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A CONCEPTUAL DESIGN AND OPERATIONAL CHARACTERISTICS FOR A MARS ROVER FOR A 1979 OR 1981 VIKING SCIENCE MISSION

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16. Abstract

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The capability for carrying Viking rovers (including deployment system) to the surface of Mars was considered first. It was found to be feasible to carry rovers of over 100 kg. Virtually all rover systems were then studied briefly to determine a feasible system concept and a practical interface with the comparable system of a 1979 or 1981 lander vehicle.

The rover as conceived under guidelines and assumptions given herein will provide remote sampling and sample analysis at distances of up to 1 kilometer from the lander. It will carry out one sortie and return to the lander daily with interesting samples for advanced analysis. The rover will perform its own multispectral panoramic imaging, but will remain dependent on the lander for communication and operational control.

This Viking rover concept was found to be a feasible addition to an advanced Viking mission in 1979 or 1981 and would add significantly to the scientific and exploratory capability of the mission.

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SUMMARY

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INTRODUCTION

On-surface exploration of Mars by the United States is scheduled to begin in 1976 when two Viking spacecraft will soft land at different sites on the planet. (See ref. 1.)

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The principal objective of the Viking mission will be to determine whether life exists, or has, or can be expected in the future on the planet. A Viking-type mission is now under study for launch in 1979 or 1981. A small surface roving vehicle could be incorporated in the lander of the 1979 or 1981 Viking spacecraft to augment the exploratory capability of the lander. The addition of the small rover will add significantly to the scientific worth of the mission.

Studies were conducted at the Langley Research Center with support from LTV Aerospace Corporation to determine the feasibility of and develop a preliminary concept of a small Mars rover which could be stowed aboard a 1979 or 1981 Viking lander and deployed on to the surface of Mars. The science objectives for this study were based on those of the Viking 1975 mission and future mission plans generated by Viking Project Office studies and other science payload studies. An analysis of the near-term availability of power system candidates was a primary factor in determining the direction taken in this study and in the resulting concept. Under this concept the rover would perform sampling and preliminary analysis of those areas judged to be of scientific interest in the general vicinity of the landing site. The rover would remain dependent on the lander for communication and power. It would return to the lander daily with interesting and unique samples for detailed analysis. Three variations or classes of this rover concept were developed to provide comparisons in capability and complexity. Their target design mass range was set at 20 to 90 kg.

Other Mars rover concepts not reported herein are being studied for application on a 1979 or 1981 Viking mission. One, under current consideration, uses a contrasting approach from the standpoint of use of power systems. Its power system will operate independently from the Viking lander. This design will require much less change of the lander for interfaces but will require greater development on the part of the rover, especially that of its independent power system. Currently, no such system exists; therefore, either modification of existing systems or development of new ones would be required.

Study Objectives

Objectives were established which would define rover concepts and the interface between rover and lander. The objectives were to

(1) Determine the maximum rover mass which can be flown to the Martian surface by a 1979 or 1981 Viking lander

(2) Define a stowage envelope on the Viking lander in which a potential rover could be transported to Mars

(3) Define a feasible deployment technique

(4) Provide gross definition of the lander-rover system interfaces for 1979 or 1981 missions

(5) Identify the lander-rover science complement

(6) Define gross design characteristics for rover concepts

(7) Develop gross system parameters for rover concepts

(8) Determine a surface operating plan for rover concepts

Study Guidelines

The study proceeded according to previously defined guidelines and known or accepted mission designs. These guidelines were strongly affected by the need to provide a minimum-cost Mars exploration mission which does not require large advances in technology and yet implements innovative techniques to meet new potentials. Guidelines of the study were as follows:

(1) Use Viking 1975 mission hardware design to the maximum degree

(2) Use Titan III E/Centaur launch vehicle capability

(3) Design for launch dates of 1979 or 1981

(4) Supply Earth communication only through lander system

(5) Use orbiter to provide an alternate communications link to Earth

(6) Place surface mission emphasis on geoscience

Study Assumptions

Performance of the study required that a number of general assumptions be made concerning the surface activities, surface environment, or lander design for a 1979 or 1981 mission. Specific assumptions relating to systems concepts are included under the appropriate system description section. General assumptions were as follows:

(1) Surface mission duration is 90 to 180 days

(2) Landing site is not excessively bouldered or inclined, but offers variation in the scientific environment

(3) Launching of one spacecraft with landing site at $+60^{\circ}$ to -90° latitude

(4) Rover surface operations are curtailed during dust storms

(5) Mars surface characteristics derived from established engineering design models including revisions from the Mariner 9 flight data. Atmosphere data were taken from the Viking 1975 Mars engineering models revised on June 8, 1972 with Mariner 9 data

(6) Science payload on 1979 or 1981 lander is advanced over that of Viking 1975

(7) Updated radioisotope thermoelectric generator (RTG) power system on lander

(8) Part use of lander's computer for rover

(9) Limited degree of adaptive capability on rover

(10) Three classes of rover, A, B, and C, with target mass intervals of 20 to 35 kg, 35 to 60 kg, and 60 to 90 kg, respectively

The purpose of this report is to present and compare three variations of a preliminary Mars rover concept. Included are study results on the mass capability of the Viking 1975 lander to bring rovers to Mars surface and a typical surface mission activity scheme for this rover concept.

1979 OR 1981 MISSION LANDED MASS CAPABILITY

The feasibility of a Viking rover concept is contingent on the spacecraft capability to deliver a rover vehicle to the Mars surface. For the launch years 1979 and 1981, somewhat different conditions will be encountered than those anticipated on the Viking 1975 mission. These conditions include spacecraft mass changes, different launch energy requirements and Mars orbit insertion (MOI) values, and the need to land an increased lander payload which is constituted of the added lander equipment, the rover, and the rover deployment system. It was, therefore, of first priority in this preliminary study to determine the capability for landing a rover and deployment system on Mars in 1980 or 1982 with the use of a Viking spacecraft which had slight changes that were considered to be commensurate with an advanced Viking mission.

It was assumed that the mission profile for a 1979 or 1981 Viking mission would remain essentially the same as that for 1975. The Titan III E/Centaur launch-vehicle capability would be used for both the 1979 and 1981 missions. The maximum mass handling capability of the 1975 Viking Lander in entry was analyzed first. This analysis was followed by an analysis of the Viking Orbiter capability to provide MOI with the additional mass.

1979 or 1981 Viking Lander Entry and Landing Capability

The capability of the 1979 or 1981 Viking lander to execute Mars entry and landing while bearing increased mass (rover and deployment system) was analyzed for the same environmental and performance ground rules and constraints as were used for Viking 1975 analysis; an important exception was the assumption of fully loaded terminal propulsion descent tanks for the 1979 or 1981 mission. Density profiles of Mars atmosphere models employed are shown in figure 1 and other Viking 1975 lander mission requirements, design

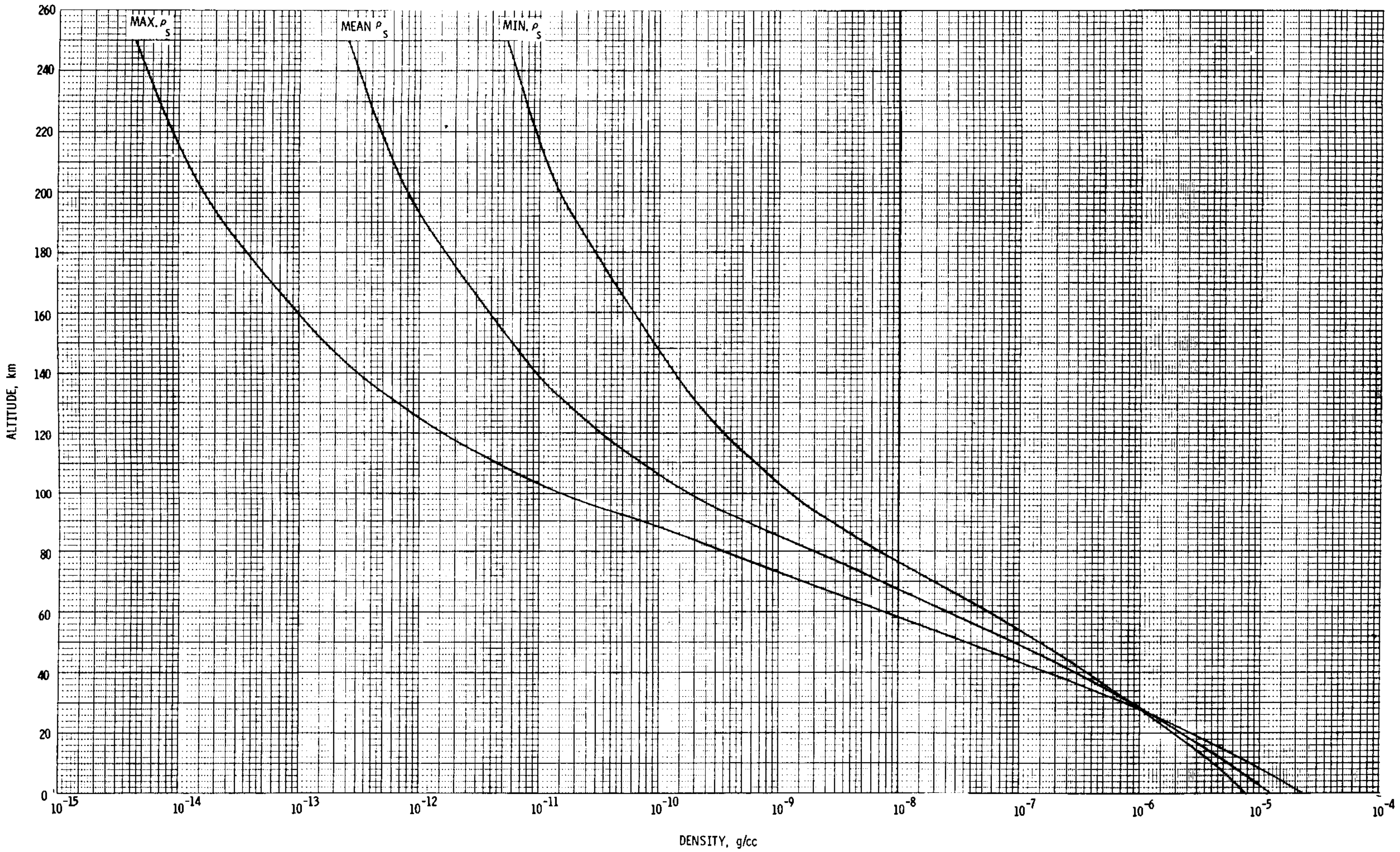


Figure 1.- Mars model atmospheric density profiles.

details, and performance characteristics are discussed in reference 2. Limiting values for certain critical mission, design, and performance parameters are repeated here for clarity:

(1) Maximum allowable entry dynamic pressure, $q_{max} = 6900\ N/m^2$

(2) Terrain height, $h_t = 0$ to 3 km

(3) Inertial entry flight-path angle, -14.5° to -18.5°

(4) Lift/drag ratio, $L/D = 0.16$ to 0.20

(5) Inertial entry velocity, 4.6 km/sec

(6) Mars orbit inclination, 50°

(7) Parachute deployment Mach number ≤ 1.9 and dynamic pressure $\leq 413\ N/m^2$

(8) Orbiter periapsis altitude, 1200 to 1800 km (synchronous period)

(9) Elapsed time from lander deorbit initiation to entry, $T_{IE} = 5$ hours

(10) Usable deorbit propellant, 80 kg

Terminal propulsion considerations.- Of particular interest herein are the results of trade-offs among entry and landed mass and landing site terrain height for the proposed 1979 or 1981 missions. Figure 2 depicts landed and entry mass capabilities as functions of terrain height. Data are presented for worst case atmosphere conditions (for Viking 1975) and for a less stringent atmosphere condition (it being assumed that Viking 1975 data indicate the presence of an atmosphere similar to the "mean" in fig. 1). At a terrain height of 3 km the landed masses are 652 kg and 696 kg for the worst case and "mean" atmospheres, respectively. If terrain height is reduced to 1.5 km (reasonable for a 1979 or 1981 mission), the landed masses increase to 682 kg and 723 kg for the two postulated environments. Even at zero terrain height (equivalent to landing at the mean Mars surface level), 704 kg can be landed in worst case conditions. These substantial increases in landed mass are attained simply by filling the terminal descent propellant tanks, which are off-loaded for the Viking 1975 lander.

Although the present rover analyses are based on the assumption of full propellant tanks, figure 3 further illustrates the relationship between landed mass and terminal descent fuel consumption. It is important to reiterate that if Viking 1975 results indicate a "mean" atmosphere, further performance gains may be realized.

Entry-corridor considerations.- In order to keep maximum entry dynamic pressure (q_{max}) on heavier entry vehicles within Viking 1975 design limits, it is necessary to reduce allowable entry angle corridor, and thereby penalize targeting flexibility. Figure 4 shows current q_{max} constraints on maximum (steepest) entry angle for worst case and "mean" atmospheres. Furthermore, because lander trajectories gradually

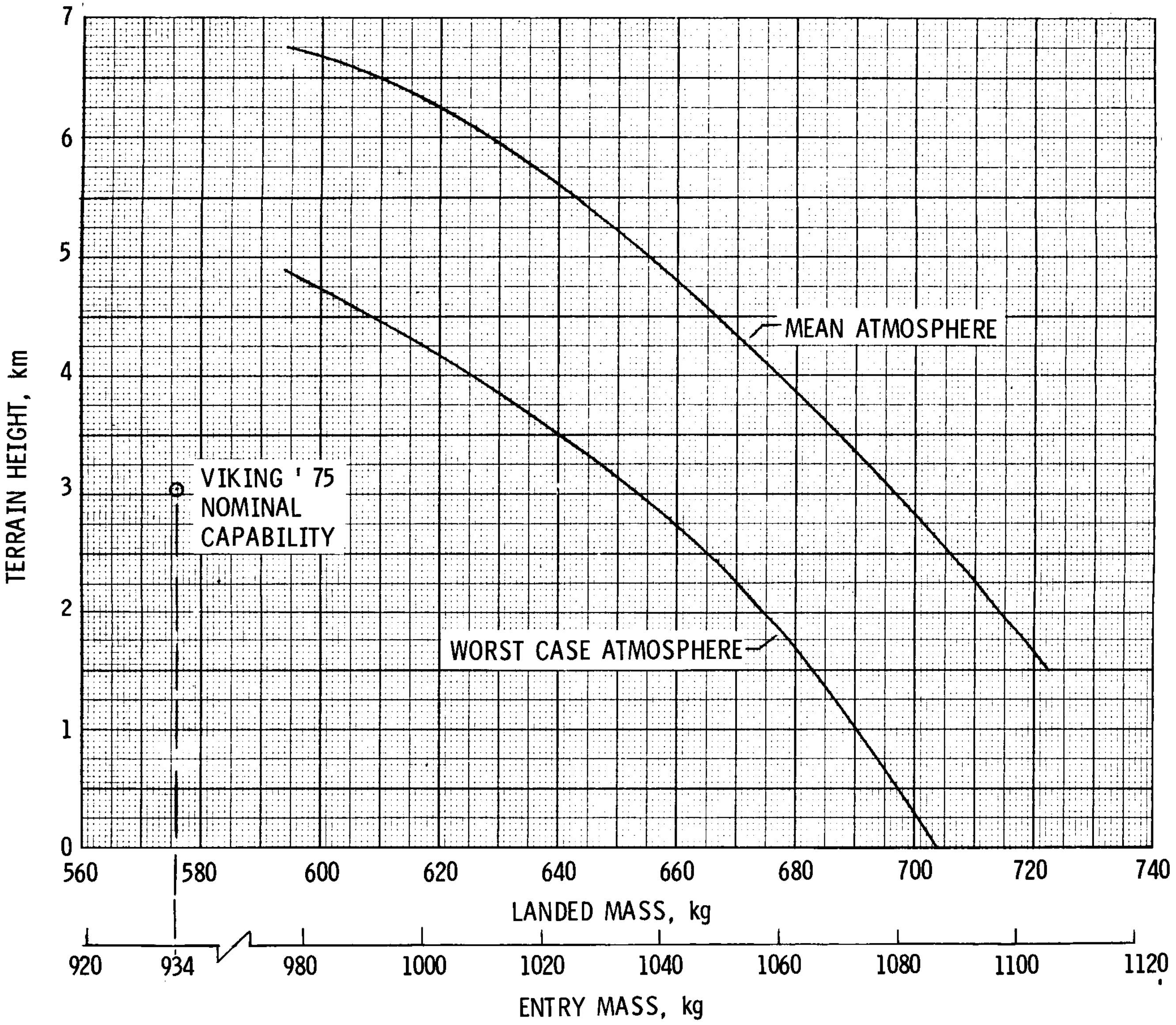


Figure 2.- Variation of terrain height capability with maximum landed and entry mass for entry in worst case and mean atmosphere models.

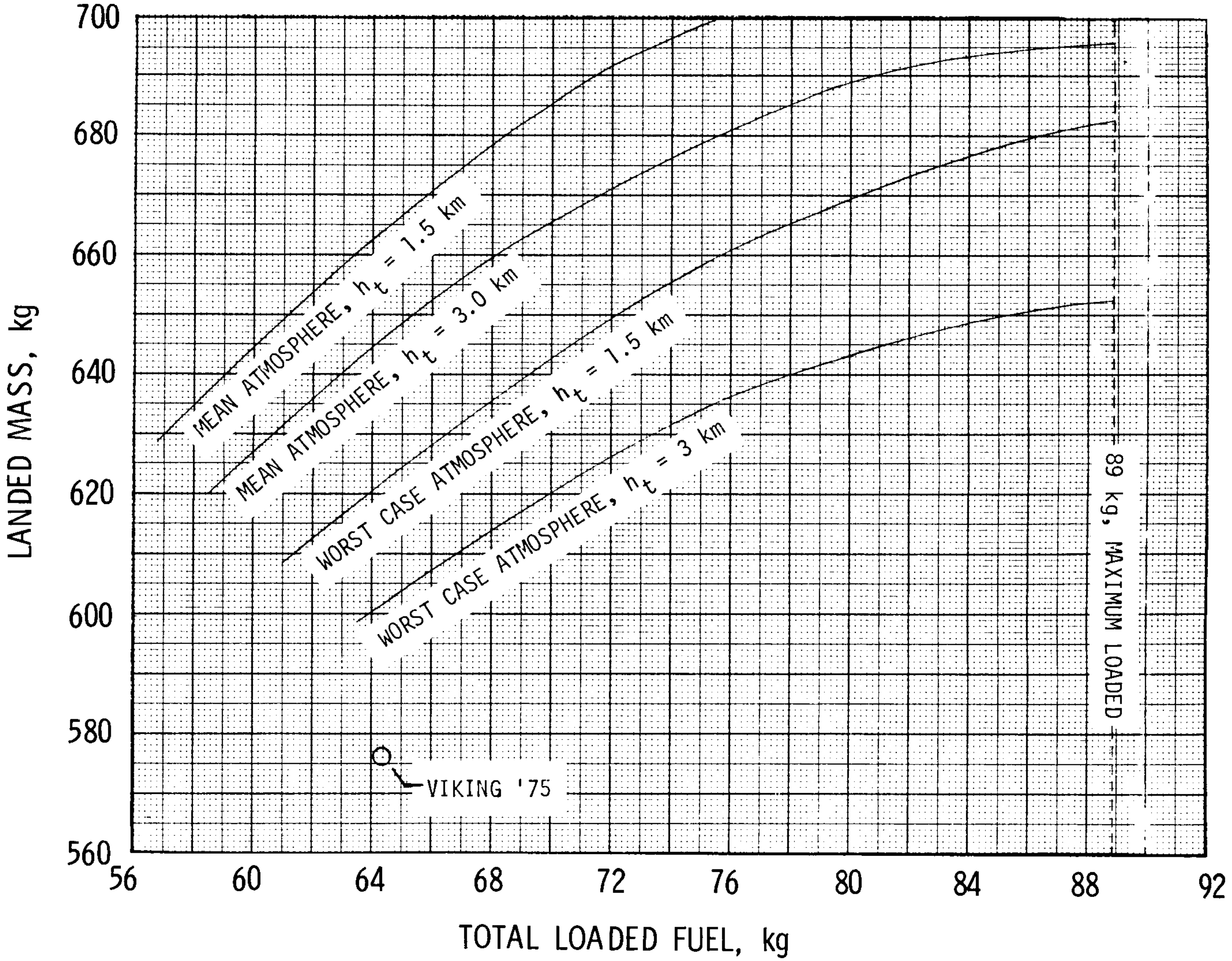


Figure 3.- Variation of landed mass with total fuel loaded for worst case and mean atmospheres and for 1.5-km and 3.0-km terrain heights. The symbol h_t denotes terrain height.

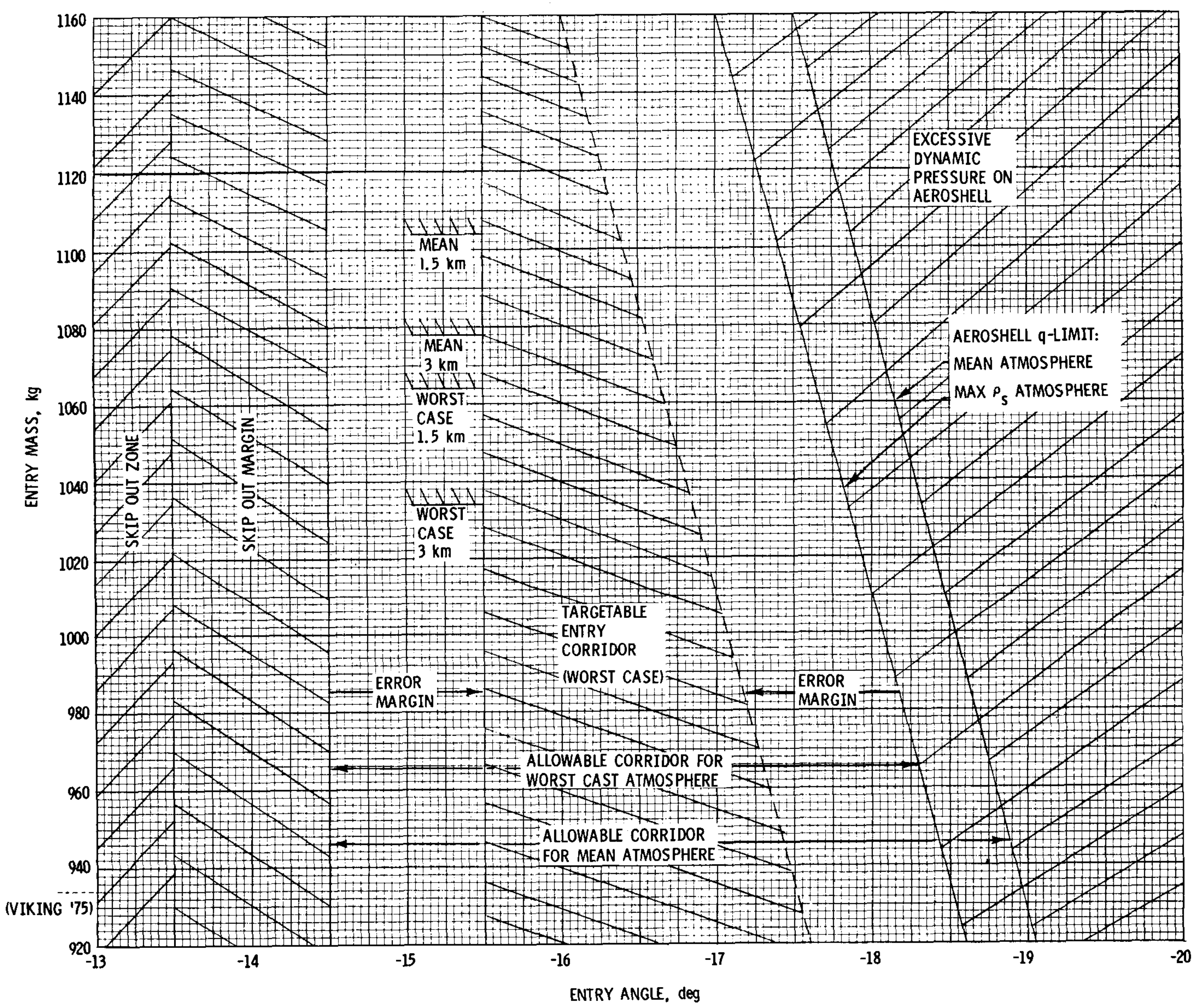


Figure 4.- Effect of dynamic pressure constraint on entry angle corridor. L/D = 0.16.

become distorted as shallower entry angles approach the skip-out limit (approximately -13.5° for the range of entry weights considered herein), a shallow angle limit of -14.5° has been used for Viking 1975 analyses and is repeated herein. The targetable corridor must also account for uncertainties of $\pm 1^{\circ}$ in lander entry angle control. The hatched area of figure 4 shows the resultant targetable corridor for the worst atmosphere and the design q_{max} of 6900 N/m^2. Within the "mean" atmosphere the targetable corridor can be extended about 0.4° on the steep side.

