77-270

Design and Implementation of Viking Mission

B. Gentry Lee, *Jet Propulsion Laboratory*
Pasadena, California
Dr. James D. Porter, *Martin Marietta Aerospace*
Denver, Colorado

AIAA
13th ANNUAL MEETING
AND TECHNICAL DISPLAY
INCORPORATING THE FORUM
ON THE FUTURE OF
AIR TRANSPORTATION

Washington, D.C./January 10-13, 1977

THE DESIGN AND IMPLEMENTATION OF THE VIKING MISSION*

B. Gentry Lee
Jet Propulsion Laboratory
Pasadena, California

and

Dr. James D. Porter
Martin Marietta Aerospace
Denver, Colorado

Abstract

The Viking missions that were actually implemented were substantially different from those that were planned prior to arrival at the planet. These differences were not, however, unexpected because the fundamental tenet of the Viking mission operations strategy (MOS) was adaptability. In this paper, this unique "design for change" strategy is explained in detail with particular emphasis on the way that the strategy allowed the missions to respond to both scientific and engineering surprises. The total result of using such an adaptive strategy is shown in a comparison of the expected mission profiles before Mars encounter and the mission profiles that were actually flown.

I. Introduction

The evolution of the Viking mission design was an extremely exciting process. Starting with a baseline mission that was designed prior to the encounter of Viking 1 with Mars and an operational strategy (MOS) that was deliberately designed to accommodate mission design changes, the Viking mission plans evolved throughout the summer of 1976. With each major scientific or engineering surprise, the plan was altered to maximize the scientific return while maintaining prudent engineering conservatism. As a result, the Viking missions that were actually implemented were considerably different from the original designs. This paper presents a snapshot of both the *a priori* and *a posteriori* Viking mission designs together with a description of the MOS and the way in which this strategy worked to change the mission.

The paper is divided into four additional sections. The next section summarizes the mission plan that existed as Viking 1 encountered Mars. The long third section explains the Viking MOS. The fourth section describes the mission that was flown and briefly explains the rationale for the major changes. The last section is a retrospective summary of the paper.

II. The Preflight Mission Design

During the years in which the Viking missions were being planned, it became obvious that some simple product would have to be developed that would allow a general view of the mission design without burdening the observer with an inordinate amount of detail. The product that resulted was called the mission profile strategy (MPS) and its preflight representation is shown in Figure 1.

Although there is a legend on the figure that can be decoded without undue effort, experience suggests that a modicum of explanation enhances one's ability to interpret the mission profile strategy. The basic scale across the bottom is time, with the range being from just before the Mars orbit insertion (MOI) of Viking 1 on June 19, 1976, through the beginning of solar conjunction, when the Sun is between Earth and Mars, on November 15, 1976. The major activities of each of the four spacecraft are shown on separate lines, from the first orbiter (VO-1) on the top line through the second lander (VL-2) on the bottom line. All propulsive maneuvers are shown symbolically with M/C representing midcourse maneuvers and MOT signifying Mars orbit trim maneuvers to adjust the orbit about Mars. The Viking orbiters are in orbits whose periods (24.6 h) are synchronous with the rotation rate of Mars at all times after lander separation except where bars on the MPS join two maneuvers. During that part of the mission the orbiter period is asynchronous and thus the subperiapsis point (i.e., the point on Mars just under the orbiter at the time that the orbiter passes closest to Mars in its elliptical orbit) is not the same each revolution.

The lander lines on the MPS show only the biology and organic analysis experiments. These two experiments dominated the scheduling of the lander mission design and were certainly the most important to be considered in making an operational timeline. The hatched areas indicate the duration of a biological investigation of a specific sample, while the small circles represent the time of occurrence of an organic analysis.

The major features of the preflight mission design for VL-1 are clearly shown in Figure 1. After a landing on July 4 at Chryse, with coordinates 19.5°N and 34°W (the preflight plan assumed certification of *the* site that had been picked on the basis of all non-Viking Mars data accumulated prior to June 1976), there would be three different samples taken for biological analysis, the first one on SOL 8 (one SOL is one Martian day which is 24.6 h), and each analysis would last for twelve days. Each of the three ovens in the Gas Chromatograph Mass Spectrometer (GCMS) would be used twice, making a total of six organic analyses of three separate soil samples. The "nominal" lander mission, which specified that commanding every other day from the Earth would be allowed, would last for 58 SOLs. A reduced mission would follow. For the 54 SOLs of the reduced mission there would be no commanding from Earth.

*This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NAS 7-100, sponsored by NASA.

