# VIKING PROJECT



## HEARINGS

BEFORE THE

## SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS

OF THE

## COMMITTEE ON SCIENCE AND ASTRONAUTICS U.S. HOUSE OF REPRESENTATIVES

NINETY-THIRD CONGRESS

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WITNESSES

# VIKING PROJECT

**THURSDAY, NOVEMBER 21, 1974**

House of Representatives,
Committee on Science and Astronautics,
Subcommittee on Space Science and Applications,
*Washington, D.C.*

The subcommittee met, pursuant to notice, in room 2325, Rayburn House Office Building, Hon. James W. Symington, chairman of the subcommittee, presiding.

Mr. Symington. The subcommittee will be in order.

Good morning everybody.

This morning, the Subcommittee on Space Science and Applications begins 2 days of legislative oversight hearings on Viking, NASA's most challenging planetary exploration project to date.

Next summer, two complex Viking spacecraft are scheduled to be launched from Cape Canaveral; their trip will take nearly a year and, in July 1976, scientific instruments will be landed on the surface of Mars.

NASA's planetary exploration program has given special emphasis to Mars for several reasons. Exploration of Mars is expected to cast light on the origin and evolution of our solar system, as well as the processes that shape our terrestial environment. As one of our closest neighboring planets, Mars is accessible to visits by our spacecraft approximately every 2 years. Moreover, Mars is the most Earth-like of all the planets, and is considered to be the place most likely to harbor life forms if any exist elsewhere in the solar system.

Mariner 4 made mankind's first close-up observations of Mars as it flew by the planet in 1965. Four years later, Mariners 6 and 7 flew past Mars and sent back more and better pictures, and additional scientific data. In 1971, the highly successful Mariner 9 surveyed Mars from orbit for several months and mapped the entire planet.

The next step involves the soft landing of scientific instruments on the Martian surface. The Viking spacecraft is designed to make direct measurements of the atmosphere, as well as chemical, physical, and biological analyses at the surface. The major scientific objective is the search for evidence of extraterrestrial life.

Viking is the most ambitious unmanned space project ever undertaken by NASA. It is also the most expensive: Estimated total costs currently exceed $1 billion.

During the past year or so, a number of technical problems have been encountered in the development of certain critical subsystems in the lander portion of the spacecraft which have resulted in substantial cost increases. Some months ago Congress was advised that all Viking contingency funds had been used up, and that more than $40 million had to be reprogramed into the project during fiscal year 1974. Recently, we were informed that nearly $50 million more must be reprogramed into the Viking project during the current fiscal year. Without objection, relevant letters from the Administrator of NASA dated April 3, 1974, and October 10, 1974, will be included in the record at this point.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

APR - 3 1974

OFFICE OF THE ADMINISTRATOR

Honorable Olin E. Teague
Chairman, Committee on Science
and Astronautics
House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

Enclosed is a report by the National Aeronautics and Space Administration on plans to conduct the Lunar and Planetary Exploration program at a level in excess of that authorized in the National Aeronautics and Space Administration Authorization Act, 1974 (87 Stat. 171), together with the facts and circumstances related to the proposed action. This report is being made pursuant to Section 4 of the above referenced Authorization Act and Section 4 of the National Aeronautics and Space Administration Authorization Act, 1973 (86 Stat. 157, 161). This report is being submitted to the Committee pursuant to the cited sections.

The report explains that this increase in the Lunar and Planetary Exploration program is necessary to provide for unanticipated growth in funding requirements for the Viking project caused by development problems in a number of systems and subsystems. As explained in the report, the additional funds for this project in FY 1974 are to be made available from savings in other parts of the program, from deferral of some less time critical efforts, and from savings of $20 million in FY 1973 funds realized in closing out the Apollo program.

Sincerely,

James C. Fletcher
Administrator

Enclosure

National Aeronautics and Space Administration

Report on Planned Actions in the FY 1974 Lunar and Planetary Exploration Program

Made pursuant to Section 4 of the National Aeronautics and Space Administration Authorization Act, 1974 (87 Stat. 171) and Section 4 of the National Aeronautics and Space Administration Authorization Act, 1973 (86 Stat. 157, 161)

The attached table shows the currently planned FY 1974 National Aeronautics and Space Administration's program levels compared to those included in the FY 1974 Authorization Act. The Lunar and Planetary Exploration program is planned at a program level in excess of the authorized amount. A comparison of the Lunar and Planetary Exploration program on which the FY 1974 authorization was based, with the current planned program follows:

Lunar and Planetary Exploration
(In Thousands of Dollars)

| Project | Basis for FY 1974 Authorization Act | Planned FY 1974 Project Levels |
|---|---|---|
| Mariner | 8,900 | 11,115 |
| Viking | 201,200 | 241,655 |
| Outer planets missions | 32,200 | 28,110 |
| Pioneer/Helios | 7,700 | 7,070 |
| Planetary flight support | 22,000 | 20,800 |
| Lunar and planetary ground based activities | 40,000 | 34,950 |
| Budget request | 312,000 | |
| Less: Authorization Act reduction | -1,000 | |
| Total, Lunar and planetary exploration | 311,000 | 343,700 |

The net change in the Lunar and Planetary Exploration program is an increase of $32,700 thousand. Within this total, the major change is an increase of $40,455 thousand for the Viking project. The Viking project, which is developing dual Spacecraft to simultaneously orbit and land on the surface of

Mars, is a technologically demanding one in terms of the compact, automated instruments themselves and in terms of their complex interrelationships. Problems have been encountered in a number of the Lander systems and subsystems during the initial sequence of tests which require prompt correction in order to allow progress on what has become a demanding schedule between now and launch in August/September 1975.

Project planning did allow contingencies in both dollars and time for a reasonable amount of problem solving during the development. The problems encountered, however, have been more extensive than anticipated and have involved a number of spacecraft and experiment systems.

A brief review of the major problems leading to the revised estimates follows:

1) Biology Instrument - Problems have stemmed from the extreme complexity of these three experiments and the limited space available for the package. Solutions for these problems are anticipated but at the cost of much time and effort. This has sharply curtailed the time available for manufacture and test.

2) Gas Chromatograph Mass Spectrometer - Corona arcing presented a severe problem which required several months of intensive effort to solve. The instrument has passed its thermal-vacuum tests and, at this time, does not have serious problems.

3) Camera - Increased expense for this instrument was primarily related to a series of bearing and gearing problems, development of the photo sensor assembly, and a decision to add a dust removal system. This system includes a jet of carbon dioxide to clear the camera window during operation on the Martian surface.

4) Guidance Control and Sequencing Computer - Several problems have been encountered with this instrument, the Lander "brain' Problems center on the plated wire memory, a technologically advanced unit manufactured by a technique of double-plating a magnetic coating on wire only two thousandths of an inch in diameter. Problems with this system remain at this date. Because of the critical nature of this system to the Lander, a backup magnetic core memory is being concurrently developed

5) Radar - Problems were encountered with this design related to temperature sensitivity and operating at minimum altitude These problems have been corrected but, as with others, required additional, unplanned time and effort.

6) Inertial Reference Unit - Problems involved hybrid circuits and operations under extreme cold temperatures. These problems have also been solved, but at a cost of extra effort.

7) Proof Test Lander - Late deliveries of the above and other subsystems, together with problems with the automated testing system, have required contractor manpower for longer periods and at higher levels than planned.

The total impact of these problems has made necessary the additional funding detailed in this report.

The additional funds required for this augmentation are being made available as follows:

1) $20 million of FY 1973 funds is to be transferred from Apollo following a more rapid and less expensive phaseout of that program than expected.

2) $10.7 million is from funds earlier planned for the Launch Vehicle procurement program. A substantial portion of this results from an increase in the number of non-NASA users of launch vehicles and a resultant increase in the portion of the costs of supporting the Launch Vehicle program for which NASA receives reimbursement. (The attachment indicates an $11.7 million difference between the authorized budget plan and the operating plan. The other $1 million of authorization was not funded when the allocation of appropriated funds was made.)

3) $2 million is being made available from the Physics and Astronomy program by reducing the planned activity in Sounding Rockets and Supporting Research and Technology.

4) $7.755 million is from other projects within the Lunar and Planetary Exploration program. Major elements of these adjustments are:

a) an increase of $2,215 thousand for the Mariner Venus/Mercury mission required to support missions operations;

b) a decrease of $4,090 thousand for the Outer Planets Missions by reducing the cost buildup on the project;

c) a decrease of $630 thousand for Pioneer/Helios due to lower current cost rates in both projects;

d) a decrease of $1,200 thousand in Planetary Flight Support thru deferral of selected activities; and

e) a net decrease of $5,050 thousand in the supporting lunar and planetary activities made available by deferral of studies of future missions; delays in the program of synthesizing lunar data; a deferral, for other reasons, in the beginning of operational use of the Arecibo Observatory and similar program changes.

The total of items 4a through 4e is $8.755 million of which $1 million is a reduction in plan following a $1 million reduction in the Authorization Act compared to the FY 1974 request, as noted in the table on page 1.

National Aeronautics and Space Administration

AUTHORIZED AND PLANNED ACTIONS
ON THE FY 1974 PROGRAM
(Thousands of Dollars)

| | FY 1974 Authorization Act (PL 93-74) | FY 1973 Funds to be Applied as Detailed in FY 1974 Budget Request | FY 1974 Authorized Budget Plan | FY 1974 Operating Plan |
|---|---|---|---|---|
| Space flight operations | 555,500 | 25,000 | 580,500 | 580,000 |
| Space shuttle | 475,000 | --- | 475,000 | 475,000 |
| Advanced missions | 1,500 | --- | 1,500 | 1,500 |
| Physics and astronomy | 63,600 | 30,400 | 94,000 | 92,000 |
| Lunar and planetary exploration | 311,000 | --- | 311,000 | 343,700 |
| Launch vehicle procurement | 177,400 | 600 | 178,000 | 166,300 |
| Space applications | 161,000 | 6,000 | 167,000 | 161,000 |
| Aeronautical research and technology | 180,000 | 25,000 | 205,000 | 168,000 |
| Space and nuclear research and technology | 72,000 | 4,000 | 76,000 | 69,000 |
| Tracking and data acquisition | 244,000 | --- | 244,000 | 244,000 |
| Technology utilization | 4,500 | --- | 4,500 | 4,500 |
| Total research and development | 2,245,500 | 91,000 | 2,336,500 | 2,305,000 |
| Construction of facilities | 112,000 | --- | 112,000 | 101,100 |
| Research and program management | 707,000 | --- | 707,000 | 707,000 |
| Civilian pay raise: January and October, 1973 | * | --- | 37,786* | 37,786 |
| TOTAL NASA | 3,064,500* | 91,000 | 3,193,286 | 3,150,886 |

*PL 93-74 authorized appropriations for such additional or supplemental amounts as may be necessary for increases in salary, pay, retirement, or other employee benefits authorized by law.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

OFFICE OF THE ADMINISTRATOR

OCT 10 1974 2859

Honorable Carl Albert
Speaker of the House of Representatives
Washington, DC 20515

Dear Mr. Speaker:

Enclosed is a report by the National Aeronautics and Space Administration indicating our plans to use in FY 1975, in the Lunar and Planetary Exploration program, funds appropriated pursuant to the National Aeronautics and Space Administration Authorization Act, 1974, (87 Stat. 171), in excess of the amount authorized therefor. This report is being made pursuant to Section 4 of the above referenced Authorization Act, and is being submitted to the Speaker of the House of Representatives pursuant to Rule XL of that House.

The need for additional funding in the Lunar and Planetary Exploration program, to accommodate Viking development problems, was explained and discussed during testimony on the FY 1975 NASA budget by NASA witnesses before the House and Senate Authorization Committees and the Appropriations Subcommittees; however, the specific additional funding required was not known at that time. The National Aeronautics and Space Administration Authorization Act, 1975 (88 Stat. 240), authorized to be appropriated $266,000,000 for the Lunar and Planetary Exploration program, of which $89,016,000 was to be applied to the Viking project. As pointed out in the enclosed report, the requirements for this year are $137,798,000, or $48,782,000 more than is available.

To meet the increased programmatic requirements of Viking, we plan to use in FY 1975, $48,782,000 of funds appropriated pursuant to the National Aeronautics and Space Administration Authorization Act, 1974. These funds are to be made available from savings in FY 1974 realized from closing-out contracts on the successful Skylab project, thus permitting the Agency to provide for Viking requirements without disrupting the programs authorized and funded by the Congress for FY 1975. It is believed that this approach is consistent with the concern stated by Congressional Appropriations Committees that other important NASA activities not be restricted because of funding problems with the Viking mission.

The NASA FY 1975 Operating Plan will contain other program element adjustments necessitated by appropriation reductions and changes in project emphasis. These changes will be communicated to the Congress on a timely basis after completion of apportionment actions.

Sincerely,

George M. Low

for James C. Fletcher
Administrator

Enclosure

National Aeronautics and Space Administration

REPORT ON PLANNED ACTIONS AFFECTING THE LUNAR AND PLANETARY EXPLORATION PROGRAM

Made pursuant to Section 4 of the National Aeronautics and Space Authorization Act, 1974 (87 Stat. 171).

Viking is by far the most sophisticated project ever attempted using automated spacecraft. It will make the first comprehensive surface study of the physical, chemical, and biological properties of the planet Mars. The Viking missions will not only yield unique observations of Mars but will also search for evidence of past or present life or the probability of future development of life on the planet.

These determinations are to be made using data from a variety of sensors in Mars-orbiting spacecraft, as well as from spacecraft designed to land on the surface of Mars. Two launches will be made in August/September 1975, each including a combination Orbiter/Lander spacecraft.

Major technical problems in three areas have delayed the completion of the Lander: (1) the guidance and control computer; (2) the biology instrument; and (3) the Lander proof test capsule qualification program. These problems surfaced a number of months ago and have resulted in an extremely tight schedule situation, even though recent progress has been good. The computer qualification unit is in test and the first two flight computers have been assembled and are also in test. A recent problem required that many of the printed circuit boards in these computers be replaced before flight. The first flight-type biology instrument has been assembled and is in factory acceptance test. The biology instruments will be delivered very late in the lander assembly and test schedule, but in adequate time for launch preparations. The Lander proof test capsule has completed sterilization tests, acoustic and vibration tests, and is now in its science tests in a simulated Mars environment. These tests are going well, although considerably later than originally scheduled.

These problems have resulted in significant cost increases, which have been partially offset through program changes. Additional effort needed to complete a backup flight lander has been deleted from the program. Assembly of one of the two flight orbiters has also been stopped and the proof test orbiter, which had an excellent test history, will be refurbished and become the second flight orbiter. We believe that these actions will enhance the probability of meeting our remaining scheduled milestones, will contribute significantly to holding down the overall cost of Viking, and will not seriously compromise the probability of mission success.

The cost increases described above will require an estimated $48,782,000 above the $89,016,000 which was our estimate of Viking project requirements at the time the FY 1975 budget was printed and distributed. We plan to use in FY 1975, $48,782,000 of funds appropriated for the Skylab program in FY 1974. These funds are available following closeout of contracts after the successful completion of that project. This action increases the funding planned for the Viking project in FY 1975 to $137,798,000 and increases the Viking usage of funds appropriated pursuant to the National Aeronautics and Space Administration Authorization Act, FY 1974 (87 Stat. 171) from $241,655,000 to $290,437,000.

According to NASA's then Associate Administrator for Space Science, Dr. John Naugle, "after holding to a ceiling cost for 4 years, the program encountered unexpected development problems which will increase runout costs by 5 to 7 percent." Since he testified last spring, that estimated increase has at least doubled.

These hearings have been scheduled in order to determine the nature of those development problems, and why they were unexpected at such a late stage in the Viking project. We shall also review the financial history of the project, and seek an expert assessment of the probability of mission success.

This morning we will hear from three members of the NASA team on Viking; tomorrow our witnesses will be representatives of the industrial contractors.

Our leadoff witness today is NASA's Associate Administrator, Dr. Rocco A. Petrone, who will give an overview of the Viking project for NASA Headquarters. He will be followed by Mr. Edgar M. Cortright, Director of NASA's Langley Research Center, which has overall project management responsibility for Viking. Our third witness will be Mr. Robert Parks, Assistant Laboratory Director for Flight Projects at the Jet Propulsion Laboratory, who will describe the development of the orbiter portion of the spacecraft.

On behalf of the subcommittee, I welcome all of you. We will begin with Dr. Petrone's prepared statement.

## STATEMENT OF DR. ROCCO A. PETRONE, ASSOCIATE ADMINISTRATOR, NASA

Dr. PETRONE. Mr. Chairman and members of the committee, I am pleased to be able to discuss with you today the status and progress of the Viking program. With me are Dr. Noel W. Hinners, the recently appointed Associate Administrator for Space Science, the office with primary responsibility for the Viking program at headquarters; Dr. Edgar M. Cortright, Director of the Langley Research Center, which has management and operational responsibility for Viking; and Mr. Robert J. Parks, Assistant Laboratory Director for Flight Projects at the Jet Propulsion Laboratory, which has responsibility for the Viking orbiter.

Today I plan to provide a perspective and overview of the Viking program. Dr. Cortright and Mr. Parks are prepared to discuss the status and progress of the program in greater technical detail.

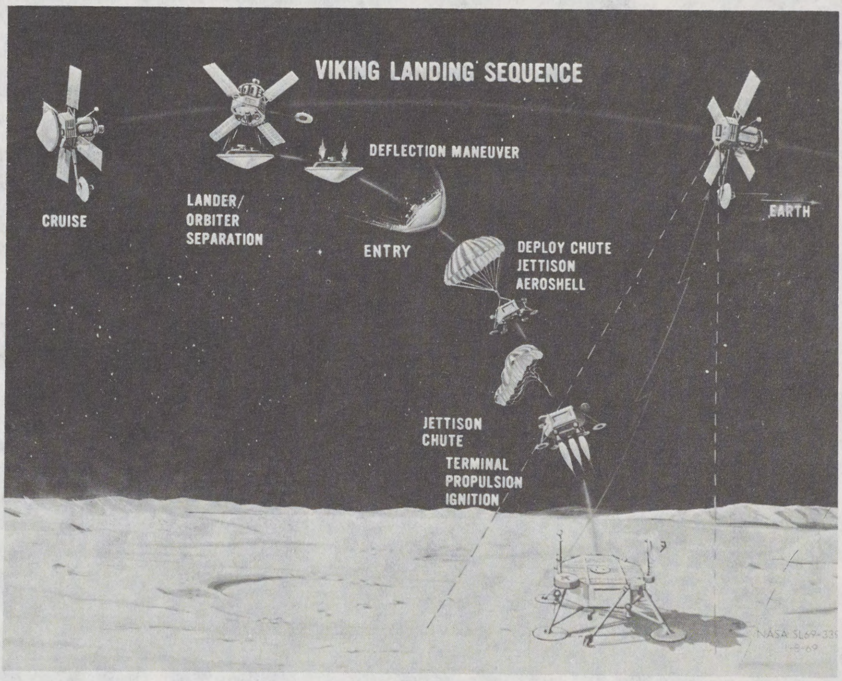
The National Aeonautics and Space Administration, shortly after its establishment, began studies for a Mars exploration program. Encouraged by the results of Mariner 4 in 1964, we initiated the Mars Voyager program to carry out detailed studies from orbit and on the surface of Mars of the chemistry of the atmosphere and surface, radiation levels, temperatures, seismic activity and search for evidence of extraterrestrial life.

A major feature of Voyager was that the orbiting spacecraft would be capable of missions to other planets and the landing capsule would be designed to carry interchangeable payloads such as an automated surface laboratory or a large roving vehicle. Voyager, first authorized by this committee in fiscal year 1966, was described in the fiscal year 1968 budget hearings as a $2.2 billion program and had strong endorsement from the NASA Lunar and Planetary Mission Board. It became obvious, however, with the reduction in the fiscal year 1968 NASA budget request of $5.1 billion to an appropriation of $4.6 billion that the Saturn V launch of two 25,000-pound Voyager planetary vehicles could not be accomplished within fiscal constraints. At that time, the agency commenced studies aimed at reducing the mission goals and commensurate expense of the Voyager while preserving the most significant science objectives of a Mars mission.

The first program option considered was discussed with this committee in the fiscal year 1969 budget hearings and was referred to as the Mars 1973 program. Studies indicated that an orbiter and a short-lived, survivable hard lander mission without life detection instrumentation could be developed for $347 million. The committee was also advised in those same hearings that NASA was studying several other mission options. The early results of those studies were presented to the committee in the fiscal year 1970 budget hearings and recommended that a Mars program called Viking, with soft landing capability and life detection capability, could be developed and the preliminary cost estimate was $364 million. During the summer of 1969, definition studies were completed, proposals were received from industry for the major hardware elements, and the baseline science payload was established using the recently received results of Mariners 6 and 7. The changes to the Viking program during this time period were discussed in special hearings before this committee in a supplemental review of NASA/OSSA projects conducted in October 1969. The program cost range discussed during these hearings was $650 to $750 million, including the Titan-Centaur launch vehicles.

The constraints on expenditures applied in the formulation of the fiscal year 1971 budget request resulted in rescheduling of the Viking program from a launch date of 1973 to 1975 which was the next Mars launch opportunity. This schedule change increased the cost range to $700–$850 million—excluding the Titan-Centaur launch vehicles—and it was presented in our fiscal year 1971 budget hearings. The cost range was further refined to $750–$830 million and presented to this committee in the fiscal year 1972 hearings.

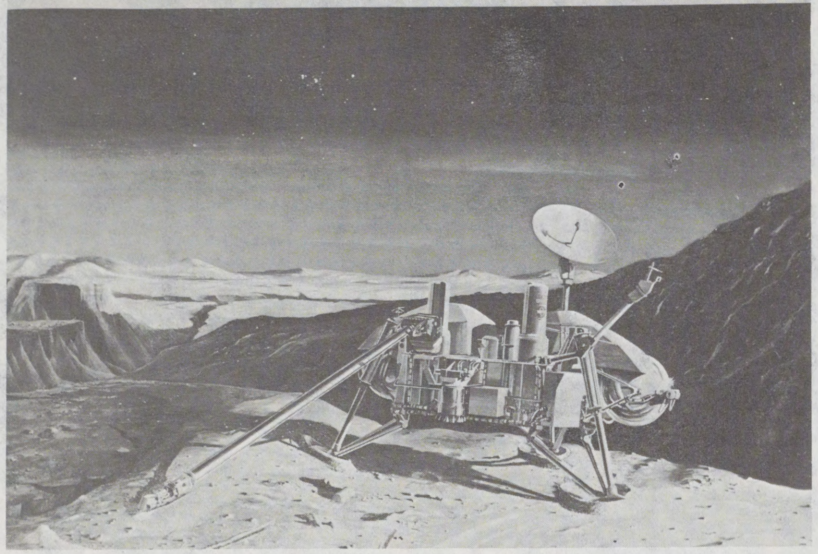
The Viking program is widely regarded as a program of enormous scientific value and one of the greatest milestones in the exploration of the solar system. Two missions will be launched, each to place an Orbiter/Lander spacecraft around Mars—chart SL69–339—this figure shows the Orbiter and Lander in Martian orbit, and then we will give the command to separate. This in effect will be our last command from Earth until after landing. We are 40 minutes away in a two-way radio journey. Guidance and control of the spacecraft must be totally automated, unlike an Apollo. There is no information or help we can give the spacecraft going in for the landing. It must be totally automatic and must totally take care of itself. The next event after separation is atmospheric entry. Here is the deployment of the chute and, finally, retrorockets bringing us down to a soft landing. The figure shows the two communication modes, relay to the Orbiter and direct to Earth. The communications are very much constrained by the power availability.




We will have that relay communication link to give us the science data after the soft landing, with the Orbiter remaining in orbit about Mars. The Lander will separate from the Orbiter and descend to a soft landing on the surface of Mars [chart SL75-15190]. The next vugraph shows the Lander on the surface. We see our long arm for the sample. One of our prime experiments will be the attempt to detect what life may be there, a very exciting prospect. We also see the two cameras on our Lander model here in front of the committee. They are shown in green on the unit here. The antenna dish is to communicate to Earth. As I mentioned in our previous slide, we communicate both to Earth with a direct dish and through the Orbiter. The data obtained from the Viking experiments will, for the first time, provide detailed specific information on the nature of the atmosphere and surface of Mars [chart SL75-15189(3)].

Our experiments are alined in three different modes. We have the Orbiter which, from the orbit of Mars, will be looking for water vapor, doing thermal mapping, and obtaining surface photographs. During entry, we will get a reading of the atmospheric composition and atmospheric structure. And then on the surface, we have the visual; we're sending pictures from our two cameras. Our biology instrument, which you will hear more about later, will look for life. We also have a molecular experiment for organic activity. These experiments will tell us something about the chemistry of organic or inorganic materials on Mars. A seismology instrument will look for quakes.

## VIKING LANDER
### ON THE SURFACE OF MARS



## VIKING
## SCIENCE SUMMARY

| | INVESTIGATIONS | INSTRUMENTS |
|---|---|---|
| ORBITER | Visual | 2 TV Cameras |
| | Water Vapor Mapper (atmospheric) | Infrared Spectrometer |
| | Thermal Mapper (surface temperatures) | Infrared Radiometer |
| ENTRY | Atmospheric Composition, Atmospheric Structure (One Science Topic) | Mass Spectrometer, Retarding Potential Analyzer, Pressure and Temperature Sensors, Accelerometers and Radar Altimeter |
| LANDER | Visual | 2 Facsimile Cameras, Color/Stereo Capability |
| | Biology | 3 Analyses for Photosynthesis, Metabolism and Growth |
| | Molecular Analysis (organic) | Gas Chromatograph Mass Spectrometer (GCMS) |
| | Mineral Analysis (inorganic) | X-Ray Fluorescence Spectrometer |
| | Meteorology | Pressure, Temperature, Wind Velocity and Wind Direction Sensors |
| | Seismology | 3-Axis Seismometer |
| | Magnetic Properties of Soil | Magnet Array on Soil Sampler, Cameras Used for Visual Study of Particles |
| | Physical Properties of Soil | Analysis of Visual and Engineering Data from Applicable Instruments and Experiments: ● Cameras–Visual Study of Soil Characteristics (e.g., clumping, grain size, cohesion, adhesion, etc.) ● Soil Sampler–(with cameras) Trenches, Engineering Force Measurements, Porosity, Bearing Strength |
| RADIO | Orbiter/Lander Location, Atmospheric and Planetary Data, Interplanetary Medium | Orbiter/Lander Radio and Radar Systems |

NASA HQ SL75-15189 (3)
11-1-74

We will investigate magnetic and physical properties of the soil; and the radio experiments, and so forth. This of course is a very ambitious program as we mentioned before in terms of stepping out to a distant planet to try to learn something about it. We have learned much from pictures. But one step on the soil, of course, with the Lander will bring us into a whole new understanding of our neighboring planet. One of the many important questions the experiments are designed to address is the question of whether life exists, has existed, or could evolve on Mars. These points are mentioned to emphasize the fact that Viking is truly unique from a scientific point of view. Viking is the most advanced, automated mission ever attempted. The Lander contains the capabilities of a chemical laboratory to analyze the chemical composition of the Martian atmosphere and the soil around the Lander for organic and inorganic makeup. It contains a meteorological station for measuring pressure, temperature and wind velocities; a seismometry station for measuring marsquakes; a biology laboratory utilizing several different techniques for detecting life in the form of microorganisms; and, a number of other experiments including high resolution color and infrared twin cameras [chart SL012PDF-01].


This is not a view of Mars. It is a view taken with the cameras showing the fidelity we expect to be able to return in color and infrared.

We can also, with the twin cameras, be able to get stereo views of certain features that I am sure will be of interest. The camera development has been an outstanding bit of work in terms of getting resolution of data from that distance. This is just a copy of what fidelity we do expect to return. The Orbiter, the companion vehicle to the Lander, utilizes Mariner spacecraft and sensor technology but still performs several new features such as its communication role in relaying Lander data back to Earth. The mission plan with its 11 months of cruise time, orbital operations, deorbit and soft landing at a predetermined landing site, data gathering and transmission operations illustrate the uniqueness and complexity of the Viking program.

At this point, I would like to mention the publication of the "Viking Mission to Mars," a copy of which has been placed before each member of this subcommittee. This is a concise description of the basic elements of the Viking mission in much more detail than time allowed me to present here this morning.

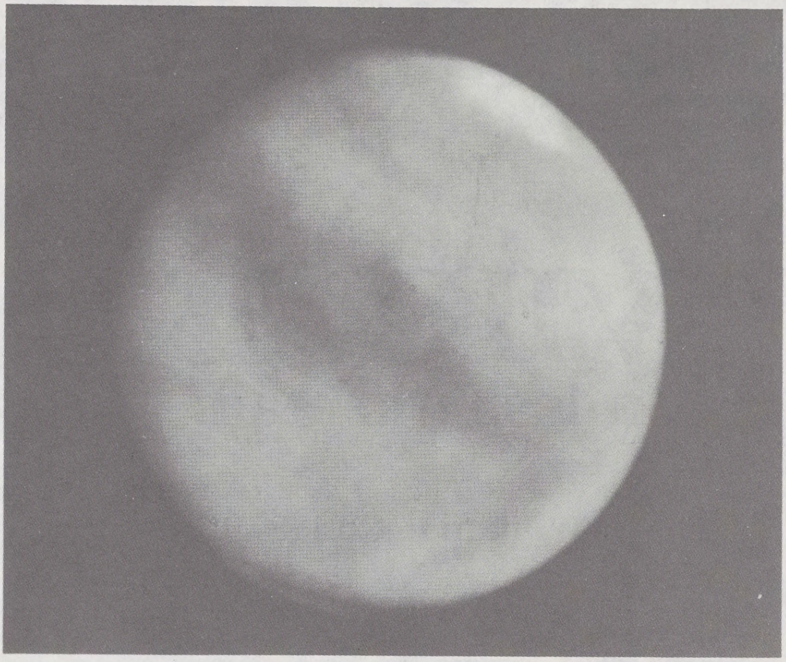
Mr. Symington. Without objection, this brochure will be made part of the record at this point.

NASA SP-334

# The VIKING mission to mars

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# The VIKING mission to mars



Only through comparative studies of other planets and their evolution will man truly begin to understand the forces which shaped his own being and the world in which he lives.

John E. Naugle
*Deputy Associate Administrator*

NASA SP-334

# The VIKING mission to mars

William R. Corliss

*Scientific and Technical Information Office* 1974
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
*Washington, D.C.*

# Foreword

This monograph describes the National Aeronautics and Space Administration's program to explore the planet that most nearly resembles the Earth. Americans have taken many giant steps for all mankind since 1776, but few as potentially momentous as the search for life on the surface of Mars that the Vikings are scheduled to begin in 1976.

The recent Mariner flights by and around Mars have yielded photographic and other data packed with surprises for scientists. The Soviet Union has also embarked on an extensive program to study Mars' surface. From the Viking instruments that are being readied now for use on the surface and in orbit around Mars, much more will be learned about the nature of the planet, possible origins of life, and the possible fate of our own environment.

In this brief account of the Viking mission to Mars, Mr. Corliss has endeavored to describe it in ways understandable to everyone.

EDGAR M. CORTRIGHT
*Director*
*Langley Research Center*

# Contents

# Chapter 1
# The Purpose of Planetary Exploration

From the Great Pyramid to Palomar, man has always searched the skies for clues to his destiny. Down the centuries the bright, wandering orbs of the planets have captured his imagination. At first, he peopled those spheres with his ancient gods and, later, with the exotic creatures of science fiction. Although the Sun's planets are devoid of those fanciful beings, they boast something much more valuable: The keys to understanding our Earth, its geological past, and how its variegated cargo of life originated and evolved.

The planets of the solar system probably had a common origin. The current view holds that all were formed by "accretion," as gravity pulled dust and rocky debris into the spherical conglomerations of matter we now call planets. Despite their similar births, each planet is different in character. Earth teems with life; Jupiter is massive with a thick and colorful atmosphere; Mercury is small with little atmosphere and baked by the nearby Sun; while Mars, the most Earth-like of all the planets, is a dry, windblown, cold desert. Their different chemistries, geologies, and meteorologies derive from their different masses and varying distances from the Sun. This diversity alone makes planetary exploration worthwhile.

What the planets can tell us about life is possibly even more important. Earth, to be sure, harbors abundant life in a relatively thin biosphere only a few miles thick but is unique among the denizens of the solar system in this regard. Data gathered from outer space—the amino acids detected in meteorites and the observed spectra of water, ammonia, and organic chemicals in interstellar space—suggest that the chemical building blocks of life are universal. Life may be an integral, perhaps inevitable, part of the unfolding evolution of the universe. Very likely some of the precursors of life exist somewhere on our eight sister planets or their several dozen assorted moons. Somewhere in the solar system, chemical evolution may have taken that one critical additional step into the realm of life, just as it did some 3.5 to 4 billion years ago on Earth.

By exploring the other solar system planets and their satellites, we should be able to study the various stages of chemical and, hopefully, biological evolution. Thereby, scientists can gain insight into the processes leading from simple molecules to man. Valuable as this detailed insight would be, just one look at that part of the drama which reveals some form of "other life" would make space exploration worthwhile.

Recognizing that many scientific secrets still lie hidden throughout the solar system, NASA has a program of solar system exploration aimed at answering the following questions:

(1) How did our solar system form and evolve?
(2) How did life originate and evolve?
(3) What are the processes that shape our terrestrial environment?

Our astronauts have begun detailed exploration of the Moon, but we have sent only a few instrumented spacecraft past or into orbit around the other planets. Among the other planets, Mars is the most potentially rewarding as an astronautical objective, especially in terms of the second question. It is neither too hot nor too cold; it possesses carbon dioxide and some water. Life could exist there, and scientists are eager to send their instruments down to the Martian surface.

The possibility of Martian life—extinct, extant, or future—is the target of the Viking program that is described in detail in this publication. The two Viking spacecraft, to be launched in 1975, will be Orbiter-Lander combinations. The Orbiters will contribute to the science objectives of the mission by taking photographs and spectra over large regions of the planet. The Landers will make *in situ* atmospheric and meteorological measurements during descent and while on the surface. Once safely landed, various other instruments will analyze the soil for organic and inorganic compounds and try to detect biological activity.

Viking is a challenging program to explore the surface of a planet millions of miles away. From the information in the stream of radio signals beamed back to Earth across that immense void, we hope to learn more about Earth through the study of the differences and similarities of the planets and, possibly, to hear first signals announcing the discovery of extraterrestrial life.

# Chapter 2
# Viking's Target: Mars

## The Red Planet Through the Telescope

Mars is the third smallest planet of our solar system. Its diameter is scarcely half that of Earth and its mass is only one-tenth that of our globe. Yet, of all the planets that circle the Sun, Mars seems most like Earth. Its year is twice ours—687 days—but the Martian day is almost exactly the same—24 hours, 37 minutes, and 23 seconds. Mars has a thin atmosphere which supports a few clouds and fierce duststorms. Because the axis of Mars is tilted at 25° to the plane of its orbit, it has seasons that superficially seem like those on Earth. When spring comes to the northern hemisphere of Mars, its northern polar cap recedes while the southern cap grows. As the white northern cap shrinks, a wave of darkening appears to sweep south toward the equator as if Sun-released moisture were reviving dormant vegetation. Little wonder that some early astronomers reckoned Mars a second Earth! Scores of science fiction stories portrayed their heroes striding across the red sands of Mars, while Phobos and Deimos, the two tiny moons, raced overhead.

Many facts about Mars can be verified through the telescope; but the older visions of Earth-like springtimes, greening vegetation, and a biosphere like our own are unwarranted extrapolations from them. Mars is still a mysterious planet. Each new phase of scientific exploration has changed our picture of it substantially. Telescope, spectroscope, flyby spacecraft, and orbiting spacecraft have in their turns revolutionized our concept of Mars.

When an astronomer trains his telescope on Mars, he sees a fuzzy reddish sphere capped in white at both poles. There are pronounced light and dark areas and, when the Earth's turbulent atmosphere holds still for a moment, fine details seem to crystallize. (See frontispiece.) It was during such moments of "good seeing" that Giovanni Schiaparelli saw and drew his famous "canali," or channels, when Earth and Mars were separated by a distance of less than 35 million miles during the opposition of 1877. Today we know there are no canals on Mars, but we still are not able to study details of the Martian surface through a telescope.

Spectroscopic studies of Mars began in 1862 when the English astronomer William Huggins first applied that technique. When a prism, or ruled grating spreads the light from Mars out into a spectrum, dark absorption bands can help to identify the atmosphere's constituents, but for more than 80 years astronomers have struggled with their spectroscopes with scant results. The atmosphere of Mars is so thin that absorption bands, if present, were difficult to discern. Finally, in 1947, Gerard P. Kuiper positively identified several infrared absorption bands due to carbon dioxide. Despite this evidence, carbon dioxide was assumed to be a minor constituent in comparison to nitrogen, even though nitrogen had not been detected. This assumption, based on analogy with the Earth's atmosphere, was proven incorrect in the 1960's. Carbon dioxide is now known to make up most of the Martian atmosphere. This turnabout and others to follow illustrate the difficulty of doing planetary research at distances of 35 million miles, the closest Mars ever gets to Earth.

The brilliant polar caps of Mars were initially assumed to be ice or at least a layer of hoarfrost (again in analogy with Earth). Water vapor was therefore expected to appear in Martian spectrograms. But the characteristic infrared absorption bands of Martian water vapor, if they existed, were masked by water vapor in Earth's atmosphere above the telescope. Finally, in 1963, scientists definitely detected Martian water vapor bands by utilizing the Doppler shift caused by the relative motion of Mars and Earth.

A rough idea of the Martian surface temperature was acquired by measuring the heat radiation emitted (not reflected) by the planet in the infrared portion of the spectrum. Temperature measurements made in 1922 indicated that Mars was a very cold planet, but not completely hostile to life as we know it. Refined techniques have led to the conclusion that shortly after midday, surface temperatures on the equator can rise to at least 25° C (77° F). (See table 1.)

The first indications that life might exist on Mars came in 1956 and 1958 when W. M. Sinton observed distinct absorption bands at 3.43, 3.54, and 3.69 micrometers in light reflected from the dark areas of Mars. Since carbon-hydrogen bonds in organic compounds display similar bands, some sort of life, probably vegetation, might occur in the dark areas. Like the canals a half century earlier, Sinton's bands, as they were called, led many to conclude that Mars indeed did support life.

A rude awakening came in 1965 when two of Sinton's bands were identified as absorption bands of the rare molecule hydrogen deuterium oxide, HDO (a type of heavy water), in Earth's atmosphere. Once again the limitations of Earth-bound astronomy had been emphasized. By this time, however, a spacecraft was on its way to Mars to observe the planet from an incomparably better vantage point as it flew past.

## TABLE 1.—*Physical Properties of the Planet Mars*

| Property | Value | Equivalent value in: Metric system | Equivalent value in: English system | Value for Earth in English system |
|---|---|---|---|---|
| Mean sidereal year,[a] days | 686.98 | ---------- | ---------- | 365.24 |
| Mean distance from Sun,[a] astronomical units | 1.52 | $217.94 \times 10^6$ (kilometers) | $141.64 \times 10^6$ (miles) | $93 \times 10^6$ (miles) |
| Distance at perihelion,[a] astronomical units | 1.38 | $206.66 \times 10^6$ (kilometers) | $128.41 \times 10^6$ (miles) | $91.40 \times 10^6$ (miles) |
| Distance at aphelion,[a] astronomical units | 1.67 | $249.22 \times 10^6$ (kilometers) | $154.86 \times 10^6$ (miles) | $94.51 \times 10^6$ (miles) |
| Close approach (opposition),[a] astronomical units: | | | | |
| August 12, 1971 | 0.38 | $56.20 \times 10^6$ (kilometers) | $34.92 \times 10^6$ (miles) | |
| October 17, 1973 | 0.44 | $65.22 \times 10^6$ (kilometers) | $40.53 \times 10^6$ (miles) | |
| December 8, 1975 | 0.57 | $84.60 \times 10^6$ (kilometers) | $52.57 \times 10^6$ (miles) | |
| January 19, 1978 | 0.65 | $97.72 \times 10^6$ (kilometers) | $60.72 \times 10^6$ (miles) | |
| February 26, 1980 | 0.68 | $101.32 \times 10^6$ (kilometers) | $62.96 \times 10^6$ (miles) | |
| Inclination,[a] degrees | 24.94 | ---------- | ---------- | 23.45 |
| Mean equatorial diameter,[b] kilometers | 6786 | ---------- | 4217 (miles) | 7926.4 (miles) |
| Mean polar diameter,[b] kilometers | 6751 | ---------- | 4195 | 7899.8 |
| Mass,[b] grams | $6.18 \times 10^{25}$ | ---------- | $1.36 \times 10^{24}$ (pounds) | $13.18 \times 10^{24}$ |
| Mean density,[b] grams per cubic centimeter | 3.945 | ---------- | 0.146 (pounds per cubic inch) | 0.199 (pounds per cubic inch) |
| Magnetic field at surface,[b] gauss | $<4 \times 10^{-4}$ | ---------- | ---------- | 0.32 |
| Length of day,[b] hours and minutes | $24^h37^m$ | ---------- | ---------- | $24^h$ |
| Mean solar irradiance,[b] watts per square centimeter. | 0.058 | ---------- | ---------- | 0.139 |
| Atmospheric pressure,[b] millibars | 5.3 | $5.3 \times 10^3$ (dynes per square centimeter) | 0.077 (pounds per square inch) | 14.696 (pounds per square inch) |
| Atmospheric composition [b] | $CO_2$ ~100% | | | 0.003% |
| | $N_2$ Trace | | | 78.0 |
| | $H_2O$ Trace | | | 0.001–0.028 |
| | $O_2$ Trace | | | 20.9 |
| | Ar Trace | | | 0.009 |
| | CO Trace | | | Trace |

[a] Data from ref. 1.

[b] Data from ref. 2.



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TABLE 2.—*Summary of Mariner Flights to Mars*

| Spacecraft | Launch date | Spacecraft weight, kilograms (pounds) | Encounter date | Remarks |
|---|---|---|---|---|
| Mariner 3 | Nov. 5, 1964 | 262 (575) | ------------- | In solar orbit (shroud failure precluded Mars flyby). |
| Mariner 4 | Nov. 28, 1964 | 262 (575) | July 15, 1965 | Closest approach: 9800 kilometers (6140 miles). |
| Mariner 6 | Feb. 24, 1969 | 414 (910) | July 31, 1969 | Closest approach: 3400 kilometers (2131 miles). |
| Mariner 7 | Mar. 27, 1969 | 414 (910) | Aug. 5, 1969 | Closest approach: 3400 kilometers (2131 miles). |
| Mariner 8 | May 8, 1971 | 1000 (2200) | ------------- | Launch vehicle failure. |
| Mariner 9 | May 30, 1971 | 978 (2150) | Nov. 13, 1971 | In Martian orbit. |

## The First Mariners

Mariner 4 flew past Mars on July 15, 1965, at a distance of 9800 km (6140 miles), snapping 22 pictures of the planet (table 2). To nearly everyone's surprise, the pictures revealed a heavily cratered surface like that of the Moon (fig. 1). Furthermore, the craters showed little evidence of erosion, suggesting that wind and water had scarcely touched the surface during the geological eons. Even though Mariner 4 had photographed only about 1 percent of the planet's surface (fig. 2) and from 9800 kilometers, the scientific interest in Mars as an abode of life quickly wavered. Mariner 4 suggested that Mars was geologically and biologically dead. To make the case for Martian life even worse, the Mariner 4 magnetometer radioed back that there was little or no magnetic field around the planet. With no magnetic field and only a very thin atmosphere to shield the surface from charged particles (and without atmospheric ozone to absorb ultraviolet radiation), life on Mars seemed unlikely indeed.

The conclusion was premature. From several thousand kilometers out, Earth also appears lifeless. Additionally, Mariner 4 photographed only a narrow strip of Mars. What did the other 99 percent look like?

Mariners 6 and 7 flew past Mars in the summer of 1969. In addition to cameras, they carried infrared and ultraviolet instruments to analyze the Martian atmosphere and surface. Again, photos of the surface showed many craters strewn across the planet's surface, but not at random. The 202 pictures (covering 20 times the area shown by Mariner 4) revealed two unexpected features: chaotic terrain composed of jumbled ridges and valleys unlike anything found on the Earth or Moon (fig. 3) and wide expanses of featureless terrain where craters had been somehow eroded (fig. 4). Mars had obviously been geologically active in the past and possessed its own evolutionary history.

The camera eyes of Mariners 6 and 7 saw no canals, but where canals were thought to be, the closeup photos revealed alinements of dark-floored craters and diffuse dark patches. Some of the alinements may be random but others probably have geological significance. Pictures taken over the southern polar cap indicated a thin layer of snow which infrared spectra suggest is mostly frozen carbon dioxide (fig. 5). The bulk of the thin atmosphere also seems to be carbon dioxide, with some water but little or no nitrogen. Atmospheric pressures were confirmed to be very low, about 6 millibars, compared to about 1000 millibars on Earth. Mars was thus found to be a unique member of the solar system.

## The Orbiter Phase

Collectively, Mariners 4, 6, and 7 photographed only about 10 percent of the surface of Mars as they cruised past and went into orbits about the Sun. Only a long-lived picture-taking Martian satellite could provide a complete photographic map of Mars. This was the task of Mariner 9, which was inserted into Martian orbit on November 13, 1971.

A planetwide duststorm concealed most of the surface when Mariner 9 arrived at its destination. It was still possible, however, to make measurements of the upper atmosphere; and a spacecraft camera caught the two moons, Phobos and Deimos, in its field of view, revealing them as irregular, cratered chunks of rock (fig. 6). In addition, infrared spectrograms of the dust itself showed it to be similar in composition to surface rocks on Earth. To geologists this indicated that the lighter materials had risen to the surface while Mars was still molten, as probably happened when Earth was evolving.

As the duststorm slowly subsided in early 1972, Mariner 9 began sending back thousands of high-quality pictures of the surface. This detailed, comprehensive look at Mars revealed several things that telescopes could not show us and that had been missed by previous Mariners.

One of the most exciting discoveries was clear-cut evidence of fluid erosion. A meandering "riverbed" (fig. 7) and braided channels were photographed. Except for the nearby craters, such scenes might have been shot by satellites over the American Southwest. Equally extraordinary were pits and slumps (fig. 8) resembling ice-formed features in Earth's polar regions. Furthermore, the region around the southern polar cap proved to be extensively eroded as if by glacial action. Mars might have had an appreciable hydrosphere within the past 100 million years with accompanying glaciation and river erosion.

To heighten the resemblance to Earth, Mars has many volcanoes.

Nix Olympica (fig. 9), the largest observed in the solar system, is 500 kilometers (310 miles) wide at its base. The sea-covered foundation of Mauna Loa, Earth's largest volcanic formation, is only about half this breadth. Mars also has vast canyon lands (fig. 10). One great "rift valley" is 121 kilometers (75 miles) wide and almost 6½ kilometers (4 miles) deep, far greater than our Grand Canyon. Geologists see this as a great crack in the Martian surface where crustal plates are pulling apart, much as they are along the deep fault that bisects Iceland. Like Earth, Mars seeems to have two kinds of surface: recent, relatively featureless terrain like Earth's sea bottoms and old, well-cratered regions similar to terrestrial continents.

Will the similarities end with geology? Perhaps somewhere on Mars near the warmth of a volcano or a similar favorable niche, life may have survived from warmer, wetter days. Or Martian life may be prospering in its present environment. For it is now believed, based on the Mariner 9 results, that the polar caps do contain a frozen-water deposit below an overlay of frozen carbon dioxide, and that at the fringes of the southernmost extremes of the northern cap temperature and pressure conditions exist for a short period of the Martian year which would allow even certain forms of terrestrial life to assimilate liquid water—or Mars may truly be lifeless. We do not know.

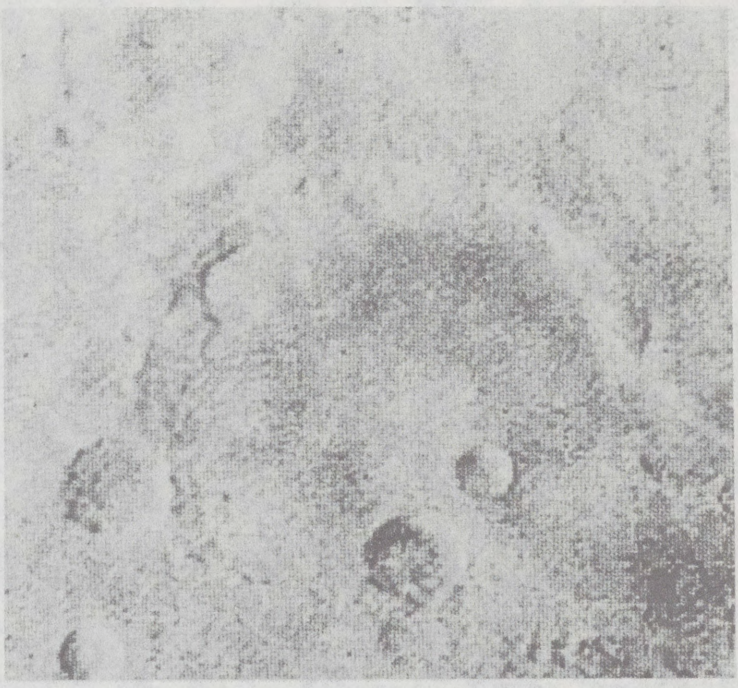

FIGURE 1.—In 1965 Mariner 4 sent back puzzling views of Mars.

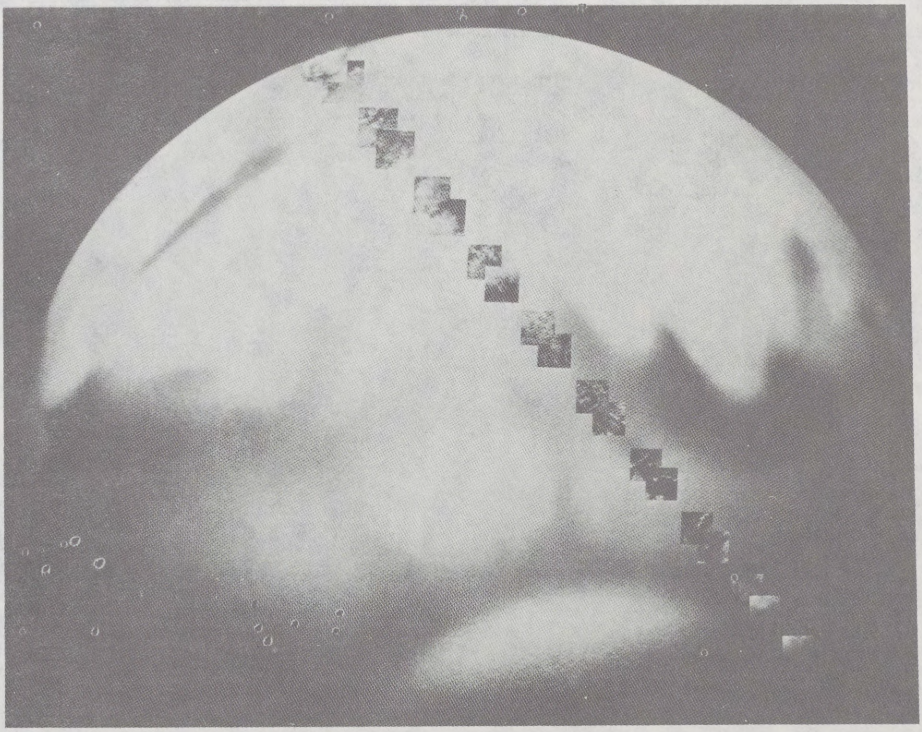

FIGURE 2.—Mariner 4 photographed 22 small parts of surface.


FIGURE 3.—Chaotic terrain was noted by Mariner 6 in 1969.

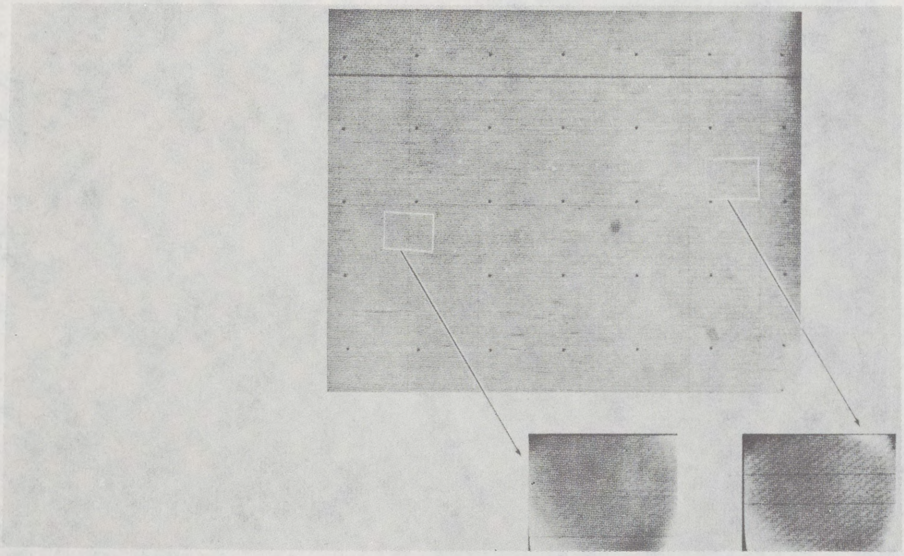

FIGURE 4.—Featureless terrain was photographed by Mariner 7 in 1969.

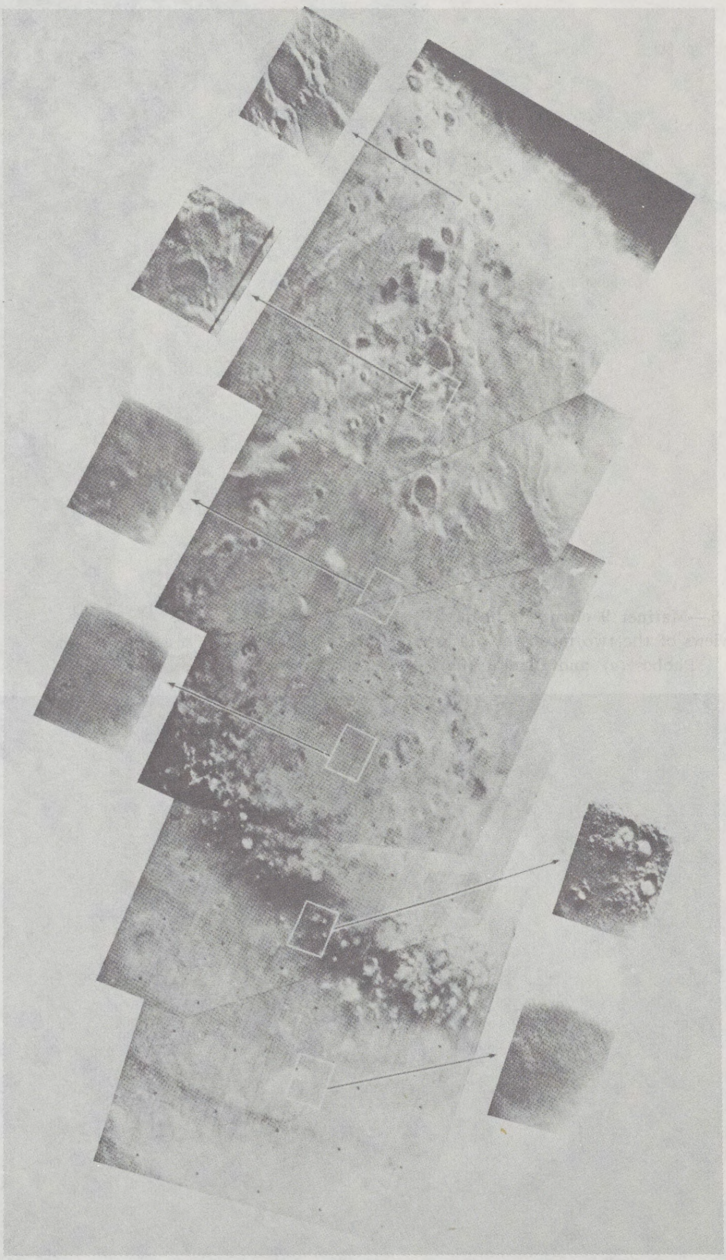

FIGURE 5.—These Mariner 7 photos showed the southern polar cap.


FIGURE 6.—Mariner 9 obtained the first closeup views of the two moons of Mars, Phobos (*a*) and Deimos (*b*).

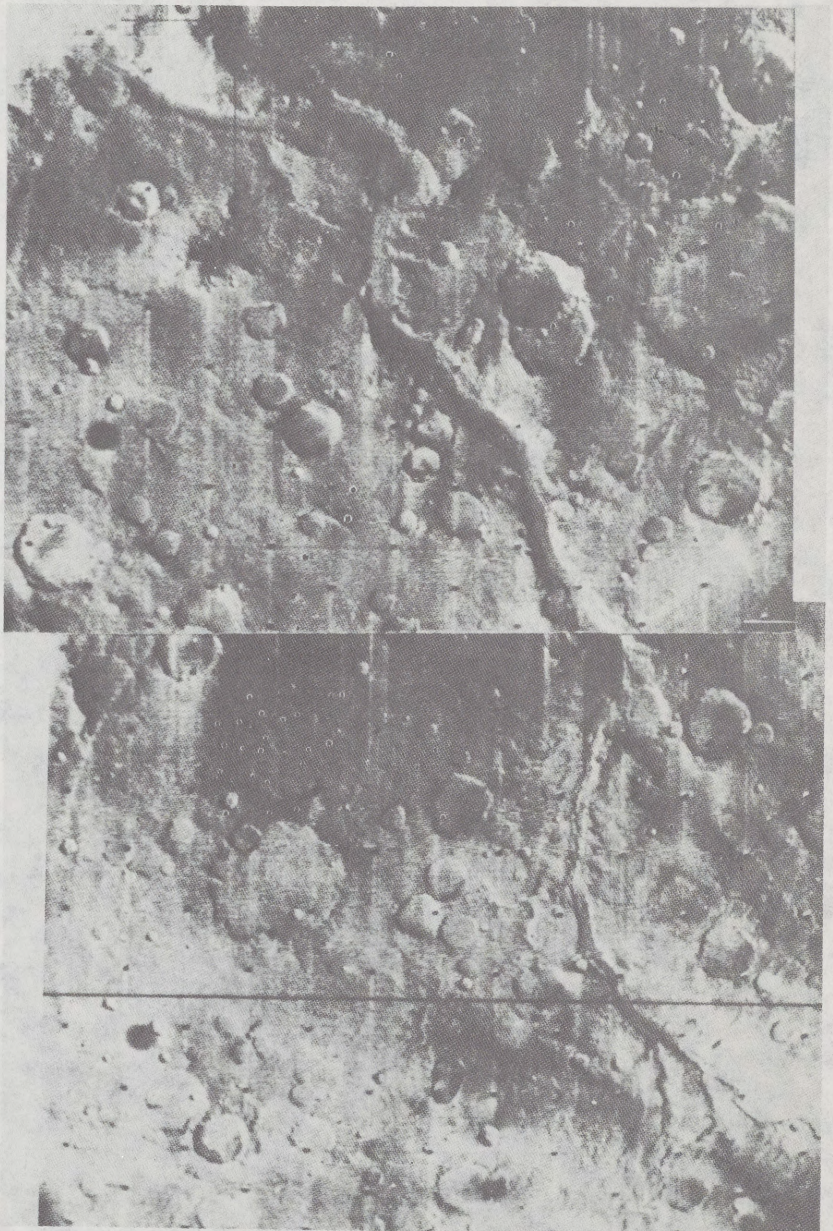

FIGURE 7.—In 1972 Mariner 9 revealed this Martian "river bed."

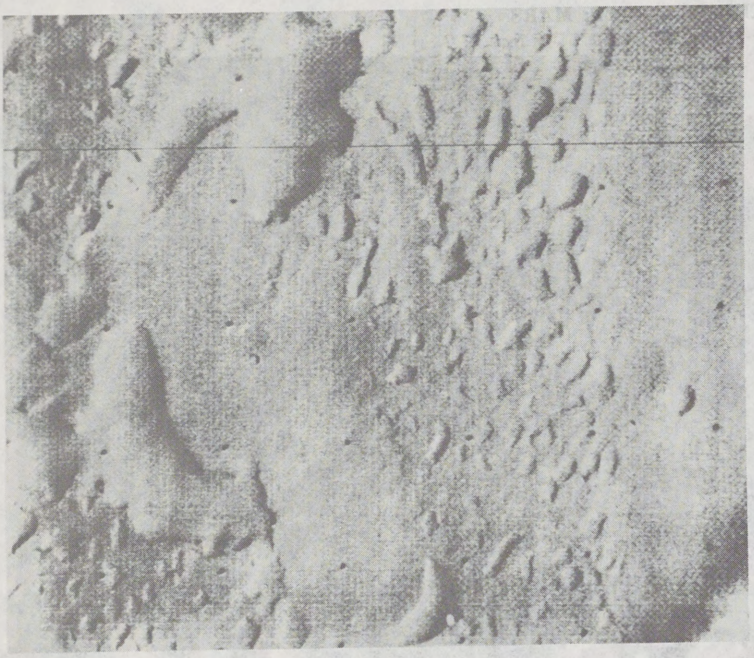

FIGURE 8.—Martian pits and slumps resemble some of the Earth.

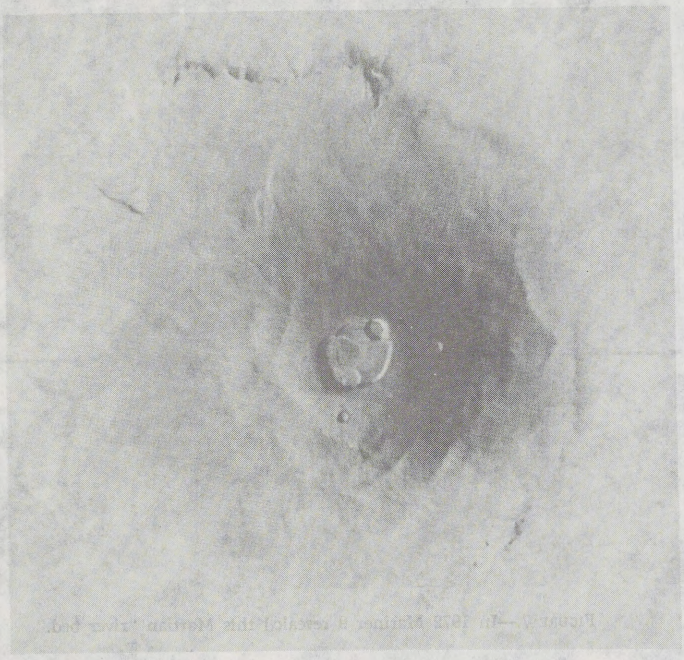

FIGURE 9.—Nix Olympica is a volcano pile twice as wide as Mauna Loa, the largest volcanic pile on Earth.

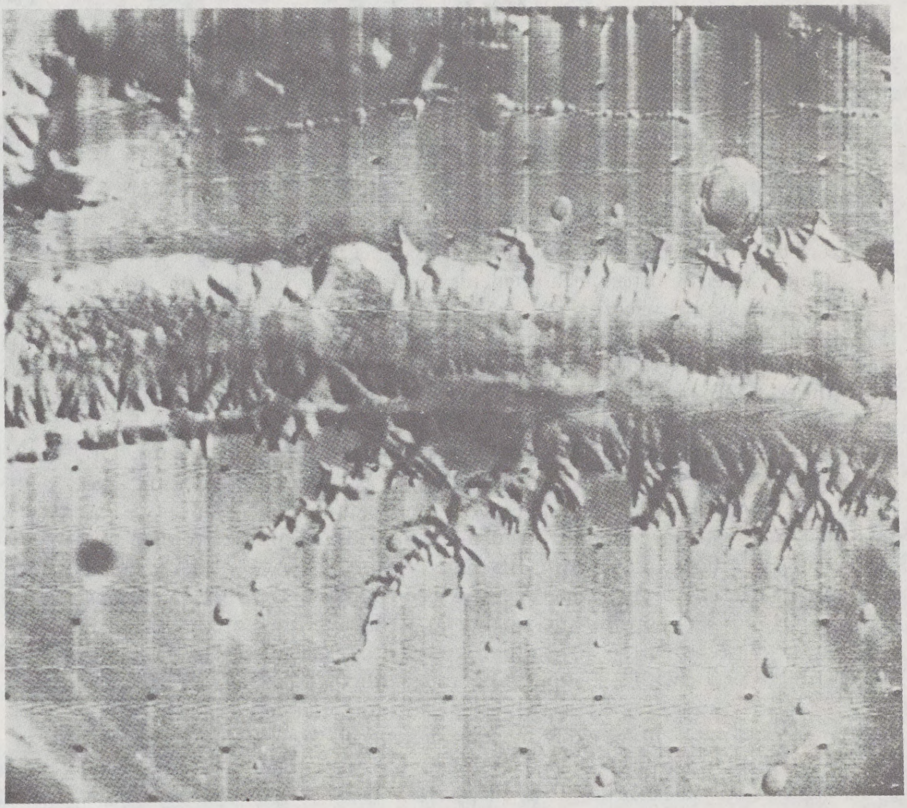

FIGURE 10.—Vast canyon lands were photographed by Mariner 9.

# Chapter 3
# The Viking Mission

## The Scientific Objectives

The goal of the NASA Viking program is to learn more about the planet Mars by direct measurements in its atmosphere and on its surface. Additional scientific data will be acquired from the Orbiter which will circle Mars in a synchronous orbit above the Lander after the latter has descended to the surface. On both the Orbiter and the Lander the primary emphasis will be on biological, chemical, and environmental aspects of Mars which are relevant to the existence of life.

The Viking scientific experiments are divided into four groups: Orbiter, entry, Lander, and radio (table 3). The Lander carries by far the most instruments. It is, in fact, a miniature automated laboratory. The entry experiments involve instruments mounted on a protective shell surrounding the Lander during its high-velocity entry into the Martian atmosphere. The entry experiments will obviously be brief but will give us a unique opportunity to analyze the characteristics of the Martian atmosphere from top to bottom. After the Lander is detached, the Orbiter plays mainly a supporting role, although it may, for selected periods of time, break its radio ties with the Lander and commence independent scientific experiments. The specific instruments associated with the four groups of experiments are listed in table 3. They will be described in more detail in chapter 5.

## The Flight Plan

The Viking flight plan consists of five major phases of operations: launch, cruise, orbital, entry, and landed. The operations which must be performed during these phases, in turn, dictate the functional capability of the various parts of the total space vehicle system (fig. 11). This system is described in more detail in chapter 4.

### Launch Phase

In the summer of 1975, the launch vehicle will first propel the spacecraft into a 165-kilometer (90-nautical-mile) orbit and, after a short coasting period, inject the spacecraft on a heliocentric trajectory which will intercept Mars nearly a year later (fig. 12).

TABLE 3.—*Viking Scientific Goals and Instruments*

| Experiment category | Scientific goals | Investigations (instruments) |
|---|---|---|
| Orbiter | Perform reconnaissance to verify or search for landing sites. | Visual imaging (2 television cameras). |
| | Monitor landing sites. | Atmospheric water mapping (infrared spectrometer). |
| | Obtain data from other areas of the planet. | Surface temperature mapping (infrared radiometer). |
| | Search for future landing sites. | |
| Entry | Determine composition and structural profile of the ionosphere and atmosphere. | Ions and electrons (retarding potential analyzer). |
| | | Neutral gases (mass spectrometer). |
| | | Pressure and temperature (pressure, acceleration, and temperature sensors). |
| Lander | Visually examine the landing site. | Visual imaging (2 cameras). |
| | Search for evidence of life. | Direct biology (3 metabolism and growth detectors). |
| | Search for and study organic and inorganic compounds. | Molecular analysis (gas chromatograph and mass spectrometer) and X-ray spectrometer. |
| | Determine atmospheric composition and its variations with time. | |
| | Determine temporal variations of pressure, temperature, and wind velocity. | Meteorology (pressure, temperature, and wind sensors). |
| | Determine seismological characteristics. | Seismology (3-axis seismometer). |
| | Determine magnetic properties of surface. | Magnetic properties (2 magnet arrays and magnifying mirror). |
| | Determine physical properties of surface. | Physical properties. |
| Radio | Conduct scientific investigations using the radio and radar systems. | Radioscience (Orbiter and Lander radio equipment). |

## Cruise Phase

During the cruise to Mars the Orbiter rocket engines will be used to make midcourse trajectory corrections based on radio-tracking data. Frequent assessments of the spacecraft's "health" will be obtained via the Orbiter's radio. Orbiter science instruments are to be calibrated and used to observe the planet as the spacecraft approaches Mars.