Certain potential orbit control errors must be correctable through control of entry angle. The sum of these requirements for entry angle variation for the 1975 lander is approximately 1.4° and must be matched by 1.4° of targetable entry corridor. If the 1975 mission is successful, reductions in some of the orbit errors can be realistically anticipated so that targetable entry corridors as small as 0.5° might be feasible for follow-on missions. This condition would provide an entry mass capability greater than the limit set by terrain-height considerations, which are also plotted in figure 4 for comparison.

Deorbit maneuver considerations.- The capability of the Viking lander to perform an appropriate deorbit maneuver after separation from the orbiter was also examined. For the ranges of synchronous orbits and entry angles treated herein, and with a deorbit initiation to entry time T_{IE} of 5 hours, the maximum entry mass capability with the available deorbit propellant (80 kg) is more than 1100 kg. This value exceeds both the terrain-height and entry-corridor constraints on entry mass (fig. 4).

In summary, it appears that terrain height is a stronger constraint on entry and landed mass growth than either q_{max}, entry corridor width, or deorbit capability. The potential lander mass growth which now appears to be feasible for a 1979 or 1981 Viking mission is summarized. Table I presents a mass breakdown for the increased landed mass for the cases of greatest interest and provides a comparison with the Viking 1975 mission.

1979 or 1981 Orbiter Mass Changes

The launch windows for 1979 and 1981 opportunities were decreased to 30 days instead of the 48 for Viking 1975 since improved launch capabilities are anticipated. In this study, only one launch was considered. The launch and encounter windows, as well as the velocity budgets used in this study for 1979 and 1981 orbiters, are shown in table II. Those values which apply for the Viking 1975 mission are given for comparison.

Because the ΔV requirements for the 1979 and 1981 orbiter's MOI differ significantly from that of 1975, it is necessary to adjust the propellant loading carried on the orbiter. For the 1979 orbiter, a decreased propellant loading can be expected; however, the 1981 mission MOI requirements make necessary an increase in the propellant load of

TABLE I.- LANDER MASS PROFILES

Item	Lander mass profiles, kg, for –			
	1975 Viking allocated worst case, $h_t \approx 3$ km	1979 or 1981 maximum landed mass cases		
		Worst case, $h_t \approx 1.5$ km	Mean, $h_t \approx 3$ km	Worst case, $h_t \approx 3$ km
Lander capsule loaded	1118	1248	1262	1218
Bioshield	111	111	111	111
Lander separated	1007	1137	1151	1107
Usable deorbit propellant	80	80	80	80
Lander at entry	*927	1057	1071	1027
Aeroshell dry	168	168	168	168
Aeroshell pressurant	3	3	3	3
Aeroshell ACS propellant	5	5	5	5
Lander on parachute	751	881	895	851
Aerodecelerator dry	116	116	116	116
Lander at terminal descent	635	765	778	735
Usable terminal descent propellant	59	83	83	83
Landed total	576	682	696	652
Terminal descent pressurant	6	6	6	6
Terminal descent residual propellant	5	6	6	6
Landed dry	565	670	684	640

*The value of 934 kg has been arbitrarily chosen by the Viking Project Office for purposes of entry analyses and has been used accordingly herein instead of the table value of 927 kg.

TABLE II.- LAUNCH WINDOWS AND VELOCITY BUDGET

	1975	1979	1981
First launch day	8/12/75	10/14/79	11/08/81
Last launch day	9/30/75	11/12/79	12/08/81
Earliest encounter	6/20/76	8/27/80	9/04/82
Latest encounter	9/22/76	9/22/80	10/04/82
ΔV for orbital insertion, m/sec	1200	1053	1313
Midcourse ΔV, m/sec	25	25	25
Gravity loss ΔV, m/sec	100	100	100
Navigation error allowance ΔV, m/sec	175	175	175
Total ΔV, m/sec	1500	1353	1613

approximately 20 percent above that for 1975. In addition, the propellant tanks of the orbiter must be enlarged to accommodate the additional propellant. This change is considered to be a feasible one and does not require major redesign of the orbiter; however, it strongly recommends use of the 1979 mission opportunity rather than that of 1981.

The orbit insertion propellant requirements were computed on the basis of a final inserted orbiting mass at Mars which included the lander with 107 kg of mass growth. This was the case for the worst case atmosphere and with 1.5-km terrain-height capability. Table III shows the spacecraft mass breakdown for the mission opportunities of 1979 and 1981, and compares them with that of the 1975 Viking mission. It should be noted that ample launch-vehicle capability is available in both 1979 and 1981, 1979 being much preferred from the energy standpoint.

ROVER STOWAGE AND DEPLOYMENT

The feasibility of stowing a small rover within the Viking lander capsule (VLC) and being able to deploy it readily is critical to the acceptability of a Viking rover mission. It was logical, therefore, that this subject be given second priority after verifying that an attractive rover mass could be flown to Mars and landed.

It was considered particularly desirable to locate the rover in such a way as to avoid having to modify the VLC afterbody or change the Viking 1975 lander configuration drastically. The stowage and deployment part of the rover study was, therefore, initiated by assessment of the external systems arrangement of the 1975 VLC. Systems which would be candidates for deletion, modification, or addition to a 1979 or 1981 Viking lander were then considered.

TABLE III.- NOMINAL SPACECRAFT MASS BUDGET

Item	Mass, kg, for –		
	Mission launch year		
	1975	1979	1981
Orbiter dry	899	899	*936
Lander capsule adapter	14	14	14
Orbiter propellant reserve	18	18	18
Orbiter propellant expended	1405	1307	1666
Orbiter pressurant	5	5	5
Orbiter gas	14	14	14
Orbiter loaded	2355	2257	2653
Orbiter loaded	2355	2257	2653
Lander capsule loaded	1117	1142	1142
Rover, deployment system (worst atmosphere – 1.5-km terrain-height case)	----	107	107
Spacecraft loaded	3472	3506	3902
Mission reserve	42	488	130
Spacecraft loaded, maximum capability of launch vehicle	3514	3994	4032
Spacecraft adapter, launch vehicle mission "peculiars"	165	165	165
Injected payload, maximum capacity of launch vehicle	3679	4159	4197

*Includes enlarged propellant tank.

Examination of the existing Viking 1975 VLC external arrangement (fig. 5) indicated that only an unacceptably small rover could be transported externally without making significant changes or resorting to radical folding of the rover for storage. Internal location appeared to be highly implausible. The area on the underside of the lander was also appraised. Here approximately 41 cm will exist between the lander and the dome of the Aeroshell (A/S) during the trans-Mars phase of the flight, but will be reduced to 22 cm on landing, and possibly pin the rover under the lander. In addition, the rover would be subjected to the surface dust raised by the descent-motor exhaust gases. Thus, it was

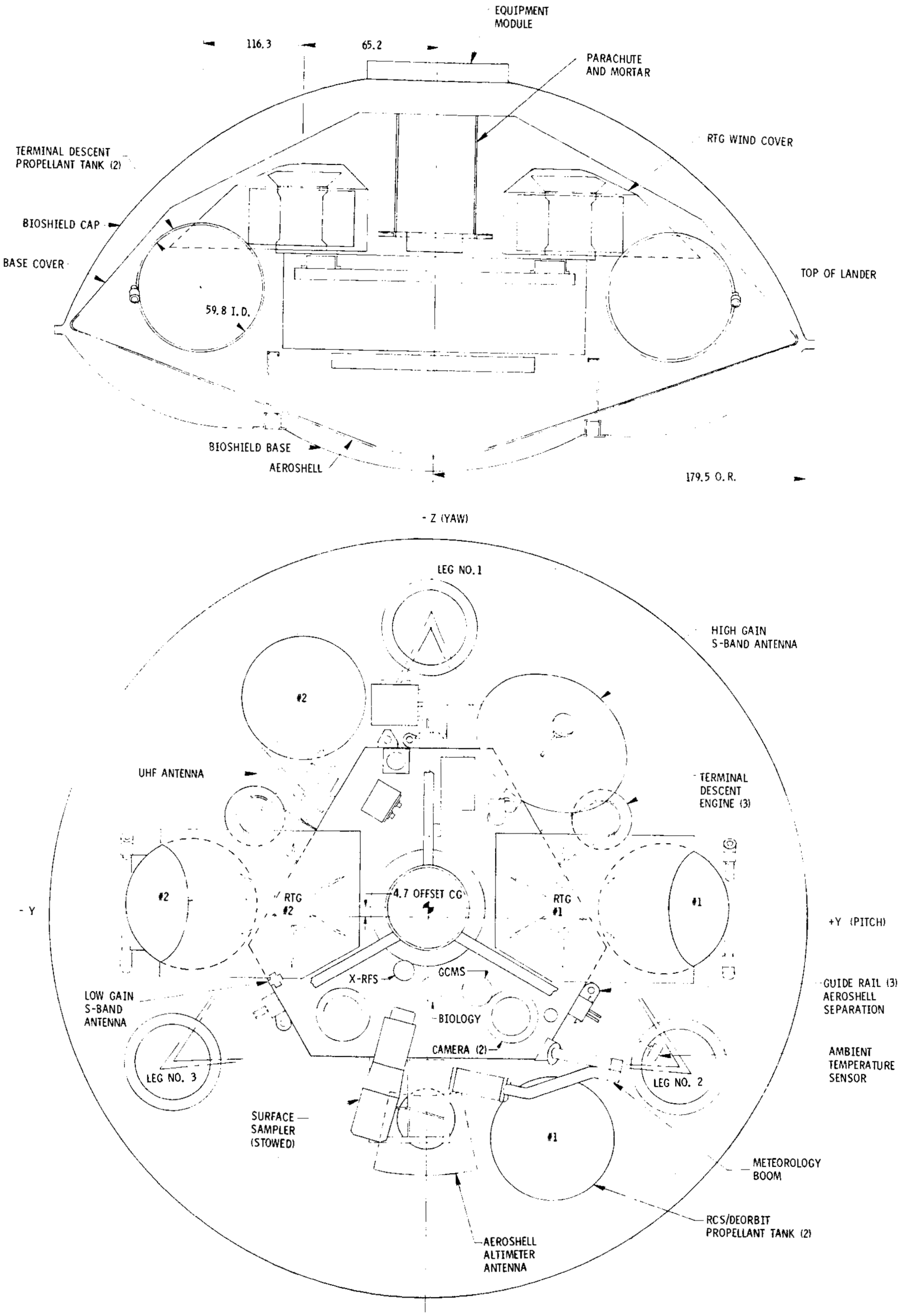


Figure 5.- Viking 1975 lander and capsule external arrangement. All dimensions are in centimeters.

concluded that the rover should be located on the top, side, or suspended over the side of the lander. It is accepted at this point that the center-of-gravity location of the Viking vehicle would be strongly affected by any such arrangement.

External modifications which have been anticipated for the 1979 or 1981 lander in order to accommodate this rover concept include the addition of a special low gain VHF antenna and electronics, and the use of one high power radioisotope thermoelectric generator (RTG) in place of the 2 SNAP-19 (ref. 3) RTG units. A new upgraded RTG is recommended which is compatible with the Viking lander and powerful enough to handle all needs. Such units are in final development at this time. The number 1 RTG on the Viking 1975 lander now located between landing legs 1 and 2 could be deleted entirely. This change would provide an open area on the deck of the lander inboard from the number 1 terminal descent tank. Within this area, an envelope considered suitable for configuring any of the three mass classes of the rover can be located.

The envelope, shown in figure 6 and selected for location of the rover, is bounded by the lander deck and the base cover from bottom to top, by the parachute mortar hub and high gain S-band antenna (folded) to the rear and sides, and by the terminal descent propellant tank in front. These boundaries define a very irregular envelope. Placement of a rover in this envelope was resolved on the following basis:

(1) Rover is equipped with four 25-cm-diameter wheels

(2) Rover underbody clearance is approximately 14 cm

(3) Approximately 1.3-cm elevation of wheels above lander deck allowed for clearance of deployment mechanism

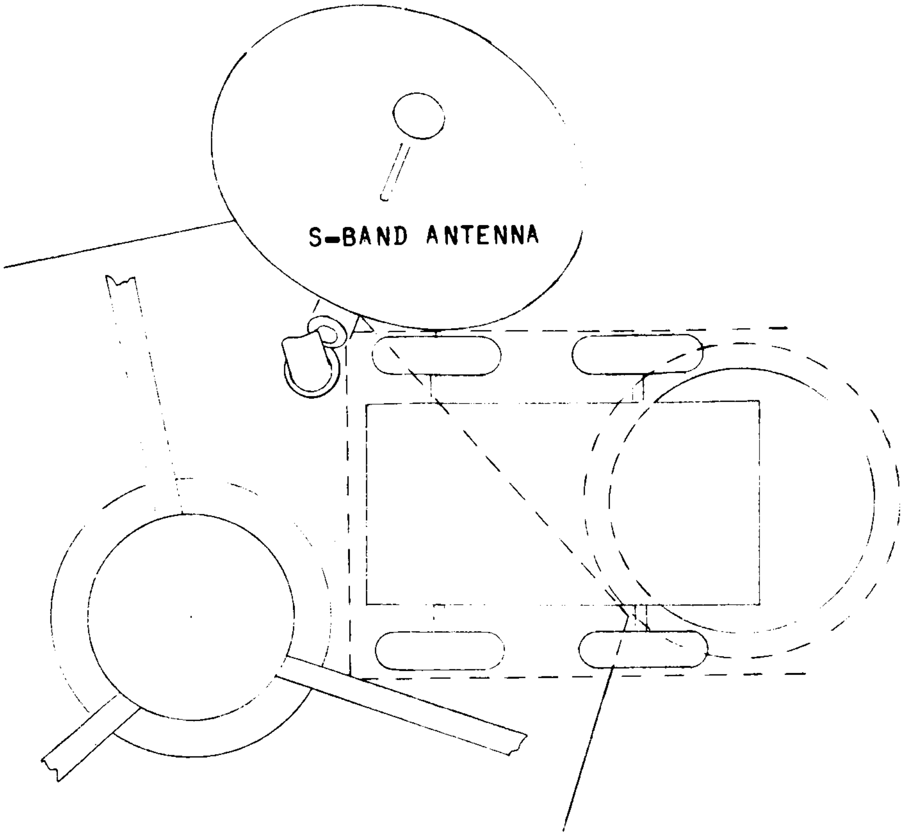
(4) Approximately 2.5-cm minimum clearance around rover body

The maximum usable envelope under these conditions was sized as follows:

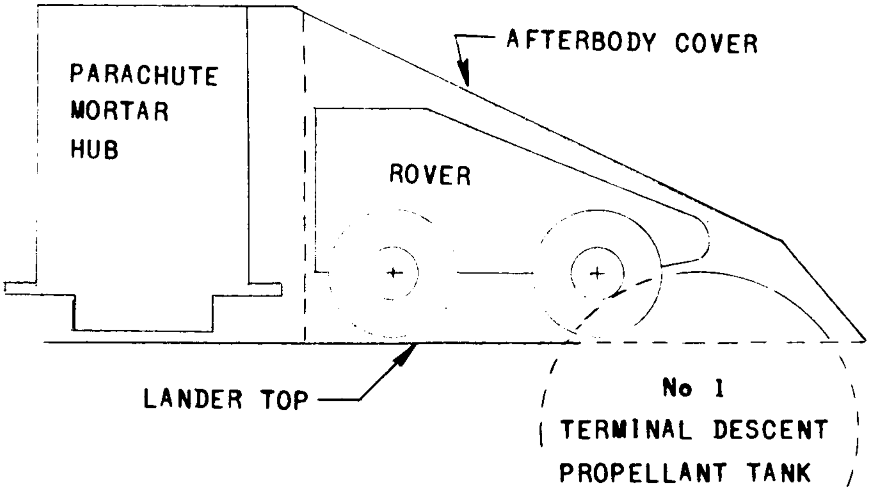
Length	94 cm
Width	71 cm
Height	56 cm

Although a rover body configuration of slightly larger dimensions could have been placed into the envelope, the more practical body configuration shown in figure 6 was adopted. This configuration was based on the restraints of deployment and obstacle clearance and on mass distribution.

Deployment of the rover from this location would require that it be moved up and over the propellant tank before descending to the surface. The Viking 1975 lander deck is nominally 81 cm above the ground plane, but the lander must also be capable of landing



(a) Top view.



(b) Side view.

Figure 6.- Viking 1979 or 1981 rover stowage envelope.

on ±19° slopes. For proof of feasibility, one deployment technique was devised to meet these conditions. It is shown schematically in figure 7.

The deployment maneuver begins with the extension of 2 parallel tracks. This extension is accomplished by using a small cable winch which pulls in an interlaced cable in each track. The rover is then pyrotechnically released from four hard points onto the tracks and the winch continues to draw, now tilting the tracks on their support fulcrum and raising the rover until the outboard track sections encounter the Martian surface, allowing the rover to egress. By scaling the deployment system illustrated, the technique was considered to be feasible for all three rover classes under consideration. The estimated maximum mass of the deployment system for each class was approximately 9, 11, and 12 kg for the class A, B, and C rovers.

ROVER SYNOPTIC DESCRIPTION

Three classes of a rover concept were considered for application to a 1979 or 1981 Viking mission. To distinguish between classes initially, target mass ranges for these classes were set as follows:

Class A	20 to 35 kg
Class B	35 to 60 kg
Class C	60 to 90 kg

Because the size and configuration of all the Viking rover classes were constrained by the stowage envelope available on the lander described previously, a common set of dimensions found in table IV was chosen for the rovers. The front section of the rover body begins with a 5.0-cm-radius nose and then tapers upward at 22° to conform to the slope of the roof of the rover envelope. The common configuration chosen for the rovers is shown in figure 8. All three rovers are four wheeled for simplicity, stability, low mass (ref. 4), and stowability. The arrangement of components in each class of rover is shown in figure 9.

The major systems which were considered in the definition of each of the three rover classes are as follows:

(1) Mobility

(2) Navigation

(3) Hazard detection

(4) Science

(5) Imagery

(6) Communication

(7) Computer

(8) Power

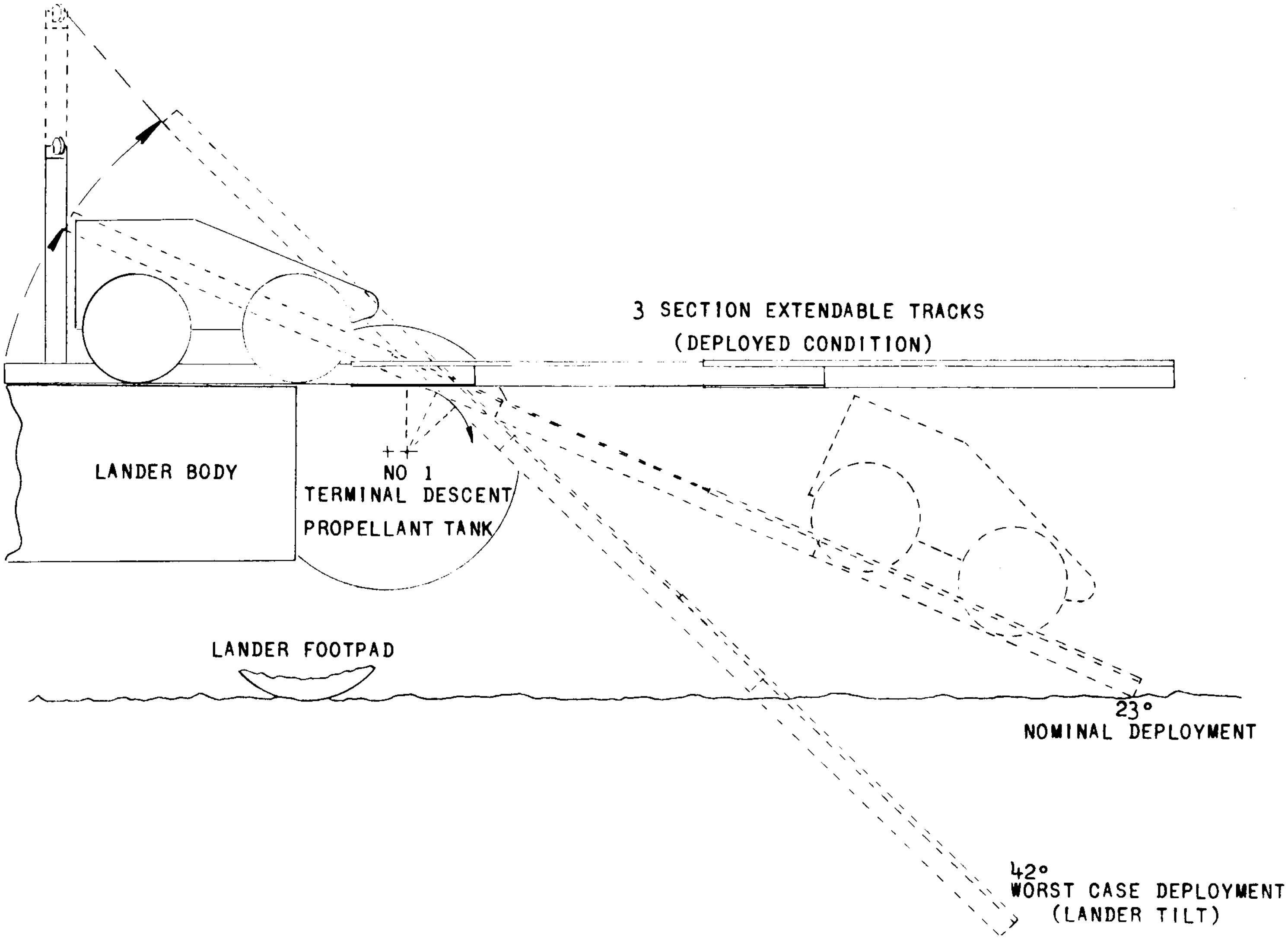


Figure 7.- Rover deployment from Viking lander.