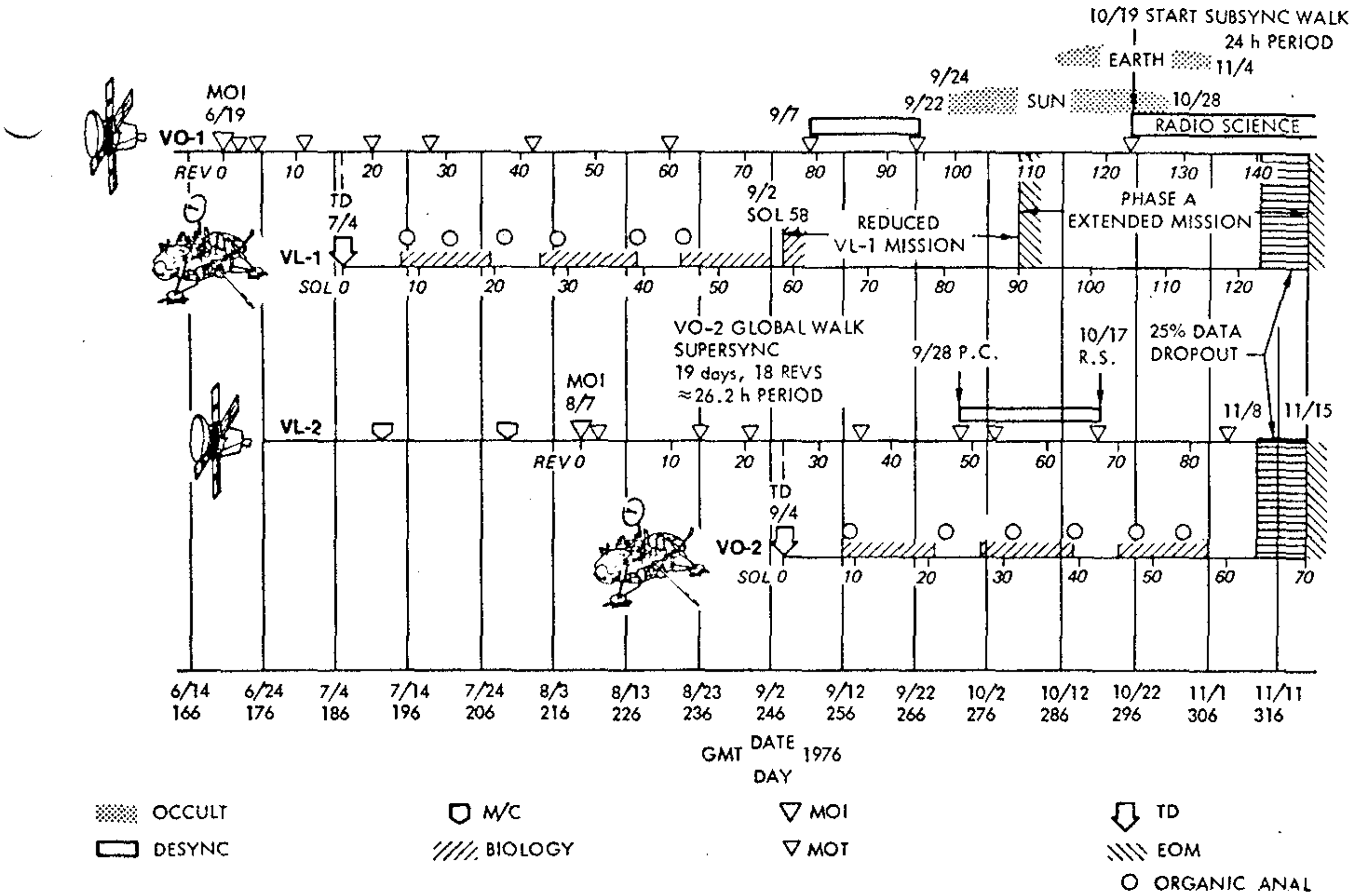

Figure 1. Preflight Mission Profile Strategy

The preflight mission design for the second Viking lander, which assumed a landing in Cydonia at 44°N, 10°W on September 4, also provided for three biological investigations of twelve days duration each and six organic analyses using each of the three ovens at two different temperatures. Its nominal or "full" mission was scheduled to last 63 days until cut short by conjunction.

