Contract NAS1-12425

NASA CR-132418

Volume II

Detailed Technical Report

March 1974

Viking '79 Rover Study Final Report

(NASA-CR-132418) VIKING '79 ROVER STUDY.
VOLUME 2: DETAILED TECHNICAL REPORT
Final Report (Martin Marietta Aerospace,
Denver, Colo.) 404 p HC $23.25 CSCL 13F
N74-19889
Unclas
G3/11 34382

MARTIN MARIETTA

NASA CR-132418

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Detailed
Technical
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Viking '79
ROVER
STUDY

Final Report

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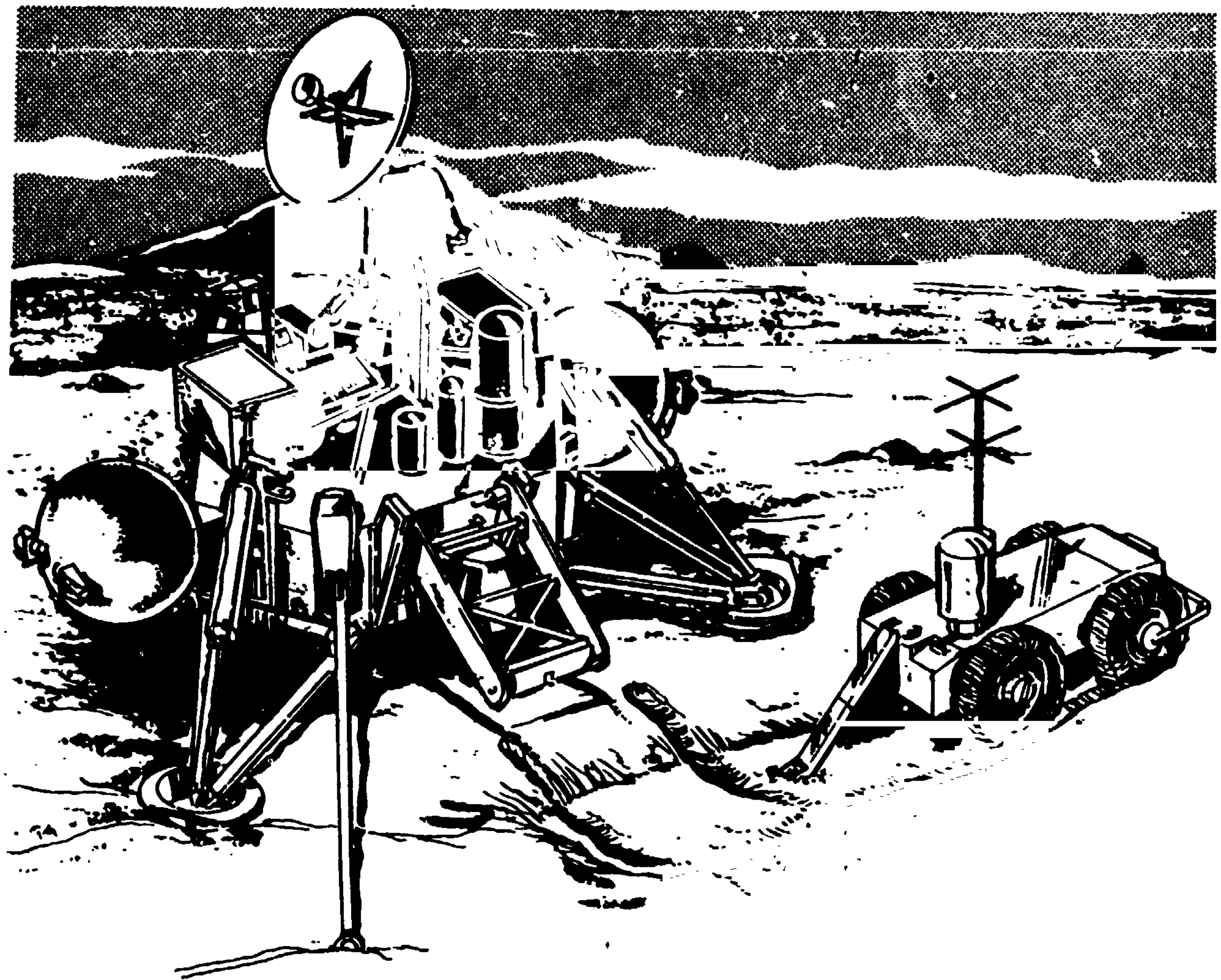

FOREWORD

This is the final report on a Viking '79 Rover Study, performed by Martin-Marietta Aerospace.

This study was performed for the Langley Research Center, NASA, under Contract NAS1-12425 between June 27, 1973 and March 27, 1974. Mr. Wayne L. Darnell of the Langley Research Center was the Technical Representative of the Contracting Officer.

This final report consists of two volumes:

Volume I - Summary

Volume II - Detailed Technical Volume

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1. SUMMARY

Introduction

This report summarizes the results of a study performed by Martin Marietta Aerospace for the NASA Langley Research Center to define a roving vehicle suitable for inclusion in a 1979 Viking mission to Mars. Although Mars rover missions have appeared regularly in proposed plans for the 1985-1990 time period, recent studies by the National Aeronautics and Space Administration's Langley Research Center and by Martin Marietta Aerospace have indicated that spare and proof-test Viking '75 lander hardware could be used as early as 1979 for missions to Mars with roving vehicles added to the landers. This evidence of an early, feasible, and cost-effective opportunity to perform Mars rover missions led to the study described in this report.

The study focused exclusively on the 1979 mission incorporating a rover that would be stowed on, and deployed from, a modified Viking lander. The overall objective of the study was to define a baseline rover, the lander/rover interfaces, a mission operations concept, and a rover development program compatible with the 1979 launch opportunity. During the study, numerous options at the rover system and subsystem levels were examined and a baseline concept was selected. Volume I of the Final Report presents the selected concept and Volume II presents all facets of the study including the analyses of those system and subsystem concepts that were examined enroute to the selected baseline rover.

Launch vehicle, orbiter, and lander performance capabilities were examined to ensure that the baseline rover could be transported to Mars using minimum-modified Viking '75 hardware and designs. The results of these analyses are presented in both report volumes and the detailed technical derivations are given in Volume II.

The remainder of this chapter briefly discusses the highlights of the study and its conclusions. The remaining chapters expand upon this material in greater detail. Volume I summarizes the analyses and results discussed in depth in Volume II.

Science Requirements

Through the eyes of Mariner 9, the planet Mars has emerged to be truly the dynamic, diverse, and complex world suspected by astronomers of old. Canals and oceans are lacking, and the inhabitants are believed to be microbes rather than an advanced civilization, yet Mars is of no less scientific interest. In place of canals, we see channels with braided and tributary substructure. Instead of oceans and continents, we see vast plains, plateaus, and multilayered sediments scarred by craters and global-scale fault networks. We see mountains that are higher and canyons that are deeper than those on Earth. The view of Mars now emerging from the analysis and interpretation of Mariner 9 data is one of a planet with a history of volcanic activity, crustal deformations, violent windstorms, alternate burial and excavation of landforms, and major climatic upheavals. The discovery of dendritic and complex channels provides new evidence favoring the hypothesis that liquid water covered at least part of the planetary surface in the past. This, in turn, greatly increases the chance of the genesis and evolution of life forms and the development of an *in situ* organic chemistry.

All these major new discoveries are undoubtedly just the tip of the iceberg. With the landing of the Viking spacecraft on the Martian surface in 1976 and the probable landing of several Soviet spacecraft between now and then, it seems safe to predict another major advance in scientific knowledge of our neighboring planet, with expectations of major surprises. Now that the Viking lander system is reaching maturity in its development, it is appropriate to consider how this technical resource can best be applied to the post-1975 exploration of Mars.

The primary goal of Viking '79 will be to capitalize on the scientific results of the Viking '75 and Soviet landers to further extend our knowledge of Mars. The diversity of the Martian surface offers many opportunities for fruitful exploration, especially because of the geologic richness of the surface, but also because the strong interplay between geologic and atmospheric factors on Mars may well result in isolated ecological niches in which Martian organisms yet survive.

Finding such niches and exploring a large variety of geological features with landed missions alone would require many, many landings because of the limitations of the present Viking sampling capability. A rover, however, could adequately explore such areas and accomplish the desired level of exploration. A rover equipped with the proper type of science experiments would greatly expand our ability to understand the Martian surface. For example, a rover with a range of 50 km could survey with its cameras an area more than 230 times greater than that which could be viewed by the '75 lander at resolution of one meter or less. Of even greater significance is that it would have an area from which to sample that would be 250 million times as large as the area that can be reached by the present Viking surface sampler head. These large increases in sampling and observation are potentially of great consequence because of the knowledge that Mars is heterogeneous on a large scale and the expectation that this variability will be proved also on a small scale.

Many key scientific questions can be posed but some of the major ones concern the history of Mars in a cosmogonic sense and particularly as it applies to the possible evolution of life forms on this, the only terrestrial planet that appears similar enough to Earth to allow this possibility. An important consideration is the present existence and past abundance of liquid water on the surface of the planet. Also, there is the consideration of whether or not Mars may have been through a geologic evolution within its bulk and on its surface similar to Earth. This is the question of tectonic activity and the motion of large areas of contiguous material of surficial crust (plates). Such dynamics do not exist on the Moon, but are the major factor in shaping of Earth crustal geology and its dynamics.

The foregoing ideas pose five scientific questions:

Has Mars been through an aqueous climatic phase?

Does free or loosely-bound water exist on Mars today?

What processes have formed and shaped the Martian crust?

Does plate tectonics apply to Mars?

Do biological organisms or organic compounds exist on Mars?

A rover can assist in answering the questions by performing the following functions:

Reaching predetermined target areas,

Exploring the surface terrain,

Collecting samples and returning them to the lander for analysis by lander-based instruments,

Conducting dual-station science between the rover and lander or rover and orbiter,

Deploying sensitive instruments away from the lander.

These functions represent potential basic requirements, some or all of which will be imposed on the Viking '79 rover depending on the scientific payload selected.

The above discussion is intended to provide a cursory survey of some of the science objectives and requirements that will affect rover design. In the final analysis, it will be the detailed selection of mission objectives and an instrument complement that will dictate specific requirements for the Viking '79 rover.

Design Criteria

It was necessary to establish key design criteria early in the rover study to define boundaries within which the selected rover and lander integration configurations must fit. These criteria are summarized in the following statements:

Spare and proof-test (PTC) lander hardware will be used with only necessary modifications.

The rover will be stowed on the lander and off-loaded after arrival on the Martian surface.

The rover must be capable of operating in the environments and under the same surface conditions for which the Viking '75 lander is designed.

The rover and any new hardware necessary for integration shall be designed with a 20 percent mass, power, and volume margin.

The center of mass (c.m.) for the lander/rover entry configuration shall be located radially 4.19 ±0.38 cm from the centerline and no farther aft than 89 cm from the aeroshell theoretical apex (including uncertainties), to obtain the proper Viking '79 entry performance.

The rover shall be designed for a surface operation period of at least 90 days, which can be extended (precluding failures) simply by increasing the Mission Operations period.

Baseline Rover System Description

The baseline system evolved from many concepts considered during the study and was developed to support a science payload recommended by a NASA science planning group chaired by Dr. I. Rasool.

The Rasool committee's payload consists of a Viking '75 facsimile camera and window duster, an alpha backscatter spectrometer, an X-ray diffractometer and grinder, and a scoop sampler.

The rover, based on Viking '75 technology to minize development risk, is shown in the Frontispiece as it would appear shortly after separation from the lander. Having erected the camera to its operating position, the rover has moved a few meters away from the lander and is ready to begin its scientific mission.

The rover has been designed with the capability to support the lander mission while within communication range of the lander. Rover support includes returning soil and rock samples to the lander for analysis and transmitting camera pictures including long base stereo pictures to the lander for storage and retransmission to Earth. In addition, the rover can perform a scientific mission completely independent of the lander, having the capability to travel many kilometers from the lander and communicate to the Earth via the orbiter. Earth commands can be relayed to the rover through either the lander or the orbiter.

Power is provided by a new 20-watt selenide thermoelectric RTG. A battery composed of Viking '75 cells is used to handle the peak loads. Thermal control of the rover is achieved by taking heat from the RTG through a Viking '75 type thermal switch to an isothermal plate on which all electronic assemblies are mounted.

A directional gyro/gyrocompass is used as a navigation heading reference. Wheel odometers are used to calculate distance traveled. Hazard sensors are used to detect rocks, holes, and excessive slope conditions, thus allowing the rover to travel hundreds of meters per day on command from earth without direct manual control from earth.

A control sequencer and memory controls the rover operational sequences based on stored sequences, ground commands, and real-time inputs from onboard sensors. A data processor buffers and formats the science data for transmission to Earth. All electronics are packaged together into a single Integrated Electronics Assembly.

The rover is configured with a single, rigid body compartment, as shown in Figure 1. The rear axle is articulated with respect to the chassis using a roll gimbal. Simple scuff steering is used.

Lander modifications that are required to accommodate the rover are the removal of one camera, installation of new RTGs, relocation of the surface sampler, installation of a new base cover, deletion of meteorology and XRFS, addition of a UHF two-way communications system, and addition of a pressure regulation system for the terminal descent propellant system. Because of the shift in the c.m. of the VLC due to the addition of the rover, components mounted to the aeroshell are also relocated. Other lander science changes include removal of biology instruments and the addition of new biology and X-ray diffractometer instruments.

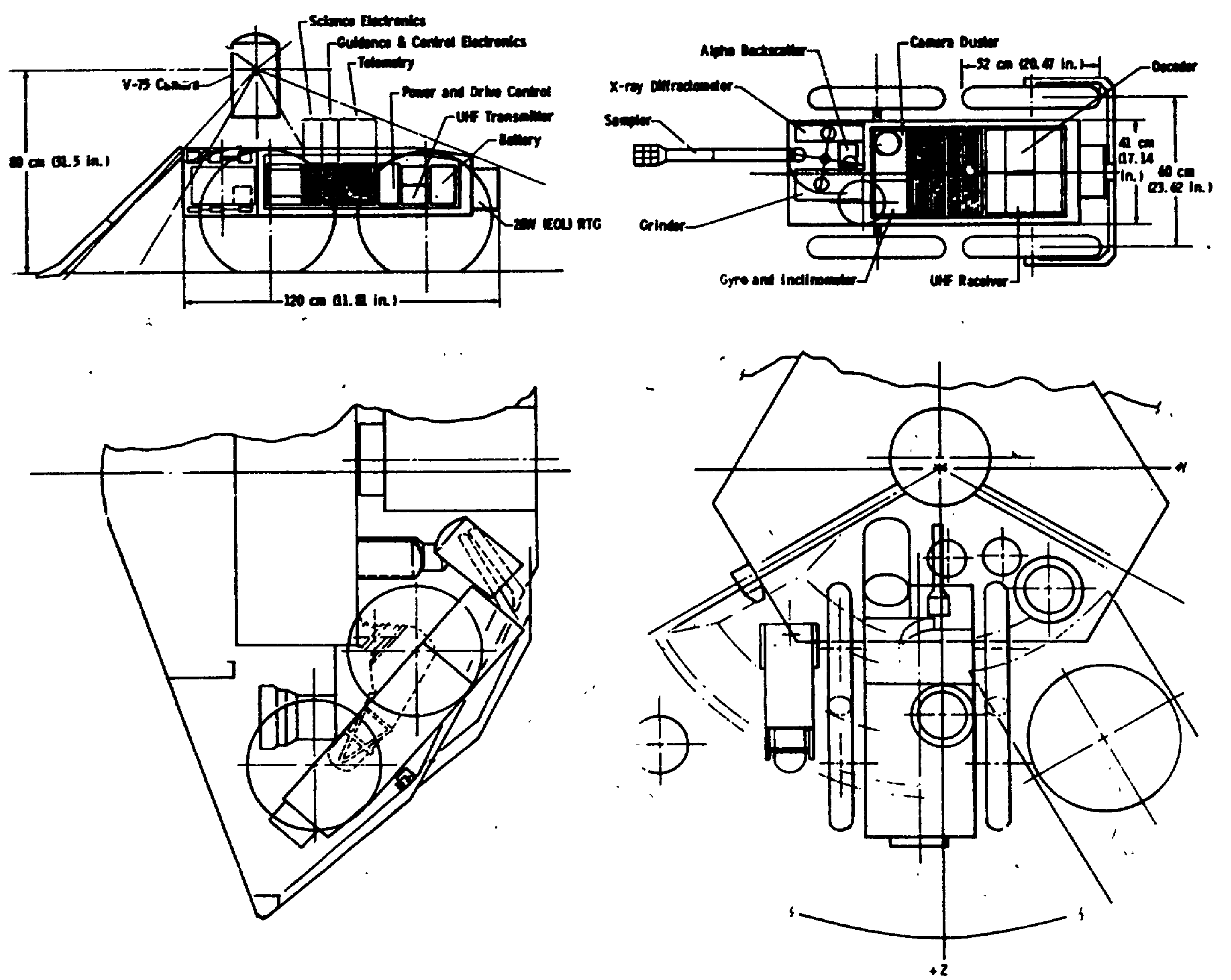


FIGURE 1 BASELINE ROVER SYSTEM

Required Technology Developments

The preliminary design of the rover system concentrated on designs that would yield a rover that could fit within the volume and mass constraints imposed by the existing Viking Lander System. In the process of looking at the various configurations and examining the associated subsystems, a number of approaches to hardware implementation were identified that would meet the requirements. Two categories of technology developments were investigated. One category is the technology that was required and included in the baseline configuration to satisfy the basic design requirements and the second category is the technology that, if adopted, would further optimize the rover system.

Developments that are included in the baseline rover are:

Radioisotope Thermoelectric Generators using selenide thermoelectric materials.

Miniaturized directional gyro/gyrocompass.

Adaptive controls using requisite hazard sensors and control sequencer software subroutines.

Technology developments that are not included in the baseline design, but that would significantly improve rover performance if adopted are:

Resonant circuit switching converter to minimize high frequency switching losses.

Hybridized circuits containing C/MOS chips.

Also identified in the preliminary design of the rover were technical areas that need additional study to fully understand the impact on the rover development. These include:

Polar ice-cap operation - if in the polar ice-cap operation is required.

Rover-to-lander soil transfers.

Rover Development Plan

The rover development plan (based on launches in 1979), which includes rover integration on the lander, is shown in Figure 2. This plan has been constructed to be compatible with the Viking '79 baseline plan, e.g., qualification of the rover is completed coincident with the start of VLC flight article assembly and test, and first flight rover delivery is immediately before lander encapsulation, because flight acceptance tests and modifications to the lander for rover integration are coincident with refurbishment of baseline lander components. Also, in the interest of minimizing the required program funding before FY 1977, the rover development program has been scheduled as late as practical.

A 36-month time span is planned for the hardware development phase. This span is predicated on the requirement that design feasibility studies (SRT activities) on science instruments and rover interface definition studies will precede the hardware development phase. The feasibility of the 36-month development phase is further predicated on the plan to conduct development and qualification tests on the complete rover assembly rather than on individual rover components. This span is compatible with the development time taken for comparable equipments for Viking '75.

Some environmental tests will be conducted on devices/components at the component level during the development phase; however, it is intended that the rover will be treated as a single component rather than an assembly of subsystems. Thus, the qualification tests will be conducted only on the complete rover assembly.

Conclusions

The objective of this study was to define a baseline Viking rover, rover/lander integration design concepts, and mission operation concepts that would provide a significant increase in the scientific capability of a Viking '79 Mission. Implicit in this objective was the derivation of a total hardware concept that makes maximum use of the Spare and Proof Test Viking '75 lander hardware. This has been accomplished.

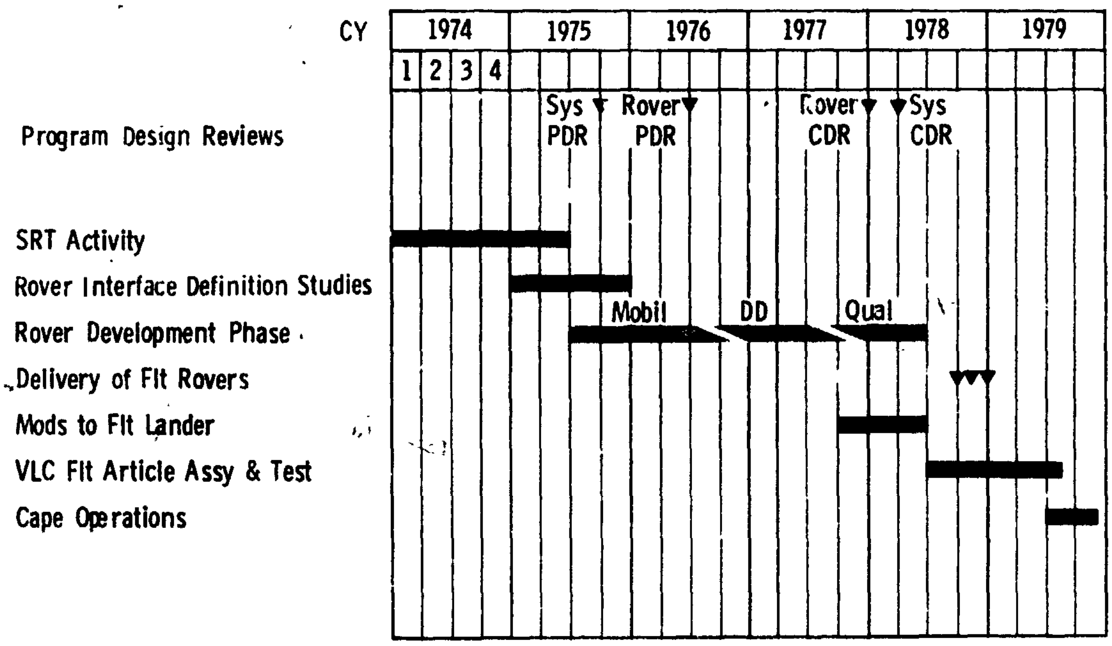


FIGURE 2 SUMMARY PLAN - ROVER DEVELOPMENT AND INTEGRATION

The key features of the 107.95 kg (238 lb) baseline rover selected as a result of the study are summarized below:

Science - 20.9 kg (46 lb) geologically-oriented payload

- Surface sampler - sample, storage, and transfer to lander
- Alpha Backscatter elemental analyzer
- X-ray Diffractometer and rock grinder
- Viking '75 facsimile camera - long baseline stereo

Power - 20 watt (EOL) RTG

Data/Commands - Two way link with both the orbiter and lander.

Mobility - Travel up to 0.5 km per day and can explore regions outside the landing footprint.

Navigation - Uses a directional gyro for heading reference, a control sequencer for semi-autonomous operation, and a hazard detection system.

Range - Limited only by system reliability and mission operations duration.

The study results clearly indicate that a significant improvement in the present lander scientific capability is achieved by including the baseline rover in the Viking '79 mission. The lander science instruments would have access to samples from a large surface area, the samples having been selected and screened for scientific interest and returned to the lander by the rover. The value of the imagery mission is tremendously improved by using the rover's camera for long baseline stereo and by taking pictures of geological interest over a large surface area.

In addition to improving the scientific value of the lander mission, inclusion of the rover in the Viking '79 mission adds a unique science exploration dimension to the overall mission. The rover has the capability to communicate through the orbiter, independent of the lander, and extend our geological knowledge of the present state and past history of Mars by sampling the many geologic units (e.g., lava flows, ejecta blankets, exposed sedimentary layers, outcrops, channel beds, escarpments, and lag gravel plains) that can be traversed by such a rover.

The impact of integrating the rover on the Viking '75 Lander can be divided into (1) those changes required to stow and deploy the rover, (2) changes in the entry and terminal descent system required to land the rover system, and (3) changes required to operate the rover with other mission elements. These changes are discussed in detail in Section 5 and 6 and are summarized below:

Rover Stowage Changes
- Remove one facsimile camera
- Move Surface Sampler
- Provide base cover bulge

Entry Performance and Landed Mass Increase Changes
- New lander RTGs
- Provide pressure regulation for the Terminal Descent Propulsion System
- 2.1° Entry Corridor
- Reduce atmospheric uncertainty
- Shift entry equipment because of c.m. change
- Remove meteorology instruments

Rover Operation
- Add UHF receiver/transmitter antenna and diplexer to lander
- Add UHF transmitter and diplexer to orbiter

An evaluation of these changes indicates that maximum use of existing Viking '75 hardware and technology has been made and that only minimum changes are required to existing hardware.

In summary, this study has verified the rover's feasibility, which was first identified in previous studies, and has proved that a Viking '79 rover mission built around the hardware and experience of Viking '75 is feasible, practical, and capable of returning rich scientific rewards.

The conclusion that the rover and its mission are feasible is based on the fact that the technological developments required to implement the concept are straightforward extensions of existing technologies. These developments can be accomplished readily in accordance with the Program Development Schedule and Plan defined during the study.

2. INTRODUCTION

This report presents the results of a study performed by Martin Marietta for the Langley Research Center to define a baseline Viking rover, lander/rover and orbiter/rover interfaces, and system operational characteristics for a 1979 mission to Mars. This mission can logically follow and respond to the results of successful Viking '75 landings in 1976; however, valuable lander/rover missions can be defined now using existing data that show Mars to be an extremely heterogeneous planet, shaped and modified by a variety of surface and atmospheric processes that make Mars the most Earth-like of our planetary neighbors.

To explore and understand the Mars surface through observation, sampling, and analysis, some form of roving vehicle is required. Earlier studies have shown that a number of different Mars rover scientific payloads are feasible, practical, and capable of providing high scientific returns (ref. 1) and that the Viking system is capable of carrying extra mass to the surface of Mars in 1979, and this mass is sufficient to allow integration of a roving vehicle (ref. 2). Accordingly, the study was initiated to determine the characteristics of Viking '79 rover candidates, define the requirements for lander/rover and orbiter/rover integration and mission operations, define a selected baseline rover and rover/lander integration concept, and evolve a program plan for implementation of the selected concept.

The study was divided into two phases. In Phase 1, a number of candidate rover configurations were prepared. In Phase 2, a selected rover, its associated lander/rover and orbiter/rover integration provisions and mission operations concept, and an appropriate program plan were defined. The candidate rover configurations varied according to the size and characteristics of the rover's science payloads; the level of modifications required on the lander; the level of technology used in the rover subsystems; and the operational relationship between the rover and the lander and/or the orbiter during operations on the Martian surface. Evolution of these candidates and the selected baseline concept took place in concert with two closely related activities. These were (1) a NASA-sponsored Viking '79 Science Planning Group was formed and its lander and rover science payload recommendations were integrated in the candidate configurations during the second phase of the study, and (2) AEC-sponsored analyses of potential radioisotope energy sources for the rover were conducted and their preliminary results were integrated into the study.

These related activities served to sharpen the focus of the study. For example, small tethered rovers capable of returning samples to the lander from ranges up to 100 meters from the lander were discarded early in the study because of their limited science potential. Analyses of power requirements for the resultant separable landers and rovers indicated that a new RTG would be required to power the rover and that the technology could be applied to new lander RTGs at a significantly lower mass, which in turn could be applied to a larger rover scientific payload. Accordingly, the AEC study of advanced RTCs was instrumental in shaping the selected concept. Given the mass, volume, and power limitations, the selected concept shown in the frontispiece was derived. This vehicle incorporates significant science capabilities, is based on Viking '75 technology, and can be integrated into the Viking System with a practical set of lander and orbiter modifications. A mission operations concept was evolved for a mission that includes six vehicles; two orbiters, two landers, and two rovers, the rovers being able to communicate with Earth through both the orbiters and the landers.

The remaining chapters of this volume present the complete analyses and results of the study.

3. ROVER MISSION AND VEHICLE DESIGN CONSIDERATIONS

Role of the Rover in Mars Investigations

The diversity of the Martian surface offers many opportunities for fruitful exploration, not only because of the geologic richness, but also because the strong interplay between geologic and atmospheric factors on Mars may well result in isolated ecological niches in which Martian organisms exist.

Finding such niches and exploring a large variety of geological features could require many, many landings because of the constraints of the present Viking sampling capability. A rover, however, could adequately traverse such areas and accomplish the desired level of exploration. A rover equipped with the proper type of science experiments would greatly expand the ability of the lander system to study the Martian surface. Compared to a single Viking '75 lander, a rover with a range of 50 km could survey an area 23 times as large with a resolution of one meter (pixel spacing) or better, and an area 2300 times as large at resolutions of one centimeter or beter. Perhaps of even greater significance is that it would have a sampling area that would be 250 million times as large as the area that can be reached by the present Viking surface sampler head. These large increases in sampling and observation are potentially of great consequence because the knowledge that Mars is heterogeneous on a large scale provides the expectation that this variability will be proved also on a small scale.

What are some of the key science questions that are presently being asked about Mars? Many questions are posed but some of the major ones concern the history of Mars in a cosmogonic sense and particularly as it applies to the possible evolution of life forms on this, the only terrestrial planet that appears similar to Earth to allow this possibility. An important consideration is the present existence and past abundance of liquid water on the surface of the planet. Also there is the consideration of whether or not Mars may have been through a similar geologic evolution within its bulk and on its surface as Earth. This is the question of tectonic activity and the motion of large areas of contiguous material of surficial crust (plates). Such dynamics does not exist on the Moon, but is the major factor in the shaping of Earth Crustal geology and its dynamics. The foregoing ideas lead to the posing of five science questions in Table 1.

TABLE 1 SOME KEY SCIENTIFIC QUESTIONS REGARDING MARS

Has Mars been through an aqueous climatic phase?

Does free or loosely-bound water exist on Mars today?

What processes have formed and shaped the Martian crust?

Does plate tectonics apply to Mars?

Do biological organisms or organic compounds exist on Mars?

How does one devise experiments designed to answer these questions? For this we must be more specific in posing the problems.

HAS MARS BEEN THROUGH AN AQUEOUS CLIMATIC PHASE? This is a question of past history and cannot be answered simply by a single piece of evidence. Mariner 9 photographs provide several examples of geomorphological evidence of liquid erosion. These are the famous channels, including braided and meandering streams, and the basins with what appears to be a single outlet. Such evidence is suggestive of a previous climate in which liquid water was in equilibrium with the atmosphere, and therefore, conditions for the development of life were more favorable than appear today. Surface science will include close range studies of geologic features, rocks, and soils. Examination of these may provide further morphological evidence for the action of liquid water such as arroyo beds and rounding of pebbles and soil grains. A first-order priority of a rover exploration mission would undoubtedly be to search for an arroyo and, once found, obtain high resolution photographs of its banks, beds, and rocks within the bed. It might also be feasible to follow the arroyo either upstream, to study the drainage pattern and search for dendritic branches, or downstream, to seek an outwash plain and study the materials transported there. Another method of providing evidence to this possible past history is to determine whether or not sedimentary rocks exist on Mars. Sedimentary rocks and deposits often consist of chemical and mineral forms and associations which are impossible to form without the chemical action of liquid water. Detection of a solid mass of limestone or a body of concentrated limonite, clay mineral, or evaporite deposits would provide strong evidence of the action of liquid water. The chances of finding such diagnostic areas can be considerably improved through use of a rover. For example, evaporite deposits are concentrated at the low point of a basin area. A rover programmed to always proceed downhill could find such potential areas, whereas a landing in such an area would be only a fortuitous concidence.

DOES FREE OR LOOSELY-BOUND WATER EXIST ON MARS TODAY? This question can be attacked directly by a number of measurement techniques, as given in Table 2. Certain of the measurements can be obtained from orbit, particularly those which ascertain the atmospheric water cycle and the polar cap composition. This provides the opportunity of studying the spatial and temporal distribution of water over large areas of the planet. Soil water content measurements are less satisfactory from orbit, because the available techniques are ambiguous with respect to the chemical and physical state of the water. *In situ* techniques

TABLE 2 THE WATER QUESTION

	INSTRUMENT LOCATION		
SCIENCE MEASUREMENTS	LANDER	ROVER	ORBITER
Atmospheric Water Content			
Quartz Microbalance, Conductivity GA	X	X	
IR Absorptometry			X
Soil Water Content			
Differential Calorimetry (DSC)	X	X	
Evolved Gas Analysis (EGA)	X	X	
Neutron Thermalization	X	X	
Microwave Radiometry, Probe	X	X	X
Effects of Water on Soil			
Macro-Geomorphology (Landforms)	X	X	X
Micro-Geomorphology (Grain Shapes)	X	X	
Soil Chemistry	X	X	
Polar Cap Composition and Structure		X	X

such as DSC and EGA (see Table 2) provide the desired information on the relative amounts of water in the forms of ice, absorbed/adsorbed phases, hydrate minerals, and hydroxides. The advantages of rover exploration over lander grab sampling are (1) specialized rocks can be sought out, (2) protected areas may be found (shadowed niches), and (3) samples of clay mineral segregates in areas enriched in the super-fine fraction by wind action could be obtained

WHAT PROCESSES HAVE FORMED AND SHAPED THE MARTIAN CRUST? Has Mars undergone extreme differentiation such as Earth has wherein a central core of iron, nickel, and other transition elements formed, surrounded by physically and chemically distinct layers of rocks? This can be ascertained by comparing the bulk chemical composition of Mars with that thought to have been present at the initial formation of Mars. The latter is determined by the composition of the solar nebula and the amount of chemical fractionation that occurred as it cooled to form the planet. To study this, one must measure the composition of igneous rocks and soils in the Martian crust. A large variety of samples is desired to determine the average composition of this crust. This means, in turn, it is desirable to land many places on the planet or to explore with a rover to sample as many different geologic units as possible. Considerable information could be derived if a region in which the outwash products from an ancient stream or impact crater ejecta could be sampled, thereby allowing rocks to be studied that were transported from relatively large distances and possibly great depths. Again, large-areal sampling afforded by a rover is virtually mandatory for studies of this type. Likewise, questions of volcanic activity, collapse of crust, Eolian (wind) erosion, and aqueous erosion of the surface can be studied best on the Martian surface with *in situ* measurements of the geomorphologic, geochemical, and mineralogic characteristics over wide areas of the surface.

An important question is the thickness of the Regolith (i.e., the soil layer) covering the bedrock on Mars. Knowledge of this thickness and the possible layering therein is required if we are to assess the relative roles of meteorite impact gardening, Eolian sedimentation/deflation, volcanic blanketing, and aqueous-phase sedimentary processes. Two most promising techniques for such studies are seismic and electromagnetic sounding using two stations (sender and receiver) separated by a distance preferably equal to or greater than the depth of the discontinuities to be studied. A rover-lander combined experiment is required in such cases. For example, if the rover contained an impact-type rock grinder, the mechanical shocks might be detected with a seismometer on or near the lander, and the signature and timing information obtained would reveal subsurface structure and provide clues to possible compositional transition.

DOES PLATE TECTONICS APPLY TO MARS? Most metamorphic rocks on Earth are caused by the extreme pressures and temperatures generated by the motion of crustal plates over the Earth. Discovery of one or more cases of these types of metamorphosed rocks on the surface of Mars would be strong evidence of present or at least past activity of this type. Such rocks are recognized by a combination of their physical structure (optical examination), their mineral composition (X-ray diffraction), and, to a lesser extent, their chemical composition. Assuming such rocks are not ubiquitous, use of the rover will vastly improve the potential of finding one or more samples of this type. The rover also offers the exciting possibility of locating an exposed outcrop of metamorphised material, the study of which could provide essential information as to its conditions of genesis. This question can also be studied by obtaining evidence of land forms peculiar to high stress conditions and the detection of seismic activity confined to belts, indicating the borders of crustal plates. Seismic studies on Mars can be significantly advanced over what will be accomplished by Viking '75 if an advanced seismometer with extended frequency response to include long period vibrations is flown. Such a seismometer would, however, suffer even more than the present one from interferences due to lander structure vibrations. It would, therefore, be highly desirable to deploy a seismometer some distance (up to 100 meters) from the lander to minimize this artificial background. A rover could provide this capability to deploy a seismometer.

DO BIOLOGICAL ORGANISMS OR ORGANIC COMPOUNDS EXIST ON MARS? This is perhaps the highest priority science question that can be asked concerning the surface of Mars. Viking '75 is intended to address this question. Within the bounds that must be placed on the first lander mission to Mars one can understand the limited area of sampling and limitations in the number of experiments that can be reasonably carried on such a lander. If life is not discovered by this first mission to Mars, it could be due to experimental techniques that are not sensitive to the indigenous life, or simply due to an inappropriate sampling location. For example, the continent of Antarctica is partially sterile, but partially populated with microbial life forms. From studies in the Antarctica dry valleys, it has been learned that life may exist in one area and yet within meters a large area may exist that is completely sterile. This situation exists when the micro-environmental conditions in the soil are different due to solar insolation (slope attitudes), availability of water, etc. The same situation possibly exists on Mars. This may even be the case for organic compounds, because the intense ultraviolet radiation that reaches the surface of Mars effectively destroys the chemical structure of large organic compounds. This, again, is a case in which even modest mobility and sampling capabilities could enormously increase the potential for finding the sought-after ecological niche.

Rover Science Modes

The preceding discussion has identified five moves in which a 10 to 100 km range rover can be used to expand and enhance the scientific value of a landed mission. These operative modes are as follows:

Reach a predetermined target area,

Explore the surface terrain,

Collect samples and return them to the lander for analysis by lander-based instruments;

Conduct dual-station science between the rover and lander or rover and orbiter, and

Deploy sensitive instruments away from the lander.

Each of these methods of operation abet the science value of the mission in different ways. It is, therefore, appropriate to discuss each separately to consider its potentialities.

Reach predetermined target. - Predetermined targets can be selected by observing features in Mariner 9 photographs and orbital pictures that will be obtained by Viking and Soviet missions. Already over half a dozen distinct terrain types on the surface of Mars have been recognized, and in favorable locations, three may be conterminous. Landing at such a conjunction, with subsequent visits to all three geologic units by a rover, is potentially of great value. If such conjunctions do not appear favorable for a safe landing, there are many other areas that do satisfy safety constraints, wherein more than one such geologic unit could be visited. Thus, it may be possible to explore both ancient cratered terrain and smooth terrain, or, for example, a channel and a large crater.

Exploration. - The category of exploration includes adaptation of the mission to the study of various targets of opportunity. This would include such geologic features as boulders, outcrops of solid rock, arroyos, escarpments, lava fields, craterlets, sand dunes, small domes, volcanic vents, or cones, etc. An enormous variety of such targets of opportunity exist that will not be visible or clearly discerned by orbital imagery, yet can provide great insight into the geologic processes that are at work on the surface. Sampling from such features as well as careful morphologic study by imagery systems is prerequisite to the construction of hypotheses of the geologic history of the surface.

Sampling for return to lander. - In the likely event that not all science instruments can be conveniently carried on a single rover, it would be a task of the rover to obtain soils and rocks that can be returned to the lander for more detailed analysis. This is a feature of the mobility aspect of the rover in providing access to large areas from which samples may be obtained without endangering the survivability of sophisticated key instruments on the lander. The sampling techniques will be determined by instruments located on the lander, but, in general, both rocks and soils are desired for geological purposes, and soils are required for biology and organic chemistry experiments. All samples should be maintained in an environment that approximates that of the normal local environment; therefore, they should not be subjected to heating, abnormal chilling, pressure changes, or other deviations from their normal environment.

When obtaining samples of biological interest, it will be important to reach areas where the micro-environments are judged conducive to life. Thus, the detection of surface water would be an important indication from which to key. In addition, one could search for signs of erosion or special chemical compositions such as concentrations of salts and other specific minerals which are required by most life forms. In the search for organics it might be justified to include an instrument that accomplishes a crude analysis of soil for total organic content without regard to chemical composition. In this way one might find areas in which organics are concentrated either due to the action of wind segregation or merely due to the sheltering effect from ultraviolet and possibly other degrading environmental influences. The presence of organics may also indicate the existence of an ecologic niche for life forms.

Dual station science. - Dual-station science includes those categories of experiments that are most appropriately conducted by two instruments between two geographically separated locations. Portrayed in Figure 3 is an active science experiment that could be conducted by placing a "thumper" device on the rover to inject seismic pulses into the surface and detect transit times of various refracted and reflected signals through the regolith using the lander seismometer. This is a convenient way of determining the local surface structure, which includes the depth of the regolith and possible subsurface layering. Other experiments that could be accomplished conveniently by dual-station science include electromagnetic probing of the subsurface, measurements of atmospheric turbidity and particle size distribution, correlation of meteorologic measurements at two locations to study wind patterns and thermal gradients and finally, use of the rover camera in conjunction with a lander camera to obtain long baseline stereo-pair photographs for accurate ranging of distant land forms.

Deployment of instruments. - Instruments may be deployed away from the lander by the rover to distances that are impractical for a boom. Several experimental techniques have been identified that would probably require such a deployment capability. These include a gamma ray spectrometer for measuring radioactive elements in the soil. The spectrometer must be deployed 100 meters or more from the lander to reduce the gamma ray interference from RTG emissions to

- Seismic Probes
- EM Probes
- Atmospheric Turbidity
- Correlated Meteorology
- Landform Ranging (Long Baseline Stereo)

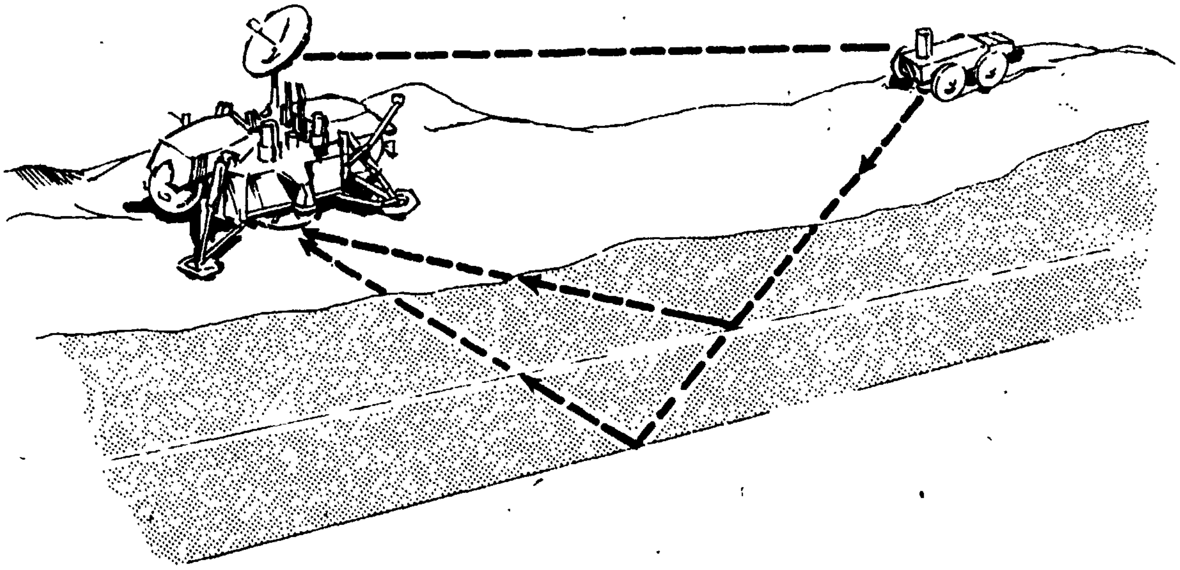


FIGURE 3 DUAL STATION SCIENCE

a negligible value. A long-period seismometer will require deployment away from the lander to avoid the interfering low frequency vibrations that would be virtually omnipresent in the lander structure due to stimulation of normal modes of vibration by electromechanical components and wind gusts. If a magnetometer experiment is employed it will have to be deployed some distance (perhaps 50 meters) from the lander to avoid magnetic interference due to the various permanent magnets and the magnetic fields induced by circulating currents in the lander. Finally, it would be desirable to deploy a meteorology station some distance from the lander to avoid the perturbations of atmospheric conditions due to the thermal emission of the lander and its non-aerodynamic shape that distorts normal wind flow patterns. Some examples of deployment are shown in Figure 4.

Detailed Rover Science Requirements

In Table 3 we present some of the requirements derived by comparing the five basic operating modes given above with the five science questions posed in Table 1. Not all of these requirements would be imposed in any given mission for, in the final analysis, it will be the detailed selection of mission objectives and an instrument complement that will dictate the actual requirements on a given rover.

Note that in reaching predetermined targets such as a geologic unit observed from orbit, the range of the rover must be equal to the size of the footprint. Of course, it is then possible to trade off engineering developments that reduce the footprint size against other developments that allow an increase in rover range, at the minimum cost. Alternatively, one could target the landing footprint to include several geologic units, and then proceed to the nearest unit. In the area of exploration, much of the detailed science would be of an adaptive nature with scientists on Earth deriving altered mission profiles based upon results obtained and indications of areas of interest from imagery and other data gathered. As a mission neared its end of great usefulness, due to instrument degradation for example, one might elect to explore areas in which rover survivability is not as highly probable as one would normally demand. Alter-

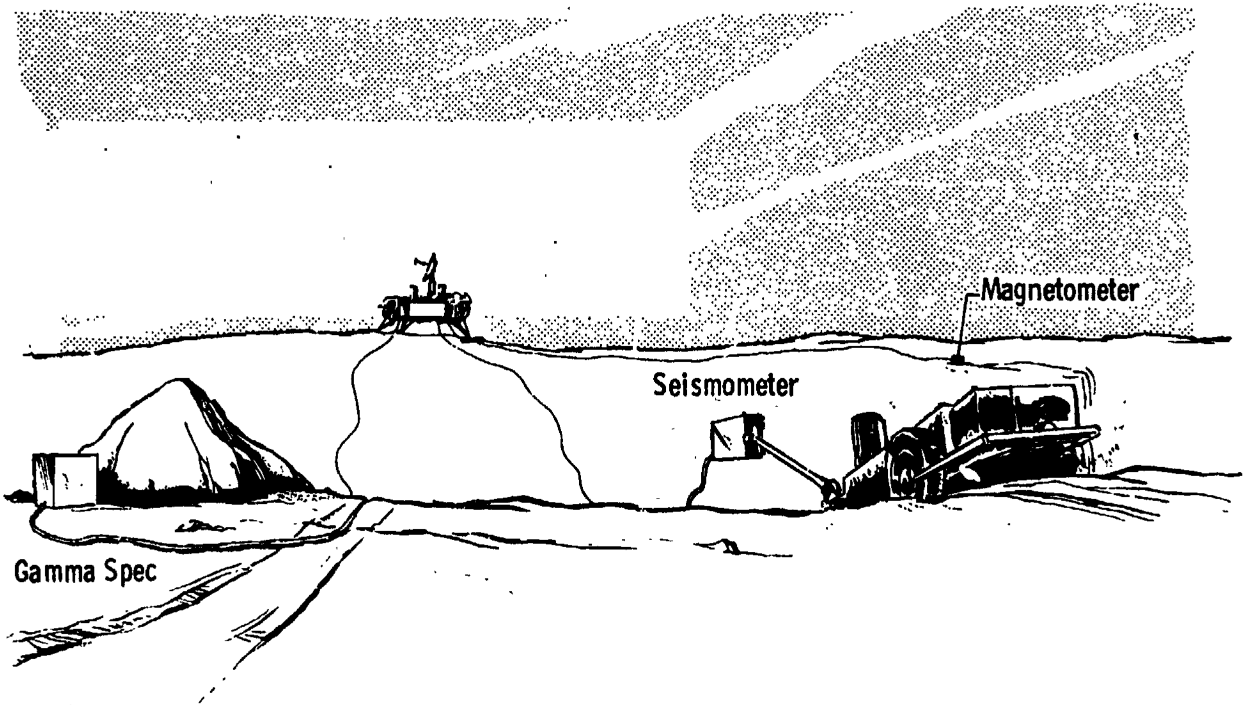


FIGURE 4 INSTRUMENT DEPLOYMENT

TABLE 3 ROVER TASKS

BASIC REQUIREMENT	DERIVED REQUIREMENTS
Reach Predetermined Target	Descent Pictures Range ≥ Footprint Min. Science: Imagery (Macro, Micro) Geochemistry Water Detector?
Exploration	Seek Outcrops, Boulders, Scarps, Other Specific Landforms Min. Science: Imagery, Articulated Geochemistry, Derived Altimetry, Physical Properties, Seismic Kamakasi?
Obtain Samples for Lander Instruments	**Imagery for Sample Documentation and Selection, Soil for Biology, Organic, Soil Water (Temp. Excursion < 10°C)** Geochemistry: Rocks 6 Each, 2-5 cm Major Diameter Soil 3 Each, 50 cc Each
Dual-Station Science	Ranging and Timing Accuracy
Deploy Instruments	Gamma Spec >100 m from RTG Seismometer > 50 m from Structure, Orientation Magnetometer >50 m from Structure Meteorology >20 m from Lander

natively the rover could be sent on a minimum interference path to cover as much ground as possible before mission termination in seeking new targets of opportunity. The rover could even detonate a large built-in seismic charge, thereby committing rover suicide to provide a well-defined and precisely timed seismic signal for the lander seismometer. These data could provide unique data on subsurface structure. Samples collected by the rover should include as large a number and variety as practical. In our derived requirements we present a rather minimum requirement of six rocks and three soil samples, the exact number being of course relatively arbitrary. If the rover includes an active geochemistry experiment that monitors the soil composition as the rover traverses the terrain, a simple computer algorithm could be employed to determine whether the chemical composition is constant or changing. Upon detecting a change, the rover might automatically stop and execute a sampling sequence. Any sampling system should also include the capability to dump samples upon command from Earth should it be decided that one or more samples already obtained are of less value than those that now could be acquired.

Requirements for deploying instruments are not known but estimates based on present studies are that they would be deployed 20 to 100 meters or more from the lander for the types of experiments that have so far been considered. In some cases it may be desired to have the instruments mounted or connected with a cable to the main lander whereas in other cases it may be more advantageous to include a low-power communication system for transmission of data from the deployed instruments to the lander or rover.

To obtain the greatest value from a science rover mission, it is desired to be able to react to the potential surprises that may greet the ground operating crew. It is thus desired that scientists be able to redirect the path of the rover as well as control in some detail the frequency of sampling, type of samples obtained, and analysis performed.

A certain amount of built-in adaptive capability through onboard electronic circuit operating modes will be necessary to guarantee the survivability of the rover. This includes the avoidance of hazards and the requirement that the rover be kept moving in the event it finds itself in a severe dust storm, so that burial may be avoided. Because such capabilities must be included in the rover, it is possible that moderate additions to the electronic functions can be used to enhance certain science objectives. An example would be that mentioned earlier of having the rover stop and sample whenever an active geochemical experiment determined that a significant change in surface composition occurs. Other examples might be the taking of imagery data in the event of sudden changes of ambient light or the detection of physical motion of an object in the field of view.

However, many of these objectives and requirements can be accommodated by a variety of rover designs and therefore the requirements are not always unduly restrictive.

The experiments discussed in the preceding material serve a number of science disciplines, including atmospheric science, with the study of atmospheric composition and dynamics; biological science, with the sampling of possible life forms and discovery of organic compounds and geological science. This latter area consists of a number of subdisciplines with which rover performance capabilities will undoubtedly be intimately associated. The key subdisciplines are: (1) geochemistry, which measures the elemental and mineral compositions of the surface material, (2) geochronology, which determines the relative and absolute ages of formation of the surface materials, (3) geomorphology, which treats the geometric relationship of the surface components, and (4) geophysical studies, which include the physical dynamics and properties of the surface and interior of the planet. These disciplines are serviced by a number of instrumental techniques of which the area of geochemistry provides the greatest number of possibilities, as shown in Table 4.

Geochemistry techniques are conveniently defined in terms of (1) methods of elemental analysis, (2) determinative mineralogy, and (3) fabric and grain morphology studies. Under elemental analysis are included X-ray fluorescence and alpha backscatter techniques, as well as a number of techniques more difficult to implement. Under mineralogy are included the X-ray diffractometer, high resolution microscopy (petrographic microscope), soil water measurements, etc. The study of individual rock grains, their size, shape, and geometric relationship as well as the nature of the intervening matrix material (fabric) requires the use of lower resolution imagery.

TABLE 4 GEOCHEMISTRY TECHNIQUES

ELEMENTAL ANALYSIS	MINERALOGY	FABRIC/GRAIN MORPHOLOGY
X-ray Fluorescence Spectrometer	X-ray Diffractometry	Magnifier
Alpha Backscatter Analysis	Petrographic Microscope	
Gamma Spectroscopy	Soil Water (DSC/EGA)	
Neutron Activation	IR Spectrometry	
Wet Chemistry (Biology, GCMS)	Magnetic Properties	
Atomic Emission		

Tables 5 and 6 include many other experimental techniques that may be brought to bear on problems in the areas of geophysics, geomorphology, geochronology, and the various aspects of the sampling problem. Under sampling, one must include acquisition as well as processing, and there are a number of devices that may be used to accomplish this.

Looking at science disciplines and subdisciplines (see Tables 5 and 6) provides a convenient method of categorizing scientific instruments in accordance with their major objectives. As discussed in Section 6.1, many of these instruments are in a satisfactory status of development for use in a Mars environment and are, therefore, candidates for a rover mission.

TABLE 5 GEOSCIENCE TECHNIQUES

GEOPHYSICS	GEOMORPHOLOGY	GEOCHRONOLOGY
Seismometry	Altimetry (Orbiter)	Stratigraphy
Passive Active	Imagery (Orbiter, Lander, Rover)	Morphology (Freshness)
Magnetometry		Age Dating (Radioactive Decay)
Microwave		
Radiometry Active Probing		
Heat Flow		

TABLE 6 SAMPLING TECHNIQUES

SAMPLE ACQUISITION	SAMPLE PROCESSING
Soil Scoop	Rock Duster
Rock Plucker	Rock Cracker
Drill	Grinder
Chisel	Sieves
Deploy Instruments to Sample	Magnetic Separator
	Thin Sections
	Chemical Fractionation

Environmental Factors

The Viking '79 Mission Environments are essentially the same as those used for the Viking '75 design except for nuclear radiation, landing shock, and thermal. The impact of the potential nuclear radiation and landing shock environmental changes are rather minor, whereas, the change in thermal environments has a much greater impact on the design of mission hardware.

The new RTGs are to use fuel elements that are as "clean" as the SNAP-19 fuel elements and therefore should not produce neutron flux densities in excess of those experienced on Viking '75. Confirmation of this preliminary evaluation must be made during the new RTG development program by the AEC.

The landing shock for Viking '79 has been evaluated and there appears to be three methods available for handling the change in landed mass. The first is to leave the present Viking '75 landing legs unmodified, which will result in a decrease in lander clearance of approximately 4 cm. The second is to change the landing leg shock absorbing characteristics (new honeycomb design) and thereby maintain the specified 22 cm clearance. The third method is to change the final descent rate from 2.44 m/s (8 ft/s) to a lower value and compensate by adding approximately .91 kg (2 lb) of propellant. Further studies must be performed to select one of these solutions and hence the actual landing shock.

The Viking '79 anticipated mission thermal environments are summarized in Table 7. Figure 5 pictorially presents a summary of the expected Viking '79 Mars surface thermal extremes. Figure 6 shows typical Mars surface hot case ground temperature profile for the Viking '79 mission.

The Viking '79 trans-Mars cruise thermal environment is changed from the '75 mission by the addition of the rover. The rover carries its own RTG, thereby increasing the VLC internal heat load during cruise, and requiring a thermal design that will reject most of the rover RTG heat to space.

Thermal analysis has shown that the lander internal temperature will increase approximately $6^{o}K$ ($10^{o}F$) above the Viking '75 level for the proposed rover RTG heat rejection design.

TABLE 7 MISSION THERMAL ENVIRONMENTS

Sterilization

All Components must survive a Minimum of Three Sterilization Cycles

Cruise:

Solar Constant, 1350 to 710 Watts/m^2 (430 to 225 Btu/Hr-Ft^2) Deep Space Sink 3°K (-453°F)

Mars Surface

	Hot Environment	Cold Environment
Landing Site Latitude, Degrees	-30°	-90°
Solar Irradiance	710 Watts/m^2 (225.0 Btu/Hr-Ft^2)	690 Watts/m^2 (219 Btu/Hr-Ft^2)
Surface Absorptivity, α_S	0.85	0.50
Surface Emissivity, ϵ_{IR}	0.89	0.90
Sky Temperature	152°K (-185°F)	85°K (-307°F)
Wind Velocity	0	40 m/sec (130 ft/sec)
Mean Ground Temperature	248°K (-12°F)	--
Peak Ground Temperature	319°K (+115°F)	147°K (-195°F)

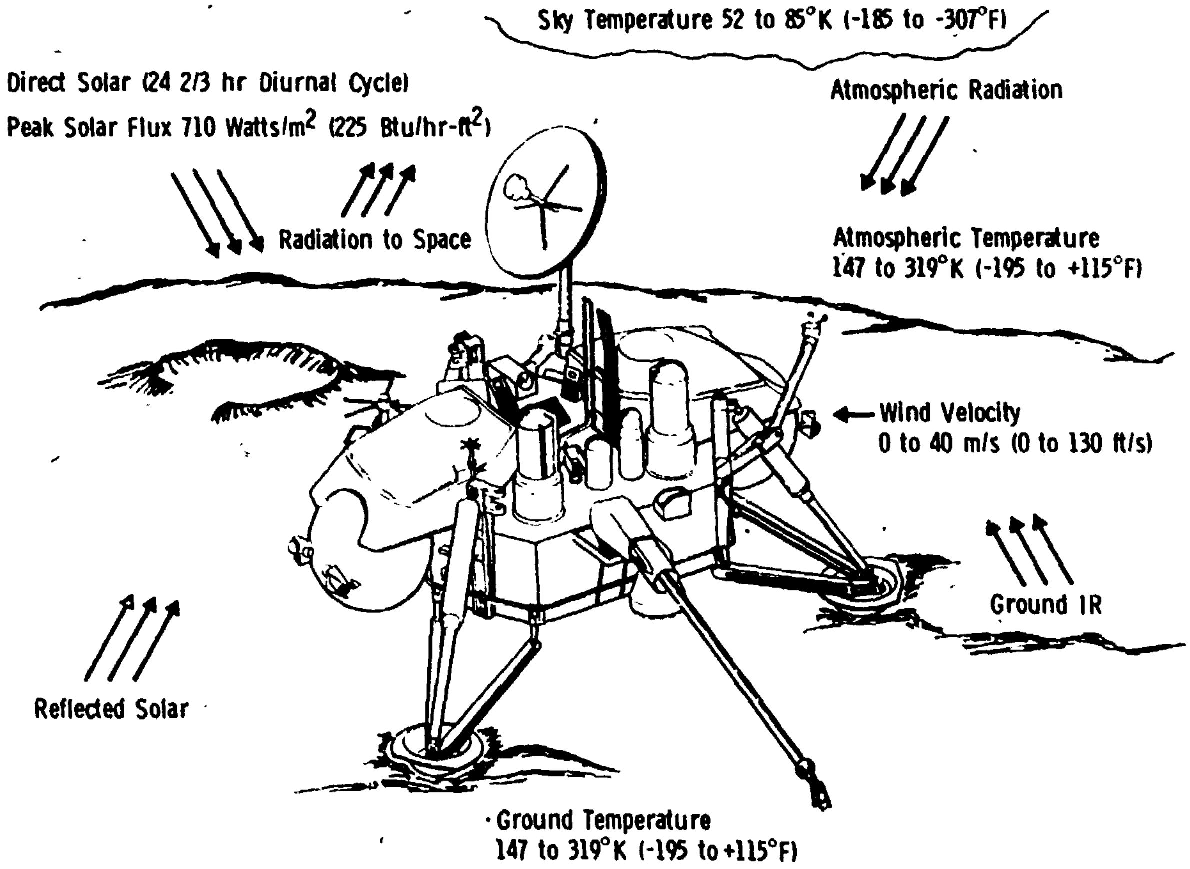


FIGURE 5 MARS SURFACE THERMAL ENVIRONMENTS (VIKING '79)

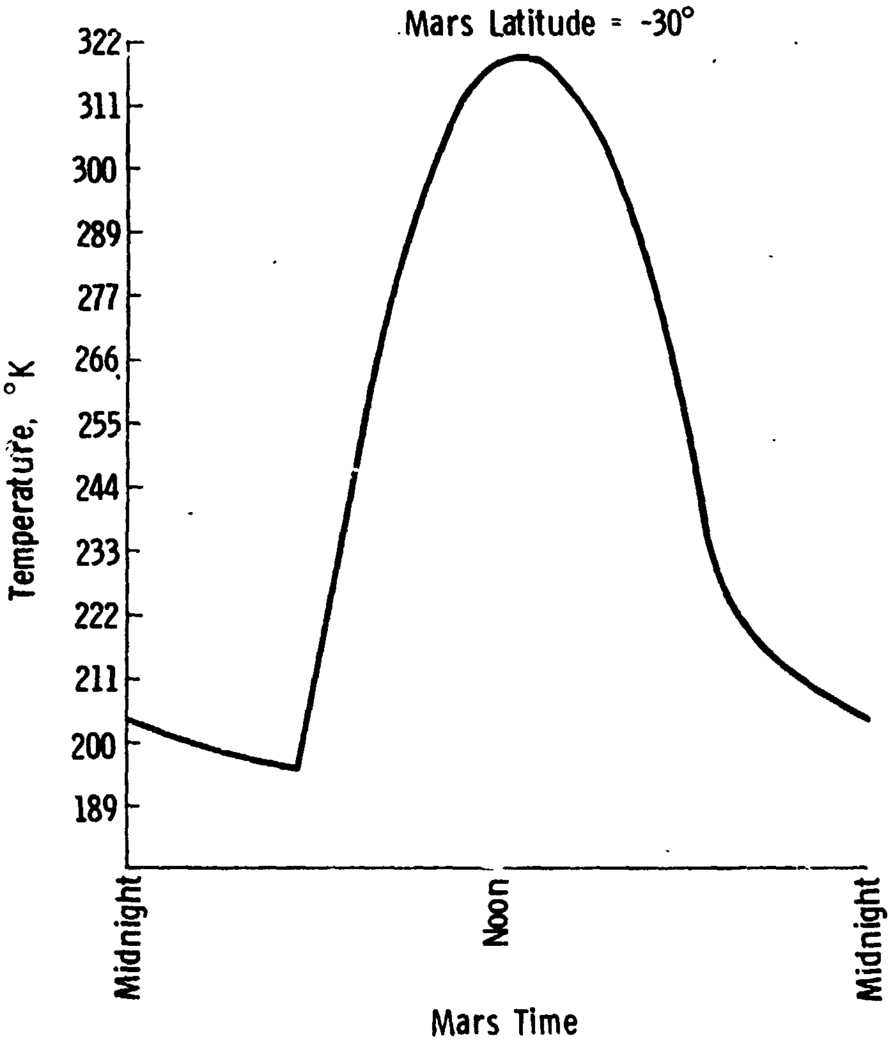


FIGURE 6 VIKING '79 - HOT AMBIENT TEMPERATURE AT END OF MISSION

Mission Operations

The goal used in defining the 1979 mission performance capability was to maximize the mass in Mars orbit and still use the Viking '75 launch vehicle and spacecraft performance characteristics without change. The goal was achieved. The Viking orbiter performance presented in following paragraphs assumed the Viking '75 characteristics of 1404.8 kg (3097 lb) of usable propellant and a (3σ low) I_{sp} of 2828 N-s/kg (286 s).

Launch period analysis. - The energy contours fro the 1975 and 1979 Type II missions are compared in Figure 7. Type I missions have prohibitively high energy requirements for both opportunities. Generally, the Earth departure energy requirements (C_3) are slightly lower for the 1979 opportunity and the Mars approach energy (V_{HE}) is slightly higher and more restrictive from an encounter date separation viewpoint. The 1979 opportunity has the additional performance limiting feature of high DLA (launch azimuth requirements) during the latter portion of the potential launch period. Values of DLA greater than approximately 26 degrees require a dog-leg maneuver during the boost phase to keep the launch trajectory from over-flying Brazil. This results in marked reductions in launch vehicle performance capability.

These basic energy characteristics are the basis for the 1979 mission performance optimization and the selection of the 1979 mission launch period and spacecraft encounter date separation. These considerations are presented in the following paragraphs.

Launch period and payload optimization. - The performance analysis to Mars orbit is based on the following characteristics and assumptions:

Launch Vehicle Capability from GDC Report, *Launch Vehicle Performance Data,* GDC-BKM 70-035-9 (NAS3-1354), June 1973.

Orbiter propulsion system;

Usable propellant = 1404.8 kg (3097 lb)

I_{sp} = 2828 N-s/kg (286 s) (3σ low)

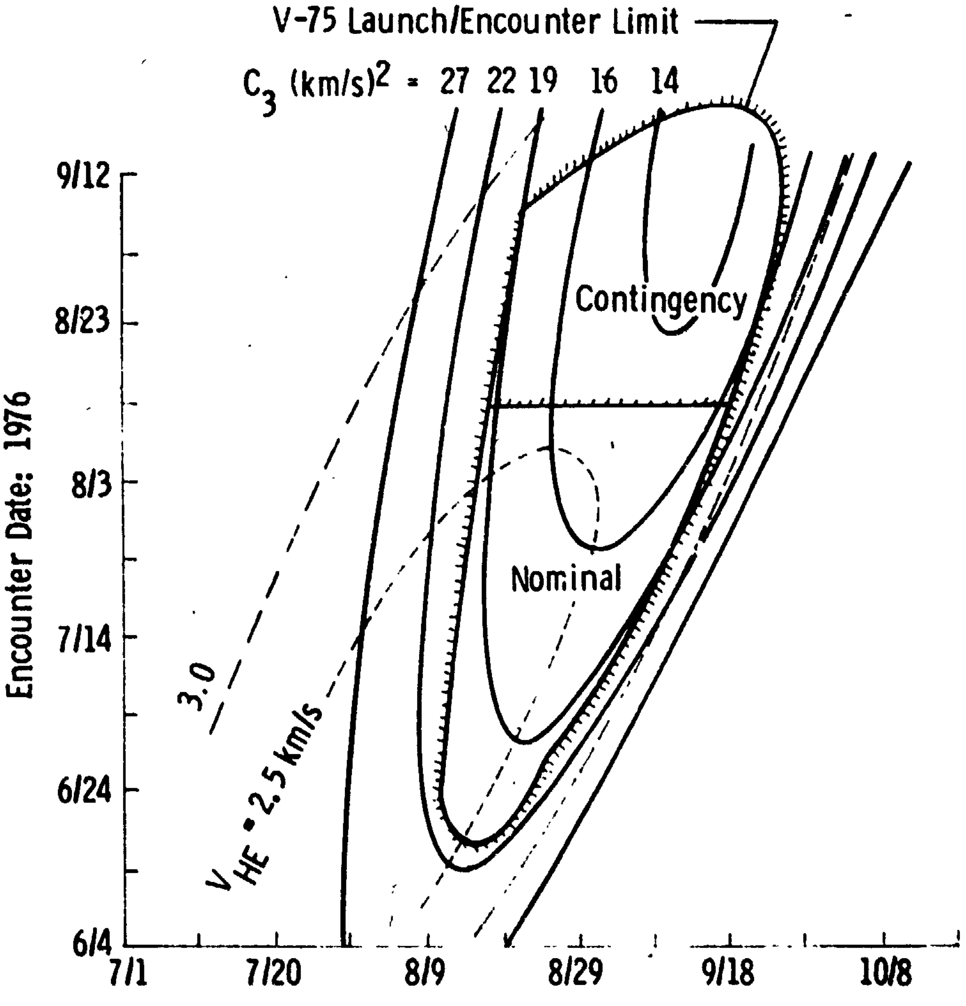


FIGURE 7 1975 MARS TYPE II ENERGY CONTOURS (SHEET 1 OF 2)

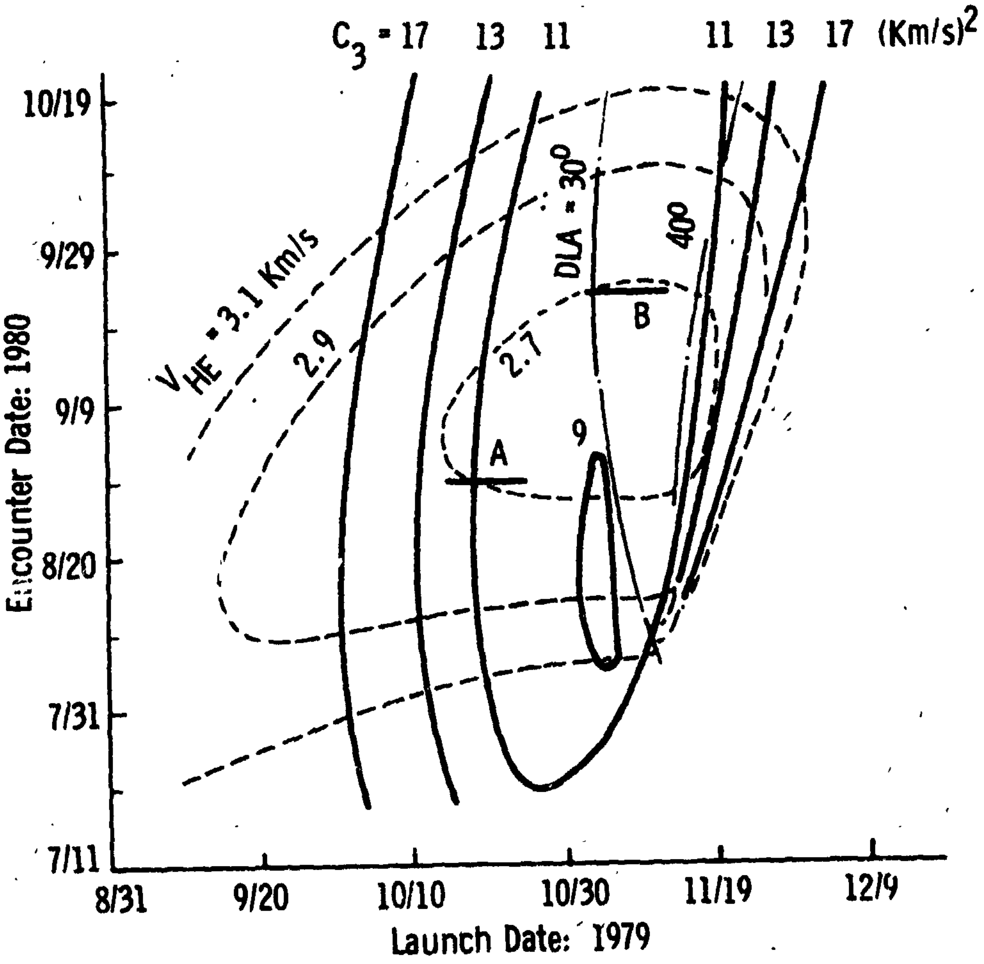


FIGURE 7 1975 MARS TYPE II ENERGY CONTOURS (SHEET 2 OF 2)

Spacecraft V budget;

$\Delta V_{M/C}$ = 25 m/s

ΔV_{STAT} = 100 m/s

ΔV_{TRIM} = 50 m/s

ΔV_{MOI} from Figure 8

Mission Operations timelines based on Viking '75, Mission A.

These characteristics and assumptions are identical to those being used for the 1975 mission analysis with the following one exception. The value of ΔV_{STAT}, preceding, has been reduced from the Viking '75 value of 175 m/s (Mission B). This reduction is possible because the Mars approach geometry in 1979 is much more favorable from a navigational viewpoint. The geocentric declination varies from -5 to -15 degrees over the launch-encounter space shown in Figure 7 and the ZAE angle varies between 130 to 160 degrees. These values are comparable to the Viking '75 Mission A characteristics where a ΔV_{STAT} of 100 m/s is required.

Another assumption is the use of the Viking '75 Mission A operational timeline. The basis of this assumption is that the 1979 rover mission will be flown to two preselected landing sites based on data from the 1975 mission. The requirement for major inflight landing site retargeting flexibility used in the 1975 mission planning may not be applicable in 1979. Sites of major interest for rover mission exploration will be selected before launch and ensued after launch.

Using the above, the performance into Mars orbit is presented for delta masses in Mars orbit of 90.7, 181.4 and 272.2 kg (200, 400, and 600 lb) in Figure 9. The mass reference used here is the October 1973 Viking Mass Properties Report that specifies an injected mass of 3680 kg (8112 lb), including 41.3 kg (91 lb) Viking Project reserve and 104.3 kg (230 lb) of launch vehicle mission peculiar equipment. A total of 210.9 kg (464 lb) is separated at injection, including the above 104.3 kg (230 lb), the spacecraft adapter 61.2 kg (135 lb), and the forward bioshield 45.4 kg (100 lb). The analysis assumes the biocap is separated after injection. Actually it is separated in Earth orbit, making the analysis slightly conservative.

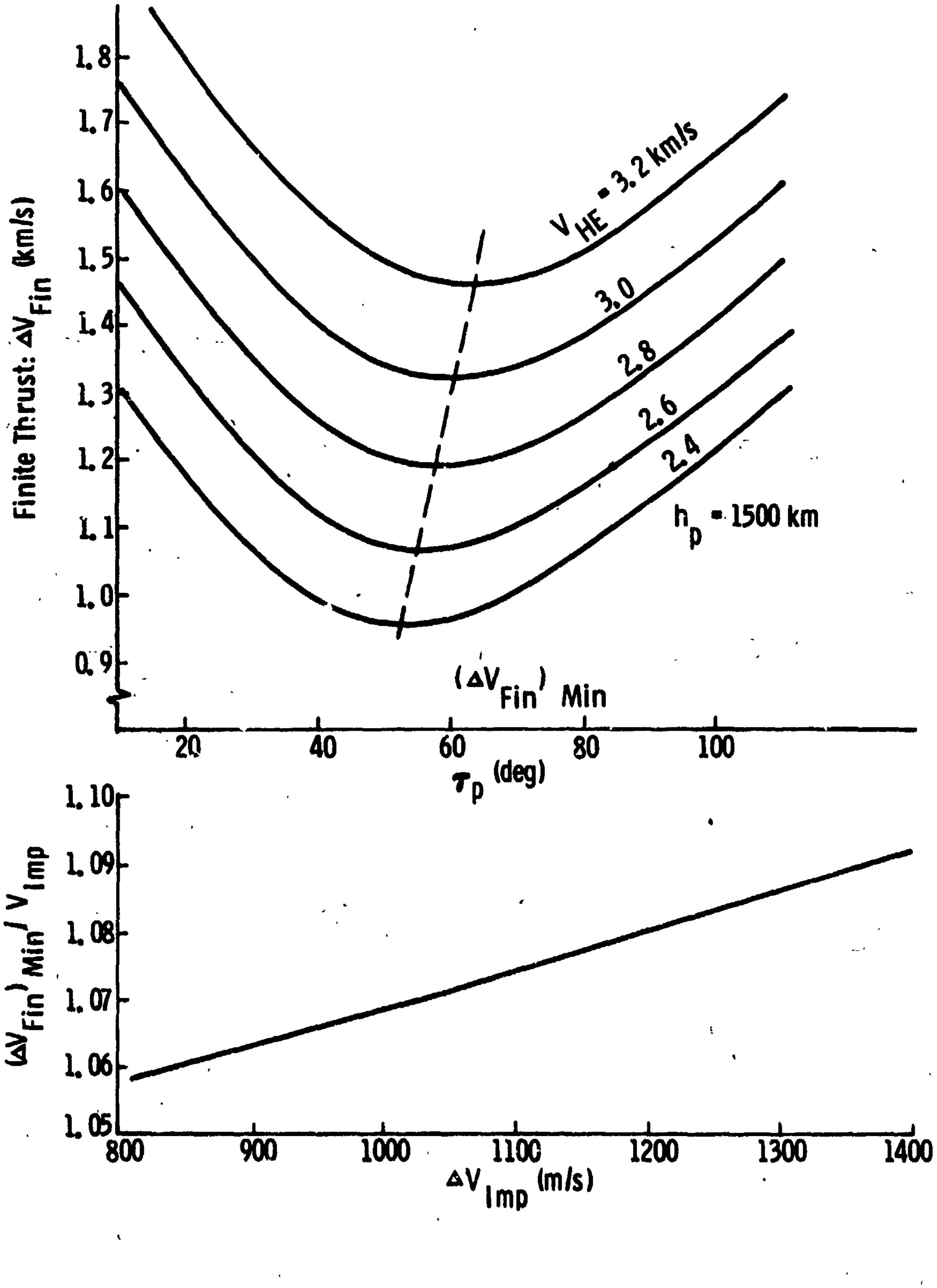
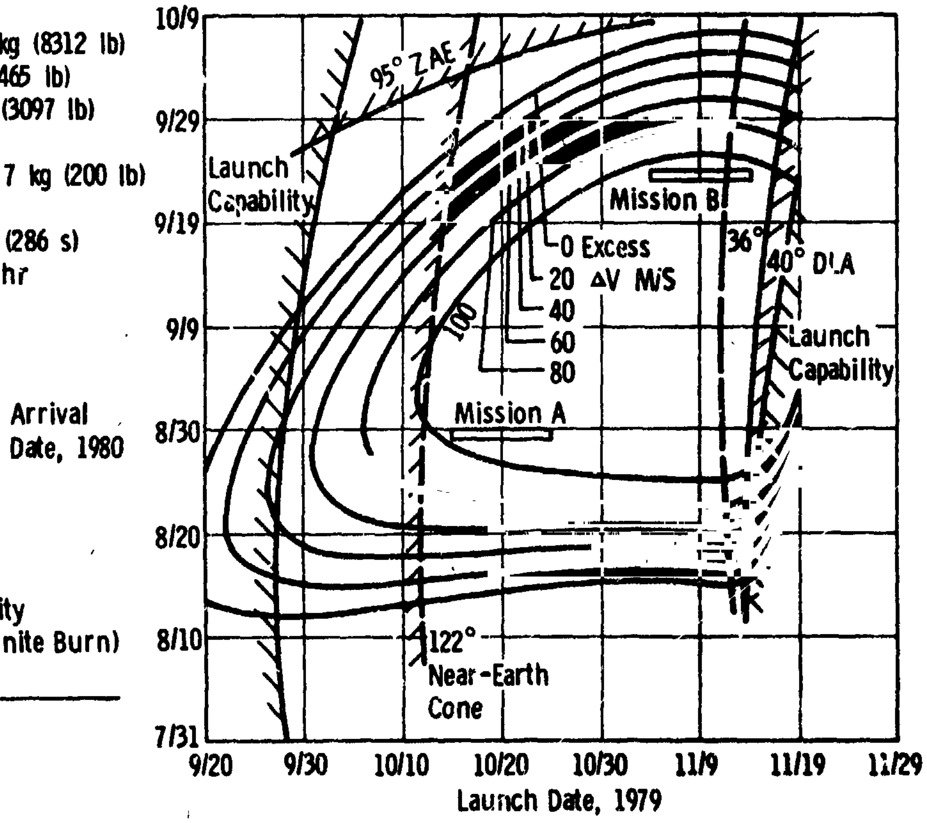


FIGURE 8 MOI FINITE THRUST CHARACTERISTICS, FIXED ALTITUDE BURN

Launch Mass = 3770.3 kg (8312 lb)
Drop Mass = 210.9 kg (465 lb)
Prop Mass = 1404.8 kg (3097 lb)
V Cap = 1408 m/s
Del Mass in Orbit = 90.7 kg (200 lb)
V Budget = 175 m/s
Prop I_{sp} = 2828 N-s/kg (286 s)
Orbit = 1500 km/24.623 hr



ΔV Capability
- ΔV MOI (Finite Burn)
- ΔV Budget

ΔV Excess

FIGURE 9 INITIAL VIKING '79 PERFORMANCE DATA (SHEET 1 OF 3)

Launch Mass = 3861.0 kg (8512 lb)
Drop Mass = 210.9 kg (465 lb)
Prop Mass = 1404.8 kg (3097 lb)
ΔV Cap. = 1362.8 m/s
Del Mass in Orbit = 181.4 kg (400 lb)
ΔV Budget = 175 m/s
Prop I_{sp} = 2828 N-s/kg (286 s)
Orbit = 1500 km/24.623 hr

ΔV Capability
$-\Delta V$ MOI (Finite Burn)
$-\Delta V$ Budget

ΔV Excess

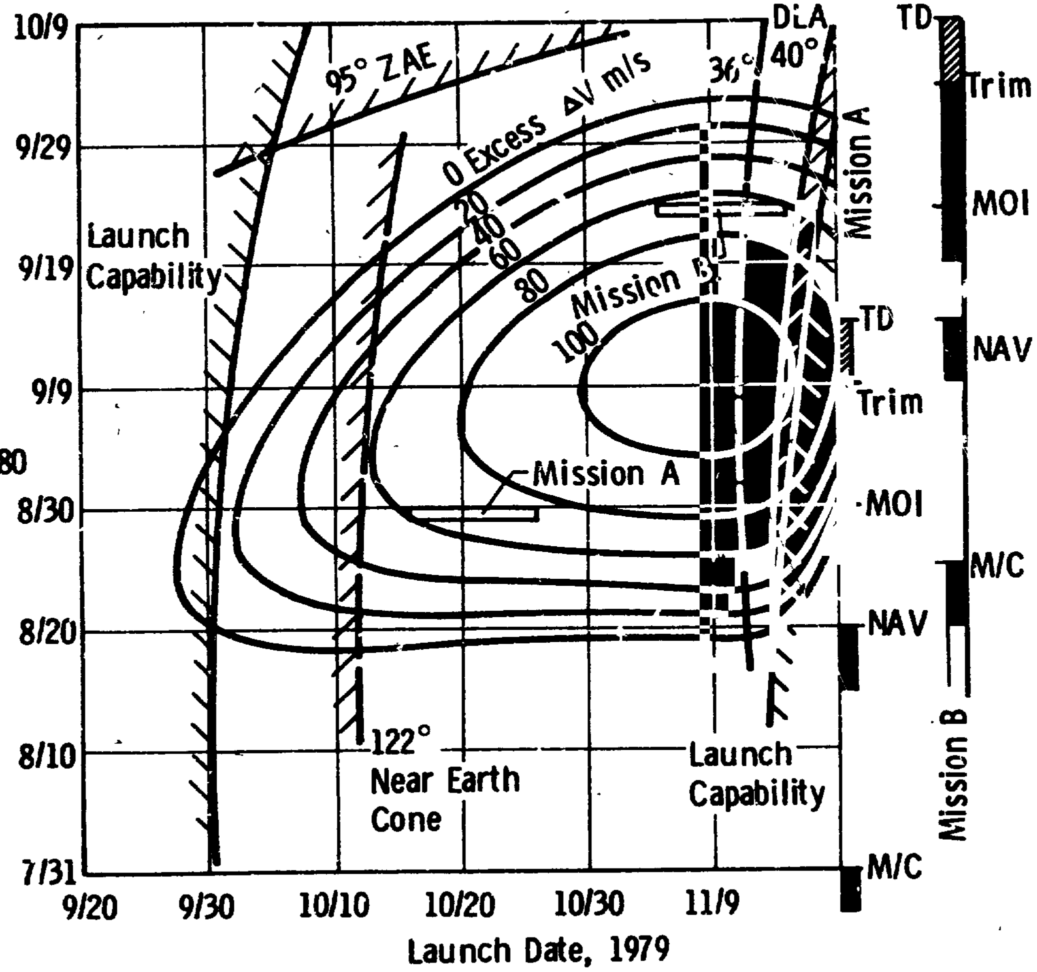


FIGURE 9 INITIAL VIKING '79 PERFORMANCE DATA (SHEET 2 OF 3)

Launch Mass = 3951.7 kg (8712 lb)
Drop Mass = 210.9 kg (465 lb)
Prop Mass = 1404.8 kg (3097 lb)
ΔV Cap = 1320 m/s
Del Mass in Orbit = 272.2 kg (600 lb)
ΔV Budget = 175 m/s
Prop I_{sp} = 2828 N-s/kg (286 s)
Orbit = 1500 km/24.623 hr

Arrival Date, 1980

ΔV Capability
-ΔV MOI (Finite Burn)
-ΔV Budget

ΔV Excess

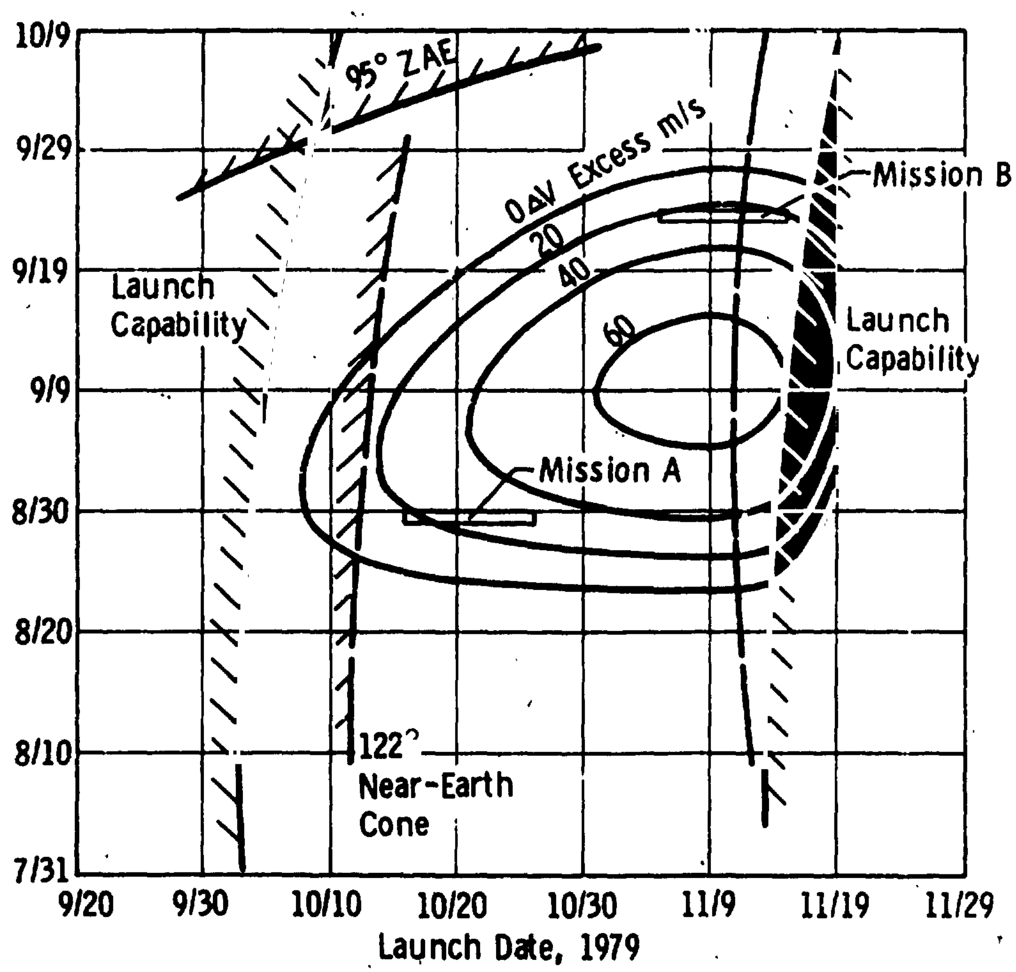


FIGURE 9 INITIAL VIKING '79 PERFORMANCE DATA (SHEET 3 OF 3)

The data in Figure 9 show the excess ΔV remaining in the spacecraft after MOI over and above the required ΔV presented in the preceding ΔV budget. This surplus performance can be used for launch period enlargement, increased encounter date separation, landing site accessibility (discussed below under Landing Site Accessibility), or increased on-orbit operations flexibility. Using the delta mass = 181.8 kg (400 lb) case (Figure 9) as an example, the selected 30-day launch period is October 16 to November 15, 1979. The represented Mission A and B 10-day launch periods are separated at encounter by 25 days.

The encounter date separation of 25 days was selected based on the 1975 Mission A operational timelines shown on Figure 9. The maximum possible encounter date separation for this example is approximately 40 days compared to the Viking '75 value of 50 days. Reducing the encounter date separation to 25 days tends to decouple the operations activity between the two missions. The Viking '75 value of 50 days was selected to allow a major retargeting of the Mission B based on the results of the Mission A data. As stated before in the assumptions, this may not be a requirement in 1979. Thus, the 25-day ecnounter date separation is recommended to minimize common operations activity overlap between the two missions.

In summary, the performance analysis of allowable mass into Mars orbit shows that the Viking '75 launch vehicle and spacecraft can deliver up to 310.7 kg (685 lb) additional mass into Mars orbit compared to Viking '75 (October 1973 mass). A launch period of approximately 35 days is possible between the VO near-Earth communication limit (122 degree cone angle) and DLA of 40 degrees. The selected launch period is not constrained by launch vehicle performance; thus, increased spacecraft adapter mass can be accommodated with no penalty if required to support the increased spacecraft mass.

VLC Constraints

The trans-Mars performance analysis presented in preceding paragraphs indicates that a maximum of 310.7 kg (685 lb) can be carried into Mars orbit over and above the allocated mass in the October 1973 Mass Properties Report. Some of this Δmass is being absorbed by increased Viking '75 mass allocations. The remainder can be allocated between the orbiter and lander/rover. The analyses presented in following paragraphs show that deorbit-to-entry performance constrains the lander/rover mass delta to a maximum of 233.6 kg (515 lb).

Lander/rover mass analysis. - The initial entry-to-touchdown performance analysis assumed no change in lander performance characteristics. Increased capability over 1975 is achieved by assuming reduced environmental uncertainties based on data return from the 1975 mission. In addition, performance capability sensitivity to both environment and lander hardware changes were generated. These assumptions and results are discussed in the following paragraphs.

Deorbit Performance Analysis - The performance characteristics of the lander deorbit/ACS system are as follows:

Usable propellant (max) = 86.3 kg (190.3 lb)

I_{sp} = 2210.4 N-s/kg (225.4 s)

Propellant allocations:

ACS Control	= 4.4 kg (9.7 lb)
Deorbit Roll Control	= 0.14 kg (0.3 lb)
Trapped Propellant	= 1.0 kg (2.2 lb)
99% Margins for I_{sp}, Loading, Deorbit roll and sensor uncertainty	= 1.54 kg (3.4 lb)

Total Available for Deorbit = 79.2 kg (174.7 lb)

These characteristics are identical to those being used for Viking '75 deorbit performance analysis. The resultant deorbit ΔV_D versus separated lander weight is shown in Figure 10.

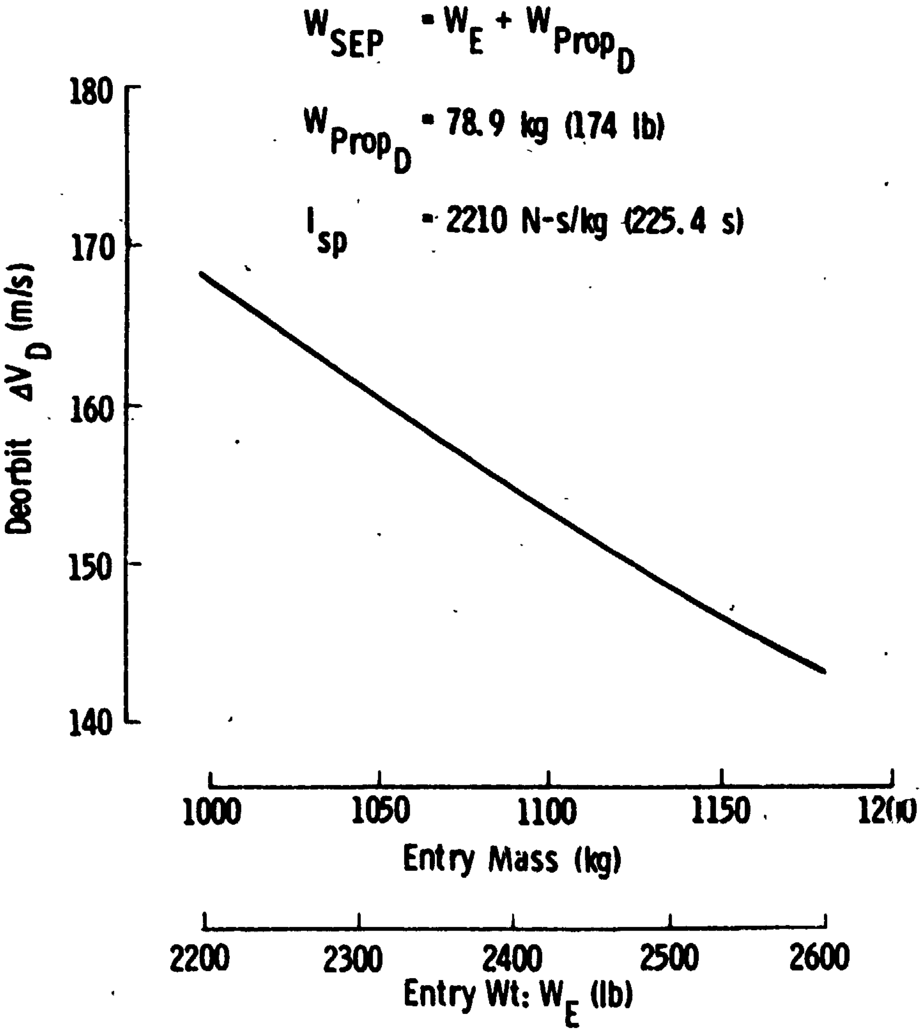


FIGURE 10 DEORBIT ΔV_D SENSITIVITY TO ENTRY MASS

Representative deorbit performance characteristics are shown in Figure 12 as a function of ΔV_D and γ_E. The data show the PER (in-plane landing site location measured from the orbit subperiapsis point), XR (crossrange distance perpendicular to the orbital plane) and coast time between deorbit and entry (Viking '75 limit of 5 hours). The Viking '75 specifications require that the orbit position relative to the landing site be within $\pm 2^\circ$ PER and $\pm 3^\circ$ XR (99%) considering all error sources. Subtracting this control capability from the performance capability of Figure 12 gives the allowable nominal PER_{NOM} that can be used for mission planning. These data are shown in Figure 13 as a function of ΔV_D, orbit periapsis altitude (h_P), and γ_E.

The data from Figures 11 through 13 are combined in Figure 14 to define maximum allowable entry mass, (or minimum allowable ΔV_D). The final Viking '75 capability of periapsis control of 150 km results in an entry mass limit of 1145 kg (2525 lb) (or $\Delta V_{D_{MIN}} = 147$ m/s) for a nominal periapsis altitude of 1500 km. A minimum h_P of 1350 km is constrained by relay link time considerations.