## Orbital Phase

Upon insertion of the spacecraft into orbit around Mars with the Orbiter rocket engines, preparations begin for the separation of the Lander capsule. During this time, the Orbiter surveys prospective landing sites chosen with the aid of Mariner 9 science data. After Lander capsule separation, the Orbiter functions as a radio relay and scientific instrument platform in support of the Lander capsule (fig. 13).

### Entry Phase

Retrorocket engines on the aeroshell decelerate the Lander capsule out of orbit (fig. 14). It descends to the surface sequentially braked by the aeroshell's aerodynamic drag, by a parachute, and finally by retro-rocket engines on the Lander.

### Landed Phase

Scientific explorations of the Martian surface can begin when the science instruments are activated and data can be transmitted back to Earth directly via the Lander radio or through a radio relay link with the Orbiter (fig. 15).

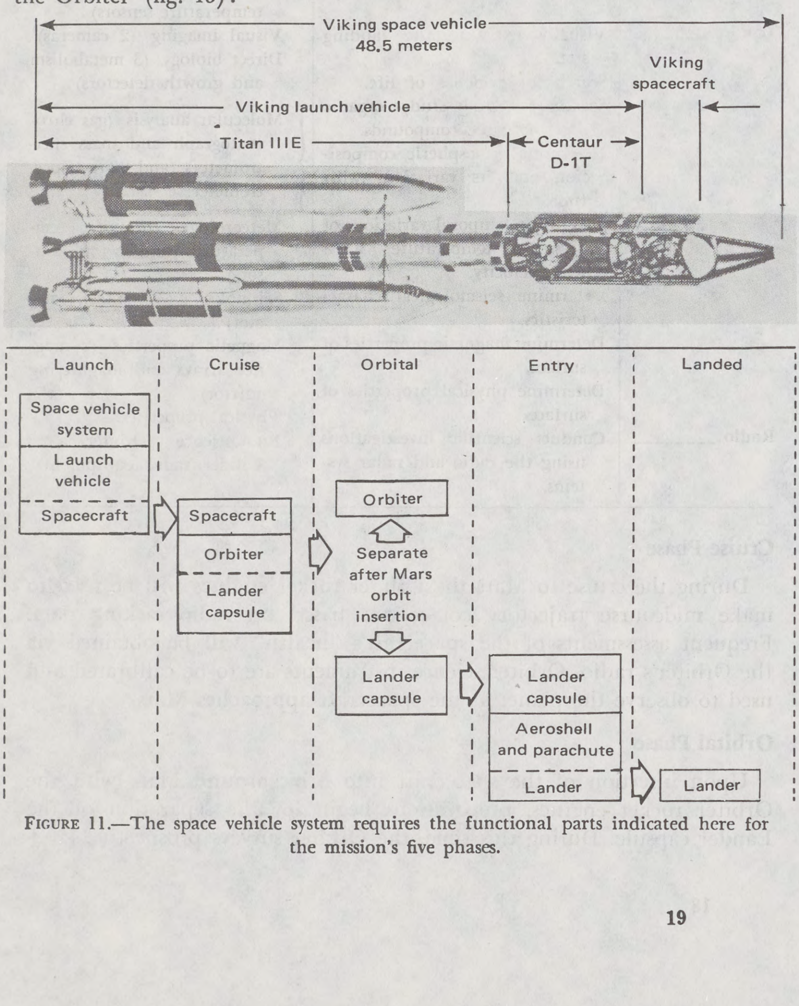


FIGURE 11.—The space vehicle system requires the functional parts indicated here for the mission's five phases.

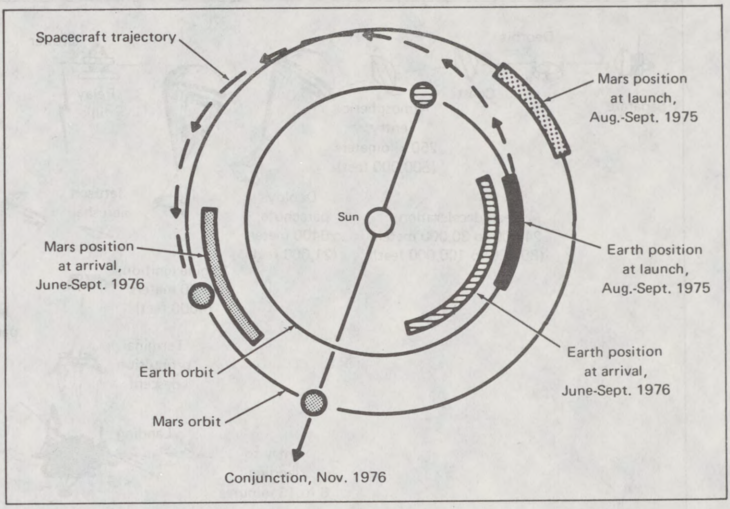


FIGURE 12.—Relative positions of Earth and Mars.

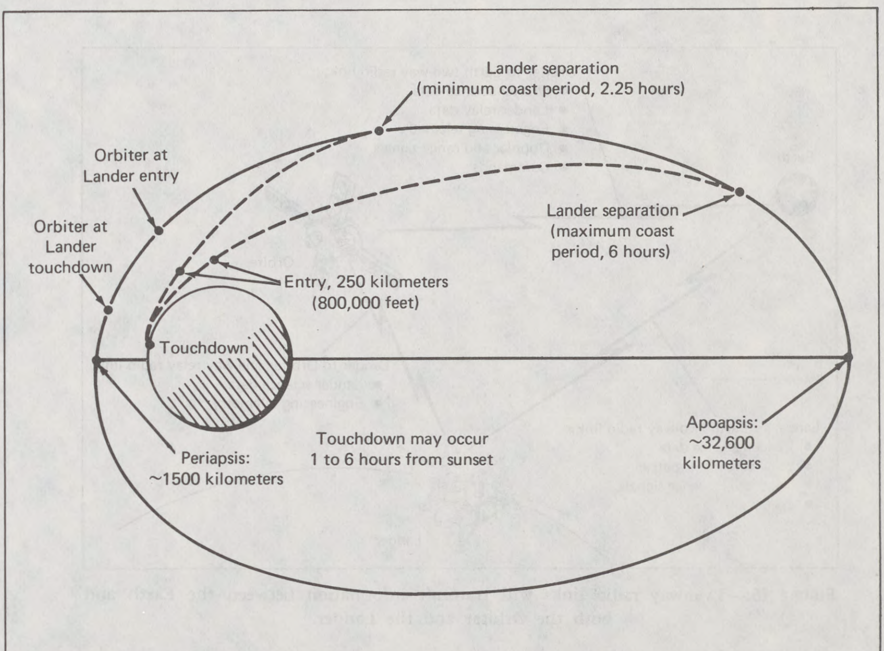


FIGURE 13.—The orbital phases of the flight.

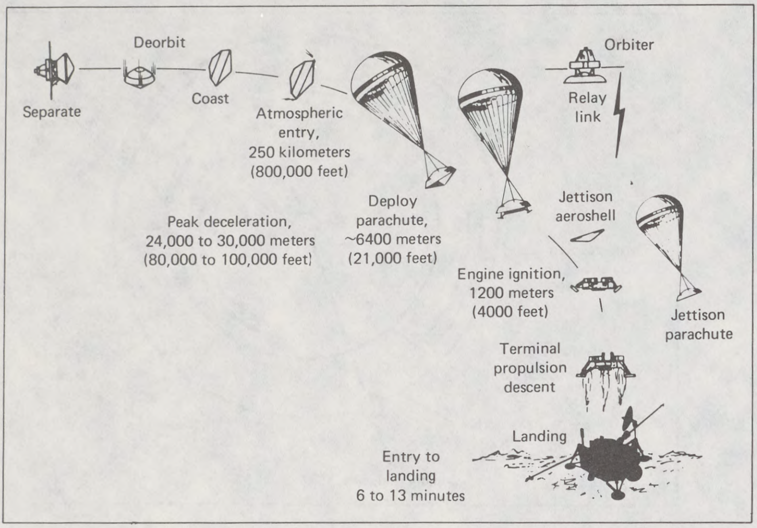


FIGURE 14.—How the Lander will reach the surface.

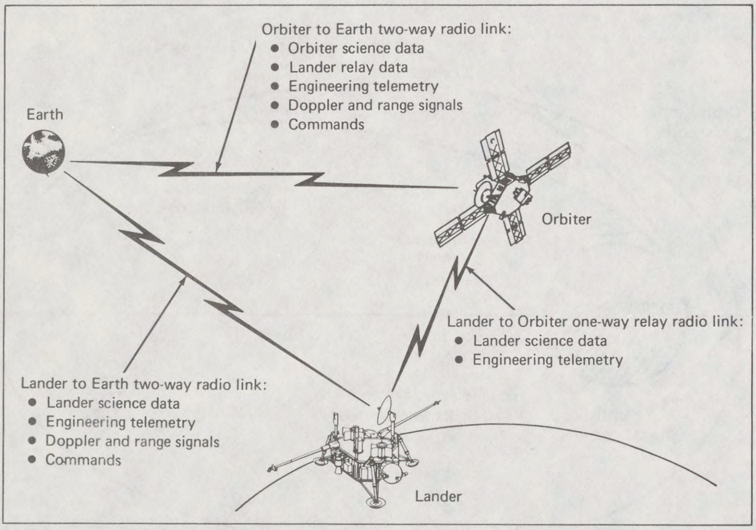


FIGURE 15.—Two-way radio links will transmit information between the Earth and both the Orbiter and the Lander.

# Chapter 4
# The Spacecraft and Launch Vehicle

The launch vehicle and spacecraft are the most novel parts of Viking. In contrast, the tracking stations, computers, and other equipment left behind on Earth get little fanfare. Yet a complete understanding of Viking demands knowledge of all pieces of interacting hardware. Viking actually comprises the six "systems" portrayed in figure 16, three of which never leave the ground. In this section, each of these systems will be described in more detail. None is independent of any other system; parts have to fit together mechanically, common radiofrequencies must be used, and a host of other "interfaces" have to be mutually compatible.

## The Orbiter

During the long flight to Mars, the Orbiter is the dominant part of the spacecraft. The Lander is maintained in a quiescent state during these 10 to 12 months. At this time the Orbiter provides spacecraft stabilization and maintains the only telemetry and command links with the Deep Space Network (DSN) back on Earth. The dormant Lander also receives life-sustaining electrical power from the Orbiter. Periodically, the Orbiter relays "housekeeping" data from the Lander to DSN antennas so that engineers can assess the Lander's mechanical well-being.

The Orbiter is much more than a nursemaid to the Lander. As the spacecraft approaches Mars, it is the Orbiter's engine which slows it down to make gravitational capture possible. After a satisfactory orbit has been attained, the Orbiter scans several preselected landing sites with its television cameras and other instruments to provide data to the flight operations team for a final choice. With this decision, the Lander is commanded to operational status and checked out for landing on the planet.

During the separation and entry of the Lander capsule, the Orbiter serves as the vital communication relay link with Earth. Even after a successful landing, the Orbiter communication relay link is the primary method of transmitting Lander data back to Earth. The Orbiter-Lander cooperation continues through the remainder of the mission, with the Orbiter storing data received from the Lander for retransmission to Earth when the planet's rotation carries the Lander to the side of Mars away from Earth. While in orbit administering to the Lander, the Or-



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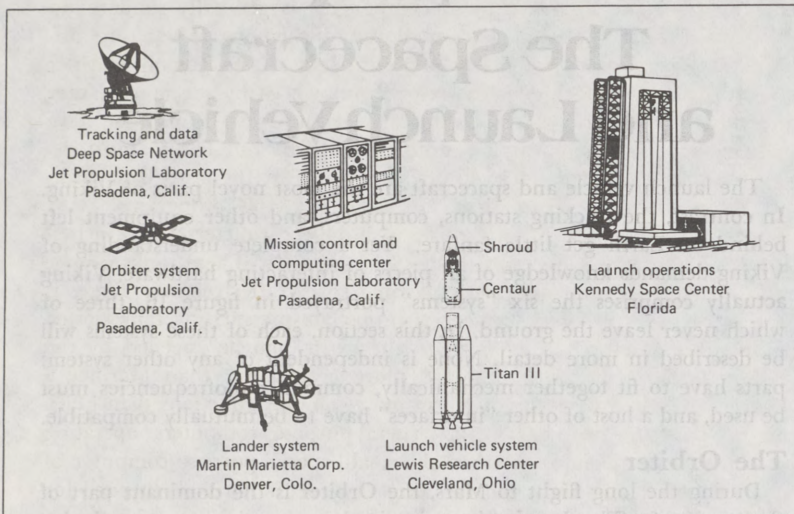



**FIGURE 16.—Viking systems.**

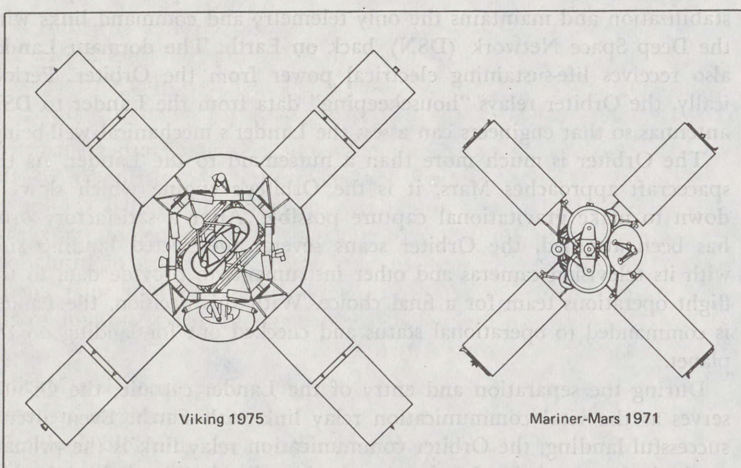



**FIGURE 17.—Comparison of Viking and Mariner spacecraft.**

biter scientific instruments also scan Mars for data for it to telemeter back to Earth.

The design of the Viking Orbiter is derived from the Mariner series of spacecraft. Originally, it had been hoped that a slightly scaled-up Mariner 9 spacecraft would suffice. The Orbiter resembles a Mariner

## THE SPACECRAFT AND LAUNCH VEHICLE

(fig. 17), for the arrangement of components is generally similar and Mariner design philosophy was employed throughout. There are differences, however, because the Viking Orbiter has tasks not on Mariner 9's list. The whole Orbiter structure was influenced by the much larger propellant tanks required by Viking. Not only does the Orbiter have to decelerate so that it can be captured by Mars but it also must decelerate the attached Lander capsule. Consequently, the propellant tanks are three times the size of those of Mariner 9—1600 kilograms (3137 pounds) of propellant in two tanks, each 140 centimeters (55.1 inches) long and 91 centimeters (35.8 inches) in diameter. These tanks can be seen in figure 18 just atop the polygonal spacecraft structure. There is a 64-centimeter (25.2-inch) spherical propellant-pressurizing tank nested within the structure. In addition to the extra "muscle" needed by the Viking Orbiter, designers provided more brainpower than Mariner 9 had. The Orbiter, having to perform more complex functions than Mariner 9, possesses two 4096-word, general-purpose computers operating in parallel or tandem rather than the small, special-purpose computer of its predecessor. The faster picture-taking rate of the Orbiter (needed for landing-site verification) required a 2.112 megabits per second tape recorder capable of storing 55 television frames, or over half a billion bits.

Like the Mariners, the shape of the Viking Orbiter structure is a rather flat octagonal prism. This structure has unequal sides 216 by 252 centimeters (85 by 99.2 inches) along the diagonals. Other Orbiter components are appendages attached to the basic octagonal structure.

Thermal control is critical for electronic and many other subsystem components. Windowblindlike louvers around the periphery of the octagon open and close automatically to permit individual cooling of 16 equipment bays built into it (fig. 19). The propellant tanks are shielded from the direct sunlight by a multilayer blanket of insulation. The propulsion module temperature is regulated by four solar energy reflectors mounted on the rim of the octagon to direct sunlight to the sides of the thermal blankets (fig. 18).

The X-shaped silhouette created by the four solar panels is a Mariner trademark. Each panel is hinged at its base to an outrigger structure and hinged again halfway out. Viking solar panels thus fold double for stowage inside the fairing of the launch vehicle instead of once like other Mariner designs. Together, the solar panels present just over 15 square meters (23,250 square inches) of solar cells to the Sun. At the distance of Mars, the cells generate 620 watts of electrical power. When this amount of power is insufficient to handle peak loads, or when the Orbiter turns away from the Sun—as it must do for the braking maneuver at Mars—supplementary power is provided by two 30-ampere-hour nickel-cadmium storage batteries.

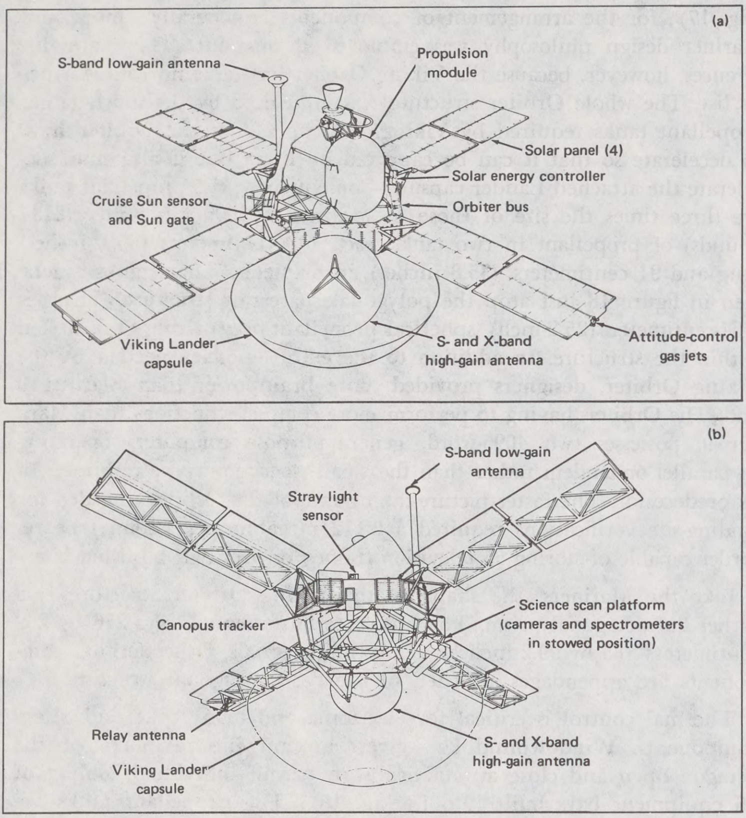



FIGURE 18.—Orbiter (with Lander capsule attached). (*a*) Top view. (*b*) Bottom view.

Information is the lifeblood of any unmanned space mission. The object is to radio as much scientific information as possible from Orbiter and Lander to Earth. The Orbiter's telecommunication subsystem is depicted in figure 20. The mainstay of this subsystem is a parabolic high-gain antenna 147 centimeters (57.9 inches) in diameter, motor-driven about two axes. The two degrees of freedom mean that the narrow cone of radio energy emitted by the antenna can be directed right at Earth. Communication at high bit rates at the distance of Mars would be impossible unless the Orbiter's transmitter power were concentrated in this way.

Communication between Orbiter and the DSN must be two-way because terrestrial controllers have to send commands to the spacecraft to carry out certain functions, such as to turn on the cameras or to separate the Lander. In fact, spacecraft designers try to insure that it is *always* possible to send commands to the spacecraft and to receive lim-

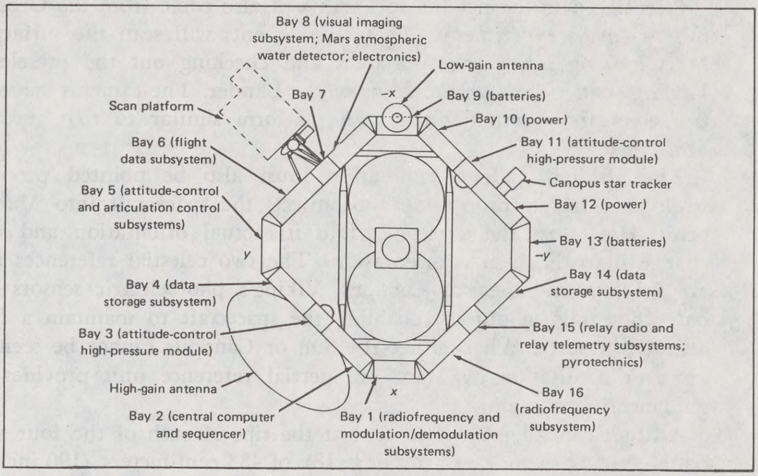



FIGURE 19.—Orbiter electronic bays.

ited telemetry regardless of whether its high-gain antenna is pointing at Earth. (It very likely will not be during some of the Orbiter's maneuvers.) Therefore, on the sunlit side of the spacecraft (fig. 18) is a rodlike low-gain antenna with a small cone at its tip. Not as directionally sensitive, it allows limited two-way communications with Earth over greater than hemispherical coverage.

The last of the Orbiter's complement of antennas is mounted on the end of one of the solar panels. This antenna is solely for communication traffic between Orbiter and Lander on the surface.

The Orbiter's role as a communication relay can be seen in figure 21, which depicts the direct communication link possible between the Lander and DSN, and the potential links that may be established between Orbiter A and Lander B and Orbiter B and Lander A.

The Orbiter's transmitter power is about 20 watts. Most terrestrial commercial radio stations broadcast hundreds of times this amount of power. How can so weak a signal be detected after traveling hundreds of millions of miles? The ultrasensitive 64-meter (210-foot) diameter antennas of the DSN help make interplanetary communication possible. They have already recorded the 10-watt signals of the interplanetary Pioneer spacecraft at well over 200 million miles. At these tremendous distances the rate of information flow is very small. Most of the time, the so-called "bit rate" will be only 8⅓ bits per second from the Viking Orbiter, which amounts to about one scientific or housekeeping measurement per second. However, when the Orbiter's high-gain antenna is directed right at a 64-meter DSN antenna, it is planned to send data at 4000 bits per second.

Scientific data telemetered to Earth will also come from the Orbiter's own scientific experiments. These instruments will scan the surface of Mars looking for warm, wet areas and checking out the preselected landing spots prior to the descent of the Lander. The cameras and spectrometers are mounted on a scan platform similar to that used on Mariner 9.

The Orbiter-Lander combination must also be pointed precisely, while the Orbiter propulsion unit injects the spacecraft into Martian orbit. How does the spacecraft find its actual orientation and then change it to the desired orientation? The two celestial references used are the Sun and the star Canopus. Viking's photoelectric sensors lock onto these known objects, enabling the spacecraft to maintain a fixed attitude in space. When either the Sun or Canopus cannot be seen because of occultation by Mars, an inertial reference unit provides the guidance information.

Attitude-control jets are located at the tips of each of the four solar panels, giving them lever arms (fig. 18) of 483 centimeters (190 inches). Nitrogen gas for the jets is stored in two 30-centimeter (12-inch) bottles. The Orbiter's attitude-control subsystem automatically commands the opening and closing of the jet valves to release bursts of cold nitrogen gas which are used to nudge the spacecraft into the desired orientation.

The Orbiter as a whole weighs 2324 kilograms (5125 pounds) at launch, compared with Mariner 9 which weighed in at 978 kilograms

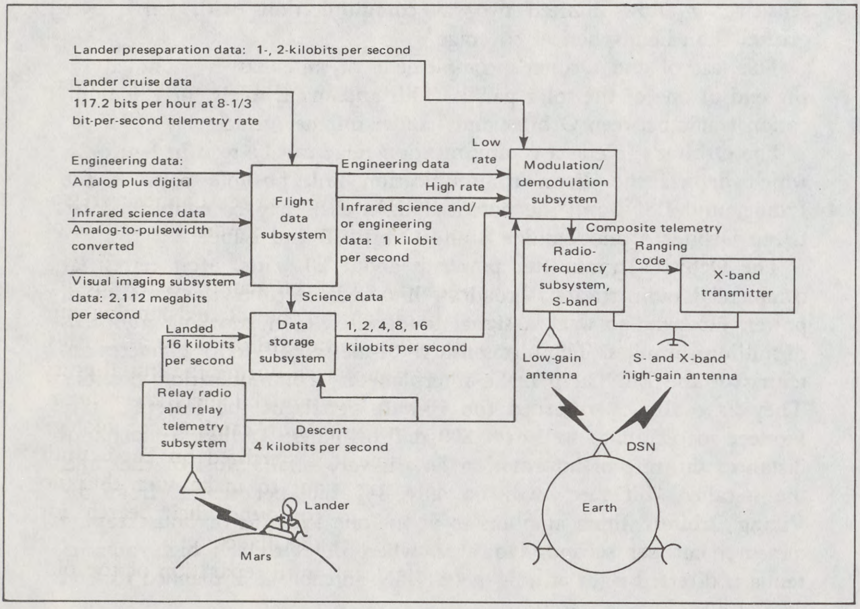



FIGURE 20.—Orbiter telecommunication subsystem.

(2150 pounds). Much of the additional weight is propellant, reflecting the bigger braking task at Mars. But the Viking Orbiter also has to provide for storage of data from the Lander, extra communications tasks, and the long job of caring for the inactive Lander during flight

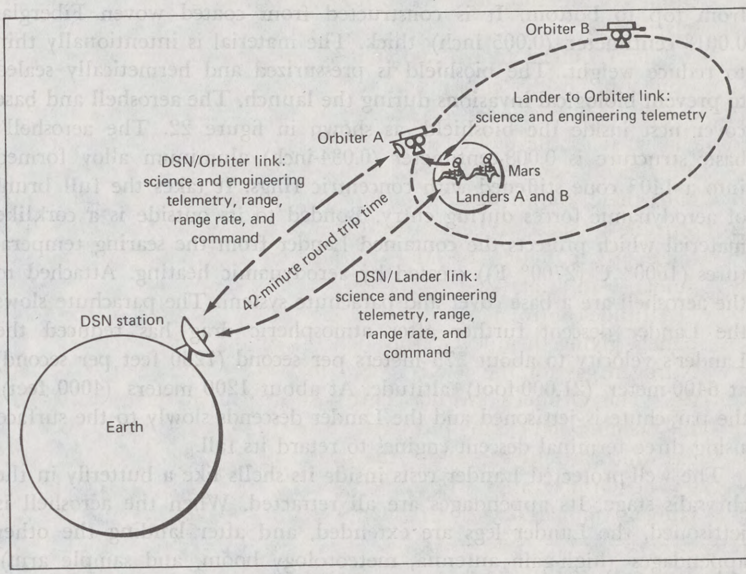



FIGURE 21.—Communication links.

from Earth. All these functions require more equipment, more power, and, naturally, more weight.

## The Lander

The focus of activity changes from the Orbiter to the Lander as retro-rockets slow the Lander down and it begins to fall toward the surface of Mars.

The first major task of the recently awakened Lander is its safe descent through the thin Martian atmosphere to the selected landing site. The Martian atmosphere, though only a hundredth as dense as Earth's, requires that the Lander be thermally protected during the initial entry phase when it is still traveling sixteen thousand kilometers per hour. A second complicating factor is the necessity for "canning" or biologically isolating the Lander from the time it is sterilized on Earth until it is outside Earth's biosphere. Scientists want to make sure that no terrestrial life forms are carried along to confound their search for native life forms on Mars or to contaminate the planet.

The Lander is actually in a double "can" until separation of the bioshield cap outside Earth's biosphere. Thus sealed and pressurized, the Lander capsule is protected against biological invasion from the unsterilized Orbiter (fig. 22). The lens-shaped bioshield is 365.7 centimeters (144 inches) in diameter and 193.8 centimeters (76.3 inches) from top to bottom. It is constructed from coated woven Fiberglas 0.0013 centimeter (0.005 inch) thick. The material is intentionally thin to reduce weight. The bioshield is pressurized and hermetically sealed to prevent biological invasions during the launch. The aeroshell and base cover nest inside the bioshield, as shown in figure 22. The aeroshell's basic structure is 0.008-centimeter (0.034-inch) aluminum alloy formed into a 140° cone stiffened with concentric rings. It takes the full brunt of aerodynamic forces during entry. Bonded to its outside is a corklike material which protects the contained Lander from the searing temperatures (1500° C (2700° F)) created by aerodynamic heating. Attached to the aeroshell are a base cover and parachute system. The parachute slows the Lander descent further after atmospheric drag has reduced the Lander's velocity to about 375 meters per second (1230 feet per second) at 6400-meter (21,000-foot) altitude. At about 1200 meters (4000 feet) the parachute is jettisoned and the Lander descends slowly to the surface using three terminal descent engines to retard its fall.

The well-protected Lander rests inside its shells like a butterfly in the chrysalis stage. Its appendages are all retracted. When the aeroshell is jettisoned, the Lander legs are extended, and after landing the other appendages (high-gain antenna, meteorology boom, and sample arm) are extended.

During the long flight from Earth, an umbilical connection through the base cover provides power to the Lander. Housekeeping data also flow through this connection. Once small explosive charges break the connections, the Lander plus aeroshell are separated from the Orbiter.

The aeroshell is not merely a passive aerodynamic shield. The two spheres shown in figure 22 contain hydrazine monopropellant to feed four small rocket engines located around the edge of the aeroshell. These rockets slow down the Lander and allow it to be pulled toward Mars by gravity. They also provide pitch-and-yaw control to orient the aeroshell in the proper attitude for entering the atmosphere. Aeroshell roll control is provided by eight similar rockets colocated with the pitch-and-yaw engines. As the Lander capsule descends (fig. 14), a solid-state pulse radar transmitting at 1000 megahertz performs as an altimeter.

At about 6400 meters (21,000 feet) above the surface, the radar signals a mortar housed in the base cover to fire and deploy a lightweight polyester parachute. Its diameter is 16.2 meters (53 feet), and extralong suspension lines separate it from the Lander by almost 30 meters (100 feet).

At about 1200 meters (4000 feet) the parachute is also jettisoned and the terminal descent engines are fired. A continuous-wave Doppler

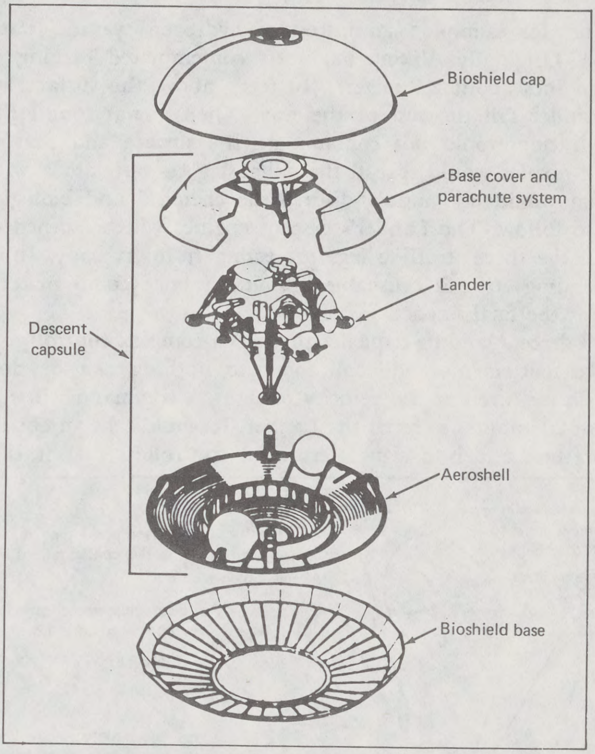



FIGURE 22.—Exploded view of encapsulated Lander capsule.

radar, which directs four canted beams toward the Martian surface and operates at 13,000 megahertz, measures the Lander's horizontal velocities to within 1 meter per second. Another radar measures its altitude. These radars provide altitude and velocity data which control the firing of three retrorockets to finally ease the Lander down to the surface. (The parachute alone cannot do the job in the rarefied Martian atmosphere.) Like the aeroshell's much smaller rockets, those on the bottom of the Lander utilize hydrazine monopropellant (fig. 23). Spaced equidistant around the Lander's frame, they control the pitch-and-yaw attitude of the Lander as well as braking its descent. Roll control is provided by four other engines located on the hydrazine tanks.

The difficult problem of "site alteration" was solved by an unusual array of 18 nozzles on each of the Lander engines. When a spacecraft eases down to a surface with its descent engines firing, the ground underneath may be scoured over a wide area by the rocket blast. Furthermore, the soil is heated—perhaps killing any indigenous life forms—and extraneous chemicals are added to the soil by the burning fuel. Ordinary hydrazine, for example, can introduce hydrogen cyanide, water, and ammonia. Originally, Viking engineers contemplated turning off the descent engines about 2.5 meters (10 feet) above the surface and letting the Lander fall the rest of the way. Then it was found that ultrapure hydrazine would not contaminate the surface and that an array of small nozzles would spread the exhaust gases out into a wide, gentle fan that would not unduly disturb the chemical and biological experiments to follow. The Lander's descent engines will be turned off by switches in the three strutlike legs projecting from its body. Inside each main landing strut is crushable aluminum honeycomb material which cushions the final impact.

The deorbit-descent-landing sequence presents a complex control problem. To make matters more difficult, next to nothing can be done from Earth because, even at the velocity of light, a command will take on the order of 20 minutes to reach the Lander. It would take an equally long time for the Lander to signal terrestrial controllers that it is in

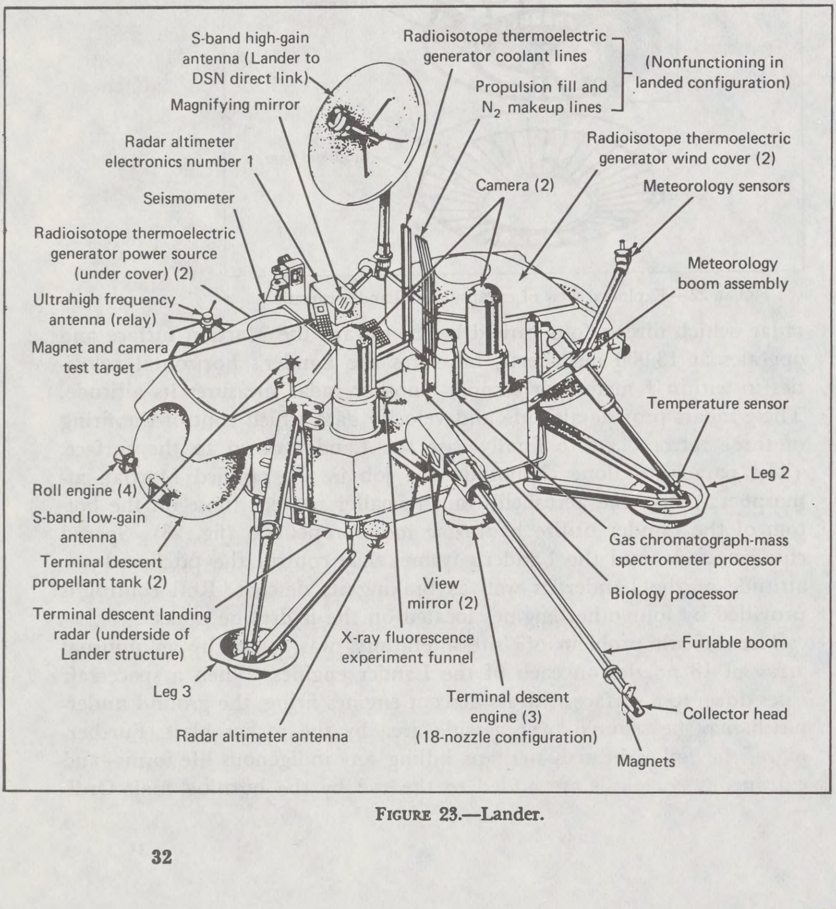



FIGURE 23.—Lander.

trouble. The only way to control the deorbit-descent-landing sequence is by automation. The Lander is on its own until touchdown. In fact, it has in its computer memory stored instructions which could control the first 22 days of experimentation without contact from Earth. The Lander is, by today's standards, a fairly intelligent robot.

Once on the surface with all its appendages extended, the Lander somewhat resembles the unmanned Surveyor spacecraft NASA landed on the Moon prior to the manned Apollo flights. The Viking Lander owes a considerable debt to Surveyor technology, but its designers have had to wrestle with three new problems: The technology of sterilization, the requirement for a much higher degree of autonomy because of signal time delay from Earth, and the yearlong dormant state.

NASA has always met the internationally established planetary quarantine requirement for payloads headed for Mars and other planets. The internationally accepted criterion for planetary quarantine is that there be only a 1-in-1000 chance (0.001 probability) of contamination by terrestrial organisms during the 50-year period beginning January 1, 1969. Because there may be many spacecraft exploring Mars within that period, the sterilization specifications for each Viking launch are more stringent: less than 1 chance in 10,000 (0.0001 probability). To achieve this low probability, the entire Viking Lander capsule sealed in its bioshield is baked in an oven for several days. The coldest part of the Lander must register about 112° C for sufficient time to insure that enough of the micro-organisms have been killed to meet these very small probabilities of contaminating Mars.

The heat of sterilization not only kills micro-organisms but also risks injury to many Lander components. Even though many pieces of Lander hardware were borrowed from space programs where they had proven themselves, the rigors of heat sterilization caused some failures during the Viking test program that necessitated a redesign of these components or selection of alternate components impervious to the heat levels.

The "brain" behind the critical descent maneuvers is called the guidance control and sequencing computer (GCSC). The sequencing part of its name refers to automation of the actions that follow a successful landing. The instructions (22 days' worth) are stored in the GCSC. They may be updated and modified by Earth once communication has been established. Even under the best conditions, however, the Lander will be out of sight about 12 hours each day as the rotation of Mars carries it around the far side of Mars where terrestrial antennas cannot communicate with it.

The GCSC was one of the greatest technical challenges of the Viking Lander. It consists of two general-purpose computers with plated-wire memories, each having 18,000 words of storage. One computer will be operational while the other is in reserve. The operating computer sends a periodic "I'm OK" signal back to Earth. If it is not OK, the Lander automatically goes into standby mode and waits for the reserve computer to take over and begin to reactivate the Lander.

With all its appendages deployed (fig. 23), the Lander structure is hard to discern. Basically, it is a hexagonal box 1.494 meters (58.8 inches) wide and 0.457 meter (18 inches) thick. The major structural materials of the box are aluminum and titanium alloys. Landing legs, antennas, and instrument sensors project from it.

Once safely on the surface, two vital functions of the Lander are the supply of electrical power and the maintenance of communication with the Earth—directly or by Orbiter relay. Let us look at the power problem first.

Sunlight is one-half as strong at the orbit of Mars as in Earth's orbit, and it is nonexistent during the frigid Martian night. The radioisotope thermoelectric generator (RTG) was the logical choice for the Viking Lander because it is a long-lived source of both electricity and heat. The two Viking RTG's (fig. 24) convert the heat from decaying plutonium-238 into 70 watts of electric power with thermoelectric elements. The "waste" or unconverted heat is conveyed via a thermal switch to a

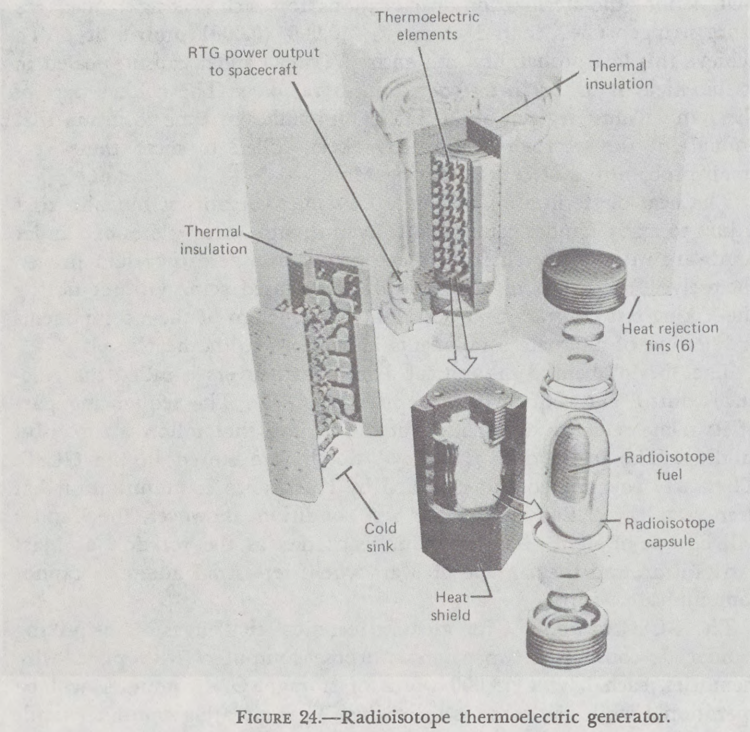
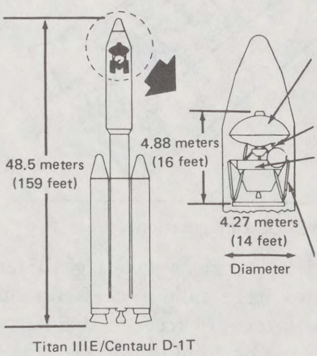



FIGURE 24.—Radioisotope thermoelectric generator.

temperature-controlled instrument compartment. A windscreen (shown covering the RTG's in fig. 23) insures that waste heat from the RTG's will be available for the instruments and not dissipated uselessly to the environment. Heat on Mars is a valuable commodity for the Lander because at night the atmospheric temperature may drop as low as −120° C (−184° F).

Data from the Lander's scientific instruments and its internal housekeeping measurements can follow either of two routes back to Earth. The highest data rate is via an Orbiter. Data stored on the Lander tape recorder can be transmitted at high speed (16,000 bits per second) along an ultrahigh frequency link to an Orbiter when it passes overhead. The Orbiter records this information on its tape recorder and retransmits it over its S-band radio link to terrestrial DSN antennas.

The second electronic pathway, completely redundant to the relay link, is the Lander's direct S-band link with Earth via its computer-steered high-gain antenna located on top of the Lander. With this 0.762-meter (30-inch) parabolic dish, the Lander can transmit directly to a 64-meter (210-foot) DSN antenna at up to 500 bits per second. If the Viking Orbiters should fail, all Lander data would take this alternate route.




| | Kilograms | Pounds |
|---|---|---|
| Lander capsule | 1118 | 2464 |
| (Usable Lander propellant) | (139) | (307) |
| Lander capsule adaptor | 16 | 35 |
| Orbiter | 2325 | 5125 |
| (Usable Orbiter propellant) | (1406) | (3097) |
| Spacecraft | 3458 | 7624 |
| Spacecraft adaptor | 61 | 135 |
| Total Viking spacecraft system | 3519 | 7759 |

FIGURE 25.—Viking spacecraft allocated weights.

## Four Tons to Mars

The weight of the Viking Orbiter and Lander plus propellants and adaptors is about 3600 kilograms (4 tons) (fig. 25). Mariner 9 weighed only 978 kilograms (2150 pounds), less than one-third the Viking payload. The Atlas-Centaur launch vehicle used for propelling Mariner 9 to Mars is much too small for Viking. On the other hand, the NASA Saturn V launch vehicle built for the Apollo program is too big by a factor of 2. The most economical approach to furnishing the requirements of Viking is to use the Titan III rocket with a Centaur upper stage, a combination that can place about 3600 kilograms (8000 pounds) in the vicinity of Mars.

The Titan III/Centaur combination (fig. 26) is a relatively new launch vehicle, although each part has been used on other missions. Standing 48.5 meters (159 feet) high on the launch pad, the Titan III/Centaur does not have the streamlined, monolithic look of the

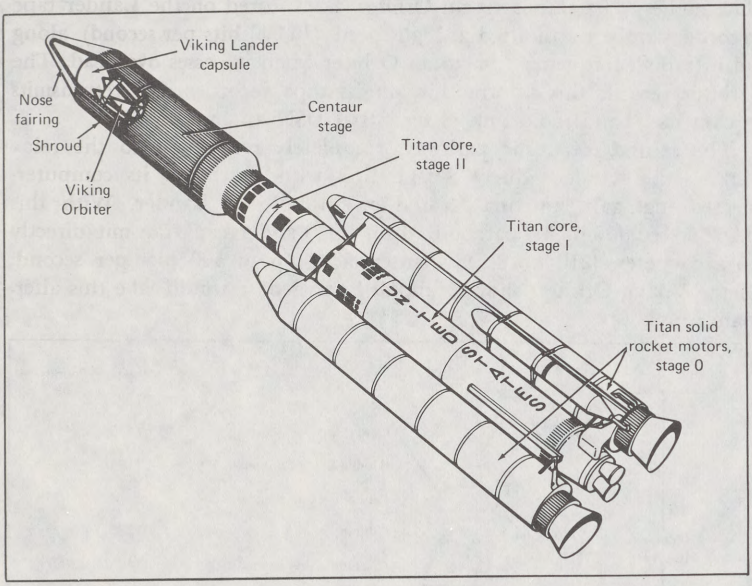



FIGURE 26.—Viking space vehicle configuration.

Saturn V. The Titan III is assembled by taking a two-stage Titan II rocket for a core and strapping on two large solid rockets for added thrust. The solid rockets are each 3.05 meters (10 feet) in diameter and 25.9 meters (85 feet) long. Their fuel is powdered aluminum in a rubber matrix. This is burned with ammonium perchlorate to generate about 4,893,230 newtons (1,100,000 pounds) of thrust per rocket at liftoff. The solid rockets (called the zeroth stage) burn out after about 2 minutes and are jettisoned over the Atlantic. The Titan core, consisting of a two-stage liquid rocket 3.05 meters (10 feet) in diameter, does not ignite until just before the solids burn out. Both liquid stages burn a blend of hydrazine and unsymmetrical dimethylhydrazine fuel with nitrogen tetroxide oxidizer. The first stage burns for about 2½ minutes; the second stage for about 3½ minutes. Then the Centaur upper stage takes over.

THE SPACECRAFT AND LAUNCH VEHICLE

The Centaur is one of NASA's high-performance upper stages, developed primarily for lunar and interplanetary work. Its two engines generate a total of about 133,452 newtons (30,000 pounds) of thrust by burning hydrogen with oxygen. A feature of Centaur is that its engines can be restarted in space, which is essential in the Viking mission. After the Titan second stage is jettisoned, the Centaur first propels the Viking into a 165-kilometer (90-nautical-mile-high) parking orbit around Earth, where it waits between 6 and 30 minutes for the proper moment to depart for Mars. When this arrives, the Centaur is restarted and injects Viking into a heliocentric trajectory to intercept Mars nearly a year later. Centaur's final act is to separate itself from Viking, and, by expelling its residual propellants, deflect itself away from the Viking trajectory to minimize the chance that it will impact on Mars.

## The Terrestrial Part of Viking

As the Titan III/Centaur lifts Viking off the launchpad, all terrestrial ties are broken except those using electromagnetic waves. By terrestrial standards, Viking's radio voice is weak (20 watts). Once it leaves its parking orbit for Mars it would be invisible and effectively lost if its radio transmissions could not be heard. To pick up the weak signals the Earth-bound part of Viking must be correspondingly large. And if Viking is to be followed continuously as Earth rotates, the network of listening stations must be worldwide.

Viking's terrestrial systems are three in number: (1) the launch and flight operations system, (2) the tracking and data system, and (3) the mission control and computing center system. The facilities that make up these systems—Kennedy Space Center, DSN, and JPL's Space Flight Operations Facility (SFOF)—are multipurpose. All NASA's interplanetary and lunar missions utilize them.

Viking will be launched at the Kennedy Space Center from Launch Complex 41. This is part of NASA's Integrate-Transfer-Launch Facility at the Cape (fig. 27). The vertical integration building will be used to assemble the liquid rocket Titan core and the Centaur upper stage. The mated liquid stages will then be transported by rail to the solid motor assembly building where the two big solid rocket stages will be attached. The entire launch vehicle will then move by rail to the launchpad. Rail-mounted vans containing necessary checkout equipment will follow. At the launchpad, the spacecraft will be mated to the Centaur and enclosed in the Centaur standard shroud. Following exhaustive tests and checkout, the spacecraft and launch vehicle will be ready to go.

At Cape Canaveral and on islands, ships, and planes along the Air Force's Eastern Test Range (ETR), radars and optical tracking instruments will follow the launch vehicle as it rises from the pad and heads downrange toward Ascension Island in the South Atlantic. ETR will continue to receive telemetry data from the Viking spacecraft until it separates from the Centaur. When the spacecraft is separated from the Centaur its radio signal will be received by the DSN stations. From that moment on, the DSN's tasks are to track Viking, receive its telemetry, and send commands to it.

The DSN is a worldwide tracking and data acquisition facility consisting of six 26-meter (85-foot) paraboloidal antennas and three 64-meter (210-foot) dishes (fig. 28). The 64-meter dishes are critical to Viking, for only they are sensitive enough to receive Viking data from Mars at sufficiently high rates. These paraboloids are spaced around Earth so that one will always have Mars in view. Their locations are in Goldstone, Calif.; Madrid, Spain; and Tidbinbilla, Australia (fig. 29). Amplifiers at the foci of the antennas are cryogenically cooled to reduce thermally induced noise. Each site was selected on the basis of lack of manmade radio noise. Only with antennas of such size, carefully designed and sited, can the faint radio signals of the Viking transmitters be heard over distances exceeding 200 million miles.

The DSN stations are tied together by a global communications network called the NASA communications network, which uses cables, microwave relays, and satellites to feed signals to the SFOF at Pasadena, Calif. (fig. 30). An impressive, four-level structure, the SFOF is a multimission terminal, data-processing facility, computer center, and control center from which mission operations are controlled. A portion of the SFOF will be turned over to the Viking program. Another part of the Viking flight team, science analysis and evaluation, will be located in an adjacent building. In total, the flight team consists of about 700 members.

FIGURE 27.—Integrate-Transfer-Launch Facility.

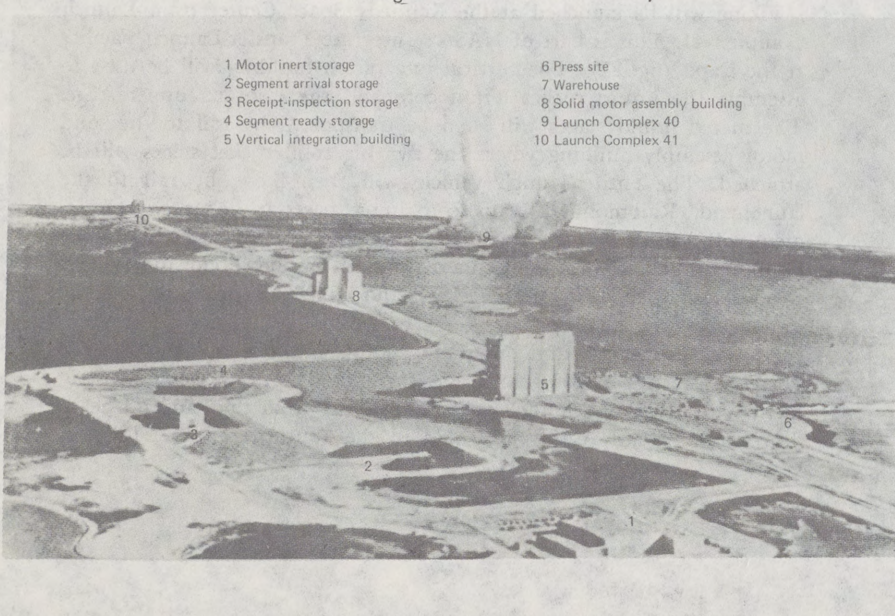
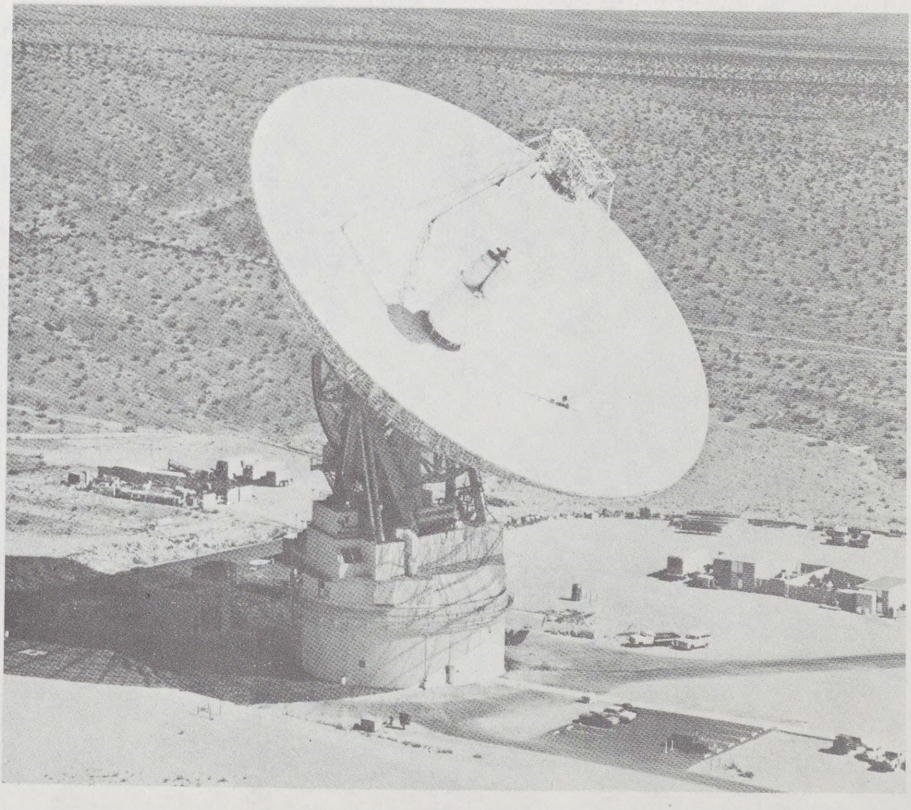


**Figure 28.—DSN antennas.** (*a*) 26-meter antenna. (*b*) 64-meter antenna.

(*a*)

(*b*)



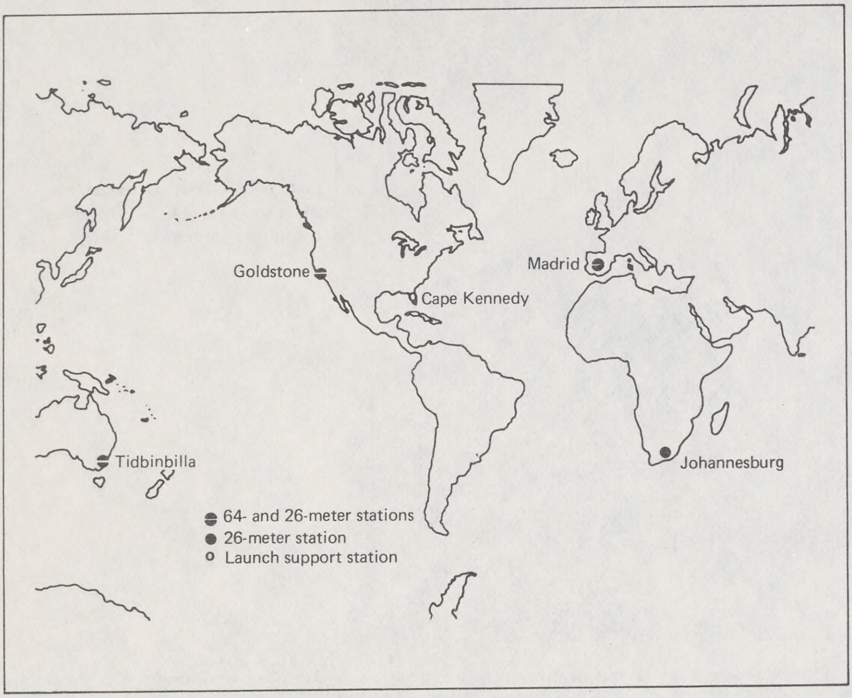



FIGURE 29.—Location of DSN stations.

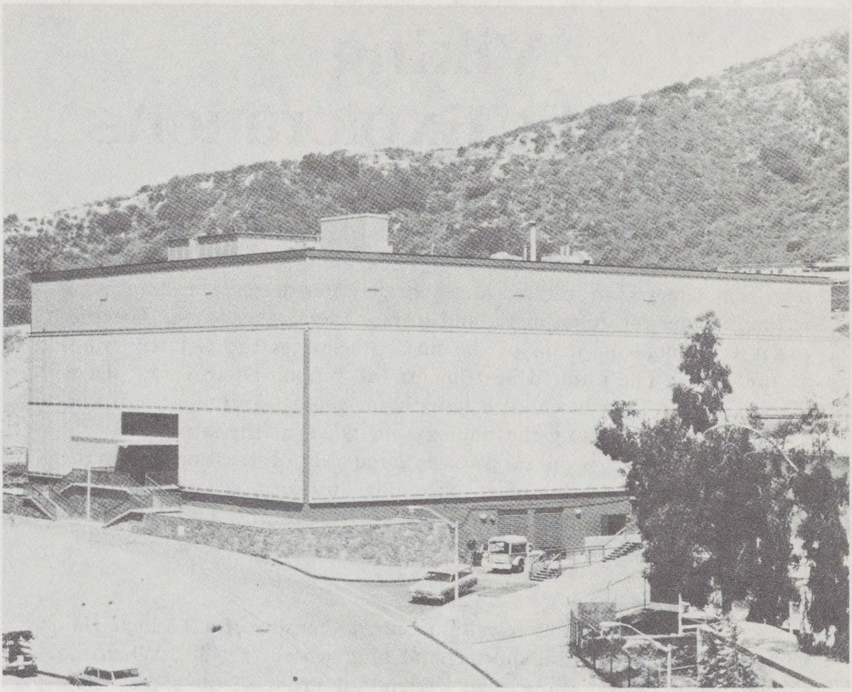


FIGURE 30.—Space Flight Operations Facility.

# Chapter 5
# Viking Scientific Explorations

## The View From Orbit

Three types of optical instruments view the surface of Mars from the Orbiter's scan platform (fig. 31). These are a pair of high-resolution television cameras, an infrared atmospheric water detector, and an infrared radiometer for atmospheric and surface thermal mapping. Together the instruments scan strips of the surface below as the Orbiter swings around Mars. The infrared instruments will pinpoint warm, wet places. These sites can then be checked visually for geological interest and suitability for landing, using the photographs taken at the same time.

Once the Lander is on the surface, large-scale observations from the Orbiter—say, the detection of an oncoming duststorm or other regional changes detectable from orbit—may be correlated with fine-scale measurements obtained by the Lander as the phenomenon sweeps over it.

### The Orbiter Cameras

Each of the two Orbiter television cameras consists of a 1.5-inch vidicon, telescope, mechanical shutter, and filter wheel (fig. 32). When the shutter of the camera is open, an electrostatic image of the scene below is formed photoelectrically on the vidicon target material, which is then scanned by an electron beam. Neutralization by the beam converts the image into electrical signals. Each image (or frame) consists of 1056 lines of 1182 spots (pixels). The intensity of each spot or pixel is transmitted as a seven-bit word. Thus, each transmitted frame consists of 8.7 million bits. Each frame is scanned every 4.48 seconds. A wheel incorporating seven different filters can be turned by command to admit light from different portions of the spectrum over the 3600- to 6500-angstrom range.

The camera axes are canted slightly so that a pair of pictures covers a solid angle 3.1° by 1.51°. During actual operation each camera takes one picture every 4.48 seconds, one camera "reading" its image, the other erasing its last one. At an altitude of 1500 kilometers the cameras photograph contiguous, nonoverlapping squares 80 kilometers on a side in swaths about 500 kilometers long. Resolution will be about 40 meters under these conditions, capable of resolving an object the size of a football stadium.

Vidicon cameras are susceptible to changes in their response to light. Just prior to Mars encounter, while the spacecraft is still in "celestial lock" (that is, its navigation sensors are still locked onto the Sun and Canopus), the cameras will take pictures of known stars for calibration purposes. A few exploratory pictures will also be taken of Mars to see if there have been any large-scale surface changes since the Mariner 9 photographs were taken.

The prelanding period will be devoted almost exclusively to checking out the potential landing sites. Emphasis will be on mapping and geologically detailing the likely spots. Following a successful landing, the Orbiter's periapsis will be kept near the landing site to make data relaying easier. During this period the cameras will be on the lookout for changes in the atmosphere and on the surface. Ultimately, the Orbiter will be released from the Lander-support task and its orbit will be varied for more comprehensive studies of the planet.

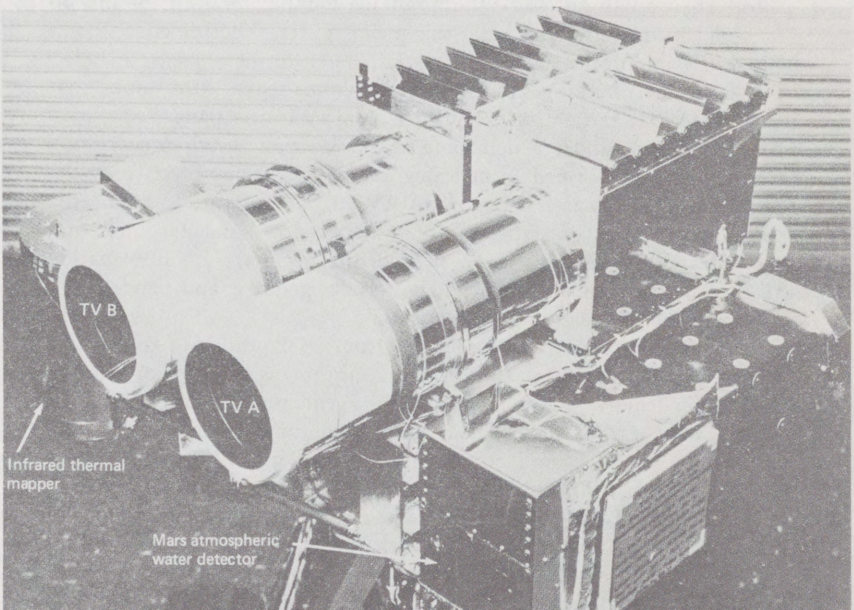



FIGURE 31.—Orbiter science scan platform.

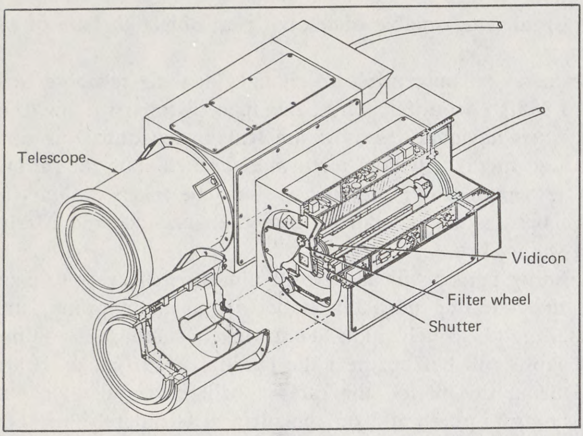



FIGURE 32.—Orbiter visual imaging subsystem.

## Mapping Concentrations of Water Vapor

More than anything else, Viking will be looking for signs of life on Mars, and in terrestrial thinking this means water. The presence of this biologically important substance should, therefore, be a factor in selection of the final landing site. Mariner 9 photos leave little doubt that liquid water has existed on the surface of Mars in the past. The atmospheric conditions under which some of the Martian clouds prevail indicate that they are formed from water ice crystals. The objective of the Mars atmospheric water detector (MAWD) is to locate areas of the surface where the concentration of water vapor (and by inference, ground water, probably as ice or permafrost) is high. This information will then be weighed with data on the terrain, geology, and temperature in making the final landing-site decision.

Once the Orbiter has been released from its landing-site duties, the MAWD can inquire into planetwide variations of water-vapor concentration, particularly in connection with geological features and the diurnal cycle. Martian meteorology has become unexpectedly interesting, and water vapor is a key factor on this unusual planet. Present atmospheric conditions inhibit the accumulation of large bodies of water as on Earth. The hydrologic cycle of Mars is different from that of Earth and what possibly existed on Mars in the past.

Water vapor is detected from orbit with an infrared spectrometer sensitive to the absorption band of water vapor existing at approximately 1.38-micrometer wavelength. Traces of water in the Martian atmosphere were first detected from Earth in this way in 1965. The optical configuration of the MAWD is shown in figure 33. Infrared radiation reflected from and emitted by the Martian surface passes upward through the atmosphere into the MAWD. Passing through a chopper, it is collimated and reflected back to a 12,000-line-per-centimeter grating which spreads out the spectrum onto an array of five lead sulfide infrared detectors. Three of these detectors are located so that they intercept wavelengths in the absorption band of water vapor near 1.38 micrometers; the other two are on either side of the band for reference purposes. The relative amount of infrared radiation detected by those sensors in the absorption band and outside it will be related to the amount of atmospheric water vapor the light has passed through. The chopper provides an alternating signal that is much easier to amplify than a steady signal.

The raster mirror indicated in the optical diagram is driven through a cycle of 15 steps by a small motor. This motion permits the instrument to scan terrain transverse to the Orbiter's motion. Fifteen staggered rectangles 3.0 by 24 kilometers are seen each sweep. A very crude 15-line "picture" of water-vapor concentration is thus formed every 4.48 seconds. The sensitivity of the MAWD is about 1 precipitable micrometer of water. In other words, if the total amount of water vapor in the column of "air" under the Orbiter increases by 1 micrometer when condensed to liquid, the MAWD will detect this change.

Although the principles are simple, the instrument itself is sophisticated and rather large. The optical portion is 71 by 20 by 28 centimeters (28 by 8 by 11 inches). Alinement is critical, and the MAWD must be rugged to preserve alinement during launch and temperature variations. The entire instrument, including the supporting electronics, weighs 15.9 kilograms (35 pounds).

**Looking for Hot Spots**

Another desirable feature of a landing site is warmth, for life, if present, would likely favor warm niches. A thermal map of the Martian surface will also give us much-needed information on cold spots and the temperatures of frost layers and the tops of clouds. These data will help explain condensation occurring in the atmosphere and perhaps help account for the fierce winds which whip up the colossal Martian duststorms. Geologists are, of course, interested in any hot spots detected because they are diagnostic (on Earth, at least) for geologically active areas such as volcanoes and hot springs.

The Viking Orbiter's infrared thermal mapper (IRTM) measures the infrared brightness of the surface below in several spectral bands or channels. The spectrum of radiation emitted by a surface—even a surface as cold as Mars—depends strongly on its temperature. Of course, corrections have to be made for reflected solar radiation. In addition, the surface emissivity depends on its composition and roughness. Previous work with Mariners and similar instruments on Earth weather satellites has given scientists considerable experience in translating radiation measurements into surface and cloud temperatures.

VIKING SCIENTIFIC EXPLORATIONS

The IRTM is a four-channel infrared radiometer:

(1) 6 to 8 micrometers
(2) 8 to 9.5 micrometers
(3) 9.5 to 13 micrometers
(4) 18 to 24 micrometers

Additional channels for measuring the atmospheric temperature and the reflected radiation (albedo) are at 16 micrometers and 0.3 to 3 micrometers, respectively. A radiometer, such as the IRTM, does not disperse the spectrum with a grating or prism. Instead, the desired portions of the spectrum are selected by filters. The Orbiter IRTM consists of four telescopes, each with interference-type filters which pass radiation in only the channels listed (fig. 34). Bimetallic thermopiles sensitive to infrared radiation measure the quantity of radiation in the spectral intervals passed by the filters.