The preflight mission plan for the first orbiter (VO-1) included three trim maneuvers (see MOT in Figure 1) to achieve a properly controlled synchronous orbit over the preselected landing site for VL 1, allocation for four stationkeeping trims to insure the radio relay link between the lander and the orbiter, a desynchronizing maneuver leading to a planetwide "walk" by VO-1 between September 7 and 22, and then a resynchronizing maneuver over VL-2 so that the relay data from the second lander would still be received during the important polar investigations by VO-2. For the preflight mission design, Sun and Earth occultations would begin on VO-1 in late September and last until early November.

For the second orbiter, the major feature of its preflight plan, after its three trim maneuvers to reach a good synchronous orbit over VL-2, was a scheduled plane change maneuver on September 28. On that day, just after the relay link between VO-1 and VL-2 had been established, the inclination of the VO-2 orbit would be raised to 75° and the orbit would simultaneously be adjusted to a nonsynchronous period that allowed diurnal studies of specific sites by the orbiter science instruments. From this orbit the North pole, whose polar cap would be close to its minimum dimension during the late Martian summer, could be studied in detail from low altitude for the first time in history.

It was realized, as MOI approached on June 19, that these preflight plans would not be implemented *in toto*. During the personnel testing in early 1976, a way to make operational mission design changes was being developed. This strategy for doing mission design *during* the mission is laid out in the next section.

III. Mission Operations Strategy

A. Background

From the beginning, the Viking mission operations were designed to provide for a certain measure of adaptability. During the early design and then during the personnel testing periods (which involved virtually all of the science team leaders in an operational, rather than scientific, role), there was one recurring question that was applied to the emerging strategy for conducting the Viking mission: How can the science adaptability be maximized while maintaining prudent engineering integrity in the uplink design and commanding process? A tested plan evolved that provided for what might be called "planned adaptability." The top-level blueprint describing the way the operations were conducted on Viking was called the mission operations strategy (MOS). It is important to understand the architecture of this strategy to appreciate the way in which all the Viking scientific data were gathered.

On Viking the operational strategy, including sizing the flight operations staffing and the computers, specifying the work shifts, and even defining the organizational structure, was based on a need for scientific adaptability. Simply defined, scientific adaptability, within the Viking context, means the ability to redesign later portions of the mission on the basis of the scientific data accumulated earlier in the mission. Obviously it was the determination of the detailed, quantitative answer to the question of how much could be changed how fast that led to the design of the mission operations strategy.

In a scientifically adaptive mission like Viking, it is clear that the science team leaders themselves become part of the operational activity. Unlike many earlier space missions, Viking required the processing and analyzing of scientific data as an operational component. For the experimenter to decide how to conduct the second cycle of his investigations in an adaptive manner, for example, it was necessary for him to understand the implications of data from the first cycle. By adding the key elements of scheduling and time lining to this scientific activity, major scientific decision points were defined. Thus, each of the scientific personnel working on the Viking flight team (VFT) became part of the overall effort of scheduling the complex Viking operational activity.

Figure 2 represents an abstract portrayal of the way that the MOS on Viking might have appeared to the scientist. The two major parameters of the diagram are freedom to change and time before commanding. The overall operational system was so designed that virtually any single change in the mission could be accommodated if it were defined at least 16 days before desired implementation. This 16-day period was the normal time required for the operational elements to change a sequence completely and verify the accuracy of the new sequence. From that point forward, with major focus points at the management meetings also indicated on the graph (these meetings will be explained in more detail in the next section), the mission design proceeded to evolve in ever more detail, scientific concepts giving way to time lines and sequences, and these in turn being replaced by commands in the binary language of the onboard computer. It was these commands that represented the penultimate translation of the desired scientific sequence. The process next moved inexorably through its last step, where the spacecraft translated the coded message and performed the commanded sequence.

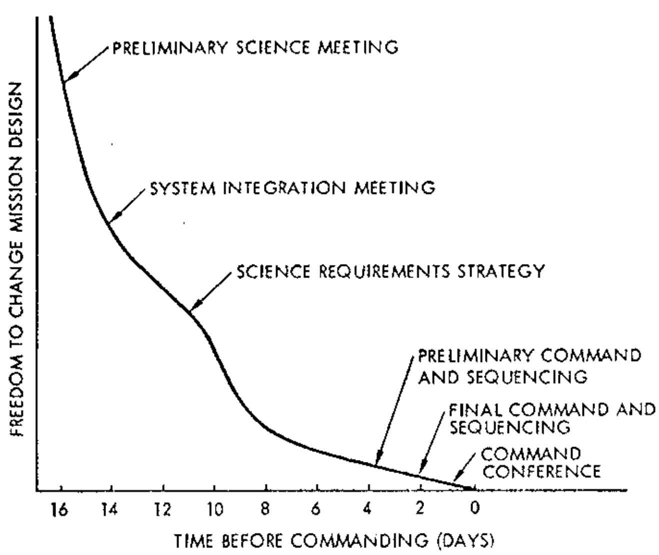

Figure 2. Time Ordinarily Required (in days) to Effect Changes in Sequence

Throughout this report focus has been centered on the Viking lander elements of the MOS. The orbiter had an analogous operational strategy, but since constant communications were maintained with the orbiter, as contrasted with the couple of hours daily available for commanding the lander, the temporal exigencies of the orbiter strategy were not nearly as severe.