Entry-to-Touchdown Performance Analysis - Achievement of increased landed mass performance in 1979 compared to Viking '75 requires making some assumptions. The principal assumptions made here are that atmospheric and terrain

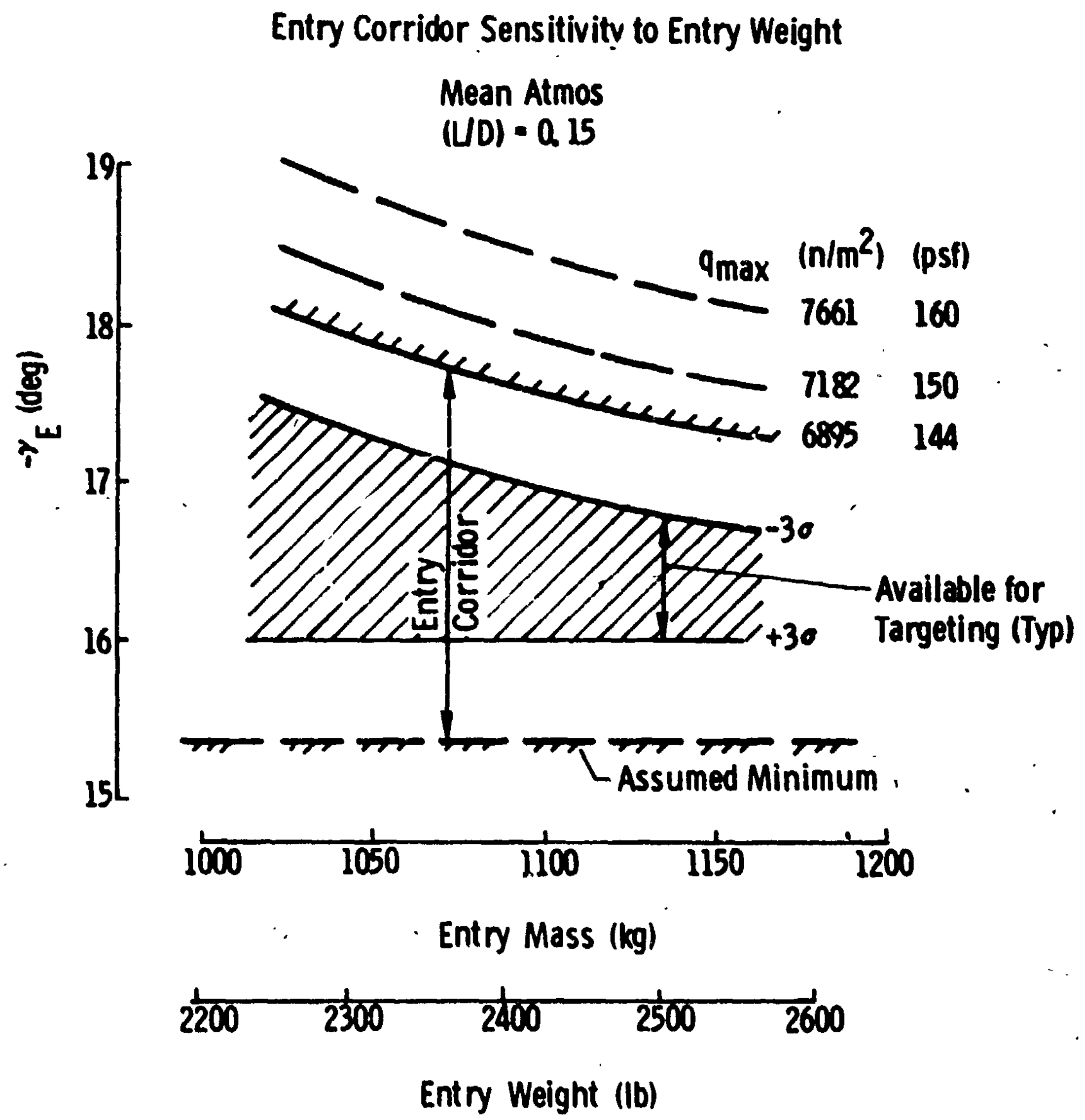


FIGURE 11 ENTRY CORRIDOR SENSITIVITY TO ENTRY MASS

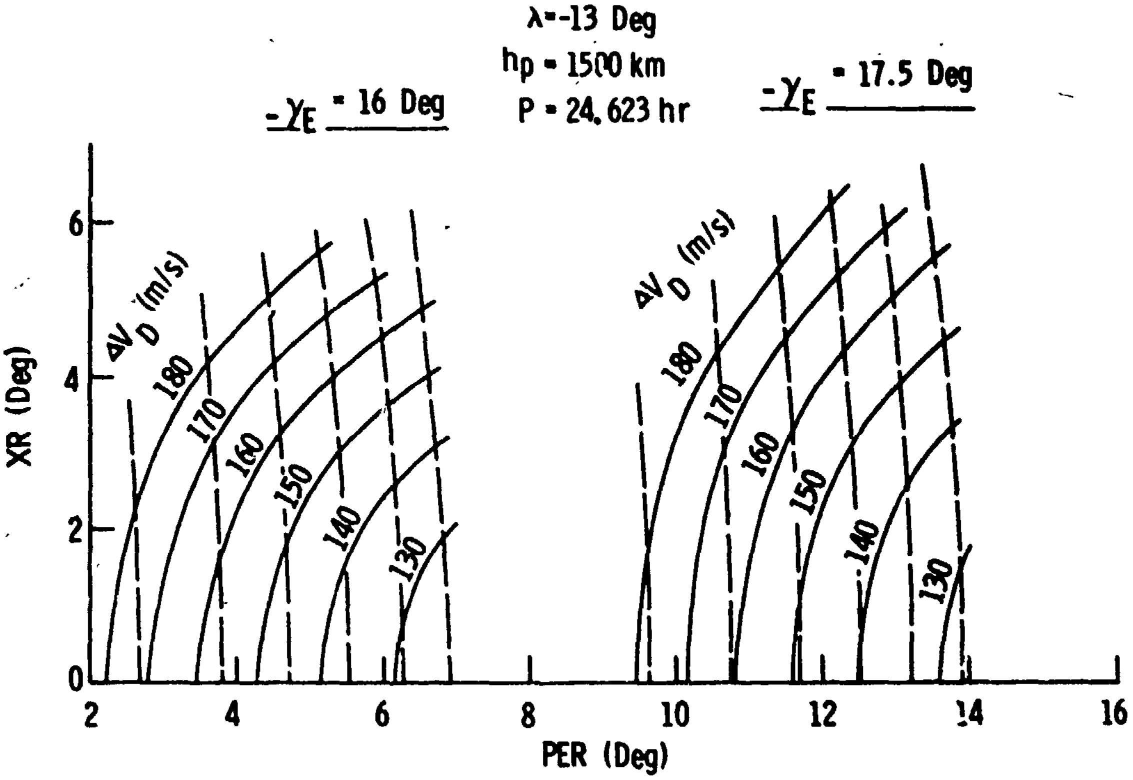


FIGURE 12 DEORBIT PERFORMANCE

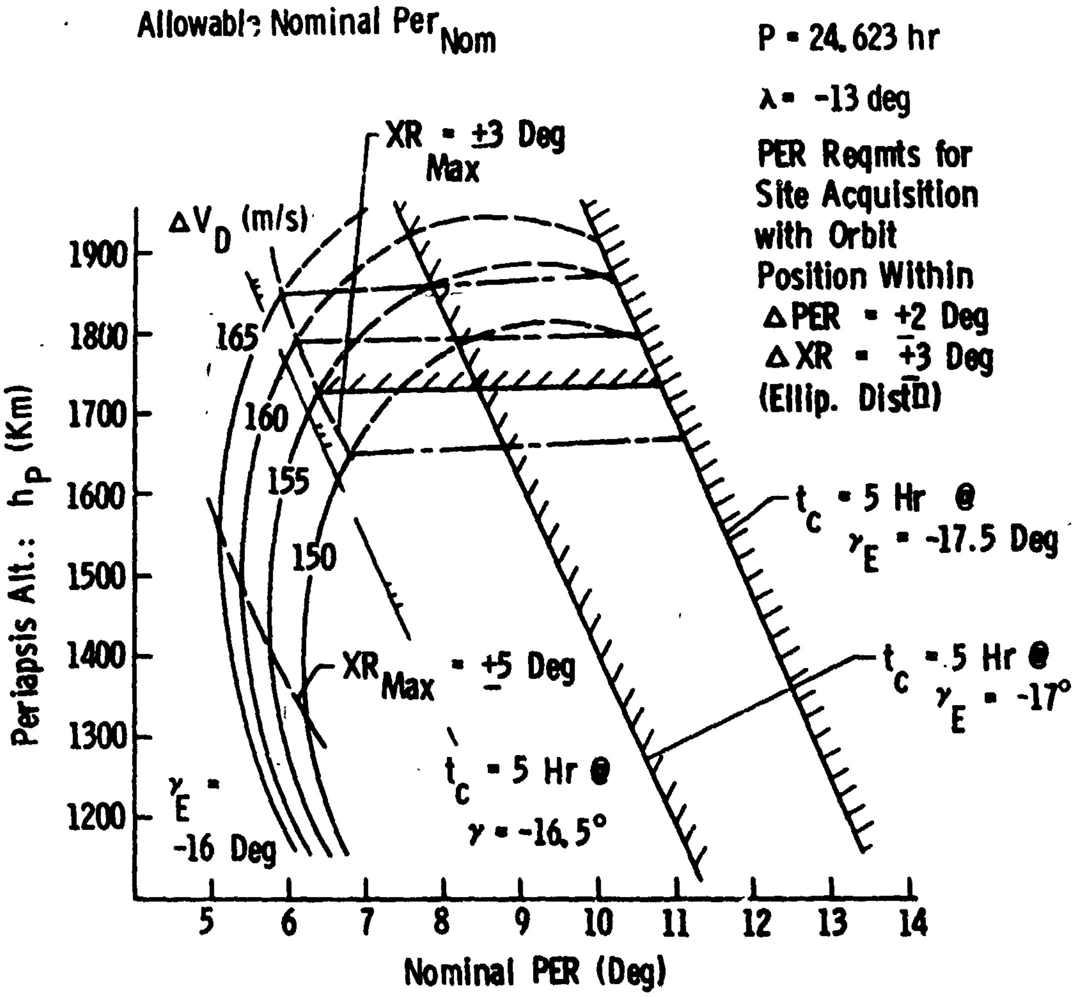


FIGURE 13 ALLOWABLE PER$_{NOM}$

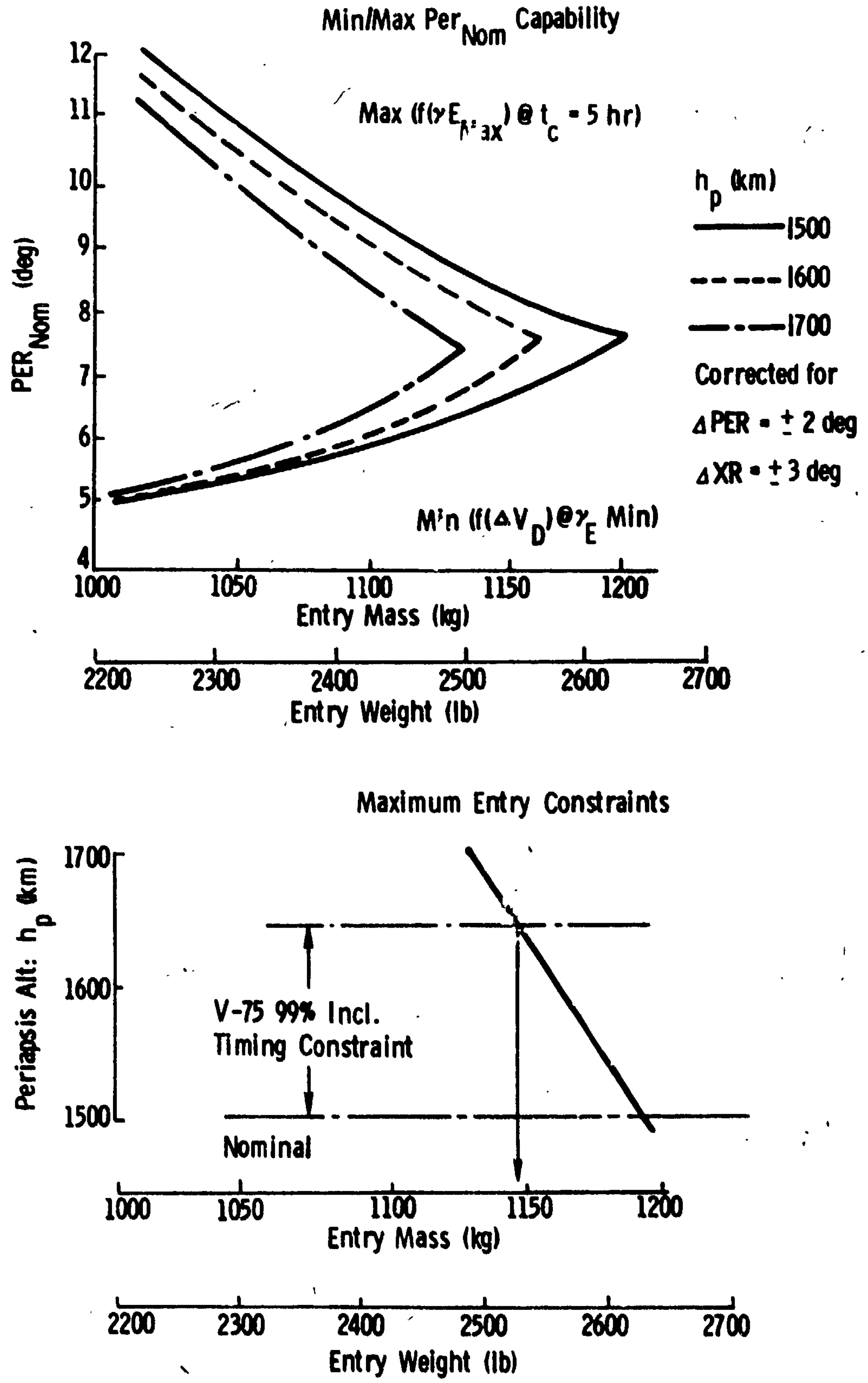


FIGURE 14 MIN/MAX PER$_{NOM}$ CAPABILITIES

height uncertainties used in the development of the Viking '75 design criteria would be reduced by a factor of two as the result of the Viking '75 and Russian missions.

The Viking '75 design atmospheric characteristics impact the entry-to-touchdown performance in the following ways:

MAXρ_S Atmosphere - Upper altitude scale height is minimum, thus maximizing peak heating rates and load factors at any given γ_E. Entry is short so that total heat is minimized. Peak aeroshell loads limit steep γ_E. Higher low altitude densities allow lowest altitude at parachute mortar fire, smallest altitude loss on the parachute, and minimum velocity at parachute separation.

MINρ_S Atmosphere - High upper altitude scale height has the lowest peak heating rates and entry loads, but the longest entry time and results in highest total heat load (heat shield design criteron). Deceleration at higher altitude results in an overshoot condition for lifting entries, which has slow recovery and results in increased velocities at low altitude for shallow γ_E entry (defines shallow γ_E limit). Low densities and low altitudes require highest altitude at mortar fire and have maximum altitude loss on the parachute (defines mortar fire trigger altitude). Low density also results in the highest velocity at parachute separation, thus designing the vernier propulsion system propellant requirements.

MEAN Atmosphere - Characteristics are intermediate between the two forementioned atmospheres in all respects.

In assuming that the atmosphere uncertainties in 1979 are half of those used in the design of the Viking '75 lander, we have selected the combination of MINρ_S/MEAN Atmospheres for evaluating the 1979 mission performance capabilities. This combination is clearly the more adverse half of the current atmosphere uncertainty band. All other atmosphere combinations result in increased performance capabilities. Sensitivities are presented in the following paragraphs.

The second primary assumption is that the terrain height uncertainty can be reduced from 3.05 km (10 000 ft) to 1.52 km (5000 ft). The original source of the terrain height uncertainty resulted from terrain elevation uncertainties of Earth-based radar measurements and their correlation with measured (deduced) surface pressures from Earth-based measurements and measurements from Mariners 4, 7, and 9. Successful Viking '75 landings will reduce these uncertainties. Lander tracking will establish the lander position (three coordinates) to approximately one kilometer (3σ). This will be correlated with current elevation maps. In addition, entry and surface measurements will provide atmosphere characteristics (pressure, density, composition, winds, diurnal effects, etc.). Thus, atmosphere data can be correlated to elevation and latitude at two locations. These data, coupled with additional orbiter data, will allow the development of much more comprehensive and accurate global atmosphere models and their relationship to elevation and latitude. These arguments, then, are the basis for reducing the terrain height uncertainty. Again, performance sensitivities are presented in the following paragraphs.

The landed mass and performance analysis is presented in two parts. The first assumes no change in any of the Viking '75 subsystems to increase performance capability. This analysis, plus sensitivities, is presented first. The second phase of the analysis assumes modification of the terminal descent (vernier) propulsion subsystem to increase the landed mass capability.

The entry-to-touchdown performance analysis includes a sensitive balance between the entry, parachute, and vernier phases of the mission. In toto, an energy per unit mass corresponding to an entry velocity of approximately 4575 m/s at an altitude of 244 km must be dissipated. Further, this must be accomplished with Viking '75 lander constraints of maximum dynamic pressure during entry of 6895 N/m^2 (144 psf) and maximum dynamic pressure at parachute mortar fire of 413 N/m^2 (8.62 psf). The variables include entry flight path angle (γ_E), choice of L/D during entry, choice of atmosphere combinations and winds, and design terrain height capability.

Appreciation of the factors influencing landed weight performance is enhanced by understanding some basic characteristics. To this end, a series of entry trajectory profiles at different γ_E are shown in Figure 15. The basic characteristic is an initial deceleration with the velocity approaching terminal velocity (V_T) for an equilibrium glide to the surface. Steep γ_E have higher velocities at an altitude of 10 km because the entry deceleration is not yet complete.

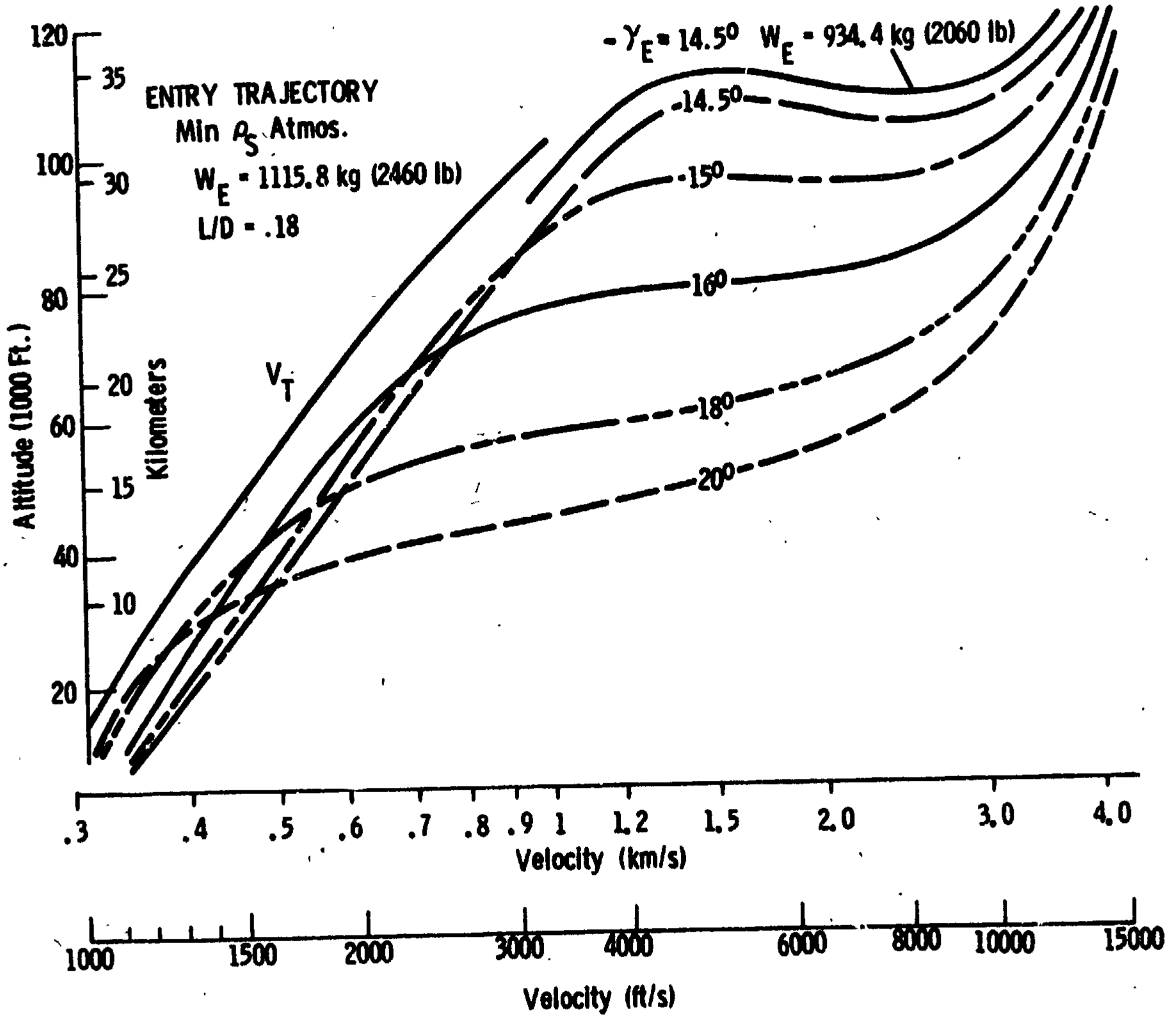


FIGURE 15 TYPICAL ENTRY TRAJECTORY CHARACTERISTICS

Shallow γ_E, however, also result in higher velocities at 10 km because of the lifting entry. This results from overshooting the equilibrium glide conditions at high altitude (30 km on the figure) and the vehicle diving to regain its equilibrium conditions (analogous to an aircraft stall). The impact of entry weight, also shown, is to raise or lower the altitude during deceleration for lower or higher weights, respectively. Decreasing L/D alleviates the shallow γ_E condition, but aggravates the steep γ_E by not having as much pullup, thus having the vehicle pass through the (limited) atmosphere quicker with less energy dissipation.

This effect is further illustrated with the data in Figure 16. These data show the altitude at the parachute deployment load limit as a function of L/D and γ_E. Low L/D result in too low altitudes at steep γ_E. Although higher L/D allow steeper γ_E, the maximum aeroshell load limit precludes taking advantage of this characteristic. In addition, the adverse effects of high L/D at shallow γ_E come into play.

The same data showing the effect of atmosphere is illustrated in Figure 17. Again, the steep γ_E is limited by maximum aeroshell loads. Although the shallow γ_E - L/D effect is pronounced for the MAX ρ_S atmosphere, the impact is not significant since the required altitude for parachute deployment for landing at 1.52 km terrain elevation is approximately 5.2 km, well below the minimum altitude for satisfying parachute deployment conditions. The shallow γ_E limit for the MIN ρ_S atmosphere does come into play strongly, however, because the parachute must be deployed at approximately 10.4 km to perform its function and still allow landing at a terrain elevation of 1.52 km. In this case, the high scale height associated with the MIN ρ_S atmosphere slows the deceleration towards terminal velocity (analogous to a longer time constant).

These considerations are now combined to establish the optimum L/D and associated entry corridor. The data in Figure 18 present the relationship between L/D and γ_E at constant altitude and maximum parachute dynamic pressure (mortar fire). The data correspond to the worst case condition for atmospheres between MIN ρ_S and MEAN. The maximum aeroshell ent y pressure constraint limits the steep γ_E between 17.5 to 18°. The required mortar fire altitude for the example

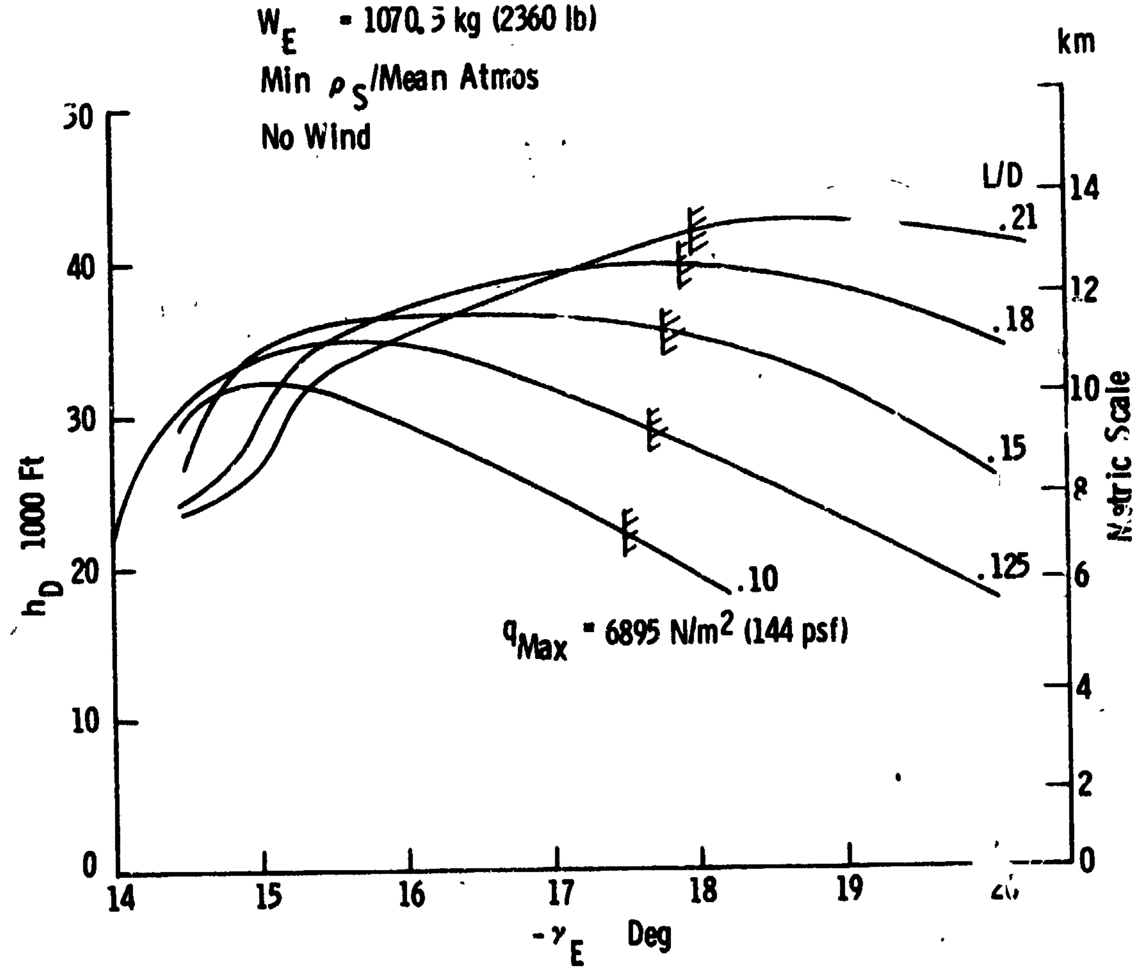


FIGURE 16 PARACHUTE DEPLOYMENT ALTITUDE

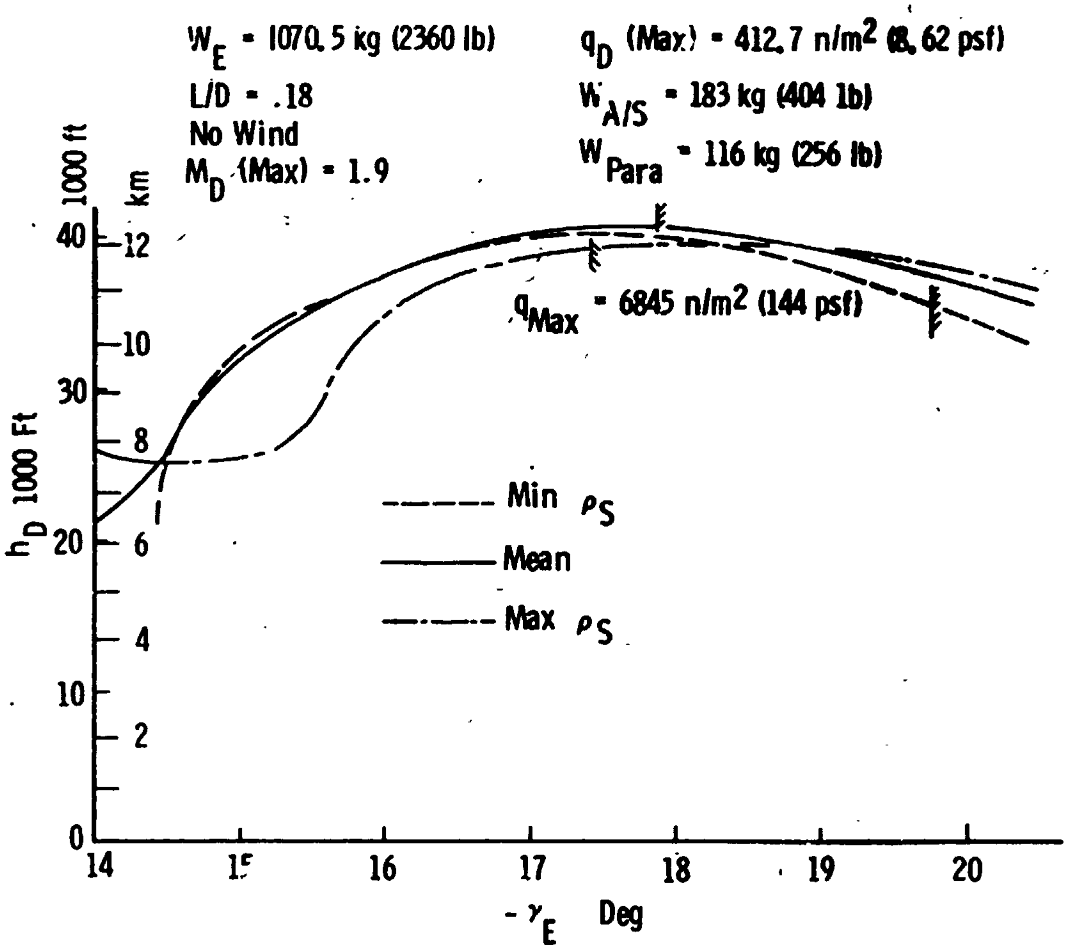


FIGURE 17 DEPLOYMENT ALTITUDE SENSITIVITY TO ATMOSPHERE

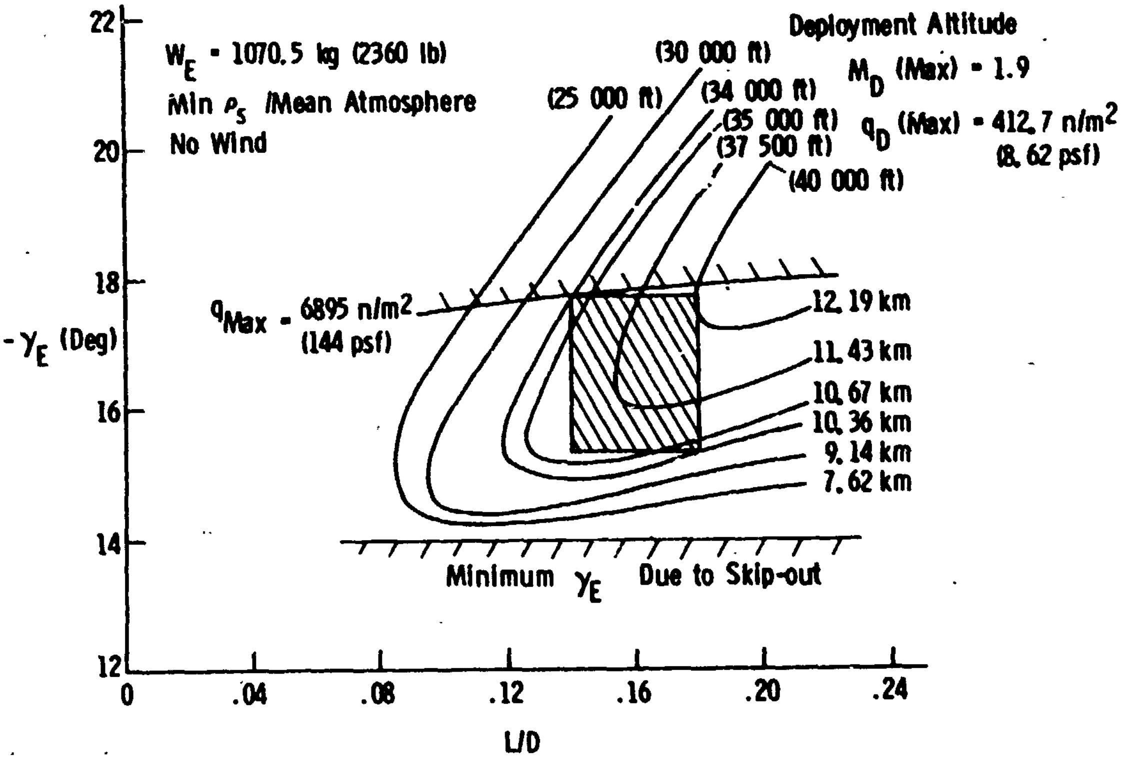


FIGURE 18 ENTRY CORRIDOR AND L/D SELECTION

shown is 10.4 km. The area between these constraints represents allowable flight conditions. The Viking '75 L/D uncertainty is ±0.02 (3σ) due to balancing control of the center of mass (c.m.). Superimposing this constraint results in the selection of a nominal L/D = 0.16 and $3\sigma\gamma_E$ limits of -15.35 to -17.75°. This compares to Viking '75 characteristics of L/D = 0.180 and γ_E between -14.5 to -18.5°

Similar data for other atmosphere combinations are shown in Figure 19. Assuming the atmosphere uncertainty is half of the Viking '75 range says that the entry corridor size ($\Delta\gamma_E$) will be between the MIN ρ_S/MEAN and MEAN/MAX ρ_S curves. The MIN ρ_S/MEAN condition is the most limiting and is assumed in all of these performance analyses unless specifically stated otherwise. If the Viking '75 mission determines the atmospheres to be closer to the other limit, this can be converted into either increased entry corridor (targeting flexibility) as shown or to provide increased landed mass margins with the same entry corridor.

Most of the preceding data assumed an entry mass of 1070.5 kg (2360 lb). Preliminary analyses such as those shown in Figure 20 indicated this mass to be close to the maximum allowable for the basic Viking '75 entry, parachute, and vernier performance characteristics. They also showed that the vernier thrust-to-mass ratio is marginal with landed mass increases of 136.1 kg (300 lb) compared to Viking '75. The data in Figure 20 shows that very little can be gained by increasing the vernier propellant capacity because of the marginal thrust. However, major performance improvement can be realized with thrust level increases, an additional 515.8 N (116 lb) for an average thrust level increase of 30 percent.

During the analysis period actual vernier engine test data became available. It became apparent that the average thrust of the tested engines was 4.6 percent higher than the specification thrust [maximum thrust of 2847 N (640 lb) versus spec value of 2722 N (612 lb)]. There is sufficient confidence in these test data that the test performance has been used in the subsequent performance studies.

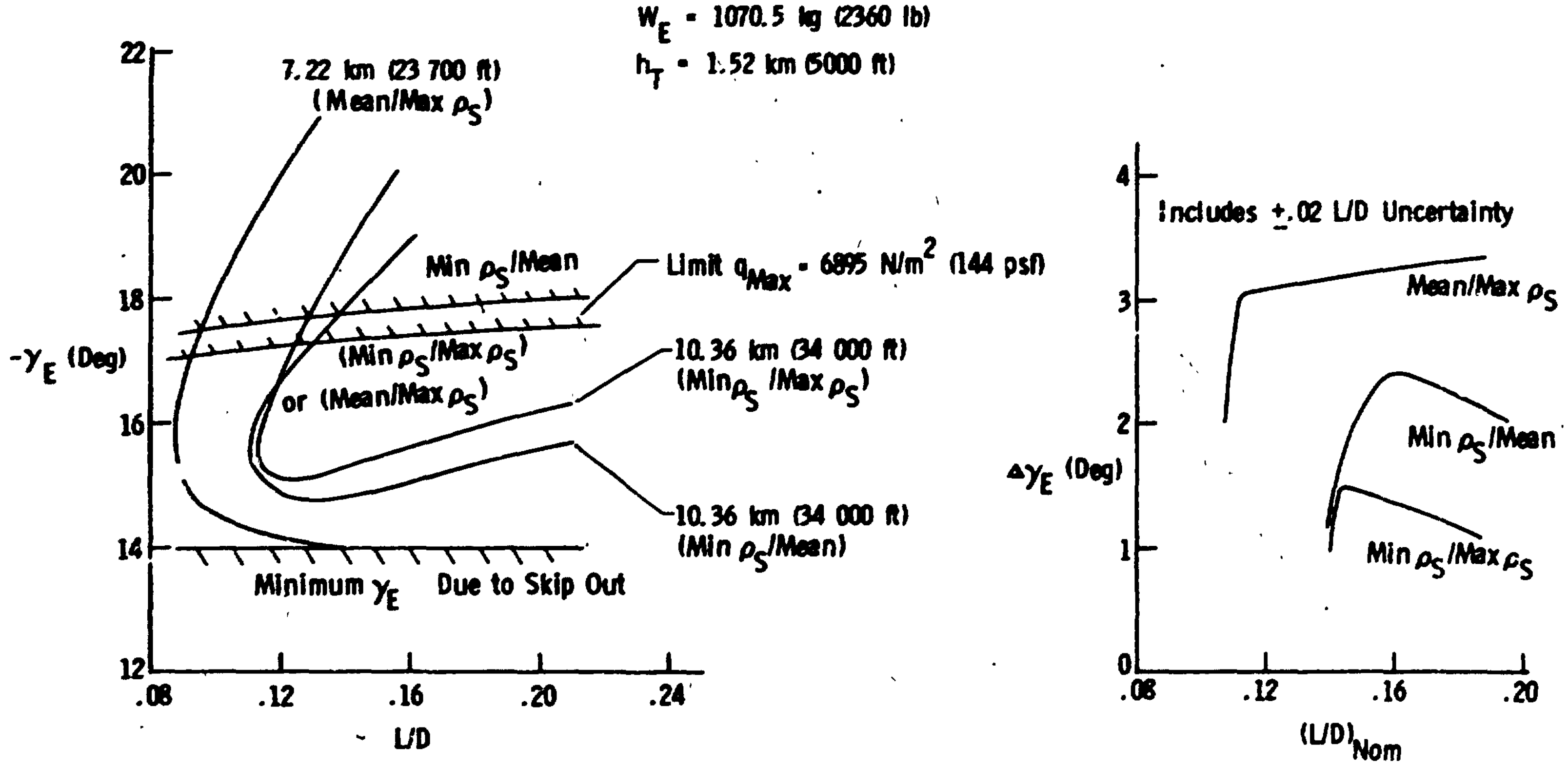


FIGURE 19 L/D AND ENTRY CORRIDOR OPTIMIZATION

Note:

1. Dry Landed Weight

   $= W_E = 312.5 - W_{Prop}$ (kg)

   $= W_E - 689 - W_{Prop}$ (lb)

2. Propellant Mass Includes All Margins and Trapped Propellants

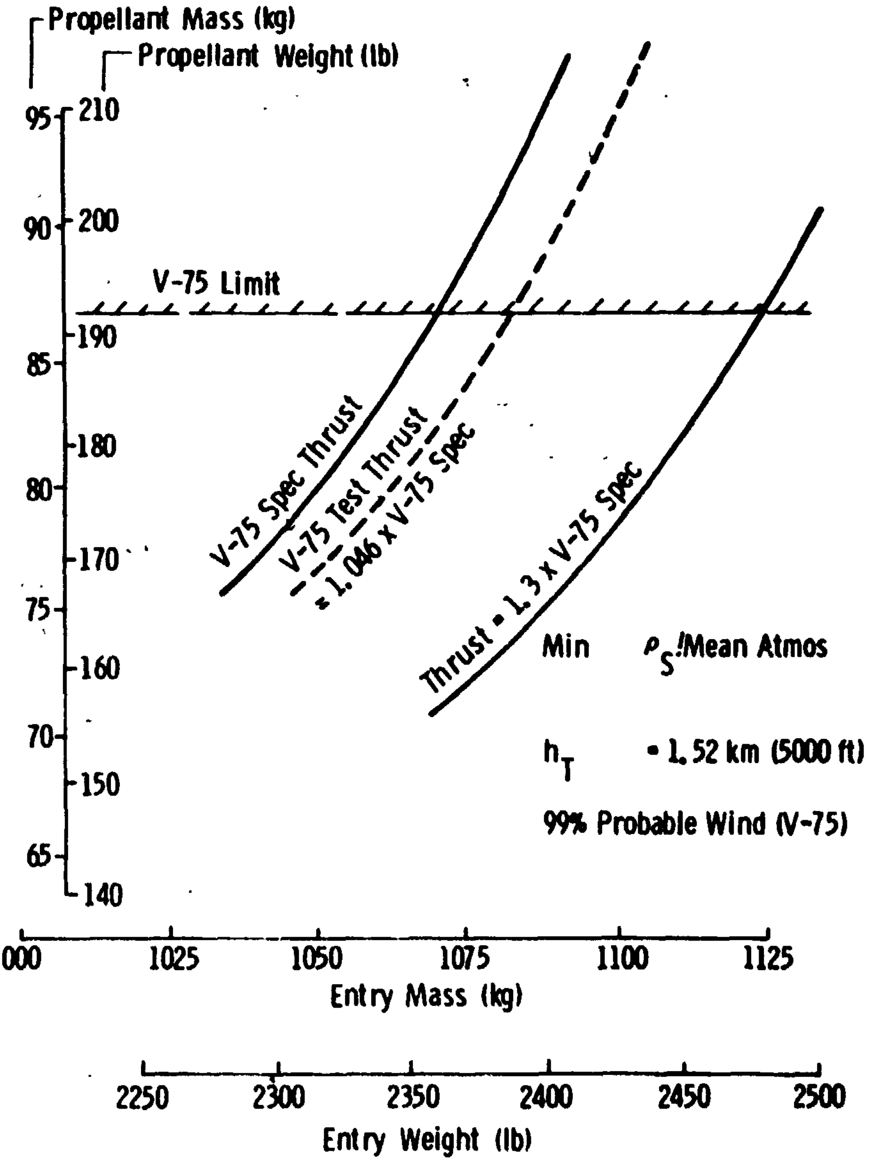


FIGURE 20 AMOUNT OF VERNIER PROPELLANT REQUIRED

The performance capability of the basic Viking '75 lander and the mass breakdown used in the analyses are summarized in Table 8 and compared with the October 1973 Viking '75 allocated masses as well as the current estimate of the anticipated Viking '75 lander mass. Care must be exercised in comparing these masses because propellant loadings and margins have changed between the allocated masses and the remaining conditions. The Viking '79 performance includes fully loaded aeroshell and vernier propellant tanks and current estimates of margins required for 99 percent probability uncertainties. In addition, some adjustments were made to reflect both current measured masses of Viking '75 equipment plus preliminary estimates of aeroshell and base cover mass increases required to accommodate a rover configuration. These masses were used in the original performance analysis presented below.

The summary of the foregoing results is that the maximum performance increases possible in 1979 (given the atmosphere and terrain height assumptions given) are:

> Spec performance allows 105.7 kg (233 lb) more useful mass on the surface over Viking '75 allocated mass and 71.2 kg (157 lb) over the anticipated Viking '75 mass.
>
> Corresponding increases using current vernier engine performance are 117.9 kg (260 lb) and 83.5 kg (184 lb), respectively.
>
> Maximum allowable loaded VLC mass increases in Viking '79 are 157.9 kg (348 lb) and 170.1 kg (375 lb) for the Specification and Test performance capabilities, respectively, over the October 1973 allocated masses.

Several sensitivities were evaluated to establish techniques for increasing landed mass performance capability. These included varying the terrain height capability (Figure 21) and design wind conditions (Figure 22); neither is recommended as a technique for increasing performance. Performance sensitivity to parachute mortar fire conditions is shown in Figure 23. This provides no payoff when maximizing entry corridor is a consideration. Finally, varying the parachute size was evaluated. This can significantly increase performance as shown in Figure 24 even when increasing the parachute system

TABLE 8 PERFORMANCE SUMMARY - VIKING '75 CAPABILITY

	V'75 ALLOCATED (OCTOBER 1973)		ANTICIPATED V'75		V'79 SPEC PERFORMANCE		V'79 TEST PERFORMANCE	
	kg	(lb)	kg	(lb)	kg	(lb)	kg	(lb)
Lander Dry Mass	564.3	(1244)	598.7	(1320)	670.0	(1477)	682.2	(1504)
Lander Pressurant	6.4	(14)	6.4	(14)	6.4	(14)	6.4	(14)
Residual Propellant	5.0	(11)	5.0	(11)	6.4	(14)	6.4	(14)
Landed Mass	575.6	(1269)	610.1	(1345)	682.7	(1505)	694.9	(1532)
Usable Propellant	59.4	(131)	68.5	(151)	80.7	(178)	80.7	(178)
Mass @ Ignition	635.0	(1400)	678.6	(1496)	763.4	(1683)	775.6	(1710)
Aerodecel. Dry Mass	116.1	(256)	109.3	(241)	111.6	(246)	111.6	(246)
Mass on Parachute	751.1	(1656)	787.9	(1737)	875.0	(1929)	887.2	(1956)
Aeroshell Dry Mass	168.3	(371)	181.4	(400)	184.2	(406)	184.2	(406)
Aeroshell Pressurant	3.2	(7)	3.2	(7)	3.2	(7)	3.2	(7)
Residual/ACS Propellant	11.8	(26)	7.3	(16)	7.3	(16)	7.3	(16)
Entry Mass	934.4	(2060)	979.8	(2160)	1069.6	(2358)	1081.8	(2385)
Usable Deorbit Propellant	72.6	(160)	78.9	(174)	78.9	(174)	78.9	(174)
Separated Mass	1007.0	(2220)	1058.7	(2334)	1148.5	(2532)	1160.7	(2559)
Bioshield Mass	110.7	(244)	127.0	(280)	127.0	(280)	127.0	(280)
VLC Loaded Mass	1117.7	(2464)	1185.7	(2614)	1275.5	(2812)	1287.7	(2839)

Note

Propellant margins and guidance policies are based on current Viking '75 operating procedures.

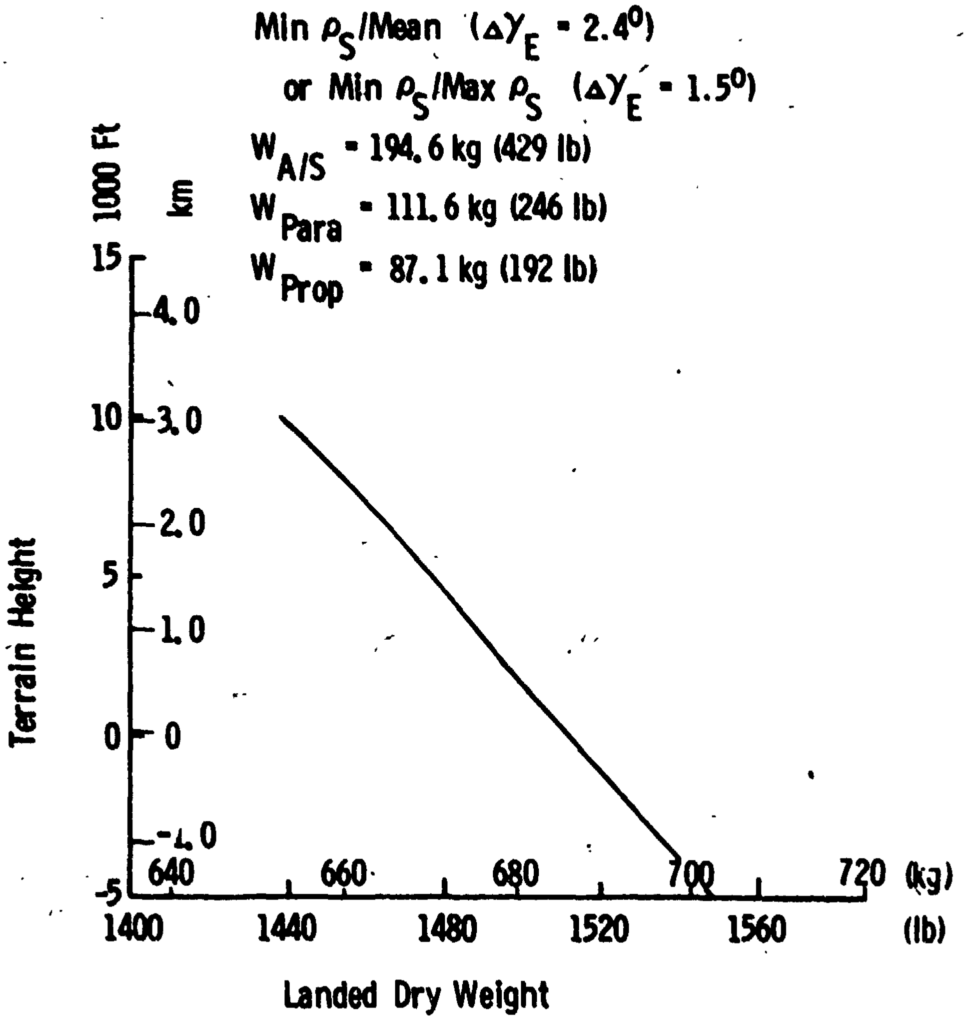


FIGURE 21 TERRAIN HEIGHT CAPABILITY

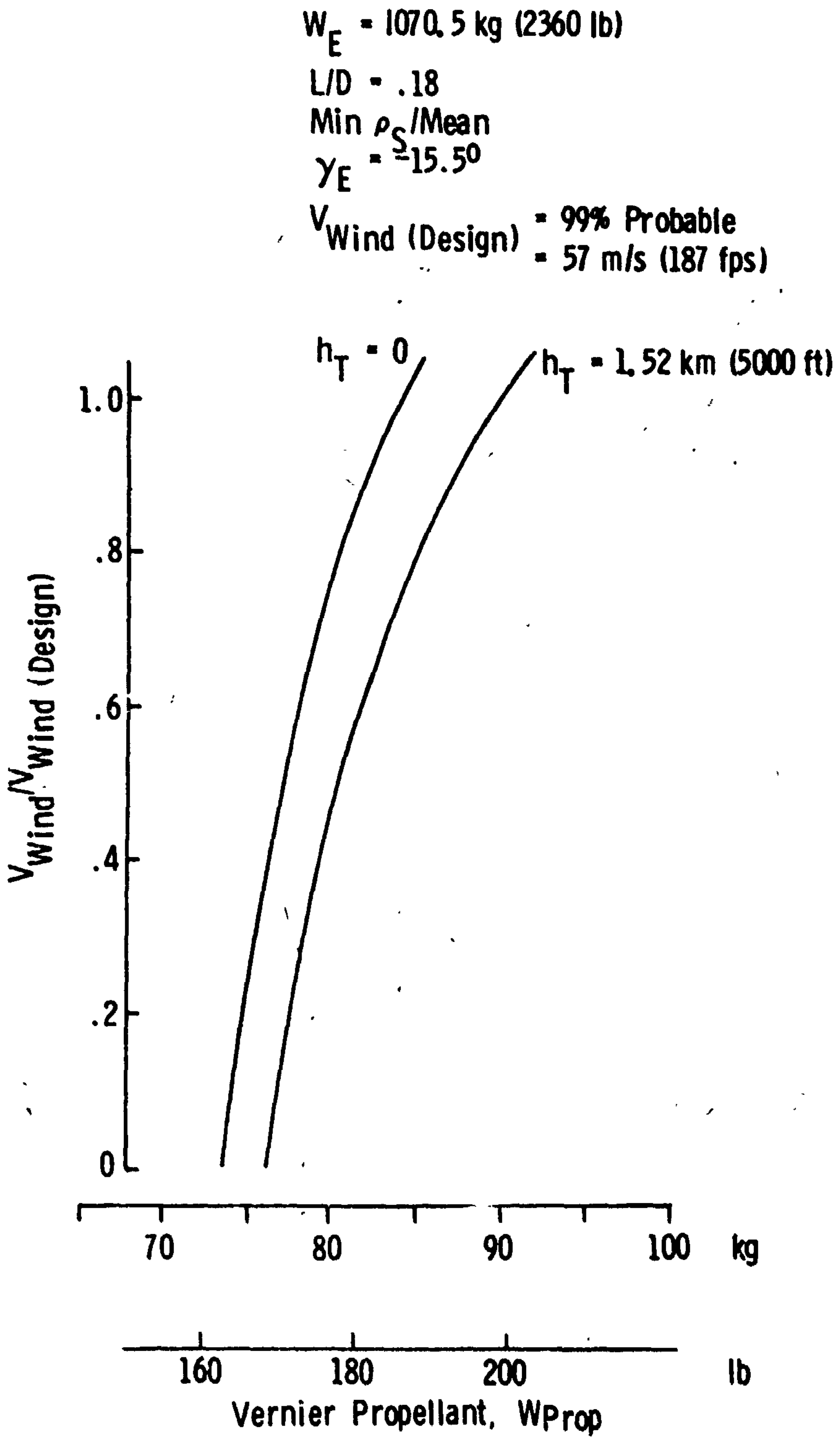


FIGURE 22 PROPELLANT SENSITIVITY TO WIND VELOCITY

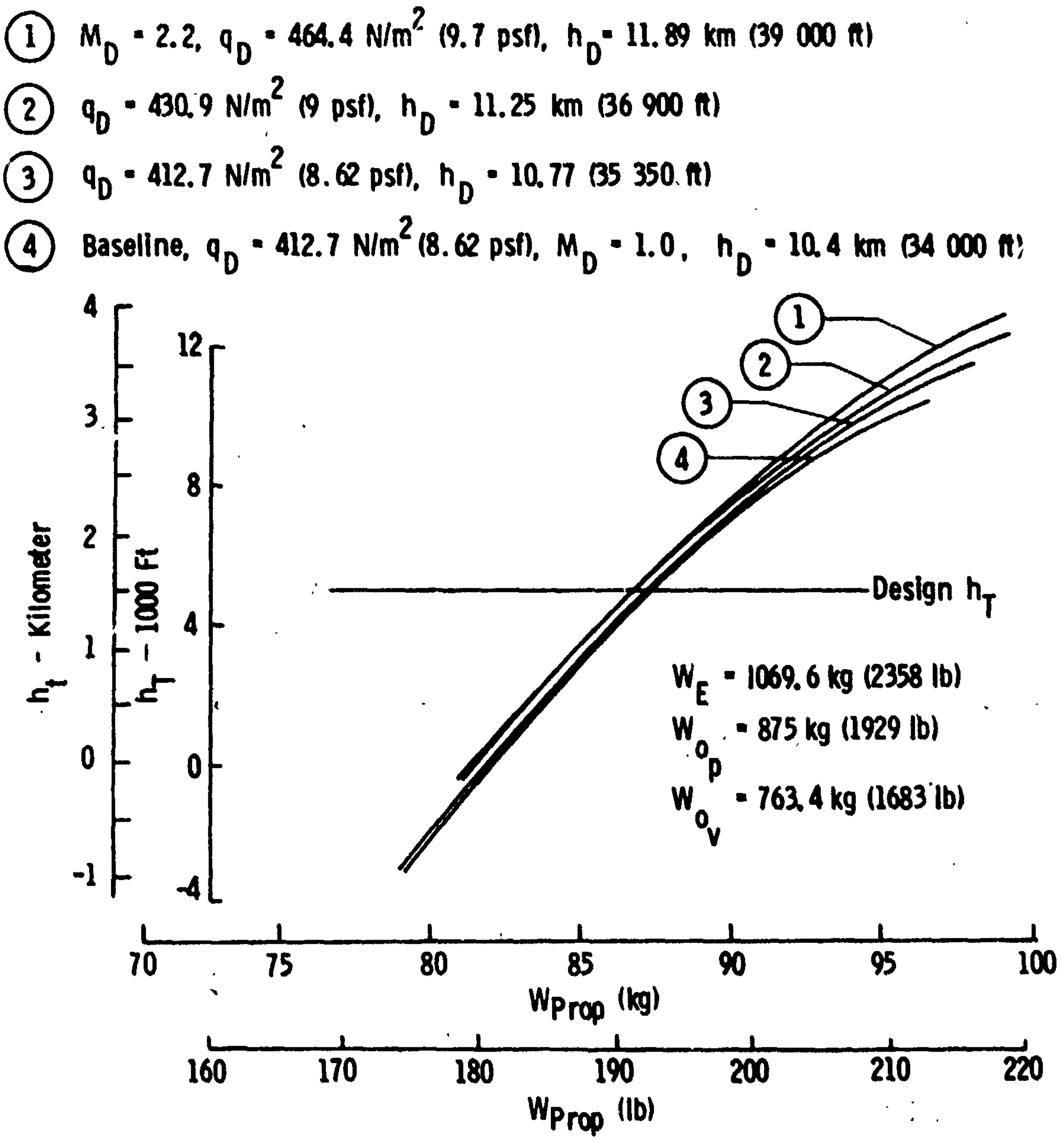


FIGURE 23 DEPLOYMENT CONDITION SENSITIVITIES

Landed Weight Sensitivity to Parachute Diameter

Min_{Ps} / Mean Atmos

γ_E = -15.35°

$L/_D$ = .16

h_T = 1.52 km (5000 ft)

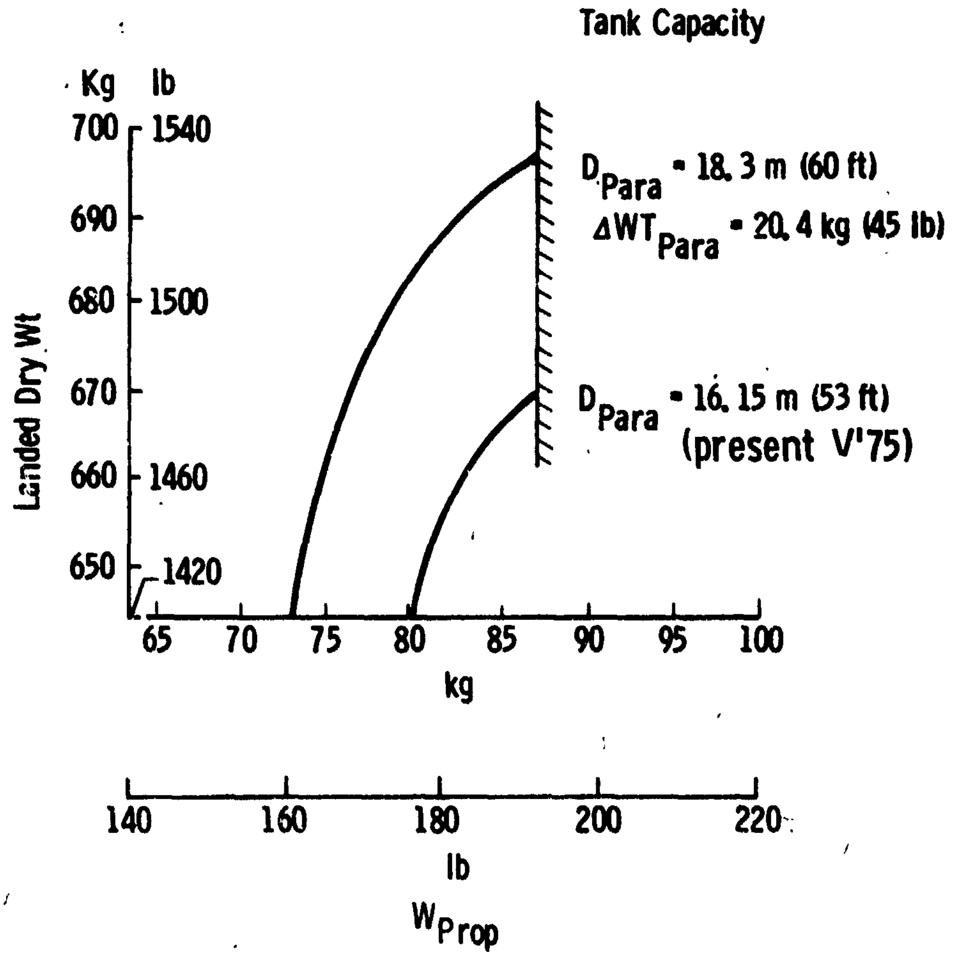


FIGURE 24 LANDED MASS SENSITIVITY TO PARACHUTE DIAMETER

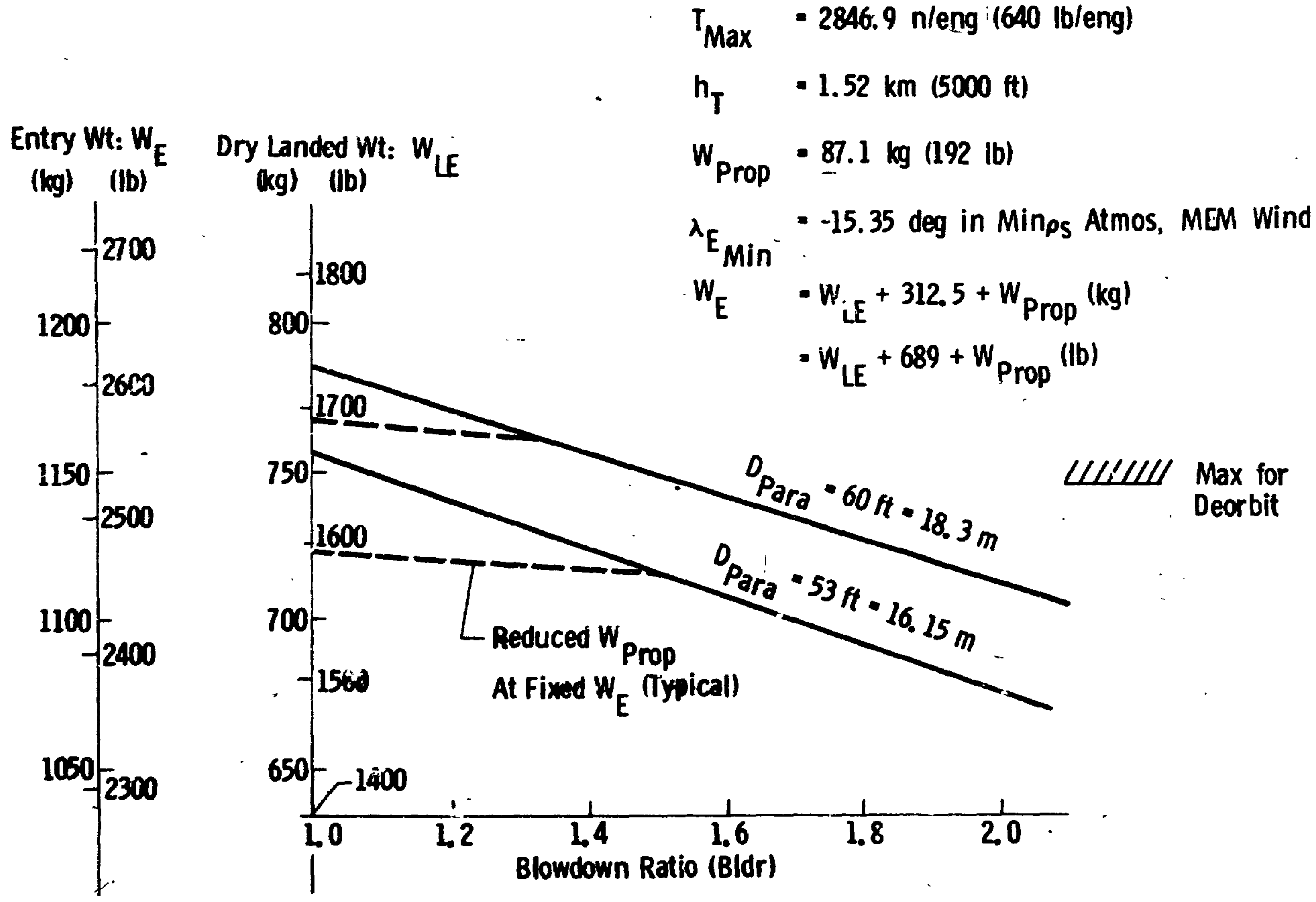
mass by 20.4 kg (45 lb). These sensitivity analyses plus the data presented earlier suggest that vernier engine thrust or increased parachute size are the most attractive ways of increasing the dry landed mass performance capability.

The vernier propulsion system is a pressurized system with a design blowdown ratio of approximately two. The maximum throttle thrust drops approximately 40 percent during the burn. The average thrust can be maintained at a higher value by increasing the pressurant volume with an additional tank either regulating the pressure in the propellant tank (blowdown ratio of one) or bleeding pressurant into the tanks to maintain the blowdown ratio at a level between one and two. The total mass penalty for this type of modification is 8.2 to 10.9 kg (18 to 24 lb) of additional hardware to be landed. No change is required in the rocket motors.

The performance capability for either modified propulsion system or propulsion modification plus increased parachute size is shown in Figure 25. Significant increases in dry landed mass capability can be realized with these configuration modifications. In fact, the performance capability at a blowdown ratio of one and using the Viking '75 16.15 m (53 ft) parachute exceeds the deorbit/targeting limit defined above and in Figure 14. On this basis, increasing the parachute size is not a recommended approach because its redevelopment problems are more complex than the proposed propulsion system changes. Further gains are available through L/D optimization.

A summary of the maximum allowable performance capability, which includes all the above considerations and the modified vernier propulsion system, is presented in Table 9 and compared to the current mass estimates. A performance margin exists at each entry phase over and above the contingency weight factors already included in the current weight estimates. Further entry performance gains are available from optimized L/D values and entry angles.

<u>Volume/shape/location/center of mass</u>. - The entry capsule is the governing factor in determining the maximum rover envelope. This envelope is developed in the entry capsule by the aeroshell, the base cover, the lander body, the lander mounted equipment, and the terminal engine plume boundary. This envelope is shown in Figure 26. The rover will be structurally mounted to the lander body and will have a minimum of 3.8 cm (1.5 in) of dynamic clearance



Maximum Landed Weight Capability

FIGURE 25 MAXIMUM LANDED MASS CAPABILITY

TABLE 9 VIKING '79 VLC PERFORMANCE SUMMARY

	MAXIMUM CAPABILITY		CURRENT ESTIMATE	
	kg	(lb)	kg	(lb)
Lander Dry Mass	745.7	(1644)	719.4	(1586)
Total Landed Mass	758.4	(1672)	732.1	(1614)
Mass at Vernier Ignition	839.1	(1850)	812.8	(1792)
Mass on Parachute	950.7	(2096)	924.4	(2038)
Mass at Entry	1145.3	(2525)	1130.8	(2493)
Separated Mass	1224.2	(2699)	1209.7	(2667)
VLC Loaded Mass	1351.3	(2979)	1336.7	(2947)

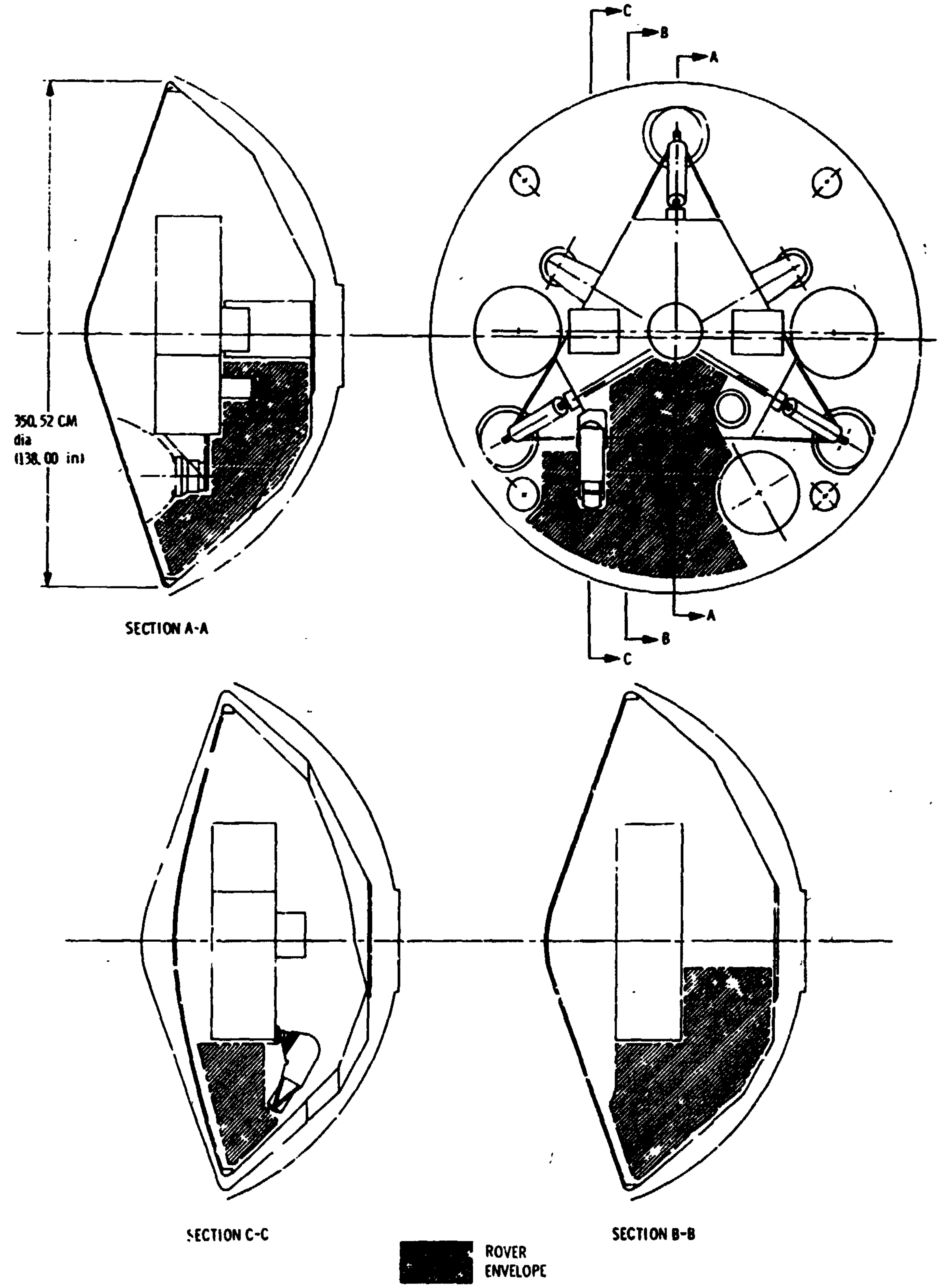


FIGURE 26 ROVER ENVELOPE

between any pont on the rover and the inside structural line of the aeroshell. The rover will have a minimum of 2.5 cm of dynamic clearance between any point on the rover and the inside structural line of the base cover. The rover will be located on the +Z side of the entry capsule and will not extend into the terminal engine plume. This location provides the maximum available volume in the entry capsule for rover stowage. The '79 lander c.m. is rotated 180 degree from that of the '75 lander.

The lateral entry c.m. will fall on a 4.19 cm radius. The longitudinal c.m. will be 80 cm aft of the theoretical aeroshell apex. The maximum mass moment that the rover can contribute to the lateral c.m. of the entry capsule is 100 kg-m.

Landing site accessibility. - Landing site accessibility is constrained only in latitude. Any longitude can be acquired by orbit timing maneuvers before lander deorbit. Latitude constraints are derived from the following:

Mars orbit insertion (MOI) performance capability.

Sun elevation-angles at touchdown (SEA_{TD}). Angles between 15 to 65 degrees are required for good predeorbit landing site pictures from orbit.

Orbiter power constraint with lander attached. No orbiter sun occultation allowed for 50 days after MOI.

Direct command and telemetry link geometry (Martian surface to Earth).

Thermal limits on lander or rover.

Thermal constraints are discussed in the preceding paragraphs and in Section 6.4. The remaining constraints are discussed in the following paragraphs.

The latitude constraints imposed by the forementioned first three factors are shown in Figure 27 as a function of Δmass in orbit (as defined under Mission Operations preceding). The maximum Northern and Southern latitudes are constrained by the low SEA_{TD} limit for both Mission A and B. The equatorial region is eliminated by the orbiter power constraint for Mission A, and by the $SEA_{TD} \leq 65$ degrees constraint for Mission B. At the current Δmass = 219 kg (483 lb) estimate, latitudes between approximately 60°N to 70°S can be acquired

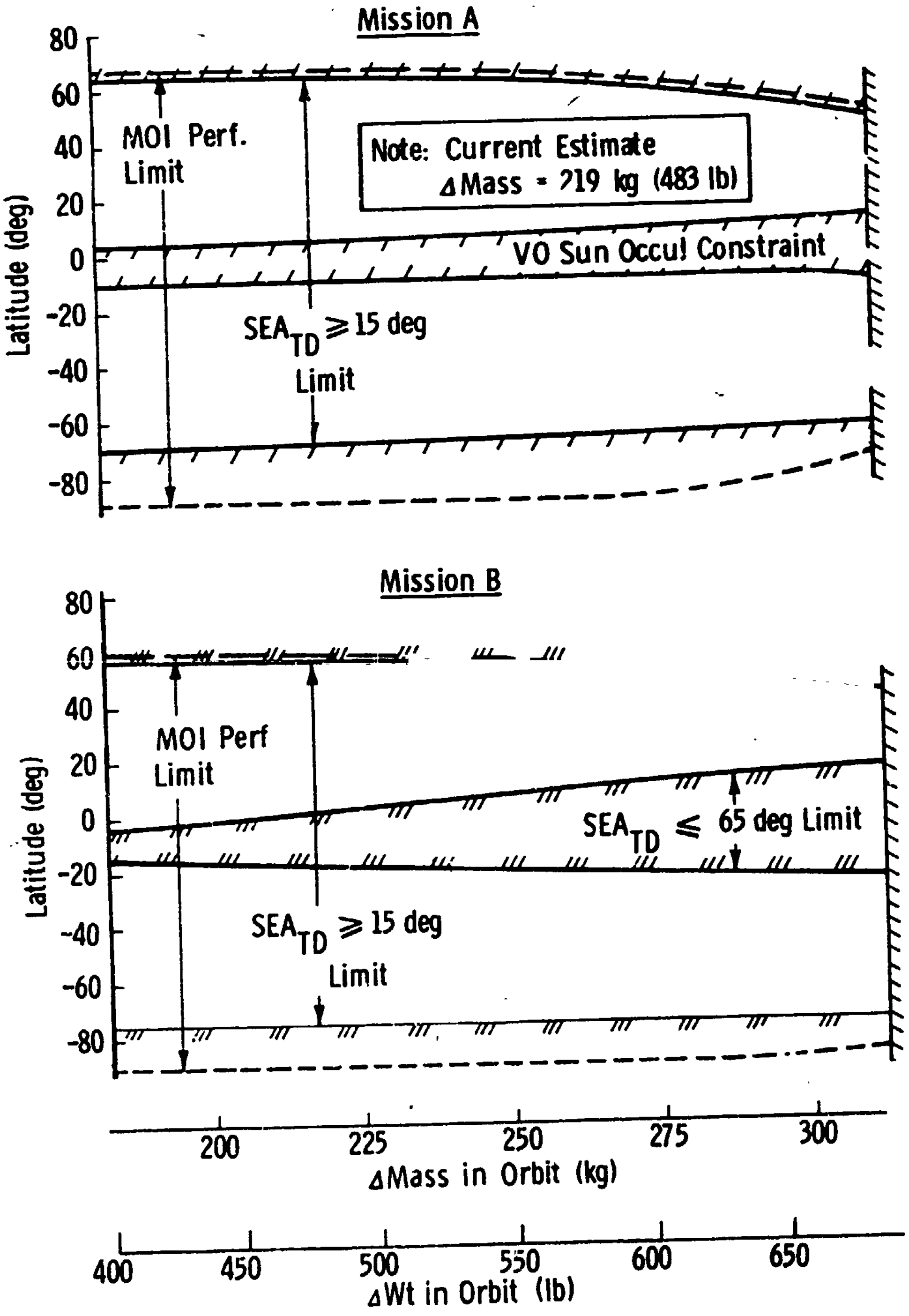


FIGURE 27 FLIGHT PERFORMANCE LIMITS ON LANDING SITE LATITUDE

with the equatorial region between 4°N to 20°S eliminated. Relaxation of the prelanding imagery constraint allows landing at the South Pole.

The requirement for direct communications between the lander and Earth further constrains the maximum Northern and Southern latitudes. The assumptions used in defining these constraints are as follows:

Minimum of 2.5 hours link time per day.

High gain antenna (HGA) operating over a 10-degree elevation mask.

Low gain (command) antenna (LGA) maximum aspect angle of 85 degrees. (Assumes 100 kw transmitter and 64 m DSN antenna).

Lander located on an adverse slope of 15 degrees.

Viking '75 radio performance.

Links required for full 90-day mission over both HGA and LGA.

The resultant communication constraints on landing site latitude are presented in Figure 28. Mission A will be constrained between 60°N and 53°S. Mission B is constrained between 53°N and 57°S. All constraints are a result of the LGA limits. Northern latitudes are constrained by links at the end of mission, and Southern latitudes are constrained by conditions at touchdown. If the slope assumption is relaxed, the latitude bands can be increased approximately ±10 degree.

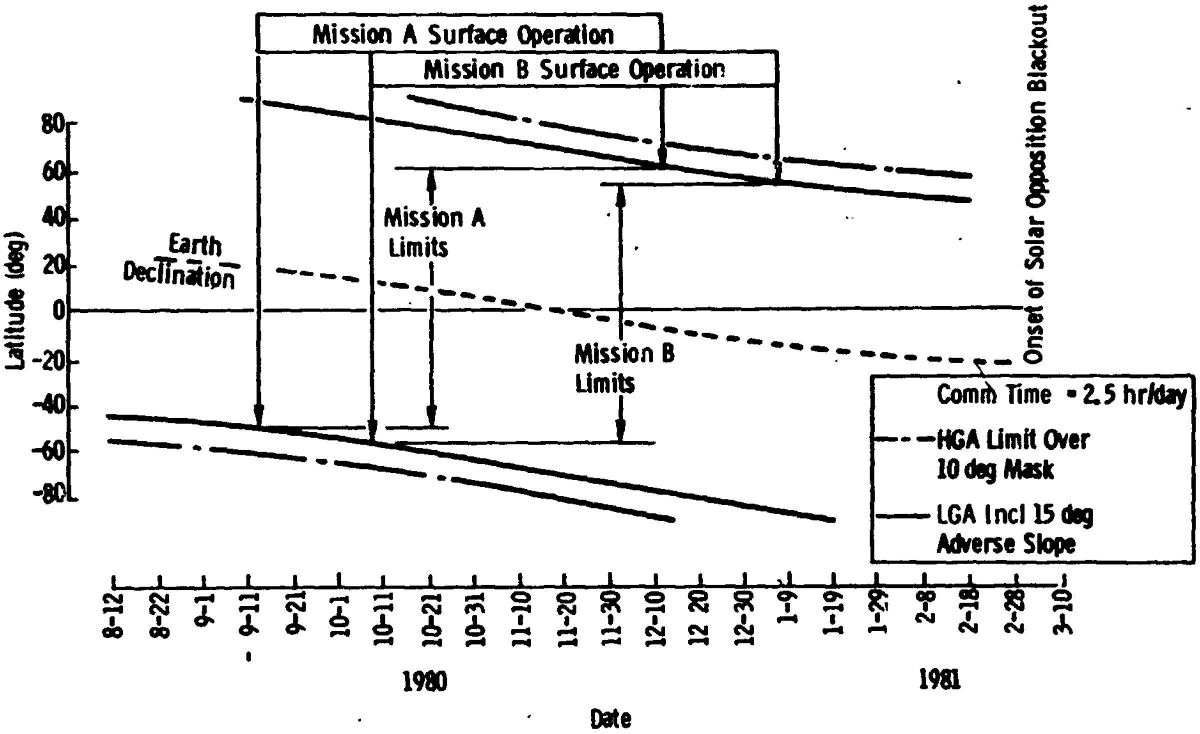


FIGURE 28 LANDER DIRECT-COMMUNICATION LINK CONSTRAINTS ON LANDING SITE LATITUDE

4.0 SPECIAL ROVER SYSTEM AND SUBSYSTEM CONSIDERATIONS

A major factor that influenced the rover conceptual designs was the rover power source. Prior studies indicated that travel beyond 0.5 to 1.0 km from the lander would require having an independent electrical power source on the rover because batteries to power such traverses would be excessively large. Solar panels were ruled out as a power source due to uncertain wind and dust conditions. RTGs offered the only acceptable source for the thousands of watt-hours required to support traverses over tens of kilometers. Accordingly, data on potential rover RTGs for a 1979 launch were requested from the AEC. Preliminary data from the AEC indicated such RTGs could be fabricated and that they would probably produce on the order of 3.3 electrical watts per kg (1.5 watts per lb) and 16 thermal watts for each electrical watt. These figures were used in defining the rover concepts examined during the study. Detailed information relative to these studies has been included as Appendix B of this report.

Constraints imposed by the Viking Lander Capsule cruise thermal control system influenced the design of the RTG-equipped rovers. During Earth-Mars cruise, the thermal output of the rover's RTG cannot be transmitted to the entire capsule without overheating some of the lander subsystems; therefore, a decision was made to design all rover candidates so the rover's RTG would be located toward the outer edge of the capsule. An insulating shield would then be used to keep the bulk of the rover RTG heat away from the rest of the capsule and to reflect the heat to a portion of the base cover especially blackened to radiate this excess heat into space.

A NASA Science Planning Group examined science objectives and payloads for advanced Mars missions. This activity influenced the study by providing rover and lander payload recommendations to NASA/LRC and MMC at the midpoint of the study. These payload recommendations were integrated in the guidelines for the study and the final selected rover and lander concepts reflect this group's recommendations.

Another major factor that influenced rover concepts was the Viking '75 Project from which Viking '79 will be derived. Throughout the study, technical results and program plans were reviewed by Viking '75 personnel at NASA/LRC and MMC. These reviews produced a number of decisions, the most significant of which was the decision at midterm to proceed with configurations incorporating Viking '75-class electronics with all electronic subsystems packaged in a single housing that also serves as the thermal control compartment. This concept was selected over concepts incorporating hybridizable microelectronics and concepts with Viking '75-class electronics packaged in individual boxes, with the boxes then installed in a thermally-controlled compartment as on Viking '75.

Viking '75 personnel also contributed to the study by assessing the various lander modifications available to increase the landed mass capability in 1979 to accommodate the rover system. Their assessment led to recommendations to alter atmospheric uncertainties in a conservative manner based on the assumption that Viking '75 data will decrease the atmospheric uncertainties. These personnel also reviewed and approved proposed modifications to the terminal descent propulsion system. These modifications were required to land the selected rover system mass.

In summary, power requirements made RTGs the only logical choice for rover power. Lander cruise thermal control constraints led to rover designs with the RTG mounted toward the outer edge of the capsule. Science Planning Group recommendations near midterm focused the study on specific rover and lander science payloads. Finally, the experience of Viking '75 personnel was brought into play to select practical subsystem technology levels for the Viking '79 rover and to assess and recommend approaches to increasing the landed mass in a 1979 mission. These influences are reflected throughout the subsequent chapters that cover candidate definition, subsystem analyses, and the baseline concept selected.

5.0 CANDIDATE ROVER SYSTEM CONCEPTS

A wide range of rover concepts, which could be carried on a Viking Lander mission, were considered in this study. These concepts ranged from small rovers that require minimal changes to the lander to larger rovers that require removal of significant portions of the lander science to provide space and mass requirements. The candidate concepts impacted the study as shown in Figure 29.

Rover candidates considered during the early part of the study were categorized and assigned letter/number designations. Letter designations are defined as follows:

A - Minimum-sized rovers, tethered to the lander. Sole function to collect and return samples to lander from ranges up to 50 meters.

B - Larger tethered rovers, imaging on rover, collect and return samples to lander from ranges up to 100 meters.

C - Lander-dependent rovers, self-supporting (no tether to lander) but must remain within communications range of lander to communicate with Earth.

D - Lander-independent rovers, self-supporting (no tether to lander) and communicates with Earth through the orbiter, therefore, it can travel longer distances from the lander.

E - Autonomous rovers. Large rovers with artificial intelligence control systems, capable of traveling hundreds of kilometers over the Martian surface.

At the outset of the study, categories A and B were eliminated from consideration because they would not provide a sufficiently large increase to basic lander capabilities. Category E was eliminated due to mass and cost limitations; therefore, the study addressed only categories C and D.

Numeral designations following the letter designations were used to differentiate between the rovers within the C and D categories. The numbers and their definitions are as follows:

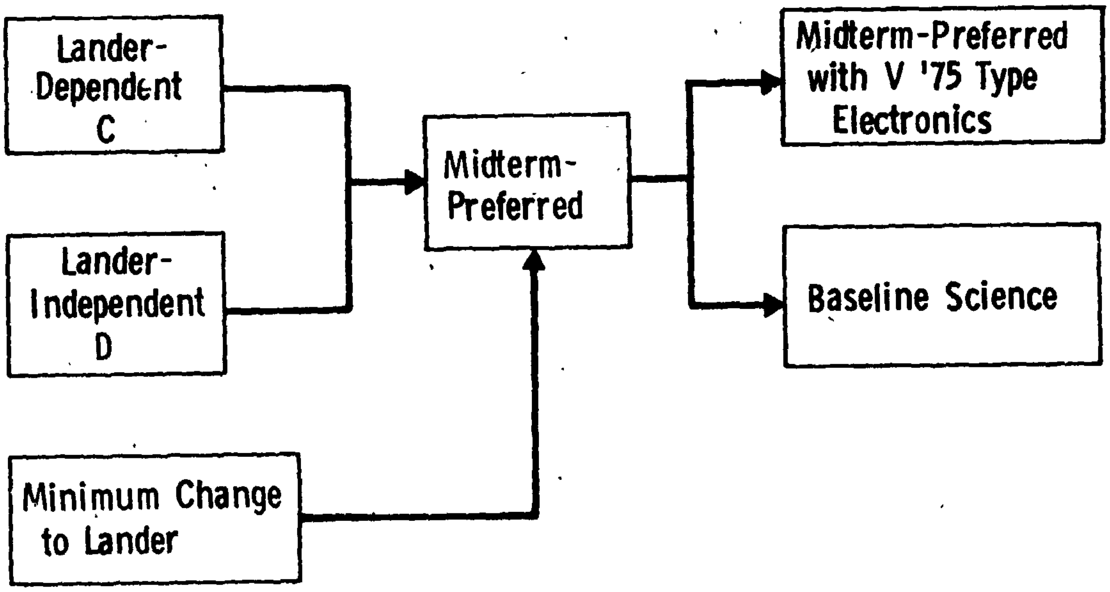


FIGURE 29 CANDIDATE ROVER SYSTEM CONCEPTS

1 - Rover that would integrate into a lander system carrying science essentially unmodified from Viking '75.

2 - Rovers associated with landers transporting modified science.

3 - Rovers carrying all of the landed science (lander no longer functions as a science platform).

4 - Rovers incorporating microelectronics. (This category was created later in the study to designate type 1, 2, and 3 rovers that had been reconfigured with microelectronics to save mass and power.)

Also considered briefly was a configuration which required no moving of lander equipment to locate the rover.

The knowledge gained from studies of these rovers was used to develop a "Preferred" configuration for the Midterm Review. This concept provided communications hardware for both lander-dependent and lander-independent operations and a 10.4 kg (23 lb) science payload.

As a result of the Midterm Review, two other concepts were studied. One simply changed the electronic packaging concept from that of hybrid microelectronics to the Viking '75 type MSI/flat pack construction. The second resulted in the final baseline configuration, consisting of the baseline 20.9 kg (46 lb) science, the Viking '75 type electronics, a new low-mass RTG, and which provides both lander-dependent and lander-independent operation.

Preliminary Candidates (C1-C4 and D1-D4)

These configurations are discussed and compared as a group for many parameters are common to two or more of the concepts, and the C4/D4 configurations are simply microelectronic versions of C1 and D1.

Science capability. - Science options are shown in Table 10, ranging from a minimal 10.4 kg (23 lb) payload (Option 1) to a maximum 60.3 kg (133 lb) payload (Option 3).

TABLE 10 EXAMPLES OF ROVER SCIENCE PAYLOADS

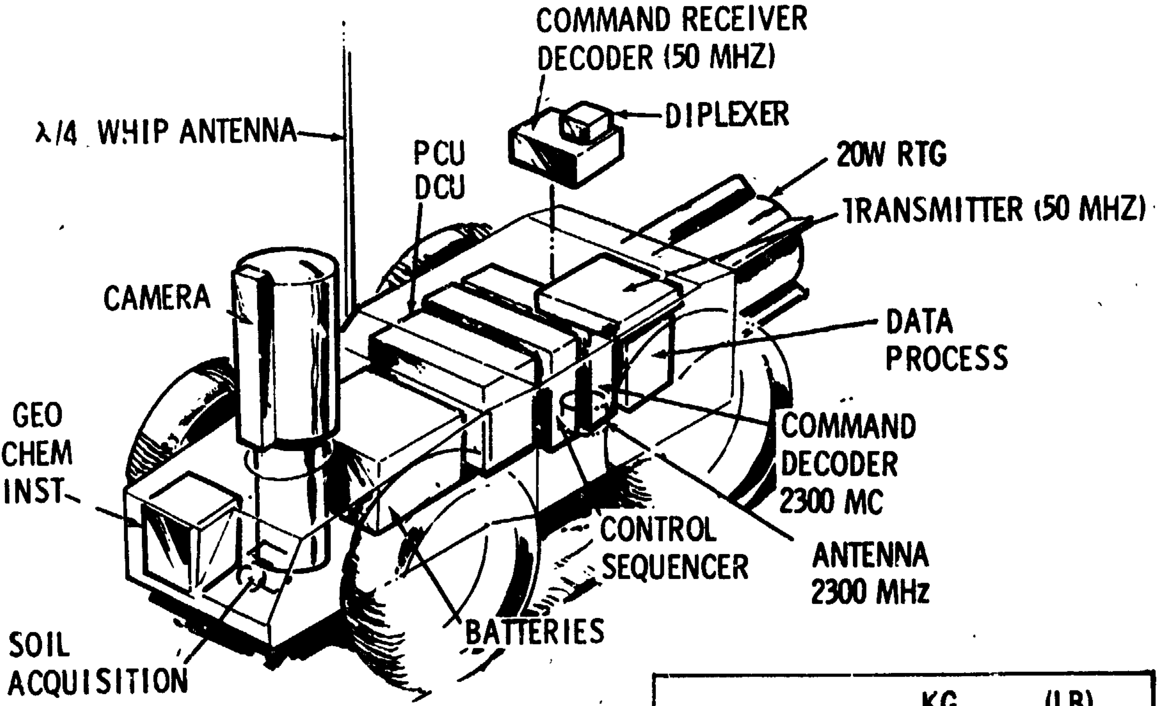
C1, D1	C2, D2	C3, D3
One Camera Geochemical Instrument Sample Acquisition & Storage	Two Cameras Geochemical Instrument Sample Acquisition & Storage Microwave Probe	Two Cameras Integrated Geochemistry Advanced Biology Soil Water Meteorology Microwave Probe Sampler (V '75)
TOTAL MASS 10.7 kg (23.5 lb)	TOTAL MASS 19.3 kg (42.5 lb)	TOTAL MASS 60.3 kg (133 lb)

The Option 1 payload consists of a Viking '75 facsimile camera, a geochemical instrument (XRFS), and a scoop sample acquisition and storage instrument.

Option 2 adds a second camera to provide stereo imagery and a microwave Regolith probe for soil water analysis.

Option 3 provides a full capability science package that includes the Viking '75 meteorology and sampler instruments.

Configuration. - Configurations C1 and D1 are shown in Figures 30 through 32. The only functional difference between the two is addition of the UHF communications link between the rover and orbiter for D1. Note that while the C1 configuration requires only a local bulge in the lander base cover to accommodate the rover, the D1 configuration requires a new base cover to accommodate the larger rover. Other changes required to support the UHF link and provide lander independent capability, include additional battery size, increased data storage, and the addition of a navigation heading reference. These are reflected in Figure 33.



	KG	(LB)
ROVER MASS	72.0	(158.3)
20% CONTINGENCY	14.4	(31.7)
TOTAL	86.4	(190.0)

FIGURE 30 CONFIGURATION C1/D1

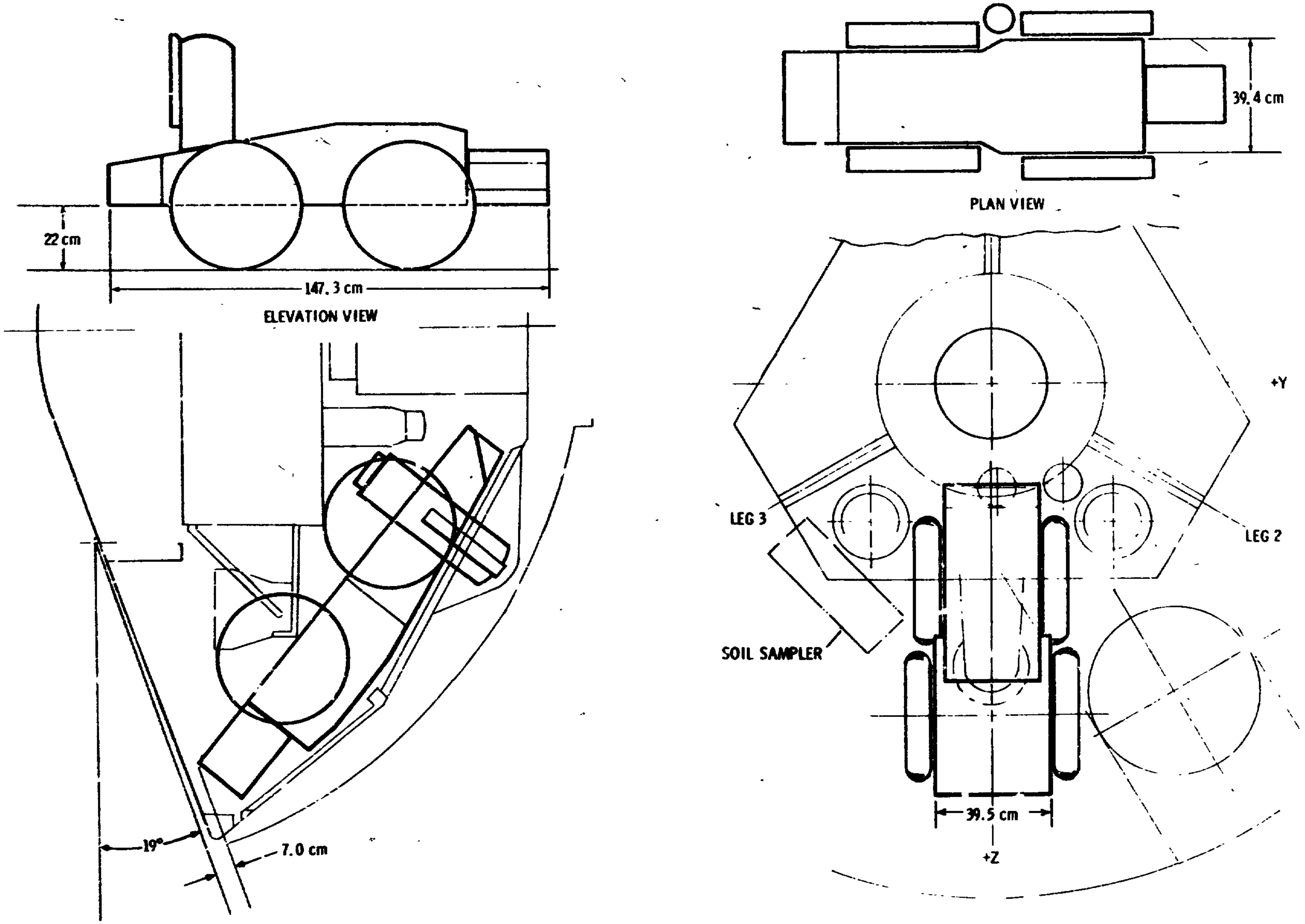


FIGURE 31 CONFIGURATION C1, LANDER-DEPENDENT ROVER

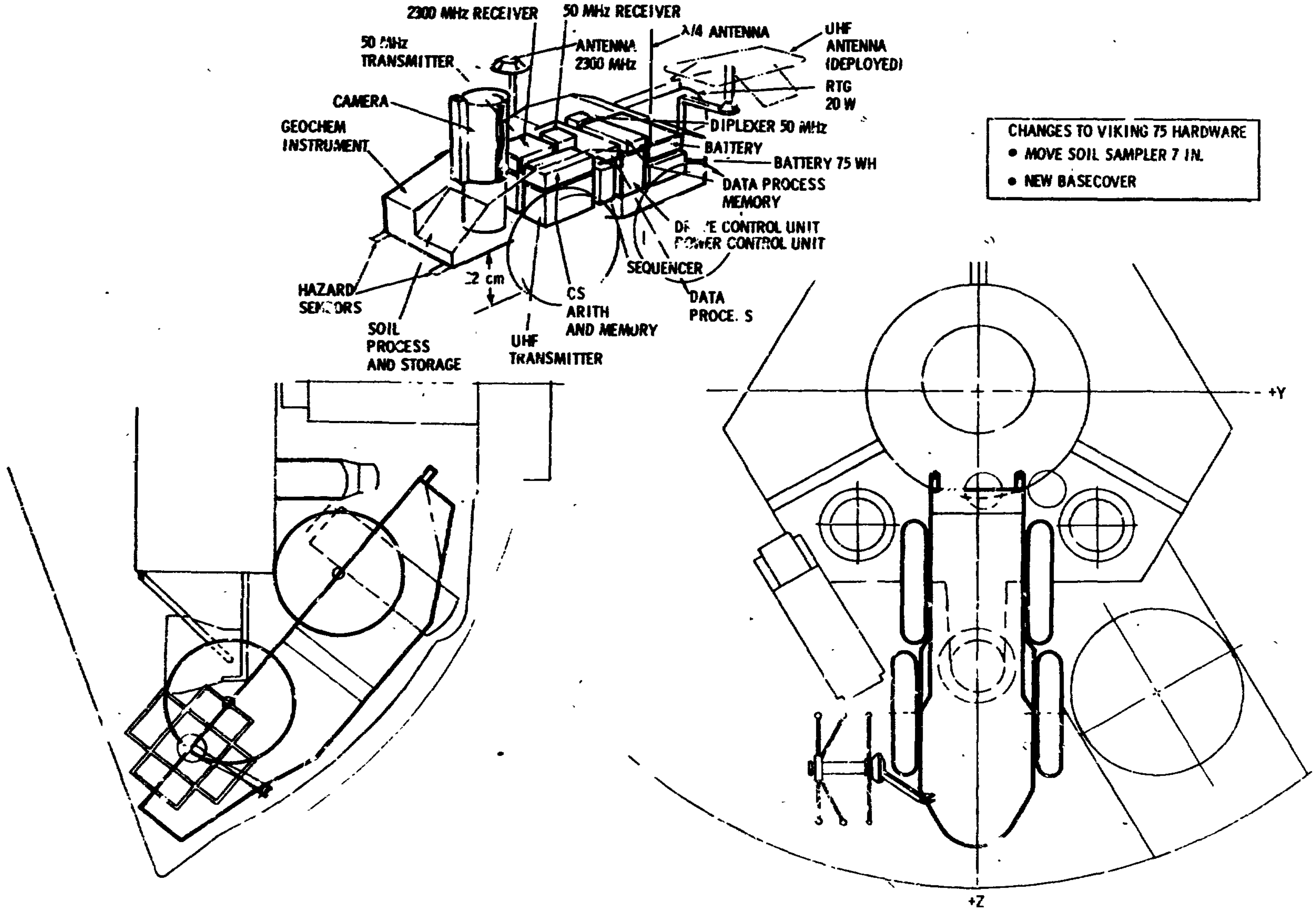


FIGURE 32 CONFIGURATION D1, LANDER-INDEPENDENT ROVER

C2

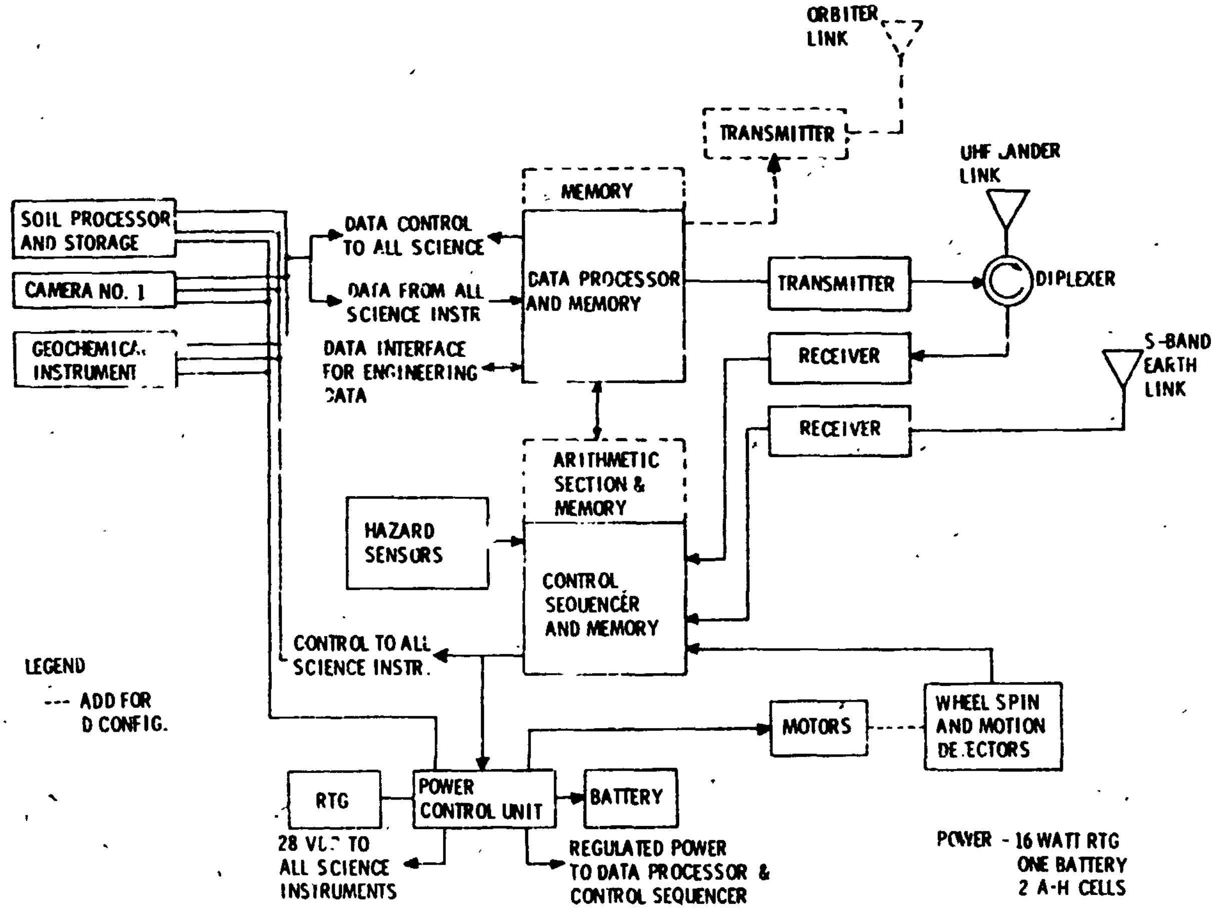


FIGURE 33 CONFIGURATION C1/D1, ELECTRONICS BLOCK DIAGRAM

Configuration C2 and D2 are shown in the composite drawings of Figure 34. The primary differences between C1/D1 and C2/D2 configurations are those required to support additional science, such as a second RTG and battery, a much larger structure, and a larger data storage capability. The differences between C2 and D2 are essentially the same as between C1 and D1, i.e., to provide the lander independent capability. This is illustrated in Figure 35. This concept requires that the lander camera No. 2 is removed completely, and that the soil acquisition unit is moved to the other side of the lander.

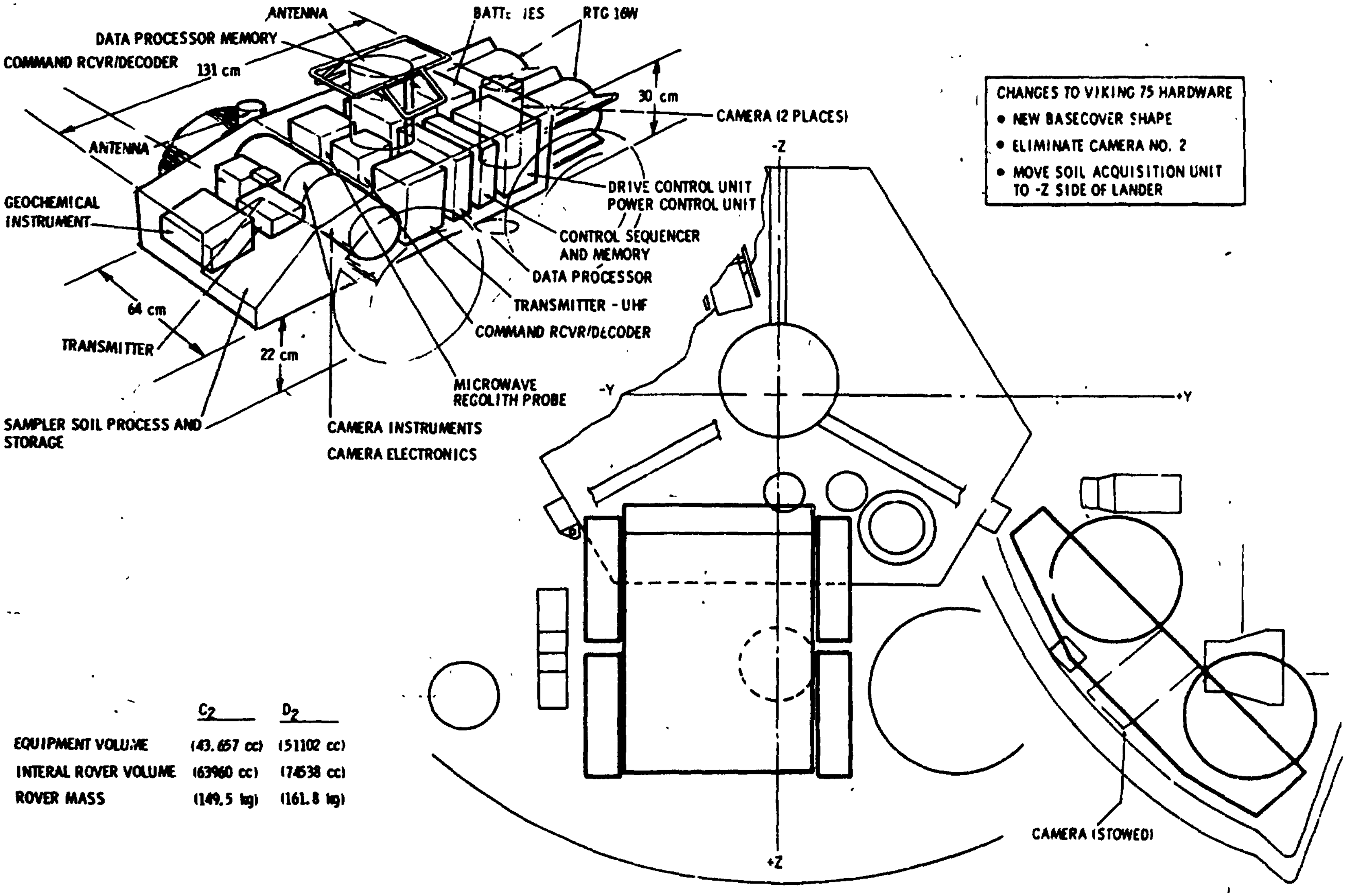
Configurations C3 and D3 are outlined in Figure 36. To support the large science payload, the battery capability is increased to 16 A-h, a 50 watt (EOL) RTG replaces the smaller RTGs of previous configurations, and the structure and drive system are significantly increased. The differences between C3 and D3 are the same as previous dependent/independent comparisons as shown in Figure 37. This concept requires that all lander science be removed.