In the Viking IRTM, each channel uses seven antimony-bismuth detectors arranged in a chevron pattern. Each detector views the Martian surface through a 0.3° field of view, which, at an altitude of 1500 kil-

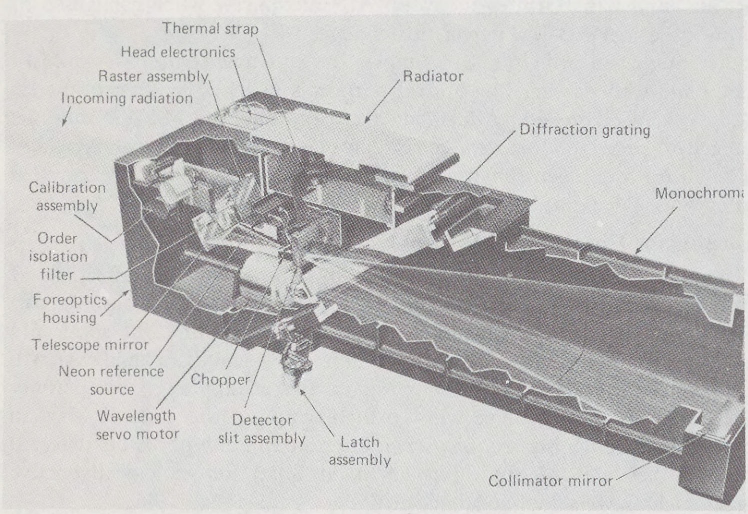



FIGURE 33.—Mars atmospheric water detection spectrometer.

ometers, is equivalent to an 8-kilometer circle on the ground. The temperature resolution of channels (1) to (3) is less than 0.1° C; that of channel (4) is 0.36° C. The scan mirror shown in figure 34 is stepped systematically through three positions: one position allows the instrument to view the planet surface; a second brings into view a reference surface at a known temperature; the third position points the detectors at deep space. A complete cycle lasts about 1.25 minutes. The scan mir-

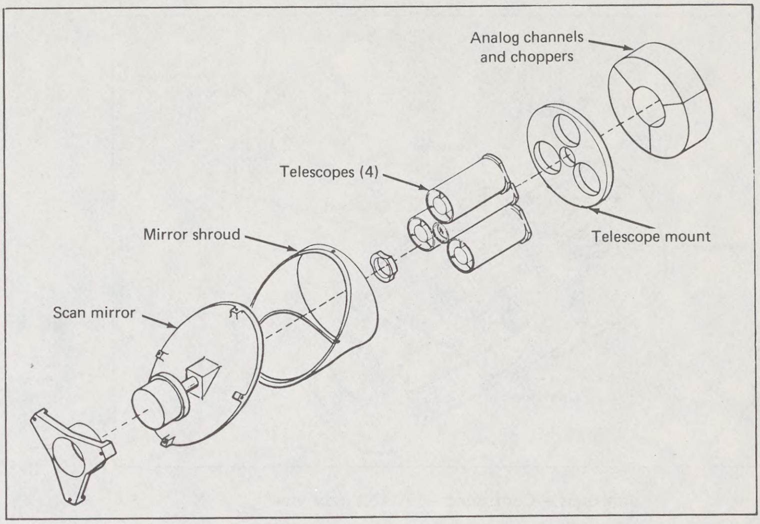



FIGURE 34.—Orbiter IRTM layout. (*a*) Exploded view.

ror has nothing to do with scanning the terrain; rather, it is the motion of the scan platform which brings each segment of terrain in the swath below into view of the staggered detectors, one channel after another.

## Experiments During Atmospheric Entry

Previous Mariners made indirect measurements of the thin layer of gases surrounding Mars, with unexpected results. Mars has a very cold lower atmosphere consisting almost entirely of carbon dioxide rather than nitrogen as was earlier supposed. In addition, radio-propagation experiments have indicated that a thin but fairly dense ionosphere exists at approximately 130 kilometers. None of the Mariners came closer than 1300 kilometers to the surface. Direct confirmation by *in situ* measurements would be highly desirable. The Viking Lander will plunge through the ionosphere and atmosphere, giving scientists a few precious minutes to sample the ions, atoms, and molecules directly.

A retarding potential analyzer and a mass spectrometer will be mounted on the aeroshell forward surface. Three other instruments will provide additional atmospheric data less directly. They are a pressure cell, a sensor to measure the temperature, and the accelerometers in the inertial reference unit (fig. 35). These instruments are concerned primarily with the aerodynamic properties of the Martian atmosphere, but will indirectly tell us much about atmospheric density and pressure when the atmosphere begins to slow the Lander.

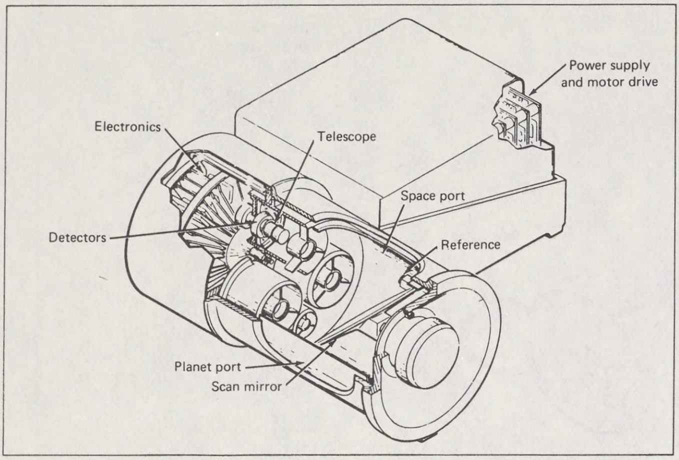



FIGURE 34.—Continued— (*b*) Cutaway view.

## Retarding Potential Analyzer

Scientists are puzzled about electrical processes transpiring in the upper atmosphere of Mars. Sunlight dissociates some of the carbon dioxide to create an ionosphere, but how does the solar wind interact? Does Mars possess a sufficient magnetic field to ward off the solar wind before it can interact directly with the atmosphere? Or do the high-velocity solar-wind ions penetrate deep into the atmosphere?

Retarding potential analyzers have been flown on many Earth satellites and space probes. Basically, they are made from a series of wire grids like those in an old-fashioned vacuum tube (fig. 36). As the voltage on the grids is swept through a range of positive and negative voltages, varying portions of the population of ions and electrons in the outside atmosphere will penetrate the grid structure. The current of electrically charged particles traversing the grids will be measured by a sensitive electrometer. In essence, the grids act as an electrical filter which admits only those particles possessing selected ranges of energies and electrical charge.

The retarding potential analyzer is located near the edge of the aeroshell. Its aperture is a 3.8-centimeter (1.5-inch) diameter circle (fig. 36). The first, second, and last of the six grids are grounded to the spacecraft. The third and fourth grids are connected electrically and make up the so-called retarding grid. The fifth grid acts as a suppressor. The 4-second instrument cycle consists of three voltage sweeps applied to the retarding grid: 15 to 0 volts in 2 seconds, −75 to 0 volts in 1 second; and −1.5 to 0 volts in 1 second. In this way, wide ranges of ions and electrons are sampled during the penetration of the ionosphere and lower atmosphere. The analyzer will be effective for particle concentrations between 10 and $10^6$ particles per cubic centimeter.

**Mass Spectrometer**

Most of the particles in the Martian atmosphere are electrically neutral. Scientists need to know their identities and concentrations as a function of altitude to understand the chemistry and thermal structure of the atmosphere. The mass spectrometer is the appropriate instrument here, and once again considerable pioneering work has already been done on scientific satellites, but there are important differences between the Viking and typical satellite missions. Viking's measurements must be made quickly during the short entry phase; the Martian atmosphere is very thin and measurements will be made at high spacecraft speeds.

A schematic diagram of the Viking mass spectrometer is shown in figure 37. As the aeroshell pushes into the sensible atmosphere, gas flows into the instrument. A beam of electrons created by the instrument bombards the incoming neutral atoms and molecules and ionizes them. These ions are first accelerated by grids and then pass through a slit into a region bounded by two parallel plates. One is at a negative voltage, the other at a positive voltage. Emerging from between the

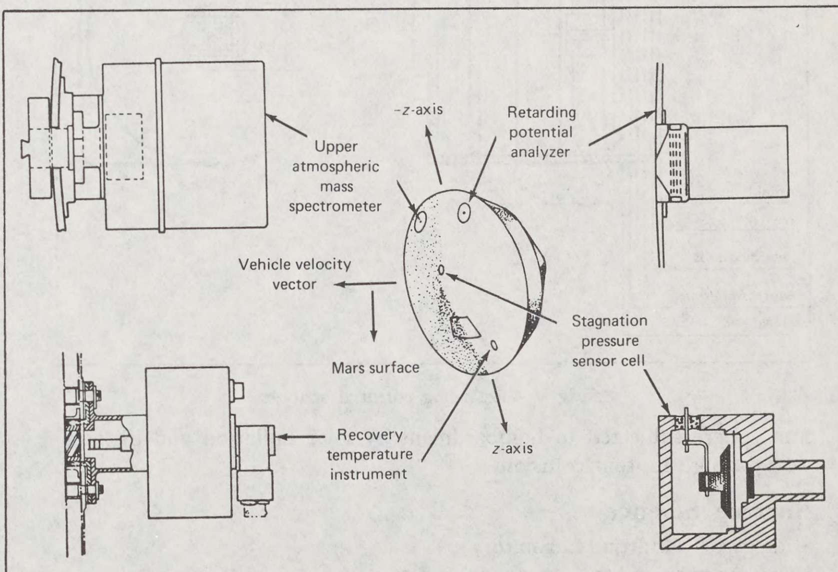



FIGURE 35.—Entry sciences aeroshell instrumentation. (Accelerometers are located internally in the inertial guidance unit of the guidance and control system.)

plates, the ions enter a fixed magnetic field which makes them curve toward two ion collectors. The electrostatic and magnetic fields work together to focus ions with certain electrostatic charges and momentum. For this reason, this type of instrument is called a double-focusing mass spectrometer. For a given combination of accelerating voltage and potential difference across the plates, two groups of ions, each with certain masses, will be focused into the two collectors. By sweeping the accelerating voltage and the potential difference across the plates, the instrument will measure ions from 1 through 50 atomic mass units. One collector handles the atomic mass unit range from 1 to 7, the other covers the range from 7 to 49 atomic mass units. The spectrum will be swept every 5 seconds during entry.

The range of the mass spectrometer is broad enough to measure carbon (12 atomic mass units), oxygen (16 atomic mass units), carbon monoxide (28 atomic mass units), and carbon dioxide (44 atomic mass units). All of these should be present in a predominantly carbon dioxide

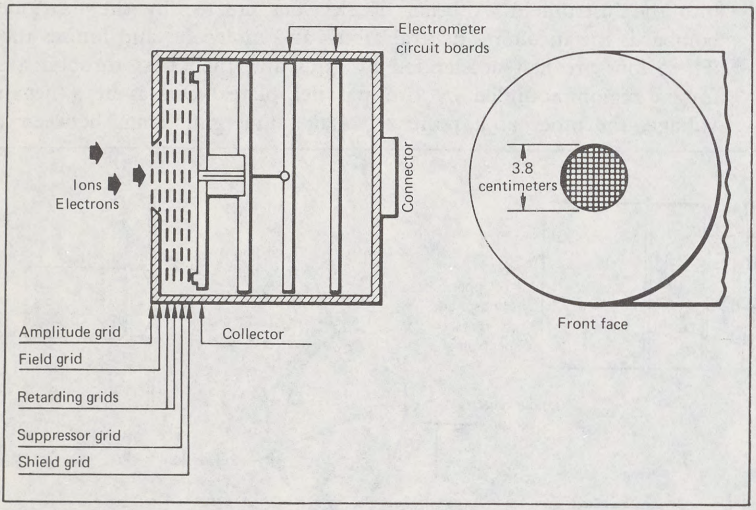



FIGURE 36.—Retarding potential analyzer.

atmosphere subjected to bombardment by solar radiation and dissociation through mutual collisions.

## Surface Science

### Strategy for a Martian Laboratory

Once Viking lands on the Martian surface after years of work by thousands of scientists and engineers, it would be tempting to turn on

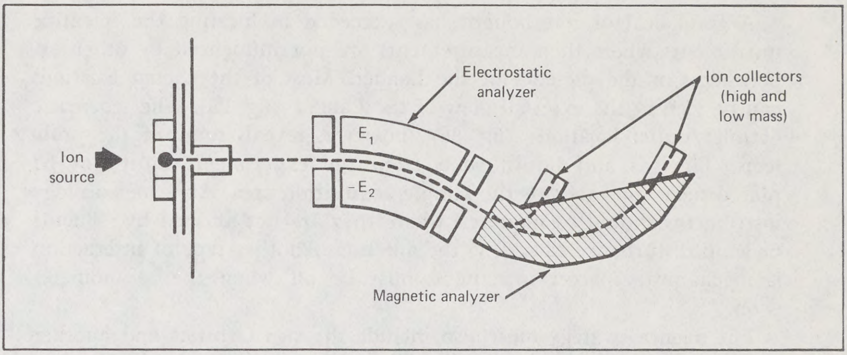



FIGURE 37.—Double-focusing mass spectrometer.

at once all the instruments to learn as much as we could about this intriguing planet. This impulsive approach would be self-defeating because the instruments are interdependent and experiments must be done carefully and, above all, in the right order. Clearly an experimental strategy is essential.

The Viking science strategy is not fully worked out yet, but some preliminary thoughts can be presented. For example, no matter how well conceived the engine design, the rocket descent is bound to stir up the surface to some degree. Some of the experimentation must wait for the dust to settle. A second delaying factor involves the engine gases liberated during descent. No atmospheric samples should be taken for several days to avoid detecting "the breath of the spacecraft."

Would just a look around with the camera hurt? It might if high-velocity winds flung sand against camera lenses, sandblasting them to the point of uselessness. Consequently, present strategy calls for one of the two cameras to be used approximately 10 minutes after landing to obtain visual imaging data, while the second camera will not be used until the meteorology instruments check and report the weather. Experiments with the mass spectrometer and biology instrument must also be carefully planned.

Imaging data of the sample area must be obtained to assure that the sample acquisition boom can safely acquire the sample. Soil samples cannot be analyzed while waiting for the air to clear of spacecraft effluents because the soil would contaminate the instrument for later atmospheric analysis.

The final science strategy will manifest itself in a long series of preprogramed instructions stored in the computer's memory. This predetermined strategy may be altered upon command from Earth if adequate communications have been established. The high degree of automation insures that experiments will progress even in the face of initial communication problems.

## VIKING SCIENTIFIC EXPLORATIONS

A good deal of forethought has succeeded in locating the scientific instruments where their measurements are not influenced by other experiments or the presence of the Lander. Most of the chosen locations can be seen in the external view of the Lander (fig. 23). The schematic of inlet/outlet locations (fig. 38), however, reveals some of the problems. The gas and liquid vents from the experiments must not be placed near any inlets or the sample acquisition area. Also, meteorology instruments should be mounted where they are not affected by effluents or wind disturbance caused by the antenna. Another type of interaction is mechanical–spacecraft motors must be off when the seismometer is on.

The science strategy must also include the two Orbiters and another Lander elsewhere on the surface. The Orbiter observations of storms and other dynamic processes can be correlated with Lander measurements. Even the Landers can help each other in the sense of providing a stereophonic view of seismic events and surface weather.

### A Look Around the Spacecraft

Camera eyes on Mars have exciting work to do. Their assignments include inspecting the geology of the landing site, observing duststorms and clouds, following the Martian satellites as they move swiftly across the horizon, and, most important, searching for possible Martian life in living or fossilized forms.

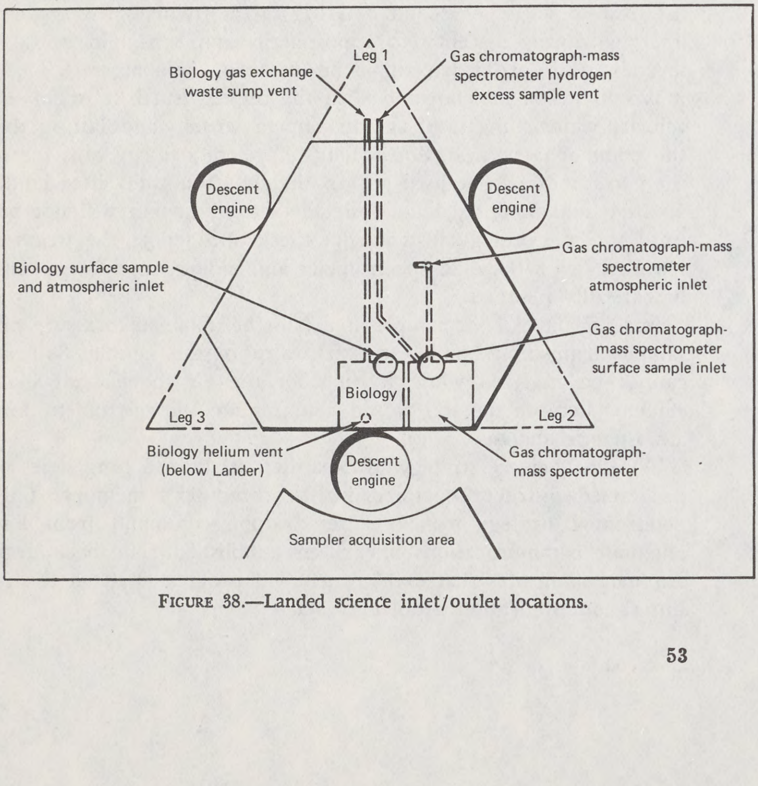



FIGURE 38.—Landed science inlet/outlet locations.

The two stereoscopic cameras are mounted on top of the Lander frame where they can take 360° panoramic pictures of the landing site. They can scan upward from the Lander footpad to about 40° above the horizon. This extensive coverage is accomplished with the help of a scanning mirror that nods up and down and with rotation of the camera as a whole.

The optical image is not formed as it is on the Orbiter's vidicon plate. Rather, the outside scene is dissected pixel by pixel by the mechanical motions of the scanning mirror and turret action of the camera (fig. 39). The image is formed only when all the pixels are assembled into a picture back on Earth. The principle is like that used in transmitting newspaper pictures by facsimile.

This type of camera can be made surprisingly versatile. Light admitted through the lens falls on an array of a dozen pinholes, each backed by a photosensor. Each photosensor generates a signal propor-

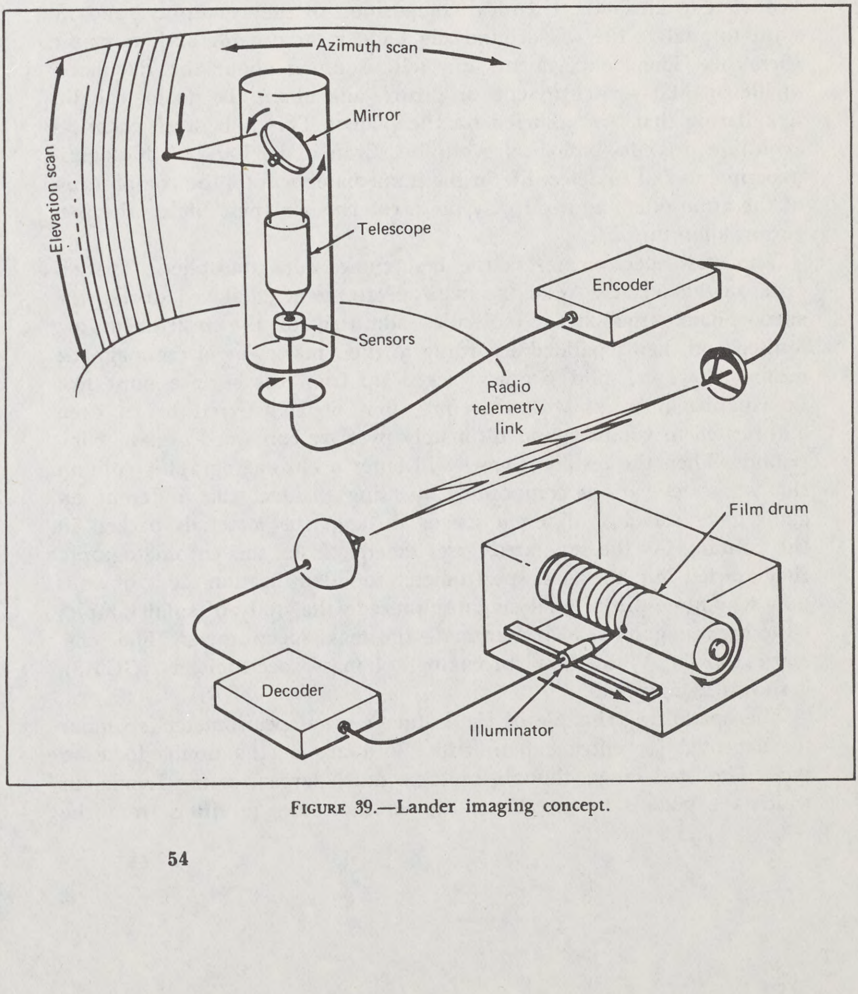



FIGURE 39.—Lander imaging concept.

tional to the amount of light falling on it. At any instant, any one of the pinhole-sensor combinations can create a pixel of the scene being surveyed. By using filters, colored pictures can be achieved. By adjusting the distance between the lens and the sensors, objects at various distances can be focused. Resolution near the footpad is a few millimeters and decreases with increasing distance to the object.

The cameras can scan at two rates, one matched to the ultrahigh frequency link to the Orbiter, 16,000 bits per second, and the other to the direct link to the Earth, 250 bits per second. The Lander cameras, like those on the Orbiter, generate data at a tremendous rate: 10 million bits for a single complete panorama around the spacecraft with a 60° scan in elevation. A similar picture in color would take three times as many bits; high resolution photography, even more.

### Automated Chemical Analyses

Three kinds of scientific investigations call for chemical analysis. We want to know the chemical composition of the atmosphere and we want to analyze the soil around the Lander for organic and inorganic chemicals. These experiments can tell us much about the likelihood of life on Mars—past, present, or future—and about the geological differentiating that has occurred on the planet. This is because chemical evolution precedes biological evolution. Even if the Lander's biological experiments fail to detect life in the immediate vicinity, the composition of the atmosphere and soil may preserve echoes of past life or the precursors of future life.

The mass spectrometer is the best choice for atmospheric analysis once on the surface. As in the mass spectrometer employed during the entry phase, atmospheric molecules admitted to the instrument are ionized and then separated according to their masses by electromagnetic means. However, solid samples picked up from the surface must first be volatilized. Solids will, therefore, first be transferred to an oven and heated to volatilize and ultimately pyrolyze contained organic compounds. Then the resultant gases will enter a chromatographic column that separates various compounds by using the fact that different organic gases travel at different speeds through the materials packed in the column. As the separated gases emerge from the chromatograph, they are fed into the mass spectrometer for identification. It is obvious now why atmospheric analysis must precede the study of solid samples —the organic gases may contaminate the mass spectrometer. The schematic for the Viking gas chromatograph-mass spectrometer (GCMS) is shown in figure 40.

The operating principle of the Lander's mass spectrometer is similar to that used for entry experiments. Both are of the double-focusing type. The mass range, though, must be much larger for the Lander in which the goal is to detect the heavier molecules resulting from the heating of organic compounds. From an engineering standpoint, it is difficult to build this type mass spectrometer to cover both the very low and the higher mass numbers. It was therefore decided to ignore hydrogen and helium and concentrate on the range from 12 to 200 atomic mass units. Compounds containing up to 10 carbon atoms can be accommodated in this range. Most atmospheric molecules will also be within range.

During atmospheric analysis, gas samples will first pass through a chemical filter capable of absorbing all of the carbon monoxide and carbon dioxide. This means that well over 90 percent of the sample will be eliminated before it enters the spectrometer, permitting the analysis to be concentrated on the more interesting minor constituents, such as oxygen, nitrogen, argon, and krypton. The chemical filter, possessing a limited absorption capability, sets a limit of about 60 sample analyses. Unfiltered analyses will also be made to observe the relative abundance of the more prevalent gases and water vapor.

Gases are far easier to handle than solids. Analysis of solids proceeds thus: First a soil sample of approximately 100 milligrams is deposited in one of several little ovens on a motor-driven holder. Then, the oven is electrically heated to about 200° C. If the sample is rich in organic compounds, many gases will evolve. If the sample is organically poor, there will be little evolution, and the temperature may have to be raised to 350° C or even 500° C. The higher the temperature the more the sample will be volatilized or pyrolyzed. Since high temperatures destroy the more complex organic molecules, low oven temperatures are applied first.

A stream of stored hydrogen carrier gas sweeps any evolving gases from the oven into the gas chromatograph column. This is simply a long tube packed with coated beads or other solids that selectively delay the passage of different gases in accordance with their adsorptive properties. Another feature of the GCMS is the "splitter," which diverts excess gas from the mass spectrometer to prevent overloading the ion pump (a device used to remove ions from the gas sample to achieve the low operating pressure required). The hydrogen carrier gas is also separated at this point.

Present plans call for making two analyses for each of three soil samples. The surface sampler will, of course, scoop these up from the most interesting areas seen through the cameras.

The inorganic and elemental analysis (described in more detail later) is not a primary part of the analyses supporting the biological investigation; however, the data acquired from this analysis are of interest to the biologists and could aid in interpreting the results of their investigation.



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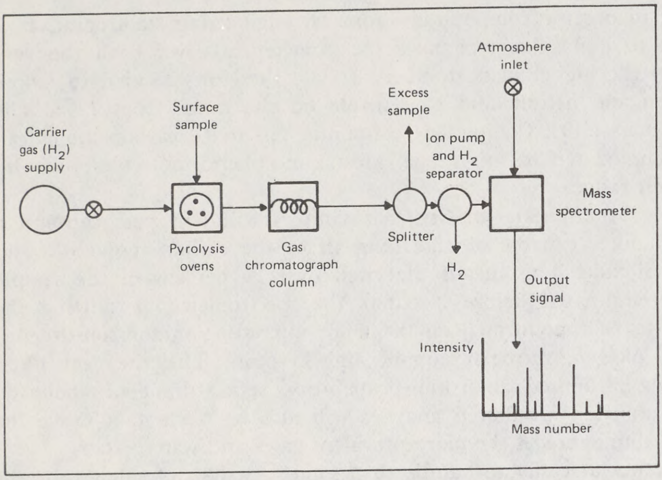



FIGURE 40.—Gas chromatograph-mass spectrometer schematic.

## The Life Detectors

While the Lander cameras may spot some unmistakable form of life, it now seems much more probable that Martian life, if it exists, will be in the form of micro-organisms. During the past two decades, many ingenious schemes have been devised for remotely detecting the presence of micro-organisms on other planets. Most techniques involve detecting the processes of metabolism and growth common to Earth life (and which are expected to be common to Martian life, too). Viking scientists have selected three approaches:

(1) *Pyrolytic release experiment:* A sample of soil is dumped into a chamber where the Martian environment is simulated in all aspects, except that some of the normal carbon dioxide atmosphere is replaced by one of carbon monoxide and carbon dioxide "tagged" with radioactive carbon-14 (fig. 41). Water vapor can be added upon command. Any life in the sample should assimilate some of this artificial atmosphere and incorporate the radioactive atoms into the organic compounds it manufactures—assuming its behavior is like that of Earth organisms. Artificial sunlight from a xenon lamp will bathe the sample to promote photosynthesis should these micro-organisms be plantlike. After several days' incubation, the sample will be pyrolyzed at about 600° C to drive off organic vapors. The vapors will be separated by a special copper-oxide vapor trap and monitored for radioactivity. The presence of radioactive

FIGURE 41.—Pyrolytic release experiment.

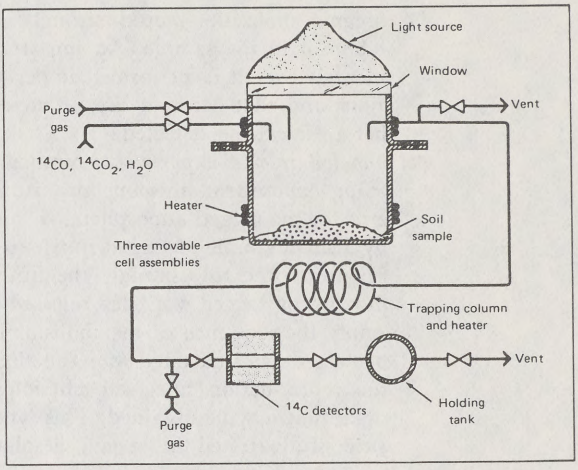



FIGURE 42.—Labeled release experiment.

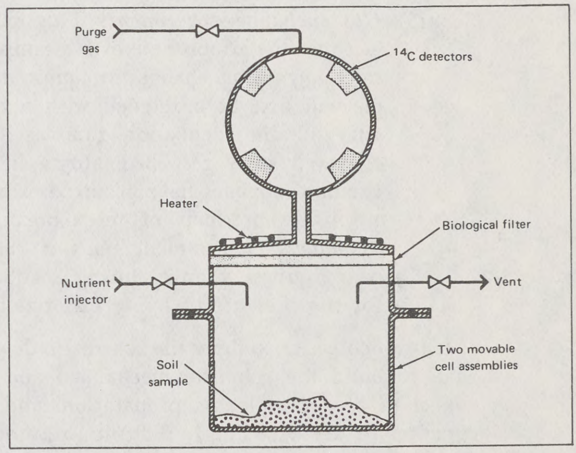
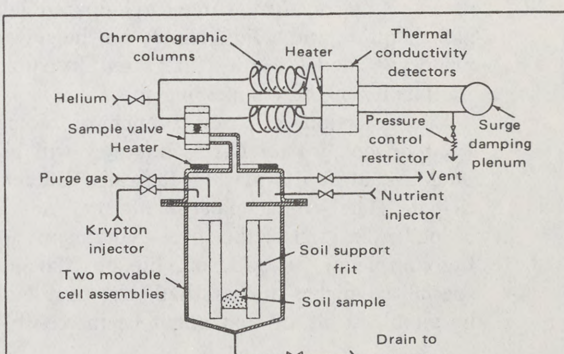



FIGURE 43.—Gas exchange experiment.



organic molecules would strongly imply terrestrial-type metabolism in the sample. An important feature of this experiment is that it is performed under essentially Martian conditions and that Martian life, if present, will not be destroyed before it can be detected.

(2) *Labeled release experiment:* Similar in principle to the foregoing experiment, this one substitutes carbon-14-tagged nutrients for the tagged atmosphere. A soil sample will be moistened by a small sample of tagged nutrients and then incubated; that is, given time to assimilate the nutrients. Any tagged carbon dioxide or tagged volatiles released during incubation would imply the existence of metabolism. By measuring the amount of tagged gases excreted as a function of time, information on the reproduction rate and physiological state of the micro-organisms may be obtained. This type of life detector has been successfully tested in several desolate but life-sustaining terrestrial environments (fig. 42).

(3) *Gas exchange experiment:* This experiment is based on the fact that the atmosphere over a sample containing metabolizing micro-organisms changes in composition with time. A soil sample will first be moistened with a rich nutrient. Periodically, after suitable incubation, samples of the atmosphere will be conveyed to a gas chromatograph to discover whether any chemical changes have occurred. Methane and carbon dioxide are likely products of micro-organisms growing in a dark, oxygenless environment; and if the concentrations of gases such as these change during incubation, it will be evidence for the presence of living material in the sample (fig. 43).

It is much easier to draw the schematic diagrams of these instruments than to build the requisite mechanical and chemical apparatus. The collection of a sample, its preparation, and its transportation to the experiments are exceedingly difficult to automate. The biology experiments really constitute three tiny, separate laboratories that must handle gases, liquids, and solids reliably on the surface of a distant planet. The prototype model of the integrated instruments (fig. 44) reflects the complexity of the engineering job.

Life detection is a new branch of biology. Its practitioners know what to look for on Earth, but they will be at a serious disadvantage on Mars. Mars life may be radically different from what scientists anticipate. The Viking experiments may not ask the right questions, so a "no" from each of the three experiments would not rule out Martian life completely. In addition, life on Mars may be highly localized in specialized niches—niches that terrestrial biologists might not consider hospitable at all, or that might be inaccessible to the sampler.

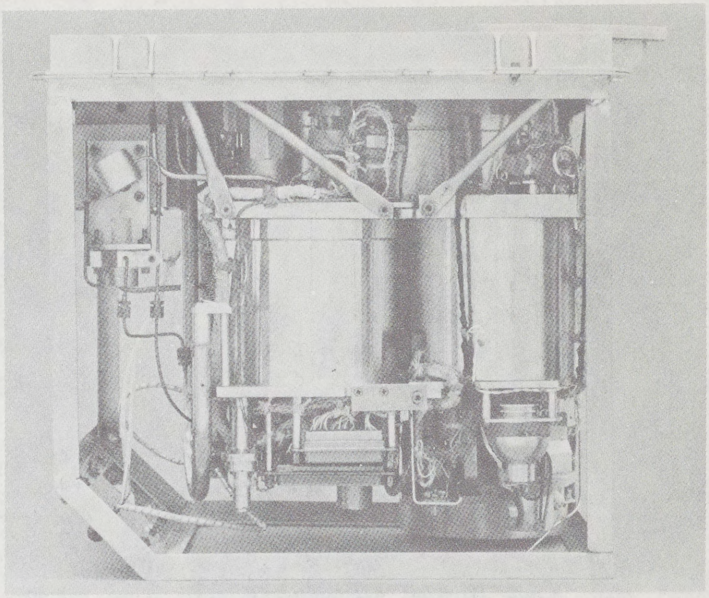


FIGURE 44.—Biology experiment prototype model.

## What Is the Surface Made Of?

The preceding experiments are concerned primarily with the chemical evolution leading up to life. Scientists interested in the evolution of the solar system are also anxious to study the inorganic portion of the Martian surface; that is, the mineralogy of the sand, rocks, or whatever constitutes the surface material. We now have extensive data on two bodies of the solar system: Earth and the Moon. Knowing the constituents of the Martian surface would give us a great deal more insight about how the inner terrestrial-type planets evolved.

The return of rock samples to Earth from Mars may be accomplished eventually by unmanned spacecraft—as it has been done for the Moon by the Russians—but this is beyond Viking's capabilities, so analysis will have to be done remotely. When only the abundance of the elements is required (as opposed to molecular analysis), some comparatively simple instrumentation from the physics lab works well. The physical technique selected for Viking is X-ray fluorescence. In this approach, the sample is bombarded by X-rays from radioactive elements. The X-rays activate atoms in the sample and induce them to emit X-rays themselves. (This is fluorescence.) The emitted X-rays are characteristic of the elements in the sample; each element has in effect its own X-ray fingerprint. By measuring the numbers and energies of the

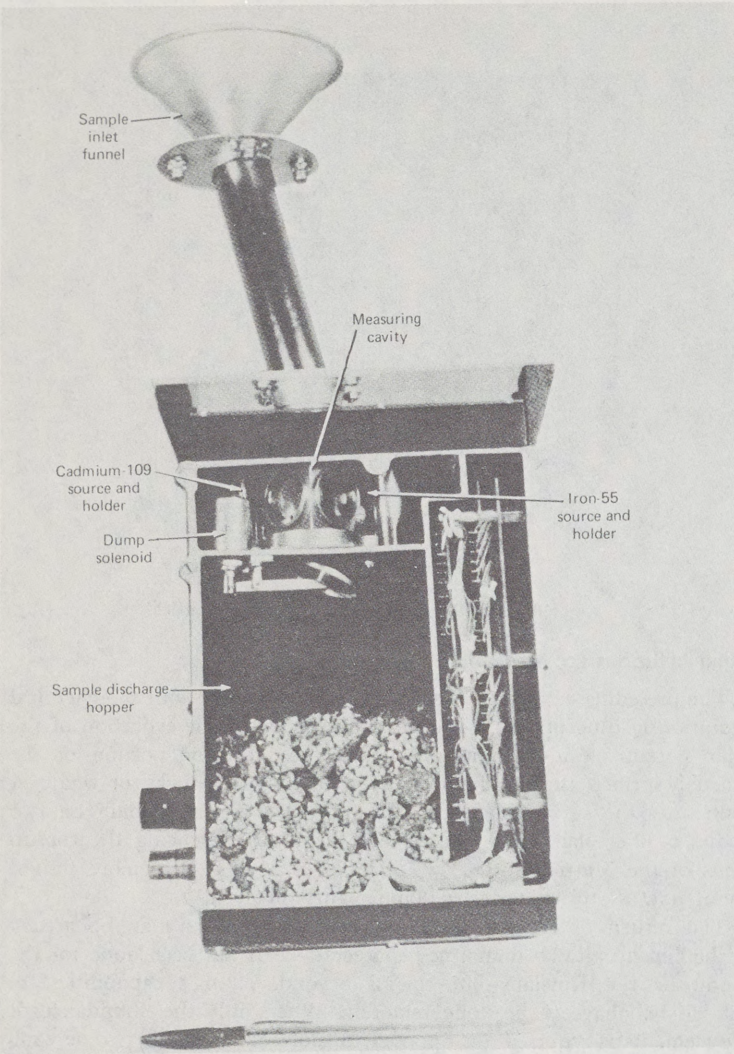



FIGURE 45.—X-ray fluorescence spectrometer.

X-rays in the fluorescence spectrum, we can calculate elemental abundances although not how they are incorporated into compounds, which has to be inferred. X-ray fluorescence is a common terrestrial analytical tool where materials must be identified without damaging the specimen.

On Viking a sample is dumped into the funnel shown in figure 45.

It falls into the measurement cavity where it is bombarded by the X-rays from radioactive iron-55 and cadmium-109. The X-rays that fluoresce from the sample are counted by four gas-filled proportional counters. The heights of the pulses delivered by the counter are proportional to the X-ray energies. A pulse-height analyzer sorts these pulses into an energy spectrum that is radioed back to Earth. The Viking instrument will detect elements with atomic numbers of 12 and higher. Each instrument cycle accepts up to 50 cubic centimeters of material from the Martian surface and analyzes it in about 5 hours.

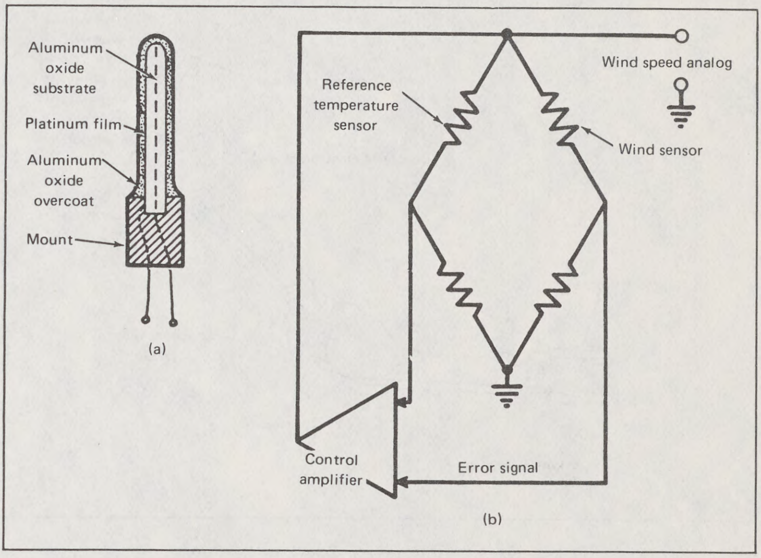



FIGURE 46.—Meteorology wind velocity sensor. (*a*) Probe. (*b*) Constant overheat circuit.

## A Simple Martian Weather Station

Mars is now recognized as a meteorologically dynamic planet with sand dunes, cloud formations leeward of some mountains, and similar Earth-like phenomena. Scientists believe that Martian weather is a simple version of our own, and that we can learn a great deal by attaching a few simple meteorological sensors to the Viking Lander. Of course, the local weather will also be a factor in interpreting the other experiments. Frequent high winds would, for example, help geologists explain formations seen through the cameras.

VIKING SCIENTIFIC EXPLORATIONS

Pressure, temperature, and wind velocity will be measured periodically throughout each diurnal cycle. The very low pressures of the Martian atmosphere (less than 1 percent of those on Earth) can be detected reliably with a stretched-diaphragm-type sensor. The thin metallic diaphragm forms one side of an electrical capacitor, with the exposed wall of an evacuated chamber forming the other. Any motion due to external pressure changes will be reflected as changes in electrical ca-

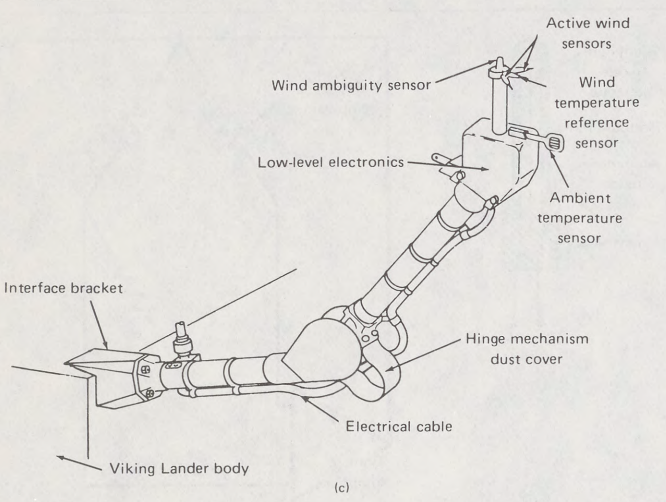



FIGURE 46.—Continued—(*c*) Boom with sensors.

pacitance. The diaphragm must be shielded from the wind, of course. Present plans are to use the same pressure sensor employed during the entry phase.

Thin-wire thermocouples will measure the "air" temperature. These, too, must be behind a windshield. In fact, the wind velocity sensor is essentially a thermocouple exposed to the wind. It is called a "hot-film anemometer" and consists of an aluminum oxide cylinder or probe about 1 centimeter long (fig. 46) heated by electrical current passing through a thin platinum film. The higher the outside wind velocity, the more the probe is cooled. Windspeed is determined by measuring the electrical power required to keep the cylinder at a certain temperature with respect to a similar unheated probe. This kind of anemometer will be accurate to about 10 percent over the range between 2 and 150 meters per second (4.5 to 340 miles per hour). The hard aluminum oxide exterior protects the probe from the effects of sandblasting.

**Marsquakes**

From the vantage point of Mariner 9's cameras, Mars appears tectonically active. Motion of crustal plates should generate quakes and and microseisms. Monitoring these phenomena alone is sufficient reason for mounting a simple seismometer on the Lander frame. (The Apollo seismometers left on the Moon may completely change our view of the internal structure of the Moon.) A Martian seismometer could also register meteor impacts and perhaps determine whether Mars has a crust/mantle/core structure like the Earth.

The Viking seismometer is a small, three-axis instrument mounted on the Lander. Seismic vibrations will travel up through the Lander legs to the frame and thence to the seismometer. Three perpendicular components of ground motion are measured with the following sensitivities: $50 \times 10^{-6}$ millimeter or less at 1 hertz and $1 \times 10^{-6}$ millimeter or less at 4 hertz. During seismic quiet the seismometer will operate at a low data rate; however, a major quake will trigger a higher data mode, giving geologists a better look at the details of the vibrations as they propagate around and through the planet.

**Does the Martian Soil Contain Magnetic Particles?**

We know that the soils of Earth and the Moon contain several types of magnetic particles, some from eons of meteorite bombardment and others the result of geological processes. The presence of native iron, magnetite, limonite, and other iron-bearing materials can tell us something about the separation of minerals (differentiation) during the evolution of Mars and the oxidization of the surface in the distant past when the atmosphere of Mars presumably possessed oxygen.

Experience with the lunar Surveyors proved that small permanent magnets can detect magnetic particles in the soil. Simple visual inspection with a camera can lead to surprisingly accurate estimates of particle abundance. A logical place to mount magnets on Viking is directly on the head of the surface sampler (fig. 47). Every time a soil sample is collected, some of the magnetic particles will adhere to the magnet array. The sampler arm can be maneuvered around so that the magnet array can be photographed directly or via a magnifying mirror. Color pictures will help identify specific minerals. Magnets of different strengths and shapes in the array will add versatility. Additional magnets will be mounted on one of the Lander's camera calibration targets for the detection of windblown magnetic particles.

**Physical Properties of the Martian Surface**

Mars very likely has a surface layer of particles or soil much like Earth and the Moon. By observing the activities of the surface sampler with the cameras and the depth of the Viking Lander's footprint, engineers can deduce bearing strength, porosity, grain size, adhesion properties, and similar soil properties. In addition, Viking Lander telemetry

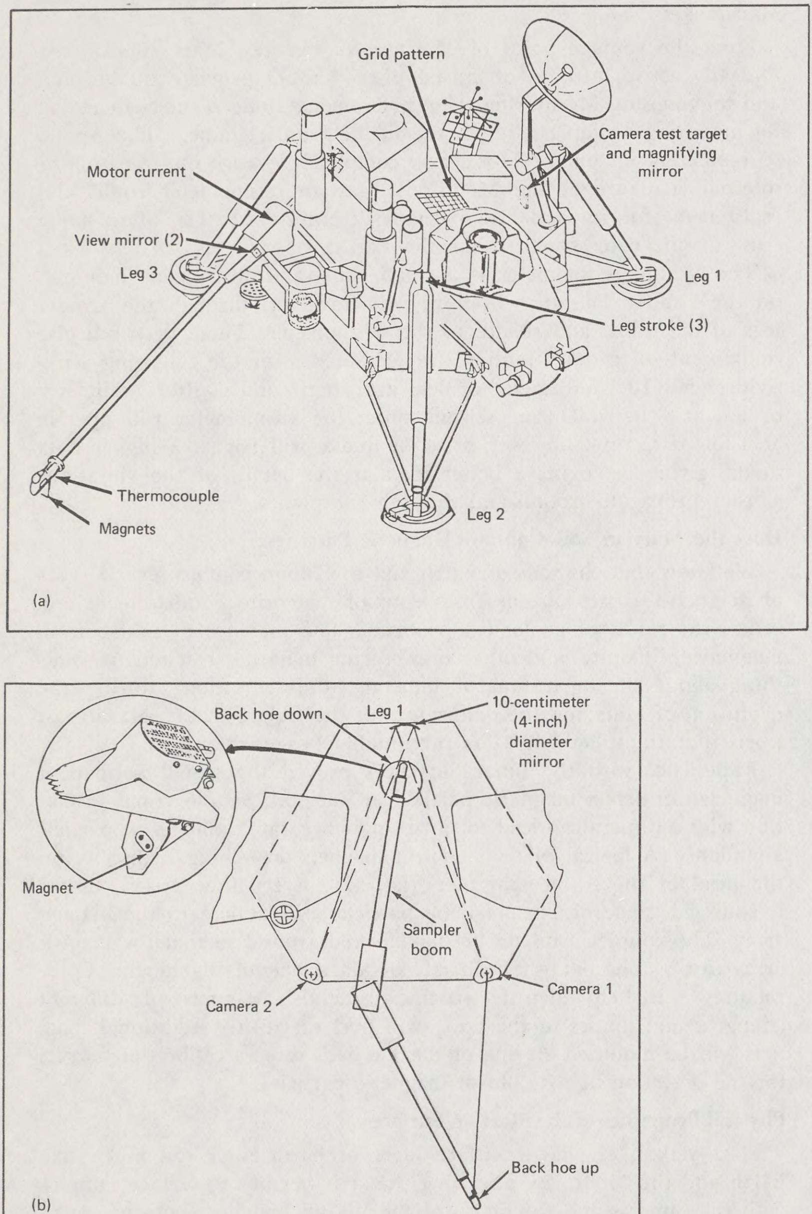



FIGURE 47.—Magnetic properties experiment. (*a*) Lander. (*b*) Enlarged view of placement of magnets.

will report on surface sampler motor currents and hence the resistance of the soil to the motion of the sampler head. The thermocouples located at various positions in the Lander to help assess the "health" of the spacecraft also can help determine the temperature and thermal inertia of the surrounding terrain.

## Radio Experiments

Even if the Viking spacecraft carried only its radio transmitter and radars, with no scientific instruments whatever, the scientific return would be impressive. On Viking, as with most other deep-space and satellite flights, one will be able to extract considerable information from radio-tracking measurements and the properties of electromagnetic waves received from the spacecraft transmitters as they are modified by matter in space and Mars itself. Some of the planned investigations are—

(1) Tracking data will refine the orbit and mass of Mars.
(2) The Lander radars will measure the surface reflectivity in the microwave range.
(3) As the Viking Orbiter swings behind Mars, its radio signals will be distorted by the Martian atmosphere and ionosphere, leading to estimates of electron density in the ionosphere, etc.
(4) Lander-to-Orbiter transmissions will indirectly measure atmospheric turbulence.
(5) Precision tracking of the Orbiter (even from Earth) will yield estimates of atmospheric drag.
(6) The differences in propagation velocities of Viking radio signals at different frequencies (S-band and X-band dispersion) will provide a measure of electron concentration between Earth and Mars.
(7) Radio signal time delay caused by the Sun during superior conjunction will add greatly to our verification of Einstein's Relativity Theory.

# Chapter 6 Touchdown on Mars

## Viking at the Cape

Before the Orbiter, Lander, and launch vehicle meet at Cape Kennedy, they will already have passed a multitude of tests. These systems and the parts from which they are constructed will have been shaken, baked, and operated under simulated space conditions. Only acceptable parts survive the testing and screening procedures. Final checkout and assembly occur at NASA's Kennedy Space Center but these procedures will be far from routine. The Viking launch will be unique in that there will be two extremely complex systems making up the spacecraft rather than the usual one and the Lander will have to be "canned" and sterilized at the Cape.

The all-important sterilization of the Lander occurs in the Viking spacecraft assembly and encapsulation building. Sterilization is preceded by intensive cleaning and frequent bioassays to check the effectiveness of the cleaning steps. Immediately following encapsulation, the already well-cleaned Lander is then sterilized by baking for no more than 3 days at about 112° C. The next living matter it contacts may be of extraterrestrial origin.

All of these events have to be synchronized with the so-called "launch period" for Mars, which occurs about every 26 months. During this period, the Earth is just catching up with Mars as the two planets fly their elliptical courses around the Sun (fig. 12). Within this period there are daily launch "windows" when the propulsive requirements are low and well within the capabilities of the Titan III/Centaur. The daily window closes when the Titan III/Centaur can no longer propel the spacecraft into an interception course with Mars. During August and September 1975, a period of at least 41 days exists for Titan III/Centaur and the Viking spacecraft.

The Titan III solids alone (stage 0) lift the launch vehicle off the pad; the first Titan III liquid stage does not fire for approximately 2 minutes. After the Titan III second liquid stage cuts off, the Centaur upper stage injects the spacecraft into a parking orbit about 165 kilometers (90 nautical miles) above Earth. At precisely the right moment, an onboard guidance computer initiates the second firing of the Centaur rocket engine, which injects the spacecraft into a trajectory which will intercept Mars in the summer of 1976.

## The Long Trip to Mars

During the 305- to 360-day cruise to Mars, the Viking Lander will be almost completely dormant and the Orbiter not much more lively. However, several very important things must be done. The first is to make sure that the spacecraft really does intercept Mars. If rocket angles and burn times are only slightly off during launch and the departure from parking orbit, the miss distance at Mars may be large. The Orbiter in conjunction with the DSN has the tasks of navigation and midcourse correction. First, the Orbiter opens its solar panels and performs a controlled search for the Sun using its inertial reference platform for spacecraft attitude reference. Then, it performs a roll search for the star Canopus. The DSN tracking antennas then acquire enough trajectory data to determine how much of a midcourse correction is needed. The Orbiter's engine then fires to nudge the spacecraft into a more accurate encounter trajectory. Up to three more midcourse corrections may be performed if needed.

During the long flight, the Orbiter will be tracked frequently (but not continuously) by the DSN. Housekeeping data will be recorded and scanned to determine the "health" of both Orbiter and Lander. Approximately every 15 days, the Orbiter will check out the Lander and carry out simple maintenance operations.

As the spacecraft trajectory begins to converge with the orbit of Mars, the Orbiter's scan platform and instruments are calibrated because they will be brought into play before the actual encounter. Approximately 10 days before encounter, the scan platform is unlatched and pointed toward Mars. Mars will still be tens of thousands of miles away, appearing as a small but rapidly increasing visible disk. The object of Viking preencounter science is to obtain global distributions of temperature and water vapor as well as pictures of the whole planet and its two moons for navigational purposes.

Encounter will occur between mid-June and late August 1976, when summer prevails in the northern hemisphere of Mars. As the spacecraft nears Mars, the Orbiter gas jets will swing the double spacecraft around so that the Orbiter engine is pointed roughly in the direction of flight. At command from Earth, the engine will burn for a little under an hour. The retrothrust reduces the spacecraft velocity by about 1480 meters per second and permits it to be captured by the gravitational field of Mars. The target orbit has a periapsis of 1500 kilometers (940 miles) above the Martian surface and an apoapsis of 32,600 kilometers (20,400 miles) and a period of 24.6 hours, the same time it takes Mars to rotate on its axis. If this rather eccentric ellipse is not obtained precisely, the Orbiter's engine can "trim" the orbit, that is, adjust it to the desired shape (fig. 13). With this milestone, the real work of the Orbiter begins.

## In Orbit About Mars

Orbiter's first task is to aid in final site selection. Prelaunch primary and backup landing sites have already been selected on the basis of Mariner 9 photos. The Viking Orbiter's cameras, water-vapor detector, and thermal mapping instrument will examine the sites in detail with an eye to scientific payoff and safe descent of the Lander. If the primary site looks risky, the Orbiter will begin examination of the backup site. Once the final selection has been made, the Orbiter's trim maneuvers will fix the orbit's periapsis right over the primary site.

Scientists would like a relatively warm, wet landing site with a thick soil layer. There should be formations of high geological interest nearby and no obstructions that would interfere with meteorological measurements. These objectives are in some degree incompatible. Warm, wet niches are likely to be at low elevations, perhaps at canyon bottoms. Unobstructed areas are likely to be featureless geologically and uninteresting biologically.

The engineers designing the Lander have an entirely different set of landing criteria:

(1) The spacecraft orbit fixes the site within the latitude band of 25° S to 75° N.
(2) The surface cannot be too rough or have too great a slope (more than 19°) or the landing will be endangered.
(3) The site must be at a low enough elevation to give the parachute enough dense atmosphere to slow the descent.
(4) The radars on the Lander require a surface with high microwave reflectivity for good, clear echoes.

After weighing the scientific and engineering factors, the Mission Director will make the final choice and give the go-ahead for landing. This decision should be made between 10 and 50 days after the spacecraft arrives at Mars.

Given a go-ahead for landing, the Orbiter attends to the task of reviving the dormant Lander. Preseparation checkout begins about 30 hours before the command is sent from Earth to sever the year-old mechanical and electrical ties between Orbiter and Lander. At separation, the Lander, which is already partially "uncanned," is separated from the Orbiter and the aft bioshield is discarded. The aeroshell's four small hydrazine engines are then ready to deorbit the Lander.

In scheduling orbital operations, it must be remembered that Viking A will be followed by Viking B, launched 10 to 41 days later. The goal here is to separate the spacecraft arrivals at Mars sufficiently to allow Lander A to get down to the surface and send back some engineering and scientific data about the descent phase and the landing site itself. If Viking B is 10 or more days away from encounter when these data are received, its trajectory can still be modified enough to choose from a wide range of possible landing sites. Once in orbit, only small latitude changes but large longitude changes are possible due to the differences in energy required.

## Descent to the Surface

Lander separation from the Orbiter is initiated by a command signal which energizes explosive nuts and allows compressed springs to separate the two vehicles. About 10 minutes later the aeroshell's four hydrazine engines fire and begin the deorbit maneuver. These engines in addition to four others for roll control are used to hold the Lander capsule in the proper attitude so that the cork-honeycomb ablative surface protects the capsule from heat and pressure and gives it a small amount of lift during entry. Between 2 and 5 hours after separation, the Lander encounters the sensible atmosphere at about 250 kilometers (800,000 feet). Peak deceleration occurs between 24,000 and 30,000 meters (80,000 to 100,000 feet; these figures are approximate because our knowledge of the Martian atmosphere is still limited) (fig. 14). By the time the spacecraft has penetrated to 6400 meters (21,000 feet) altitude, its velocity has decreased to about 375 meters per second (1230 feet per second). The parachute can be opened safely at this point. A few seconds later the aeroshell is separated via explosive bolt-compressed spring devices. (These and all other descent activities are carried out automatically by the Lander because it takes too long to transmit the pertinent atmospheric data to Earth and to return the appropriate command signal.) In about a minute the parachute-suspended Lander drifts down to 1200 meters (4000 feet) where it is falling at a rate of about 60 meters per second. Here, the Lander terminal-phase engines are ignited and the parachute is cut loose upon signal from the radar altimeter. Touchdown should occur at a vertical velocity of 2.44 meters per second (5.5 miles per hour). The entire sequence from atmospheric entry to touchdown takes between 6 and 13 minutes. In this short and very crucial span of time, all of man's knowledge of aerodynamics and the Martian atmosphere must be brought to bear. If successful, we will have soft landed our first cargo of scientific instruments on another planet of the solar system.

## Lander Operations Begin

Once safely on the surface, the Lander's first order of business is the establishment of communication links with the Orbiter and with the DSN antennas on Earth. Neither link is continuous because Mars rotates on its axis and the Orbiter's position relative to the Lander precesses slightly (fig. 48). Once again, we have time windows. The ultrahigh frequency Orbiter relay link window is open when the Lander sees the

Orbiter 25° or more above the horizon and within 5000 kilometers. This window will be open for between 10 and 40 minutes once a day. The window governing the direct radio link to Earth is open for about 12 hours a day, but can be used only when the Lander's high-gain antenna can contact a DSN 64-meter dish. Lander electrical power limitations restrict radio communication to 2 hours a day.

Early in the mission, the direct link to Earth can transmit about 3.6 million bits of information during the daily 2-hour window. As the Mars/Earth distance increases, the rate decreases to 1.8 million bits daily. The ultrahigh frequency link to the Orbiter can carry up to 16,000 bits per second, compared to a maximum of 500 bits per second direct to Earth. The relay link window, however, is not open as long, and the maximum number of bits per day will be about 38 million. Although

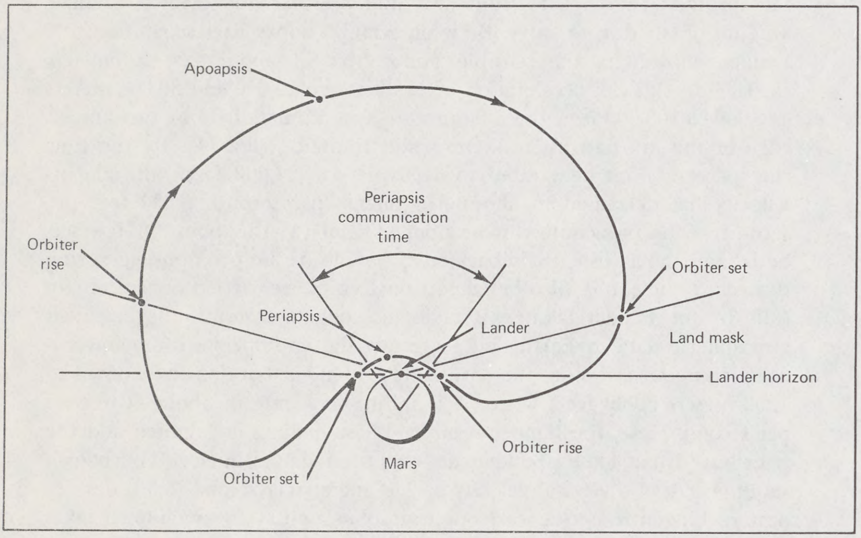



FIGURE 48.—Lander-to-Orbiter communication geometry.

these numbers sound very large, the Lander cameras can consume as many as 10 million bits per picture. Other instruments are less voracious in terms of bits. Obviously, priorities have to be established for the instruments.

Operating plans, too, must be carefully formulated. The present plan is to keep Orbiter A with its periapsis over the site of Lander A for a complete scientific cycle—about 22 days. While relaying Lander A's data to Earth, Orbiter A will survey potential landing sites for Lander B, some 7 weeks behind the Viking A schedule. If the promising Viking B sites are too far away from Orbiter A's orbit, it may be commanded to break off its support of Lander A and begin reconnoitering sites for Lander B. When Viking B arrives and its Lander is successfully soft landed, many options become possible. Orbiter A may act as a relay for Lander B, and Orbiter B may act as a relay for Lander A. Or, one Orbiter may be delegated to serve both Landers while the other begins scientific missions on its own. (Orbiter design life is 140 days after attaining orbit. The Lander design life after landing is 90 days.) This flexibility will be invaluable should trouble develop with any of the spacecraft. This pairing of spacecraft and communication links and the large-scale redundancy of spacecraft components yield a high probability of success for the Viking mission as a whole, even if one of the spacecraft should fail completely. A scientific bonus also results from joint Orbiter-Lander operations in that the Orbiter can prepare the Lander for oncoming atmospheric disturbances and then observe the phenomena from orbit while the Lander takes *in situ* measurements.



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# Chapter 7
# The Viking Team

The Viking project involves thousands of people building and operating complex machines to achieve specific objectives within a certain timespan for a given number of dollars. Viking differs from other large technological enterprises mainly in the hundreds of millions of miles between its radio-connected systems and in its scientific objectives—the exploration of another planet of the solar system.

The human organization of the Viking project parallels the organization of the machine; that is, each major Viking system has a "people counterpart." As illustrated in figure 49, the six Viking systems are split neatly in two: three systems of flight hardware and three ground-based systems which are manned by human controllers who communicate with and command the flight hardware. Here we get into the realm of management, with its organization charts, contractors, schedules, etc.

Overall program management begins at NASA Headquarters, Washington, D.C., in the Office of Space Science. The major portion of the management task is delegated to NASA's Langley Research Center, located at Hampton, Va. Langley's Viking Project Office, consisting of about 250 engineers and scientists, directs the day-to-day progress of the program. NASA Headquarters has assigned responsibility for the six Viking systems in the following way:

(1) *Lander system.*—Langley's Viking Project Office oversees Martin Marietta Aerospace's Denver Division, the contractor responsible for designing and building the Lander.

(2) *Orbiter system.*—The Jet Propulsion Laboratory has the responsibility for designing and building the Orbiter.

(3) *Launch vehicle system.*—Responsibility for this system has been assigned to NASA's Lewis Research Center. Martin Marietta Aerospace builds the Titan III booster while the Centaur stage is a product of General Dynamics Corp.

(4) *Launch and flight operations.*—Langley's Viking Project Office manages this operational system with design and implementation by Martin Marietta Aerospace, the Jet Propulsion Laboratory, and the Kennedy Space Center. Kennedy Space Center is responsible for conducting the actual launches at the Cape.

(5) *Tracking and data system.*—The DSN, built and operated by the Jet Propulsion Laboratory under the sponsorship of NASA, is the only U.S. network capable of tracking and communicating with spacecraft as far away as Mars. The Jet Propulsion Laboratory has management responsibility for this system. Ground communication, i.e., transmission of data from radio stations to control center, is achieved via landlines. The NASA Goddard Space Flight Center is responsible for this function.

(6) *Mission control and computing center system.*—The Jet Propulsion Laboratory's SFOF is equipped with the computers and displays needed for directing interplanetary missions. Responsibility for this system is assigned to the Jet Propulsion Laboratory.

So far, the organization of the Viking project follows traditional lines: The flight hardware is divided into handy systems and assigned to specific operation components of NASA and associated industrial contractors. Systems incorporating the ground-based hardware and the incredible amount of software (computer programs) have been assigned to "systems managers." When it comes to science—which is what Viking is all about—there has been a distinct departure from tradition. Most

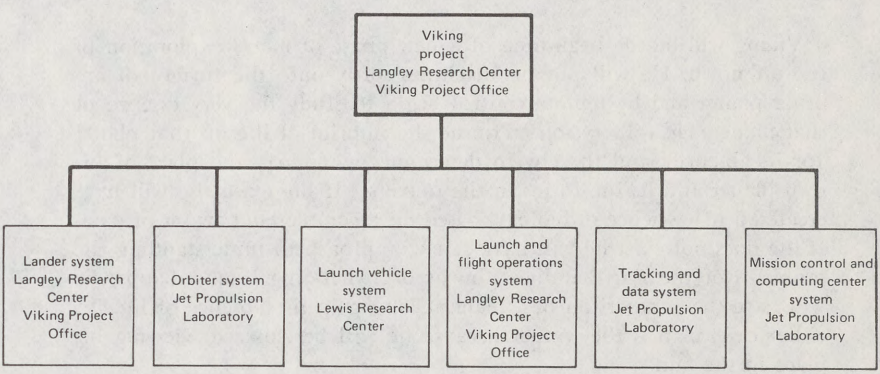


FIGURE 49.—Viking project structure.

NASA space science to date has been organized around principal investigators, individual scientists who propose a specific study, develop an instrument for flight, analyze data received, and publish results. Viking instead makes use of individual scientific teams. Each team has a leader who represents the team to the Viking project, but the scientists in each team participate on an equal basis.

**THE VIKING TEAM**

Most of the scientific instruments are on the Lander. The associated science teams are—

(1) Imaging
(2) Seismology
(3) Molecular analysis
(4) Biology
(5) Entry
(6) Magnetic properties
(7) Meteorology
(8) Inorganic chemical
(9) Physical properties

The Orbiter is also an instrument carrier and has the following science teams assigned:

(1) Imaging
(2) Water vapor mapping
(3) Thermal mapping

Lastly, a radioscience team, which uses the Orbiter and Lander radio signals, has been formed to study the properties of interplanetary space, celestial mechanics, and the Martian atmosphere by means of their effects on radio signals transmitted back to Earth or their perturbations of the spacecraft.

* * *

Viking will be the beginning of a new phase of man's exploration of the unknown. He will put his machines softly onto the surface of another planet and by remote control begin to study the very essence of that planet. He will try to determine the imprint of life on that planet (or its absence) and thereby to determine by analogy the place of his own planet and its life forms in the universe. If life exists, he will have created a new science of biology, based on a completely new set of data. If life does not exist he will have a new approach to understanding the problems of the Earth induced by its overwhelming biota; that is, he will have the comparison of a planet evolving in the absence of life. In either case, man is the winner because he will be closer to viewing his place in the Sun.

# References

1. Michaux, C. M.: Handbook of the Physical Properties of Mars. NASA SP-3030, 1967.
2. Mars Engineering Model. NASA, Apr. 14, 1972.

# Suggested Reading

Applied Optics. (Special issue), July 1969.

Astronautics and Aeronautics. (Special issue), Nov. 1969.

Glasstone, Samuel: The Book of Mars. NASA SP-179, 1968.

Hammond, Allen L.: Mars as an Active Planet: The View From Mariner 9. Science, vol. 175, Jan. 21, 1972, pp. 286–287.

Icarus. (Entire issue), Feb. 1972.

Kraemer, Robert S.: Solar System Exploration Strategy for the 1970's. Paper presented at the 17th Annual Meeting of the American Astronautical Society, Seattle, Wash., June 28–30, 1971. (AAS71-100) (See also IAA Abstract A71-37930)

Martin, James S., Jr.: Project Viking. Paper presented at the Int. Astronaut. Fed. Meeting (Vienna), 1972.

Martin, James S., Jr.: Mars Exploration With Viking. Paper presented at the 10th Space Congress, Cocoa Beach, Fla., April 11 through 13, 1973.

Martin, James S., Jr.; and Soffen, Gerald A.: The Viking Mission. Paper presented at the AAS 11th Goddard Memorial Symposium, Washington, D.C., March 8 and 9, 1973.

Murray, Bruce C.: Mars From Mariner 9. Scientific American, vol. 228, Jan. 1973, p. 48.

Ponnamperuma, Cyril; and Klein, Harold P.: The Coming Search for Life on Mars. The Quarterly Review of Biology, vol. 45, no. 3, Sept. 1970.