One last point should be mentioned before beginning a detailed explanation of the structure of the MOS. The strategy that evolved may appear to be cumbersome, routine, and even bureaucratically rigid. However, from the beginning it was a design goal to develop a strategy whose rules and procedures would be clear enough that little effort would have to be expended in making the process run regularly. Once the strategy was thoroughly defined, it was reasoned, it would become second nature to all the participants and would allow these critical people to expend their efforts on the less routine, more creative aspect of their involvement with Viking — the understanding of the scientific data returned from Mars.

B. *Viking Flight Team Organization*

Before describing the way in which the science sequences for Viking were put together for eventual transmission to the spacecraft, it seems worthwhile to explain briefly the unique organization of the VFT, for without some concept for the overall organization, the operational strategy cannot be understood. Each instrument [for example, the biology instrument, the gas chromatograph-mass spectrometer (GCMS), the Mars atmospheric water detector] was represented on Viking by a team. This team, which was managed by one of the scientists, consisted of a blend of scientific and engineering personnel.

Each of the lander teams, for example, was composed of scientific investigators, instrument hardware engineers, instrument software engineers who designed or built (or both) the computer programs that analyzed the data from the instrument, and a senior systems engineer who understood the interfaces between the individual instrument and the lander and assisted the team leader in the operational planning. All the orbiter science teams were organized as an element called the orbiter science group. Similarly the lander science teams formed the lander science group, where they were joined by two other all-engineering teams, the lander science sequencing team, who provided uplink integration, and the lander science data management team, whose integration role covered the downlink data processing.

The two science groups, which contained all the scientists on the project, belonged to the science analysis and mission planning directorate (SAMPD) along with 30 or so persons in the mission planning group whose specialty was trajectories, celestial mechanics, and the design of the mission sequences to meet the scientific objectives. THE SAMPD was one of three operational directorates on the VFT. The other two were the mission control directorate (MCD), which integrated and scheduled the activities of the entire VFT and conducted real-time operations, and the spacecraft performance and flight path analysis directorate (SPFPAD), which was responsible for all the spacecraft hardware except lander science instruments, performed all the navigation work, and provided the detailed expertise necessary to translate scientific sequences described by SAMPD into binary commands for the spacecraft. The number of people in these three directorates was 800. The three directors reported to the Viking mission director, who in turn reported to the Viking project manager.

C. *The Uplink Process*

The uplink process really began on Viking with a concept inside the mind of one of the scientists. From something that he had seen in his data, either data from Mars or data taken during his instrument testing, a particular way of operating his instrument was suggested that required a modification to his existing instrument strategy. Could the desired sequence be accommodated? If so, when would be the best time to implement it? His ideas were carried first to the preliminary science meeting (PSSM), a meeting of all the science team leaders and key operational personnel. This meeting was held every 6 days and covered a 6-day period during the mission. Since the Viking lander was commanded every other day for science purposes, the PSSM span of interest was three lander command loads.

The PSSM was the first of a sequence of meetings that were clearly defined in the Viking procedures. Sixteen days after the PSSM, the first commands to the lander that originated from ideas discussed at the PSSM would reach the spacecraft. In between, these ideas would have undergone considerable transformation, from science concept to mission time line to detailed sequence of events to coded commands, and would have been subjected to a number of management reviews to consider the advisability of the recommended science protocols in view of the increasing information about the capability of the system to implement the sequence. As the details of the process increased, changes became more and more difficult to make. In other words, the inventory of possible changes in the science sequences continued to decrease. At the front end (the PSSM) of the process, the system could accommodate virtually any single change. By the time of the command conference just before the commands were sent to the spacecraft, only an emergency would result in an approved sequence change. During the intensive testing of the VFT between February and April, the kinds of changes that could be safely permitted at each port were carefully defined.