Comparisons. - A summary of the mass implications of this set of configurations is shown in Table 11. Note that all configurations except C1 and D1 require mass reduction efforts to fall within the maximum landed mass (constrained by providing a reasonable entry corridor) capability of approximately 738.4 kg (1628 lb). Further, all but C1 would require propulsion changes (or other methods for increasing capability) to achieve the capability to land this mass.

TABLE 11 CONFIGURATION MASS SUMMARY, C1/D1 THROUGH C3/D3

CONFIGURATION	LAUNCH		ENTRY		LANDED (DRY)		ROVER	
	(kg)	(lb)	(kg)	(lb)	(kg)	(lb)	(kg)	(lb)
V'75 (Reference)	1185.7	(2614)	979.8	(2160)	598.7	(1320)		
C1	1276	(2813)	1080.9	(2383)	700	(1543)	86.2	(190)
D1	1294	(2853)	1088.2	(2399)	707.2	(1559)	97.5	(215)
C2	1354.9	(2987)	1148.9	(2533)	767.9	(1693)	149.2	(329)
D2	1363	(3005)	1157.1	(2551)	776.1	(1711)	161.5	(356)
C3	1414.3	(3118)	1208.4	(2664)	827.4	(1824)	270.3	(596)
D3	1422.9	(3137)	1217	(2683)	836	(1843)	280.3	(618)

Maximum landed mass with no lander propulsion change = 681.3 kg (1502 lb)



CHANGES TO VIKING 75 HARDWARE

- NEW BASECOVER SHAPE
- ELIMINATE CAMERA NO. 2
- MOVE SOIL ACQUISITION UNIT TO -Z SIDE OF LANDER

	C_2	D_2
EQUIPMENT VOLUME	(43.657 cc)	(51102 cc)
INTERAL ROVER VOLUME	(63960 cc)	(74538 cc)
ROVER MASS	(149.5 kg)	(161.8 kg)

FIGURE 34 CONFIGURATION C2/D2

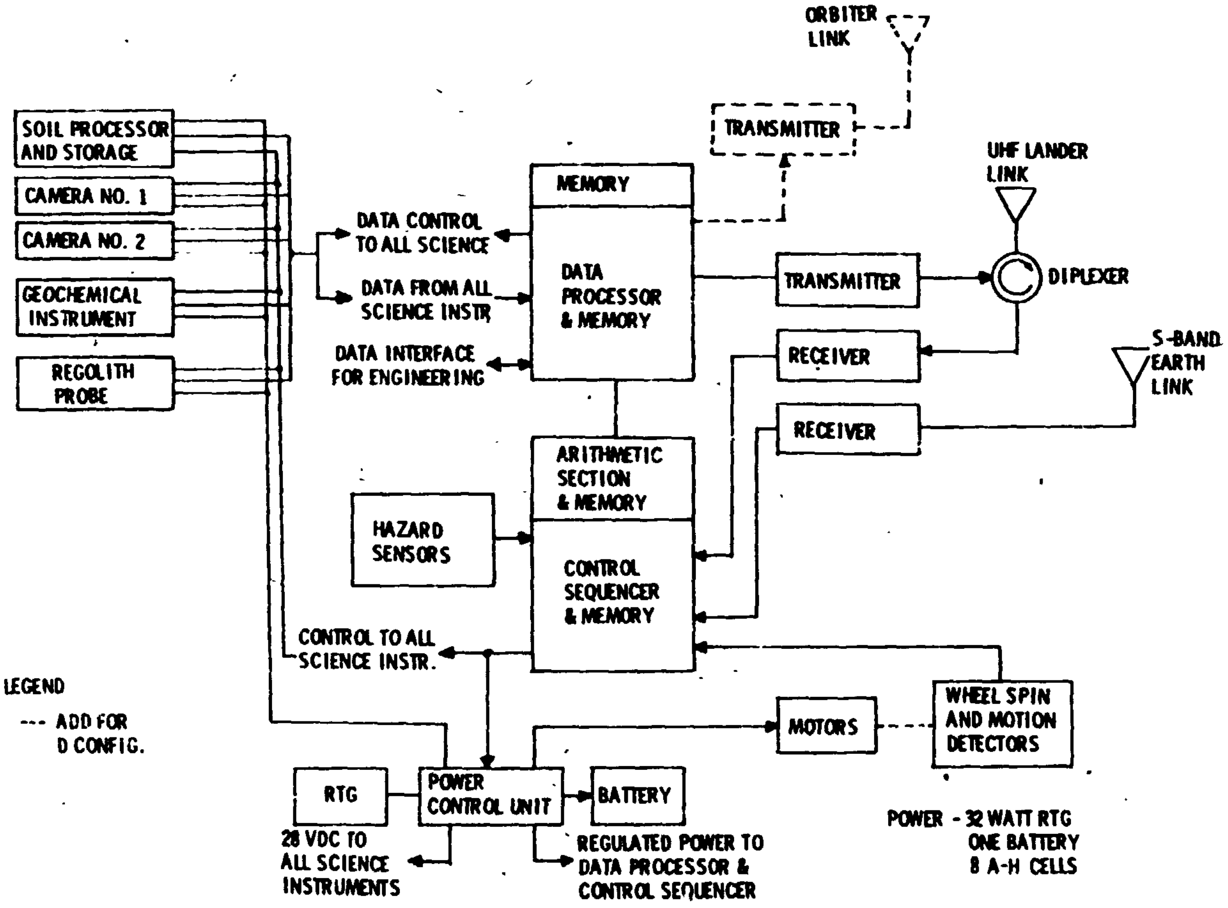
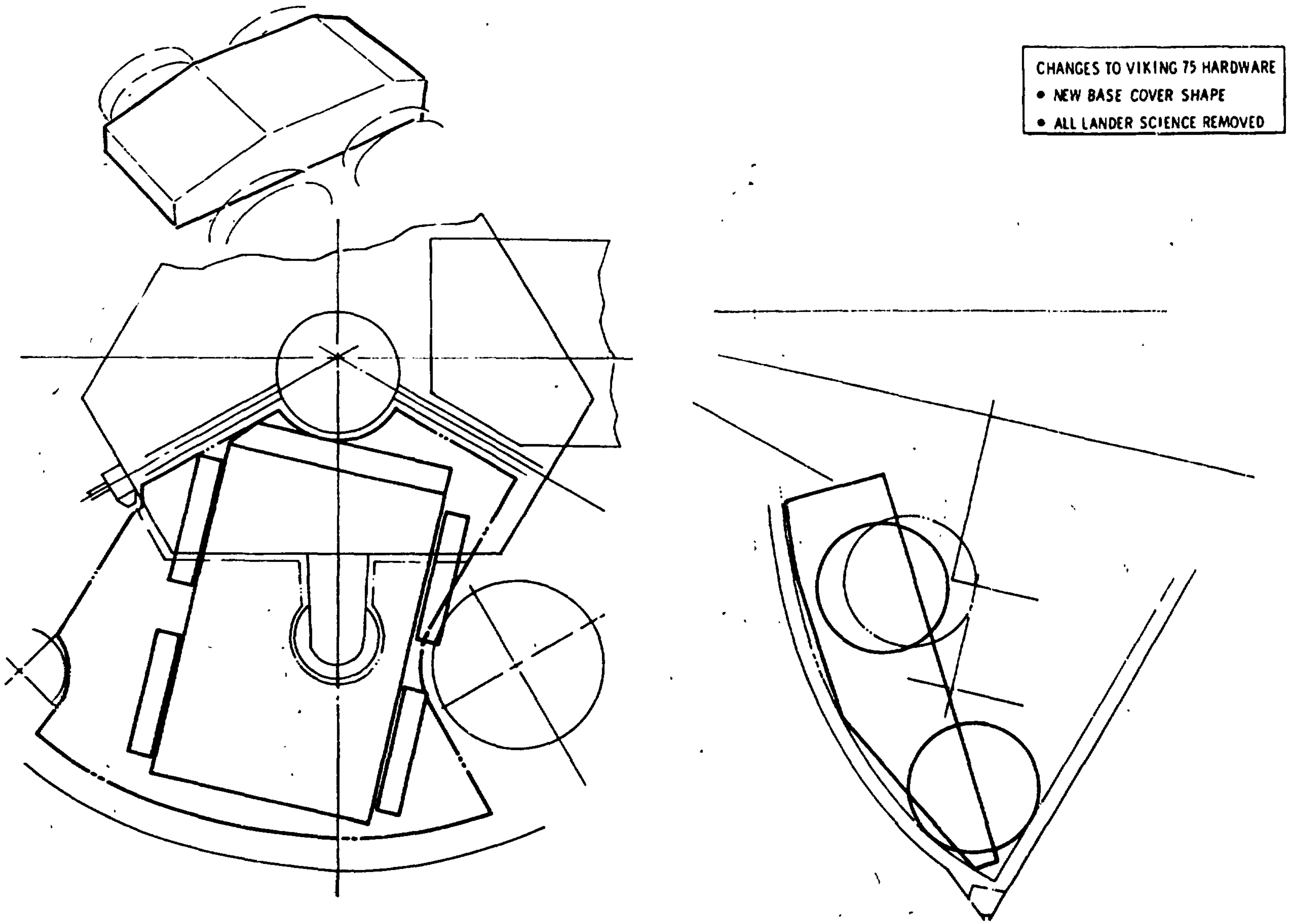


FIGURE 35 CONFIGURATION C2/D2, ELECTRONICS BLOCK DIAGRAM



CHANGES TO VIKING 75 HARDWARE
- NEW BASE COVER SHAPE
- ALL LANDER SCIENCE REMOVED

FIGURE 36 CONFIGURATION C3/D3

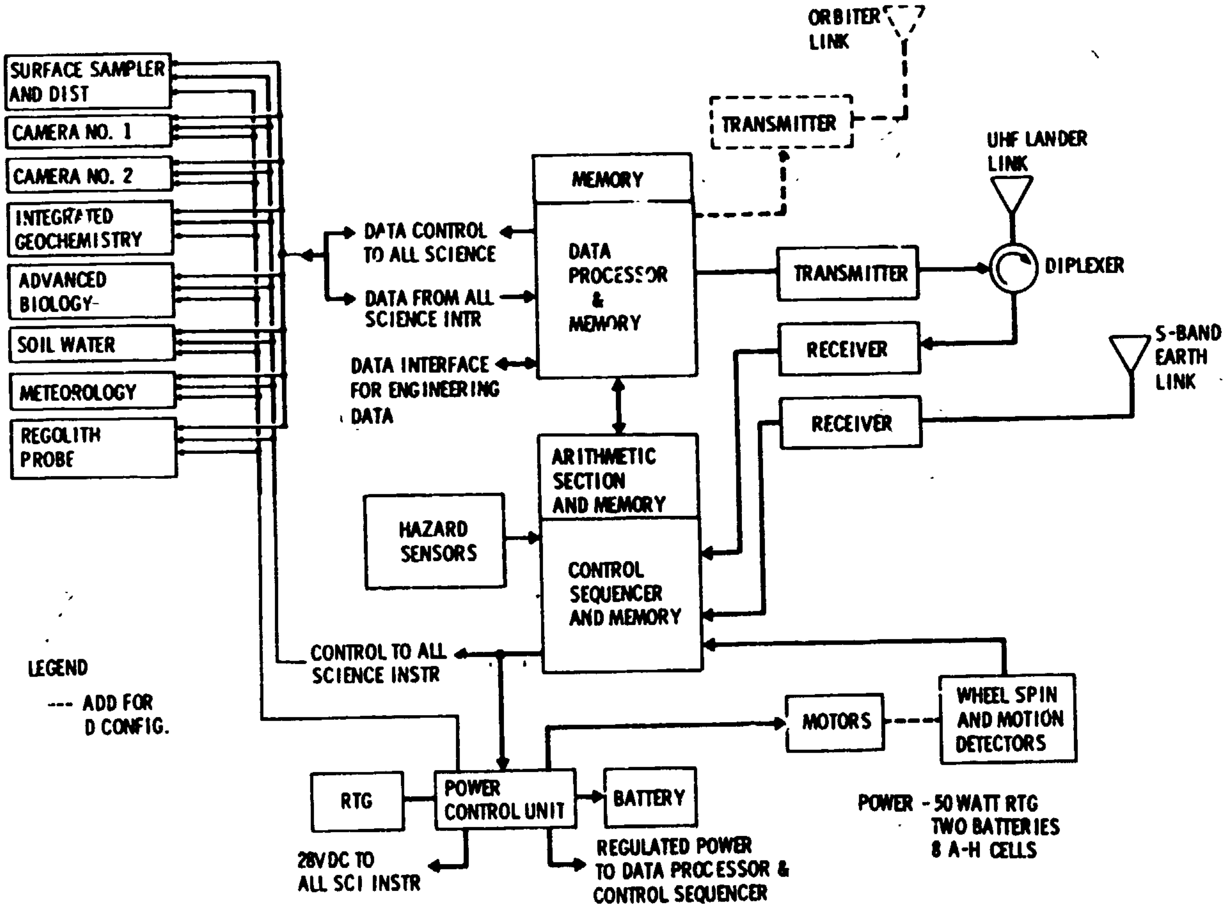


FIGURE 37 CONFIGURATION C3/D3, ELECTRONICS BLOCK DIAGRAM

Lander modifications that form a part of these concepts are as follows:

Configuration C1 - D1

- Add communications transmitter and receiver
- Move surface sampler seven inches to locate rover
- Delete X-ray fluorescence instrument
- Add new base cover (to D1 only)

Configuration C2 - D2

- Add communications transmitter and receiver
- Remove camera No. 2
- Move surface sampler to -Z side of lander
- Add new base cover
- Modify thrust of terminal engines

Configuration C3 - D3

- Add communications transmitter receiver
- Remove one RTG (rover RTG shares lander loads until off-loading)
- Remove all lander science
- Add new base cover
- Modify thrust of terminal engines

A summary of the characteristics of this set of configurations is shown in Table 12.

The next concepts to be considered are designated C4 and D4. Functionally, these are the same as configurations C1 and D1 except for electronics packaging. Viking '75 components are replaced with hybrid packages wherever possible, and all electronics are placed in a single case, saving the mass of individual cases.

These configurations are shown in Figures 38 and 39. The mass reduction achieved by the use of the integrated microelectronics is illustrated in Table 13. A comparison of configurations C1 through C4 is shown in Table 14.

TABLE 12 ROVER CONFIGURATION CHARACTERISTICS, C1/D1 THROUGH C3,D3

	C1	D1	C2	D2	C3	D3
Standby Power (Watts)	5.0	5.0	10.0	10.0	16.0	16.0
Operate Power (Watts)						
Data Mode	43.6	75.0	75.0	105.0	66.7	172.0
Mobile Mode	25.0	25.0	39.0	39.0	39.0	39.0
Energy (Wh/day)						
Required	202.0	264.0	410.0	410.0	636.0	636.0
Capacity	275.0	275.0	456.0	456.0	816.0	816.0
Data @ 16 kbs (hr/day)	0.5	0.5	0.5	0.5	0.5	0.5
Navigation	Dead Reckoning	Odometer RDF	Dead Reckoning	Odometer RDF	Dead Reckoning	Odometer RDF
Command Link	Lander-to-Rover Earth-to-Rover					
Mobility (hr/day)	0.5	0.5	1.0	1.0	2.0	2.0
(km/hr)	0.5	0.5	0.5	0.5	0.5	0.5

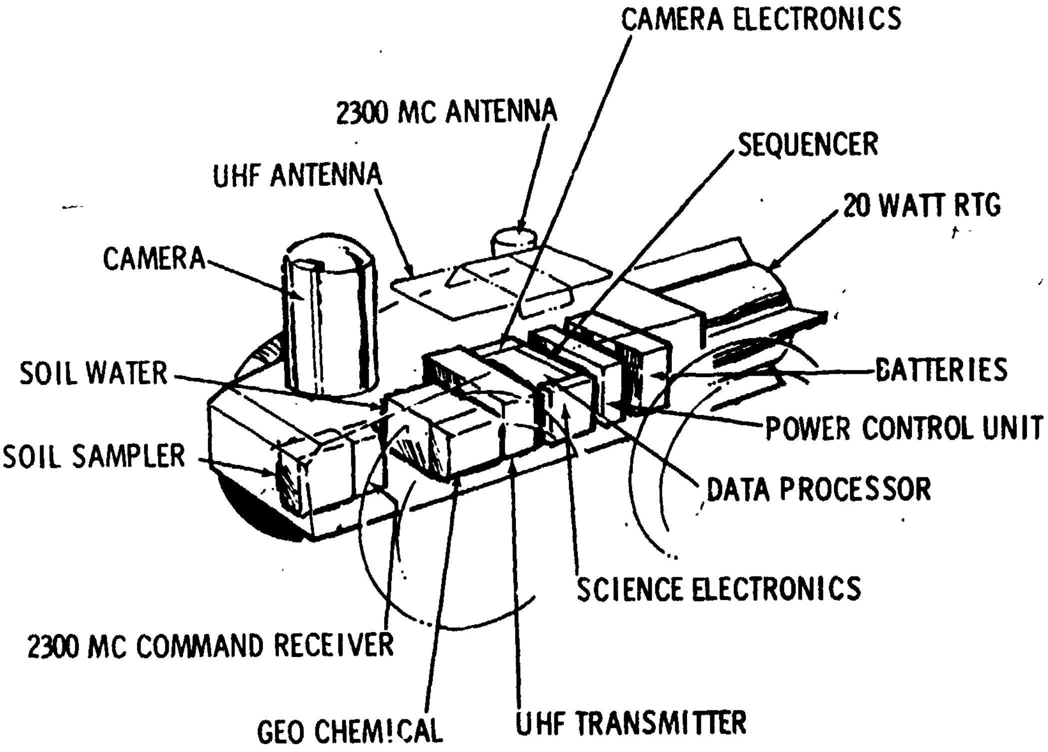


FIGURE 38 CONFIGURATION C4, LANDER-DEPENDENT ROVER (USING MICROELECTRONICS)

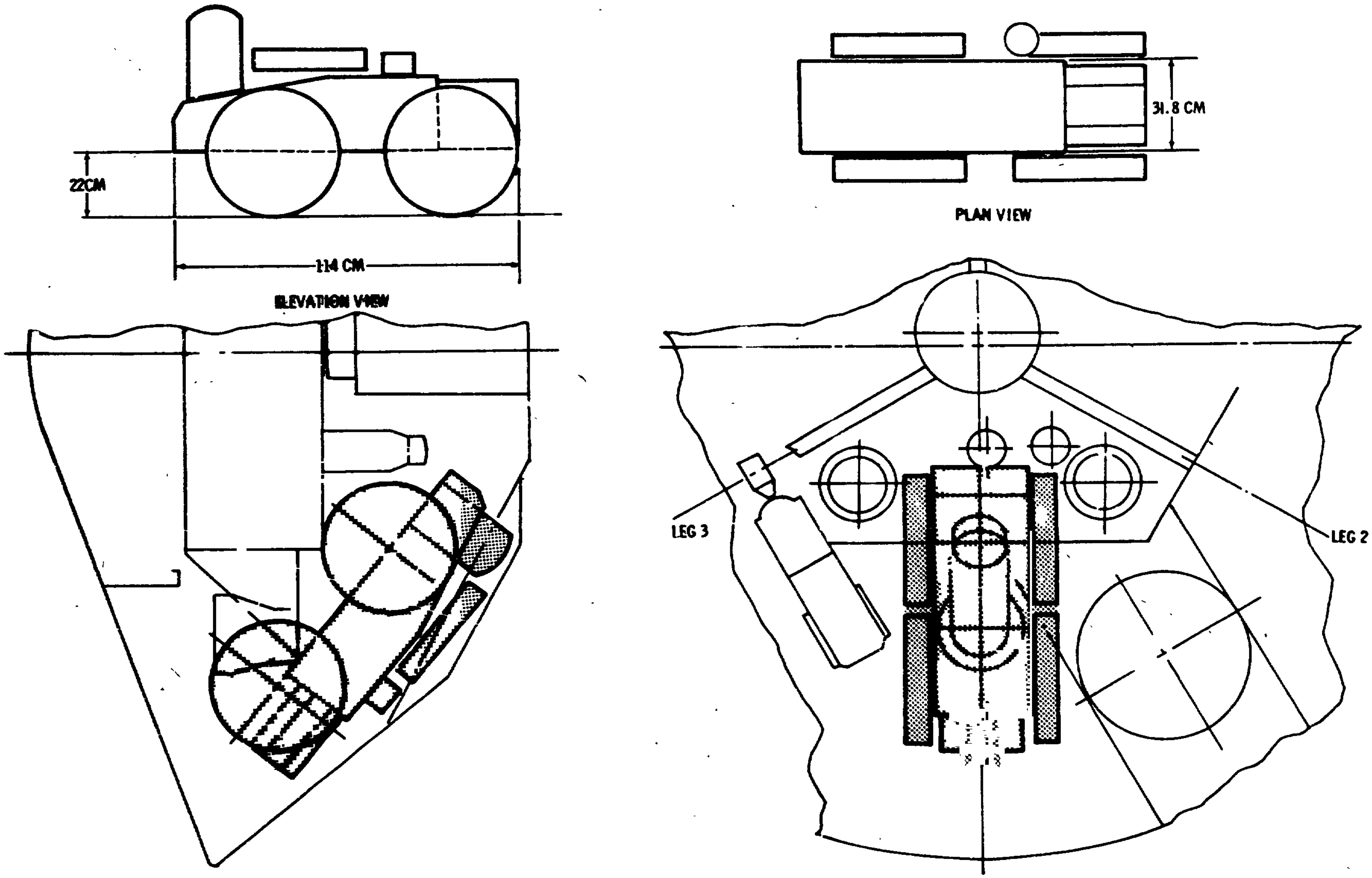


FIGURE 39 CONFIGURATION C4, STOWED

TABLE 13 MASS COMPARISON OF MICROELECTRONICS CONFIGURATIONS TO C1

SUBSYSTEM	C1		C4	
	(kg)	(lb)	(kg)	(lb)
Science	11.3	(25.0)	10.4	(23.0)
Power	14.7	(32.5)	12.7	(28.0)
Telecommunications	7.3	(16.0)	7.2	(15.8)
Guidance & Control	4.5	(10.0)	3.2	(7.0)
Thermal Control	7.1	(15.7)	4.6	(10.1)
Structural & Mechanical	23.9	(52.7)	21.6	(47.9)
Cabling	2.9	(6.4)	1.8	(4.0)
	71.7	(158.3)	61.5	(135.8)
20% Contingency	(14.4)*	(31.7)*	12.3	(27.2)
	86.1	(190.0)	73.8	(163.0)
Stow & Deploy	12.9	(+28.5)	11.3	(25.0)
Total Rover System	99.0	(218.5)	85.1	(188.0)

*Earlier mass statements used 10%

TABLE 14 COMPARISON OF LANDER DEPENDENT CONFIGURATIONS

ELECTRONICS	SCIENCE MASS kg (lb)	ROVER MASS* kg (lb)	LANDED MASS kg (lb)	VOLUME EQUIPMENT/ INTERNAL cc (cu in)	LANDER MODIFICATIONS
C1 Viking '75 Technology Component Box	11.3 (25.0)	86.3 (190.3)	700.1 (1543.5)	21200/31950 (1292/1950)	Add Transmitter & Receiver Reposition Soil Sampler 7 in. Delete X-ray Fluorescence New Base Cover
C2	19.3 (42.5)	149.4 (329.4)	765.7 (1688.1)	43600/63990 (2662/3900)	Add Transmitter & Receiver Remove Camera No. 2 Reposition Soil Sampler to -Z Side New Base Cover Terminal Engine Thrust Increase
C3	60.3 (133.0)	270.5 (596.3)	825.1 (1819.0)	142500/202000 (8700/12221)	Add Transmitter & Receiver Remove one RTG Remove all Landed Science New Base Cover Terminal Engine Thrust Increase
C4 Micro-electronics Component Box	10.4 (23.0)	73.8 (163.0)	686.0 (1512.3)	12190/15290 (743/932)	Add Transmitter & Receiver Reposition Soil Sampler 7 in. Delete X-ray Fluorescence

*Includes 20% Contingency

System Level Trades

During the course of the study, many system level decisions that guided the evolution of the configurations were made and trade studies performed. Although these trades were not all performed at a point in time between the C4-D4 configurations and later candidates, they will be discussed here as a group.

These studies/trades can be generally classified as follows:

Operational studies and trades. - Associated with the surface operational requirements and constraints, such as operating out of the range of the lander, communicating through the lander, orbiter, or both, and the effect of the long communications delay for earth commands.

Level of technology to be used in the rover systems. - Available hardware, existing designs and Viking '75 piece parts, or some level of advanced technology.

Configuration considerations. - The effects of the lander interfaces and mobility and thermal designs on the configurations.

Additional landed mass capability methods. - Included propulsion thrust level, regulated tanks, and parachute size.

Operational Trades

Operational trades centered around (1) the range from the lander over which the rover would be required to operate, (2) whether or not the rover would be required to return soil/rock samples to the lander for analysis, and (3) whether or not the rover would communicate with the lander, the orbiter, or the Earth. Included in these trades was the consideration of the delay time over the Earth-Mars communications range.

The landing footprint for Viking '79 is expected to be no greater than ±70 km downrange by ±40 km crossrange (3). It was assumed that a scientific feature would be located on the outer edge of the footprint along the minor axis, thus requiring a minimum rover range of 40 to 50 km. This study did not attempt to develop a maximum range requirement, because the rover life could exceed 90 days, thus providing additional range.

The limited range of the soil sampler arm is frustrating to mission scientists, particularly when interesting rocks or soils are visible in the camera pictrue but out of range of the sampler. Therefore, the capability to bring samples back to the lander from outside this range was a desirable feature. Because the rover mobility is approximately 735 m/day, and the time spent returning samples would reduce total available rover range, it was concluded that 5 km was a reasonable limit from which to return samples to the lander. The operational overview of Section 7 reflects this decision, by providing several days of operations in close proximity of the lander, including returning samples, before departing on it's own scientific mission.

These conclusions obviously had a great influence on the decisions concerning the communications link requirements. Operating the rover out of communication range of the lander required that a two-way link be provided between the rover and orbiter. For the times when the rover is within range of the lander, the trades involved restricting the communications to the orbiter (limited imaging to real time), providing the storage on the rover for several pictures (tape recorder), or providing the rover/lander link and using the lander DSM to store the pictures. It was decided to provide the rover/lander link, which requires the addition of a lander receiver, to be able to store rover pictures in the lander tape recorder. Subsystem level trades were conducted to determine the frequency and bit rate for these links (see Section 6.0 for details of these trades).

For uplink commands, the trade centered around having an S-band Earth/rover link or not. Earlier configurations included this link, requiring that the rover include both UHF and S-band receivers and command decoders. Later configurations dropped the S-band uplink, saving the rover mass and power at the operational expense of allowing rover commands only through the lander or orbiter.

Level of Technology

One of the basic decisions that must be made in any future mission study is the level of technology to be used in the development of the hardware. This can range from the use of existing hardware from previous programs, to systems requiring extensive research and development.

Because dollar cost is an important consideration for a Viking '79 mission, the decision was to make maximum use of existing technologies, and use Viking '75 lander/orbiter hardware where possible.

Mass and power constraints on the rover led to the use of C/MOS electronic logic and memory elements and a lower mass RTG. The C/MOS devices, although not used on the Viking '75, have been flown on other spacecraft. The new RTG achieves its lighter mass through improved fuel pellet configuration, thermoelectric units, and overall packaging design.

Two other mass saving changes were considered in the electronics area. The first change was to integrate all electronics into a single box, as opposed to the many individual assemblies in standard approaches, saving mass and dollar cost of providing individual cases. This concept was incorporated in all configurations from C4/D4 through the final preferred configuration. The second change was the use of hybrid electronic packaging, i.e., packaging up to 10 individual MSI chips into a single flat pack, resulting in a reduction in electronics volume by up to this factor of 10. While some hybrid packages were used on Viking '75, widespread use of hybrids would require a major development effort. This concept was included in the C4/D4 and midterm preferred configurations, after which it was dropped at the request of VPO because of the development requirement and associated risks.

Configuration Considerations

The primary driving force in the configuration area was to fit the rover into the Viking Lander Capsule (VLC) with minimum changes to the lander and base cover. Early rover configurations ranged in size from one that required removal of all lander science to another that required no changes to the VLC except those to actually support and off-load the rover. These trades evolved into concepts that approach the maximum mass that can be landed, and at the same time limit the lander changes to relocating the lander soil sampler and providing a new or bulged base cover. Other lander changes depended on the specific rover configuration.

The two other major configuration decisions involved the chassis (single or multiple; rigid or articulated) and steering (scuff or some form of articulated wheels). Though a rover with multiple body components and an articulated chassis can be packaged more efficiently into the lander, the thermal control and insulation requirements significantly reduce the internal volume of each compartment to the extent that insufficient internal volume is available. Thus the single chassis was used throughout this study.

The steering decision was based on the results of previous studies performed both by Martin Marietta Aerospace and other contractors. Scuff steering not only results in mass saving because of the lack of articulated wheels and a steering actuator, but also has the capability to turn in place, which is an advantage in hazard avoidance. For these reasons, scuff steering was selected.

Early configurations had the four wheels rigidly attached to the chassis. A trade study was performed just before midterm to provide a method for keeping all four wheels in contact with the ground when traveling over uneven terrain. Otherwise, all wheels are not available to provide the driving force, which is a particular problem when negotiating obstacles. The resulting concept was incorporated into all succeeding configurations. In this concept one pair of wheels are mounted to an axle, which is attached to the chassis through an articulated joint (see Section 6.2).

Additional Landed Mass

The various ways in which additional landed mass capability could be provided for the heavier configurations was investigated. Methods that were considered included (1) using the tested value for the thrusts of the Lander Terminal Descent engines, rather than the lower specification value, (2) decreasing the blow-down ratio of the descent system by providing a separate pressurant tank, (3) providing pressure regulation for the descent system, (4) deleting the GCMS, and (5) increasing the parachute diameter.

Considered in the tradeoffs were the sensitivity gain/cost; gain being the maximum additional capability which could be achieved, and cost being the complexity and associated dollar cost of making the modifications. The recommended method (see Section 3 for the details of the trades) uses the test value for engine thrust and provides the pressure regulation system, resulting in a net landed-mass capability increase of up to 75.75 kg (167 lb).

Final Candidates

Minimum lander change concept. - Another concept considered in an attempt to minimize the changes to the lander was to move or remove no lander equipment, but merely add the equipment necessary to stow and off-load the rover. The required configuration, which fits between the cameras and provides approximately 32750 cu cm (2000 cu in.) of internal rover volume, is shown in Figure 40.

Several problems exist with this configuration. All four wheels must be deployed and, because of their stowage orientation, a failure to deploy is a serious failure. The ratio of surface area to internal volume is larger, requiring additional thermal control power. The foregoing and the inefficient packaging result in a 4.5 kg (10 lb) mass penalty for the concept; therefore, this concept was not pursued further.

Midterm review preferred configuration. - The preceding studies led to the definition of a preferred configuration, combining some of the concepts from both the independent and dependent configurations, and including the results of the various subsystem trade studies. The results of these studies/trades are summarized as follows (see Section 6 for further details).

Data Processing - Centralized collection and formatting of data was selected over performing the same functions in the individual rover assemblies (decentralized approach).

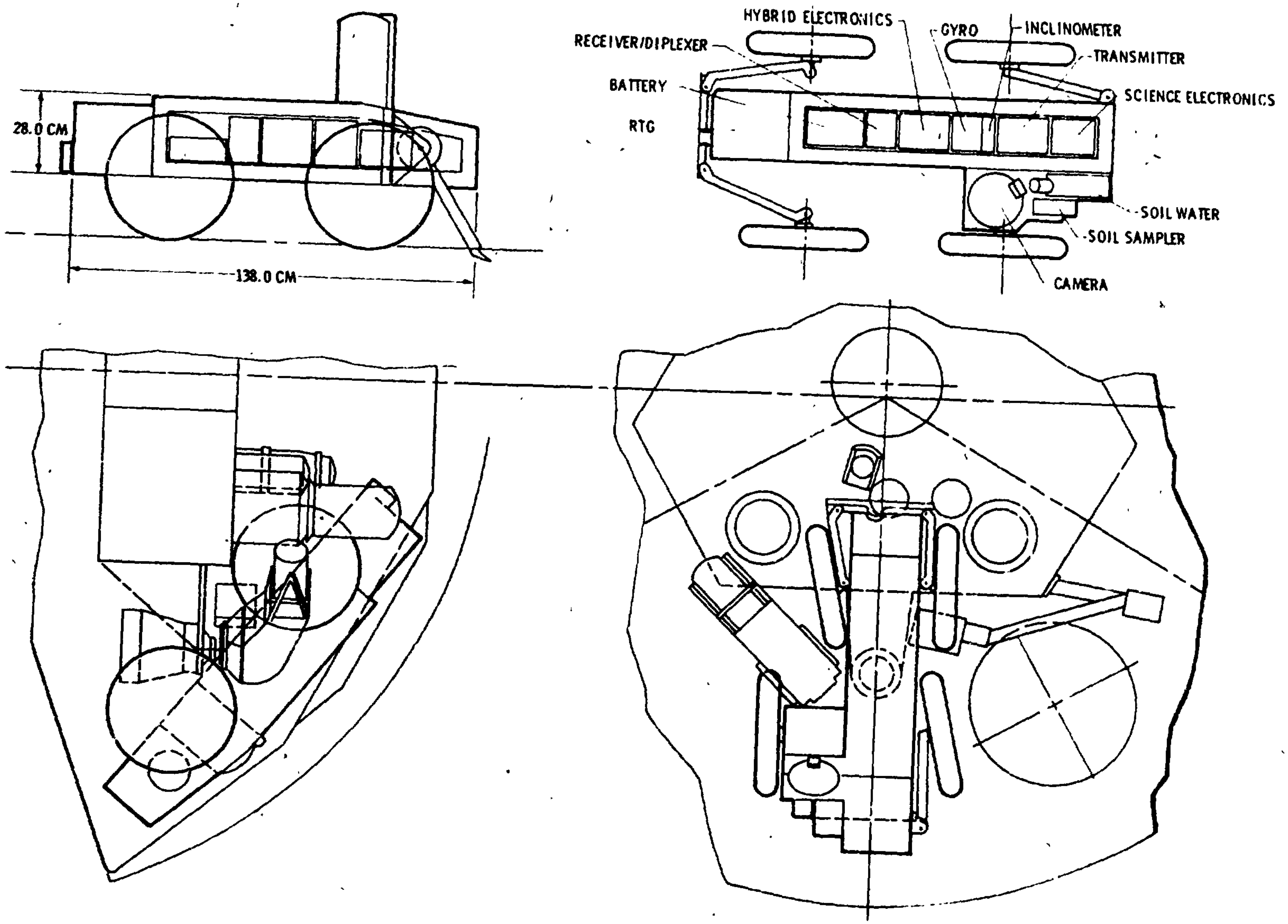


FIGURE 40 MINIMUM LANDER CHANGE CONFIGURATION

Power - Bus voltage level of 15V selected over 28V system. Distribution of all regulated voltages selected over distribution of bus power to individual converter/regulators. Use of batteries to handle peak loads selected over sizing RTG for peaks.

Heading Reference - Directional gyro-gyrocompass selected over other candidate instruments.

Control Sequencing - Performed in a rover sequencer as opposed to using lander GCSC.

Communications - Two-way UHF links to both lander and orbiter. Deleted Earth/rover command links of previous configurations.

Electronics Packaging - Integrated hybrid electronics for science and engineering.

Mobility - Roll articulation provided between chassis and rear axle.

The preferred configuration is shown in Figures 41, 42, and 43. The lander changes required for this concept are as follows:

Lander -

Remove XRFS experiment
Relocate surface sampler
Relocate meteorology boom assembly
Add rover mounting provisions and deployment mechanism
Revise RTG collant loop to include rover RTG
Add UHF receiver and antenna

Aeroshell -

Relocate the radar altimeter antenna
Relocate the entry science instruments
Add mounting provisions for the rover RTG thermal radiation shield

Base Cover -

Provide a domed glass phenolic panel

The mass summary for the midterm-preferred configuration is shown in Table 15. Note that this configuration, though combining the best features of previous concepts, has a total mass of slightly less than the 73.9 and 75.3 kg (163 and 166 lb) masses of C4 and D4.

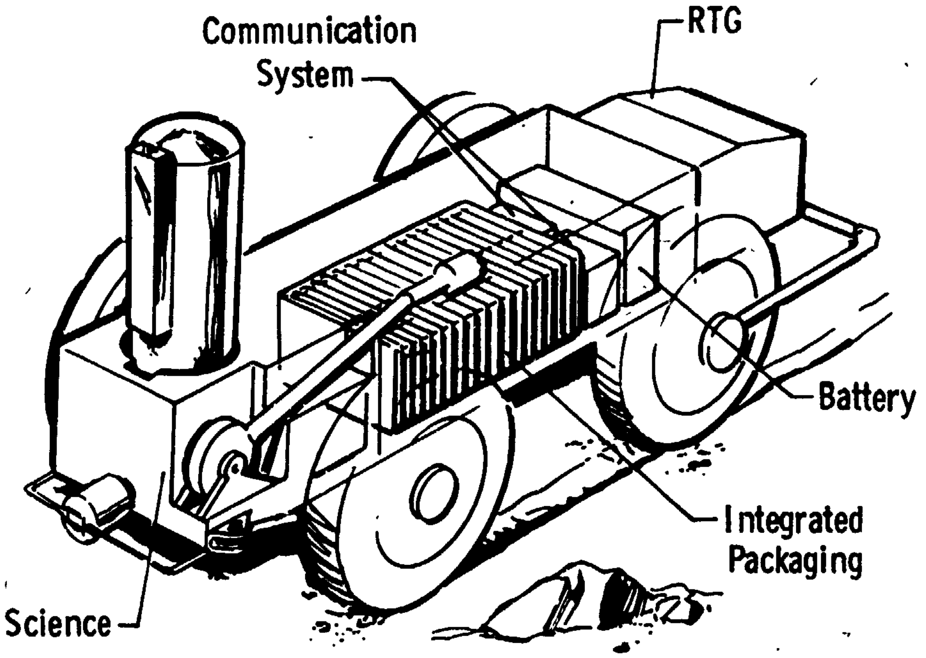


FIGURE 41 MIDTERM-PREFERRED CONFIGURATION

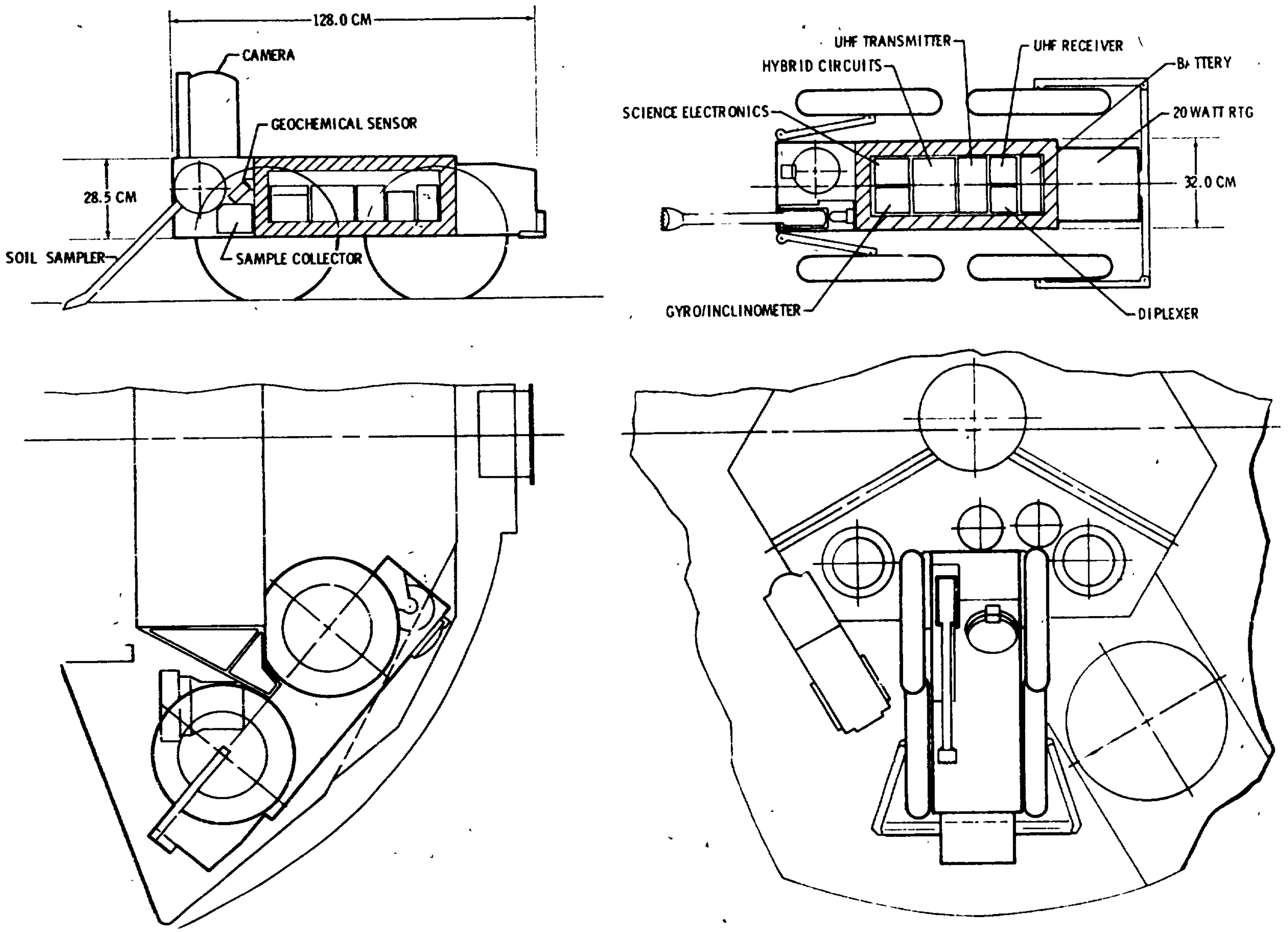


FIGURE 42 MIDTERM-PREFERRED CONFIGURATION, STOWED

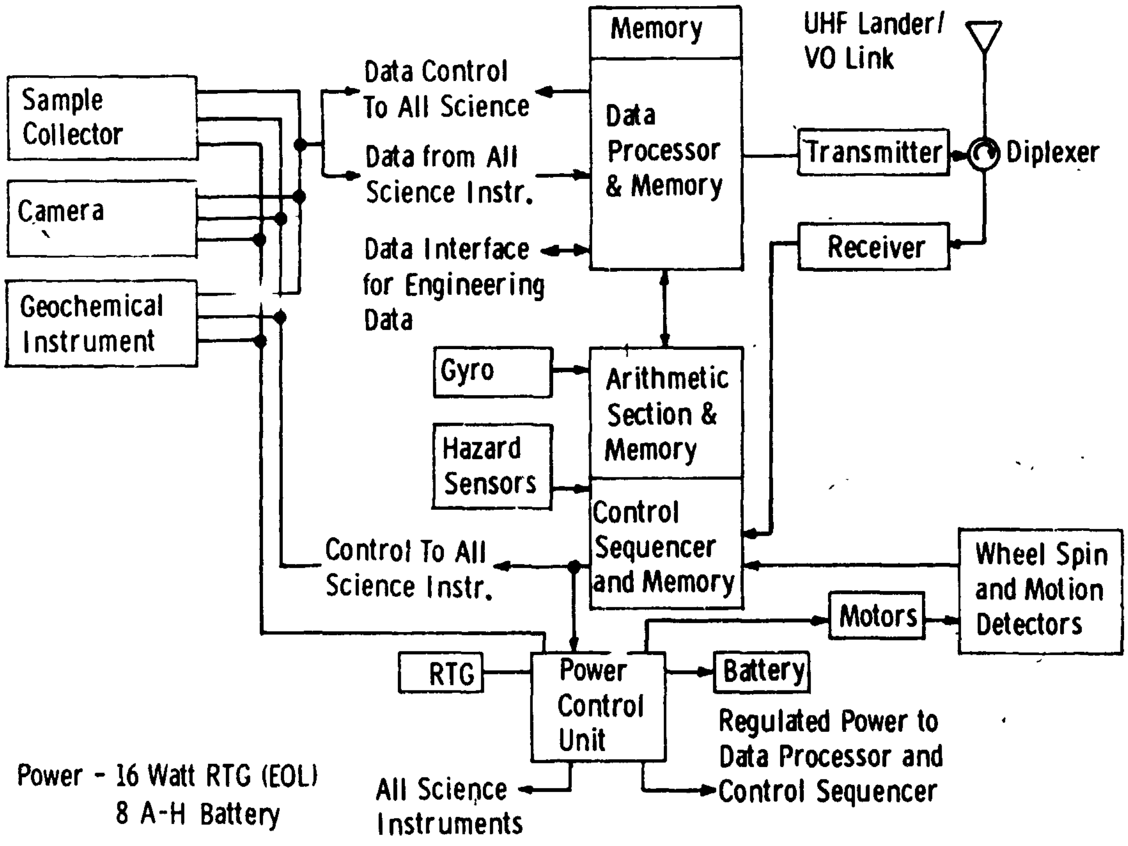


FIGURE 43 MIDTERM-PREFERRED CONFIGURATION, ELECTRONICS BLOCK DIAGRAM

TABLE 15 MIDTERM-PREFERRED CONFIGURATION MASS SUMMARY

	kg	(lb)
Rover		
Science	10.4	(23.0)
Structure	11.8	(26.0)
Mechanism	0.9	(2.0)
Thermal	4.1	(9.0)
Drive System	7.7	(17.0)
Telecommunications	6.4	(14.0)
Power	11.8	(26.0)
G & C	5.4	(12.0)
Cabling	1.8	(4.0)
	60.3	(133.0)
Contingency (20%)	11.8	(26.0)
Total Rover Mass	72.1	(159.0)
Lander		
Stowage and Deployment	8.2	(18.0)
Communication	3.2	(7.0)
Relocate Equipment	0.5	(1.0)
Thermal	0.8	(1.7)
	12.7	(27.7)
Delete XRFS	- 2.0	(- 4.4)
	10.7	(23.3)
Contingency (20%)	2.1	(4.7)
Total Lander Delta	12.8	(28.0)
Total Rover System	84.9	(187.0)
Most Probable Viking '79 Landed	585.1	(1290.0)
Viking '79 Landed Dry Mass	670.0	(1477.00)

Midterm review preferred configuration with Viking '75 type electronics. - A brief study was undertaken to determine the effect on the midterm-preferred configuration of replacing the hybrid electronics with Viking '75 devices. Because the integrated electronics concept (no individual cases) was maintained, the effect was to increase the number of printed circuit boards and their associated volume by a factor of 10 (approximately 10 chips were packaged per flat pack in the hybrid concept). This is reflected in the increased mass of the electronic subsystems and the structure in Table 16. The resulting configuration is shwon in Figure 44. It should be noted that two other evolutionary changes were also incorporated into configuration. These changes, reducing the insulation thickness from 5 cm (2 in.) to 2.5 cm (1 in.) and using a new, lower volume RTG, allowed this configuration to fit within the envelope shown in Figure 44 without seriously affecting the mass change information shown in Table 16.

Baseline science configuration. - The final configuration considered in this study, the baseline concept, which is recommended for more detailed examination in subsequent studies, was developed to carry the baseline science payload and use Viking '75 electronics. Otherwise, it is similar to the midterm-preferred configuration. The baseline science, which includes the lander science changes, is summarized in Table 17.

The configuration is shown in Figure 45. The major differences from preceding configurations are the stowage location for the rover camera and a lower, wider chassis. This wide chassis, which is accommodated by removing one of the lander cameras and moving the soil sampler out onto a bracket, eliminates the requirement to deploy the wheels after off-loading to obtain the desirable track width. The Viking '75 RTGs on the lander are replaced with those of the rover RTG technology class with significantly lower mass.

The mass summary is shown in Table 18, resulting in a total landed mass that exceeds the capability of the unmodified lander system. Several options were considered to increase this capability. The recommended option is to (1) use the test value of the terminal descent engine thrust of 2847 N (640 lb_f), rather than the lower Viking '75 specification value, and (2) provide pressure

TABLE 16 MASS SUMMARY

MIDTERM-PREFERRED CONFIGURATION WITH
VIKING '75 TYPE ELECTRONICS

Rover	Midterm		With Viking '75 Electronics	
	kg	(lb)	kg	(lb)
Science	10.4	(23.0)	10.4	(23.0)
Structure	11.8	(26.0)	14.5	(32.0)
Mechanism	0.9	(2.0)	0.9	(2.0)
Thermal	4.1	(9.0)	4.5	(10.0)
Drive System	7.7	(17.0)	8.6	(19.0)
Telecommunications	6.4	(14.0)	9.5	(21.0)
Power	11.8	(26.0)	14.1	(31.0)
G & C	5.4	(12.0)	6.8	(15.0)
Cabling	1.8	(4.0)	1.8	(4.0)
	60.3	(133.0)	71.1	(157.0)
Contingency (20%)	11.8	(26.0)	14.2	(31.0)
Total Rover Mass	72.1	(159.0)	85.3	(188.0)
Lander				
Stowage & Deployment	8.2	(18.0)	9.5	(21.0)
Communication	3.2	(7.0)	3.2	(7.0)
Relocate Equipment	0.5	(1.0)	0.5	(1.0)
Thermal	0.8	(1.7)	0.9	(2.0)
	12.7	(27.7)	14.1	(31.0)
Delete XRFS	-2.0	(-4.4)	-2.0	(-4.4)
	10.7	(23.3)	12.1	(26.6)
Contingency (20%)	2.1	(4.7)	2.4	(5.4)
Total Lander Delta	12.8	(28.0)	14.5	(32.0)
Total Rover System	84.9	(187.0)	99.8	(220.0)
Most Probably V'75 Landed	585.1	(1290.0)	585.1	(1290.0)
V'79 Landed Dry Mass	670.0	(1477.0)	684.9	(1510.0)

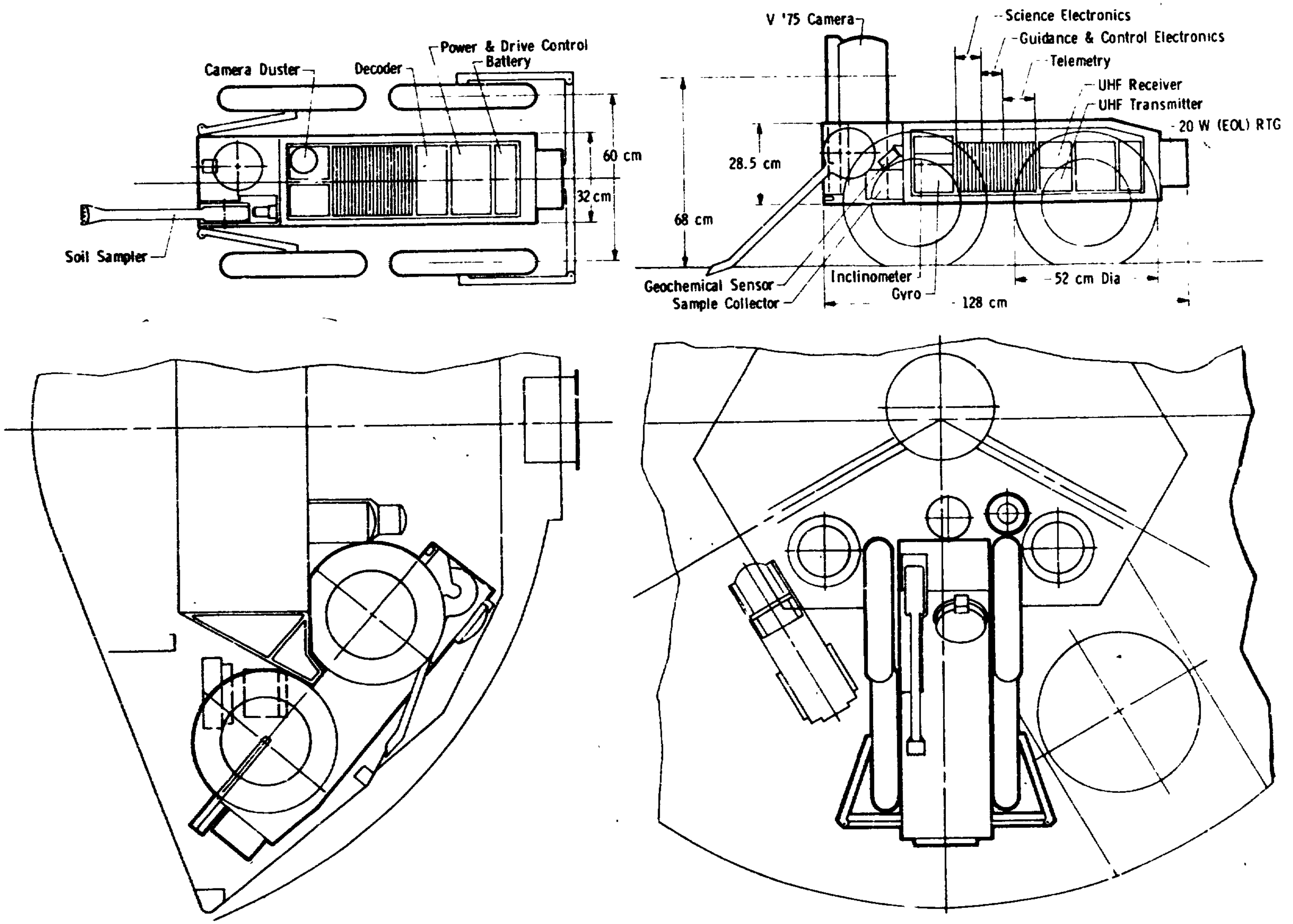


FIGURE 44 MIDTERM-PREFERRED CONFIGURATION WITH VIKING '75 ELECTRONICS

TABLE 17 BASELINE VIKING '79 SCIENCE PAYLOAD

		MMC MASS ESTIMATE	
		kg	(lb)
Rover			
Viking '75 Fax Camera & Duster		6.4	(14)
Alpha Backscatter Spectrometer		2.7	(6)
X-ray Diffractometer & Grinder		7.3	(16)
Sampler		4.5	(10)
		20.9	(46)
Lander			
Additions:	New Biology	16.4	(+36)
	X-ray Diffractometer	7.3	(+16)
	20% Contingency	4.5	(+10)
		28.2	(+62)
Deletions:	Meteorology	- 4.5	(-10)
	Fax Camera	- 6.8	(-15)
	Biology	-17.3	(-38)
	XRFS	- 2.3	(- 5)
		-30.9	(-68)
Net Lander Mass Change		- 2.7	(- 6)

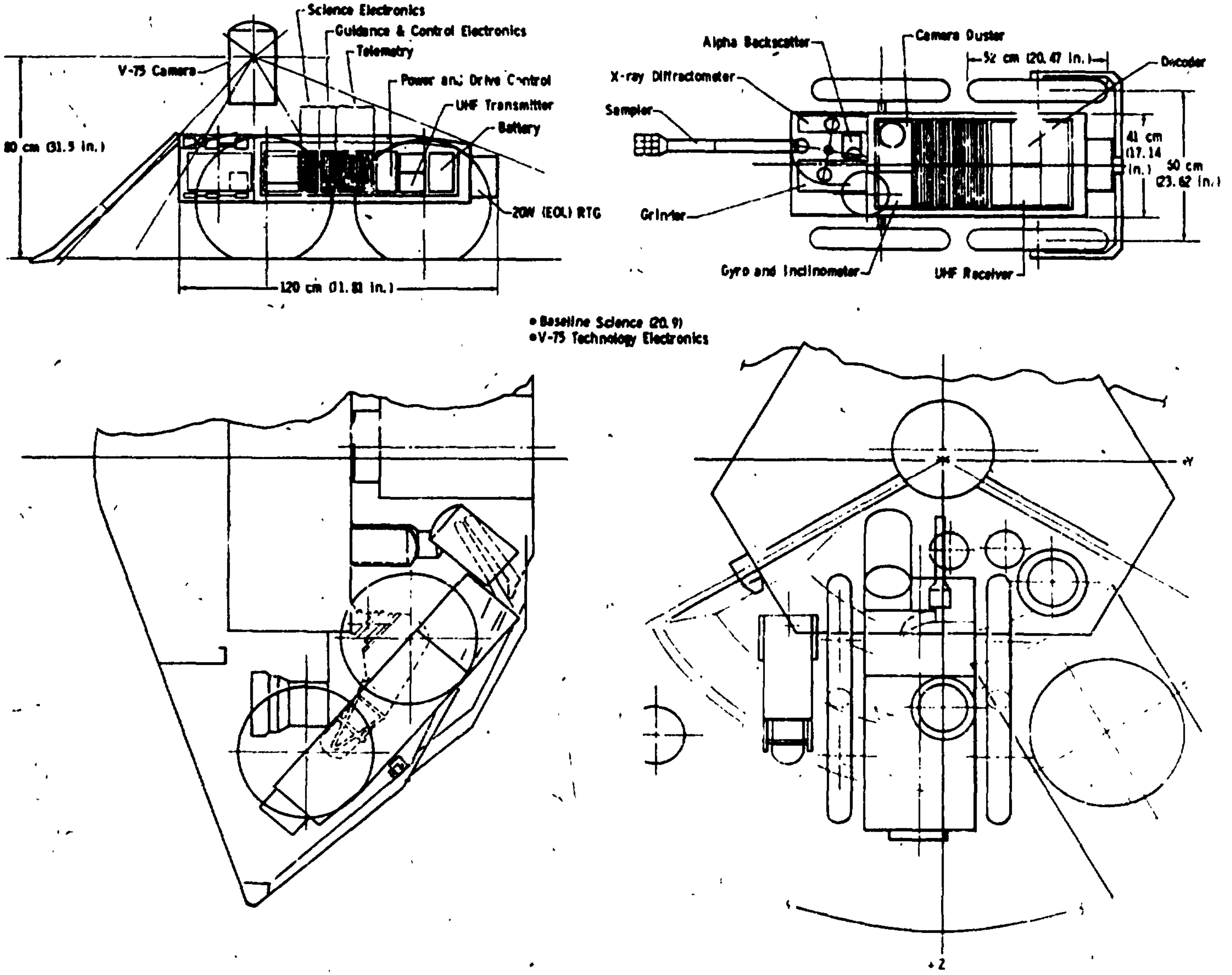


FIGURE 45 BASELINE SCIENCE CONFIGURATION

TABLE 18 BASELINE SCIENCE CONFIGURATION MASS SUMMARY

	kg	(lb)
Rover		
Science	20.9	(46.0)
Structure	17.3	(38.0)
Mechanisms	0.9	(2.0)
Thermal	5.0	(11.0)
Drive System	10.4	(23.0)
Telecommunication	11.3	(25.0)
Power	15.4	(34.0)
G&C	6.8	(15.0)
Cabling	2.3	(5.0)
	90.3	(199.0)
Contingency (20%)	17.7	(39.0)
Total Rover Mass	108.3	(238.0)
Lander		
Stowage and Deployment	12.2	(27.0)
Communications	3.2	(7.0)
Relocate Equipment	0.5	(1.0)
Thermal	0.9	(2.0)
	16.8	(37.0)
Contingency (20%)	3.2	(7.0)
Net RTG Change	-14.5	(-32.0)
Net Science Change	- 2.7	(- 6.0)
Total Rover System	110.8	(244.0)
Most Probable Viking '75 Landed*	598.7	(1320.0)
Viking '79 Landed Dry Mass	709.5	(1564.0)

* Includes an added 13.6 kg (30 lb) of growth, based on latest Viking '75 data.

regulation of the propulsion tanks, rather than the Viking '75 blowdown systems. These changes provide approximately 48 kg (106 lb) of added capability at a cost of approximately 10.9 kg (24 lb) additional landed mass, resulting in a feasible configuration in which the capability meets the requirements, including a 20% contingency.

The electronics block diagram for the baseline configuration is shown in Figure 46.

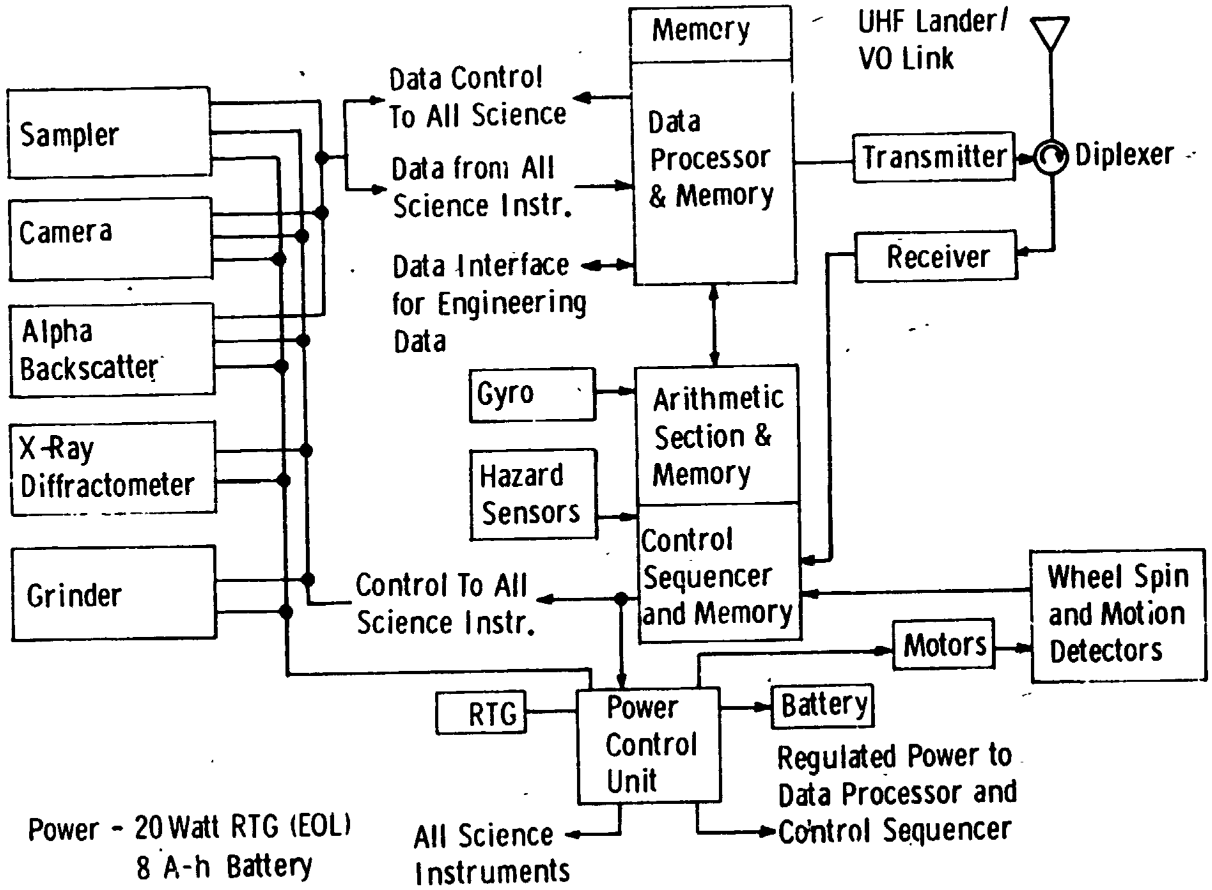


FIGURE 46 BASELINE SCIENCE CONFIGURATION ELECTRONICS BLOCK DIAGRAM

6.0 ROVER SUBSYSTEM ANALYSES AND TRADE STUDIES

6.1 SCIENCE

Analyses and trade studies of science payloads can only be conducted in a general sense because of the large number of possible payloads. Detailed science objectives and payload instrument complement will not be selected until a later date by advisory committees to NASA; however; the general objectives are well established and a number of the detailed objectives are already evident. As well, there are certain instruments and techniques suitable for use on rover missions that are already partially developed. Therefore, it is possible to consider certain science objectives, as discussed in Section 3, and from the available instruments derive a number of possible payloads for the rover. These payloads are termed straw-man payloads for they provide typical groups of instruments whose engineering characteristics may be estimated and from which it is possible to evaluate the abilities of a given rover design to satisfy the science requirements.

Instruments that should be considered are listed in Table 19. These instruments can be grouped into five general categories:

Imagery Systems
Water Detectors
Inorganic Chemistry and Mineralogy Instruments
Geophysical Instruments
Sampling and Sample Preparation Systems

Imagery systems. - One possibility is to use the present Viking '75 facsimile camera system unaltered. It is also possible to refine the engineering of this camera by repackaging in a centralized electronic system where many of the functions normally provided by the '75 camera are accomplished by a central system, such as power conditioning and data handling. Such a camera is estimated to weigh 4.5 kg (10 lb). If a new camera were developed with an object of minimum mass, current engineering estimates are that such a camera could be made as light as 2.7 kg (6 lb) using advanced technology such as a miniature vidicon system or a charge-coupled device (CCD). Such a camera would

TABLE 19 CANDIDATE ROVER SCIENCE INSTRUMENTS

INSTRUMENT	MASS		COMMENTS
	kg	(lb)	
IMAGERY SYSTEMS			
V-75 Facsimile Camera	6.8	(15)	No Modification
V-75 Refined Camera	4.5	(10)	Same Performance, Microelectronics
Minimum Mass Camera	2.7	(6)	Low Resolution, Minimum Mass
Optimum Camera	6.8	(15)	Panorama; Intermediate Field Magnifier
WATER DETECTORS			
Neutron Scattering Probe	1.8	(4)	
Microwave Probe	4.5	(10)	
Soil Water Experiment	1.4 - 2.7	(3-6)	DSC/EGA for Example
INORGANIC CHEMISTRY & MINERALOGY			
V-75 Advanced XRFS	2.3	(5)	Requires Sample Delivery
Alpha Backscatter	2.7	(6)	
Articulated Geochemical Instrument	1.4 - 4.1	(3-9)	Several Possibilities
X-Ray Diffractometer	4.5 7.3	(10) (16)	Includes Sieve, but no Grinder With Grinder
GEOPHYSICAL INSTRUMENTS			
Magnetometer, Gravimeter or Gamma Spectrometer	5.5	(12)	
Heat Flow Probes Deployment	9.1	(20)	Includes Drill
SAMPLING SUBSYSTEMS			
Sampler, Type 1	1.8	(4)	No Storage. Acquires Soil for Rover Instruments Only or Manipulator.
Sampler, Type II	3.2	(7)	Acquires Soil Only and Store 3 Samples. (Biology Oriented)
Sampler, Type III	4.5	(10)	Acquires and Stows Rocks (5 ea) and Soils (3 each) (Geology Oriented)

be a new development and would have a minimum scientific performance. The fourth camera listed is a so-called optimum camera estimated at 6.8 kg (15 lb). Its capabilities would be greater than that of the facsimile camera for it would provide not only the panorama and immediate field measurements but would include a magnification system to photograph rocks and soils at high resolution with a goal of 30 microns resolution at the sample surface.

The present Viking '75 facsimile camera loses focus for all objects closer than approximately 1.6 meters and has a resolution of one millimeter at the optimum distance of 1.6 meters. Althoush this is satisfactory resolution and focusing performance for studying the geologic setting of the surroundings, it does not provide the capability of studying the grain size distribution and structural relationships among grains within individual rocks. Further, it does not permit a determination of the relative roundness or angularity of indicidual soil grains that could provide important historical data, i.e., whether they have been subjected chiefly to wind erosion or stream erosion.

Water detectors. - Soil water experiments fall into two categories: Those accomplished by remote sensing (which are here termed probes) and those that provide data on the basis of treatment of a sample acquired and brought on board the rover. Neutron scattering is a technique of measuring moisture content through the presence of the hydrogen atom, which effectively scatters neutrons and causes them to quickly lose energy. Therefore, if a high energy neutron beam is directed towards the ground the intensity of low energy neutron backscatter is a measure of the amount of hydrogen present in the soil. Assuming that organic compounds are at a level much lower than that of water, the hydrogen measurement therefore indicates the amount of water present. A microwave device can be used to measure the amount of moisture in soil because of the high dielectric constant of liquid water compared to that of rock or soil. However, if the moisture is present in the form of ice the dielectric effect is not too strong and it is more difficult to measure small quantities of the material. The neutron probe measures the amount of H_2O regardless of its physical state - liquid, solid, or gas.

A soil water experiment would acquire a sample and in some way measure the water content. The most feasible method of accomplishing this that has been proposed to date appears to be a system for evolved gas analysis (EGA). In this experiment the sample is heated and the water or ice is changed to water vapor and the vapor is detected by a special detector. In Appendix A this device is referred to as DSC/EGA because it also incorporates measurements of the thermal properties of the soil using the technique of differential scattering calorimetry (DSC).

Inorganic chemistry and mineralogy instruments. - These instruments are designed to measure the geochemical and mineralogic makeup of the soil. These include the techniques of X-ray fluorescence spectrometry, neutron activation, alpha backscatter, and X-ray diffractometry. Instruments listed are specified further in Appendix A. The diffractometer, in particular, exists in at least three possible forms, all of which are potentially suitable for use on a rover.

Geophysical instruments. - Geophysical instruments include devices for: measurement of magnetic fields, gravity fields; the rate of heat flow from the interior of the planet to the surface, seismic activity; the magnetic properties of the *in situ* material, and the electrical transmission properties of the soil. Although a number of instruments are possible such as magnetometers, gravitometers, seismometers, and heat flow probes, all face rather severe difficulty in implementation because of the requirements for deployment. Heat flow probes in particular require drilling to a depth of at least one meter (preferably three meters) to implant several probes in an array to measure the thermal gradient versus depth at several locations (the array is required to determine if there are also horizontal gradients in the soil due to the particular location where such measurements are made - e.g., proximity of a geothermal source).

Sampling subsystems. - Several types of samples are possible, depending upon the scientific requirements for the samplers. A minimum sampler will only acquire soild for rover instruments and can be made rather simply. This, we have termed a Type I sampler. On the other hand, a Type II sampler could acquire soil and could store several samples to provide material for use by biological life detection instruments on the lander and also for geological instruments based either on the rover or lander. A Type III sampler would be one that not only acquires soils but also acquires rocks within a certain size range, a requirement of high priority for geological study, but of no importance to biological or organic compounds detection.

In the instrument list of Table 19, it is implicitly assumed that no life detection experiment will be carried by a rover. This should not be completely ruled out though incorporation of a biology instrument into the rover has not been part of this study. However, it is straightforward for the rover to acquire a sample that appears to have biological interest such as a sample taken at the bottom of an arroyo or a sample in a salt bed or other chemical differentiate, store the sample without thermally stressing it, and return it to the lander for life-detection analysis. Similarly we have not shown an organic measurements system, although an instrument is described in following paragraphs that shows some feasibility for use as a detection method.

Science Payload Selection

Selection of science payloads from the instrument list will depend upon detailed objectives, as noted. Some of the possibilities may be considered by inspecting the science questions posed in Table 1. In Table 20 we present a list of these five questions, the rover tasks that can be derived from the questions and then a list of rover experiments that can be used to accomplish the tasks. Noteworthy is that imagery appears in four of the five cases because it can be used also to detect the presence of environments that would be conducive to life forms or the presence of organic compounds. Therefore, a camera system would be included on most payloads that could be envisioned for a rover. This science requirement for imagery is supported by engineering requirement for navigation and for rover position determination.

We will now turn to the construction of straw-man payloads of various masses and various science objectives (Table 21). In some cases the payloads will be dedicated to only one of the five questions but in other cases the payloads will be intended to be more broadly-based and to satisfy several scientific objectives.

TABLE 20 ROVER EXPERIMENTS FOR SCIENCE QUESTIONS

SCIENCE QUESTION	ROVER TASKS	RCVER EXPERIMENTS
Water in the Past?	Photo and Geochemical Reconnaissance	Imagery, Geochemical Instrument
Water Today?	Survey for Surface and Subsurface Water	Non-contacting Water Detector, Soil Water Experiment, Sampler
Active Processes?	Photo and Geochemical Reconnaissance, Dual Station Seismometry	Imagery, Articulated Geochemical Instrument, Geophones or Seismic Source
Plate Tectonics?	Photo Reconnaissance, Rock Sampling, Deploy Seismometer	Imagery, Rock Sampler, Seismometer Deployment Mechanism
Life or Organics?	Find Ecological Niche and Sample	Imagery, Water Detector, Sampler, Geochemical Instrument

TABLE 21 CANDIDATE ROVER SCIENCE PAYLOADS

PAYLOAD		kg	(lb)
1	Imagery Mission		
	Dual Optimum Cameras (High Resolution, Automatic Exposure Control)	9.1	(20)
	Microcomputer for Data Compression	1.4	(3)
		10.5	(23)
	Option: One Megabit Data Storage	4.5-9.1	(10-20)
		15.0-19.6	(33-43)
2	Life Detection Mission		
	Sampler, Type II	2.3	(5)
	Minimum Camera	2.7	(6)
	Neutron Water Probe	1.8	(4)
	Soil Water	2.3	(5)
		9.1	(20)
3	Life Detection Mission		
	Sampler, Type II	2.3	(5)
	Minimum Camera	2.7	(6)
	Organics Detector	4.5	(10)
		9.5	(21)
4	Minimal Cost Rover Science Mission		
	V'75 Camera	6.8	(15)
	V'75 XRFS	1.8	(4)
	Sampler, Type I	1.8	(4)
		10.4	(23)
5	Geoscience Mission (No samples to lander)		
	V'75 Refined Camera	4.5	(10)
	Soil Water Experiment	2.7	(6)
	X-ray Diffractometer (no grinder)	4.5	(10)
	Sampler, Type I	1.8	(4)
		13.5	(30)

TABLE 21 continued

PAYLOAD		kg	(lb)
6	Geoscience (No samples to lander)		
	V'75 Camera	6.8	(15)
	Neutron Water Probe	1.8	(4)
	Articulated Geochemical Instrument	2.7	(6)
		11.3	(25)
7	Geoscience (Rasool Committee Payload)		
	V'75 Refined Camera	4.5	(10)
	Duster	1.8	(4)
	Alpha Backscatter	2.7	(6)
	X-ray Diffractometer (Including Grinder)	7.3	(16)
	Sampler, Type III	4.5	(10)
		20.8	(46)
8	Geoscience Mission		
	V'75 Refined Camera	4.5	(10)
	Duster	1.3	(4)
	Magnifier Attachment	1.8	(4)
	Articulated Geochemistry Experiment	4.1	(9)
	Sampler, Type III	4.5	(10)
		16.7	(37)
9	Geophysics Mission, Lander Independent		
	V'75 Camera	6.8	(15)
	Deploy Seismometer	1.4	(3)
	Microwave Probe	4.5	(10)
		12.7	(28)
10	Geophysics Mission, Lander Independent		
	Minimum Camera	2.7	(6)
	Deploy Seismometer	1.4	(3)
	Deploy Heat Flow Experiment (Including Drill)	9.1	(20)
	Traverse Magnetometer or Gravimeter	5.5	(12)
		18.7	(41)

Payload 1 is an example of a rover mission that is solely imagery. Such a mission has been proposed by some scientists as being a minimal, but a valuable scientific approach for exploiting the mobility feature of a rover. If a camera were the only instrument on a rover, it would be desirable to have two for the purpose of redundancy. Also included is a microcomputer system for data compression, that could compress the data by up to a factor of three. An important option would be a large data storage system of the one megabit class to store compressed pictures. This level of mass data storage would allow the accumulation of as many as 10 pictures between transmissions. It is important to note that all rover systems presently envisioned do not include mass data storage. Instead they rely on a 250 kilobit data memory to store small amounts of data with the main picture taking mode being via relay to the lander or orbiter. In a real time mode this restricts picture taking to those times when the rover is within line of sight communication with the lander or the daily 20-minute period when the orbiter is within communication range. Therefore, a mission devoted to imagery would be significantly enhanced if a large data storage system could be obtained. The range shown on the data unit of 4.5 to 9 kg (10 to 20 lb) arises from the circumstance that the amount of mass depends upon the technology used. The 9 kg estimate is based on using C/MOS integrated circuit elements.

Before examining possible geological payloads let us briefly consider some examples of payloads devoted to a mission of life detection. Payloads 2 and 3 are of this type. Each payload contains a Type II sampler, and a minimum camera but differ in the standpoint that in one case the payload is devoted to detecting the presence of water (for example, by a neutron water probe and a soil water experiment) whereas the second approach seeks the detection of organic compounds, which on Earth is a reasonably diagnostic indicator of whether or not soil conditions can support life. Either approach could be followed or a combined approach could be employed. The minimal payloads in this category weigh in the order of 9 kg but with improved imagery and more sophisticated sampling would weigh considerably more.

Payload 4 is an example of a minimal cost science payload. This is the case because the two scientific instruments proposed are taken directly from the V'75 mission and could use identical designs. This would be a facsimile camera and an X-ray Fluorescence Spectrometer, used as a soil analyzer. This payload, though inexpensive, would suffer in many respects in that the geochemical measurements would be only on soil acquired by the sampler and loaded into the measuring cavity. There could be neither survey of the ground for chemical composition as the rover traversed, nor analyses of rocks. One could, of course, rely upon advanced instrumentation in the lander and employ a Type III sampler to return samples to the lander.

Payloads 4 through 8 are chiefly directed toward geological exploration. We have already considered payload 4 as a minimum cost approach. Payload 5 contains simply a Type I sampler to service the soil water experiment and the diffractometer located onboard. This payload does not include the mass of a rock grinder and therefore the value of the diffractometer is limited to the information that can be obtained from soil alone. This could greatly detract from the value of such a mission for soils are mechanical mixtures of ground rock material from a variety of sources, and probably have been transported over long distances across the planetary surface by the great dust storms. Rocks, on the other hand, are either representative of local bed rock or are representative of bed rock transported by the action of impact ejection or stream transport.

Payload 6 includes no sampler at all. It would be a rover mission that would be independent of any instrumentation on the lander itself. This would allow exploration of the surface out to large ranges particularly if this rover accomplished communication to Earth via orbiter or on a direct link rather than through the lander. It would provide measurements of the surface material that would define its geology via an articulated geochemical instrument. This instrument is one that could be moved on a boom so it could be placed close to the ground or on the side of an outcrop or large boulder that otherwise could not be sampled. A neutron water probe could provide a record of the water concentration profile as a function of distance. These types of data are important relative to the geomorphologic evidence of terrain types and is another way of mapping the surface of Mars in terms of parameters of fundamental interest to geology, biology, and atmospheric science. It would also provide ground truth information to compare with orbital instruments such as water detection via infrared spectroscopy and chemical differentiation by infrared and visible imaging techniques. Payload 7 contains a camera system including a duster subsystem of CO_2 gas that removes dust periodically from the camera lenses. This may be required for future missions if the '75 mission experience justifies its inclusion. An Alpha Backscatter Instrument would provide analysis of acquired samples especially for light elements, which include most of the major and minor elements expected in soil materials. It could also observe samples prepared by the grinder and thereby perform analyses of rocks. As this experiment requires 5 to 12 hours for data acquisition, it could not be used to monitor the composition of the surface during a traverse. The X-ray Diffractometer in this payload includes a grinder and can therefore analyze all types of materials that could be acquired. The Type III sampler would be capable of acquiring not only soils but rocks in a certain size range. This payload is the maximum mass payload that has been considered to date but can be accommodated by rovers in the classes studied.

Payload 8 also has a geologically-oriented payload but does not include a diffractometer, relying instead upon a diffractometer located in the lander. This approach would include an articulated geochemistry experiment that could monitor soil and rock specimens collected by the Type III sampler and discard those specimens that are redundant or of little interest. With a magnifier attachment to the camera, rocks could be examined at high resolution to determine their structure. Combining the imagery and geochemistry data would provide the information from which scientists could make decisions as to which samples to keep, and whether or not extremely interesting samples were being obtained in sufficient quantity to justify a beeline return to the lander for further analysis.

Payloads 9 and 10 can be classified as geophysics-oriented missions. They include deploying various geophysics instruments as well as monitoring subsurface structures or fields during traverses. A heat flow experiment is probably too ambitious for a first generation rover mission to Mars for it entails drilling several holes and placing heat probes into these. However, if deemed of sufficient scientific interest, it is likely that its feasibility could be demonstrated in a straightforward manner.

Detailed descriptions of instruments that have been identified for potential use on this payload and which are presently under development are given in Appendix A.

6.2 MOBILITY SUBSYSTEM

This Section describes the evolution of the mobility subsystem concept used in the vehicles described in Section 5. The material covers the design criteria and guidelines, the options considered, the trade studies conducted, and the selected mobility subsystem concept.

Design Criteria and Guidelines

Two basic design criteria were established at the onset of the study. First, the mobility subsystem had to be compatible with a rover design that could fit within the volume and shape constraints imposed by a minimum-modified Viking Lander Capsule system as discussed in Section 3. Second, the mobility subsystem had to be designed to operate satisfactorily on all surface material models contained in the Mars Engineering Model (see reference 3.). This criterion is required because the rover flight hardware design and fabrication will be in progress before receipt of Viking '75 data, which might reduce the range of anticipated surface material characteristics.

A third criterion established was based on the requirement to operate under the worst conditions expected at the landing site. Because the lander is designed to survive rocks up to 22 cm in height and slopes up to 0.33 rad (19°), a decision was made to require mobility on surfaces having any combination of rocks and slopes up to these maximum values. While worse conditions may exist adjacent to the lander without affecting the landing success, any selection of a worse set of conditions for rover operations in the area would be arbitrary. Accordingly, such conditions were not considered during the study.

A fourth criterion, to be able to turn in place, was derived during the study. This capability is required due to limitations in the number of hazard detection sensors practical on the size vehicle being considered. By turning in place, the vehicle can remain on surfaces known to be safe during the turn.

Also, the vehicle can be extricated from a complex hazard situation more easily if it does not have to move forward or backward during a turn.

A fifth criterion was to provide a vehicle having no built-in limitations on range from the lander. This applies to several subsystems in addition to mobility but it requires special attention to component lifetime in the mobility subsystem. By meeting this criterion, the rover should be able to leave a safe landing footprint area and reach more complex regions of high scientific interest. A specific goal is to be able to travel in excess of 50 km from the lander although this could require more than 90 days of surface operations.

Guidelines established at the start of the study were to use Viking '75 components and technologies wherever possible

Mobility Subsystem Options and Trade Studies

The mobility subsystem was divided into five parts for analysis and trade studies. The five parts are: chassis structure, body compartments (as they influence chassis design), traction elements, steering components, and drive-motors.

Numerous studies have shown that multiple-segment vehicles that distribute the vehicle's mass over six or more wheels possess high mobility capabilities, i.e., they can traverse higher steps and larger rocks than rigid chassis vehicles. A good example of this type of vehicle is shown in Figure 47. This JPL Mars Rover concept has three main body segments connected by longitudinal leaf springs which allow roll and pitch motion between the body segments.

While the mobility capabilities of this type of vehicle are desirable, it became apparent early in this study that essentially all of the rover's electronic, power, science, and thermal control hardware would have to be integrated into one unit to meet the rover mass and volume constraints imposed by the lander. Therefore, a decision was made to pursue only those configurations embodying a single body compartment. This decision did not eliminate consid-

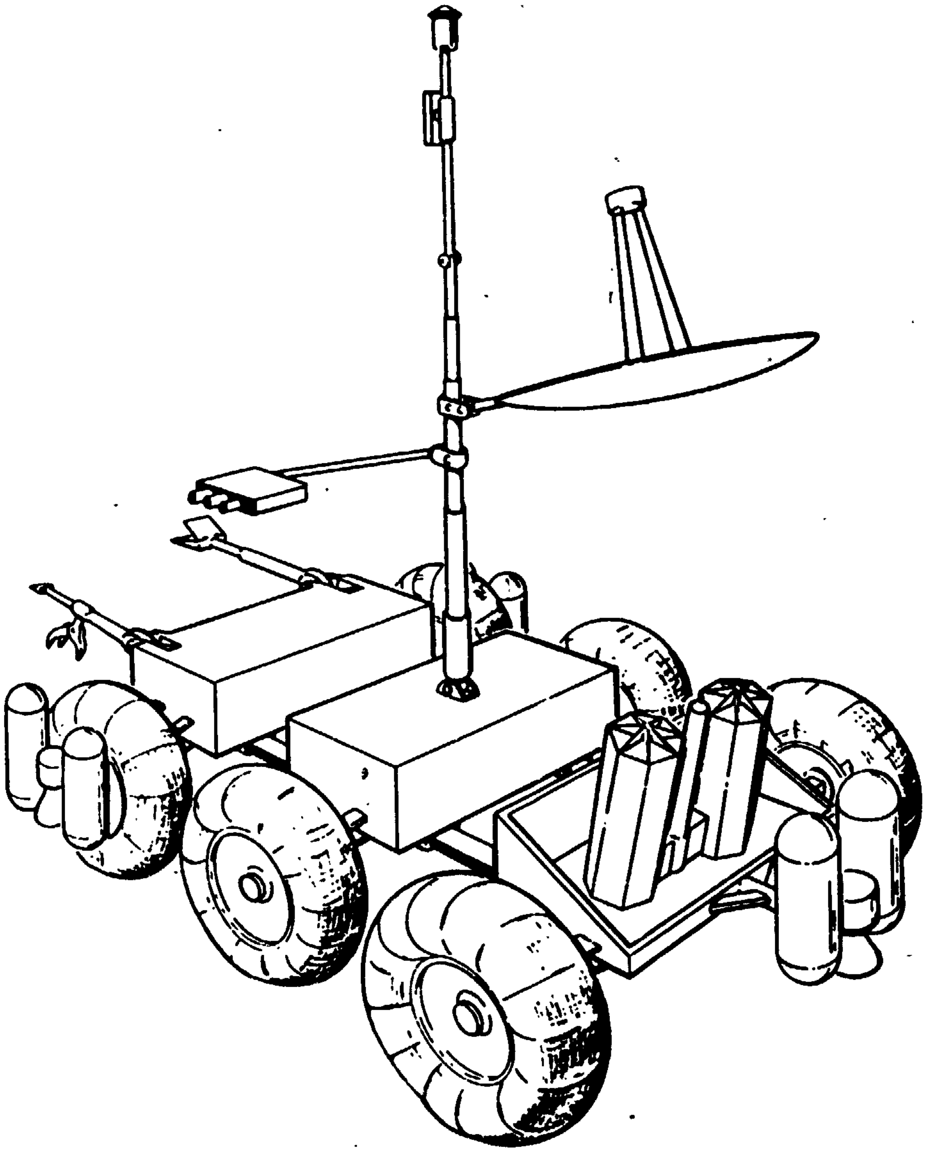


FIGURE 47 JPL MARS SEMI-AUTONOMOUS ROVER CONFIGURATION

eration of using an articulated chassis on the single body compartment. This topic is addressed in a later paragraph (Chassis Configuration Trade Studies).

The third part of the mobility subsystem, traction elements, covers those elements which will ride on the Martian surface, i.e., wheels, tracks, or legs. The last was discarded at the onset due to a lack of proven or anticipated technology in this area, particularly in the controls required for a legged system. Due to mass and complexity considerations, the only track-type system considered was the Lockheed Elastic Loop Mobility Subsystem (ELMS). The trade studies for wheels and the ELMS are presented in the Traction Element Trade Studies paragraph.

Steering options can be placed in two categories: actuated and scuff. Actuated systems involve using steering actuators to turn axles, wheels, or tracks through angles relative to the main rover body and then executing a turn by moving the vehicle in a forward or reverse direction. Scuff-steerable vehicles use different drive velocities on the two sides of the vehicle to execute a turn. The traction elements in this case remain parallel to the vehicle's longitudinal axis. A tank is a good example of a scuff-steerable vehicle. The Steering Trade Studies paragraph presents the trade studies of actuated and scuff steering.

The final mobility subsystem part considered was the drive system or actuators that power the traction elements. The only drivemotors being developed for use in the Mars surface environments are the motor drive assemblies for the Viking '75 Surface Sampler Subsystem. Accordingly, these assemblies were investigated to assess their suitability for the rover mobility drive application. Results of this investigation are presented in Drivemotor Studies.

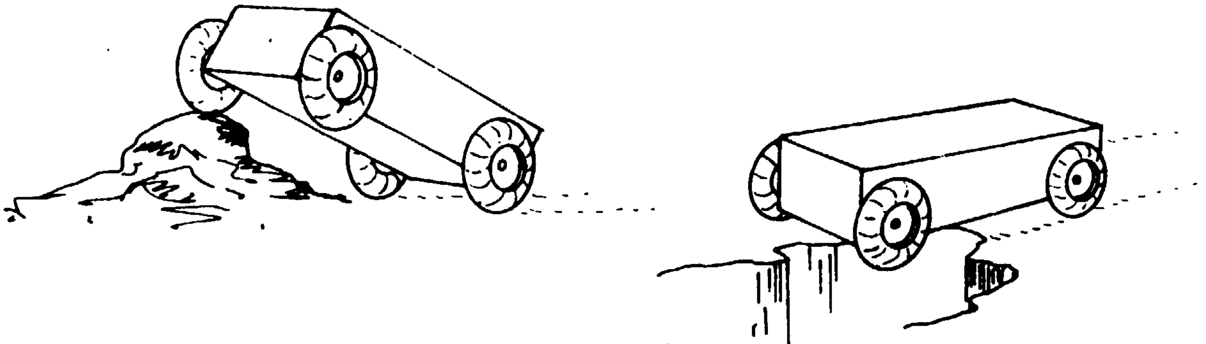
The following paragraphs present the mobility subsystem trade summary introduced in this section. Included is Selected Mobility Subsystem Study that describes a typical mobility subsystem implementation concept utilizing the selected subsystem parts.

Chassis Configuration Trade Studies

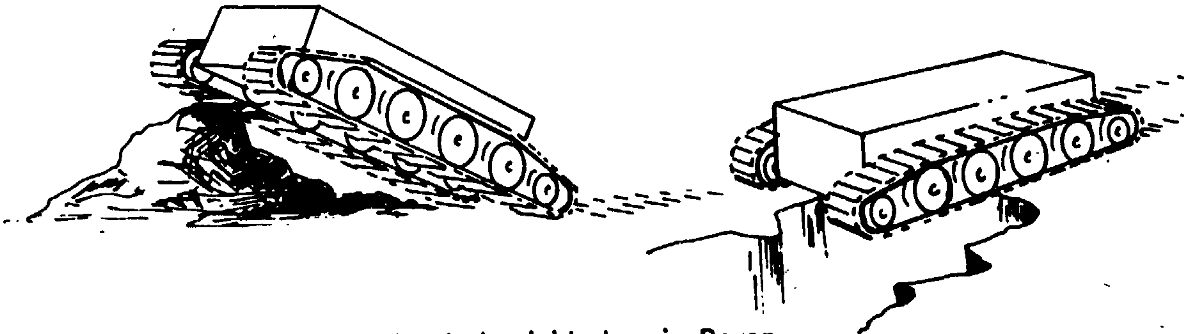
Having concluded that a single body compartment is required, the question remains whether to provide a rigid or articulated link between the traction elements and the body. It should be noted that spring suspension elements are not required on this class of vehicle due to its low operating velocities (< 5 cm/sec) nor are they desirable because the rover's control system must monitor the ground contact points to assess the vehicle's current state and spring suspension deflections are awkward to monitor. The question, therefore, becomes whether to use a rigid chassis or to provide gimballed joints between the traction elements and the chassis.

Rigid chassis, four wheeled vehicles, although simple, have one basic characteristic that produces a set of performance problems. The basic characteristic is that on irregular surfaces, all traction elements do not remain in contact with the surface at all times. Figure 48 illustrates this condition for wheeled and tracked rigid chassis vehicles encountering a rock and a cliff under one side of the vehicle. Neither vehicle has, at either hazard, sufficient information available to define the surface contour under the vehicle. In the case of the rock, both vehicles would proceed forward and tip abruptly to the left side of the vehicle. If the vehicles were on slopes at the time of rock encounter, the abrupt tipping could result in the vehicle overturning. At the cliff face, both vehicles would proceed unknowingly until their centers of mass reach the cliff's edge. This condition would produce, as a minimum, a hangup on the cliff's edge or, worse, a fall to lower elevations.

Figure 49 illustrates the behavior of articulated vehicles encountering these same hazards. The roll-articulated, wheeled rover has a single roll gimbal between the rear axle and the body. The walking beam vehicles have a pitch pivot between the traction elements of each side and the vehicle's side. Because the body cannot be split to allow one-half of the body to pitch with each side's traction elements, a mechanism is required to keep the body centered in pitch between the traction elements of the two sides.

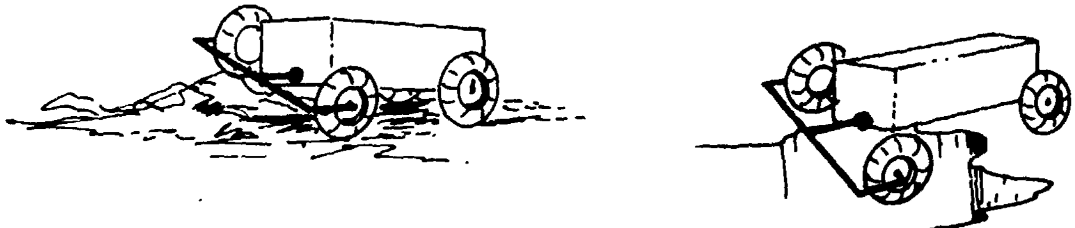


Wheeled, rigid chassis Rover

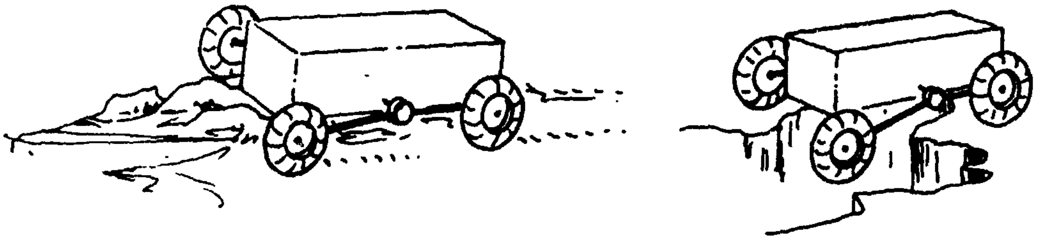


Tracked, rigid chassis Rover

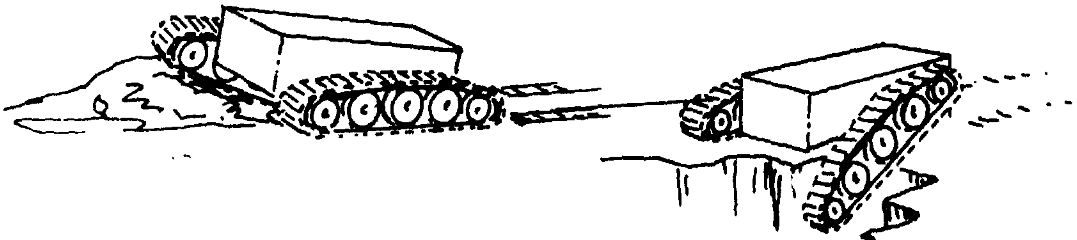
FIGURE 48 RIGID CHASSIS VEHCILES AT ROCK AND CLIFF HAZARDS



Roll articulated wheeled Rover



Walking beam wheeled Rover



Walking beam tracked Rover

FIGURE 49 ARTICULATED CHASSIS VEHICLES AT ROCK AND CLIFF HAZARDS

The roll-articulated vehicle, by reading inclinometer and gimbal angle sensor data, can understand its current state, (Figure 49), that is, an elevated terrain segment is under its right front wheel or, in the case of the cliff, an abrupt dropoff is under its left front wheel. At the low vehicle velocities this rover would be able to assess each situation in time to respond by backing away. The wheeled walking beam vehicle can monitor the surface contours over which it is traveling with the same accuracy and safety as the roll-articulated rover. The walking beam tracked rover follows and can monitor the surface contours better than the rigid chassis tracked rover and, therefore, has a better opportunity to detect and avoid hazards. At a cliff face, the walking beam tracked rover would proceed until, in the case shown, the left track starts to tip abruptly over the cliff face. The vehicle must sense this immediately and reverse direction before the vehicle's c.m. passes over the cliff's edge.

Based on these observations, a decision was made to proceed with vehicles incorporating articulated chassis. Knowing that the rover can operate more safely if it has access to more accurate data on the local surface contours, the comparisons given above also indicated that a wheeled vehicle, or at least a vehicle having four independent ground contact points, would be preferred over a walking beam tracked vehicle that would have to respond rapidly at cliff faces. It is also apparent that if wheels are selected for the traction elements, the simplest articulated chassis would incorporate a single roll gimbal between one of the axles and the chassis. The other axle would be attached rigidly to the chassis. By comparison, the walking beam arrangement involves two pitch pivots, one on each side, and a mechanism to center the body in pitch between the pitch angles of the two walking beams. Because of its simplicity, the single roll pivot was selected for all wheeled rover candidates.

Traction Element Trade Studies

As identified previously, two primary traction element candidates were considered: the Lockheed ELMS and wheels. Figure 50 illustrates a Lockheed-proposed concept for a Viking Rover using the ELMS concept. This vehicle

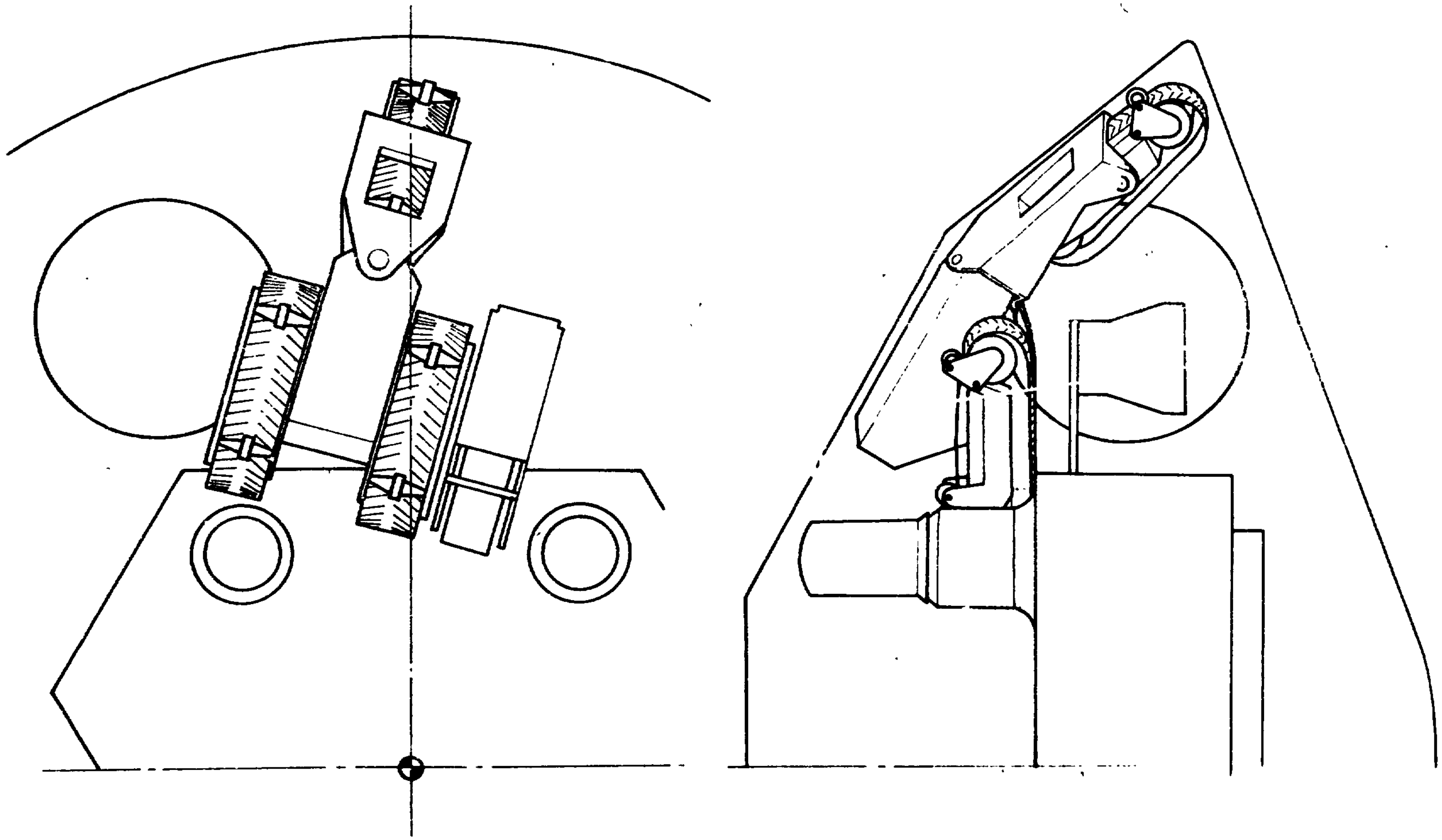


FIGURE 50 ELMS-EQUIPPED VIKING ROVER (LOCKHEED CONCEPT)

requires segmented or divided body compartments to realize the benefits of the ELMS. Data supplied by Lockheed (Reference 4) to NASA/LRC and MMC were evaluated to determine if the ELMS would provide a mass advantage large enough to offset the body complexity. The Lockheed mass values are summarized in Table 22 for vehicles equipped with loops of the materials shown.

