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-- NOTES --

AUTOMATED LUNAR LANDING MISSIONS USING THE VIKING SPACECRAFT*

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Abstract

This paper examines the feasibility of using a modified Viking Spacecraft to carry out automated lunar exploration missions during the 1976-1980 time period. Results indicate that science payloads on the order of 454 kg (1000 Earth pounds) can be landed at any point on the lunar surface by substituting a Burner II stage for the aerodecelerator and making a few modifications at the subsystems level to the present Mars Viking (orbiter-lander) spacecraft. Other lunar mission concepts such as a rover and sample return have been integrated into the Viking design envelope and are presented. A lunar Viking lander using a growth tandem burner instead of the Viking orbiter is also discussed.

Introduction

The Space Science Board,[1] at its 1970 summer meeting in Woods Hole, Massachusetts, recommended that fully automated landers and rovers should provide the basic approach to follow-on Apollo lunar explorations, and remote-control and return capabilities need to be developed. In the present budgetary climate, a new and costly lunar exploration program appears unlikely. However, an automated lunar exploration program that can effectively use the hardware and other technical resources of an ongoing NASA space program could be very attractive from the standpoint of cost, reliability, and programmatic considerations.

At the present time, the Mars Viking spacecraft system is the only NASA automated lander space system being designed and built which, if modified, could fill a program gap in the NASA lunar exploration program in the late 1970's. Modifying a prototype spacecraft system, such as Viking, to perform multipurpose space missions (i.e., lunar and Martian missions) could be feasible and cost effective or could result in prohibitively large system modifications and compromises in system efficiency, depending on the degree of commonality that exists between the proposed lunar missions and the present Viking Mars mission.

This paper presents the results of a feasibility study of using a modified Viking spacecraft (orbiter and lander) to carry out automated lunar exploration missions during the 1976-1980 time period. Analyses were conducted in areas of mission design, communications, guidance and control, propulsion, thermal control, power, and structures. This study can conveniently be divided into two parts: (1) A description of a baseline lunar Viking mission which examined the Viking spacecraft systems and subsystems in considerable depth, and (2) a conceptual look at the lunar Viking spacecraft's ability to perform several different types of lunar missions (i.e., rover, surface sample return, etc.). It should be noted that these studies focused primarily on the Viking lander system where it was thought most of the modifications would be required, and, to a lesser degree, on the Viking orbiter system.

Goals and Objectives of the Study

In general, the objectives of the study were to provide information concerning the feasibility of using a modified Viking spacecraft as an economical automated lunar exploration vehicle. Specific study objectives were:

(1) Develop a lunar mission profile and determine whether those requirements can be met within the present Viking launch vehicle/spacecraft performance capabilities.

(2) Identify changes in the spacecraft subsystems that must be accomplished to adapt a Viking Mars '75 spacecraft to a lunar mission with minimum modifications.

Study Ground Rules and Constraints

In developing a baseline lunar Viking mission, the following ground rules and constraints were defined:

1. Titan IIID/Centaur launch vehicle
2. Viking orbiter/lander spacecraft concept
3. Minimum modifications to the Viking spacecraft
4. Maximize the lander payload within the constraints of (3)
5. Mission lifetime to be 1 year duration

Lunar Viking Baseline Mission Description

Using the above study ground rules, a lunar baseline mission (Table 1) was developed. It was assumed that the Viking spacecraft would be placed in a polar, 1000-km circular lunar orbit. The selection of a polar orbit permits landings at any latitude or longitude by proper selection of wait time in orbit and allows the lunar orbiter to perform landing site reconnaissance. A far-side

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landing site was selected because of its potential scientific value and because it provides the most severe operational environment.

The sequence of events during the descent and landing of the lunar Viking lander is illustrated in Figure 1. After separation of the orbiter and lander, the lander fires a solid rocket motor (TEM 364-4), especially installed to remove sufficient velocity so that the Mars Viking terminal propulsion system can perform a soft lunar landing. This motor performs the same function as the aerodecelerator system for Mars missions.