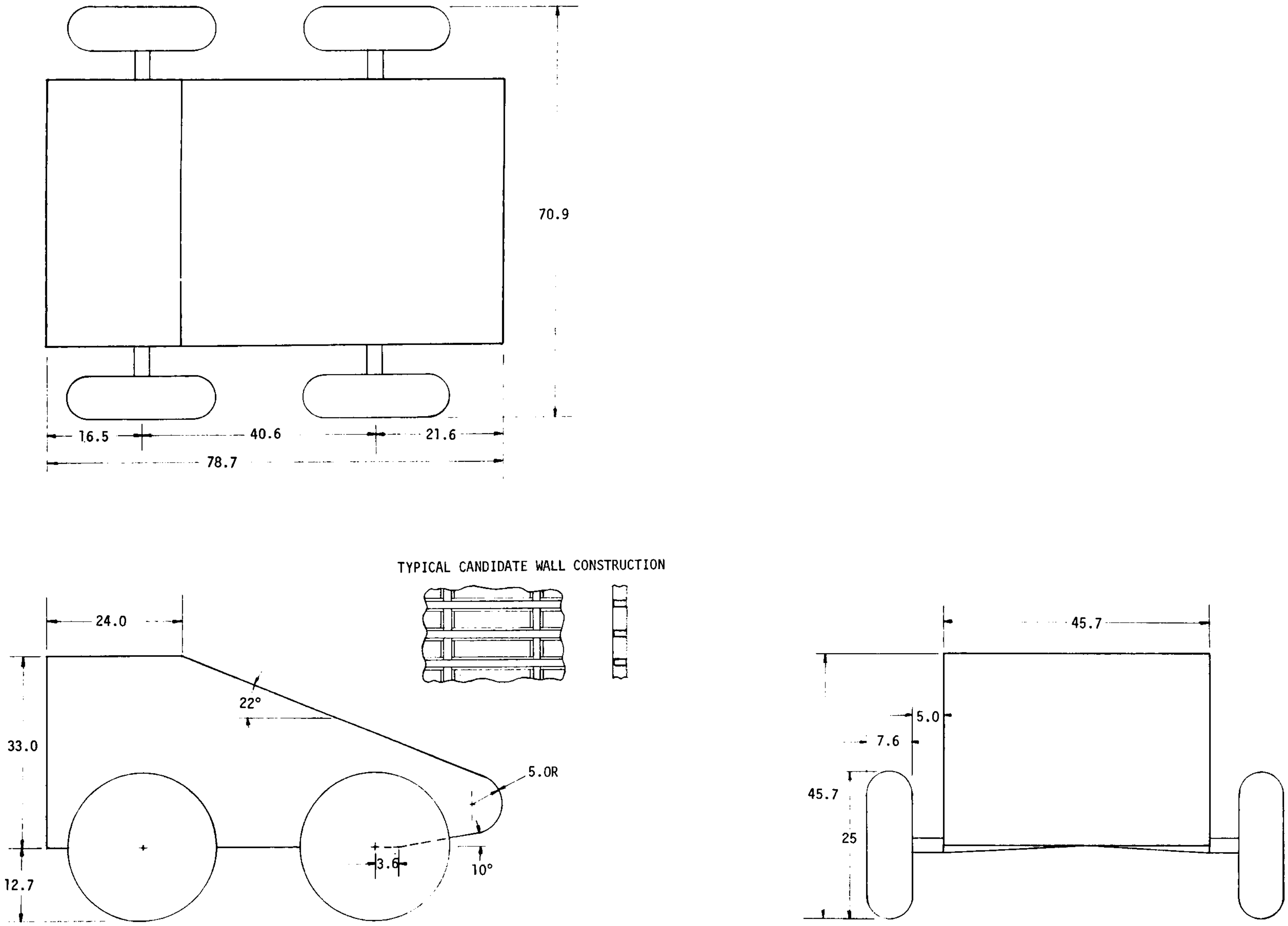
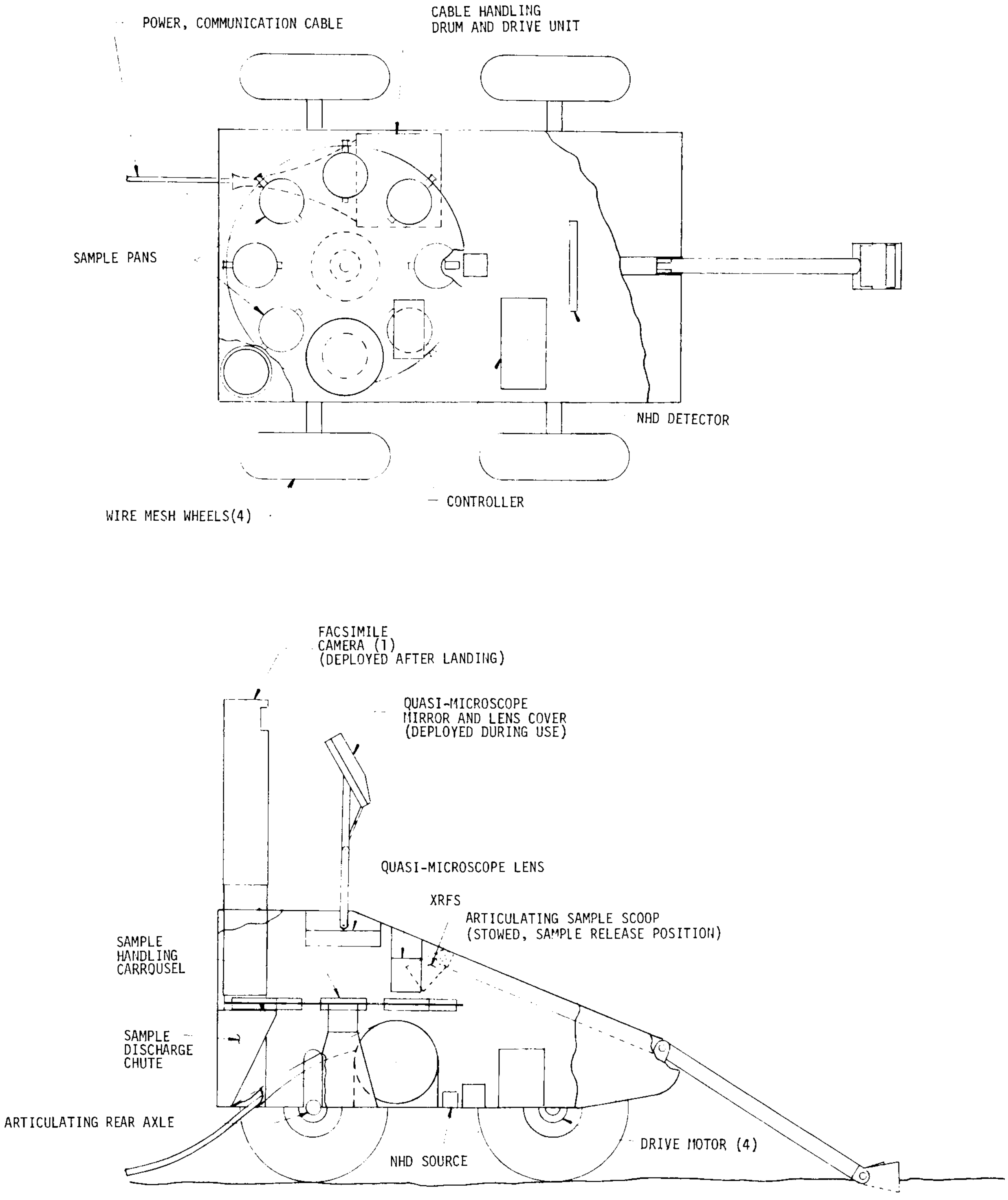
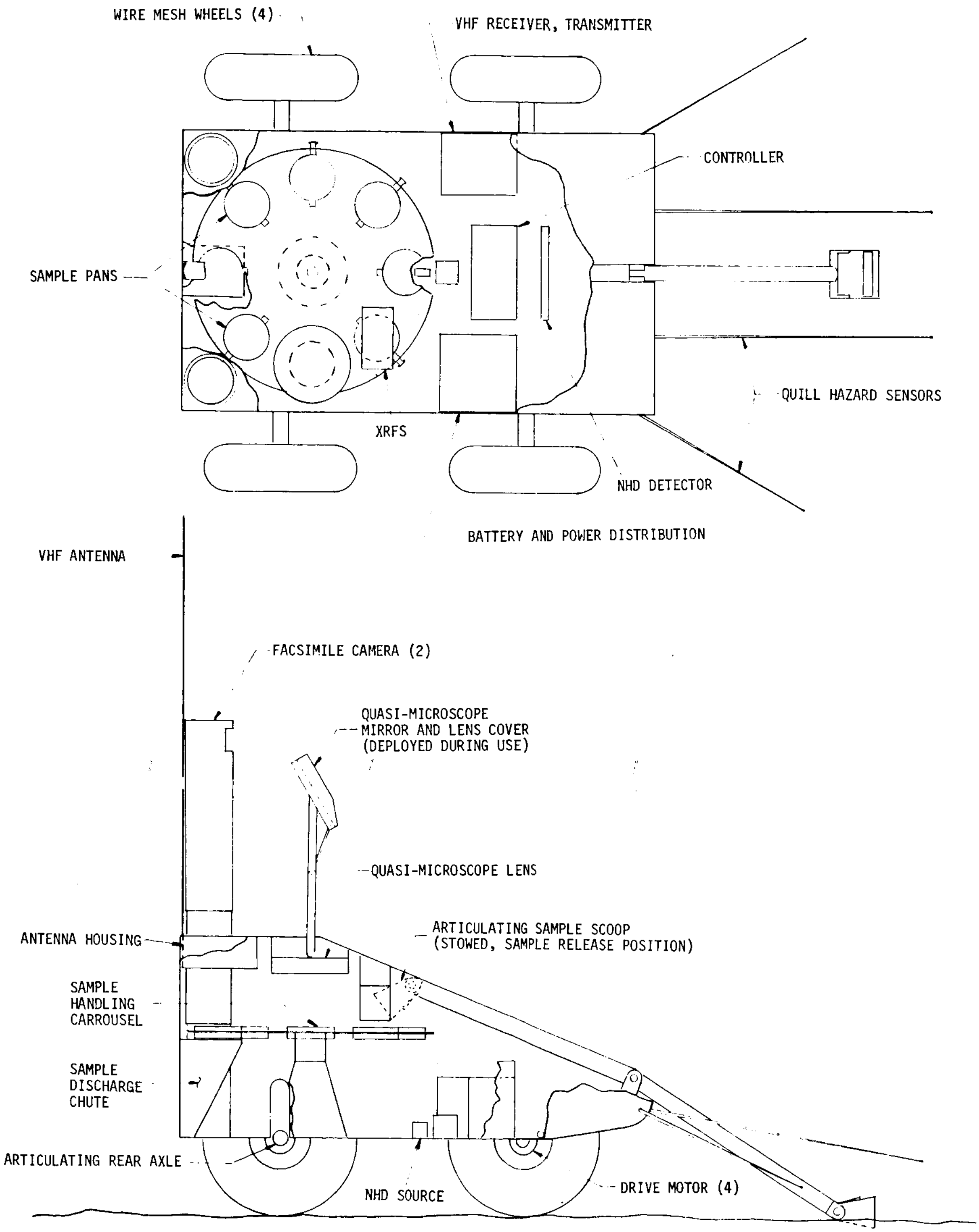


Figure 8.- Rover configuration (all classes). Dimensions are in centimeters.



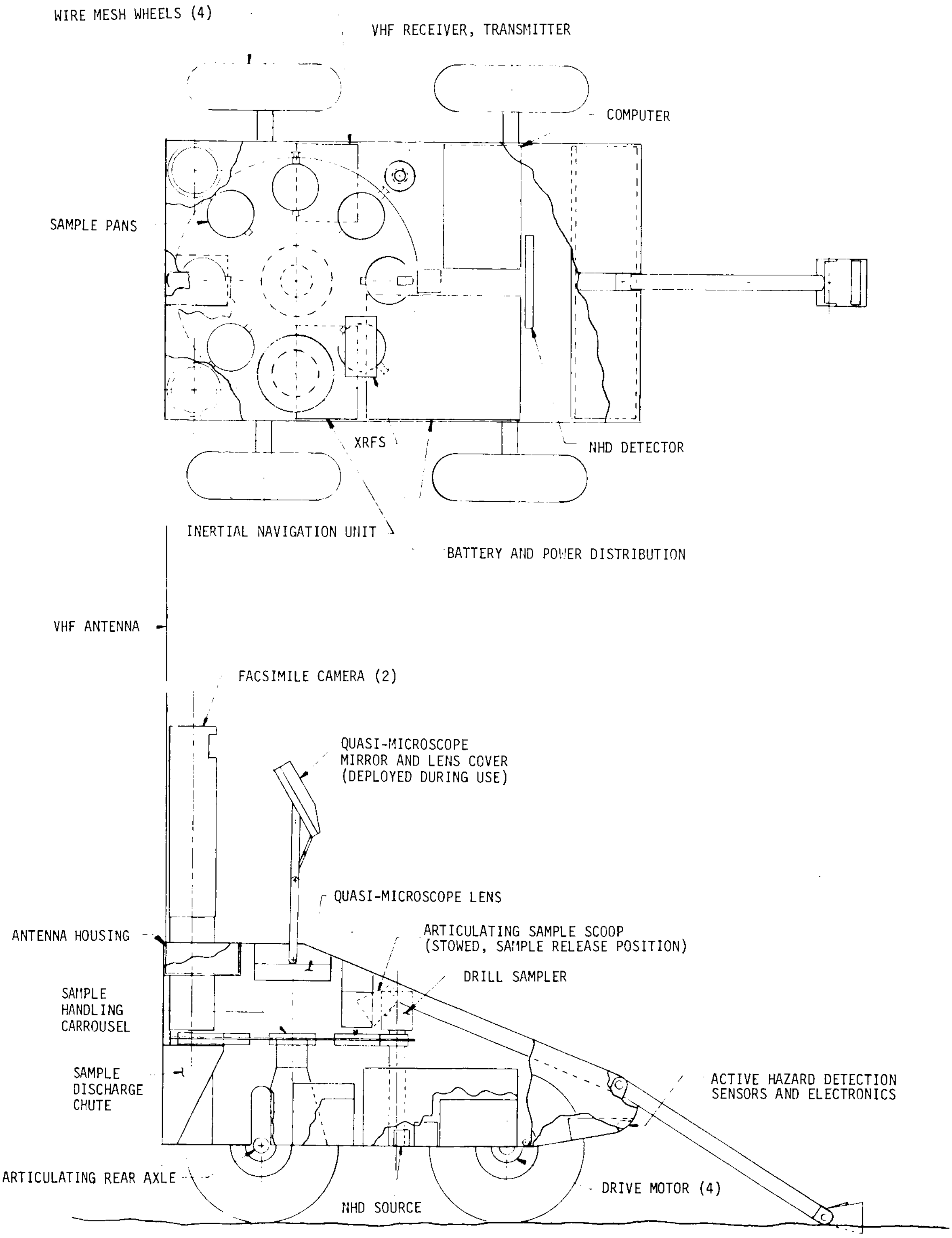
(a) Class A rover.

Figure 9.- Viking 1979 or 1981 rover component arrangement.



(b) Class B rover.

Figure 9.- Continued.



(c) Class C rover.

Figure 9.- Concluded.

TABLE IV.- ROVER DIMENSIONS FOR ALL CLASSES

Envelope:	
Length	78.7 cm
Width	70.9 cm
Height	45.7 cm
Wheels:	
Number	4
Diameter	25.0 cm
Width	7.6 cm
Body:	
Length	78.7 cm
Width	45.7 cm
Height	33.0 cm
Wheelbase	40.6 cm
Ground clearance	12.7 cm

The general makeup of these systems is summarized in table V. Specific details on each system are presented in later sections. System masses are presented in table VI.

For mobility, each rover class utilizes four wire mesh wheels, each driven by a planetary gear motor. An articulating rear axle and scuff steering are proposed for all rovers. The class A, B, and C rovers are intended to provide radial ranges of approximately 50, 200, and 1000 meters, respectively, about the lander.

Navigation of the class A rover will come from the lander guidance control and sequencing computer (GCSC) through an umbilical line. Distance traversed will be determined by its system of odometers and corrected by lander and rover imagery data where possible. The class B rover will utilize the lander and rover imagery data along with an Earth-based terrain map in a landmark navigation scheme. The class C rover will house a gyrocompass/odometer inertial navigation system using the landmark scheme to provide periodic updates to the inertial system.

Obstacle detection capability on the rovers will vary with their intended range. The class A rover will have only inclinometers to determine rover pitch and roll. The class B and class C rovers will also utilize a system of two inclinometers to monitor the rover pitch and roll attitude, but detection of obstacles in the path of the class B rover will be provided by a system of tactile sensors, whereas class C rover hazard detection will be provided by an active, short-range system using X-ray radiators. For all classes the

TABLE V.- MAJOR ROVER SYSTEMS

System	System for rover class		
	A	B	C
Mobility	Wire mesh wheels (4) Articulating rear axle Planetary gear motors (4) Scuff steering	Wire mesh wheels (4) Articulating rear axle Planetary gear motors (4) Scuff steering	Wire mesh wheels (4) Articulating rear axle Planetary gear motors (4) Scuff steering
Navigation	Landmark Odometer	Landmark Odometer	Landmark Odometer Gyrocompass
Hazard detection	Imagery data	Imagery data Tactile sensor	Imagery data X-ray (obstacle) sensor
Science	X-ray fluorescense Neutron hydrogen detector Magnet array Articulating sampler Imagery	X-ray fluorescense Neutron hydrogen detector Magnet array Articulating sampler Imagery	X-ray fluorescense Neutron hydrogen detector Magnet array Articulating sampler Drill sampler Seismic packet Imagery
Imagery system	Facsimile camera (1) Quasi-microscope	Facsimile cameras (2) Quasi-microscope	Facsimile cameras (2) Quasi-microscope
Communication	Umbilical	VHF	VHF
Computer	Controller	High-order controller	Computer and controller
Power	Umbilical	AgZn batteries	AgZn batteries

TABLE VI.- ROVER SYSTEM MASSES

[Nearest whole number average used]

Rover systems	Masses, kg, for rover class –		
	A	B	C
Mobility	4	4	4
Chassis structure	14	15	18
Umbilical	2	0	0
Power	1	3	9
Navigation	1	1	10
Hazard detection	0	1	2
Computer	1	2	3
Imagery system	1	2	2
Communication	0	1	1
Science	8	8	14
Thermal control	1	1	2
Actuators	1	1	1
Electronics	1	1	3
Total rover	35	40	69
Deployment system	9	11	12
Total on lander	44	51	81

imagery system will be used to depict obstacles for the Earth-based personnel to evaluate and map.

A tentative science system for the class A and B rovers consists of an X-ray fluorescence spectrometer, neutron hydrogen detector, magnet array, multiple surface sample storage device, and an articulating scoop sampler. The class C rover uses a drill sampler in addition to an articulating scoop sampler for surface sample acquisition. Since the class C rover traverses up to 1000 meters from the lander, several explosive packets for an explosion-seismometry experiment are included in the class C science package. The imagery system aids the science systems in surface sample viewing on all rovers.

The imagery system for class B and C rovers consists of two low-mass horizontal stereo facsimile cameras (ref. 5) and a quasi-microscope. Rover imagery data are used by the navigation system of the class B and C rovers and aid the science systems in surface sample examination. Imagery for the class A rover will consist of one facsimile camera and a quasi-microscope.

The class A rover communicates with the lander through an umbilical cable. The class B and C rovers communicate through a two-way line-of-sight VHF communication system. Low-gain VHF system hardware must be added to both the lander and rover. Because of the large power and equipment requirement, Earth to rover communication is accomplished only through the lander.

The class A and class B rovers will rely on the lander guidance control and sequencing computer (GCSC) to provide their required computer capability. They will require an onboard controller to decode and route commands to and from the lander. The class C rover will have an onboard computer to monitor and control its power output and cell discharge as well as control mobility, navigation, and hazard-detection functions. Other class C rover functions will be controlled by the GCSC.

Power for the class A rover will be provided directly from the lander through the umbilical cable. A cable and cable management system will be housed onboard the class A rover. The class B and class C rovers are battery powered. Silver zinc (AgZn) batteries are currently considered to be most feasible from a mass and reliability standard. The batteries are recharged at the lander during the night cycle.

MISSION SCIENCE

The mission science goals and the instrumentation which would meet these goals on advanced Viking missions have been surveyed in several past studies for the Viking Project Office. These included mission studies for 1977, 1979, and 1979 or 1981 launch opportunities. The Viking 1975 mission science has been taken as a baseline from which changes can be made to reflect anticipated variations in a 1979 or 1981 mission. The results from Mariner 9 have also been considered where appropriate.

A 1979 or 1981 Viking type mission can be expected to concentrate on the areas of geoscience and bioscience with decreased emphasis on entry measurements. The primary emphasis will be geoscience if Viking 1975 is successful and if life indicators are not found. Geoscience investigation will require the gathering of samples over wide areas, if possible, selectivity of samples being highly desirable. In situ imaging and analysis, even if cursory, would appear to be invaluable. These scientific goals can be met through an optimum combining of lander and rover capabilities.

Most of the scientific investigations for the advanced Viking mission proposed herein will be performed on the surface by the lander science payload augmented by a small rover. A rover capable of making sorties of 1000-meter radius about the landing site increases the sampling area by orders of magnitude over that of the Viking 1975 mission. In addition to increasing the sampling area, the rover will also perform other valuable in situ experimentation. The 1979 or 1981 Viking lander and rover science systems will take advantage of various scientific instrument improvements which have occurred since the Viking 1975 science system was developed.

1979 or 1981 Lander Science System

For the purposes of designing a rover, a model lander science system is presented. The lander science system can be divided into four subsystems: atmospheric science, geoscience, bioscience, and imagery. The subsystems consist of Viking 1975 instrumentation and new science instruments suggested in the mission studies mentioned previously. The model Viking lander science package is presented in table VII.

TABLE VII.- VIKING 1979 OR 1981 LANDER SCIENCE MODEL

	Mass, kg	Power, watts
Atmospheric science:		
Ambient temperature and pressure measurement	1.0	4.0
Meteorology	5.0	5.0
Geoscience:		
Alpha backscatter spectrometer	5.0	3.0
(night survival requirement)		(0.5)
X-ray spectrometer	1.0	1.0
X-ray diffractometer	4.0	4.0
Seismometer (two 6-component seismometers or 1 broad band 3-component seismometer)	5.0	<10.0
Magnetic properties	1.0	1.0
Physical properties	1.0	1.0
Bioscience:		
Wet organic chemistry	7.0	10.0
Observation of metabolically evolved gas	7.0	25.0
Imagery:		
Two facsimile cameras	5.0	28.0
Quasi-microscope	1.0	2.0
Total	43.0	(*)

*Total power requirement varies with frequency and duration of use of each instrument.

The atmospheric science for the advanced Viking lander consists of instruments to measure the ambient environment at the surface of Mars. The Viking 1975 ambient temperature and pressure measurement and meteorology investigation will adequately supply this information for the Viking 1979 or 1981 mission.

The advanced Viking mission will attempt to place major emphasis on the geoscience investigation. Four instruments plus magnets will be used to measure geochemical and geophysical properties of Mars.

The alpha backscatter spectrometer (ABS), used during the Surveyor mission to analyze elements making up 99 percent of the lunar surface material, is the only instrument considered feasible for making an elemental chemical analysis of elements between hydrogen (atomic number 1) and titanium (atomic number 22). An X-ray fluorescence spectrometer (XRFS), part of the Viking 1975 lander science system, will be used to detect all elements above atomic number 6. Information concerning the mineralogy of the Martian surface can be provided by an X-ray diffractometer (XRD). The XRD identifies the solid phases present in the surface sample and determines abundance, composition, and degree of ordering of each phase. In addition to the upper crust composition of the surface, volcanic rocks and fragments of meteorites can be detected by the XRD.

The seismic experiment proposed for the 1979 or 1981 Viking mission will use one three-component or two six-component seismometers. Two of the six-component seismometers would be used in conjunction with the class C rover. The seismometers will be taken from the lander and deployed in a manner allowing maximum separation. By using simultaneous operation of seismometers, seismic events are more accurately located and ambiguities of interpretation of seismic data could be reduced. If the smaller rover classes are selected, the lander would use the broad-band, three-component seismometer. This seismometer would be located on the lander leg as on Viking 1975 or on the bottom of the lander body and deployed after touchdown. The magnetic and physical property investigations for Viking 1979 or 1981 are similar to those of Viking 1975.

Regardless of the results of the Viking 1975 biology investigations, additional bioscience analyses are required. Of the two organic chemistry investigations currently competing, gaseous and wet, wet chemistry seems to be the better choice. The wet chemistry system has been developed and tested, but the electronics have not been miniaturized.

A second biological investigation recommended in the previous mission studies is the measurement of metabolically evolved gas from Martian soil samples, used to detect or observe biological growth, reproduction, or metabolism. A breadboard model of the instrument has been constructed and used for testing earth soil samples.

The imagery system proposed for the Viking 1979 or 1981 lander will use two facsimile cameras operating in horizontal stereo as on Viking 1975. The cameras are to have an ultraviolet imaging capability in addition to black and white, color, and infrared imagery. The imagery system will be augmented during sample examination by use of a quasi-microscope.

Rover Science System

The purpose of the rover is to acquire surface samples, perform elemental analyses, and return interesting samples to the lander for further analysis. The rover will require low mass instrumentation and will have low power and communication requirements. A list of the various science instruments selected for the three rover classes with their masses, power requirements, and sizes is provided in table VIII.

TABLE VIII.- ROVER SCIENCE SYSTEM FOR ALL CLASSES

Instrument	Mass, kg	Power, watts	Volume, cc
X-ray spectrometer	0.5	1 at 30 V dc (4 hrs)	295
Neutron hydrogen detector	0.4	2	508
Quasi-microscope	0.9	2	410
Magnet array	0.04	0	16
Sample handling	3.6 to 4.5	2	328
Articulated scoop	1.8	15 (peak)	787
Drill*	2.3	<15	82
Seismic explosive packs (2)*	4.5	----------	---

*Class C rover only.

The X-ray fluorescence spectrometer (ref. 6), discussed previously as part of the Viking 1975 science package, will be proven before a Viking 1979 or 1981 rover-augmented mission. The X-ray fluorescence spectrometer does not allow for detection of hydrogen and provides no information on sample water content, but can provide a cursory in situ elemental analysis of rover samples.

The neutron hydrogen detector will analyze surface materials for total hydrogen content. The neutron source and detector are located at openings under the rover body. (See fig. 9.) Development of the neutron hydrogen detector has reached the breadboard and testing stage. (See ref. 7.) The presence of water in a surface sample provides an excellent test for whether samples should be taken to the lander for further biological investigation.

Sample investigation at the rover will be further enhanced by the use of a quasi-microscope. A ×60 quasi-microscope is currently being developed at Langley Research Center. (See ref. 8.) The quasi-microscope requires only actuator power and operates with one facsimile camera. It consists basically of adding a magnifier lens and mirror into the light path between the sample and camera. The microscope will be available for a 1979 or 1981 flight. It can provide information concerning the geological and biological history of Mars.

The seismic experiment for the 1979 or 1981 Viking mission would be enhanced with the selection of the large class C rover. This rover would carry and deploy two six-component seismometers from the lander. The class C rover would also carry explosive packets to various locations and emplace them for radio detonation by the lander at a specified time. Seismic activity resulting from the explosion is monitored by the seismometer system. If the small or intermediate rover, class A or class B, is chosen, the lander seismic experiment will not be aided by the rover.

Surface sampling for all rover classes will be performed with an articulating scoop on a stiff arm which can be lowered to the surface. This design has particular utility for collection of particulate material.