TABLE 22 MASS BREAKDOWN FOR ELMS-EQUIPPED VIKING ROVER (LOCKHEED DATA)

	Vehicle with Glass-Reinforced Epoxy Loops, Polyurethane Foam Treads	Vehicle with Titanium Loops and Tread
Mobility Subsystem (chassis, loops, loop suspension, drivemotors)	25 kg	32.5 kg*
Power, Science, Communications, Navigation, Thermal Control	65 kg	65 kg
Total Rover Mass	90 kg	97.5 kg

* Lockheed data provided by telephone to MMC to supplement Ref.4

The glass-reinforced epoxy loops with polyurethane foam treads are not suitable for Mars surface operations due to loop and tread embrittlement at the low temperature extremes and also due to organic contamination considerations. Accordingly, only the titanium-loop vehicles were used in comparisons with wheeled systems.

These data indicate that approximately one-third of the vehicle mass must be allocated for the mobility subsystem and chassis of an ELMS-equipped vehicle. By comparison, the mass breakdowns for the wheeled vehicles given in Section 5 indicate that the mobility plus chassis subsystems in these vehicles would require 30-33% of the vehicles' masses, making the wheeled systems essentially equal to the ELMS. Because the ELMS does not possess a mass advantage to cover the disadvantages of the required segmented bodies, wheeled rovers were selected for further consideration.

Regarding wheel design for the Viking '79 Rover, various types of wheels have been developed and tested for lunar and planetary rover applications. While additional candidates such as the wheels developed by Grumman and Bendix should be considered during Phase B of a Viking '79 Rover Program, wheels of the type developed by General Motors for the Apollo Lunar Rover Vehicle (LRV) were selected for the baseline Viking '79 Rover because of their known characteristics and proven performance. This type of wheel, as illustrated in Figure 51 was analyzed to obtain a mass estimate for wheels for the Viking '79 Rover. Each 5.5 kg (12.2 lbm) wheel used on the LRV supported a 273 N (63 lb_f) static load and additional loads imposed by travel at up to 16 km/hr (10 mph) and slopes up to 0.35 Rad (20^o). Each wheel on a 100 kg (220 lbm) Viking '79 Rover must support a 92.5 N (21.3 lb_f) static load and dynamic loads caused by travel at 100 meter/hr (1.1 in/sec). Ratioing wheel mass on the basis of static load alone gives a Viking '79 Rover wheel mass of $\frac{92.5\ N}{273\ N} \times 5.5\ kg =$ 1.86 kg per wheel. However, the much lower velocity of the Viking '79 Rover will produce much lower dynamic loads and it is estimated that this will allow a one-third reduction in the 1.86 kg wheel mass, giving 1.24 kg per wheel for a 100 kg rover. Because the baseline rover's mass differed from 100 kg for the various configurations, the wheel mass was adjusted accordingly.

Steering Trade Studies

The mobility subsystem, to this point, consists of a roll-articulated set of wheels attached to a single body compartment. The next question is whether or not actuated or scuff steering is preferred for a Viking '79 Rover. As shown in Figure 52, scuff steering involves driving the wheels on one side of the vehicle forward and the wheels on the other side backward to pivot the vehicle about its center. Studies have shown that this concept is practical only if the ratio of wheelbase to tread width (side-to-side distance between wheels) is 1.25 or less. If this ratio is appreciably larger than this value, the steering efficiency decreases, scuff steering being totally ineffective for long, narrow vehicles.

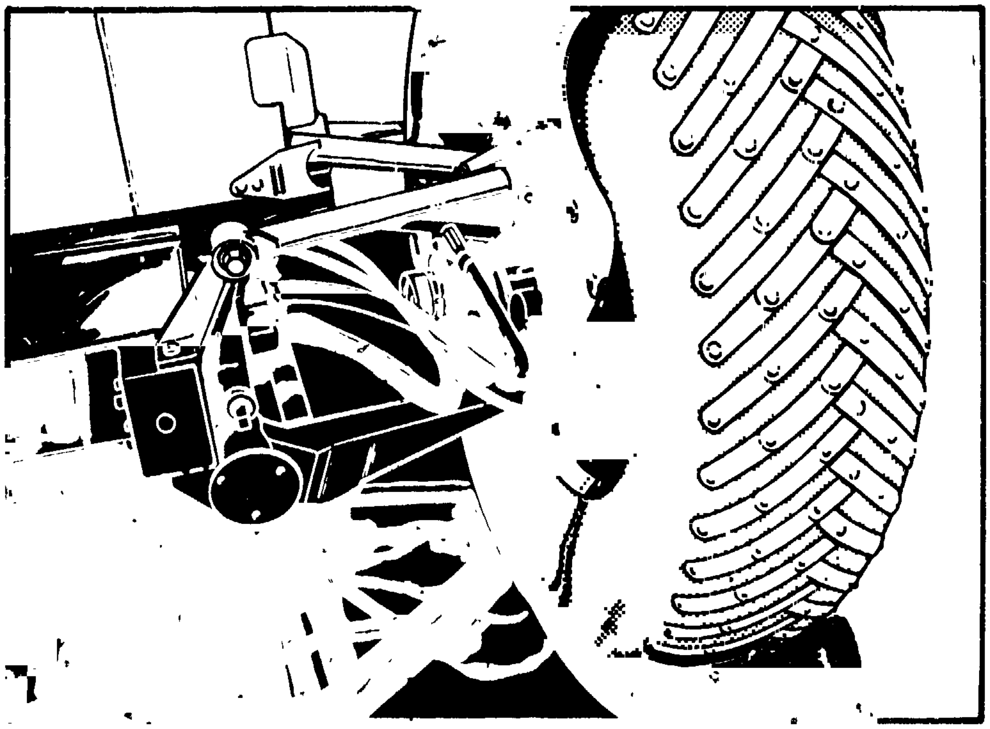


FIGURE 51 APOLLO LUNAR ROVING VEHICLE WHEEL DEVELOPED BY GENERAL MOTORS

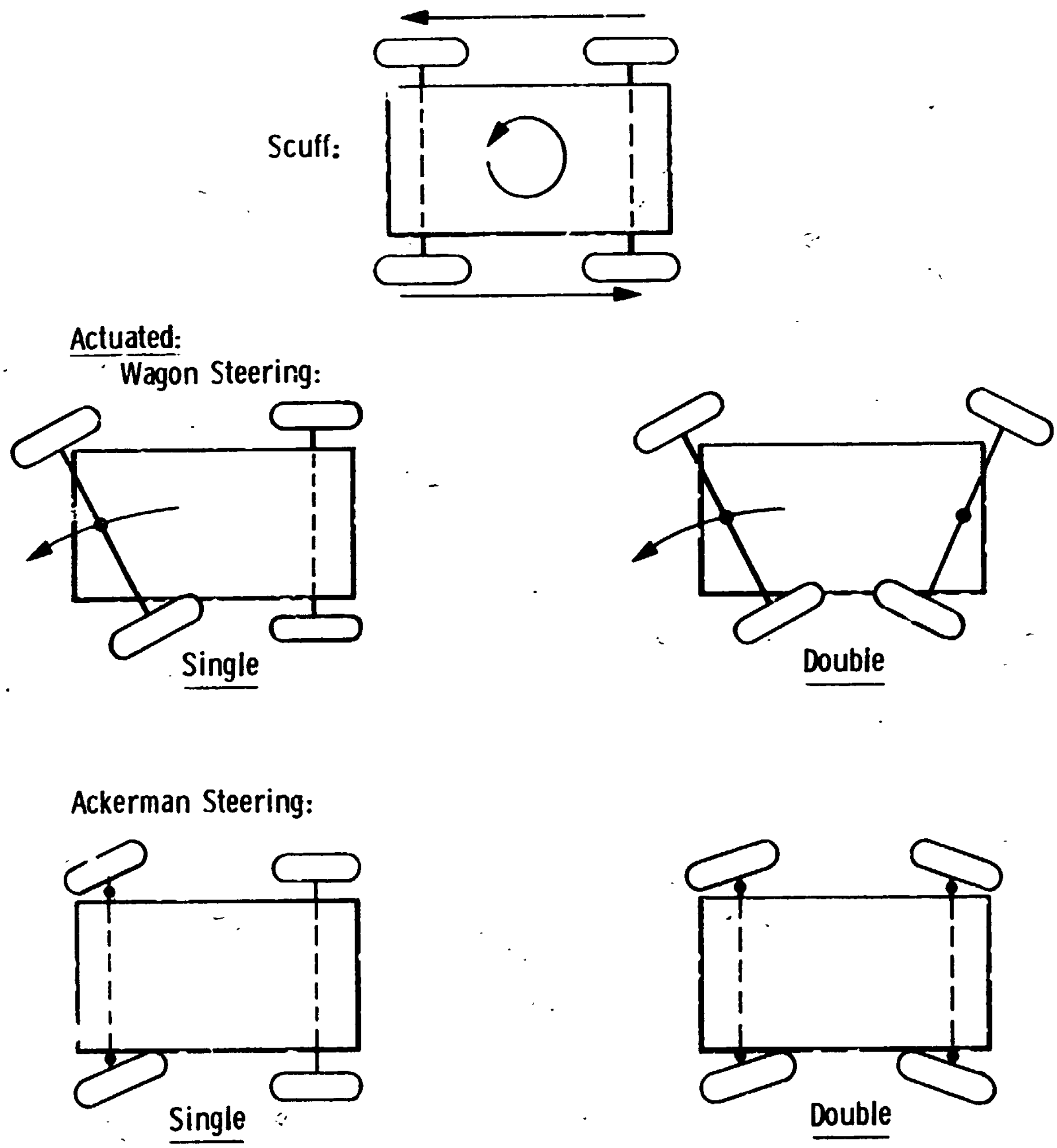
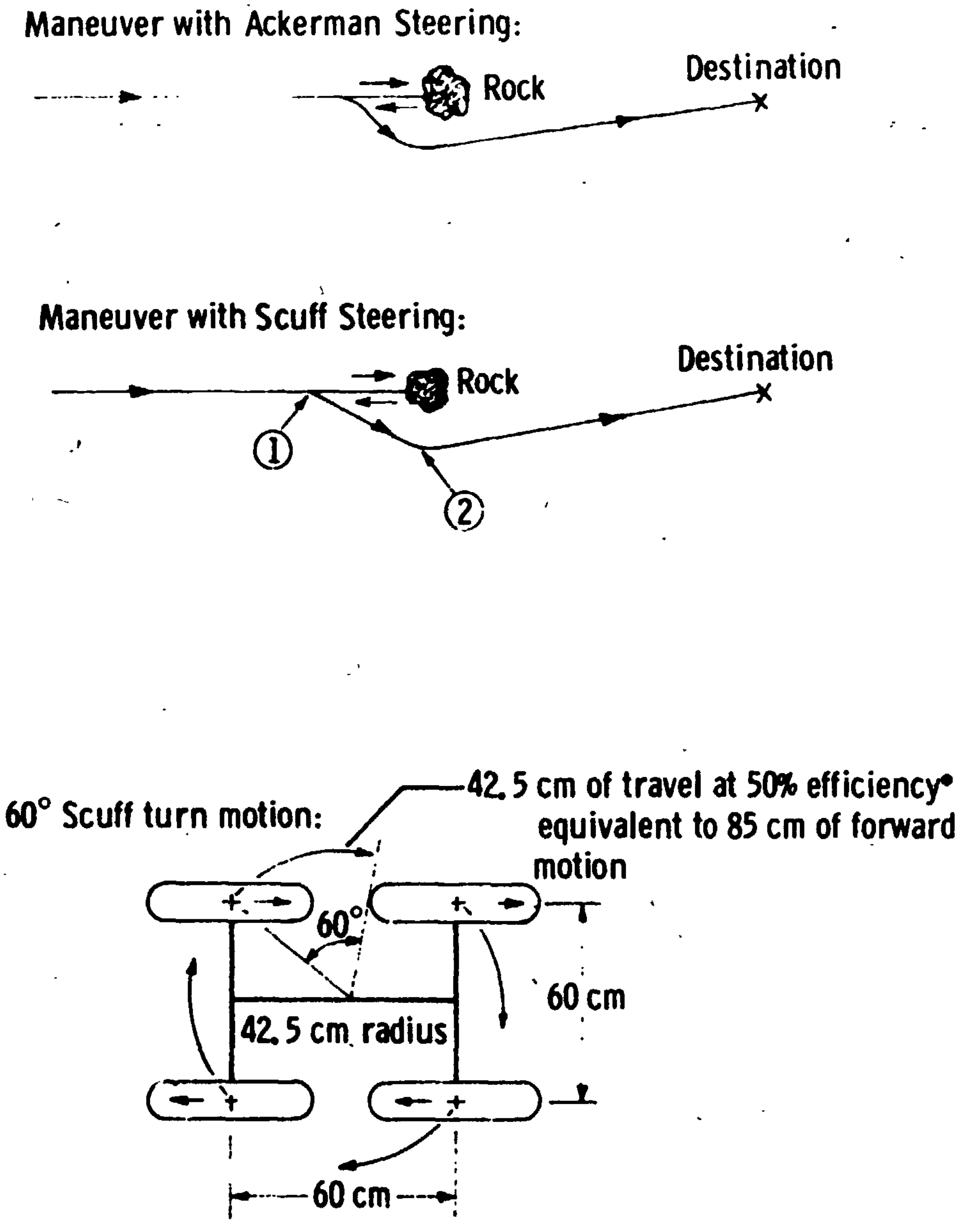


FIGURE 52 CANDIDATE SCUFF AND ACTUATED STEERING CONCEPTS

Two basic types of actuated steering, wagon and Ackerman, are shown in Figure 52. Both are appropriate candidates for the Viking '79 Rover. The first, wagon steering, involves yawing one or both axles relative to the body and executing a turn by moving forward or backward. The axle yawing can be accomplished with an actuator on the yaw pivot or by using an electrically driven lock on the yaw pivot, yawing in this case being accomplished by driving one wheel forward and the opposite wheel backward with the lock released. When the proper yaw angle is reached, the lock is engaged. Ackerman steering (the type of steering used on automobiles) is the second type of actuated steering suitable for a Viking '79 Rover. Ackerman steering can be incorporated in either end or both ends of the vehicle. It is preferred over wagon steering because the Ackerman-steered wheels align with the tangent to the turning circle being followed by the wheels without requiring large volume clearances to accommodate wheel displacements fore and aft. Actuators are required to generate the steering angles and body clearance must be provided to accommodate the steering angles.

It is appropriate to note that a wagon-steered or an Ackerman-steered vehicle can also be scuff-steered with its wheels aligned fore and aft if appropriate drivemotor controls are provided, i.e., if the wheels can be driven in opposing directions as shown for scuff steering in Figure 52. Therefore, such a vehicle can be made to turn in place, meeting that mobility subsystem requirement. The tradeoff, therefore, is the higher efficiency and complexity of actuated steering versus the simplicity of scuff steering.

Statistical data from the Mars Engineering Model indicate that a rover requiring a one meter wide clear path and having 22 cm ground clearance will have to avoid a rock taller than 22 cm approximately once in every 50-100 meters of travel. For comparison purposes, the avoidance maneuvers shown in Figure 53 were selected. Both maneuvers include backing up over terrain already covered because the front of the vehicle has, due to mass limitations, the only hole detector on the vehicle. In these examples, the distances traveled are essentially equal. Neglecting the slight amount of power required for steering actuators, the major difference is the amount of energy required



Maneuver with Ackerman Steering:

Maneuver with Scuff Steering:

60° Scuff turn motion:

- • Typical value for wheels sideslipping at a 45° angle in soft surface materials

FIGURE 53 ROCK AVOIDANCE MANEUVERS USED IN STEERING EFFICIENCY COMPARISONS to execute scuff turns at points 1 and 2 in the illustration. Assuming that the two turns added together equal a 1.05 rad (60°) turn, Figure 53 shows that this is equivalent to 0.85 m in forward motion on a scuff-steered vehicle with a 60 cm wheelbase and 60 cm treadwidth. If this extra motion is required with the scuff-steered vehicle once in every 50 m, the mobility energy penalty is 1.7% compared to an actuated-steered vehicle. This penalty is not large enough to justify selection of the heavier and more complex actuated steering. This factor, augmented by scuff steering's greater volume efficiency (no clearances are required for wheel yawing), led to selection of scuff steering for all the study's final rover candidates.

Drivemotor Studies

The motor drive assemblies for the Viking '75 Surface Sampler were examined to determine if they were suitable for the Viking '79 Rover wheel drive application and to provide typical size, mass, and power figures for inclusion in the selected rover concept description.

Motor torque and speed requirements were established as follows. A 100 kg rover (220 lb, typical value) on Mars, places a nominal vertical load of 92.5 N (21.2 lb) on each of the four wheels. When a wheel encounters a block-shaped rock as tall as one wheel radius, that wheel's leading edge must lift the stated vertical load. Given wheels of 22 cm radius under load to provide the required 22 cm ground clearance, the torque load on the wheel while starting to ascend the rock will be 20.4 N-m (185 in-lb). The wheel drive must not stall under these conditions.

On a dry, level, particulate surface, torque requirements will be approximately 5% of the typical maximum loads defined above. As stated in the vehicle design requirements, a vehicle velocity of 75-100 meters per hour is desired. With a wheel radius of 22 cm, the 100 m/hr requires 1.2 revolutions per minute. Therefore, a satisfactory drivemotor must have stall torque in excess of 20.4 N-m (185 in-lb) and output equivalent to 5% of this torque at 1.2 rpm. These requirements are summarized in Table 23.

TABLE 23 DRIVEMOTOR TORQUE AND RPM REQUIREMENTS FOR A FOUR-WHEELED, 100 kg, 100 METER/HOUR ROVER

APPLIED TORQUE N-m (in-lb)	RPM
1.02 (9.2)	1.2
20.4 (185.0)	> 0

Three different permanent magnet dc gearmotors are being developed for the surface sampler boom assembly, these motors being used to drive azimuth, elevation, and extend/retract motions. Specifications for these motors (Reference 5) indicated that the elevation motor's output was approximately correct when operated at 15 V input, a desirable voltage from the standpoint of the power subsystem.

Accordingly, elevation motor data were requested and obtained from the manufacturer, Singer-Kearfott. These data, obtained under the test conditions shown, are presented in Table 24. If 7:1 reduction gearing is added to the output of this motor, it would have the characteristics shown in Table 25, Comparing these data with the requirements in Table 23 indicates that this motor's output is close to the values required. Accordingly, it was selected for use in the final rover configuration to represent a typical motor suitable for this application.

TABLE 24 SURFACE SAMPLER ELEVATION MOTOR DATA*

APPLIED TORQUE N-m	APPLIED TORQUE (in-lb)	RPM	POWER (Watts)	INPUT CURRENT (mA)
0.0	(0.0)	8.8	1.4	90
0.14	(1.3)	8.4	1.5	100
1.37	(12.5)	7.2	2.6	170
3.08	(28.0)	4.4	4.8	320

*15V input, 20°C ambient temperature

TABLE 25 SURFACE SAMPLER ELEVATION MOTOR DATA WITH ADDITIONAL 7:1 REDUCTION GEARING AND 15 V INPUT

APPLIED TORQUE		RPM	POWER	INPUT CURRENT (mA)
N-m	(in-lb)		(Watts)	
0.0	(0.0)	1.3	1.4	90
1.0	(9.1)	1.2	1.5	100
9.59	(87.5)	1.0	2.6	170
21.5	(196.0)	0.6	4.8	320

Braking systems are an additional factor in the drive system design. The vehicle must be able to stop and hold position on slopes up to 19°, preferably without using power to hold position. The elevation motor selected as typical for the rover has a requirement to provide at least 1.37 N-m (12.5 in-lb) of backdrive resistance torque with the power off. Production models of this motor are delivering 1.54-1.65 N-m of backdrive resistance torque with power off. With 7:1 reduction gearing for a 100 kg rover, this provides 10.8-11.6 N-m of backdrive resistance torque on each wheel. This is over half of the maximum powered torque required from each wheel as shown in Table 23 and is enough backdrive resistance to stop and hold the vehicle in position on slopes up to 30°. It is probable that the vehicle will not attempt to negotiate 30° slopes because slipping and loss of effective motion control occurs on particulate surfaces having slopes approaching the surface material's natural angle of repose. Therefore, the elevation motor's backdrive resistance torque is sufficient to provide effective braking and position holding on anticipated slopes.

This motor's backdrive resistance torque is largely due to friction between the brushes and commutator. The brush force on the commutator is made abnormally large to generate the resistive torque that keeps the surface sampler boom from descending, unpowered, while fully extended. These motors are being qualification tested for 80 operating hours. In order to travel a total of 50 kilometers on the Martian surface, the rover's drivemotors must operate satisfactorily for 500 hours. Qualification testing will last approximately 1000 hours. Elevation motor data indicate that the existing brush/commutator design will probably fail before 1000 hours due to wear, even with the lower current density on the brushes with the 15V input. Therefore, if this motor design is selected as a basis for the rover wheel drivemotor, some development work should be expected to extend brush life. Also, gear lubrication may have to be improved to achieve 1000 qualification hours although this is not expected to be as large a problem as brush wear.

Selected Mobility Subsystem Summary

This section describes the mobility subsystem concept selected for the baseline vehicle based on the mobility subsystem trade studies. The engineering details of the mobility subsystem for the selected vehicle are given in Section 7.

The selected mobility subsystem is shown pictorially in Figure 54. It incorporates four wheels on two axles, one of which is attached rigidly to the rover's body compartment and the other is free to roll relative to the body. Each wheel encloses a modified Viking '75 surface sampler elevation motor, the modifications being long-life brushes and improved lubrication. These motors have sufficient output torque at 15V input to provide vehicle velocities on the order of 100 meter/hr and sufficient unpowered backdrive resistance torque to provide braking and position holding on slopes up to 30°. Conventional scuff steering is accomplished by driving one side forward and the other backward to pivot in place.

The axle yoke on the roll-pivoted axle reaches outside the wheels to prevent interference between the yoke and the body during roll motions. The yoke also places the two axle lines close enough together to remain within the wheelbase to treadwidth ratio limit of 1.25 required for effective scuff steering.

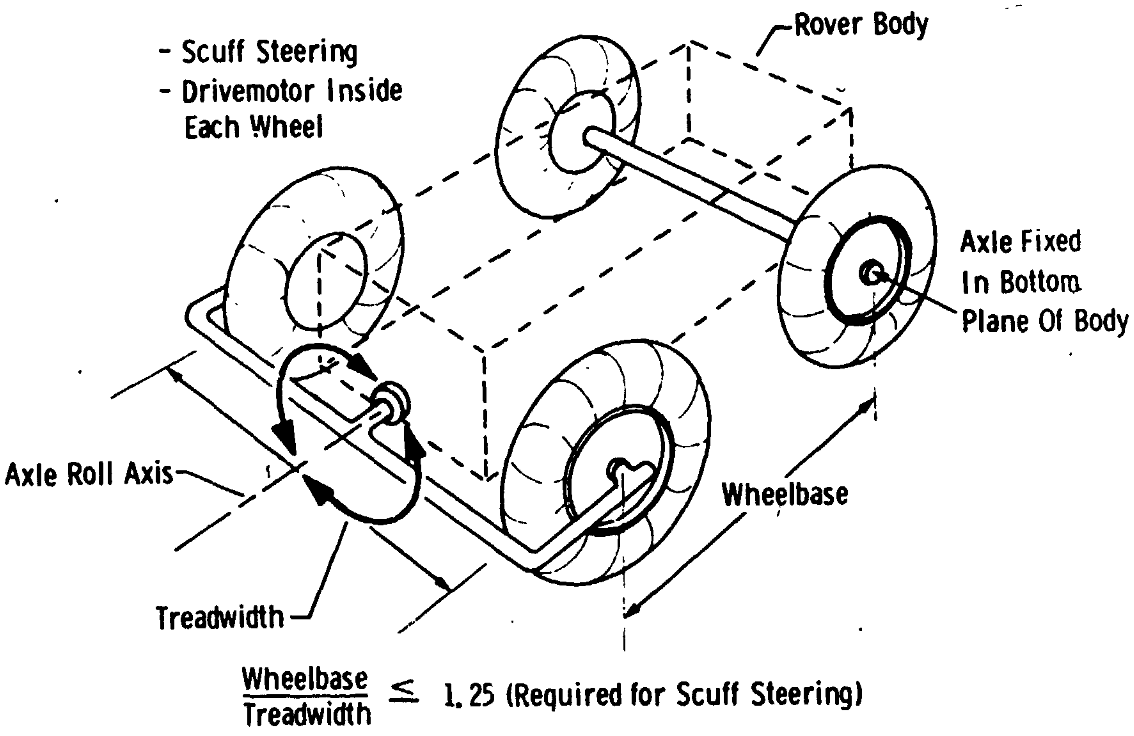


FIGURE 54 SELECTED MOBILITY SUBSYSTEM CONCEPT

6.3 POWER SUBSYSTEM

This Section summarizes the analyses and trades that were made in the selection of the power subsystem configuration. The requirements imposed on the power subsystem include using a GFE-supplied RTG for source power and conditioning this power to provide all rover equipment with regulated power. The tradeoffs that were performed were centered around the selection and sizing of the power components required to power the loads in the various rover configurations discussed in Section 5.

At the start of the study it was decided that tethered rovers would not be considered, therefore, rovers would require a self-contained power source. An in-depth study for selecting this power source was not performed. An RTG was selected as the power source early in the study based on the Viking '75 studies (no new information is available that would indicate a better source for this type of application).

The various configuration tradeoffs included a determination of the total power required in each operating mode. This determination was accomplished by preparing a listing of component power requirements that was then used in a typical sequence of events. From this listing was derived both RTG and battery sizes required for the specific configuration under consideration. In these tradeoffs the battery sizes varied from 1.5 to 8.0 A-h and the RTGs varied from 16 to 35 watts. The battery type was not traded off because the Viking '75 battery development proved that a NiCd battery would satisfy this application. However, consideration was given to eliminating the battery completely and using the RTG as the only energy source. Because the peak power required by the communication subsystem was larger than the largest RTG that could be considered for the rover, it was determined that a battery was required.

The primary tradeoff performed in the power subsystem related to approaches for minimizing the hardware required for power conditioning. These tradeoffs included the following considerations:

Power conversion and regulation in each component versus conversion and regulation in one component.

Power bus voltage level of 28 volts versus 15 volts.

Distribution of logic voltage directly from RTG versus performing conversion and regulation in a separate converter.

The power subsystem that resulted from the above tradeoffs and one that would support the remainder of the selected baseline rover was a subsystem that contains a 20 watt (EOL), 5 volt RTG; an 8 A-h, 15-volt NiCd battery, and a Power Control Unit to provide centralized power conditioning and voltage regulation.

Functional Description

After selecting a baseline concept, detailed functional requirements for the power subsystem were derived. These requirements are listed below:

Power system capability. - Must be adequate to ensure flexible Mars surface operation including up to eight hours mobility per day.

Provide a battery for energy storage for peak loads. - To exceed the conditioned output of the RTG. The battery will be flown discharged and recharged by the rover RTG before use.

Utilize one Government-furnished RTG. - To generate 20 watts (EOL) at 5 volts and condition this power for use by the rover subsystems including battery charging.

Provide power conditioning that will: - Boost RTG output to a 15-volt equipment bus and a set of regulated voltages to within ±10%; charge battery when required and dissipate excess battery energy when required; and under control of the Control Sequencer switch rover loads on and off as required using a discrete signal interface.

Power equipment. - Provide power to motors, solenoids, and pyrotechnic drive circuits.

Analyses

Analyses of voltage requirements and operating modes were performed to arrive at a subsystem with the capability to satisfy preceding requirements.

Equipment bus. - The electrical bus connecting the output of the Power Control Unit and the battery is called the equipment bus. This bus supplies voltage through switches. The voltage on the bus will be regulated by the battery characteristics and charge level as a function of loads.

Direct current voltage is +13 to +18V excluding noise and ripple at the equipment input terminals. The minimum voltage will occur when the battery is providing maximum current (8A) to the bus through a diode with a maximum of 0.5 volts line drop to the equipment.

The nominal operating voltage will be 15 volts when discharging. The maximum operating voltage will occur when the battery is fully charged in the system and has excessive energy being dissipated through the shunt regulator.

Transients will not cause the equipment input voltage to be less than 10 volts or greater than 20 volts for a period greater than 5 msecs. Transients may occur due to load changes during system operations.

The equipment bus voltage will change as a function of load changes because the output of the battery is not regulated.

Unregulated 15 volts is provided to the user equipment. The power will be wired directly or switched by the PCU as shown below:

Direct	Switched
Power Control Unit	Camera Motors
X-ray Diffractometer	Camera Duster
Hole Detector	Sample Motor (2W)
Gyro	Grinder Motor (20W)
UHF Transmitter	Mobile Drive System

Regulated Voltages

The power system will provide regulated voltages to the rover equipment. An arbitrary set of voltages has been selected for sizing the system. A centralized regulated voltage system has been selected to minimize weight, volume, and optimize power use. The regulated 5 volts is obtained by regulating the RTG output to 5 volts. This voltage will be provided to user equipment directly where applicable. The following voltages will be distributed:

Regulated +5 volts ±10% and ±10V at the user equipment including noise and ripple. The following equipment will be supplied, the +5 volts either switched or direct as designated.

Direct	Switched
Data Processor	Camera
Control Sequencer and Memory	X-ray Diffractometer
PCU	Hole Detector
UHF Receiver	UHF Transmitter

Other voltages, regulated at plus or minus ±10% will be provided to the following equipment:

Direct	Switched
Camera	Alpha Backscatter Spectrometer
X-ray Diffractometer	Gyro
Hole Detector	
UHF Receiver and Decoder	
UHF Transmitter	
Control Sequencer	

Operating Modes

Operating modes are defined as standby, mobile, imagery and store, communications, communications-command, and science.

Standby mode. - Standby power includes the critical loads as well as the normal losses associated with power conditioning (converter losses and power supply losses with no load). The battery will normally be charged during this operating mode. Power, for all loads, shown in other operating modes is a delta to the standby power.

LOAD	POWER FOR EACH VOLTAGE (WATTS)				TOTAL MODE POWER (WATTS)
	+15V	+5V	+10V	-10V	
UHF Receiver		1.0			
Control Sequencer		0.5			
Data Processor		0.5			
Power Control Unit	0.5	0.5			
SUBTOTAL	0.5	2.5			3.0

Mobile mode. -

LOAD	POWER FOR EACH VOLTAGE (WATTS)				TOTAL MODE POWER (WATTS)
	+15V	+5V	+10V	-10V	
Drive System	6.5				
PCU	1.0	1.0	0.5	0.5	
Control Sequencer		1.5	-	0.5	
Data Processor & Memory		2.0	0.5	0.7	
Hole Detector	1.0	0.5	0.25	0.25	
Gyro	2.0		0.5	0.5	
SUBTOTAL	10.5	5.0	1.75	2.45	
LOSSES (Regulator)	-	-	1.8		21.5

Imagery and store mode. -

LOAD	POWER FOR EACH VOLTAGE (WATTS)				TOTAL MODE POWER (WATTS)
	+15V	+5V	+10V	-10V	
Camera Duster	Negligible				
Camera	10.0	3.0	1.0	1.0	
Control Sequencer		1.5	-	0.5	
Data Processor & Memory		2.0	0.5	0.7	
SUBTOTAL	10.0	6.5	1.5	2.2	
LOSSES (Regulator)	-	-	1.6		21.8

Rover/orbiter communications mode. -

LOAD	POWER FOR EACH VOLTAGE (WATTS)				TOTAL MODE POWER (WATTS)
	+15V	+5V	+10V	-10V	
UHF Receiver & Decoder		1.5	0.75	0.75	
UHF Transmitter	70/20	0.5	1.0	1.0	
Data Processor & Memory		2.0	0.5	0.7	
Control Sequencer		1.5	-	0.5	
PCU	1	1.0	0.5	0.5	
SUBTOTAL	71/21	6.5	2.75	3.45	
LOSSES (Regulator)	-	-	2.65		86.4/36.4
WITH CAMERA	10.0	3.0	1.0	1.0	101.9
LOSSES (Regulator)			3.2		

Rover/orbiter communications-command mode. -

LOAD	POWER FOR EACH VOLTAGE (WATTS)				TOTAL MODE POWER (WATTS)
	+15V	+5V	+10V	-10V	
UHF Receiver & Decoder		1.5	0.75	0.75	
Data Processor & Memory		2.0	0.5	0.7	
Control Sequencer		1.5	-	0.5	
PCU	1.0	1.0	0.5	0.5	
SUBTOTAL	1.0	6.0	1.75	2.45	
LOSSES (Regulator)			1.8		13.0

Science modes. -

LOAD	POWER FOR EACH VOLTAGE (WATTS)				TOTAL MODE POWER (WATTS)
	+15V	+5V	+10V	-10V	
Control Sequencer	-	1.5	-	0.5	
Data Processor & Memory	-	2.0	0.5	0.7	
PCU	1.0	1.0	0.5	0.5	
With X-Ray Diffractometer & Store	28.0	1.0	0.5	0.5	
SUBTOTAL	29.0	5.5	1.5	2.2	
LOSSES (Regulator)	-	-	1.6	-	39.8
With Grinder	20.0	-	-	-	
SUBTOTAL	21.0	4.5	1.0	1.7	29.3
LOSSES (Regulator)	-	-	1.1	-	
With Sampler	2.0	-	-	-	11.3
With Alpha backscatter spectrometer	-	-	0.5	0.5	10.8

Operating Constraints

The batteries will be flown discharged and recharged after landing by using the rover RTG. The sequence must be such that battery energy is not required until battery charging is complete (12 to 15 hr).

The rover power system will not be operating from prelaunch through landing. The RTG will be shorted and no rover battery energy will be used.

The RTG and rover battery may be used for rover system checkout after completing battery charging. The RTG will remain unshorted after lander/rover separation and power transfer. The rover will not have the capability to reapply the RTG short after separation.

The only active power interface from the lander will be the signal to activate the RTG. After launch all operations must be accomplished during rover internal power. This implies that no rover checkout capability exists between launch and landing.

The converter and regulator efficiencies will vary as a function of temperature, bus voltage, and rate of battery charging. The converter efficiency for average operating conditions will be 82% (based on using existing Viking '75 design approach and a 5 volt minimum input from the RTG to converter). The PCU regulator efficiency (±10 volt) will vary significantly as a function of load. The +5 volt system has no regulator losses because the loads are connected directly to the RTG output (regulated input to the converter). The average regulator efficiency is assumed to be 70% for purpose of analysis.

The maximum available energy from the battery will be based on the following criteria:

The depth of discharge for any one cycle will not exceed 75% (90 Wh) of the rated capacity of the NiCd battery.

The nominal depth of discharge on repetitive days will not exceed 50% (60 Wh) of the rated NiCd battery.

The battery will not be required to accept a charge when the charge rate is less than C/30 (4 W). The average charge rate should be greater than C/20 (6 W).

The rover power system will be capable of supplying peak loads of 120 watts when the battery capacity is greater than 50% rated capacity.

The loads on the regulated bus will be constrained to a maximum value not to exceed the power supply capability.

System Power and Energy Available

Battery energy storage is 120 Wh based on use of twelve (8 A-h) cells with an average discharge of 15 volts. (Usable energy is limited by the constraints specified herein.)

An undervoltage sensor on the equipment bus that initiates off-switching of non-critical loads and provides a status signal to the command control sequencer will be used to avoid any failure that would result in a battery cell reversal and compromise normal system operation.

In addition, charge control logic to prevent continued charging of an overtemperature battery is provided. This logic will sense the condition and disable the battery from charging. This system implementation is necessary due to the passive thermal design that could not prevent battery overtemperature from occurring if the battery were fully charged and the excess energy were being dissipated as heat within the battery. Use of the 8 A-h and a 15-volt system results in a more effective power-to mass ratio than would a smaller cell designed specifically for the rover requirements that would support a higher voltage system.

The battery sizing considered the following criteria:

Available hardware (Viking '75)
Energy Storage required for typical surface operation
  - Science
  - Mobile Operation
Average energy available for battery charging (C/20 minimum charge rate desirable to assure recharge and support cycle requirements).

The minimum RTG output is 20 watts at the end of mission, resulting in approximately 15.5 watts usable energy based on 1.0 watt line loss and converter efficiency at 82% if all of the load were supplied directly to the bus. The net system efficiency is greater because part of the loads will be connected directly to the 5 volt RTG output.

Note

> The converter efficiency is based on Viking '75 experience and design concepts. It is expected that this is a minimum efficiency and detailed analysis and design evaluation would be performed to establish improvements that could be made.

The maximum RTG output is not expected to be significantly higher than the 20 W projected EOL due to the proposed design approach for the RTG. The RTG converter will be designed to be compatible with the maximum capability.

Configuration

The functional requirements will be met by the Power Control Unit (PCU), one 20 watt (EOL) RTG and one 120 Wh (8 A-h) NiCd battery. This equipment will be functionally interconnected as shown in Figure 55.

Interfaces. - The power system major interfaces (internal and external) are shown on Figure 55. These interfaces are signal or power.

Signal interfaces are provided from the lander for initiation of system operation. Rover operations are controlled by signals provided by the Control Sequencer. One signal is provided to the Control Sequencer [illegible] detecting an under-voltage condition.

The power system will provide the following data to the data processor.

Bus Current
Battery Charge and Discharge Current
Bus Voltage
Regulated Voltages
RTG Voltage

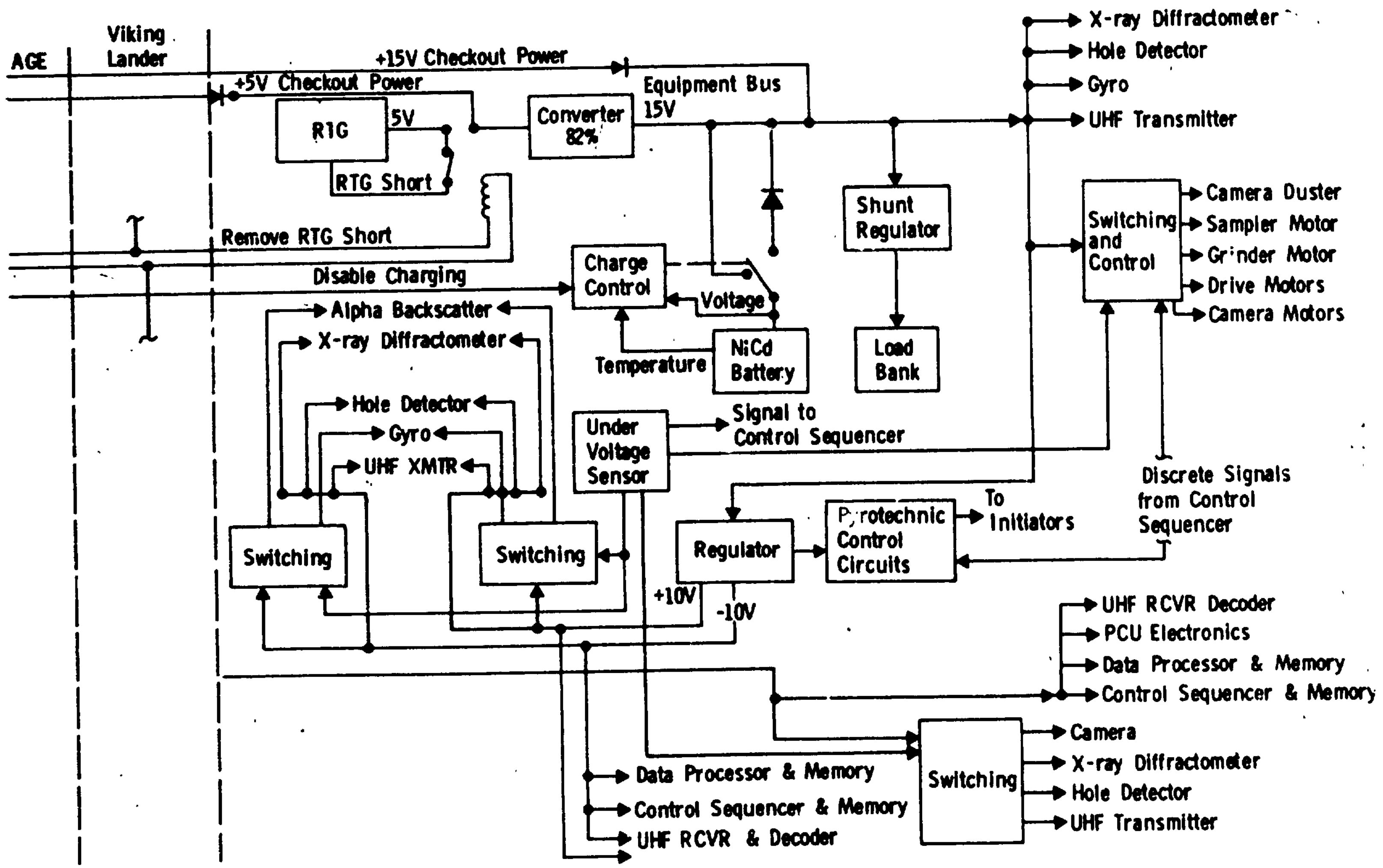


FIGURE 55 POWER SYSTEM BLOCK DIAGRAM

Battery Temperature

Battery Voltage

Charge Control Status (ON/OFF)

External power will be provided through the lander interface for ground system checkout. This will include 15 volts to the equipment bus and +5V to the converter input. Two signals will be provided, Disable Battery Charging and Remove RTG Short.

Power system masses. - The power system masses are allocated as shown below. The masses are based on the subsystem description defined herein and assume the following ground rules:

Battery - The battery cell (8 A-h) will use the existing Viking '75 cell design of 12 cells and will be packaged as a component.

Power Control Unit (PCU) - The PCU will not be a self-contained assembly and therefore does not include packaging structure mass for the integrated package. It includes parts, circuit boards, shielding and wiring interconnection within PCU interfaces.

Load Bank - Load bank will be mounted external to the rover; the mass is included in the battery mass.

Summary of Mass

Battery	6.8 kg	(15.0 lb)
PCJ	3.2 kg	(7.0 lb)
RTG	5.4 kg	(12.0 lb)
Total	15.4 kg	(34.0 lb)

6.4 THERMAL CONTROL ANALYSES AND TRADE STUDIES

Thermal control for the '79 Mars mission involves control of the rover and the lander. The rover, as an original concept, is designed to survive and operate anywhere on Mars. The lander is assumed to be the '75 lander with minimum design changes to permit the lander to survive in environments that will be thermally more severe than the '75 environments.

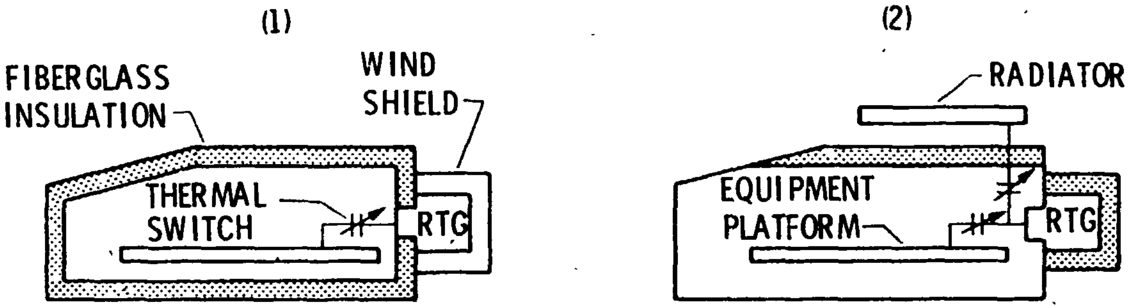
Rover Thermal Control Requirements and Constraints

Mission guidelines established for the rover thermal design are (1) the rover must operate anywhere on Mars, and (2) '75 Viking technology must be used wherever possible.

Thermal constraints imposed on the rover design are (1) if possible all temperature-sensitive equipment should be contained in one thermal compartment; (2) the thermally controlled components are to be mounted on an efficient thermal plate (the thermal plate is used to distribute the RTG heat to the various components), and (3) science sensors that must be external to the main thermal control compartment are to be clustered together as much as practical.

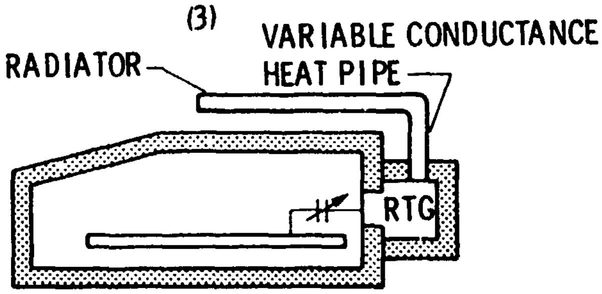
Rover Thermal Control Design Tradeoffs

Several alternate rover thermal control schemes as shown in Figure 56 are (1) the baseline rover thermal control system as described in a later paragraph, (2) a system that dumps the excess RTG heat to an external radiator via a double-acting thermal switch, (3) a system that dumps the excess RTG heat to an external radiator via controllable heat pipes, and (4) an active pumped-fluid loop system. Item (4) would present the most positive method of controlling all components of the rover (including the camera), but would involve considerably more development of the thermal control fluid loop elements. The thermal design that was chosen as the baseline [Item (1)] was the one that will provide adequate rover thermal control, and yet will be a mostly passive system.



THERMAL SWITCH WITH RTG WIND SHIELD

DOUBLE ACTING THERMAL SWITCH



THERMAL SWITCH WITH RTG COUPLED TO RADIATOR VIA VARIABLE CONDUCTANCE HEAT PIPE

PUMPED FLUID SYSTEM

FIGURE 56 ROVER THERMAL DESIGN APPROACHES

Rover RTG. - The RTGs to be used for the '79 Mars mission (including the lander RTGs) are to be designed as a total energy source (electrical and thermal). New thermocouple materials (selenides) are proposed that will operate at higher temperatures than the '75 RTG thermocouples (lead/telluride). The higher operating temperature allows a higher thermal interface (RTG-to-thermal switch) temperature, causing more heat to be available for input into the rover (and lander) thermally controlled compartment. This greater heat flow in turn allows the rover insulation to be thinner. The RTG will also require a smaller windshield for Mars surface operation, due to the higher operating temperatures (radiation heat transfer is more efficient at higher temperatures). The windshield is required to prevent the RTG from cooling too much in the cold case. The smaller windshield could be built as an integral part of the RTG. A prelaunch cooling loop will be required for the RTG, which could also be designed as an integral part of the RTG.

Final rover thermal design. - The final rover thermal design is as shown in Figure 57. Those components that cannot survive the Mars environments, and do not by operational necessity have to be located external to the rover are located in a thermally controlled compartment. The RTG carried by the rover for electrical power is also used as thermal energy. A thermal switch controls the flow of heat from the RTG to the rover thermally controlled compartment. The thermal compartment is insulated with one inch of low density fiberglass insulation to minimize the thermal compartment heat loss. The RTG heat is distributed internally to the thermal compartment by a heat pipe equipment mounting plate (isothermal plate).

Components to be thermally controlled are mounted to the isothermal plate. The performance of the rover thermal control system is shown in Figure 58, with the design point at 2.54 cm (1 inch) of insulation. The thermal control range for the thermal compartment is determined by the battery's operational temperature range (272°K to 311°K (+30°F to +100°F)). See Table 26.

For the most part, thermal control components are '75 Viking technology (i.e., use of RTG heat, thermal switches, and fiberglass insulation). The isothermal plate is not '75 technology, but is an extrapolation of existing heat pipe technology. The isothermal plate is required for efficient distribution of RTG heat because the RTG heat is input to the end of the mounting

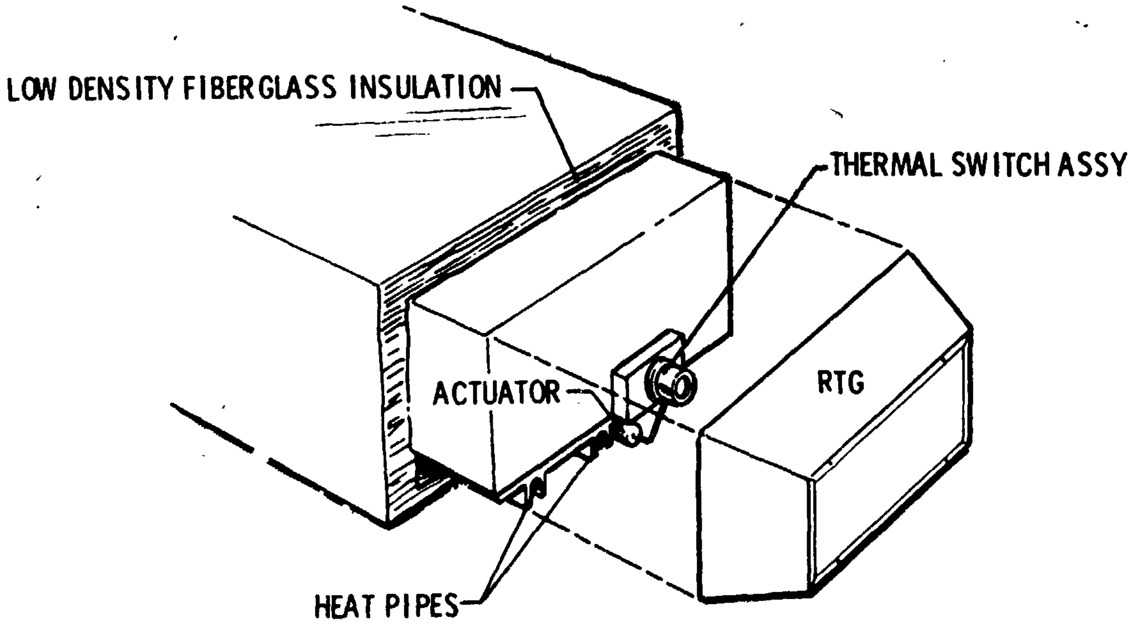
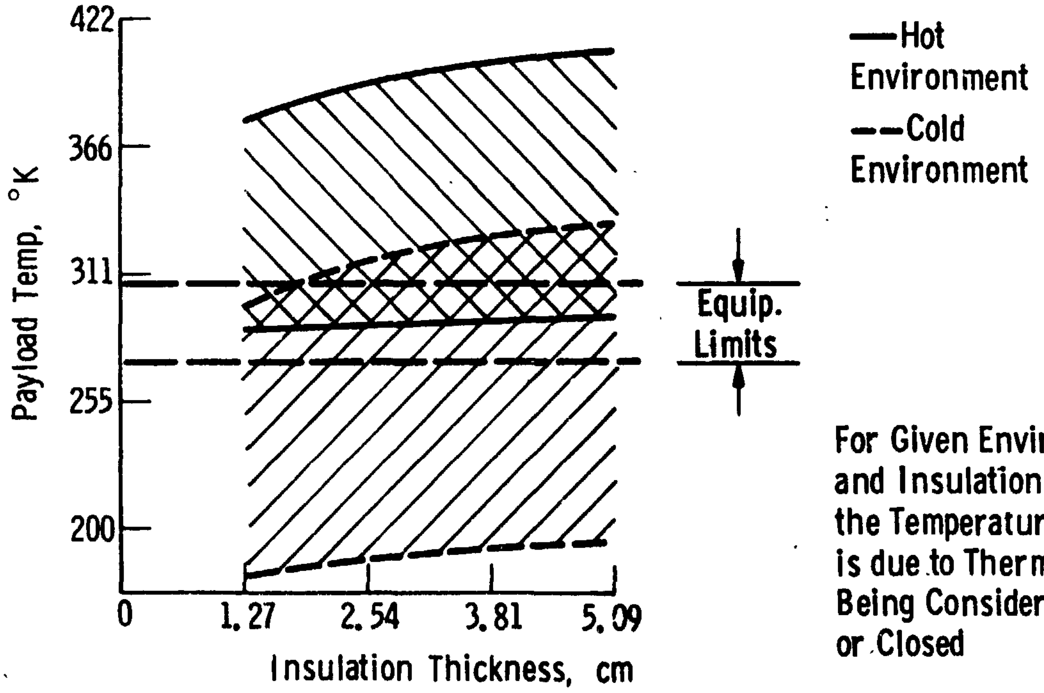


FIGURE 57 BASELINE THERMAL DESIGN



For Given Environment and Insulation Thickness the Temperature variation is due to Thermal Switch Being Considered Open or Closed

FIGURE 58 ROVER THERMAL PERFORMANCE

TABLE 26 ROVER COMPONENT DESIGN TEMPERATURE RANGES

I.	**Components External to Rover**		
	RTG with windshield	147 to 333°K	(-195 to +140°F)
	Camera deployment mechanism		
	Camera duster		
	Drive system		
	Wire harness		
	UHF antenna		
	Antenna deployment mechanism		
	Soil sampler		
	Wind detector		
	Hole detector		
	Odometers		
	Bumper switches		
	Roll articulation angle sensor		
II.	**Main Thermal Control Compartment Components**		
	Battery	272 to 311°K	(+30 to +100°F)
	Power and drive control	241 to 325°K	(-25 to +125°F)
	Data Processor	241 to 325°K	(-25 to +125°F)
	Data Processor memory	264 to 325°K	(+15 to +125°F)
	UHF receiver	247 to 325°K	(-15 to +125°F)
	UHF transmitter	247 to 325°K	(-15 to +125°F)
	Diplexer	241 to 325°K	(-25 to +125°F)
	Control Sequence and memory	241 to 325°K	(-25 to +125°F)
	Gyro	255 to 325°K	(0 to +125°F)
	Inclinometer	255 to 311°K	(0 to +100°F)
	Science electronics	241 to 325°K	(-25 to +125°F)
III.	**Science Sensor Thermal Control Compartment**		
	X-ray Diffractometer	225 to 325°K	(-55 to +125°F)
	Alpha Backscatter	225 to 325°K	(-55 to +125°F)

plate instead of near the center (as in the lander design), and a large temperature gradient could exist in the mounting plate, with those components farthest from the RTG receiving little heat. The isothermal plate also aids in reducing potential hot spots, which could be caused by a component producing a large amount of heat during a short period of time. The isothermal plate would quickly remove the heat toward a cooler part of the plate.

The rover science sensors are to be located in a separate thermally controlled compartment, forward of the main thermal compartment. (The bulk of the science electronics is located in the main thermal compartment.) The science sensors are separated from the rest of the thermally controlled components because the sensors will require so many penetrations as to cause a severe thermal leak if housed in the main thermally controlled compartment. The science sensors can, in general, operate at colder [225°K (-55°F)] and hotter [325°K (+125°F)] environments. The forward compartment will be insulated, as much as possible, and heated by conductively leaking heat from the main thermal control compartment.

Of the science sensors, the rover camera is a special thermal problem, as it must be exposed to the environment away from the rover body for optimum operation. There also is a stowage problem for the camera for it must be deployed by rotation around a hinge after the rover deployment, and there is no convenient (and reliable) method of pumping heat to the camera around the hinge. The camera would be effectively thermally controlled with thermostatically controlled electrical heaters, but this method has been ruled out due to the extreme shortage of electrical energy for the rover. In lieu of electrical heaters, a scheme is proposed where radioisotope heater units (RHUs) are placed on a platform at the location where the camera will be deployed. After camera deployment, the RHUs would then be in contact with the camera, and will conduct and radiate heat to the camera. This configuration would also prevent the camera from getting too hot during the trans-Mars mission phase. The thermal power required from the RHU would be approximately 5 watts.

<u>Prelaunch through Mars landing Environments</u>. - The rover must not only survive the Mars surface environments, but must survive all mission environments from prelaunch through Mars landing. These include (1) sterilization,

in which the rover must survive a minimum of three, 40-hour cycles of hot nitrogen gas soak at 386°K (236°F), (2) a 10-month, trans-Mars cruise vacuum soak at 241°K (-25°F) to 325°K (+125°F), and (3) the earth launch and the Mars entry transients. Preliminary analysis shows that these transient environments do not present unsurmountable thermal problems.

Of special concern is the trans-Mars cruise mission phase. The present lander ('75 mission) is running warm during the cruise phase. The addition of a rover (into the VLC) with its own RTG increases the heat load in the VLC and may cause the lander internal temperatures to exceed acceptable levels. It has been determined that if the additional heat input into the VLC from the rover RTG is below 100 watts, then the effect on the lander will be minimal (see Table 27). The remainder of the rover RTG heat must be rejected to space. For a 300 to 400 thermal watt RTG, operating at 477°K (400°F) cold junction (case) temperature, the excess heat may be driven through the base cover as shown in Figure 59. The rover RTG is enclosed by a reflective, reradiating, surface (insulated on the outside) to drive the RTG radiated heat through the base cover. The base cover would be locally painted IR black to aid in radiation heat transfer.

Thermal considerations for other rover configurations. - Thermal control problems for the other rover configurations considered:

Early proposal configurations (C1/D1 through C4/D4) presented essentially the same thermal problem, the major difference being the external area. These rovers were all rectangular box shapes. Enough heat is available from the proposed RTG to maintain thermal control for any of these configurations by varying the insulation thickness.

The L-shaped rover was proposed to maximize available volume inside the VLC. This shape presents no significant thermal problems over a rectangular box shape as commented on in the preceding paragraph.

For any rover design with an articulated chasis, with two or more compartments, the thermal control problem becomes extremely difficult.

TABLE 27 TRANS-MARS CRUISE THERMAL IMPACT ON LANDER OF ROVER RTG IN VLC

COMPONENT	TETM TEST DATA °K	ROVER RTG HEAT INTO VLC			
		150 W		300 W	
		ΔT* °K	TEMP.** °K	ΔT* °K	TEMP.** °K
BATTERIES 3 & 4	294 (+70°F)	3	297 (+75°F)	8	302 (+85°F)
TWTA 1	89 (+60°F)	3	291 (+65°F)	8	297 (+75°F)
GCMS	286 (+55°F)	5	291 (+65°F)	11	297 (+75°F)

*Temperature increase of component for rover RTG heat input

**Temperature of component for rover RTG heat input

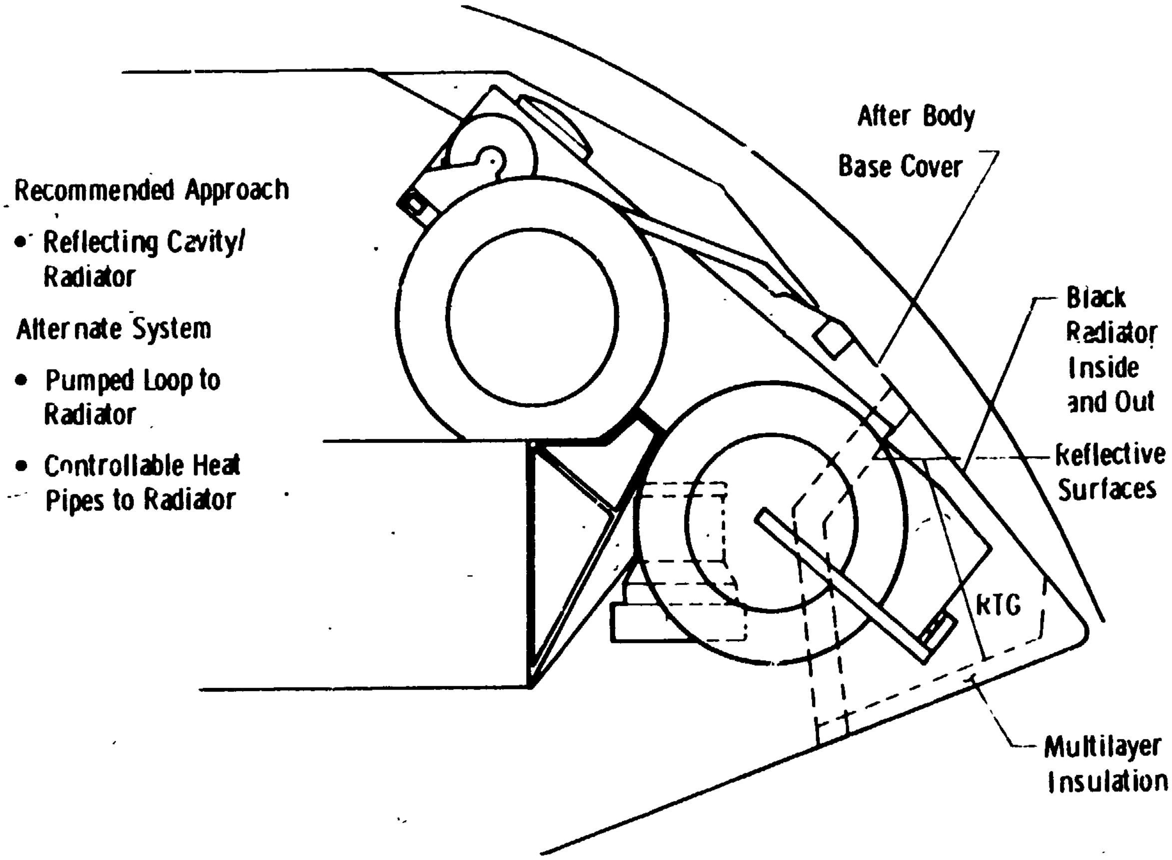


FIGURE 59 CRUISE THERMAL DESIGN

Lander Thermal Control

A major objective of the '79 mission, as defined in this report, is to land the rover anywhere on Mars (excluding those areas that will have no sunlight during the mission). The thermal analysis for the lander, for this rover study, was therefore limited to (1) definition of the Mars surface geographical limits for the unchanged '75 lander, and (2) definition of minor fixes that could be made to allow the lander to survive the more severe '79 thermal environments.

Lander thermal control elements. - The lander thermal control system is composed of (1) an equipment mounting plate (EMP) that transfers heat from the RTG to the components mounted to the EMP (in practice large gradients may exist in the EMP because it is too thin to effectively distribute the available heat, and because of heat leaks at the EMP edge support points), (2) Radioisotope Thermoelectric Generators (RTG) that supply electrical power for lander operation and also provide heat into the lander EMP for thermal control, and (3) two thermal switches that control the flow of heat from the RTGs into the EMP, upon demand. The heat balance of the lander is completed by the loss of heat through insulation on all sides of the lander. This insulation has been sized to (1) maintain internal (EMP mounted components) lander thermal control during the cold case by keeping the insulation heat loss to a minimum, and (2) allow the rejection of enough heat through the insulation, during the hot case, to prevent overheating of the lander internal components.

Lander '75 thermal limitations for the '79 Mars mission. - The '79 Mars mission environments are more severe than the '75 environments. Mars is approaching solar perihelion with the Northern Hemisphere getting colder and the Southern hemisphere approaching summer. See Figure 60. The '75 lander in the '79 mission can survive between +10 to +50 degrees Mars North latitude with no change to the thermal control and assuming present '75 design constraints.

The changes (in hardware and constraints) described in the following section will allow the lander to survive in more severe environments.

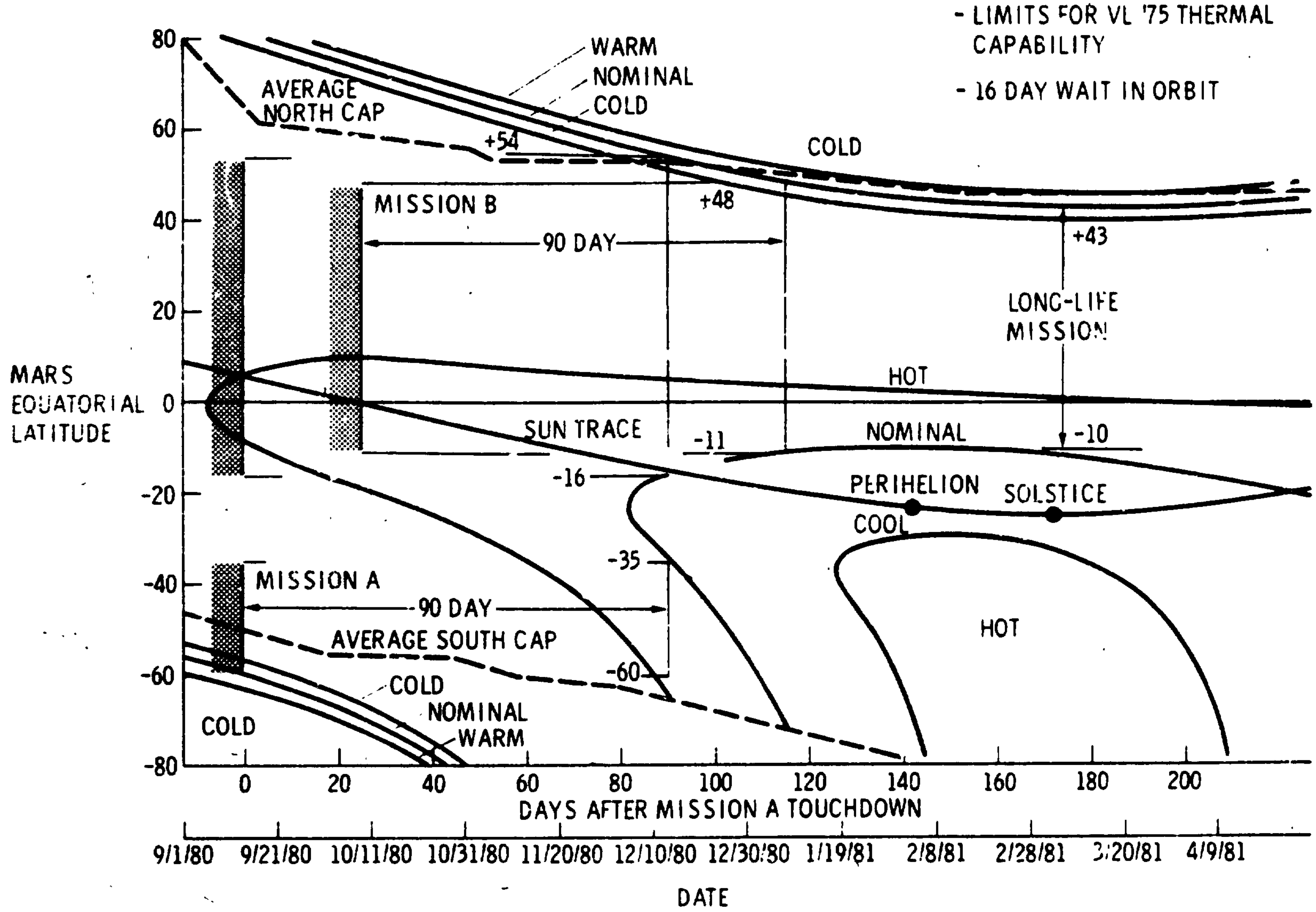


FIGURE 60 THERMAL ENVIRONMENT LIMITS

Lander-Mars Surface Performance

1979 Mars surface hot case. - For the 1979 Mars surface hot case, Table 28 presents the lander EMP component interface temperature changes, for going from the worst case 1975 lander design point in the 1979 environment (10 degrees North Mars latitude, at the beginning of mission) to the hottest 1979 environment (30 degrees South Mars latitude at the end of mission). The data of Table 28 represent the 1975 lander thermal control system with no changes. The average lander internal temperature will increase about 6°K (11°F) for the above latitude change. At the hottest '79 Mars mission site as defined in this report, with the '75 lander thermal design, there are no components that will exceed their qualification temperature limits. The biology instrument interface temperature, as shown in Table 28 indicates that the instrument qualification limit will be exceeded. The biology instrument thermal performance, however, is a complex transient situation and the increase in the peak interface temperature will primarily result in a power increase for thermoelectric cooling during the peak temperature period.

The Mars surface '79 mission hot case environment has been extrapolated from the Thermal Effects Test Model (TETM) test data (see Table 29). The temperature changes of the lander (external) side beams, as compared to the Mars soil temperature change, was used as the criteria for extrapolating the '79 Mars surface hot case conditions. The TETM test run No. 227 represents the anticipated '75 hot case. The TETM test run No. 223 was made with 170% solar flux to simulate a dust covered lander, but was found to be an overtest condition. Table 29 shows a TETM soil simulator temperature increase of 12°K (21°F) from run No. 227 to run No. 223. The lander side beams, as they will have approximately a 0.5 view factor to the soil, should really increase less than 1°K for each 1°K rise in soil temperature. There is, however, a 12°K (21°F) temperature rise for the side beam average temperatures from test run No. 227 to test run No. 223. There also is a 13°K (+23°F) temperature rise from the predicted test run No. 227 soil temperature (236°K (-34°F)) to the predicted '79 hot case average soil temperature (249°K (-12°F)).

TABLE 28 VIKING 1979 MARS SURFACE HOT ENVIRONMENT

Lander Internal Components Mounting Interface Temperature,

Component		Qualification Temperature Limit °K	°F	+10° MARS LATITUDE Peak °K	Min °K	0° LATITUDE Peak °K	Min °K	-10° LATITUDE Peak °K	Min °K	-20° LATITUDE Peak °K	Min °K	-30° MARS LATITUDE Peak °K	Min °K
BIOLOGY		308	+95	301	283	304	284	307	286	310	287	313	289
UHF		325	+125	304	286	305	287	306	289	297	290	308	291
BATTERY	1/2	311 317	+100 Charge +110 Discharge	302	291	304	292	307	293	309	294	312	295
BATTERY	3/4	311 317	+100 Charge +110 Discharge	304	291	306	292	307	294	309	295	311	296
MEA		325	+125	301	281	304	282	307	283	310	284	313	285
TWTA1		328	+130	307	281	307	282	309	283	310	284	311	285
SSCA		325	+125	299	277	382	279	305	280	308	282	311	283
GCMS		325	+125	299	276	302	278	305	280	309	281	312	283
XPNDR2		325	+125	296	279	299	280	301	281	304	282	307	283
XPNDR1		325	+125	296	279	299	280	301	281	304	282	307	283
.CDA		325	+125	296	283	299	284	301	285	304	286	307	287
T.R.		325	+125	299	279	301	280	304	281	307	282	310	283
SEA		325	+125	295	279	298	280	301	282	304	283	307	284
CCU		325	+125	296	281	299	282	301	283	303	284	305	285
MCA		325	+125	296	283	299	284	302	285	305	286	307	287
DAPU		325	+125	300	285	302	287	305	278	308	289	311	291
TWTA2		328	+130	307	281	308	282	309	283	311	283	312	285
GCSC		325	+125	298	283	301	284	303	286	305	287	308	289

NOTE: +10° MARS LATITUDE IS AT START OF 1979 MISSION
-30° MARS LATITUDE IS AT END OF 1979 MISSION

TABLE 29 VIKING 1979 MARS SURFACE PREDICTION/TEST CORRELATION FOR HOT CASE

CASE	SOIL TEMPERATURE (AVERAGE PREDICTED) °K	TEST SOIL SIMULATOR AVERAGE TEMPERATURE °K	TEST SIDE BEAM AVERAGE TEMPERATURE °K
(1975) TETM Run No. 227 (100% Solar)	236 (-34°F)	242 (-24°F)	264 (+16°F)
(1975) TETM Run No. 223 (170% Solar)	-	254 (-3°F)	276 (+37°F)
(1979) Mars Surface Hot Case	249 (-12°F)	-	-

Additionally, the TETM test run No. 223 soil simulator average temperature (254°K (-3°F)) is warmer than the predicted '79 hot case average soil temperature (249°K (-12°F)). Therefore, it is assumed for the purpose of estimate for the '79 mission that the TETM test run No. 223 is close to, or exceeds somewhat, the hottest anticipated '79 environment. The TETM test run No. 223 data are then used for the '79 component predictions. Data for the "in-between" latitudes (between +10° and -30° Mars latitude) are linearly extrapolated from the end conditions.

As was mentioned earlier, none of the lander components will exceed their qualification temperature limits for the '79 hot case (see Table 28). The temperatures of Table 28 that were used for comparison to the component qualification limits are, furthermore, peak temperatures. If the mean temperatures were compared to the respective component qualification limits, there would be a large temperature margin for all components for the '79 hot case.

The batteries could possibly exceed their qualification limits only if charging were to occur during the hottest period of the day. (The battery qualification temperature limits are 317°K (110°F) for discharge, and 311°K (100°F) for charging.) For the '75 mission, the batteries are normally discharged during the daytime (hottest time) when most lander electrical activity is occurring, and the batteries are charged during the night when minimum activity is occurring, and environmental temperatures are lower. It is anticipated that the '79 mission power profile would be similar to the '75 mission profile. Assuming then that the batteries will not be charged during the day (qualification limit of 317°K (+110°F)), the batteries will have an adequate margin of safety during the peak temperature period. During the night, the batteries will be between 295°K (72°F) and 304°K (87°F), for the hottest '79 case, and assuming that the batteries are being charged (the charging qualification temperature limit is 311°K (+100°F)), the batteries will also have an adequate margin.

Based on the foregoing, there would appear to be no hardware changes required to the '75 lander thermal control system to allow it to perform in the '79 Mars hot environment; no component will exceed its qualification temperature limit.

For the cold case, Table 30 presents the component temperature prediction data. These data were generated by running the Viking '75 computer thermal model, modified to simulate a South Polar cap landing. As may be seen from Table 30 for the lander with no changes from the '75 system, several components (batteries) will come close to or exceed their qualification limits. With either the addition of a heat pipe system (to improve the thermal efficiency of the EMP), or the addition of new RTGs (with improved thermal capability of directing heat into the EMP), the lander performance is similar to the worst case '75 performance. The heat pipe addition could be an extensive rework of the '75 lander EMP and is therefore not proposed at this time. The new RTGs are considered, however, because they will improve the lander thermal performance to allow a '79 South Polar Cap mission, and the '75 Viking SNAP-19 units will probably not be available for the '79 mission. Table 30 shows the effect of removing lander camera No. 2 presently planned for the '79 mission. The overall lander temperature profile is not significantly altered by removal of camera No. 2, except for an increase in temperature of the EMP area from which camera No. 2 is presently supported.

If the new RTGs are installed for the '79 mission, and if camera No. 2 is removed, there does not, at this time, appear to be a thermal problem for the '75 lander operating at the South Polar Cap.

A potential cold case problem area, for the South Polar Cap landing, will be ice forming (CO_2 or water) on external gear (soil sampler, S-band antenna). This problem as yet has not been investigated in detail, and it would appear that a test program would be the most effective way of determining whether an icing problem does exist. Such a test program could be performed by Martin Marietta Corporation in its present Space Support Laboratory. If it is shown that icing could occur, electrical heaters and insulation would likely be required to prevent the ice from forming in moving parts.

Lander prelaunch through Mars landing Performance. - The '79 lander thermal control, in the VLC, during trans-Mars cruise will be similar to the '75 lander thermal control. A passive thermal control scheme will be employed, with the lander heat from the RTGs rejected through the base cover by means of thermal control coatings. The major changes to the VLC for the '79 mission

TABLE 30 VIKING 1979 MARS SURFACE COLD ENVIRONMENTS

Lander Internal Components Mounting Interface Temperatures													
				TETM Test Run 231		South Polar Cap Computer Run No Heat Pipe 1975 Lander RTGs		South Polar Cap Computer Run With Heat Pipe 1975 Lander RTGs		South Polar Cap Computer Run No Heat Pipes New RTGs		South Polar Cap Computer Run No Heat Pipes New RTGs Camera #2 Removed	
		Qualification Temperature Limit °K	°F	Minimum Temperature °K	°F	Minimum Temperature °K	°F	Minimum Temperature °K	°F	Minimum Temperature °K	°F	Minimum Temperature °K	°F
BIOLOGY		247	-15	257	+3	254	-3	270	+26	248	+13	263	+14
UHF		247	-15	273	+32	266	+19	269	+24	277	+40	278	+41
BATTERY	1/2	269	+25	287	+58	266	+19	270	+26	279	+43	283	+50
BATTERY	3/4	269	+25	286	+56	271	+28	270	+26	284	+52	285	+54
MEA		241	-25	266	+20	267	+21	271	+28	278	+41	277	+40
TWTA1		247	-15	263	+14	266	+20	271	+28	274	+34	276	+37
SSCA		241	-25	261	+10	247	-15	269	+25	256	+2	266	+20
GCMS		241	-25	255	0	255	-1	269	+25	264	+16	264	+16
XPNDR2		247	-15	261	+10	262	+13	270	+26	271	+28	272	+29
XPNDR1		247	-15	261	+10	262	+13	270	+26	271	+28	272	+29
PCDA		241	-25	267	+22	268	+23	273	+32	275	+35	276	+38
T.R.		266	+20	261	+10	277	+40	274	+33	281	+47	290	+62
SEA		241	-25	261	+10	264	+15	268	+23	274	+34	274	+34
CCU		247	-15	264	+15	266	+20	271	+28	274	+34	276	+37
MCA		247	-15	267	+22	266	+20	271	+28	274	+34	276	+37
DAPU		241	-25	275	+35	262	+13	271	+28	272	+29	272	+31
TWTA2		247	-15	264	+16	269	+25	272	+29	276	+38	279	+43
GCSC		241	-25	269	+24	264	+15	269	+25	274	+34	275	+35

will be the proposed addition of a Mars rover. The rover will be mounted to the lander science side, and will be carrying its own RTG. It is proposed that the heat from the rover RTG be radiated through the base cover in the vicinity of the rover RTG. Less than 100 watts is to be allowed into the VLC to minimize the thermal input on the lander. Table 27 shows the estimated effect of the rover RTG into the VLC on lander EMP temperatures. From this table it may be seen that if less than 150 watts is added to the VLC thermal balance that the lander interior (EMP) temperature would rise less than 3 to 6°K (5 to 10°F). Any VLC heat inputs greater than the 150 watt level would result in lander EMP temperature during cruise that will be higher than the components mounted to the EMP could survive.

The '79 Mars mission transient environments (launch and Mars entry) do not appear to be significant problems. The times involved are short, and the changes from the '75 VLC configuration are of small consequence for these transients.

Lander RTGs. - For the '79 Mars mission, it is anticipated that the SNAP-19 RTGs will not be available. Volume, mass, and power constraints force the development of a new RTG for the rover and the same technology may be employed for development of new lander RTGs. These new RTGs would be more efficient, both electrically and thermally, and the mass savings could be significant due to smaller windshields, and lighter mass.

The new RTGs will operate at higher case (cold junction) temperatures. This increased temperature will mean more heat will be available for the lander interior thermal control, allowing the lander to survive colder environments.

Lander science. - Several new experiments have been proposed for the '79 lander. In general, if the new experiments are self-contained with the lander with minimum external penetrations, there should not be any significant thermal problems. If an experiment has a special requirement (such as the constant cold temperature requirement for the biology instrument) then thermal control for that experiment may be difficult. If an experiment requires many penetrations to the lander, a thermal problem exists for the instrument, and the lander thermal balance may be affected. The particular requirements of two of the proposed experiment changes for 1979 are discussed below:

The '79 Mission Advanced Biology Experiment would have similar interfaces to the '75 biology experiment, and therefore the impact of substituting the new experiment on the lander thermal balance should be minimal. There are various biology experiments that have been proposed for the '79 mission, but the details of their operating and associated thermal control schemes are not complete or available at this time. An estimate of the effect of the '79 environments on the thermal control of an advanced biology experiment might be made, however, by considering the impact of the '79 environments on the present '75 biology instrument. For the hot case, the '79 environment will be warmer (approximately $6^{o}K$)) than the '75 hot environment; therefore, more power would be required to operate the '75 biology thermoelectrics in the '79 environment. For the '79 cold case, the lander EMP is predicted to be running at approximately the same temperature as the '75 cold conditions; therefore, no more heater power would be required for biology operations in the '79 cold case.

Lander Camera No. 2 will likely be removed if a rover is sent on the '79 mission. The rover would take up the lander exterior space now occupied by camera No. 2. If this camera is not included for the '79 mission, it will help the lander thermal control by decreasing the heat leak from the lander from the camera No. 2 EMP mounting.

6.5 COMMUNICATIONS

This Section summarizes the analysis and trades that were made in the selection of the communication subsystem configuration. Reference is made to previous studies that apply to a '79 mission and led directly to the development of the Viking '75 relay link (lander to orbiter to earth) communication subsystem configuration.

The rover communications link will relay science, navigation, and engineering data (telemetry data) from the rover to the lander or orbiter for subsequent relay to Earth. A direct S-band downlink was considered briefly, but was dropped because of the excessive weight, power, and complexity of such a system. A command link is also required to provide the rover with earth command information (command data). The primary study tradeoffs for these links were operating frequency, antenna types, modulation schemes, and power levels. These tradeoffs were evaluated with consideration given to existing Viking '75 communications links with the intention of minimizing lander and orbiter hardware changes, in addition to considering the allowable mass, volume, and power available on the rover. Another aspect of the Viking '79 mission, which impacted the overall communication system, was the landing site considerations. This did not impact the rover communications but is discussed briefly below.

As discussed in Section 5, the rover configurations considered were for a lander-dependent system and a lander-independent (orbiter-dependent) system. For these configurations, the following rover links were considered:

For transmitting telemetry data from the rover to the lander, a VHF system that uses a 1/4 wavelength whip antenna and a transmitter operating at 50 MHz was evaluated. To receive Earth commands an S-band system identical to the existing Viking '75 low gain antenna and receiver was considered. This rover link configuration was used on the lander-dependent configurations.

A UHF system using a turnstile antenna and a UHF transmitter was considered for transmitting telemetry data to the orbiter, and an S-band system using a low gain antenna and receiver was used for receiving Earth commands. This configuration was used on the orbiter dependent configurations.

Another approach using a UHF system on the rover that consisted of a turnstile antenna that operates in two directivity modes for transmission to either the orbiter or the lander at 405 MHz was evaluated. A UHF receiver using the same antenna was considered for the command system whereby Earth commands would be relayed to the rover via the orbiter. This link configuration was the preferred configuration at the Midterm Review and is the configuration that was used for the selected baseline rover.

The selected rover links are shown in Figure 61. This illustration also shows the links for the lander, orbiter, and Earth for the Viking '79 mission. The block diagram, together with the pertinent characteristics for the preferred Viking '79 communication system, is shown in Figure 62. These trades, which were performed to select a rover communication link, assumed landing sites in the Northern latitudes to a maximum Southern latitude of 60°.

Although it has no effect on the rover link, a communications system for a 60° South to 80° South latitude was evaluated. This link is shown in Figure 63. From a communications viewpoint, the primary problem, relative to landing site area was the fact that the lander S-band direct link could not be accessed for the full duration of the mission in this polar landing site. No further discussion is given to this link configuration in the remainder of this Section and is included here primarily to show that it was considered.

Orbiter-to-Martian Surface Links

A non-coherent UHF, wideband, FSK system was selected for the two-way communication links between orbiter and rover. The rationale for this selection is supported by a study performed for the Viking '75 mission by the Radio Corporation of America. This study included consideration of lander entry and landed environments and is documented in ref. 6. Other factors in this selection were consideration of the information to be gained during the Viking '75 mission regarding the performance of these systems in the actual Martian environment, together with the trades previously discussed.

C-3

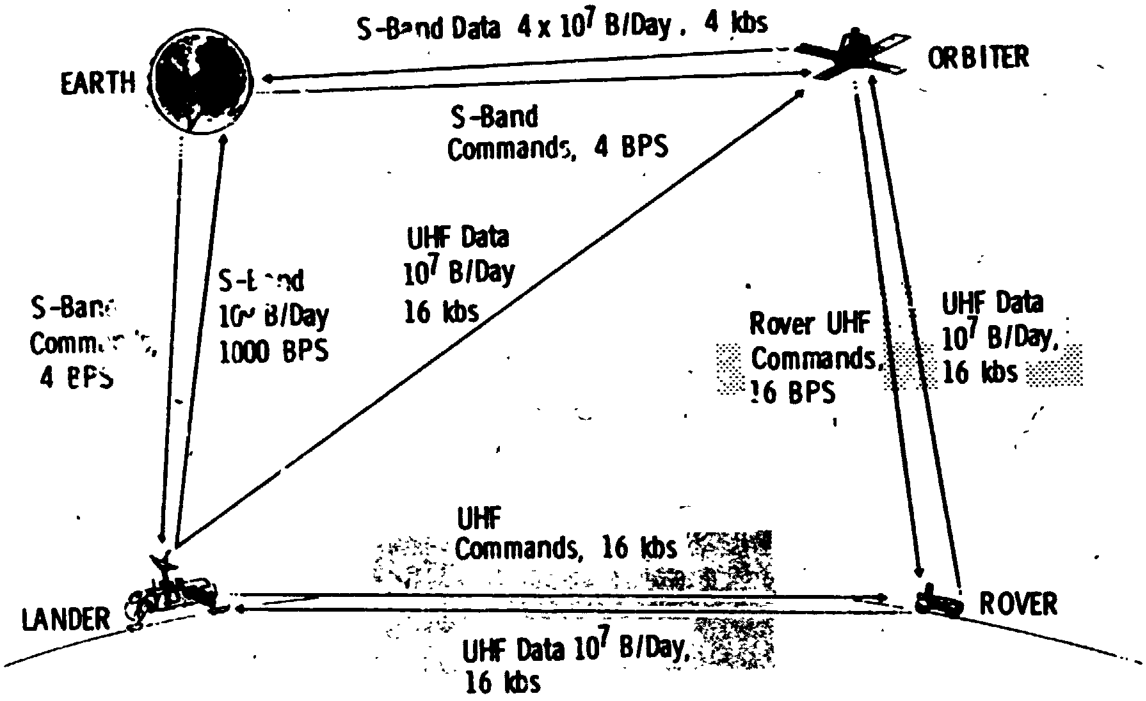
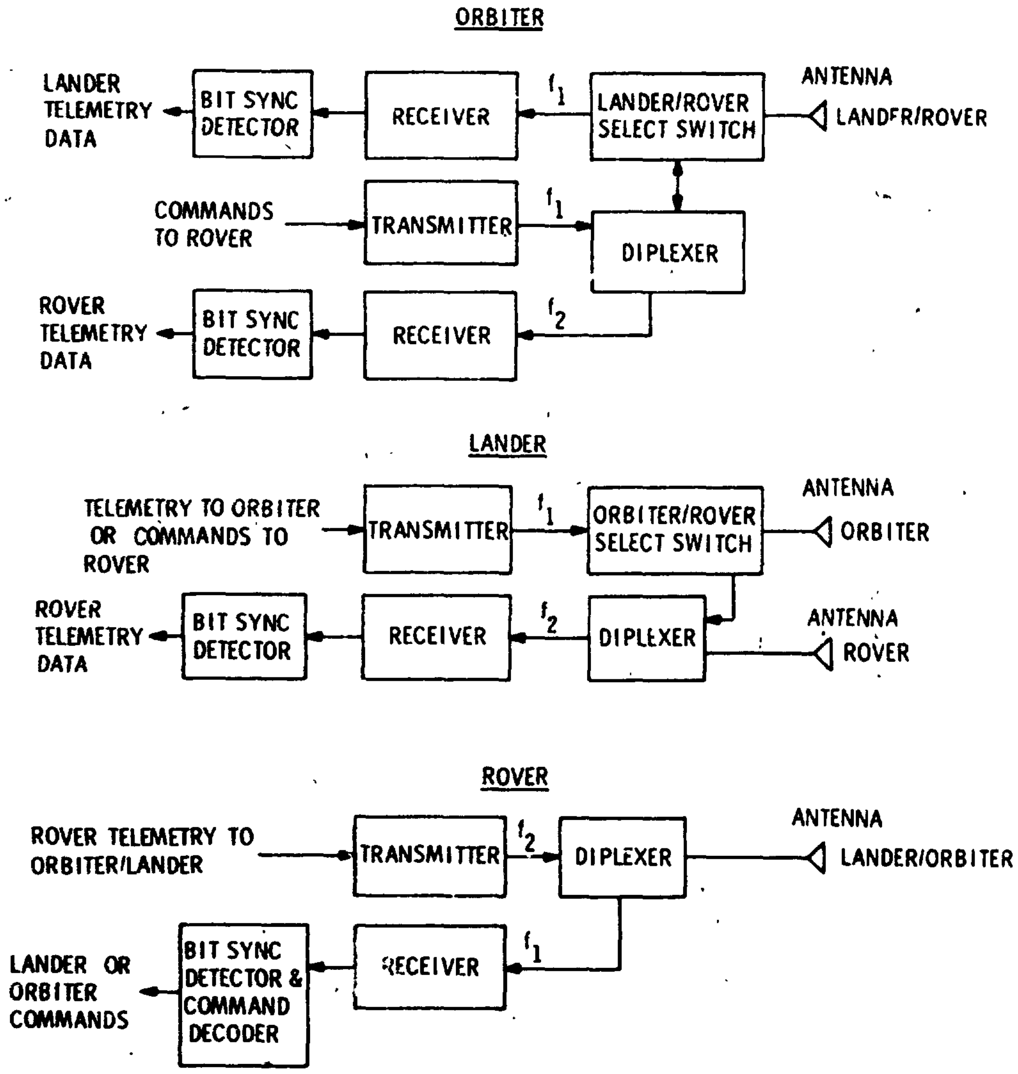
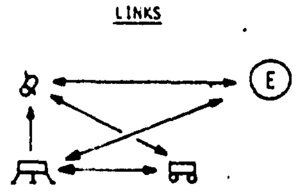


FIGURE 61 BASELINE VIKING '79 COMMUNICATION LINKS

NOTE: The UHF data quantity shown is the Viking '75 performance requirement. It is expected that the rover up-link will provide a data quantity of 2×10^7 B/Day.

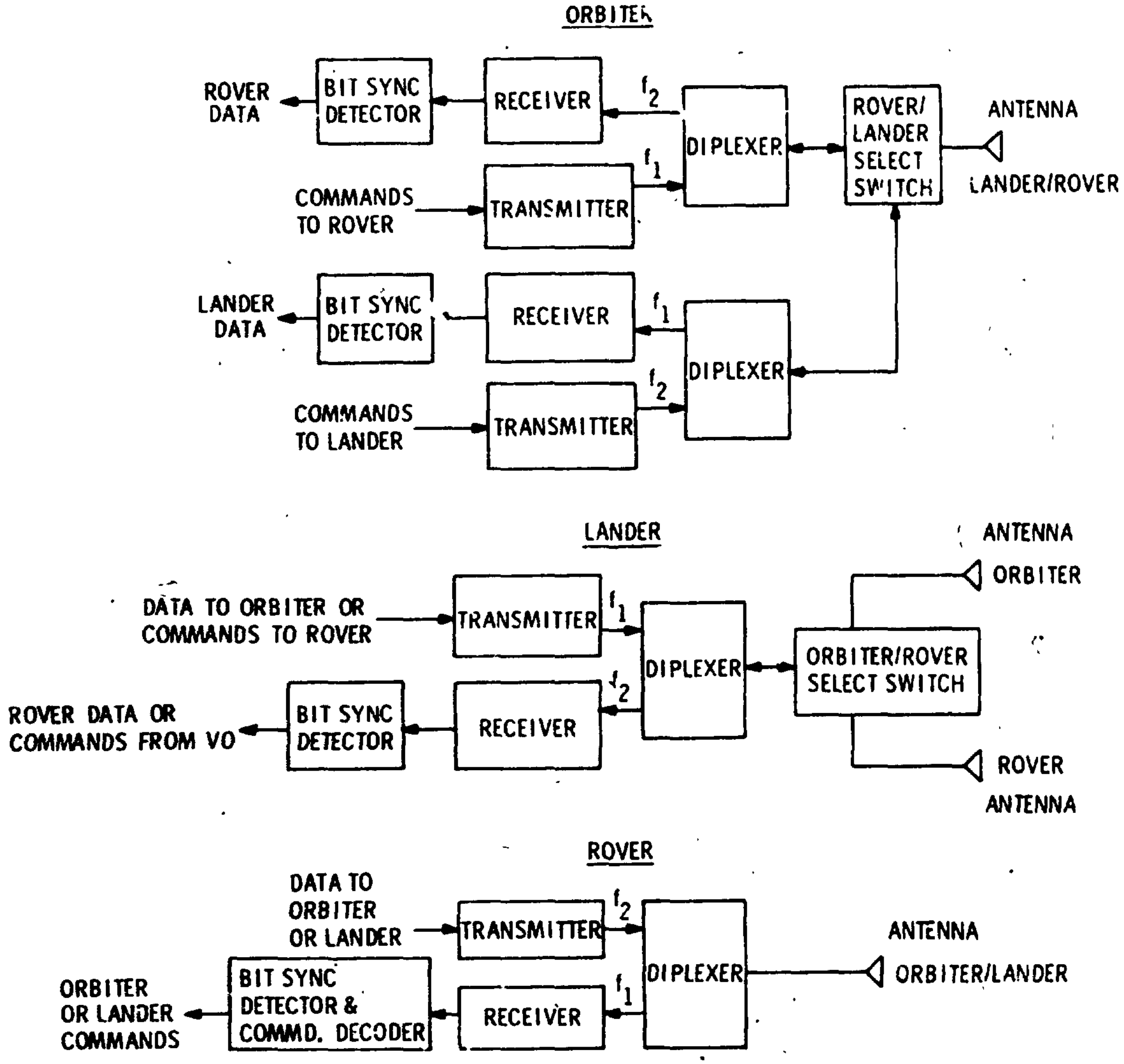


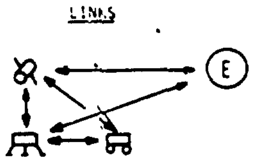


NOTES ON CONFIGURATION

1. Landing site - North latitude to 60° south latitude with rover
2. Add command and data link (UHF) orbiter to rover, and lander to rover.
3. f2 = 405 MHz; f1 = 381 MHz.
4. Command data rate orbiter to rover is 16 bps Telemetry data rates lander to orbiter are 4 Kbps and 16 Kbps and rover to orbiter are 16 Kbps, and lander/rover rate is 16 Kbps
5. Maximum command message is 450 bits, which includes 50 bits parity. Orbiter will use existing orbiter decoder and will verify, back to Earth, correct message receipt. Orbiter will store message. Orbiter will transmit a coded command to rover. Rover will use a Viking '76 decoder. Lander will code commands using the orbiter technique.
6. Orbiter antenna will be single position boresite.
7. Link duration - 25 minutes.
8. Either orbiter will service either rover
9. Lander S-band will remain unchanged.
10. Modulation will be FSK for both command and telemetry.

FIGURE 62 SELECTED VIKING '79 COMMUNICATION SYSTEM BLOCK DIAGRAM





NOTES ON CONFIGURATION

1. Landing site - North latitude to 60°-[illegible]° South latitude with rover.
2. Add orbiter to lander UHF co[illegible] and link, lander rover command and data link.
3. Add orbiter to rover command and telemetry data link.
4. f2 = 405 MHz; f1 = 381 MHz.
5. Telemetry data rates from either lander is 4 kbps or 16 kbps and 16 kbps from rover
6. Maximum command message is [illegible] 24-bit words for lander or 51 8-bit words for rover [illegible] lander coding and idle sequence requirements total bit requirement is 6870 bits for lander or 1000 bits for rover
7. Orbiter will use existing orbiter decoder and will verify, back to earth, correct message receipt. Orbiter will store coded message
8. Lander S-band system will remain unchanged Lander S-band decoder will be used to decode UHF commands. Rover will use decoder identical to lander for decoding UHF commands.
9. Either orbiter will service either pair of rovers or landers. Orbiter antenna will be a single position boresite.
10. Link duration - 25 minutes.
11. Command data rate shall be 16 bps.
12. Modulation will be FSK for both command and telemetry.
13. Simultaneous communication orbiter/lander and orbiter/rover not required.

FIGURE 63 COMMUNICATION SYSTEM BLOCK DIAGRAM FOR POLAR LANDINGS

The command and telemetry functions required for a '79 mission will be implemented around the Viking '75 relay link hardware. The radio frequency relay link hardware operates at a frequency of 381 MHz. The 381 MHz carrier will be diplexed with a second RF carrier at 405 MHz to implement the telemetry and command functions required for a '79 mission. The 405 MHz carrier frequency was selected to resolve isolation problems in the diplexer and radio equipment, and the bandwidth requirements on the antenna.

Lander-to-Rover Link

The same RF carrier frequencies as used in the orbiter/Mars links will be used for this link although the propagation characteristics will differ considerably. The rover-to-orbiter two-way link is expected to exhibit nearly free space characteristics, whereas the surface link will be influenced by the surface terrain separating the rover from the lander. Background noise was one factor in the choice of frequency for the rover/lander link. At 381 MHz, the principal contribution to noise is the receiver itself and a noise temperature of 1000°K is easily obtained. At lower frequencies, radiators in our galaxy become more important. At 50 MHz (about the lowest frequency for which it is practical to provide an efficient antenna) the galactic noise temperature is in the neighborhood of 10 000°K or 10 dB higher than what can be achieved at 381 MHz. This increase in noise at lower frequencies cancels much of the advantage that could be obtained from increased diffraction over terrain obstacles. The other factor in the choice of frequency is the common use of radio hardware required for the orbiter-to-surface links. Capability does not exist to simultaneously communicate from the Rover to both the lander and orbiter.

Configuration

As shown in Figure 62, the Viking '79 orbiter relay subsystem will be configured to support simultaneous command and telemetry functions with its rover. The same orbiter hardware could be configured to provide receive capability from its lander and rover simultaneously. Simultaneous transmit and receive capability is preferred for maximum use of the relay link window. Simultaneous transmit and receive for the VL and the rover, however, cannot be achieved.

Link Performance Predictions

The performance of the Viking '75 S-band direct command link from Earth together with estimates for the orbiter-to-rover link and the lander-to-rover surface link describe the performance capabilities of the selected '79 communication subsystem. These are described in the following paragraphs.

Lander Direct Command Link

The primary command mode to the lander from Earth is via the S-band low gain antenna (LGA). The opportunity for command is a function of the Deep Space Net transmitter and the installed LGA radiation characteristics. To support the command link, a gain of -10 dB or greater is required. This calculation is performed in Table 31 as the receive antenna gain less the antenna pointing loss.

Figure 64 was derived from measured radiation characteristics of the installed S-band LGA. That portion of the LGA radiation sphere with adequate gain to support the command link is identified. A typical Earth track from rise to set as seen at the lander from an extreme landing site latitude (near polar) is shown. The actual track is a function of landing site latitude, surface slope, and lander azimuth orientation. For the example shown, commanding the lander from Earth would be constrained for a short period of time following Earth rise.

Lander-to-Rover Link

Modeling of the Martian surface is the important factor in analyzing the performance of this link. The electrical properties of the soil as well as detail terrain features must be known. Performance estimates summarized here are based on a relatively simple model that assumes a flat, smooth surface with specular reflections and a relative dielectric constant of 3.2 for the soil.