The ΔV requirements for each maneuver of both the lander and the orbiter are given in Table 2. The total fuel budget required for the lunar Viking orbiter is 1450 kg which is about the same as for the Mars Viking orbiter. This result permits the Viking orbiter propulsion system to remain unchanged for the two missions. For the lander, the solid rocket provides a ΔV of 1710 m/s during the main descent, and the terminal propulsion system supplies the remaining ΔV of 173 m/s which is required.

Of further importance for the far-side landing mission is the accuracy of the landing footprint. An illustration of the landing dispersion is shown in Figure 2. The primary contribution to the downrange errors are the 3σ errors during the solid rocket motor burn and the lack of tracking data throughout the propulsive deorbit (SRM) and terminal descent maneuvers. Although these landing dispersions (27 km by 6 km) are acceptable for most far-side landing sites, it is expected that these dispersions will become smaller as the SRM (TEM 364-4) is further developed.

The lunar far-side landing also requires a relay communication link between the lander and the orbiter. The proper combination of orbital altitude and landing site latitude and longitude can be selected to obtain the maximum lander/orbiter viewing time. The results of an analysis of this orbit design problem are shown in Figure 3. It can be concluded from this figure that in order to maximize the total real-time data for polar orbital relay missions, landing site latitudes above 75° and high-altitude orbits (between 1000 and 3000 km) should be selected. The data transmission rate versus orbital altitude for the lunar Viking relay link is shown in Figure 4. The dotted lines on this figure identify the present lunar Viking communication system design. As an example for an orbital altitude of 1000 km and a power level of 30 w on a UHF transmitter, a data rate of 85,000 bps is available. Since 85,000 bps is not a sufficient data rate for high resolution information, it is suggested that larger antenna gains or higher power levels (50 watt range) or both, be incorporated into the lunar Viking communication subsystem for far-side lunar missions. It should be emphasized that these suggested communication modifications are for far-side lunar missions, and that the Viking lander S-band subsystem is completely adequate for real-time communications for lunar front-side missions.

An S-band relay link via a quasi-stationary relay satellite, near the lunar libration point L_2, was also considered for a far-side communication relay link. This HALO satellite[2] would be in a 3500-km orbit about the L_2 libration point and would have communication distances of 65,000 km from the lunar surface. Using a 12-foot antenna, the HALO satellite could have a 10^6-bps data rate. Considering the lander power subsystem operating time constraint of 176 minutes per 24 hour period, the total data volume would be 10.56×10^9 bits per 24 hours.

Lunar Viking Spacecraft Design

Some modifications to the Viking spacecraft system are required to perform a lunar mission. Since Mars has an atmosphere and the Moon does not, most modifications to the Viking spacecraft system are in the descent propulsion system. The aeroshell and parachute of the Mars Viking lander are replaced by a solid rocket motor in the lunar Viking lander and the Mars bioshield is removed, since there are no sterilization requirements for lunar missions. A sketch of the lunar Viking lander with the solid rocket motor attached is presented in Figure 5. The shaded areas show the solid rocket motor and the reaction control nozzles. A propellant tank is also shaded here which represents the use of one of the Mars RCS tanks as a lunar terminal propulsion tank. The total number of tanks and their size are the same in the Mars Viking and lunar Viking spacecraft design.

Differences in surface temperatures, distance from the Sun, and the day-night cycle between Mars and the Moon necessitate modifications to the lander thermal control system and the orbiter's power and thermal control systems. The modifications to both the orbiter and lander to adapt to this lunar environment appear to be minor and well within present state of the art. The Viking lander will use a passive radiator and multilayer insulation to solve the lunar thermal environment. A sketch of these modifications is shown in Figure 6.

The effect of all modifications is reflected in the mass of the systems. The resultant mass statement for the lunar Viking lander and orbiter is presented in Table 3. It is interesting to note that the lunar Viking orbiter is within 23 kg of the Mars Viking orbiter, while the mass of the lunar Viking lander is approximately 1270 kg more than the Mars Viking lander. The mass difference is reflected in the mass of the solid rocket motor and the increased payload capability of the lunar Viking lander. The new payload capability is approximately 454 kg and can be used for additional science and support equipment. A landing stability analysis of this configuration was performed assuming the lunar Viking landing weight was 1135 kg, and that the 454 kg payload had a center-of-gravity location 25 centimeters above the lander equipment mounting deck. Results of this analysis indicate positive stability for lander body attitudes of 24° for 3σ errors in landing velocities (vertical and horizontal).