Radmer, Richard; and Kok, Bessel: A Unified Procedure for the Detection of Life on Mars. Science, vol. 174, Oct. 15, 1971, pp. 233–239.

Sagan, Carl: Mars, The View From Mariner 9. Astronautics and Aeronautics, vol. 10, Sept. 1972, pp. 26–41.

Soffen, Gerald; and Martin, James S., Jr.: Viking Project—How We'll Search for Life on Mars. Popular Science, Feb. 1971.

Steinbacher, R. H.; et al.: Mariner 9 Science Experiments: Preliminary Results. Science, vol. 175, Jan. 21, 1972, pp. 293–323.

Young, Richard S.: Automated Life Detection. Astronautics and Aeronautics, vol. 4, Oct. 1965, pp. 70–76.

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Dr. Petrone. Now I want to address the current cost picture. As I mentioned earlier in my statement, in the fiscal year 1971 hearings we presented a cost range of $700–850 million for the mission as now defined. Dr. Naugle and others have discussed before this committee on several past occasions both the progress and the development difficulties that occurred in the program. In past testimony, we discussed problems with several of the experiments and spacecraft systems as they developed. These problems were tracked very carefully and you were advised in NASA's annual budget hearings of our progress and the actions taken to hold the costs of the program to our estimates. We summarized the status of the program before the committee last spring, during the fiscal year 1975 hearings, indicating that after more than 4 years of holding to the fiscal year 1971 estimate for program completion, we would probably exceed the upper bound of that estimate by about 10 percent. Progress on the program since last spring indicates that we have a fundamentally sound and technically achievable program; however, several technical problems have persisted and their resolution required an increase in the estimate to complete the program to $950 million. The problems and the established cost goal were discussed in our reprograming letter to your committee dated October 10, 1974.

As as result of the cost growth in the program, we have made a detailed review of the problems yet to be resolved and have assessed the likelihood of meeting the launch schedule with a fully acceptable spacecraft. Dr. Cortright intends to discuss in detail the major problems encountered and their solutions so I will not cover them here but I do want to state that a plan has now been developed by the contractors and the respective NASA managers in each of the major problem areas which gives me confidence of their timely solution within the schedule and cost estimates now established.

Every week I review in detail the program costs, manpower levels of the major contracts, and the critical milestones essential to completing the program successfully. We have levied a $930 million cost target for completion of the program on the Langley Research Center and that is the level Dr. Cortright will discuss. The establishment of this cost target for the Center allows a prudent contingency to be maintained at the headquarters level which cannot be spent without my specific approval.

Our efforts in the past few months have concentrated on developing approaches to solving the outstanding technical problems, taking action to reduce manpower on the program, and in making a detailed review of the technical content of the program. Based on this review, we have eliminated those tests and other activities that we now feel are not absolutely necessary to the success of the program. This included the elimination of one Orbiter and Lander which were to be used as backup hardware.

We believe the steps I have described will enhance the probability of meeting our remaining scheduled milestones, will contribute significantly to staying within the $950 million cost goal and will not seriously jeopardize the probability of mission success.

Mr. Chairman, I believe we have acted responsibly in the management of the Viking program. The cost increases we have experienced resulted from developing the most advanced automated space equipment this country has ever attempted. The problems in the development are largely behind us and we have confidence in our present technical approach and our ability to meet cost goals. NASA has taken every reasonable action to assure mission success, to provide the world new knowledge about the planet Mars through direct measurement in its atmosphere and on its surface, and to hopefully answer the centuries-old question of whether life exists on Mars.

Mr. Chairman, this concludes my statement. Dr. Cortright and Mr. Parks are prepared to discuss the program in greater technical detail.

Mr. Symington. Thank you, Dr. Petrone, for a very good overview of the progress and current status of the Viking project. I think, if it is satisfactory with my colleagues on the committee, before we address questions to you it might be well to proceed with Dr. Cortright's statement.

Dr. Cortright, would you like to proceed with your statement?

## STATEMENT OF EDGAR M. CORTRIGHT, DIRECTOR, LANGLEY RESEARCH CENTER, NASA

Dr. Cortright. Mr. Chairman, I welcome this opportunity to appear before you and your subcommittee to discuss the status of the Viking project. Over 6 years have passed since the Congress authorized NASA to undertake the Viking mission to land on the surface of Mars for the purpose of scientific exploration. During this period you have provided unwavering support and encouragement, for which all the Vikings are grateful. We fully understand and share your concerns over technical and schedule problems and rising costs. Today I will try to address each of those concerns, and to show you why I believe we have all of those problems under control. Subsequent testimony by key officials of the Jet Propulsion Laboratory (JPL), the Martin Marietta Corp. (MMC), Honeywell, Inc. (HI), and TRW Systems will provide additional insight into the project status.

My statement will address the areas of cost growth, cost control, and program status.

Before summarizing the cost history of the Viking project, I would like to call to your attention that, at the start of the project, I requested NASA headquarters to assign a full-time audit team to reside at Langley and provide audit services.

Mr. Symington. Is that a normal procedure?

Dr. Cortright. No; it is not. We recognized the magnitude of the job and felt the best thing to do is go open books from the beginning.

In addition, in November 1970 a GAO team from Norfolk commenced a more or less continuing series of Viking project audits. And they have spent much time at our center and contractors plants. The resulting audits have not only helped us avoid some pitfalls, but have provided a clear record of all that has transpired. The Viking cost history is shown in figure 1.

VIKING PROJECT COST HISTORY

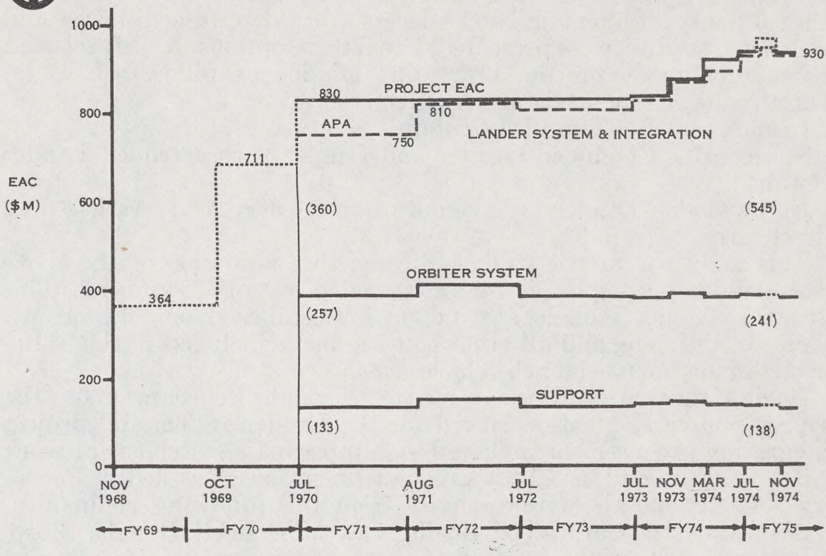



FIGURE I

November 1968–July 1970. This period covers the time from NASA's first in-house estimates, through the firm contracting for a 1973 launch, and up to and including the redirection and restructuring of the contract for a 1975 launch date. In other words, the dotted portion of this curve is the 1973 mission and the solid portion is the 1975 mission.

In mid-1967, the Langley Research Center began studies of an Orbiter/nonsurvivable probe mission to Mars for 1973. The President's Scientific Advisory Committee reviewed this mission concept along with other candidate Mars missions in late 1967 and concluded that the 1973 mission should obtain data from the surface of Mars. In other words, a nonsurvivable probe was not adequate for the mid-seventies timeframe. Thus, the NASA headquarters provided guidelines to the Langley Research Center in January 1968 for the conduct of studies of a 1973 mission that emphasized the return of landed scientific data.

The Langley Research Center initiated in-house and contracted studies directed toward defining this 1973 mission concept. A tentative mission definition was published in April 1968, which further defined science and other requirements and provided a basis for continuing mission study efforts. The National Academy of Sciences/Space Science Board held a summer study to further science objectives for the 1973 mission. Results of this summer study were utilized by NASA headquarters to develop revised guidelines which were provided to the Langley Research Center in July of 1968. The revised guidelines were reflected in a new mission definition in August which was incorporated into all study activities.

A comprehensive mission mode briefing, incorporating various mission options, was given to NASA headquarters in early November 1968. Twenty different mission concepts, based on the in-house and contracted studies, were presented. From these options, NASA selected the mission mode for the 1973 Mars mission as follows: It is essentially the mission mode we are still on today.

Launch vehicle—Titan III Centaur.

Spacecraft—Combined Orbiter and Lander with extended Lander lifetime.

Entry mode—Lander to have out-of-orbit entry mode, rather than direct entry.

This early parametric study indicated that a mission of the above class could be accomplished for an estimated cost of $364 million. This estimate did not include any factor for escalation or contingency. This cost estimate, and all other cost estimates included in this statement, did not include launch vehicle costs.

During the period December 1968 through February 1969, the NASA Source Evaluation Board for the Lander system and project integration procurement reviewed and approved a statement of work which was included in NASA's request for proposals issued in February 1969. Proposals were received from the following companies: Martin Marietta Corp., The Boeing Co., McDonnell Douglas Corp.

Proposal evaluation consisted of a detailed assessment of each proposal during which deficiencies, omissions, and ambiguities were identified and communicated to the offerors. This was followed by plant visits during which each offeror was given an opportunity to support, clarify, correct, improve, or revise his proposal.

The results of the overall evaluations were presented to the administrator in May 1969. Martin Marietta Corp., was the selected contractor. At that briefing it was reported that the project target cost was estimated to be a minimum of $530 million—but possibly running as high as $588 million—including 5 percent annual escalation. The total estimated runout cost with contingency was $695 million. At that time the actual accrued costs on the project were approximately $2 million. I state that figure to point out things were still in a fairly preliminary situation, although we did have the proposals of the contractors which significantly upgraded our understanding of the job.

In early June 1969, a limited go-ahead was given Martin Marietta Corp., for initiation of necessary long lead activities. An updated version of the mission definition was issued in June 1969 and the final version on August 11. The cost, weight, and requirements constraints for Viking science were established at a science review at NASA Headquarters (SSA) in September 1969.

Subsequent to the selection of the Martin Marietta Corp., but prior to completion of contract negotiations, technical discussions between the Viking Project Office (VPO) and Martin Marietta resulted in the identification of a number of potential changes to the basic scope of work. The negotiation activities were completed by mid-September and, following NASA headquarter's review, the contract was executed on October 20, 1969.

Mr. Symington. Was that a fixed price contract?

Dr. Cortright. No, it was a cost-plus incentive award fee.

Mr. SYMINGTON. Is that the type contract Martin has executed with its subs?

Dr. CORTRIGHT. The types of contracts Martin holds with the subcontractors vary. In the case of Honeywell; for example, they had a fixed price for some parts of the project.

Mr. SYMINGTON. NASA never had a fixed price contract with Martin?

Dr. CORTRIGHT. No.

Concurrently with the above described activities, the Jet Propulsion Laboratory evaluated the effect of the Martin Marietta Corp. Lander design concept on the Orbiter baseline. Changes necessary to achieve hardware compatibility, and those resulting from a weight reduction program, to arrive at a spacecraft weight that would provide a minimum launch period of 30 days, were reviewed by the VPO in early August 1969.

At the conclusion of program definition and cost negotiations with MMC and JPL, the estimated target cost—wherein I will repeat, the systems were made initially compatible—the estimated target cost, including 5-percent escalation, was revised to $610 million. With contingency of $101 million—16 percent—the total cost was estimated to be $711 million.

Mr. SYMINGTON. That was upward revision of $80 million.

Dr. CORTRIGHT. Yes; when referenced to the minimum target cost, but not in the total which went from $695 million to $711 million.

Mr. SYMINGTON. What were the factors that contributed to that increase?

Dr. CORTRIGHT. I will list some of those for you in just a moment. Basically, the Lander system was growing in weight and complexity as we negotiated it out and these in turn reflected in the Orbiter system. We found that the Orbiter system, for example, could not use as much of the Mariner technology and hardware as we anticipated so it grew in cost also during that period. The Lander grew $32 million due to changes in design, engineering changes, and ground equipment additions. In addition, cancellation of the MOL contract at Martin Marietta increased the overhead. The Orbiter cost increased $3 million due to engineering changes. Estimates of support costs increased to $45 million. These were expenses associated with the science team, provision for the award fee, instrument development changes, and facilities additions. These were all details which were not apparent to us until we got into this detailed negotiation.

Mr. SYMINGTON. Would you put that in the record in detail?

Dr. CORTRIGHT. Be glad to, Mr. Chairman.

Mr. SYMINGTON. Describe them as particularly as you can.

*May–October 1969 target cost changes—*

| | *Millions* |
|---|---|
| Lander: | |
| Science definition changes (includes GCMS changed to GFE) | $14.0 |
| Engineering definition changes | 7.4 |
| Master schedule change (additional AGE) | 7.4 |
| Increased overhead due to MOL termination | 6.7 |
| Delete inverted Lander capability | (−1.3) |
| Delete facilities (computers) | (−2.1) |
| Subtotal | 32.1 |
| Orbiter: | |
| Engineering definition changes | 5.2 |
| Credit for schedule adjustment | (−2.4) |
| Subtotal | 2.8 |
| Other: | |
| Adjustments: | |
| Science team support | 10.7 |
| Ames biology support | 0.6 |
| Langley support | 4.7 |
| MMC award fee | 9.0 |
| DOD contract support | 3.2 |
| Support contracts | (−1.2) |
| Organic/atmospheric analysis instrument | 3.9 |
| New items: | |
| Back-up instruments | 12.0 |
| Facilities (computers) | 1.9 |
| Subtotal | 44.8 |
| Total | 79.7 |

Dr. CORTRIGHT. Mr. Chairman, at this time period, in August of 1970, the then chairman of this subcommittee, Congressman Karth accompanied by Mr. Hammill, I believe, and perhaps others of the committee, visited the Langley Research Center to obtain a detailed understanding of where the cost increases had arisen from the outset of the program to that point in time. This cost history was provided him at that time. In the event that it is no longer in your records, I would like to resubmit it for the committee's use because it goes into these changes in very great detail and may meet your needs.

Mr. SYMINGTON. All right.

[The information follows:]

# VIKING 75 PROJECT

COST HISTORY

(JANUARY 1968 TO JULY 1970)

AUGUST 1970

(FOR OFFICIAL USE ONLY)

Prepared by the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Langley Research Center
Viking Project Office

# VIKING PROJECT

## COST HISTORY

JANUARY 1968 TO JULY 1970

AUGUST 1970

Authorized for release: James S. Martin, Jr.
Viking Project Manager

# SUMMARY

The adjacent chart summarizes the Viking cost estimates at the conclusion of specific phases of project development. Additionally, the chart identifies these phases and depicts cost incurred. A detailed description of each of these phases is given in the subsequent sections of this presentation. A summary of the factors that contributed to the cost changes is given in the chart.

Definitions of the cost elements and levels given in the chart are defined below:

Lander Cost - Lander and Project Integration Prime Contract cost.

Orbiter Cost - Jet Propulsion Laboratory Orbiter System cost.

Other Cost - Project management; lander support (not included in contract); orbiter support (not included in JPL funding).

Examples of "Other Cost" are financial support provided for Viking scientist, support services contracts, and Government Furnished Equipment to the lander contractor.

Target Cost - Current best estimate of project cost with no contingency.

Cost presented in this report excludes cost for the Launch Vehicle and Tracking and Data Systems.

Contingency - The cost estimated for unknown but anticipated approved changes required to meet project objectives.

Possible Cost - The total of Target Cost plus Contingency.

## VIKING COST ESTIMATES SUMMARY

($ Millions)

| | Nov. 1968 (Mission Mode Selection) Target Cost Unescalated | Escalated | | May 1969 (Receipt of Proposals) Target Cost Min./Max. | Possible Cost | | October 1969 (Start Viking '73) Target Cost | Possible Cost | | February 1970 (Viking '75) Preliminary Target Cost Min/Max | | July 1970 (Viking '75) Target Cost | | Possible Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LANDER | 218.0 | 251.0 | Larger Lander Based on "Point" Design; Escalation | 281.5/309.7 | 362.3 | Science Definition Chgs.; Design Refinement; MOL Cancellation; Additional AGE | 313.6 | 365.6 | Two Year Slip; Escalation; Test Program Adjustment; Mission Design Changes; New Mars Engineering Model | 345 / 380 | | 359.5 | | 405.0 |
| ORBITER | 131.0 | 159.0 | Designed to Larger Lander; Large Deviation to Mariner '71; Escalation | 199.7/219.6 | 263.4 | Design Refinement | 202.5 | 236.4 | Two Year Slip; Escalation; Mission Design Changes; Hardware Commonality Gains | 237 / 272 | | 256.9 | | 272.0 |
| OTHER | 15.0 | 18.0 | Estimating Technique Chg'd Fixed Percentage (7% of Lander) vs Assessment by Line Item | 48.9/58.5 | 69.1 | Science Team Support; Back-up Science Instrument Devel.; GCMS Instrument; Facilities Contract; MMC Award Fee | 93.7 | 109.0 | Two Year Slip; Escalation; Back-up Instruments Deleted; Additional Lander Support | 109 / 124 | | 133.6 | | 153.0 |
| TOTAL | 364.0 | 428.0 | Lander 30.5; Orbiter 40.7; Other 30.9; Total 102.1 | 530.1/587.8 | 694.8 | Lander 32.1; Orbiter 2.8; Other 44.8; Total 79.7 | 609.8 | 711.0 | Escalation 51.0/51; Lander 12.0/47; Orbiter 11.9/47; Other 6.3/21; Total 81.2/166 | 691 / 776 | Change Oct. 69 Target Cost: Escalation 56; Lander 16; Orbiter 37; Other 31; Total 140 | 750.0 | Contingency Through Project Completion (≈15%) | 830.0 |

| Timeline | CY 68: O, N, D | CY 69: A, M, J | S, O, N | CY 70: J, F, M | J, J, A | CY 71 | CY 77 |
|---|---|---|---|---|---|---|---|
| Phases | Early Planning; Preproposal/Proposal | Negotiation | Viking '73 Implementation | Viking '75 Program Planning; Viking '75 Negotiation | | Viking '75 Implementation | |
| ACTUAL VIKING PROJECT COST INCURRED (W/TERMINATION LIABILITY) | 0 | 1.9 | 12.0 | 24.3 | 37.0 | | |

This chart summarizes the major sources of cost increases since November 1968. Subsequent sections will delineate the factors that are included in each of the items shown on this chart.

# VIKING PROJECT
## MAJOR SOURCES OF COST INCREASE
## November 1968 to Present
## ($ Millions)

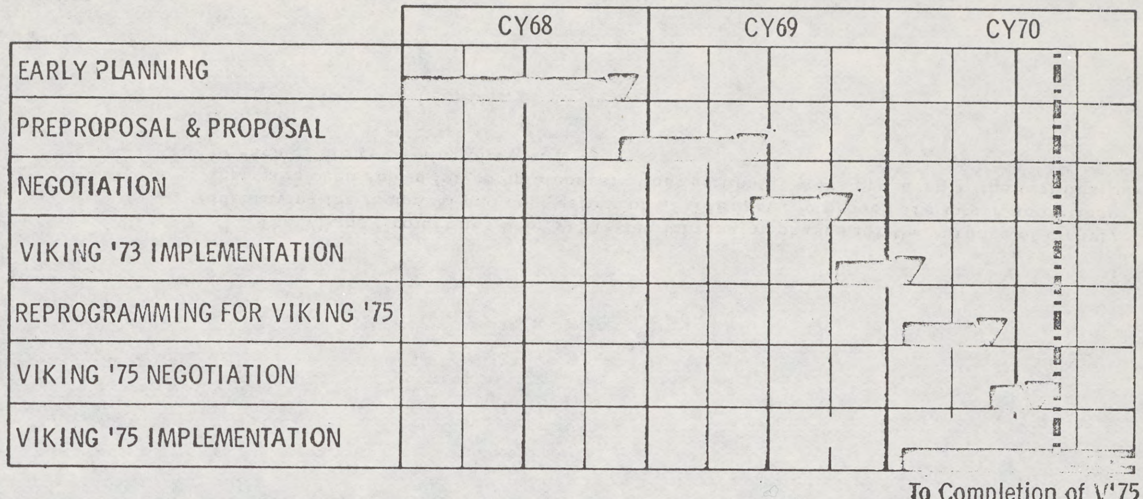
| | | |
|---|---|---|
| **Viking '73** | | |
| Escalation (for unescalated preliminary estimate) | 64 | |
| Lander | 63 | |
| Orbiter | 43 | |
| Other (Project Management, Lander and Orbiter Support) | 76 | |
| TOTAL | | 246 |
| **Viking '75** | | |
| Escalation (two year slip in '73 program) | 56 | |
| Lander | 16 | |
| Orbiter | 37 | |
| Other (Project Management, Lander and Orbiter Support) | 31 | |
| TOTAL | | 140 |
| Contingency | | 80 |
| TOTAL COST INCREASE | | 466 |

VIKING PROJECT

DETAILED TECHNICAL AND COST REPORT

The Viking Project has been separated into major phases for the purpose of clearly identifying the technical and cost definitions. The last two phases are future activities that have been shown for completeness. Cost estimates were prepared at the termination of each of the remaining phases.

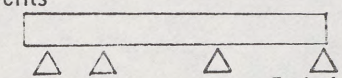
MAJOR PROJECT PHASES



The subsequent sections, which describe each of the major project phases, are divided into four topics. A description of the significant activities occurring during each phase is given under the heading of "Major Events". At the end of each phase a science and engineering definition is given to provide the technical basis for the cost estimate. The cost estimating technique and sources of changes from the previous phase are identified.

## FORMAT FOR DISCUSSION OF EACH PHASE

- Major Events



End of Phase

- Science Definition
- Engineering Definition
- Cost Estimate

# EARLY PLANNING PHASE

## JANUARY 1968 TO NOVEMBER 1968

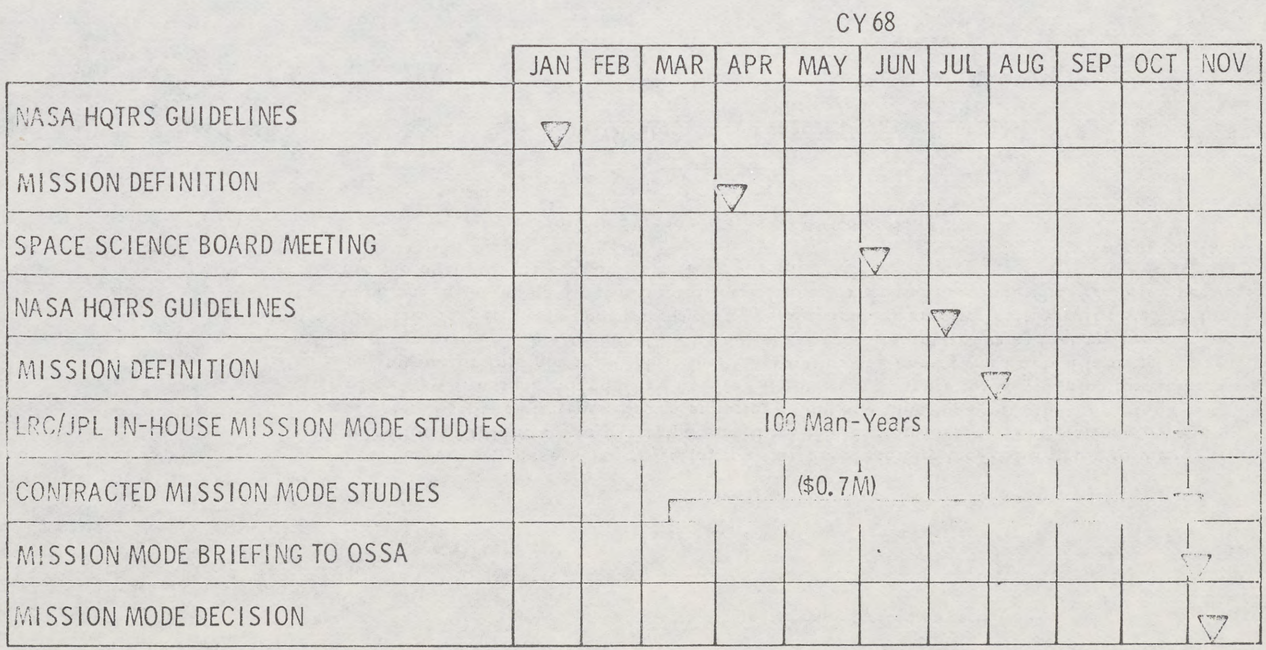
In mid-1967, the Langley Research Center began studies of an Orbiter/nonsurvivable probe mission to Mars for 1973. The President's Scientific Advisory Committee reviewed this mission concept along with other candidate Mars missions in late 1967 and concluded that the 1973 mission should obtain data from the surface of Mars. The NASA Headquarters provided guidelines to the Langley Research Center in January 1968 for the conduct of studies of a 1973 mission that emphasized the return of landed scientific data. The Langley Research Center initiated in-house and contracted studies directed towards defining the 1973 mission concept. A tentative mission definition was published in April 1968, which defined science and other requirements to give continuity to the study efforts. The National Academy of Sciences/Space Science Board held a summer study to better define objectives for the 1973 mission. Results of the summer study were utilized by NASA Headquarters to develop revised guidelines which were provided to the Langley Research Center in July. The revised guidelines were reflected in a new mission definition in August which was incorporated into all study activities. A mission mode briefing was given to NASA/OSSA in early November. Twenty different mission concepts, that were based on the in-house and contracted studies, were presented. The mission mode for the 1973 Mars mission was established by the NASA to be as follows:

Launch Vehicle: Titan III/Centaur

Spacecraft: Combined Orbiter and Lander with extended Lander lifetime

Entry Mode: Lander to have out-of-orbit entry mode.

## MAJOR EVENTS



The early phase science definition was developed by the NASA prior to the selection of scientists to participate in the 1973 Mars mission. The National Academy of Sciences/Space Science Board summer study and meetings with the Lunar and Planetary Missions Board were used as the primary inputs for developing the science definition for this phase. The science status for the end of the Early Planning Phase is given below. This science status delineates the weight and cost that correspond to the science definition shown on the adjacent chart. A similar status will be given for each phase including a definition of the changes from the previous phase and the reasons for the changes.

Science Status as of November 1968

| Weight (lbs) | | |
|---|---|---|
| Orbiter | Lander | Cost ($M) |
| 128 | 55 | 54 |

## SCIENCE DEFINITION

(Mission Definition No. 1)

**Orbiter**

- Imaging (Mariner '71 System)
- Infrared Thermal Mapping
- Infrared Spectrometry (Mariner '71 System)
- Infrared Water Vapor Mapping

**Lander**

Entry:
- Atmospheric Structure
- Atmospheric Composition (lower atmosphere)

Landed:
- Imaging
- Biology (three experiments)
- Organic Analysis
- Atmospheric Composition
- Soil Water
- Meteorology

The engineering definition was established by the NASA as a result of the early November mission mode briefing. A Phase B report was prepared following the mission mode briefing that documented the data used in defining the engineering definition.

The details of the Orbiter definition were based on Jet Propulsion Laboratory studies using the criterion that the Orbiter be a direct derivative of Mariner '71 with only those changes necessary to support the Lander and the Science definition. Changes were required in the propulsion system to provide the velocity change capability to place both the Orbiter and Lander into orbit about Mars. Structural changes were necessary to support the Lander and the relay Communications System was added to provide the capability of obtaining Lander data by way of Orbiter relay as well as directly from the Lander to Earth.

The Lander definition was based on the contracted studies and Langley Research Center studies discussed in the "Major Milestones" section. A soft lander with extended life capability (approximately 90 days) was selected. To provide the extended life capability, a power regeneration system was necessary. The Lander communications system consisted of relay by way of the Orbiter, direct transmission to Earth, and direct command from Earth.

A considerable amount of mission analysis (trajectory analysis, navigation studies, etc.) information for a 1973 Mars mission was developed as a part of Voyager studies. This information served as a valuable foundation for developing the mission concepts during the Early Planning Phase and provided confidence for the technical decisions.

## ENGINEERING DEFINITION

### Orbiter

- Derivative of Mariner '71 Orbiter to Support 1800-lb Lander
- Weight

  Dry: 1925 lbs
- Major Changes From Mariner '71

  Increased Propulsion Capability
  Redesigned Structure
  Added Relay Communications System

### Lander

- Soft Lander
- Extended Life with Power Regeneration
- Relay, Direct to Earth, Direct from Earth Command Communications Capability
- Weight

  1700 lbs
- Science Interface

  Instruments Weight: 55 lbs (entry 18, landed 37)

The $364 million target cost was derived from estimates based on actual costs of prior lunar and planetary projects and was stated in 1968 dollars. For those items not included in the historical base, engineering estimates were used (for example, Lander radar and terminal propulsion systems). A factor of 5% per year was used to escalate 1968 dollars to the $428 million estimate. The "Other" costs were substantially underestimated during this phase of the project.

Advanced Planetary Missions Technology funds were used to support the activities performed during the Early Planning Phase. The total cost incurred during this phase was $0.7M. Approximately 100 man-years were expended by the Jet Propulsion Laboratory and the Langley Research Center during this phase.

TARGET COST ESTIMATE

($ Millions)

| | 1968 Dollars | Escalated Dollars |
|---|---|---|
| Lander | 218 | 251 |
| Orbiter | 131 | 159 |
| Other | 15 | 18 |
| Total - November 1968 | 364 | 428 |

44-128 O - 75 - 9

## ESTIMATING METHODS

Lander - Cost Model Based on Lunar Orbiter (LO) Experience

Characteristics:

- Subsystems - LO Subsystem Cost Per Pound
- Support - LO Subsystem Cost Per Pound Less the Mechanical and Structure Subsystems
- Management - Percentage of LO Management Cost to LO Subsystem Cost
- Operations - LO Per Month Cost Rate - Before and After Launch

Additional Factors:

- Sterilization
- Contractor Fee
- Escalation (1965 to 1968)
- Project Integration

Orbiter - Planning Research Corporation (PRC) Cost Model

Assumptions:

- Significant Inheritance of Mariner '71 Hardware
- Subsystem Level Contracting
- Prototype Model
- Upgraded Mariner '71 Science

Characteristics:

- Historically Derived Factors (e.g., cost per pound)
- Cost Values in 1968 Dollars

Other - Based on Lunar Orbiter Experience

# PREPROPOSAL AND PROPOSAL PHASE

## NOVEMBER 1968 TO MAY 1969

The NASA Administrator approved the Viking Project on February 8, 1969, at a planned cost of $364 million for two missions to Mars in 1973 using Titan IIID/Centaur launch vehicles, and modified Mariner '71 Orbiters to deliver the soft landers from an orbital entry.

Lander Science Instrument Teams were selected by NASA Headquarters in February 1969 to participate in mission planning and science instrument development.

The Baseline Orbiter Conceptual Design Document was developed during the early part of this period and was released on March 1, 1969. This provided the basis for the Orbiter cost estimate. A VPO Cost Review Team examined the proposed costs of $199.7 million during early May 1969. On May 7, 1969, VPO was briefed by JPL and the VPO Team on the results of this review.

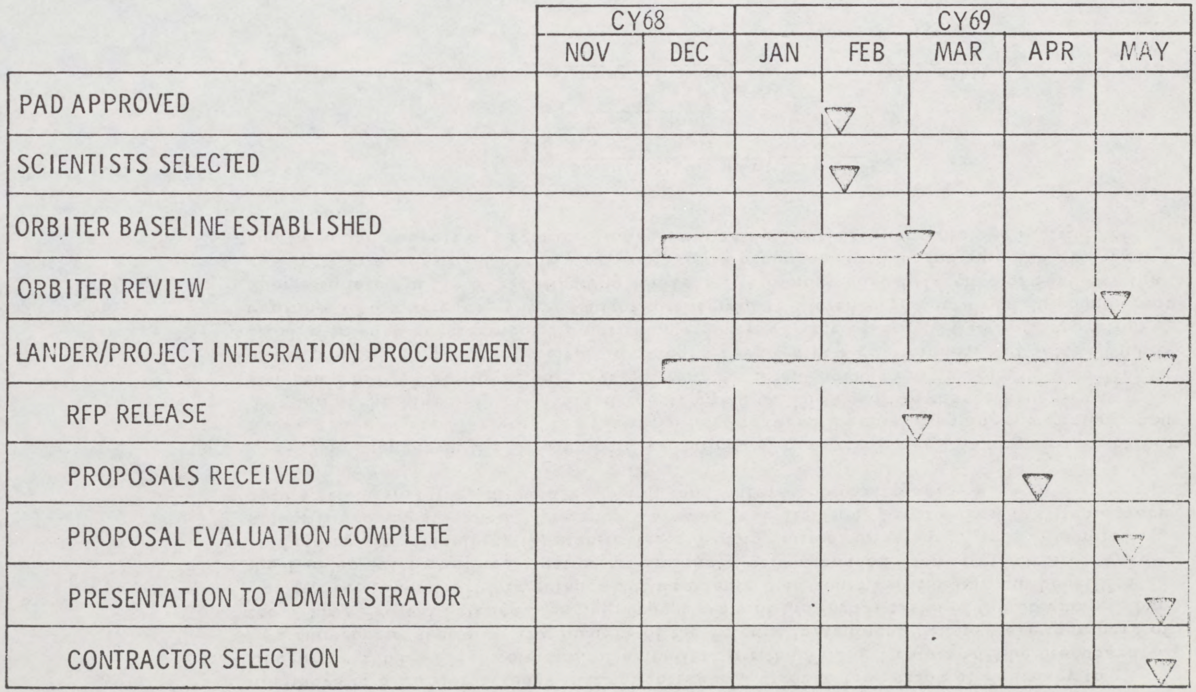
During the period December 1968 through February 1969, the Source Evaluation Board for the Lander System and Project Integration procurement approved the Statement of Work and Request for Proposal. Proposals were received from the following companies:

Martin Marietta Corporation
The Boeing Company
McDonnell Douglas Corporation

Proposal evaluation consisted of a detailed assessment of each proposal during which deficiencies, omissions, and ambiguities were identified and communicated to the offerors. This was followed by plant visits during which each offeror was given an opportunity to support, clarify, correct, improve, or revise his proposal.

The results of the overall evaluations were presented to NASA/OSSA and the Administrator in May 1969. Martin Marietta Corporation was the selected contractor.

MAJOR EVENTS



Approximately 40 scientists were selected to participate in planning activities as members of 8 Lander Science Instrument Teams through the period of February to December 1969. Final selection of scientists for the Viking Project will be discussed in a subsequent section. The leaders of the Science Instrument Teams were members of the Viking Project Science Steering Group. One of the initial tasks of the Steering Group was to recommend Orbiter science requirements that would be of maximum benefit to the Lander scientific investigations. The three recommended uses of the Orbiter were (1) landing site selection, (2) monitoring of landing site after landing, and (3) general scientific reconnaissance. The most valuable investigations for the first two items were defined to be imaging, thermal mapping, and water vapor mapping.

The changes in the Orbiter science definition required a new imaging system rather than a reuse of the Mariner '71 system, a new infrared thermal mapping instrument, and deletion of the Mariner '71 infrared spectrometer. The result of these changes was a reduction in the Orbiter science system weight and an increase in complexity because of the new imaging system. Orbiter changes resulted in a cost increase of $6M. The Lander science requirement did not change; however, the Martin Marietta Corporation estimate of the science system weight to accomplish the requirements was 20 pounds more than estimated in the Early Planning Phase. The Lander cost difference of $6M was the result of an assessment of the Martin Marietta proposal, funding for selected scientists, and in-house support of organic/atmospheric analysis (GCMS) and biology instrument development.

Science Status as of May 1969

| | Weight (lbs) | | |
|---|---|---|---|
| | Orbiter | Lander | Cost ($M) |
| Nov '68 | 128 | 55 | 54 |
| Changes | -28 | 20 | 12 |
| May '69 | 100 | 75 | 66 |

## SCIENCE DEFINITION

Orbiter - Differences From Early Planning Phase

- Imaging System Changed to Provide Higher Resolution and Contiguous Coverage at High Resolution
- Infrared Thermal Mapping Concept Changed to Provide Higher Resolution and More Coverage
- Infrared Water Vapor Mapping Investigation Better Defined
- Infrared Spectrometer Deleted

Lander - Same as for Early Planning Phase

The Orbiter definition for the Preproposal and Proposal Phase was significantly different from that given in the Early Planning Phase. This difference is reflected in the weight and subsequent cost increases. The primary reasons for the Orbiter changes are the requirement to support a larger Lander and the new science system. These changes resulted in a much larger deviation from Mariner '71 than had been previously estimated.

The Martin Marietta Corporation proposal presented a specific Lander design with a weight estimate of about 2200 pounds. Previous weight estimates were based on parametric studies. As a result of tests performed during this phase, the sampler capability was increased to allow a 10-foot reach to procure soil samples that are not excessively modified by the Lander.

## ENGINEERING DEFINITION

Orbiter

- o Designed to Support 2200-lb Lander
- o Weight

  Dry - 2300 lbs - Increase of 375 lbs
- o Power Requirements Increased to Support Lander
- o New Science System

Lander

- o Weight

  2200 lbs - Increase of 500 lbs
- o Science Interface

  Instruments Weight: 75 lbs (Entry 18, Lander 57)
  Surface Sampler: Increased Capability to Reach 10 Feet
- o Major Differences From Early Planning Phase

  Specific Design
  Addition of Redundancy to Increase Reliability
  Increased Science Related Weights

The minimum target cost increase from the preliminary estimate in November 1968 to May 1969 was $166. 1 million. This growth was due to engineering and science definition changes, a significant decrease in Orbiter inheritance from the Mariner '71 program ($71. 0M), incorporation of inflation at the rate of 5% per year ($64. 0M) and an underestimate of "Other" costs ($31. 0M). A maximum target cost of $587. 8M was reported to represent the changes anticipated in the Lander Contractor and JPL proposals and estimates for "Other" cost. A possible cost of $694. 8M was established.

The cost estimates given in the three competitive proposals for the Lander ranged from $279M to $310M. Two separate cost analyses were made during the assessment of the proposals. The cost model technique of estimating was applied to the proposed Lander weight statement. A detailed cost analysis of each proposal was performed as a part of the Source Evaluation Board proposal evaluation process. The results of these independent analyses were approximately the same and verified the cost estimates. The Lander cost estimate given on the adjacent chart was derived from the Martin Marietta Corportion's competitive proposal.

Orbiter cost was developed by Jet Propulsion Laboratory based on detailed estimates at the subsystem level. The engineering definition for the estimates is documented in the "Baseline Orbiter Conceptual Design Description" discussed previously. An adjustment for escalation was made to arrive at the total estimated cost. The Viking Project Office analyzed the estimate in detail and concluded that the target cost was acceptable. Viking Project Office approval of the baseline description and the associated cost estimate constituted approval for Jet Propulsion Laboratory to proceed.

In the previous section, "Other" cost was estimated to be 7% of the Lander cost. During this phase the estimating technique was changed to an assessment of each item not included in either the Lander or Orbiter categories. This identified several new items which resulted in a significant increase in the "Other" cost.

The total cost incurred at completion of this phase was $1. 9M (0. 3% of Viking '73 Target Cost, October 1969).

COST ESTIMATE
($ Millions)

| | Nov. 1968 | Delta Cost | | May 1969 | | |
|---|---|---|---|---|---|---|
| | | | | Target Cost | | Possible Cost |
| | Unescalated | Escalation | Changes | Min. | Max. | |
| Lander | 218.0 | 33 | 30.5 | 281.5 | 309.7 | 362.3 |
| Orbiter | 131.0 | 28 | 40.7 | 199.7 | 219.6 | 263.4 |
| Other | 15.0 | 3 | 30.9 | 48.9 | 58.5 | 69.1 |
| Total | 364.0 | 64 | 102.1 | 530.1 | 587.8 | 694.8 |

## SOURCE OF DELTA COST

| | $M |
|---|---|
| **Lander** | |
| ° Engineering and Science Definition Changes | 30.5 |
| ° Estimate Based on Specific Design | |
| **Orbiter** | |
| ° Engineering and Science Definition Changes | 40.7 |
| ° Mariner '71 Hardware Inheritance Decrease | |
| ° Estimate Based on Specific Design | |
| **Other** | 30.9 |
| ° Identification of Cost Items | |
| Science Teams | |
| Support Services Contracts | |
| Ames Research Center Biology Support | |
| GFE to Martin Marietta Corporation | |
| ETR Operations | |
| Data Handling | |
| Award Fee to Martin Marietta Corporation | |
| JPL Mission Analysis Support | |
| JPL Lander Systems and Science Support | |
| Facility Modifications | |
| DOD Contract Support | |
| Langley Support | |
| ° Estimate Based on Engineering Assessment | |
| Total of Delta Cost | 102.1 |
| Escalation | 64.0 |

# NEGOTIATION PHASE

## MAY 1969 TO OCTOBER 1969

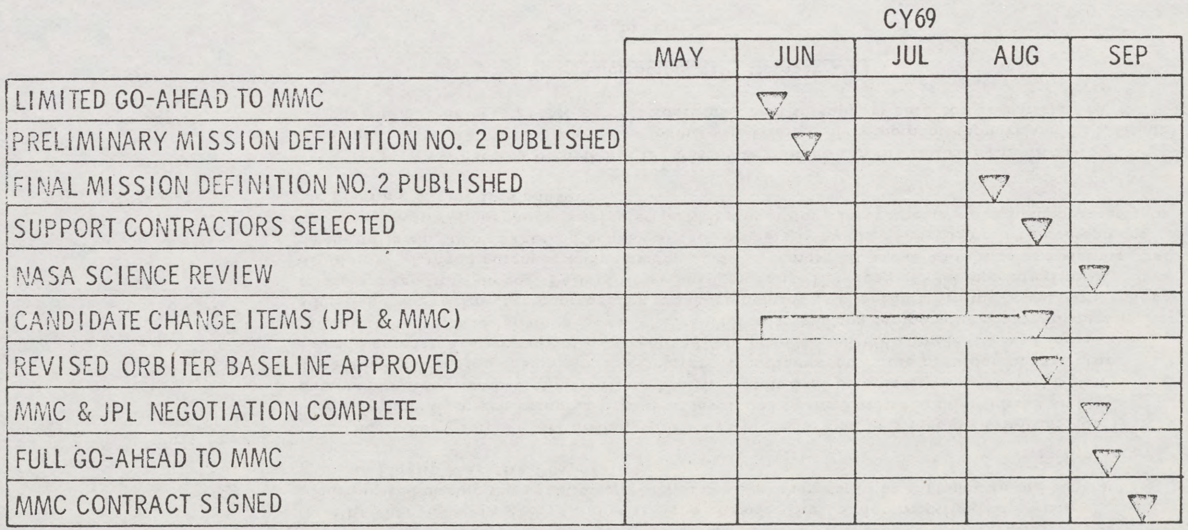
In early June 1969, a limited go-ahead was given Martin Marietta Corporation for commencement of necessary long lead activities. Contracts were awarded to the General Electric Company and Beckman Instruments to perform support services for the Viking Project.

A preliminary version of Mission Definition No. 2 was issued in June 1969 and the final version was issued on August 11, 1969. The cost, weight, and requirements constraints for Viking science were established at a science review at NASA Headquarters (OSSA) in September 1969.

Subsequent to the selection of the Martin Marietta Corporation, but prior to contract negotiation, technical discussions between the Viking Project Office and Martin Marietta resulted in the identification of a number of potential changes to the basic scope of work. These included such items as the addition of Lander simulators for Orbiter testing, combining the attitude control system and deorbit system to allow common development and increased reliability, and the new science definition. Martin Marietta was directed to submit proposals for these candidate changes during the period June to September 1969. The basic proposal and the candidate change items were analyzed in detail during the same time period. Decisions were made as to which change items were to be included in the Martin Marietta scope of work. The negotiation activities were complete with a full go-ahead given Martin Marietta in mid-September. Following NASA Headquarters review, the contract was executed on October 20, 1969. Advisory price analyses submitted by the Department of Defense were utilized during the negotiation.

Concurrently with the above described activities, the Jet Propulsion Laboratory evaluated the effect of the Martin Marietta Corporation's Lander design concept on the Orbiter baseline. Candidate changes necessary to achieve hardware compatibility, and those resulting from a weight reduction program (to arrive at a spacecraft weight that would provide a minimum launch period of 30 days) were reviewed by the Viking Project Office in early August 1969. The candidate changes and related cost were reviewed by the Viking Project Office. Approved changes were incorporated into the Orbiter baseline in late August 1969. These included structural changes, power system changes, and the addition of two Orbiter simulators to be used in the Lander test program.

MAJOR EVENTS



As was discussed in the previous phase, scientists were selected in February 1969 to participate in Viking Project planning. Significant modifications in the science definition were necessary to accommodate the recommendations of the scientists. The Orbiter changes were given in the previous phase. The Lander modifications were incorporated during the negotiation phase such that they could be included in the contract with the Martin Marietta Corporation.

The revised science definition, which was incorporated in Mission Definition No. 2, was significantly more complex than that developed in the Early Planning Phase and documented in Mission Definition No. 1. This additional complexity was in the Lander area since the major changes in the Orbiter were discussed in the previous phase. The Lander science system weight was reduced five pounds, but the complexity was increased in both the entry and landed phases. For entry, a stagnation temperature instrument was added and the regime for composition measurements was changed from the lower atmosphere to the upper atmosphere. Both of these changes caused increased systems integration problems. Landed science changes were made in almost all areas and these are summarized on the following two charts. Because of the complexity and the short time for development, backup organic/atmospheric analysis (GCMS) and biology instruments were incorporated into the planning during this phase.

The factors that are included in the cost change shown in the following table are (1) Lander changes $18.5M (includes inhouse instrument development support and GFE GCMS), (2) backup instruments $12M, and (3) additional cost to support selected scientists $10.7M:

Science Status as of October 1969

| | Weight (lbs.) | | |
|---|---|---|---|
| | Orbiter | Lander | Cost ($M) |
| May '69 | 100 | 75 | 66 |
| Changes | 0 | -5 | 41 |
| Oct. '69 | 100 | 70 | 107 |

## SCIENCE DEFINITION

### Mission Definition No. 2

**Orbiter**

- Imaging
- Infrared Thermal Mapping
- Infrared Water Vapor Mapping
- Radio

} Same as for Preproposal and Proposal Phase

**Lander**

Entry:
- Atmospheric Structure
- Atmospheric Composition (Upper Atmosphere)

Landed:
- Imaging
- Biology (4 Experiments)
- Organic Analysis
- Atmospheric Composition
- Soil Water
- Meteorology
- Seismometry
- Ultraviolet Photometry
- Radio

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## SCIENCE DEFINITION - Continued

### Major Differences From Negotiation Phase and Preproposal/Proposal Phase

**Orbiter**

None

**Lander**

Entry: Changed Regime for Making Atmospheric Composition Measurements From Lower Atmosphere to Upper Atmosphere.

Landed: Added an Additional Biology Experiment and Increased Complexity of Other Three Experiments.

Added Requirements for the Organic Analysis Investigation; Dual Ovens (Different Sizes), Direct Input to Mass Spectrometer, and Gas Chromatograph Detector.

Modified Soil Water Investigation to Delete Subsurface Probe and Increase Requirements for On-Board Instrument.

Added Azimuth Redundancy and Vertical Profile Requirements to Meteorology Investigation.

Added Seismometer, Ultraviolet Photometer, and Range Rate Measurement by Orbiter-to-Lander Relay Link.

The Orbiter definition was essentially the same as for the previous phase with some design refinements to accommodate the revised lander.

Lander changes were made to provide a more reliable design concept, incorporate the new science definition into the Lander science system, and accommodate the changes in other Lander systems due to the revised science system.

## ENGINEERING DEFINITION

### Orbiter

- Same as for Previous Phase With Following Exceptions:

  Design Refinement (Orbiter Weight Reduction)
  Additional Orbiter Simulators (2)
  Added Range Rate Measurement Capability to Relay Link
  Added Single Channel Command

### Lander

- Same as for Previous Phase With Following Exceptions:

  Changes Necessitated By New Science Definition
  Increased Core Storage
  Additional Lander Simulator
  Combined Attitude Control and Deorbit Systems
  Additional Wind-Tunnel Tests
  Additional AGE

Cost growth during this period was principally due to the increase in Lander science requirements, the Orbiter and Lander design refinements, and "Other" cost.

The "Other" cost growth was due to previous underestimates of the items defined in the Preproposal and Proposal Phase and the identification of new items requiring substantial cost allocations.

The total cost incurred at completion of this phase was $12M (2.0% of Viking '73 Target Cost, October '69).

## COST ESTIMATE

($ Millions)

| | May 1969 | | | October 1969 | |
|---|---|---|---|---|---|
| | Target Cost (Min.) | Target Cost (Max.) | Delta Cost (May Min. to Oct. Target) | Target Cost | Possible Cost |
| Lander | 281.5 | 309.7 | 32.1 | 313.6 | 365.6 |
| Orbiter | 199.7 | 219.6 | 2.8 | 202.5 | 236.4 |
| Other | 48.9 | 58.5 | 44.8 | 93.7 | 109.0 |
| Total | 530.1 | 587.8 | 79.7 | 609.8 | 711.0 |

## SOURCE OF DELTA COST

| | $M | |
|---|---|---|
| **Lander** | | |
| ∘ Science Definition Changes (includes GCMS changed to GFE) | 14.0 | |
| ∘ Engineering Definition Changes | 7.4 | |
| ∘ Master Schedule Change (Additional AGE) | 7.4 | |
| ∘ Increased Overhead Due to MOL Termination | 6.7 | |
| ∘ Delete Inverted Lander Capability | (-1.3) | |
| ∘ Delete Facilities (computers) | (-2.1) | |
| | | 32.1 |
| **Orbiter** | | |
| ∘ Engineering Definition Changes | 5.2 | |
| ∘ Credit for Schedule Adjustment | (-2.4) | |
| | | 2.8 |
| **Other** | | |
| ∘ Adjustments: | | |
| Science Team Support | 10.7 | |
| Ames Biology Support | 0.6 | |
| Langley Support | 4.7 | |
| MMC Award Fee | 9.0 | |
| DOD Contract Support | 3.2 | |
| Support Contracts | (-1.2) | |
| Organic/Atmospheric Analysis Instrument | 3.9 | |
| ∘ New Items: | | |
| Back-Up Instruments | 12.0 | |
| Facilities (computers) | 1.9 | |
| | | 44.8 |
| Total Delta Cost | | 79.7 |

# VIKING '73 IMPLEMENTATION AND REPROGRAMMING FOR VIKING '75 PHASES

## OCTOBER 1969 TO JULY 1970

During the implementation of the Viking '73 Project (Oct. '69 to Jan. '70) no significant change was identified in the total cost estimate. Science and engineering changes were minimum during this phase and did not affect the cost estimates given in the previous section.

On January 13, 1970, the NASA Administrator announced that Viking would be reprogramed to the 1975 launch opportunity.

Concurrently, stop work orders were issued to Martin Marietta Corporation, Jet Propulsion Laboratory, and Viking support contractors. VPO teams visited MMC and JPL to outline the ground rules and constraints which would apply to the replanning for the 1975 opportunity. Manpower levels were promptly reduced. Only critical long lead procurements were continued. Stop work orders were issued as appropriate to subcontractors.

The results of MMC's and JPL's replanning were presented to VPO on January 27 and 28, respectively. VPO, on completion of these planning activities covering the entire project, presented the Viking '75 planning status to NASA Headquarters on February 3 and 5, 1970.

Authorization to implement plans for the 1975 missions was received from NASA Headquarters on February 7, 1970. Stop work orders were lifted and redirection instructions issued in mid-February 1970. Guidelines governing the preparation and submission of proposals covering the redirection were provided MMC and JPL in mid-March 1970. Firm cost proposals were submitted in May/June 1970. Negotiations were completed with both MMC and JPL during June and NASA Headquarters briefed on the Viking '75 resource planning based on the following Milestones and Guidelines:

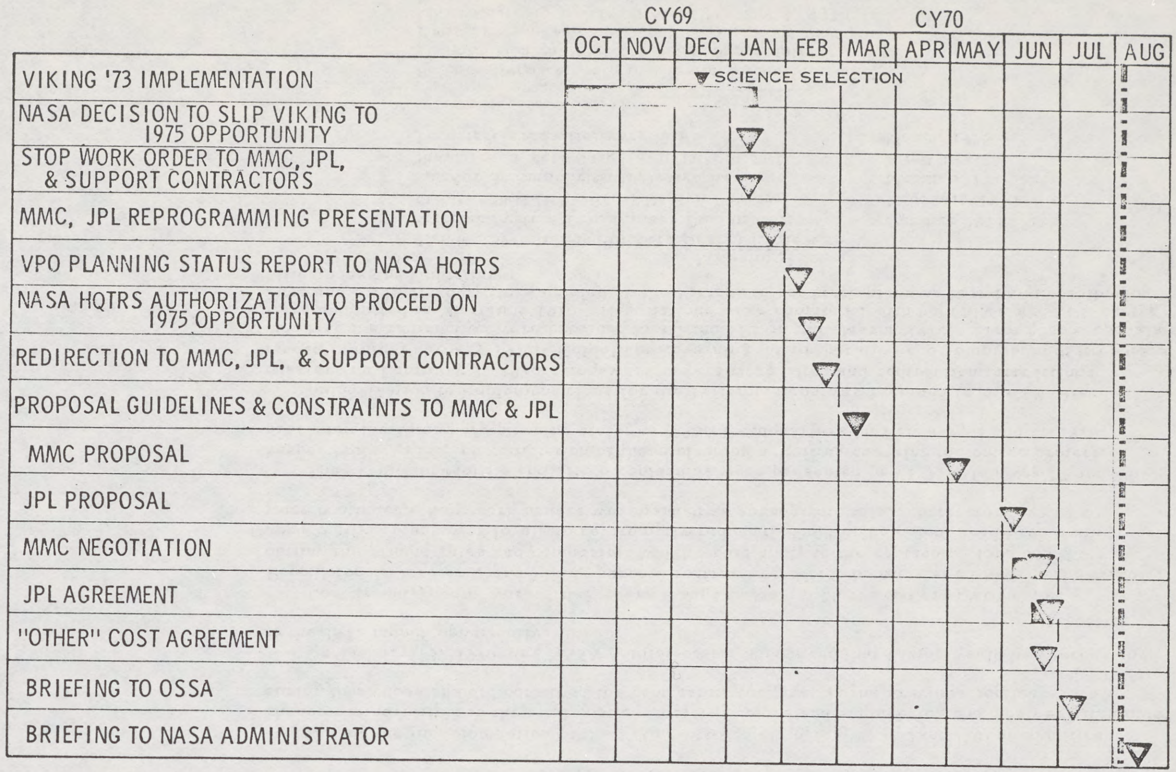
Milestones

| | |
|---|---|
| Lander System Preliminary Design Review | July 1971 |
| Orbiter System Preliminary Design Review | October 1971 |
| Orbiter System Critical Design Review | February 1973 |
| Lander System Critical Design Review | March 1973 |
| Start Proof Test Spacecraft Test at JPL | April 1974 |
| Lander/Orbiter Delivery to KSC | March 1975 |

Guidelines

Science Requirements in Mission Definition No. 3
Mission Design for '75 Launch Opportunity
Critical Procurement Development in FY 70/71
Mars Engineering Model dated March 13, 1970
Deletion of Tests and Test Hardware Consistent with the Schedule Stretchout
Orbiter System Component Commonality with Venus Mercury 1973

VIKING '73 IMPLEMENTATION & REPROGRAMMING FOR VIKING '75



The NASA selected the scientific investigations and the associated scientists for the Viking Project in mid-December 1969. Sixty-two scientists were selected to be members of eight Lander Science Teams, three Orbiter Science Teams, and a combined Orbiter/Lander Radio Science Team.

No significant changes were made in the Orbiter science requirements that affected the science cost. The 30-pound weight increase is the result of a refined engineering estimate and the addition of the X-band system.

Several significant changes were made in the Lander science definition. Ionospheric properties, physical properties, and magnetic properties investigations were added and the complexity of several other investigations was significantly increased. A summary of the changes is given by the two following charts.

The Lander weight increased 27 pounds. Present estimate of the science target cost is $134M. The $27M change is comprised of Lander science changes, additional support for scientists, and attendant science cost increases attributed to the slip.

Science Status as of July 1970

| | (Weight (lbs)) | | |
|---|---|---|---|
| | Orbiter | Lander | Cost ($M) |
| October '69 | 100 | 70 | 107 |
| Changes | 30 | 27 | 27 |
| July '70 | 130 | 97 | 134 |

## SCIENCE DEFINITION

## (Mission Definition No. 3)

**Orbiter**

- Imaging
- Infrared Thermal Mapping
- Infrared Water Vapor Mapping
- Radio

**Lander**

Entry:
- Atmospheric Structure
- Atmospheric Composition (Neutral)
- Ionospheric Properties

Landed:
- Imaging
- Biology (4 Experiments)
- Organic Analysis
- Atmospheric Composition
- Meteorology
- Seismometry
- Physical Properties
- Magnetic Properties
- Radio

## SCIENCE DEFINITION - Continued

### Major Differences

Orbiter

- Imaging ~ Increased Resolution
- Radio ~ Added X-Band System

Lander

- Entry: Ionospheric Properties ~ New Investigation
- Landed: Biology ~ Deleted One Experiment, Added One Experiment, Significant Increase in Complexity
  - Meteorology ~ Increased Accuracy Requirements, Added Flexible Data System
  - Seismometry ~ Added Lander Calibration Tests, Added Flexible Data System
  - Physical Properties ~ New Investigation
  - Magnetic Properties ~ New Investigation
  - Radio ~ Deleted Requirement for Range Rate Measurement by Lander-to-Orbiter Relay System
  - Deleted Ultraviolet Photometry and Soil Water Investigations

The trajectory type (Type I) planned for the 1973 mission requires launch energies in 1975 that exceed the capabilities of the Titan/Centaur launch vehicle. For this reason, a different trajectory type (Type II) that is compatible with the Titan/Centaur will be used.

Type II trajectories are characterized by Earth-Mars trip times of approximately one year as compared to the seven month trip time planned for Viking '73. Additional requirements are caused by more difficult navigation conditions and the different estimated Mars environment that will be encountered by Viking '75. A factor of 1.5 increase in the wind velocities is an example of the different environment. This is due to the arrivals in 1976 occurring during a different Mars season.

The impact of the reprogramming to 1975 and the new science definition are included in the July 1970 resource estimates.

## ENGINEERING DEFINITION

Orbiter

- Same as for Previous Phase With Following Exceptions:

  Additional Solar Panels
  Added Command System Redundancy
  Propulsion System Changed to Two Tanks

- Mission Design Changes

Lander

- Same as for Previous Phase With Following Exceptions:

  Revised Science System in Accordance With New Science Definition
  Test Program Changes
  Change to Lifting Entry
  Change to Ni Cad Batteries
  Bioshield Design Changes

- Mission Design Changes

Cost increases from October 1969 to February 1970 arose as a result of reprogramming Viking to a 1975 launch opportunity. The February 1970 target cost is expressed as a range from the minimum to the maximum because of the uncertainties in the Viking '75 engineering definition in that time period. Part of the estimated cost increase for Viking '75 is due to the longer trip times (engineering definition). These longer trip times will require a corresponding increase in the duration of the mission operation activities and consequently an increase in the mission operations cost.

During July 1970 a firm target cost for the Viking '75 was established based on identification of engineering, scientific, and economic requirements influencing the Viking Project.

## TARGET COST ESTIMATE

($ Millions)

| | October 1969 | Delta Cost | | Feb. 1970 Escalated | | July 1970 Target |
|---|---|---|---|---|---|---|
| | | Min. | Max. | Min. | Max. | Cost |
| Lander | 313.6 | 31.4 | 56.4 | 345.0 | 380.0 | 359.5 |
| Orbiter | 202.5 | 34.5 | 50.5 | 237.0 | 272.0 | 256.9 |
| Other (Support) | 93.7 | 15.3 | 23.3 | 109.0 | 124.0 | 133.6 |
| Total | 609.8 | 81.2 | 130.2 | 691.0 | 776.0 | 750.0 |

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## SOURCE OF DELTA COST (OCT. 69 TO JULY 70)

| | $ M | |
|---|---|---|
| **Lander** | | |
| o Slip Launch to 1975 | 14 | |
| o Science Definition Changes | 11 | |
| o Engineering Definition Changes | 2 | |
| o Test Program Adjustments | (11) | |
| | | 16 |
| **Orbiter** | | |
| o Slip Launch to 1975 | 25 | |
| o Engineering Definition Changes | 12 | |
| | | 37 |
| **Other - (Project Management and Lander Support)** | | |
| o Slip Launch to 1975 | 12 | |
| o Additional Requirements | 19 | |
| | | 31 |
| Total | | 84 |
| Escalation | | 56 |
| | | 140 |

# VIKING '75 IMPLEMENTATION PHASE

## JULY 1970 TO PROJECT COMPLETION

An allowance for contingency has been established for the Viking '75. This adjustment maintains within the total budget an increment of funds set aside for supporting unknown but anticipated mandatory technical changes required to achieve the project objectives. NASA, Office of Space Science and Applications, experience on previous planetary programs has indicated that contingency of 15 to 20% of target cost has been required. The Viking Project contingency has been established by OSSA at approximately 10% of target cost due to the degree of definition now attained by the project.

The distribution of the contingency between the project elements varies with the degree of uncertainty in each element.

# CONTINGENCY

## POSSIBLE COST SUMMARY

($M)

| | Target Cost | Contingency | Possible Cost |
|---|---|---|---|
| LANDER | 360 | 45 | 405 |
| ORBITER | 257 | 15 | 272 |
| OTHER | 133 | 20 | 153 |
| TOTAL | 750 | 80 | 830 |

The conclusions delineated on the adjacent chart are based on the Viking Project experience which is documented in this presentation. A major milestone that was planned as a part of Viking '73 was a NASA Management Review in April 1970. This meeting was established such that a complete review could be made after the development of good engineering and science definitions and the corresponding cost estimate. A similar review is scheduled as part of the Viking '75 Program.

## CONCLUSIONS

- Realistic Costs Are Difficult to Estimate Utilizing Phase B Parametric Studies
- Realistic Cost Estimates Can Be Developed Prior to Large Expenditure of Project Funds

Dr. CORTRIGHT. At this point when we were at an estimated completion cost of $711 million, the actual cost we had accrued was $12 million. From October 1969 until January 1970, there were no significant changes identified in the total cost estimates for the 1973 mission.

On January 13, 1970, the NASA Administrator, faced with a very tight budgetary problem, announced that Viking would be reprogramed to the 1975 launch opportunity. As a result of this decision, stop-work orders were issued to Martin Marietta Corp., Jet Propulsion Laboratory, and Viking support contractors. VPO teams visited MMC and JPL to outline ground rules and constraints which would apply to the replanning for the 1975 opportunity. Manpower levels were promptly reduced. Only critical long-lead procurements were continued. Stop-work orders were issued as appropriate to subcontractors.

Mr. SYMINGTON. Considering the problems you face today, do you think all those manpower reductions and stop-work decisions were correct? Maybe we should have kept a few of those things humming along. Do you think that the problems we are facing today could not have been anticipated or, if they could, that the situation could not have been improved by any changes in your winding down operation?

Dr. CORTRIGHT. I think that is a very good question, and if we had known enough about the project at that point in time, to have long-lead work done on the computer and the biology experiment, I think it would have subsequently helped the project.

Mr. SYMINGTON. As I understand it, you ceased considering the 1973 launch for purely budgetary reasons. You didn't feel you were running into any particular technical problems that would make launching during that window difficult?

Dr. CORTRIGHT. That is correct.

Mr. SYMINGTON. Of course, if you had kept some of those people on the job they might have turned up some of the technical problems a little sooner than they were actually discovered, is that possible?

Dr. CORTRIGHT. We, of course, did keep some work going. As I pointed out, the problem with keeping effective work going is to specify the systems well enough for the subcontractors to know what to do in that period.

Mr. SYMINGTON. All right.

Dr. CORTRIGHT. The results of MMC's and JPL's replanning were presented to the VPO in late January of 1970. The VPO, on completion of its own assessment of project plans, presented a Viking 1975 proposal to NASA headquarters on February 3 and 5, 1970. Authorization to implement plans for the 1975 missions was received from NASA headquarters on February 7, 1970. Stop-work orders were lifted and redirection instructions issued in mid-February 1970. Guidelines governing the preparation and submission of proposals covering the redirection were provided MMC and JPL in mid-March 1970. Firm cost proposals were submitted to the VPO in May/June 1970. Following completion of negotiations with both MMC and JPL during June, NASA headquarters was given a complete update on Viking 1975 resource planning in June of 1970.

The rephasing to the 1975 launch opportunity changed the estimated total cost estimate from $711 million to $830 million ($750 million target cost, including escalation, and $80 million contingency-designated allowance for program adjustment (APA)). Actual cost incurred at this time was $37 million.

Mr. SYMINGTON. What were the factors that caused you to increase your estimate?

Dr. CORTRIGHT. In the case of the Lander, there were science additions totaling $11 million, but these were counterbalanced by reductions in the test program. Spacecraft changes accounted for $2 million. The escalation costs were $30 million for the Lander. A $14 million increase was related directly to the 2-year slip, that is the stretchout in work and having people work longer to accomplish the same job. In other words, we had to keep a minimal part of the team together during that period.

Mr. SYMINGTON. That $11 million addition for science, what kind of changes were involved?

Dr. CORTRIGHT. They were associated with better definition of the biology experiment and the GCMS and the addition of the seismometer.

Mr. SYMINGTON. With respect to the biology experiment, was there a technical problem they had encountered with it, or was something added to it, do you know?

Dr. CORTRIGHT. I think the simplest way to answer that is that we had not really defined the biology experiment or selected the subelements of it prior to this time.

Mr. SYMINGTON. Well, I am just looking at your dates there. You canceled the 1973 launch in January. Up to that point, you hadn't made any changes in the biology experiment or maybe you hadn't gotten around to getting it structured, but then it was just a few months later you added $11 million to it.

Dr. CORTRIGHT. Yes.

Mr. SYMINGTON. It would suggest to me that you must have flagged something. If it was important enough to add $11 million in 2 or 3 months, maybe if you had increased the effort, really poured it on, you would be in better shape today with that experiment.

Dr. CORTRIGHT. Mr. Chairman, I think I would like to give you a little more detailed indication here of some of the changes in the science definition at that point in time. These are all listed in the document that I just submitted to you that we had shown to Congressman Karth on page 29–V.

Mr. SYMINGTON. Why don't we get a copy of that up here so we can follow your testimony?

Dr. CORTRIGHT. Your question is why these changes were made as part and parcel of the change in launch date, I think it really relates to the fact that we were at that point of mission definition when the contract was revised. In any event, as you can see, the ionosphere properties during entry was a new investigation. One experiment on the biology was deleted and one added; there was a total increase in complexity. The accuracy requirements on the meteorology were increased and the flexible data system added. We added seismometry. We added Lander calibration tests and improved the data system. The physical property experiment was new. The magnetic properties experiment was new. In the case of radio science, we deleted a requirement for rate measurement. We deleted an ultraviolet photometry and soil investigation. I think I mentioned that the science changes netted out at zero because we took out as much as we added.

The real buildup in Lander costs was in the 2-year slip, $14 million for work stretchout and $30 million escalation. I haven't given you the Orbiter figures yet. There was $25 million associated with work stretchout, $17 million with escalation, and $12 million in additional engineering changes to the spacecraft.

In the support category, there was a $12 million figure associated directly with stretchout, $9 million additional escalation, and a net of $19 million in additional requirements covering mission operations, and Government support and Government-furnished equipment.

If you need additional detail on these, we can supply it.

Mr. HAMMILL. On our last visit to the Jet Propulsion Laboratory, they told us, if I remember correctly, that they made very good use of the 2-year delay and that rather than causing an increase in the total cost of the Orbiter portion of the spacecraft, the delay resulted in a cost decrease. Is that so?