A synopsis of the major milestones in this uplink flow is shown in Figure 3. At each of the defined

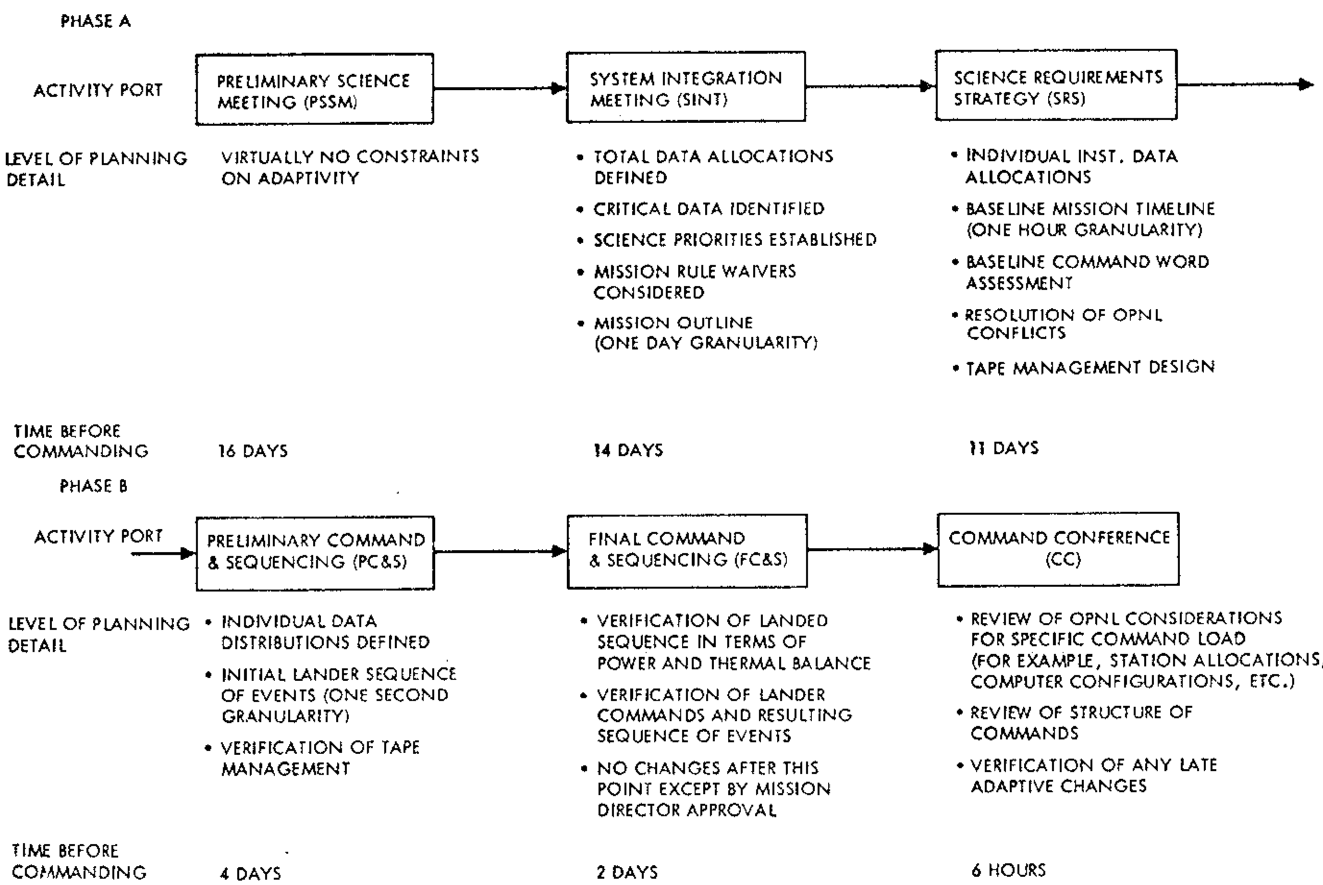

Figure 3. Viking Lander Mission Operations Strategy is Shown for Phase A and Phase B of the Sequence Development Process

"ports," a management meeting was held to review the progress of the design. In between these meetings all the detailed work was done. After the PSSM, for example, representatives of the mission planning group and the lander science sequencing team worked to define the feasibility of the suggestions made by the scientists. By the time of the system integration (SINT) meeting 2 days later (14 days before commanding), trade-off studies had been done, and possible options for the 6 days under question were presented. Since the experiments all used the same data and communication systems, the scientific desires of the different teams were often in conflict and these conflicts had to be resolved. At the SINT meeting, not only were the major science options for the 6-day cycle laid out before the project management, but also the representatives from the SPFPAD and MCD reported any conditions in the hardware or ground systems that could impact the science data acquisition for the cycle.