Lunar Viking Baseline Mission Summary

Modifications required of Mars Viking spacecraft to perform a lunar Viking baseline mission can be summarized in the following remarks:

(1) The lunar Viking lander, including its necessary subsystems (i.e., communication, guidance and control, power, etc.) can land, in a piggyback fashion, a payload of approximately 454 kg (1000 Earth pounds).

(2) Surprisingly few modifications are required to adapt the Mars Viking spacecraft to lunar missions. A summary of these modifications is presented in Table 4. The main modifications to the Viking lander are in the propulsion and thermal control system, while the main modifications to the Viking orbiter are in the power and structural systems. It should be noted that all these modifications are well within the present state of the art.

Other Lunar Viking Mission Concepts

In addition to the baseline mission, several other lunar Viking missions concepts have been studied. These studies were not held as rigidly to the minimum modification philosophy, nor have they been studied to the depth of detail of the lunar Viking baseline mission.

Lunar Viking Rover Concept

A lunar rover concept was developed that can be carried piggyback by the baseline lunar Viking lander spacecraft. The purpose of this conceptual design was to develop lunar rover systems and missions descriptions in sufficient detail to permit a realistic evaluation of the rover's science potential. Study guidelines emphasized state-of-the-art components and minimum impact with the lander's design and function. A sketch of the lunar Viking rover is shown in Figure 7. This four-wheel rover measures 213 cm in length and 152 cm in width and is powered by one RTG (140 watt) unit (plus batteries). This rover design uses 0.6 scale GM LRV wheels (developed for the Apollo lunar rover vehicle) that have a contact pressure equal to 4137 N/m^2. The ground clearance is approximately 30 cm. Four-wheel rover designs have been studied extensively in the Apollo LRV program and are particularly desirable from a packaging management point of view. Six- and eight-wheeled rover designs appear to have more mobility than four-wheel rovers, however.

The four-wheel configuration could be located on the Mars Viking lander with only minor modifications. The total mass of the rover is 372-386 kg. A breakdown of this mass into support elements is given in Table 5 for both a UHF and S-band configuration. It should also be noted that 141 kg is available for science payload. Sixteen science instruments, with associated volume and power requirements, are listed in Table 6 that could be accommodated with such a payload capability. These 16 instruments were primarily selected from a larger unpublished list of candidate lunar experiments developed by the Illinois Institute Technology Research Institute (ITTRI).

Lunar Surface Sample Return Concept

A lunar surface sample return (SSR) design concept was developed using the design guidelines shown in Figure 8. The design guidelines having the largest influence, in size and mass, on the design of the lunar SSR module were (1) minimum impact on the Viking lander, therefore maximum landed payload capability of 454 kg, and (2) lunar sample size to be 4 to 13 kg. The SSR module, shown in Figure 9, is delivered to the lunar surface, in piggyback fashion, by the lunar Viking spacecraft developed in the baseline mission. The SSR module uses a liquid, restartable, propulsion system and attitude/velocity control system. An Apollo-shaped entry capsule was assumed for the Earth return phase of the mission since the Earth entry velocities would be the same as those in the Apollo missions.

The baseline return mission from the Moon involves two major bowered maneuvers, launch to lunar orbit, and trans-Earth injection. A baseline ΔV budget for this mission is presented in Table 7. In order to accommodate surface sample returns from any point on the lunar surface, a mission profile which used a lunar parking orbit prior to trans-Earth injection was selected. Direct entry at Earth was selected since the velocities' budgets for Earth capture orbits range from 2000 to 3200 meters/sec. A mass breakdown of the lunar surface sample return module is presented in Table 8. The total mass of the module, 375 kg, is well within the 454-kg payload capability of the lunar Viking baseline mission. A mass breakdown of the propulsion module which assumes use of the Viking orbiter engine is shown in Table 9. This engine was selected because of its present development status and because its thrust level and restart capability adequately fit the mission profile.