Dr. CORTRIGHT. I guess I would like Mr. Parks who is here with us, to comment on that. I am not familiar with that statement.

Mr. PARKS. I am not specifically familiar with the conversation you are referring to here, but the facts of the matter are, there was an increase in the Orbiter costs as a consequence of that 2-year delay. We did make good use of that time in doing more detailed planning for the 1975 mission. And we were able to take advantage of that planning during the later implementation phase. But there was a total cost increase due to that delay.

Mr. HAMMILL. That was a misunderstanding on my part.

Dr. PETRONE. The 2 years did make it a tougher mission. You are communicating over a large distance. Transmitting had to be beefed up to take account of that. You added about 20 or 30 percent communication distance because of the relative orientation of Mars at that particular time. It did increase certain complexities in that mission. The big dollars, as he pointed out, was the escalation in both Lander and Orbiter over the 2 years.

Mr. SYMINGTON. Supposing there hadn't been that budget constraint that you testified to, do you think you could have flown the mission in 1973 successfully?

Dr. CORTRIGHT. We often ask ourselves that question, Mr. Chairman, and the answer we come up with is, we think we could have flown a mission in 1973, but it would not be the mission we are flying in 1975.

Mr. SYMINGTON. What would be the significant difference?

Dr. CORTRIGHT. I think there is no question the science would be simpler, the systems would all be simpler, less sophisticated. The spacecraft would be lighter and we would have done things differently. I think that there is a high probability we would have flown a mission but it would have been tight, very tight.

Mr. SYMINGTON. It would have included a biology package?

Dr. CORTRIGHT. It certainly wouldn't have been the 1975 design.

Mr. SYMINGTON. Does your testimony generally, Dr. Petrone, establish the distinction between the type and character of the two missions so that in going before the public with explanations of various kinds we can make it clear what was actually gained, perhaps unexpectedly, by the delay?

Dr. CORTRIGHT. This document which I submitted to the committee contains some of this information. My statement does not.

Mr. SYMINGTON. OK. Does it contain the information explicitly or just by inference?

Dr. CORTRIGHT. I think it would be helpful to the committee, Mr. Chairman, if we supplied a statement just answering that question.

Mr. SYMINGTON. Yes, that would be very helpful.

[The information follows:]

**Long lead development: Radar; biology; and communications.**

**Added system redundancy.**

**Following science changes made possible: Orbiter imaging—Increased resolution; radio—Added X-band; biology—Increased capacity; meteorology—Increased accuracy—Added flexible data system; seismometry—Added calibration tests—Added flexible data system; physical and magnetic properties added; and ultraviolent photometry and soil water deleted.**

**Changed to lifting entry.**

**Test program reduced.**

Mr. SYMINGTON. May I ask you a question about your statement to the effect that "the complexity of what NASA was asking the industry to accomplish became more apparent." Wasn't that what NASA was asking from the very beginning? In other words, had there been insufficient communication up to that point? Why did it suddenly come into focus and not before?

Dr. CORTRIGHT. I think, as we got into some of these systems in more depth, Mr. Chairman, and, when the subcontractors themselves got into the subsystems in more depth, that it became clear that we were asking for advances in the state of the art that were substantial. That certainly was true in the cases of the biology experiment, the GCMS, and the computer.

Mr. SYMINGTON. This would have been the case if you were still aiming for a 1973 launch.

Dr. CORTRIGHT. That is probably correct.

Dr. PETRONE. I think that is a correct statement. One puts out a set of requirements for things you would like to do and you define the results you want until someone converts that, starts engineering drawings, and one sees how much one has in the package. What happened in the interim with respect to requirements was that we found things we wanted to do on the surface. Things we started then became a tremendous step forward. I do believe the same would have applied for the 1973 mission as the 1975, no question about that.

Mr. SYMINGTON. It would have made the 1973 mission much tougher?

Dr. PETRONE. Very much tougher, in my estimation.

Mr. SYMINGTON. As this complexity became more apparent at that point, you had 5 years before the launch.

Dr. CORTRIGHT. I think we would have had to descope our objectives at that point in time if we were still on the 1973 path.

July 1970–August 1971. This period is significant because it covers the preliminary design phase of the Viking spacecraft, during which the project firmed up the system design and uncovered numerous underscoped items. The complexity of what NASA was asking the industry to accomplish became more apparent. During that time period, the estimates for project target cost grew from $750 to $810 million.

This growth required the application of $60 million of project APA to accommodate the cost growth and left a project reserve of only $20 million. The JPL Orbiter costs did not increase in this time period. From this period to the present date, Orbiter costs have in fact decreased, and therefore will not be discussed in detail in this statement. The major cost increase was experienced in the Lander—$41 million—and was attributed to underestimates in MMC in-house and subcontract activities, and to VPO-directed changes for redundancy and design refinements [figure 2].

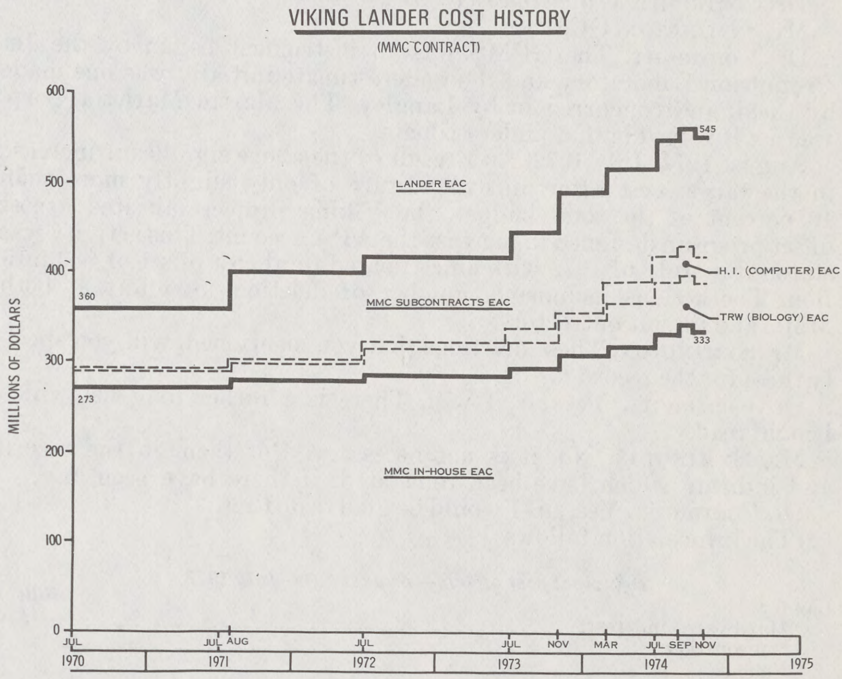


FIGURE 2

Mr. SYMINGTON. These will be submitted for the record?

Dr. CORTRIGHT. Yes, sir.

[The information follows:]

*Principal target cost changes—July-August 1971*

| | *Millions* |
|---|---|
| Lander: | |
| Subcontracts | $19 |
| MMC In-house | 14 |
| Redundancy | 5 |
| Design refinements | 3 |
| Subtotal | 41 |
| Orbiter | 1 |
| Support: GCMS | 18 |
| Total | 60 |

Dr. CORTRIGHT. This figure deals exclusively with the Lander situation, wherein most of our costs growth occurred throughout the project, and is broken down, Mr. Chairman, into Martin in-house increases and subcontractor increases. I have put the numbers on for TRW and

Honeywell because they will be testifying, not because they were the only subcontractors with cost containment problems. As you can see from the chart, the total subcontractor bill more than doubled whereas Martin in-house bill did not increase such a large percentage.

In addition, support costs increased $18 million, due primarily to underestimates of the effect to design, test, and fabricate the complex gas chromatograph mass spectrometer (GCMS) instrument. Actual accrued costs were $87 million in August 1971.

Mr. SYMINGTON. Was that a contractor's underestimates?

Dr. CORTRIGHT. Which one? GCMS?

Mr. SYMINGTON. GCMS?

Dr. CORTRIGHT. The GCMS was an instrument begun by the Jet Propulsion Laboratory and the underestimate initially was one made by them, and concurred in by Langley. The Martin Marietta Corp. was not involved in that underestimate.

August 1971–July 1972. As a result of the above significant increase in the target cost after an expenditure of only slightly more than 10 percent of the total budget, the Viking project initiated a cost offset program designed to increase the APA account. This activity was statused in July of 1972 with an estimated total cost offset of $39 million. The actions included a number of deletions of effort at both MMC and its subcontractors.

Mr. SYMINGTON. These deletions that you mentioned, will you specify these for the record?

Dr. CORTRIGHT. Yes, sir, I will. There is a rather long list which I could read.

Mr. SYMINGTON. No, it is not necessary. Put them in the record and indicate which have been reinstated, if there have been any.

Dr. CORTRIGHT. Yes, sir. I would be glad to do that.

[The information follows:]

*Principal cost offsets—August 1971–July 1972*

| | *Millions* |
|---|---|
| Lander: | |
| Hardware and test | $10 |
| Subcontractor | 6 |
| Science | 3 |
| Subtotal | 19 |
| Orbiter: | |
| Hardware and test | 2 |
| Mission operations | 1 |
| Reserve requirements | 5 |
| Subtotal | 8 |
| Support: | |
| Test | 2 |
| Support contractors | 2 |
| Science | 6 |
| Subtotal | 10 |
| Total | 37 |
| Miscellaneous | 2 |
| Total | 39 |

None of these cost offsets were subsequently reinstated.

Mr. WINN. Could I ask a question?

Mr. SYMINGTON. Yes.

Mr. WINN. At anytime when all these underestimates, cost overruns and everything was going on, did NASA ever once give any idea to giving this thing up, because it was pretty obvious from the start it was getting out of hand? You got some of the finest subcontractors we ever had in this field, that in this program were constantly underestimating, redesigning, retooling, whatever, all this little nitty-gritty you're talking about here, which I think can save a lot of time for the committee if you just don't tell us who reported to who, because I don't think we care. I think it is the end result. Did you ever think maybe the taxpayers wouldn't pay for this program?

Dr. CORTRIGHT. No, sir.

Mr. WINN. I didn't think so.

Dr. CORTRIGHT. We felt we could bring in this job for $830 million for the first several years. With things going right we could have, but the problems did not get solved in as expeditious a manner as we hoped, and that is why we are at $930 million today.

Mr. WINN. Does NASA, and do all the subcontractors just constantly think "let's keep on going, let's redesign, let's redo this, we have underestimated the committee rigamarole," somewhere somehow they will get this thing bought?

Dr. CORTRIGHT. Sir, that gets tested every year by both the executive and legislative branches. The OMB looks at it and, in the case of this project, I imagine the President looked at it. Certainly the Congress has looked at it at least once a year and generally almost continuously.

Mr. WINN. I am trying to tell you, though, I think that some of us that have supported your programs down through the years, I am telling you right now and I have got a lot of friends sitting out here, I am going to start saying no to a lot of these programs. The American people are fed up with cost overruns. If you look at some of the people in both parties, they campaigned on this issue. I am saying you guys are not going to be able to stick this stuff down our throats anymore.

Thank you, Mr. Chairman.

Mr. SYMINGTON. There is another dimension to Mr. Winn's point. From your testimony, it appears that you would have flown a 1973 mission if OMB had not stepped in to stop you, true?

Dr. CORTRIGHT. I can't remember whether OMB said that. I believe the Administrator made the judgment.

Mr. SYMINGTON. We know OMB has nothing to do with budget constraints.

[Laughter.]

Mr. SYMINGTON. So if you hadn't had these budget constraints, you would have flown a 1973 mission which now appears would have been jerry-rigged in order to get ready in time to launch. Then because of the budget constraint a decision was made to delay for 2 years, and I imagine that there were those among you who might have said, "How are we going to keep the team together?" But you not only lived with that decision, you made a virtue of that necessity by improving your instrumentation, getting things ready to go, better experiments et cetera to the point where in retrospect you are probably greatful it is a 1975 launch rather than a 1973 launch because of all the new things you are going to learn.

Why wouldn't the same reasoning cause a number of people to wonder, since we are again under the financial gun, why not wait another 2 years and make it an even more beautiful project? Granted, it might take an additional $100 million or some such figure, according to some conversations I have had. Another delay would provide equipment that really works; not only works but works well. That might be preferable, rather than to fly something that is not quite ready in terms of a reasonable expectation of mission success that you would like to have in your minds as scientists. In that way you would be able to demonstrate to the American people that their investment really was well spent, and has paid off.

What are the reasons that would make another 2-year delay inadvisable? In retrospect reasons were found to be quite sufficient to justify the first 2-year delay.

Dr. PETRONE. May I address that, Mr. Chairman?

Mr. SYMINGTON. Yes.

Dr. PETRONE. In terms of looking at a further delay, and we are obviously in a different timeframe than the 1970 delay, certainly the question of costs have come into the picture. We have attempted to steer a path, fiscal responsibility, not asking Congress for more money for that purpose.

Now, at the same time, we will not launch a Viking that we feel has little chance of success. A delay in my opinion would not necessarily increase the chances of success. With the need to keep a team two additional years, there is always a question of changes people want to make. We are now, in effect, trying to closeout our subcontracts—the people not required onboard at the time we conduct this mission. So a delay at this stage of the game is quite different than a delay in the 1970 timeframe wherein there may have not been full definition of the requirement of things to be done, which became apparent in the summer of 1970. Today we have our equipment. We think we have defined and constrained. We know we have hurdles yet ahead of us to make. We do believe we can bring this to a point of a proper mission in terms of returns we expect to get and make our launch date of next August at Cape Canaveral.

Mr. SYMINGTON. I think that is a succinct answer to my question, one we ought to try to flesh out in even greater detail so we can explain it to the average taxpayer.

Mr. WINN. Mr. Chairman?

Mr. SYMINGTON. Yes.

Mr. WINN. I'd like to refer back to Mr. Cortright's prepared remarks where on page 3 he said "from these options, NASA selected the mission mode for the 1973 Mars mission." He lists these other things and that means we are going in that direction. Several times after that, you talk about redesign of the Lander, underestimates by the contractor, but at the top of page 4, you say that could be accomplished for an estimated cost of $364 million, the price is going up everytime you turn a page.

It says, "This estimate did not include any factor for escalation or contingency." I always thought for the 8 years I have been on this committee there was a built-in factor for escalation and contingency. Have I been wrong for 8 years?

Dr. CORTRIGHT. It used to be, as I recall my early years, that it was not the practice to put escalation in, and frequently not contingency either. I really am very sympathetic with your position that you are tired of overruns. I believe that the way we have to approach that problem, in addition to managing as best we can and initially defining the job as best we can, is to do a respectable amount of work on the project before we commit to costs, and before you commit to support through completion.

Mr. WINN. Just one of the contractors, I believe Martin Marietta, was on a cost-plus basis?

Dr. CORTRIGHT. It is a share.

Mr. WINN. Yes; I know, an incentive. I know how it works. We have looked into some of these contracts.

Dr. CORTRIGHT. There really is no way in my opinion to take on a job this complex with a fixed-price contract. The Agency is trying every technique it knows how to meet its cost targets for the Congress. I think the Agency is doing better. There are projects that have done better than this one, most certainly.

Mr. WINN. That's for sure. I don't think we would still be in this committee, I don't think you would have jobs, if NASA hadn't done a better job than they have done on this one.

Dr. CORTRIGHT. If I could just say one thing, this is not intended to belittle the increase, because it has been large, but after we had the contractors on board and had defined the 1975 mission, we incurred a 12-percent increase over what we said it was going to cost in 1970. I wish that was zero, but experience shows that the most complex R. & D. jobs increase as much or more.

Mr. WINN. I want to give you time to finish the rest of your comments, and we will have some other questions.

Thank you, Mr. Chairman.

Mr. SYMINGTON. Thank you.

I want to ask a question which refers to your prepared remarks on page 8, Mr. Cortright. The deletion of the light scattering investigation which was one of the four original biology instruments, why was that decision made? Was the task too difficult technically, or too expensive?

Dr. CORTRIGHT. There were several reasons. We had a weight problem, we had a volume problem, and we had a cost problem, and it just simplified the bioinstrument.

Dr. PETRONE. This is a case of desires and requirements. When you finally get them translated into what the hardware is going to look like and what it takes, in that particular case I think we made a prudent decision, not an easy one to the scientist that had that experiment, he did go through agony on it. We made the necessary hard decision to take it off to try to stay within costs and weights and volumes for that particular experiment. It did show this question I mentioned earlier, the requirements driving the program and not well understood at the time they were leveled.

Mr. SYMINGTON. That was part of the biology package. It would have added to its weight?

Dr. PETRONE. Immensely to the complexity of the package.

Mr. SYMINGTON. The weight is what now?

Dr. PETRONE. It is an 11-inch cube in terms of dimensions. We have 11 inches of cube. Three major experiments. This would have been the fourth. It would have just increased our job immensely.

Dr. CORTRIGHT. About 40 pounds.

Dr. PETRONE. Eleven-inch cube.

Mr. SYMINGTON. The light scattering experiment would have increased it by how much?

Dr. CORTRIGHT. I wouldn't know, Mr. Chairman.

Dr. PETRONE. We would have had to change our interface dimensions.

Mr. SYMINGTON. Weight, and size, and configuration; all would have been affected. OK, I just wondered.

Dr. CORTRIGHT. Mr. Chairman, I realize that plotting this cost history isn't the most interesting material in the world. It is responsive, I feel, to what was asked. However, I think I could save some time if you wish, if I could submit the next two pages for the record and move on to the problems of the last year:

This cost offset effort was to continue and, as a matter of fact, is still active. In addition, one of the four biology investigations—light scattering—was deleted within the biology instrument. But, at the same time, the science steering group proposed to add an inorganic investigation to the Lander science package by the incorporation of an X-ray fluorescence instrument. The action was approved by NASA headquarters in July 1972.

During this period of Viking subsystem and component preliminary design, the Lander continued to show problems in subcontract and in-house labor cost growth. It is important to recognize that cost growth was a problem common to most subcontractors, and not just TRW and HI.

The JPL demnstrated its active participation in the cost offset program by reductions in the areas of spacecraft design, science and test areas, for a total decrease of $10 million. During July 1972, the Viking target cost was reestimated at $805 million, and the APA was $25 million. At this time the project was 3 years away from launch and accrued costs had reached $285 million.

July 1972 to July 1973. This period is identified as that of final design and development. The project continued to encounter technical problems on a number of Lander components. Although we maintained an active cost offset program, it was obvious that the Lander target cost at MMC was continuing to grow. The project target cost during July 1973 was estimated at $824 million. The resulting APA of $14 million, 2 years prior to launch, was judged to be marginal with several identified areas of concern. The July 1973 accrued cost was $514 million. A NASA accounting change increased the $830 million to $838 million in 1973.

It is worth noting here that our continuing cost offset program—figure 3—had by this time identified and implemented more than $54 million in cost reductions. When combined with the application of $66 million of our planned reserve, a total of $120 million in anticipated problems had been absorbed within the project to this point.

JULY 1973–MARCH 1974

During the fall and winter of 1973, the computer and biology development and build problems intensified. We were still having some development problems in certain of the other Lander components, although with a lesser cost impact than in the earlier period. Also, the fall of 1973 saw the start of Lander system level tests on the proof test capsule (PTC), to be followed by flight article testing. This effort proved to be generally underscoped, both as to the resources and time required.

Beginning in 1973 we were also caught in the inflationary spiral and our previous escalation factor of 5 percent a year, on which our forward estimating was based, was inadequate to cover rising costs of material and labor. In November 1973, our estimated total cost was $878 million. This included $10 million of APA. By March 1974 these continuing problems, along with a realistic-increase in the APA needed to cover the remainder of the program, drove Langley's estimate of total cost to $920 million including APA of $25 million. At that date, $668 million in costs had been accrued.

On March 13, 1974, Dr. John Naugle reported to the Subcommittee on Space Science and Applications a possible 10-percent increase in the $838 million, which corresponded closely to Langley's projected $920 million.

March 1974 to date. Although the Lander computer, biology, and GCMS problems that had plagued us earlier were well on the way to solution, the schedule stretchout of the effort due to these problems continued to add substantial increments of cost. We also experienced additional cost in the Lander systems test area, mostly due to continued problems with proof test capsule testing and delays in starting test of flight Landers caused by late component deliveries. Software development problems and other lesser MMC in-house efforts, along with an additional increment for inflation, accounted for additional cost growth.

Mr. Symington. I have a couple of questions on these pages. Without your reading them, I will just refer to them, if I may.

You say it is important to recognize cost growth was a problem common to most subcontractors. I would simply ask you to furnish a list of subcontractors that experienced significant cost growth, if you would?

Dr. Cortright. I have that with me. I would be glad to do that.

[The information follows:]

*Lander subcontractor cost growth*

| *Subcontractor and item* | *Millions* |
|---|---|
| ITEK—Camera | $13 |
| TRW: | |
| Biology | 42 |
| Meteorology | 2 |
| Hamilton-Standard—Inertial reference unit | 6 |
| Ryan—Terminal descent landing radar/radar altimeter | 10 |
| RCA—Communications | 6 |
| LEC—Tape recorder | 2 |
| Bendix: | |
| Seismometer | 1 |
| Upper atmosphere mass spectrometer | 3 |
| Honeywell—Computer | 24 |
| EM and M—Core memory | ----- |
| Rocket research: | |
| Terminal engine | 1 |
| Deorbit engine | ----- |
| Celesco/Singer—Articulated boom/motors | 3 |
| Kearfott | ----- |
| Other | 3 |
| Total | 116 |

Mr. Symington. You mention at the top of page 9 the projects continued to encounter technical problems on a number of Lander components.

Are those described anywhere else in your material where we can see them, or would you like to submit them also for the record?

Dr. Cortright. I would be glad to submit a list of problems in that time period.

Mr. Symington. Would you?

Dr. Cortright. It is a long list. We had lots of problems.

[The information follows:]

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## LANDER HARDWARE

## ELECTRONIC COMPONENTS

## TECHNICAL PROBLEMS

7/72 - to - 1/74

- ALL - Cabling connector pins were found to be brittle - extensive failure analyses and corrective action was required, as material and process changes were incorporated. Case material had to be changed from magnesium to alumnium due to magnesium creep (fasteners loosened).

- PCDA - Case design had to be modified to accommodate connecting harnesses between boards. Revised switching to allow dissapating RTG energy in external load bank. Timer capacitor failed - had to be redesigned and new item obtained. Revised logic to protect against GCSC transfer due to a power-down of detectors.

- PCDA/LPCA - DC/DC connectors showed interrupted performance at lower temperatures; transformers had to be redesigned.

- BPA - A number of single point failures were discovered during CDR requiring circuit redesigns.

- DAPU - Extensive corrective action was required due to PC board warping. Oscillator crystal problems required their being redesigned out of the system.

- SSCA - Power supply redesigned to accommodate higher current requirements of SSAA "level detector" circuits. Solenoid and motor driver circuits were revised to supply the power increases demanded by Nash solenoids and Kearfott motors.

## LANDER HARDWARE

## VEHICLE

## TECHNICAL PROBLEMS

7/72 - to - 1/74

- Structures Manufacturing - Tooling and fabrication was underscoped. Complexity of thin, lightweight structure caused numerous problems and errors in numerically controlled tape machining and inexperience with fabrication phenolic-fiberglass laminate. (Lander body, base cover, RTG windscreens, Aeroshell)
- Aeroshell - Two unexpected failures created major design, manufacturing and test impacts. (First elastic failure added stiffening clips; second failure, of a catastrophic nature, added more clips, design changes to inner cone and addition of the belly-band reinforcement.) Failures caused a stretchout in testing of the LSTM major static test program in addition to incorporating a proof test on each flight aeroshell.
- Mortar Fire Tests - High mortar shock responses measured on first LDTM firing caused design changes and two additional verification tests.
- High Gain Antenna Deployment Mechanism - Extensive failures in development and during qualification testing caused numerous delays.
- Bioshield - Lack of sufficient attention to the thermal gradient problem associated with very large lightweight ring, prior to manufacturing caused excessive detail changes, rework and additional separation testing.

## LANDER HARDWARE

## VEHICLE

## TECHNICAL PROBLEMS

(cont'd)

7/72 - to - 1/74 (cont'd)

- Terminal Tank - Terminal tank ruptured during cryo-proof test - failure due to Alpha contamination of titanium hemisphere during heat treat; solution was devised to detect any Alpha contamination of flight type hemisphere which had been fabricated. Terminal engine went thru many design mods during development progress, which pushed state-of-the-art. Ability of catalyst bed design to meet vibration and thermal expansion requirements, yet not crush catalyst, was an overriding problem.

- Thrusters - Insufficient thermal control of RCS/Deorbit thrusters mounted on pylon modules was discovered when TETM was in cruise thermal vacuum test. Passive thermal improvements were made, but in simulated cold tests one thruster failed to operate because partially frozen propellant solidified in the valve. Additional pylon heaters were added in parallel with each thruster injector heater to provide necessary warm-up prior to deorbit $\Delta$ velocity.

- Sterilization Chambers - MMC's concern for reliability of vendor supplied chambers as well as large amount of rework needed to get Denver chamber in operation and resulted in termination of vendor and in-house MMC build of remaining two chambers for KSC use.

## SURFACE SAMPLER (SSMAA)

## TECHNICAL PROBLEMS

7/72 - to - 1/74

- Organic Cleaning - Redesign of the hardware was required to obtain the cleanliness levels dictated by the organic analysis experiment.
- Instrument Integration - Many design changes were required to the Surface Sampler PDA's in response to Biology and GCMS instrument interface changes.
- Science Changes - Several studies and design changes were required to support changing science requirements or objectives; susceptibility of the GCMS to $M_0S_2$ and toxicity of the Biology to certain elements required material changes in the Surface Sampler; more detailed definition of the Magnetic Properties Investigation required several redesigns of the back-hoe; increased sand and dust levels required increased testing and design modifications to the hardware.
- GCMS/PDA Bolt Cutter - Failure of the pyrotechnic bolt cutter on the GCMS/PDA to meet leakage requirements necessitated several studies, late in the program, directed toward its elimination.
- Boom Motor Vendor Default - The failure of Nash Controls to deliver acceptable flight motors for the Surface Sampler Boom resulted in slowing of delivery of motors to other Surface Sampler components.

## X-RAY FLUORSCENCE

## TECHNICAL PROBLEMS

7/72 - to - 1/74

- Rotary Solenoid - The Itek camera rotary solenoid was also used for the XRFS and constant failures occurred as the XRFS duty cycle was considerably different from that of the camera. A new solenoid had to be ordered and qualified.
- Proportional Counter (PC) Tubes - Wide, non-repeatable changes were noted in the tubes during surface thermal tests. New tubes with an additional insulating washer were required.
- Wind Spoiler - A large loss occurred at Mars wind levels in the sample delivered to the XRFS funnel. A wind spoiler had to be designed, tested in wind tunnels, flight qualified.
- Redesigned Electronic Boards - To save space, the electronic discriminator circuits for the XRFS were incorporated in the logic board. Cross compling from the logic board traces caused excessive distortion and noise in the discriminator circuits. A separate discriminator board and a revamped logic board had to be used.
- Parts Problems - Failure of the 2700 Oper. Amp. part; shorted printed circuit boards; and 1080 A/D converters screening problems delayed build schedule.
- Test Set - Original design was poor causing difficulty in acquiring quality XRFS spectral data. Redesign was required.

## FLIGHT SOFTWARE

## TECHNICAL PROBLEMS

7/72 - to - 1/74

- VCS Requirement Changes - Changes in Lander system redundancy concept caused redesign of major software routines affecting (1) major Guidance software modules such as IRU, TDLR, VDA, RA; (2) major Lander software such as Meteorology (movable to fixed boom), Antenna Pointing, Biology, GCMS, LCS, UHF Beacon Relay; and (3) major changes to pre-separation/pre-launch checkout philosophy. A completely new baseline design had to be developed.

- Viking Controls Mock-up - The build-up and check-out of this facility was grossly under-scoped. Major hardware modifications were necessary to the IC-7000 computer to upgrade its capabilities. The first support software operating system (simulation master control system) had to be abandoned and a new operating system developed (run time system) to permit the facility to operate in real time.

- Gross Shortage of Manpower/Talent - The ability to cope with major changes and major technical problems has been limited by a shortage of talented personnel who can expediously diagnose and prescribe remedial solutions.

- Lack of GCSC Hardware - As a result of GCSC development problems, the inability to obtain GCSC hardware and adequate hardware documentation impeded the ability to develop, check-out, and validate the IC-7000 emulator. Simulation of the GCSC I/O structure was the most seriously impacted area.

## FLIGHT SOFTWARE

## TECHNICAL PROBLEMS

(cont'd)

7/72 - to - 1/74 (cont'd)

- Software Fixes to Hardware Problems - Due to the schedule pressure to wrap-up the hardware development and build, many hardware problems required software fixes. Software redesign in these areas caused software development slips in the areas of (1) camera - encoder position, (2) IRU - high rate mode lock-up, (3) RA - false target discrimination, (4) TDLR - harmonic lock up. Another major design impact was the requirement for a software refresh routine to handle the GCSC memory distrubance problem.

## ASSEMBLY AND TEST

## TECHNICAL PROBLEMS

7/72 - to - 1/74

- Late delivery of components to PTC (up to 4 months).
- Underestimate of the complexity of building special test sequences and the related software for PTC testing.
- Design changes to the lander system required significant changes to the STE.

## BIOLOGY INSTRUMENT

## TECHNICAL PROBLEMS

7/72 - to - 1/74

- Thermal Problems - Overheating of cells during incubation required separation of electronics subsystem from experiment mechanical modules to reduce heat loads. After all passive means taken it was still necessary to provide active thermoelectric cooling.

  Failure to achieve sterilization temperature for control experiment - required redesign of head end, line and valve block heaters.

  Nutrient freezing - required addition of heaters for control experiment modules.

- Solenoid Valve Problems - Nutrient Compatibility - difficulty in finding materials compatible with nutrients required redesign of valve to diaphragm type.

- Valve Stiction - Valve poppet material adhered to valve seat due to combination of thermal environments, requiring change of material.

- Pyrolytic Release Experiment, High Second Peak - Excessive $^{14}CO_2$ retention in organic vapor trap interfered with determination of $^{14}C$ - labelled organic compounds. Extensive investigation defined problem to be caused by affinity of vapor trap for $CO_2$ after heating in helium stream to oxidize organic as part of experiment sequence. Required rework of operational sequence to permit ambient $CO_2$ to diffuse into trap from Martian atmosphere.

- Cell Seal Material Problems - Requirement for sealing at sterilization temperature (> 160°C) and pyrolysis temperature (> 200°C) followed by operation at temperature as low as 0°C produced problems of sticking and leakage.

## GCSC/DSM

## TECHNICAL PROBLEMS

7/72 - to - 1/74

- Flex Cables - Poor fixtures and quantity of handling caused many failures and lost time (new fixtures and training required - back up cable design and procurement was implemented).
- Tunnel Build - Poor yield of tunnels due to stuck tooling wires and plating of keepers (registration, air honing, change in process for lubricating and removing tooling wire - additional NASA developed tools).
- Memory Shields - Original material magnetostrictive at cold temp. causing loss of attenuation (new material and dimension change required).
- Word Strap Keepers - High remanence and poor etch registration (change in keeper design, material, and process).
- Single Film Plated Wire - Poor yield at half stack level of testing, poor magnetostrictive characteristics, low output (change in wire design).
- Half Stack Testers - Single channel tester not capable of handling quantity of wire testing nor accurate enough (additional half stack testers required and significant design improvements implemented).

## GCSC/DSM

### TECHNICAL PROBLEMS
(cont'd)

7/72 - to - 1/74 (cont'd)

- Printed Circuit Boards - Poor quality plated-through holes (new supplier required).
- Timing Problems I/O and Memory - WCA indicated race conditions, (special part screening 54L's and sense amp's required).
- Parts Problems - RLRO5 resistor cracking, delay line voids, tantalum capacitors.
- Power Supply - Filtering and added testing for stability.
- Various Processor, I/O, DRU Problems - EXI not lost, interrupt redesign, RA discrete, BPA sympathetic discrete, ERI caused by illegal jump, 10 watt race.
- Lack of Memories - Cause usage of external core's on DD-1, CDU (1), and PTC (1); also initiation of back-up core program.
- System Level Testing Inadequacies - Purchase of history memories. Increase in diagnostic software capability.

## LANDER

## CAMERA

## TECHNICAL PROBLEMS

7/72 - to - 1/74

- Photo Sensor Array - Continuing technical problems, inadequate technical depth, and inadequate program control led to termination of the supplier of the photo sensor array in early '73. The MMC took over the assembly effort with a team effort with NASA supplying mechanical parts.

- Electronic Design - Itek continued to experience major electronic design problems during the first 2/3 of this period, including:
  (1) application of the Harris 2600's and 2700's
  (2) servo design problems led to dropping the position (zero-crossing) control vertical servo
  (3) Teledyne hybrid deliveries of up to 7 months late resulted in program inefficiencies
  (4) reworking, redesigning, and changing suppliers for printed wire boards.

- Bearings/Motors - Major problems in this area included:
  (1) bearing redesign to accommodate rates on the vertical scanner (retainers)
  (2) change from dry to wet lube on vertical scanner bearings (including addition of Labyrinth)
  (3) selecting ratio of Moly/Carbon for brushes, for specific application
  (4) redesign of brush assembly to maintain tension through environments.

# INERTIAL REFERENCE UNIT (IRU)

## TECHNICAL PROBLEMS

7/72 - to - 1/74

- Accelerometer - The manufacture of Bell accelerometers was moved from Cleveland to Buffalo prior to the Viking build. Manufacturing start-up problems at Buffalo were more extensive than anticipated. Also, accelerometer bias stability was found to be degraded by temperature hysteresis. This item required extensive investigation.
- Weight. - Structural parts were redesigned and discrete electrical parts were replaced with hybrid circuits and film resistor networks to reduce weight.
- Suspension - Shock and vibration isolation requirements could not be satisfied with the original metallic suspension. The metallic suspension was replaced with an elastomeric suspension.
- High Rate Mode - The duration of high rate mode operation in the Viking mission was found to be longer than originally specified. Investigation of the problems associated with longer high rate mode operation was a significant effort.
- Gyro - Gyro flexleads ruptured during low temperature environmental tests. Extensive tests were performed to investigate this problem.
- Wiring/Cabling - Assembly and repair of the IRU as originally designed was difficult. To correct this problem, internal wiring and cabling were changed and terminal boards were added.

## TERMINAL DESCENT LANDING RADAR (TDLR)

### TECHNICAL PROBLEMS

7/72 - to - 1/74

- Antenna Redesign - Redesign of the phased array antenna to reduce sidelobe levels to eliminate false locks was required.
- Power Supply Redesign - The power supply had to be redesigned to obtain separate power for each beam to provide redundancy within the unit.
- Addition of Shock Mounts - Redesign of TDLR mounting feet and addition of shock mounts was required to survive vibration requirements.
- Mixer-Diode Problem - Manufacturing problems with low noise mixer diodes caused additional lot buys and considerable hardware retesting.

## RADAR ALTIMETER (RA)

## TECHNICAL PROBLEMS

7/72 - to - 1/74

- Transmitter Pulse Breakup - Problems with breakup on the transmitter pulse resulted in tracker false locks which required substantial effort in the SSX circuitry to correct.
- Addition of "Tail-Bite" Circuits - Rapid turn off of the transmitter pulse trailing edge to achieve the 100 foot minimum altitude performance required the addition of several special design tail-bite circuits.
- Transmitter Corona - Corona was experienced in the transmitter pulse microstrip circuits during testing in vacuum. This required the coating of certain microstrip circuits with a silica sphere process ("pink sand").
- Circulator Ringing Problem - False targets were produced by ringing of the circulator ferrite material. Aging and stability testing had to be performed.

## GCMS

## TECHNICAL PROBLEMS

7/72 - to - 1/74

- Parker Hannifin Valves - Leakage around E B welds and leakage of poppet/seat at high temperature - redesign required; status indicator switch welding - redesign required; conversion of Benzyl Cyanide group - stainless steel liners added.
- Hydrogen Separator - Ruptures - numerous materials and processing revisions required.
- Thermal Zone - Energy requirement excessive - redesigned to reduce energy requirement.
- Effluent Divider - Performance unsatisfactory - significant redesign and EBB test required.
- Mass Spectrometer - Corona failures in high voltage potting - power supplies redesigned, potting material changed, and new test techniques required; analyzer performance inadequate - numerous design changes required; filament vibration failure - redesign of filament mounting required.

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GLOSSARY LIST

1. BPA - Bioshield Power Assembly
2. CDR - Critical Design Review
3. CDU - Command Decorder Unit
4. DAPU - Data Acquisition and Processor Unit
5. DC/DC - Direct Current to Direct Current
6. DRU - Driver Receiver Unit
7. DSM - Data Storage Memory
8. EB - Electronic Beam
9. EBB - Engineering Breadboard
10. ERI - Error Interrupt
11. EXI - External Interrupt
12. GCMS - Gas Chromatograph Mass Spectrome ter
13. GCSC - Guidance Control and Sequencing Computer
14. I/O - Input/Output
15. IRU - Inertial Reference Unit
16. KSC - Kennedy Space Center
17. LCS - Launch Complete Set (Equipment)
18. LDTM - Lander (Structual) Dynamic Test Model
19. LPCA - Lander Pyrotechnic Control Assembly
20. LSTM - Lander (Structural) Static Test Model
21. MMC - Martin Marietta Aerospace
22. NASA - National Aeronautics and Space Administration
23. PC - Printed Circuit

24. PCDA - Power Conditioning and Distribution Assembly
25. PDA - Processing and Distribution Assembly
26. PTC - Proof Test Capsule (Lander)
27. RA - Radar Altimeter
28. RCS - Reaction Control Subsystem (VOS)
29. RTG - Radioisotope Thermoelectric Generators
30. SSAA - Surface Sampler Acquisition Assembly
31. SSCA - Surface Sampler Control Assembly
32. SSX - Solid State Transmitter
33. STE - System Test Equipment
34. TDLR - Terminal Descent and Landing Radar
35. TETM - Thermal Effects Test Model
36. UHF - Ultra High Frequency
37. VCS - Viking Change Summary
38. VDA - Valve Drive Amplifier
39. WCA - Worst Case Analysis
40. XRFS - X-ray Fluorescence

Mr. Symington. In the middle of page 9, you state that you identified and implemented more than $54 million in cost reductions. We certainly would like to have those details, as well.

Dr. Cortright. Be gled to do that.

[The information follows:]

*Principal cost offsets—August 1971–July 1973*

| | *Millions* |
|---|---|
| Lander: | |
| Hardware and test | $13 |
| Hardware and test support | 5 |
| Subcontractor | 9 |
| Science | 4 |
| Subtotal | 31 |
| Orbiter: | |
| Hardware and test | 2 |
| Mission operations | 1 |
| Reserve requirements | 5 |
| Subtotal | 8 |
| Support: | |
| Test | 3 |
| Support contractor | 3 |
| Science | 6 |
| Subtotal | 12 |
| Total | 51 |
| Miscellaneous | 3 |
| Total | 54 |

VIKING PROJECT COST OFFSET HISTORY

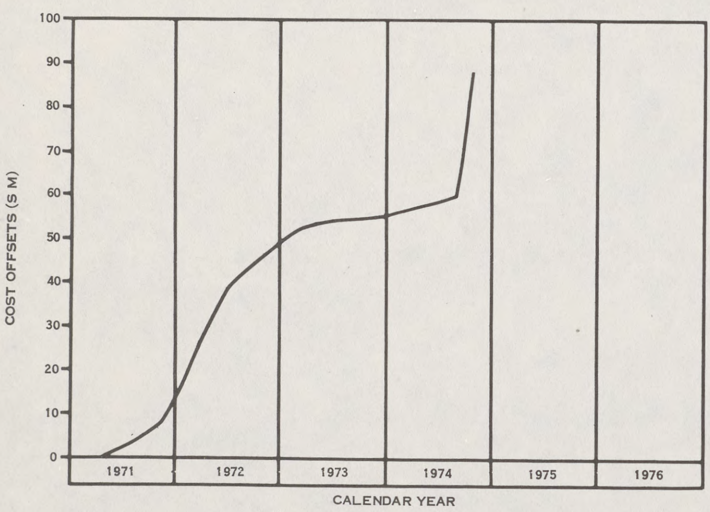



FIGURE 3

Mr. Winn. Mr. Chairman, in fairness to Mr. Cortright and to the committee, I think we ought to be sure that any pages that you skip because of time should be included in the record.

Mr. Symington. Oh, yes, they will certainly be in the record. The record will contain his statement with my interventions or those of other members where they appear. I am trying to call attention to those spots.

Again, at page 9 where you say "when combined with the application of $66 million of our planned reserve, a total of $120 million in unanticipated problems had been absorbed within the project to this point," this point being July 1973?

Dr. Cortright. Yes, sir.

Mr. Symington. $120 million constitutes a lot of surprises. How do you maintain your overview of subcontractor and contractor activities?

Dr. Cortright. Well, the cost offsets or cost reduction items are a matter of tabulated record. We have generated throughout the project a long list of possible ways to get the costs down, some of which were acceptable and some not. These are all, as I say, a matter of record. The application of our reserve is not really very magic. It was applied as it was originally intended to cover unanticipated problems. All I am really trying to say here is that at this point in time we had not yet broken the $838 million ceiling by both the application of the reserve contained therein, and the generation of cost reduction items.

Mr. Symington. I think I will let you return to your statement where you wish.

Mr. Hammill. I am not sure you understood the thrust of the chairman's question, Mr. Cortright.

I think what he was asking was: what techniques does Langley have for maintaining visibility over the activities of contractors and subcontractors? Because it appears that $120 million worth of surprises, that is to say, unanticipated problems, is a lot. It reflects, I think, unfavorably upon any techniques that you have for maintaining visibility.

Mr. Winn. Any kind of oversight.

Mr. Hammill. Yes.

Dr. Cortright. The way we basically manage the project is this. We have had about 140 to 150 people at Langley in the project office supported by another 140 in technical divisions around the center. We have residents at Martin, Martin in turn has resident teams at all subcontractors.

Mr. Hammill. Can you give us the numbers? How many residents do you have at Martin, how many does a Martin have at the various subs, and so forth?

Dr. Cortright. Yes, we can. That varies with time. At this time there are a lot of NASA people at Denver as we progress through the test period, there are 28 at the moment. These are not just Langley people: we supplemented the Langley team with teams from Johnson and Kennedy.

Mr. Hammill. Right. But, you see, the question really is: If you are doing a good job of watching what's going on, how can you come up with $120 million of unanticipated problems?

Dr. CORTRIGHT. Well, Mr. Hammill, I guess I would have to answer that in this way. The subcontractors have to solve their own problems by and large as does the prime contractor. We all work together to help each other, but each man on the team has to carry his load. The technique that we use is to have individuals assigned to watch every component and subsystem, both in the project office and in the Martin Marietta Corp., Denver Division. We, of course, try to work and help the subcontractors solve their problems. The fact that problems were bigger than originally anticipated, I think, reflects mostly on the ability to get the job done. That is my personal feeling. We have been playing catch up ever since because of the low estimates to start with.

Dr. PETRONE. This question of unanticipated problems is a direct relation to the state of the jump you're taking in technology. The packages, biopackage or computer for this particular spacecraft represent new technology, new things being done. This is a question of a new memory system being developed for this computer in going to what is called 2-mil thickness wire. There were difficulties in introducing and getting the state of technology to where it needed to be. Today it is there. We have it. But these difficulties certainly were not anticipated, because if it had been, we would have taken a different path. This is the nature of it, as we push technology, think of the new techniques, unfortunately we will run into difficulties which will cost more money than has been anticipated. There is sort of a direct relationship to the step one takes forward as to the degree of uncertainty of the ground that you're stepping in.

Mr. SYMINGTON. Thank you. Would you continue Dr. Cortright?

Dr. CORTRIGHT. Mr. Chairman, figure 3 is the record of the cost offset program throughout the course of the project. We had sort of leveled off in this time period at about $55 or $60 million. The upturn in 1974 was the last major cost reduction exercise, which I am going to talk about in just a moment.

I would recommend then that we move all the way to page 11. I can summarize my statement in between by saying that on March 13, 1974, John Naugle indicated to the Congress a possible 10-percent increase over the $838 million which corresponds closely to our $920 million number. Then, in the intervening period between Dr. Naugle's testimony and midsummer, we are still unable to contain the cost growth on the project. Now, basically, what happens when you near the end of a project, all of your manpower curves are supposed to "turn the corner," as we say. The ability to do that is very frequently the primary measure of whether you make your project on time and on cost. And we were experiencing tremendous difficulty getting to that point of maturity with the hardware that we could really turn the manpower curve down.

Continuing cost estimate assessment indicated that the final cost of Viking would substantially exceed $920 million. In September 1974 our latest cost estimate was brought to headquarters and discussed at length with Dr. Petrone and Dr. Hinners, who were then wrestling with very severe fiscal year 1975 and fiscal year 1976 resource problems. Faced with this substantial Viking increase, NASA headquarters "drew the line." Langley was directed to develop a plan, constrained to severe fiscal year 1975–76 limits, that would substantially reduce the estimated cost and provide assurance that cost containment actions would be effective. The goal was to continue to accomplish the stated mission science objectives with acceptable risk. Any prudent reserve was to be created through cost reduction actions. There were to be no "sacred cows" within the program—except mission success itself. It was a tough assignment so late in the program, but we set out to cut $25 million out of the target cost, an amount judged necessary to meet fiscal year constraints and generate a modest unallocated reserve. This target has been achieved and we now expect to complete the project for $930 million. I will now tell you how the NASA/industry team achieved this goal.

Mr. WINN. May I ask right there, when NASA drew the line, did that include any changes in personnel?

Dr. CORTRIGHT. Within NASA?

Mr. WINN. Yes.

Dr. CORTRIGHT. No, sir.

Mr. WINN. None. Any changes of authority?

Dr. CORTRIGHT. Well, in the sense that the reserve funds were held within headquarters and not put in the Center, yes.

Mr. WINN. I'm talking about individual people personally?

Dr. CORTRIGHT. No, sir.

[NOTE.—However, the project team had been strengthened.]

Mr. WINN. Nothing.

Dr. CORTRIGHT. I would now like to return to my statement and discuss cost reductions. The $25 million cost offset program represented a major redirection of project effort, coming as it did late in the project's maturity, and included cancellation of both a backup Lander and an Orbiter spacecraft in order to achieve the required cost savings. In summary, the reduction was made as follows:

| Project element: | *Reduction in millions* |
|---|---|
| Lander | $14 |
| Orbiter | 7 |
| Support | 4 |
| Total | 25 |

In order to give you an idea of the specific types of actions required to reach $25 million, figure 4 lists some of the major program actions we took at MMC, JPL, and other installations. Although each action was important in its own right, I would like to briefly cover two areas of reduction: One, deletion of the third Lander and Orbiter, and two, reductions in the planned mission operations activity.

FIGURE 4.—*Principal recent cost offsets*

| | *Thousands* |
|---|---|
| Lander: | |
| Deletion of third Lander | $5,500 |
| Deletion of all captive firing and hover tests | 440 |
| Consolidation of systems and test engineering for test team activities | 725 |
| Accelerate computer deliveries | 1,120 |
| Modification of biology instrument test program | 590 |
| Reduction of mission operations | 3,096 |
| Orbiter: | |
| Delete third Orbiter | 4,420 |
| Reduction of mission operations | 3,174 |
| Support: | |
| Reduction of mission operations | 1,876 |
| Reduction of support contracts | 750 |
| Replan of biology test standard modules effort | 250 |

Mr. HAMMILL. May I interject here?

The third Lander and Orbiter must have been well along in development when the decision to delete was made. They must almost have been built; isn't that true?

Dr. CORTRIGHT. They were well along. The components required to assemble them were almost all delivered, and assembly had begun.

Mr. HAMMILL. So that represents a very large investment?

Dr. CORTRIGHT. Yes.

Mr. HAMMILL. In hardware?

Dr. CORTRIGHT. Yes.

Mr. HAMMILL. But they will not be completed now?

Dr. CORTRIGHT. Yes.

Mr. HAMMILL. In order to save what appears to be, in light of the history of the program, a relatively small amount of money? I am not suggesting that you shouldn't try to save money in the program, but——

Dr. PETRONE. I would like to add that one has to look at the money to be spent. I know there has been an investment made. We knew we were going to fly. How do we fly within the fiscal resources available to us. The judgment has to be made in that context. It is a very difficult decision. We reached a point in terms of dollars as well as the program structure, and we looked at dollars to be spent and made a decision that that money we would rather save.

Mr. HAMMILL. Is there any way we could determine the amount of that investment in the canceled Orbiter and Lander?

Dr. PETRONE. I think we can, if we could submit that for the record.

[The information follows:]

*Lander.*—Recurring cost to fabricate, assemble, and test a Viking lander is estimated at $20 million. The deletion of the Viking third lander avoided $5 million of planned expenditures. Therefore, the remaining $15 million is the amount invested in the deleted third lander. We do, however, have this hardware available for logistical support of the two remaining flight landers and the Proof Test Capsule (PTC). However, all surplus material could be utilized in a future Viking launch opportunity.

*Orbiter.*—Recurring cost to fabricate, assemble, and test a Viking orbiter is estimated at $20 million. The deletion of the third orbiter avoided $3 million of planned expenditure. JPL feels that a majority of the hardware is usable in support of the Viking '75. It is estimated that approximately $5 million was spent in the assembly of the structure that will not be utilized in support of the 1975 launch opportunity. However, all surplus hardware from Viking '75 could be utilized on a future Viking mission.

DELETION OF THIRD LANDER AND ORBITER

Dr. CORTRIGHT. A major cost reduction was achieved with the deletion of the third Lander and Orbiter. In so doing, however, it was necessary to replan our pathfinder operations at KSC, and to alter our philosophy on spare spacecraft. Let me explain.

The Proof Test Orbiter—PTO—and the third Lander had been planned to go through all of the handling and processing required at KSC as pathfinders, in advance of the flight articles. Following this, the PTO would revert to a troubleshooting status during the mission, and the third Lander would become a flight spare. In our revised plan, the pathfinder operations are reduced to include only those steps which have not been performed at the factory.

Equipment used at the factory for various stages of the testing will also go to the cape. Therefore, in the process of our normal testing, many of the mating actions and operational actions which would have been done in the pathfinder are seen at least once in the factory. So we were able to eliminate some of those. The pathfinder operations that remain are accomplished with flight articles. This is possible because of the large amount of factory test equipment which will be used at KSC.

With the deletion of the third Orbiter, the PTO is being refurbished to become a flight spacecraft. This is practical since it completed its qualification testing at JPL in very good condition. It passed the qualification test so well and emerged in such good condition that we are confident it will be a flightworthy Orbiter.

The situation with regard to the third Lander is slightly more complex. In 1969, the program plan included a minimum 30-day launch window. In order that we could survive a Lander failure on pad and still launch two spacecraft to Mars in the launch window, it was determined that three Landers were needed. As the design weight matured and mission trajectories were calculated, it has been possible to extend the launch window to the order of 45 days. Thus, this provides a longer opportunity to repair and resterilize a Lander that has failed and still launch a second spacecraft late in the launch window.

The deletion of the third Lander increases the risk that, in the event of Lander 2 malfunctioning on the launch pad, coupled with a late second spacecraft launch attempt due to weather, launch vehicle, or other problems, it may not be possible to repair and resterilize the Lander and still launch. We have made the judgment that this increased risk is acceptable, consistent with NASA and Viking fiscal constraints.

An additional point worth noting is that the associated reduction in work at MMC and at KSC not only reduces costs, but also reduces the risk of schedule problems during the remaining months preceding launch. In other words, it ventilates the schedule and does not require working three shifts a day, 7 days a week from now until launch, which can be an impossible situation. We now have more shift margin to get the work done than we had.

## MISSION OPERATIONS

Another major cost reduction was made in the mission operations budget. Although this activity has been managed very effectively over the past year, additional reviews revealed that a reduction of $8 million, or 15 percent, could be achieved without a serious impact to the mission operations plan.

The largest cost offset is the reduction from 850 to 730 people in the size of the Viking flight team that will be responsible for operating the spacecraft—2 Orbiters and 2 Landers—after launch. There will be some reduction of mission flexibility to respond to new information and problem solving capability but this is considered acceptable. In-depth training exercises are planned which will verify the acceptability of the planned staffing level.

Manpower efficiencies have been realized by using test and training personnel in operational positions; having the Lander science imaging team operate the Lander image reconstruction equipment; and having people that have completed their hardware development responsibility work on non-Viking activities until their flight team position must be filled, thus eliminating the retention cost. Development of procedures not required until the planetary phase of mission operations has been delayed to a time when they can be more efficiently incorporated into the work plan, while still meeting the need date.

Lander and Orbiter imaging comprise a large portion of the data to be returned by Viking. Reductions have been made in computer enhancement capability and the number of duplicate products has been minimized. No reduction has been made in the amount of data acquired, however. This decision was carefully reviewed with the Viking science steering group and is acceptable to them.

In a supporting area of mission operations, the Lander proof test capsule will be available for problem solving in an ambient environment during mission operations, but funds originally planned to operate the Lander in a chamber simulating the Mars surface environment have been deleted. Consistent with Mariner 10 practice, an assembled Orbiter will not be available for operations support.

### MANPOWER MANAGEMENT

Having established a firm new schedule and cost baseline for the work to go, the Viking project office also moved to strengthen its cost management and control activities. The key to containment of costs at MMC—and its major subcontractors—was to jointly establish and adhere to stringent new manpower plans—the major element of cost—while still maintaining successful implementation of schedule milestones. Manpower no longer needed on the project is offloaded immediately. At MMC, for example, manpower plans identify by surname most of the people charged to the Viking contract. This provides the basis for weekly time-phased offload plans by individual in each of the major task areas.

RECENT MANPOWER PERFORMANCE

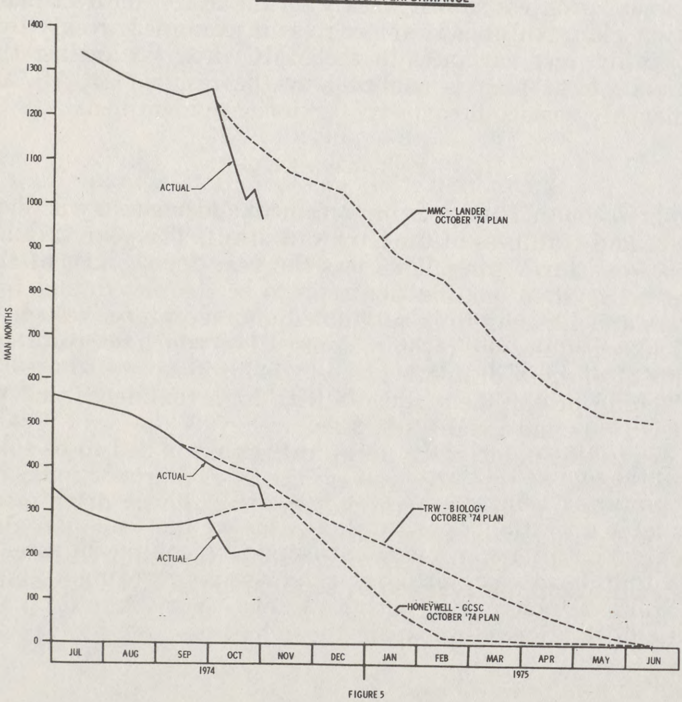



FIGURE 5

The in-house effort at MMC now follows the manpower plan as shown on figure 5. Note particularly that MMC performance against the October 1974 plan has been consistently good since the program was restructured. Data obtained since the figure was prepared shows a slight increase, so the curve will not continue to come down as steeply as indicated, but we are under plan at the moment.

At TRW and Honeywell, the situation is much the same and is evidenced by the manpower curves also shown on this figure. If our contractors can stay below the planned manpower levels, we will have some margin for unforeseen problem solving, while still making our target costs. And the target costs are those which would conform to the $930 million completion cost.

CONTRACT RESTRUCTURING

Another key feature of our current relationship with the MMC is a contract restructuring which is now being formalized with the company. Under this award fee arrangement, the Martin Co., will be judged and rewarded on its ability to live within the $539 million estimate for their part of the project, a target compatible with our $930 million project ceiling. In our judgment, the contract restructuring has resulted in greater motivation for the contractor, and has provided a substantially greater assurance to the Government on the matter of cost containment. I believe contractor actions and manpower offloading during the past 6 weeks support these assertions.

INDIRECT COSTS

In addition to the manpower offload plan referred to earlier, we have also agreed to a firm indirect cost management action plan with MMC. Our monitoring of indirect cost performance against plan is based upon actual progress shown weekly on the MMC indirect manpower reduction plan. An update of progress is examined weekly by VPO. Additionally, any variances in the MMC progress against their indirect manpower plan is analyzed by the resident DCAS/AFPRO on a monthly basis and corrective actions are identified.

PROGRAM STATUS

The final concern which is important to address today is that of the progress and readiness of the hardware itself. The year 1974 has been a crucial one for Viking. This was the year for the last of the component and system qualification tests to be completed, and for flight Orbiters and Landers to be assembled and acceptance tested. Despite technical, schedule, and cost problems, all of which necessitated workarounds of one sort or another, most of this has come to pass. We are approaching preshipment reviews with high confidence that we have good hardware and a viable schedule.

To get to this point, many technical problems had to be solved. To illustrate some of the more recent: the X-ray proportional counters required redesign to eliminate voltage breakdown; drive motors for the surface sampler boom required redesign at a very late date; the metal tape in the Lander recorder, which was required to withstand heat sterilization, was plagued by scratching; to UHF transmitter ran hot during PTC testing; the upper atmospheric mass spectrometer suffered persistent failures to eject a protective cover; the GCMS encountered stubborn corona problems; and the inertial reference units—IRU's—developed helium leaks.

Mr. SYMINGTON. Could we have advantageously incorporated those provisions earlier on? It seems to me that the motivation is important for cost cutting. Could you have introduced those elements earlier or not?

Dr. CORTRIGHT. We had motivation for cost containment in terms of a cost share arrangement with the company, but the fee losses due to overruns had eroded that to the point where the large incentive prior to contract restructuring was on mission success. And one could reason although I don't think Martin was doing this, that this would incline a contractor to keep extra men on to assure mission success. What we did was redistribute the available fee between the mission success award portion of it, and a portion to be awarded at launch which would be a measure of whether or not the company had met their target cost to that point in time. This also gives the company an opportunity to realize some fee prior to July 1976 if they do this manpower management job well.

Mr. ESCH. Mr. Chairman, if you would yield, we are in the usual process of running to three committees. I have read the testimony so far.

I am concerned about a different perspective in the same area and that is the relationship between the Viking lander and the lunar lander. It seems to me if we have the right precept, we ought to look at the question of cost in relationship to the complexity of the two. I would like to hear someone discuss very briefly the relationship between the Apollo and Surveyor in terms of both the complexities of the operation and the relationship to costs. It seems to me, I want to come down hard on you fellows in terms of cost, too, and at the same time we ought to recognize that the two are not completely analogous. To the degree to which they are not analogous we ought to recognize some variables in cost. In fact, what we may be doing is moving out into a new field. I assume they are not analogous.

Dr. PETRONE. I believe we have stated in our testimony, this is the most complex automated spacecraft NASA has ever undertaken. No one else has ever undertaken anything comparable. In terms of Apollo and its need to support life I don't believe there is a comparison, but with Surveyor there probably is a direct comparison. Thus, you had a Lander that was going to go to a close body as contrasted to 200 million miles away. When one compares what Surveyor was doing compared to the Viking here, there are many orders of magnitude in complexity in terms of science objectives. The prime objective of Surveyor was soil testing. Those things we needed as a precursor to know it would be safe to land our men. Here we are really moving the biology laboratory we have here on Earth. We are moving the biology laboratory to Mars because of the inability to return the sample using methods we developed on Apollo for reasons that are very clear because of the distance involved. Here is a case of moving your laboratory 200 million miles out, taking your samples and testing them to find out whether or not we might find some life. The question of reading seismometry, the quakes and so forth, requires a whole different approach in planetary exploration because of the distance involved. We are seeking some of the same answers we got from the Moon, but doing it at a much greater distance. The question became one of automating the spacecraft to do that and to also take care of itself. We are 40 minutes away from communicating with that spacecraft from the time we tell it to do something, as contrasted to 2½ seconds to the Moon is a significant task. So the complexity makes it very unique and, I think, speaks for itself in terms of the objectives we have outlined for that spacecraft.

Mr. Esch. I am concerned about that in relation to cost. It seems to me we should recognize we are beginning to pattern out a new concept at least in terms of unmanned exploration of our planets, so we need a new approach.

Dr. Cortright. Yes, sir, I can make the Surveyor comparison. We had worked this out awhile back. I was reluctant to present it because it sounded self-serving. I am glad you asked the question because it is an interesting point.

If we take the Surveyor contract with Hughes and escalate it to today's dollars, it comes to $518 million for seven spacecraft. The Martin Marietta lander comes out to $545 million. Now, we get seven spacecraft with Hughes at about 750 pounds each, and we are getting two with Martin at three times that weight, so it comes out to roughly the same number of pounds for the same number of dollars. The difference is in the complexity. The packing density, for example, in the Viking in terms of complex electronics and other equipment is far higher.

Just to give you a feel for it, the electronic parts count in the Surveyor was 28,700 and the electronic parts count in the Viking lander can be as high as 967,000. Now, the reason this is a little misleading is that it counts integrated circuits as multiple parts because they have multiple electronic functions. That is a little unfair. Correcting for this, I would guess that there are still several hundred thousand parts in the Viking lander. So roughly we are getting the same pounds of hardware for the same price, but a lot more in each pound.

Mr. Esch. Thank you.

Mr. Symington. Mr. Brown?

Mr. Brown. One of the interesting strategic aspects of the competition between this country and the Russians in space was our decision to undertake a program to put a man on the Moon and their decision to go with an unmanned program. This leads me to feel that possibly they had done more and earlier work with unmanned probes than we had and I wanted to raise that question with you. Is there a possibility that closer cooperation with the Russians in terms of their unmanned technology might have given us a little more insight into some of the problems we are experiencing with this Viking operation on Mars, or has there been any interchange of information bearing on this point?

Dr. Petrone. There have been discussions with the Russians.

Dr. Hinners participated in some of those planetary exploration discussions. We, unfortunately, have not learned much about their hardware.

Dr. Hinners. Right. You are well aware——

Mr. Brown. It's their science package that would be most relevant, I think, to what we are trying to do here.

Dr. Petrone. Science and also techniques of landing. The Russians have had a very ambitious program to land on Mars. They launched three missions in 1971, four launches instead of two like missions in 1973, and they have not succeeded yet in putting a Lander down successfully on Mars to get data back.

They have had successful Orbiters. No successful Landers. One Lander did return approximately 20 seconds of data from what was believed to be the surface. But there is no good confirmation. We have had science discussions with the Russians in trying to exchange data and there have been some exchanges.

Dr. Hinners. Right. We have had some information from their spacecraft, the ones that have been partially successful in terms of the pressure coming into the atmosphere which we have then fed back into our models of the Mars environment which will be helping us in our landing attempts. We have also seen some of their science data which has been released. They have taken photographs from their Orbiter in their last attempt which were of quite good quality, and they have conducted a couple of experiments which we have not and are not now planning to do in our Viking mission.

Most of their successes in the automated area have been in their lunar program where they have put down successfully two automated roving vehicles, and have had two successful automated sample return missions. Although the last sample return mission several weeks ago did not succeed, they have developed that technology. What we have found is their ability to interpret their results has been fantastically enhanced by the results we have obtained from Apollo because of our much more extensive scientific investigations. The caliber, the quality of the science is one big item to be considered in talking with them, and considering what future missions we might do. The state of technology that we employ is very much advanced over what they are generally doing in their science investigations. Some of that shows up within the complexity of what we are attempting to do.

So, in our successes I think we are much further ahead in the amount and the quality of the scientific data we acquire.

Mr. Brown. In other words, closer cooperation would not have made it any easier to solve some of the problems we have encountered with the biology package on the Viking?

Dr. Hinners. That is correct.

Mr. Brown. I thought because their emphasis was on the automated procedures, there could have been some prospects for our learning from them. Certainly an option we ought to continue to consider.

Dr. Hinners. We do talk with them and exchange information and when they have a program, we are in contact with them, exchange information on what they saw and what they think in many instances when they did not succeed.

Mr. Brown. Thank you.

Mr. Symington. Thank you, Mr. Brown.

Dr. Cortright. To solve these problems, it was necessary to pull together teams of experts from wherever we could find them—the contractor's own staffs, NASA centers, or other Government and industry organizations around the country. This team approach paid off time and again.

Some technical problems are still with us. We are not yet fully satisfied with a proposed solution to a radar altimeter false lock problem. Retest may be required. The GCMS soil distribution unit has been subject to jamming. As in many other instances, the Langley fabrication shops have worked with our contractors in developing alternative fixes.

Our most serious component problems this past year were encountered in the Honeywell computer (GCSC) and the TRW biology package. Since these will be discussed tomorrow, I will not dwell on them here.

To interject a thought here, each of these problems could occupy us for 10 or 15 minutes were we to go into them. I tried to give you a sampling of the current flurry of problems.

At the system level, the Lander system design verification test on the proof test capsule (PTC) was replanned in March 1974 to accommodate delays in the component design development phase and unexpected startup problems with the systems test software and automated systems test equipment (STE).

Mr. SYMINGTON. Since Langley is Project Manager, it would be enlightening to the committee to get your viewpoint of these problems.

Dr. PETRONE. On those two, he will be glad to discuss that.

Mr. SYMINGTON. I think it might be helpful just to give us a few thoughts, and if you think this requires extensive discussion, you can put it in the record. But we'd like to be encouraged to believe that you feel all is being done.

Dr. PETRONE. We would be glad to address it right now.

Dr. CORTRIGHT. Let me begin with the computer. I think during earlier congressional testimony, you were made aware of the type problems we were having with the computer, one of which was getting memory wire that met specifications. We decided about January, I believe it was, to initiate a coupled film wire development, rather than the single film wires we were using. These wires are 2 mils in diameter, and coupled film wire was to give the wire the lifetime, the margin of signal-to-noise, that we needed to get through this mission.

At the same time, we began a backup development of a core memory unit for the computer. As it turned out, both of these have succeeded. Although it is getting very late, we have core memories on the shelf ready to use if needed. In the meantime, the Honeywell Co. solved its wire problems, and has now completed the development of a computer to the point where the two flight units are nearly ready for delivery. One of them is buttoned up and should not be opened up again and the other had a minor problem which was repaired this week, or is being repaired this week. The spare is being refitted with some new multilayer circuit boards, which is another problem we had this year. We found we had multilayer circuit boards that had gotten into the computer that were not reliable. There were breaks in the circuitry through the holes from one plane to another. These boards had to be replaced. All of this has been accomplished. The company is on a schedule that supports the Lander and we will ship the two flight computers the first week of December.

Mr. HAMMILL. In other words, a final decision has been made to go with the Honeywell memory and not with the backup?

Dr. CORTRIGHT. That is right. One of our cost reduction items was to stop all work on the backup.

Mr. HAMMILL. After an investment of how much?

Dr. CORTRIGHT. $7 million.

Mr. HAMMILL. And the Honeywell contract is going to run to how much, total project cost?

Dr. CORTRIGHT. I will get that for you in just a moment; $29.9 million.

Mr. BROWN. May I inquire in a small matter like this backup work on the computer which cost us $7 million is there any benefit to be obtained in the future from the technology and development that has been done here or is this just cost that has to be written off?

Dr. CORTRIGHT. The memories themselves are usable. They are 20,000-word memories each. While they represent very excellent memories, we have not identified a use for them at the moment. They are quite usable core storage memories, but I don't know what their future will be.

Mr. BROWN. They were developed for the specific function of this Viking program so there would not be any applicability to terrestrial application, I suppose?