A low-mass drill sampler will be used to provide subsurface sampling on the class C rover. The drill will be situated inside the rover body and deployed to the surface for sample acquisition. The drilled sample is dumped from the drill tube into the sample handling system receiving pan. The drill sampler is expected to provide sufficiently small fragments to perform analyses without additional grinding or sorting and provides a quick, low-power technique for subsurface sampling. The drill sampler is located under the rover to provide sufficient mass for the initial penetration and to keep the drill from "walking" if a particularly hard surface is encountered.

ROVER SURFACE OPERATIONS

The rover will actively explore the area surrounding the lander vehicle. It will be responsible for bringing samples of interest to the lander for detailed analysis and for performing its own cursory in situ analysis on many samples at assigned points of investigation over a period of 3 to 6 months. The surface operational techniques anticipated for a 1979 or 1981 Viking rover will be described in this section and the rover's exploratory capabilities, detailed in various other sections, will be summarized.

Surface Operating Modes

The surface operation of the rover will be restricted to one of four operational modes. These modes are sleep, mobility, science, and emergency. During the sleep mode, all but maintenance systems are shut down and these systems will require a wakeup, warmup period each morning when the mobility mode is initiated. The mobility mode provides for mobility systems and cameras to operate. In the science mode, all rover systems except the emergency system may be operational. The selection and operation of any particular system or instrument is through the rover sequencer and the lander GCSC (and class C rover computer). During the emergency mode, the rover will be constrained to operate through special circuits. In this condition, the rover will attempt to determine its failure or problem. The problem is identified and reported to Earth-based personnel for help. After a corrective action relieves the problem, the previous mode is reestablished.

Sorties

Each of the three rovers has been designed to provide a different degree of surface exploration capability, including the length of traverse or sortie which they would nominally perform each Martian day. As the mission progresses, the sorties will be lengthened to their maximums. Each morning after wakeup and warmup of the systems, the rover will receive instruction from the lander GCSC which has been updated by commands from Earth-based personnel. The rover will disconnect from its electrical interface with the lander (in the case of class B and C rovers) and proceed on a reference circle (approximately 5-meter radius) about the lander to the assigned starting position. After assuming the proper direction, it will calibrate its odometers (or inertial system) with the lander computer. The sortie is then initiated and monitored at 50-m or 100-m intervals by the computer. At some of these points, imaging takes place. When the rover reaches the maximum point of the sortie where imaging, sampling, and analysis take place, the rover requests an update of its position. This information is available from Earth by the completion of the sampling and sample analysis. The class A rover would then reposition itself for the return trip which is along the original path. The class B and class C rovers may return by an alternate path, if desired. A sketch of a typical sortie for the class B rover is shown in figure 10. The class A rover, restricted by its umbilical cable will operate to radial distances of 50 meters. Its cable-handling system manages the cable payout during travel outward from the lander and the cable reel-in when the rover returns by backing up. In an emergency situation the cable handling system can winch the rover back to the lander. It is assumed that serious hazards can be seen by the cameras of the lander and that sortie paths can be assigned which would avoid nonnegotiable obstacles. Therefore, minimal hazard avoidance has been planned for the class A rover. It navigates under power provided through the umbilical line from the lander and under the direct guidance from the lander's computer section dedicated wholly or partially to rover control and guidance.

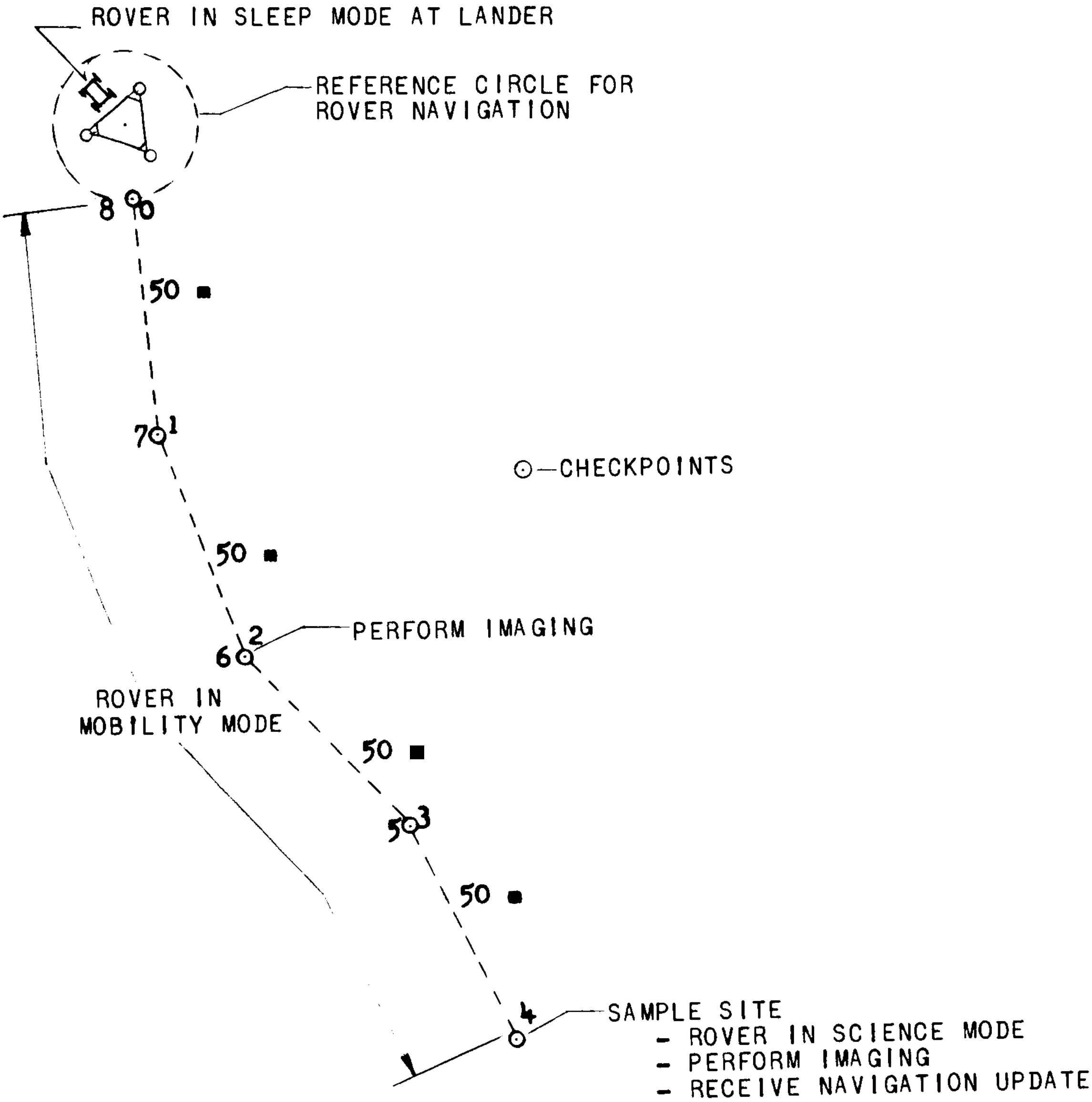


Figure 10.- Typical class B rover sortie maneuver.

The class B rover has the capability for greater mobility and is designed with more hazard-detecting capability. It does not have greater sample analyzing capability, but has the potential to reach more samples of interest. It is independent from the lander for the period of one sortie, which is one Martian day, before it must return for a battery recharge. During this period, it can travel a distance as great as $2\frac{1}{2}$ times its radial distance limitation of 200 meters. A passive obstacle detection system stops the vehicle if it encounters a nonnegotiable obstacle. An imagery mode is initiated and a subsequent command from the Earth-based personnel redirects the rover onto an avoidance path.

The class C rover is also independent of the lander during the Martian day. It is capable of greater ranging and sampling than the class A or class B designs. A radial distance of 1000 meters or total travel of 2500 meters within that radius is allowed. This rover checks its position against the assigned traverse points for correction with the use of its own computer in addition to that on the lander which is the master control. It detects obstacles by use of a short-range active obstacle detection system, although it has only a limited avoidance capability and may ultimately require direction from Earth through imaging of the problem. For the cases where the class C rover is assigned a sortie of maximum capability (2500 m), a sunlight period of 9 hours is required. Thus maximum distance sorties must be reserved for sunlight and communication periods of greater than average whereas shorter sorties could be done during shorter periods of sunlight.

Sampling

Surface sampling is the most vital function of the rover. Therefore, special attention has been given to sampling techniques for the rovers. Each will use the same methods except that the class C design will also permit the taking of drilled samples. Surface materials will be gathered by a stiff-armed, articulated scoop which can be lowered to the surface in front of the vehicle. Initially, the lowered scoop is pointed downward so that on reaching the surface it forms a backhoe. When the vehicle is backed up, a ditching capability exists to reveal fresh surface material at the bottom. The scoop is then rotated forward and the forward motion of the vehicle fills the scoop. The scoop then rotates to an upward position and sample materials which exceed the desired maximum sample volume overflow through the preset window. The sample is brought into the rover sample handling system (see fig. 9) by swinging the stiff arm back to its stored position and rotating the scoop downward to permit the contents to fall into the sample pan. The scoop and arm remain in this rest position except during sampling.

No provision for sample preparation is provided except that several sieve filters can be used if desirable to condition the sample as it falls into the pans. The basic assumption for surface sampling has been the gathering of loose materials only. Very small rocks will be permissible and desirable for some cases, but chipping of rock to produce fragments is not anticipated in the present design.

A drill will be used on the class C rover design to permit 30-cm-deep samplings of the subsurface materials. The drill is lowered to the surface and the drill shaft is filled as the penetration takes place. Then the drill is raised, the bit reversed, and the sample expelled into a funnel trough which leads to a sample pan.

In Situ Analysis

Limited analysis of the Martian surface will be carried out on site by the rover. The analyses will be used to indicate whether the sample is unique and/or scientifically interesting. The local area may merit further exploration later or special attention at that time. Secondly, the interesting samples will be returned to the lander for additional analyses.

Three analyses can be performed in situ by each rover design. Initially, the surface material will be examined for free or trapped water content. This examination is achieved through neutron irradiation of the surface area under the rover. Penetration of the irradiation is 10 cm or more below the surface. Samples which are brought inside the rover will be analyzed by an X-ray fluorescence spectrometer for detection of elements heavier than sodium which might be present. Further, the sample can be viewed under a quasi-microscope at ×40 to ×60 to determine grain sizes and clastic makeup. The quasi-microscope uses the imagery system of the rover. The imagery capability of the rover should prove valuable in viewing the sampled area and providing multispectral data to correlate with the sample. Magnets on the sampling scoop will be viewed to assess the magnetic properties of the Martian surface material.

Samples will be handled inside the rover by a carousel arrangement of pans. Unwanted samples are rotated to the reject position and dumped. The moisture detection and X-ray fluorescence spectrometer (XRFS) instruments on the rover will have their own capability to process information until final results are obtained. They will then transmit the final results to the lander.

Communication

The data results from each sample analysis must be sent to the computer of the lander for assessment, storage, or transmission. In response, the lander computer must direct the rover to save or dump samples and to stop or to continue sampling.

Also important is the communication of navigational data. This communication will not be continuous, but will take place at selected points along the sorties. The rover position will be indicated by its odometers. This information will be compared with the assigned stop positions; then direction corrections will be made by the rover to rendezvous at the next assigned checkpoint. In the case of the class C rover, however, a gyrocompass-odometer system will be used. Class B and C rovers communicate through a radio-frequency system whereas the class A rover has direct communication through its umbilical cable.

Rover Docking and Sample Transfer

At the conclusion of each sortie, the rover must achieve a rendezvous with the lander reference circle and then move to the docking position for positive connection of the electrical interface and for transfer of its sample load to the lander. The rover is designed to unload its sample through a rear discharge chute. The Viking 1975 lander arm and scoop have been considered as tentative for the transfer mechanism and could provide the electrical interface. When the lander scoop is placed under the rover discharge chute, its samples can be sequentially dumped from the carousel holding pans.

ROVER MOBILITY SYSTEM

The rover mobility system consists of the supporting body structure, axles, wheels, the drive subsystem mechanisms, and electronics. The steering is incorporated in the drive subsystem. The body of the rover is basically a dust shield and thermal cover for equipment inside. The design is a thin gage aluminum sheet with localized top hat stiffening sections added at bearing points and stress locations. (See insert in fig. 8.) This technique is used in place of structural members and chassis to reduce mass. The front axle of the rover is rigidly attached and the rear axle pivots vertically at the midpoint to permit continuous four-wheel traction and differential roll sensing of the terrain. Four wheels, independently driven, were chosen for the rover on the basis of simplicity, mass, and stowability. (See ref. 4.) To enhance traction and reduce weight, lunar-rover-type wire wheels have been selected. Scuff steering is used since wheels are independently driven and controlled. (Ackerman steering is heavier and more complex and wagon steering is less stable.) The rover is driven by four planetary geared electric motors which are independently powered under the control of the vehicle navigation system. Differential control to each wheel will allow the rover to perform various steering maneuvers ranging from gradual scuff turns to hard in-place rotating turns to bring about abrupt azimuth changes. Under normal conditions, the rover is expected to proceed along a straight path for at least one segment length and then make a heading correction, if necessary, before beginning the next segment of its sortie. Scuff steering is favored for this mode of operation. This section presents the energy and power required for mobility of the three rover classes. Obstacles which cannot be negotiated by the rovers are also defined.

Mobility Surface Model

In order to size the power requirement for locomotion of a rover on the Martian surface, it was necessary to assume a model representative of the surface to be traversed. For this model, a surface texture similar to the lunar surface was assumed. (See ref. 9.) This surface is relatively soft and noncohesive. For other physical characteristics, the Viking 1975 Mars engineering model and the model of reference 10 were assumed. Obstacles were not defined for the surface model, but the topography at the edge of the polar caps, two desirable landing sites on Mars, was studied to assess this problem. A brief discussion of the topography of the polar regions of Mars is presented in appendix A.

Rover Mobility Resistive Forces

The forces opposing the rover's thrust consist of rolling resistance, surface geometry resistance, and acceleration resistance. Rolling resistance consists of the internal and external resistance of the flexible wheels. On hard surfaces rolling resistance is mostly internal. On soft surfaces external resistance of the flexible wheel becomes very important and increases as the vehicle sinks into the soil. If the vehicle load exceeds the yield strength of the soil, the deflections and soil displacements become permanent, and, as a result, work is lost to this soil deformation. Total rolling resistance for the four-wheeled Mars rover operating on a soft surface is computed by summing internal and external resistance. The resistance to rover thrust due to geometry is produced by grade and obstacle resistance. The grade resistance is the same for rigid wheels, flexible wheels, or tracked vehicles. The maximum average long term slope to be navigated by the small rovers was set at 7.5°, a value considered as conservative for polar region slopes. Determining resistance due to obstacles is a complex problem. Surface factors, obstacle shape, vehicle configuration, speed, and suspension must be well known before an accurate calculation can be made. For this preliminary analysis, all other resistances were summed and 5 percent of this total was assumed as an estimate of obstacle resistances. (See ref. 11.) The inertial force opposing the rover's acceleration must also be determined. The rolling, geometry, and acceleration resistances were calculated for each rover class with the assumed terrain model. Results are presented in table IX. The methods used to determine the various resistances are presented in appendix B.

Mobility Energy and Power Requirements

Energy requirements based on the maximum distance each rover design might travel per sortie were computed. Sorties having a maximum radial distance from the lander of 50, 200, and 1000 meters were planned for the class A, B, and C rovers, respectively. The rovers have been designed to traverse a maximum of $2\frac{1}{2}$ times their maximum radial sortie distances. One sortie is anticipated per 8-hour daytime

TABLE IX.- CALCULATED ROVER SURFACE RESISTANCES FOR ASSUMED TERRAIN AND MOBILITY MODELS

	Class A	Class B	Class C
Internal resistance, newtons	2.60	2.98	5.13
External resistance, newtons	11.28	11.48	15.05
Grade resistance, newtons	17.00	19.42	33.50
Obstacle resistance, newtons	1.94	2.11	3.10
Acceleration resistance, newtons	4.20	4.80	8.28
Total resistance, newtons	37.02	40.79	65.06

period for all three classes. Battery recharge would occur at night. This design required certain assumptions regarding the surface conditions mentioned previously in the resistance calculations.

Maximum energy requirements were calculated by assuming that the entire sortie was carried out in soft soil and under a constant 7.5° average uphill grade. The vehicle was further assumed to be in a state of acceleration 50 percent of the time and a 50-percent drive motor efficiency was used. By using this maximum energy and an average speed of 0.35 km/hr the maximum power requirement was calculated. The results are shown in table X.

TABLE X.- SORTIE MOBILITY REQUIREMENT

	Rover class		
	A	B	C
Total resistive force, newtons	37.0	40.8	65.1
Approximate sortie distance, meters	125	500	2 500
Maximum energy/sortie, joules	4365	19 195	152 300
Maximum energy/sortie, watt-hr	1.21	5.31	42.12
Average energy/sortie, joules	1666	7 265	56 700
Average energy/sortie, watt-hr	0.46	2.01	15.72
Maximum power requirement (assuming a 50-percent gear-motor efficiency), watts	6.8	7.4	11.8
Average power requirement (assuming a 50-percent gear-motor efficiency), watts	2.6	2.8	4.4

An average energy requirement was also calculated by assuming 50 percent of the sortie to be on soft surface, a 7.5° grade over 25 percent of the sortie, and an acceleration mode 20 percent of the sortie distance. The average power requirement was then calculated by assuming a 50-percent gear-motor efficiency as discussed previously. These sortie mobility values are presented in table X.

Mobility energy and power requirements were also sized for the failure case where one wheel is assumed to be locked. The remaining three motors must then provide the normal power requirement plus the power to overcome the drag of the inoperative wheel. The energy and power requirements for the class A, B, and C rovers with one wheel assumed to be in a locked position are presented in table XI. A 50-percent gear-motor efficiency was assumed in these calculations. The "bulldozing" equation used for this computation is presented in appendix B.

TABLE XI.- LOCKED-WHEEL MOBILITY REQUIREMENTS PER SORTIE

	Rover class		
	A	B	C
Locked wheel drag, newtons	22.79	26.05	44.93
Energy to overcome drag, joules	2 849	13 025	112 325
Energy to overcome drag, watt-hr	0.79	3.61	31.11
Power to overcome drag, watts	2.22	2.53	4.37
Bulldozing resistance, newtons	16.27	16.57	21.77
Energy to overcome bulldozing, joules	2 034	8 285	54 425
Energy to overcome bulldozing, watt-hr	0.56	2.30	15.09
Power to overcome bulldozing, watts	1.58	1.61	2.12
Three-wheel drive resistance, newtons	13.33	14.53	22.68
Three-wheel energy, joules	1 666	7 265	56 700
Three-wheel energy, watt-hr	0.46	2.01	15.72
Three-wheel power, watts	1.29	1.41	2.20
Total resistive force, newtons	52.39	57.15	89.38
Total energy, joules	6 549	28 575	223 450
Total energy, watt-hr	1.81	7.92	61.92
Total power, watts	5.09	5.55	8.69
Rover mobility requirements (assuming 50-percent gear-motor efficiency):			
Force, newtons	104.78	114.30	178.76
Energy, joules	13 098	57 150	446 900
Energy, watt-hr	3.62	15.84	123.84
Power, watts	10.18	11.10	17.38

Definition of Nonnegotiable Obstacles

The ability of the rover to negotiate surface protrusions and depressions was examined. This procedure required, initially, the definition of nonnegotiable obstacles. Nonnegotiable obstacles were defined relative to rover design and surface geometry.

The ground clearance and step-ditch obstacle height for positive and negative vertical steps are very important when the negotiability of surface protrusions and depressions is considered. All three rover classes being considered have like wheel systems. Ground clearance for the rovers as currently designed is 12.7 cm if the small loss due to wheel deflection is neglected. It was determined that an 18-cm step is the largest obstacle which can be negotiated without causing chassis hangup. However, vehicle performance causes a significant reduction in the maximum step-ditch obstacle which can be negotiated by the rover.

The ratio of obstacle height z to wheel diameter D alone was found by Rettig and Bekker (ref. 12) to be sufficient for specifying the step-ditch obstacle performance of a four-wheeled vehicle. For any given coefficient of friction, there is an upper limit to obstacle performance, and this limit increases with increasing coefficients of frictions. If the coefficient of friction is assumed to be 0.6, and the rover center of mass is located 38 cm from the rear of the rover, 15 cm up from the plane of the axle, and 36 cm inward from the outer side of the wheel, the maximum step-ditch obstacle height is found in reference 12 to be 5.0 cm. This value also sets a maximum height on step-ditch obstacles which can be negotiated while traversing longitudinal or vertical slopes.

These conditions provide a preliminary definition of nonnegotiable obstacles. Wheel deflection required to provide an optimum frictional characteristic with the Martian surface must be determined for each of the three rover classes. Results of such investigations could alter the definition of a nonnegotiable rover obstacle.

Rover Cornering and Stopping Ability

Vehicle stability while cornering has a large influence on avoidance of nonnegotiable obstacles. While turning, the centrifugal force developed on the rover can exceed the sum of the frictional forces on the rover. Sliding or tipping occurs when this condition occurs. Sliding occurs when the lateral frictional force developed by the wheels is equal to or less than the centrifugal force imposed on the vehicle. By assuming a 90-cm turning radius and the velocity of 0.35 km/hr, the minimum coefficient of friction which would cause sliding was determined to be 0.003 (a value far below 0.6 considered to be reasonable for Mars).

Tipping of the rover when negotiating a curve is experienced when the resultant of the centrifugal force and the rover gravitational force passes through the point of contact of the outboard wheels with the ground. Minimum tipping velocity was calculated to be

7.08 km/hr when the center of mass (CM) previously defined, the turning radius of 90 cm, and the coefficient of friction of 0.6 are assumed.

The minimum sliding and tipping velocities for a curve having a 90-cm radius are both much larger than the 0.35 km/hr limit set for the Mars rover velocity and should not be a problem on level terrain for the Mars rovers as currently conceived. Maneuvering on slopes with various frictional coefficients is an area requiring additional research.

Stopping or skidding distance also needs to be defined before an obstacle-avoidance technique can be determined. The skidding of stopping distance of a Mars roving vehicle is approximately three times as great as that on Earth because of the gravitational difference. The kinetic energy to be overcome is constant whereas maximum tractive force is approximately three-eights that on Earth. Tractive force depends on the surface and wheel tread characteristics. By assuming that the wheel is sliding and that the surface is hard, smooth, and level, a simplification of the skidding analysis would be permitted. In this manner, vehicle mass is canceled out and braking help from soil, such as compaction, bulldozing, and drag may be neglected. Thus, the minimum stopping distance D_S for all wheels locked on a level surface is about 0.2 cm.

From these data on tractive stopping capability, it has been assumed that the major braking consideration will be in the design of the drive motor selected. The rovers must be capable of rapid wheel stoppage to avert an obstacle which may be sensed immediately in the vicinity of the vehicle. Motor designs were not considered in this concept study.

The various mobility characteristics defined in this section are presented in table XII. The computation techniques used to calculate the characteristics are presented in appendix C:

TABLE XII.- FACTORS AFFECTING ROVER MOBILITY
FOR ALL CLASSES

Ground clearance	12.7 cm
Step-ditch obstacle height	5 cm
Maximum crevice width	18 cm
Minimum sideslipping velocity*	5 km/hr
Minimum tipping velocity*	7 km/hr
Locked wheel skid**	0.2 cm

*Assumes a turning radius of 90 cm on level surface.

**On level surface, 0.35 km/hr.

ROVER NAVIGATION SYSTEM

All three rovers will require a navigation guidance and control system. Gross mapping data from the Mariner 9 and Viking 1975 missions combined with the Viking 1979 or 1981 lander and orbiter imagery data should provide sufficient information for the Earth-based personnel to select an interesting target site and an obstacle-free path to the site. Because of the power limitations and the large communication time, the rovers will provide only intermittent position and heading information. Thus, Earth-based personnel cannot have a continuous display of the actual rover path. The purpose of the rover navigation system then is to keep the rover on the path selected initially.

All rover classes will use a landmark navigation scheme to provide updates to Earth-based personnel on the range and direction of the rover. Landmark navigation for the rover requires a camera system onboard the rover and a terrain map at the mission control center (MCC). Landmarks in the camera field of view are located on the terrain map at the MCC. Lines of position are determined and the vehicle position and heading are computed. Earth-based personnel having only a regional location of the vehicle can successfully determine the vehicle position in 90 minutes. To reduce this time, a landmark navigation computer program (LNCP) was written by Jet Propulsion Laboratory (ref. 13). The computer program has been developed and tested. The LNCP cuts the location time by an order of magnitude. The landmark navigation technique system is simple and accurate and with the development of the LNCP much more attractive timewise. Time required to relay the rover imagery data to Earth will be the greatest restriction on the landmark navigation technique. One-way communication times of 14 to 19 minutes are expected for the 1979 or 1981 Viking missions.