Since the total mass of the SSR module is about 375-386 kg, approximately 90 kg are available for sample acquisition. Figure 10 illustrates several concepts for loading samples into the return module. The first concept uses an unmodified Viking soil acquisition boom to load the lunar sample. The second concept requires a modification to the Viking soil acquisition boom displacements. The third concept involves using a soil acquisition boom on a roving vehicle.

Lunar Viking/Growth Tandem Burner Concept

The purpose of this phase of the study was to develop a lunar Viking spacecraft concept that can perform simpler and less expensive unmanned exploration missions to the Moon than the baseline lunar Viking spacecraft (orbiter plus lander). Also, several lunar Viking missions concepts would not necessarily require the support of an orbiter. These missions include front-side landings and multiple far-side missions in which one orbiter could provide the relay communications for several landers.

The growth tandem burner vehicle, using the Viking lander to perform certain spacecraft intelligence functions (GCSC, ACS, etc.) was, therefore, substituted for the Viking orbiter in this conceptual lunar mission design. A drawing of this concept is shown in Figure 11. The growth tandem burner consists of two solid rocket motors (TEM 364-4), support structure, attitude reference, and RCS systems. The growth tandem burner is in an early design status, but the tandem burner concept using smaller solid rocket motors has been flight tested and proven. For this application, the lunar Viking lander would supply the power, communications, and a Sun-Canopus reference system during the translunar cruise phase of flight.

A mass profile and ΔV budget is shown in Table 10. For this lunar mission mode, the translunar injection mass (~3418 kg) barely exceeds the upper limits of the TIIIC/transtage capabilities. The first stage of the growth tandem burner performs the lunar orbit insertion maneuver. The second stage of the growth tandem burner performs the lunar deorbit maneuver which is the same mission mode as in the lunar Viking baseline mission.

This design concept delivers the lunar Viking baseline spacecraft (454 kg payload) to any point on the lunar surface. Also, there are very large cost savings to using the lunar Viking/growth tandem burner concept, since the cost of the growth tandem burner is a small fraction of the Viking orbiter spacecraft.

Concluding Remarks

The use of the Viking spacecraft for carrying out automated lunar exploration missions in 1976-1980 time period has been studied. Studies have indicated that a large degree of commonality exists between lunar and Martian missions.

Specifically, results of the studies show that:

(1) Payloads on the order of 454 kg can be landed at any point on the lunar surface.

(2) The use of a growth tandem burner in place of the Mars Viking orbiter looks very attractive from a program cost standpoint.

(3) Lunar rover and lunar surface sample return missions can be integrated into the baseline lunar Viking lander with minimum modifications.

References

[1] Space Science Board: Priorities for Space Research 1971-1980. National Academy of Science, 1971.

[2] Robert W. Farquhar: The Control and Use of Libration-Point Satellites, NASA TR R-346.

FAR SIDE LANDING OUT OF POLAR ORBIT

ORBIT DESIGN TO SATISFY RELAY AND LANDING SITE RECONNAISSANCE

IDENTIFY LANDER ACCURACY FOR FAR SIDE LANDING SITES

TABLE 1. Lunar Viking baseline mission.

MANEUVER	ORBITER Δ VELOCITY (mps)	ORBITER FUEL (kg)	LANDER Δ VELOCITY (mps)	LANDER FUEL (kg)
MIDCOURSE CORRECTION	15	25	--	--
LUNAR ORBIT INSERTION	858	1233	--	--
ORBITAL TRIM	6	7	--	--
DESCENT ORBIT INSERTION	53	107	--	--
ALTITUDE TRIM	2	2	—	--
LANDER PLANE CHANGE	--	--	12	13
POWERED DESCENT	--	--	1710	1040
TERMINAL DESCENT	--	—	173	80
ORBITER CIRCULARIZATION	4	33	--	--
STATION KEEPING	122	43	--	--
TOTAL	1176	1450	1895	1133

TABLE 2. Delta velocity budget.

