after touchdown. The engines effectively slowed the spacecraft down to a final touchdown velocity of 2.4 m/s (8 ft/s). The required thrust for deceleration and pitch and yaw control were provided by three large terminal descent engines, each one characterized by eighteen smaller exhaust nozzles. Each of these large engine assemblies provided 2700 N (600 lbf) of thrust. Four smaller engines controlled roll, each effectively producing 44.5 N (10 lbf) of thrust. The inputs and outputs for this propulsion sub-assembly were similar to those for the reaction control system.

Structures Subsystem

Much of what will be discussed in this section surrounds the design of structural and/or mechanical assemblies and equipment. Some of the lander's primary structures, which will be subsequently discussed, are as follows:

1) bioshield

2) aerodecelerator
3) lander body structure
4) landing legs

More precise details (in the form of text and attached engineering drawings) on each of these structures can be found in the NASA publication. The reader is encouraged to view these drawings as they provide the subsystem design engineers the necessary visual aids for understanding the geometric complexity of the various subsystem interfaces.

Bioshield

As Ido Dubrawsky noted in his analysis of the Viking probe, there was significant emphasis placed on the contamination problem posed by sending a terrestrial probe to the surface of Mars. That is to say, that the Viking lander was specifically manufactured to meet the environmental requirements (internationally accepted) imposed by COSPAR, the Committee on Space Research. The requirement was "...that the probability of contaminating the planet with terrestrial organisms during the period of biological exploration would be less than .001."[8] With this in mind, the bioshield was offered as a means for spacecraft sterilization before and after total assembly.

Aerodecelerator

This subsystem provided the lander with lifting entry into the Mars atmosphere. An aeroshell (with ablative coating) satisfied aerodynamic and heat dissipation requirements during entry. The aeroshell protected the bottom half of the lander. A separate base cover heat-shielded the top half of the lander. At an altitude of about 4 to 5 miles the aeroshell was jettisoned, at which point a parachute was deployed for further deceleration to an altitude of 1400 m (4600 ft). At this point the terminal descent system was activated and the parachute assembly (consisting of a base cover, parachute and mortar, and mortar support truss) was jettisoned.

Inputs

Interfaced with the pyrotechnic subsystem to provide the timely firing of pyrotechnics for proper jettison of the aeroshell and parachute assembly

Outputs

Before jettison, the aeroshell structure served as a mounting structure for reaction control system engines and hydrazine tanks, radar altimeter, upper atmosphere mass spectrometer, stagnation pressure and temperature sensors, and various other sensors.

Lander Body Structure

Primary structural materials were machined aluminum and titanium. The lander body structure was "configured and sized to provide minimum weight and optimum instrument placement."[9]

Inputs

Heat loads from RTGs

Outputs

The body structure provided the structural integrity of the lander, the necessary mounting of various subsystem equipment (power, communication, propulsion, scientific, etc.), and resistance to Martian sand and dust abrasion.

Landing Legs

In addition to enabling the lander to remain rigidly upright in a landing position for Martian exploration, the landing legs had to absorb impact energy and minimize the landing shock loads on the lander. For load attenuation, "bonded crushable aluminum honeycomb was used in the struts."[10]

Inputs

Signals from the guidance, control and sequencing computer to activate pyrotechnic pin pullers to allow for leg extension

Outputs

Signals to activate the terminal engine shutdown switch at initial leg contact with the Martian surface

Thermal Subsystem

As seen from other subsystem briefs, the thermal subsystem was actively and passively involved in all phases of the mission. Most of the other subsystems made use of thermal control in some form or other. Passive thermal control was achieved by way of thermal coatings (with proper emittance and absorptance properties), proper placement of heat sensitive equipment with respect to heat rejecting equipment (RTGs), thermal insulation (as in the propellant systems), and geometric considerations (such as the aeroshell). Active thermal control involved such things as air-conditioning and water coolers (for prelaunch), heaters, and thermal switches.

Inputs

Loads from solar intensity, RTG heat dissipation, cold temperatures of deep-space vacuum environment, entry heating effects, engine plume heating, and Mars thermal environment

Outputs

Active thermal control achieved by thermal switches. These maintained "internal equipment minimum temperature limits by controlling the heat transfer from each RTG and the equipment mounting plate."[11]

Computer

The computer of the Viking lander was very similar to the one on the orbiter. The main difference was that the lander computer was designed to operate autonomously. At the time of landing, the computer had instructions for performing many days of operation in case contact was not possible. The computer would have carried out a complete mission including taking pictures, obtaining and analyzing samples, and recording weather, seismometry, and other scientific measurements.[12]

This then concludes the analysis of the Viking Lander subsystems. Several subsystems were left out of this report because of the vast amount of information available for each in the NASA report. A brief outline of the inputs and outputs into these subsystems would be too simplistic, vague and perhaps even inaccurate. These subsystems are: the communications subsystem, guidance and control subsystem, pyrotechnics subsystem, telemetry and data handling subsystem, and science subsystem. With the exception of the pyrotechnics and science subsystems, the reader is encouraged to look into these subsystems if he/she possesses advanced knowledge in these areas. These subsystem analyses are rather involved and perhaps beyond the scope of a preliminary design endeavor.

Lander Design Strengths and Weaknesses

Perhaps one weakness to be found in the lander is the fact that no part of the lander was recoverable. Of course, the option for recovery would have meant much greater fuel requirements for the entire mission and additional docking mechanisms between the orbiter and lander. Basically, the option for recovery would have meant an entire redesign process. An additional weakness, though possibly unavoidable, is the creation of several large debris fragments due to the series of equipment jettisons required for the landing (not to mention the lifeless lander after completion of the mission). As for strengths, there are too many to list. The fact that the spacecraft landed was an achievement in itself.

Finally, for the purposes of a general understanding of the Viking Lander configuration and subsystem interfacing, the illustration at the end of the report is offered. The illustration and numbered list of equipment is taken from "The Illustrated Encyclopedia of Space Technology." Some technical data is also included.

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