The characteristics of the rover and lander antennas are described in Figures 65 and 66. The rover antenna has two pattern modes that are derived from the phasing at each turnstile element feed point. Directivity in the ver-

TABLE 31 DESIGN CONTROL TABLE - EARTH/LANDER COMMAND (LGA) (ESTABLISHES MINIMUM LANDER GAIN FOR LINK OPERATION AT Σ OF ADVERSE TOLERANCES)

PARAMETER			TOLERANCE	
Total Transmitter Power	(dBm)	+ 80.0*	+ 0.50	- 0.00
Transmitting Circuit Loss	(dB)	- 0.0	+ 0.00	- 0.00
Transmitting Antenna Gain	(dB)	+ 60.4	+ 0.70	- 0.70
Transmitting Antenna Pointing Loss	(dB)	- 0.03	+ 0.03	- 0.00
Space Loss: F=2115 MHz, R=380x10^6 km	(dB)	- 270.55	+ 0.00	- 0.00
Polarization Loss	(dB)	- 0.00	+ 0.00	- 0.00
Receiving Antenna Gain	(dB)	+ 4.0	+ 0.50	- 0.50
Receiving Antenna Pointing Loss	(dB)	- 13.87**	+ 13.87	- 0.00
Receiving Circuit Loss	(dB)	-1.30	+ 0.2	- 0.2
Net Circuit Loss	(dB)	- 221.35	+ 15.30	- 1.40
Total Received Power	(dBm)	- 141.35	+ 15.80	- 1.40
Receiver Noise Spectral Density Noise Temperature	(dBm/Hz) (°K)	- 167.99 1150.0	- 0.83 -200.0	+ 0.82 +240.0
Carrier Modulation Loss	(dB)	- 2.50	+ 0.20	- 0.20
Received Carrier Power	(dBm)	- 143.85	+ 16.00	- 1.60
Carrier APC Noise BW 2 B_{Lo} = 18 ± 2 Hz	(dB·Hz)	+ 12.55	- 0.51	+ 0.46
Carrier SNR in 2 B_{Lo}	(dB)	+ 11.59	+ 17.34	- 2.88
Carrier Threshold SNR in 2 B_{Lo}	(dB)	+ 8.65	- 0.00	+ 0.00
Threshold Carrier Power	(dBm)	- 146.79	- 1.34	+ 1.28
Performance Margin	(dB)	+ 2.94	+ 17.34	- 2.88
DATA CHANNEL				
Subcarrier Modulation Loss	(dB)	- 4.00	+ 0.20	- 0.20
Waveform Distortion Loss	(dB)	- 0.00	+ 0.00	- 0.00
Loss Through Radio System	(dB)	- 1.50	+ 0.20	- 0.20
Subcarrier Demodulation Loss	(dB)	- 0.00	+ 0.00	- 0.00

* 100 K Watts

** Includes Polarization loss

TABLE 31 DATA CHANNEL (continued)

PARAMETER			TOLERANCE	
Bit Sync Detection Loss	(dB)	- 0.00	+ 0.00	- 0.00
Received Data Power	(dBm)	-146.85	+ 16.20	- 1.80
Symbol Rate (4 Sym/Sec)	(dB)	+ 6.02	+ 0.00	- 0.00
Received ST_{Sym}/N_o	(dB)	+ 15.12	+ 17.03	- 2.62
Required ST_{Sym}/N_o	(dB)	+ 11.50	- 1.00	+ 1.00
1×10^{-5} Error Rate				
Threshold Subcarrier Power	(dBm)	-150.47	- 1.83	+ 1.82
Performance Margin	(dB)	+ 3.62	+ 18.03	- 3.62

- 64 Meter DSN Antenna
- Viking 75 Low Gain Command Antenna Installed Characteristics
- Lander Command Window Open in Region Outside Shaded Contour

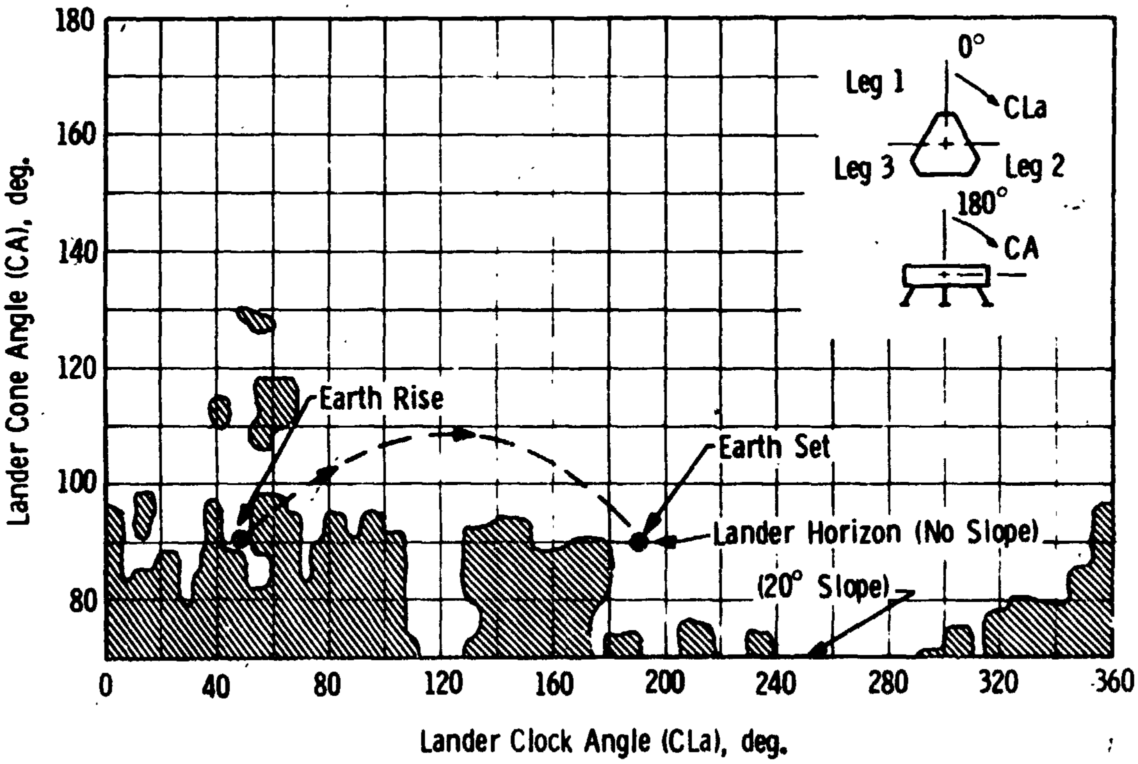
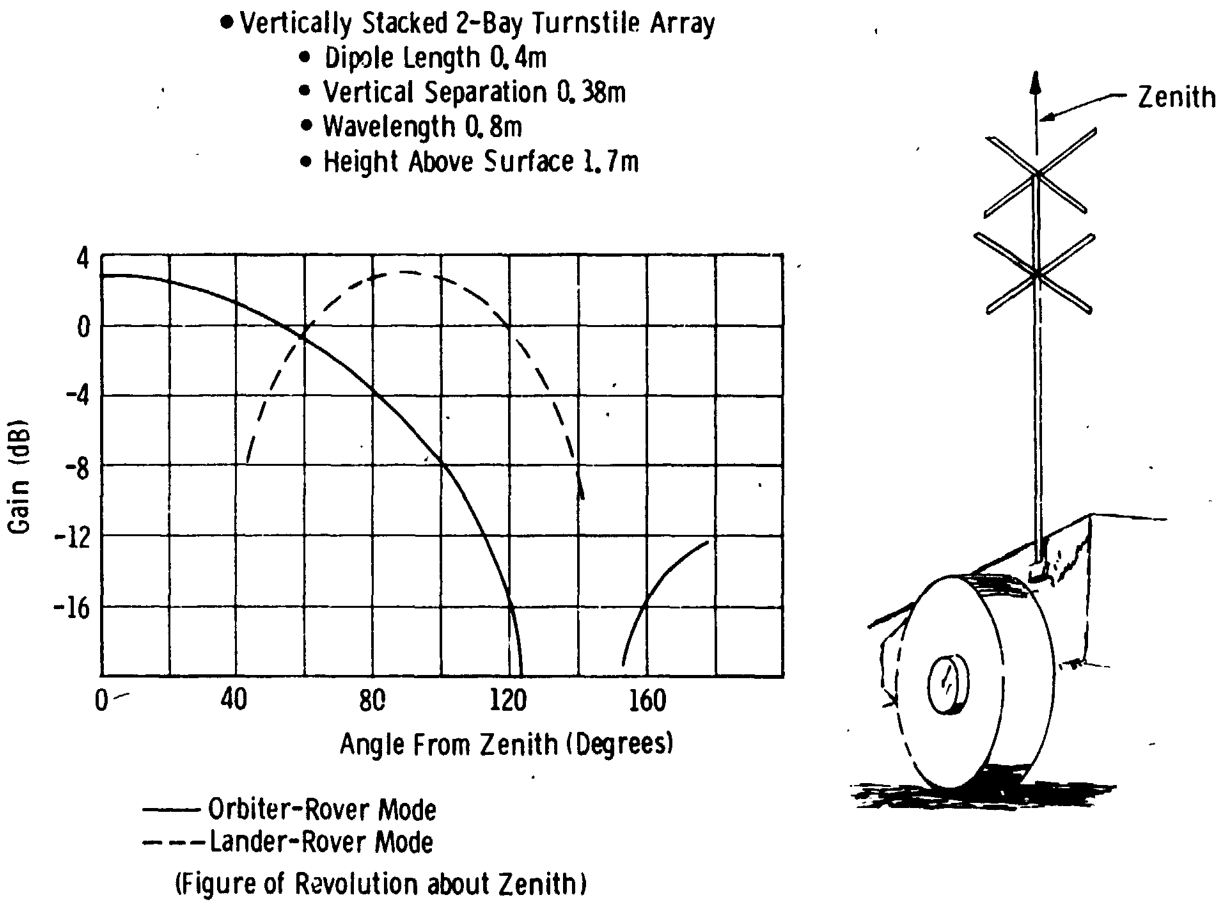


FIGURE 64 EARTH-TO-LANDER S-BAND COMMAND LINK PERFORMANCE



- Vertically Stacked 2-Bay Turnstile Array
  - Dipole Length 0.4m
  - Vertical Separation 0.38m
  - Wavelength 0.8m
  - Height Above Surface 1.7m

(Figure of Revolution about Zenith)

FIGURE 65 ROVER ANTENNA CONFIGURATION

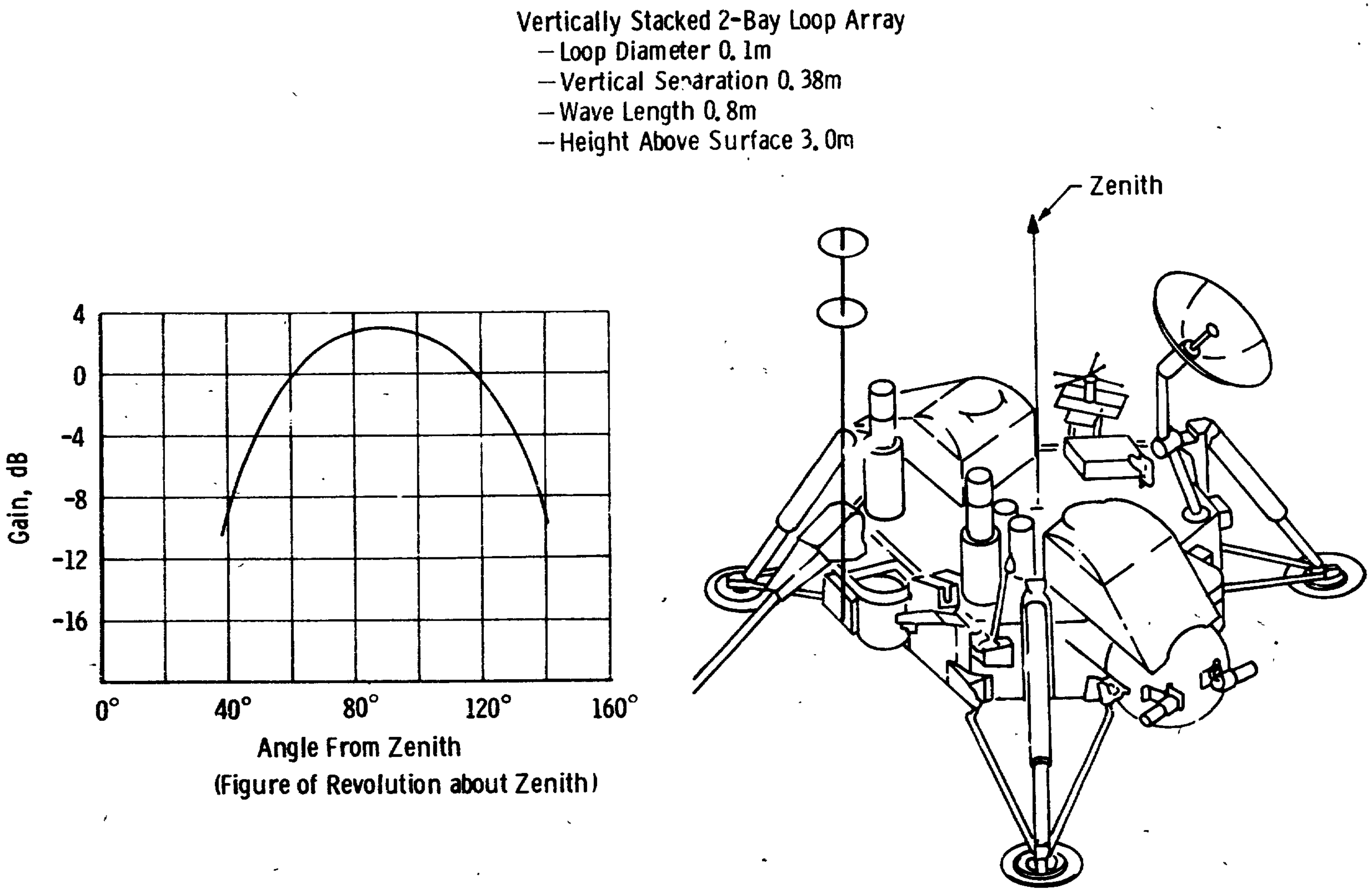


FIGURE 66 LANDER-TO-ROVER ANTENNA CONFIGURATION

tical plane for the orbiter-rover mode is obtained by feeding the turnstile elements 180° out of phase. Circular polarization is required for this mode and is obtained by feeding the dipole elements of each turnstile in phase quadrature. Feeding the turnstile elements in phase produces directivity in the horizontal plane for the lander-rover mode. The lander-rover antenna supports only the rover and provides directivity in the horizontal plane.

Design control Tables 32 and 33 establish the total propagation loss between rover and lander for system operation at the sum of adverse tolerances. The total propagation loss includes adverse effects of surface reflections, terrain defraction and the signal loss due to free space propagation. The design tables show that the command link with 2 watts RF power at 16 BPS will withstand approximately 4 dB more propagation loss than the telemetry link with 26.7 watts of RF power (Viking '75 transmitter, 30 watt RF mode) at 16 kbs.

Figure 67 depicts link margin versus rover-lander communication range using using the Martian surface model described in the preceding paragraph. The curves represent the telemetry link performance that is based on the link parameters defined in Table 32 which is for a 26 watt transmitter. Two curves are shown, A and B which depict a design nominal and a worst case condition, respectively. Also shown for comparison are estimates of the telemetry link performance for 2 watts fo RF power. The nominal and worst case link margin is approximately 4 dB higher than curves A and B. Rolloff of the curves is due to multipath loss, which increases exponentially with increasing range.

The most recent available quantitative data on Mars terrain irregularities is found in the preliminary report of the Viking Data Analysis Team (M75-144-0). Earth-based radar data were analyzed to get the probability distributions of slope angles over baseline lengths of 7.15, 23.7, and 94.8 km. In Figure 68 the 50 percentile (median) and the 99 percentile slopes for these baselines have been plotted as crosses. The dashed-line curves indicate extrapolations based on terrestrial slope distributions.

To get an estimate of how badly terrain occultations will affect the signal, the signal diffracted by a knife-edge ridge was calculated in ref. 7. Lines for 20 dB and 30 dB reduction of a 381 MHz signal are drawn on the figure. The slope baseline is equated with the distance of the closer terminal to the ridge,

TABLE 32 DESIGN CONTROL TABLE - ROVER/LANDER TELEMETRY LINK

PARAMETER	DESIGN NOMINAL	FAVORABLE TOLERANCE	ADVERSE TOLERANCE
Total Transmitter Power 26.7 Watts	+ 44.27 dBm	0.50	0.50
Transmitting Circuit Losses	- 1.00 dB	0.20	0.20 (1)
Transmitting Antenna Gain	+ 3.50 dB	0.50	0.50
Transmitting Antenna Pointing Loss ($\alpha = \pm 20^{\circ}$)	- 1.80 dB	1.80	0.00
Free Space Loss: Frequency 405 MHz (Range 1000 Meters)	- 84.59 dB	0.00	0.00
Polarization Loss:	- 0.06 dB	0.60	1.60
Multipath Loss	- 69.78 dB		(2)
Receiving Antenna Gain	+ 3.50 dB	0.00	0.00
Receiving Antenna Pointing Loss ($\alpha = \pm 20^{\circ}$)	- 1.80 dB	0.00	0.00
Receiving Circuit Losses	- 1.00 dB	0.20	0.20
Net Circuit Losses	-153.57 dB	5.60	3.00 (1)
Total Received Power	-109.30 dBm	6.10	3.50
Threshold Received Power (BER = 3×10^{-3}) Data Rate = 16 kbs	-115.45 dBm	2.77	2.65
Performance Margin	+ 6.15 dB	8.87	6.15

<u>Note</u>

(1) Transmit/receive circuit loss change (±0.5 dB) not considered.

(2) Losses above normal space loss due to surface reflections and terrain defraction.

TABLE 33 DESIGN CONTROL TABLE - LANDER/ROVER COMMAND LINK

PARAMETER	DESIGN NOMINAL	FAVORABLE TOLERANCE	ADVERSE TOLERANCE
Total Transmitter Power 2 Watts	+ 33.0 dBm	0.50	0.50
Transmitting Circuit Losses	- 1.00 dB	0.20	0.20 (1)
Transmitting Antenna Gain	+ 3.50 dB	0.50	0.50
Transmitting Antenna Pointing Loss ($\alpha = \pm 20^\circ$)	- 1.80 dB	1.80	0.00
Free Space Loss: Frequency 381 MHz (Range 1000 Meters)	- 84.06 dB	0.00	0.00
Polarization Loss: ($20^\circ \pm 20^\circ$)	- 0.60 dB	0.60	1.60
Multipath Loss	- 69.78 dB		(2)
Receiving Antenna Gain	+ 3.50 dB	0.50	0.50
Receiving Antenna Pointing Loss ($\alpha = \pm 20^\circ$)	- 1.80 dB	1.80	0.00
Receiving Circuit Losses	- 1.00 dB	0.20	0.20 (1)
Net Circuit Losses	-153.04 dB	5.60	3.00
Total Received Power	-120.04 dBm	6.10	3.50
Threshold Received Power (BER = 1×10^{-5}) Data Rate = 16 bps	-130.53 dBm	2.77	2.65
Performance Margin	+ 10.49 dB	8.87	6.15

Note

(1) Transmit/receive circuit loss change (±0.5 dB) not considered.

(2) Losses above normal space loss due to surface reflections and terrain defraction.

Basis for Estimate

- Design Control Tables
- Flat Smooth Surface (Specular Reflections)
- Antenna Height Above Surface

  Lander: 3.0 meters

  Rover: 1.7 meters

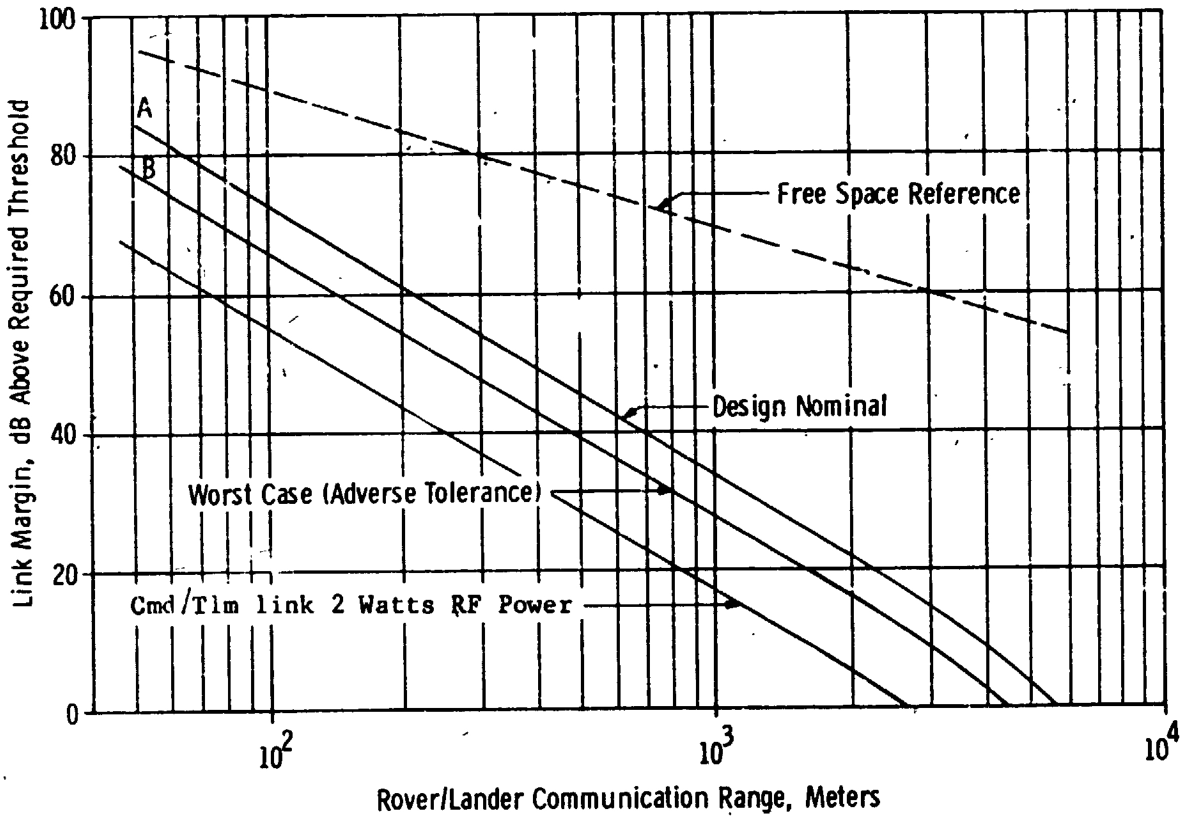


FIGURE 67 LANDER/ROVER LINK PERFORMANCE ESTIMATES (TLM/CMD)

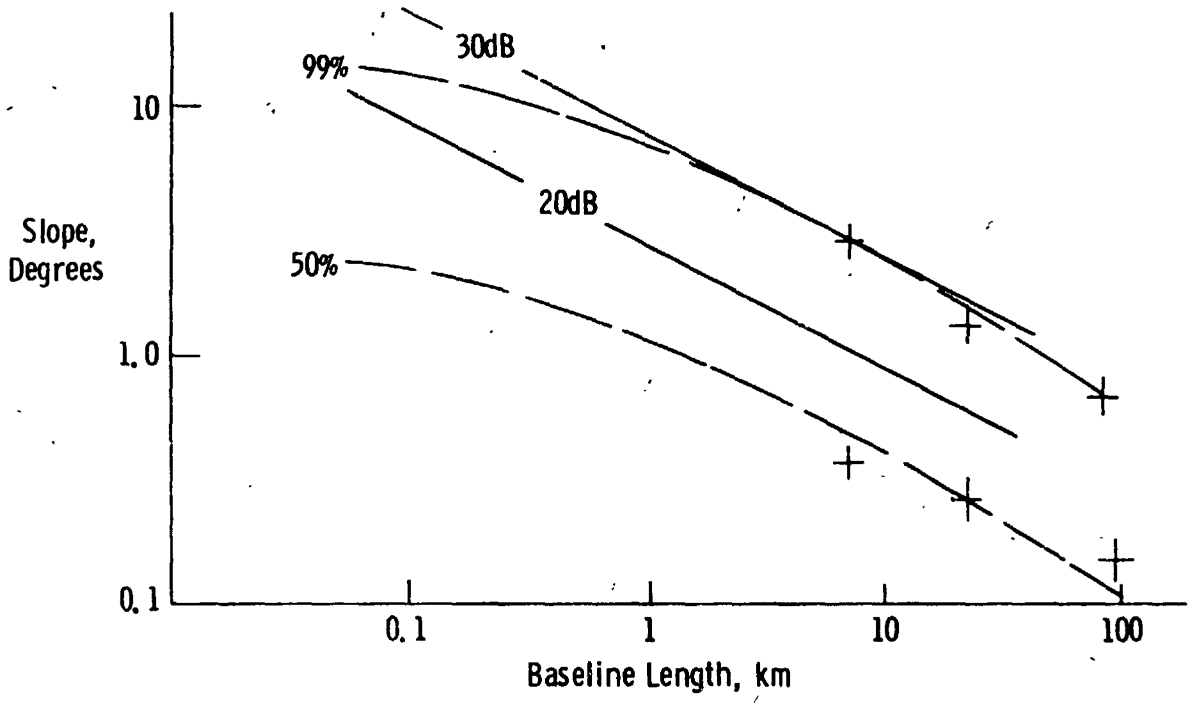


FIGURE 68 MARS SURFACE SLOPE DISTRIBUTION

and the slope angle is equated to the angle through which the ray must be diffracted. The diffraction loss is to be subtracted from the estimated link margins of Figure 67.

The results suggest that if the flat-planet calculation indicates a margin of 25 dB then communication can still be maintained behind most of the ridges that will be encountered.

Caution is needed in applying these results. Flat-topped or broadly rounded terrain features will give larger diffraction losses than idealized knife-edges. On the other hand, an intervening ridge can actually increase the signal if it reduces the reflected ray more than the direct ray.

Increasing the height of the lander and rover antennas above the surface will reduce the reflected signal power and result in improved link performance. This improvement is shown in Figure 69. The design point identifies the antenna heights assumed for this study. Much additional work is needed to select the optimum antenna heights, assess the advantage of vertical polarization for this link, and further define the effects of the terrain on the performance of this link.

Orbiter-to-Lander/Rover Link

Link performance estimates for the Viking '75 lander-to-orbiter telemetry link are shown in Figures 70 and 71. These curves are predictions for early in the landed mission for Missions A and B. The predictions are based on the measured installed antenna pattern data for both the orbiter and lander relay antennas. The other link parameters are documented in the Viking Orbiter System to Lander System Interface Requirements Document (ID 3703101).

These predictions should be typical of the lander-to-orbiter telemetry link performance for a '79 mission. The margin for the orbiter-to-rover command link will be approximately 4 dB better than that shown in Figures 70 and 71 with an assumed 2 watt orbiter command transmitter.

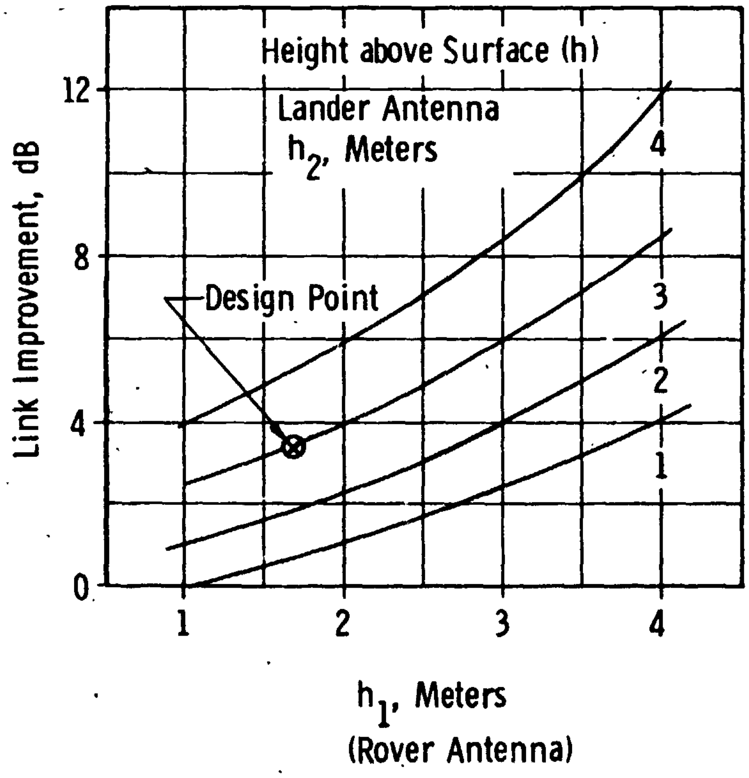


FIGURE 69 LINK PERFORMANCE VERSUS ANTENNA HEIGHT

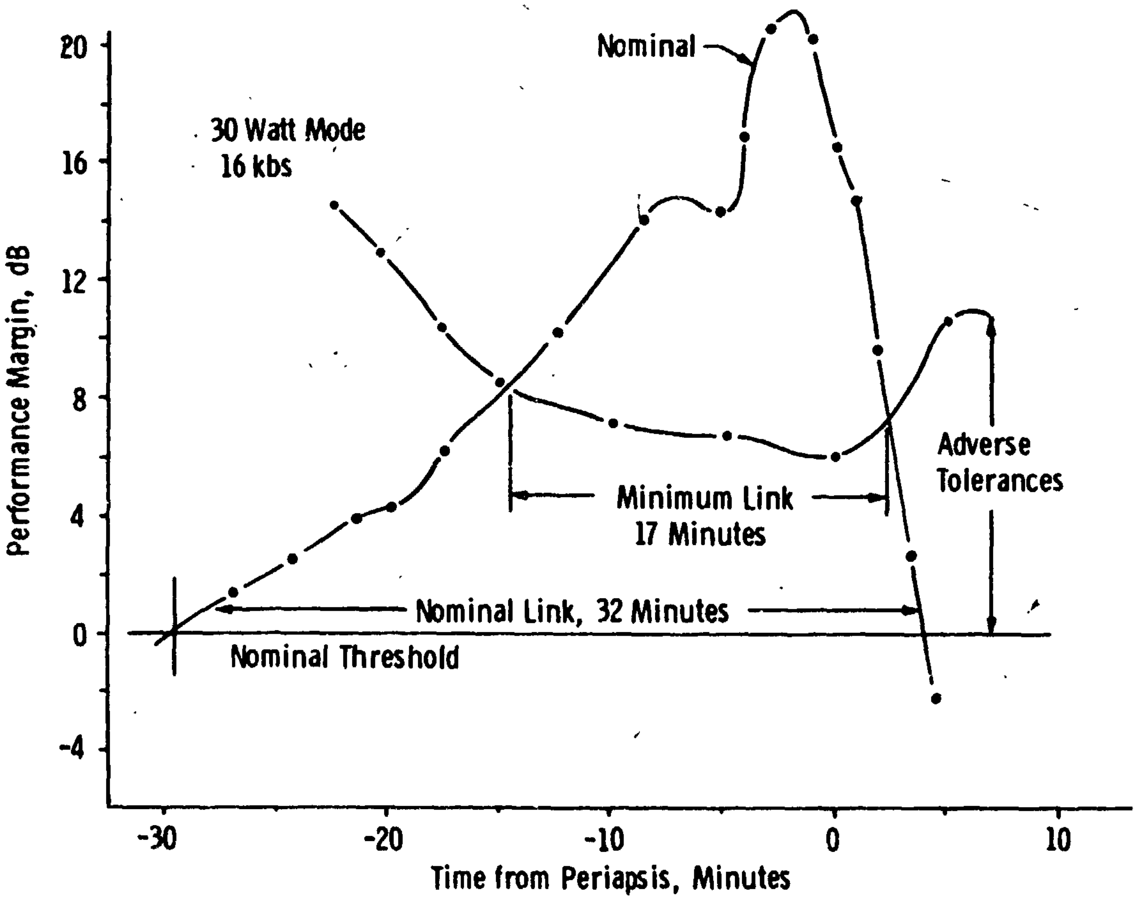


FIGURE 70 VIKING '75 MISSION A LANDED TELEMETRY PERFORMANCE, LANDER-TO-ORBITER

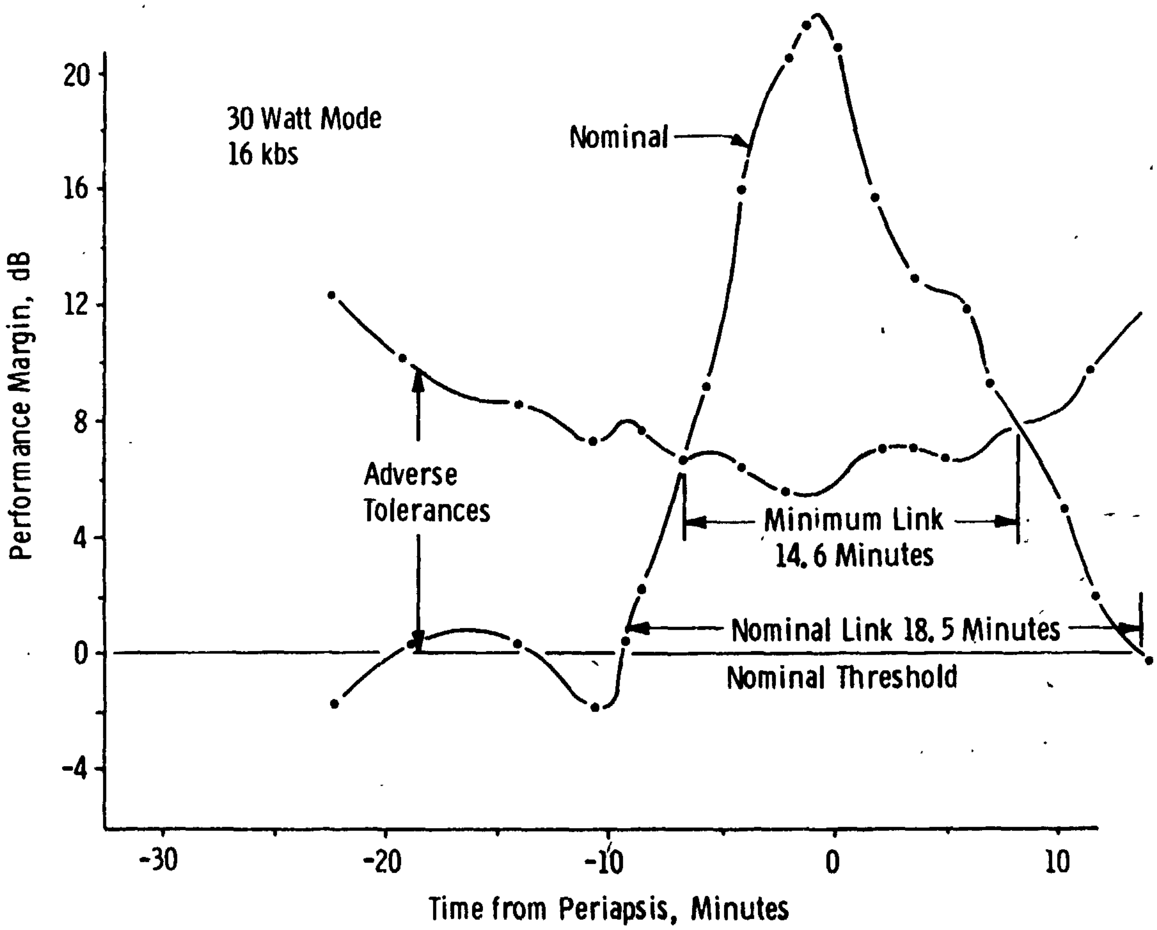


FIGURE 71 VIKING '75 MISSION B LANDED TELEMETRY PERFORMANCE, LANDER-TO-ORBITER

Dips in the performance curves are the result of nulls in the lander antenna radiation pattern. These nulls are caused by lander structural interference. The rover antenna will have a well behaved symmetrical radiation pattern because it is deployed above the rover structure. This will result in additional improved performance for the orbiter to rover links compared with the lander-to-orbiter links.

6.6 DATA HANDLING AND PROCESSING

This Section summarizes the analysis and trades that were made in the selection of the data handling and processing subsystem configuration. Requirements that are imposed by the Rover System on the Data Handling and Processing Subsystem include the following:

Provide hardware for multiplexing, signal conditioning, conversion, coding, formatting, and memory storage for all engineering data including navigation and control data.

Provide transducers and associated circuits for making temperature, current, voltage, and pressure measurements.

Format and code data that is provided to the radio subsystem.

Establish formatting requirements for all rover data sources including science instruments.

Implementation of the above general requirements included a tradeoff as to whether a rover data system should consist of a centralized or decentralized data system. In the decentralized data system, all required electronics for processing and storing data are contained in the circuits for each data source. As opposed to this, the centralized data system makes maximum use of common electronics thereby reducing mass, volume, and power, but in some situations restricting operation. Because the rover is severely restricted in allocations of weight, power, and volume, the tradeoff concluded that the best data system for the rover was the centralized data system.

The actual electronics for the centralized data system then becomes determined by the number and types of data sources (science instruments) on the rover. The preferred configuration for the Data Handling Subsystem, which is discussed in the following paragraphs, is based on a specific science payload.

Implementation of a data storage memory becomes one of the most difficult functions to implement in the centralized data system. The sizing of the memory is determined by the memory requirements of the data sources. As these change so changes the memory capacity. The preferred configuration uses a 250 K-bit memory to satisfy the requirements of the Alpha Backscatter Spectrometer.

Establishing the maximum size of the memory becomes a tradeoff between an optimum science payload versus power, mass, and volume that can be allocated to accomplish this function.

Data Requirements

Data processing requirements are derived from two primary requirements:

The volume of data collected on a daily basis by the science payload together with the engineering data required to analyze subsystem performance.

The volume of data that can be either stored or transmitted on a daily basis.

The latter item establishes the upper limit on the data that can be collected for it determines the total amount of data that can be returned by the communication link. Because the preferred communication system for Viking '79 uses the orbiter to relay data back to earth from either a lander or a rover, the amount of data that can be transmitted is determined by a 16 kbs maximum data rate for approximately 25 minutes per day during which the orbiter communication system can be accessed. This is a maximum capability of 2.4×10^7 bits/day. However, this capability is for both the rover and the lander.

The data storage capability that exists on the lander is 2×10^5 bits in the Data Storage Memory and 4×10^7 bits in the Tape Recorder. The amount of data storage required in the rover is obtained by determining the amount of data collected by the rover, the data collection rate, and the most effective use of the lander memory. The constraints in establishing the rover data memory are power, mass, and volume.

Science data sources. - Various science payload configurations have been investigated with the selected science payload having been established after the midterm presentation. Consideration of the various payloads, however, has led to certain conclusions relative to the sensitivity of the rover data handling configuration due to different science payloads.

One conclusion relative to the data handling subsystem, is that each science experiment will not have a data buffer but in fact will use one common rover data buffer. In addition, because this common rover data storage is limited in storage capacity to 250 K-bits, because of rover mass, volume, and power constraints, the following constraints are imposed on the types of scientific instruments used on the rover:

If the quantity of data per day exceeds 250 K-bits and if the data collection rate is less than 16 kbs, the scientific objective of that instrument becomes dependent on the lander. The mode of operation would be to collect and store the data on the rover in 250 K-bit bytes and to periodically transmit these data to the lander for storage and later transmission to earth via the orbiter relay link.

If the quantity of data exceeds 250 K-bits and the data rate is 16 kbs the scientific experiment would be operated in real time in that the data would be collected and transmitted to the orbiter simultaneously. This would restrict operation of the instrument to that one 25-minute period per day when the orbiter can be accessed. In this case the instrument would be independent of the lander.

To be able to perform this experiment at any time during the day would require simultaneous collection and transmission of data to the lander for storage and later relay to the orbiter.

If the quantity of data per day is less than 250 K-bits regardless of the collection rate, data can be stored on the rover and transmitted to the orbiter at the appropriate time. In this case the experiment is independent of the lander. Lander storage, however, can be used if the lander communication link can be accessed from the rover.

The number of experiments that can be operated in a single day and be independent of the lander, from the data standpoint, is limited to a total data collection of 250 K-bits at any time during the day plus 20×10^6 bits during the 25-minute real time mode. Note, however, that this cannot occur every day because the relay link, which has a capacity of approximately 20×10^6 bits per day, is shared by both the rover and the lander.

The preceding has assumed a fixed memory size and associated implications. Although the memory size can vary about the 250 K-bit capacity, the intent has been to indicate that mass, volume, and power constraints do not permit the use of a tape recorder on the rover to achieve a large memory capacity.

Science data. - The selected science (Rasool) payload for this study consists of the following:

Viking '75 Fax Camera
Alpha Backscatter Spectrometer
X-ray Diffractometer
X-ray Fluorescence (crevice detector)

Camera data. - In a high resolution mode, approximately 29 x 10^6 bits are required to obtain a panoramic picture (342 degrees azimuth) while 9.5 x 10^6 bits is required to obtain a panoramic picture in the low resolution mode. For partial pictures, 85 325 bits/azimuth degree are collected in the high resolution mode or 27 304 bits/azimuth degree in the low resolution mode.

Alpha Backscatter Spectrometer. - During a five-hour analysis a total of 2 x 10^6 bits is collected. If these data are processed on board the rover using data compression techniques, the data storage requirement for this instrument becomes 2 x 10^5 bits/5 hour analysis.

X-ray Diffractometer. - During a two-hour analysis, a total of 10^4 bits of data is collected.

X-ray Fluorescence. - This instrument, which is presently used as a crevice detector, will also provide science survey data and requires 8 K-bits per analysis with 80 K-bits per day to perform ten analyses.

Engineering Data. - Engineering data for the rover consists of current, voltage, temperature, and pressure measurements of critical elements on the rover together with memory read-out of the Control Sequencer.

Measurements will consist of the following:

Electronics compartment temperature
Battery voltage, currents, and temperature
RTG voltage, currents, and temperatures

RTG pressure
Equipment bus voltage

Control Sequencer memory read-out will generally consist of that portion which is programmable although a format will exist which will provide all memory read-out including the read-only portion.

A total of 12 kilobits/day of engineering data has been allocated to take care of the above engineering data requirements.

Data Handling

The types of data handling required on the rover consist of multiplexing, signal conditioning, conversion, coding, formatting, and data compression.

Data sources provide data in the form of either low level (0 to 40 mV) or high level analog (0 to +5 volts), bilevel (0 to +10 volts), and digital (0 to + 5 volts) signals.

Data collection is controlled through the use of prestored formats. A format is used for each science experiment (three formats) and two formats are used for collecting engineering data. This will provide five formats for rover data. Formatting of data must be consistent with the lander formatting wherein each format is preceded by a 31-bit synchronization word (000010010110011111000 1101110101) followed by a 5-bit data source ID word. The maximum number of bits between sync words must not exceed 5215 bits. However, it is desirable not to exceed 2048 bits between sync words. Data must be time tagged so that correlation can be performed during the data reduction process.

The Format Generator provides addresses at the required sampling rates. These addresses provide the controls for the multiplexer. All multiplexed analog signals are conditioned to a full scale range of +5 volts. During the sampling interval these multiplexed signals are converted to 8-bit digital signals. Digital data are organized as required by the format and are either stored in the Data Processor memory or sent to the UHF transmitter for real time transmission to the orbiter or the lander. To accomplish the requirement of 16 K-bits transmission real time, the A/D converter must have the capability to sample and convert in a period of 496 microseconds.

Control Sequencer control of the data handling equipment is provided by allowing the Control Sequencer to provide addresses to the Data Processor Multiplexer. Data for these selected addresses are then supplied to the Control Sequencer. This allows maximum use of common hardware. When the Control Sequencer is requesting data no formatting operations take place.

Coding. - Data that are collected real time or data that are read out of the Data Processor Memory or Control Sequencer memory shall be bi-phase coded with alternate bits being complemented and then routed to the UHF transmitter. Alternate bit complementing is required for lock-up of the receiver in the orbiter or lander. The data rate before coding shall be 16 kbs or 4 kbs and shall be accurate and stable to ±0.01% with a time jitter not to exceed 364 nanoseconds RMS.

Transducers. - Temperature transducers are provided for the rover system. No other types of transducers have been identified as a requirement. The Data Processor will provide the transducer reference voltage for these transducers.

Implementation

Implementation of the above data handling requirements is primarily constrained by the mass, power, and volume available on the rover. Subsystem tradeoff studies have provided allocations to the various subsystems that make a feasible rover system. The tradeoff study, which was performed in the Data Handling Subsystem, focused on concepts that reduce the mass, power, and volume for the hardware.

One of the operational characteristics of the rover system is that most functions are performed in sequence. This characteristic is established by the amount of electrical energy available on the rover to perform functions. The impact that this operational characteristic has on the data handling is that one data source never provides data when another data source is generating data. This feature, then can be capitalized on by recognizing that most of the data processing electronics for all data sources are similar, if not identical; therefore, this hardware can be used to service more than one data source.

Figure 72 shows a decentralized data system. Shown in block diagram form are the functions performed by the science instrument data sources and how they interface with the engineering data source and telemetry data system. Included in each of these data sources are the data memory requirements.

Figure 73 shows the centralized data system where advantage is taken of the fact that instruments are operated sequentially and common electronic circuits are shared. The mass and volume savings that can be achieved using a centralized data system depends on the number of data sources considered. As an example, for the midterm-preferred configuration, which consisted of a science payload with two data sources, a savings of 0.91 kg (2 lb) was obtained.

In addition to using common electronics, other schemes that have been investigated for reducing mass, volume, and power are the following:

Use a common dc-to-dc converter in the Power Control Unit. This eliminates having a separate power supply in each component.

Package all rover electronics in one case, thereby eliminating the case weights normally associated with packaging electronic components.

Use complementary MOS-logic (C-MOS) in place of the Viking '75 low power TTL logic elements. This reduces the logic power by a factor of 100, reducing the impact on the power supply electronics and requiring less power for accomplishing a given mission. This type of logic also makes it feasible to implement a solid state memory for data storage. Without C-MOS logic solid state memories are not practical because of the large power required.

Use of microelectronics (i.e., hybrid packaging techniques) reduces mass and volume by a factor of ten. The scheme that was investigated in the study was to package ten C-MOS chips on a 1-inch square substrate in flat-pack form. This scheme makes the solid state memory extremely practical because the C-MOS reduces the power and the hybrids reduce the mass and volume.

Of the above items investigated all but the last item have been implemented for the final selected configuration of the centralized data system. This latter item was not selected due to potentially high development costs and risk.

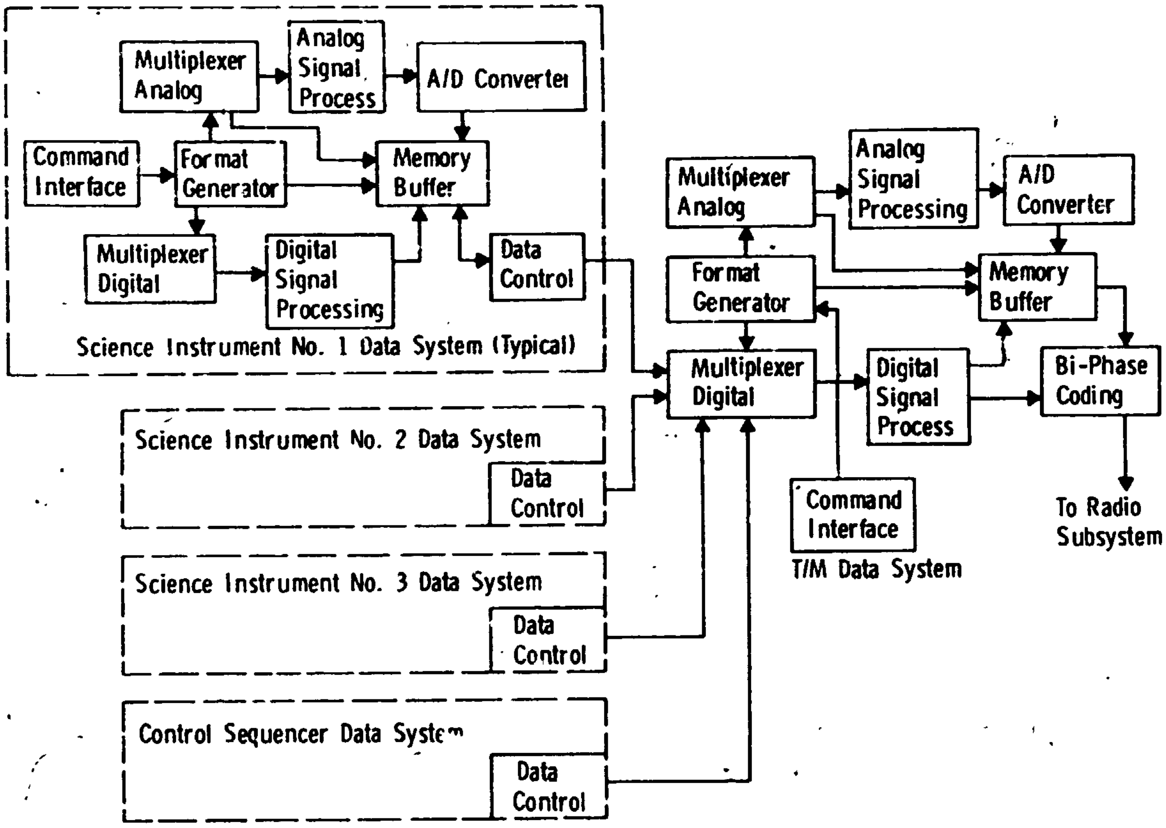


FIGURE 72 ROVER DECENTRALIZED DATA SYSTEM BLOCK DIAGRAM

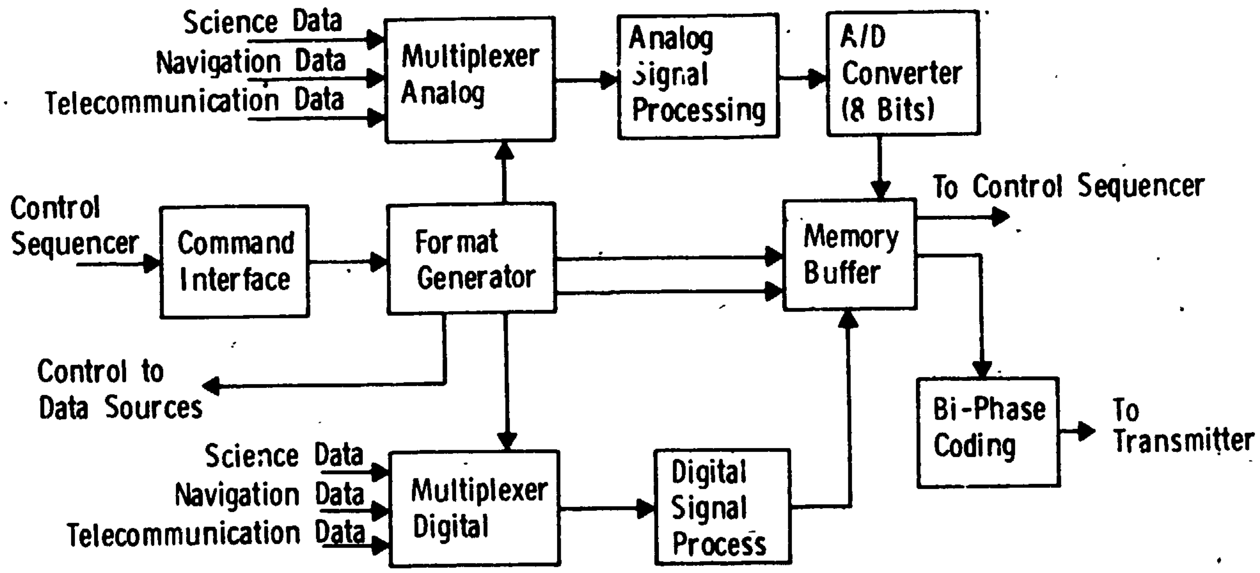


FIGURE 73 ROVER CENTRALIZED DATA SYSTEM BLOCK DIAGRAM

Data compression. - Because of the limited data storage capacity available on the rover the application of onboard data compression techniques would significantly increase the amount of information that could be obtained from the rover. This becomes more important when one considers that the science data could be used by the navigational system to enhance the mobility of the rover.

Identification of the data compression techniques that would be used and the overall impact on the rover hardware is extremely dependent on the science payload. Because the Control Sequencer contains computational capability, implementation of specific data compression techniques can be delayed in terms of defining hardware impact for they become software routines.

If data compression techniques are implemented on any specific data source, the impact to the Data Processor hardware would be that the final data formatting would be done as though the Control Sequencer was the data source and therefore hardware impact would be minimal.

Memory characteristics. - Because the centralized data handling concept has been selected for the selected configuration, the data storage memory requirements are now sized, within certain constraints, by the science experiments. The selected configuration has a memory capacity of 250 K-bits, which is established by the Alpha Backscatter Spectrometer and X-ray Diffractometer combination.

Performance requirements of the memory are as follows:

Data should be stored and read out on a first in, first out basis. Once data are stored they must be held in memory until the first read out. Destructive read out is acceptable.

The memory size is 31 250 8-bit words and physically sized for 4.5 kg (10 lbm). This memory has been implemented in this study using C-MOS Random Access Memories. In this case power must be applied to the memory continuously so that stored data are not lost. The use of a core memory has also been investigated. At a maximum data rate of 16 kbs, the power requirement of the core memory is within the rover constraints even though the peak powers are extremely high (23 watts average for 4 microsecond). However, the memory electronics can be powered off when not in use.

Interfaces

The Data Processor and Memory electronics that perform data handling and processing have the following interfaces which are defined for the preferred configuration:

Power Control Unit. - The Data Processor and Memory receives three regulated voltages from the Power Control Unit, +5V and ±10V. The Data Processor uses 1.5 watts while the memory uses 2.2 watts.

Control Sequencer. - The Data Processor receives commands from the Control Sequencer. The sequencer identifies the modes in which the processor will operate. The capability also exists for the sequencer to provide control signals to receive digital data from the processor. For data that are to be compressed, the processor provides these data to the sequencer for compression and then receives the compressed data for formatting.

Science Instruments. - The Data Processor accepts analog, bi-level and digital signals from all science instruments. Under Format Control these data inputs are sampled and converted to digital data and sorted in a predefined format.

UHF Radio. - The Data Processor provides bi-phase coded data in serial form to the UHF transmitter.

6.7 NAVIGATION

Requirements

Requirements for an onboard navigation system are heavily dependent on the science objectives and the nature of the terrain over which the rover must travel. In the extremes, this could range from essentially no onboard navigation (e.g., for a very short range exploratory rover with no specific targets, or a fly-by-wire rover controlled from the Earth) to a sophisticated rover which has the capability to pinpoint its location in the planet coordinate system.

For the Viking '79 rover, the scientific requirements can generally be classified as follows:

Targets several kilometers from the lander, selected from orbiter photographs. - This requires that the rover have the capability to navigate to within visual range of the target, either relative to the lander (range and heading) or in Mars coordinates.

Visible targets several kilometers from the lander, such as prominent hills. - This merely requires that the rover maintain a reasonable heading accuracy, with periodic updates provided by ground commands based on rover camera pictures.

Return surface samples to the lander. - From several kilometers this requires that the rover navigate to within visual range of the rover for heading updates. In addition, the sample transfer requires a rendezvous with the lander and possibly a docking (depending on the sample transfer mechanization).

A small visible target within one day's travel of the rover. - Because camera updates are time consuming, the rover should be able to autonomously navigate such a distance with the required accuracy limits.

It should be noted that taken collectively the preceding requirements from a very diverse set, i.e , heading and distance accuracies acceptable for the short range traverses are unacceptable when propagated over longer ranges.

For the Viking '79 mission, the following navigation requirements were developed:

Navigate to distant targets, using daily camera pictures as required. - Arrive within an error circle whose radius is 10 percent of the distance traveled.

Return to within visual range of the lander. - When returning from a distance of 5 km, the rover will autonomously position itself within 0.5 km of the lander. This distance is considered to be a practical operational limit from whose imagery can be used by ground controllers to position the rover so that samples can be returned to the lander.

For a single day's travel. - Navigate to within a 10 percent error circle of the desired end-of-day position.

The landing site and the Martian terrain and atmosphere place restrictions on the types of navigation systems that can be considered. High latitude landing sites increase the errors in a gyrocompass system and when combined with local slopes may preclude using the sun as a reference. The Martian dust places severe restrictions on all optical systems. In addition, the rover is limited in the mass and power available for navigation.

Requirements for a Heading Reference

The simplest system to consider would be one with no heading reference and uses visual updates to make short traverses. A simple simulation of such a traverse shows the errors involved with this approach.

The heading change due to a wheel climbing over a rock (considering only the fact that this wheel travels a longer path than the others) is shown in Figure 74. The distribution of rocks within the range of interest is shown in Figure 75 based on the models of the Viking Mars Engineering Models. These data were used to obtain the simulated traverses shown in Figure 76, each of which represent a different 'random' set of rocks in the path of the rover. This can be considered as the minimum heading change error for only one type of error was used. Other errors include wheel slippage during rock climbing, hazard avoidance, mismatch between wheel speeds, and the difference between

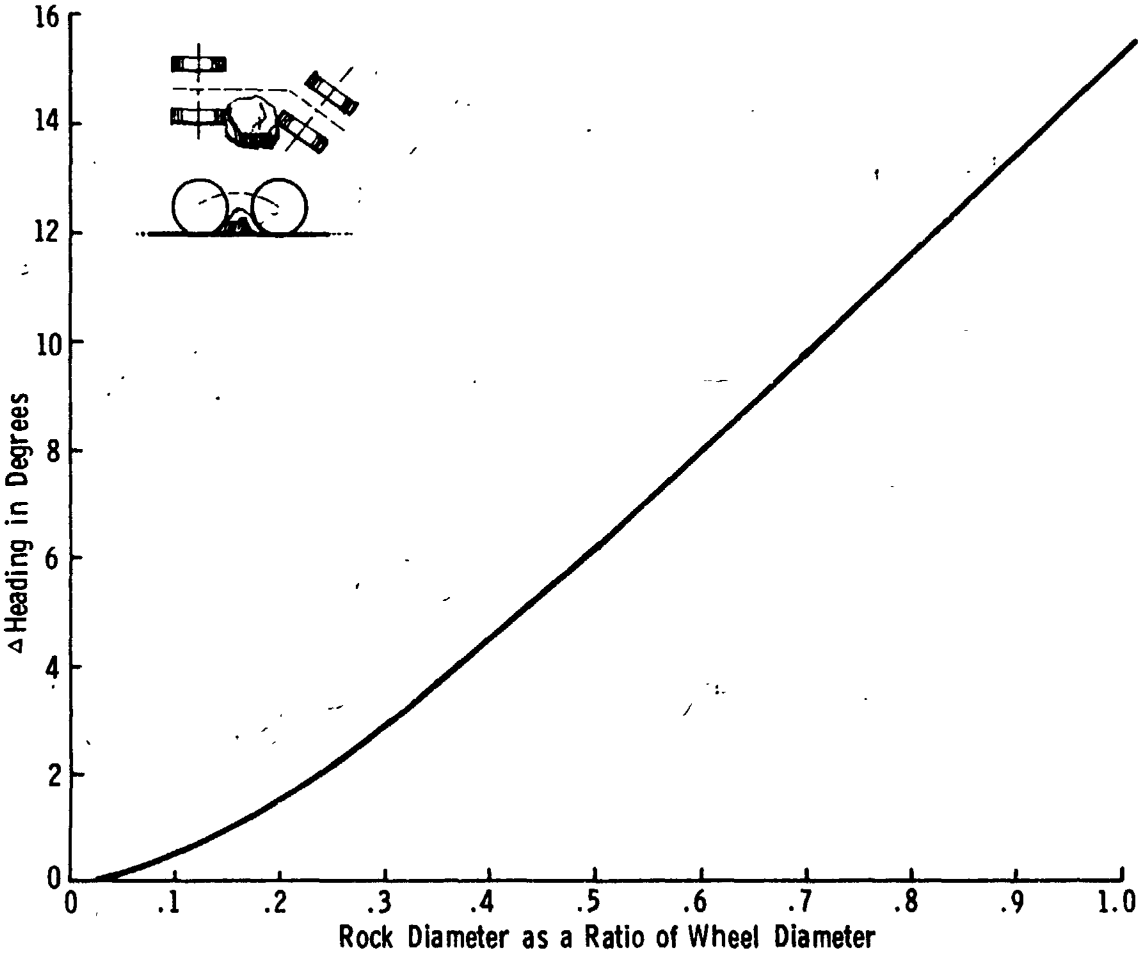


FIGURE 74 MINIMUM HEADING CHANGE DUE TO ROCKS

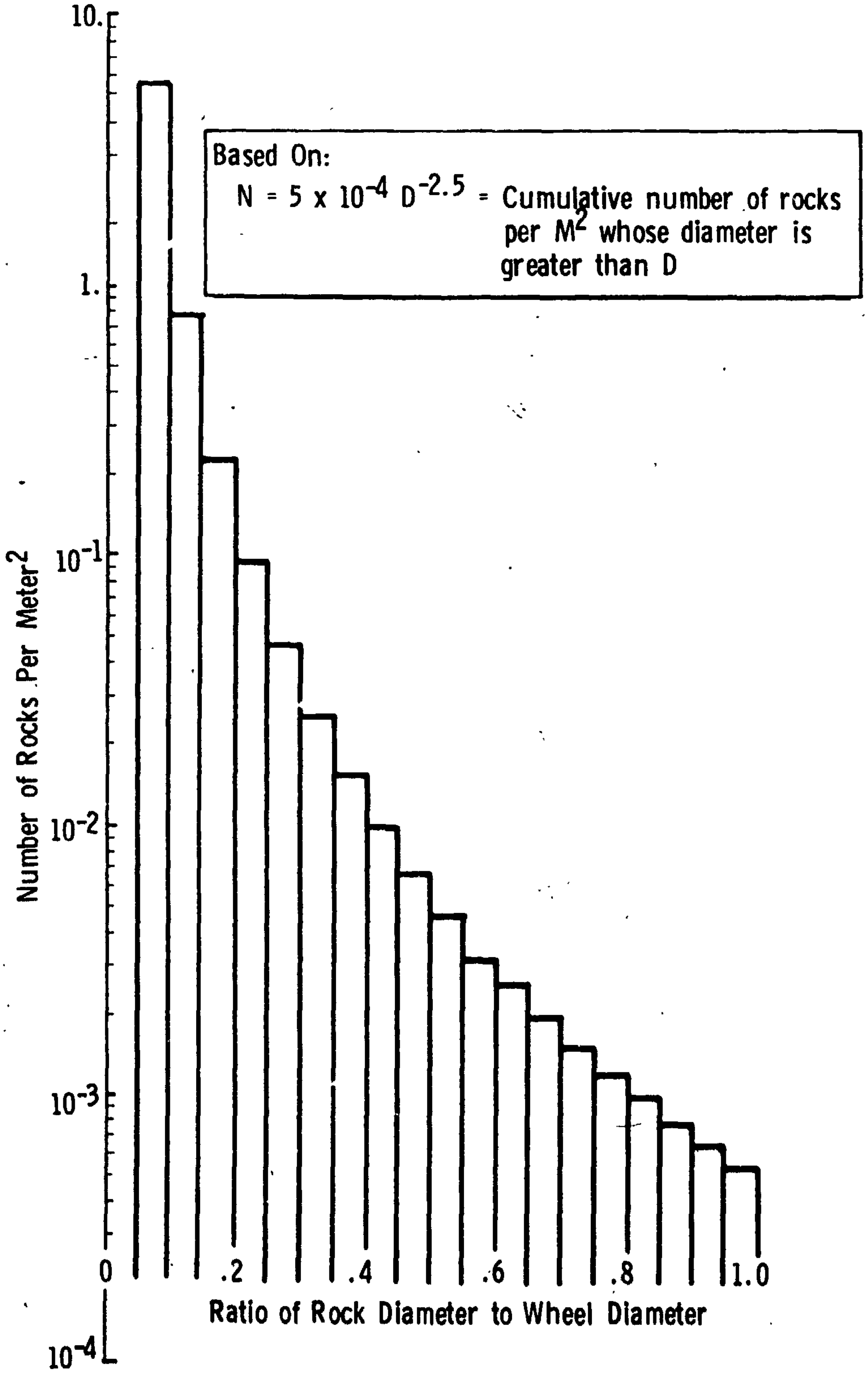


FIGURE 75 ESTIMATED DISTRIBUTION OF ROCKS IN THE SURFACE OF MARS

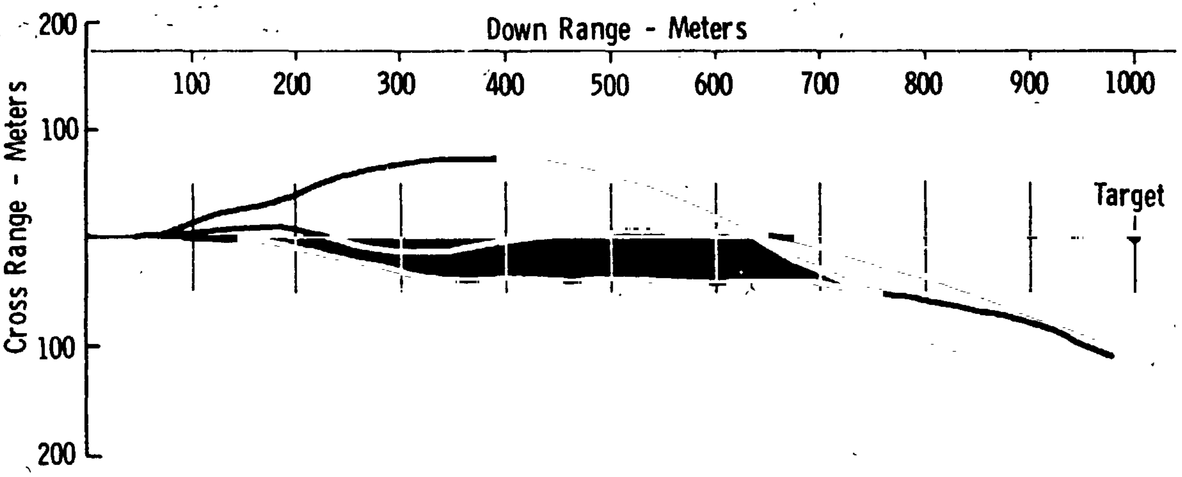


FIGURE 76 TYPICAL RANDOM WALK DUE TO ROCKS

the straight line distance to the target and the ground distance traveled by the rover over the surface contours.

It can be seen even from the small sample of possible paths shown in Figure 76, that the probability of meeting the 10 percent error criteria for a day's travel (500 meters) would be low. Therefore, this type of system can only be used when the rover can be closely controlled in a fly-by-wire mode from the ground and is not suitable for the Viking '79 mission.

Heading References

References available for navigational use include the sun, stars, Earth, Mars north pole, lander, and Martian surface features. Also to be considered are systems that measure changes in rover attitude referenced to some initial conditions. While it is conceptually possible to use the extra-Martian references, such as the sun or stars, to determine the rover's absolute location on the surface of Mars, this requires accurate sensors combined with long tracking arcs. Therefore, all navigation references will be considered to provide heading information, and the rover's position will be computed relative to the lander.

The candidate heading reference instruments are summarized in Table 34 based on existing technology.

Stars. - Can be sensed with a star tracker or with an imaging system such as the science camera. The values shown are typical of a Viking Orbiter class Canopus tracker and would be limited to stars brighter than 0.1 times Canopus, which limits the number of stars available as references. A TV system could achieve the same accuracy (limited more by the gimbal system and the knowledge of the rover attitude than by the instrument itself) at a higher mass and power penalty. However, the Martian dust precludes the use of optical sensors except as a possible backup for the primary sensor.

Sun azimuth. - Can be determined with either a sun compass, or a sun 'pipper' similar to that used in the Pioneer spacecraft. Either device could achieve good accuracy and would be the lightest and lowest power device.

TABLE 34 ONBOARD NAVIGATION SYSTEMS

Reference/ Instrument	Typical Parameters					Comments
	Accuracy		Mass kg	(lb)	Power (Watts)	
Stars - Tracker or TV	4.4 mr	(0.25°)	4.5	(10)	5	Both complex and have dust problems, TV picture requires processing
Sun - Compass or 'Pipper'	17.5 mr	(1°)	0.45	(1)	2	Dust problems, limited to lower latitudes
Radio Direction Finding	87 mr	(5°)	0	(0)	0	Rotate rover, use for homing to within visual range
Inertial Reference Unit	0.5μ rad/sec	$(0.1^\circ/\text{hr})$	4.5	(10)	20	Complex
Gyro Compass	35 mr	(2°)	2.7	(6)	8	True North reference, limited to lower latitudes, can be used in D.G. mode
Directional Gyro	0.5μ rad/sec	$(0.1^\circ/\text{hr})$	1.37	(5)	3.0	Initialization with respect to lander

However, the dust precludes consideration of these as the primary navigation sensor.

Sun sensors also have latitude constraints. For the Viking '79 mission the declination of the sun ranges from $+10^\circ$ to -20°. Therefore, (referring to Figure 77) for the sun's elevation relative to the rover to be greater than 0° for a minimum of 8 hours per day while traversing a 19° slope (19° horizon mask elevation) requires that the landing site be between $+20^\circ$ and -30° latitudes. Requiring that the sun be visible when negotiating a 22 cm rock on this adverse slope would reduce the available travel hours significantly.

<u>Radio Direction Finding</u>. - Can be used within communications range of the lander. Since the rover must operate out of this range, RDF cannot be considered as the primary navigation sensor. It can, however, be considered as a homing device that will operate in the area between the edge of the communications range and the visual range of the camera system. Because the homing updates are required infrequently, and only when returning to the lander from a long traverse, the rover itself can be rotated to provide the RDF information thus saving the mass penalty involved with rotating the antenna or providing electronic scan capability.

<u>Inertial Reference Units and Inertial Platforms</u>. - Are readily available, but are generally complex, heavy and consume too much power to be considered. In spite of their complexity, they provide little more information than is available from simpler inertial devices. Therefore, development programs to reduce these physical quantities should not be pursued. The values shown in Table 34 are typical for the Mariner/Viking Orbiter Class IRU. The Lander IRU, which has passed sterilization, weighs 15 kg and requires 60 watts.

<u>Gyrocompasses</u>. - Commonly used navigation instruments, though existing units tend to be large and power consuming, being designed for marine or aircraft applications. The true North reference error is given by

$$\theta_E = \frac{\omega_D}{\Omega \cos \lambda}$$

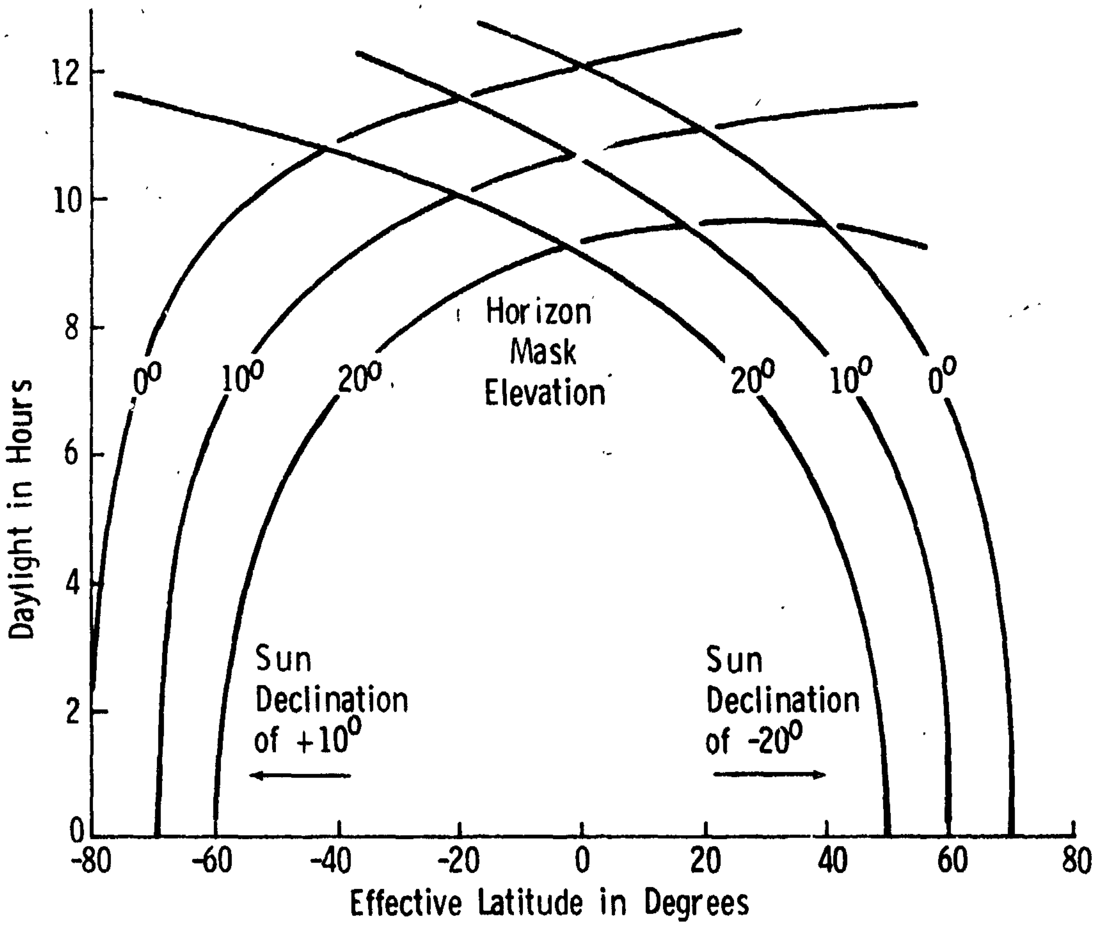


FIGURE 77 HOURS OF SUNLIGHT AVAILABLE FOR MARTIAN NAVIGATION

where θ_E = Azimuth error

ω_D = Gyro drift rate

Ω = Mars rate

λ = Landing latitude

Typical accuracies quoted are 2° (3σ) at 60° latitude, implying that this error is doubled at 75° latitude. The mass and power values of Table 34 are vendor estimates based on existing designs.

Directional Gyros. - Provide heading information referenced to initial conditions. Because the heading error is a direct function of gyro drift, the cross-range error is approximately:

$$Y = \frac{\omega_D X^2}{2v}$$

where Y = cross range error
X = down range distance traveled
v = rover ground speed

This is illustrated in Figure 78 where X is plotted as a percent of Y for several drift rates and rover velocities. This implies that to traverse 50 km to a target area seen from the orbiter and to arrive to within 5 km of that target with no heading updates require a drift rate of less than 0.1°/hr and an average rover velocity of greater than 500 M/hr, a difficult set of parameters to achieve. A traverse using the baseline parameters is shown in Figure 79. Again the mass and power of Table 34 is based on vendor data.

Selection

The scenario for rover surface operations includes the general requirements categorized in preceding paragraphs. These are (1) long and short range

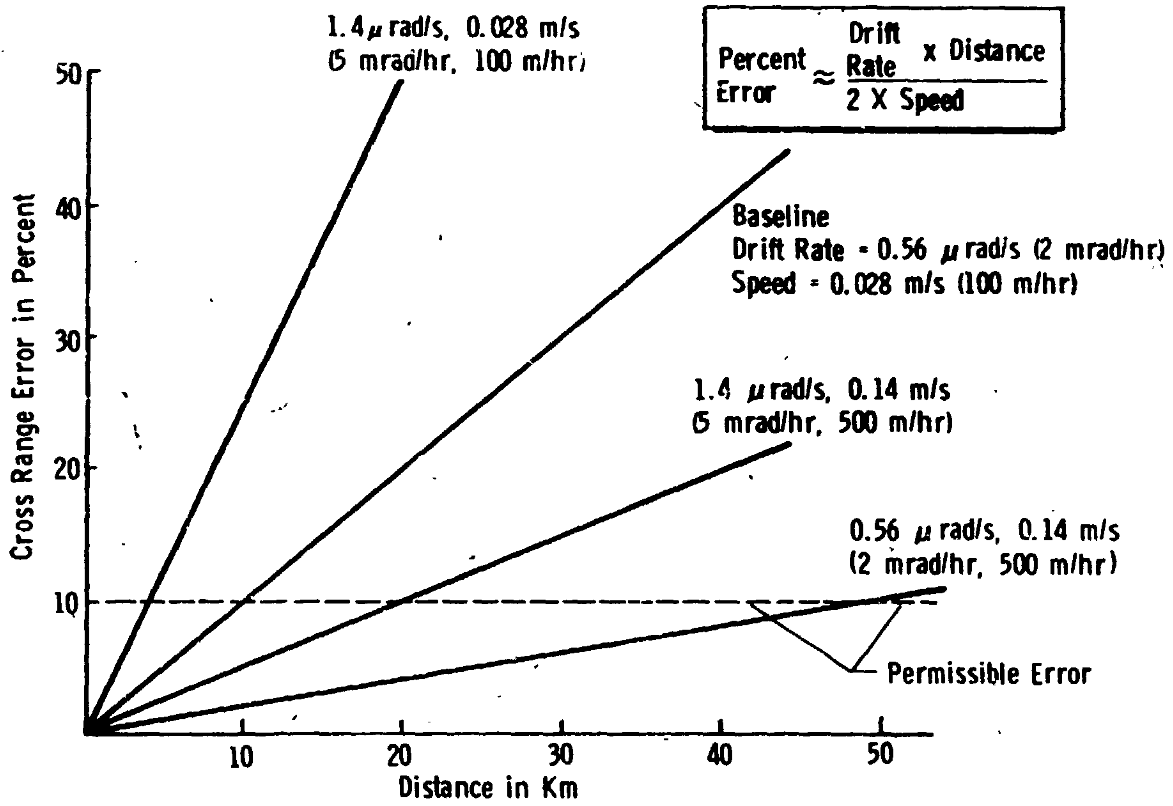


FIGURE 78 CROSS RANGE DEAD RECKONING ERROR

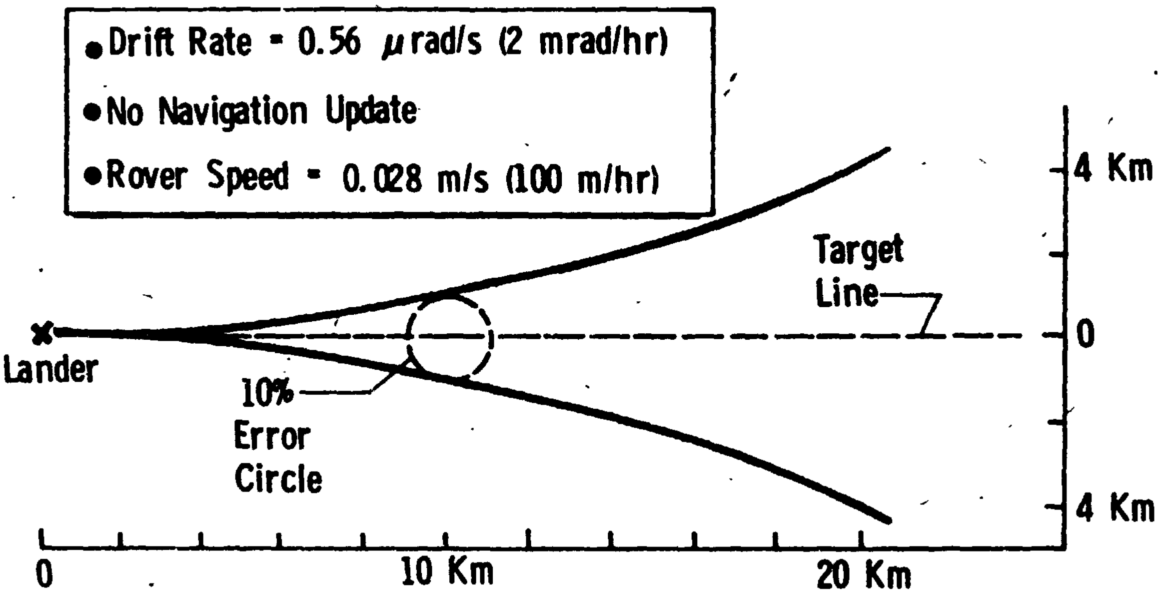


FIGURE 79 DEAD RECKONING ERROR BOUNDS FOR CONSTANT GYRO DRIFT

usable targets, (2) return to the lander from a distance of several kilometers, and (3) travel to a target seen from the orbiter, many kilometers from the lander.

The existence of the Martian dust eliminates the simplest instrument, the sun sensor, as the primary navigation sensor. The dust plus the relative complexity and physical constraints, eliminates the star tracker and TV as primary sensors. Because RDF is limited to the communications range between the lander and rover, it cannot be considered as the primary navigational reference system. Because the inertial platforms and IRUs require too much mass and power, and provide little additional information, the major tradeoff is between using a directional gyro alone or in combination with a gyrocompass for daily updates.

Typical daily traverses are shown for the combination system in Figure 80, for various latitudes. Note that the error due to the D.G. drift is small compared to the basic heading accuracy of the gyrocompass. This system is compared to the D.G. system in Figure 81. Thus for the lower latitudes ($<60^\circ$) the combination system provides better performance for distances greater than 4 km from the lander.

The real disadvantage of the D.G. system is in attempting to return to the lander. Two such attempts are illustrated in Figure 82. The rover moves along the trajectory until it is decided to return to the lander. Because it assumes that it has been traveling along the target line, it makes a 180° turn at the turnaround point, and backtracks to the end point, only to find that the lander is not within sight. The distance from this end point to the lander is shown as a function of the distance the rover travels from the lander in Figure 83. Thus for a 20-day traverse (16 km) the rover would return to within 5 km of the lander, which is within RDF range under most terrain conditions.

The daily update eliminates this problem, as shown in Figure 81. While the heading taken by the rover is in error by the accuracy of the heading reference, it will return along approximately the same path, and may be classed as a "I may not know where I've been, but I can get back to where I started from" - system.

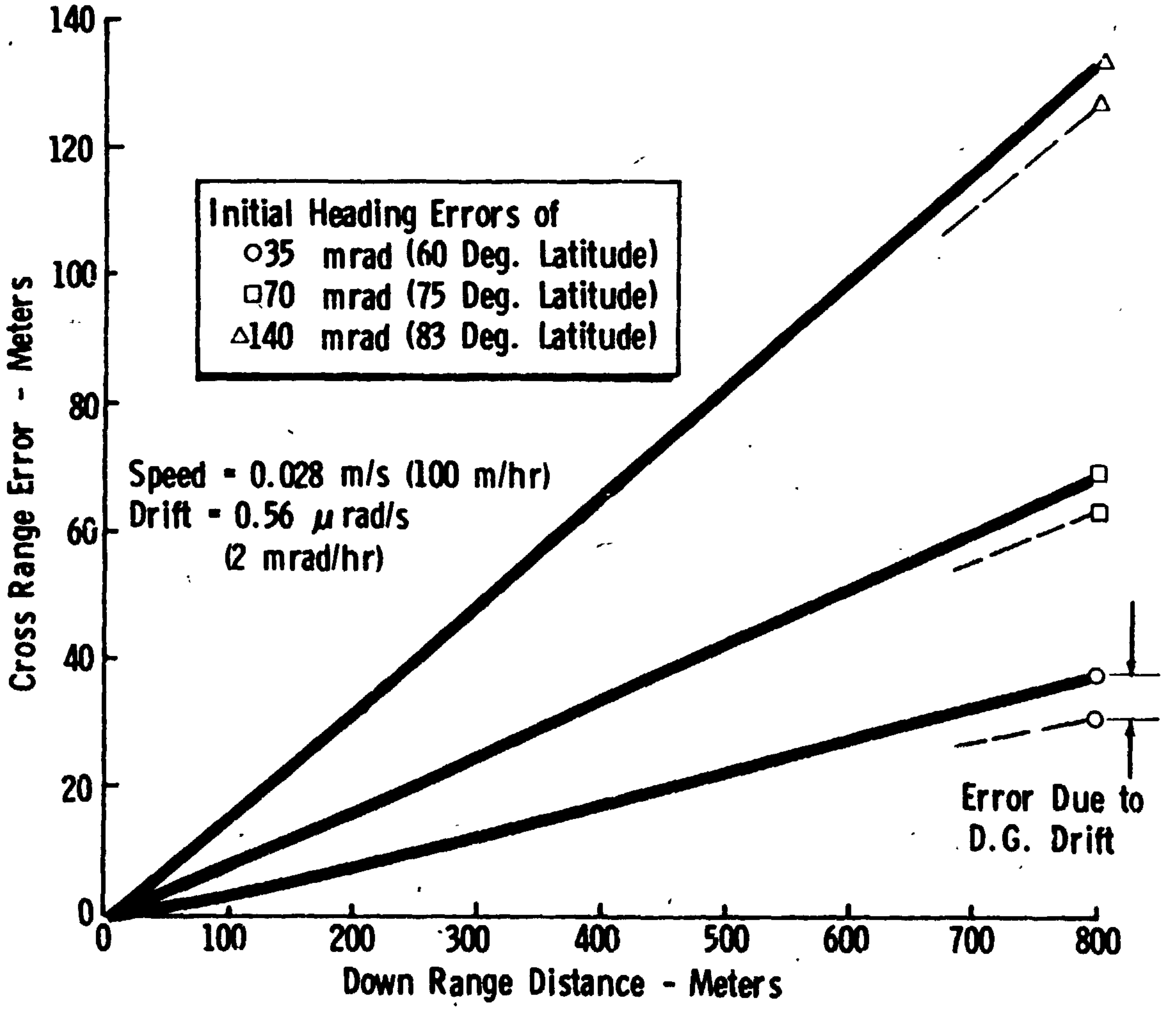


FIGURE 80 EIGHT-HOUR TRAVERSE USING DIRECTIONAL GYRO

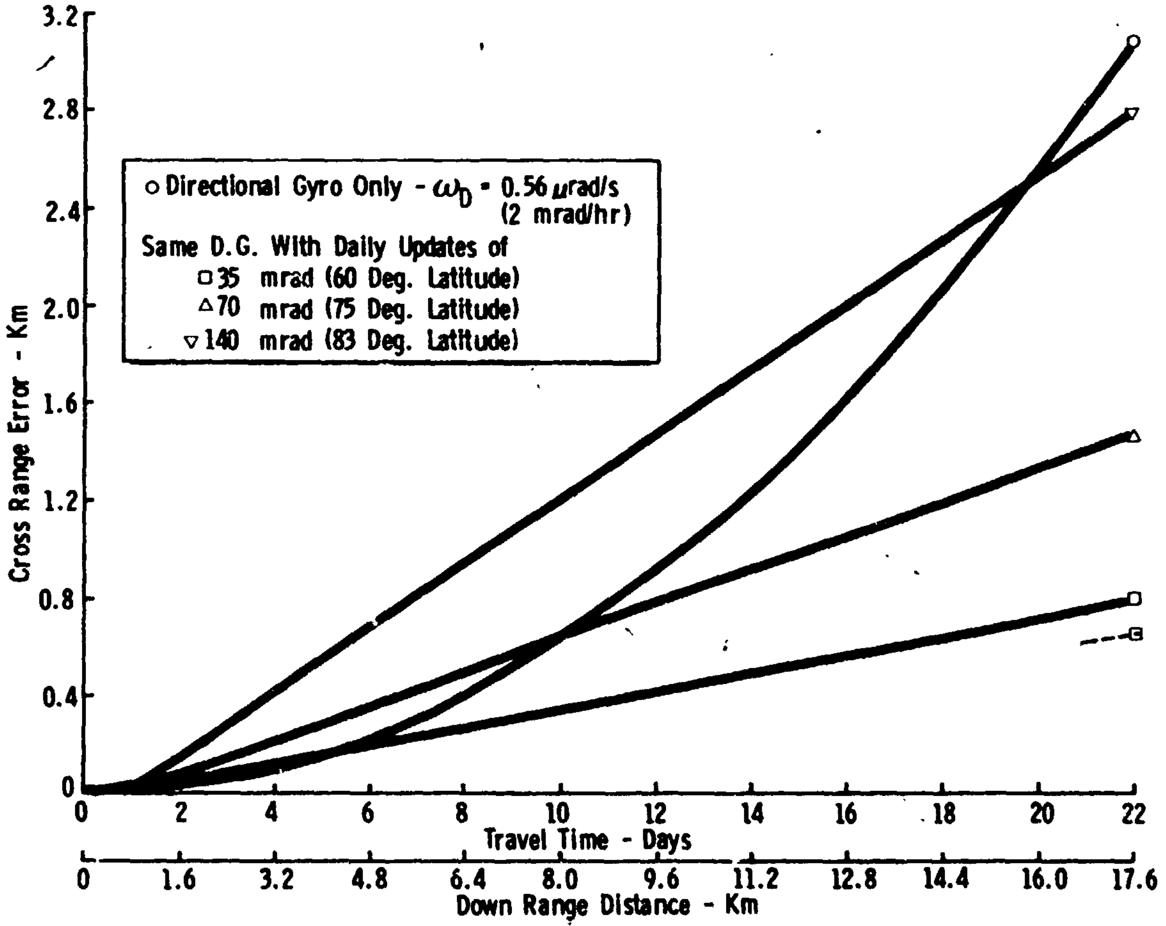


FIGURE 81 ERRORS WITH AND WITHOUT DAILY HEADING UPDATES

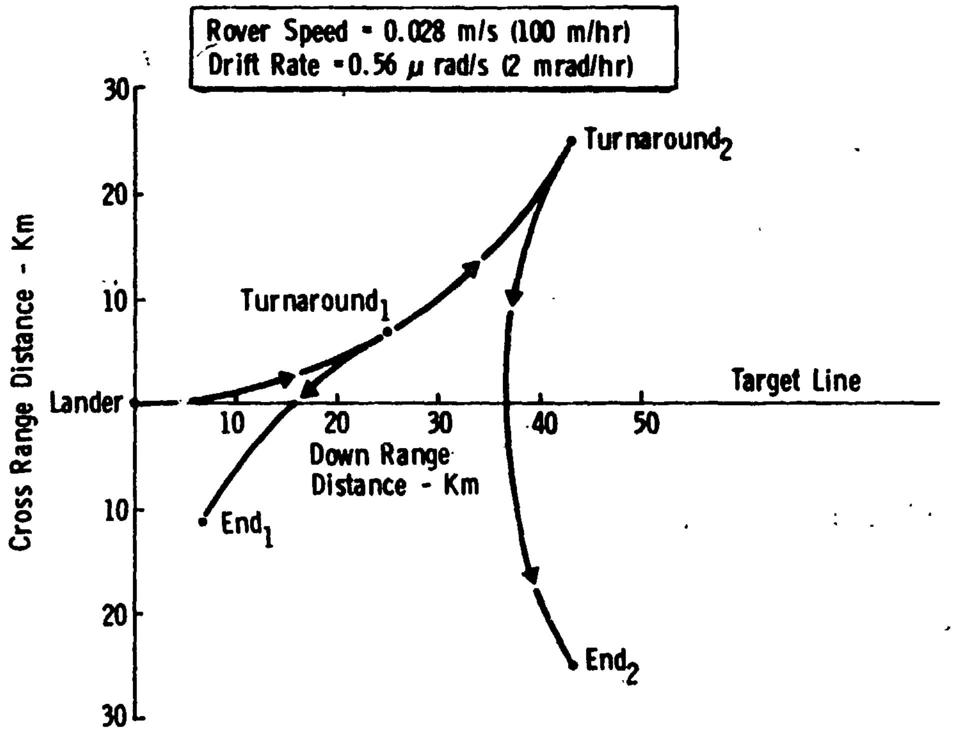


FIGURE 82 ATTEMPTS TO RETURN TO LANDER WITH A CONSTANT DRIFT ERROR

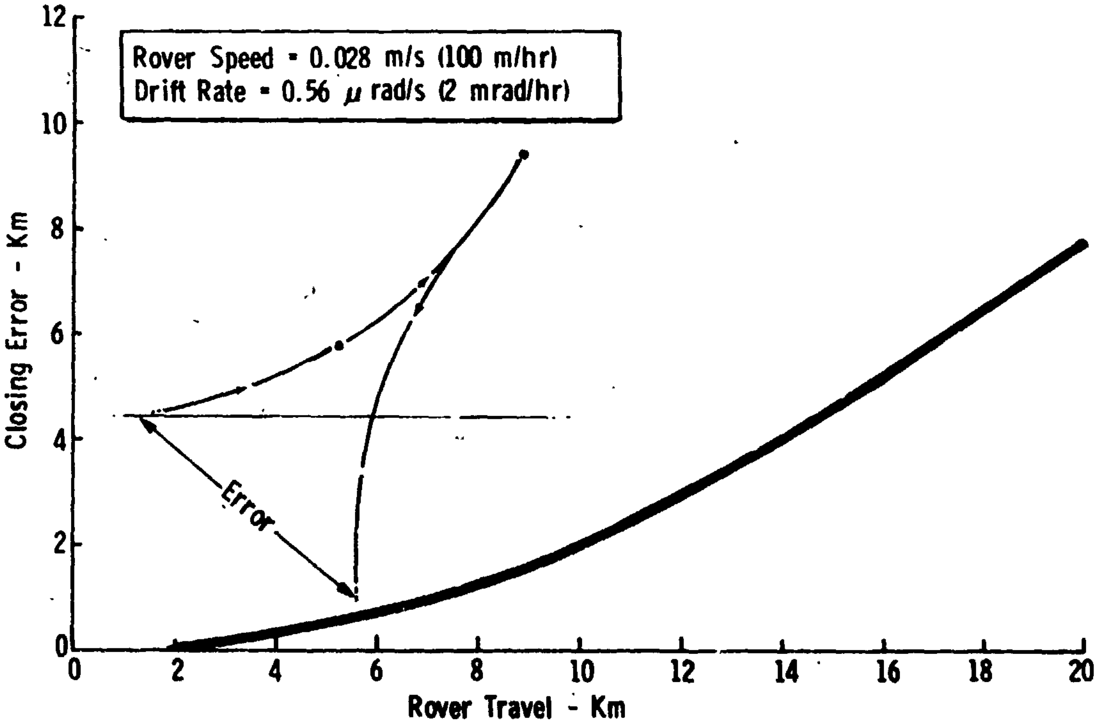


FIGURE 83 ERROR IN RETURNING TO LANDER

Therefore, to meet the 10% cross range error criteria for ranges of tens of kilometers and to return to within 0.5 km from traverses of 5 km, the combination system is selected.

Distance and Hazard Sensors

The preferred distance and hazard sensors are shown in Figure 84. Four odometers, one per wheel, were selected as the simplest method of measuring distance. Each odometer is of the cam and microswitch type that provide eight pulses per revolution of wheel motion. All four odometers are summed and averaged to provide an input to the calculations of distance traveled.

Two-axis linear inclinometers provide rover attitude information required both in the navigational calculations and to avoid excessive slopes. Simple pendulous potentionmeter devices can be used to minimize the mass and power required. Quantization of the A/D converter will be approximately 1°. While the functional requirement for slope stability is ~40° (19° slope plus a 22 cm rock), the actual limit will be a variable due to computations based on the traction coefficient of the soil.

Simple bumpers and microswitches will be used to detect nonnegotiable rocks.

The most difficult type of hazard to detect is a crevice. Unfortunately, crevices are also more dangerous to a four-wheel vehicle than other types of obstacles. A wide variety of sensors are available. Extra wheels pushed ahead of the vehicle is a straightforward approach, but they require deployment and add excessive volume. Contact sensors such as 'feelers' are uncomplicated devices but fabrication and operation are complex (easily broken, calibration of pressure or motion to actuate switch, rover reverse motion, etc.).

The baseline system is based on the work of ref. 8 that covers non-contact hazard sensors, namely reflected energy intensity ranging. This system consists of a source of optical or X-ray energy, two detectors, and associated electronics. It is desirable that this system be combined with the XRFS in a single science/hazard detection instrument.

① Left and right bumpers in front of chassis.
② Chassis pitch and roll inclinometers
③ Chassis roll gimbal angle sensor
④ X-ray fluorescence spectrometer/ranger
⑤ Drivemotor current sensors
⑥ Imager for earth-based path selection
⑦ Odometers

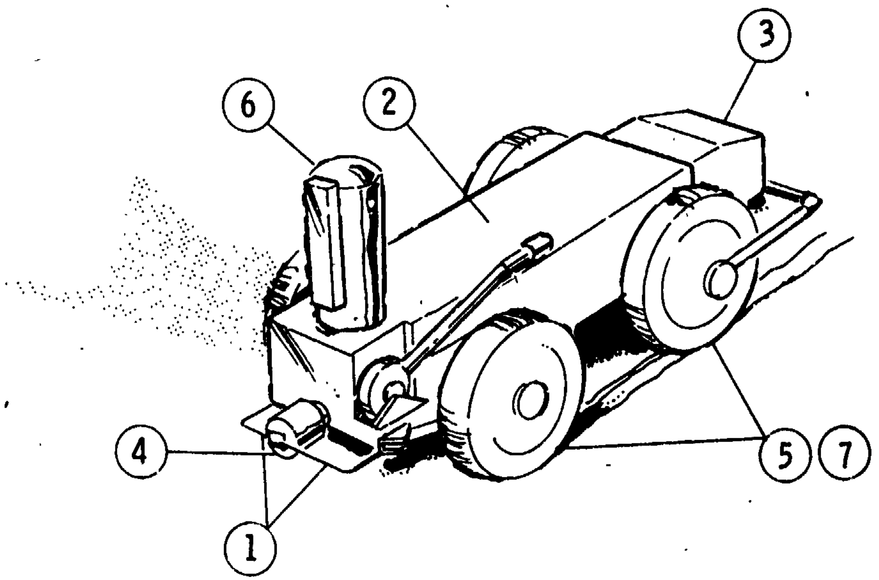


FIGURE 84 DISTANCE AND HAZARD SENSOR COMPLEMENT FOR PREFERRED VEHICLE

Description of Preferred Navigational System

Based on the preceding discussions and trades, the following is a summary of the preferred navigational components.

Primary heading reference. - Directional gyro/gyro compass (preliminary vendor data)

Performance (by mode)

Level - 0.29 mrad (1 $\widehat{\text{min}}$) within 60 s of time

Gyrocompass - Coarse/fine align to 35 mrad (2°) within 1800 s of time

Directional Gyro - long term drift 0.75 μrad/s (0.15°/hr)

Physical Characteristics

Volume - 2 cm by 2.4 cm by 1.6 cm (5 by 6 by 4 inches)

Mass - 1.37 kg (3.0 lb)

Power - 6 watts (starting), 3 watts (operating)

Configuration - 2 gimbals
- dc torquers on each gimbal
- Synchro or resolver readout of outer gimbal angle

Gyroscope - 2 degrees of freedom, non-floated

Backup heading reference. - Provided by science camera pictures of the sun. Sun azimuth, time, and rover attitude can be used to calculate the rover heading. The camera also provides navigational pictures once per day to be used by ground controllers in planning the traverse for the following day.

Direction and Hazard Sensors. -

Odometers - Viking '75 class microswitches operated by cams; one per wheel.

Inclinometers - pendulous linear potentiometers, pitch and yaw axes, integrated into the gyro package

Roll Gimbal Angle - potentiometer

Positive Hazards - mechanical bumpers and Viking '75 class microswitches

Negative Hazards (Holes) - XRFS instrument mounted at the front edge of the chassis

Areas for Further Investigation

The nature of the studies to date has limited the analyses, physical data, and tradeoffs to a first order level, and all conclusions must be considered preliminary. Future studies must refine the data, investigate other possible concepts, and provide more detailed analyses. In particular, these studies should include:

Costs. - Determine the physical and dollar costs of providing the gyrocompass capability or a simple directional gyro. More vendor data are required to increase the confidence that the performance can be provided for the given physical characteristics.

Platform navigation. - More data are needed on small platform navigational systems to determine if these systems are feasible alternatives to a gyrocompass/D.G. system. Although generally more complex, their existing level of development may make them desirable.

Sun sensor dust analysis. - Because the potentially simplest device, a sun sensor, is precluded by the Martian dust, a more detailed analysis is required to determine how restrictive this dust really is (i.e., does it preclude the use of a sun sensor altogether, or merely place operational constraints on its usage). Also, it should be determined if a sensor operating over a frequency range other than the optical range could be used.

Error analyses. - The error analyses of this study have been limited to using worse cases for single error sources. More detailed error analyses that consider the statistics of the errors and the propagated effect of their combination should be performed.

Computer Simulation Model. - To provide a visual picture of the rover navigation performance, a computer simulation model should be developed, using the work previously accomplished under supporting research as a test bed for the navigation algorithms.

6.8 CONTROL SEQUENCER

Functional Requirements

The general requirement of the control sequencer is to provide total control of the rover operations. These operations include navigating, scientific instrument sequencing, power switching, and controlling data processing. Specifically the system must provide the capability to:

- Navigate from point A to point B, using heading, distance, and rover attitude information. Included are such special features as hill climbing (steepest ascent) and contour following (constant altitude).

- Avoid hazards such as nonnegotiable rocks, holes wider than 0.6 of a wheel diameter, and local slopes of greater than a predefined maximum.

- Compute the traction coefficient of the soil being traversed. This computation is then used to define the maximum slope that can be safely negotiated by the rover.

- Control the power sequencing to rover equipment, based on a predefined or self-formulated sequence of events, ground commands, and rover events.

- Issue commands to the rover data processor to control the formatting and sequencing of the data processing and transmission.

- Issue command sequences for all scientific instruments to control their movements, their sample rates, and the transmission of the data to the data processor.

- Modify the rover's predefined operational sequence while traversing as a result of hazards or interesting science detected by the scientific instruments.

The following features will be incorporated in the programming of the rover computer and will provide adaptive control of the rover engineering and scientific payload:

- Multiple course legs up to 1 km in total length can be ordered per day in one command session. In difficult terrain much shorter traverses would be required.

- Hazard identification and avoidance will be automatically handled by the rover, providing that not more than three avoidance maneuvers are required. In this case, the rover will take a picture of its surroundings and await ground commands.

- The rover will regularly make automatic measurements of the traction coefficient of the soil and make allowances for wheel slippage to maintain accurate dead reckoning positions. In addition, the rover is able to operate closer to its maximum capability on slopes without knowing the characteristics of the soil; however, the rover motion must be restricted to slopes that are negotiable with the worst soil conditions expected.

- In addition to the capability of ordering course legs in terms of azimuth and distance, the rover can be commanded to proceed to a given absolute location in a coordinate system centered on the lander, follow an altitude contour for a specified distance, climb a maximum positive (or negative) slope until a level pitch is found (top of a hill or bottom of a valley).

- Monitor composition of the soil during a traverse with the XRFS hole detector to alert the scientific system when a new type of soil is found.

- Ground commands to obtain pictures and samples of soil and rocks to analyse the samples can be interspersed between mobility commands.

In addition to the reaction to ground commands, the adaptive system will be able to schedule its activities in response to priority equations transmitted by ground command. The following scientific and engineering functions will be automatically controlled:

a. Power/Battery Charge - Real-time surveillance of the power load allows the computer to schedule activities so a full battery charge is available before orbiter passage.

b. Thermal Control - If the thermal control system is unable to maintain proper operation temperatures, the adaptive system will control equipment needing protection so it will not be required to operate outside its operating limits.

c. Data Handling - In addition to coding and formatting of data, the adaptive system can permit autonomous selection of the degree of data compression required before transmission of TV data. For example, certain landscape panoramas should provide all the resolution and detail the camera is capable of, whereas, a view to show an obstacle around the rover need not be as detailed.

d. Orbiter Communications - In addition to providing maximum battery charge before orbiter passage, the system can require the rover to proceed until it is resting on a sufficiently level spot to provide optimum antenna coverage.