EVENT	LUNAR VIKING MASS (kg)			MARS VIKING MASS (kg)		
	TOTAL	ORBITER	LANDER	TOTAL	ORBITER	LANDER
AFTER TRANSLUNAR INJECTION	4705	2405	2300	3447	2381	1066
AFTER LUNAR ORBIT INSERTION (858 mps)	3446	1146	2300	2073	1007	1066
AFTER ORBIT TRIM	3338	1035	2300	2036	988	1066
AFTER SRM BURN (2815 mps) AND JETTISON		1035	1076		988	1066
AFTER LANDING		1035	998		988	543

TABLE 3. Lunar Viking mass profile.

PROPULSION SYSTEM
- ADDITIONS OF TEM 364-4 SOLID ROCKET MOTOR

THERMAL CONTROL SYSTEM
- MODIFY LANDER INSULATION SYSTEM AND RADIATOR
- ADD HEATERS AND INSULATION FOR PROTECTION DURING CRUISE
- MODIFY ORBITER LOUVER CONTROL

POWER SYSTEM
- ORBITER - SERIES - PARALLEL WIRING OF ARRAY MUST BE CHANGED FOR 1AU OPERATION

COMMUNICATIONS SYSTEM (FOR FAR SIDE OPERATION)
- PROVIDE ORBITER AND LANDER COMMAND CAPABILITY
- MODIFY ORBITER AND LANDER ENCODING TO INCREASE DATA RATES ABOVE 16 KBS
- INCREASE LANDER'S ANTENNA GAIN AND TRANSMITTER OUTPUT POWER

STRUCTURAL
- NEW LANDER TO SRM AND SRM TO ORBITER TRUSSES
- STRENGTHEN ORBITER TO CENTAUR ADAPTER TRUSS

TABLE 4. Baseline Viking spacecraft modifications.

	MASS (kg) UHF CONFIGURATION	MASS (kg) S-BAND CONFIGURATION
BASIC ROVING VEHICLE		
STRUCTURE	34	34
WHEELS/DRIVES/SUSPENSION	23	23
FENDERS	2	2
THERMAL CONTROL	9	9
	68	68
SCIENCE PAYLOAD	141	141
SUBSYSTEMS	136	150
TOTAL	345	359
LANDER-MOUNTED STOWAGE/DEPLOYMENT MECHANISM	27	27
TOTAL ADDED MASS	372	386

TABLE 5. Allocated mass summary.

INSTRUMENTS	MASS (kg)	POWER (w)	VOLUME (cm^3)
FACSIMILE CAMERA SYSTEMS (2)	5	38	2096
TELEVISION CAMERA SYSTEMS (2)	16	62	4916
QUASIMICROSCOPE & TELESCOPE	6	15	0
MAGNETOMETER	4	5	6555
MANIPULATORS & SAMPLE HANDLING, PROCESSING, & DISTRIBUTION EQUIPMENT	29	223	24581
BULK SCOOP	7	50	0
SAMPLE ANALYZER	14	25	7128
SUBSURFACE SAMPLER	10	200	0
SUBSURFACE ANALYZER	1	3	213
SEISMOMETERS	10	8	14339
ACTIVE SEISMIC SOURCES	11	5	0
GAS DETECTORS	5	15	4097
GRAVIMETER	14	10	8194
CHARGED PARTICLE DETECTORS	2	10	2048
METEOROID/DUST DETECTORS	5	5	1636
FIFTH WHEEL	2	2	0
TOTALS	141		75803 (.0758) m^3

TABLE 6. Rover science payload.

FUNCTION	ΔV (m/sec)	Fuel (kg)
LIFTOFF TO LUNAR ORBIT	1840	179
ORBIT TRIM (ACS)	6	1
TRANSEARTH INJECTION	870	52
MIDCOURSE MANEUVERS (ACS)	60	2
SPIN MANEUVERS	12	1
	2788	235 *

* INCLUDES 4 kg OF ACS MONOPROPELLANT FUEL.

TABLE 7. Baseline ΔV budget.