Landmark navigation will be used for updating the class C rover inertial heading system and as the primary navigation mode for the class A and B rovers. All rover classes will navigate a predetermined rover path. The predetermined path will consist of straight-line segments of 50 or 100 m. Each wheel of the rover will house an odometer with the output averaged to determine rover range. Upon completion of several path segments, the class B rover performs a 360° panoramic scan of the area, relays the information to the Earth-based personnel, and waits for the range and heading update to complete the sortie. After completion of the final segment, the same sequence could be performed to provide accuracy in locating the target. It is not necessary that the class C rover communicate with the Earth-based personnel until the target site is reached. At this time, a navigation system update using landmark navigation will be made. The class A rover also gets one update at the target site which allows it to make its best return to the lander.

A gyrocompass-odometer system was chosen for class C rover navigation because it required only daily external updates. Present gyrocompass-odometer navigation systems weigh approximately 10 kilograms and require 10 watts of continuous power; thus this system is inapplicable to the class A and B Viking rovers. (See ref. 14.)

Sensing of Nonnegotiable Obstacles

One of the most critical areas of development for rover navigation is hazard detection and avoidance. A hazard-detection system should take advantage of previous and present knowledge of the Martian surface. This system requires an efficient interfacing of sensor outputs with the control system. Broad mapping by the 1971 Mariner and 1975 Viking missions, coupled with localized mapping by the Viking 1979 or 1981 orbiter and lander, is expected to provide coarse information on rover hazards. A planetary landing site selection system now being studied may provide additional high-resolution imagery data. (See ref. 15.) The lander facsimile cameras will provide a high-resolution panoramic scan of the area 100 meters around the lander.

One hazard which must be monitored on the Martian surface is the slope of the terrain being traversed by the rover. Rover stability can be adversely affected by sharp positive or negative slopes. Slope detection requires measurement of the vehicle pitch and roll angles. Simple microswitch devices can be used to sense pitch and roll limits of the rover. These devices provide only "red line" protection but no angle readout. An extended roller-type device equipped with a potentiometer may be necessary to provide roll and pitch angle readout of impending terrain. Three instruments were considered for this rover concept: the inclinometer, the pendulous accelerometer, and the liquid pendulum.

A system of two inclinometers was chosen to monitor the rover pitch and roll angles. One inclinometer will be placed at each of the two rover axles. The front inclinometer will monitor roll attitude while the rear inclinometer will monitor pitch attitude.

The class A rover, which will provide 50-meter sorties, will not be equipped with any short-range obstacle sensor. The imagery data provided by the orbiter and lander camera systems is of high resolution. These data combined with knowledge of the planet gained by previous missions are considered to be sufficient for the Earth-based personnel to select an obstacle-free path to the science site.

On the class B rover, short-range obstacle detection will consist of a passive system of four quill-type tactile sensors extending outward approximately 46 cm from the front of the vehicle at axle level. These sensors will detect step obstacles, boulders, and sudden slopes. Crevices and/or holes must be detected by the imagery data.

The class C rover will use an active short-range obstacle detection system consisting of four X-ray radiators. Two radiators are located to irradiate an area 20 cm or more in front of each front wheel while the remaining two instruments irradiate the areas in front of the vehicle on each side of the sampler arm. The X-ray radiation technique is used to detect crevices, downslopes, and step obstacles. The intensity of the backscattered radiation is calibrated to determine the distance from the sensor to the surface. This active obstacle sensor is used to provide the information required to allow the rover to avoid obstacles while traversing the predetermined path. The complete system of four detectors and the required electronics have a mass of approximately 2 kilograms and require less than 2 watts of power. Computer requirements for obstacle detection and avoidance will be handled by the class C rover computer. The inertial navigation system for the class C rover will also rely on this computer in addition to a sequencer. A computer having a memory of 4000 words should be sufficient and is available at a mass of 3 kilograms. The computer will be required for the determination of the position, velocity, and attitude of the class C rover. The hazard detection and avoidance operational requirements for each rover class are presented in table XIII.

TABLE XIII.- HAZARD DETECTION AND AVOIDANCE SYSTEM CHARACTERISTICS

	Rover class		
	A	B	C
Hazard detector type	None	Quill (4)	X-ray radiators (4)
Hazard avoidance mode . . .	Imaging, control commands	Imaging, control commands	Imaging, control commands
Data to lander required . . .	108 kbits/sec (for imagery use)	108 kbits/sec (for imagery use)	None
Control mode	Sequencer	Sequencer	Sequencer and computer
Power requirement, watts . .	----------------	≤0.5	≤2
Detector mass, kg	----------------	1.4	2.3

Navigation and Hazard Avoidance Scheme

Initial sorties will probably use only a fraction of their maximum distance. As the confidence level of the rover navigation increases, sorties of greater distance will be made.

The class A rover will provide sorties of a maximum radial distance of 50 meters from the lander. The class A sortie is expected to be a straight-line one-segment traverse. (See fig. 11.) However, the rover position could be altered by an update if it was

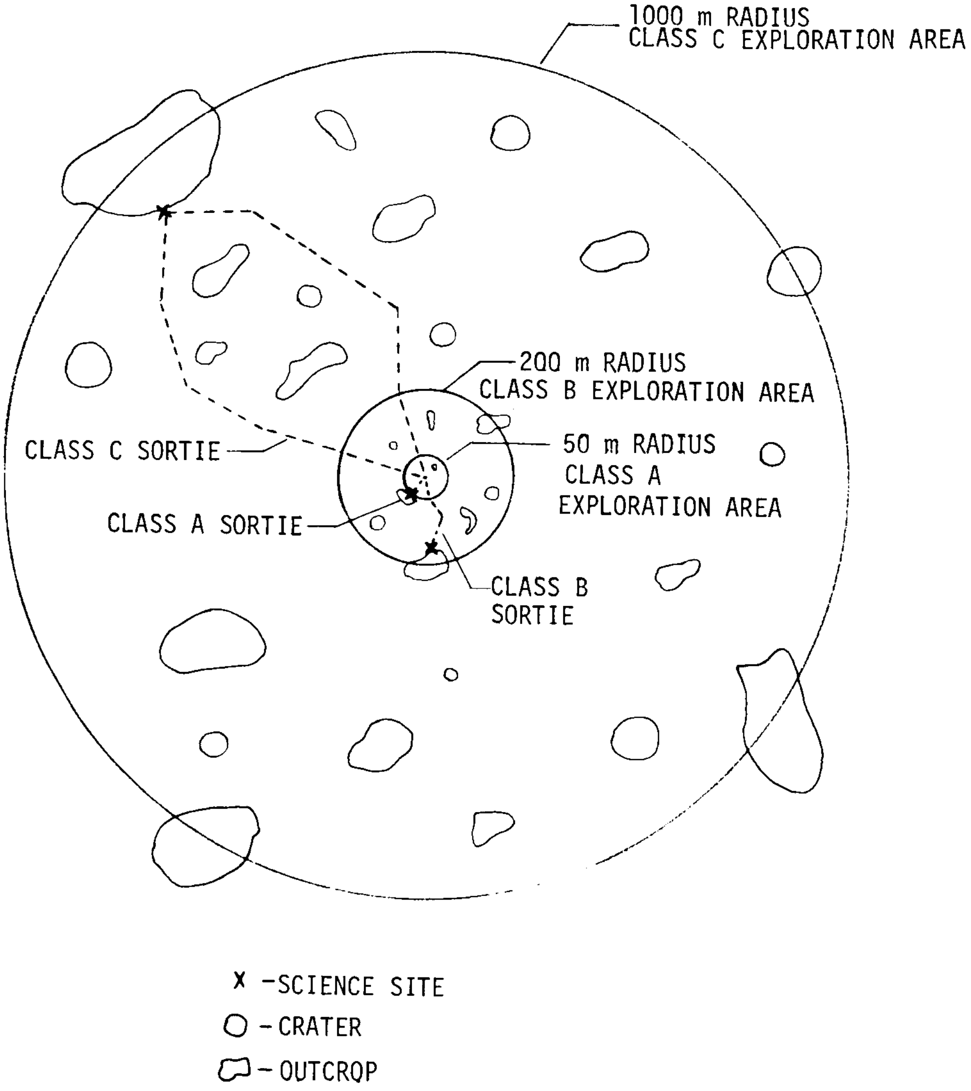


Figure 11.- Comparison of exploration areas and sortie geometry for class A, B, and C rovers.

determined to be necessary. It is expected that the area about the lander will be relatively uniform. The lander imagery should provide data to Earth-based personnel so that a 50-meter radial area will be well mapped. Thus, an obstacle avoidance mode was not designed for the class A rover. A navigation control diagram for the class A rover is presented in figure 12.

Sorties of up to 200 meters radial distance from the lander will be performed by the class B rover. A position update will be made after the rover has traveled 150 meters from the lander. A class B sortie could consist of several segments with varying headings. (See fig. 11.) As the rover gets farther from the lander, the probability of encountering an inline nonnegotiable obstacle increases. Upon encountering a nonnegotiable

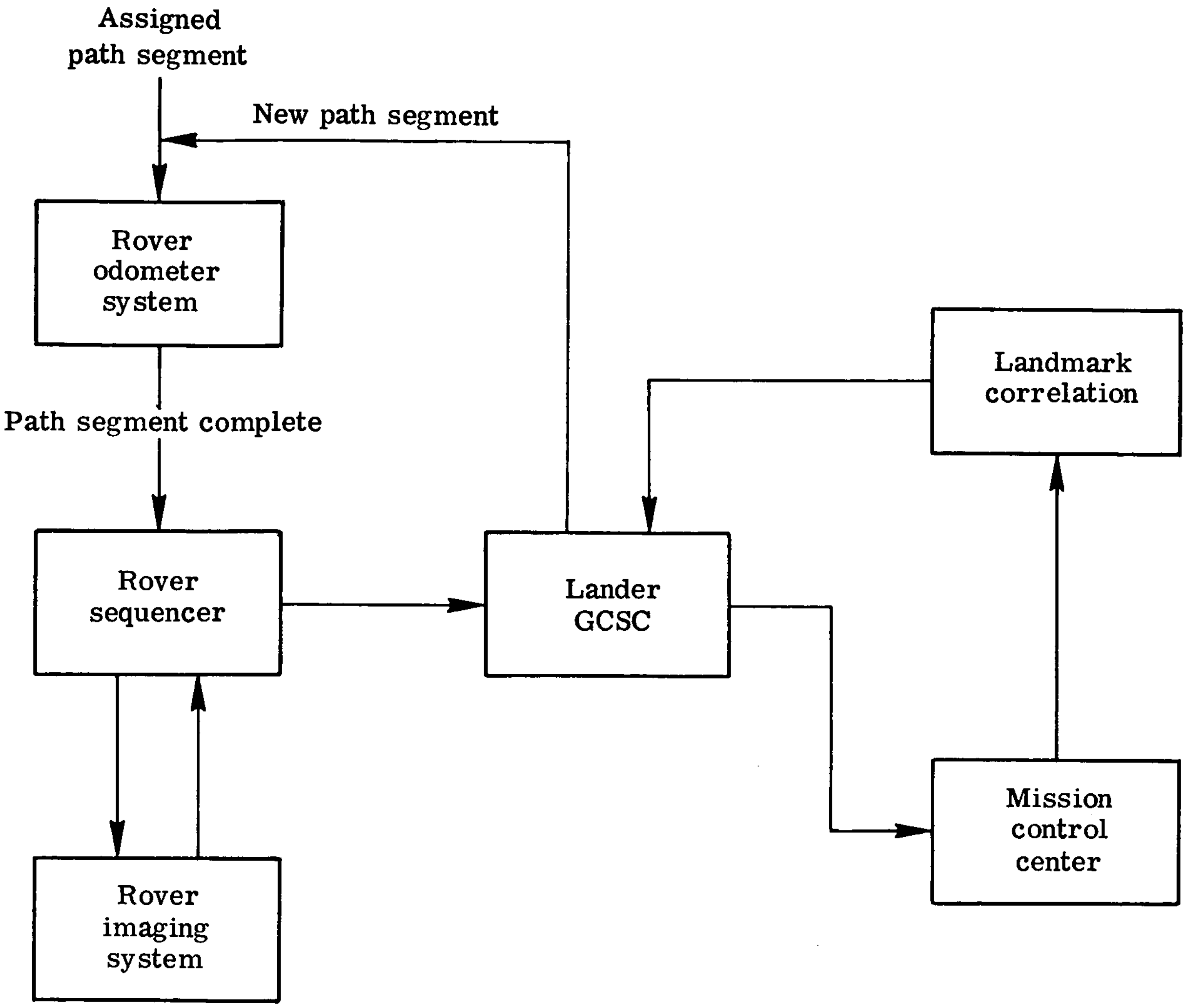


Figure 12.- Class A rover navigation control diagram.

obstacle, the rover stops, backs up, scans the area with its camera system, relays data to the Earth-based personnel, and waits for a command. These personnel will either terminate the sortie, define an alternate path around the obstacle to the target site, or select a secondary target site and a new rover path. A navigation control diagram for the class B rover is presented in figure 13.

The maximum radial distance for the class C rover sortie is 1000 meters. (See fig. 11.) The class C rover navigation system can receive an update by landmark navigation after arriving at the target site.

The class C rover will have an autonomous guidance and control mode for avoidance of inline obstacles. If the inclinometer detects a nonnegotiable slope, the rover will stop, backtrack for two rover lengths, and then go into the avoidance mode used by the class B rover. By using this active avoidance mode, the class C rover will attempt to circum-

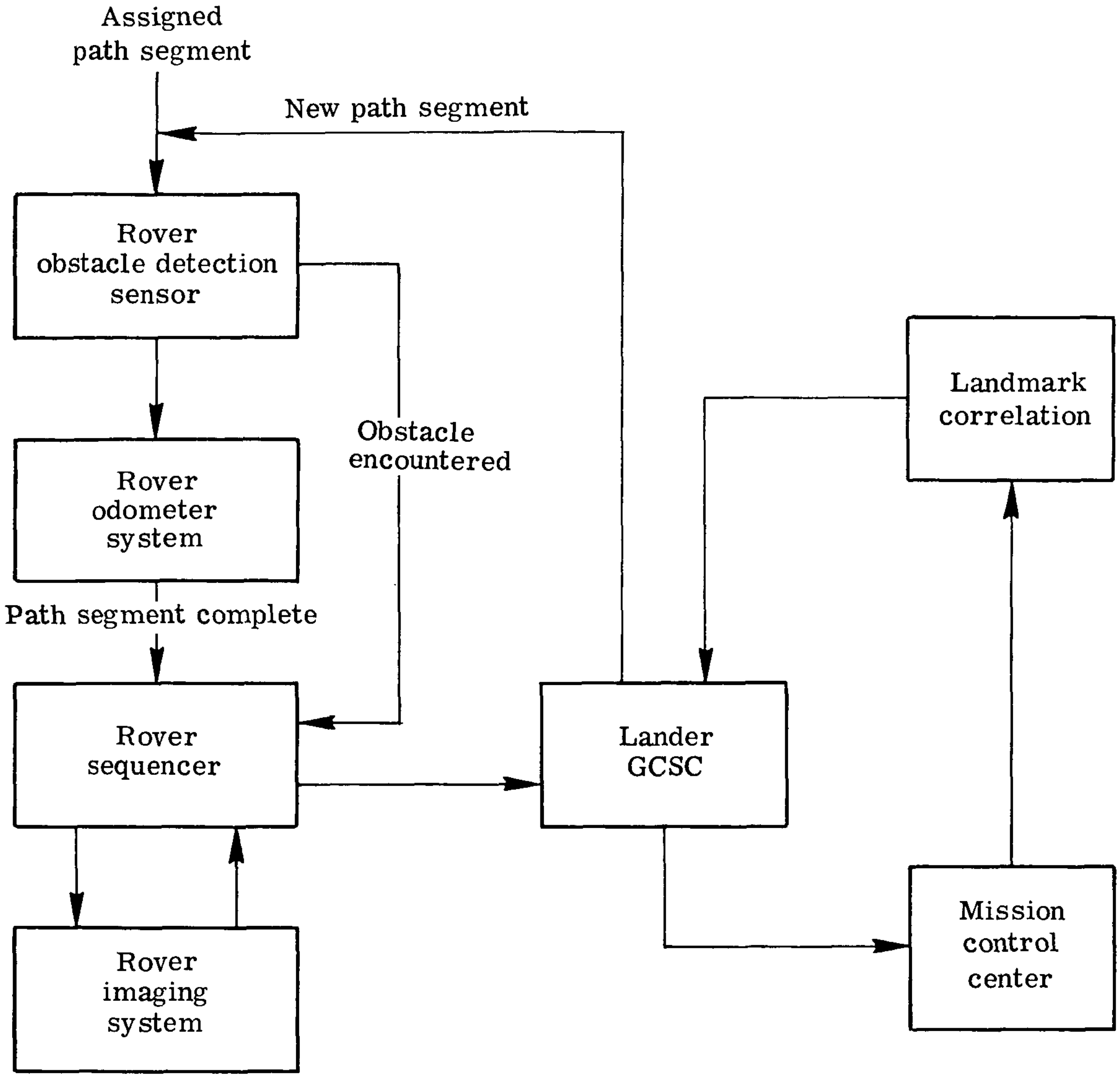


Figure 13.- Class B rover navigation control diagram.

navigate an inline obstacle without aid from the Earth-based personnel. They would intervene only in an emergency mode. A navigation control diagram for the class C rover is presented in figure 14.

ROVER COMMUNICATION SYSTEM

The rover must have its own communication system to receive commands as well as to transmit results which accrue from the executed commands. The rover will communicate only with the lander. The lander will provide an active relay link to send and receive data between Earth and Mars and to send data to the orbiter. The lander and rover may

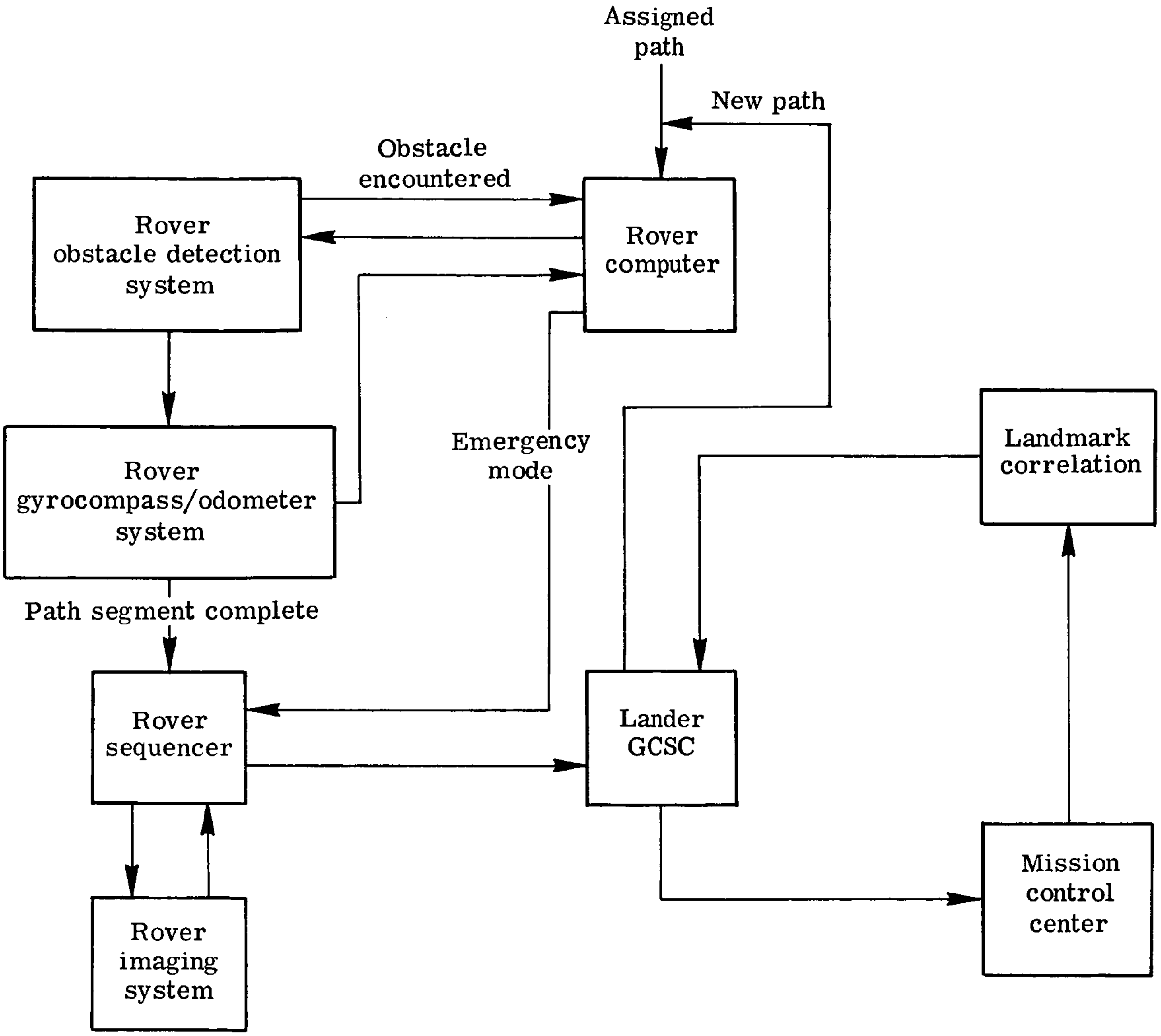


Figure 14.- Class C rover navigation control diagram.

also communicate information between themselves when the lander's computer is used to provide decisions, commands, or data storage for the rover. The lander's computer will be expected to handle the decisions to store or transmit rover-generated data. Communication of information between the rover and the Mission Control Center (MCC) by means of the lander will generally be of high priority and must be allowed precedence over other lander operations and communications.

Earth-Mars Communication Window

The Earth-Mars communication window will be affected by several geometric factors. They are basically the range across which the signal must be sent and the visibility between lander and Earth antenna (or between lander and orbiter antenna). The range can be expressed in minutes of transit time for the signal to travel between the lander and Earth antenna. The 1979 and 1981 mission signal transit time variation with date is presented in figure 15 (from ref. 16). The period considered herein for a 1979 Viking mission assumes a launch in October-November of 1979 and arrival in August-September of 1980. A 1981 mission would be launched in November-December with arrival in September-October of 1982. Surface mission duration has been defined herein as a 3- to 6-month period.

The second factor, visibility between the communicating antenna, is a function of (1) the relative positions of Earth, Mars, and Sun, (2) the latitude of the landing site, (3) the attitude of the lander on Mars' surface, and (4) the instantaneous relative rotational positions of Earth and Mars.

The relative positions of Earth and Mars for the 1979 and 1981 missions will be generally one of superior conjunction. Earth and Mars will be approaching opposite sides of the Sun as the surface mission progresses. Mars will be occulted by the Sun for approximately 1/2 month or more. The mission could either be phased to continue after occultation or planned to be concluded beforehand.

The latitude and attitude of the lander on Mars will affect the daily communication window size. Figure 16 provides quantitative information on these relationships. The antenna beam width, articulation, and pointing ability must be considered in window calculations.

The choice of Mars landing longitude will affect the time of the daily communications window. Roving activity on Mars will be limited to sunlight periods when imagery can be done. Therefore, the periods of sunlight at the lander site must be chosen to coincide with the communication window periods since night times will be reserved for battery recharge and quiescent activities.