Dr. CORTRIGHT. I don't believe so. I think there may yet be an application in a space project, but even that is uncertain. I wouldn't like to hold that hope out. I do think they represent about the best in the state of the art of small core memories. And I am sure that both we and the company that developed them learned something from that operation. The company, Electronic Magnetics and Memories, did an outstanding job and I would like to give them a plug.

Mr. BROWN. I have a vague recollection of similar problems that were experienced during the Manhattan project; for example, developing some way of producing a casing for the uranium segments that went into various—I think what they called a cladding problem during World War II in which numerous alternative methods were made to develop the technology to encapsulate the uranium, and I always wondered if we completely waste the effort we make in studying various alternatives to solutions of these problems.

Dr. CORTRIGHT. I would like to say, sir, when we began the backup core memory, we didn't know whether we would ever have either a wire memory or a core memory. We were just about to give up on the single film plated wire. You will hear more about that tomorrow. We undertook these courses of action because the mission could not be flown without a computer. I think it is gratifying they both have come through for us. Naturally, I would like to see that $7 million back in the bank, if it would be possible. But we felt that we could not risk not having a computer.

Mr. BROWN. I have the same question about what we are going to do with the work that has already been done on the Lander. Do we just warehouse this equipment and so forth? Is there a conceivable future use for it? I don't want to explore that at the present time.

Mr. HAMMILL. May I ask one question regarding the computer. The 2-mil wire memory for the computer had never been done before. It was a brand new development. It seems to me that I recall that some contractor had proposed using a 5-mil wire memory, which had been done before, if I am not mistaken.

Now, my guess is that weight was not a consideration in selecting 2-mil instead of 5-mil wire.

Why didn't we go to the 5-mil wire on the basis of reliability instead of going to something that was totally unknown?

Dr. CORTRIGHT. There are several parts to the answer to that question. In the first place, we had extreme weight, volume, and power constraints on the computer, and we pushed the state of the art as far as we thought was reasonable to do so in order to meet those constraints.

Now, the second part of the answer is I don't really believe it was the shift from 5-mil to 2-mil that caused most of our problems. It was meeting the sterilization requirement wherein the contractor had to change his materials and processes which delayed for almost a year the buildup of this computer. Mr. Rynearson will talk about that tomorrow. Whether or not we could have made it with single film 5-mil wire, I don't know. We may have needed a coupled film there also.

Information I have here says that the 2-mil is more stable than the 5-mil and we probably would have had the same problems with the 5-mil wire, in addition to the weight, volume, and power, so I don't really think that is what tripped us up.

I would like to talk for a moment about the biology package. You will hear in some detail tomorrow about the status of the problems. We have been plagued with many of them during the past year. Rather major redesign of many of the pieces within the experiments have had to be undertaken to eliminate such problems as valve seal material sticking as a result of the thermal environment and contamination of valves which is an assembly-type cleanliness problem that has been extremely difficult to solve. The instrument is full of heaters because it has such a difficult thermal environment to meet. Heater debonding held us up for a long period of time. It really was a long series of little nitty-type problems with that instrument.

Mr. SYMINGTON. Were these all problems you would have had to confront for a 1973 window?

Dr. PETRONE. With the same package, yes, sir.

Mr. SYMINGTON. I don't see how you could have made it.

Dr. CORTRIGHT. We never would have had that instrument for 1973. It would have had to be a much simpler biology experiment.

Mr. SYMINGTON. It was the biology experiment which is of such key interest to the scientific community.

Dr. CORTRIGHT. Yes, sir.

We might say it would have contained a single experiment rather than three packed together, and perhaps one that was not so precise in its measurements as we have here.

Mr. SYMINGTON. Yes, that is a point to remember.

Mr. BROWN. Could I ask one very small question. When you're designing valve seals in this kind of a situation, what kind of temperature limits are you designing for?

Dr. CORTRIGHT. There are many ranges within the instrument depending on where the value is located. We are talking about temperatures between zero and 400° F, I think, on typical valve seals. And, of course, these are very miniaturized valves we're talking about with allowable leak rates that are almost immeasurable. The biology experiments are scheduled for delivery in March and April. The two flight biology packages will be installed in Florida. In addition, two test biology packages will be complete in December. I believe, Mr. Chairman, most of the known technical problems are behind us. But we still face a problem with these instruments in building them with precision.

Mr. SYMINGTON. How about fitting them into the Lander?

Dr. CORTRIGHT. Fitting them into the Lander is no problem. Having them built with everything working perfectly is the problem that we still face, and we are not quite there.

Mr. SYMINGTON. It is immaterial that you will be testing your flight Lander next week without the biology package because the package can be inserted like a cartridge?

Dr. CORTRIGHT. It is not immaterial. We do plan to put one of the test biology instruments back in the PTC Lander in January to verify its operation. At the same time, we are going to conduct some additional tests on GCMS that were not completed in the last test. So we are going to pick that up at the same time. One of these will be operating at TRW labs processing dirt, to make sure that we can work with real soil and the scientists can interpret the data.

Mr. SYMINGTON. Fine.

Dr. CORTRIGHT. The replanning extended the PTC test work plan and required augmentation of the MMC test team to provide additional technical skills and accommodate an accelerated schedule—7-day week, three shifts per day. In addition, experienced NASA test personnel from KSC and JSC moved to Denver to help us. Since August, Lander test activities have been on schedule. Figure 6 shows a list of major milestones completed since March 1974.

FIGURE 6.—*Major schedule accomplishments—March through November 1974*

| | *Completed* |
|---|---|
| Lander–PTC: | |
| Heat compatibility test | May 1974 |
| Acoustic/vibration test | June 1974 |
| Post separation/solar vac test | August 1974 |
| MSS/SEET test | October 1974 |
| Pyro shock | In progress |
| Lander–Flight: | |
| Structural assembly | July 1974 |
| EMC testing | August 1974 |
| Orbiter–PTO: Quality testing | July 1974 |
| Orbiter–Flight: | |
| VO–2 flight acceptance tests | November 1974 |
| VO–1 flight acceptance tests | In progress |
| Launch operations activation: Spacecraft assembly and encapsulation buildings (2) | October 1974 |
| Mission operations: | |
| Ground data system test | July 1974 |
| Flight operations software development (launch phase) | August 1974 |

In the interest of time, because Mr. Parks has yet to testify, I don't think we will work through that list with you.

I would like to spend a few minutes talking about the work remaining between now and August 11, 1975, the day the Viking launch window opens. The first flight Lander will go into its flight acceptance thermal vacuum tests next week. Following the completion of these tests and the vertification of Lander performance, it will be shipped to KSC and will arrive there on January 17, as shown on the master schedule (fig. 7). Flight Lander No. 2 will go into the thermal vacuum chamber as soon as No. 1 comes out. This Lander will arrive at KSC on or before February 24. The two Viking Orbiters are in the final phases of post environmental systems test and will arrive at KSC on February 12 and February 17.

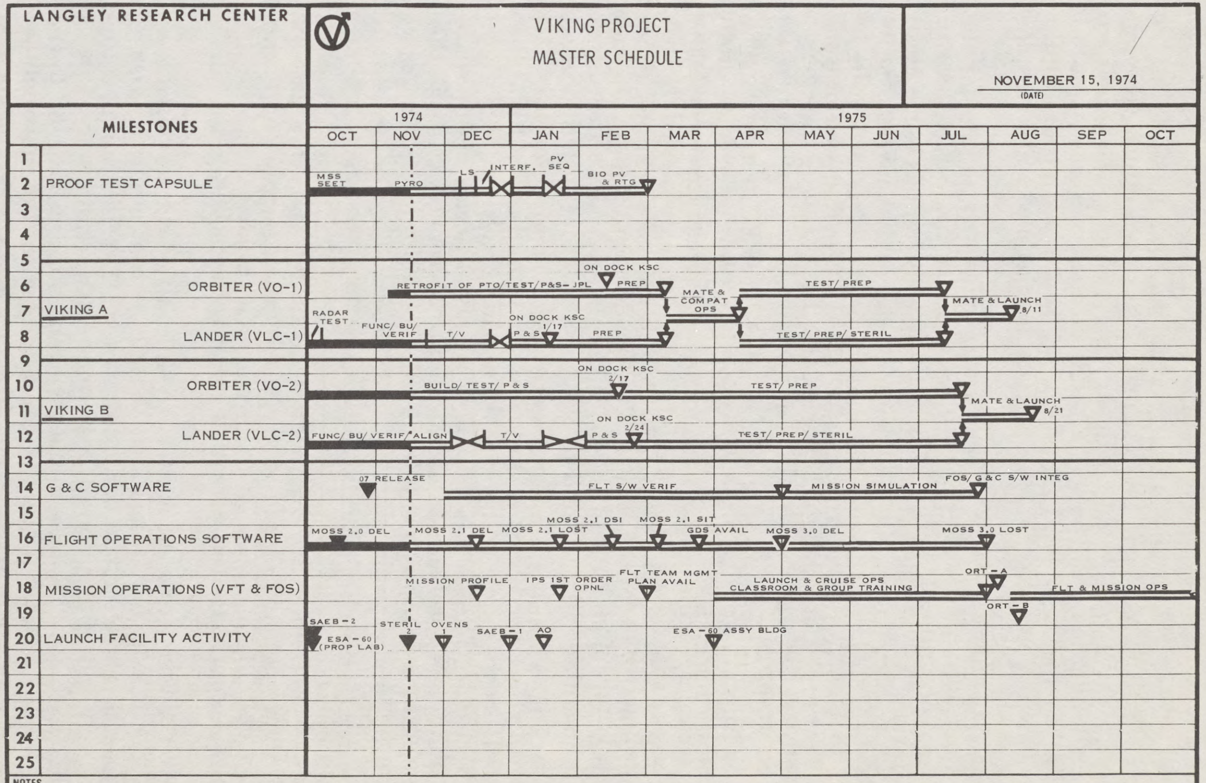

LANGLEY RESEARCH CENTER
VIKING PROJECT
MASTER SCHEDULE
NOVEMBER 15, 1974
(DATE)
MILESTONES
1974
1975
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
2 PROOF TEST CAPSULE
MSS SEET
PYRO
LS
INTERF.
PV SEQ
BIO PV & RTG
6 ORBITER (VO-1)
7 VIKING A
8 LANDER (VLC-1)
RETROFIT OF PTO/TEST/P&S- JPL
ON DOCK KSC
PREP
MATE & COMPAT OPS
TEST/ PREP
MATE & LAUNCH 8/11
RADAR TEST
FUNC/ BU/ VERIF
T/V
ON DOCK KSC 1/17
P & S
TEST/ PREP/ STERIL
10 ORBITER (VO-2)
11 VIKING B
12 LANDER (VLC-2)
BUILD/ TEST/ P & S
ON DOCK KSC 2/17
MATE & LAUNCH 8/21
FUNC/ BU/ VERIF/ ALIGN
ON DOCK KSC 2/24
14 G & C SOFTWARE
07 RELEASE
FLT S/W VERIF
MISSION SIMULATION
FOS/ G & C S/W INTEG
16 FLIGHT OPERATIONS SOFTWARE
MOSS 2.0 DEL
MOSS 2.1 DEL
MOSS 2.1 LOST
MOSS 2.1 DSI
MOSS 2.1 SIT
GDS AVAIL
MOSS 3.0 DEL
MOSS 3.0 LOST
18 MISSION OPERATIONS (VFT & FOS)
MISSION PROFILE
IPS 1ST ORDER OPNL
FLT TEAM MGMT PLAN AVAIL
LAUNCH & CRUISE OPS CLASSROOM & GROUP TRAINING
ORT – A
ORT – B
FLT & MISSION OPS
20 LAUNCH FACILITY ACTIVITY
SAEB – 2
ESA – 60 (PROP LAB)
STERIL 2
OVENS 1
SAEB – 1
AO
ESA – 60 ASSY BLDG
NOTES

FIGURE 7

At KSC an early significant activity will be the mating of Lander 1 and Orbiter 1, the encapsulation of combined spacecraft in the Centaur Standard Shroud, and then the mating of the encapsulated spacecraft with the Titan Centaur launch vehicle on pad 41 at ETR. A simulated countdown will be performed to demonstrate the compatibility of all of the flight hardware with the launch pad ground equipment. This important pathfinder activity is scheduled to be complete the first week in April.

Following this test, the spacecraft will undergo a series of flight mission compatability tests that will demonstrate and verify the compatability of the flight spacecraft with the ground system, particularly the ground data system and software to be used in the Viking Mission Control Center at JPL.

The Landers will then proceed through a final buildup for flight with the installation of flight batteries, the flight biology instrument, and RTG's. This activity will continue until mid-June when the Landers will be ready for sterilization in the ovens at KSC. Following sterilization, Lander propellants for the attitude control system and the terminal descent engines will be loaded and the Lander is then ready for flight.

During this same time period, the two flight Orbiters will be undergoing final flight preparations. This includes moving the Orbiters from hangar AO at ETR to an explosive-safe area where fueled propulsion modules will be mated to the Orbiter bus. The Orbiters are then ready for flight.

Starting the second week in July, Orbiter 1 and Lander 1 will then be mated, encapsulated, and will move to pad 41 to be mated with the launch vehicle. This will be complete August 1. Ten days of spacecraft and launch vehicle tests and simulated countdowns are then planned. These practice countdowns will be monitored by the Viking flight team located in the VMCCC in Pasadena. The final tests of all equipment, facilities, and people will be complete to support a launch on August 11.

Meanwhile, Orbiter 2 and Lander 2 will have been encapsulated in the Centaur standard shroud in the spacecraft assembly and encapsulation building at KSC. In the event of a problem with the first Viking spacecraft, the second will be ready to replace it on the launch pad.

As you can see, from the master schedule, all of the supporting activities necessary for launch and flight are continuing in Denver and at JPL. These include flight software final verification and continuing test and integration of operations software.

Last month we ran a comprehensive series of science end-to-end tests with the Lander proof test capsule. Due to the unavailability of a biology instrument, end-to-end testing with biology was not possible.

Mr. SYMINGTON. Among other things, your qualification tests on the biology package are not yet complete?

Dr. CORTRIGHT. That is correct.

Mr. SYMINGTON. When will those tests be completed?

Dr. CORTRIGHT. End of March.

Mr. SYMINGTON. End of March. You don't expect that those tests will result in a different flight type instrument?

Dr. CORTRIGHT. We don't expect any major changes to come from that. In fact, it would be very difficult, if not impossible, to make major changes. The modules that go into the bio experiments have been tested at flight levels. This is the system tests we are talking about which is one reason we don't expect any major redesign problems to come out of it.

We therefore plan to put the PTC with a flight-type biology instrument back in the thermal vacuum chamber in late January, and will run simulated mission profiles with biology experiments during the month of February. These tests will be conducted with test standard gases such that comparisons can be made with similar tests conducted at TRW at the instrument level. In this same time period, another flight-type biology instrument will be undergoing instrument level tests using dirt with live organisms at TRW.

The work to go, as I have described above, has been carefully planned to provide adequate contingency at KSC and matches well with our fiscal constraints. We believe that all of the hardware will be adequately tested and that the present plan will be achieved on schedule.

In summary, I believe our posture is as follows:

1. We continue to have a good science payload, with most of our science instruments in excellent shape. Biology and the GCMS, however, must be watched carefully.

2. Our other component deliveries are very close to completion. Only the computer remains a major concern, although its progress is much better in recent months.

3. Our systems testing is proceeding well, with our flight spacecraft expected to be delivered to the Cape on schedule in early 1975.

4. Our planning and preparations for the mission operations are on schedule. Our Mars landing sites have been selected and approved, our mission rules, strategy, and procedures are in good shape, and formal team training will begin in the spring.

5. Our costs have been contained and management procedures to contain these costs are working well. Barring major unforeseen problems, we expect to complete the project for $930 million.

6. I find our NASA/industry project team, after over 5 years of working together, is seasoned, cohesive, and confident. This is probably the most important factor influencing the success of the project.

In conclusion, I believe that we stand in a good position today. Although we have much work ahead of us as we swing into the final test and operational phases of the project, I am confident that we will be successful. Like Dr. Petrone, I will continue to give Viking my close personal attention.

Mr. Chairman, this concludes my statement.

[The charts attached to Dr. Cortright's statement are as follows:]

VIKING PROJECT COST HISTORY

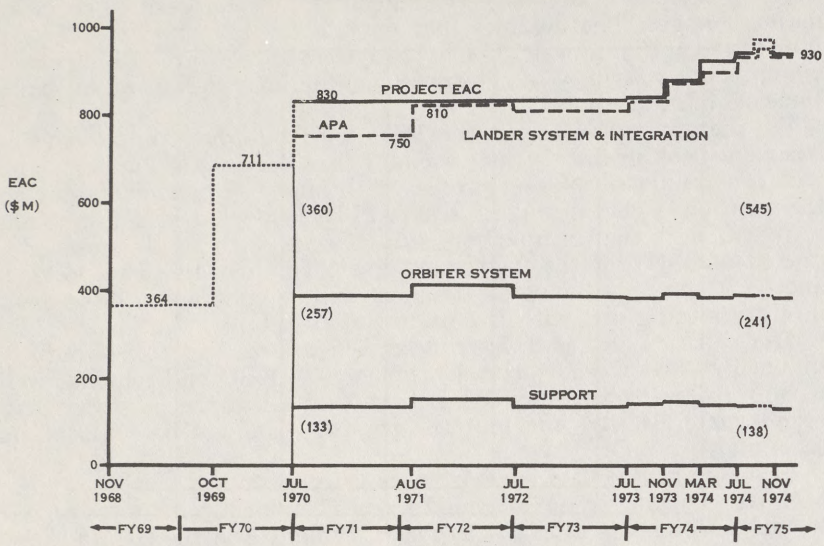



FIGURE I

VIKING LANDER COST HISTORY

(MMC CONTRACT)

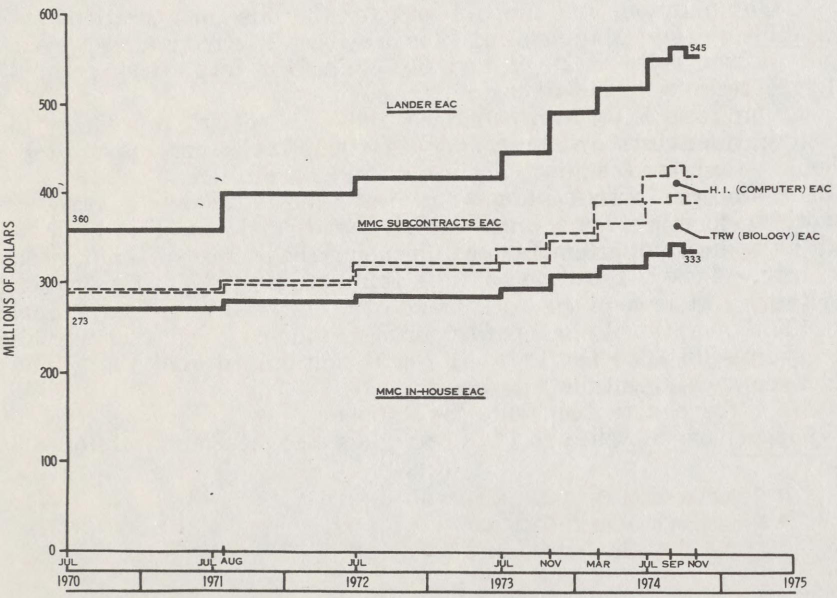



FIGURE 2

## VIKING PROJECT COST OFFSET HISTORY

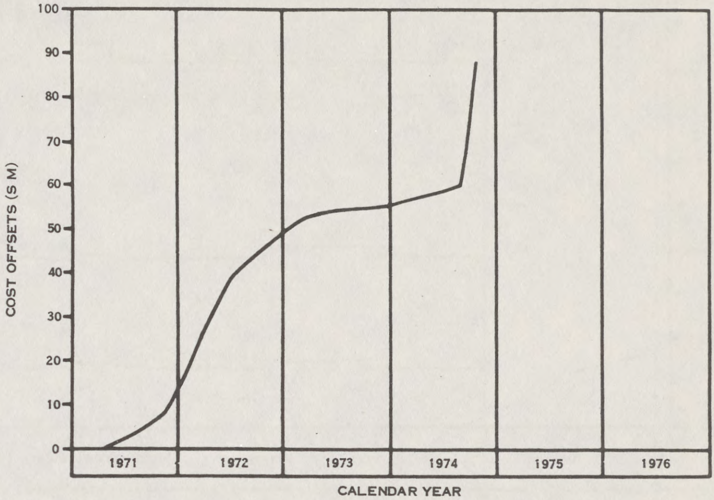



FIGURE 3

## PRINCIPAL RECENT COST OFFSETS

LANDER:

| | |
|---|---|
| ° Deletion of Third Lander | 5500 |
| ° Deletion of All Captive Firing and Hover Tests | 440 |
| ° Consolidation of Systems and Test Engineering for Test Team Activities | 725 |
| ° Accelerate Computer Deliveries | 1120 |
| ° Modification of Biology Instrument Test Program | 590 |
| ° Reduction of Mission Operations | 3096 |

ORBITER:

| | |
|---|---|
| ° Delete Third Orbiter | 4420 |
| ° Reduction of Mission Operations | 3174 |

SUPPORT:

| | |
|---|---|
| ° Reduction of Mission Operations | 1876 |
| ° Reduction of Support Contracts | 750 |
| ° Replan of Biology Test Standard Modules Effort | 250 |

Figure 4

RECENT MANPOWER PERFORMANCE

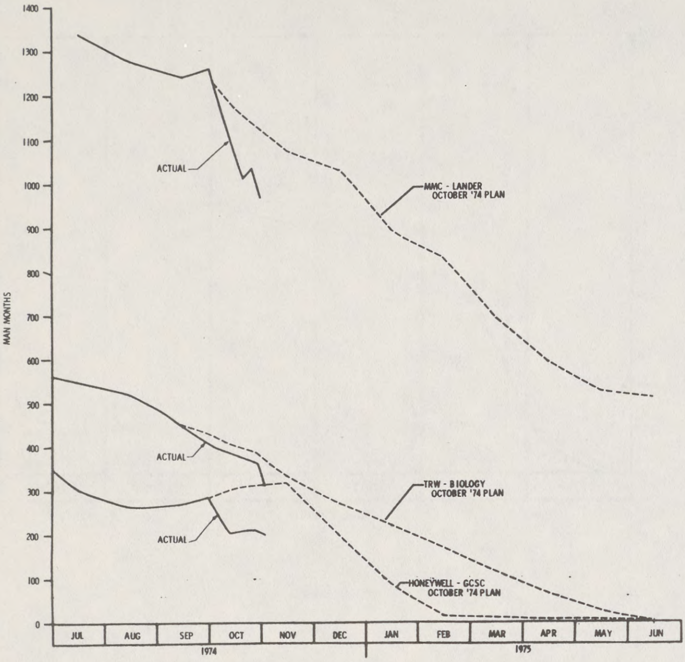
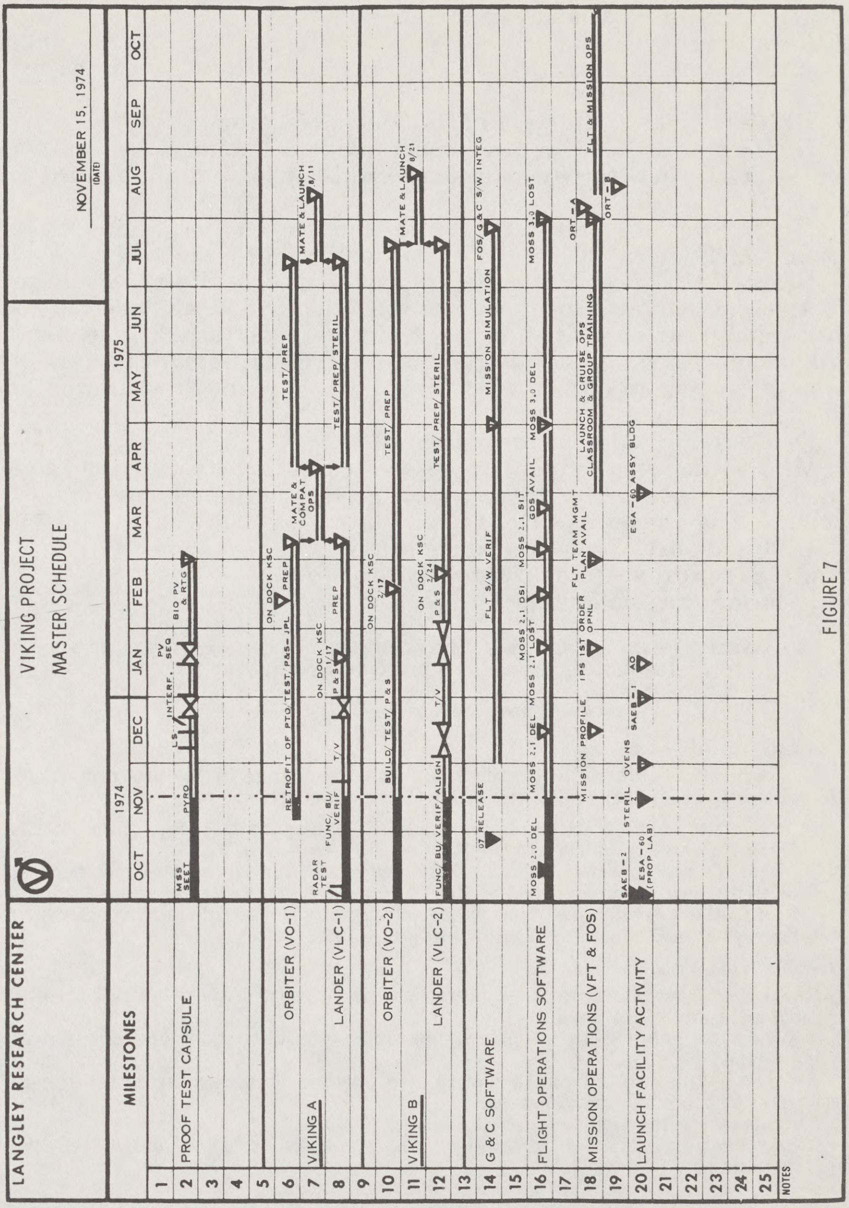



FIGURE 5

MAJOR SCHEDULE ACCOMPLISHMENTS
MARCH THROUGH NOVEMBER 1974

| | COMPLETED |
|---|---|
| LANDER - PTC: | |
| ° Heat Compatibility Test | May 1974 |
| ° Acoustic/Vibration Test | June 1974 |
| ° Post Separation/Solar Vac Test | August 1974 |
| ° MSS/SEET Test | October 1974 |
| ° Pyro Shock | In Progress |
| LANDER - FLIGHT: | |
| ° Structural Assembly | July 1974 |
| ° EMC Testing | August 1974 |
| ORBITER - PTO: | |
| ° Qual Testing | July 1974 |
| ORBITER - FLIGHT: | |
| ° VO-2 Flight Acceptance Tests | November 1974 |
| ° VO-1 Flight Acceptance Tests | In Progress |
| LAUNCH OPERATIONS ACTIVATION: | |
| ° Spacecraft Assembly and Encapsulation Buildings (2) | October 1974 |
| MISSION OPERATIONS: | |
| ° Ground Data System Test | July 1974 |
| ° Flight Operations Software Development (Launch Phase) | August 1974 |

Figure 6


LANGLEY RESEARCH CENTER
VIKING PROJECT
MASTER SCHEDULE
NOVEMBER 15, 1974
(DATE)
MILESTONES
1974
1975
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT
PROOF TEST CAPSULE
VIKING A
ORBITER (VO-1)
LANDER (VLC-1)
VIKING B
ORBITER (VO-2)
LANDER (VLC-2)
G & C SOFTWARE
FLIGHT OPERATIONS SOFTWARE
MISSION OPERATIONS (VFT & FOS)
LAUNCH FACILITY ACTIVITY
MSS SEET
PYRO
LS
INTERF.
PV SEQ
BIO PV & RTG
RETROFIT OF PTO/TEST, P&S - JPL
ON DOCK KSC
PREP
MATE & COMPAT OPS
TEST/PREP
MATE & LAUNCH 8/11
RADAR TEST
FUNC/BU/VERIF
T/V
ON DOCK KSC 1/17
P & S
TEST/PREP/STERIL
BUILD/TEST/P&S
ON DOCK KSC 2/17
MATE & LAUNCH 8/21
FUNC/BU/VERIF/ALIGN
ON DOCK KSC 2/24
07 RELEASE
FLT S/W VERIF
MISSION SIMULATION
FOS/G&C S/W INTEG
MOSS 2.0 DEL
MOSS 2.1 DEL
MOSS 2.1 LOST
MOSS 2.1 DSI
MOSS 2.1 SIT
GDS AVAIL
MOSS 3.0 DEL
MOSS 3.0 LOST
MISSION PROFILE
IPS 1ST ORDER OPNL
FLT TEAM MGMT PLAN AVAIL
LAUNCH & CRUISE OPS CLASSROOM & GROUP TRAINING
ORT - A
ORT - B
FLT & MISSION OPS
SAEB - 2
ESA - 60 (PROP LAB)
STERIL 2
OVENS 1
SAEB - 1
AO
ESA - 60 ASSY BLDG
NOTES
FIGURE 7

Mr. SYMINGTON. Thank you, Mr. Cortright.

Regarding the Viking landing sites, is there any remote possibility that they would be areas that the Russians may already have impacted wittingly or unwittingly?

Dr. PETRONE. Dr. Hinners can address that question.

Dr. HINNERS. No. Our proposed candidate landing sites are not in the areas where the Russians have had their landing programed to date.

Mr. SYMINGTON. I ask that because I am not really sure how clean their vehicles were when they hit. We don't want to learn old news.

I think for the record it might be good to incorporate a brief précis of the contract revisions that have been made, that you referred to, for example, after revision of the Honeywell contract. I understand that manpower assigned to Viking increased quite dramatically, and it would give you an idea of what sort of events result in what kind of changes.

Dr. CORTRIGHT. Be glad to do that.

Mr. SYMINGTON. And how you used the contract structure and formulation to pursue our objectives, a good education for us here. I think you have given us some of that.

Dr. CORTRIGHT. We will certainly do that.

Mr. SYMINGTON. It would certainly be helpful.

[The information follows:]

## LANGLEY RESEARCH CENTER/MARTIN MARIETTA VIKING LANDER AND PROJECT INTEGRATION CONTRACT RESTRUCTURING

### CONTRACT RESTRUCTURE—CPIF/AF TO CPAF

*Reasons for Restructuring*

To provide an equitable adjustment for a major change in the program (deletion of the third lander) and to revitalize the cost incentive:

Deletion of the third lander had a significant potential impact on Martin Marietta's ability to achieve the Mission Success Award Fee.

Due to cost overrun, Martin Marietta had run out of the specific cost incentive in the summer/fall of 1972, had eroded all of the available Periodic Performance Award Fee, and was eroding potential earnings of the Mission Success Award Fee to be determined in late 1976.

*Benefits from Restructuring*

Revised cost incentive provided more immediate reward and penalties for cost management and containment.

Appropriate balance between mission success and cost containment was reestablished.

All open changes to the contract were incorporated, thus permitting total management attention to work progress.

Provided consideration for third lander deletion.

Kept the parties in substantially the same fee position as before the restructuring.

## MARTIN MARIETTA CORPORATION/HONEYWELL, INC.—VIKING COMPUTER CONTRACT RESTRUCTURING

### CONTRACT RESTRUCTURE—FPI/AP TO CPAF

*Reasons for Restructuring*

To enhance the probability of meeting fixed delivery requirements with a reliable computer:

A series of technical problems required many research and development-type studies, analyses and tests to find solutions or acceptable alternatives.

FPI contract type did not provide the needed flexibility to effectively implement and conduct these studies.

These activities set up "constructive change" situations that took significant time of technical managers at both Honeywell and Martin Marietta.

Work was behind schedule to meet fixed delivery requirements.

Schedule/cost tradeoffs were apparently being made in favor of cost due to the ceiling limitations of the FPI contract type.

*Benefits from Restructuring*

Required emphasis on problem solving and work progress was obtained:

Additional resources were provided by Honeywell.

Additional management techniques were installed such as production control room and problem management center.

Team approach (Honeywell/Martin Marietta/Langley Research Center) was facilitated which contributed significantly to work progress.

Management and cost performance in the form of award fee appraisals facilitated direction to the program and added appropriate emphasis on cost containment.

Mr. Brown, do you have any questions?

Mr. Brown. Just one point. Your statement does touch lightly on the sterilization problem. I know from the beginning of the concept of this experiment that in the scientific community there was a great deal of concern about the matter of sterilization and contamination of Mars.

Has that controversy been satisfactorily resolved within the scientific community?

Are the sterilization procedures we and the Russians are using adequate to give some assurance at least we are not seriously endangering Mars with Earth contamination?

Dr. Petrone. I will ask Dr. Hinners to address that.

Dr. Hinners. I believe that all our scientists are satisfied now with our procedures on the sterilization; that we will meet the limits which we have derived on the sterilization; and, that we are not taking an undue risk in contaminating the planet.

One of the biggest efforts, of course, is being made to assure ourselves that not only do we not contaminate Mars for its own sake, but that we do not run the risk of having a false indication from the biology experiments of life on Mars and that is being examined very closely now in light of recent information to be sure that we do have confidence in the answers we get from the biology experiments.

Mr. Brown. Are there any members or groups within the scientific community that are publishing critical material on this, on the science aspects of this program? I am not aware of any, but I am not sure.

Dr. Petrone. Critical in the sense of not being satisfied with what is being done? I am not aware of any.

Dr. Hinners. I am not aware of any either.

Mr. Brown. Scientists that are writing critical reviews on everything else that we do.

Dr. Petrone. Well, I am sure in balancing the program—like when we talked about deleting the No. 4 experiment on the biology package in 1972—you make someone unhappy. We add one and make someone happy. I believe one has to expect that. Whether yours is flying or not determines the happiness, and also the type of experiment we do affects certain elements of the scientific community. I would say overall we have a good balance on the Viking program.

Mr. SYMINGTON. One way to delay the mission would be to require an environmental impact statement of the impact on Mars.

Dr. PETRONE. Our soft landing, totally sterilized, we probably have one of the best environments one could imagine.

Dr. CORTRIGHT. I can put a number to that, Mr. Chairman, if you like, in answer to Mr. Brown's question. When COSPAR decided to what extent they were going to protect Mars, they allocated out to various people trying to land on Mars, an allocation of probability of contamination. It turns out each Viking is permitted 1 chance in 10,000 of releasing a viable organism on Mars.

Therein is a long story, but the end of that story is we have qualified this spacecraft to take sterilization temperatures of 111° centigrade, actually by baking it at 123° to prove the capability. This had never been done before, and worried us a great deal at the beginning of the program. It has bitten us in a few places, such as the computer.

Mr. SYMINGTON. The biology package is affected, too, by the high heat?

Dr. CORTRIGHT. It has to withstand that.

Dr. PETRONE. You hurt your valve seals by your sterilization procedures. We had to design valves for that and the extreme temperatures one could encounter in the mission.

Dr. CORTRIGHT. There was a tremendous amount of detail work done in the early part of the program to identify parts and procedures which would make it possible to sterilize the equipment.

Mr. SYMINGTON. What is the temperature you expect to encounter at the landing site?

Dr. PETRONE. Plus 70° in the day time; minus 150° at night.

Mr. SYMINGTON. Quite a variance for instrumentation.

Dr. PETRONE. I do want to mention, we do take steps to have heaters in our various parts of the program. We mentioned on the biology package that the number is in the 40's. There are heaters in various places to stabilize the temperatures within the Lander. The radio thermal generators will be used as the primary source of heat to try to keep a balance to see that temperatures are held within limits. Where necessary, we will compensate with heaters on board the Lander.

Mr. BROWN. Well, I am concerned about the financial aspects of this program, of course, but also about the scentific aspects. It would be highly unfortunate if by a combination of circumstances we ended up with something that was both financially and scentifically not in accordance with the best interests of the country, and I suppose that possibility always exists in anything as complicated as this program.

I have no further questions, Mr. Chairman.

Mr. SYMINGTON. Thank you, Mr. Brown.

Mr. Winn.

Mr. WINN. I have just one question. I don't care who answers it. Either yesterday or the day before in the Washington Post, Mr. O'Toole wrote an article about Viking and said it might be up to its neck in dust.

Will you comment on that?

Dr. PETRONE. I would like to have Dr. Hinners comment on that. The story about this test stated that it had been made in recent weeks, but it turns out the test had been made some years ago. And we were aware of it. The test referred to in the article was not of recent origin. Some radar data correlation has been recent. But it is relatively old data.

I would like Dr. Hinners to comment who was present at some of the interpretation of the radar data.

Dr. HINNERS. We have been observing Mars for well over a decade with radar observations. The best of the observations though, occurred in the last year or so. From the radar results one can get two things: a measure of surface roughness comparable to the state of the wavelength used in the radar, and also an estimate of the physical properties of the soil in the upper several feet. What we have seen in the radar results is, first, that the proposed landing sites for the first mission appear to be quite acceptable in terms of the slope, slope distribution, and appears to be well within the capability of the Viking Lander. We do not have radar results and will not for the proposed sites for the second mission. It is above the area in terms of latitude where we can get results. In terms of the soil properties, the radar results indicate a variation in a measurement of what I call the dielectric constant. We take that measurement and interpret it in terms of a soil density, how much soil is packed into a given volume. Now, most of the area on Mars appears to be of acceptable soil density such that there would not be a sinkage problem. The sites, again, for the first Viking landing appear to be acceptable in terms of the apparent soil density. The radar indicates that there are areas on Mars which have possible densities much lower than we would think might be acceptable for a landing. These areas are not our current landing sites. The uncertainty occurs in that we do not have radar results for the sites we are considering for the second landing.

What we are doing now is looking for alternative possibilities for that second mission, sites for which we will have good radar results so that if during the first landing we have any problem and find that there is reason to doubt our interpretation of the radar, we could go to a second site for which we do have radar results, rather than to those sites we now have for which we do not have radar information.

Mr. WINN. The question they raised in the article—it is feasible we may have misjudged the landing surface.

Dr. HINNERS. No; I don't think in those direct terms that is quite true. There are areas where we think there might be soils of low density. I think to compare it to quicksand is not quite right because quicksand is full of water such that when you walk into it you have almost no buoyancy, and you go on down into it. We don't know of any mechanism on Mars which would create that kind of a condition. We have, based on those earlier tests, increased the area of the landing footpads. Also the undersurface of the spacecraft itself is flat so that if you do get into a situation where the footpads do start to compress the soil, then you hit the flat undercarrier of the spacecraft which additionally acts as a load-bearing surface.

Mr. SYMINGTON. This arm would be——

Dr. PETRONE. You can work from here (indicating).

Mr. SYMINGTON. It can work up.

Dr. CORTRIGHT. We had a hard time finding what set of circumstances would lead to a soil situation which would be so drastic as to cause a sinking "up to the eyeballs." We will do everything we can to avoid the doubtful areas and to go where our photographic and radar information indicate we stand the best chance of having a firm surface within the specification of the Lander.

Mr. WINN. Thank you.

Mr. SYMINGTON. Inasmuch as these radar studies, as you say, occurred over the last year, and have given you a more precise understanding, then I take it they were not available at the planning of the 1973 launch?

Dr. HINNERS. The best results have been available for the last year. We have had radar observations since the mid to early 1960's and some of the Goldstone results have come in at a later time. The initial ones were from the Haystack up in Massachusetts. We did not have as good observations then. We will have some observations close to the time of the Viking landing from the Arecibo Observatory. But I don't think we will be putting a lot of reliance on the measurement at that time. Mars is very far from the Earth and the radar signals at that time are just at the marginal point where we think we will be able to say for sure that the site is good. If it is marginal, you would have a hard time saying so because of the weak signal at that time of the year.

Mr. WINN. Have the Russian landing observations been of any benefit to us as far as soil compaction?

Dr. PETRONE. I don't know of direct information——

Mr. WINN. They sent pictures.

Dr. PETRONE. Pictures from orbit. We, of course, in our Mariner missions got some high quality resolution. You can correlate, with the radar data of the site and correlate the pictures and start to derive some interrelationships there. It does not give you a direct measurement, but you can get some inferences from correlating the pictures with the radar data. This correlation gives us better information, but it does not give you direct density.

Dr. CORTRIGHT. None of the Russian spacecraft have given any useful data from the surface. One of the speculations of the failure mode is very soft material, so that to that extent, we should try hard to avoid areas that might threaten us that way. I think the answer is that this spacecraft has a tremendous bearing area, if need be on its bottom.

Mr. SYMINGTON. I have but one last question. We do want to hear from Mr. Parks.

In 1973 the GAO did a report on Viking and they made certain recommendations. Let me quote from the report: "We believe that data on changes in costs, schedule milestone, and performance characteristics—similar to DOD reports on major weapons systems—would be useful to the Congress in evaluating the Viking project." They suggested NASA prepare such reports periodically for submission to Congress and they suggest the reports contain details on budgeted and actual cost of testing and other significant information regarding risk and meeting performance characteristics, things like that.

Has NASA actually followed a pattern of providing periodic reports to Congress in your own view?

Dr. CORTRIGHT. We have made all of our information available to the GAO. The way we attempted to respond to that is simply to make all internal working documents available.

Mr. SYMINGTON. I am sure you are completely willing, if not anxious, to keep us advised. I am not precisely certain in my own mind what kinds of reports DOD gives or how it gives them, but it might not be a bad idea to take a look at that and see if there is some way we can keep the Congress more up-to-date on the progress of complex projects like Viking. The way it has seemed to me to have occurred is every now and then we get some rather tough news and then we have to sort of think back and wonder how we got into that problem. Occasionally the committee will take a trip and we will learn something horrendous at that point we hadn't expected. Maybe there is no perfect way to keep us all advised. The sooner that we all know there is a problem on the horizon, the better we can work together to resolve it.

I do want to thank Dr. Petrone and Dr. Cortright for a very excellent and complete statement.

We may have questions from the committee in writing which I trust the witnesses will be happy to answer as best you can. We may not have covered all the details, but we certainly got a lot done.

I also thank Dr. Hinners for his contribution.

Mr. Parks, I think we will now hear from you.

## STATEMENT OF ROBERT J. PARKS, JET PROPULSION LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY

Mr. PARKS. Mr. Chairman, my name is Robert J. Parks. I am the assistant laboratory director for flight projects at the Jet Propulsion Laboratory (JPL) of the California Institute of Technology. Thank you for the opportunity to appear before your committee today to discuss JPL participation in the Viking project.

The Jet Propulsion Laboratory is contributing to the Viking project in several areas, as you know, for which it is responsible to the Viking project office at the Langley Research Center.

The prncipal JPL assignments are to provide (1) the Orbiter System, (2) the Tracking and Data Acquisition System, and (3) the Mission Control and Computing Center System. In addition to these major tasks, JPL is supporting the mission design and the flight operations activities and is performing several small tasks in support of the Viking Lander.

The laboratory efforts for the Orbiter include the System design, the design and procurement of the subsystems through contracts with the aerospace industry, providing the Orbiter science instruments, conducting the assembly and system test of the Orbiter, and the final launch phase preparations.

The Tracking and Data Acquisition activities include worldwide data reception; tracking, and command support for the two Orbiters and two Landers, utilizing, as appropriate, both the 26-meter and 64-meter facilities of the NASA deep space network. This effort involves increasing transmitter power capability and providing X-band coverage (in addition to the normal S-band coverage) on a worldwide basis.

JPL support for the Mission Control and Computing Center covers the ground computing and data display requirements as well as the facility capabilities needed to command and control the spacecraft in flight. It includes specialized facilities, computers, software, display devices, and associated personnel. This activity covers both the Orbiter and Lander as well as any special operations required during the launch phase.

Support of the mission design activities includes design of the Earth-to-Mars transit trajectories, the Mars orbital trajectories, the navigation system concept, and the Orbiter science collection plans.

For the flight operations activities, JPL is preparing and will provide the following functions: Orbiter performance and analysis, Orbiter science operations, and overall spacecraft navigation. In addition, JPL personnel are assigned to key positions in the flight team.

JPL is also assisting the Viking project by performing the first and second order enhancement of the images sent back by the Lander cameras and is supporting the calibration of the Viking Lander cameras, in conjunction with these same tasks for the Orbiter cameras. In addition, JPL is developing the ground software required to process the Lander telemetry data.

The laboratory was selected to carry out these tasks for the Viking project because of the recent and applicable experience in all of these areas resulting from prior Mariner projects, particularly the Mariner Mars 1971 orbiter mission.

In 1970, when the Viking 1975 mission was first scheduled and authorized, the plan envisioned an Orbiter generally based upon, but considerably more capable than, the Mariner 1971 orbiting spacecraft. The Viking Orbiter would carry both itself and the Lander into orbit at Mars and be capable of releasing the Lander for descent to a preselected landing site. The Orbiter would also provide relay communications to Earth for the Lander and conduct the assigned orbital science investigations. The schedule for the Orbiter system was established primarily by the requirements of interacting with the Lander; somewhat more time was provided than was required for the Orbiter alone.

The plan for the Tracking and Data Acquisition, Mission Control and Computing Center, and flight operations support activities was based upon the Mariner Mars 1971 experience, with only generally defined limits on both adaptive mode processing and simultaneous control of the two Orbiters and two Landers. The schedule for these activities anticipated readiness for orbital operations at the time of launch.

In 1970 the cost of the JPL Viking effort, exclusive of Tracking and Data Acquistion and Mission Control and Computing Center support, was estimated at $257 million, which included provision for 5 percent per year cost escalation and a contingency or reserve allowance of $10 million.

The activities have generally proceeded on schedule and are well within the budget. In particular, during the last year, the design qualification of the Orbiter System and its subsystems was completed, the flight Orbiters have been assembled and are in test, the Orbiter flight operations software has been delivered to integration, and compatibility between the Orbiter and critical Lander components has been demonstrated.

The activities related to the Orbiter have been accomplished within the 1970 schedule. The schedule for the flight operations software has slipped somewhat but is compatible with the current plan and does not appear to portend any future major problems. The project has modified the overall schedule so that some operations capability, which is needed only for the orbital period, will be developed and demonstrated during the 11-month cruise period. This approach is believed to be workable and appropriate.

The recent cost reduction activities initiated by the Viking project office have changed the approach to several of the JPL tasks. The proof test Orbiter is being reassembled and is now scheduled for flight. Work on what was intended to be the second flight Orbiter has been terminated. We will prepare the proof test Orbiter and the other flight Orbiter using a single test team—as compared with the originally planned two—for all of the remaining activities scheduled at JPL and at the eastern test range.

The cost reduction steps have also reduced the number of people supporting flight operations and will modestly affect the adaptive mode capability. We believe this reduction can be accommodated without serious penalty to the operations.

At present, the second flight Orbiter installed in the solar vacuum chamber is under test; the first flight Orbiter—previously the proof test Orbiter—is being reassembled for final system tests prior to shipment to the eastern test range. The flight operations software integration is well underway.

The outlook for the Tracking and Data Acquisition and Mission Control and Computing Center support for Viking is generally good. Initial demonstration tests to confirm compatibility with Viking mission requirements have not revealed any major problems. The modification of the 64-meter stations is expected to meet Viking launch and planetary test schedules.

The incorporation of late changes in the Lander flight operations software, which must be integrated with all of the other flight operations software, is of some concern. The integration of the Orbiter flight operations software, although well underway, is being watched carefully since this has been a troublesome area in past projects.

The current cost-at-completion target for the JPL effort exclusive of Tracking and Data Acquisition and Mission Control and Computing Center support is $239 million. This figure represents a reduction of $18 million from cost estimates made in 1970. The cost-saving efforts discussed above have contributed to this saving. There is no contingency in the $239 million budget, but every effort will be made to hold to this cost.

Mr. Chairman, that completes my prepared statement. I will be happy to answer any questions.

Mr. Symington. Thank you, Mr. Parks.

At the bottom of page 4 you refer to the incorporation of late changes in the software as being of some concern, and then you speak of integration of the orbiter flight operation software.

Can you describe the problems with greater particularity?

Mr. PARKS. Yes, sir. The software I am referring to here as to do with that software that is used in the ground computers to analyze and interpret the data that is being sent back by both the Orbiter and Lander. This ground software, of course, has to be compatible with and consistent with the specific design of the flight hardware and its software. The fact that the Lander is somewhat behind its original schedule and has had some modifications in the design of the hardware and/or late development of this software, simply indicates that there might be a problem. At the present time, we have no specific indications of any problem in making sure that that software integrates properly with all of the rest of the ground software. By integrates properly, I mean that it must work in the computers properly and work simultaneously with all the other software that has to be operated in the computer. We have had some difficulty in past projects as I alluded to in my statement, in insuring that this software integration was accomplished properly.

We have been able to overcome all of these problems in the past and we fully expect to be able to do so here. It is highlighted here to note the fact that we are alert to this concern and are doing everything we know how to be prepared to overcome any of these late problems, should they in fact occur.

Mr. SYMINGTON. Mr. Winn, do you have any questions?

Mr. WINN. I have no questions.

Mr. SYMINGTON. Mr. Cortright said you were developing the GCMS experiment and there has been some cost growth there. Perhaps you can describe the problems giving rise to that?

Mr. PARKS. Yes, sir. We initiated the development of the GCMS experiment and carried it through to a point in time where we believed that the basic development was essentially completed. At this time, it was a decision by the Viking Project Office to transfer the responsibility for the continuing GCMS efforts from the JPL to the Langley Research Center. They then undertook this task themselves. We have not had any direct involvement with it subsequent to that time. Prior to the time it was transferred there was a significant cost growth as Dr. Cortright indicated, and their cost growth must be attributed to the same types of problems that he referred to. This was a new instrument, it was in effect taking a laboratory technique and when applied in the laboratory requires a room full of equipment and miniaturizing it to an instrument of the size that could be flown on a Viking Lander.

There was an underestimate of the effort that would be required to accomplish that complete miniaturization to the requirements that were needed. We had to do a number of things to try to contain the cost growth and to assure that there was a good plan established to complete that effort. At the time the job was transferred, it was our judgment that those eccomplishments had been achieved.

Mr. SYMINGTON. This spectrometer, what was its function exactly?

Mr. PARKS. The technique here is to try to measure the Martian soil to determine what kind of organic materials it actually contains; and whether these be of actual biological type origin or whether they be simply a complex organic molecule not necessarily of biological origin. This is a sophisticated technique that combines the use of a gas chromotograph to separate the material in the soil in a way that it can be handled effectively by the mass spectrometer which in turn looks for specific indications of organic type material.

Mr. SYMINGTON. You say JPL had this well in hand. Why was it transferred then to Langley?

Dr. CORTRIGHT. I think I probably should answer this, Mr. Chairman.

We did it as a cost containment movement at the time. I believe the cost estimate at the time of transfer was about $39 million. We hoped to do the job for less than that by managing it with fewer people. JPL proposed a rather large team. We thought we could do it with fewer people and get those people off the Viking payroll. We did it with fewer, but the cost came out the same. So in a sense, what really happened was the money we saved on JPL salaries went back into paying cost growth. The job came out at the number they predicted.

Mr. SYMINGTON. This was in August of 1971?

Dr. CORTRIGHT. March, 1972.

Mr. HAMMILL. After JPL had worked on it, for how long?

Dr. CORTRIGHT. It started well back in the advanced technical development phase, maybe 5 or 6 years ago. The only reason we took it over was because we felt we were ready to settle down and build something and stop researching.

Mr. HAMMILL. In general, when a project is taken over by someone else, the costs are increased rather than decreased because each new organization has to go through a learning procedure and usually must learn some of the things the other one has already learned. Is that not true in this case?

Dr. CORTRIGHT. I don't believe so. We had worked closely with JPL. We essentially stayed on their plan, the same contractor.

Mr. HAMMILL. Who is the contractor?

Dr. CORTRIGHT. Litton is the prime, supported by Beckman and Perkin Elmer.

Mr. HAMMILL. For the record could you insert a statement of the financial history of that development, what it was supposed to cost in the beginning, what the problems were that were encountered?

Dr. CORTRIGHT. It will appear in the other cost history asked for and we will add some additional comments.

[The information follows:]

GAS CHROMATOGRAPH MASS SPECTROMETER COST GROWTH

[In millions of dollars]

| | July 1970 | August 1971 | July 1972 | July 1973 | January 1974 | November 1974 |
|---|---|---|---|---|---|---|
| GCMS support (including JPL effort) | 15.5 | 18.8 | 9.8 | 9.8 | 9.8 | 9.8 |
| Contractual effort | 7.0 | 21.1 | 20.5 | 25.1 | 28.6 | 30.6 |
| Total | 22.5 | 39.9 | 30.3 | 34.9 | 38.4 | 40.4 |

*Cost changes occurred due to the following major causes*

| | |
|---|---|
| July 1970–August 1971 | Litton was selected by JPL for negotiations in July 1971. Significant redesign activity was identified as systems contract was definitized. |
| September 1971–July 1972 | The Litton contract was novated in March 1972 by the Langley Research Center. The cost decrease was due to deletion of all JPL effort related to subcontract management, restructuring of the Litton Systems contract and instrument simplification. |
| August 1972–July 1973 | Identification of need for additional development work based on deficiencies found in development test unit (DTU). |
| August 1973–January 1974 | Occurrence of corona problem in PTC mass spectrometer and resolution. |
| February 1974–November 1974 | Lander pyrolyzer assembly problem and schedule slippage based on this problem and numerous minor manufacturing problems. |

Mr. SYMINGTON. On page 9 of your statement at the bottom, you say that the Lander system level tests on the PTC to be followed by flight article testing was an effort which proved to be generally underscored both as to resources and time required. Can you enlarge on that for us?

Dr. CORTRIGHT. Yes, sir; I can.

The numbers of people involved in running the test on the proof test capsule were underestimated and the amount of difficulty that we encountered in getting those tests completed was underestimated. Part of this was due to problems we experienced with ground test equipment. That equipment still continues to bother us and probably will off and on throughout the remainder of the project.

We also ended up with quite a bit of parallel testing going on at the company plant, which for some period of time at least involved additional test people.

Mr. SYMINGTON. When you encounter problems that you are able to overcome through restructuring management and remotivating people and new ways of changing the contracts, I hope that all becomes a part of your experience that is incorporated in any new ventures that you undertake, or is it that each project develops its own problems in such a neat way there is nothing much to be learned managerially from the experience?

Dr. CORTRIGHT. I will give you my answer and Dr. Petrone will probably have his own.

I believe we learn the same lessons repeatedly in the development of high technology projects and it probably relates at least in part to the fact that people are imperfect creatures.

Dr. PETRONE. I would like to add that one step Langley did take here in testing at Martin, where new procedures had to be produced, was to call upon the Kennedy and Johnson Centers for what was available from Apollo testing, to go to Denver and assist in setting up certain, different techniques in scheduling, in trying to anticipate problems. There was a case where experience was available within NASA, specifically in the area of tests when a deficiency in effect was encountered. Langley did take the steps, Dr. Cortright, personally, in trying to get assistance from two of our centers, which had this experience from Apollo and did move people who are still in residence at Denver. I use the word anticipate, that is a difficult thing to do. That is also the key to move on, all of which takes time and manpower.

Mr. Symington. Dr. Petrone, what in retrospect, if anything, would you have done differently in the preparation of Viking project? That is a rather broad question. I am sure there must be some thoughts.

Dr. Petrone. The one that comes to mind, I would understand the requirements better. That is an easy statement to make and a very tough one to live by. It is the one item I do believe, and we also see it in our discussion with the DOD and some of their projects, the question of a clear delineation of the requirement and feedback as to what that is going to mean. Now, when you are in the business of exploration, and pushing technology, you, of course, want to take on those challenges. If you are not going to develop technology or make the advance, then it is a question of what balance you take. I predict we will always have unanticipated problems. If we do not, we are not taking the steps for the country and the committee they would like us to take. The question of understanding the requirements, do you have enough technology basis work, we refer to our R. & D. base to develop, work the problems in a research phase, so then you have that material to build on as you go into a hardware project. When one goes into fundamental research problems, when you have the mainstream contractors in line you are going to encounter delays which mean money and resources. The biggest lesson I see in this, and in other projects we have had, is this question of research base and having looked at the requirements with sufficiently keen eye to try to see where the weak spots are, what needs more work before I kick off my main line program.

Mr. Symington. Well, we thank you. We know that you are doing your level best, which is a very good job indeed to get this project going and without taking unacceptable risks to cut costs and bring them into line.

So, we thank you very much, Dr. Hinners, Dr. Petrone, and Dr. Cortright, Mr. Parks for being here. I am sure we will be conversing frequently with you in the future.

We will reconvene in this room tomorrow at 9 a.m. Today's meeting is adjourned.

[Whereupon, at 12:05 p.m., the subcommittee was adjourned to reconvene at 9 a.m., Friday, November 22, 1974.]

# VIKING PROJECT

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**FRIDAY, NOVEMBER 22, 1974**

House of Representatives,
Committee on Science and Astronautics,
Subcommittee on Space Science and Applications,
*Washington, D.C.*

The subcommittee met, pursuant to notice, in room 2325, Rayburn House Office Building, Hon. James W. Symington (chairman of the subcommittee), presiding.

Mr. Symington. The subcommittee will be in order.

This is the second day of legislative oversight hearings on Viking, NASA's most complex and expensive planetary exploration project.

Yesterday, the Subcommittee on Space Science and Applications heard witnesses from NASA Headquarters, Langley Research Center, and the Jet Propulsion Laboratory. Today, we will take testimony from representatives of Martin Marietta Corp., the prime contractor, and from two major subcontractors—TRW Systems, and Honeywell, Inc.

Representatives of these industrial contractors are here to describe their companies' participation in the Viking project. These witnesses are in the best position to provide details on the critical technical problems that have been encountered in this very demanding development program, as well as their impact upon costs.

We recognize that these hearings also provide a forum for these fine industrial organizations to recount their technological achievements, and we welcome a report on the extraordinary difficulties that have been overcome during the past 5 years. At the same time, we expect a candid description of the current status of the project, including problems that remain to be solved. Finally, we seek their expert opinion on the probability of mission success, a matter of growing concern to the committee as the Viking story unfolds.

Our first witness this morning is Mr. L. J. Adams, vice president and general manager of the Denver Division of Martin Marietta Aerospace. He is accompanied by Mr. W. O. Lowrie, vice president and Viking program director.

Welcome, gentlemen. Mr. Adams, you may proceed with your prepared statement.

[The complete prepared statement of Mr. Adams follows:]

# STATEMENT OF LAURENCE J. ADAMS
# VICE PRESIDENT AND GENERAL MANAGER
# MARTIN MARIETTA AEROSPACE DENVER DIVISION
# VIKING LANDER PROGRAM

## INTRODUCTION

The Viking Lander Program is about to enter its final checkout and launch preparation phase. After having completed the development phase and being essentially complete in the component and spacecraft qualification phase, the program is in a sound technical and schedule posture. Very high confidence exists that the launch window will be met with hardware having a high degree of maturity and integrity.

A number of serious technical problems were resolved during this past year. The most severe problems were airborne computer development, biology instrument development, and the achievement of total functioning of the ground test and checkout systems. In addition, slippage which had accrued in the development of many of the lander hardware components and science instruments had to be accommodated in the down stream program. These problems were compounded by the fixed launch window. The resolution of these problems resulted in a significant cost growth. Vigorous action over the last several months has cut back some of this cost growth. These vigorous actions on the part of NASA, Martin Marietta and the subcontractors, coupled with the rather significant hardware maturity which now exists, provide a high degree of confidence the program can be completed without further growth.

## CURRENT STATUS

The Viking Lander Program has reached a very high level of maturity and is therefore in a good position to move on into the final launch checkout phase. Of all of the parts, materials, processes, devices and components that go to make up the Viking Lander, ninety-seven percent (97%) are now through their final qualification. Ninety-four percent (94%) of the hardware required to build the two flight landers or to support their launch in the form of spares is now either in the flight landers or in stockrooms in Denver. The Proof Test Capsule, a complete flight-like capsule intended specifically for environmental qualification tests at the spacecraft level, is now eighty-five percent (85%) through the qualification program. PTC completed three sterilization cycles more severe than the flight landers will see in terminal sterilization; it has been vibrated and bombarded with acoustic energy more severe than will be experienced during launch; it has been exposed to a thermal qualification more severe than the cruise to Mars and more severe than the surface conditions on Mars; and it has recently completed a comprehensive series of science end-to-end tests. These tests demonstrated the capability of the science system, with the exception of biology, to operate in an environment similar to that on the surface of Mars. The tests included the digger picking up dirt and delivering it to the Gas Chromatograph Mass Spectrometer and the X-ray spectrometer. Pyrotechnic and landing shock environmental testing currently in progress, and another Martian-surface-environment-simulation test to check out the flight-type biology instrument in the lander, will complete the Lander Qualification Test Program. Successful completion of these tests in February will provide confidence in the integrity of the lander hardware system. The flight software, the load that goes into the airborne computer, has also completed a series of evolutionary steps including development and testing. During the past year the preliminary version of this software was tested against computer emulation and in the hardware. Problems resulting from these tests have been resolved and the flight version of this software is now released for higher order compatibility testing. It will now be tested with the ground data system and the Flight Landers. The final formal verification of the software package also has started and will be completed in April. The flight capsules have completed their initial buildup and checkout. A series of radar tests and electromagnetic compatibility tests have been run on the Flight Landers, and Flight Lander 1 is just entering its final thermal vacuum test after which it will be shipped to the KSC in January. Flight Lander 2 is on schedule and will arrive at the KSC during February. Figures 1 through 6 are photographs representative of the above mentioned activities.

The favorable health of the program is also depicted by general management indicators. Three of these are shown on the accompanying graphs. The engineering change activity, Figure 7, shows a very healthy downward turn since May of this year. In May there was a peak of 213 change packages processed, but by October that had been cut in half and the overall slope is sharply downward.

Lander discrepancies, Figure 8, also show a downward trend—although not as dramatic. This data has not been normalized for the very pronounced increase of system test activity over the past several months. If it were normalized, it would also show a much sharper downward trend in terms of discrepancies per hour of tests. These two items are typical of the Project trends over the past several months. As a result of this maturity, a significant reduction in force was achieved in the month of October which reinforced the downward trend in manpower. This is shown in Figure 9. There is every reason to believe the continued downward trend in manpower can be achieved and that the overall manpower plan can be met. This is of course of primary significance with regard to cost-to-complete, since labor is our remaining largest major manageable item.

All of the above described indications are positive and provide the necessary confidence in completing the remaining parts of the program within technical, schedule and cost constraints.

## PROBLEMS OF THE YEAR

While dramatically improved performance was evident this past year on most of the major components, most notably on the imagery system and the radars, several severe problems were encountered. Major among these were the serious memory development problems in the main computer; numerous technical problems in the biology instrument; the impact to the major system test program of late deliveries of many components; and finally, difficulties in getting the lander test and checkout program moving efficiently.

Mr. Rynearson of Honeywell will discuss in some detail the computer problem and its impact. In summary, continuing technical problems in the development of the memory system required the initiation of a major parallel development of a core memory to be used as a backup program. The late development also forced the use of less than flight-grade computers to accomplish a number of the early system tests in Denver. Consequently, the technical problems associated with this very difficult development impacted costs in three areas: the basic computer development, the backup memory system program, and the impact on the system test program. A very extensive cooperative effort on the part of NASA, Martin Marietta and Honeywell has resulted in the resolution of the technical problems. The critical qualification tests have been completed, and the first Flight Lander computer will be delivered to Denver in a matter of days.

Dr. Solomon of TRW will subsequently discuss the development status of the biology instrument in some detail. In summary, a year ago there was serious concern that the biology instrument could not be developed for Viking on the required time schedule or, at the very least, would require a radical departure from requirements. The instrument was beset with a number of significant problems which in the aggregate were almost unresolvable within the packaging constraints imposed upon the mechanical subsystem. A vigorous corrective action program was initiated at TRW with strong support from Martin Marietta and NASA. As of today, the open problems have been largely resolved. The first flight-type biology instrument will be delivered to Denver in the next few days for use in the spacecraft level tests previously mentioned. The confidence level in having two perfect biology instruments for flight is now quite high. However, the test maturity is considerably lower than that for the computer, and it still remains the single highest risk element on the lander. Although the late delivery of biology is highly undesireable, the interaction of this subsystem's late delivery with the lander system test program is not as serious as that of the computer. Consequently, the cost impact is primarily associated with the biology instrument development problems alone.

The component development-and-qualification program on Viking has been completed—on the average—about five months later than originally planned as a result of technical problems. In the current year this development slippage has had a significant effect on the ability to efficiently conduct the system test program. The lateness in delivery of flight hardware required the use of earlier generation hardware in a number of instances to get tests started. This was inefficient and resulted in a significant amount of additional procedures, test sequences, data reductions, test troubleshooting and anomaly investigations. With ninety-four percent (94%) of the flight hardware delivered, this problem has diminished. However, it had a serious cost impact during the year.

The last major problem area experienced this year was associated with making the ground test system work efficiently with the checkout of the lander. This of course includes the sequences or procedures used to run tests. Part of the problem was the result of the previously discussed item. In addition, there was a significant period earlier this year when the instances of down time of the ground complex were far too high. An extensive, detailed design review and a stiffening of preventive maintenance was instituted to improve the equipment reliability. At the same time, the number of people designing and developing tests and their automatic sequences was significantly increased. Test progress in recent months, including the complex science end-to-end test on the Proof Test Capsule, has shown that the corrective action has worked. The capability has now been demonstrated to run the necessary test programs from now through launch.

## PROGRAMMATIC ACTIONS

The lander system-level-test-and-checkout program has undergone a significant change during the past year. There have been a number of tests eliminated and a number of tests added. These are summarized in Figure 10. These changes occurred for several reasons: new knowledge indicated the need to add tests such as the Radar System Test; new knowledge allowed the elimination of tests such as the heat sterilization in Denver; schedule conflict required revamping of the test program, such as the redesign of the two thermal vacuum tests into a single test because of schedule conflict in the vacuum chamber; or the elimination of tests to save dollars where additional risk would not be large, such as the elimination of acoustics and vibration. This revised test program is a well balanced program providing all the necessary design and confirmation data, as well as control through testing of the Flight Articles. The other significant programmatic change has been the elimination of the third Flight Lander. This action was taken specifically to minimize Viking costs, with some slight increase in risk; the risk being associated with the probability of getting two spacecraft launched from the same launch pad within the launch period. At the outset of the Viking program, a major concern existed in the ability to develop a lander capable of heat sterilization without some very significant probability that hardware failures would occur during the terminal sterilization. Consequently, the third lander existed because of a strong belief that one or more recycles of the hardware would occur as a result of such terminal sterilization failures. Experience to date on flight components and on the complete PTC spacecraft indicates that the probability of failure is much lower than originally anticipated. This of course has resulted from a very heavy attention to detail in materials, processes, and component packaging. Consequently, when one analyzes the various time lines for launching two spacecraft, using actual program experience, the assumption of increased risk by eliminating the third lander is not high.

All of the programmatic actions taken on the lander system in the past year have of course been accomplished in close cooperation with the NASA. Although there is some increase in risk, it is not large; and certainly, the basic concept and intent of the Viking Program has not been altered by the actions taken.

## CONCLUSION

The lander system has reached a high level of maturity, and the confidence exists that the lander will be ready for the August 1975 launch period. More importantly, the lander will be there with very high grade hardware capable of accomplishing the very difficult Mars mission. It is unfortunate that the technical and schedule accomplishment could not have been achieved without the cost growth that has been experienced. Viking has been the most difficult technical challenge Martin Marietta has faced, and it is the most complicated unmanned space program undertaken by this Nation. It is my opinion that, although the program cost will exceed our initial projections, it is not out of proportion with the degree to which the technical challenge exceeded our initial understanding. I am proud of the overall results that we have achieved, and I am dedicated to completing this program with a highly successful mission on the surface of Mars.