PROPULSION MODULE (INCLUDING ADAPTER)	291
PROPULSION MODULE THERMAL PROTECTION	2
SAMPLE RETURN CAPSULE STRUCTURE	14
SAMPLE RETURN CAPSULE THERMAL PROTECTION	2
ATTITUDE CONTROL SYSTEM	17
GUIDANCE AND NAVIGATION EQUIPMENT	16
COMMUNICATION EQUIPMENT	10
POWER (AG-ZN BATTERY)	8
DROGUE AND MAIN PARACHUTES	2
SAMPLE CONTAINER	1
TOTAL	363
TOTAL WITH 13 kg OF LUNAR MATERIAL	376

TABLE 8. Mass breakdown (kg).

DESCRIPTION

136 kg ORBITER ENGINE, MMH FUEL, N_2O_4 OXIDIZER

RESTARTABLE AND GIMBALED, 289 sec SPECIFIC IMPULSE

MASS BREAKDOWN (kg)

USEABLE PROPELLANT	236
RESIDUAL PROPELLANT	12
PROPELLANT TANKS	7
PRESSURANT TANKS	8
PRESSURANT (H_e)	1
LINES, FITTINGS, AND REGULATOR	3
ENGINE	8
SUPPORT AND ADAPTOR STRUCTURE	16
TOTAL	291

TABLE 9. Baseline propulsion system.

	GROWTH TANDEM BURNER	LUNAR VIKING LANDER	LUNAR VIKING (TOTAL)
1. MASS AT LUNAR INJECTION	2302	1125	3417
CENTAUR ADAPTER	- 47		
2. MASS AT SEPARATION	2255	1115	3370
Δ VELOCITY - 15 m sec for MIDCOURSE CORRECTIONS (2)		- 24	
3. MASS AT BURNER STAGE I IGNITION	2255	1091	3346
EXPENDED INERTS	- 10		
SOLID PROPELLANT (Δ VELOCITY-1113 m/sec)	-1037		
JETTISON MASS	- 180		
4. MASS AT BURNER STAGE II IGNITION	1064	1092	2160
EXPENDED INERTS	- 9		
SOLID PROPELLANT (ΔVELOCITY-1534 m/sec)	- 866		
JETTISON MASS	- 194		
5. MASS AT TERMINAL PHASE INITIATION		1091	1091
LIQUID PROPELLANT FOR TERMINAL PHASE (ΔVELOCITY - 172 m/sec)		- 80	
6. MASS AT TOUCHDOWN		1012*	1012*
7. TOTAL PROPELLANT CONSUMED (kg)	1903	103	2006
8. TOTAL Δ VELOCITY (m/sec)	1205	85	1258

* INCLUDES 23.6 kg OF UNUSED PROPELLANT

TABLE 10. Mass profile and delta velocity budget.

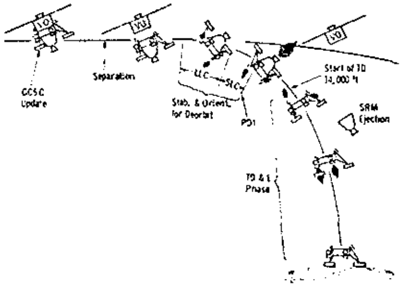

Figure 1. Guidance and control during descent and landing.

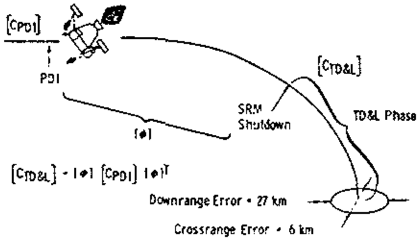

Figure 2. Estimate of landing accuracy.