Typical navigation capabilities are shown in Figures 85 and 86. In Figure 85, A is the starting point and E is a desired destination. Between these points is a deep gully shown by the contour lines. To avoid this gully, the following commands are issued to the rover:

Proceed at heading h until your elevation is decreased by 1.5 meters, B.

Follow a contour with your left side facing down hill for a distance of 60 meters, point C.

Proceed to point E 35 meters north and 125 meters east of your starting point.

The rover uses a heading sensor and an odometer to keep track of its position, and at Point C it computes the heading that will take it to destination E. At D, however, it encounters an unforseen obstacle which it gets around on the third try. During the evasive maneuver, it keeps track of its position and recomputes the heading to destination E.

In Figure 86 the rover starts at the lander, point F, with these instructions:

Follow the path of steepest ascent to the top of a hill.

Take a picture.

Proceed to I, 65 meters south and 110 meters east of starting point F.

Proceed to M, 95 meters south and 38 meters east of F.

Proceed to P, 55 meters south and 10 meters west of F.

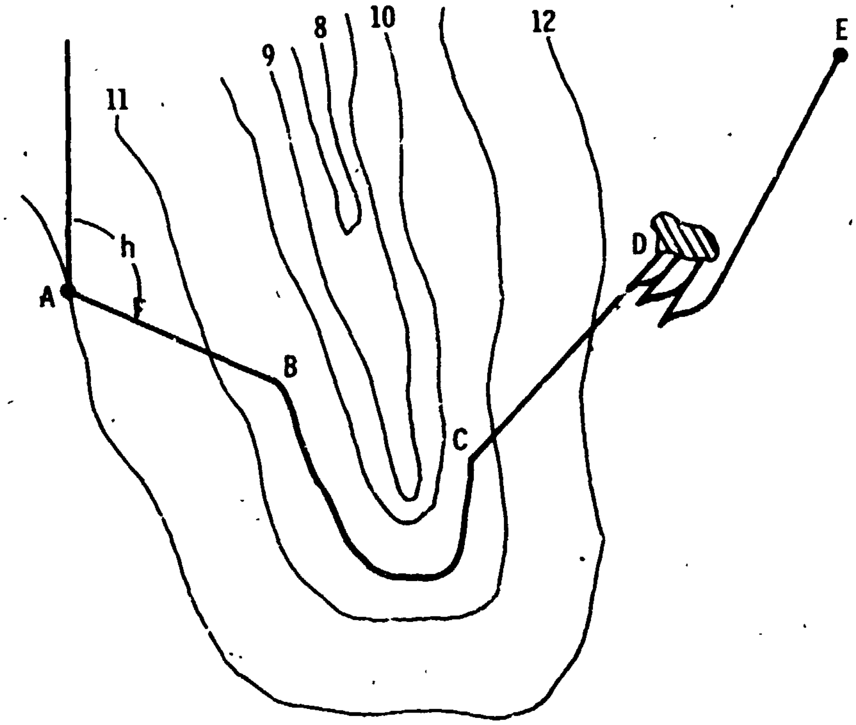


FIGURE 85 TYPICAL ROVER TRAVERSE - I

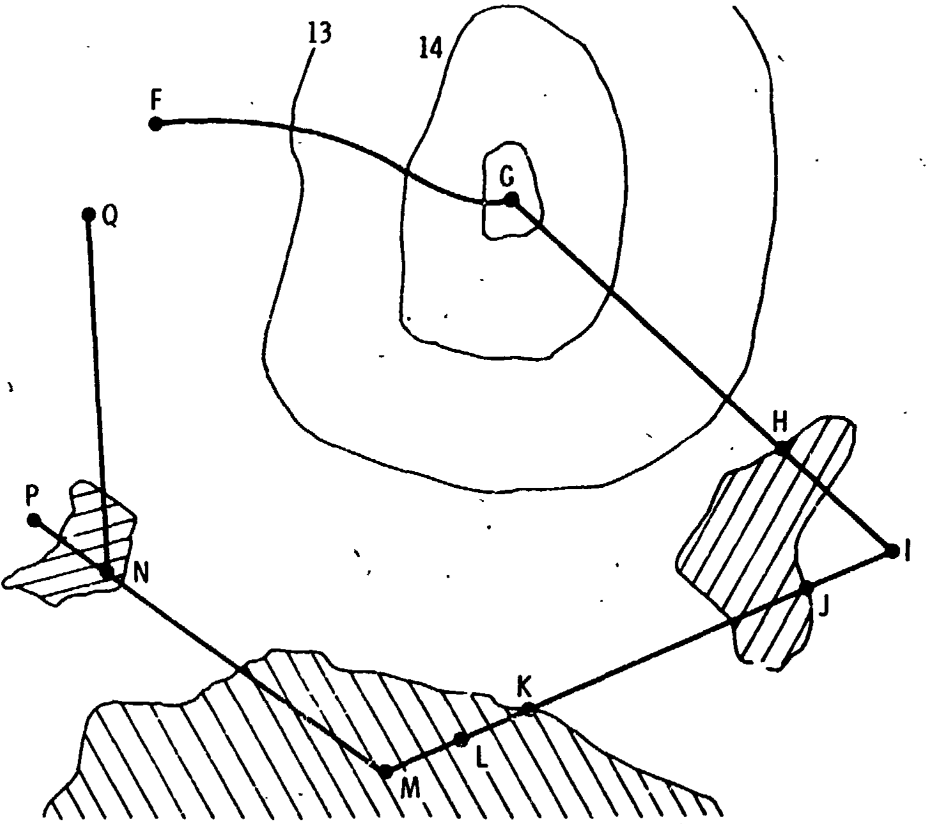


FIGURE 86 TYPICAL ROVER TRAVERSE - II

The hill climb takes place according to plan. At H a new type of soil is detected by the XRFS and the rover backs up, takes a picture, gathers a sample, and continues to the intermediate destination I.

It then starts the leg toward M. At J it again encounters the patch of different soil, but it does not take another sample because it remembers that it already has one of this type.

At K it enters a region of soil that is mechanically different from the surroundings. It detects this fact when it makes a routine check of traction coefficient at L. It takes a picture but does not pick up a sample because the scientific team that established the priorities did not consider mechanical differences interesting enough to be worth taking a sample back to the lander for detailed analysis.

On the way from M to P the XRFS detects a soil type that is so interesting that the rover reevaluates its priorities and heads immediately toward the lander at F. Because of inaccuracies in heading and odometer, it goes instead to Q, near enough for a rendezvous guidance system to take over.

Software Requirements

The software required to implement such an adaptive control system is shown in Figure 87 as derived from the sizing studies of ref. 9 and 10. These studies were based on the use of a computer/sequencer consisting of an 8-bit processor-on-a-chip and a solid state read-only memory.

Adaptive control includes basic housekeeping, power management, data processing and transmission control, and a full adaptive capability. This module is estimated at 5400 words.

Arithmetic functions include the floating point, trigonometric and double precision functions not available in the basic instruction set. These functions were coded under the referenced studies and require 1011 words.

Rover control includes navigation, hazard avoidance, computing hazard coefficient, motor control, and special features such as hill climbing and

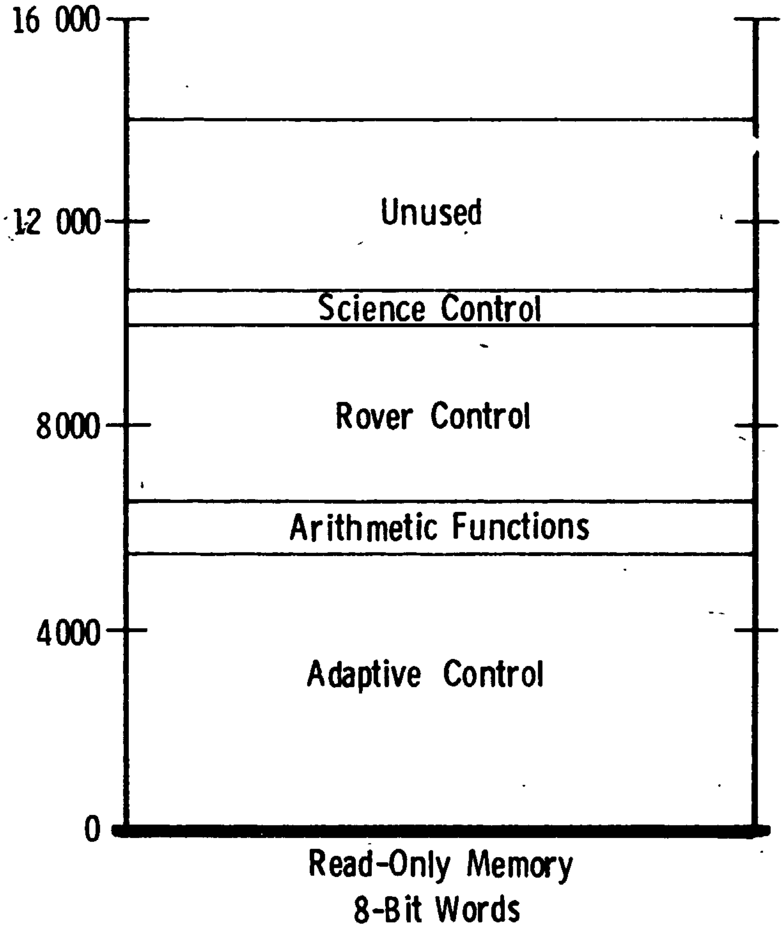


FIGURE 87 ROVER SOFTWARE STORAGE REQUIREMENTS

contour following. About 50% of the estimated 3600 words have been coded under the referenced studies.

Science control includes all sequences necessary to articulate instruments, set parameters, initiate data gathering, and route scientific data. This is estimated to require 650 words.

The routines required to implement the adaptive features are shown in Table 35 with a status code and the number of microcomputer programming words required.

An alternate executive that determines the priorities from a fixed set of equations is being programmed under the referenced study, rather than the more adaptive capability of routine EXEC. This routine, PRIOR, requires 386 words, resulting in a total sequencer storage of only 5363 words.

The coded portions of the software, which form the minimal or inflexible system in which the priorities of performing noncommanded actions are calculated from fixed logical relationships, is shown in Figure 88.

As shown in this figure, ground commands from the communications system are introduced at junction 1 and stored in a memory array. At junction 2 the next successive command is activated, branching the computer to a specific routine, which in general either controls the movements of the rover or the operation of a scientific instrument. The computer remains in the control of one of these commanded mobility or scientific routines until this action is completed.

Time sharing of the computer is required for those functions that cannot wait until a given course leg is finished. For example, in the case of one of the mobility routines, several mobility control routines must be sampled at regular intervals (e.g., once a second) to assure that the rover does not become struck on an obstacle or to up-date the dead-reckoned position of the rover.

At junction 3, the scientific and mobility routines must branch through routine (PRIOR or EXEC) to determine the priority of performing other possible operations. Once these priority determinations have been made, the computer branches to junction 4 where the present operation is interrupted whenever a new operation obtains a priority higher than that assigned to the present one.

TABLE 35 ADAPTIVE ROUTINES

NAME	DESCRIPTION	CODE*	WORDS
	Arithmetic routines	PR	1 011
DESTN	Directs rover to specific X and Y Position	PR	253
AZIMU	Direct rover along azimuth for specific distance	PR	75
CONTUR	Directs rover along constant altitude contour	PR	367
HILL	Directs rover up (or down) steepest slope	PR	296
SAMPL	Controls rover and scoop to take soil sample	PR	54
ROCK	Controls rover and scoop to select single rock	ES	75
PICTUR	Controls camera by providing control parameters	ES	75
GRIND	Controls sample carousel and grinder operation	ES	250
XRFS	Analyzes three channel spectral data	PR	328
ALPHA	Controls Alpha Backscatter instrument	ES	75
XDIF	Controls X-ray Diffractometer	ES	125
HED	Translates heading reference to proper format	ES	50
NAV	Maintains X, Y, Z position of rover	FR	282
HAZAV	Controls rover avoidance path around obstacle	FR	510
HI	Determines presence of a hazard	FR	132
TRACTN	Measures soil traction coefficient	FR	144
PWR	Controls battery charge	ES	175
THER	Provides temperature shutdown when limits are exceeded	ES	125
DATA	Data handling routine	ES	500
COMM	Controls rover attitude before communication	ES	75
EXEC	Executive that stores and processes priority and feasibility equations that determine rover scheduling	FR/ES	5400
			10 377

*CODE

PR - Routine is programmed but not completely checked

FR - Routine in FORTRAN; translate to machine language

ES - Size of routine is an estimate based on complexity

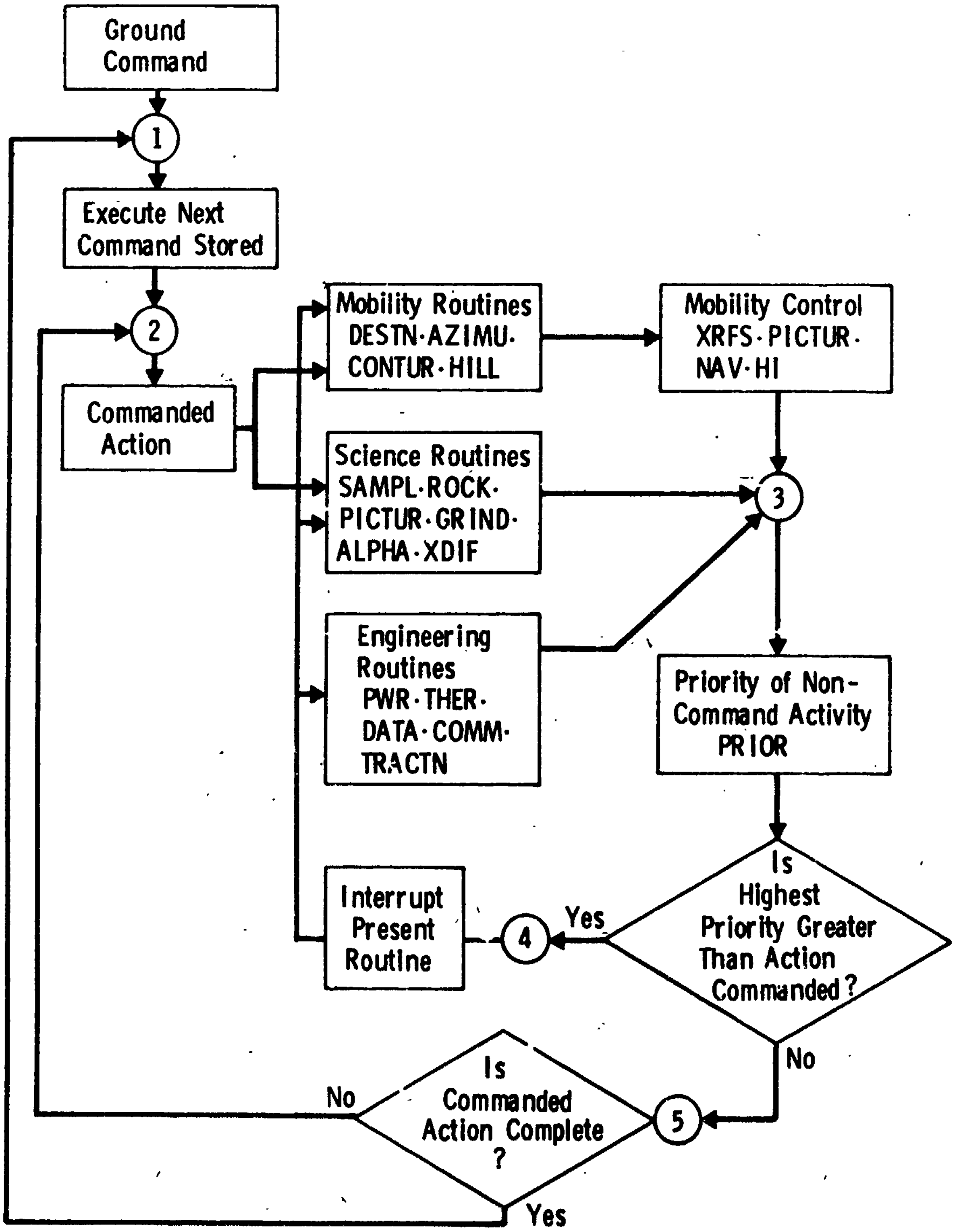


FIGURE 88 CONTROL SOFTWARE FLOW CHART

At this point, the higher priority routine is entered. Most mobility and scientific routines and all of the engineering routines may be assigned this higher priority. Generally speaking, engineering routines govern functions such as battery charge control that must be monitored on the rover rather than by ground control, due to transmission time constraints.

When the calculated priorities are all lower than the priority assigned to ground command, a decision is reached at junction 5 as to whether or not the present command action is completed. If finished, the computer branches to junction 1 to execute the next command; if not finished, to junction 2 to continue the present operation until it is completed.

Capability of Lander Guidance, Control, and Sequencing Computer (GCSC) to Perform Rover Control Function

One of the basic questions to be answered by this study concerns the capability of the lander GCSC to (1) perform the basic functions of rover check-out, off-loading and command/data interfacing, (2) perform the entire rover control function via the lander/rover communications link, and (3) the trade-off (if GCSC controls were feasible) between using the GCSC and an onboard rover computer/sequencer.

General GCSC utilization constraints. -

Memory - Additional memory capacity for both program and data could be obtained from three sources; full utilization of existing margin, overlay of unused data base once landed, and overlay of unused programs once landed. This is illustrated in Figure 89.

Time - Current estimate of GCSC-landed duty cycle is 1.5%. On the average little processing time is required, and indeed the "on" time is dominated by the overhead time required to awake, determine what to do (if anything), and return to sleep. Minimum wake time may be 10-100 msec, which would allow plenty of time for issuing commands to scientific devices and the like. If the rover science and subsystems were treated in a manner similar to Lander science (i.e., no adaptive science) then there would be ample computation time.

Power - The real constraint on GCSC utilization is power, or energy consumed. The GCSC duty cycle is sensitive to wake up period (nominal 180 s),

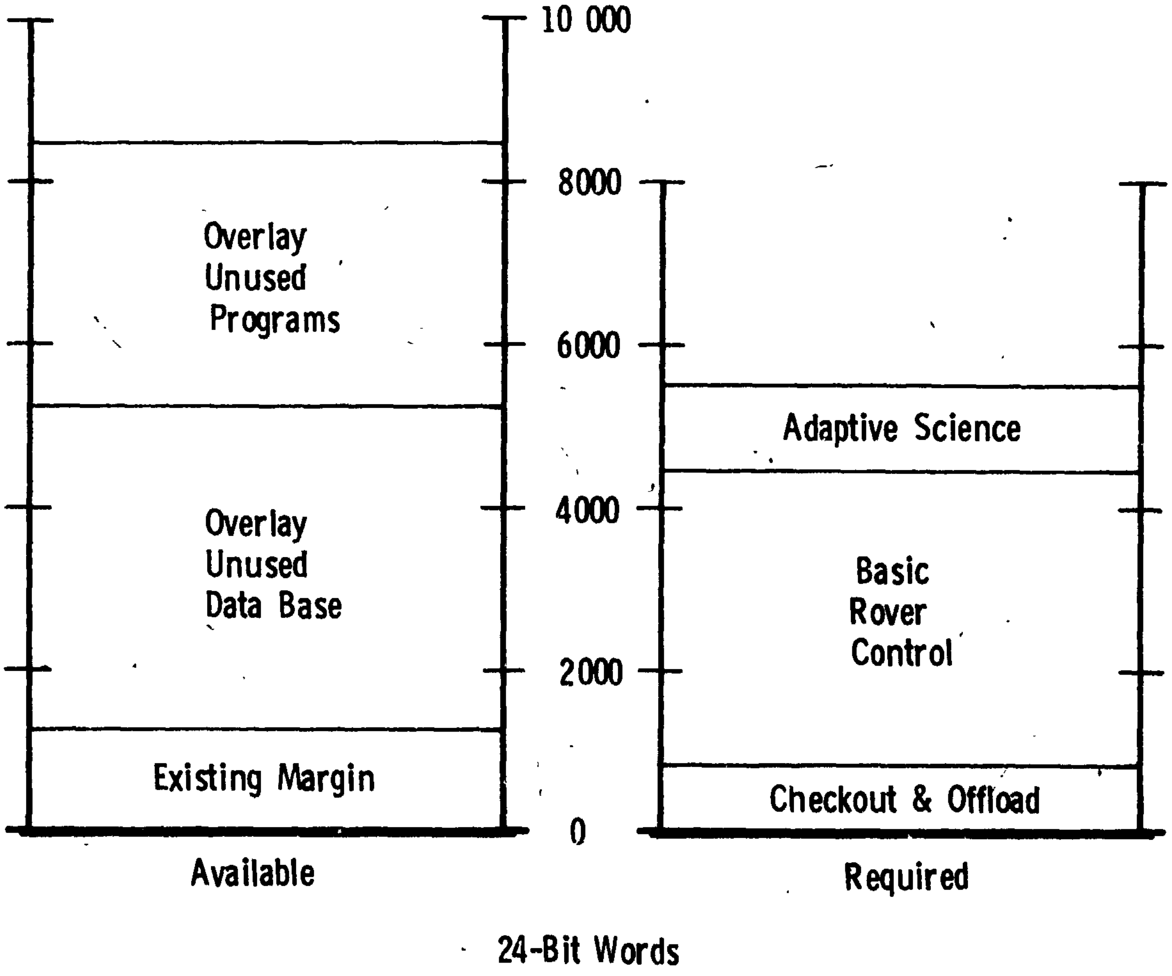


FIGURE 89 GCSC STORAGE

and memory readout during communication periods. Such activity has to be tightly controlled by Flight Operations to keep the average duty cycle within acceptable limits.

For example: Assume a wakeup on 1-second boundaries with minimum "on" time of 10-100 msec. This is commensurate with rover control and rover science data acquisition. Taking the power switching overhead into account, the resulting duty cycle could vary from 3 to 13%. This would be acceptable for several hours per day but would require careful energy management. During each wake period 600 to 7000 instructions could be executed.

Thermal - Once landed there is no known thermal problem with the GCSC, even with 100% duty cycle for long periods.

Science Data Access - One spare experiment channel currently exists on the GCSC. This channel has full logic, circuitry, addressing and connector space for command output, data output, and status input (each up to 24 bits via register R1). Spare interrupt and discrete lines also exist. If the XRFS experiment were removed from the lander, one more channel, as described above, would be available.

Plenty of I/O addressing space in the I/O command word is available for additional registers and devices, but not implemented except as indicated in the preceding paragraph.

The GCSC does not have access to telemetry system data [(nor is there a datum signal path to or from the buffer memory (DSM or tape recorder)]. This is the most serious deterrent to adaptive science via the GCSC. Lander control of the rover data science could be accessed and processed like engineering data (a few 24-bit words/s) for limited adaptive science based on rover data.

Note

> At 16 kbs serial data rate, it requires 1.5 msec/ GCSC word or a maximum of 67 words in a 100 msec period (wake time).

Rover checkout capability. -

Prelaunch - In the lander this process is currently overlaid before launch (prelaunch is 1000 words). The rover prelaunch checkout could be accommodated in the same manner. The impact is solely that of a new rover checkout program and data, 500 words maximum.

Preseparation - Unless there is an alternate device or process to be selected at separation, preseparation checkout will not be required.

Landed Initialization - Checkout should be accomplished before rover off-load. The off-load sequence will require 160 words. This is the sole impact of rover on lander flight software after launch through landed initialization. Uplink will provide rover related code and data incrementally after landed initialization.

Memory sizing for GCSC control of rover. -

Sizing - The rover sequences are based upon an 8-bit word processor vs the 24-bit GCSC. A straightforward 3:1 ratio for sizing is not applicable for a variety of reasons that include data packing inefficiencies, differences in operation codes, completely different internal structure, and the like. Trial examples based upon preliminary coding yielded a ratio of 2:1 through 2.5:1.

A conservative ratio of 2:1 was used to obtain the GCSC estimates shown in Figure 89, with the basic arithmetic operations of GCSC plus the existing Math Utilities routines eliminating the need for the 8-bit machine floating point/basic arithmetic package.

Memory Loading - Command data to the lander is accommodated at the rate of one word each eight seconds. During a two hour communication period, 900 words could be uplinked. Uplink, with suitable procedures, may be used to change both data and programs, including program overlay. Before separation from the orbiter, it may be useful to consider overlay after preseparation checkout.

Conclusions. - The existing GCSC has the capacity to accommodate rover science and engineering functions with minimal change, if the current lander philosophy prevails (i.e., no science data processing other than control). No hardware changes are required.

Tradeoff Between GCSC and Rover Sequencer

Because the GCSC was determined to be a feasible option for rover control, a tradeoff study was performed between the two options. This tradeoff is summarized as follows.

Using the GCSC for rover control. - This option requires a continuous communications link with the rover. Thus there exists no lander-independent mode of operation. Also, the lander transmitter must be on continuously during the mobility mode, drastically increasing the lander power drain.

The GCSC duty cycle is increased to approximately 13%, implying a further 5 watt average power consumption during mobility mode.

To avoid hardware modifications that would be required to increase the GCSC memory size for the rover control software, this coding must be overlayed after landing. At an effective uplink bit rate of 3BPS, this would require a minimum of 15 hours to load the memory, exclusive of memory checking and retransmission to correct errors.

To provide adaptive science capability, the GCSC would require acces to the science data, implying changes to both the Viking '75 philosophy and the hardware.

Providing a rover sequencer. - The sequencer must be developed and built, an obvious dollar cost. Note, however, that a considerable portion of the hardware is involved with the input circuitry for the various sensors and the output drivers, which must be built in either case.

The rover sequencer would carry a mass penalty of less than 1 watt and less than 1.36 kg (3 lb) (exclusive of the I/O) based on the use of C/MOS memories and other circuitry, and the use of an LSI processor-on-a-chip as the heart of the arthimetic and logic unit.

Selection. - The rover sequencer was selected based on the small mass and power penalties on the rover, against the larger similar penalties on the lander, and the capability to have a lander-independent rover.

Rover Sequencer Hardware Description

The hardware sizing is based on the design of a demonstration sequencer developed under ref. 10. A functional block diagram of such a sequencer is shown in Figure 90. It is to be noted that some functions required in the sequencer are also required in the Data Processor and therefore one set of hardware will be used for both.

Existing C/MOS ROM technology provides 1024 x 1 bits per chip, requiring 110 chips to provide the 14 080 word ROM. The RAMs are available in 256 x 1 bits per chip, requiring 64 chips to provide the 2048 word storage. An estimated 100 chips are required to provide the remainder of the circuitry, including memory and processor chip interfacing, and the I/O. Note, however, that no consideration has been given to any form of redundancy or error checking anywhere in the system.

A brief comparison is shown in Table 36, between a single string of the GCSC and the rover sequencer.

When comparing the GCSC and the rover sequencer, the following points should be considered:

The GCSC size, speed, and complexity are driven by the requirements of the entry mode. In the landed mode, which is a better comparison for the rover sequencer requirements, the GCSC uses only a small percentage of its capability.

The rover has a centralized clock and regulated power supply and a common chassis, so these are not charged to the sequencer.

The rover sequencer I/O is all parallel, and requires none of the I/O management of the GCSC. Any parallel to serial conversion is charged to the various devices.

The rover sequencer is a slower machine, has no sleep mode, and essentially no interrupts.

The present design is single string, and has no malfunction detection, no self test, no parity checks and, of course, no switch-over capability.

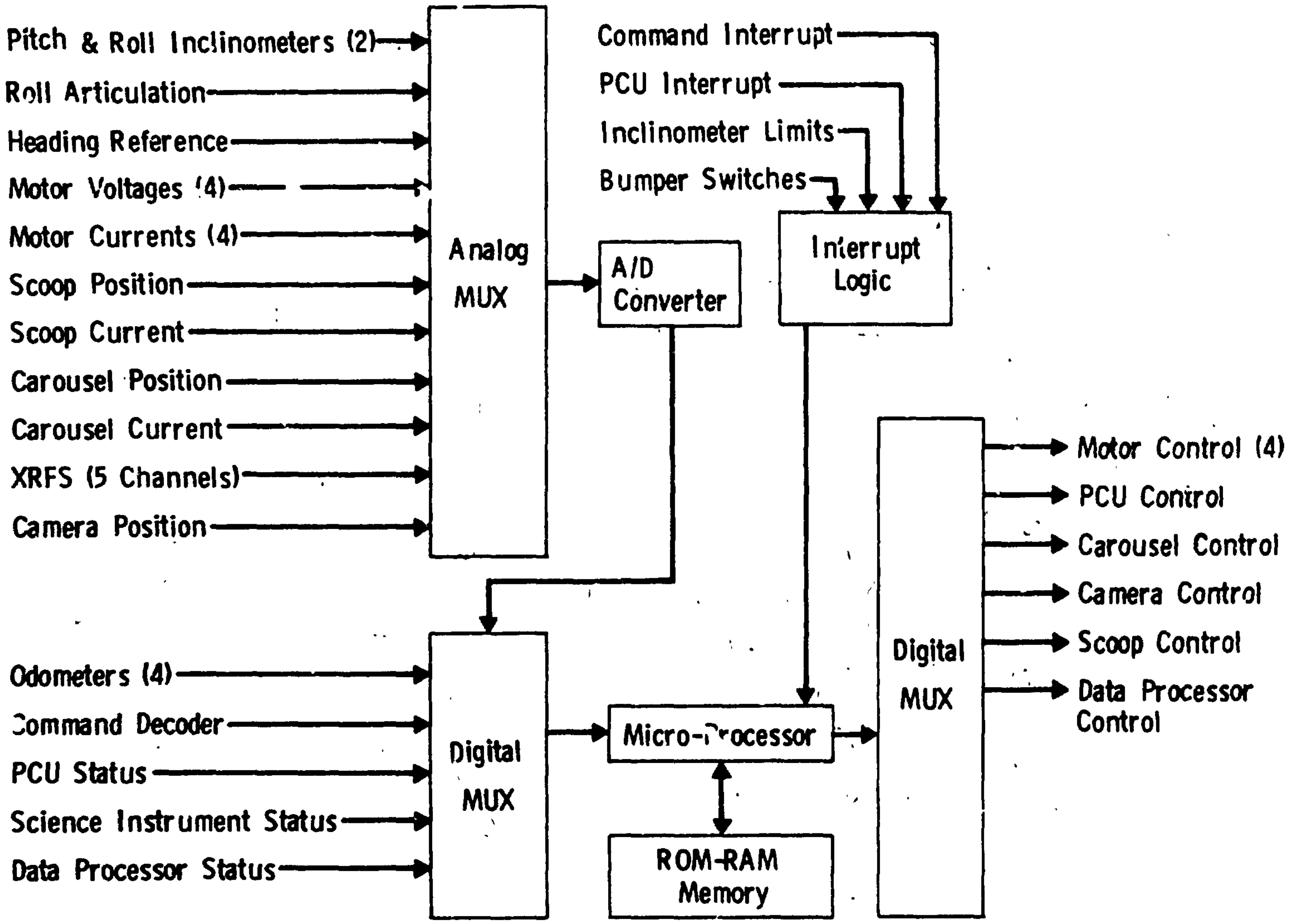


FIGURE 90 CONTROL SEQUENCER FUNCTIONAL BLOCK DIAGRAM

TABLE 36 GCSC/ROVER SEQUENCER COMPARISON

CHARACTERISTIC	GCSC	ROVER SEQUENCER
Parts Count	3800 on 12 Boards (Single String Processor and I/O Only)	275 on 5 Boards
Design Maturity	Old design but quantity built has been less than 100	New designs, but builds of 100 000 processor chips not unusual by 1975
Technology	Discrete parts + MSI	MOS/LSI
Memory Type	2-mil plated wire Was New Technology	MOS semiconductor now off-the-shelf
Memory Storage	18K 25-bit words	14K 8-bit words
Computational Speed:		
Add Immediate	9 Microseconds	40 Microseconds
Add Value From Memory	9 Microseconds	120 Microseconds

A summary of the physical parameters of the rover sequencer are as follows:

Mass - 0.45 kg (1 lb)

Power - 2 watts

Electronic Configuration, based on 16.5 cm by 33 cm (6.5 by 13 in) cards

Processor and I/O - 2 cards

Memory - ROM - 2 cards

RAM - 1 card

Recommendations for Future Study

Most of the rover sequencer conclusions and designs are based on the work of references 9 and 10. Future efforts should verify the conclusions for the particular Viking '79 rover application and should include:

A more detailed software sizing study for the rover sequencer, with particular emphasis on the tradeoff between various word lengths available using the C/MOS devices.

A definition of the nominal error checking or redundancy required, and the associated additional hardware.

A more detailed study of the I/O portion of the sequencer, which is the most uncertain area in hardware requirements.

A continuing effort to keep abreast of the development of higher density C/MOS memory chips and flight qualifiable processor-on-a-chip LSI devices.

An analysis and tradeoff between the baseline solid state RAM and a small core or plated wire memory to provide the required read/write capability, considering mass and power penalties of the alternates versus the power transient susceptibility of the baseline system.

6.9 LANDER/ROVER INTERFACE MECHANISMS

Stowage

The rover will be stowed in the position shown in Figure 91 as defined in Section 3. The rover chassis will be attached structurally to the lander body at three points as shown in Figure 92. All the static and inertial loads generated by the rover from earth liftoff to landing on Mars will be reacted into these three points that have tension and shear capability. The tension attachments between the rover and the lander will be accomplished with a bolt/pyrotechnic release nut. The nuts will be located and fired from the lander side of the interface as shown in Figure 93. The rover side of the interface will provide extraction and retension of the bolt. The shear in the joint will be transferred by a ball and socket arrangement. The rover loads will be reacted into the lander body side beams.

The Viking '75 lander body will be modified as follows to accommodate the rover attachment hardware. The No. 2 terminal engine supporting bracket will be replaced with fittings that incorporate the rover mounting provisions, the terminal descent engine supports, and the off-loading mechanism provisions. The upper and lower chords of the side beams will be strengthened with additional fittings to accommodate the increased load of the rover.

The rover will interface with the off-loading mechanism as shown in Figure 92. The interface between the off-loading mechanism and the rover will consist of two bearing pads and a tension tie. The tension tie will be accomplished with a pyrotechnic pin puller that is mounted to the rover side of the interface. The off-loading mechanism is powered from the lander side of the interface. The pin puller, which releases the rover from the lander, is fired from the rover side of the interface. The rover will have an electrical connector interface between the rover and the off-loading mechanism. This connector will be separated at the same time that the rover is released mechanically from the lander. The rover will have an interface with the RTG radiation shield attached to the aeroshell. The metal parts of the radiation shield will have a

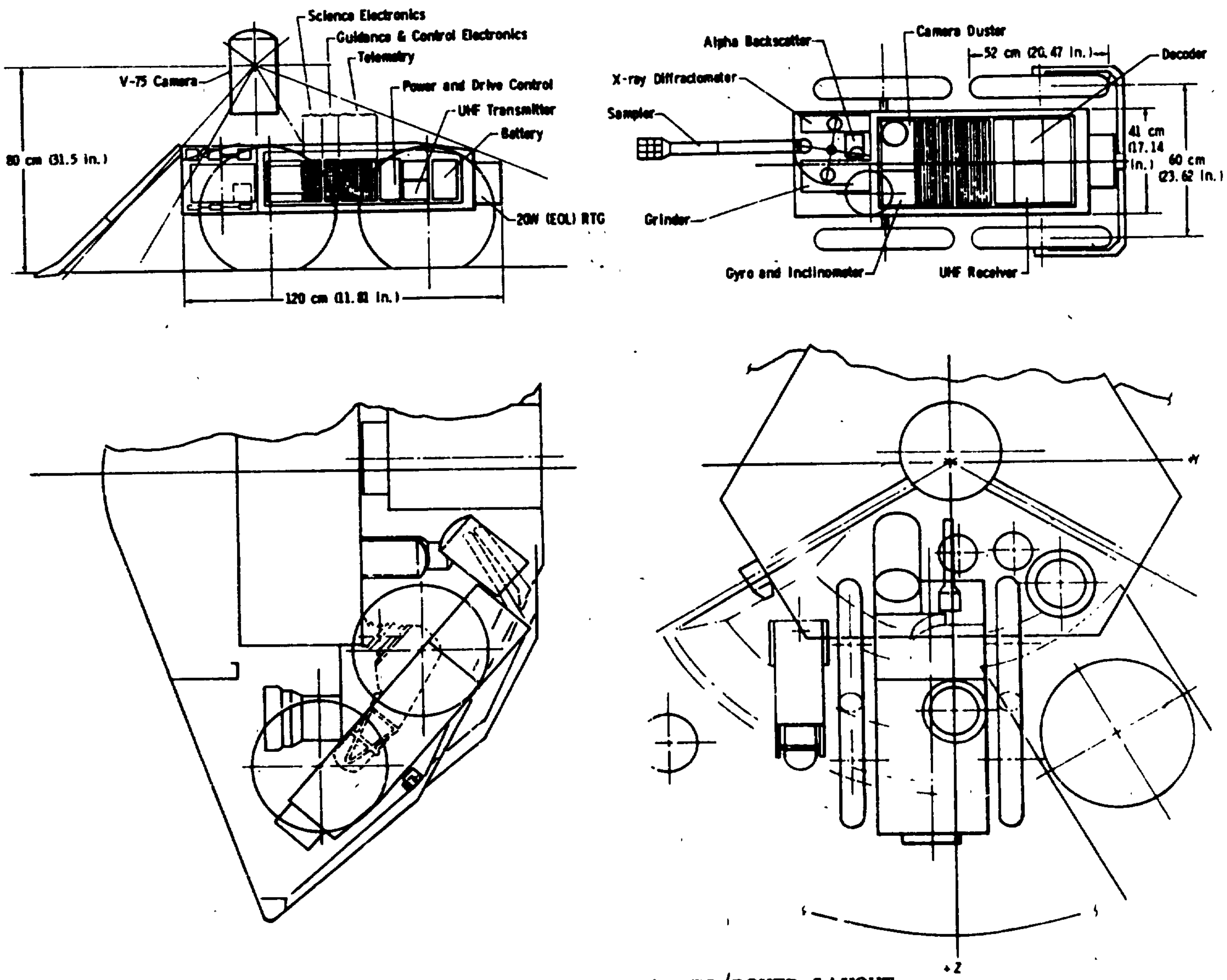


FIGURE 91 BASELINE LANDER/ROVER LAYOUT

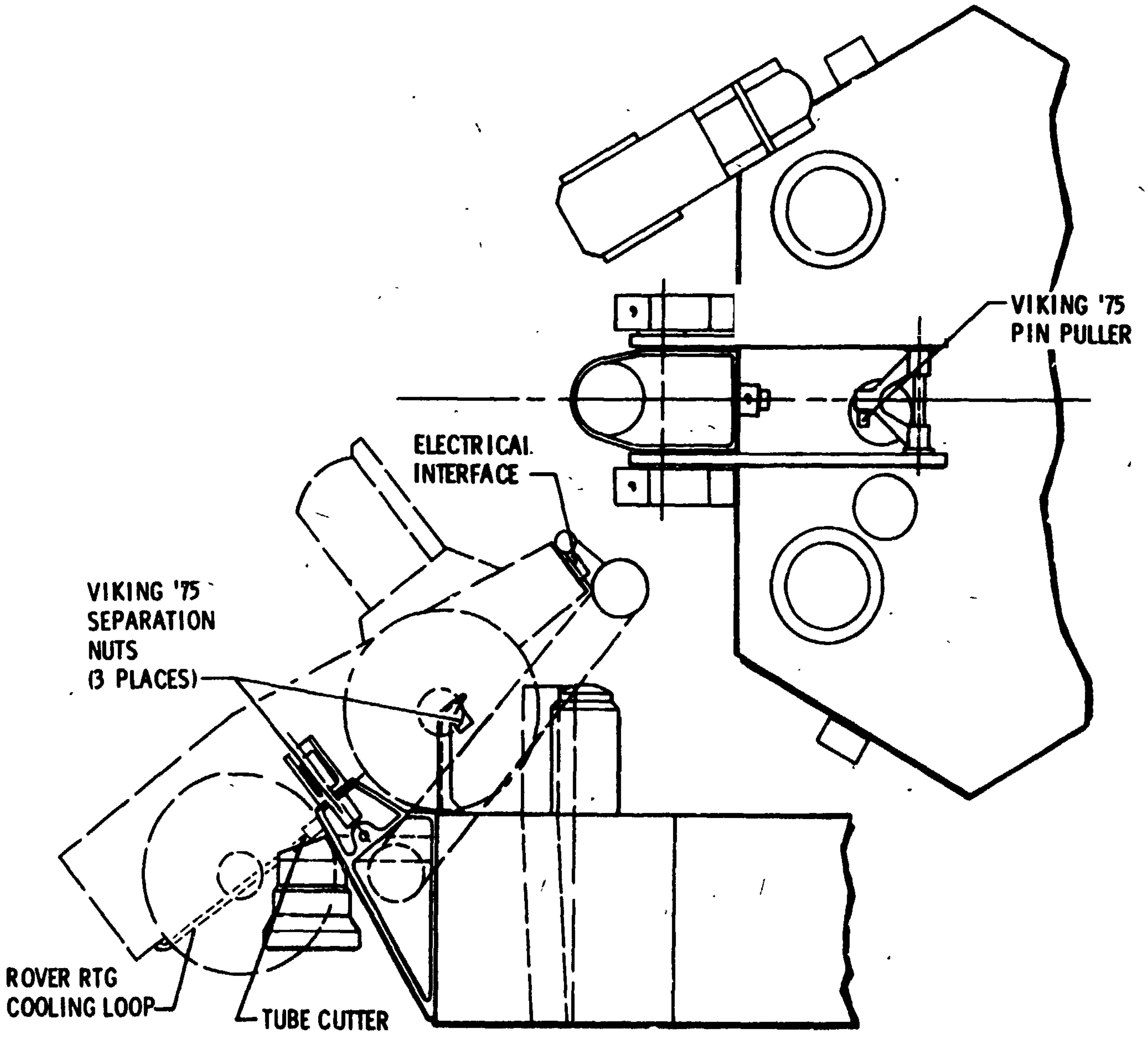


FIGURE 92 LANDER/ROVER INTERFACES

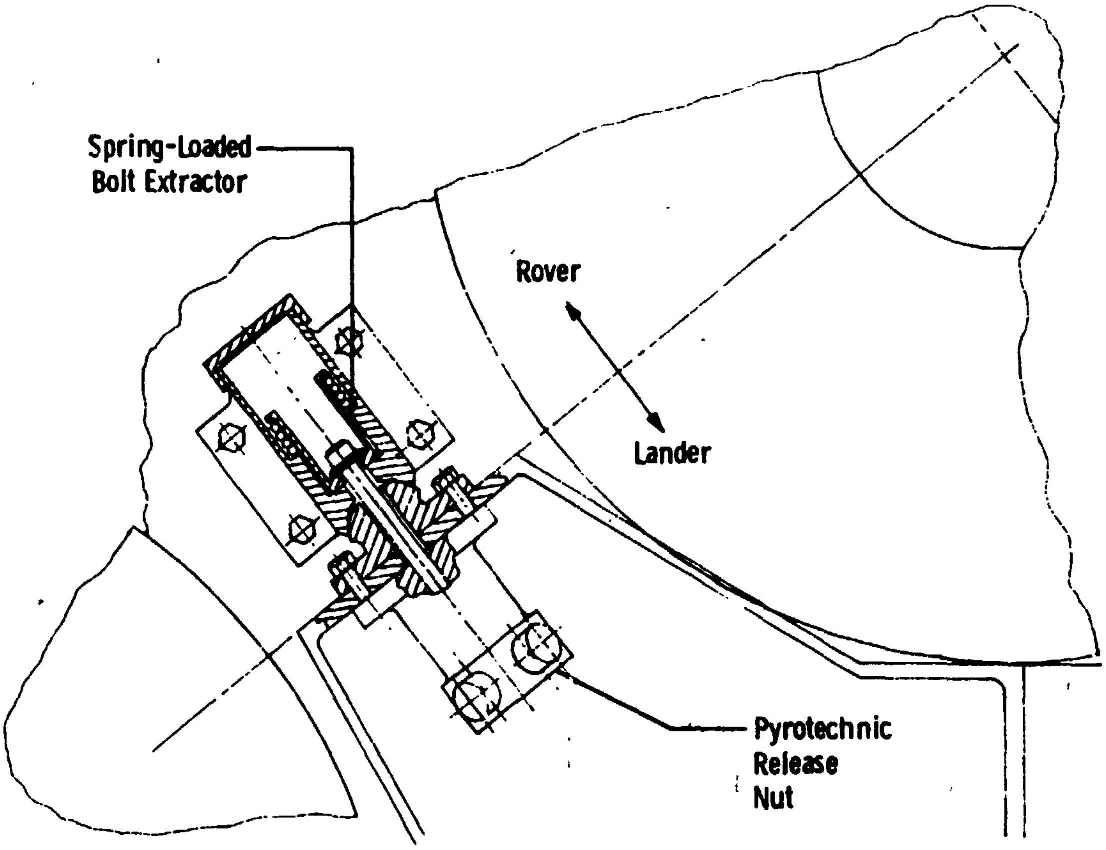


FIGURE 93 LANDER/ROVER SEPARATION CONCEPT

minimum of 3.8 cm clearance between the rover and the radiation shield. A flexible membrane will attach the rover to the radiation shield. This membrane will be designed to tear away when the aeroshell is released.

Four candidate offloading mechanisms were considered during this study. These are the (1) crane concept, (2) rail concept, (3) tip-off concept, and (4) linkage concept. The motion necessary to offload the rover is a combination of elevation and translation. The concepts are illustrated in Figures 94 through 97. The candidate concepts were evaluated against the following criteria: system mass; ability of the system to accommodate sloping surface terrains and rocks; interference between the system and normal surface sampler activities after the rover has been offloaded, and system complexity. Each of these systems is discussed in the following paragraphs.

The rail system, shown in Figure 94, uses two rails, one on each side of the terminal descent engine. The rails are stowed in a folded position. After landing the rails are deployed and raised to an elevated position by spring-loaded actuators. The rover backs down the rails under its own power. As the rover moves further away from the lander, the increasing moment causes the actuators to compress, lowering the rails and the rover to the surface. The actuators can be sized to accommodate both positive and negative sloping terrains for any given rover mass by varying the spring rate of the actuator springs and the length of the rails. The distinct advantage of this system is that it uses the rover power for offloading and does not require an additional drive system. A disadvantage is that the rails, after the rover is offloaded, severely reduce the normal surface sampling area. To overcome this problem the rails could be removed from the lander after offloading. The removal could be accomplished with pyrotechnic disconnects.

The tip-off system is shown in Figure 95. This system supports the rover from the aft end. After landing the rover is pivoted upwards until it is almost vertical; rotated 180° about its longitudinal axis, and then pivoted downward until the wheels contact the surface. At this time the rover is disconnected from the lander with a pyrotechnic release. These motions can be accomplished with a motor drive system to accomplish the pivotal action and a combi-

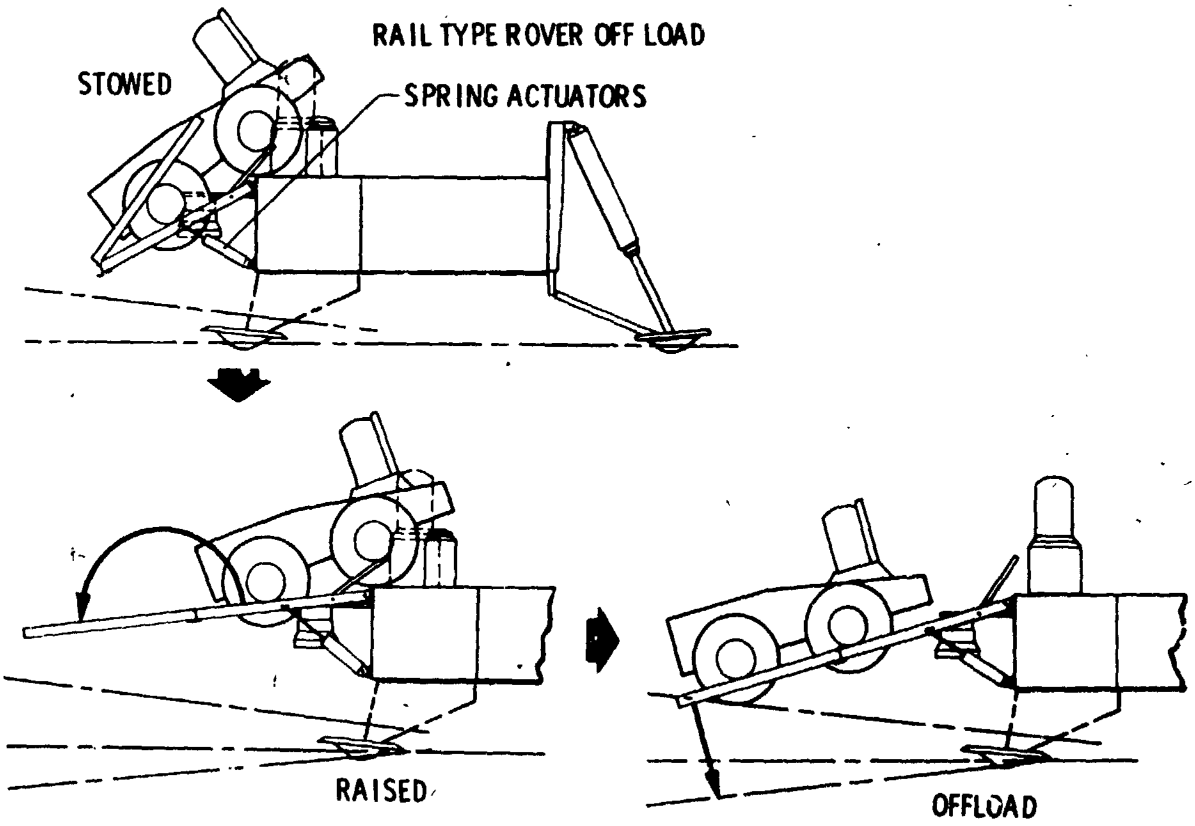


FIGURE 94 ROVER RAIL SYSTEM OFFLOADING

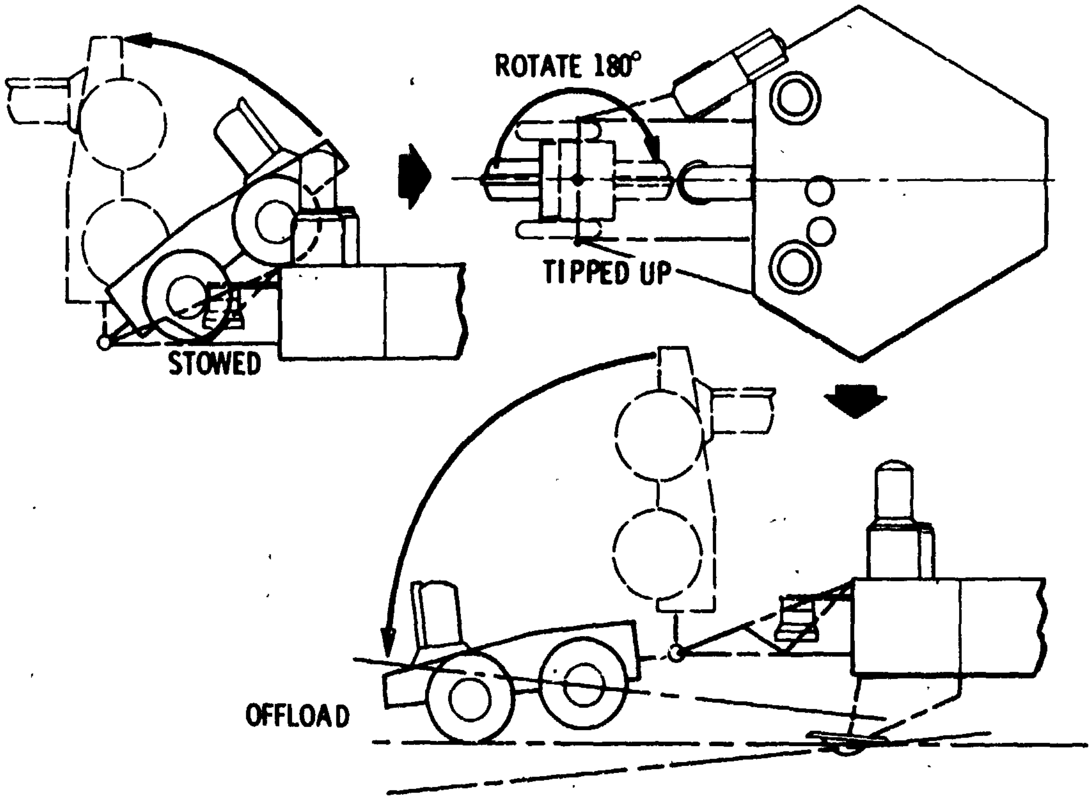


FIGURE 95 ROVER TIP-OFF SYSTEM OFFLOADING

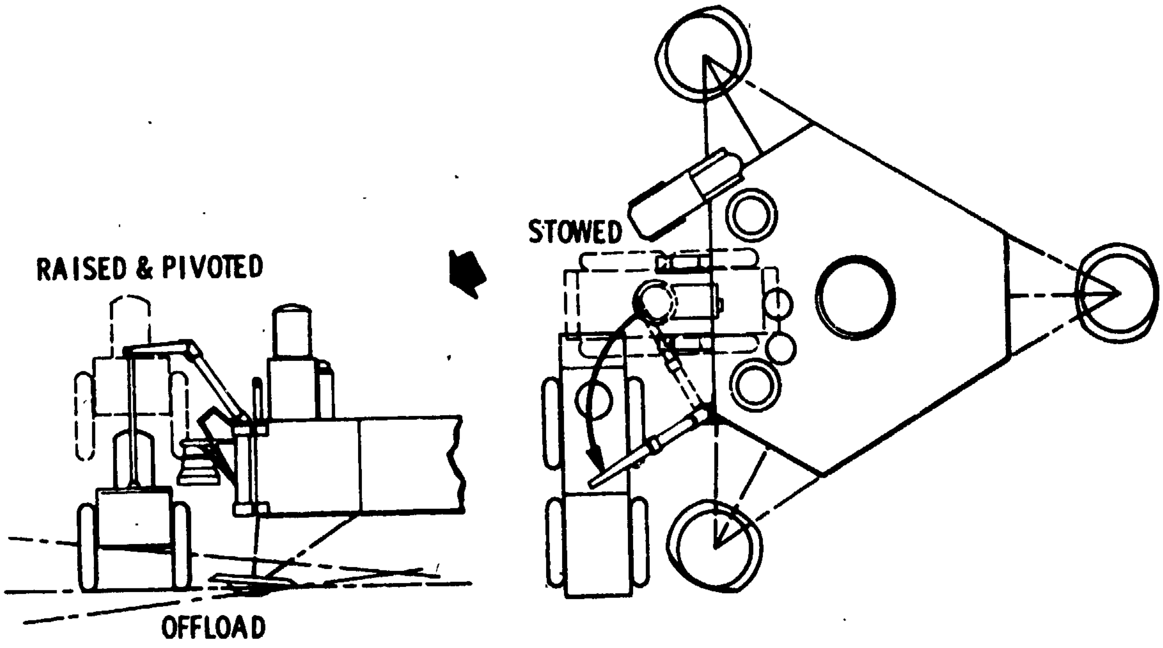


FIGURE 96 ROVER CRANE SYSTEM OFFLOADING

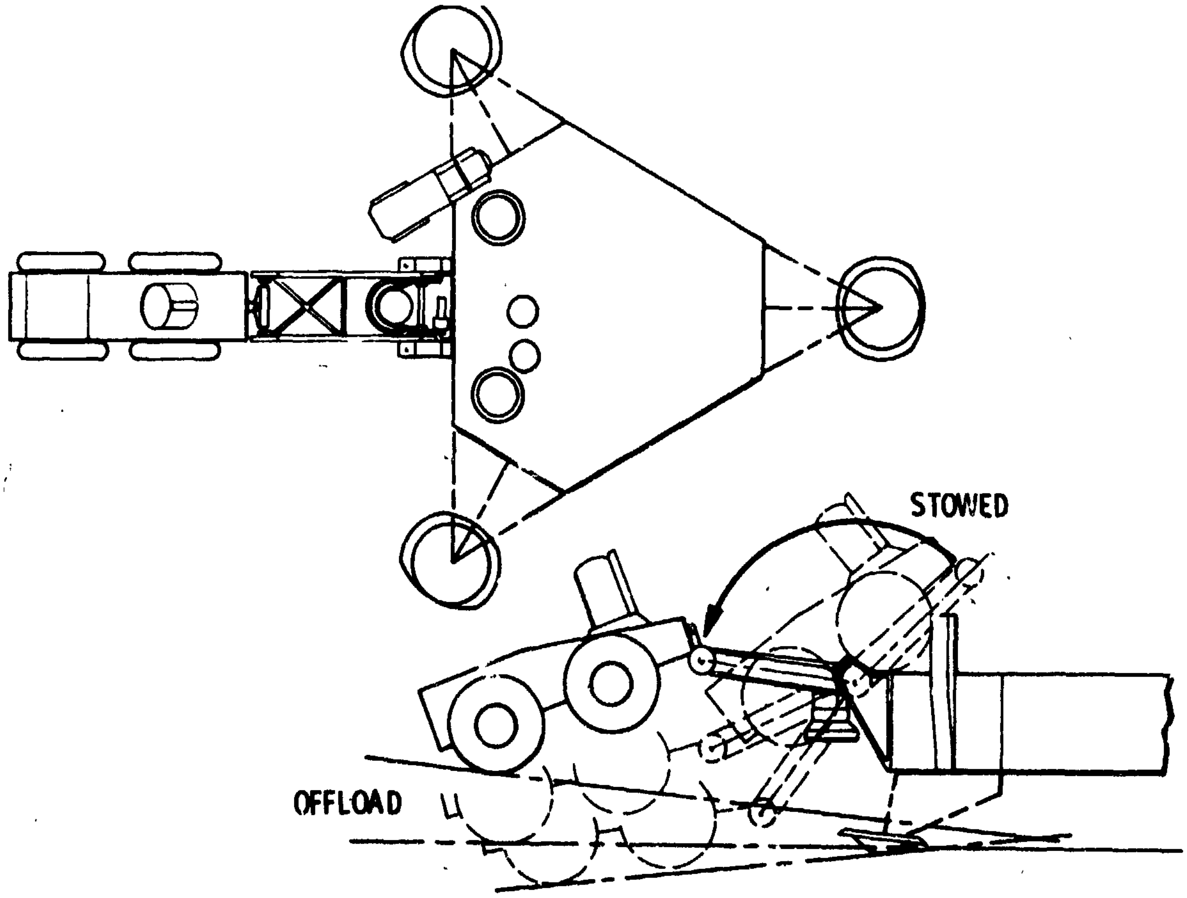


FIGURE 97 ROVER LINKAGE SYSTEM OFFLOADING

nation of bevel gears and stationary shafts to accomplish the rotary motion. The primary advantage of this system is that it permits the rover to be stowed with a wheel nested around a fixed lander component. The minimum lander change rover described in Chapter 5 requires this offloading system. The disadvantage of this system is that it leaves a fixed structure to interfere with the lander sampler activities. To eliminate this problem the structure would have to be disconnected from the lander after the rover has been offloaded.

The crane offloading system shown in Figure 96. This system incorporates a boom that is attached to a corner of the lander body. The crane stows above the rover. The crane manipulates the rover with a pulley and cable arrangement. After landing, the crane lifts the rover, swings it into position over the fixed components on the lander, and lowers it to the surface. The rover is released from the cable with a pyrotechnic release. The preceding motions can be accomplished with a motor-driven winch and a series of off-center pulleys and latches. Advantages of the crane system are that it has some flexibility for positioning the rover before lowering, and the system can accomodate large relative angles between the lander and the local terrain.

The linkage offloading system shown in Figure 97. This system consists of a link with tension straps. The system action is similar to the operation of a pivotal arm drafting machine. After landing the system is actuated by a motor drive system. The rover is held at a constant angle relative to the lander until the rear wheels of the rover contact the surface. After the rear wheels contact the surface, the tension strap goes slack and the link continues to lower the front end of the rover. The rover is disconnected from the link mechanism with a pyrotechnic release, and the link continues to rotate downward until it is completely out of the soil sampler path. The system has the advantage of being able to accommodate large angles between the lander and the local surface.

Selection

The linkage system was selected as the baseline system. A mass analysis of the various systems shows that all the concepts fall between 7.75 and 9.0 kg. This slight difference is not considered significant because of the level of detail at which the masses were attained; therefore, the selection was made on the basis of the linkage system being a simple single motion and its abilities to accommodate large positive and negative relative angles between the lander and the local terrain.

Sampler Transfer

A brief study was conducted into methods of transferring rock and soil samples from the rover to the lander for analysis by lander instruments. While many candidate systems exist, including those requiring docking maneuvers, a relatively simple system was devised that requires minimum changes to the lander and no docking maneuver.

The rover sampler will be designed so it can dump a sample. The lander sampler collector head will be modified by adding a cup as shown in Figure 98 and a funnel-shaped guide that runs from the front of the rover to the rover sample dump will be designed into the rover sampler.

A typical sample transfer sequence would be as follows. The rover would return to the lander with a stored sample. The rover would be commanded to position itself within the operational field of the lander soil sampler, and within view of the lander camera. The rover camera and the lander camera will photograph the relative positions of the two vehicles. The relative positions will be analyzed on the ground and commands will be sent to the lander to instruct the lander sampling system of the exact position of the rover sampling dump. The lander sampler will extend and position its collector head in the rover dump chute as shown in Figure 98. The funnel-shaped guide will compensate for small errors in positioning. The rover will dump the sample into the lander cup. The lander then will proceed to dump and analyze the sample.

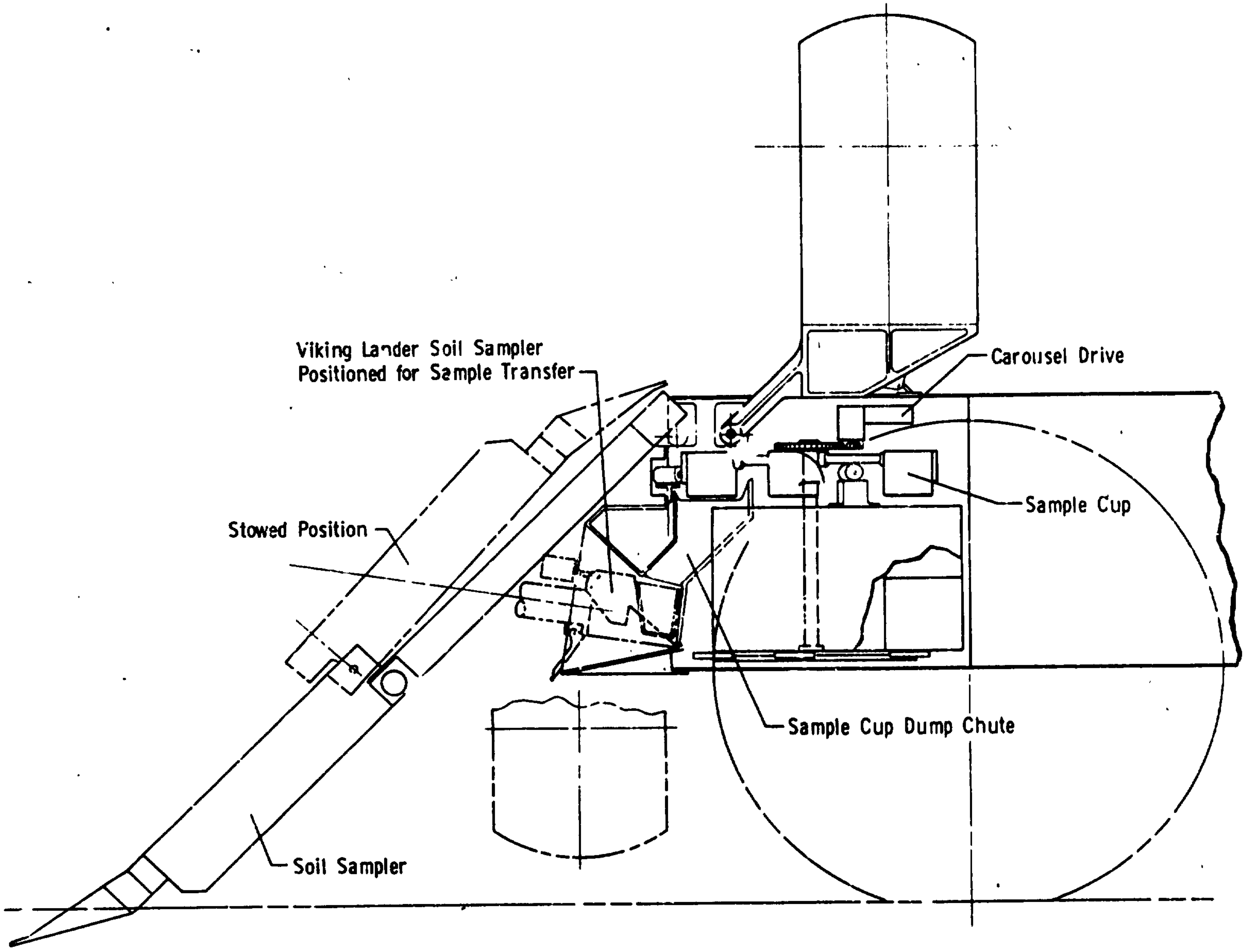


FIGURE 98 ROVER/LANDER SAMPLE TRANSFER

7. BASELINE ROVER SELECTION AND DESCRIPTION

Introduction

The baseline rover configuration was selected through a process of studying different configurations as discussed in Section 5. Each of these configurations was based on a different set of criteria. The study and evaluation of this wide variety of configurations was valuable in that we were able to assess the inherent advantages and disadvantages of each and select a baseline configuration that contains the largest number of desirable features.

The maximum rover mass (107.95 kg (238 lb) and volume (116 000 cc (7080 cu in.) are provided in the baseline configuration as determined from these studies. The baseline configuration also has the capability to operate through the lander or through the orbiter. From our lander-dependent rover studies it was determined that insufficient power was available to perform rover guidance and navigation computations on board the lander, therefore, the baseline rover is capable of performing these functions on board. Further, the rover was constrained to operate within a 6 to 7 km range of the lander. It was determined that the science mission would be greatly enhanced by the capability to leave the lander and examine areas at greater distances. This eliminated all lander-dependent configurations and focused our attention on lander-independent or orbiter-dependent rovers that used an orbiter/rover UHF link for commands and data. Evaluation of this class of rovers pointed out the need for a large amount of data storage on board the rover to allow the collection of imagery data at various times during the day. (The large data storage capacity on board the lander was used for this purpose in the lander-dependent rovers.) Studies of the lander-independent rovers concluded that the mass and volume for a 5-10 M-bit data storage unit was not available on board the rover. Thus, the selected baseline rover is configured so it can communicate with both the lander and orbiter providing the capability to take imaging data at various times during the day when near the lander and to leave the lander and explore distant areas (40-50 km range), taking pictures in real time only when in communication with the orbiter.

The baseline rover contains the 21 kg (46 lb) science payload recommended by the Rasool Committee, which provides the capability to perform scientific analysis of the wide variety of surface samples available within range of the rover.

The candidate vehicles in Section 5 featured either hybridized C/MCS microelectronics or Viking '75 electronics technology for use in the bulk of the rover's electronic subsystem. Viking '75 electronics technology was selected for the baseline vehicle to minimize developmental risks.

A summary description of the baseline rover and its performance characteristics are described in the following paragraphs. The baseline rover block diagram is shown in Figure 99.

Baseline Rover Description

Rover system layout. - The baseline rover is shown in the stowed position and operational configuration in Figure 100. The Viking entry capsule defines the maximum rover dimensions. The rover is stowed above the No. 2 terminal descent engine in the lander capsule with the wheels in the operational track width and wheel base position (i.e., wheel deployment is not required). The rover RTG is located at the aft end of the rover so when stowed the RTG is near the base cover and RTG heat generated during cruise can be radiated to space.

Table 37 is a mass breakdown for the baseline rover. The rover subsystem total of 90.26 kg includes 20.9 kg of science, with 20% of the total allocated for contingency. The total baseline rover mass is 107.95 kg. Table 38 incorporates this rover plus the baseline lander science changes, the new RTGs, and the regulated propulsion system to arrive at a landed dry mass of 719.25 kg. Tables 39 and 40 use this landed mass, build the masses to the total launch mass, and compare these masses to Viking '75 mass. Tables 41 and 42 show the mass properties for the baseline system. With the baseline rover configuration, 15.68 kg of ballast on the -Z side of the aeroshell is necessary to adjust the c.m. to the 4.19 cm.offset. The Y c.m. offset is -2.032 cm.This offset gives a 29° angle between the entry capsule pitch plane and the Z-Z axis. If the Y offset is nulled out so the c.m. lies on the Z-Z axis, the ballast required is 20.9 kg.

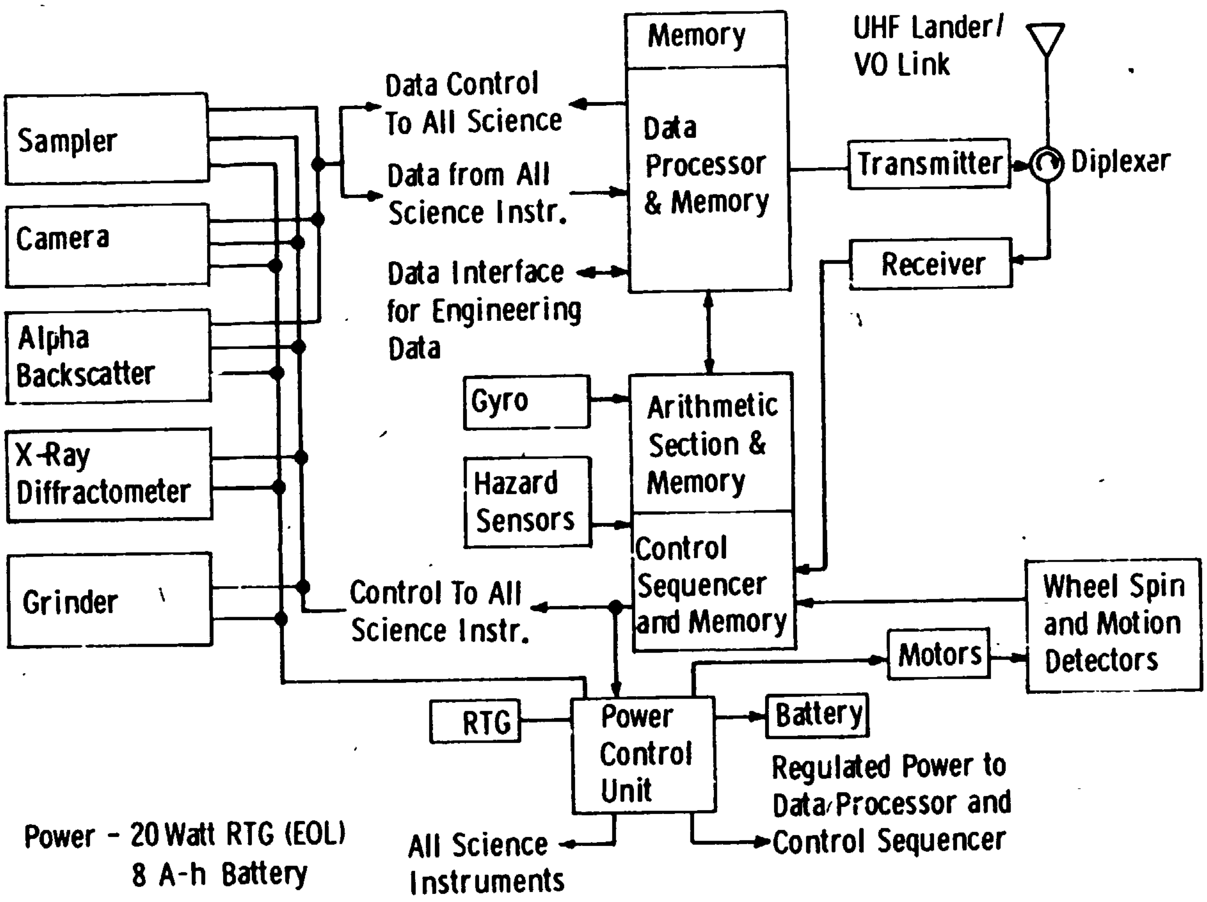


FIGURE 99 BASELINE CONFIGURATION, ELECTRONICS BLOCK DIAGRAM

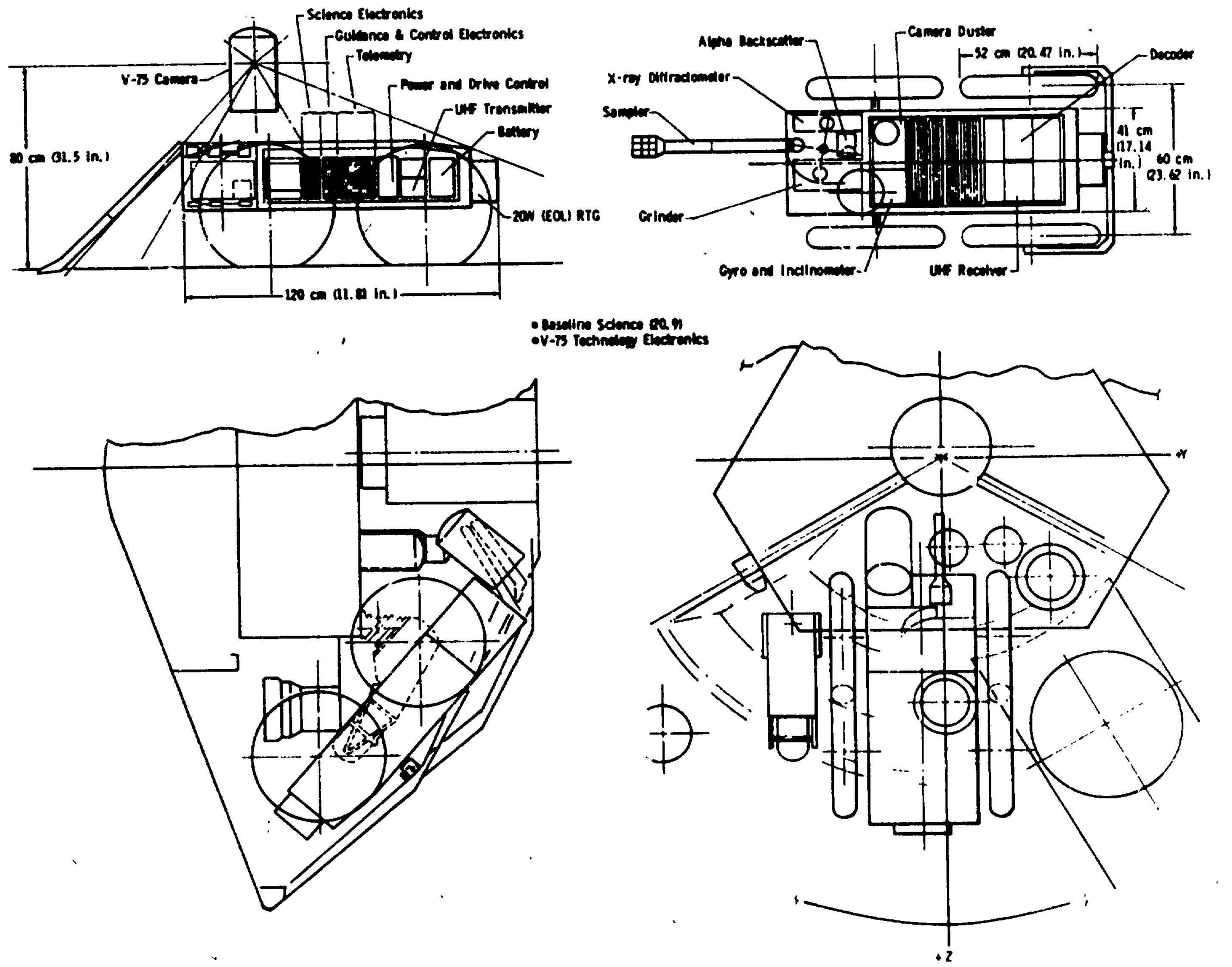


FIGURE 100 BASELINE ROVER LAYOUT

TABLE 37 BASELINE ROVER MASSES (WT)

SUBSYSTEM	kg	kg	(lb)
Science		20.87	(46)
Viking '75 Camera	4.54		
Camera Duster	1.81		
Alpha Backscatter	2.72		
X-Ray Diffractometer	7.26		
Sampler	4.54		
Structure		17.24	(38)
Mechanism Camera Deployment		0.91	(2)
Thermal		4.99	(11)
Thermal Switch	1.81		
Insulation	1.36		
Paint	0.45		
RTG Cooling	0.45		
Heat Pipes	0.91		
Drive System		10.43	(23)
Motors & Gears	4.08		
Wheels	5.44		
Axles, Bushing, Seals	0.91		
Power		15.42	(34)
Battery	6.80		
RTG	5.44		
Power & Drive Control	3.18		

SUBSYSTEM	kg	kg	(lb)
Telemetry		5.44	(12)
Data Processor	1.36		
Data Processor Memory	3.63		
Transducers	0.45		
Communication		5.90	(13)
UHF Receiver	1.36		
UHF Transmitter	2.72		
UHF Antenna	0.91		
Diplexer	0.91		
Guidance & Control		6.79	(15)
Gyro	1.36		
Inclinometer	0.45		
Bumpers	0.91		
Control Sequencer & Memory	2.26		
Wind Detector	0.45		
Odometer	0.45		
Hole Detector	0.91		
Cabling		2.27	(5)
		90.26	(199)
Contingency (20%)		17.69	(39)
TOTAL ROVER		107.95	(238)

TABLE 38 BASELINE VIKING '79 MASSES (WT)

	kg	(lb)
Lander Additions		
Stowage & Deployment	12.25	(27)
Communication	3.17	(7)
Relocate Equipment	0.45	(1)
Thermal	0.91	(2)
New Biology	16.33	(36)
X-Ray Diffractometer	7.26	(16)
New RTG	17.24	(38)
Reg. Propulsion System	9.98	(22)
	67.59	(149)
Contingency (20%)	13.15	(29)
	80.74	(178)
Lander Deletions		
1 Camera	-6.80	(-15)
Meteorology	-4.54	(-10)
XRFS	-2.27	(- 5)
Biology	-17.24	(-38)
V'75 RTG System	-37.19	(-82)
	-68.04	(-150)
Total Rover	107.95	(238)
Lander Additions	80.74	(178)
	188.69	(416)
Lander Deletions	-68.04	-(150)
	120.65	(266
V '75 Anticipated Landed Mass	598.74	(1320)
V '79 Landed Dry	719.39	(1586)

TABLE 39 VIKING 1975-1979 MASS COMPARISONS (METRIC UNITS)

	V-75 ALLOCATION (kg)	ANTICIPATED V-75	V-79 BASELINE	ROVER DELTAS
LANDER DRY MASS	564.15	598.62	719.25	120.63
LANDER PRESSURANT	6.35	6.35	6.35	0
RESIDUAL PROPELLANT	4.99	4.99	6.35	1.36
LANDED MASS	575.49	609.96	731.95	121.99
USABLE PROPELLANT	59.41	68.48	80.72	12.24
TERMINAL IGNITION MASS	634.90	678.44	812.67	134.23
AERODECELERATOR DRY MASS	116.10	109.29	111.56	2.27
MASS ON PARACHUTE	751.0	787.73	924.23	136.50
AEROSHELL DRY MASS	168.25	181.40	195.91	14.51
AEROSHELL PRESSURANT	3.17	3.17	3.17	-
RESIDUAL/ACS PROPELLANT	11.79	7.26	7.26	-
ENTRY MASS	934.21	979.56	1130.57	151.01
A/S USABLE DEORBIT PROPELLANT	72.56	78.91	78.91	-
SEPARATED LANDER MASS	1006.77	1058.47	1209.48	151.01
BIOSHIELD BASE DRY MASS	65.30	72.56	72.56	-
BIOSHIELD CAP DRY MASS	45.35	54.42	54.42	-
VLC LOADED MASS	1117.42	1185.45	1336.46	151.01

TABLE 40 VIKING 1975-1979 WEIGHT COMPARISONS (ENGLISH UNITS)

	V-75 ALLOCATION	ANTICIPATED V-75	V-79 BASELINE	ROVER DELTAS
LANDER DRY WEIGHT	1244	1320	1586	266
LANDER PRESSURANT	14	14	14	0
RESIDUAL PROPELLANT	11	11	14	3
LANDED WEIGHT	1269	1345	1614	269
USABLE PROPELLANT	131	151	178	27
TERMINAL IGNITION WEIGHT	1400	1496	1792	296
AERODECELERATOR DRY WEIGHT	256	241	246	5
WEIGHT ON PARACHUTE	1656	1737	2038	301
AEROSHELL DRY WEIGHT	371	400	432	32
AEROSHELL PRESSURANT	7	7	7	0
RESIDUAL/ACS PROPELLANT	26	16	16	0
ENTRY WEIGHT	2060	2160	2493	333
A/S USABLE DEORBIT PROPELLANT	160	174	174	0
SEPARATED LANDER WEIGHT	2220	2334	2667	333
BIOSHIELD BASE DRY WEIGHT	144	160	160	0
BIOSHIELD CAP DRY WEIGHT	100	120	120	0
VLC LOADED WEIGHT	2464	2614	2947	333

TABLE 41 BASELINE VIKING '79 MASS PROPERTIES (METRIC UNITS)

DESCRIPTION	WEIGHT (kg)	CENTER OF GRAVITY (cm)			MOMENTS OF INERTIA (kg-m^2)			PRODUCTS OF INERTIA (kg-m^2)		
		X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}	P_{XY}	P_{XZ}	P_{YZ}
ROVER	107.95	-128.02	-6.07	93.22	9.45	8.14	2.71	-	-	-
LANDED MASS	731.95	-96.70	-2.79	9.73	439.34	287.47	229.16	1.41	-39.73	-7.35
TERMINAL IGNITION MASS	812.67	-94.95	-2.51	8.20	440.7	291.54	231.88	1.76	-41.70	-7.66
VL ON CHUTE, AERO-SHELL JETTISONED, GEAR EXTENDED	881.15	-97.94	-2.26	7.47	508.5	344.42	280.69	0.96	-39.70	-8.34
ENTRY MASS	1130.57	-93.83	-2.03	4.19	871.91	608.84	461.04	4.24	-46.75	-4.91
SEPARATED LANDER MASS	1209.48	-92.71	-1.91	3.89	1006.15	710.54	496.30	4.52	-47.32	52.37
VLC AFTER BIOSHIELD CAP SEPARATION	1282.04	-89.26	-2.72	3.05	1087.5	778.34	565.45	-3.47	-54.88	51.18
VLC LOADED MASS	1336.46	-90.81	-2.59	3.07	1190.57	856.99	641.39	-3.91	-54.43	51.46

TABLE 42 BASELINE VIKING '79 MASS PROPERTIES (ENGLISH UNITS)

DESCRIPTION	WEIGHT (LB)	CENTER OF GRAVITY (IN)			MOMENTS OF INERTIA (SLUG-FT^2)			PRODUCTS OF INERTIA (SLUG-FT^2)		
		X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}	P_{XY}	P_{XZ}	P_{YZ}
ROVER*	238	-50.40	-2.39	36.70	7	6	2	-	-	-
LANDED WEIGHT	1614	-38.07	-1.10	3.83	324	212	169	1.04	-29.30	-5.42
TERMINAL IGNITION WEIGHT	1792	-37.38	-0.99	3.23	325	215	171	1.30	-30.75	-5.65
VL ON CHUTE, AEROSHELL JETTISONED, GEAR EXTENDED	1943	-38.56	-0.89	2.94	375	254	207	0.71	-29.28	-6.15
ENTRY WEIGHT	2493	-36.94	-0.80	1.65	643	449	340	3.13	-34.48	-3.62
SEPARATED LANDER WEIGHT	2667	-36.50	-0.75	1.53	742	524	366	3.33	-34.90	38.67
VLC AFTER BIOSHIELD CAP SEPARATION	2827	-35.14	-1.07	1.20	802	574	417	-2.56	-40.47	37.74
VLC LOADED WEIGHT	2947	-35.75	-1.02	1.21	878	632	473	-2.88	-40.14	37.95

*THE COORDINATE SYSTEM SHOWN IS THE VIKING LANDER COORDINATE SYSTEM

The rover is stowed with the forward wheels compressed four cm against the top of the lander. The baseline rover has 52 cm diameter wheels. This diameter was determined by the 22 cm rock clearance criterion and a four cm combination of wheel compression and sinkage into soft surfaces. The rover has a wheel base of 60 cm and a track width of 60 cm. The major rover assemblies are a science compartment, a thermally-controlled electronics compartment, a mobility subsystem, and an RTG. The baseline rover has the two front axles fixed to the chassis and the rear axial is articulated on a roll pivot aft of the RTG. The rover equipment arrangement is shown in Figure 100. The thermally-controlled compartment contains the electronic equipment, the communication equipment, the gyro, the camera duster, and the battery. Table 43 is a tabulation of the volume and mass of the components on board the rover. The science compartment is also thermally-controlled but it has a wider temperature limit band. Due to volume and mass constraints, a concept of integrated electronics packaging was used in the baseline rover configuration.

The integrated packaging concept removes the cases from the electronic boxes and mounts the printed circuit and component boards directly to the chassis. All the subsystems requiring electronic components, with the exception of the communication equipment and the science sensors, are packaged in the integrated electronics module. All the boards within this module are interwired. All wires terminating at other components such as science sensors and communication will have harnesses terminating with connectors. The boards in the electronics module are 16 x 33 cm spaced at 1.25 cm. A typical cross-section through the rover showing a concept of how the boards would be mounted is shown in Figure 101.

The rover's aluminum chassis is inside the insulation. The chassis consists of two side beams, an isothermal plate with heat pipes bonded to the plate, two end bulkheads, and a top plate. The science compartment is supported from the forward bulkhead, the forward axles are supported from the side beams, and the RTG, the thermal switch, and the rear axle pivot are supported from the aft bulkhead.

The function of the thermal switch is to couple or uncouple the chassis thermally from the RTG. The thermal switch has an actuator located on the isothermal plate and a contactor between the aft bulkhead and the RTG. The RTG

TABLE 43 ROVER INTERNAL COMPONENTS MASSES AND VOLUMES

COMPONENT	MASS		VOLUME		BOARDS IN ELECTRONICS MODULE
	kg	(lb)	cm^3	(in^3)	
Alpha Backscatter	2.73	(6)	525	(32)	-
X-Ray Diffractometer	4.55	(10)	2450	(155)	-
Grinder	2.73	(6)	4920	(300)	-
Science Electronics	*				6
Camera Duster	1.82	(4)	3280	(200)	-
Gyro	1.37	(3)	1800	(110)	-
Inclinometer	0.46	(1)	645	(40)	-
Control Sequencer & Memory	2.27	(5)	-		5
Data Processor	1.37	(3)	-		4
Data Processor Memory	3.64	(8)	-		8
Power and Drive Control	3.18	(7)	-		6
UHF Receiver	1.37	(3)	1230	(75)	-
UHF Transmitter	2.73	(6)	2460	(150)	-
UHF Diplexer	0.92	(2)	1230	(75)	-
Battery	6.82	(15)	4510	(275)	-

*Science electronics mass is included in the individual instruments.

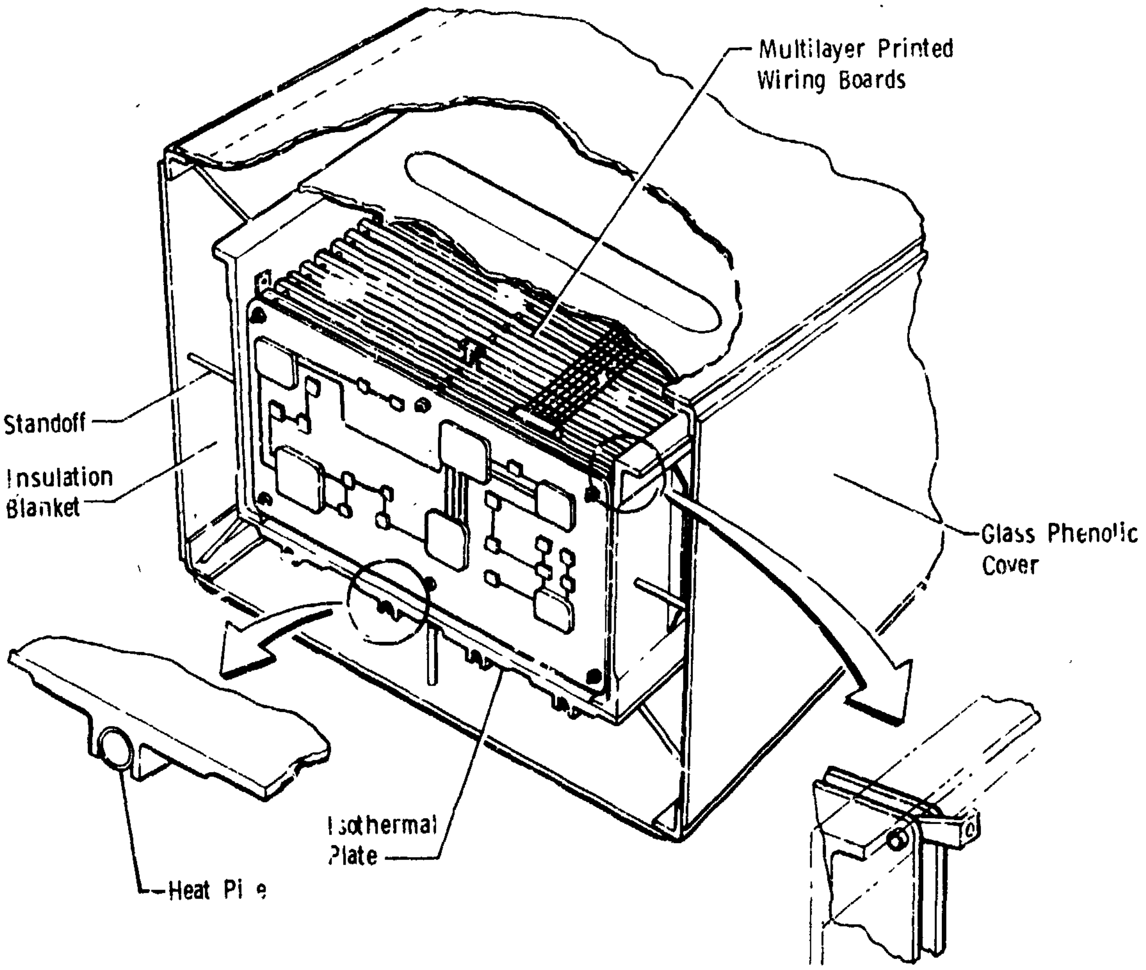


FIGURE 101 INTEGRATED ELECTRONICS CONCEPT

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will be mounted from the aft bulkhead with a thermal isolator. The insulation around the thermally-controlled compartment is 2.54 cm thick. A thin glass phenolic cover protects the insulation and maintains a controlled insulation thickness. The protective cover is supported by non-metal standoffs that are attached to the chassis. Brackets that penetrate the insulation to support the front axles, the rear axle pivot, and the antenna support will be constructed from titanium to minimize the heat leak through these penetrations.

The UHF antenna will be deployed with a Stacer spirally-wound, self-extending tube. The rover camera will be deployed after landing and before off-loading the rover. The camera will be mounted to the camera deployment mechanism. The mechanism will be a simple hinge joint driven by a motor system. The camera will be held in the stowed position by a hot wire pin puller. In the operational position the mechanism will be locked in place by a spring-loaded latch. Five radioisotope heating units will be mounted in the latch plate. With the heaters in this position, the heaters will only supply heat to the camera when the camera deployment mechanism is actuated.

Science payload description. - A typical payload has been selected by NASA for detailed study of its implementation into the selected rover design. This payload, listed in Table 44, is No. 7 from Section 6.1 and consists basically of an X-ray diffractometer system with grinder, an Alpha Backscatter Geochemical instrument, a sample scoop that is capable of obtaining rock and soil samples, and a storage mechanism by which samples may be retained and transferred to the lander sampling assembly on return of the rover to the lander. The imagery system specified in a Viking '75 lander camera. No attempt has been made at this point to improve the resolution of this camera by the addition of external magnifier optics. It will provide adequate data for interpretation of the environment in which the rover finds itself but will not provide all geologic information desired on rock structure or soil particle shapes. The camera will have the capability to take panoramic pictures by taking a picture, moving from one to several meters, and taking another picture. In this manner, a stereo pair can be generated from which it will be possible to determine relative distances of observed land forms and features. The payload list shown in Table 44 includes pertinent physical characteristics of the instruments as they are presently known.

TABLE 44 SCIENCE PAYLOAD CHARACTERISTICS

INSTRUMENT	MASS	VOLUME	POWER	DATA	REMARKS
Viking '75 Camera	6.4 kg		30.2W (Max Avg Survey Scan)	29.2×10^6 Bits - Hi Resol Mode (Panoramic)	Duration of Experiment Determined by Dividing Data Quantity by Data Rate (16 Kbps or 250 Bps)
Sensor (3.7 kg)		1300 cc			
Electronics (0.9 kg)			107W (Slew Mode 4 Sec Max)	9.5×10^6 Bits - Lo Resol Mode (Panoramic)	
Camera Duster (1.8 kg)		4300 cc	4.5W (Avg) 66W Peak for 10 msec	--	Powered on When Camera is Operating
Alpha Backscatter Spectrometer	2.8 kg				
Sensor (1.4 kg)		700 cc	4 Watts	2×10^5 Bits/ Analysis	5 Hours/Analysis
Electronics (1.4 kg)					
X-ray Diffractometer	4.5 kg	2500 cc	30 Watts (Avg)	10^4 Bits/Anal	2 Hours/Analysis
Grinder	2.8 kg	4100 cc	40 Watts (Avg)	--	20 Minutes/Day. Used before Each X-ray Diffractometer experiment
Sampler	4.5 kg	-	2 Watts (Avg)	--	5 Minutes/Day. Power is for two Motors
X-ray Fluorescence (Add-on Option)	1.4 kg	100 cc	2.6 Watts (Avg)	8.192×10^3 Bits/ Analysis 81.92×10^3 Bits/ Day	If used as Science Instrument Operates 15 Minutes/Analysis; 10 Analysis/Day

The total mass of this payload is 20.9 kg (46 lb). Power consumption varies enormously depending upon the mode of operation; however, in no case is it necessary to operate more than one instrument at a time. Therefore, the camera, diffractometer, and the grinder, which require high power levels, can be operated sequentially to prevent overload of the power supply. Data requirements are relatively minimal except for the alpha backscatter spectrometer and the camera. The alpha backscatter data analysis will require about 80 percent of the rover data storage capacity per analysis. A single low resolution camera picture of dimensions 25° in azimuth by 20° in elevation also will require approximately 80 percent of the data storage capacity. Therefore, it will not be possible to operate and store data from both experiments without an intervening communication link to either the lander or orbiter. In fact, most picture taking must be made via one of these two direct communication links with real-time transmission of data as it is taken by the cameras. This limits picture taking, except for the small pictures mentioned above, to times of the day when coverage by the lander or the orbiter is possible. Early in the mission it may be desired to operate the camera in the following mode for reasons of rover survivability: In a given 100 meter planned traverse the camera would take a small picture in the direction of travel; this picture would be stored in the central memory; after the rover reached its target point some 100 meters away, and all systems were performing satisfactorily and if the rover were not ensnared by a hazard, another picture would be taken of the next 100 meter segment ahead, replacing the previously stored picture. Thus, if the rover did become trapped in a hazard situation, the memory would contain a picture of the area in which the problem occurred as taken from a different vantage point. This would be transmitted at the next opportunity to the lander or to the orbiter. Combining this with a second picture taken by the rover in its location of difficulty would provide valuable information as to the best strategy for disengagement.

The alpha backscatter spectrometer (Figure 102) employs alpha and proton spectroanalyses in its measurements. Recently it has been proposed to add a cryogenic detector to this unit to allow detection of x-ray fluorescence stimulated by the X-ray emissions that accompany the alpha emission in the radioactive source assembly of this instrument. This has not been included in the present

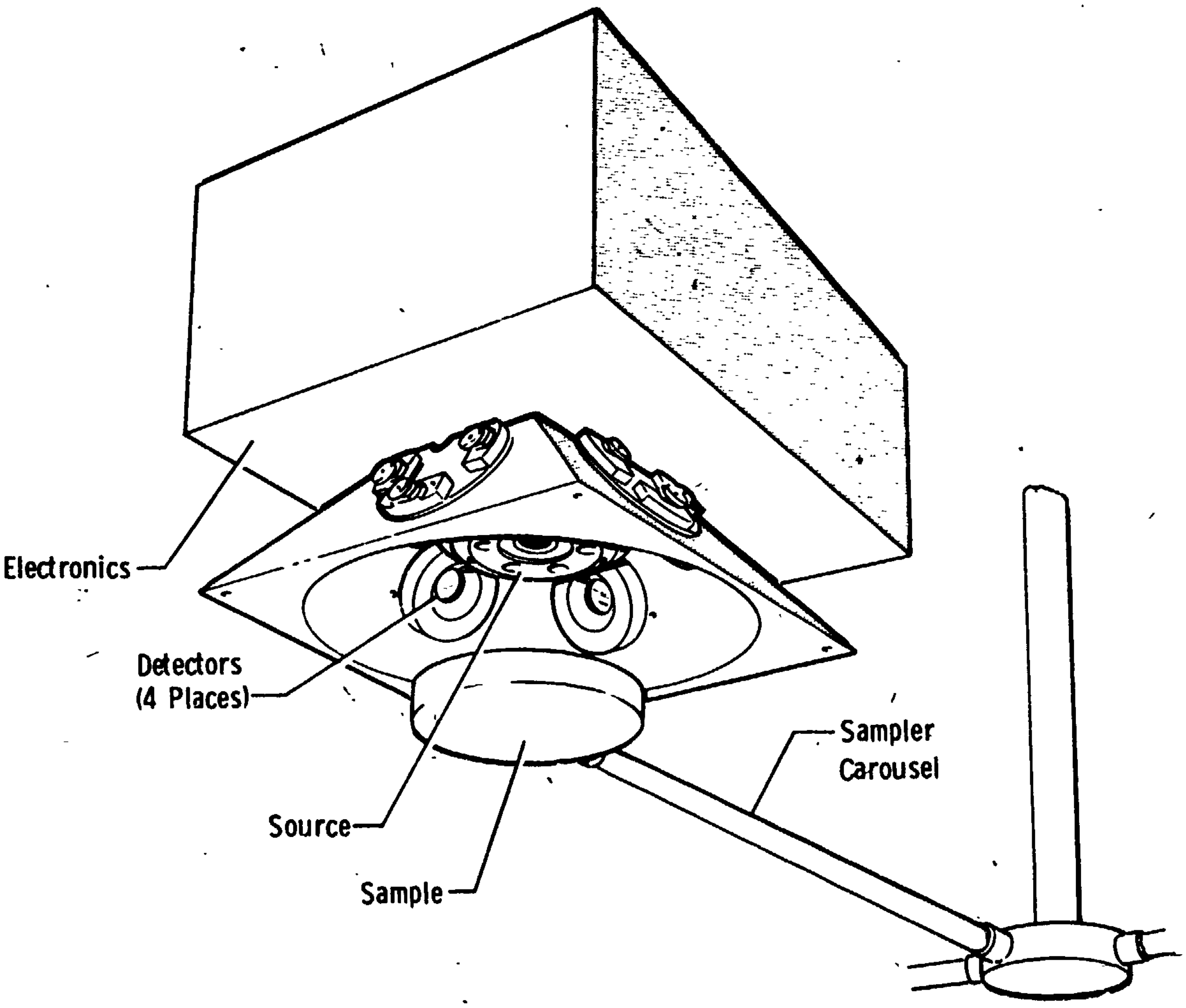


FIGURE 102 ALPHA BACKSCATTER INSTRUMENT

package because of the only recent information on its availability. Because the cryogenic system contains an expendable supply of gas, it is suitable for only a limited number of analyses, perhaps three to six. This cryo-system is based on the Joule-Thompson effect, employing a high pressure gas reservoir and small orifice through which the gas is expanded to achieve cooling. Another X-ray fluorescence option is included, however, and is based upon the XRFS technique presently employed on the Viking '75 lander. This system can analyze an unlimited number of samples, requires only 15 minutes to perform the analysis, and generates a relatively small number of bits per analysis.

The grinder (Figure 103) assumed is of drop hammer design and may be capable of transmitting sufficient energy through the rover body and wheels into the ground to be detected by the lander seismometer. This would provide some capability of probing the subsurface in the vicinity of the lander. Several X-ray diffractometer designs are available and the 4.5 kg (10 lb) allotment is in the range of most proposed approaches. The design considered in the present study (Figure 104), however, does not include the cryogenic detector approach also recently proposed, but could be modified to do so. Analysis by the diffractometer is relatively slow unless this cryogenic approach is selected.