Three days after the SINT meeting, the Viking project management met for a science requirements strategy (SRS) meeting. It was now 11 days before the first command resulting from this cycle would be implemented. By the time of the SRS, a detailed science time line to roughly 1-hour intervals had been developed for all the spacecraft. A preliminary system assessment had also been made to determine that the command loads were within the size constraints, that there was sufficient room on the tape recorders to acquire all the data, and that there was sufficient downlink time for the data to be played to Earth. At the SRS, open items that may have required more study from the SINT were formally closed. After the SRS, there was a significant change in the nature of the uplink process. Prior to the SRS the effort was expended trying to figure out how best to meet the scientific objectives. After the SRS, the principal function of the VFT was to implement the science contained in the SRS manifest that was the formal product of the SRS meeting.

From the PSSM through the SRS, the design process treated a 6-day portion, or cycle, of the mission. After the SRS, the detailed design began, and each separate uplink to the spacecraft followed its own time line. For the Viking lander, as mentioned earlier, there were three uplinks, each spanning 2 days, in each 6-day cycle.

Between the SRS and the lander preliminary command and sequencing (PC&S) meeting, as shown in Figure 2, 7 days elapsed. It was during this period that lander personnel expert in command and sequencing took the details of the mission time line down to the 1-second level. Sequencing conflicts (for example, instrument A cannot be transferring data from its buffer while the relay link between the lander and orbiter is working) were resolved at the working level by engineers who understood the science intent in the SRS. As the sequence became developed in more detail and the investment in personnel resources increased, the science changes that could be accommodated necessarily decreased. At the time of the SINT, for example, all that was known was the total science data allocation for all the lander instruments. By the time of the SRS this had been subdivided among the instruments and could not be changed. By the time of the PC&S, even the specific data distributions, including the times of day that the data are acquired, were not allowed to change.

After the PC&S, which occurred just 4 days before commanding, the sequence was verified by the hardware engineers in many ways. Detailed computer analyses of the power and thermal characteristics of the vehicle were conducted along with a bit-by-bit simulation of the way the lander computer would respond to the developed binary commands. Between the PC&S and final command and sequencing (FC&S) ports, only those changes that did not impact power, thermal data management, or communications were permitted. Examples of such permitted "adaptive" changes were gain settings on the instruments. At the FC&S meeting just 2 days before commanding, the results of the sequence verification were reviewed. Science changes after this point could not normally be reverified by all the validation tools and were forbidden except by special consent of the Viking mission director.

The final activity in the uplink process was the command conference. Except for cases where special approval had been granted for what are called "late adaptive" science changes, the command conferences were not concerned with the science content of the commands. The focus of the command conference was usually the structure of the command segments, any potential tracking station issues, and the ground data system configuration necessary to support the commanding.

This description and the diagram in Figure 3 define the baseline uplink process that was incorporated in the Viking MOS. Its purpose was to provide a balance between flexibility and safety in the sequences transmitted to the spacecraft. There were times when events required more rapid response than the normal process allowed. These necessary deviations were accommodated on Viking primarily because of the familiarity that all the participants, both scientist and engineer, had with the structure of the underlying process.

D. The Downlink Process

The data management scheme that determined when the Viking scientific data would reach Earth was of course defined as part of the uplink process. These data were received by the Deep Space Network (DSN) tracking station in California, Spain, or Australia and transmitted to the mission operations control center at the Jet Propulsion Laboratory (JPL). There the data were processed into separate packages by a complex set of computer software that prepared the data files for each team according to procedures established when the software system was being designed.

Because the science content of the Viking data was used in operational decisions, the computer software that did at least first-order analysis of the science data resided on the operational computers at JPL. Detailed scheduling of the flight operations indicated to each of the science teams on a daily basis when their data files would be ready for their software to process. If special data were needed in a timely manner to support a quick operational decision, these data were marked as URSA (urgent response science analysis) data and hurried through the system by the flight controllers.

So that communication of science results would stimulate interdisciplinary scientific discussion, a daily project meeting was held to report on results from the experiments. This meeting was called the science data summary (SDS) and represented the major project forum by which Viking scientific results were disseminated throughout the organization. As mentioned earlier, those scientific results that led to requests for changes in instrument strategies were also discussed at the PSSM that initiates the uplink process.

E. *The Strategy at Work*

During the early testing of the MOS in February and March 1976, there were times when it did not seem possible that the strategy would ever converge and become an operational construct that could function smoothly day after day. Adverse reaction to some of those early problems might have resulted in too little adaptability. However, a concept was worked out by the engineers and scientists which ameliorated the process, and by the time of the landing the strategy was workable. During the mission, further insights into the process streamlined the strategy even more.