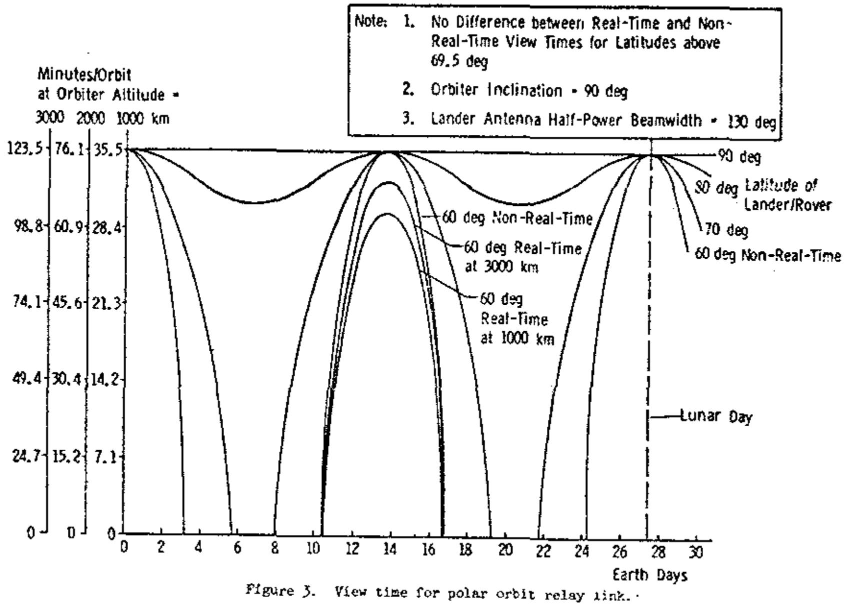

Figure 3. View time for polar orbit relay link.

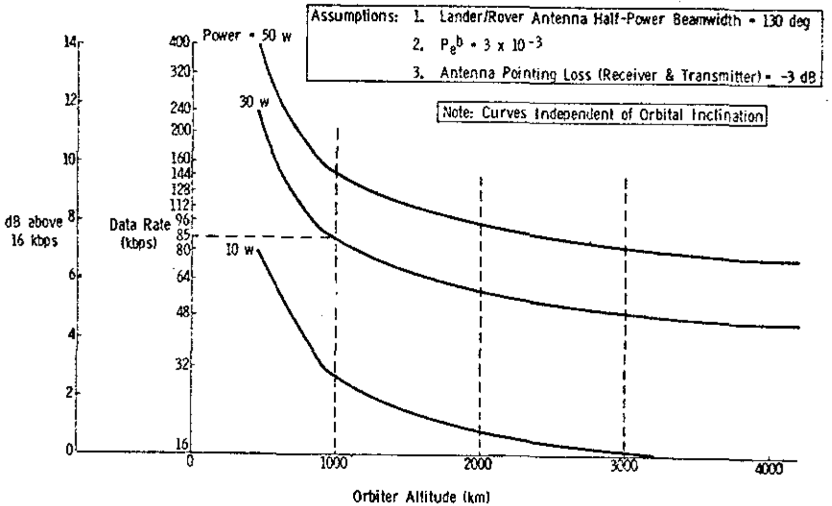

Figure 4. Data rate capability for relay to orbiter.

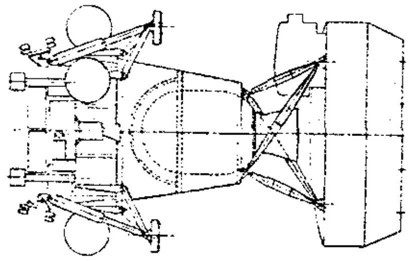

Figure 5. Lunar Viking configuration.

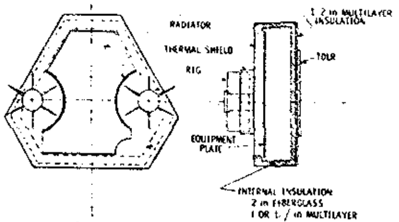

Figure 6. Lander thermal control subsystem schematic.

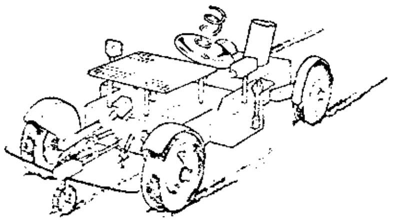

Figure 7. Lunar Viking rover deployed.

- Minimum Impact on Current Lander
- Lunar Sample ~ 10 to 30 lb
- No Quarantine on Lunar Material
- Lander Has No Other Function after Lunar Liftoff
- Communications Available for Backside Landing Sites
- Direct Earth Entry
- Use Currently Available Components

Figure 8. Design guidelines and assumptions.