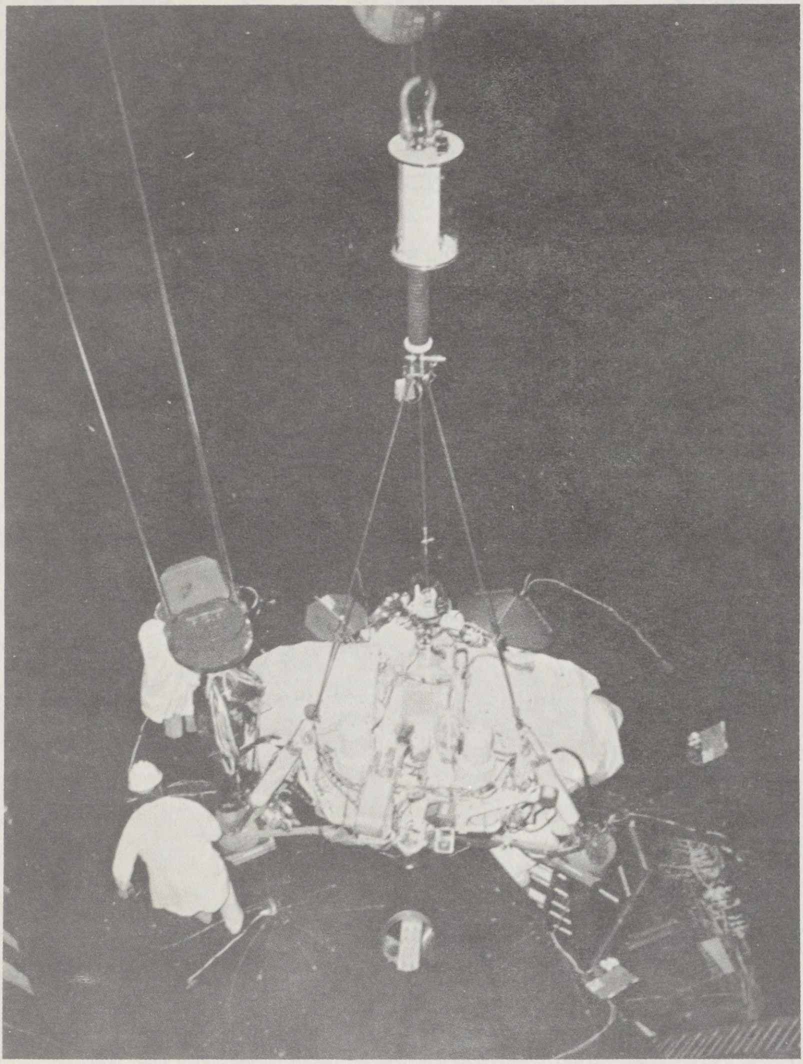


*Fig. 1 Proof Test Capsule being Readied for Science End-to-End Test*

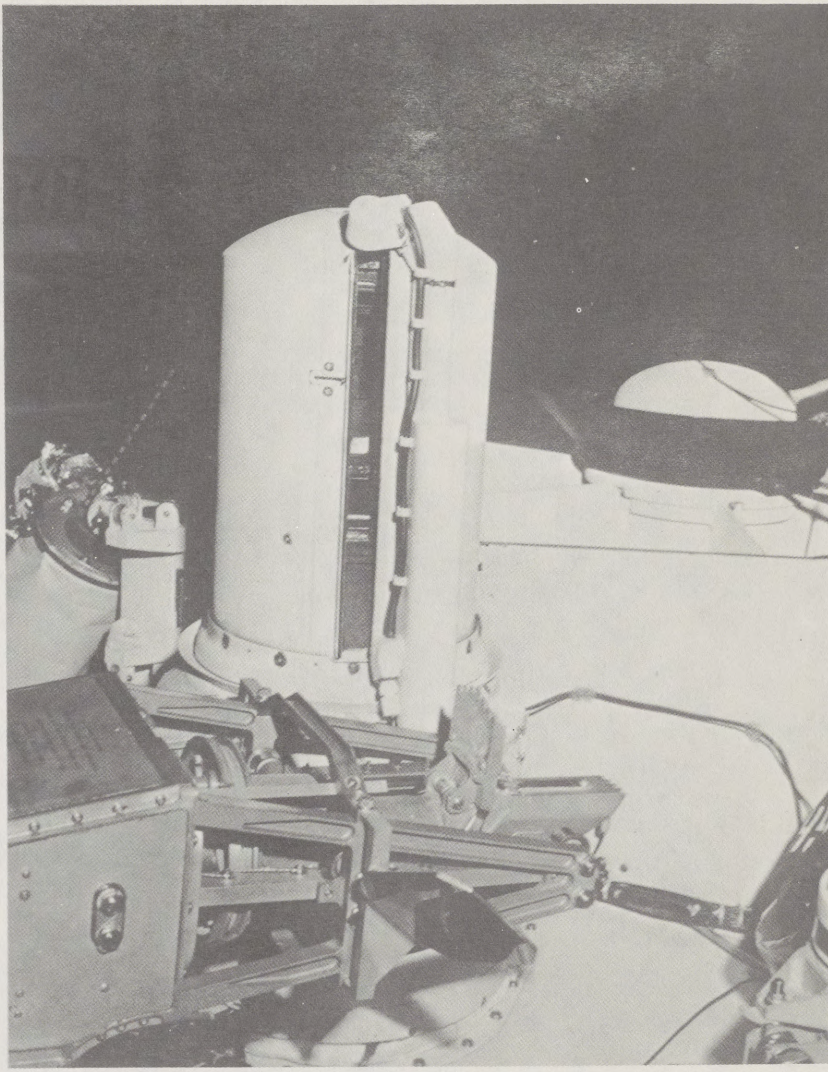


Fig. 2 Close-up of Boom-Digger Assembly and Camera

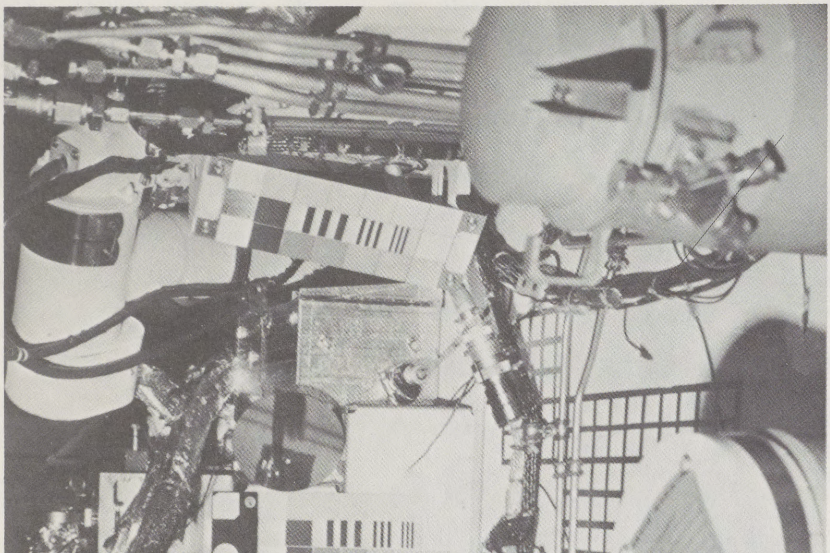


*Fig. 3 View of Camera Targets*

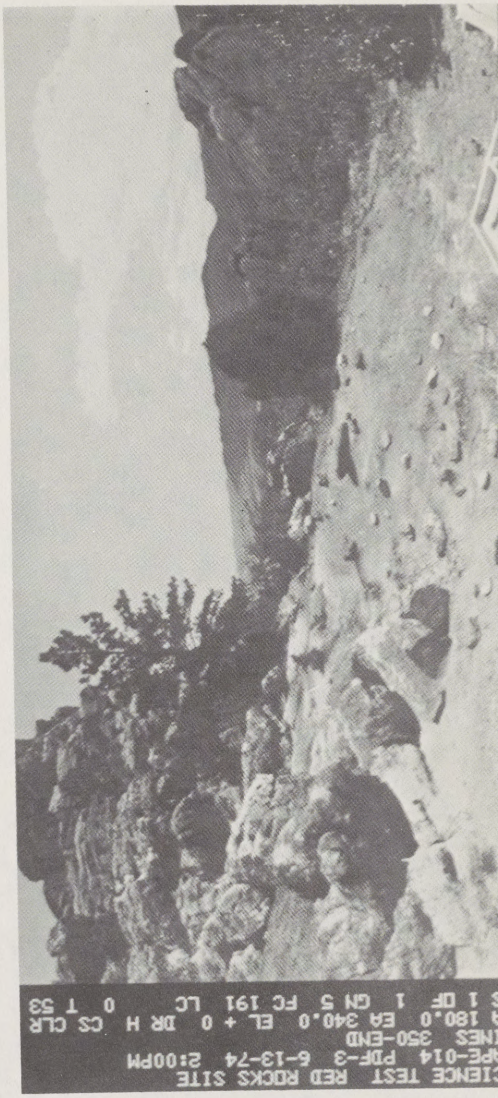



*Fig. 4 Example High Resolution Picture from Lander Science Test*

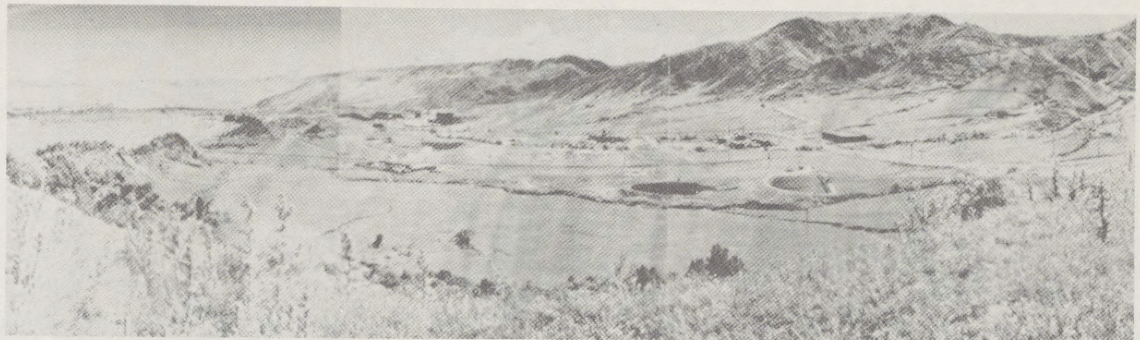


Fig. 5 Example Panorama Picture from Lander Science Test

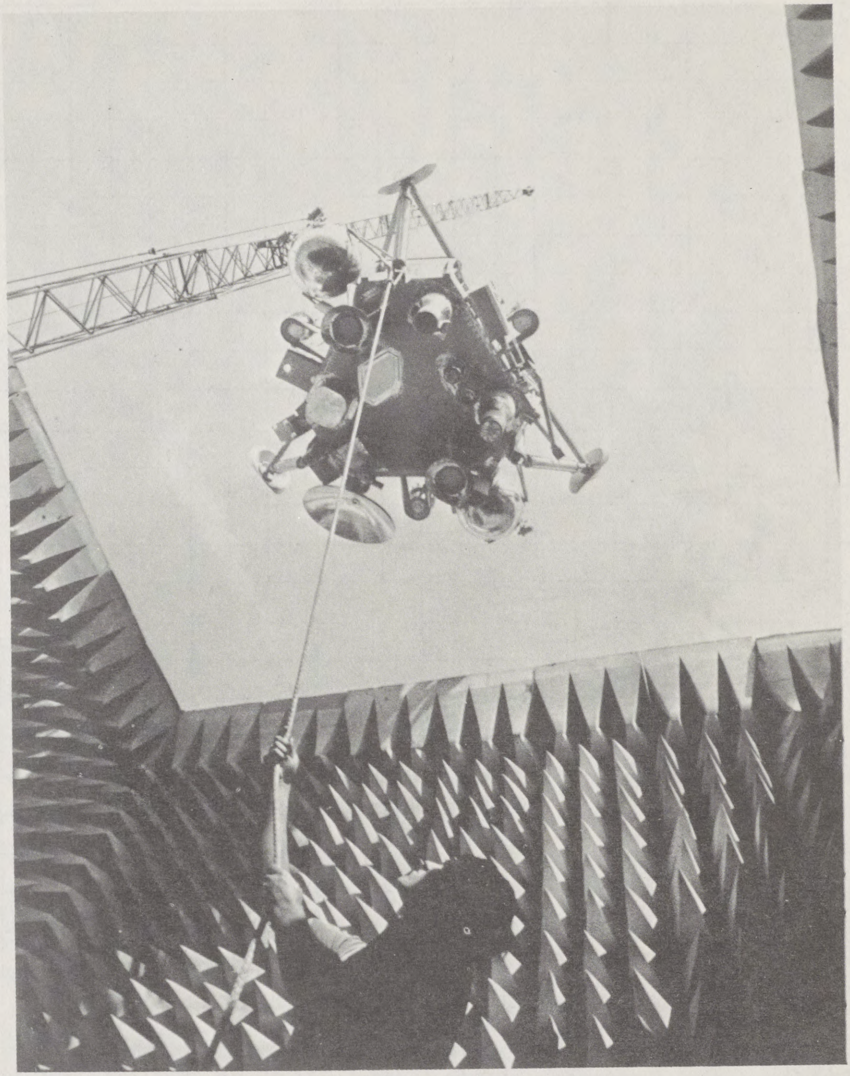


*Fig. 6 Test Model being Prepared for Radar System Proof Test*

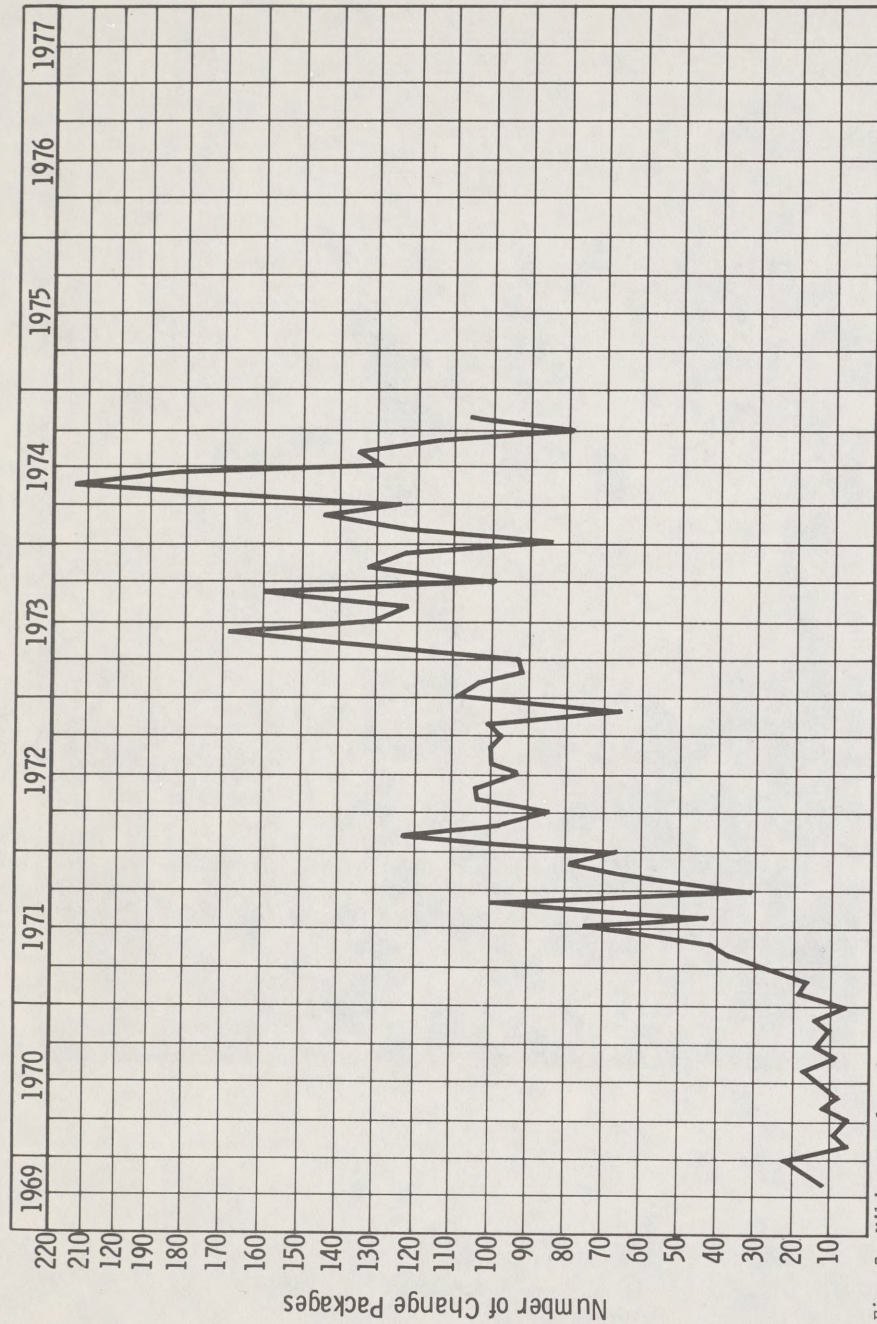



*Fig. 7 Viking Lander Change Packages*

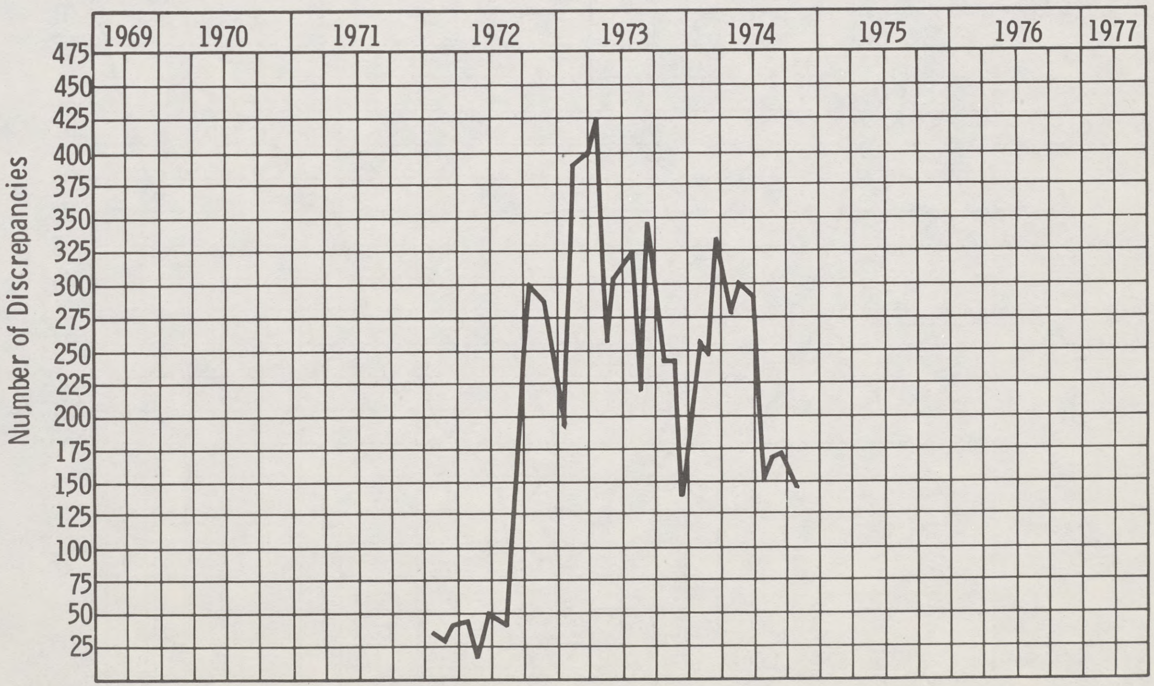



*Fig. 8 Viking Lander Discrepancy*


*Fig. 9 Martin Marietta Viking Manpower*

| ARTICLES | DELETIONS | ADDITIONS |
|---|---|---|
| Proof Test Capsule | 2 Cycles Heat Compatibility<br>Y and Z Axis of Vibration<br>Cruise Thermal<br>Software/Hardware Compatibility<br>Electromagnetic Compatibiliby<br>Captive Firing<br>KSC Pathfinder | Science End-to-End Test<br>Biology Performance Verification<br>Radar System Tests |
| Lander Dynamics Test Model | None | Propellant Load & CG Verification |
| Flight Articles | Denver Heat Compatibility<br>Vibration<br>Acoustics | Plugs-Out Test<br>Radar System Tests<br>100 Word Update Test<br>Precursor Tests<br>- VO/VLC Mate<br>- EMC/S/C Compatibility<br>- Encapsulation Test<br>- Launch Pad Tests<br>Electromagnetic Compatibility |

*Fig. 10 Lander System Level Tests*

## STATEMENT OF LAWRENCE J. ADAMS, VICE PRESIDENT AND GENERAL MANAGER, MARTIN MARIETTA AEROSPACE, DENVER DIVISION

Mr. ADAMS. Thank you, Mr. Chairman and members of the committee. I welcome the opportunity to appear here today to discuss the status of the Viking Lander program.

The Viking Lander program is about to enter its final checkout and launch preparation phase. After having completed the development phase and being essentially complete in the component and spacecraft qualification phase, the program is in a sound technical and schedule posture. Very high confidence exists that the launch window will be met with hardware having a high degree of maturity and integrity.

A number of serious technical problems were resolved during this past year. The most severe problems were airborne computer development, biology instrument development, and the achievement of total functioning of the ground test and checkout systems. In addition, slippage which had accrued in the development of many of the Lander hardware components and science instruments had to be accommodated in the down stream program. These problems were compounded by the fixed launch window. The resolution of these problems resulted in a significant cost growth. Vigorous action over the last several months has cut back some of this cost growth. These vigorous actions on the part of NASA, Martin Marietta and the subcontractors, coupled with the rather significant hardware maturity which now exists, provide a high degree of confidence the program can be completed without further growth.

I would like now to review in some detail the current status of the program.

The Viking Lander program has reached a very high level of maturity and is therefore in a good position to move on into the final launch checkout phase. Of all of the parts, materials, processes, devices and components that go to make up the Viking Lander, 97 percent are now through their final qualification; 94 percent of the hardware required to build the two flight landers or to support their launch in the form of spares is now either in the flight landers or in stockrooms in Denver. The proof test capsule, a complete flight-like capsule intended specifically for environmental qualification tests at the spacecraft level, is now 85 percent through the qualification program. PTC completed three sterilization cycles more severe than the flight landers will see in terminal sterilization; it has been vibrated and bombarded with acoustic energy more severe than will be experienced during launch; it has been exposed to a thermal qualification more severe than the cruise to Mars and more severe than the surface conditions on Mars; and it has recently completed a comprehensive series of science end-to-end tests. This later series demonstrated the capability of the science system, with the exception of biology, to operate in an environment similar to that on the surface of Mars. The tests included the soil sampler digger picking up dirt and delivering it to the gas chromatograph mass spectrometer and the X-ray spectrometer.

I might add that very few design problems of any substance were encountered in these tests. The ones which were encountered have been fixed, revised and are well on the way to completely being resolved. Pyrotechnic and landing shock environmental testing currently in progress, and another Martian-surface-environment-simulation test to check out the flight-type biology instrument in the Lander, will complete the Lander qualification test program. Successful completion of these tests in February will provide confidence in the integrity of the Lander hardware system.

Mr. SYMINGTON. May I interrupt at this point? The biology package won't be ready in February, will it?

Mr. ADAMS. The first biology instrument will be delivered to us very shortly, and we will install it into the PTC and its testing will be completed in this simulated Mars surface testing in February. The dirt qualification testing on biology will be performed on one of the flight-type units and will be completed later—I believe the date is March.

Mr. SYMINGTON. In other words, the package will not undergo any change as a result of qualification testing?

Mr. ADAMS. That is the intent.

Mr. SYMINGTON. That is the intent?

Mr. ADAMS. Yes. We have a fair bit of testing now on the biology experiments at TRW. They have been through the complete functional test-out with the system which they are going to deliver to us in early December. That one has been through the complete functional testing and we then have built up a fair bit of confidence from that testing. All of the units are basically built at this time, and they are in their checkout, final checkout testing.

The flight software, the load that goes into the airborne computer, has also completed a series of evolutionary steps including development and testing. During the past year the preliminary version of this software was tested against computer emulation and in the hardware. Problems resulting from these tests have been resolved and the flight version of this software is now released for higher order compatibility testing. It will now be tested with the ground data system and the Flight Landers.

Mr. SYMINGTON. What kind of problems were they that you resolved?

Mr. LOWRIE. During the development of the software, we ran into several problems. One of the major phases of the software is to control the whole descent cycle, taking radar data and inertial reference data, and navigating to the ground. We ran into some timing problems and storage problems. We had to do some reframing which is reasonably typical in the development of this kind of software package. That has been completed and we can now run descent runs in the emulation mode at will. So all the major problems are behind us in the software. The things you get now are minor incompatibilities in subsequent testing with the final hardware. So we should not see any major problems from now on in software.

Mr. ADAMS. The final formal verification of the software package also has started and will be completed in April. The flight capsules have completed their initial buildup and checkout. A series of radar tests and electromagnetic compatibility tests have been run on the Flight Landers, and Flight Lander 1 is just entering its final thermal vacuum test after which it will be shipped to the KSC in January.

Earlier Walt had some discussion that it may go on somewhat earlier than that. However, the scheduled date is mid-January.

Flight Lander 2 is on schedule and will arrive at the KSC during February.

I'd like to go through a series of photographs which we brought along to demonstrate some of the events I have been talking about. I think they are a little better than the ugraphs. They are in color and come through better than this thing here.

This first picture shows the PTC being prepared for the science end-to-end testing as it is being placed into the chamber. In this test, the Mars surface environment was simulated in the space chamber at Denver and the simulation there included the atmospheric composition and density, day and night thermal variations which were accomplished through the use of a solar simulator in the chamber, plus rotation of this particular test article. To simulate the day and night variations and then the radiation characteristics of the surface of Mars, temperatures were simulated upon the pad on which the vehicle is located. In the course of this testing, then, we provided boxes containing simulated Martian soil and the soil sampler actually picked up soil from the boxes, delivered it to the instruments and it was analyzed by the instruments in the test. The overall test program from this science end-to-end testing is completed, as I mentioned before, with the exception of biology. The test will be completed later on with biology because it was not available at this time.

The next chart is a view taken by one of the cameras at the other camera which is shown up here and the soil sampler and boom assembly which is down here. The boom itself is rolled up in this box here, and then it is extended. This is the "digger" sampler and this is extended on out. The whole sampler is controlled by a series of electric motors. During the test, then, it was extended as I mentioned, picked up soil and returned it back to the instruments.

The next picture is of the targets we had in there for the camera system itself. Pictures were taken of these, actually the colored boxes on here, and then the photos from the camera were compared with the actual photos, with the actual samples themselves and the fidelity there was very good.

The next two photos were part of the science test on the camera and were taken at our Denver facility. The first is a view of the landscape there at Denver and you can see the very high resolution that we are getting from the system. The next one is another picture of Denver. This happens to be our plant layout taken from back up on one of the hills there, and again you can see the very good fidelity out at great distances.

The next picture is of a radar test which we instituted later in the program. As I said, I will discuss that a bit later on. This is a full-scale model of the vehicle being lowered into a chamber for testing on the radar system. This test had not been initially in the program. It was added when we found some problems at lower level tests, so we did construct this chamber over in our space simulation chamber, specifically for running the tests. It was used in troubleshooting, in pinpointing the problems.

These are just some views of that test program and the activities that went on there.

Figures 1 through 6 are photographs representative of the abovementioned activities.

The favorable health of the program is also depicted by general management indicators. Three of these are shown on the accompanying graphs. The engineering change activity, figure 7, shows a very healthy downward turn since May of this year. In May there was a peak of 213 change packages processed, but by October that had been cut in half and the overall slope is sharply downward. This particular downward trend, then, is a very healthy trend, and we believe it is a very good indicator of the status of development of the system itself. I might point out that this high peak of activity is really the area when most of the development and qualification testing activity was going on. That is now completed. The peak activity up here occurred about the time we were delivering the first flight components to Denver and a major activity in cleaning up all the open paperwork and those sorts of things was initiated there which caused the change package count to go up but did not necessarily affect the hardware.

Mr. SYMINGTON. The change package, what is that exactly?

Mr. ADAMS. The change package involves generally one specific problem which is to be solved. For example, if it is necessary to provide a fix on a piece of the structure, then a change package is initiated to do that and it includes all of the impact on the other parts of the system, be they software, hardware, procedures, or whatever. So the change package covers all the activity for one problem, one specific problem.

This did go up slightly back here. But again, if you look at the trend right now, it is on the way down still, so that is a very healthy indicator.

Mr. SYMINGTON. Even though that curve is going down, are any of those remaining change packages possibly critical ones or are they all just minor?

Mr. ADAMS. Walt, why don't you address that?

Mr. LOWRIE. I don't have at the moment any items of an open nature that I would call critical at this phase of the program. You do have to clean up items, the radar tests which Mr. Adams is going to speak of shortly. I have an open-change input on the radar altimeter; we have to open the box up and change a resistor to get a different gain setting in order to play better with the Lander. I would not consider that as a critical change. I have a number of that type of activities. I don't have any critical issues facing me.

Mr. ADAMS. Lander discrepancies, figure 8, also show a downward trend—although not as dramatic. This data has not been normalized for the very pronounced increase of system test activity over the past several months. If it were normalized, it would also show a much sharper downward trend in terms of discrepancies per hour of tests. The lander discrepancies occur on the program, when some discrepancy is noted either in the paper, the drawings, the operation of the system or errors made by an operator. A formal form is filled out to note the discrepancy and then a formal action has to take place to close it out. That is what the discrepancies are. Again, you can see the discrepancies have been on a very sharp downward trend even here. Even this is somewhat misleading in that the total number of test activities going on during that period is significantly higher than it has been in the past, so the number of discrepancies during a test hour is really down quite sharply. These two items are typical of project trends. As a result of this maturity, a significant reduction in force was achieved in the month of October which reinforced the downward trend in manpower. This is shown in figure 9. Again, here you can see that we have started a sharply downward curve. I might digress for just a moment on this curve. It does tell you a lot about the program. We moved up the program reasonably well along through the first years. Mid 1972 was our really first significant departure from our original plan.

At that point, we had intended to be able to peak out the manpower and start back down again. It turned out we were not able to do that. This was the point where we were bringing into being most of the major subsystem test articles—the structural test article, the propulsion test article and the thermal test article. All were being built at this time, and that was the place where real maturity on those kinds of systems was achieved. The designs had to be finalized, lots of change activity was taking place in terms of these particular phases at that time. A lot of activity was going on in the shop. It was necessary to actually push the manpower up to this higher-than-anticipated peak. We did achieve the completion of those articles, basically on the schedule we wanted but it cost us some money to do that. We had anticipated at this point—about a year ago—that we were going to be able to continue down a steep curve which is almost parallel to the one we are coming down now. This is a point where the problems which I am addressing here today really got to us, and we found that as opposed to being able to take people off this point, we actually had to put some on. I will discuss the reasons for that as we move along here today.

There is every reason to believe the continued downward trend in manpower that has recently started can be achieved and that the overall manpower plan can be met. This is, of course, of primary significance with regard to cost-to-complete, since labor is our remaining largest major manageable item.

All of the above described indications are positive and provide the necessary confidence in completing the remaining parts of the program within technical, schedule, and cost constraints.

I would like now to review briefly some of the major problems, primarily the past year which have caused this manpower problem I referred to earlier.

While dramatically improved performance was evident this past year on most of the major components, most notably on the imagery system and the radars, several severe problems were encountered. I will digress here just a moment. A year ago these were burning problems, as you may recall. Since that time, they have shaped up extremely well. All of the imaging systems are now in Denver and they are working beautifully. The radar systems have all been there. The radar altimeters are being turned around for a minor modification at this point. The majority of the systems are there now. We have accomplished the completion of development of those two major complex systems.

Mr. Symington. Who is the subcontractor?

Mr. Adams. ITEK is the subcontractor on the imagery and Teledyne-Ryan is the contractor on the radars.

The major problems of the year were the serious delay in memory development on the main computer; numerous technical difficulties in the biology instrument; the impact to the major system test program of late deliveries of many components; and finally, difficulties in getting the Lander test and checkout program moving efficiently.

Mr. Symington. For the record, you might list those components that came in late. Would you provide that for the record and the cost impact?

Mr. Adams. All right, we will do that.

Mr. Symington. For each one.

[The information follows:]

The cost impacts on the test program due to the late delivery of flight components was $4.3M. The following components were late to the scheduled delivery dates by the number of weeks indicated as follows:

| *Component* | *Weeks late* |
|---|---|
| Radar altimeter No. 1, FA–2 | 12 |
| Communications system | 11 |
| Tape recorder, FA–1 | 7 |
| Surface sampler control assembly, FA–2 | 6 |
| Data storage memory workaround SP—Non flight Unit | 6 |
| Seismometer, FA–1 | 9 |
| X-ray fluorescence, FA–1 | 8 |
| Surface sampler control assembly, FA–3 | 5 |
| Power conditioning distribution assembly, FA–2 | 12 |
| Battery power assembly, FA–3 | 2 |
| Tape recorder, FA–2 | 10 |
| Radar altimeter No. 1, FA–3 | 22 |
| Lander power control assembly No. 2, FA–2 | 4 |
| Tape recorder, FA–3 | 30 |
| Gas chromatograph mass spectrometer, FA–1 | 30 |
| X-ray fluorescence, FA–2 | 25 |
| Valve drive amplifier | 2 |
| Tape recorder, FA–4 | 33 |
| Surface samplier boom assy, FA–1 | 13 |
| Lander pyrotechnic control assembly No. 1, FA–4 | 15 |
| Data acquisition and processor unit, FA–3 | 9 |
| Inertial reference unit, FA–2 | 4 |
| Terminal descent landing radar, FA–4 | 6 |
| Surface sampler control assembly, FA–4 | 8 |
| Biology PDA, FA–1 | 20 |
| Seismometer, FA–2 | 12 |
| X-ray fluorescence, FA–3 | 31 |
| Data storage memory, FA–1 | 12 |
| Power conditioning and distribution assembly, FA–3 | 13 |
| Inertial reference unit, FA–3 | 33 |
| Surface sampler boom assy, FA–2 | 15 |
| Data storage memory, FA–2 | 14 |
| Data acquisition and processor unit, FA–4 | 23 |
| Guidance control and sequencing computer, FA–1 | 28 |
| Radar altimeter No. 2, FA–3 | 14 |
| Biology PDA, FA–2 | 17 |
| X-ray fluorescence, FA–4 | 30 |
| Deorbit tanks, FA–4 | 14 |
| Power conditioning and distribution assembly, FA–4 | 17 |
| Meteorology, FA–2 | 18 |
| Decelerator system, FA–1 | 15 |
| Decelerator system, FA–2 | 16 |
| Inertial reference unit, FA–4 | 26 |
| Biology, FA–2 | 15 |
| Camera, No. 1, FA–2 | 4 |
| Data storage memory, FA–3 | 12 |
| Terminal tanks, FA–4 | 21 |
| Decelerator system, FA–3 | 19 |
| Decelerator system, FA–4 | 19 |
| Seismometer, FA–3 | 10 |
| Radar altimeter No. 2, FA–4 | 16 |
| Biology PDA, FA–3 | 20 |
| Camera No. 2, FA–2 | 10 |
| Upper atmosphere mass spectrometer, FA–1 | 16 |

| | Weeks late |
|---|---|
| Meteorology, FA–3 | 15 |
| Gas chromatograph mass spectrometer PDA, FA–1 | 20 |
| Gas chromatograph mass spectrometer, FA–2 | 19 |
| Guidance control and sequencing computer, FA–2 | 20 |
| Camera No. 1, FA–3 | 10 |
| Biology PDA, FA–4 | 18 |
| Seismometer, FA–4 | 13 |
| Camera No. 2, FA–3 | 9 |
| Gas chromatograph mass spectrometer, FA–3 | 21 |
| Gas chromatograph mass spectrometer, PDA, FA–2 | 20 |
| Gas chromatograph mass spectrometer, FA–4 | 7 |
| Gas chromatograph mass spectrometer PDA, FA–3 | 20 |
| Camera No. 1, FA–4 | 9 |
| Camera No. 2, FA–4 | 7 |
| Upper atmosphere mass spectrometer, FA–3 | 13 |
| Guidance control and sequencing computer, FA–4 | 11 |
| Biology, FA–1 | 8 |
| Upper atmosphere mass spectrometer, FA–4 | 10 |
| Biology, FA–3 | 6 |

Mr. Adams. Mr. Rynearson, of Honeywell, will discuss in some detail the computer problem and its impact. In summary, continuing technical problems in the development of the memory system required the initiation of a major parallel development of a core memory to be used as a backup program. The late development also forced the use of less than flight-grade computers to accomplish a number of the early system tests in Denver. Consequently, the technical problems associated with this very difficult development impacted costs in three areas: The basic computer development, the backup memory system program, and the impact on the system test program. A very extensive cooperative effort on the part of NASA, Martin Marietta and Honeywell has resulted in the resolution of the technical problems. The critical qualification tests have been completed on the computer and the first Flight Lander computer will be delivered to Denver in a matter of days.

Mr. Symington. Could I ask you about the 2-mil plated wire system that you selected? We have been told GE proposed a core memory that was technically superior to that system. Was that not known? You decided to try that system without it ever having been produced before. That is the Honeywell system. Was it your judgment that it was superior to GE's system?

Mr. Adams. I am not personally familiar with that particular piece of the program.

Walt, were you there at the time?

Mr. Lowrie. No, I wasn't. It was my understanding that the core memory system as proposed did take more power and more weight and we were severely limited at that point in time. Consequently, 2-mil wire was selected. There were some characterization tests done on wire that gave us the belief that the wire would meet sterilization requirements and you are going to get quite a bit more detail this morning on that.

The summary of the thing that burned us was the aggregate of all the material changes in the total memory system to meet sterilization requirements. That is maybe an overgeneralization. You are going to hear some more detailed testimony later.

Mr. Symington. Was that Honeywell contract a fixed-price contract?

Mr. Lowrie. Yes; fixed price.

Mr. Symington. Was it changed?

Mr. ADAMS. Yes; it was changed from a fixed-price to a cost-type contract, with an award fee provision. This occurred approximately a year ago.

Mr. SYMINGTON. And did Honeywell then step up their efforts at that point, and employ more men and apply more resources?

Mr. ADAMS. That is sort of a subjective question in terms of being able really to tell that. Certainly, the manpower increased. That is a matter of record. On the other hand, the work activity, Honeywell also had to increase at that time because that was when they entered the test program. They cranked up into the major test program at that point so a lot of new manpower came on to the program. I can't say in my belief that Honeywell was dogging it in any sense previous to that.

Mr. SYMINGTON. We would like to know the specific cost impact in each of the three areas that you mentioned?

Mr. ADAMS. All right.

Mr. SYMINGTON. Of those technical problems that you encountered.

Mr. ADAMS. I have those numbers and we shall provide them for the record.

Mr. SYMINGTON. If you would provide the information for the record.

Mr. ADAMS. We will do so.

[The information follows:]

The cost growth associated with the Honeywell Computer contract was $23.8 M, including the cost impact of the Martin Marietta Resident Team. The complete Core Memory back-up program cost $6.8 M. Late delivery of computer hardware impacted test start dates, necessitated test software modifications and made trouble shooting more difficult. The approximate cost impact to the test program was $1.2 M.

Mr. LOWRIE. I might add a word on this manpower increase in Honeywell. It is also wrapped up in the very essence of the reason for the restructuring at this point in time. We had entered into such a difficult situation we had to go on a number of parallel paths and do significantly more development than was contemplated or that was intended, certainly, in a fixed price type of contract environment. And so at the same time we were restructuring the contract, we were also directing Honeywell and working with NASA to move out on parallel work. For example, coupled-film-wire development which you heard about yesterday. A number of those things caused an increase in manpower, also; not just the contract change per se.

Dr. Solomon, of TRW, will subsequently discuss the development status of the biology instrument in some detail. In summary, a year ago there was serious concern that the biology instrument could be developed for Viking on the required time schedule or, at the very least, would require a radical departure from requirements.

Mr. SYMINGTON. That was just a year ago?

Mr. ADAMS. About a year ago.

Mr. SYMINGTON. On a particular day, suddenly you discovered this?

Mr. ADAMS. What actually happened was that TRW went through a development cycle and completed the construction of a development model of the biology instrument. The development testing program was then conducted and uncovered this series of problems. We had had some confidence, that we had a design which we could proceed on into production with and actually were prepared to do so. We discovered in the course of these development tests that the design was not of a quality which would allow us to proceed into the production, and the number of open problems which I am sure Dr. Solomon will go into a little later on, really was quite imposing at that time.

Mr. SYMINGTON. There was no way to flag them in any case from your standpoint earlier than that developmental threshold?

Mr. ADAMS. We have asked ourselves that question. This whole business of, you know, when you get into the major problems on the major subcontracts is one which has caused us much concern. We have gone back and reviewed our activities in that regard. In the course of setting up the subcontracts, in the biology in particular, we and NASA, and potential suppliers established criteria which we believed reasonable and achievable at the time.

We had the best technical smarts that were available to help us make those decisions. We awarded the contracts, in this case, to TRW who we considered to be the best and most competent company available to do the job. We established firm controls at the outset of these programs in terms of very rigorous design reviews with participation from the NASA, ourselves and consultants. We had frequent management reviews with ourselves and NASA. We established resident Martin Marietta management teams at the outset of each of these subcontracts, and we thought at the time we were doing it much more responsively than ever before. We had management level people heading the teams. We had a top designer from our operation as a member of the team, and we had an overall businessman as a member of the team in each case. So we felt that we were doing the right thing in that regard.

We established high management involvement right off the bat. We set up a management council in which we asked a high executive of each of these companies to attend. This included TRW. Yet, in spite of these actions, we got caught in these particular kinds or problems. This one was more serious than any that we had. Biology was also, I think, a more challenging problem than any we had.

Mr. SYMINGTON. Were these multidisciplinary teams?

Mr. ADAMS. The teams were multidiscipline.

Mr. SYMINGTON. Technical and scientific people?

Mr. ADAMS. Management man, technical man, management system and quality control.

Mr. SYMINGTON. In your judgment, In which one of these areas do you think the failure actually took place. Can you say that if you had had a little more strength and prescience in one area you might have headed it off the path a little sooner?

Mr. ADAMS. If I were to go back and, you know, again analyze that a bit, I am not—I don't really believe it was a function of the team makeup itself. I think it was a function of the degree to which we were pushing the state of the art. It was more a function of the forward step we were trying to take, and in this case, we underestimated the forward step we were trying to take, not in any specific area. We understood the sterilization problem, I think, quite well. We understood the weight problem quite well. We understand the thermal problem quite well, the volume constraints, and so forth. When all of these got interacting in the actual design of the instrument, then we found the interactions between them were causing problems which we had not expected to encounter. And I believe the front end is where the problem comes mostly, not after you're into it. I don't think the management was particularly delinquent in that sense, in answer to your question, where could we have beefed this up.

Mr. SYMINGTON. Was sterilization the main problem?

Mr. ADAMS. On the biology instrument, no. It was one of the problems. I think the principal problem is that associated with the weight and density of the packaging. The requirement then for miniaturization in the extreme on new pneumatic devices and this sort of thing, in all of the mechanical systems that went in there. Extreme miniaturization beyond that which we achieved before was a major problem, and packing that all together very densely resulted in thermal problems. It resulted in extremely difficult maintainability problems, a failure down in the middle of this thing is cause for days and even weeks of delay to get at it and fix it.

Mr. SYMINGTON. And if it isn't quite right next March, it will be almost impossible to get back into it in time?

Mr. ADAMS. That is true.

Mr. WINN. Don't you have to say, though, that going back, the original design was your basic problem? I am not trying to lay blame because we are all aware that you prime contractors and subcontractors all work together and no one's ever going to blame anyone else for anything, but if you got a design that was submitted and approved by NASA, and approved and submitted, I gather by the prime contractor which in this case, I think, would be Martin Marietta with the advice and counsel of designers of TRW, that is where your problem started, you had a three-wheeled machine to start with?

Mr. ADAMS. The problem begins, yes, at the design phase. You are correct. And the reason you have the problem in the design phase, in my opinion, is in terms of your estimates, your judgments of how far you can push the state of the art in terms of density and weight in these things on an instrument like biology. And the best judgments we had were brought to bear on that. When we got into the design, we found that to achieve such a design was more difficult than we had anticipated that it would be.

Mr. WINN. Does any of these teams that you put together, anywhere along the line, anybody ever say "By God, we can't back it?"

Mr. ADAMS. It came very close to that about a year ago.

Mr. WINN. Or "let's keep spending money, we will get it one way or another"?

Mr. ADAMS. We had a major decision to make approximately a year ago in that regard when we reached the point where we had a long list of technical problems, design problems. And we had a large session on that which was attended by NASA Headquarters personnel, Langley personnel, ourselves, JPL was brought in to run a special study at that time, TRW people had done some special work to look to see whether we should back off and say "We will have to settle for something significantly less than we wanted in the program."

Mr. WINN. Was this because of the design or because your costs were skyrocketing?

Mr. ADAMS. It was a combination of both. It was because primarily of concern that the design could be recovered in time to achieve the fixed launch window, and also within the costs that we had available.

Mr. WINN. This was in 1972?

Mr. ADAMS. 1973. About a year ago now.

Mr. WINN. There is no way this thing could have flown in 1973?

Mr. ADAMS. Not this experiment. In 1973, it would have flown with a much less ambitious biology experiment. But that is what happened at that time and the decision was made by that group that the biology experiment as we have it was such an important piece of the Viking program that we really should not compromise it if we had some reasonable chance of making it with what we had. I believe that circumstances have borne out that to be a proper decision. I think the biology experiment now is coming along, and I think we are going to have a good biology experiment on each of our two flight landers.

Mr. BROWN. Could I pursue that just a moment?

I think it is obvious that the biology experiment from the scientific standpoint is the heart of the operation. But you had a point in time in which there were probably a couple of strategic choices open to you. One was to pursue the continued development of the package within the weight and volume and density constraints and possibly another option, and I have asked this question, was to review these constraints and see if they could be modified.

Was that a viable option at the time?

Mr. ADAMS. Well, it wasn't really a very viable one. It turns out the lander itself is extremely densely packed. It turns out the weight constraints on the total weight which we can go with are quite severe.

Now, we did make one compromise along the way. At one time we had the electronics and the mechanical package all together and we separated those and then we made another compromise later when we actually removed one of the four experiments. There were four experiments in the instrument. This was somewhat in regard to cost saving, but it was also in regard to achieving more space for the remaining experiments. So these steps were done. No big step, you know, where you made a major change in philosophy.

Mr. LOWRIE. I might add one thing. When we got into the real deep trouble in biology, which was about a year ago, we did provide some significant power increase which allowed TRW to solve their thermal problems. We also allowed, some minor volume changes. We were pretty restricted other than making a total redesign of the lander to open up and give any significant repackaging. It was sort of late to repackage the whole biology experiment anyway. There were some power changes and volume changes within the capability that late in the game.

Mr. BROWN. When you mentioned one of the experiments being removed, that was not a part of the biology package?

Mr. ADAMS. That was part of the biology package. The biology package at one time had four separate experiments in it. It now has three.

Mr. BROWN. I see.

Mr. LOWRIE. I might quote Dr. Kline now in a meeting we had several months ago at TRW. Dr. Kline is head of the biology experiment team. He felt that the implementation of biology with the three experiments now was a better implementation because we had added some new features to the other experiments. So it was a better overall biology balance than the original four experiments, and that is almost a direct quote.

Mr. Symington. The systems team that you sent to TRW, at the beginning, first time you sent a team, how many people were on the team?

Mr. Adams. I believe there were four.

Mr. Symington. And how many people now?

Mr. Adams. I expect there are probably 15 at this point or 20.

Mr. Lowrie. We had a peak of 19 people.

Mr. Adams. Several things were done there in augmenting that team. Actually, we got into the design problems, and we got into this problem of having the concurrent design, build and test programs going on. We actually sent people to supplement some TRW capability, where we had some specific capability that they could use, for example, in the thermal area. We sent out one or two of our thermal analysts who worked actually with their group. In the program planning and scheduling effort, we added a couple of people that worked actively with their people. We actually, in the team at that time, had expertise from Denver supplementing some of the areas of TRW.

Mr. Symington. Counsel has a question.

Mr. Hammill. You mentioned concurrent design and manufacturing and testing. Is that really possible to do? Can you be designing or redesigning something and manufacturing it at the same time?

Mr. Adams. Well, I can put that in this context. The biology experiment had been through essentially a complete design phase, and TRW at this time in solving these major problems set up what they called "tiger teams" on each of the major problems. There was a group of people, and in some of these teams we had representatives and NASA had representatives, but generally they were TRW teams to go and resolve each of the problems.

Now, as the problem got resolved, the engineering would immediately be revised and the manufacturing would go on on the detailed parts on the revised engineering. At the same time, we were proceeding with the, I will say, the design confirmation testing, so you were in the process of frequently building parts which had not had the design completely verified through the test system, and there was—this was necessary in order to work the scheduled problem. So that is possible. There is some risk in it, but it is possible.

Mr. Hammill. It sounds as though you might end up throwing away quite a lot of hardware if any significant redesigning had to be done because the manufactured parts would be no good, would they?

Mr. Adams. That is a fact. I don't have a good feel on how many cases we missed on. We missed occasionally. I don't think badly in that case. You must remember, we were on the second cycle on biology and judgments were made by a group of people including the program manager at TRW and our senior man on the site and NASA's senior man on the site, generally, to proceed in those sorts of things by mutual agreement after evaluating the risk.

Mr. Lowrie. To be sure we don't confuse you, Viking was basically made not to have concurrence. By and large we achieved that in most areas and the two areas, in the biology area and computer, because of problems in the earlier development phase and having to go through a second cycle, then your final production was concurrent with something you had to clean up as a result of qualification of the hardware. That certainly does give you a risk of scrappage of parts and replacement of parts anytime you run a concurrency program. You do run that risk and we had some in both instances, where we had to replace parts where you took that risk and moved ahead.

Mr. ADAMS. The instrument was beset with a number of significant problems which in the aggregate were almost unresolvable within the packaging constraints imposed upon the mechanical subsystem. A vigorous corrective action program was initiated at TRW with strong support from Martin Marietta and NASA. As of today, the open problems have been largely resolved. The first flight-type biology instrument will be delivered to Denver in the next few days for use in the spacecraft level tests previously mentioned. The confidence level in having two perfect biology instruments for flight is now quite high. However, the test maturity is considerably lower than that for the computer, and it still remains the single highest risk element on the lander. I have to put that in context. The confidence is quite high as compared to a year ago. It is quite high. If I look at the lander overall where the confidence level is extremely high. Biology has to be considered as the highest risk item still around. Although the late delivery of biology is highly undesirable, the interaction of this subsystem's late delivery with the lander system test program is not as serious as that of the computer. Consequently, the cost impact is primarily associated with the biology instrument development problems alone.

Mr. SYMINGTON. What was the cost impact again?

Mr. ADAMS. In the last year, it was in the neighborhood of $21.4 million escalation on biology.

Mr. BROWN. May I ask another question at this point?

The computer system, of course, is essential to the operation of the lander itself, to the landing process. I suspect rather significantly, but is the computer also involved in the operation of the biology package? Are there elements of the operation which are controlled by the computer?

Mr. ADAMS. Yes. All of the operations of the lander are controlled by the computer, so the computer is an extremely vital piece of equipment.

Mr. BROWN. As well as the actual landing process itself?

Mr. ADAMS. The whole system, getting landed is itself a major element and after you have landed, it controls the entire process.

Mr. SYMINGTON. You test the computer without the biology package; does it work with a simulated biology package?

Mr. ADAMS. Yes; we have a simulator in there when we do system testing, and that has been in all of these test programs so you get the right signals back, and so forth. The computer, theoretically, is looking at the instrument. However, the real interactions we still have to get by putting the real biology in these tests, which we still have to run.

Mr. SYMINGTON. That is your April test or February?

Mr. ADAMS. That is our January——

Mr. LOWRIE. The first basic compatibility is in December. As soon as I get the instrument, I put it in the lander and function it, so I will get that interface checked, that the computer talks to it properly and the functional interface works.

The next test, which is February, which Mr. Adams spoke about before, is when I run a simulated biology experiment in the vacuum chamber also.

Mr. SYMINGTON. When you're talking to the computer, that is a 40-minute conversation for one message?

Mr. ADAMS. That is between Earth and Mars. Between the computer and biology. We have the software loaded in the computer.

Mr. SYMINGTON. I just wondered, now, I am thinking of the actual operaton.

Mr. ADAMS. If you reprogram, then you have that 40-minute cycle.

Mr. SYMINGTON. I see.

Mr. ADAMS. The basic program is loaded into the computer, and updates are put in over the link.

Mr. HAMMILL. The biology package has begun its final acceptance tests, but they won't be completed until late in March. If, during the course of these tests, something serious is disclosed, what happens to all of the tests that you are doing on this article that they have sent to you specifically for your testing?

Mr. LOWRIE. That is a pretty general question. It's very tough to answer. I believe that we are far enough along now with our previous testing base on the biology instrument to not expect a gross wipeout in that final test, which is taking the flight-type unit, putting dirt in and running an experiment, a series of experiments for the scientists. That is the test that you're speaking of that will be done at TRW. I do not envision that that test will wipe out completely and change the instrument.

We may have to—if we have problems, either take some slight degradation in performance or make some modifications to the instrument. But I think the basic interface with the lander which is the control sequence probably will stay fixed and I don't anticipate any serious interface-type problem.

Frankly, to be perfectly honest, we don't have time, you know, from that point on to change the biology instrument. I do have the confidence we are not going to have something major. It isn't a question of cost or anything else. It's a question of time and getting an instrument to fly with.

Mr. HAMMILL. If something does come up, that is fairly significant during these final acceptance tests, what would you propose? To degrade the biology experiment to make the launch next August or have you considered the possibility of not flying until the 1977 opportunity?

Mr. LOWRIE. Of course, that would fundamentally have to be a NASA decision, as you well know. We have had conversations with the biology experiment team and I am trying to extrapolate what you might get into, you might end up not quite getting the sterilization temperature, just to use an example, in the module. If you got a little bit less, they could accept it and they would still be satisfied they were running decent biology.

It depends what exactly you come up with, the circumstances of the case. If you were way off on the temperature——

Mr. ADAMS. It really is a NASA decision in this case.

Mr. HAMMILL. Yes, but the NASA decision would be based on your recommendations?

Mr. ADAMS. It would be based heavily on recommendations and what was the specific problem.

Mr. LOWRIE. I cannot envision at the moment we could have sufficient problems with biology that we would recommend not flying. I really can't. Sometimes our vision isn't as good as we think. I think we have got enough testing behind us now. I am sure you will want to ask Dr. Solomon the same type of question. I cannot envision we would so degrade our biology to the point we would recommend not flying.

We will come up with a decent experiment for Viking.

Mr. ADAMS. The component development-and-qualification program on Viking has been completed—on the average—about 5 months later than originally planned as a result of technical problems. In the current year this development slippage has had a significant effect on the ability to efficiently conduct the system test program. The lateness in delivery of flight hardware required the use of earlier generation hardware in a number of instances to get tests started. This was inefficient and resulted in a significant amount of additional procedures, test sequences, data reductions, test troubleshooting and anomaly investigations. With 94 percent of the flight hardware delivered, this problem has diminished. However, it had a serious cost impact during the year.

The last major problem area experienced this year was associated with making the ground test system work efficiently with the checkout of the Lander. This of course includes the sequences or procedures used to run tests. I should point out here, we have a much more automatic test system than we have normally had on other systems. It is computer controlled and the tests then are normally programed and run by the actual operation of the computer. The test sequences are prepared and converted in some software for the computer and then the test itself is run essentially automatically.

Part of the problem was the result of the previously discussed item. In addition, there was a significant period earlier this year when the instances of down time of thet ground complex were far too high. An extensive, detailed design review and a stiffening of preventive maintenance was instituted to improve the equipment reliability. At the same time, the number of people designing and developing tests and their automatic sequences was significantly increased.

Mr. SYMINGTON. Can you give us a before and after on that?

Mr. ADAMS. Can we provide that for the record?

Mr. SYMINGTON. Yes.

[The information follows:]

In January of 1974, our projection for the average number of people required to design, develop tests, write the automatic sequences, and conduct tests was 169. It was necessary due to the lateness of hardware and a more complex test program to increase this average to 216 people.

Mr. ADAMS. Test progress in recent months, including the complex science end-to-end test on the proof test capsule, has shown that the corrective action has worked. The capability has now been demonstrated to run the necessary test programs from now through launch.

Yesterday Dr. Cortright mentioned we have been on schedule since August. Actually, with the exception of a few relatively minor deviations, we have been pretty well on the test schedule since May of this year. We have been on or ahead since August and we were on and slightly behind since May. We have been making that progress.

As I mentioned before, the principal cost impact of these Denver problems were a result of the sharply increased manpower requirements.

The Lander system-level-test-and-checkout program has undergone a significant change during the past year. There have been a number of tests eliminated and a number of tests added. These are summarized in figure 10. These changes occurred for several reasons: new knowledge indicated the need to add tests such as the radar system test; new knowledge allowed the elimination of tests such as the heat sterilization in Denver; schedule conflict required revamping of the test program, such as the redesign of the two thermal vacuum tests into a single test because of schedule conflict in the vacuum chamber; or the elimination of tests to save dollars where additional risk would not be large, such as the elimination of acoustics and vibration. This revised test program is a well balanced program providing all the necessary design and confirmation data, as well as control through testing of the flight articles.

I would like to spend some time in reviewing this chart.

The point was made yesterday by someone in the testimony that in a complex development program like this, the future not necessarily all that clear all the time. I think, this chart will show that the program has reacted to the situations as it developed on the program, not only technically but also in the cost and schedule sense. I would like to spend some time and run through these items.

First of all, you will notice a lot of deletions in the heat compatibility and thermal areas; for instance, two cycles of heat compatibility were deleted on the proof test capsule. We initially had scheduled four there. That was reduced by two. We removed the cruise thermal test on that particular vehicle, and we removed the Denver heat compatibility test on the flight articles shown down here.

The thermal design of Viking was one of the areas which we considered to be most challenging when we began the program. We set about then doing that in a very vigorous and cautious fashion. We started out our first major thermal test, what we called a thermal test model which was in effect a complete lander model with simulated heat-producing devices; et cetera, and subjected that to the total testing in the space chamber. We then moved on into the heat compatibility testing on the PTC as the major system area. The results of those tests were extremely positive. It turned out that the thermal design was excellent, that we had good margins throughout the system, and then our concerns with the thermal became significantly less. It also turned out during the heat compatibility testing, the sterilization testing, where we had had some rather serious concerns in the beginning of the program about parts, materials, and processes. (This entails cooking the entire capsule for approximately 40 hours at about 230 degrees Fahrenheit.) Careful attention to those during the course of the development resulted in those not showing up as problems. Those tests went very smoothly.

We concluded we had all that good test data behind us. It would suffice to run a single thermal vacuum test and delete this cruise thermal, and do the actual heat compatibility testing on the flight articles down at the Cape. So we were able to delete those items.

Another area you see several changes in is vibration. You see the "Y" and "Z" axis of vibration and vibration of acoustics eliminated down here. This is another environment which had given us some significant concern earlier in the program.

In the course of running the early precursor vibration tests on the dynamics test model, we discovered the excitation in these two axis were very minor and, therefore, we were able to eliminate them and do only the "X" axis with its very high excitations.

Again, in the course of the dynamics test model and PTC test, which were done on the "X" axis, we found the vehicle to have very good margins in all the dynamics types of environment and thus we were able to with confidence delete these tests on the flight articles.

The next series of tests up here, software-hardware compatibility, electromagnetic, captive firing and PSC pathfinder, are in the nature of tests to determine compatibility between various elements of the system.

Software-hardware compatible tests—we have replaced these with, we think, a much better test which is this plugs-out test. We will run it at the Cape on the flight articles. In this test, we actually isolate the entire system, hardware and software, from the ground system and play the total system together, so the total compatibility is demonstrated.

The EMC test was deleted here primarily as a schedule item. We found we were really stacked up on PTC. We had some open time on the first Flight Test Article, so we moved that test over there. It has been completed successfully on that article.

The captive firing was a test which was primarily to demonstrate the compatibility of the propulsion system, and also to give some verification of the total end-to-end performance of flight controls. In other words, the engines in themselves are the actuators, which bring you the stability on the vehicle when it lands. We are hoping to get some end-to-end testing on that.

The propulsion system testing we did earlier on the total complete system. The changes which occurred in the propulsion systems were very negligible. We felt the earlier test was adequate to demonstrate that compatibility.

On the flight controls aspect of the captive firing, we were never really able to come up with a test, a system test, without so much simulation and so much artificial things in it we would believe the results anyway.

At least, that was our opinion on the item, that we felt the effort would be largely wasted, so that test was deleted, and the total end-to-end capability of the Flight Control System has to be demonstrated through some of these other total system tests.

And finally, in the recent reprograming we deleted using the PTC as a pathfinder. We replaced that with several of these tests you see here, the precursor tests on the flight article. These, again, are compatibility tests between the Lander, the Orbiter and the launch vehicle and facility down there. In addition, we added a test which is this propellant-load and CG verification from Denver. So we have in essence replaced the significant pieces of the Pathfinder with other kinds of activity.

I dwelled on this in some detail to try and leave you with the feeling that it has been a fairly dynamic situation, in terms of the total test program. I believe, we have reacted properly to findings in the program, both schedule cost and technical, as we moved down through the program.

Mr. SYMINGTON. These test deletions and additions each have a cost impact?

Mr. ADAMS. Yes.

Mr. SYMINGTON. Presumably deletions reduce cost. You might, for the record, indicate how that balances out test by test.

Mr. ADAMS. We will do that.

Mr. SYMINGTON. I take it that none of the deletions present you with any qualms in mission performance or success?

Mr. ADAMS. No, they do not. They were examined in great detail by ourselves and by the LRC people in recent weeks, and by the NASA headquarters people. We had the active participation of some of the NASA people from both Johnson and Kennedy in helping us rework the total test program recently.

Mr. SYMINGTON. These deletions were made for budgetary reasons, weren't they?

Mr. ADAMS. Many of them were. Some of them were for scheduling.

Mr. SYMINGTON. Maybe we should note the difference.

Mr. BROWN. There is a third type of deletion, too. For example, as I recall your discussion of the Y and Z axis of the vibration test. I think that is a re-examination of the technical need for it, isn't it?

Mr. ADAMS. Yes. This is tied in with cost, however.

Mr. BROWN. You would have done something that was unnecessary if it wasn't for the cost constraints?

Mr. ADAMS. We wouldn't do something that was unnecessary, if it was expensive, I hope. I wouldn't say we never have, but we try not to.

Mr. SYMINGTON. What would be your best example of a test you deleted solely for budgetary reasons? Even though there were some merit to it?

Mr. ADAMS. I think the Pathfinder is probably the best example. We have moved the Pathfinder operation to a flight article from PTC. I believe that was primarily for a budget reason and we made a tradeoff and decided the technical risk was not so great that we could not do it.

Mr. SYMINGTON. Describe the risk?

Mr. ADAMS. The risk is that when you arrive at the Cape with your flight article that you will have an incompatibility between the Lander and Orbiter which will cause perhaps a design change, or between the Lander and the facility or between the combined flight vehicle and the launch vehicle, this sort of thing, which you would have gotten some lead time on to change had you done it earlier. I think that is the major risk of that.

Walt, do you concur?

Mr. LOWRIE. The potentiality of finding something later and, therefore, work a little harder to get it fixed, we carefully went through it and said this is a proper cost tradeoff, deleting it with the maturity we have in the program today and the probability of finding those kinds of things now is smaller but clearly, if you weren't working on a budget, yes, we would probably have left the Pathfinder in, too.

Mr. SYMINGTON. On that, how much do you save there? You can supply that for the record.

Mr. ADAMS. I don't believe we have that as a broken-out item.

Mr. LOWRIE. We can give a cost of each of these.

Mr. SYMINGTON. I would like them all, and also a brief description, if you haven't already got it in the record here.

Mr. ADAMS. It is not detailed, as I discussed here.

[The information follows:]

The technical descriptions of the system-level test and checkout program identified on Figure 10 are included in the testimony starting on Page 138, line 22 and concludes on Page 146, line 1. The schedule and cost impacts associated with each test deletion or addition are identified in the following table:

LANDER SYSTEM LEVEL TESTS

| Articles | Deletions | Schedule impact [1] | Amount (millions) | Additions | Schedule impact [1] | Amount (millions) |
|---|---|---|---|---|---|---|
| Proof test capsule | 2 cycles heat compatibility. | 9 | $0.1 | Science end-to-end test. | 90 | $1.5 |
| | Y and Z axis of vibration. | 9 | .1 | Biology performance verification. | 99 | .8 |
| | Cruise thermal | 63 | .4 | Radar system tests | 12 | .1 |
| | S/W-H/W compat | 10 | .4 | | | |
| | Electromagnetic compatibility. | 54 | .4 | | | |
| | Captive fire | 80 | .4 | | | |
| | KSC pathfinder | 410 | 2.8 | | | |
| Landerdynamics test model. | None | | | Propellant load and CG verif. | 130 | .9 |
| Flight articles | Denver heat compatibility. | 20 | .1 | Plugs-out test | 10 | .4 |
| | | | | Radar system tests | 30 | .1 |
| | Vibration | 28 | .2 | 100-word update test | 4 | .1 |
| | Acoustics | 20 | .1 | Precursor tests | 36 | .2 |
| | | | | Electromagnetic compatibility. | 50 | .4 |
| Total | | 703 | 5.1 | | 461 | 4.5 |

[1] Based on 8-hr shifts.

Mr. SYMINGTON. Thank you.

Mr. ADAMS. The other significant programmatic change has been the elimination of the third flight lander. This action was taken specifically to minimize Viking costs, with some slight increase in risk; the risk being associated with the probability of getting two spacecraft launched from the same launch pad within the launch period. We can go out to 45 days with some minor degradation in mission. So we actually have a total of 45 days in that launch period.

At the outset of the Viking program, a major concern existed in the ability to develop a lander capable of heat sterilization without some very significant probability that hardware failures would occur during the terminal sterilization. Consequently, the third lander existed because of a strong belief that one or more recycles of the hardware would occur as a result of such terminal sterilization failures. Experiment to date on flight components and on the complete PTC spacecraft indicates that the probability of failure is much lower than originally anticipated. I discussed that when I was talking about the thermal situation. The thermal situation has turned out to be a very favorable one on the program at this time. This of course has resulted from a very heavy attention to detail in materials, processes, and component packaging. Consequently, when one analyzes the various time lines for launching two spacecraft, using actual program experience, the assumption of increased risk by eliminating the third lander is not high.

We still have time in the program for problems and recycles and still being able to make the launch. I believe that was discussed some yesterday by Dr. Cortright.

Mr. HAMMILL. That third lander must be nearly built?

Mr. ADAMS. The third lander was almost complete. Not all of the components were available yet. We made some significant savings at some of the subcontractors and in-house. When you say it's built, you must remember that a large part of the cost of the building is installation of the components and final tests on that whole system.

And if you look at the third Lander itself, in the total dollars that, you know, I will say are lost because you set it aside, I don't have a precise number on it, but they are lower than you would anticipate because the major program costs are in the development costs, the component qualification costs, the system qualification costs and then the checkout of the complete system when you finish.

So the actual hardware that is there is not really the major item, although obviously it is a significant item. The other thing I should mention is that the Lander is nearly complete and is certainly a prime candidate for another mission at some later time and would go a long way toward reducing costs, if such a later mission were planned. It is available for that. It is a perfectly good piece of hardware.

All of the programmatic actions taken on the lander system in the past year have of course been accomplished in close cooperation with the NASA.

And, in fact, we are absolutely living together very closely. We have a fairly large test support team in Denver and this has been worked out as a mutual kind of a program.

Although there is some increase in risk, it is not large; and certainly, the basic concept and intent of the Viking program has not been altered by the actions taken.