The most impressive credentials that the Viking MOS can proffer are the extensive changes that were made in the Viking mission design as a result of the feedback from the scientific data that were acquired. Most of these changes were made in a way that was consistent with the strategy. However, and this is an important point, because the strategy worked so effectively, time and energy were available to make changes that were scientifically important but could not be handled as part of regular operational procedure.

A perfect example of a scientifically important late adaptive change occurred after the relay link data from SOL 32 on VL-1. At that particular time, the x-ray fluorescence instrument was going through a sequence of discard operations designed to clear its cavity of the first soil sample and to prepare the instrument for the second sample. Since the first sample had been "fines" and the second sample was to be rocks that might have been constructed of different elements, it was of considerable importance that the first sample be removed so that the analysis of the rocks would not be corrupted.

The relay link from SOL 32 contained the results of x-ray analyses conducted after each of the first two discard operations. These data indicated that the Martian fines were far "stickier" than any test soils that had been used and, more importantly, an extrapolation from these data suggested that the x-ray instrument would still not be very clean at the conclusion of the four discard sequences planned prior to the acquisition of the rock sample. The x-ray team requested that the operating rules be waived to allow a late adaptive uplink that would specify two extra discard operations, bringing the total to six, before the sample acquisition. Complicating their request was the fact that the commands would have to be transmitted on SOL 33, 12 hours after the request, when there was not even a normal command load planned.

Through familiarity with the uplink activity, the x-ray team and their engineering support knew the right path to take to have the sequence altered. A few engineering specialists were detailed to construct the command files pending the possible outcome of the decision. The project management weighed the scientific rationale against the engineering risks and decided to prepare the commands. Six discards were made before the new sample was acquired.

Numerous examples similar to the x-ray extra discard request could be cited. At one point, also on VL-1, there was some slight concern that single-channel counting might be necessary to validate fully the second peak of pyrolytic release on the biology control experiment. It would have required a late adaptive command to implement this change but since the science rationale was overwhelming, the flight operations personnel were marshaled in an overtime mode to prepare the contingency sequences. The commands were not needed, it turned out, but all the work had been completed by the time the data were available to obviate the additional commands.

Although some attention has been focused on those examples where Viking's adaptability was more rapid than that normally provided for in the strategy, most of the time the MOS met the response requirements. The evolution of both the biology and GCMS instrument strategies was significantly influenced by the acquired data. The strategy changes were not only in the Viking 1 mission design but also extended to the initial lander sequences for Viking 2. Taking advantage of the early determination of the low amount of argon in the atmosphere, for example, the GCMS team designed an enrichment sequence that would highlight the less abundant gases and increase the accuracy of key isotope ratios. Virtually every investigation altered its strategy in a similar manner on the basis of early scientific results.

IV. The Actual Mission Design

As expected, the adaptability concepts imbedded in the MOS were put to regular use during the actual mission. The first big change came soon after Viking-1 was in orbit. The original landing site at 19.5°N and 34°W was declared unsuitable and a couple of weeks were spent before a new site, farther west in the Chryse basin, was selected. Figure 4 reflects the change in touchdown date to July 20 (actual touchdown coordinates were 22.4°N, 48.0°W) and the resultant shrinking of the time that VL-1 was highly active on the surface. On the ground, the fundamental precepts of the MOS were stretched to the limit. During the period just before the landing site was selected, multiple mission options and sequences were being maintained by the Viking Flight Team so that the project could ensure landing of VL-1 before the second spacecraft drew too close to MOI.

After the safe and historic landing of Viking-1, a new problem faced the mission designers. Since the project resources could not support two fully active landers simultaneously and since a decision had been made not to delay the landing of the second spacecraft, how could the 43 SOLs before the planned landing of VL-2 be used to meet almost all the objectives of the preflight mission design? One of the answers came from the performance of the relay link between the lander and the orbiter. The preflight mission design had assumed that the 16 kbits/s link between the two vehicles would be good enough for high quality data about 18 min per revolution and all the preflight protocols were