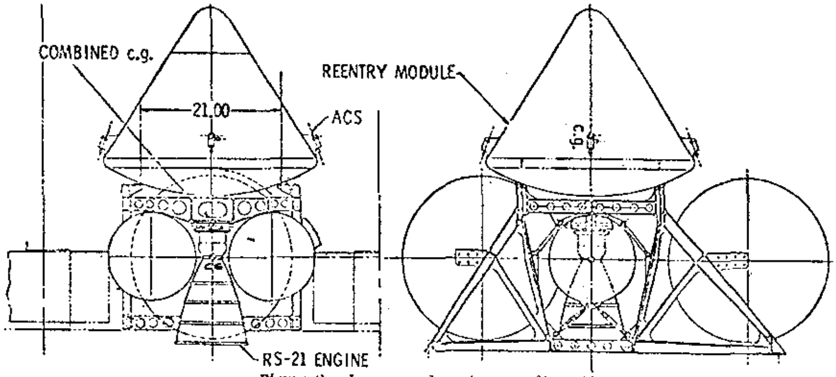

Figure 9. Lunar sample return configuration.

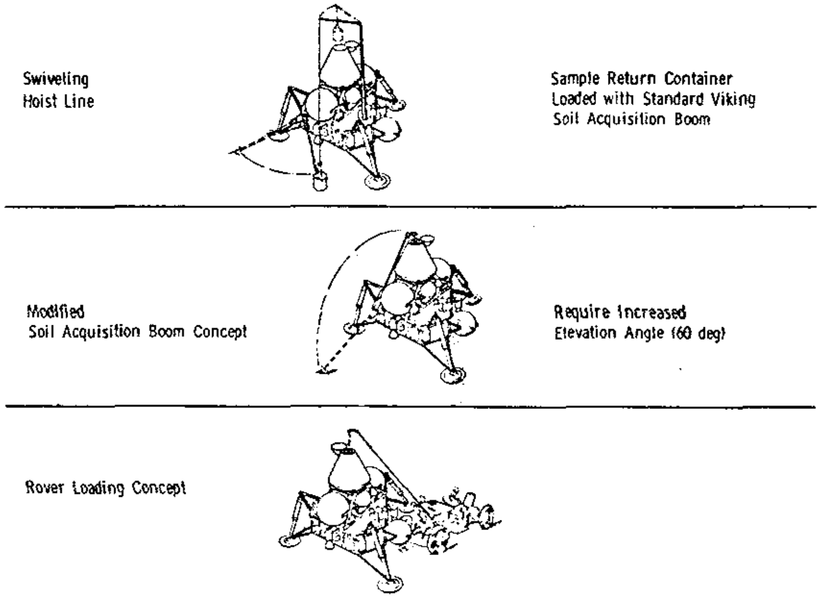

Figure 10. Sample loading concepts.

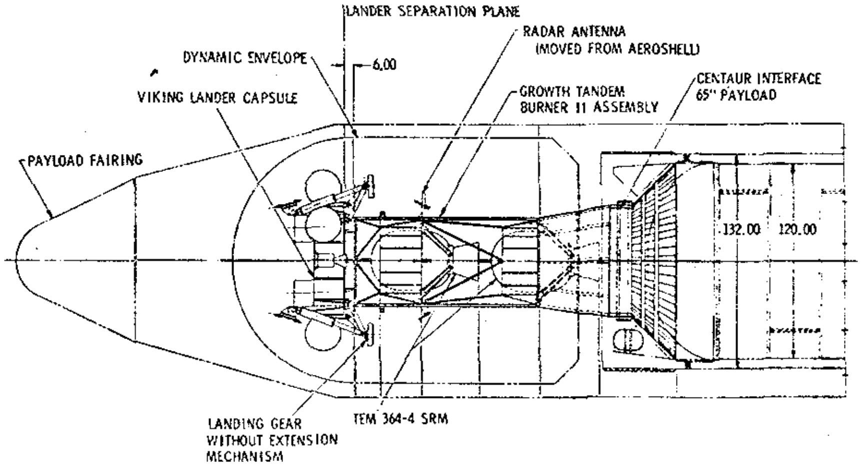

Figure 11. Lunar Viking launch configuration-growth tandem burner concept.