The Lander system has reached a high level of maturity, and the confidence exists that the lander will be ready for the August 1975, launch period. More importantly, the lander will be there with very high grade hardware capable of accomplishing the very difficult Mars mission. It is unfortunate that the technical and schedule accomplishment could not have been achieved without the cost growth that has been experienced. Viking has been the most difficult technical challenge Martin Marietta has faced, and it is the most complicated unmanned space program undertaken by this Nation. It is my opinion that, although the program cost will exceed our initial projections, it is not out of proportion with the degree to which the technical challenge exceeded our initial understanding. I am proud of the overall results that we have achieved, and I am dedicated to completing this program with a highly successful mission on the surface of Mars.

Mr. Chairman, this concludes my testimony.

Mr. SYMINGTON. Thank you, Mr. Adams.

We have asked periodically throughout your testimony for the names of subcontractors or a definition of problems and cost impact and so on. Perhaps a general request for the whole works would be what we would make at this time, when you have a chance to put together contractors problems, costs, and so forth.

Mr. ADAMS. In essence, you want a listing of cost and cost impact.

Mr. LOWRIE. Summary history by some breakdown.

Mr. ADAMS. We have that data here and we will put it together.

Mr. LOWRIE. We need to compile it.

Mr. SYMINGTON. I am sure you have compiled it in your way just for your own purposes. Thank you very much.

[The information follows:]

From September 1970, baseline for the '75 million, through October 1974, the Viking Project costs at Martin Marietta have increased by $181.2M. This increase in cost has occurred due to the following:

1. Additional work items added and associated award fees increased the amount of the contract by $36.4M. The major items contributing to this growth are as follows:

| | Million |
|---|---|
| a. GCSC/DSM and core memory back-ups | $21.8 |
| b. Award fees | 6.1 |
| c. X-ray fluorescence/inorganic anal | 3.0 |
| d. Spacecraft test lander | 2.9 |
| e. Separate processors | 1.7 |
| f. North Polar region landing capability | 1.7 |
| g. Cost reduction items | (4.5) |

2. Subcontract and purchased material has contributed $113.9M to the total cost growth. This growth is attributable to the unforeseen complexities during design, development, test and fabrication, and economic impacts experienced by our suppliers to date. The major contributors to this increase are as follows:

| | Million |
|---|---|
| a. TRW—biology | $41.5 |
| b. ITEK—camera | 13.1 |
| c. Ryan—TDLR/RA | 10.4 |
| d. Honywell—GCSC/DSM | 10.2 |
| e. RCA—communications | 5.8 |
| f. Hamilton Standard—IRU | 5.6 |
| g. Bendix—UAMS and seismometer | 4.4 |
| h. Celesco—articulated boom | 2.8 |
| i. TRW—meteorology | 1.9 |
| j. Lockheed—tape recorder | 1.6 |
| k. Goodyear—decelerator | 1.4 |

3. The balance of the total growth is attributable to in-house cost increases in labor, burden (including burden associated with the subcontract and material growth) and other Direct Charges in the amount of $30.9M. The major contributing factors to this increase are as follows:

| | Million |
|---|---|
| a. Burden associated with subcontract and purchased materials growth | $5.7 |
| b. Test | 10.3 |
| c. Engineering | 8.9 |
| d. Components | 4.3 |
| e. Software | 3.5 |

Mr. SYMINGTON. Are there any questions?

Yes, Mr. Brown?

Mr. BROWN. You raised in your last few paragraphs a matter which is of considerable interest to me because my primary concern has been with the basic longrun scientific content of our space program. I see the Viking mission as being the prototype of what may be the sense of our additional steps in space exploration for many years, maybe a generation. The possibility of using that third lander incomplete as it is as a component of an additional mission seems at least a reasonable matter.

The question I have perhaps should be better directed to the NASA people, but to your knowledge has there been a discussion of the follow-on program to Mars based upon the input from the science experiments in this program?

Mr. ADAMS. Yes, there has. There has been considerable discussion and we have done several studies in-house studies, and studies for the NASA on this subject.

We have done the preliminary work for instance, in modifying the third lander to a mobile configuration and a relatively straightforward modification has been evolved from that which is the addition of a small crawler on each of the three landing points and with this capability, then, the Lander could move many kilometers over a course of a period of time and then actually get data from different points on the planet.

Mr. BROWN. That requires some modification also to your power system, doesn't it, and some other types of modifications?

Mr. ADAMS. Actually, the basic power that we have available, I believe, we upgraded the RTG's to some degree. The basic power system did not turn out to be a severe problem. The amount of power required to move this thing really isn't all that great, and the half-life on the basic isotope in these generators, is very long, so that we can work for very long periods of time. If you aren't in too big of a hurry and can take your time, you can move about quite well.

Mr. BROWN. I am used to the Earth environment where moving things around is not very easy.

Mr. ADAMS. The Science Committee has indicated a very high interest in that type of a mission and so also has NASA. Now, the obvious situation is that of the budget constraints. How does this fit into the budget of other programs going on?

Mr. BROWN. Quite obviously, looked at from this standpoint, this is a part of an on-going unmanned exploration of not only Mars but possibly other planets. In effect we are solving problems here that will contribute to our more economical ability to carry on this program, and this does give you a slightly different perspective on the overruns even though they are substantial.

Mr. LOWRIE. I might just add something. The crawlers we looked at in this feasibility study came out of the lunar program. Huntsville had done some development work as part of the Apollo program. We are building on their technology development out of Apollo. So the feasibility studies used the crawlers, they had developed from that program.

Mr. SYMINGTON. Mr. Winn?

Mr. WINN. I'd like to know who pays for the feasibility studies and the additional work that is done on the crawlers, for instance?

Mr. ADAMS. There was some minor funding from Langley.

Mr. LOWRIE. Less than $100,000, as I recall.

Mr. ADAMS. It was under $100,000, I am sure. It was a minor one. Some of the funds that had gone into it are from our in-house study and they are paid for ultimately, at least part of them, by the Government. It is a cost-sharing kind of arrangement.

Mr. WINN. Who is the Government?

Mr. ADAMS. Well, in our case, the Government is all of our customers and that includes the NASA and the Air Force primarily.

Mr. WINN. Air Force?

Mr. ADAMS. Yes.

Mr. WINN. I am not aware of any plans for a future landing with the third Lander?

Mr. ADAMS. Dr. Hinners has been addressing that as part of his responsibility in the NASA headquarters, and I don't know whether he has had discussions with the subcommittee.

Mr. LOWRIE. In the sense Mr. Winn is describing this is not an authorized program. These are exploration R. & D. type studies to look at the feasibility of setting up a future program.

Mr. ADAMS. Strictly a feasibility type of thing.

Mr. WINN. I don't have any further questions.

Mr. SYMINGTON. Thank you, Mr. Winn. Thank you very much.

Thank you, Mr. Adams and Mr. Lowrie, for your very helpful testimony.

We will now hear from Dr. George Solomon, vice president and general manager of TRW Systems.

## STATEMENT OF DR. GEORGE SOLOMON, VICE PRESIDENT AND GENERAL MANAGER, TRW SYSTEMS

Dr. SOLOMON. Gentlemen, I know that you have on other occasions been briefed on the function and operation of the Viking Lander biology instrument that we are building at TRW, but it might be helpful to briefly review it again at this time. As you know, the purpose of the instrument is to search for signs of life in small samples of Martian soil. This is a very exciting task, as well as a difficult one, and all of us at TRW who have worked on it are enthusiastic about the job because of its obvious significance and scientific value.

The instrument itself consists of three completely separate experiments. The original plan was to carry four experiments, but one was eliminated in March of 1972 as a packaging and cost-saving measure. Each instrument uses a different approach to the detection of possible life in the Martian soil samples, and each one corresponds to a complete biochemistry laboratory, including the laboratory staff. In addition to the experiments, there is a set of supporting equipment that includes a complex electronics assembly with its own computer that controls the experiments and processes the resulting data for transmission back to Earth.

The three experiments were selected by NASA when the individual scientists were selected to be part of the Viking biology science team as experimenters in 1969. The selected experiments were assigned to TRW for implementation from various experiments in different stages of laboratory development in NASA, universities, and industrial laboratories. The head of the science team is Dr. H. P. Klein, Assistant Director for Life Sciences, NASA/Ames Research Center. The members of the team who have experiments on the Viking biology instrument are (1) Dr. Norman Horowitz, California Institute of Technology, pyrolytic release experiment; (2) Mr. Vance Oyama, NASA/Ames Research Center, gas exchange experiment; and (3) Dr. Gilbert Levin, Biospherics Inc., labeled release experiment. The two remaining team members are Dr. Joshua Lederberg, Stanford University, and Dr. Alexander Rich, Massachusetts Institute of Technology.

Mr. Chairman, at this point, I would like to show you some photographs of the equipment, the actual instruments that we will be delivering—those we will deliver and those that are called the test standard modules.

As I mentioned, these experiments are normally a complete laboratory, a room full of equipment and staff. These photographs show the first step in the miniaturization of those experiments. On these first three which cover the three present experiments, the test module is the flight module, the actual experiment, plus the surrounding rack of electronic equipment and pneumatic control equipment. The next step in the miniaturization is to reduce these racks to the same scale.

The next photograph shows the experiments in their completely miniaturized form; it also gives you a feeling for the cleanliness standards we worked toward in assembling and operating this instrument. One of those photographs, the one labeled serial No. 102, is the complete instrument has finished its functional verification, and is now in its performance verification testing, and goes into biology testing in December of this year. The final photograph, serial No. 103, is the first instrument which will be delivered to the Martin Co. in the first week of December.

One experiment looks for life forms that might function like many Earth organisms, metabolizing food and producing carbon dioxide. In this one, a pinch of Martian soil is wetted with a few drops of a nutrient medium that contains radioactive carbon. If organisms of this type exist in the soil, their metabolic processes will release radioactively labeled carbon dioxide that will be detected by a miniaturized radiation detector built into the experiment. In this and the other two experiments, the judgment as to whether or not life processes have been observed will be based on comparing the results to those from an identical sample that has been sterilized by heating to over 300° F.

The second experiment looks for life processes such as photosynthesis, where carbon dioxide is incorporated into cellular material. Labeled carbon dioxide is injected into the atmosphere in the incubation cell, and a small xenon lamp provides a simulation of the Martian sun. After the incubation period, the labeled atmosphere is removed and the sample is toasted and analyzed by a radiation detector to determine whether it has assimilated any of the labeled carbon dioxide.

The third experiment is based on the fact that all known organisms produce or take up gases as part of the process of living. A miniaturized gas analysis system is used to make periodic measures of the gas composition in a sealed cup containing the soil sample and a nutrient.

The three experiments can analyze at least four different surface soil samples during the planned 90-day operational period on the surface of Mars. The complete instrument, like the rest of the Lander, must withstand prelaunch sterilization at 230° F for 20 to 40 hours. It must also keep the test cells within the narrow range of suitable incubation temperatures while the Martian atmosphere fluctuates over 200 degrees from day to night.

Your subcommittee has been following the progress of the biology instrument over the years, so I will not dwell on the events before August 1973 when you last reviewed the program.

Mr. SYMINGTON. I might say, it would be helpful if you would submit for the record the date on which TRW was selected. Perhaps we have it somewhere else; just a statement of what the amount was of the original contract, and then a case history highlighting the technical problems. I am sure some of that is in your testimony.

Mr. SOLOMON. We are prepared to do that.

SUMMARY OF MAJOR TECHNICAL AND COST EVENTS ON TRW VIKING LANDER BIOLOGY INSTRUMENT (VLBI) PROGRAM

| DATE | TECHNICAL EVENT | ESTIMATED COST AT PROGRAM COMPLETION ($000 OMITTED) |
|---|---|---|
| June 1970 | Negotiated and started performance of Phase I one-year contract. Its objective was to fabricate and test breadboard models of each of the four (4) experiments in the VLBI and perform the necessary engineering effort to establish flight hardware design criteria. The contract specification contained many "TBS'" (to be supplied) for various technical criteria. The TBS' were to be provided to TRW in a "timely manner". | $924 |
| October 1970 | Agreement reached with MMC on final contract definition and cost for Phase I contract. | $1,039 |
| | Agreement reached with MMC on Phase II contract. Its performance was to start on June 1971 at the completion of the Phase I contract. The contract called for three (3) design-development 'DD' units, DD Tests, Qualification unit and tests, then fabrication of five (5) flight units, for delivery by mid-1974. The Target cost for the Phase II contract: | $10,582 |

| DATE | TECHNICAL EVENT | ESTIMATED COST AT PROGRAM COMPLETION ($000 OMITTED) |
|---|---|---|
| June 1971 | Phase I contract completed within cost, but the technical objective to produce flight hardware design criteria was not completely achieved, principally because a large portion of the TBS' had not been supplied to TRW and necessary specification changes were not permitted nor implemented by MMC. | $1,038 |
| | Authority to commence the Phase II contract was issued in June. The Preliminary Design Review (PDR), to be based upon the Phase I contract output, was postponed from July to October 1971. | $10,582 |
| July 1971 | Some, but not all, of the missing 'TBS' criteria were provided to TRW, including the third increase in thermal environment since the contract had been negotiated. | |
| October 1971 | Preliminary Design Review (PDR) revealed a very complex instrument with an estimated weight of 30 pounds (vs a requirement of 18). TRW advises MMC that the EAC, including an estimated $4.3 million for change orders received is: | $19,200 |
| | After a second Design Review meeting, TRW is authorized to proceed with a study effort to simplify the design. | |

| DATE | TECHNICAL EVENT | ESTIMATED COST AT PROGRAM COMPLETION ($000 OMITTED) |
|---|---|---|
| December 1971 | Detailed estimate of program costs completed. Including a forecasted $7.2 million overrun, cost now is estimated by TRW at: | $23,200 |
| January 1972 | Simplified instrument study results in major specification change order direction. Cost now: | $24,400 |
| February 1972 | Thermal problem is identified - the changed interface with the Lander does not provide an adequate heat sink to dissipate enough heat generated by the Biology Instrument. | |
| March 1972 | The Light Scattering experiment is deleted from the VLBI reducing EAC by $2 million to | $21,700 |
| June 1972 | TRW proposes that an active thermal control system be added at an estimated $1.9 million. Without this change but including estimates for the 24 change orders received since contract start, the EAC now stands at | $23,500 |
| August 1972 | MMC authorizes an active thermal system. | |
| October 1972 | Design/Development as specified in the contract is completed. | $25,027 |
| November 1972 | Manufacturing readiness review approves start of hardware fabrication for qualification/flight units. | |
| December 1972 | First Design-Development (DD) unit completed. | |
| January-May 1973 | DD Testing reveals significant problems: Hybrid microcircuits, pneumatic leaks, seals, thermal. | $25,700 |

| DATE | TECHNICAL EVENTS | ESTIMATED COST AT PROGRAM COMPLETION ($000 OMITTED) |
|---|---|---|
| May 1973 | Critical Design Review (CDR) completed. Redesign activities identified to resolve thermal problems encountered in DD tests. Test program identified to determine cause of high second peak readings in PR experiment. | |
| May-July 1973 | Retrofit DD unit before completing DD tests. | $26,300 |
| August 1973 | Testing of DD unit continues. A detailed cost estimate, including a forecasted $12.4 million overrun, is now | $30,656 |
| September 1973 | Qualification unit 101 completed and testing started. LLE noise problem requires added shielding and grounding. | |
| October 1973 to January 1974 | Qualification testing on unit 101 discloses problems: sticking and leaking valves; heaters; vertical actuator; contamination; seals; restrictors; bonding and nutrient metering. | |
| November 1973 to March 1974 | Program structure reorganized. Intensive redesign and problem solving activity adds heavily to manpower. EAC now is: | $39,548 |
| March 1974 | Design frozen. JPL reviews experiment approach. Manufacturing of flight hardware resumes. Retrofit of 102 instrument to incorporate design changes starts. Detailed cost estimate based on final design increases cost (including $26.1 million forecasted overrun) to: | $47,996 |
| May 1974 | Contract direction received to build Instrument S/N 107. (Long-lead parts procurement had been authorized in November 1973). | |

| DATE | TECHNICAL | ESTIMATED COST AT PROGRAM COMPLETION ($000 OMITTED) |
|---|---|---|
| July 1974 | EAC adjusted for recent actual manufacturing and test experience to: | $50,596 |
| September 1974 | Complete S/N 103 and start testing it. Although some problems encountered, S/N 103 is acceptable for Performance Verification (PV) Lander tests to be run by MMC in Denver. | |
| | S/N 107 build is stopped, reducing EAC $608K. With numerous offsetting changes received, EAC is now: | $50,400 |
| October 1974 | S/N 102 retrofit completed and its testing started. | |
| November 1974 | S/N 104 and 105 completed. Acceptance testing started on S/N 104. Acceptance Test requirements reduced. S/N 103 in final test for early December delivery to Denver for PV tests. Including $27 million overrun and recent change orders, EAC is now: | $50,545 |

Dr. Solomon. You will recall that we found the technical difficulties even greater than we had anticipated, and that the cost of the program had grown accordingly. But during the past 15 months, we have pursued an intensive program of redesign and verification testing which, although costly, has given us renewed confidence that it will indeed be feasible to conduct a search for life on the Martian surface by means of a complex and miniaturized automated biology laboratory such as the one we are now preparing for the flight to Mars.

In August of 1973, the basic engineering, design, and development phase of the program was thought to be complete and the instrument ready for qualification and systems testing. Tests had been performed on the development instrument, changes had been incorporated to correct various deficiencies found in developmental testing, and the critical design review had been completed. All open action items from that review were closed. The program was then nominally in the manufacturing and test phase, with the major emphasis being on building and delivering the instruments on the required schedule.

By this time the schedule problem was becoming severe, and to help deal with it we restructured the project completely and assigned a new project manager. At the same time, Martin Marietta assigned a special audit team to work with the new TRW management team to define a feasible delivery plan and a realistic cost estimate for completing the program. At that time, the total cost of the program was estimated to be just over $30 million. This estimate was based on the assumption that no major technical problems remained from the design and development phase.

Mr. Symington. I have a question at this point. That sentence you just read seems a little inconsistent to me, at first glance, with the first full paragraph of the same page, where you say that:

> All open action items from that review were closed. The program was then nominally in the manufacturing and test phase, with the major emphasis being on building and delivering the instruments on the required schedule.

That is August. Then came September; that was a bad month. What happened?

Dr. Solomon. I think that prior to August we had done insufficient testing at the unit, component, and subsystem level and it was in the August–September time frame that we just began to get into the real testing. We started that testing at the instrument level. We began to find problems. That was the cause of that change between August and September.

Mr. Symington. I think we must ask if that isn't the kind of surprise that could have been avoided by a more indepth analysis of the potential difficulties further upstream? It seems as if you almost had the whole thing in the box ready to go without really knowing what was involved?

Dr. Solomon. We had done insufficient testing prior to that point.

Mr. Symington. How long had you been on it before August of 1973?

Dr. Solomon. We competed for the program in early 1970 and were selected as the contractor in March of 1970, but then we had bid to the 1973 launch. There was that revision. I think we finally had an agreement on the work statement and so on in mid-1970, October 1970. We were into the program about 2½ years.

Mr. SYMINGTON. Two and one-half years.

And how much had you spent by that time? You say the later program cost was estimated to be $30 million. How much had been spent?

Dr. SOLOMON. At September 1973?

Mr. SYMINGTON. Yes.

Dr. SOLOMON. About $24 million.

Mr. SYMINGTON. I guess we asked Mr. Adams how much had to be added for the biology improvements, I believe he said $20 million. Is that about right?

Dr. SOLOMON. From that point?

Mr. SYMINGTON. From that point.

Dr. SOLOMON. From late 1973 until now, about $20 million, I will comment on this a little later.

Mr. SYMINGTON. Yes; I was getting ahead of you here.

Dr. SOLOMON. In September the qualification instrument was completed and testing was started on it. At approximately the same time the development instrument was refurbished and soil biology testing was begun. The tests of both instruments over the next 4 months resulted in numerous failures. The failures encountered during these tests were widespread and encompassed many technological fields. The failures included failure of high-temperature heaters caused by debonding, thermal and electrical stresses which prevented sterilization of the test cells; stiction of the elastomeric material in the valve seats at low temperature which prevented valves from operating; and failures of vertical actuators during heat compatibility testing which prevented the test cells from being raised and lowered.

Electronic failures were also experienced. The noise in the low-level electronics system which amplifies and counts the radioactive carbon signals was excessive and prevented counting of the signal. In addition, the Xenon arc lamp which reproduces Martian sunlight in the pyrolytic release experiment was found to operate erratically and below the needed level of performance when coupled with its high voltage starting circuit, mirrored reflectors and optics at the instrument level. Perhaps the most serious problem identified at that time was that of micron size particulate contamination in restrictors, lines, and orifices which prevented flow of nutrient and gases to the experiments.

These failures, together with the results of detailed design reviews and audits conducted at the same time, provided conclusive evidence that major redesign and additional development work would be needed to give assurance of meeting the performance requirements. In parallel with this test and review activity, production was continuing on the fabrication of parts, subassemblies, and modules for all flight instruments.

Mr. SYMINGTON. Wasn't production suspended during the redesign period?

Dr. SOLOMON. No, it was not. The schedule faced us. I will comment in a moment about the cost of doing that which was really minimal.

Mr. SYMINGTON. I wonder how you can redesign and continue to manufacture at the same time?

Dr. SOLOMON. We produced to the original designs with the thought being that much of that produced hardware could be useful even after redesign. Redesign was not that specific.

In December 1973 a program review was held with participation by all involved parties, including the science community. Relief in noncritical specification requirements was obtained in various areas from both the science team and the prime contractor to permit redesign of the instrument within the current state of technology. A massive redesign, development, and engineering verification test program was initiated with full approval of Martin Marietta and the NASA Viking Project Office. This redesign effort required a buildup in TRW manpower from approximately 250 people in November 1973 to 400 people in March of 1974, primarily in additional technical and engineering disciplines. Because of the commonality of technology of the various experiments, all experiments were involved in the redesign. The redesign effort involved valves, cell seals, vertical actuators, restrictors, low-level electronics, nutrient metering systems, contamination and cleanliness, heaters, heater bonding, as well as a total thermal redesign. To accomplish this redesign within the schedule constraints, TRW assigned "tiger teams" to the various problems and also, with the concurrence of Martin Marietta and the NASA Viking Project Office, assigned a special assistant to the project manager for management of problem investigations and solutions.

In March of 1974, all areas requiring redesign had been identified, the redesign and develop effort was well underway and engineering was being released to the floor. At this point in time, the cost of the program had increased to $40 million, a growth of $10 million, attributable primarily to the extensive redesign and development effort. The March cost estimate was only a partial estimate of the total program cost, since it did not include the impact of the redesign on the manufacturing and test effort. Recognizing this, an estimate to complete for the program was initiated in late March to determine the full impact of the redesign on the manufacturing and testing of the instrument. This estimate to complete was finalized in April, with an estimated program cost of $48 million. The April estimate to complete included an expanded test program at the subassembly and module levels—which test program accounts for 1½ million of the cost growth—the extensive rework of components and subassemblies which had already been fabricated, and the rebuilding from scratch of components and subassemblies which could not be reworked.

Mr. Symington. I asked you a moment ago about the advisability of going forward with production of certain components and subassemblies and you said that was possible during redesign because the redesign was not that substantial.

Now, suddenly there is an $8 million cost increase in about 1 month. Is that because you encountered massive redesign problems that couldn't be anticipated?

Dr. Solomon. That $8 million—the increase to $40 million—was a redesign and development effort. Going from 40 to 48 was the additional manufacturing, but mostly testing; in large part it was testing. The detailed testing starting at the unit level, component level, subassembly level, and the complete instrument level which we had not really done prior to late 1973. So that most of that cost increase was in testing; we did scrap some material, but our estimate is not over a million dollars' worth.

The rework and rebuild effort was responsible for $2½ million of the increase. Most of the remaining increase was a result of a decision to work on an around-the-clock, 7-day-week basis to insure schedule maintenance. That is what I meant by the much more extensive testing program.

In March of 1974, the NASA Viking project office established a special task team to make an independent review of the program to determine the feasibility and probability of delivering the three-experiment biology instrument within schedule constraints imposed by the 1975 launch window. This task team was comprised of technical specialists from the Jet Propulsion Laboratory, the Langley Research Center, and Martin Marietta. TRW supported the task team by providing drawings, data, and other technical information. The task team was led by a technical specialist from JPL and performed their review at JPL in March and April of 1974. As a part of this review, the task team studied the technological aspects of each of the experiments, as well as the instrument in toto; and to give you an understanding of the complexity and technologies involved, I would like to summarize some of their findings. The task team identified 35 different technologies that are involved in the design of the instrument. Eighteen of these technologies are equally important to each of the experiments; three additional technologies are required for the labeled release experiment; five additional technologies are required for the gas exchange experiment; and eleven additional technologies are required for the pyrolytic release experiment. These technologies ranged from movable vacuum type seals to high density electronics packaging, from metering liquid flow systems to thin film electronics, and from narrow hand temperature control systems to detection and counting of radioactive gases.

As a result of their review and findings pertaining to technological aspects of the experiments, the task team concluded that, independent of cost, the three-experiment instrument would be very difficult to build, test, and deliver within the schedule constraints imposed by the 1975 launch window, and hence recommended a single-experiment approach as the most probable means for insuring delivery within the schedule. The task team's findings and recommendations were reviewed during the April 22, 1974, management review meeting at TRW with NASA headquarters, NASA Viking project office, Martin Marietta, the Jet Propulsion Laboratory science team, and TRW in attendance.

TRW did not concur with the task team's recommendation for the following reasons: First, the selection of the experiment which would be least susceptible to further development problems was at best problematic because of the lack of proven experience in the manufacturing and test of any of the experiments; secondly, the three-experiment instrument provided the highest probability of accomplishing the mission, that is, the search for life on Mars, in that if any one experiment could not be made to work, the mission could still be performed by the other two experiments; and finally, TRW was confident that by adding manpower and working around the clock 7 days a week the three-experiment instrument could be delivered in time for the 1975 launch.

During this meeting, TRW was directed to proceed with the three-experiment instrument and to initiate actions for manufacturing and test on an around-the-clock basis. As a result, in April 1974 manufacturing and test activities were reinstituted in full force for the three-experiment instrument.

From April through August 1974, the program emphasis was primarily on delivering working instruments on schedule within the projected program costs. Work on all instruments proceeded on an around-the-clock, 7-day-week basis to attain the highest assurance of meeting schedule commitments. In July a new estimate to complete was performed based upon the manufacturing and test experience during the time period of April, May, and June, and the program costs were then estimated at $50.3 million, a growth of $2 million primarily attributable to increased costs to maintain schedule and to unanticipated occurrences in manufacture and test of the various experiment modules. Manpower during this period peaked at 576 equivalent heads with paid overtime running at approximately 17 percent.

By September 1974, the manufacturing and test problem content had decreased significantly and manufacture and test of the experiment modules for all instruments was in progress, although somewhat behind schedule. The manufacture of the first instrument was completed and the instrument subjected to test, and the second instrument was essentially complete and ready for test. In late September, one instrument was deleted from the program with a cost reduction in the order of $600,000.

Mr. SYMINGTON. Why was that decision to delete that experiment made in September?

Dr. SOLOMON. That was what we called the number 107 instrument. It would have been the fourth flight experiment but with the direction that was taking place in the overall program it was no longer needed.

Mr. SYMINGTON. Was that a NASA decision?

Dr. SOLOMON. I believe so. The decision to eliminate the third lander was made by them.

Mr. SYMINGTON. That was the third lander.

Dr. SOLOMON. Concurrently numerous cost reduction options were studied and analyzed, leading to the adoption of a new plan in October with a further cost reduction of $280,000. The new plan, implemented in October, reduced the acceptance test requirements for two of the flight instruments and curtailed other test activities.

During the period from August to the present, TRW initiated and implemented a detailed destaffing program to control project manpower while maintaining program schedule, cost, and performance requirements. This effort has been eminently successful and our current manpower was reduced to 300 equivalent heads; today it's like 280. The current estimate at completion is $50.4 million. This figure includes in scope since July of approximately $1 million, as well as the cost reductions previously mentioned.

Today, we have successfully completed the manufacture of four instruments, with manufacturing of the final instrument scheduled to be complete on November 22. The Denver test instrument has essentially completed the test program and is scheduled to be delivered to Martin Marietta on November 27, 1973. The soil biology test instrument, Serial #102, which will be tested at TRW, has successfully completed all functional tests and is currently in the performance verification test. Soil biology testing is scheduled to begin in mid-December 1974 and to be completed in March of 1975.

I might add parenthetically with regard to those test standard modules we demonstrated that the basic experiment does work.

Mr. SYMINGTON. If between now and March those tests don't prove out, there really isn't any time to redesign or make modifications?

Dr. SOLOMON. It will depend on the problem, if any, we find.

Mr. SYMINGTON. It might not be possible?

Dr. SOLOMON. We don't forecast or foresee any problems.

Mr. SYMINGTON. OK.

Dr. SOLOMON. The first flight instrument, which will undergo limited qualification tests, as well as flight acceptance tests, is now undergoing functional verification tests and is scheduled for delivery to Martin Marietta in mid-March 1975.

Mr. SYMINGTON. That would make it how much later than the original delivery date?

Dr. SOLOMON. I believe we had originally planned on having one at Martin in early October or late September. As of about a year ago, the plan was early October.

Mr. SYMINGTON. I see.

Dr. SOLOMON. The second flight instrument is also undergoing functional verification tests with delivery to Martin Marietta also scheduled for mid-March 1975. The spare flight instrument is scheduled to start into the test program on December 2 and to be delivered to Martin Marietta in mid-April 1975.

To summarize where we stand today, during the past 15 months we solved the major technical problems, redesigned the instrument, and built and assembled four of the five instruments. We have encountered a few nagging problems in the test phase, primarily associated with particulate contamination, but are confident that we can deliver instruments capable of performing the mission on Mars. Although we have not completed the testing of the flight instruments, our current progress in instrument test makes us confident that we can deliver the biology instruments in time for the 1975 launch and within the projected costs.

That is the end of my statement, Mr. Chairman.

Mr. SYMINGTON. Well, I want to thank you for a fine statement, Dr. Solomon. Obviously TRW has made a remarkable recovery, and had faith in its own people and in its own system to prevail in what must have been an historic meeting to get the go-ahead. I think all of us are glad to know there is a good chance of the three experiments being successful. I suppose we would have been somewhat disappointed if we had to go only with one.

The big question now is, can we go with the three?

Dr. SOLOMON. We can.

Mr. SYMINGTON. We are very anxious to see that that happens, and I want to compliment you on your perseverance and your testimony today.

Are there other questions?

Mr. BROWN. I am interested in why, in view of your obvious concern with the assembly under clean-room conditions, you continued to encounter this particulate contamination. Have you identified the reasons for that?

Dr. SOLOMON. We found—I believe we have found them. We found, for example, in the gas exchange experiment there was a problem that when back flushed it was putting particles in the plumbing. We put in filters for that. That is an example of the kind of thing you find in the test program. We have cleaned it up.

Mr. BROWN. In other words, there were contaminants being produced within the operations of the system?

Dr. SOLOMON. Correct.

Mr. BROWN. OK.

Mr. SYMINGTON. Thank you, Mr. Brown. Thank you very much, Dr. Solomon, and good luck.

We will now hear from Mr. Robert Rynearson, vice president and general manager of the Aerospace Division of Honeywell.

Mr. RYNEARSON. Mr. Chairman, and members of the committee, I would like to introduce Stan Moeschl, who is chief engineer of our guidance and control activity and was from January of 1973 until very recently our program manager, and I would like him to assist me in this presentation.

Mr. SYMINGTON. We are glad to have him with us.

Mr. RYNEARSON. I have a prepared statement, which we provided, which does summarize Honeywell's activities on the Viking program. I would like to give my statement in a more extemporaneous fashion so I could deal with some of the questions and issues raised during yesterday's session and this morning.

Mr. SYMINGTON. Without objection, we will include the prepared statement in the record at this point. We may have questions on it in due course. In the meantime, you may proceed as you wish.

## STATEMENT OF ROBERT L. RYNEARSON, VICE PRESIDENT AND GENERAL MANAGER, HONEYWELL AEROSPACE DIVISION

Mr. RYNEARSON. I would like to first describe our equipment so that you may have some feel for the complexity of the system as it exists, and then I will describe our status, and then go through the major program events that have been the source of our problems.

As it has been described, our computer is called the brain of Viking lander, and I think as Mr. Adams stated, it essentially is responsible to be the pilot during the landing phase, to be the lab technician directing the science activity.

The brain cells, so to speak, of this computer are really the unique feature. Stan, would you distribute them? They are the 2-mil plated wire you have heard about. In those plastic tubes is a 16-inch length, and if you'll pull the cap off and look carefully, you can find it. The wire has been bent in the middle and that is what we call a hairpin. Each one of those wires, in effect, carries 450 bits of information, or 225 bit pairs.

We build the computer, if you notice the photograph provided (fig. 1), by having operators insert those wires in what is called a memory plane, which is what I am holding. The operators insert them in the end of the plane and each operator inserts 250 per plane. The wires are 2/1000ths of an inch thick and the tunnel is approximately 4/1000ths of an inch in diameter. An entire computer has 4,000 wires in it, which is approximately a mile of wire.

FIGURE 1

The total computer then is assembled, as shown in the first slide (fig. 2). This is the picture of the processor. The electronics are contained on those boards and it is assembled much like pages in a book, into the entire frame. The entire computer is about a cubic foot in volume, weighs about 50 pounds, and it has an integration speed of about a millionth of a second—the ability to read or write into any of those 900,000 bits. It must do that, of course, after having been baked at 240° for 7 days, which is the sterilization requirement.

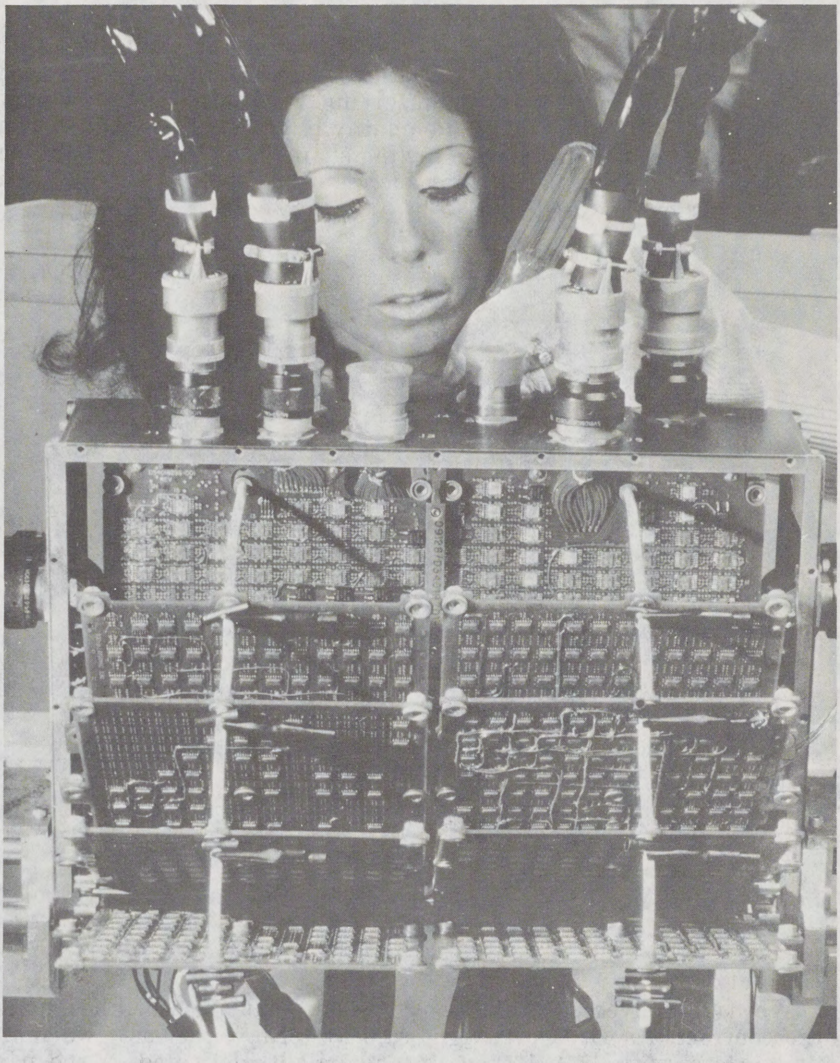


FIGURE 2

The next picture is the computer in its finished form (fig. 3).

The most appropriate way to describe our status would be to say that—it would be better to give this presentation next Thursday, which is our national day of Thanksgiving. I am sure all of the Honeywell team members have a great empathy for the feelings the pilgrims had on that first Thanksgiving, having shared the common experience of surviving a very difficult year successfully. I believe success is the word that should be used here.

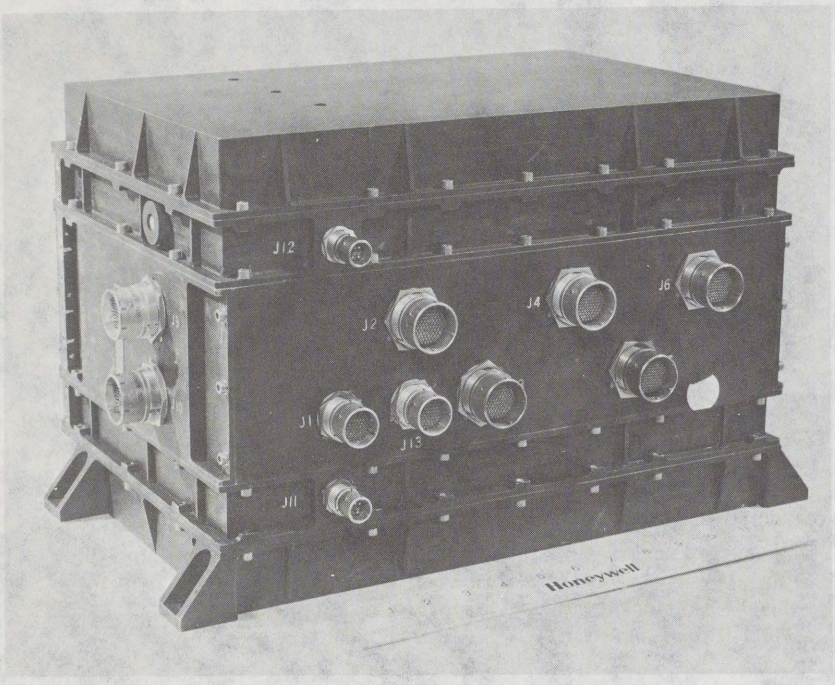



FIGURE 3

We have delivered 15 of the 17 systems that are scheduled under the contract. As Dr. Cortwright said yesterday, the last two flight units are essentially buttoned up and will be delivered in the next few weeks.

We will have one unit that will be reworked and delivered in January to complete our development and fabrication program.

We have high confidence in this equipment. I will describe the problems that we have had, but we have done an enormous amount of verification testing to insure that it will operate in its vital role.

It is difficult to describe the kind of testing, but I think perhaps this will give you some feel: Each computer memory has 86-billion electrical measurements made on it: 86-billion electrical measurements made on it, provided there is no retest or anything of that nature required. Those measurements verify that each bit will really perform when it is needed under the conditions at Mars. So it is a piece of hardware that has been thoroughly evaluated.

I'd like now to discuss our program activity, and let me first give you background to our technical base when we entered into this program.

We had completed 36 subcontracts and programs on plated wire memories and computers. The largest of these was a very large program for the Air Force on a Minuteman computer. I think that program ran some $90 million. It was a large program of hardware build and development and we also had done a fair amount of work on 2-mil plated wire. The bulk of our experience was on 5-mil plated wire, which is only five one-thousandths of an inch thick instead of two one-thousandths of an inch thick.

We had built a small memory, again for the Air Force, that was 2-mil wire.

Mr. HAMMILL. May I interrupt at this point? I seem to recall in your statement you indicated that you proposed for the Viking computer either 2- or 5-mil plated wire?

Mr. RYNEARSON. That is correct.

Mr. HAMMILL. You must know why the 2-mil wire was selected instead of the 5 mil, in spite of the much longer experience you had with the 5-mil wire?

Mr. RYNEARSON. The basic reason for selecting the plated wire over core was power saving and the 2 mil did have the advantage of even more power saving and size and weight and volume saving than the 5 mil. I don't have those numbers, but we could provide the actual differences. But it was power, weight, and volume considerations.

Mr. HAMMILL. Well, now, 5-mil wire is still very tiny?

Mr. RYNEARSON. Yes. That is correct.

Mr. HAMMILL. And so as between 2- and 5-mil wire, the weight saving would be very small?

Mr. RYNEARSON. It isn't the weight saving of the wire. It is the size of the computer itself, which arose as a function of the more power you have to use to drive the wire. Power in effect drives the weight up on the computer for the supporting electronics.

Mr. HAMMILL. In your opinion, would a 5-mil wire computer have been satisfactory for the Viking mission?

Mr. RYNEARSON. I can't address whether Viking could have accommodated the larger power requirements, but a 5-mil computer certainly could have been built with less technical risk than the 2-mil computer.

Mr. HAMMILL. Yes; particularly with respect to the handling of the wires. We understand that the 2-mil wires are very delicate and break easily, and it is very difficult to fabricate the various components that make up the computer.

Mr. RYNEARSON. The original 2-mil wire we started with was very strain sensitive. That is a problem I will discuss later, the current 2-mil wire we are now making, and used for the Viking program, is actually less strain sensitive than our original 5-mil. We achieve better yield in our 2-mil than 5-mil wire.

Mr. BROWN. Does each of the 2-mil wires have the same memory capacities, if that is what they are, as the 5-mil wire would have?

Mr. RYNEARSON. What I would call the margin of the voltage output of 5-mil wire is significantly higher than the 2-mil wire. So there was more margin in that context than the 2-mil.

Mr. BROWN. I am trying to compare this with the volume figures. Obviously, a 5-mil wire, the volume goes up as the square of the cube of the radius, I guess, so that the question that I have is whether the

2-mil wire has additional characteristics, additional capabilities, as far as storage is concerned, or 5-mil wire is equivalent to it.

Mr. RYNEARSON. Yes. The storage density on 2-mil wire is superior by a factor of approximately 2 to 1 to 5-mil wire. We store bits on 0.025 centers, approximately; in other words, every twenty-five thousandths of an inch on that wire is a different bit. On 5-mil it was typically twice that. So there is more dense storage, which again contributes to the greater weight and volume of a 5-mil computer.

Mr. WINN. More density using less power?

Mr. RYNEARSON. That is true. To give you a better feel for why we believed 2-mil was an acceptable risk, here is a curve that shows the output of the wire (fig. 4).

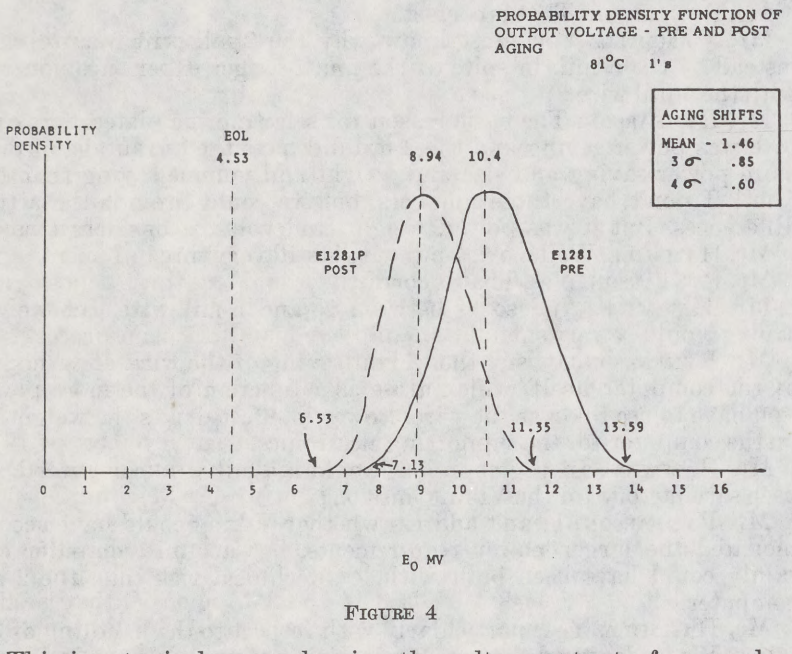



FIGURE 4

This is a typical curve showing the voltage output of a sample of 2-mil wire. The curve shows the average output of this whole sample to be 10 millivolts. We did run aging tests, to determine the effect of sterilization on the wire, and we got a shift down to about 9 millivolts.

Now, the end of life requirement that we believed we needed at that time was about 4½ milivolts, so we felt quite confident that it was practical to proceed with this new 2-mil wire.

Now, this margin was much less than we had had in 5 mil. Five mil would have been out several more milivolts, but it was still sufficient even though the margin had been reduced. It did appear to be a very adequate basis for proceeding with such a design.

Now, the problem was that the data sample was limited. When you have a limited sample of data, you have high confidence or you have good confidence on the mean. In other words, we found as we continued to produce this wire, we did achieve those averages. The shape of the curve is what you don't have much confidence in, because there is very little data supporting these tails.

Essentially, these two things happened. The end of life requirement did move up and these tails moved out a little bit. The tail only has to cross a small amount because it is not the average output that is important. It is the poorest output that is important. Every bit on that wire must meet the end of life. So we started to get some bad bits on the wire, and recognize there are, like, 450 changes on the wire to get a bad bit. If you have a 50-50 chance of getting one bad bit on a wire, you start having poor odds on being able to stuff 500 wires in a memory plane and have a good memory plane. That is the essence of the problem that developed.

Now, I'm a little ahead of myself. That is the technical base that we had at the beginning of the program.

The other thing that was difficult was the requirement for sterilization. We understood that the requirement existed. We had conducted engineering tests and understood that we had to select different materials from the materials we had used in our other computers, and memories. For example, we knew the materials had to be changed in the boards that we had developed in the Minuteman program, and other components where we had a very large data base.

We had identified other materials that could be used that would service the sterilization requirements. The primary requirement is no out-gasing under temperatures which would in turn deposit unwanted material around the spacecraft. We hadn't had a chance to really develop the new materials into our manufacturing processes to verify that those materials could really achieve the kind of yields we had in our previous manufacturing. That is really where we got in trouble in the first year of the program.

Essentially, we had a 3-year program starting in November of 1971. It was a rational program but it was a tight program. I am simplifying it a little bit. We had a year to design, about a year for verification, and a year for fabrication or manufacture.

We determined in building our first engineering models that we did have some basic process problems. There were two major problems. The tunnels that store the wires are an epoxy-type board that is built up. We did have to change the material because of sterilization. The new material required higher bonding pressures. We construct these tunnels by laying a tooling wire in the epoxy, bonding the board, and then pulling out the tooling wire, leaving the tunnel.

We found with the new material and the higher pressures that we had to use that we would occasionally, in fact all too often, get a stuck tooling wire. We couldn't pull it out. It would actually be bonded into the tunnel. This required us to stop and redevelop a new process of building tunnels, which we did successfully, but it did take time and it did take money.

We had a similar problem in the keepers, which are the magnetic paths that are deposited into that board for interrogation of the memory elements.

Again, we had changed materials for two reasons: sterilization and the desire to compress the size. Sterilization requirement on the wire lowered its output, and we wanted to get the paths as close as possible to the wires to compensate.

We found that the new material was strain sensitive in the sense that if you flex the board you would get magnetic hot spots. This, of course, created large noise signals in the computer. We stopped and developed a new material for the magnetic paths, and we did solve the problem and move on.

But the net effect of these problems was that engineering verification was delayed approximately a year.

This delay meant several things to us and really was the cost problem that we dealt with.

It meant, No. 1, that to support the Viking program, we now had to conduct engineering verification of the design on a parallel basis with the hardware build. This was compounded by the problem that to support the Viking program, our engineeering models had to be used to support the systems test at Martin, Denver. This action minimized the time we had to use that hardware to debug our design to find latent problems in the system.

This was a recognized risk, but it was a tradeoff, that had to be made, and we did proceed on that basis. The obvious risk was that any problem that existed caused not merely a change of the design, but caused rework of the other hardware in process.

We did have two major problems during the time period from about September of last year through the next 6 to 8 months.

As we went into the fabrication of our proof test capsule model, and our first engineering model, we had the plated wire problem that I mentioned earlier. Even though we had had enough output margin on average, we simply were not achieving the yields that we needed. We run billions of electrical measurements on each memory system which is a significant cost. If you have to send it back to rework, one has to repeat that set of tests. It does demand a very high yield at system memory tests.

We did have another type wire, which is called a coupled film wire. This wire was developed on our independent I.R. & P. programs, separately from Viking. It had not been proposed originally, because it was not mature enough at the time of our original proposal.

With the delay, we had started to apply it to some of our other programs. It particularly was attractive because it was much less strain sensitive than the original 2-mil wire, and it also had higher voltage output. It gave us more margin. The decision was made in January 1974 to convert to the coupled film wire, and that was a very successful change.

In just a few months we manufactured all of that wire and put that problem completely to bed.

We did have other problems in the building and testing of the fight hardware.

One in particular was electronic noise in the computer. The requirement to achieve high-density, small volume in the Viking program meant that we had to compact the electronics as much as possible. It is typical in that type of hardware to obtain some unwanted coupling between circuits which causes a problem. The purpose of engineering models is to work through those kinds of problems and clean the design up prior to building the flight hardware.

It is really not practical to try to completely solve all problems in the first paper design.

We did have a problem called sense amplifier misfire. It was noise coupling in the circuitry. We did have to stop and effect solutions to those problems, not just on the engineering qualification models, but in the flight hardware as well. This rework did contribute significantly to the cost growth we have had in the past year.

You have asked a question about the change in our staffing level at the conversion point. It was in this time period that we were building up program activity. I have a chart (fig. 5) which I think shows that change. Mr. Adams commented on the change in activity at our organization.

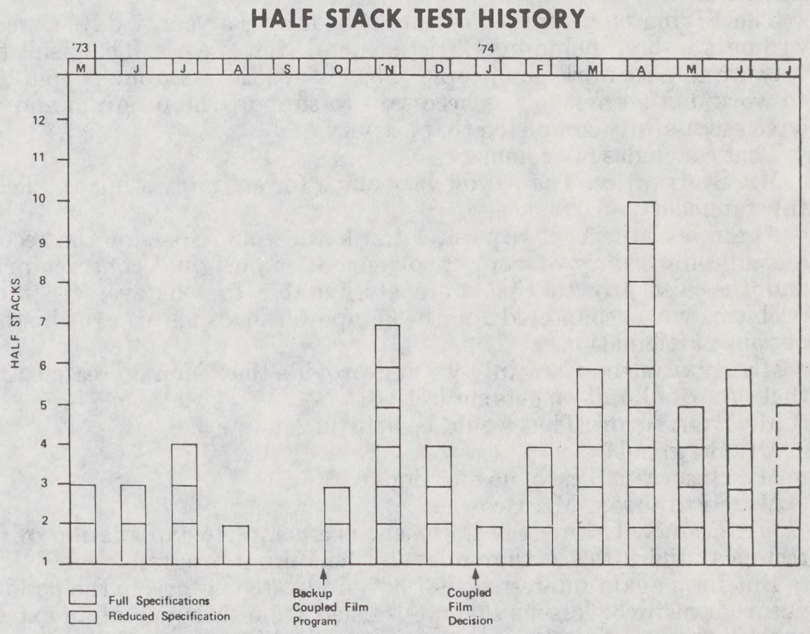



FIGURE 5

This chart shows our halfstack memory test history. We tested each model. If you will note in the time period of September–August, there was very little hardware that was in that halfstack test level. Of course, there was production of subassemblies, but notice the buildup in November and December and even more in the first quarter of the following year.

The point is that in the September time period, we essentially had only production and engineering people. But we built up in November–December time period very rapidly to staff the test teams that functioned around the clock. That is three sets of test teams, 7 days a week, to run the tests on those half-stacks, and other subsystem and system tests.

You will also note that many of the first stacks were run at less than spec. Those are the single-film wire stacks and that was done to conserve cost. The purpose of the engineering models really didn't require the end of life performance of a flight model so compromises were made to conserve costs in that phase of the program.

Obviously, the flight hardware had to be to the full specification level.

In summary, then, the major problem that really compounded our program was our lack of sufficient technical data on the total impact of sterilization on our memory design.

We had a strong data base. We really felt confident we could build and produce this type of device in very short order. It did cause us major process types of problems.

These problems required us to collapse 2 years into one and to conduct the program to maximize schedule and to buy time in any fashion we could.

The Viking team worked essentially for over a year, 7 days a week, 24 hours a day, including Christmas and New Year's. That isn't the way we like to work our people. That is not the way our people like to work, but we felt it was necessary to support the program and we have successfully completed that activity.

That concludes my comments.

Mr. SYMINGTON. Thank you very much for an interesting and helpful statement.

Again, as a general request, I think we would like for the record a composite history of your involvement, the original contract price and the cost growth that were attributable to whatever technical problems you encountered and the manpower loadings over the history of your participation.

Mr. RYNEARSON. Certainly we will provide that. You do realize that that type of allocation gets subjective.

Mr. SYMINGTON. That would be helpful.

Mr. Bergland?

Mr. BERGLAND. I have no questions.

Mr. SYMINGTON. Mr. Brown?

Mr. BROWN. I think the statement is a complete explanation of the technical difficulties as they relate to the Viking program.

But I am again interested, as I have indicated before, in the possible future benefits or lessons that we learned from this type of an experience. I presume that having gone through this exercise that we won't anticipate similar problems in the event of future efforts to move ahead with an additional program in the space exploration field.

In other words, if we had a follow-on program for the Viking, this could be accomplished with far less difficulty than we have experienced here?

Mr. RYNEARSON. Given we stay with this level of technology, which certainly can do the Viking job, those problems are behind us. I think we have relearned some management lessons the hard way, that even though the data looks very good, you must have done it to really know where you are at.

Mr. BROWN. The computer field is probably the area in which the technological changes are occurring most rapidly of any field.

Do you see the technology continuing to change at this same pace, and again, this is not particularly related to the Viking program, can we anticipate new generations of technical developments which would make a major change in the kind of hardware you are producing in this area?

Mr. RYNEARSON. You are correct, the technology certainly is moving rapidly, primarily in the area of having more computation capability per cubic foot. I think the answer to your question varies with characteristics; by that I mean, the savings you would achieve by improving the technology from a size, weight, power standpoint get to be small savings now because our quiescent level of operating the computer is something like 5 watts. I believe one might make some savings that percentagewise would be significant, but you can't save more than 5 watts. I think you're reaching a point in some areas of diminishing returns.

Mr. BROWN. Is there any spinoff from the kind of development that you have done for the Viking that fits into our concept of technology transfer that might be useful in nonspace applications, or is this something that basically has had to be tailored just for the space program?

Mr. RYNEARSON. The 2-mil wire does have, and we are now producing this coupled film wire for other DOD applications. Its characteristic of low power and nuclear hardness, radiation hardness, make it very attractive for that type of DOD requirement.

Mr. BROWN. Well, while your power demands are not particularly great in the computer business, we still seem to be moving to an era in which the requirement for minimum use of energy is going to be extremely great.

Is there a possibility that we have learned something here that would help us in some other energy areas?

Mr. RYNEARSON. I believe that much larger machines without the requirement for radiation hardness will utilize semiconductor memories. These also will be very low power in the future and in the commercial environment will dominate the scene.

Mr. BROWN. I have no further questions.

Mr. SYMINGTON. On page 3 of your prepared statement, you mentioned during the preliminary design review, need for design changes were identified. Was this just an in-house identification or did someone come in and say that they thought you needed to change?

Mr. RYNEARSON. It was a design review with participation of NASA and Martin Marietta.

Stan, would you like to address those changes more specifically?

Mr. MOESCHL. All the major programs have what we call a PDR which is a preliminary design review where you set in concrete the specifics of how you're going to conduct the detail design and a critical design review prior to committing production. So the preliminary design review was the first time that all the people involved in the program got a look at how Honeywell was building the computer. There were three modifications to our initial cut at the design during that review. They are listed there on page 3.

Mr. SYMINGTON. When does the computer begin to function during the mission? Does it have a job to do right away, or later on as it approaches the target?

Mr. MOESCHL. It is turned on during the cruise phase for some minor tasks to do.

The real work begins in the descent modes and once on the surface.

Mr. RYNEARSON. It is designed as a redundant computer, and it is designed so that there is no single point that can cause failure. This feature is, of course, related to the fact that during the descent phase it must work.

Mr. SYMINGTON. Describe again when the space craft moves into the threshold of a descent phase, is the computer then beginning to play a role in the descent itself?

Mr. MOESCHL. The computer actually comes on prior to the separation of the Lander from the orbiter and automatically controls the spacecraft during the undocking from the orbiter and total descent mode.

Mr. SYMINGTON. It's pretty much on its own?

Mr. RYNEARSON. It is the pilot.

Mr. SYMINGTON. You wouldn't have to give it new instructions presumably.

Mr. MOESCHL. It's preprogramed.

Mr. SYMINGTON. Having achieved a safe landing it then begins to direct the operation of the experiments?

Mr. RYNEARSON. At that time, you have time, of course, to provide updates from the Earth.

I hear Walt in the background very nervously. We are answering his kind of questions.

Mr. SYMINGTON. I am trying to think what it is that we experience in the control room here on Earth as the spacecraft nears Mars and what messages we might be inclined to send before we are assured that things are functioning?

Mr. RYNEARSON. I suggest that Walt Lowrie address that.

Mr. SYMINGTON. That suits the committee.

Mr. RYNEARSON. I suggest that Walt Lowrie address that.

Mr. SYMINGTON. Yes; indeed.

Mr. LOWRIE. I missed the last part of your question.

Mr. SYMINGTON. As the lander strikes Mars, from the point of impact, we learn about that back here——

Mr. LOWRIE. Twenty-two minutes later.

Let me spend just a minute and walk through the general flight pattern. When we are sitting on the launch pad ready to go, we have stored the flight software program into the computer. One of the last things we do is execute a prelaunch checkout and that is one instruction to the computer which then makes the lander go through self-check. It says, "Yes, I am healthy. I am ready to go to Mars." That is the first major function. Then we proceed, presuming the launch is successful, and we are on our way to Mars. There are several times during the 11-month cruise period where we will do some health checking, also with prestored programs.

Finally, when we are in orbit around Mars and getting ready to go down, we run what we call a preseparation checkout. This is very similar to what we ran in the prelaunch phase. Again we execute a command that says, "Tell me how healthy I am." At this time a few elementary decisions are made. For example, I look at the two radars, and if one happens to be bad I will lock it out. So there are a few functions that I can command. But once I do that, then I say, "Now, I am ready to go," and I execute the separation and total descent phase. From there on, the software in the computer and the computer automatically control the total sequence, including the initial landed activities like setting up the meteorological station, taking the first picture, and so on and so on. All that is preprogramed.

Mr. SYMINGTON. What tells you the spacecraft is in orbit around Mars?

Mr. LOWRIE. When you're in orbit?

Mr. SYMINGTON. Yes.

Mr. LOWRIE. The deep-space tracking stations, Goldstone and so forth. They track the Orbiter as you're coming into Mars, and based on the navigation information from that you determine how long to burn the engine on the Orbiter. That puts you in orbit around Mars. Subsequently, that same tracking station network determines the precise orbit you are in.

Mr. SYMINGTON. The Spacecraft is not taking any pictures at that point?

Mr. LOWIE. Oh, yes, you're taking pictures from the Orbiter on its approach to Mars and then in Mars orbit the first few days. We recertify the landing site. It is one of the prime functions of the Orbiter at this point in the program, to be satisfied the landing site isn't degraded from our last close-up look at it.

One last thing—the computer has stored in it, I forget the exact number of days, I think it is like 22 days of landed functions. If we never get a command up for some reason, some accident occurs, but we are still capable of relaying down through the Orbiter and getting data back, you will run 22 days of science on the surface of Mars, which is a pretty good start. You would get one biology and the GCMS, and you get certain other things in a preprogramed fashion. That is an emergency feature, of course.

Mr. SYMINGTON. If you should land in some soft soil or otherwise difficult terrain, and the lander sinks down a little bit, that arm that comes out to do the soil testing just automatically seeks the level of the surface?

Mr. LOWRIE. Yes, based on the—if you literally broke a leg or something, you could have some problems without pictures. You need pictures to reestablish a reference. One of the first things we do when we are on the surface is read the inertial platform, which was used during descent. This inertial reference, when you're sitting on Mars, tells you what angle you're at, gives us some up-date information which then the computer recycles and determines where the digger is going to go on the first pass.

Of course, we take pictures, and we proceed in the mission and then we will update and command it and get a better and better result.

Mr. SYMINGTON. Well, it sounds pretty good.

Any other questions?

Counsel would like to ask a question.

Mr. HAMMILL. The fact that the Honeywell contract with Martin was restructured and changed very substantially from fixed price to cost plus, indicates that the fixed-price-contract was inappropriate in the first instance, wouldn't you say?

Mr. RYNEARSON. I think it is a matter of opinion whether it was inappropriate to begin with. At the point of restructuring, it really was unworkable. The program had changed quite a bit from the initial stages; for example, our shipping the engineering model to Martin to allow systems to begin compounded our risk of being able to build our flight hardware, and there was no basis for being able to estimate that in a fixed price environment.

There were many factors, such as that, which made it administratively unmanageable.

Your first statement asked for an opinion, and, in my opinion, yes.

Mr. HAMMILL. I was wondering why Honeywell had agreed to such a contract. It appears when you're building a flight computer with 2-mil wire that has never been done before, that the risk would be very high, and a fixed-price contract would be inappropriate?

Mr. RYNEARSON. That was a risky decision. We did have the base of a very large Minuteman program, very successful. We had just built a plated wire memory computer with very stringent requirements.

We did have the kind of data discussed earlier and had outside evaluation. Martin Marietta hired an organization to evaluate this wire and all of the data said there was more than sufficient margin. It turned out to be a bad risk.

Mr. HAMMILL. And the original contract price was how much?

Mr. RYNEARSON. About $6 million before the scope changes on it, I think. I'm sorry—it was approximately $6½ million.

Mr. HAMMILL. And the runout cost will be?

Mr. RYNEARSON. Approximately $30 million.

Mr. HAMMILL. Right. And with regard to the scope changes, I think the chairman has asked you to indicate in more detail the history of the program, including scope changes and the cost impact of such scope changes?

Mr. RYNEARSON. Yes.

[The information follows:]

Mr. Frank Hammill
Counsel
House Committee on Science and Astronautics

SUBJECT: Response to Request for Information Regarding Honeywell's Viking Subcontract

Dear Mr. Hammill:

During our appearance before the House Committee on Science and Astronautics on 22 November 1974, the Committee requested that Honeywell provide a summary of the cost history and manpower levels for the Viking Subcontract.

Honeywell's basic Subcontract was awarded in November 1971 at a ceiling price of $6,780,000. The current program projected cost is $31,550,000. The four primary reasons for the growth in Honeywell's Viking Subcontract are:

1) Changes in scope that affect both hardware and software (documentation).
2) Sterilization related problems/changes.
3) Special studies/analysis.
4) Hardware modifications due to concurrent development and production.

The details of these individual increases in the contract cost are shown in Attachment 1.

Scope changes, which accounted for $9,520,000 were divided between hardware and software changes. The major hardware changes were due to: (a) a redesign of the memory from 20,000 to 18,000 words, (b) redesign of the processor to eliminate single point failure modes and to re-identify spare interface signal requirements, (c) fabrication of new special test equipment at the computer level, memory system level and half stack level, (d) fabrication of option computer and data storage memory units.

The major elements of software scope changes were primarily in the Quality Assurance and testing areas. In early 1973, MMC added a requirement to perform detailed failure analyses for all subassembly test failures and modified inspection/test techniques. At the time of contract conversion, the Quality Control program was redefined to include 3 shift coverage of all test stations by Quality Test Monitors, and requirements were increased for documenting test operations and hardware failures. Margin tests and $10^7$ testing were requirements added after contract award.

The sterilizatin related problems/changes, which accounted for $3,630,000, consisted of the following major elements: (a) plated and etched keeper studies, (b) frozen tooling wire investigations, and (c) memory redesign for worst case margins.

Special engineering studies/analyses, which accounted for $:510,000, were required due to problems encountered in the following areas: (a) low output from single film plated wire (later converted to coupled film plated wire), (b) investigation of plated through hole failures in printed circuit boards, (c) investigation of memory sense amplifier misfire problems.

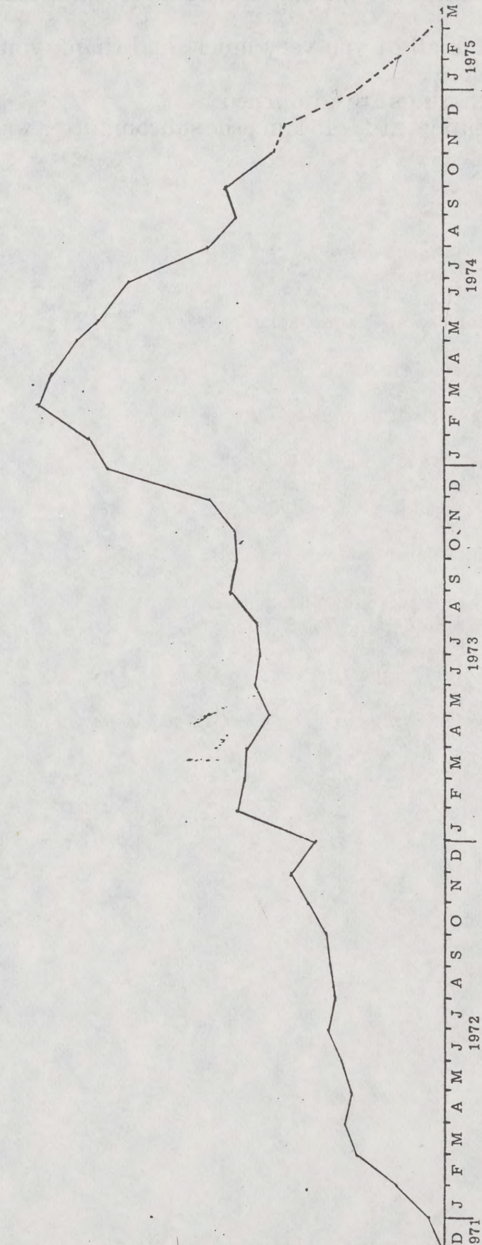
Cost associated with concurrent development in production operations accounted for $11,110,000 of the total contract cost. The major items which have required hardware modification/retrofit are: (a) conversion from single film to coupled film wire, (b) replacement of printed circuit boards, (c) memory noise problems at half stack levels, (d) sense amp misfire problems at memory system level.

Of the total program cost of $31,550,000, Honeywell has absorbed $3,500,000 leaving a final projected contract cost to the Government of $28,050,000.

Attachment 2 is a graph of the equivalent manpower expended on the Viking Subcontract from contract inception through October 1974 and projections for the total manpower requirements through February 1975.

VIKING CONTRACT COST SUMMARY

| | | (000) |
|---|---|---|
| Basic Contract (At Ceiling) | | $ 6,780 |
| Scope Changes | | |
| • Hardware | 4,230 | |
| • Software | 5,290 | |
| Sub-Total Scope Changes | | 9,520 |
| Sterilization Related Problems/Changes | | 3,630 |
| Engineering Studies/Analysis | | |
| • Coupled Film Wire | 300 | |
| • Sense Amp Misfire | 120 | |
| • Printed Circuit Boards | 90 | |
| Sub-Total Studies/Analysis | | 510 |
| Cost Associated with Concurrent Development and Production | | 11,110 |
| Total Projected Program Cost | | 31,550 |
| Honeywell Support to Program (Fixed Loss) | | 3,500 |
| Contract Cost | | $28,050 |




VIKING EQUIVALENT MANPOWER

Mr. Symington. We may have further questions directed in writing to you.

We thank all of you very much, and thank you for your very helpful testimony.

These hearings are adjourned.

[Whereupon, at 11:45 a.m., the subcommittee was adjourned.]

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