In Figures 105 and 106 we see the integrated rover science package. Prominent is the sample scoop, which acquires samples by being lowered to the surface to collect material as the rover drives forward. The grid over the scoop allows 2.5 cm and smaller rocks to enter the scoop platform. When the arm is raised this material passes down a tube containing a fine screen (probable opening, 2000 microns) that permits soil to fall into a lower compartment and then enter directly into a sample cup at the base. The arm then may be lowered so that the material that did not pass the soil screen falls into a second compartment of 1.9 cm square openings. Materials smaller than this are then discharged from the sampler leaving as residue rocks that pass the 2.5 cm screen but do not pass the 1.9 cm screen. By again raising the sampler arm, these rocks are transported to a sample cup. Between these operations, the sample cup carousel is rotated so that soil and rock are collected separately. If grinding is desired, a cup is then positioned over the grinder, and through actuation of a cam the material

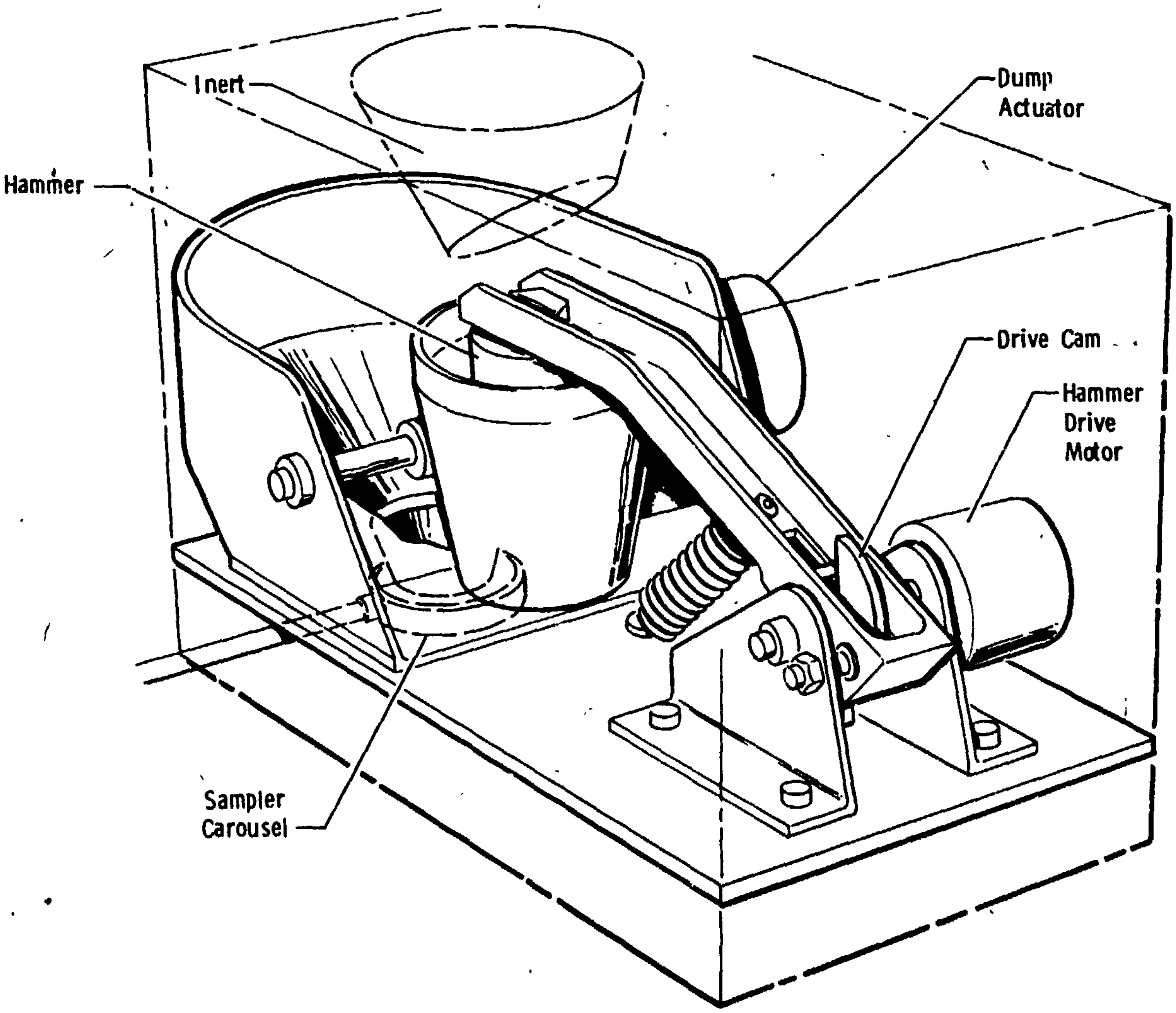


FIGURE 103 DROP HAMMER GRINDER

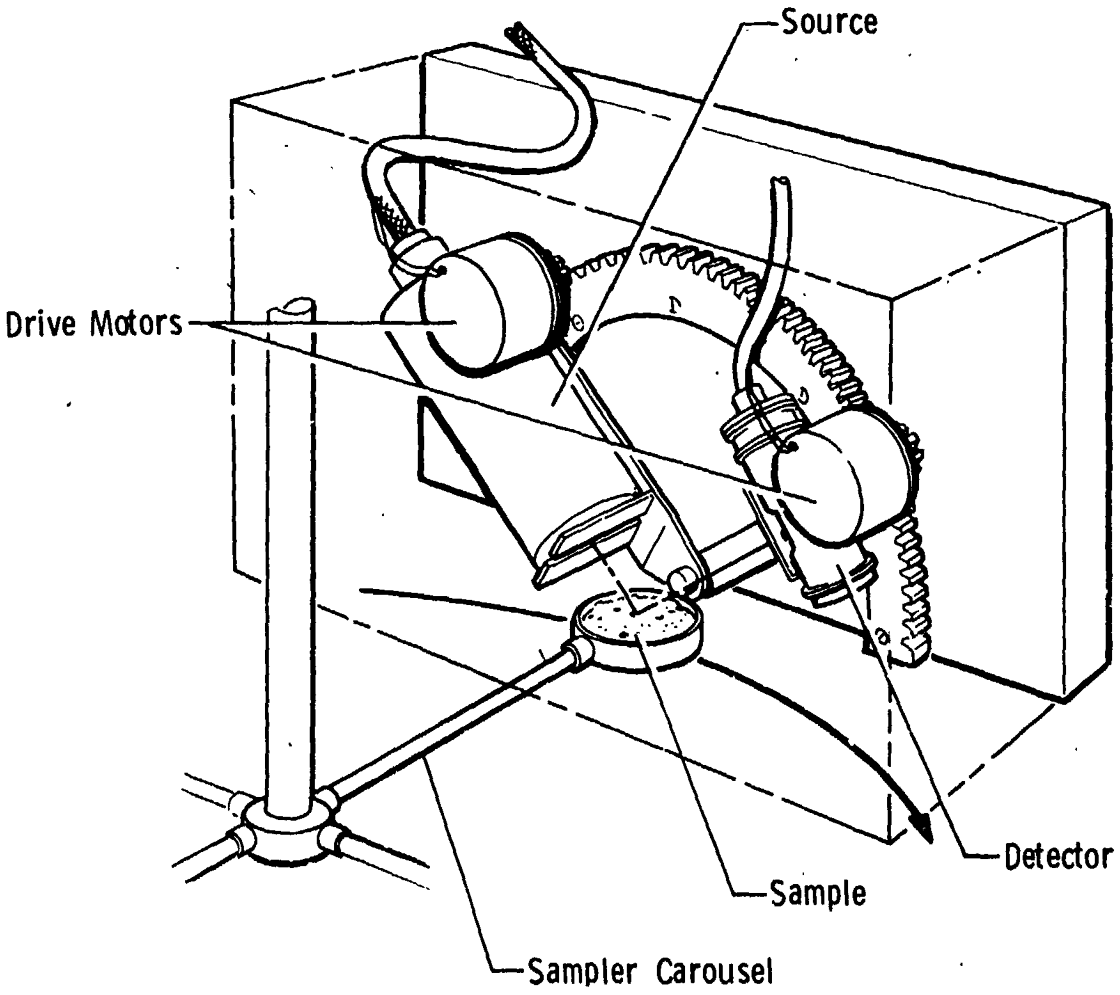


FIGURE 104 X-RAY DIFFRACTOMETER

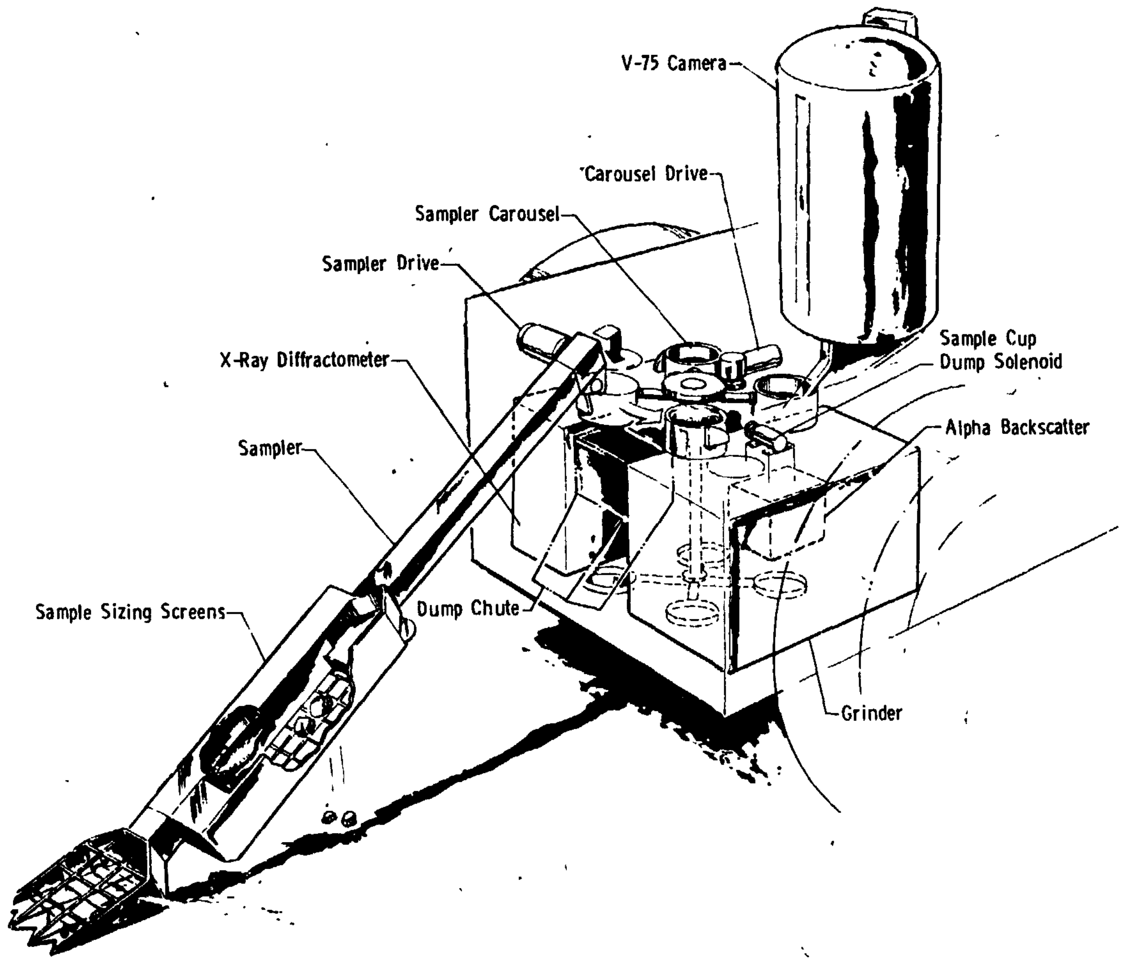


FIGURE 105 INTEGRATED SCIENCE PACKAGE

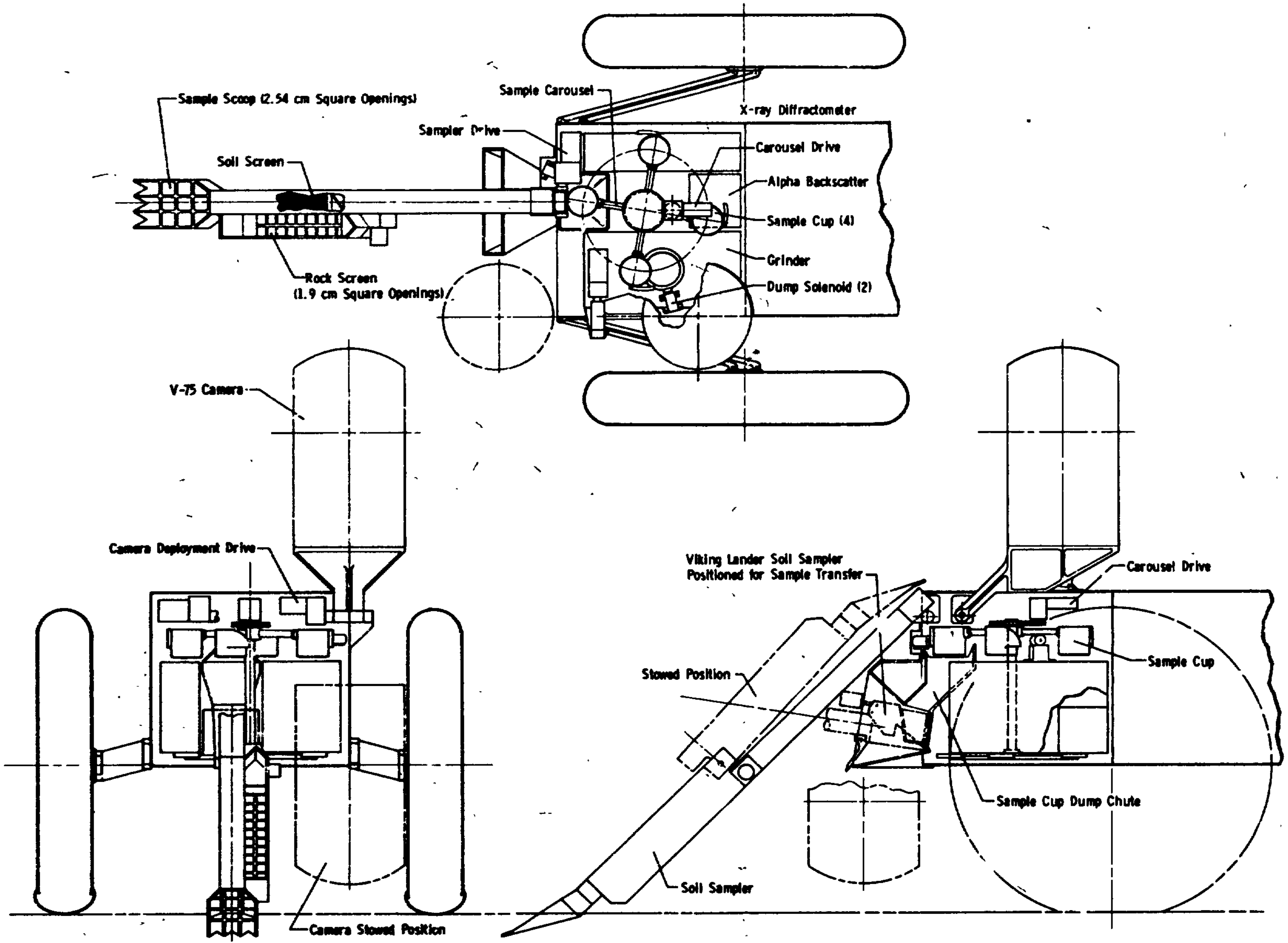


FIGURE 106 INTEGRATED SCIENCE PACKAGE, LAYOUT

is passed into a lower sample cup that mates with the diffractometer system and also can be positioned below the alpha backscatter analysis system. If a sample is desired to be dumped without grinding or further analysis on the rover, it can be positioned over a chute that empties to the ground in front of the rover. Alternatively, the surface sampler from the Viking lander can place a receptacle beneath the chute and the sample can thereby be transferred to the lander sampler arm and thence to lander instruments for subsequent analysis. Imagery of the sample must be accomplished while the sample remains in the scoop because of geometrical considerations. Both soil particles that have been collected and rocks when they are in position over the 1.9 cm rock screen can be imaged.

This payload contributes to a variety of the science objectives of interest. As it is capable of collecting samples and returning them to the lander, any number of potential analyses such as soil water, biological, and organic analyses can be performed on samples obtained great distances from the lander. A mission operations trade off will be to compare the value of having the rover return to the lander for sample transfer versus the desirability of exploring even more territory. As the rover contains an imagery system, an inorganic analysis system, and a mineralogic analysis system, it can obtain a wealth of pertinent information on the surface characteristics of Mars at any location. Thus, even when it is not practical to return to the lander because of distance or intervening hazards, the rover will remain as an excellent science platform in itself from which to conduct exploration of the planet. With the types of instrumentation included it will be possible to address a large number of the scientific questions that can now be posed as to the origin and evolution of the Martian surface.

Baseline rover mobility subsystem. - The mobility subsystem concept selected for the baseline rover is illustrated in Figure 107. Figure 108 illustrates a potential wheel/motor design incorporating a Viking '75 surface sampler elevation motor inside a wheel derived from the Apollo Lunar Rover Vehicle wheel. Table 45 summarizes the parameters of this concept that was selected for the 108 kg (238 lbm) baseline vehicle based on the mobility subsystem analyses and trade studies discussed in Section 6.2.

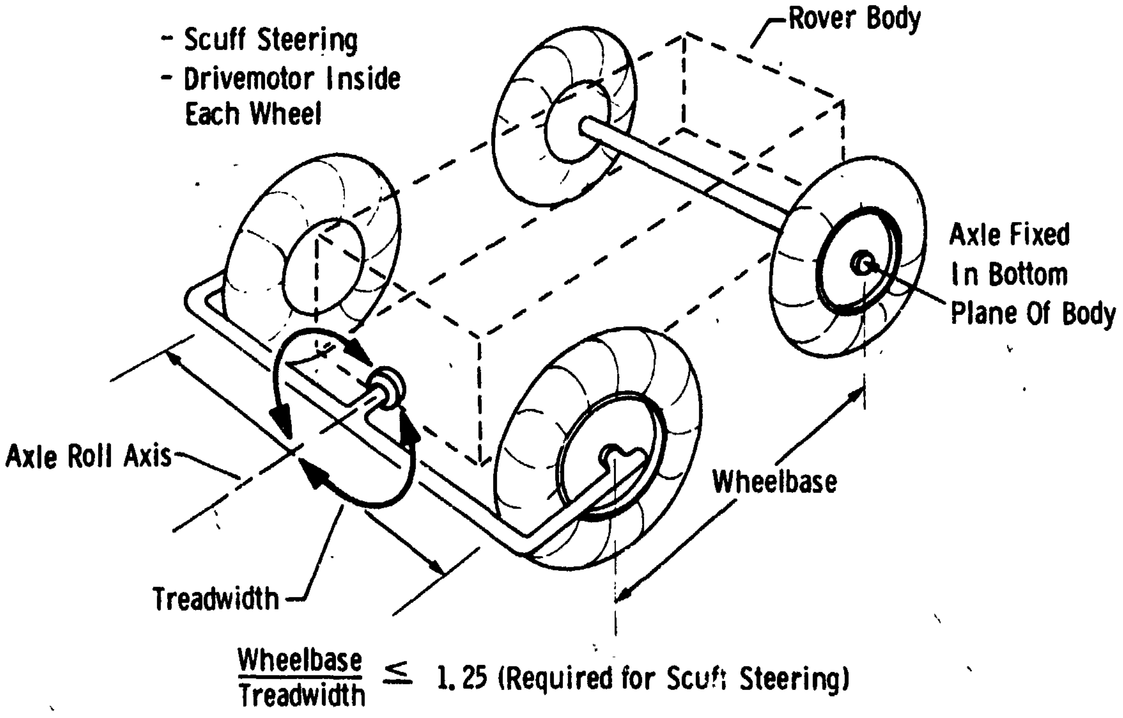


FIGURE 107 BASELINE ROVER MOBILITY CONCEPT

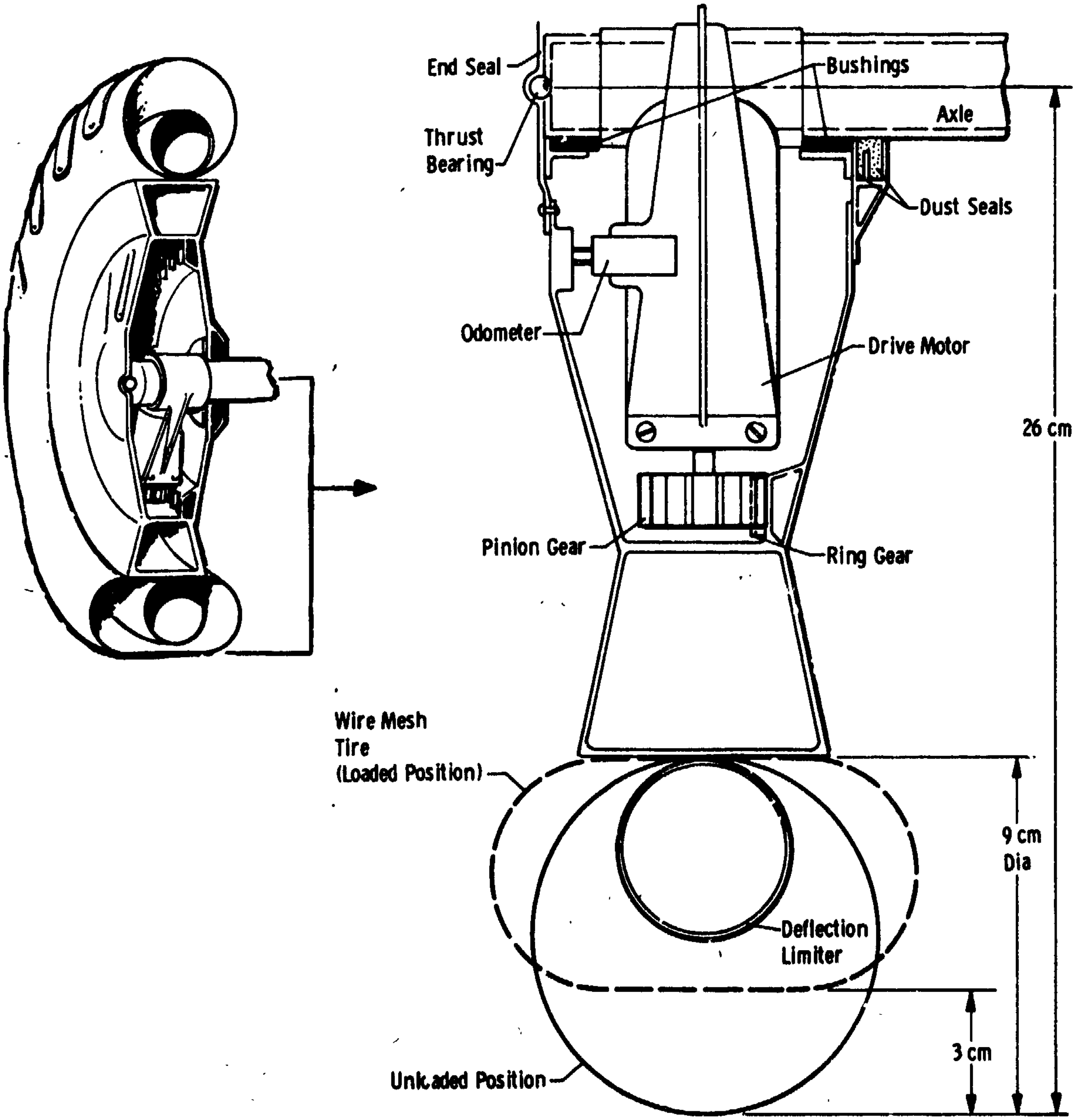


FIGURE 108 POTENTIAL WHEEL/MOTOR DESIGN FOR BASELINE ROVER

TABLE 45 BASELINE ROVER MOBILITY SUBSYSTEM PARAMETERS

	kg	(lbm)
Mass (1 Wheel Unit):		
Drivemotor	0.90	(2.00)
Wheel	1.36	(3.00)
8:1 Output Gearing	0.15	(0.33)
Axle	0.12	(0.26)
Motor Mount	0.05	(0.10)
Bushing/Seal	0.03	(0.06)
Total	2.61	(5.75)
Mass (4 Wheel Units)	10.4 kg	(23.0 lbm)
Wheel Diameter	52.0 cm	(20.5 in)
Wheel base	60.0 cm	(20.3 in)
Treadwidth	60.0 cm	(23.6 in)
Ground Clearance:		
On Loess	21.0 cm	(8.3 in)
On Harder Surfaces	23.0 cm	(9.1 in)
Vertical Load/Wheel	100.0 N	(23.0 lb)
Nominal Power Consumption (Loess, 0° Slope)	6.5 Watts	
Nominal Operating Velocity	88.0 meters/hour	(292.0 ft/hr)
Maximum Slope Capability	5° less than natural angle of repose	
Roll Stability Limit	40°	
Pitch Stability Limit	60°	
Steering:		
Type	Scuff	
Nominal Turning Rate	1.6 deg/sec	

Figure 109 presents soil bearing capacity data from the Viking '75 Mars Engineering Model. The wheel shown in Figure 108 will produce contact loads in the region indicated, thereby producing sinkage of less than 2 cm (0.8 in) in the worst-case surface material, loess. This occurs with an average contact pressure of 0.5 N/cm^2 (0.74 lb/in^2) which assumes, for each wheel on loess, a contact area 10 cm (3.9 in) wide by 20 cm (7.8 in) long and a vertical load of 100 N (23 lb).

Power subsystem. - The power subsystem consists of those components that provide electrical power to the rover and it consists of three major components, an RTG, a battery, and a Power Control Unit (PCU). The RTG is a GFE item, which is a 20 watt end-of-life unit. The battery that will be used for the rover uses the existing Viking '75 NiCd battery cells, packaged into a 15-volt battery (12 cells). The PCU contains all the electronics for conditioning the RTG outputs, battery charging, providing regulated voltages and providing the electronics for driving all motors, solenoids, and pyrotechnics.

The primary features of the power subsystem are:

480 watt hours (at 5 volts) of electrical energy is available each day from a GFE RTG;

Battery energy storage is 120 watt-hours;

Regulated voltages are provided to all rover electronics;

Five volts is taken directly from the RTG to power all 5-volt circuits;

Rover bus voltage is set at 15 volts;

Power loads are switched as required to minimize power consumption;

Fault protection is provided to minimize impact of loss of science experiments due to circuit failures in other science instruments;

Twenty percent power margin is provided in the system capability.

Physical characteristics of the power subsystem are:

The battery is packaged in its own case and together with the load bank has a mass of 6.8 kg (15 lb).

The RTG mass is 5.5 kg (12 lb).

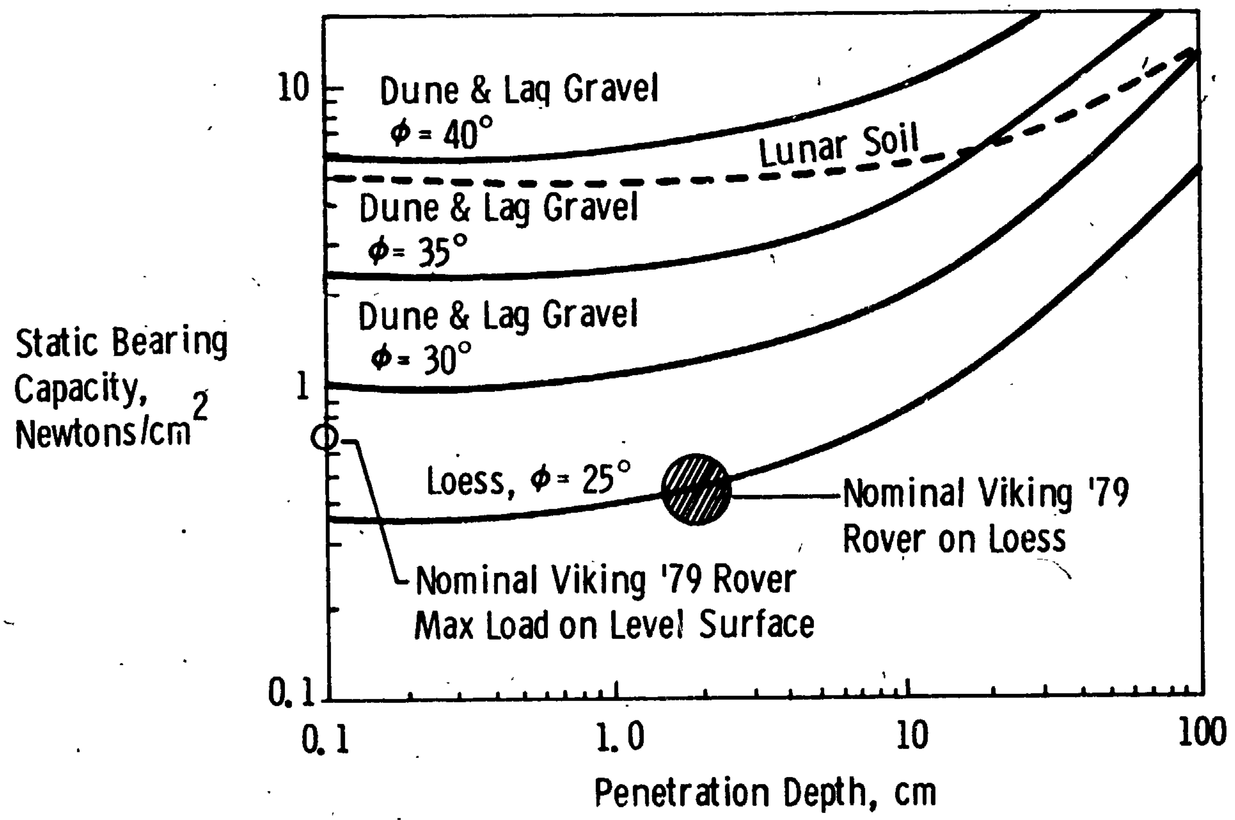


FIGURE 109 MARS ENGINEERING MODEL SOIL BEARING CAPACITIES

The power control unit, which is packaged with the integrated electronics assembly, has a mass of 3.2 kg (7 lb) and is packaged on five printed wiring boards.

Thermal control. - The final rover thermal design is as shown in Figure 110. Those components that cannot survive the Mars surface environment, and do not, by operational necessity, have to be mounted externally to the rover, are located in a thermally-controlled compartment. The RTG carried by the rover for electrical power is also used for thermal energy. A thermal switch controls the flow of heat from the RTG to the rover thermally-controlled compartment. The thermal compartment is insulated with low density fiberglass insulation to minimize the compartment heat loss. The RTG heat is distributed internal to the thermal compartment by a heat pipe equipment mounting plate (isothermal plate). The mass of the thermal components is 5 kg (11 lb).

Communications. - The communications subsystem consists of those components that allow the rover to communicate with either the orbiter or the lander. The system consists of an antenna, a diplexer, a transmitter, and a receiver. Transmission from the rover to either the orbiter or the lander occurs at a UHF frequency of 405 MHz and receives from the orbiter or lander at a frequency of 381 MHz. The modulation scheme is a non-coherent, wideband FSK system. Rover-to-lander communications will use a rover transmitter power of 2 watts that will allow the rover to operate at a maximum radius from the lander of 2 km. When transmitting to the orbiter, the rover will use a 20 watt RF power mode and maintain link times of approximately 25 minutes. The rover/orbiter link duration will be improved over Viking '75 because of the fact that a two-way transmission exists and the link does not depend on a specific time for turn on. The capability exists to transmit and receive simultaneously. Data rates will be 16 kbs.

The rover antenna has two pattern modes to allow it to communicate with both the lander and the orbiter. By controlling the phase of the signal applied to the turnstile elements, directivity in either the vertical plane or the horizontal plane is obtained. Rover-to-lander communication of up to 2 km range can be obtained by deploying the rover antenna 1.7 m above the surface.

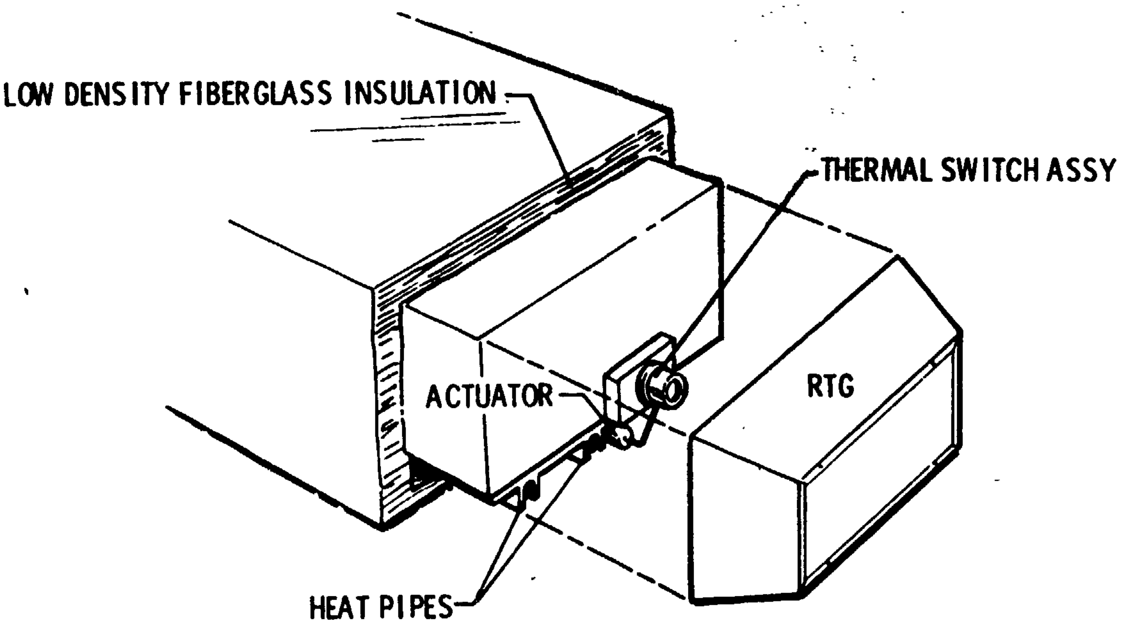


FIGURE 110 BASELINE ROVER THERMAL DESIGN

The transmitter and receiver will be packaged in their own case and will be mounted inside the thermally-controlled compartment. The antenna will be stowed before launch and will be deployed when the rover is activated on the surface of Mars. The communication subsystem mass is 5.9 kg (13 lb).

Data handling and processing. - The data handling and processing subsystem consists of those components that collect and process data and consists of a data processor, a 250 kilobit memory, and temperature transducers. A centralized data processing system is used wherein circuits to multiplex, signal condition, analog to digital conversion, formatting, and data storage are common to all data sources. These data sources include engineering data and all science instrument data. A total of five formats are provided for collecting data. Format construction is compatible with Viking '75 formats and snychronization schemes. Outputs to the UHF transmitter are biphase coded with alternate bit complementing. Data rates are 16 kbs or 4 kbs with data rates being accurate and stable to ±0.01% with a time jitter less than 360 nanoseconds.

The Data Processor and Memory are packaged on 12 printed wiring boards as part of the integrated electronics assembly. Total mass for the data handling and processing subsystem is 5.5 kg (12 lb).

Navigation. - The navigation subsystem includes the sensors required for navigation and hazard avoidance. The navigation sensors include sensors for heading and distance. For hazard avoidance, sensors are included to detect rocks, holes, and adverse slopes, and to measure the angle between the articulated axle and the chassis.

The selected heading sensor is a directional gyro (DG) with a gyrocompassing capability, which provides an initial heading reference error of less than 35 mrad (2°) in the gyrocompassing mode, and a drift rate of less than 0.72 μrad/s (0.15°/hr) while traversing in the DG mode. The package has an estimated mass of 1.37 kg (3 lb) and consumes 3 watts while operating.

Four odometers, one per wheel, were selected as the simplest method of measuring distance. Each odometer is of the cam and microswitch type, providing 8 pulses per resolution of wheel motion. All four odometers are summed and averaged in calculating distance traveled.

Two-axis linear inclinometers provide rover attitude information required both in the navigational calculations and to avoid excessive slopes. Simple pendulous potentiometer devices will be used to minimize the mass and power required. Quantization of the A/D converter will be approximately 17.5 mrad (1°). Although the functional requirement for slope stability is 0.78 rad (45°), the actual limit will be a variable, the computation based on the traction coefficient of the soil.

Simple bumpers and microswitches will be used to detect nonnegotiable rocks.

The most difficult type of hazard to detect is that of a crevice. Unfortunately, crevices are also more dangerous to the vehicle than other obstacle types. The baseline system is of the noncontact type, namely reflected energy intensity ranging. This consists of a source of X-ray energy, detectors, and associated electronics. The electronics are packaged as two boards in the integrated electronics assembly.

Control. - The control sequencer and memory provides total control of the rover operations, including navigation, science instrument sequencing, power switching, and data processing instructions. More specifically the system provides the capability to:

Navigate from point A to point B, using heading, distance, and rover attitude information. Included are such special features as hill climbing (steepest ascent) and contour following (constant altitude).

Avoid hazards such as nonnegotiable rocks, holes wider than 0.6 of a wheel diameter and local slopes of greater than a calculated maximum.

Compute the traction coefficient of the soil being traversed. This is then used to define the maximum slope that can be safely negotiated by the rover.

Control the power sequencing-to-rover equipment, based on a predefined or self-formulated sequence of events, ground commands, and rover events.

Issue commands to the rover data processor to control the formatting and sequencing of the data processing and transmission.

Issue command sequences for all science instruments to control their movements, sample rates, and transmission of their data to the data processor.

Modify the rover's predefined operational sequence, based on hazards or interesting science detected by the science instruments while traversing.

The baseline sequencer and memory (CSM) consists of approximately 14 000 words of C/MOS read-only memory, 2000 words of C/MOS random access memory, a microprocessor and the associated I/O. These C/MOS devices, operating at a 500 kHz clock frequency are used to minimize the power required. Word length is 8-bits and the sample interval is less than one second. The CSM is packaged as five boards in the integrated electronics assembly.

Baseline System Performance Summary

Rover subsystems described in preceding paragraphs provide the capability of performing a scientific mission, navigating, and controlling the mobility of the rover, and establishing communications with either the orbiter or the lander. The extent to which any of these functions can be performed with the selected hardware are limited primarily by the amount of power available.

Design margins for the rover include 20 percent in the areas of mass, volume, and power.

Table 46 summarizes the primary features and performance characteristics for the rover.

Section 6.3 details the power requirements for all of the electronic components and loads. Using these requirements together with the available RTG and battery energy available a mission profile has been created and shows that in a maximum traverse mode approximately 735 meters can be covered in a 24-hour period or in a maximum science mode of each of the science instruments can be operated. Each of these maximum type modes ends up the day with a fully charged battery, which never reached a 75 percent depth of discharge.

TABLE 46 ROVER FEATURES AND PERFORMANCE SUMMARY

SURFACE OPERATION

- 22 cm Rock Clearance
- Stable on 19° Slopes (Including 22 cm Rocks)
  - Pitch Stability Limit >60°
  - Roll Stability Limit >40°
- Detects and Avoids Slopes
  - 5° < Natural Angle of Repose
- Detects and Avoids Crevices/Holes >0.6 Wheel Diameter
- Detects and Avoids Rocks >22 cm Under Body
- Soil - Operates on all MEM Soils
- Speed >80 M/Hr (Forward and Reverse)
- Braking - Stops in <5 cm, Holds Position (Power off) on Slopes 30°
- Turns - Scuff Steering (Pivots in Place)
- Survives Thermal Environment at any Point on the Planet
- Operates Independent of Lander
- Mission Limited to Orbiter/Rover Life
- Move >500 M/Day

PHYSICAL FEATURES

- Payload - 20.87 kg Science
- Rover System Mass - 107.95 kg
- Rover Body: 40 cm Wide x 110 cm Long x 26 cm Deep
- Wheelbase = 60 cm
- Track = 60 cm
- Three Point Attachment to Lander
- One Point Attachment to Deployment Mechanism
- Wheel Spin and Motion Detectors
- Wind Detector
- Deployment - on Slopes < ± 19°
- Soil Collector
- Deployable Camera

FUNCTIONAL

- Integrated Science and Engineering Electronics (Data/Power)
- Dual UHF Data Output Links $< 2 \times 10^7$ B/Day
- Dual UHF Relay Command Input (VL or VO)
- Cross Range Error < 10% of Distance Travelled
- All Navigation and Guidance Functions on Board
- Evasive Maneuvers Around Hazards
- Soil Collection and Return to Lander
- Data Storage of 250 Kbits

Inherent in these mobility and science sequences is the fact that the maximum available energy is 20 watts.

Once a load profile is defined for a particular mode, 20 percent of this load is added as power margin before the operational sequence is defined. The standby power for the rover is a constant 3.5 watts. Other losses include distribution losses of 5 percent, converter losses of 14 percent and battery charging losses of 45 percent.

The timelines for the maximum traverse day and maximum science day are shown in Figure 111, which also identifies the quantity of data that is processed. The associated power profile for these two modes is shown in Figure 112 and Figure 113. These two figures show the resulting charge state of the battery for the loads required in the particular mode and assumes that the 20 watt RTG is available to be used as required and does include providing the previously defined losses and standby power.

Science payload performance. - With the baseline science payload and the necessary supporting hardware, the rover has the capability to collect surface samples and separate rocks and soil. During operations around the lander, samples are transferred to the lander for analysis. Samples analyzed by the rover are routed through a mechanism to the alpha backscatter instrument where a geochemical analysis, which includes both major and minor elements in the soil, is performed. The sample can also be routed to the X-ray diffractometer via a grinder when rocks are analyzed for their mineral content.

The camera is used to survey the Martian terrain to support the scientific mission in addition to providing data to understand the terrain to be traversed by the rover.

Typical rover surface mission. - A preliminary operational overview of a rover mission is presented in these paragraphs. This preliminary analysis is the basis for developing operational philosophies that are consistent with a scientifically good rover mission in conjunction with a Viking '79 dual orbiter and lander mission. It is intended to be the first step of an iterative procedure that will demonstrate the operational feasibility and scientific value of this type of mission.

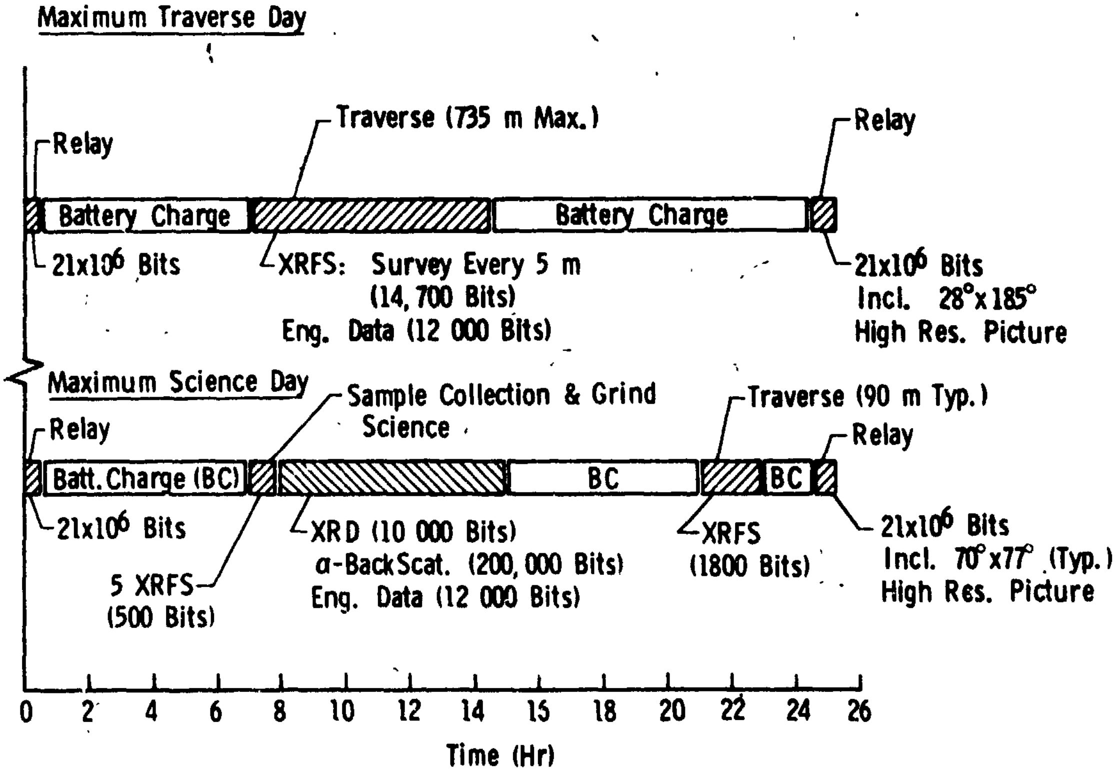


FIGURE 111 TYPICAL DAY TIMELINES AND DATA RETURN

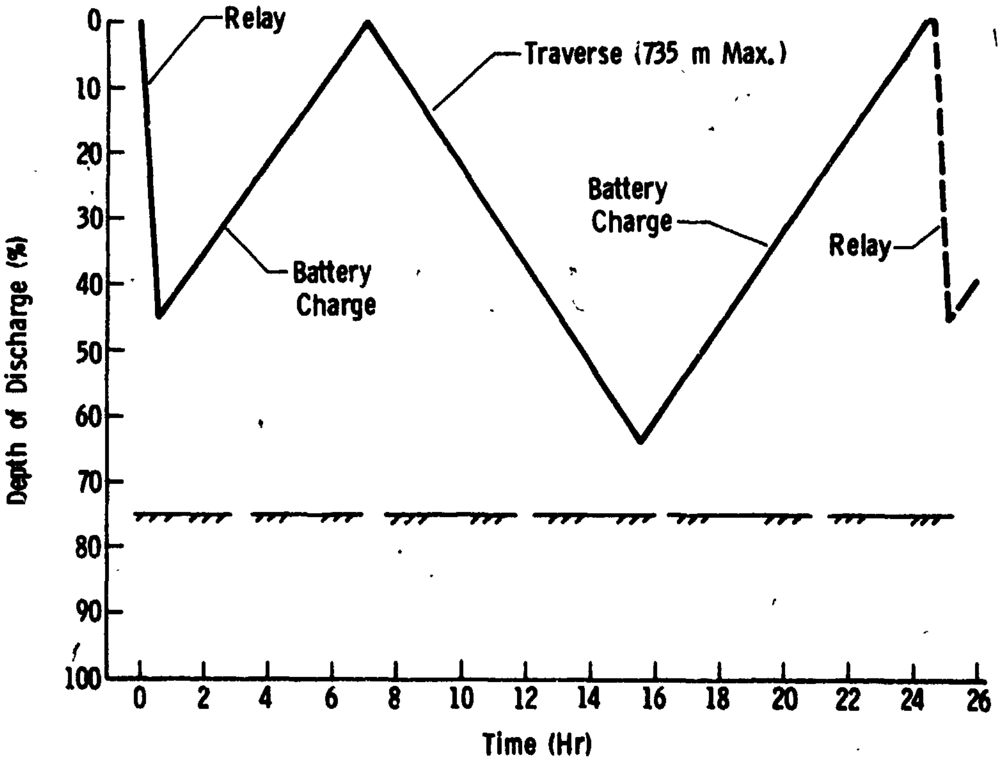


FIGURE 112 MAXIMUM TRAVERSE POWER PROFILE

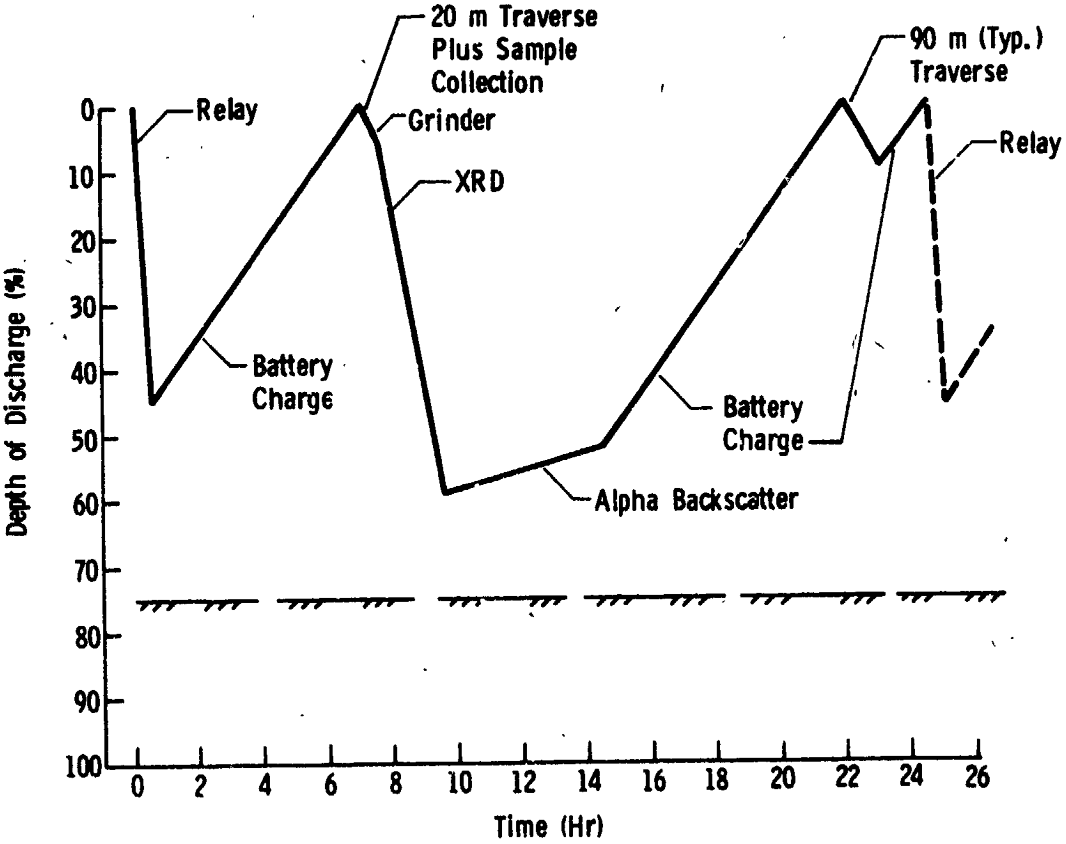


FIGURE 113 MAXIMUM SCIENCE POWER PROFILE

An initial cut is made on the operational timeline for the mission between MOI and end of mission. A specific portion of the mission is timelined in some detail; the remainder is just outlined and will be studied in more detail at a later date. The portion presented in more detail corresponds to the time in the mission after the rover has left the lander and arrived at the preselected area of scientific interest. A known caldera in the Sahara Desert (Emi Koussi) is used as an example because photographs and detailed contour maps are available to preplan mission (based on pictures) and then find operational problems (detailed maps) as the mission progresses.

The preliminary analysis of this mission has suggested several operational philosophies. These, plus the assumptions used, are presented in following paragraphs. Subsequent analysis in greater detail will justify (or modify) these philosophies and allow their expansion.

Top Level Assumptions and Philosophies - The principal assumptions on which this analysis is based are as follows:

The VMCCC will have the same capability in 1979 that it has for the 1975 mission.

Effective operational procedures will be developed within the VMCCC capability before the Viking '75 mission and be further refined during the mission.

Total multi-spacecraft data volume from the 1979 mission will be the same as that from the Viking '75 mission because the same communication link times and link performances are assumed.

The general operational philosophies that evolved from this preliminary analysis are presented in the following paragraphs. The rationale is presented during the discussion of the operational timelines.

The rover mission will be conducted in two parts. Initially it will support the lander's science mission; then it will leave the lander to perform its own science mission.

After the rover leaves the lander, the lander will depend primarily on its direct communication link for both commands and data return. During this time, the rover will have priority on the orbiter relay link.

The rover mission design will be adaptive; however, maximum scientific effectiveness is obtained by a plan that allows the rover to leave the lander for a specific area of scientific interest (crater, caldera, mountain range, etc.). Once there, the rover selects areas of local scientific interest and follows a mission plan that includes a few days traverse time divided between areas of local interest followed by a few days dwell time in the area of interest for scientific observation.

Rover's degree of autonomy will allow either daily specific commands for science data acquisition or traverse commands that will allow the rover to travel a multi-leg traverse from point A to point B over a period of a few days.

Rover commands will be validated before final transmission to the rover (i.e., in the orbiter, if orbiter relay command is used). Commands transmitted to the rover will be coded to the extent required to accept or reject command message segments. Accepted commands will be executed upon receipt. The rover design will be "fail safe" with respect to receipt of bad commands (i.e., stop and wait for correction.

Rover Mission Profile Overview - A representative rover mission profile from post-MOI is summarized in Table 47.

A checkout sequence is performed shortly after touchdown. All rover tie-downs are pyro-fired just after touchdown except for the rover-lander umbilical and final tie-down bolt on the rover disembarkation mechanism (later released by the rover). Finally, the rover timer is initiated and the command receiver on-time timer is initiated. This will allow a possible rover disembarkation by direct command if the lander does not survive the landing and the rover is still operational.

The next three days are devoted to initiating lander science and preparing for rover disembarkation. The latter activity includes imagery by both the lander and deployed rover cameras of the disembarkation area and near vicinity of the lander. This imagery leads to the disembarkation commands to be implemented on day TD + 3d. The disembark maneuver can be initiated by the direct

TABLE 47 ROVER MISSION OVERVIEW (POST-MOI)

Sep. - 30h	Preseparation checkout (rover and lander)
Touchdown	Separate rover from lander except for umbilical and final tie-down bolt. Perform rover preseparation checkout routine. Initiate timed rover command receiver operation.
TD to TD + 3d	Take pictures of rover disembarkation area (lander and/or rover camera).
TD + 3d	Disembark rover and move few meters from lander and park.
TD + 3d to 5d	Exercise rover in area local to lander. Verify operation with both lander and rover imagery. Develop initial near-lander mission profile.
TD + 5d to 13d	Traverse around lander in four steps. Take 180 deg (typical) high resolution pictures at each stop from both lander and rover for complete panoramic stereo pictures. Complete near lander mission profile. Complete orbiter imagery of area within 100 km (typ) of lander. Complete lander position determination. Develop rover traverse mission profile.
TD + 13d to 25d	Rover collect sample for second biology cycle and return to lander. Continue investigations in vicinity of lander. Finalize initial rover traverse to area of interest. Identify possible en route areas of local interest and probable landmarks. Depart lander.
TD + 25d to 60d	(Typical) Traverse to major area of interest. Take 180 deg (typical) panorama of area from high ground.
	Detailed sequence continued in Table 48

link commands a few hours before the next relay link. The rover will leave the lander and drive a few meters to a preselected park area near the lander and perform a few simple maneuvers. Real time imagery during the following relay pass from both the lander and orbiter will verify the proper mobile operation of the rover.

The next two days will be spent exercising the rover near the lander to complete its checkout and familiarize the operations team with its operations. In addition, lander imagery can be used to identify the sample area for the first soil sample. The option here is to start the first biology cycle with a lander-collected sample so this first cycle can be completed while the rover-lander completes lander local panoramic imagery (stereo) and potentially more interesting sample areas are identified.

The next eight days in the sequence are used to move the rover around the lander in four equal steps. At each location, the lander and rover can take high resolution pictures in 180 degrees azimuth for virtually complete stereo coverage in all directions around the lander. This imagery sequence will return approximately 80 x 10^6 bits from both vehicles. This imagery is the basis for continued rover-to-lander support, soil sample collection, and preliminary rover traverse planning.

During this whole period the lander position will have been determined by ground-based tracking and the orbiter will have mapped the total area around the lander. These data will be used to plan the rover traverse to the area of greatest probable scientific interest. This traverse will include area selection, traverse landmarks, and intermediate local areas of interest.

The next twelve days is spent doing the forementioned planning. During this period the rover will continue operations in the vicinity of the lander to support and augment lander science. Near the end of this period the rover will collect and deliver a soil sample to the lander for the next biology cycle. An alternate approach is not to start the lander biology cycle a few days after touchdown and have the rover deliver the first sample to the lander at about TD + 15d. This option will limit the number of biology cycles before lander end of mission.

At the completion of this period (approximately TD + 25d) the rover will complete its lander support function and begin its rover-independent mission. The philosophy is to traverse, as quickly as possible, to an identified area of interest (caldera, crater, mountain range, gorge, etc.) with the intent of detailed study of the area. Orbiter pictures will provide apparently good routes to the area and potentially interesting scientific features to be investigated en route. Although the rover mission is adaptive and can react to "surprising" data during this traverse, the general plan is to get the area of interest as quickly as possible so a maximum scientific effectiveness mission can be performed. This thought is amplified in the detailed mission sequence example evaluated in following paragraphs.

The subsequent analysis assumes the area of interest is a caldera. In particular, the Emi Koussi caldera (Sahara Desert) is used in the subsequent analysis because we know something about it and can play the parallel game of rover mission planning based on photographs and problem generation based on knowledge from detailed maps.

Mission to Emi Koussi - The scenario presented in subsequent paragraphs has been developed around available photographs and maps of generally known terrain. Although some artistic license is applied, the mission profile has been developed based on the data at hand.

The sequence is useful in that it is used to define both rover capabilities, constraints, and inflight options for rover mission design as well as forming a basis for estimating the impact on the ground operations activity. The characteristics described apply equally well to the part of the mission described in preceding paragraphs.

The final phase of the rover mission involves the detailed exploration of a caldera identified in a Viking '75 or Viking '79 orbiter picture. The crater shown in Figure 114 (a Mariner 9 B-frame picture) is approximately the size of Emi Koussi (slightly smaller) as it would appear in a Viking '75 frame from 1500 km. The landing dispersion in Viking '79 (semiminor axis) would place the lander approximately two-thirds of the distance from the crater to the upper left hand corner of the picture. This, then, represents the type of data avail-

FIGURE 114 REPRESENTATIVE VIKING '75 ORBITER PICTURE

able to plan the basic traverse away from the lander. Potential science explorations between the hypothetical lander and the objective (crater or caldera) might include investigating one of the windblown tails on a projection and looking into the channel to the left of the crater. In addition, careful examination might indicate the most favorable approach to the rim for potential descent to the bottom.

The final stage of the sequence presented in the preceding paragraph includes good rover imagery of the approach to the caldera rim. An overview of the caldera is shown in Figure 115. The approach is assumed from the general area in the lower right corner. Peak P.3210 is the objective. This hill, approximately 20 m wide near the top, should be recognizable in rover pictures about three to four days before arrival with the Viking Lander '75 fax camera (line spacing less than 2 cm at this distance). The rover is commanded to the hill, climb to the top, and stop (one of the command options). At the next orbiter over-fly, the rover will take and transmit a 180 degree azimuth, 30 degree elevation high resolution picture (20 x 10^6 bits) of the caldera. The resultant picture is nearly the size shown in Figure 116. The picture has resolution comparable to that of the Viking '75 fax camera (Note the azimuth scale on the picture. Pixel spacing will be 8 to 25 pixels per degree for low and high resolution pictures, respectively. This is more than adequate to plan the mission sequence defined below). The sun angle at the time of transmission of the pictures will be approximately the same as that of the picture, but somewhat closer to the horizon.

During critical mission phases, such as major rover traverse operations, the VMCCC picture processing software (through first order enhancement and video display) will have a priority. On this basis, the first caldera picture should be available for viewing within five hours after transmission (Table 48). This initial picture has two primary functions. The first is to determine the most likely path for descent to the caldera; the second is to define the preliminary objectives of the caldera science mission.

The picture shows two potential descent paths. The first, and most probable, is from P.3261 (Az 144°W) at the far left of the picture. The second is through the pass Porte de Modioungo shown at right center, azimuth Az 7°E. The

FIGURE 115 EMI KOUSSI TOPOGRAPHICAL MAP

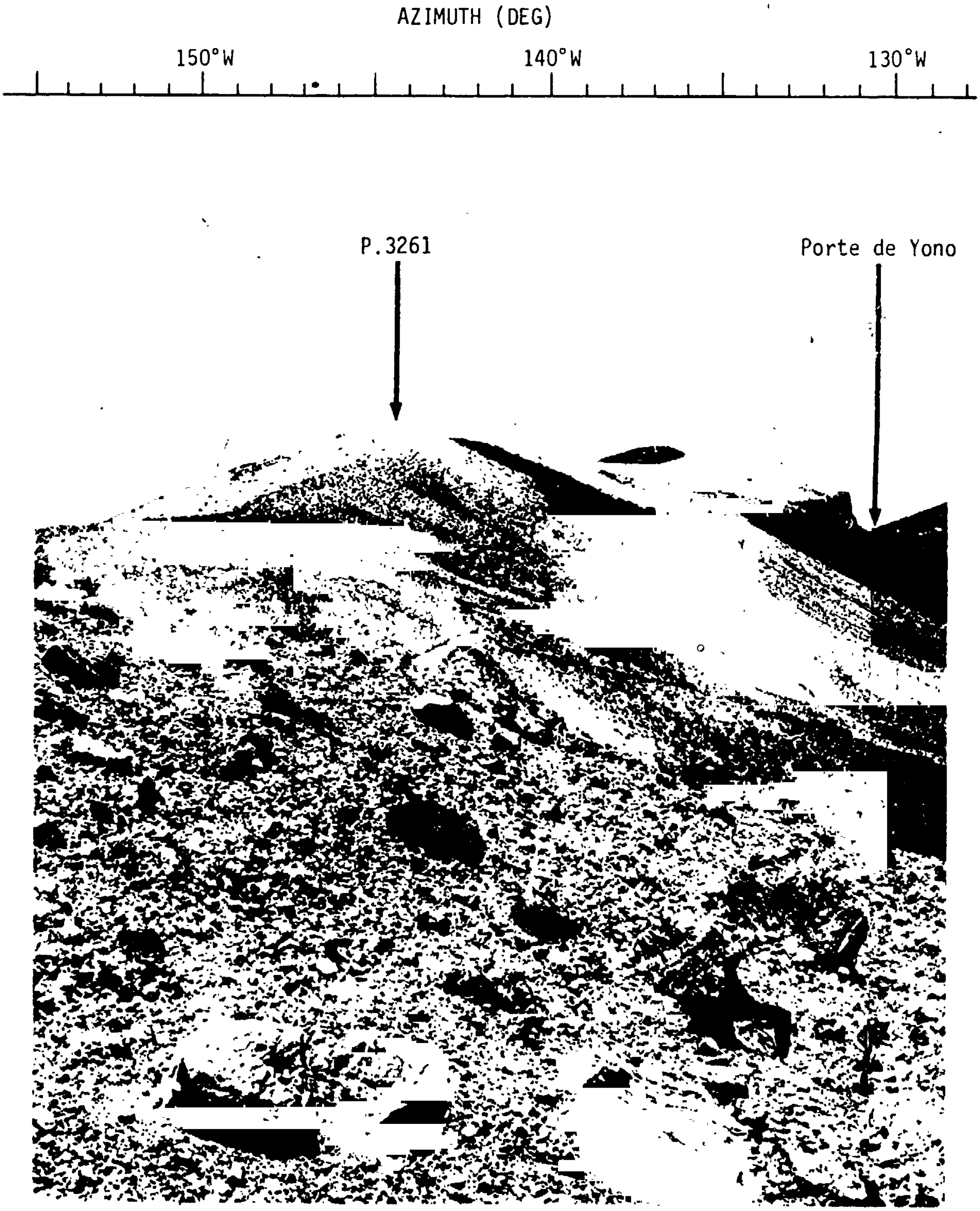


FIGURE 116 REPRESENTATIVE ROVER PANORAMA OF EMI KOUSSI (SHEET 1 OF 7)

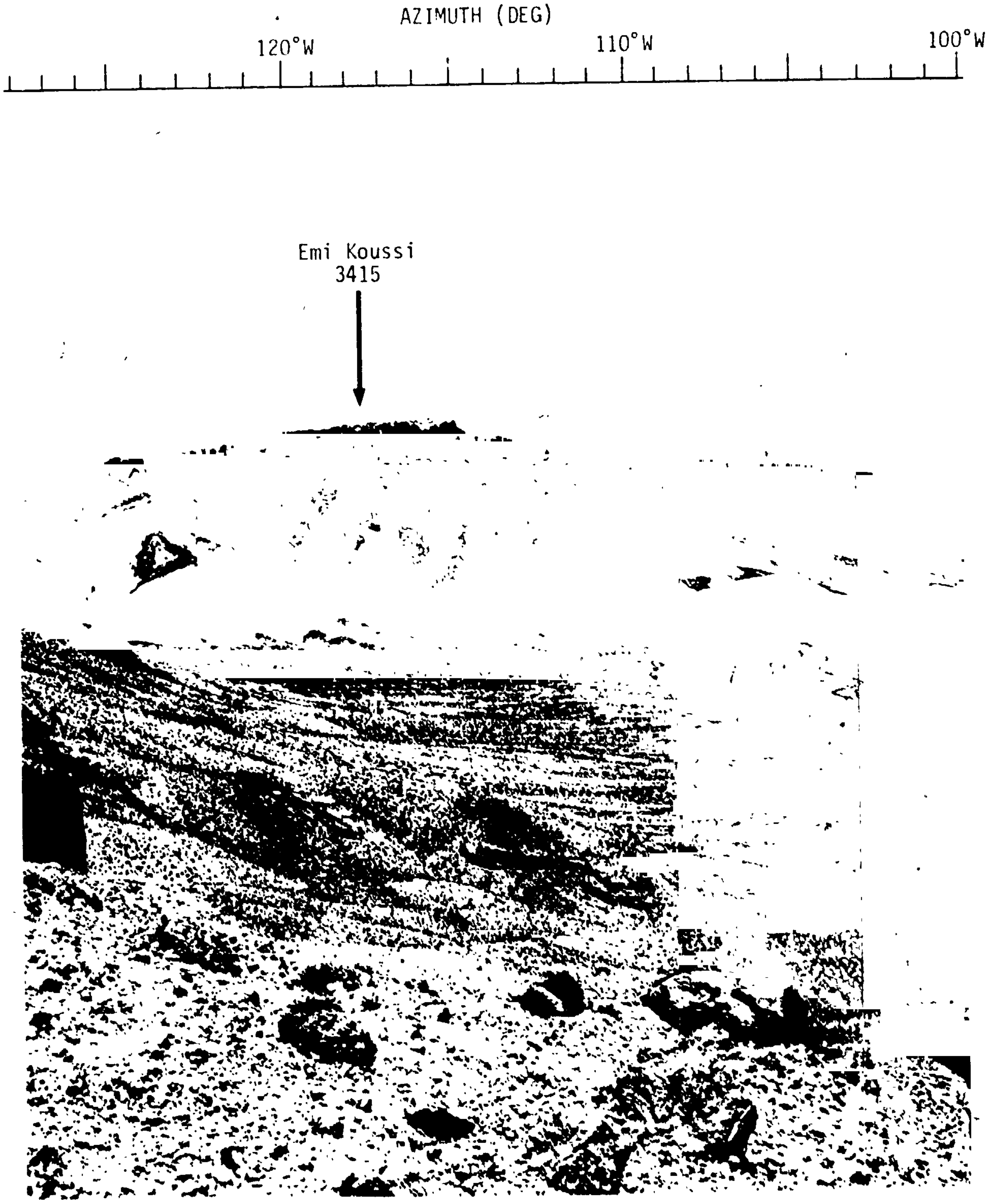


FIGURE 116 REPRESENTATIVE ROVER PANORAMA OF EMI KOUSSI (SHEET 2 OF 7)

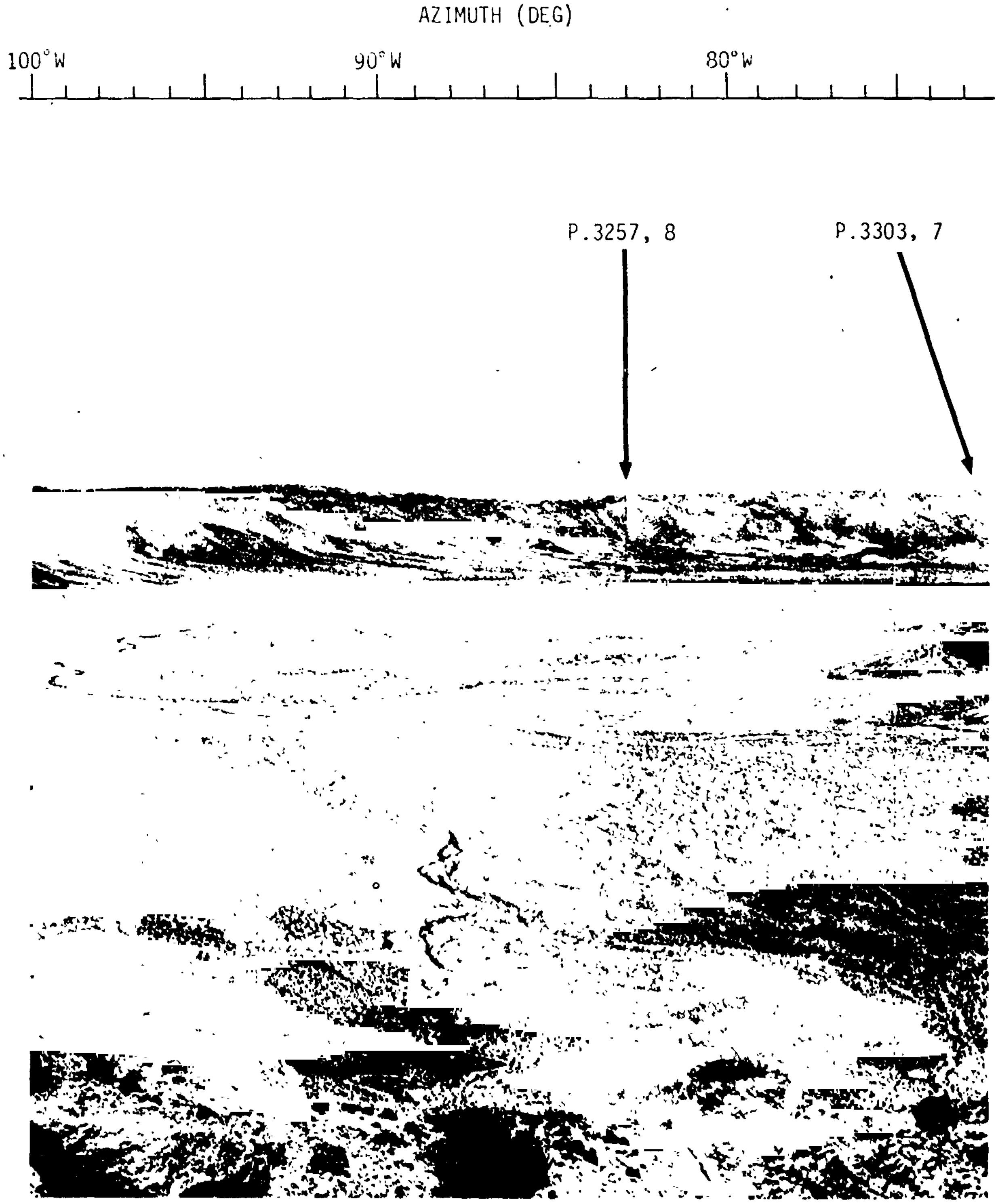


FIGURE 116 REPRESENTATIVE ROVER PANORAMA OF EMI KOUSSI (SHEET 3 OF 7)

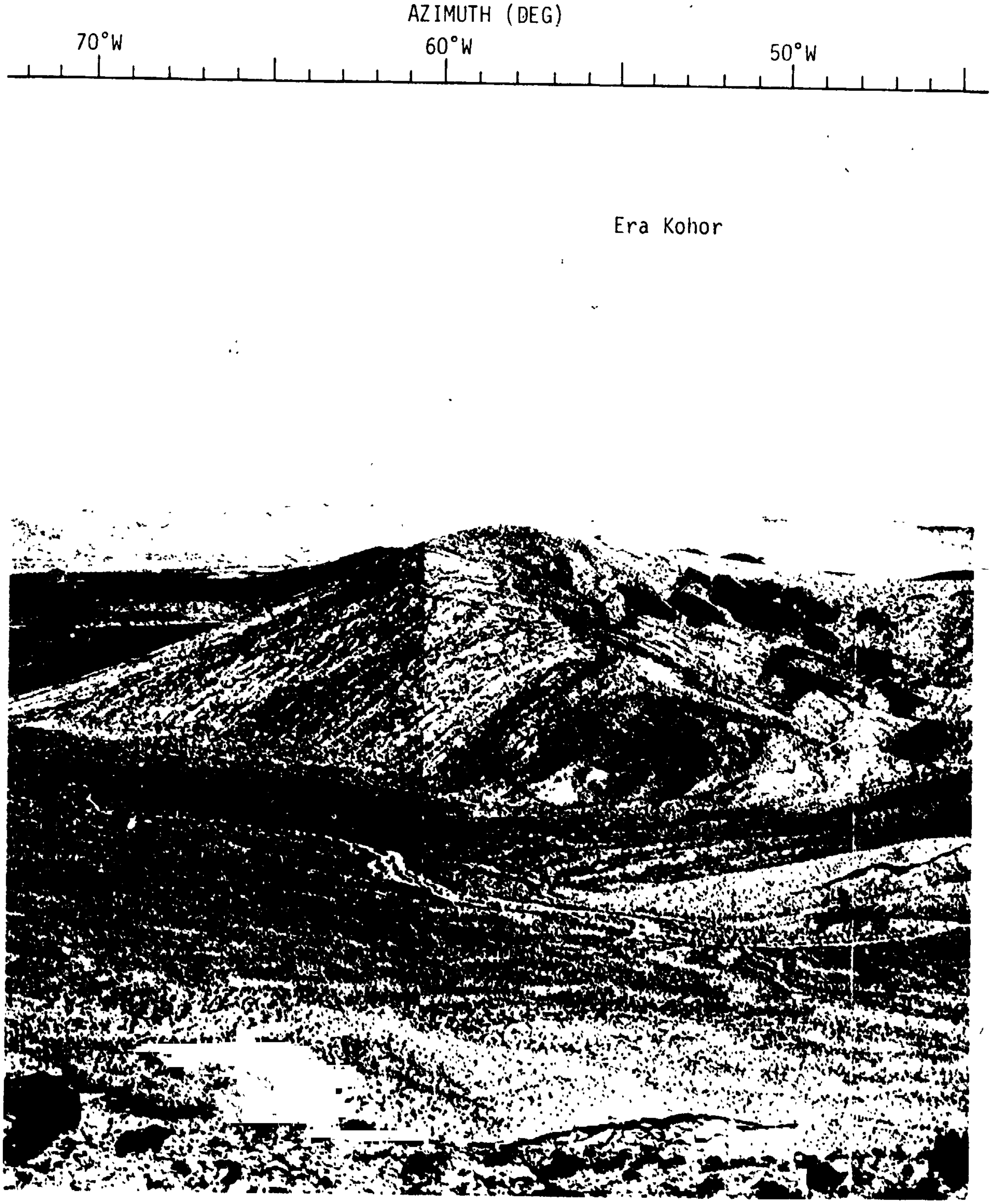


FIGURE 116 REPRESENTATIVE ROVER PANORAMA OF EMI KOUSSI (SHEET 4 OF 7)

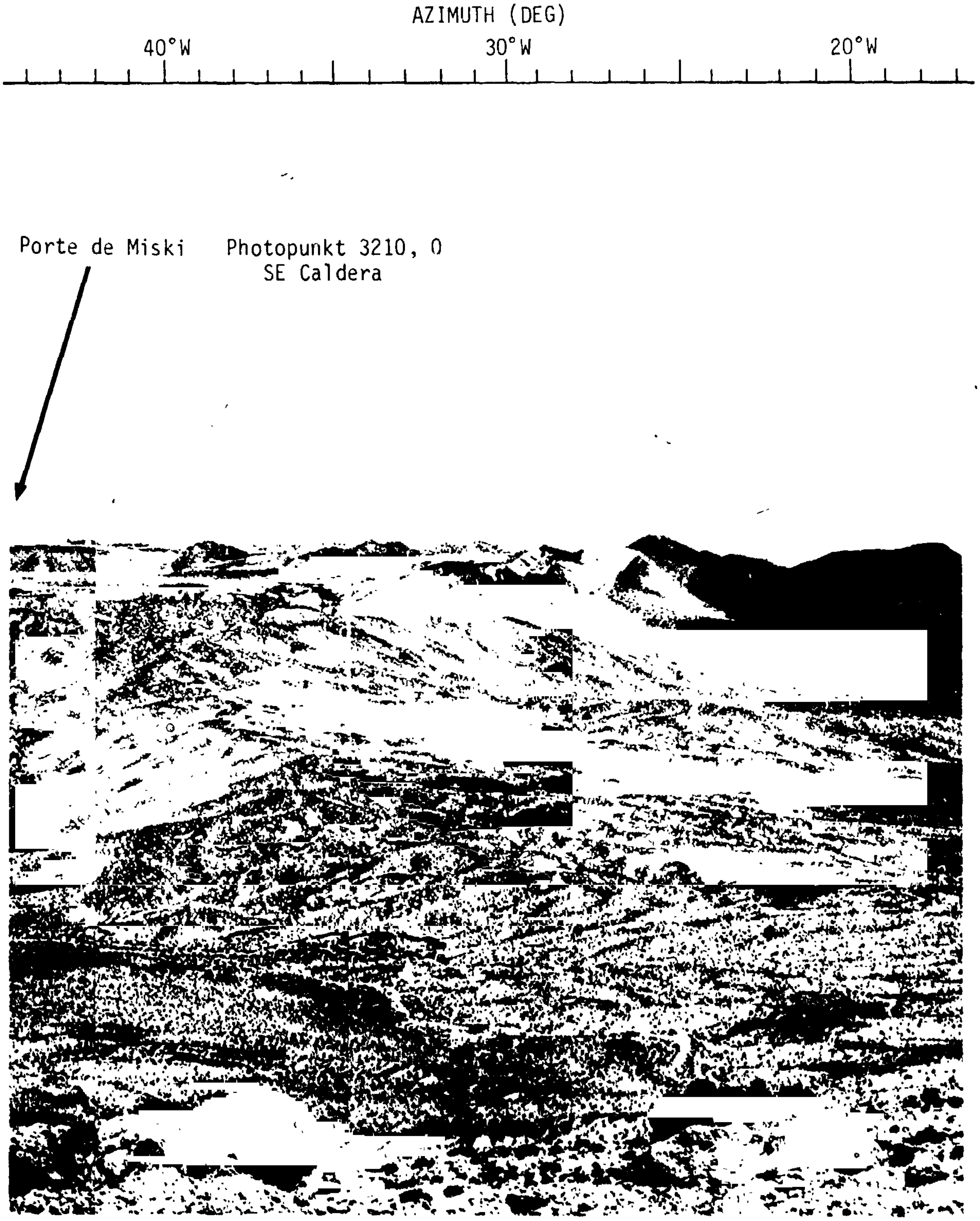


FIGURE 116 REPRESENTATIVE ROVER PANORAMA OF EMI KOUSSI (SHEET 5 OF 7)

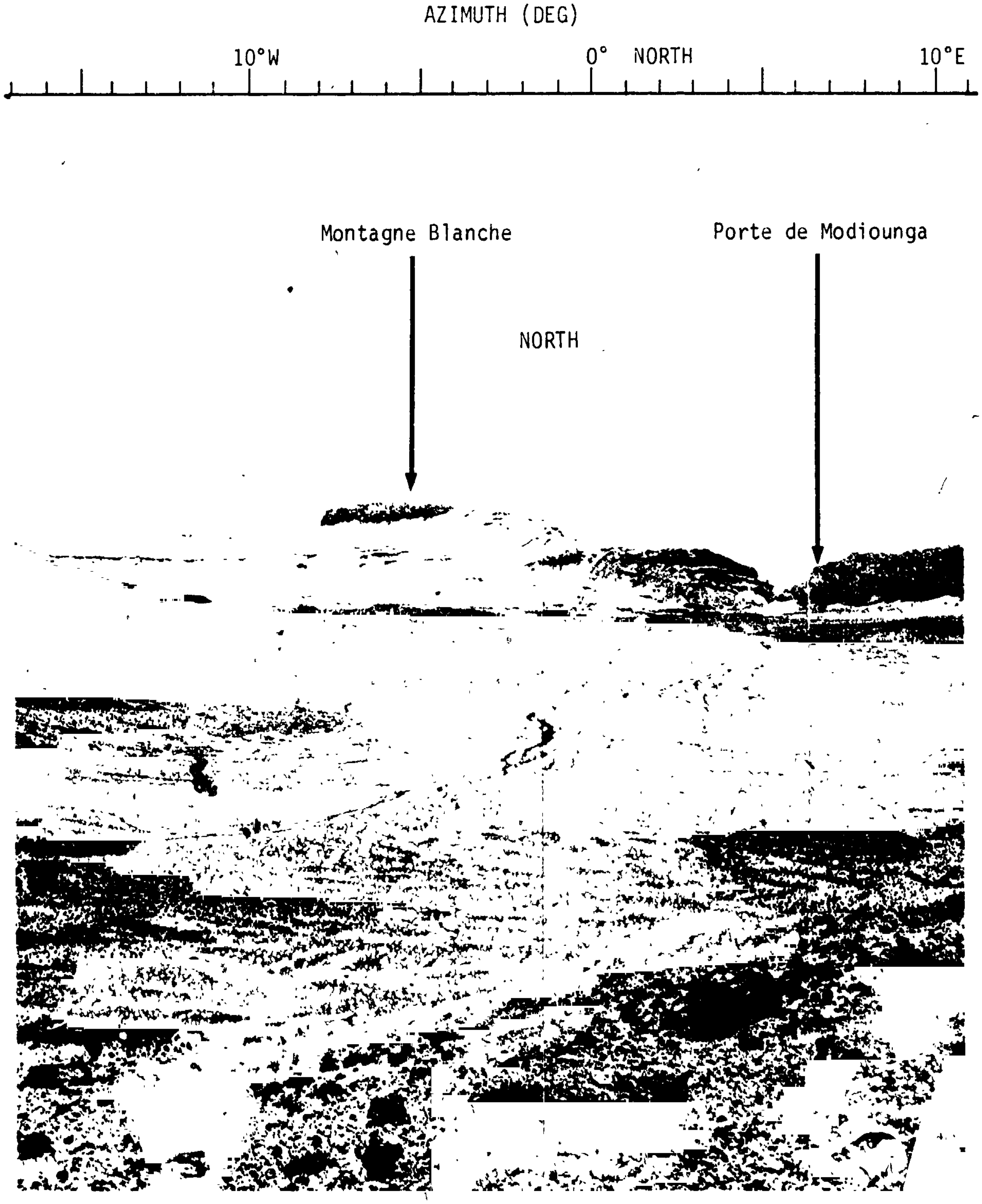


FIGURE 116 REPRESENTATIVE ROVER PANORAMA OF EMI KOUSSI (SHEET 6 OF 7)

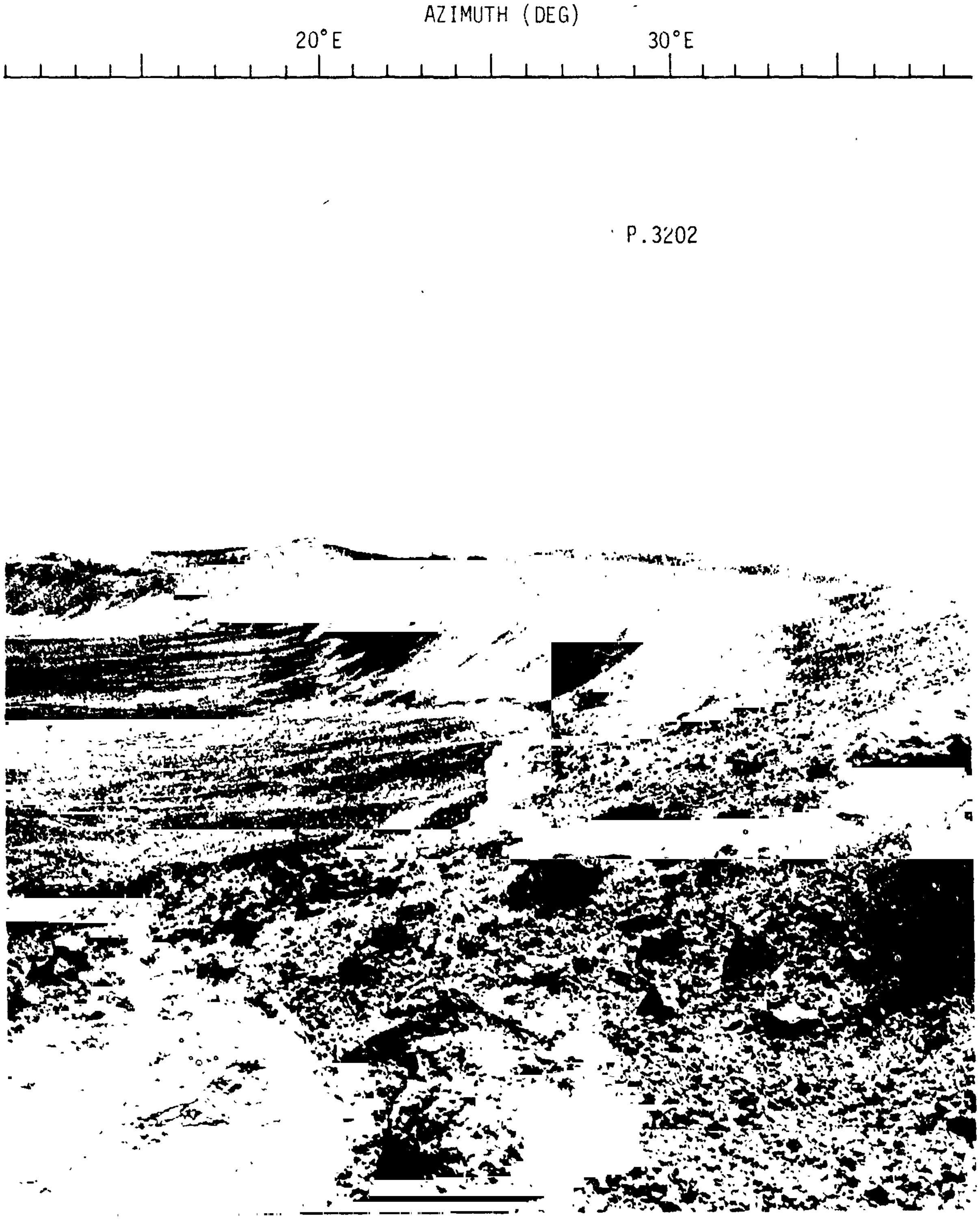


FIGURE 116 REPRESENTATIVE ROVER PANORAMA OF EMI KOUSSI (SHEET 7 OF 7)

TABLE 48 EMI KOUSSI MISSION TIMELINE, START TO END OF DESCENT

A + 0 (sol 0)	Arrive at hill top (P.3210), dwell for battery charge, transmit 180 degree panorama of caldera.
A + 2.5h	VO completes picture transmission to Earth.
A + 5h	Picture processed by VMCCC through first order enhancement.
A + 12h	Most likely descent path identified.
A + 14h	Next day rover imagery program commands generated and transmitted to orbiter.
A + 18h	Commands in VO validated.
A + 24.6h (sol 1)	Commands transmitted to rover to back up three meters and transmit 60 degree azimuth picture toward P.3261. Receive picture.
A + 27h	VO completes picture transmission to Earth.
A + 29.5h	Picture processed by VMCCC.
A + 36.5h	Traverse to P.3261 defined. Three day traverse selected along with most likely track.
A + 38.5h	Rover commands generated and transmitted to orbiter.
A + 42.5h	Commands in VO validated.
A + 49.25h (sol 2)	Commands transmitted to rover for three day traverse to P.3261. Can also command an additional (science selected) picture during this relay pass.
A + 2d, 11h	Rover start day-one traverse of 550 m.
A + 3d, 1.8h (sol 3)	Command and receive navigation picture pair.
A + 3d, 22h	Rover start day-two traverse of 400 m.
A + 4d, 2.5h (sol 4)	Command and receive navigation picture pair. Update day-three traverse commands if required based on sol 3 pictures.

TABLE 48 (continued)

A + 5d, 3.1h (sol 5)	Transmit 180 degree (plus panorama of caldera) from P.3261.
A + 5d, 8h	Receive pictures from sol 4 and 5 for evaluation of most likely descent path.
A + 5d, 15h	Select most likely descent path. Initiate rover mission redesign (see text).
A + 6d, 3.7h (sol 6)	Command rover move for stereo picture of most likely descent paths (stereo with sol 5 picture).
A + 6d, 9h	Receive picture from sol 6 and (stereo) combine with sol 5 picture.
A + 6d, 16h	Identify descent path. Initiate command generation.
A + 7d, 4.4h (sol 7)	Transmit descent commands to rover (see text).

latter selection, however, is improbable for at least three reasons:

Resolution at this distance is poor,

Distance to be traveled before descent is large (time consuming),

There is no guarantee of descent path when the rover arrives at that point.

Thus, P.3261 is the selected point for descent. The next rover task is to move a few meters and take another picture towards P.3261 for stereo coverage for distance determination and detailed navigation planning.

The preliminary science evaluation of the initial picture shows several interesting features. These include:

Outcropping on hill P.3261

Apparent drainage patterns in bottom of caldera

Outcropping in hill at azimuth Az 50°W

Black hill at Az 19°W

Drifted sand at Az 5°W

Rocks at cliff base

Pictures of cliffs

On this basis, the preliminary rover mission plan shown in Figure 117 is defined. It includes a 1140 m traverse to the descent point, then a 5 km path to the black hill with four intermediate local areas of interest. An alternate plan with an earlier stop at the cliff base, which covers a 6 km path with five local areas of interest, is also shown. The mission design intent is to get a second "high ground" panorama from P.3261 to give good stereo coverage (long baseline with current picture) before "finalizing" the baseline mission with relatively accurate ranging.

A key mission design philosophy evolves from these considerations. It is apparent that several features of varying types of scientific import can be identified from this single picture. They are well within the operating range of the rover. From this, the pattern of a mission plan based on a few days

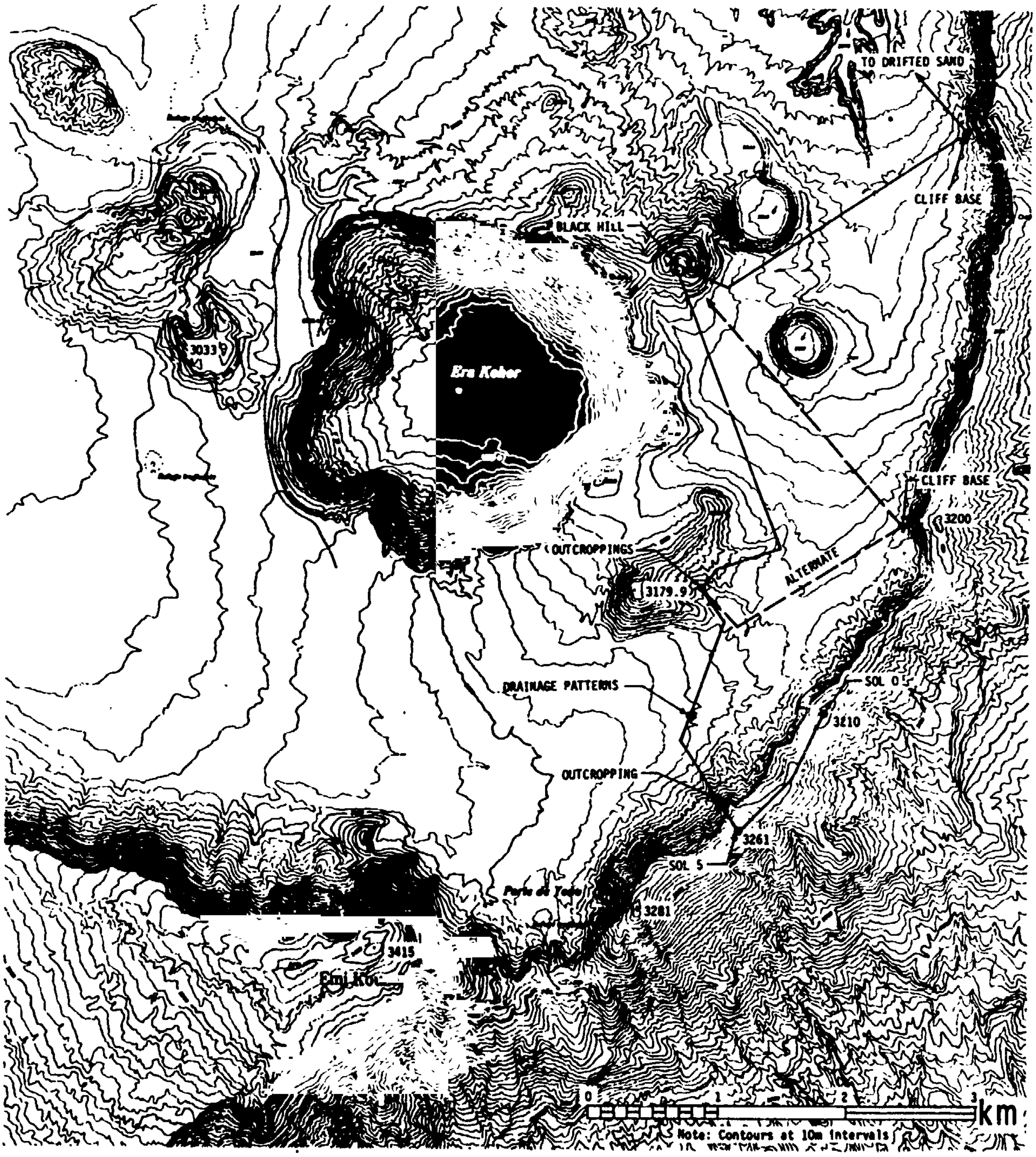


FIGURE 117 ORIGINAL MISSION PLAN

traverse followed by a few days of local science investigation has evolved. Daily mission replanning is possible, but at the expense of more "global" objectives (or mission time).

A second philosophy associated with this type of mission is the desirability of getting at least two separated pictures of the caldera from high ground before proceeding. This provides good ranging information upon which the most effective science mission can be planned. It also provides a good basis for performing a reasonable backup mission if the rover camera fails after descent into the caldera.

Before continuing with the sequence, two rover command options must be discussed. It is necessary that the rover be capable of receiving and executing commands on a daily basis. This requirement allows reasonable mobility and science return in a minimum mission time. It leads to the rover design requirements stated previously that the rover command system be capable of receiving and executing commands without final validation and that the rover be "fail safe" with respect to this philosophy. From a command viewpoint, two modes are considered: direct and relay (via orbiter or lander). The sequence presented in following paragraphs (and in Table 48) assumes the latter, but the mission/system/science trades, which must be evaluated in more detail, are presented here for traverse sequence implications and for science data return implications.

The direct (Earth-to-rover) command approach generally allows commands to be sent to the rover an hour or two before the next orbiter relay pass. Picture taking commands for the pass, plus any rover motion required for stereo pictures, will arrive at the rover before the relay session. Relay commands (from the orbiter) require, during traverses, transmission of commands to the rover and execution during the same relay pass. This includes limited rover motion (for stereo pictures) and picture commands. A typical (partially preprogrammed) command sequence might be to take a 30-degree azimuth (about four minutes) picture, move three meters in some direction (about two minutes) and repeat the picture. Although tight from a timing viewpoint, this type of sequence is entirely feasible with a rover designed to do it.

The major trade study parameters between these command techniques are as follows:

Direct commands are transmitted "in the blind." Time for lock-up at best the frequency uncertain.

Direct command limits rover latitudes to about ±40 degrees.

Relay command requires transmitting an idle sequence during rover motion to maintain orbiter receiver lock or ability to receive intermittent data.

Relay command will result in less data during navigational passes, but data return appears adequate for navigational requirements.

Command coding/decoding requirements may be different for both approaches to maintain a given correct execution probability (total bits/command).

Impact on ground operations and timing is still TBD.

Again, the subsequent analysis assumes an orbiter relay command system except as noted.

The sequence presented in Table 48 shows command sequence at A + 24.6h that directs the rover to back up three meters and obtain a second picture of the path towards peak P.3261 for stereo pictures (with those transmitted at A + 0h). This picture pair defines the distance to P.3261 as 1140 m. Thus, a three-day traverse is planned to go from the current position to a point near the peak of P.3261, but 5 to 10 m down the caldera side of the hill. The path is to leave the current position at an azimuth of 124°W for eight meters, then turn left to an azimuth of 149°W to the base of P.3261. At that point, a right turn to an azimuth of 137°W for the traverse up the hill will be made. This turn will be made at a distance of 550 m from the current position.

The first picture (Figure 116) clearly shows a rocky terrain for approximately 500 m. The larger rocks are in the 15 to 30 cm size category and must be avoided. Fortunately, there is a clear path that can be followed. A key mission design philosophy emphasized here is that the local rock field will not be scientifically explored at this time. The top priority is to descend to the caldera as soon as possible, and then explore the rock fields at the base of the cliffs during the course of the mission.

Additional mission planning information from the first stereo picture pair shows the terrain to fall away at about one degree slope for the first 500 m then climb at an average slope of six degrees to the top of P.3261. (The actual elevation contour over this traverse is shown in Figure 118 as evaluated from Figure 114.) The mission plan, from this point on is developed assuming the following rover characteristics:

The rover can travel for eight hrs/day (level ground) in the traverse mode (current predicted capability).

Traverses will be planned so there is sufficient time to recharge the batteries between the end of the traverse and relay link initiation.

The rover velocity and power consumption as a function of slope and roll angle is that shown in Figure 119. The "sand" curve is used. Nominal ground power (four wheels) is 6.5 watts.

Rover traverse efficiency is 0.8 to compensate for hazard avoidance maneuvers (based on MEM Surveyor rock data).

Using these data and assumptions, the maximum rover range per day on a one-degree downslope is approximately 594 m and 433 m on the six-degree upslope. Thus, the rover cannot quite make the top of P.3261 in two days (1140 m required versus 1027 m capability after hazard avoidance efficiency is subtracted).

This, then, leads to a planned traverse of 550 m on day one (up to the azimuth change point of 149°W to 137°W, above). On day two, the rover will start the upslope climb of 400 m. The final day will be a 190 m (± 100 m for range and rover odometer uncertainties) traverse to the peak using the "climb to hill top" guidance mode followed by turn to azimuth 20°W and travel 10 m to stop. This will place the rover on the caldera downslope side of P.3261 for good imagery of both the caldera as well as downslope terrain for the next traverse. The short traverse will insure full battery power for the next relay pass.