Telecommunication of Mars Data

The area of exploration, which each of the three classes of rovers will be capable of, has been designated as a circle of 50-, 200-, and 1000-m radius for the classes A, B, and C, respectively. The sorties carried out within these areas will be divided into 50-m or 100-m segments. It is anticipated that rover-lander communications will occur mainly at the anticipated checkpoints or at sampling sites. During these stops imagery data may be sent to the lander at extremely high bit rates (108 kbps) and thus must be tape recorded before being sent to Earth at lower speeds. (See ref. 5.) Rover position and attitude data will be sent to the lander computer, and at exploratory stops, scientific data will also be forwarded to the computer. These data will be sent real time to the MCC via the lander S-band link. The rover's imagery, position, and attitude data will be

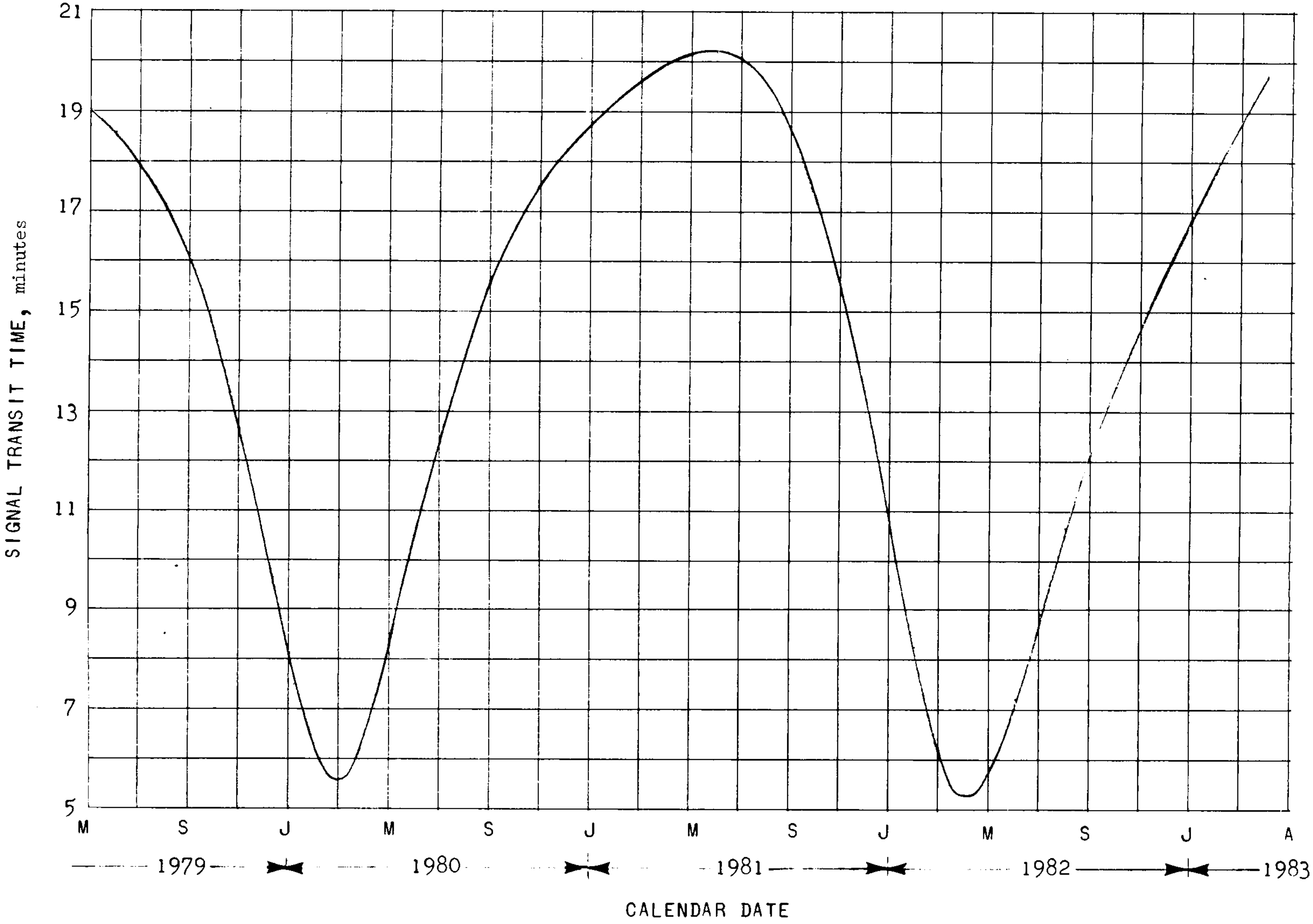


Figure 15.- Mars-Earth signal transit time (one way).

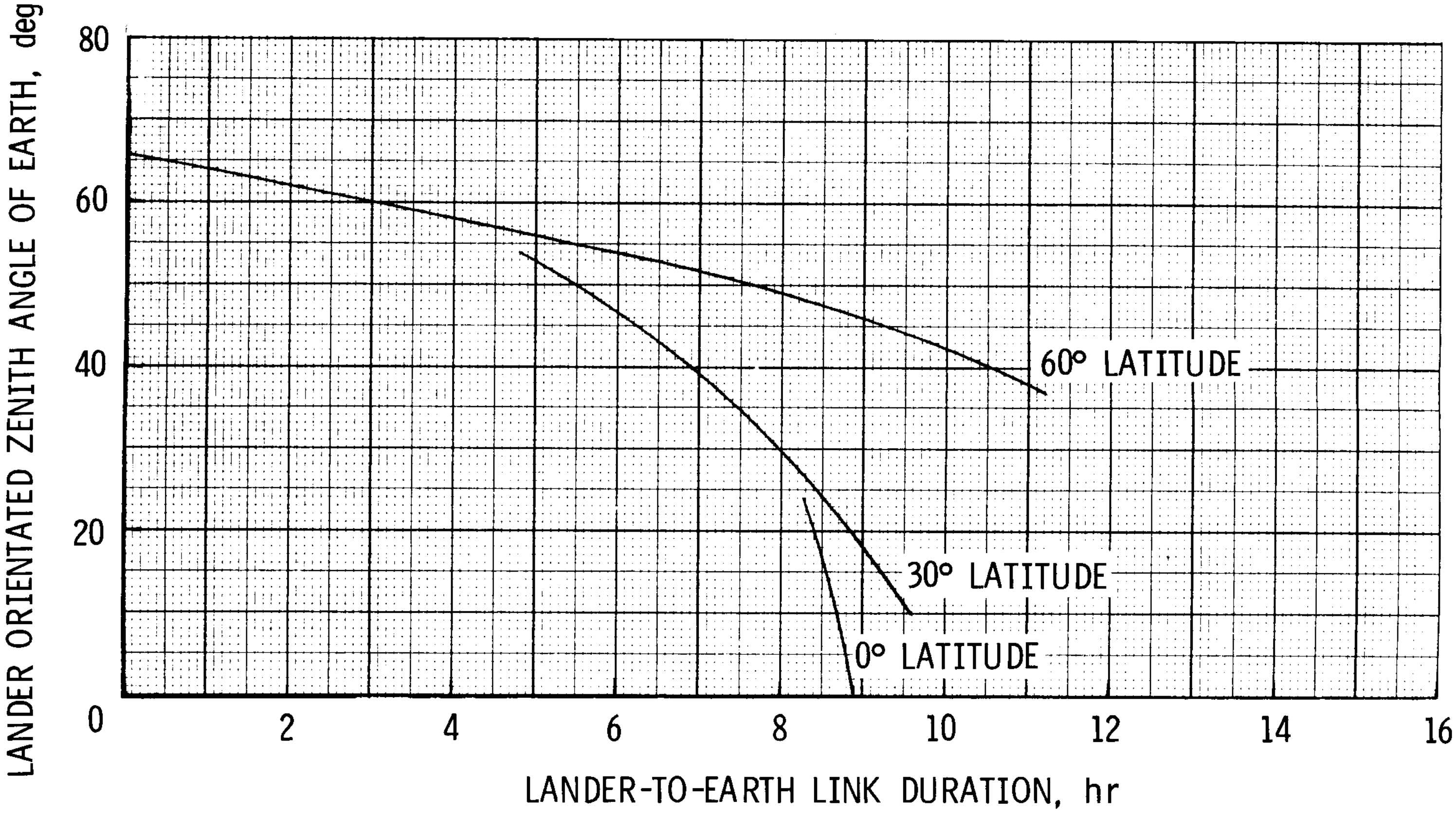


Figure 16.- Variation of daily communication time window with lander attitude for several latitudes on Mars.

used to provide updates for the Mars map. Earth-based personnel will then decide the guidance command to send back to the rover. A minimum turnaround time of 50 to 60 minutes can be anticipated. During this interval the rover may continue to relay surface exploration data to Earth through the lander if it is at a designated sample site. If the rover is at a checkpoint, the rover communication can be temporarily closed and the lander's data can be transmitted until the rover's guidance command reaches the lander from Earth.

The scientific data which are generated by a rover and a lander in combination are the end products which justify a mission to Mars. Planning for the proper handling and telecommunication of these data should therefore begin at an early stage. As a first step in this preliminary communication study the data type and quantity to be communicated both to and from Earth because of lander and rover actions were surveyed. The gross magnitude of the data volume in bits was tabulated from best estimates. The results are given in tables XIV and XV which apply to each class of the rover and to the lander, respectively.

TABLE XIV.- GROSS ROVER COMMUNICATION DATA VOLUME

[Totals are based on estimated uses per day and numbers of instruments of each type on rovers]

Source	Output, bits/use			Input, bits/use		
	Rover class			Rover class		
	A	B	C	A	B	C
X-ray spectrometer	5000	5000	5000	100	100	100
Neutron hydrogen detector	17	17	17	10	10	10
Facsimile cameras, per each . . .	10^6	10^6	10^6	600	600	600
Quasi-microscope	10^6	10^6	10^6	600	600	600
Soil sample system	100	100	100	300	500	600
Drill			100			300
Inclinometers, per each	100	100	100	0	0	0
Odometers, per each	100	100	100	0	0	0
Hazard detectors, per each	2	2	500	0	0	0
Steering	100	100	100	200	200	200
Power control	100	100	100	100	100	100
Sequencer				100	300	
Computer						1000
Gross daily total	3×10^6	6×10^6	8×10^6	1×10^4	2×10^4	4×10^4

TABLE XV.- GROSS LANDER COMMUNICATION DATA VOLUME

Component	Output, bits/use	Input, bits/use
Ambient temperature	100	0
Ambient pressure	100	0
Meteorology/day	5×10^4	200
Alpha backscatter/day	10^4	200
X-ray diffractometer/spectrometer	10^6	200
Seismometer/day	10^5	200
Physical properties/day	10^5	1000
Wet organic laboratory/day	5×10^4	1000
Metabolic gas evolution experiment/day	5×10^4	200
Facsimile cameras, each	1×10^7 (16 kbps)	1000
Quasi-microscope	10^5	500
Antenna steering	200	1000
Sampler	500	5000
Sample handling		500
Engineering data/day	10^6	1000
Gross daily total	3×10^7	2×10^4

The Viking 1975 lander communication systems were considered as a baseline for the 1979 or 1981 mission although certain new requirements need to be met. The Viking 1975 lander will receive its telemetered commands from Earth at 4 bps. The Earth commands will be used mainly to alter programed sequences of lander instrument operation. An exception is the lander's sampler operation which can be programed from the Earth to perform specific activities. For the 1979 or 1981 mission involving the rover, an earth-lander-rover communication link must also be available to allow more real time communication to the rover. It would be advantageous to achieve a higher Earth-to-lander communication bit rate to provide greater command capability. It is felt that 6 to 8 bps may be required for the 1979 or 1981 mission. This requirement would assume use of an increased power level from the Deep Space Network (DSN) stations. This higher power level is currently available.

Transmission of information to Earth from the 1979 or 1981 lander will hopefully be as high as 2 to 3 kbps (250 bps for Viking 1975). This rate could potentially be accomplished by the use of high power TWT amplifiers (ref. 17), larger antennas, or use of X-band instead of S-band links. X-band looks attractive but would require use of more precise antenna pointing capability than that of Viking 1975. The lander-to-orbiter data rate used on Viking 1975 (16 kbps) should be sufficient. The rover-to-lander data rate requirement may be above 108 kbps to accommodate a high-density, high-speed output from the rover cameras. The communication window between Earth and the lander (fig. 16) will allow from 2 to 10 hours communication per day. (Ten hours will produce a heavy power drain on the lander and build up internal heating.) At a lander to Earth transmission rate of 2500 bps, the transmitted data volume would be approximately 5.4×10^7 bits per average day (8 hours). This volume would allow several rover stereo facsimile camera scans plus lander camera scans and data dumps from various instruments. (See tables XIV and XV.) Less imperative data could be transmitted by means of the UHF relay link to the orbiter. Here approximately 20 minutes (minimum 10) of transmission per day should be available at 16 kbps for a volume of 1.9×10^7 bits/day.

Rover-Lander Communication System Description

The communication system for the anticipated Viking 1979 or 1981 mission will bear many similarities to that of the 1975 mission. The main difference will be the requirement for the additional two-way low-power surface communication link between the lander and the rover.

Communication for the class A rover with the lander will be through an umbilical line which also supplies power and can act as a winching line. Internally, the line must be a multiconductor to maintain power and communication links simultaneously. Externally, the cable wrap must provide electrical insulation of the leads and resistance to breaking under the severe thermal conditions of Mars. Tests have shown that external wrap materials are available which are lightweight and capable of withstanding the Martian environment.

The class B and C rovers' communication with the lander will be through a very high frequency (VHF), line-of-sight, continuous-wave (CW) transmission link. The transmitter and receiver systems used on the rover must be carefully designed to be compact, use minimum power, and remain low in mass. A receiving and transmitting antenna must be used which is deployable, omnidirectional, has low mass, and is able to withstand the ground motion of the rover.

A small biconic antenna is an attractive candidate for the rover. It offers a 360^o azimuthal radiation pattern and can be designed to minimize radiation losses; however, its mass and stowage volume are greater than that of the ribbon whip antenna. Required transmission ranges will be very short, but ground losses due to multiple paths and surface reflections of the signal over undulating terrain can be expected to be severe. Signal strength may vary greatly over the roving area because of constructive and destructive interferences. These phenomena and the use of line-of-sight linkages will require antennas which are located reasonably high and designed to radiate long wavelength signals. VHF wavelengths are suggested.

In examining preliminary power and weight requirements for the class B and class C rover-lander communication links, elementary calculations were carried out. A range of 1000 m was used for the transmission distance and 0.34 milliwatt of power output was found to be required. By assuming an input-to-output power conversion efficiency of 5 percent, the rover transmitter energizing power requirement was 6.8 milliwatts. A more conservative value of 50 milliwatts was used to provide for unknown losses in the rover transmitter system and to allow a more comfortable margin in signal variations due to surface reflections. A low-power transmitter for the rover can be fabricated, by using solid-state components, with a mass of less than 0.05 kg and a volume of less than 40 cm^3. The encoder and modulator needed with the transmitter should require less than 0.34 kg mass and 340 cm^3 of volume. The total power requirement for transmitter, encoder, and modulator should be less than 6 watts.

The lander's ground link transmitter can be of even lower power since a lower data rate is required. A transmitter power of 47 microwatts was found to be sufficient. By assuming a power conversion efficiency of 20 percent for the lander's transmitter, the input power requirement was about 235 microwatts. To cover unanticipated losses and to provide a working margin, 7 milliwatts was used as the lander transmitter input power requirement.

Receivers for both lander and rover VHF transmissions can be low-power miniaturized types. The lander receiver must cover a wider bandwidth, but the rover receiver must have a higher accuracy requirement. In both cases, however, the operating power requirement should be less than 5 watts, including the detector and decoder.

1979 or 1981 Viking Lander-to-Earth Communication System

Discussion of the 1979 or 1981 lander communication system is included herein only as an interfacing system which provides an Earth link for the rover. The Viking 1975 communication system could be used in 1979 or 1981 but with several important changes. These changes are to go to an X-band direct Earth link and to increase TWT power somewhat. The Viking 1975 communication system is considered a subsystem of the lander capsule and consists of two principal elements: S-band direct communications system (DCS) and relay communications equipment (RCE).

The DCS will provide simultaneously the landed engineering telemetry and science data transmissions or engineering data transmissions and planetary ranging. The RCE will transmit engineering and science data to the Viking Orbiter and can act as a backup to the DCS for data transmission.

The Viking lander command subsystem, which will handle all uplink command data, will receive and decode command data transmitted from Earth by the DSN. Three DSN stations will be available, each with a 64-meter-diameter parabolic dish antenna for transmitting the commands and receiving the downlink telemetry from the orbiter and from the lander. (See ref. 18.)

Proposed Viking 1979 or 1981 landed communication system characteristics are summarized in table XVI. The questions of redundant links and components will require further attention and consideration, but were not treated in this study. A sketch of the proposed 1979 or 1981 communication links is seen in figure 17.

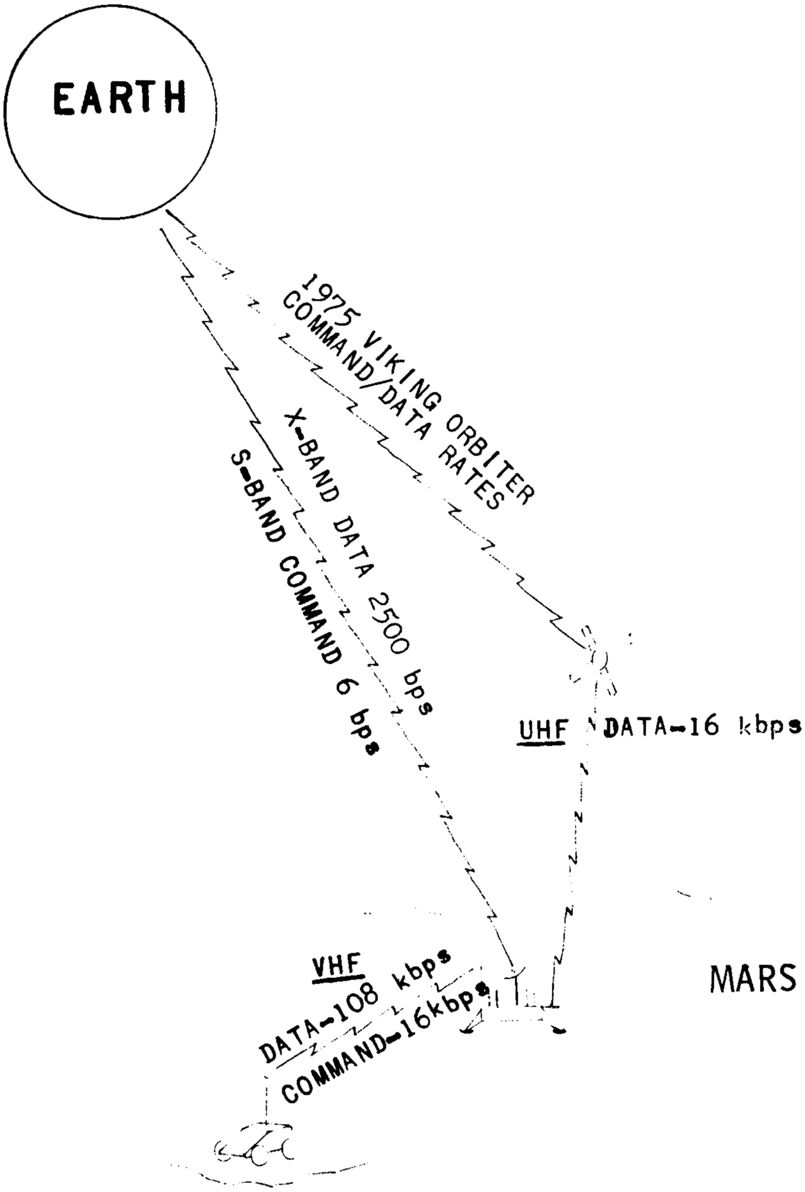


Figure 17.- Proposed communication links.

TABLE XVI.- ANTICIPATED 1979 OR 1981 VIKING MISSION LANDED COMMUNICATION SYSTEM CHARACTERISTICS

System	Transmit equipment	Receiving equipment	Rate, bits/sec	Volume, bits
Data:				
Relay	Lander; low gain turnstile antenna; UHF, 30 watts	Orbiter; low gain quadrafilar helix antenna	16×10^3	1.9×10^7/pass
Direct	Lander; high gain 0.76-m dish antenna; X-band, 30 to 50 watts	Earth; 64-m dish antenna	2.5×10^3	5.4×10^7/8-hr day
Command:				
Primary	Earth; 64-m dish antenna; S-band, 20 to 100 kilowatts	Lander; low gain turnstile antenna	6	1.3×10^5/6-hr day
Secondary	Earth; 64-m dish antenna; S-band, 20 to 100 kilowatts	Lander; high gain 0.76-m dish antenna	6	1.3×10^5/6-hr day

ROVER COMPUTER SYSTEM

To direct and monitor its various operations, each class of rover will require computer control. New problems in vehicle control will be encountered when the rovers are sent to explore and sample remote areas. Science instruments must be operated and their data conditioned and stored (or transmitted at the proper time). The more functions which the rover can perform autonomously, the greater its usefulness and efficiency. If all rover functions were directed from the Mission Control Center (MCC), the rovers' activity time could be severely limited. Each round trip communication costs 30 to 40 minutes of the rovers' potential activity period.

The Viking 1975 lander uses a double block redundant digital computer which is also applicable to the 1979 or 1981 Viking mission. The Viking 1975 guidance control and sequencing computer (GCSC) provides computational logic, sequencing of events, and controlling of functions for the entry guidance and control, science, power, telemetry, and communication subsystems for the Viking lander. The GCSC weighs nearly 23 kg and has a power requirement range between 3.5 and 38.3 watts. This information was extracted from material provided by NASA Contract No. NAS 1-9000. The GCSC will have an 18 000 word capacity plated wire memory. Each computer word contains 24 bits. The guidance and control (G & C) functions of the GCSC were estimated to require 5000 computer words and sequencing 13 000 computer words. Since the GCSC will be flight tested on the Viking 1975 mission and used again for Viking 1979 or 1981 mission, it is reasonable to use the lander GCSC to handle the rover computer requirements.

At least 5000 of the 1979 or 1981 lander GCSC's 18 000 word memory can be used by the rover if the G & C portion is reprogramed by the MCC after the landing is complete. If reprograming is not permissible, a 5000 to 8000 word memory module can be added to the GCSC. This module would have a mass of only a couple of kilograms and would add little to the GCSC power requirements. Secondary computing capability can be achieved by placing a minicomputer directly on the rover.

The computer requirements for the rover science, mobility, hazard avoidance, navigation, and communication systems were assessed and are presented in this section. The GCSC meets the necessary computer requirements for the class A and class B rovers; however, the GCSC combined with an onboard minicomputer were selected for the class C rover. As presently conceived, the minicomputer will control the class C rover mobility, hazard detection and navigation systems, and monitor the rover power supply whereas the GCSC will sequence the imagery and science systems and control the communication system.

Operational flow control diagrams suggested for each rover class are presented in figures 18 to 20. The class C rover minicomputer design specifications, assuming an inertial navigation system, are presented in table XVII. These computer specifications were taken from a list of computer designs given in reference 19.