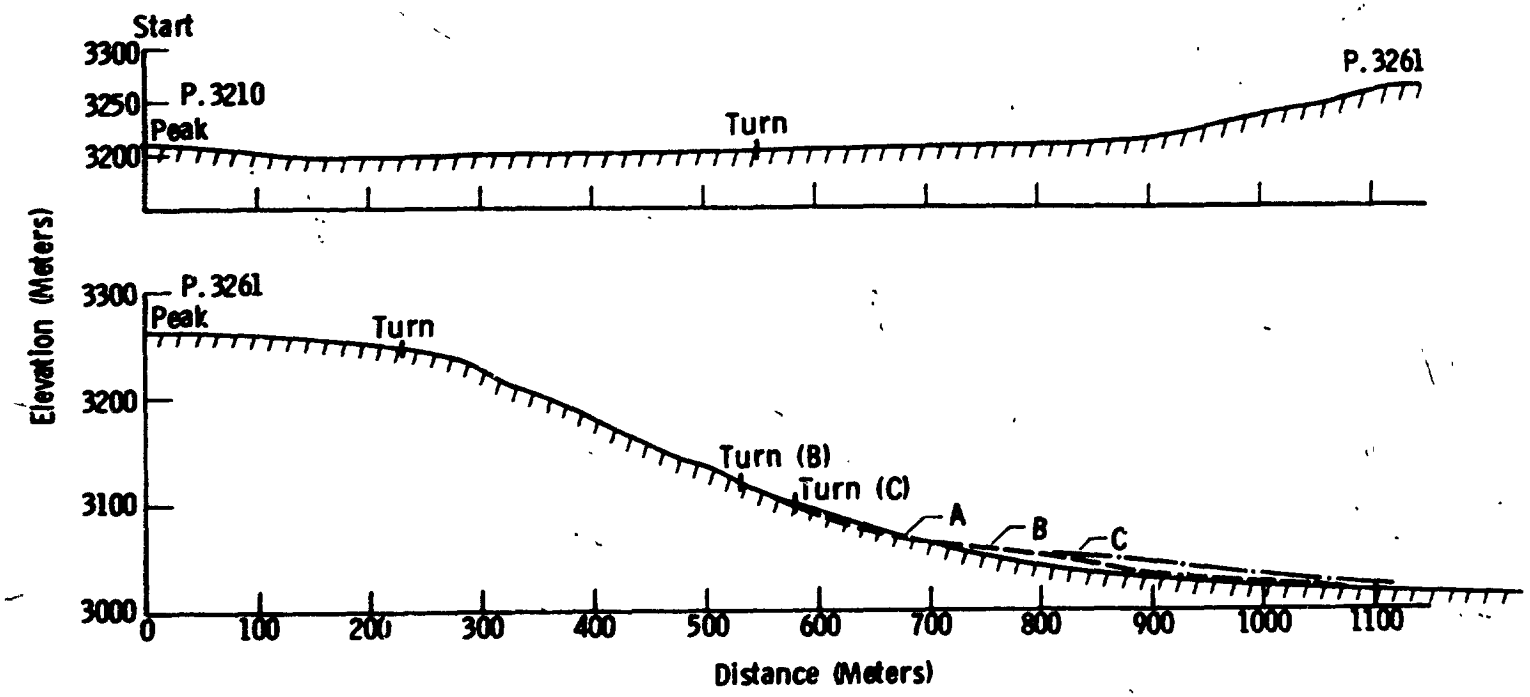


FIGURE 118 ELEVATION PROFILE FOR DESCENT TRAVERSE

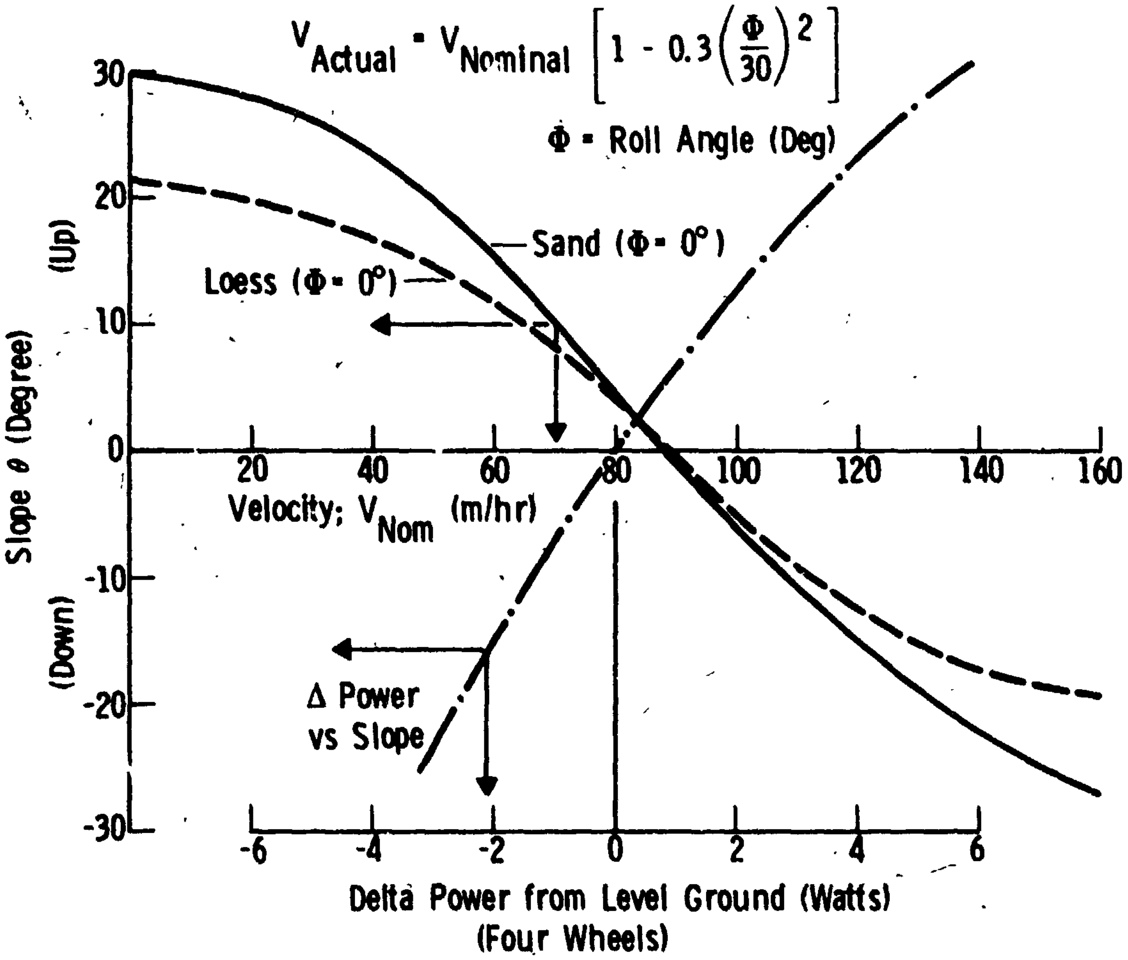


FIGURE 119 ROVER SPEED AND POWER VS SLOPE

During the three-day traverse navigation picture pairs are transmitted at the end of each traverse (Table 48). These data are used to confirm the rover traverse, evaluate rover navigation accuracy, and allow time for command modification on the subsequent relay session.

After arrival at P.3261, the initial panorama will provide data on possible descent paths. In addition, this picture can be combined (in stereo) with the picture from P.3210 to provide a detailed layout of the caldera, including good ranging data of the major features. This process can take two to three days (not time critical). In addition, the mission profile has no rover (traverse) activity between sol 6 and sol 7 and no required picture during the sol 7 relay session. Thus, the sol 4 and sol 5 pictures can be used to direct the rover (on sol 6) to perform a limited science exploration in the vicinity of P.3261 during this period.

No panoramic picture is available from the sol 5 location. However, the aerial photograph (Figure 120) and Figure 115 can be used to deduce what might be seen. For the actual mission, the P.3261 panoramic picture (sol 5) shows two important facts not readily identified from the sol 0 picture at P.3210. First, the initial selection of descent path (shown in Figure 117) is not possible. The sol 5 picture will show a cliff in that region (based on data from Figure 115). However, alternate possible descent paths, Figure 121, which are negotiable, can be observed. This requires redesigning the descent traverse between the sol 5 picture receipt and sol 7 command session (two days).

The second important "finding" from the sol 5 picture is that there is a secondary depression (Era Kohor) in the bottom of the caldera that is not readily visible in the sol 0 picture because it is shielded by peak P.3180 (Az 60°W in Figure 116). This prompts a science mission redesign that will initially take place in the four-day period between sol 5 and sol 9 (i.e., time it takes the rover to negotiate the descent to the caldera). A preliminary decision to investigate this newly found secondary depression will allow the descent maneuver to be planned based on path B or C in Figure 121. This will redirect the caldera mission from going to the east of P.3180 (Figure 117) to the west of it so the caldera investigation will be either to the east of Era Kohor or between Era Kohor and P.3180. The final decision on this path does not have

FIGURE 120 AERIAL PHOTOGRAPH OF EMI KOUSSI

FIGURE 121 POSSIBLE DESCENT PATHS

to be made for several days. During this time, the rover will descend to the caldera and will scientifically explore one of the original targets, the drainage patterns seen in Figure 115 (sol 0 picture).

Continuing with the mission plan, preliminary evaluation of the picture set on sol 5 and 6 indicates a downhill run of near zero slope for about 200 m and an average slope of approximately 13.5° for the next 1000 m. This compares to the actual elevation profile shown in Figure 118, which has a peak slope of 24° in the region between 260 to 610 m. These data, plus the foregoing assumptions and the data of Figure 119, result in the predicted versus actual mobility system power use shown in Figure 122 for course B. The predicted data indicate a potential travel distance capability of 830 m.

At this point, a traverse versus science decision can be made. It is apparent from the sol 5 and 6 pictures that a descent near the outcropping at Az = 135°W (Figure 116) is not practical; however, following course B (Figure 122) with a daily stop at the second turn (elevation 3120 m) would allow another picture of the outcropping from a third aspect. That is, the outcropping is in the sol 0 picture (viewed at Az 135°W, 940 m, pixel spacing = 65 cm), the sol 5 picture (viewed at Az = 10°W, 20 m, pixel spacing = 1.4 cm), and from the turn point during descent (viewed at Az = 64°E, 440 m, pixel spacing = 31 cm). This picture sequence of the outcropping (from three sides) should provide data on major layering. It is desirable to approach the outcropping to investigate local rocks, but these should not be different from those at other points along the cliff base and this latter science investigation is planned later in the mission.

The alternate is to continue the planned traverse on the next day to a maximum distance of 750 to 800 m, which includes the second turn. This would still allow a picture of the outcropping at an Az = 95°E, 530 m, pixel spacing = 37 cm; however, the power margin for both the outcropping picture plus navigation picture would be small. In addition, the combination of long traverse, two turns, and an oblique traverse down the hill lead to potentially large navigational uncertainties, compounded by it being a critical and difficult part of the mission.

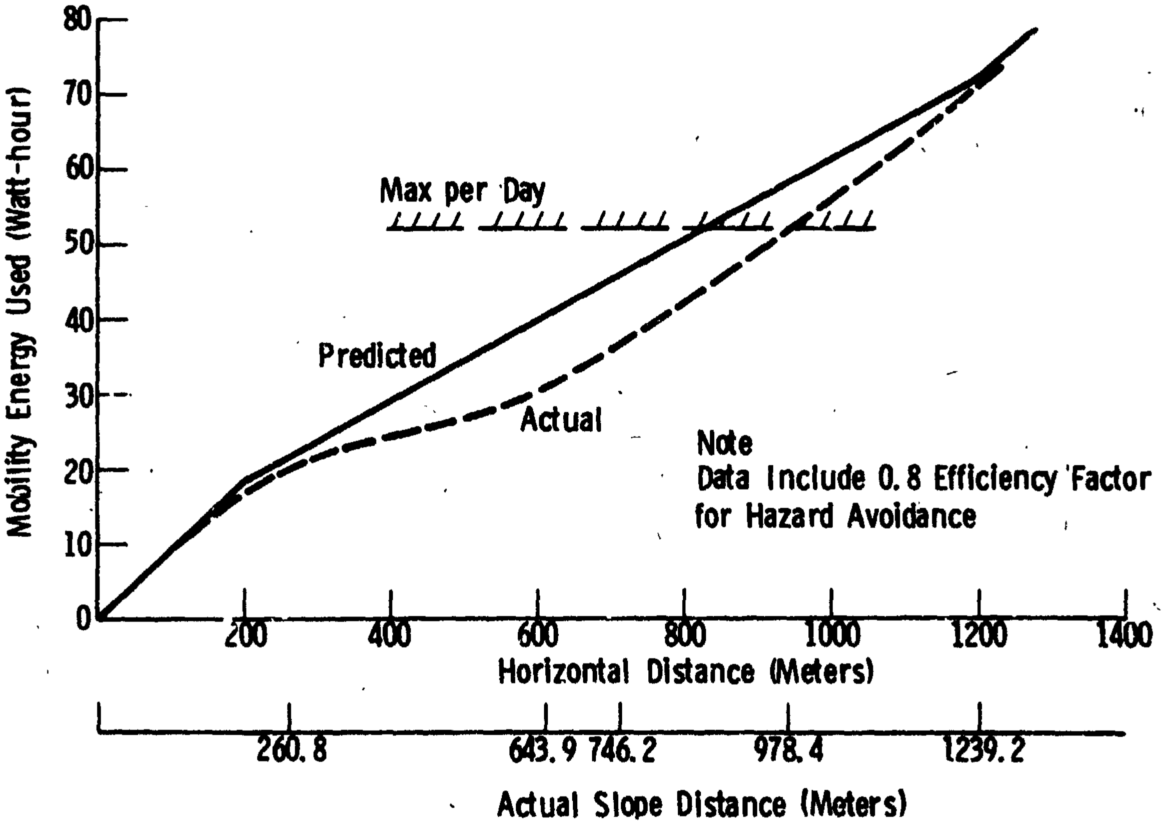


FIGURE 122 POWER USED BY MOBILITY SYSTEM DURING DESCENT ON COURSE B

From these considerations, a planned traverse of 625 m (horizontal distance to elevation 3080 m) is selected. In addition, a one-day delay at the stop will be planned to allow receipt and evaluation of a navigational picture pair before continuing the descent.

The command sequence sent to the rover on sol 7 then becomes:

Leave P.3261 at Az = 124°W, move 230 m.
Turn to Az = 62°W and move an additional 309 m (300 m horizontal).
Turn to Az = 31°W for final 98 m (95 m horizontal).
Stop and prepare to transmit dual (navigation) picture pair in downslope direction at next relay link (sol 8).
Prepare to transmit single (or stereo pair) picture in outcropping direction on sol 9.

The rover will execute this sequence starting approximately 10 hours after the relay session with fully charged batteries. This traverse will take 6.8 hours including 20 percent contingency for hazard avoidance. The remaining time before the sol 8 relay session is more than adequate to fully recharge the batteries again.

During the period between receipt of the sol 5 and 8 pictures (it is assumed) a new rover caldera mission is defined. It includes going from the sol 8 position to the base of the outcropping at Az 135°W (Figure 116) for rock sampling and analysis. Then, travel to the drainage patterns and fully investigate them while following them generally to the west and northwest. The rover will then tract east again to the black hill at P.3033 (barely visible behind hill at Az 61°W Figure 116) and partially climb it to obtain pictures into the secondary depression, Era Kohor, as well as navigation/science-related pictures to the north and east. The mission will continue with one or two stops near the edge of Era Kohor for detailed pictures of the cliff faces and floor of the depression, then continue to the northeast towards the Montagne Blanche sand dunes. This revised rover mission plan is illustrated in Figure 123.

On the basis of this mission redesign, the sol 8 picture command sequence is revised to provide a stereo pair in the direction of the outcropping during the sol 8 relay session and another stereo pair farther in the caldera on the

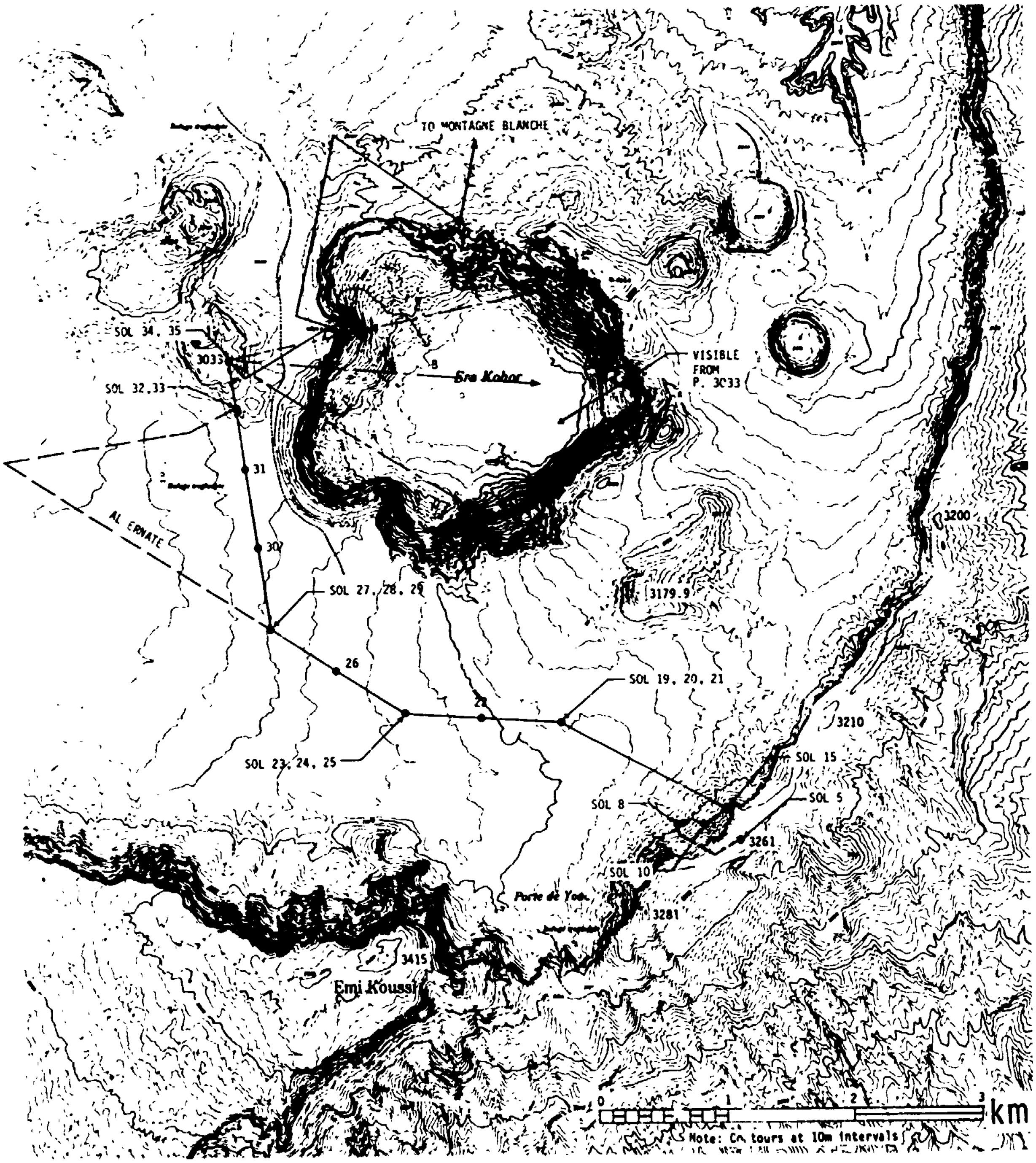


FIGURE 123 REVISED MISSION PLAN

sol 9 relay session. The sol 8 pictures are used to define the commands that will take the rover to the base of the outcropping. The sol 9 pictures will be used for preliminary planning of the traverse between the outcropping and the drainage patterns.

The rover is commanded to the base of the outcropping during the sol 9 relay session. This command sequence is as follows:

Turn to 65°E and travel 150 m.
Turn to 123°E and travel 125 m.
Stop and prepare to take stereo picture pair between 40°E to 90°E during sol 10 relay pass.

It should be noted that the decision to investigate cliff-base rocks at the base of the outcropping rather than at the base of Emi Koussi (P.3415), which is more along the general direction of travel, was made on the basis of sun angle. For real-time imagery, the sun is generally to the west, or behind the rover as it looks at the outcropping. Conversely, the eastern face of Emi Koussi is in the shade.

The rover will proceed to the base of the outcropping after the sol 9 relay session after time to recharge the batteries (approximately seven hours). The commanded sequence will place the rover near the western end of the outcropping and approximately 5 to 10 m from the vertical wall. The commanded picture will provide stereo imagery along the cliff base during the sol 10 relay session. These data will provide the information to navigate along the cliff base and to identify areas for rock sampling. In addition, the rover commands during the sol 10 relay session will define the initial cliff face imagery sequence, which will start during the sol 11 relay session. These commands will be based on the pictures taken during the sol 8 and 9 passes.

Details of this science investigation have not yet been developed; however, preliminary planning allows four days to traverse a straight line distance of 200 m along the cliff base. During this period the rover can obtain at least one alpha backscatter experiment per day, multiple measurements with the X-ray diffractometer, and 10 to 20 measurements per day from the hole detector (XRFS). The sol 10 stereo pair will provide the data for directing the rover. The daily pictures of the cliff face can be commanded on a day-by-day basis.

The rover will start this sequence with commands received on sol 11. It will arrive at the eastern end of the cliff base on sol 15. The picture command for this relay pass will be for a stereo pair toward the northwest for navigation to the bottom of the caldera. These commands will be transmitted to the rover during the sol 16 pass while the rover is transmitting a final science objective picture of the outcropping area. Thus, the rover will have devoted six relay passes to transmitting outcropping science data (experiments and pictures).

The mission plan is to continue to the drainage patterns. Because the mission is adaptive, the "discovery" of anything unusual in the outcropping area can result in redirecting the rover back to this location; however, the decision to do this must always be weighed scientifically against going on to another type of science investigation.

The sol 16 commands will direct the rover to travel along an azimuth of 63°W for 1470 m on a three-day traverse. This will place the rover near the southeastern end of the drainage pattern. During this traverse, the daily imagery sequences will generally be of the navigational type (stereo pairs in the forward direction with 80 degree azimuth coverage) although other sequences could be improvised if the sol 15 and subsequent pictures show a relatively hazard-free path. In addition, 10 to 20 readings per day from the XRFS hole detectors will be transmitted to Earth for evaluating the type of terrain being traversed. As the drainage pattern area is approached, the wheel traction force measurements may also contribute to the science data return by identifying markedly different soil characteristics in the drainage patterns.

The sol 19 pictures will be a stereo pair to the west along the drainage patterns. These pictures will form the basis for the first scientific investigation of the patterns. An area close to the rover (within 10 to 20 m) will be identified for a soil analysis with both the alpha backscatter and X-ray diffractometer (plus XRFS). These commands will be transmitted to the rover during the sol 20 relay pass.

At sol 20, the rover will transmit a (minimum) 180-degree panorama of the eastern sector (azimuth 0 to 180 degrees). The picture will serve the dual function of photographing the caldera cliff face between peaks P.3202 and P.3281 at ranges between 3200 to 1400 m (pixel spacing of 2.23 m to 0.98 m) and providing sufficient data for rover position determination by triangulation from several landmarks (peaks P.3180, P.3202, P.3208, P.3210, and P.3281 as a minimum).

The traverse down the drainage patterns will follow the pattern of a two-day traverse (1200 m) and a one-day exploration with the sequence to follow that defined for sol 16 through sol 20. Again, the adaptive nature of the rover mission allows deviations when special discoveries are made. The planned track is shown in Figure 123.

This plan results in six full scientific investigations of the drainage pattern region with three of them at arbitrary locations, and three at nearby, preselected locations. A typical timeline is shown in Table 49. As noted, additional data from the rover engineering measurements (XRFS and traction force) are returned during the two-day traverses. In addition, the navigation panoramas on sol 24 and 28 will be directed to the southwest and northwest, respectively, to provide both triangulation and caldera rim data.

On sol 28 and 29 the decision must be made to either continue with the drainage pattern investigations or to proceed northward toward the black hill at P.3033 and Era Kohor. A factor in the decision is that more drainage patterns may be found north of Era Kohor based on the pictures at sol 5 (and will be, in fact, for this example). The latter course is assumed here.

The rover will continue north towards P.3033 and stop on sol 32 for a final navigation pair before starting the climb. It will be close enough to the "black" material to perform another detailed scientific investigation between sol 32 and 33. The sol 33 commands will direct the rover to the peak of P.3033 and call for a stereo pair towards Era Kohor on sol 34 covering the band shown in Figure 123. Based on the elevation contours shown in Figure 124, the inner portion of Era Kohor, which can be seen from P.3033, is also shown in Figure 123.

TABLE 49 TYPICAL DRAINAGE PATTERN TIMELINE

Distance Travel (m)	
	Sol 19 - Arrive: Stereo pair for navigation and science.
0	- Experiments at location
	20 - Panorama (navigation)
20	- Special Experiment (based on sol 19 picture)
	21 - Navigational pair
600	- XRFS and Traction Force
	22 - Navigational pair
600	- XRFS and Traction Force
	23 - Stereo pair for navigation and science
0	- Experiment at location
	24 - Panorama (navigation)
20	- Special experiment (based on sol 23 picture)
	25 - Navigational pair
600	- XRFS and Traction Force
	26 - Navigational pair
	etc.

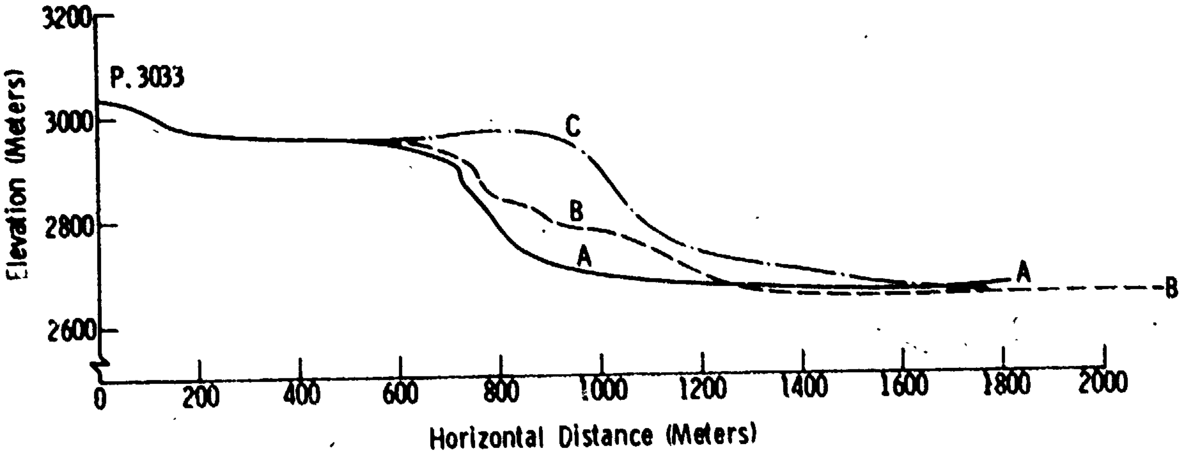


FIGURE 124 ELEVATION CONTOURS FROM P.3033 INTO ERA KOHOR

The course from P.3033 to the western rim of Era Kohor will be planned between sol 34 and 35. The rover will perform another full scientific investigation at the top of P.3033 during this interval. On sol 35, the rover will be commanded to the western rim (Figure 123) for detailed pictures into Era Kohor. During the sol 35 relay pass, the rover will take a panoramic picture to the northeast (centered on Montagne Blanche) to provide pictures of the region not visible from the sol 0 to sol 5 pictures and for preliminary mission planning to that region.

The near term mission plan beyond sol 35 is to stop on the western and then northern rim of Era Kohor for detailed pictures of this secondary depression. The mission can then proceed toward the drifted sand at Montagne Blanche with stops at additional drainage patterns, areas of different albedo, and rocky areas until the mission operations are terminated.

Baseline Rover Support

Lander Hardware Changes - Lander hardware changes and the reason for the changes are tabulated for the lander and the rover with the baseline science payloads in the following listing.

Change	Reason for Change
Lander Body Changes	
Remove XRFS Experiment	Science definition
Remove Meteorology	Science definition
Remove one Lander Camera	Science definition
Replace Biology	Science definition
Lightweight Lander RTGs	Gain mass for the rover
Add Regulated Propulsion System	Gain landed mass capability
Relocate Surface Sampler Acquisition Unit	Provide volume for the rover
Revise RTG Cooling Loop System	Include rover RTG cooling in series with the lander cooling loop
Add UHF Receiver, Diplexer, and Antenna	Rover communication with the lander

Change	Reason for Change
Lander Body Changes (continued)	
Add Rover Mounting and Deployment provisions	Addition of a rover
New Internal and External Wiring Harness	Addition of the rover and new or changes science
Revise the Power Control and Distribution Assembly	Component additions and deletions and interface with the rover and lightweight RTGs
Revise the Lander Pyro Control Assembly	New pyro functions for rover off-load and regulated propulsion system
Revise Data Acquisition and Processing Unit	Interface with the added receiver/decoder for rover communication
Aeroshell Changes	
Relocate the Radar Altimeter Antenna	Viking '79 c.m. is on the +Z axis as opposed to Viking '75 that is on the -Z axis
Relocate Entry Science Instruments	Viking '79 c.m. is on the +Z axis
Add Provisions for Rover RTG Thermal Radiation	Thermally isolate rover RTG from lander in the cruise configuration
Base Cover Changes	
Provide a Domed Glass Phenolic Panel	Provide volume for the rover

Orbiter Hardware - Orbiter hardware impact as a result of the rover is the addition of hardware to provide a two-way UHF link between the orbiter and the rover and the keeping of the existing receiving link for the lander. A block diagram of the orbiter system is as follows in Figure 125.

The antenna will change from the Viking '75 system as a result of having to transmit at 381 MHz and receive at 405 MHz. To provide simultaneous transmit/receive capability, a diplexer, a transmitter, and an additional receiver are required. To provide the capability for communicating with either the rover or the lander, a lander/rover select switch is required. To obtain optimum link performance, the orbiter antenna will be a single boresite antenna but the

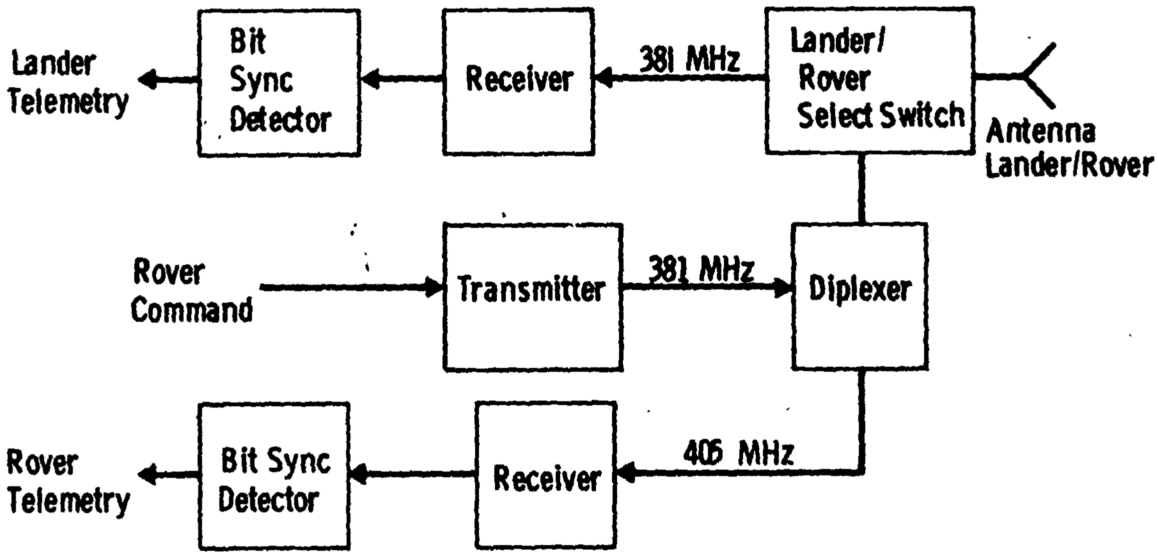


FIGURE 125 ORBITER-TO-ROVER/LANDER COMMUNICATIONS

orbiter will use maneuvers for improving link performance. The orbiter must provide the capability to receive 450 bits of command information for the rover from Earth and verify receipt of the message before storing the command in memory.

Mission Operations. - Changes in the Mission Operations System include modification to procedures and ground data system software, and incorporation of new rover peculiar software in the ground software system.

The major impact of the rover on the Viking operational procedures from liftoff to touchdown is the rover checkout operations and rover offloading. The relative simplicity of the rover minimizes the impact of these operations. Primary changes are modifications to the orbiter and lander flight computers to handle the new telemetry format. Post landing procedures will have to be modified to include the orbiter command function and rover/lander interfaces as described in Section 7, paragraph titled Typical Rover Surface Mission.

Rover ground operations, as currently conceived, will include provisions for transforming a suitable orbiter picture to a surface map. As surface pictures become available, this map will be expanded. The rover mission traverse will be hand-plotted on this chart from knowledge of commands sent to the rover and results from rover navigation imagery. Rover FPA, SPA, and SSCA functions will be new.

A preliminary evaluation of the Viking '75 ground data software system indicates some modification to 21 programs. These modifications are identified in Table 50. Modifications include addition of the rover in the mission planning software set, addition of the rover relay command in the orbiter telemetry set, addition of rover telemetry in the orbiter and lander telemetry set, and possible modifications to the imagery software to include rover azimuth and inclinometer data for stereo picture evaluation.

New software required for the rover is identified in Table 51. It includes software required for navigation, spacecraft performance, and science evaluation as well as software required to interface with existing mission planning, and command, and telemetry software. A total of 17 new programs is estimated.

TABLE 50 SOFTWARE MODIFICATIONS FOR THE ROVER MISSION

EXISTING SOFTWARE SYSTEM (VIKING '75)

PROGRAM	ORIGINATOR		MODIFICATION REQUIRED FOR ROVER	PROGRAM	ORIGINATOR		MODIFICATION REQUIRED FOR ROVER
	MMC	JPL			MMC	JPL	
MOIOP		X		LPWR	X		X
MOTOP		X		LTOP	X		
MDPLAN	X		X	LATS	X		
POGASIS		X		LTRAN	X		X
ORCON		X	X	LTEMP	X		X
VLPLAN	X		X	DECSET	X		X
COALES	X		X	PREPR	X		
MFILE	X		X	LTARP	X		
DPTRAJ		X		MKIV		X	
MMOP		X		ICAN	X		
TRAP		X	X	ATMORG	X		
APOP		X		SANMET	X		
PSOP		X		SASEIS	X		
MAPS		X		SEDRGN	X		X
SEQGEN		X	X	IMAGERY S/W		X	(Possible Minor Mods)
SCANOPS		X		VOTLMP		X	X
OSTRAN		X	X	ETGE		X	
OCOMSM		X	X	MAWDAPT		X	
PSPA		X	X	MAWDRAD		X	
CINDA3G		X	X	MAWDMAP		X	
CRS				IRTMAN		X	
LOHARP		X		IRTMAV		X	
LDLINK	X			IRTMTP		X	
RLINK	X			OPSYS		X	
CASPER	X			OMSET		X	
BIOLGY	X			VISRAP		X	
LSEQ	X			VOTPP		X	X
LCOM	X			TDRP		X	
LCOMSM	X		X	AVTPAP		X	X

TOTALS (excluding Imagery)	
MMC	11
JPL	10

It is assumed that all MCC, DSN, and basic Flight Path Analysis software (i.e., DPODP, etc.) is unchanged.

TABLE 51 NEW PROGRAMS REQUIRED FOR ROVER MISSION

PROGRAM	ORIGINATOR		REQUIRED FOR
	MMC/INTEG	ROVER	ROVER
RPLAN	X		X
I/R with VO Cmd	(JPL)		X
RCLINK (R Cmd)	X		X
RRLINK (Relay)	X		X
CLSEQ (I/F)	X		X
LCINF (LCOM I/F)	X		X
RSEQ		X	X
RCOM		X	X
RCOMSM		X	X
RPWR		X	X
RTEMP		X	X
RNAV		X	X
RNAVSM		X	X
RPOS		X	X
SAALPHA		X	X
SAXR		X	X
RHAZ		X	X

TOTALS		
	MMC/INTEG	5
	Rover	11
	JPL	1

Note

The above assumes the Rover contractor will develop the rover peculiar software from requirements generation through coding and testing. A more effective approach to reduce the number of new interfaces is to have the rover contractor establish requirements and UATs and have MMC/Integration code and test.

Mission profile. - The Viking '79 rover mission from launch to touchdown is identical to the corresponding Viking '75 mission profile. The minimum launch period is 30 days with 10 days allowed for each of the two launches and a minimum of 10 days between launches. The interplanetary phase is similar in duration to the 1975 mission, taking between 308 to 323 days. The midcourse correction policy is identical to Viking '75.

The overview timeline for the 1979 mission is shown in Table 52. The timeline between MOI and touchdown for the Mission A is identical to the current Viking '75 Mission A, taking 16 days. Mission B MOI-to-touchdown timeline has been extended an additional two days to allow completion of the Rover A support of Lander A phase of the Mission A before Mission B touchdown. Assuming a rover mission timeline similar to that presented in foregoing paragraphs, the rover missions will have the Rover A on its long traverse during Rover B-to-Lander support and Rover A detailed science mission during the Rover B long traverse. Because the rover missions are adaptive, this would allow the Rover A detailed science data return to influence the last third of the Rover B mission design.

TABLE 52 OVERVIEW TIMELINE

	MISSION A	MISSION B
LAUNCH DATE (FIRST)	10-16-79	11-5-79
C_3 $(km/s)^2$	12.0	10.5
MARS ORBIT INSERTION	8-29-80	9-23-80
V_{HE} (km/s)	2.72	2.70
TOUCHDOWN DATE	9-14-80	10-11-80
DISEMBARK ROVER	9-17-80	10-14-80
ROVER DEPART LANDER	10-9-80	11-5-80
NOMINAL END OF MISSION	12-13-80	1-9-81

8. REQUIRED TECHNOLOGY DEVELOPMENTS

The conceptual design of the rover system has been constrained to designs that would fit within the volume and mass constraints imposed by the Viking '75 Lander System. The design process involved an investigation of a number of rover configurations that could fit within these constraints. In the process of looking at the various configurations and examining their associated subsystems, a number of approaches to hardware implementation were identified that would meet all the requirements. Some approaches required more technology developments than others; the selected configuration was based largely on technology consistent with that being developed for Viking '75; however, a more advanced technology could be used to provide either a lighter and smaller rover, or provide more capability within the mass, volume, and power envelope.

Two categories of technology developments are discussed in this section. One category is the technology that was included in the basic design configurations and the second category is the technology to further optimize the rover performance. Also identified in this Section are those technical areas that need additional study to determine the magnitude of development required and to determine if new technology is indeed required.

Microelectronics

Two areas in microelectronics technology have been considered for use in the rover electronic subsystems for reducing mass, volume, and power. These are large scale integrated circuits and hybrid circuits.

Large scale integrated circuits have been included in the selected rover configurations. Although LSI technology is not new, there are a number of new circuits that the LSI manufacturers are adding to their product lines. The basic process technology for LSI circuits is proven and test data exists on these processes; however, test data on the new LSI circuits do not exist. It should be noted that some LSI circuits were used on the Viking '75 lander system. The LSI circuits that are incorporated in the rover design include a microprocessor chip, read-only-memory chips, random-access-memory chips, and other arithmetic and logic chips. Complementary MOS field effect transistor technology for making these LSI circuits is incorporated in the design, primarily for reducing power consumption. The technology development that needs addressing in LSI circuits is in the development of methods for qualifying new circuits and MOS processes, particularly to the sterilization requirements.

Hybrid circuits were considered in the study for reducing mass and volume; however, these were not included in the selected baseline configuration as a result of VPO direction. Hybrid circuit technology, though not a new technology, has encountered developmental problems for some of the hybrids that were selected for use on Viking '75. The approach investigated during the study was the packaging of ten complementary MOS chips in a 2.54 cm package. The C/MOS chips, being low power, reduce the total power for the system and potentially increase the reliability of the hybrid because the power per unit area on the hybrid substrate is extremely low. This concept of packaging C/MOS chips in hybrid form makes it feasible to have a solid state memory that can store the same amount of data in a significantly lower volume. Exploration of this concept can significantly improve the electronics packaging efficiency, especially in the area of the memories for both the Data Processor and Control Sequencer.

It should be noted that the rover baseline design uses hybrid relay driver circuits and diode matrix circuits that were developed for the Viking '75 program without any significant problems.

Power Conditioning

Boosting the low output voltage from RTGs requires regulators that use magnetics and capacitors whose mass is inversely proportional to operating frequency. However, use of higher frequencies in square wave converters creates inefficiencies because of power switching losses. New technology developments in the design of converters would increase the power conversion efficiencies and increase the performance capability of the rover. Martin Marietta Aerospace has, as a part of research projects, investigated this area of design and has provided conceptual ideas which at this time appear quite feasible for improving converter designs. These approaches need to be proved with breadboard tests.

Radioisotope Thermoelectric Generator (RTG)

The AEC has been exploring the use of selenide thermoelectric material in RTGs with a goal of providing more electrical power per unit of mass. Selenide designs not only increase the power efficiency of the RTGs, but they significantly increase the RTG operating temperature, thereby improving the RTG volumetric efficiency and providing the potential for a greater heat flow into the thermally controlled compartments of both the lander and the rover. A ramification of this increased volumetric efficiency is a much smaller wind screen and a substantially lower mass for the lander RTG/windscreen compared to the Viking '75. This lower mass has been applied to enhance rover capability. The AEC studies and development work needs to be continued and focused to the Viking '79 program.

Directional Gyro/Gyrocompass

Existing DGs are designed primarily for marine or aircraft use and hence are too heavy and too power consuming for a rover application. Another concern of existing DGs is their ability to withstand Viking environments, particularly the sterilization environment. The rover baseline incorporates a minaturized DG having the following general characteristics:

Gyrocompass accuracy: 35 mr (3σ) at 60° latitude

Mass: Less than 1.36 kg

Power: Less than three watts of regulated power

Volume: Less than 1311 cc

Environments: Sterilization

Wheels

The baseline rover incorporates 1.34 kg (3.0 lb) wheels of the design type used by the Apollo Lunar Rover Vehicle (LRV). This wheel mass estimate is based on the Apollo LRV design, taking into account the Viking '79 rover's much slower velocity and much lower dynamic loads. An appropriate approach would be to use LRV wheel design methods and fabricate and test a 50 cm (20.5 in.) diameter wheel to determine its weight and performance characteristics for the rover application to confirm the predicted Viking '79 rover wheel mass, and traction performance. Also required in the development of wheels for the rover are the seals to protect mechanisms and lubricants. This development is required because of the fine particle and dust environment to which the wheels will be exposed, combined with the longer lifetime required of the mechanisms and lubricants than has previously been experienced.

Adaptive Control

The baseline rover includes the capability to adapt partially to its environment. The requisite sensors and software subroutines have been incorporated in the basic design to allow the rover to perform its commanded mobility functions semi-autonomously, i.e., with commanded operations from Earth but without commands to solve a certain class of rover problems. The adaptive control capability allows operational changes to be made on the basis of scientific discoveries and variations in performance of rover equipment. It also simplifies the interface between the mission controllers and the rover and permits an increase in autonomy of the rover as the mission progresses.

Many basic concepts and algorithms have been developed in the past for autonomous control of roving vehicles; this effort must be continued with particular emphasis on simple methods of analyzing data and determining from a practical standpoint those decisions that can properly be made autonomously by the rover, and those that must be made on Earth. Further development is required in the area of priority determination for actions to be taken by a rover, based on its analysis of science and engineering data within the priority conditions commanded from Earth.

Wheel Drivemotors

The Viking '75 Surface Sampler boom elevation motor was selected for the baseline rover. This motor has excellent output torque and backdrive resistance characteristics. However, the qualification test for this motor in the Viking '75 program is for 80 operating hours. The Viking '79 rover wheel drive applications will require on the order of 1000 operating hours during qualification tests. Data on the '75 motor indicate that the particular motor brushes and commutator will probably not function for 1000 hours and the particular lubrication may not be adequate from a long term gear wear point of view. To insure successful resolution of these problems, the brushes, commutators, and gear lubricants should be investigated. These investigations should include analysis, design, fabrication, and test of motors and gears to meet the 1000 hour qualification requirement.

Hazard Sensors

The rover must be equipped with a sensor(s) that can detect holes and crevices before coming in contact with these hazards. The proposed method for accomplishing this function on the baseline is to use an X-ray sensor and associated electronics. This, and other approaches should be examined in some detail and a breadboard of one or more approaches built and tested for final selection.

Technical Development Requirements

During the rover study, a number of technical problems arose that require further study to determine their impact on the rover development. These problems are discussed in the following paragraphs.

Thermal switch. - A significant developmental effort was required to obtain the Viking '75 thermal switch. The baseline rover incorporates a smaller, lighter weight switch. To achieve this, however, does not mean that the Viking '75 switch can be directly scaled down. This development should result in a prototype thermal switch that will provide predictable and repeatable switch conductance, open/close actions, stroke distances, and switch closing forces.

Polar Operation

If the scientific mission requires landing in the polar region, an evaluation must be performed on the effect of ice buildup on hardware, especially mechanisms. Whether or not the ice buildup can be tolerated and what approaches could be used to eliminate any undesirable effects must be determined by tests conducted under simulated Martian polar environmental conditions.

Gyrocompass errors also increase as the landing site approaches a pole. Evaluation must be performed, and possibly, alternate navigational systems developed.

Soil Transfer

The rover baseline operations concept provides that the rover will collect soil samples and transfer them to the lander for analysis. The depth of the rover study did not permit an evaluation of the number of possible approaches conceived to provide this soil sample transfer. Follow-on effort must involve the evaluation of mechanisms for collecting soil and transferring the soil in addition to an evaluation of the navigation and control of the rover to position its soil dump for sample transfer to the lander.

9. PROGRAM DEVELOPMENT SCHEDULE AND PLAN

The rover development plan, which includes rover integration on the lander, has been constrained to be compatible with the Viking '79 baseline plan. This constraint has established the need for completing the rover qualification program by July 1, 1978 so assembly of the VLC flight articles can proceed without risk of configuration change. The plan has also established the required dates for rover flight article deliveries (two flight articles and one spare) in that they must be assembled on the flight landers for acceptance testing before encapsulation.

The early part of the rover development plan has been constrained by the desire to minimize the required funding before the start of FY 77. This funding constraint has resulted in the development program being delayed as long as practical, consistent with a 1979 launch. The complexity of the rover development dictates that hardware development commence at the beginning of FY 76 and requires that conceptual studies and program definition studies commence before FY 76. These early studies will enable interface definition between the rover, lander, and orbiter to be completed by January 1, 1976, thus enabling hardware development to proceed in an orderly manner.

Because integration of the rover on the lander and the hardware elements of the rover vary in nature and complexity, four separate plans are presented to encompass the total tasks, and are shown in Figures 126 through 129.

The first of these plans (Figure 126), entitled "Program Plan - Rover Option," identifies the required schedule for long lead conceptual and program definition studies, and identifies the significant milestones associated with rover development and integration activities on the Viking Lander Capsule.

The total time span allocated for rover development is thirty-six months. This span is based on similar developments for Viking '75, and is predicated on conducting development and qualification tests on the complete rover assembly rather than at the subassembly level. It is intended that the rover be treated as a component rather than an assembly of subsystems. This does not, however,

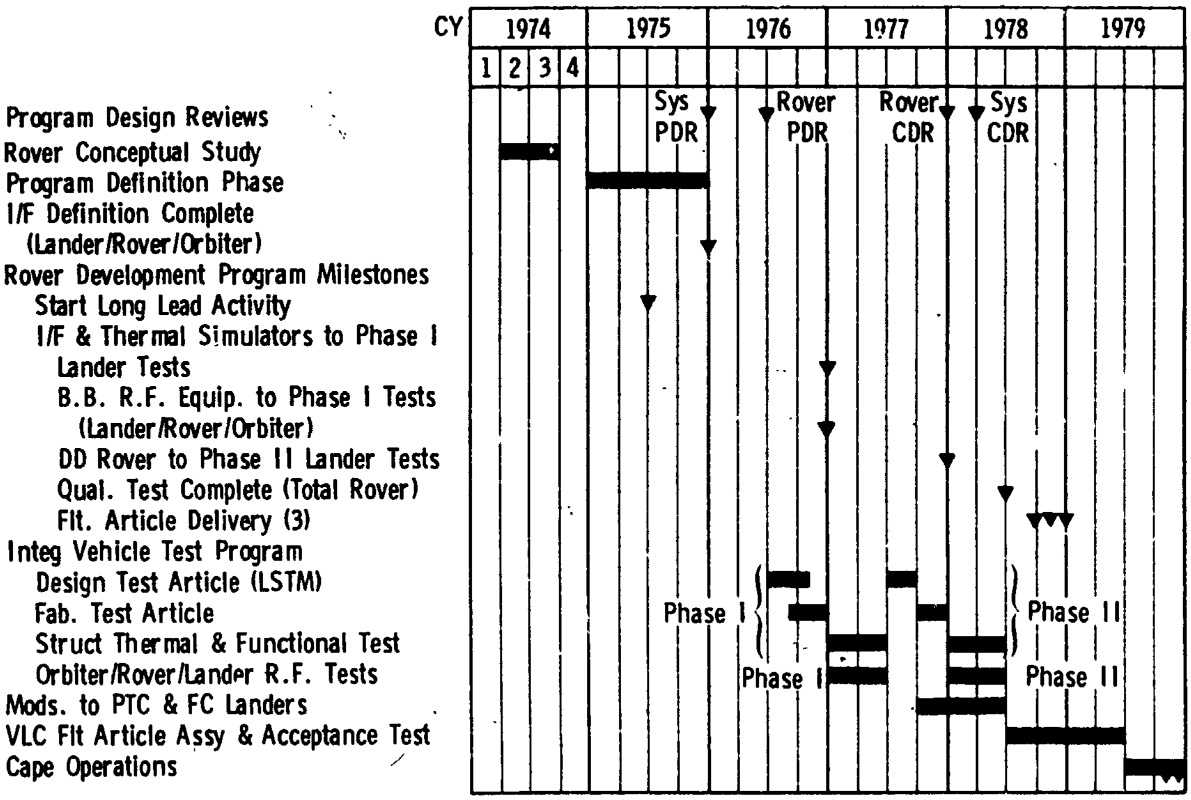


FIGURE 126 PROGRAM PLAN - ROVER OPTION

preclude the need for some environmental testing at the device/subassembly level during the development test phase.

Viking Lander Capsule system level compatibility tests are to be conducted in two series designated as Phase I and II. The existing LSTM lander body will be modified to include rover mounting and deployment capability as well as the necessary mass/thermal simulators to enable thermal, structural, and functional compatibility tests to be conducted. The Phase I tests will be used to obtain design data, and the Phase II tests, with operating hardware, will be used for design verification. In addition, RF link compatibility tests will be conducted during the same time spans. These RF tests will require rover, lander, and orbiter communications equipment.

The other three plans indicate the detailed development schedule for (1) Structural and Mechanical Hardware, Figure 127, (2) Typical Electronics Hardware, Figure 128, and (3) Typical Science Instruments, Figure 129. The allotted thirty-six months for science instrument development is considered to be a viable plan only if it is preceded by design feasibility work under SRT activities as shown.

Development of electronic assemblies for the rover will be accomplished in a thirty-month span. Although the total time span is less than for the rover as an entity, the development test span and the qual test span are coincident with those of the rover to facilitate combined testing.

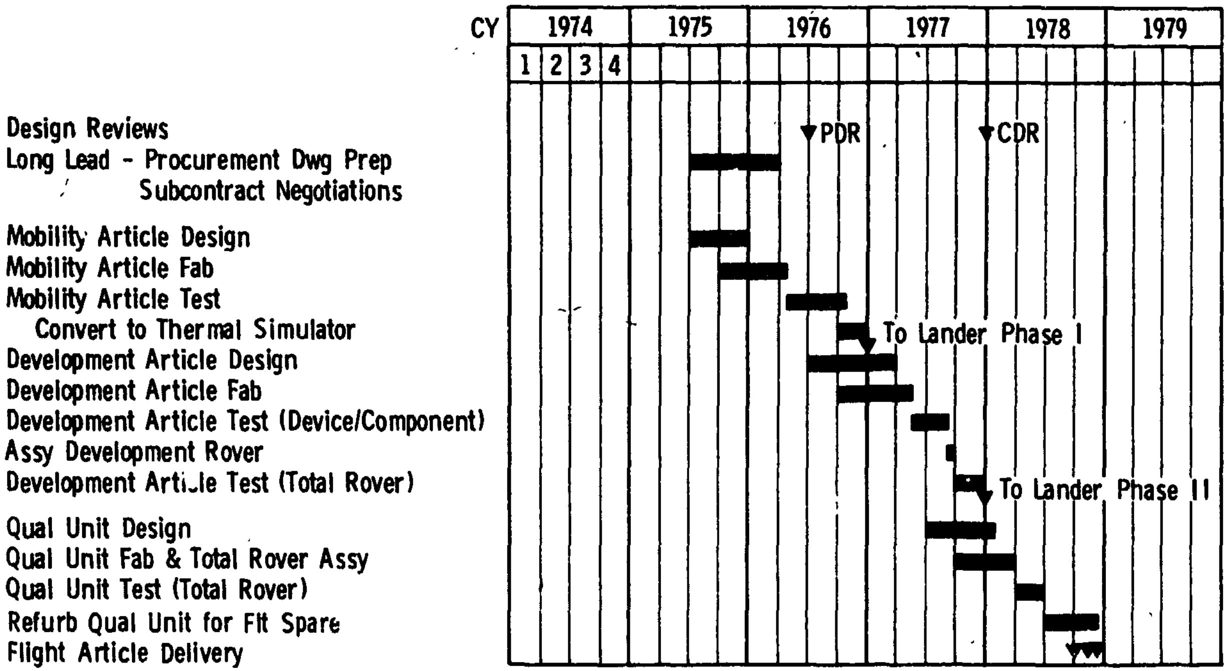
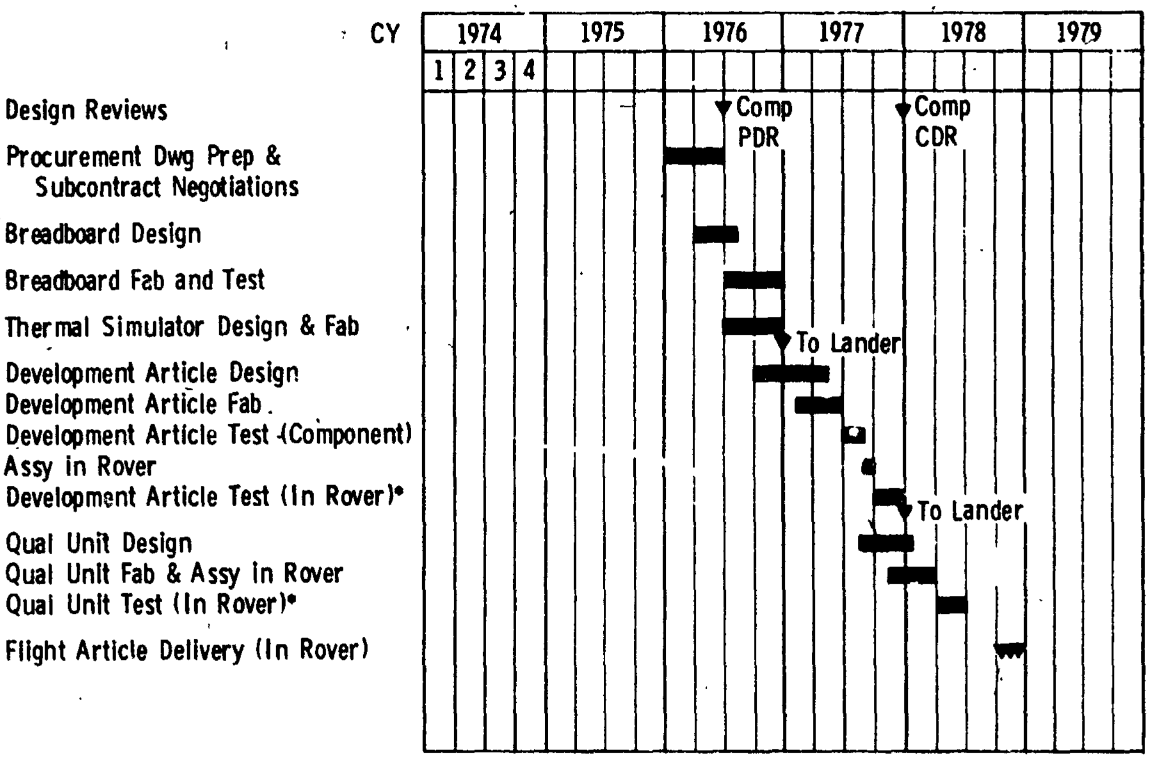
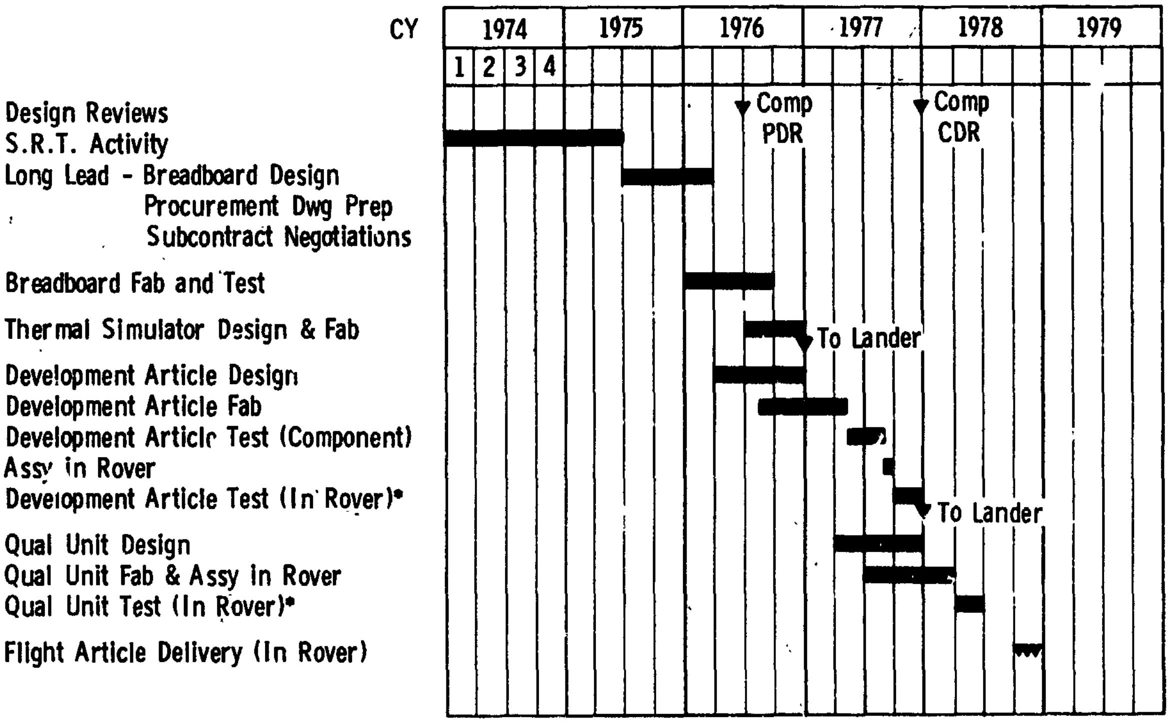


FIGURE 127 ROVER STRUCTURAL/MECHANICAL DEVELOPMENT PROGRAM



*Rover Components will be tested with the complete rover unit.

FIGURE 128 TYPICAL DEVELOPMENT PROGRAM FOR ROVER ELECTRONIC COMPONENTS



*Science Instruments will be tested with the complete rover.

FIGURE 129 TYPICAL ROVER SCIENCE INSTRUMENT DEVELOPMENT PROGRAM

10. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The objective of this study was to define a baseline Viking rover, rover/lander integration design concepts, and mission operation concepts that would provide a significant increase in the scientific capability of a Viking '79 Mission. Implicit in this objective was the derivation of a total hardware concept that makes maximum use of the Spare and Proof Test Viking '75 lander hardware. This has been accomplished.

The key features of the 107.95 kg (238 lb) baseline rover selected as a result of the study are summarized below:

Science - 20.9 kg (46 lb) geologically-oriented payload

- Surface Sampler - sample, storage, and return to lander
- Alpha Backscatter elemental analyzer
- X-ray Diffractometer and rock grinder
- Viking '75 facsimile camera - long baseline stereo

Power - 20 watt (EOL) RTG

Data/Commands - Two-way link with both the orbiter and lander.

Mobility - Travel up to 735 m/day and explore regions outside the landing footprint.

Navigation - Use a directional gyro for heading reference and a control sequencer for semi-autonomous operation and a hazard detection system.

Range - Limited only by system reliability and mission operations duration.

The study results clearly indicate that a significant improvement in the present lander scientific capability is achieved by including the baseline rover in the Viking '79 Mission. The lander science instruments would have access to samples from a large surface area that have been selected and screened for scientific interest by using the rover sample return capability. The value of the imagery mission is tremendously improved by using the rover for long baseline stereo capability and for its ability to explore and take pictures of geological interest over a large surface area.

In addition to improving the scientific value of the lander mission, inclusion of the rover in the Viking '79 Mission adds a unique science exploration dimension to the overall mission. The rover has the capability to operate through the orbiter, independent of the lander, and extend our geological knowledge of the present state and past history of Mars by sampling the many geologic units (e.g., lava flows, ejecta blankets, exposed sedimentary layers, outcrops. channel beds, escarpments, and lag gravel plains) that can be traversed by such a rover.

The impact of integrating the rover on the Viking '75 Lander can be divided in three categories, i.e., (1) those changes required to stow and deploy the rover, (2) changes in the entry and terminal descent system required to land the rover system, and (3) those changes required to operate the rover with other mission elements. These changes are discussed in detail in Sections 5 and 6 and are summarized below:

Rover Stowage Changes
  Remove one facsimile camera
  Move Surface Sampler
  Provide base cover bulge

Entry Performance and Landed Weight Increase Changes
  New lander RTGs
  Provide pressure regulation for the Terminal Descent Propulsion System
  2.1° Entry Corridor
  Reduce Atmospheric uncertainty
  Shift entry equipment because of c.m. change
  Remove Meteorology

Rover Operation
  Add UHF receiver/antenna and diplexer to lander
  Add UHF transmitter and diplexer to orbiter

An evaluation of these changes indicates that maximum use of existing Viking '75 hardware and technology has been used and that only minimum changes are required to existing hardware.

Recommendations

The conclusions reached as a result of this study indicate the feasibility of the rover design and integration concepts, and of developing these concepts for a Viking '79 mission. To continue in the process leading to final definition of the rover system and the integration requirements, follow-on activities in the form of technology development and definition studies are identified in Section 8. These activities should be undertaken in a timely manner if the rover development is to proceed along the time span of the development plans for a Viking '79 mission.

ABBREVIATIONS

AEC	Atomic Energy Commission
A-h	Ampere-hour
Atmos	Atmosphere
A/D	Analog to digital
A	Amperes
Bldr	Blowdown Ratio
BPS	Bits per second
B/day	Bits per day
BER	Bit error rate
c.m.	center of mass
C/MOS	Complementary metal-oxide-semiconductor
C/30, C/20	Battery charge rate
C1, C2, C3, C4	Rover configurations
CLa	Clock angle
CA	Cone angle
Cmd	Command
C_3	Earth departure energy $(km/s)^2$
D1, D2, D3	Rover configurations
DD	Design development
DSC/EGA	Differential scattering calorimetry/evolved-gas analysis
dB	decibel
dBm	decibels using one milliwatt as reference power
dc	direct current
D.G.	directional gyro
DLA	declination of the departure asymptote (related to azimuth). (degrees)
D_{PARA}	parachute diameter
DSN	deep space network
ELMS	elastic loop mobility system (Lockheed)
EOL	end of life
EMP	equipment mounting plate

EGA	evolved gas analysis
EM	electromagnetic
FSK	frequency shift keying
FOV	field-of-view
fps	feet per second
GCSC	Guidance Control and Sequencing Computer
GCMS	Gas Chromatograph Mass Spectrometer
GDC	General Dynamics Corporation
HGA	high gain antenna
Hz	hertz
in.	inch
I/O	input/output
JPL	Jet Propulsion Laboratories
kg	Kilogram
km	Kilometer
°K	degrees Kelvin
kbs	kilobits per second
LGA	low gain antenna
LSI	large scale integrated circuits
MCCC	Mission Control and Computing Center
Min	minimum
MOI	Mars orbit insertion
MSI	medium scale integrated circuits
m/s	meters per second
msec	millisecond
MEA	Meteorology Electronics Assembly
Max	maximum
MHz	Megahertz
MUX	multiplexer
MEM	Mars Engineering Model
mrad/hr	milliradians per hour
N	Newton
N-s/kg	Newton-second/kilogram
N/m^2	Newton per meter^2

nsec	Nanosecond
PCDA	Power Conditioning and Distribution Assembly
psf	pounds per square foot
RTG	Radioisotope Thermoelectric Generator
RHU	Radioisotope Heater Unit
RCVR	receiver
Ref.	reference
RF	radio frequency
RDF	radio direction finding
ROM	read-only-memory
RAM	random-access-memory
s	second
SSCA	Surface Sampler Control Assembly
SYS	system
sym/s	symbols per second
TETM	Thermal Effects Test Model
TWTA	Traveling Wave Tube Amplifier
TR	tape recorder
Tlm/Cmd	telemetry/command
TTL	transistor-transistor logic
TD	touchdown
UHF	ultra high frequency
VO	Viking orbiter
VLC	Viking Lander Capsule
VMCCC	Viking Mission Control and Computing Center
W	watt
Wh	watt hour
XRFS	X-ray fluorescence spectrometer
XMTR	transmitter
XPNDR	transponder
ZAE	angle at Mars created by the Earth to Mars vector and spacecraft to Mars vector

SYMBOLS

Al	aluminum
Ca	calcium
C	carbon
Fe	iron
h_D	parachute mortar fire altitude above mean Mars surface (km)
h_p	periapsis altitude (km)
h_t	terrain height above mean Mars surface (km)
I_{sp}	rocket motor effective exhaust velocity divided by Earth G
L/D	Viking lander hypersonic lift to drag ratio
M_D	Mach number at parachute mortar fire
Mg	magnesium
NiCd	nickel-cadmium
Na	sodium
O	oxygen
P	orbital period (hours)
PER	touchdown location measured in orbit plane back from the subperiapsis point (degrees)
q	dynamic pressure (N/m^2)
q_D	dynamic pressure at parachute mortar fire (N/m^2)
SEA_{TD}	sun elevation angle at touchdown (degrees)
sol	time between Viking lander to Viking orbiter relay links - approximately one sidereal day
t_c	Viking lander coast time from deorbit to entry (hours)
TMI	trans-Mars injection
T	terminal descent engine thrust (per engine)
V_{WIND}	wind velocity from the MEM (m/s)
V_{HE}	hyperbolic excess velocity at Mars (km/sec)
ΔV	velocity change (m/s)

ΔV_{MC}	midcourse correction, ΔV budget (m/s)
ΔV_{STAT}	Δvelocity budget to compensate for navigation uncertainties through MOI (m/s)
ΔV_{TRIM}	ΔV allocation for in-orbit trim maneuvers (based on spacecraft mass) (m/s)
ΔV_{IMP}	impulsive ΔV_{MOI} (m/s)
ΔV_{CAP}	total ΔV capability of the spacecraft (m/s)
ΔV_D	deorbit ΔV (m/s)
$W_{A/S}$	mass (kg) dropped at aeroshell separation
W_{PARA}	mass (kg) dropped at parachute separation
W_{PROP}	mass (kg) of terminal descent propellant (total)
W_{SEP}	mass (kg) of VL at separation from the VO
W_E	mass (kg) at VL entry
W_{PROP_D}	mass (kg) of the VL deorbit propellant (total)
XR	touchdown location measure perpendicular to the orbital plane (degrees)
γ_E	VL entry flight path angle (degrees)
λ	Orbiter lead angle; relative angular position or the VO and VL at entry measured at the center of Mars (degrees)
TD + nd	touchdown plus "n" days
A + mh	time reference defined in text plus "m" hours

DEFINITIONS

Component	An electronics black box.
Converter	Power supply which accepts a DC voltage and converts it to other DC voltages.
Deflation	The removal of material from a land surface by the wind.
Eolian	Of or related to action of the wind.
End-of-life	Characteristic of a piece of hardware and the term is used as being synonymous with end-of-mission.
Ecological Niche	A combination of environmental factors (soil composition climate) that favor the existence of only certain life forms.
Limonite	Hydrous iron oxide that is brown, yellow, or red in color.
Regolith	The layer of loose, incoherent rock material that rests upon the underlying solid or "bed" rock. Synonymous with soil.
System	Description of a group of subsystems that when combined perform a specific function, i.e., rover system.
Subsystem	Description of a group of related components and functions that perform a specific task, i.e., power subsystem.
Plate Tectonics	The widely accepted theory that the surface of the Earth is covered by several distinct units or plates, which move relative to one another.

APPENDIX A

SCIENCE INSTRUMENT PROFILES

SCIENCE INSTRUMENT PROFILE

Instrument Nomenclature: Viking '75 Facsimile Camera

Mass: From 6.1 to 6.8 kg (13.5 to 15.0 lb)

Dimensions: Optics - 18 cm (7 in.) diameter by 36 cm (14 in.)
Electronics - 25 cm (10 in.) diameter by 20 cm (8 in.)

Scientific Performance: 0.04° high resolution black and white, 0.12° low resolution and color, 1.7 m to infinity focus, 6 bits grey level encoding, 10 bit range, +40° to -60° FOV elevation, 340° FOV azimuth, 20° minimum size in elevation, 2.5° minimum in azimuth. Camera eye 46 cm above dust cover. (85 to 110 cm above surface.)

Operating Requirements: Not Applicable

Power Profile:

Mode	Power (watts)	Duration	Remarks
Survey	25	Up to 27 minutes	
Color	21	Up to 27 minutes	
Calibrate	20		
Heaters	2	Continuous	15 peak. Keep alive, mostly for electronics

Data Profile:

Mode	Bits/meas	Duration	bps during Meas	
Min Picture	192 K	12 seconds	16 K	(each vertical line always 3.4 Kbits)
Max Picture	27 K	27 minutes	16 K	

Environmental Tolerances:

Wind, dust: Dust no problem, sand serious problem.

SCIENCE INSTRUMENT PROFILE

Instrument Nomenclature: DSC/EGA - Soil Water Experiment

Mass: 2.7 kg (6.0 lb)

Dimensions: 15 by 15 by 28 cm (6.0 by 6.0 by 11.0 in.)

Scientific Performance: Differential scanning calorimetry (DSC) to 750°C, and evolved-gas analysis (EGA), water specific. Provides qualitative and semi-quantitative analysis for water-ice, absorbed and adsorbed water, hydrate minerals (especially clays), hydroxides, nitrates, sulfides and carbonates.

Operating Requirements: Requires delivery of 0.1 cc of soil

Power Profile:

Mode	Power (watts)	Duration
Analysis	20	2 hr

Data Profile: TBD

Environmental Tolerances: TBD

SCIENCE INSTRUMENT PROFILE

Instrument Nomenclature: Viking '75 X-ray Fluorescence Spectrometer (XRFS)

Mass: Current 1.93 kg (4.24 lb); Allocated 2.0 kg (4.40 lb)

Dimensions: 25 by 7.5 by 15 cm (10.0 by 3.0 by 6.0 in.) (excluding funnel)

Scientific Performance: Assay for element composition of soil and gravel samples. The following elements are detected in typical rock speciments: Mg, Al, Si, K, Ca, Ti, Fe, Rb, Sr, Zr, and "O".

Operating Requirements: Requires delivery of soil to funnel inlet

Power Profile:

Mode	Power (watts)	Duration
Normal	3.5	1 hr

Data Profile:

Mode	Rates (bits/s)	Duration	Remarks
Normal	1.0	4.5 hr	16.384 K/meas

Environmental Tolerances: Not Applicable

SCIENCE INSTRUMENT PROFILE

Instrument Nomenclature: X-ray Diffractometer

Mass: 4.5 kg (10.0 lb)

Dimensions: 6.5 by 15 by 25 cm (2.5 by 6.0 by 10.0 in.)
(Does not include central electronics)

Scientific Performance: Obtains powder diffraction pattern for all crystalline components with d-spacings between 1.1 and 20 Angstroms; permitting identification of major and minor mineral phases.

Operating Requirements: Requires powdered sample (1 to 300 microns size range)

Power Profile:

Mode	Power (watts)	Duration	Remarks
Warm-up	6	10 minutes	
Fast scan	20	30 minutes	
Slow scan	20	120 minutes	Programmed for peak profiles only

Data Profile: Buffer Size: 2.0 K

Mode	Bits/meas	Duration	Meas/day	Bits/day
Fast scan	9.0 K	30 minutes	N/A	--
Slow scan	9.0 K	120 minutes	N/A	--

Environmental Tolerances:

RTG: Gamma interference requires background calibration.

Wind, dust: Requires protection because of mechanisms.

SCIENCE INSTRUMENT PROFILE

Instrument Nomenclature: Advanced X-ray Fluorescence Spectrometer

Mass: 1.4 kg (3.0 lb)

Dimensions: 7.5 by 5.0 by 4.0 cm (3.0 by 2.0 by 1.5 in.)
(Does not include central electronics)

Scientific Performance: Same analyses as Viking '75 XRFS, but with electronic pulse-height analyzer to greatly increase speed of obtaining data (only 15 minutes/analysis required), and sharing of central electronics to decrease mass and volume. Can analyse soil or rock samples *in situ* or in a sample cup.

Operating Requirements: Not Applicable

Power Profile:

Mode	Power (watts)	Duration
Analysis	2.6	15 minutes

Data Profile:

Mode	Bits/meas	Duration
Analysis	8.2×10^3	15 minutes

Environmental Tolerances:

Thermal:	-100°F to +125°F
Wind, dust:	Protection of counter window from dust and high-velocity sand.

SCIENCE INSTRUMENT PROFILE

Instrument Nomenclature: Articulated Geochemistry Experiment and Hazard Detector

Mass: From 1.4 to 4.1 kg (3.0 to 9.0 lb)

Dimensions: 7.5 by 5.0 by 4.0 cm (3.0 by 2.0 by 1.5 in.)
(Does not include central electronics)

Scientific Performance: Same analyses as Viking XRFS except degraded for the elements Mg and Al because of atmospheric attenuation. Correlation of backscatter intensity and element concentration profile allows accurate ranging to ground surface, and detection of rock, holes, crevices, and other terrain-height variations.

Operating Requirements: Mounted to view surface just in front of rover.

Power Profile:

Mode	Power (watts)	Duration
Monitor	1.8	On during rover motion
Analysis	2.0	15 minutes

Data Profile:

Mode	Bits/meas	Duration	bps during meas	Meas/day	Bits/day
Monitor	20	4 seconds	5	5000	100 K
Analysis	8.2 K	15 minutes		10	82 K

Environmental Tolerances:

Wind, dust: Must protect detector windows

C5

SCIENCE INSTRUMENT PROFILE

Instrument Nomenclature: Viking '75 Seismometer

Mass: Current 1.7 kg (3.8 lb); Allocated 1.9 kg (4.1 lb)

Dimensions: 14 by 15 by 16 cm (5.4 by 6.0 by 6.25 in.)

Scientific Performance: 3-axis, 0.1 to 10 Hz, programmable filters with cutoff frequencies of 0.5, 1.0, 2.0, and 4.0 Hz

Operating Requirements: Not Applicable

Power Profile: Not Applicable

Data Profile: Buffer: 2,094 K

Mode	Rate (bits/s)	Duration	
Background	1.6	23 hr/day	GCSC allows only 158 buffers day (323 K/day)
Trigger	39	1 hr/day	Can be commanded or automatic
High data rate	485	1 min/day	This mode available only by Earth command. Can update so GCSC allows 600 buffer transfers per day (1.2 Mbit per day)

Environmental Tolerances: Tolerates all Viking thermal compartment environments.

SCIENCE INSTRUMENT PROFILE

Instrument Nomenclature: Apollo Gravimeter

Mass: 9.1 kg (20 lb)

Dimensions: 20 by 20 by 60 cm (8.0 by 8.0 by 24.0 in.)

Scientifie Performance: Range 370 to 980 cm/sec^2;
Resolution 5×10^{-4} cm/sec^2

Operating Requirements: Must deploy or isolate from rover. Position known within ±30 meters over a 10 km traverse. Know ±10 meters elevation relative to lander location.

Power Profile:

Mode	Power (watts)	Duration	Remarks
Each Measurement	15	5 Minutes	(Includes warm-up)

Data Profile:

Mode	Rates (bits/s)	Duration
Measurement	10 bits/meas	

Environmental Tolerances: No problems identified.

SCIENCE INSTRUMENT PROFILE

Instrument Nomenclature: Traverse Magnetometer

Mass: 4.5 kg (10 lb)

Dimensions: 20 by 20 by 50 cm (10 by 10 by 20 in.)

Scientific Performance: 3-axis, 0.1 gamma sensitivity, 0 to ±400 gamma range, 0 to 1 Hz frequency response.

Operating Requirements: Rover-to-lander distance should be known to ±5%.

Power Profile:

Mode	Power (watts)	Duration
Average	8	1 Minute
Peak	12	

Data Profile:

Mode	Rates (bits/s)
Normal	100

Environmental Tolerances:

Thermal: -22 to +140°F

SCIENCE INSTRUMENT PROFILE

Instrument Nomenclature: Seismometer (Alsep-Type)

Mass: From 11.4 to 13.6 kg (25 to 30 lb)

Dimensions: 29 by 23 cm (11.4 by 9.0 in.)

Scientific Performance: Measures seismic waves to determine planetary structure, physical properties, tectonic activity, core size. Essentially short and long period seismometers in one box - i.e., not a broadband instrument.

Operating Requirements: Not Applicable

Power Profile:

Mode	Power (watts)	Duration
Various	4.3 - 7.4	Continuous

Data Profile:

Mode	Rate (BPS)	Duration
High data rate	500	20 s
Trigger	50	Intermittent up to max data allowance

Environmental Tolerances:

Heat Sterilization: Current Viking Specifications

SCIENCE INSTRUMENT PROFILE

Instrument Nomenclature: Alpha Backscatter Experiment

Mass: 2.7 kg (6.0 lb)

Dimensions: 8.9 by 8.9 by 7.5 cm (3.5 by 3.5 by 3.0 in.)
(Does not include central electronics)

Scientific Performance: Assay for element composition of soil and ground rock samples. The following elements are detected in typical geologic specimens; C, O, Na, Mg, Al, Si, Ca, Ti, and Fe.

Operating Requirements: Requires flat sample (rocks analyzed if first ground)

Power Profile:

Mode	Power (watts)	Duration
Normal	4	5 hr
Calibrate	4	1 hr

Data Profile: Buffer size: 200 K

Mode	Bits/meas	Duration
Normal	2.0×10^5	5 hr
Calibrate	2.0×10^5	1 hr

Environmental Tolerances:

Wind, dust: Requires protection from dust and sand.

SCIENCE INSTRUMENT PROFILE

Instrument Nomenclature: Seismometer

Mass: Deployed Unit: 0.5 to 0.8 kg (1.1 to 1.8 lb); 10-wire cable, depends on distance, lander electronics, 0.9 kg (2.0 lb)

Dimensions: 7.5 by 7.5 cm (3.0 by 3.0 in.)

Scientific Performance: Remotely deployed 3-axis broadband seismometers, dc to 10 Hz, in 4 filtered bands, (1) 10 Hz - 10 s (2) 5 s - 100 s (3) 50 s - 2000 s (4) 1000 s - dc. Remote unit contains 3-axis sensors, phase-sensitive detectors, caging and leveling motors, heaters. Lander electronic includes filters, trigger, data compression, MUX, A/D, buffer, control logic.

Operating Requirements: Deployed from lander 100 ft or more on level surface (±6°)

Power Profile:

Mode	Power (watts)	Duration	Remarks
High data rate			Sample broadband data
Background Monitor	4	Continuous	Sample tides (1/10 min) Compress normal modes (1/30 sec)
Trigger (event)			
Remote sensor	6	Continuous	

Data Profile:

Mode	Rate (bits/s)	Duration	Remarks
High data rate	500	20 s	On command only
Background Monitor	0.25	Continuous	Tides and normal modes
Trigger	50, intermittent up to maximum data allowance (50 K bits/day?)		

Environmental Tolerances:

Heat Sterilization: Current Viking Specifications

APPENDIX B

ADVANCED RTG POWER FOR THE VIKING '79 ROVER MISSION

ADVANCED RTG POWER FOR THE VIKING '79 ROVER MISSION

Because of the weight and space constraints imposed on the Lander and Rover vehicles, search for more compact, efficient, and lightweight power supplies was initiated. In order to afford maximum likelihood of satisfying those requirements, application of advanced technology RTG's employing selenide thermoelectric materials was studied. This type of generator is presently under consideration for development at the 400 to 500 watt output level (AEC-Air Force sponsored ERTG program), and it shows high efficiency (greater than 10% for the ERTG), high specific power, and low cost potential exceeding that of any other RTG power system developed to date.

1. Initial Studies

The first investigation of selenide technology RTG's for the Viking '79 mission was concerned with maximum rejection temperatures of 330 to 380°F, conditions similar to that studied for the ERTG program. At the relatively low temperatures, enhancement of heat transfer to radiating surfaces was desirable, and copper-water heat pipes were applied. Both constant and variable conductance types were employed to obtain minimum weight and envelope configurations. Typical results contained in Table I show 13 to 19 pound Lander RTG's producing 30 watts, depending on windscreen size and generator configuration. The single Rover RTG represents a "best" compromise between size and simplicity and the 13 pounds is representative for the relatively severe constraints operating. As noted in the table, these weights do not include windscreens or provision for prelaunch cooling. For comparison, the Viking '75 Lander RTG's (35 watts) weigh 35 pounds and the non-integral prelaunch cooling and spacecraft interface attachment contribute an additional 5 pounds and the windscreen about another 9 pounds, to yield a total weight of nearly 50 pounds for each of the two power supplies.

Although the low rejection temperature selenide generator designs yield significant weight savings for the Lander, the windscreen area requirement for the Rover RTG is too large. Further, the addition of prelaunch cooling and windscreens yields a power system weight in excess of that desired.

In order to satisfy the requirements for reduced envelope and weight, maximum heat rejection temperatures were raised to the 400 to 500°F range and appropriate conceptual RTG designs were introduced and studied.

2. Conceptual Design Selection

The advantages of raising maximum (Martian daytime) heat rejection temperatures of the RTG's are:

a) Satisfaction of 2 ft^2 windscreen area limitation for the Rover.

b) Reduced envelope with smaller total weight for the Lander RTG's.

c) Facilitation of control of heat transferred from the RTG's to the instruments of both Lander and Rover.

It was found that these advantages could be achieved despite reduced conversion efficiency from the RTG's operating at the conservative hot junction temperature limit of 800°C. Further, the materials technology for RTG housings operating at temperatures in the 550°F range has been demonstrated in the SNAP 27/Apollo program.

A primary result of increased heat rejection temperature is the reduction of radiator area to the extent of obviating the use of heat pipes. Thereby, a simpler RTG housing is afforded which facilitates windscreen and prelaunch cooling accommodation. Thus, the selected conceptual designs presented in Table II contain integral prelaunch cooling and windscreen capability.

The weight savings afforded by the selected conceptual designs are considerable. It is seen that 70 watts can be obtained from a Lander RTG power system weight of only 42 pounds, less than half of the present Viking '75 power system weight. Likewise, the Rover power system total weight is 12 pounds and the envelope requirements for the rear mounted RTG (approximately 15" x 9" x 5") are satisfied.

The attached sketches show the component configurations and approximate envelopes of 30 watt and 35 watt Lander RTG designs and the 20 watt Rover RTG. These drawings are intended to show rough outlines of the selenide RTG's and specific spacecraft-generator interfacing considerations may alter such details as mounting provisions, coolant pipe locations, and envelope shape.

The voltages specified for each RTG are obtained from series connection of all thermoelectric elements in the generator. The Viking '75 generators contain a series-parallel arrangement (couple pairs in parallel), but the two Lander generators are connected in series to yield 8.8 volts. Reliability evaluation of each approach depends on the specific generator-power conditioner configuration and is therefore a subject for interface consideration in subsequent work.

Minimum housing temperatures of 250 to 400°F are calculated for Martian night conditions of convective and radiant cooling and with 100 watts transferred directly to the vehicle through a thermal control device with minimal temperature drop. Although these calculations are only preliminary, designs can be made to accommodate a wide variety of conditions.

Advantages of the thermopile are not the only attribute of these advanced technology generators. The heat sources possess improved fuel containment capability. Background work on lower reentry velocity heat shield packages and noble metal cladding is being pursued by AEC laboratories and contractor (Isotopes Energy Systems Division) studies.

Conclusions

It has been shown that advanced technology selenide generators yield very attractive power sources for the Viking '79 Lander/Rover mission. Through integrated studies, significant weight savings can be obtained. Initiation of detailed spacecraft/power supply design efforts are required to realize the full potential available. Through an early start on integrated efforts, the optimal use of selenide RTG's can enable accommodation of power requirements within weight and envelope constraints with maximum return for effort expended.

TABLE I

VIKING '79 RTG CONFIGURATION LOW TEMPERATURE HEAT REJECTION

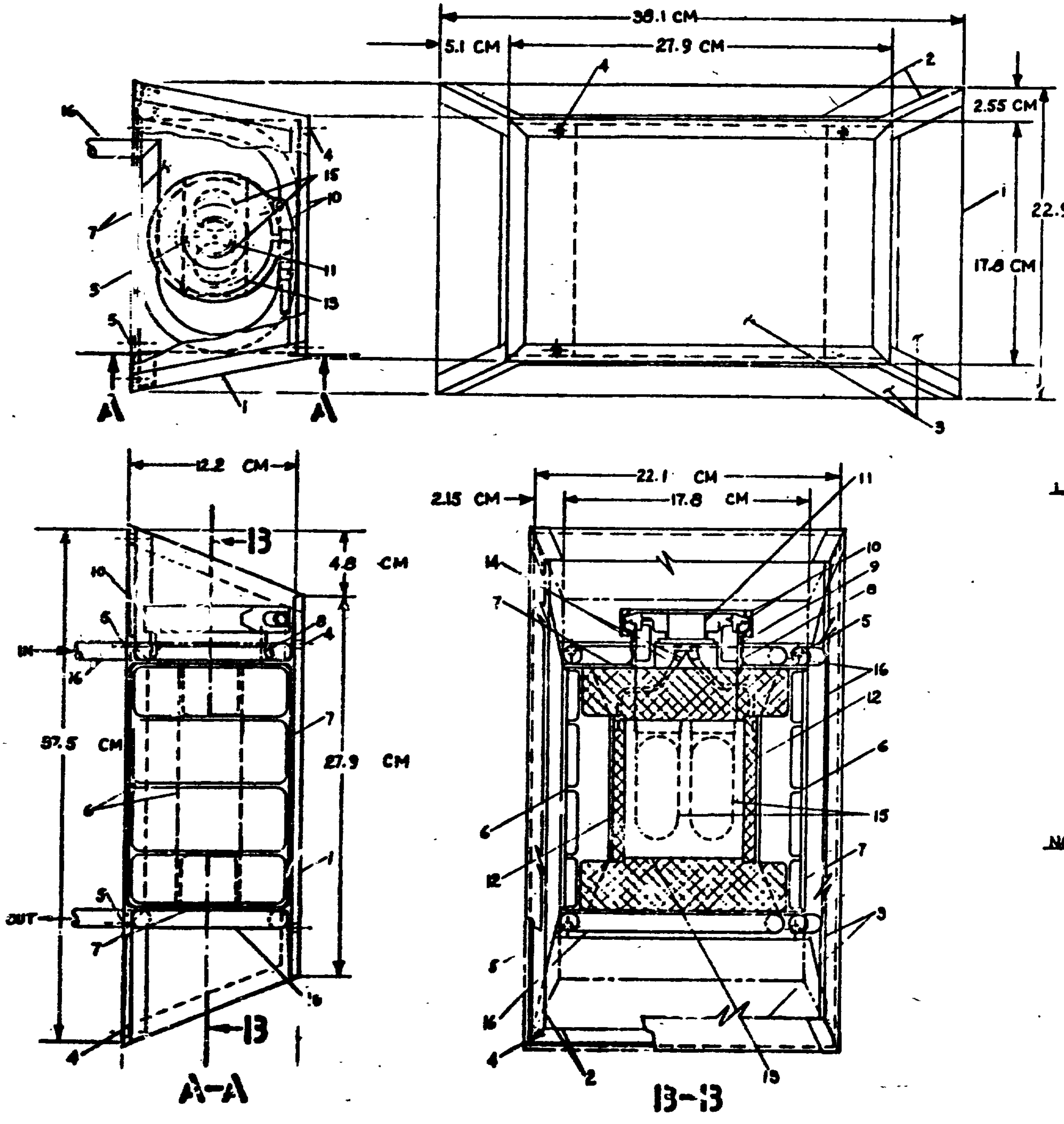
Vehicle	Power/Voltage at End-of-Mission (watts/volts)	Converter/Heat Reject Configuration	Windscreen Area (ft^2)	Thermal Loading (watts)	RTG Weight (less hardware) (lbs.)
Lander	30/8.8	1 module/conductive	12	350	19
	30/8.8	2 modules/heat pipes	18	335	13
	30/8.8	2 modules/conductive	12	350	15
Rover	20/6.0	1 module/conductive	4.5	245	13

TABLE II

SELECTED CONCEPTUAL DESIGNS FOR VIKING '79 POWER SUPPLIES

Vehicle	Power/Voltage (watts/volts)	Windscreen Area (ft^2)	Thermal Loading (watts)	Total Weight* (lbs.)
Lander	30/8.8	4	440	19
	35/8.8	5	510	21
Rover	20/6.0	2	295	12

*Includes windscreen and prelaunch cooling components



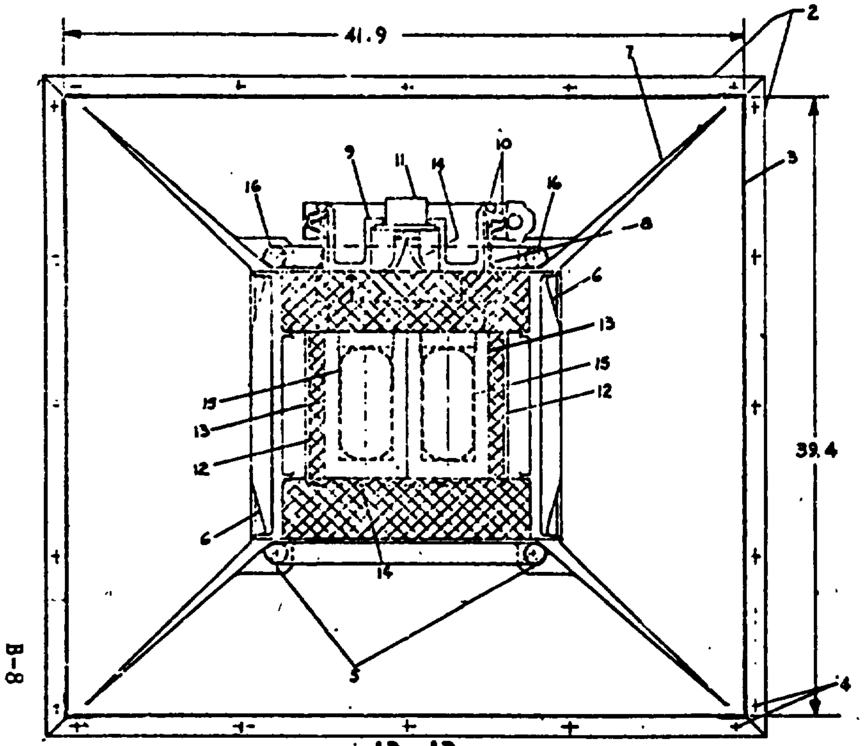
LEGEND

1. WIND SCREEN
2. WIND SCREEN FRAME, 125 CM LEG BENT UP ANGLES .25 MM THK, Ti, WELDED.
3. WIND SCREEN FACE, .25 MM THK. SILICONE RESIN FIBERGLASS CLOTH SHT., BONDED TO FRM.
4. WIND SCREEN MOUNTING POINT.
5. MOUNTING HOLES.
6. SIDE COVERS WITH INTEGRAL HEAT SINK BARS, Be
7. HOUSING WITH INTEGRAL FINS, Be.
8. FUELING PORT NECK, Be.
9. FUELING PORT COVER, Be.
10. "CONOSEAL" FLANGES, CLAMP & GASKET, STA STL.
11. ELECTRICAL OUTPUT RECEPTACLE, STA. STL. SHELL
12. THERMOELECTRIC MODULE, 3M CO. TPM ELEMENTS
13. HEAT BLOCK, POCO GRAPHITE AXF-Q1.
14. POWER LEADS, FLEX. STRANDED Cu.
15. FUEL CAPSULE, PPO FUEL IN Pt-Rh-W LINER & TZM STRENGTH MEMBER.
16. END CAP COOLER TUBING, Ti, BRAZED TO HOUSING

NOTES

1. PARTS INDICATING ATTACHMENT BY WELDING ARE TIG ARC BRAZE WELDED USING 99.9% Ag FILLER WIRE.
2. ▨ = MIN-K THERMAL INSULATION

A DESIGN FOR A
20 W RTG (EOL) FOR
VIKING 79 ROVER
WITH WIND SCREEN & END CAP COOLER
SCALE: ½ DESIGN: 12/5/79



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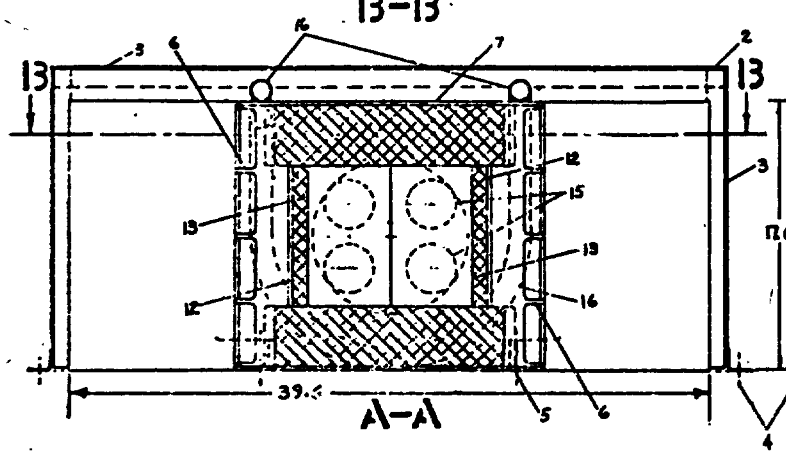

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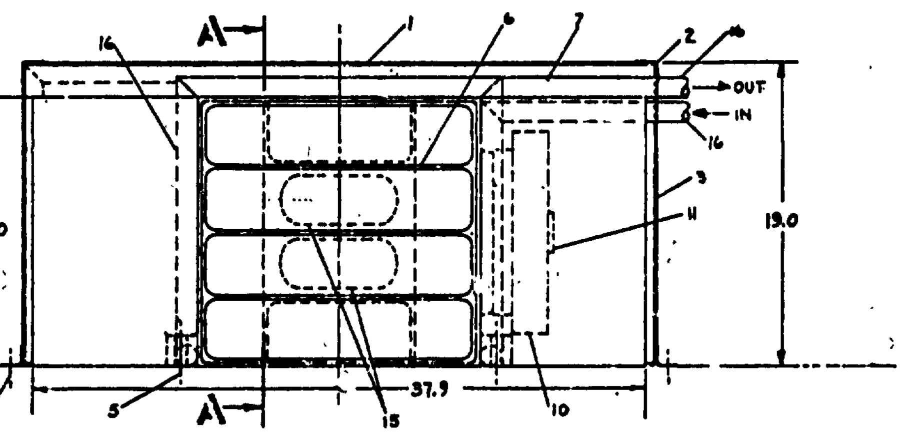


SIDE VIEW
NEAR SIDE OF WIND SCREEN
REMOVED

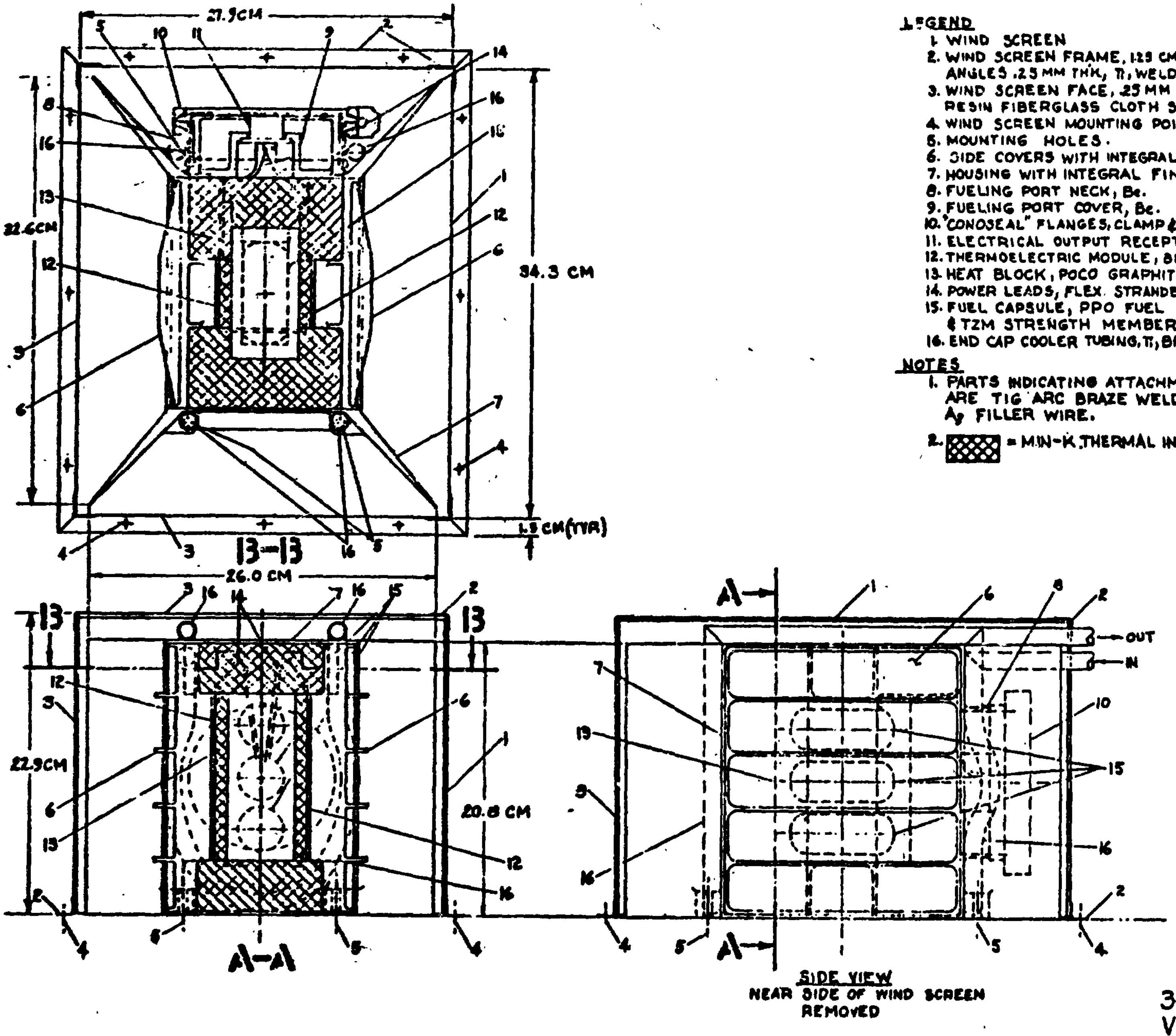
LEGEND.

1. WIND SCREEN
2. WIND SCREEN FRAME, 1.25 CM LEG BENT UP ANGLES .25 MM THK., Ti, WELDED.
3. WIND SCREEN FACE, .25 MM THK. SILICONE RESIN FIBERGLASS CLOTH SHT., BONDED TO FRM.
4. WIND SCREEN MOUNTING POINT.
5. MOUNTING HOLES.
6. SIDE COVERS WITH INTEGRAL HEAT SINK BARS, Be.
7. HOUSING WITH INTEGRAL FINS, Be.
8. FUELING PORT NECK, Be.
9. FUELING PORT COVER, Be.
10. "CONOSEAL" FLANGES, CLAMP & GASKET, STA. STL.
11. ELECTRICAL OUTPUT RECEPTACLE, STA. STL. SHELL.
12. THERMOELECTRIC MODULE, 3M CO. "TPM" ELEMENTS.
13. HEAT BLOCK, POCO GRAPHITE AXF-QI.
14. POWER LEADS, FLEX. STRANDED Cu.
15. FUEL CAPSULE, PPO FUEL IN Pt-Rh-W LINER & TZM STRENGTH MEMBER.
16. END CAP COOLER TUBING, Ti, BRAZED TO HOUSING.

NOTES

1. PARTS INDICATING ATTACHMENT BY WELDING ARE TIG ARC BRAZE WELDED USING 99.9% Ag FILLER WIRE.
2. ▩ = MIN-K THERMAL INSULATION.
3. ALL DIMENSIONS ARE IN CENTIMETERS.

A DESIGN FOR A
35 W RTG (EOL) FOR
VIKING 79 LANDER
WITH WIND SCREEN & END CAP COOLER
SCALE: ½ DESIGN: A. Hall 1/14/74



SIDE VIEW
NEAR SIDE OF WIND SCREEN
REMOVED

LEGEND

1. WIND SCREEN
2. WIND SCREEN FRAME, 1.25 CM LEG BENT UP ANGLES .25 MM THK, Ti, WELDED.
3. WIND SCREEN FACE, .25 MM THK. SILICONE RESIN FIBERGLASS CLOTH SHT., BONDED TO FR'M.
4. WIND SCREEN MOUNTING POINT.
5. MOUNTING HOLES.
6. SIDE COVERS WITH INTEGRAL HEAT SINK BARS, Be.
7. HOUSING WITH INTEGRAL FINS, Be.
8. FUELING PORT NECK, Be.
9. FUELING PORT COVER, Be.
10. "CONOSEAL" FLANGES, CLAMP & GASKET, STA. STL.
11. ELECTRICAL OUTPUT RECEPTACLE, STA. STL. SHELL.
12. THERMOELECTRIC MODULE, 3M CO. "TPM" ELEMENTS.
13. HEAT BLOCK, POCO GRAPHITE AXF-Q1.
14. POWER LEADS, FLEX. STRANDED Cu.
15. FUEL CAPSULE, PPO FUEL IN Pt-Rh-W LINER & TZM STRENGTH MEMBER.
16. END CAP COOLER TUBING, Ti, BRAZED TO HOUSING.

NOTES

1. PARTS INDICATING ATTACHMENT BY WELDING ARE TIG ARC BRAZE WELDED USING 99.9% Ag FILLER WIRE.
2. ▨ = MIN-K THERMAL INSULATION.

A DESIGN FOR A
30W RTG (EOL) FOR
VIKING 79 LANDER
WITH WIND SCREEN & END CAP COOLER
SCALE: ½ DESIGN: J. Hall 12/4/73

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