TABLE XVII.- DESIGN SPECIFICATIONS FOR ROVER MINICOMPUTER

Mass, kg	2.75
Power, watts	10.0
Size, cm^3	2000
Memory type	Plated wire or MOS
Memory size, words	4000
Word size, bits	24

Science

The science investigation performed by all three rover classes will be sequenced by the lander GCSC. The GCSC will initiate the scientific investigation after the rover imagery system completes a scan of the area about the sampling site. The science investigation sequence must be directed as follows:

(1) Position the rover camera for terrain imaging and magnet viewing

(2) Control sampler to acquire the surface and subsurface samples

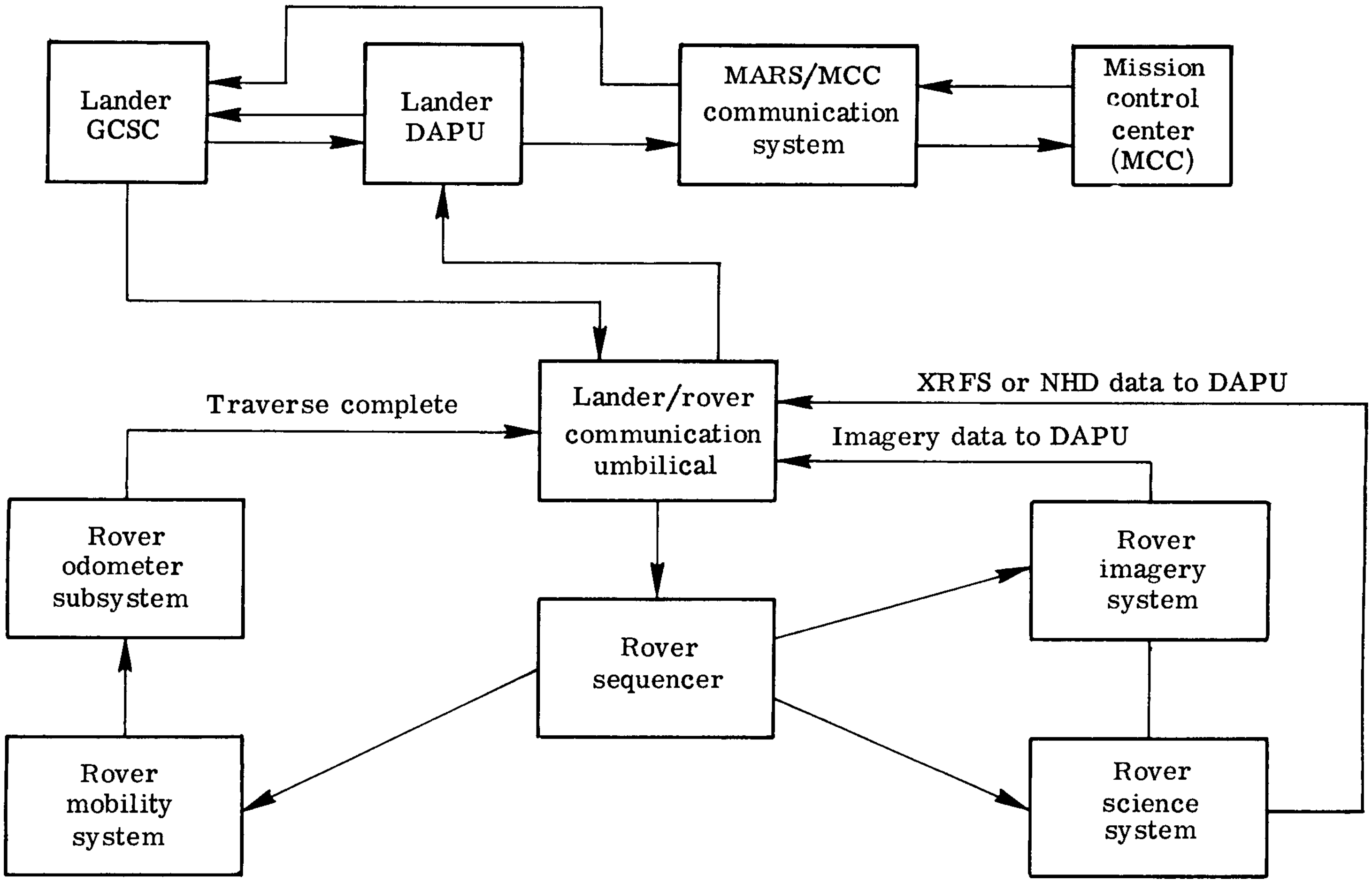
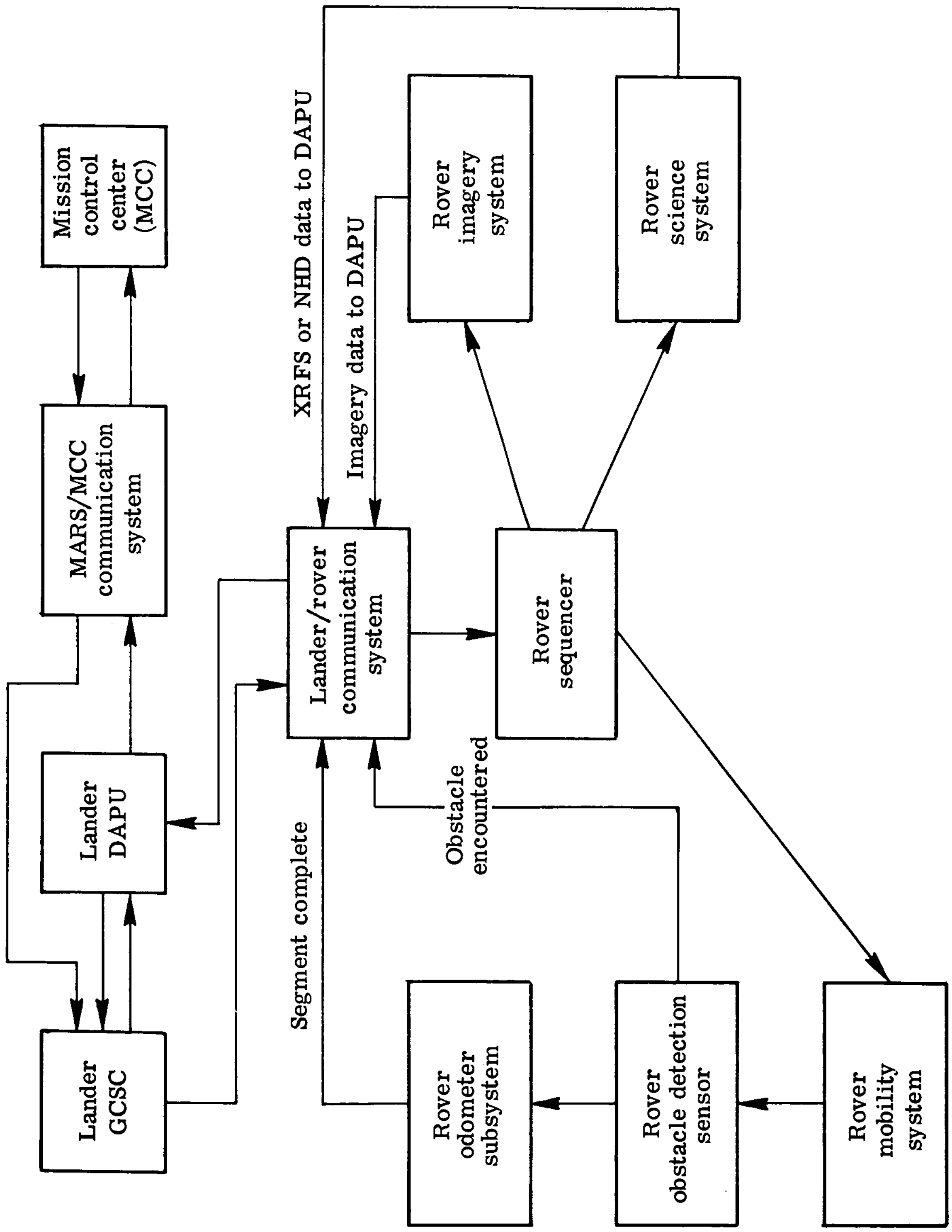


Figure 18.- Class A rover control loop.


Mission control center (MCC)
MARS/MCC communication system
Lander DAPU
Lander GCSC
XRFS or NHD data to DAPU
Imagery data to DAPU
Lander/rover communication system
Segment complete
Obstacle encountered
Rover imagery system
Rover science system
Rover sequencer
Rover odometer subsystem
Rover obstacle detection sensor
Rover mobility system

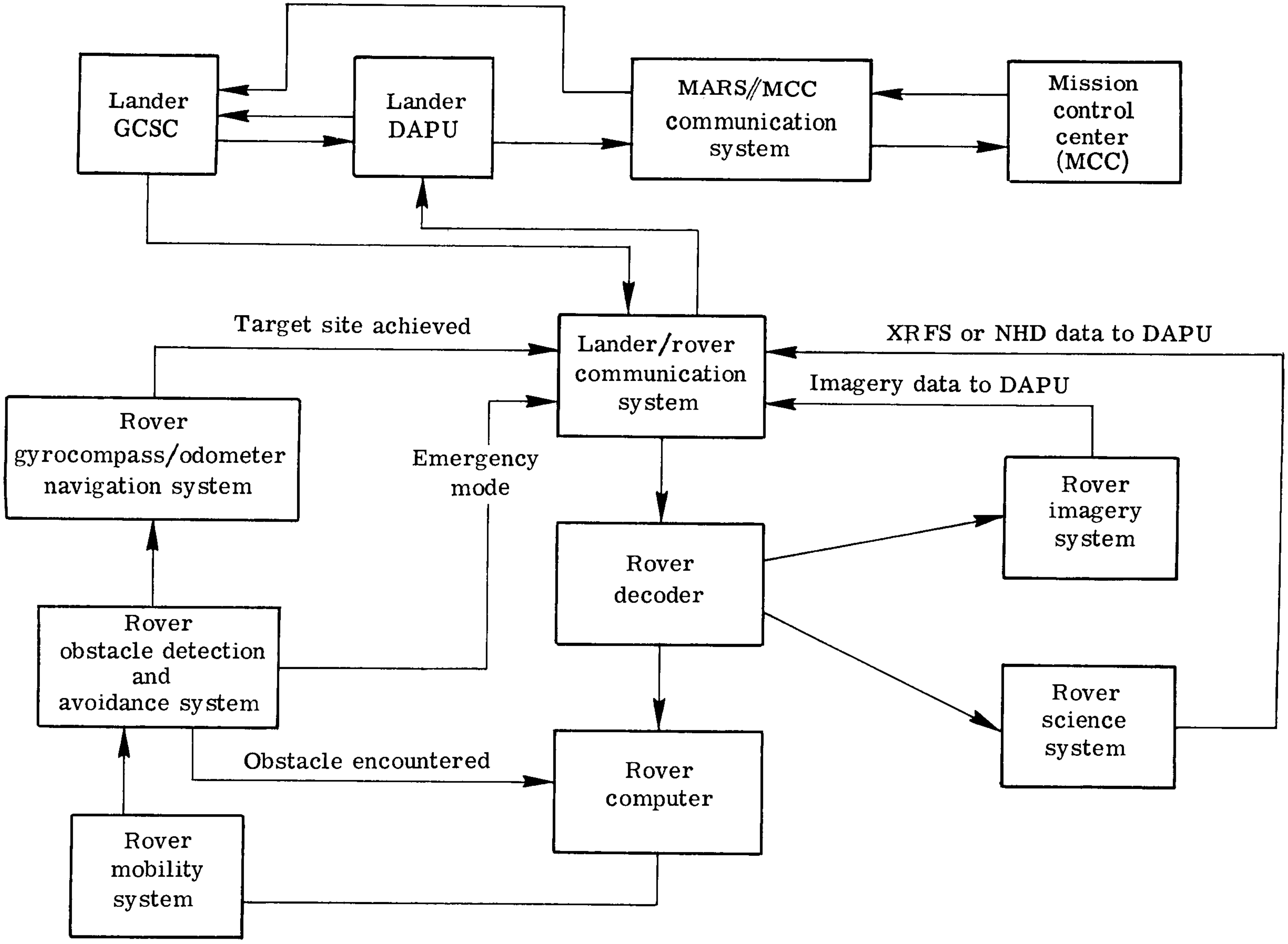


Figure 20.- Class C rover control loop.

(3) Operate the sample handling system for processing, storage, and dumping

(4) Activate the quasi-microscope to view samples

(5) Perform the NHD and XRFS experiments

(6) Send imagery and instrument data to the lander data acquisition and processing unit (DAPU)

This same sequence of events is applicable to all three rover classes. The lander GCSC will have the additional responsibility of controlling the deployment and eventual firing of explosive seismic packs if the class C rover is used. It should be noted that the GCSC will also control the operation of the subsurface drill on the class C rover.

Mobility

The lander GCSC will be used to control mobility for the class A and class B rovers. Path-segment data, range, and heading angle will be sent to the rover mobility system. Heading will be adjusted and the rover will proceed for the specified range. Upon completion of the segment, the odometer system will key the GCSC. The GCSC will then either send data for another path segment, begin a navigation update, or begin a scientific investigation.

The class C rover, controlled directly by the onboard minicomputer, will receive multiple-segment path assignments from the GCSC. Upon completion of the path segments, the rover computer will send an appropriate message to the GCSC and stand by for the next series of activities.

All three rover classes will utilize scuff steering that requires continuous monitoring and controlling of the power being supplied to each wheel motor during heading-change periods. Since the class B and class C rovers are battery powered, it will be necessary to monitor the state of cell discharge. If a cell is discharged below a safe level, then no more power can be taken from this cell. The rover will either work at a lower power consumption or tax the remaining cells to work at a higher power output level.

Hazard Avoidance

The class A rover will not use the computer to avoid hazards. It will be assigned a new sortie from Earth, if it encounters an obstacle or nonnegotiable slope. When an inline nonnegotiable obstacle is detected by the class B rover, it stops and sends an appropriate message to the lander DAPU. The DAPU relays this message to the GCSC which initiates the hazard avoidance mode. The hazard avoidance mode is as follows:

(1) Rover stereo cameras scan the immediate area

(2) Imagery data are relayed to the DAPU and then to the MCC

(3) Avoidance commands are formulated and sent by the Earth-based personnel to the GCSC and relayed to the rover

(4) The rover executes an avoidance route and returns to the path

The class C rover uses an algorithm preprogramed into the rover minicomputer to furnish the guidance for the rover to avoid obstacles autonomously while traversing the predetermined path. (See ref. 20.) If the autonomous mode of hazard avoidance fails, the rover minicomputer sends a signal to the lander DAPU, which, in turn, keys the GCSC to begin the emergency hazard avoidance mode listed for class B.

Navigation

The lander GCSC will sequence the landmark navigation technique for all rover classes. The sequence is as follows:

(1) Position camera and scan area

(2) Relay imagery data to DAPU

(3) DAPU relays the imagery data to the MCC

(4) Earth-based personnel using a landmark navigation computer program (LNCP) locate the rover on a terrain map

(5) Rover heading and range corrections are sent to lander

(6) The GCSC receives corrections and relays the new commands to the rover mobility system

Updates must be minimized because of the tremendous amount of imagery data generated by the facsimile cameras, and because the Earth to Mars communication times range from 14 to 19 minutes. A minimum of 50 to 60 minutes would be necessary for a navigation update.

The class C minicomputer will make the calculations necessary for the continuous determination of the position, heading, and attitude, but will depend on the GCSC for occasional updates such as at the sampling sites where lengthy stops exist.

Communication

All the data generated by the rover will be relayed through the lander DAPU. The DAPU will control the flow of the data. The rover imagery data will be generated by the rover camera system at a much higher data rate than feasible for direct transmission to the MCC. A tape system must be used to store the data until transmission is possible at a lower rate.

The GCSC will be in charge of priority decisions to receive rover data for later transmission to Earth or to send it immediately. The GCSC will also be in charge of special communication during an emergency which exists on the rover.

ROVER POWER SYSTEM

The rover power system must provide a dependable supply of electrical energy at rates which vary widely. In addition, a power-handling and distribution unit must be devised to deliver proper voltage and current to each operating instrument on command from the lander or rover computer-controller-sequencer. The most stringent demands on the power system will be the long term of operation under severe environmental conditions.

In the gross definition of the science, mobility, navigation, communication, and computer systems, information on their individual power requirements was generated. From these inputs a power system to supply the electrical needs was chosen. Considerations examined before selecting a feasible rover power system were the anticipated operational modes, the frequency and length of sorties which the rover will travel, the interrelation of traversing, sampling, and analysis, and the extent of imaging needed. The power system interface with the lander was also considered and will be discussed herein.

Operational Modes

The use of power by the rover will vary according to the operational mode under which the rover is operating at any time. Total energy required will be a function of the type mode and its duration. The anticipated modes are: science, mobility, sleep, and emergency.

During each of these modes, activities of the rover will be restricted to particular tasks. This restriction will result in less difficulty in directing the operation of the rover and in better control of its power usage. Obviously, all equipment cannot be operated simultaneously from a power standpoint as well as a practical standpoint.

In the science mode, sampling, sample analysis and handling, and imaging of the sample as well as the local terrain can take place. The mobility, navigation, and hazard detection systems of the vehicle will be active to make small movements necessary to help the scoop gather samples and to maintain positional knowledge of the vehicle.

While in the mobility mode, the vehicle mobility, navigation and hazard-detection systems are operative. In addition, the facsimile cameras are powered as needed for landmark investigation.

The sleep mode is for nighttime operation when the rover is back at the lander. Each night the rover is expected to reside at the power connect-interface with the lander for recharge of the rover batteries. During this time, activity of the rover has ceased and all systems are off except the power system for regulation of the recharge.

An emergency mode must exist during which sections of the rover can be operated in a bypass condition. This mode would allow the mobility, imagery or navigation systems to be operative, but not the science system. Its major distinction is that the normal power distribution circuits will not be used, but a bypass circuit will be available to maneuver the rover out of a failure condition, if possible. After the vehicle is considered to be safe or recovered, the emergency mode is terminated.

Anticipated Energy Requirements

The energy and power necessary to operate the rover can be assessed if certain assumptions and approximations concerning the time-energy use relationship are allowed. The approach used herein was to consider the requirements for the rover energy on a per Mars day basis where one sortie per day is to be the goal. The rover will move to the sampling site in 50- to 100-m segments, sample, analyze, and then return in a similar manner. As described in the preceding section, the rover will operate in power-limiting modes during each day.

It was assumed that the surface mission duration may vary, depending on the class of rover used and the extent of scientific value offered at the chosen landing site. For the purpose of power allocation, the mission was assumed to extend over a minimum of 3 months and a maximum of 6 months. Therefore, the number of sorties under consideration was 90 to 180. The nominal rover operating day was taken as 8 hours, leaving 16 hours per day of nighttime operation. (The class C rover will require a 9-hour operating day to complete a 1000-m range sortie.)

A typical operating day for the class C rover is described in table XVIII and the description illustrates the mission profile anticipated and the use of various operational modes to achieve a sortie of 1600-m round trip distance.

Gross power and energy requirements for operating individual components or subsystems have been tabulated in table XIX for each of the three classes of the rover concept being formulated. The total energies and power requirements were based on anticipated usages per sortie or per 8-hour day since total energy requirements for a battery-powered rover are sized for per day operation with nighttime recharge. Table values include the peripheral electronics required for each component's operation or output. The seismometer expends no operational energy from the rover; however, it must be transported by the rover, and will cost mobility and manipulation energy. Imagery will be required for both terrain scanning and sample surveillance, including the use of the quasi-microscope. The rover can remain somewhat flexible in its schedule of operation and usage of components as long as it does not exceed energy allotment per sortie. Reliability and safety margins must be included in any such energy profile so that the rover is assured of completing its return to the electrical interface of the lander;

TABLE XVIII.- TYPICAL OPERATING DAY – CLASS C ROVER

Event	Event duration, min	Event time completion, hr:min	Power, W	Energy, W-hr
Warmup	15	0:15	30	7.5
Receive Earth command	3	0:18	30	1.5
Navigate segment 0 (on lander reference circle)	2	0:20	31	1.0
Calibrate position	2	0:22	30	1.0
Navigate segments 1, 2, 3, 4, and 5	50	1:12	31	25.8
Stereo imaging	3	1:15	40	2.0
Navigate segments 6, 7, 8, 9, and 10	50	2:05	31	25.8
Stereo imaging	3	2:08	40	2.0
Navigate segments 11, 12, 13, 14, and 15	50	2:58	31	25.8
Stereo imaging	3	3:01	40	2.0
Sampling	6	3:07	48	4.8
Sample handling	1	3:08	31	0.5
Sample analysis (NHD)	10	3:18	26	4.3
Sample analysis (XRFS)	10	3:28	15	2.5
Quasi-microscope	3	3:31	36	1.8
Drill	10	3:42	39	6.5
Sample handling	1	3:42	31	0.5
Sample analysis (NHD)	10	3:52	26	4.3
Sample analysis (XRFS)	10	4:02	15	2.5
Quasi-microscope	3	4:05	36	1.8
Receive Earth update	3	4:08	30	1.5
Calibrate	2	4:10	30	1.0
Navigate segments 16 to 30	150	6:40	31	77.5
Navigate segment 0	2	6:42	31	1.0
Rover docking	3	6:45	31	1.6
Sample transfer	2	6:47	31	1.0
Total				207.5

TABLE XIX.- ROVER POWER REQUIREMENTS

Item	Power requirements for rover class					
	A		B		C	
	watts	W-hr per day	watts	W-hr per day	watts	W-hr per day
Power handling and distribution* . . .	0.5	4	0.5	4	1	8
Communication*	--	--	6	16	6	16
Computer – controller*	0.5	4	0.5	4	10	80
Hazard detection*	--	--	0.5	1	2	15
Navigation*	0.5	1	0.5	1	10	74
Mobility*	2.6	1	2.8	4	4.4	31
Thermal control**	1	24	1	24	2	48
Science*:						
(1) XRFS	1	1	1	1	1	1
(2) NHD	2	1	2	1	2	1
(3) Sampler	15	3	15	3	15	2
(4) Drill	--	--	--	--	15	5
(5) Sample handling	2	1	2	1	2	1
Imaging*	8	1	12	2	12	4
Quasi-microscope (including imaging)*	8	2	8	2	8	2
Average power use	†5	43	†8	64	†36	288

*Values are based on sorties that are 125 percent of maximum assigned sortie radii and the acquisition of four samples.

**Based on a 24-hour day.

†Values based on nearest whole number average power use for an 8-hour activity period.

consequently, emergency mode operations must be considered, battery discharge levels must be assigned with margins (class B and C rovers), and periodic monitoring of watt-hour use is required. The rover computer (on class C rover) and the lander computer will be required to maintain a working status of consumed energy. Some redundancy must be allowed for in the rover power subsystem concept, but this subject was not treated in this feasibility and concept study.

Rover Power Systems

Several types of power systems (energy supply) were considered for the 1979 or 1981 Viking rover concept described herein. Slight variations in power requirements from class to class of the rover complicated the selection of the best energy source. Choices have been made for each class, but these choices were based on a power system technology which is changing rapidly. As new developments become available, other energy system options may appear equally or more desirable.

The power system for the Viking rovers was selected on the basis of mission duration, watt-hour requirement per Martian day, power output, mass, size, complexity, and reliability.

The candidate rover power systems were the RTG, fuel cell, and batteries (ref. 21). Also considered for the class A rover has been the use of an umbilical line which draws energy from the power plant of the lander. The fuel cell was considered to be too heavy and complex to be a serious contender. Small RTG's for use with and without batteries were considered. The SNAP-19 RTG, the only known and applicable small unit, appeared to be too large and too heavy in its present form to be suitable for the rovers. Approximately 20 kg could be allocated for the total power system weight for the class C rover. By very judicious use of RTG peripheral support equipment and with no battery storage, it might be possible to accommodate the SNAP-19 RTG (from a mass standpoint). However, this use would impose a special low power profile on the rover to fit the output of the RTG. Heat rejection and packaging problems would present severe problems.

If the use of any present RTG on the rover is not feasible, two alternatives remained. These were (1) the use of secondary batteries on the rover which are recharged by RTG power on the lander and (2) operation of the rover through an umbilical line from the power system of the lander. For the class B and C rovers, alternative (1), the use of the batteries which can be recharged at the lander, appeared to be more reasonable. This system permits the rover to move independently during the battery discharge period. The class A rover, because of its target mass limitation was considered only marginally able to afford both the battery and communications system weights necessary to achieve independent operation. Thus, it has been designed for the use of an umbilical line for its power and communication. However, the added mass of a cable-handling system necessary to reel the line in or out behind the rover must be traded off against the battery and communications system masses and deserves more study.

Class B and C Rover Power System

The battery system selected for the class B and C rovers is a AgZn type (ref. 22), sized to deliver sufficient energy per charge cycle to sustain the vehicle for one Martian day. A discharge level maximum of 60 percent was used with a 25-percent safety margin. The watt-hour capacity which must be provided by the batteries for each rover was approximated. Battery weights are based on a current design and its test data (ref. 23). Power system data are presented in table XX for the class B and C rovers. These rovers must return to the lander at least once per day (or sortie) to recharge the batteries. Mobility system reliability must take into account that the rover will fail if it cannot make a daily electrical interface with the lander. It is anticipated that this electrical lockup can be effected at the point about the lander at which the rover would normally transfer its samples to the lander; that is, on the lander sampler side. Recharge of these batteries can be made for much better than 90 times without appreciable battery capacity loss, but some degradation can be expected for 1/2 year or greater missions. By using solid-state power controls and few operating instruments, the complexity and weight of this distribution and conditioning equipment can be kept low. Estimates for these components are included in table XX.

TABLE XX.- ROVER POWER SYSTEM VALUES

	Values for rover class		
	A*	B	C
Consumable energy required per day, W-hr	43	64	288
Residual battery energy (at 60-percent discharge), W-hr	29	43	192
Safety margin on battery (25 percent), W-hr	18	27	120
Total energy of source (ideal), W-hr	90	134	600
Average nighttime charging rate required (16 hr), W	2.7	4.0	18.0
Number of 40 A-hr batteries (ref. 23) required (60 W-hr battery)	2	3	10
Total energy of source (actual), W-hr	120	180	600
Total battery mass required, kg (0.85 kg/battery)	1.7	2.6	8.5
Estimated power conditioner mass, kg	0.1	0.2	0.2
Estimated power distribution mass, kg	0.3	0.4	0.5
Total system mass anticipated, kg	2.1	3.1	9.2
Total system volume required, cm^3	1200	1700	4500

*For comparison only; concept A is expected to use an umbilical cable.

Class A Rover Power System

Data on a battery-powered class A rover have been included in table XX as a matter of interest. However, it is conceived to use power direct from the lander carried through an umbilical cable. Further study is advisable on the trade-offs between cable-fed direct lander power and secondary battery power.

Brief studies of the anticipated weights for cables and cable-handling systems have been made. Tests were made to determine dielectric breakdown voltage, thermovacuum characteristics, and resistance, of 26- to 32-gage (AWG) wires (ref. 24). It was found that the best candidate for spacecraft hookup wire was a polyimide tape wire weighing about 0.01 kg/m for two conductors.

The exploratory radius of this rover has been limited to 50 meters principally because of the constraints presented by an umbilical line. This class of the rover concept is less flexible than class B and class C, but may prove to be sufficient to meet the specific goals for the 1979 or 1981 Viking mission, which have yet to be defined in detail.

It may be determined that the 1979 or 1981 Viking lander is the preferred location of energy storage and will therefore be provided with sufficient RTG power to energize all surface activity including rover mobility and sampling.

Anticipated 1979 or 1981 Viking Mission Surface Power Requirements

Power will be required to support lander science instrumentation and supporting subsystems, lander communications, lander sample processing, and the sampler itself. Imaging has been included with science. In addition to these items, many of which are in existence and basically unchanged from the 1975 Viking mission, power will be required for rover operation. It is the intent here to assess on a gross basis the overall increase in power requirement necessary for a 1979 or 1981 Viking mission which includes a rover utilized in the manner proposed herein. The purpose is to foresee requirements imposed on candidate power systems.

Onboard science instrumentation, appropriate to the needs and weight-space capabilities of a future Viking lander, have been discussed previously in the science section. These science instruments represent an increase in power consumption of less than 20 watts over those of Viking 1975 (Contract NAS 1-9000). Power requirements for communications will increase slightly because of the link with the rover (5 watts). Computer requirements will increase because of expanded size and fuller use (10 watts). The sampler power will not increase although it may be used more frequently. The sample distribution and handling subsystem will undergo changes to accommodate slightly different requirements, but it is assumed that its operating power will not change significantly. The proposed rover will add a new power requirement on the surface mission. It was shown previously (table XX) that rover requirements will be 43, 64, and 288 watt-hours per day for the class A, B, and C rovers, respectively.

The increased power and energy requirements for the 1979 or 1981 mission can now be summarized. (See table XXI.) Lander energy requirement increases were calculated by assuming the use of power for an 8-hour duty cycle per Martian day.

TABLE XXI.- POWER AND ENERGY INCREMENTS REQUIRED

	1979 or 1981 power increment, W	1979 or 1981 energy increment, W-hr/day, for rover class –		
		A	B	C
Lander science	20	160	160	160
Lander communications	5	40	40	40
Lander computer	10	80	80	80
Rover	--	43	64	288
Total energy increment, W-hr/day . . .		299	320	544
Average power increment/24 hr, W . . .		12	13	23

A worst case average power increment/24 hr value of 25 watts was assumed for a very severe case where the class C rover is used and lander science, computer and communication systems are also active simultaneously during the daytime operation. Likewise, a worst case value of 15 watts was assumed for the class A rover use. With a nominal 70-watt output for Viking 1975 RTG, this value brings the anticipated 1979 or 1981 mission gross power requirements to a total of approximately 95 watts or 85 watts, respectively.

For the gross assumptions used here, the 70-watt output of the two SNAP-19 RTG units on Viking 1975 has been shown to be too low by 21 to 36 percent to meet the proposed increase of a 1979 or 1981 Viking mission. Several options were available to increase the power output to the vicinity of the 85 to 95 watts mentioned previously. The two SNAP-19 RTG units presently planned for Viking 1975 can be augmented with yet another SNAP-19, or a newer SNAP-19 RTG design can be selected which incorporates a higher specific power rating and a power output sufficient to handle the 1979 or 1981 requirement. Alternately, one large high power RTG can be used which has high efficiency and ample power. This mode, suggested in the early sections of this paper, allows the area vacated by a SNAP-19 to be used for the rover envelope. It should be noted that the rover design described herein and its location on the lander are predicated on this choice. This approach was selected because of the lack of the availability of small RTG units which were suitable. A 150-watt RTG (ref. 25) which is an advanced SNAP-19 type has been under development by the Atomic Energy Commission since June 1972. The program is scheduled to provide flight-ready RTG units for planetary missions by the mid-1970's. Somewhat lower power level versions of this unit can also be fabricated. Such units provide ample power for a 1979 or 1981 mission and would be compatible with the Martian environment. However, the Viking lander design would require a radical change in its thermal design to accommodate this unit. These trades present difficult decisions which will be heavily affected by costs.

CONCLUDING REMARKS

The feasibility of transporting, landing, and deploying a small Mars rover using a Viking 1975 spacecraft was examined and a preliminary rover design concept was generated. The design concept was developed in three variations to allow comparisons between rover mass and complexity.

It was found feasible to transport and land small rovers of well over 100-kg mass. Such rovers also can be stowed and deployed by the lander vehicle without radical reforming of the Viking lander afterbody. This can be accomplished by replacing the two Viking 1975 RTG units with one updated higher power RTG and placing the rover on top of the lander where one RTG has been removed. An upgraded RTG may require a bulge in the lander afterbody depending on the power level selected.

The rover science concept was oriented toward a geoscience type of mission. The rover will perform remote, in situ surface sampling, and cursory analyses. The analyses consist of inferred water detection, elemental analysis, magnetic properties, and quasi-microscope sample viewing. Samples of warranted interest can be returned to the lander for detailed analysis. Facsimile cameras will permit morphological studies and multispectral analysis of the rover surroundings. One variation of the rover concept will have a subsurface drill and the capability to carry and deploy seismometers away from the lander and emplace seismic explosive packs at remote points.

The three rover concept variations have masses of 35 kg, 40 kg, and 69 kg, but each was configured the same to fit the available stowage envelope. The three rovers were designed to travel radial distances of up to 50, 200, and 1000 meters from the lander during a Mars day. The smallest of the rover designs (class A) would receive its power directly from the lander through an umbilical cable. From a weight standpoint this power concept has little advantage over a AgZn battery system for the class A rover. The remaining two rover designs (class B and C) can easily perform independently from the lander for 1 day at a time by the use of secondary AgZn battery systems while performing their sorties. They must depend on the lander power system, however, as a primary energy system for recharge. The lander must have an upgraded RTG system to handle this recharging plus other increased demands for the 1979 or 1981 mission.

Communications rates for 1979 or 1981 between lander and Earth must be raised to accommodate an increased data and command load produced by the rover operation. This increase appears to be possible by changing to X-band and by using higher power TWT amplifier in the lander transmitter. The class A rover will transmit information to the lander and recieve commands from the lander through the umbilical cable also used to supply power. The class B and C rovers will have a direct VHF link to the lander for communication.

The lander guidance and control sequencing computer (GCSC) has been determined to be adequate for controlling the science, mobility, power, and communications systems of the class A and B rovers. As presently conceived, the class C rover would house a minicomputer to interface with the lander GCSC. The minicomputer would control the rover's mobility, hazard detection and avoidance, inertial navigation systems, and would monitor the rover power system. The GCSC would sequence the science and communication systems of the class C rover.

It has been a primary goal during this concept study to hold the requirement for advanced technologies to a minimum. Little new technology development beyond that in progress for the 1975 Viking mission appears to be necessary. The X-ray fluorescence spectrometer can be expected to achieve flight-ready status because of the efforts for Viking 1975 with only minor modification required for use on the rover. The neutron hydrogen detector would require more developmental effort. The miniaturized facsimile camera requires design modification to overcome certain performance problems. The quasi-microscope should not present a technology problem.

Modifications to the 1979 or 1981 lander which may be desirable and may require technology advancements include wet chemistry, alpha backscatter spectrometer, X-ray diffractometer, and the seismic experiment. Rover technology advances which are desirable, but not necessary for a 1979 or 1981 mission, are in the following areas:

(1) In situ age dating

(2) Improved directional navigators

(3) Improved active hazard detection systems

(4) Miniaturized guidance and control computers

(5) Adaptive control capability

(6) Miniaturized imagery systems

The use of "artificial intelligence" on the 1979 or 1981 mission rover is highly questionable. It is desirable to send rovers to Mars with a versatile and intelligent control capability enabling them to perform scientifically and safely, with a minimum of earth control; however, this technology base in computer architecture is not anticipated for active rover use before the mid-to-late 1980's. Earlier rover designs must, therefore, operate with less autonomous activity, but will use a state of computer art which is advanced several years over that which currently exists. Both institutional research groups and NASA are pursuing the application of artificial intelligence to rover guidance and image analysis.

In summary, a 1979 or 1981 Viking mission using a class A, B, or C rover can provide a viable exploratory capability with very little new technology. After examining the rover-lander interfaces, it appears that the lander if modified slightly can provide all supportive requirements for the rover. These include the power, computer, and communication needs of the rover. Given this support, the rover can provide the sampling and initial sample analyses for the lander and may help in the deployment of seismometers and the distribution of seismic explosive packs.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., November 26, 1973.

APPENDIX A

TOPOGRAPHY OF THE POLAR REGIONS OF MARS

A landing near the edge of the polar regions of Mars is one of current interest for the Viking 1979 or 1981 mission (60^{o} latitude). The outer part of the polar caps is covered mainly by CO_2 with possibly some H_2O in frozen form (ref. 26). During the summer months as the cap recedes and the H_2O vaporizes, some may remain in a liquid state. Free water can exist on Mars in thermally protected areas. Since the polar regions have a possible source of water, they are of particular interest for scientific investigation. The southern hemisphere of Mars will be experiencing its spring-summer cycle and the northern hemisphere its fall-winter cycle during the anticipated Viking 1979 or 1981 surface mission. (See fig. 21.) The actual area to be explored will be determined by a science panel after a complete analysis of the data provided by the Viking 1975 mission.

There are three general types of Martian terrain: cratered, chaotic, and featureless. (See refs. 27 and 28.) The polar caps consist of cratered terrain, and except for minor amounts of moisture held by capillary tension, it is thought to be dry. Craters in the polar areas are as abundant as, and like in appearance to, craters in other areas which are not seasonally frost covered. Slopes in this area appear to be no greater than 5^{o}. (See ref. 29.) It appears that the mobility of the small four-wheeled rovers being considered for the Viking 1979 or 1981 mission should not be hampered by the slope height and crater frequency in this area.

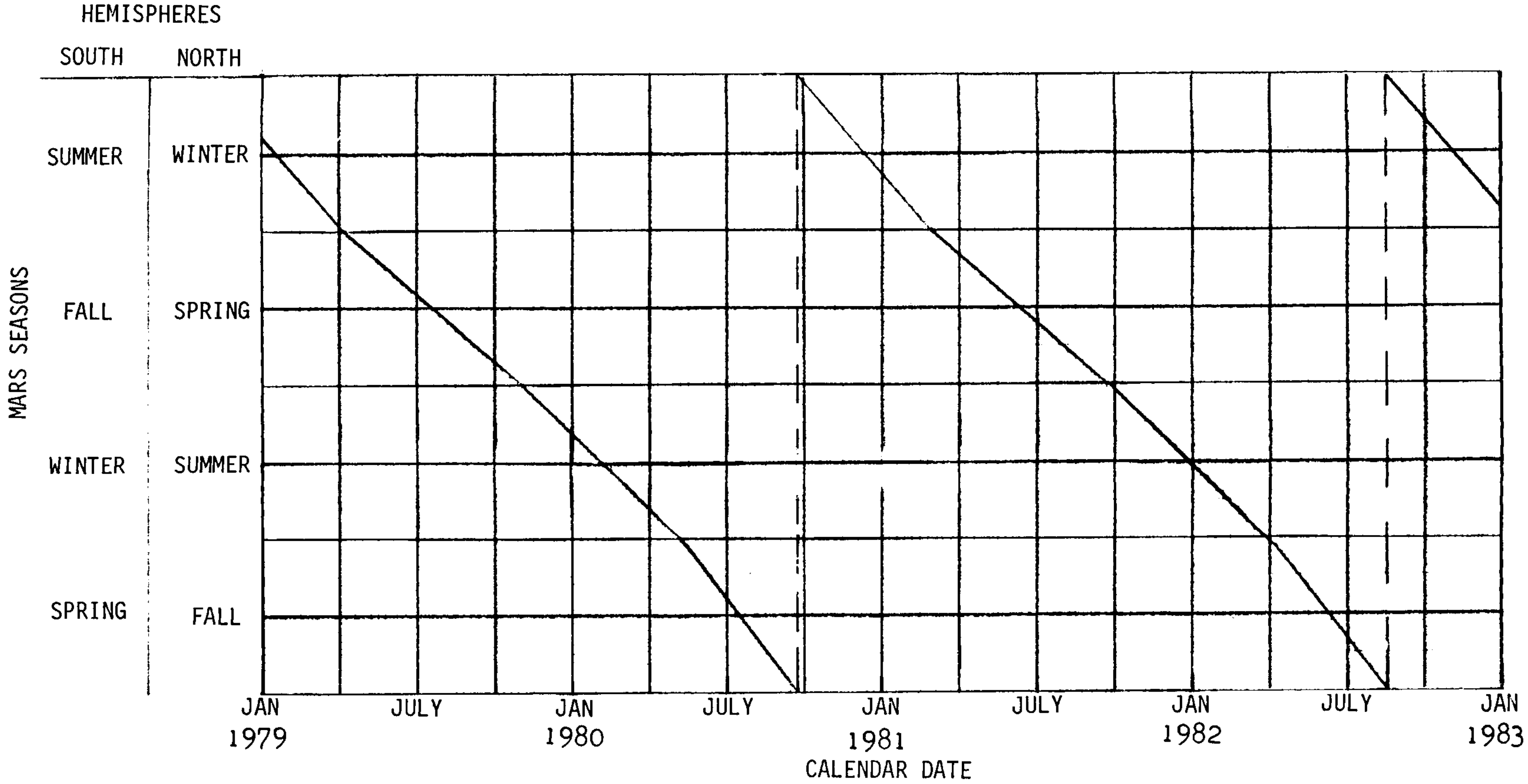


Figure 21.- Mars seasonal variation as a function of Earth year.

APPENDIX B

ROVER MOBILITY POWER AND ENERGY CALCULATIONS

The forces opposing the rover's thrust consist of rolling resistance, surface geometry resistance, and acceleration resistance. Rover rolling resistance $\left(R_R\right)$ consists of the internal $\left(R_I\right)$ and external resistance $\left(R_E\right)$ of the flexible wheel plus the internal bearing friction, that is, $R_R = R_I + 4R_E$.

Internal resistance R_I is calculated by the following equation (ref. 11):

$$R_I = f_t\left(Mg_{Mars}\right)$$

The unit coefficient of rolling resistance f_t of a flexible wheel due to bearing friction and wheel deflection is found by experience to average from 0.010 to 0.020. The M in this equation is the rover mass in kilograms (35, 40, 69) and g_{Mars} is Mars gravitational acceleration.

External resistance per wheel is calculated by using the following equation (refs. 30 and 31):

$$R_E = \frac{\left[b\left(P_i + P_c\right)\right]^{(n+1)/n}}{\left(k_c + bk_\phi\right)^{1/n}(n + 1)}$$

where, in this case,

b	wheel contact width 5.7, 5.8, and 7.6 cm for the class A, B, and C rovers, respectively
P_i	unit pressure on ground due to internal pressure $P_i = 0$ for wire wheel
P_c	unit pressure on ground due to carcass stiffness $P_c = 0.517\ \mathrm{N/cm^2}$ (ref. 11)
n	sinkage exponent (1)
k_c	cohesive modulus of deformation ($0\ \mathrm{N/cm^2}$)
k_ϕ	friction modulus of deformation ($0.27\ \mathrm{N/cm^3}$)

The resistance to rover thrust due to geometry R_G is produced by grade and obstacle resistance. The grade resistance R_g is calculated in the following manner (ref. 11):

$$R_g = \left(Mg_{Mars}\right)\sin\theta_s$$

where

M	mass of rover (35, 40, and 69 kg)
θ_s	longitudinal slope (7.5°)
g_{Mars}	Mars gravitational acceleration (3.72 m/sec^2)

The grade resistance is the same for rigid wheels, flexible wheels, or tracked vehicles. Surface factors, obstacle shape, vehicle configuration, speed, and suspension must be well known before obstacle resistance can be calculated. For a preliminary analysis, all other resistances were summed and 5 percent of this total was assumed for obstacle resistance R_o. This value is added to the grade resistance to obtain the geometry resistance, R_G; that is, $R_G = R_g + R_o$.

The acceleration resistance R_{acc} for the rover is computed by the following equation (ref. 31):

$$R_{acc} = C_F Ma$$

where

C_F	mass factor which adds the inertia effect of rotating equipment to the translational mass (1.2 is a good average value)
M	rover mass (35, 40, and 69 kg)
a	rover acceleration limit (0.10 m/sec^2)

Results of the rolling, geometry, and acceleration resistance computations for each rover class are presented in table IX.

Mobility energy and power requirements were examined for the failure case where one wheel is assumed to be locked. The remaining three motors must then provide the normal power requirement plus the power to overcome one-fourth of the maximum tractive force or locked-wheel drag. The maximum tractive force was calculated by using the following equation (ref. 30):

$$F_t = \left(Mg_{Mars}\right)\tan \phi$$

where

M	mass of rover (35, 40, and 69 kg)
ϕ	angle of internal friction (35°)
g_{Mars}	Mars gravitational acceleration

The increased bulldozing resistance from the locked wheel must also be computed. Bulldozing resistance R_b was calculated in the following manner (ref. 10):

$$R_b = \frac{b \sin (\partial + \phi)}{2 \sin \partial \cos \phi}\left[\gamma Z^2\left(\frac{2N_\gamma}{\tan \phi} + 1\right)\cos^2\phi + 2ZC\left(N_c - \tan \phi\right)\cos^2\phi\right]$$

$$+ \frac{\pi\left[Z \tan^2\left(45 - \frac{\phi}{2}\right)\right]^3 \gamma(90 - \phi)}{540} + \frac{C\pi\left[Z \tan^2\left(45 - \frac{\phi}{2}\right)\right]^2}{180}$$

$$+ C\left[Z \tan^2\left(45 - \frac{\phi}{2}\right)\right]^2 \tan\left(45 + \frac{\phi}{2}\right)$$

where

$$\partial = \cos^{-1}\left(1 - 2\frac{Z}{D}\right) = 31.8^{\circ}$$

$$Z = \left(\frac{P_i + P_c}{\frac{k_c}{b} + k_\phi}\right)^{1/n} = 1.9 \text{ cm}$$

γ	unit weight of soil (1.5 g/cm^3)
C	cohesive force (5×10^{-4} N/cm^2)

N_γ	soil stability factor (25)
N_c	soil stability factor (40)

The energy and power requirements for the class A, B, and C rovers when one wheel is assumed to be in a locked position are presented in table XI. A 50-percent gear-motor efficiency was assumed to determine the final mobility requirements presented in table XI.

APPENDIX C

CALCULATION OF ROVER OBSTACLE CLEARANCE CAPABILITY

The purpose of this appendix is to present the analytical technique used to determine the obstacle clearance capability of the rover. This analysis does not consider power or tractive requirements, but relates to vehicle stability and geometry such as the ground clearance and chassis hangup height for positive and negative vertical steps. This is important when the negotiability of surface protrusions and depressions is being considered.

Ground clearance for the rovers as designed was 12.7 cm when the small loss due to wheel deflection is neglected. If the rover chassis is to clear either a positive or negative vertical step of height Z with width at least as great as that of the rover wheel base, the relationship stated below must be satisfied (ref. 31)

$$\frac{S}{R} < \frac{\sin \theta + \cos \theta}{\sin \theta \cos \theta}$$

where

S	wheel base, 41 cm
R	wheel radius, 12.7 cm
Z	obstacle height, 18 cm

$\theta = \sin^{-1}(Z/S)$

Calculations made by using this equation showed that an 18-cm step is the largest which can be negotiated without causing chassis hangup. However, vehicle performance causes a large reduction in this number. If a 0.6 coefficient of friction and a center of mass located 38 cm from the rear of the rover, 15 cm up from the plane of the axle, and 36 cm inward from the outer side of the wheel is assumed, the maximum step-ditch obstacle height is found to be 5 cm. This value can be found in figure 22 which is extracted from reference 12.

Sideslipping occurs when the lateral frictional force F_{fric} developed by the wheels is equal to or less than the centrifugal force imposed on the vehicle because of turning; that is, $F_{fric} \leq \frac{MV^2}{r_c}$ where V is the rover velocity. If a 91-cm turning radius and a 0.6 coefficient of friction μ is assumed, the sliding velocity was calculated (ref. 10) as

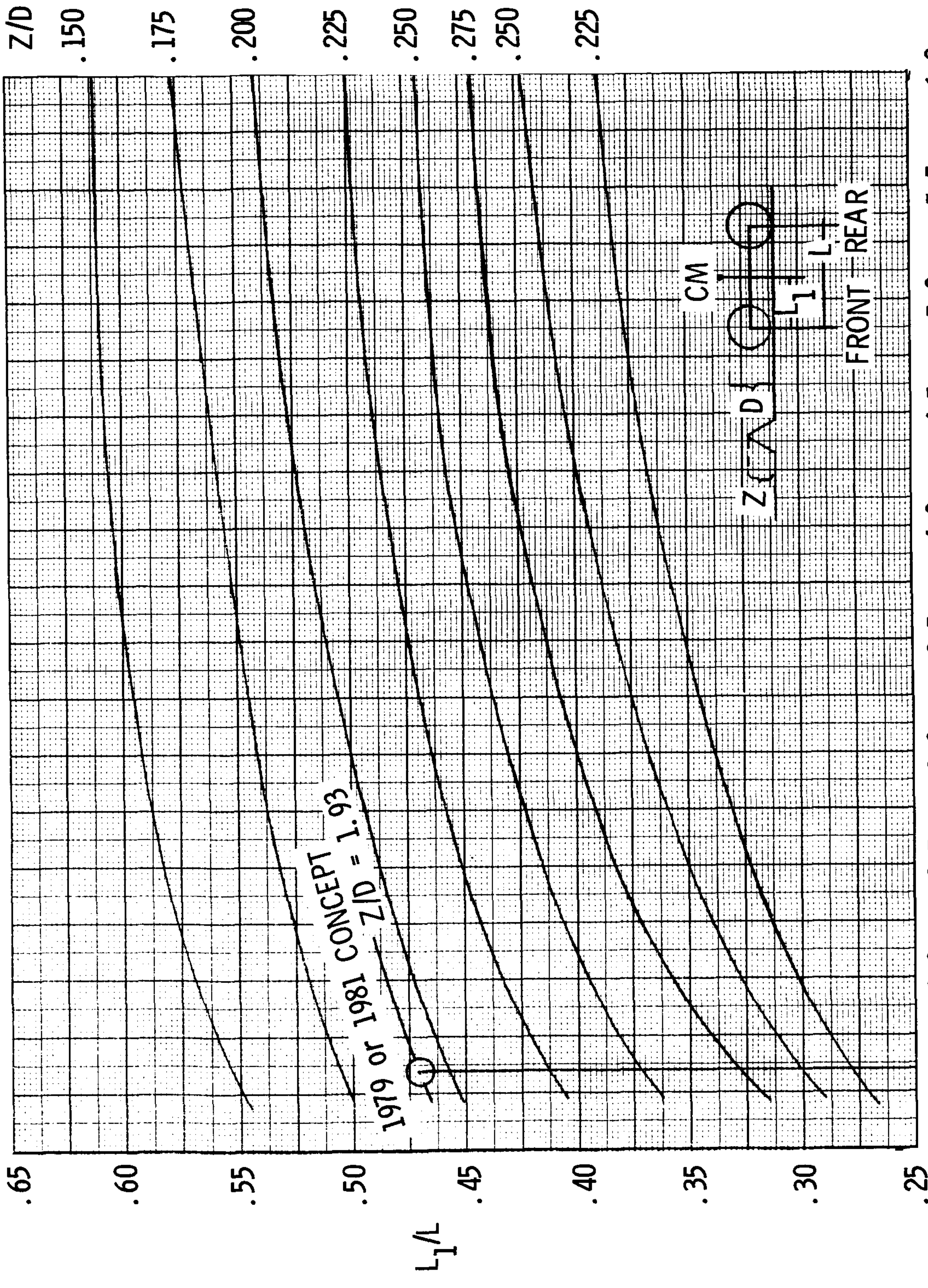
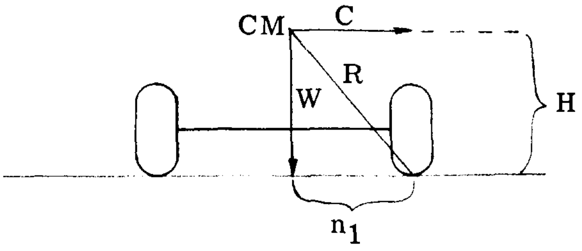


Figure 22.- Lines of constant obstacle height and wheel diameter ratio (Z/D) for μ = 0.6.

$$V_s \geqq \sqrt{g_{Mars} r_c \mu} \geqq 5.16 \text{ km/hr}$$

Tipping of the rover on a curve is experienced when the resultant of the centrifugal force and the rover weight passes beyond the point of contact of the outboard wheels with the ground; that is, $W(n_1) - C(H) = 0$. (See sketch (a).)



Sketch (a)

The velocity required to provide a tipping force while turning V_t can be calculated as follows (ref. 10):

$$V_t = \frac{\sqrt{g_{Mars} r_c n_1}}{H}$$

where

g_{Mars}	Mars gravitational acceleration (3.72 m/sec^2)
r_c	turning radius
n_1	distance from plane of wheel center to cm location
H	height of center of mass (CM) from ground

Tipping was calculated to be 7.08 km/hr when the CM previously defined is assumed.

Stopping or braking distance needs also to be defined before an obstacle avoidance technique can be determined. The minimum stopping distance D_s for all wheels braking on a level surface is calculated as follows (ref. 11):

$$D_s = \frac{V^2}{2g_{Mars}\mu} = 0.2 \text{ cm}$$

where V is the rover velocity (0.35 km/hr).

The various obstacle avoidance factors investigated and the components defining a nonnegotiable obstacle are summarized and presented in table XII.

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