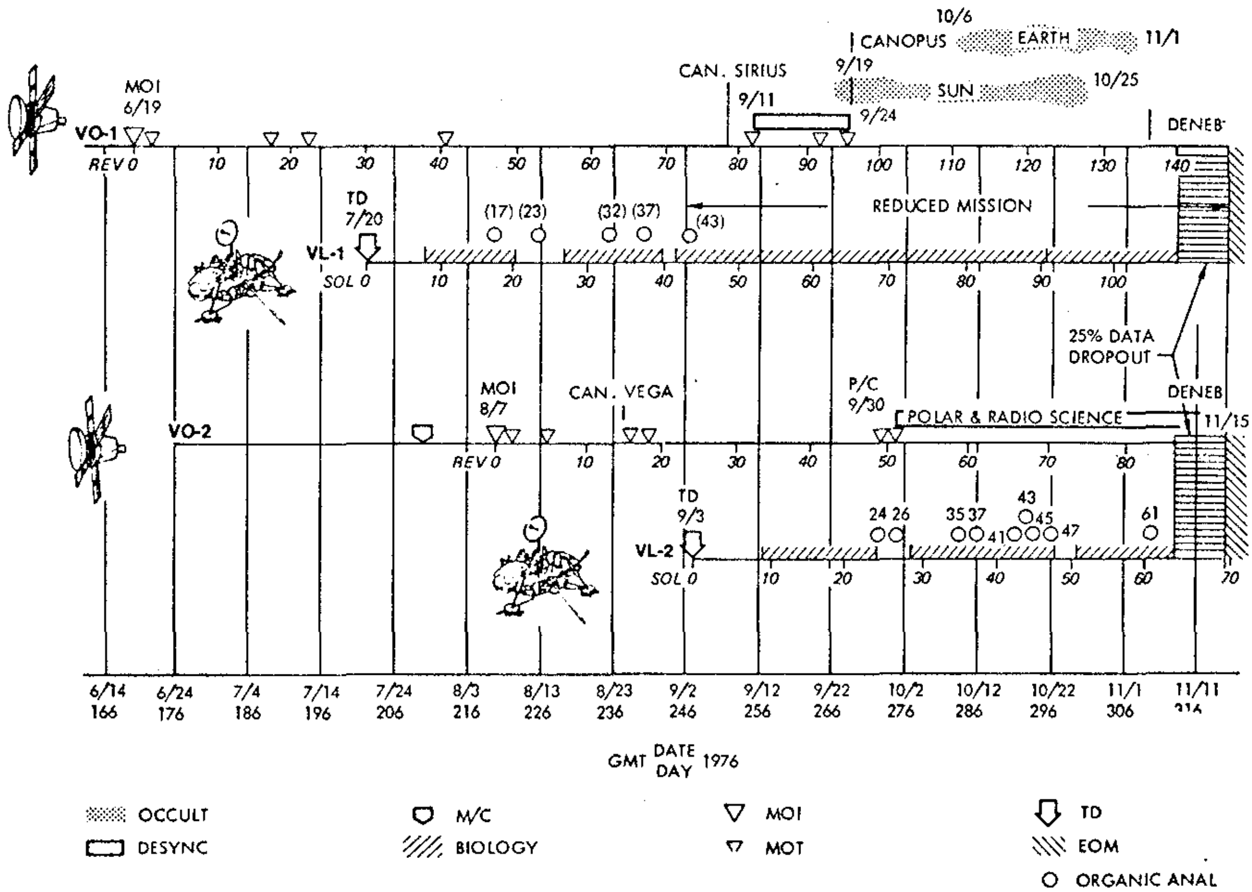

Figure 4. Viking Mission Profile Strategy "As Flown"

based upon that number. The actual relay performance was, however, between 32 and 34 min, a spectacular improvement that allowed the lander to gather and store more data each SOL.

During the personnel testing that had been conducted several months prior to encounter, one of the tests that had been designed to test both the personnel and the design of the operations strategy assumed relay performance of 30 min. The test proved that to handle "success" (that is, above average engineering performance) could be as difficult as handling failures. With the extra data allocations available, sorting through the legitimate science claims was difficult under the pressures of operational timelines. However, the experience from the testing proved invaluable. The procedures that were developed from the test allowed efficient transition to the higher data mode in the actual mission and by ten days after the relay link parameters had been computed, the new science sequences were on the lander and the extra data were being acquired. Without the extra relay performance, the dedicated people, and the smooth functioning of the MOS, there could have been no way that almost all of the original objectives for the VL-1 mission could have been met in 43 SOLs. Three biology samples, one a control, were deftly scheduled in the time period. All the lander imaging that had originally been planned in the preflight mission design was also accomplished.

The orbiter missions were also significantly different from those planned before Viking-1 encountered Mars. Since it had been difficult to select a landing site for VL-1, it was apparent that a more general "site search" would be required to find a landing site for VL-2. The latitude band (40°-50°) for VL-2 was in an area that was not as well understood from earlier data as the 20° latitude area. Both VO-1 and Viking-2, after its orbit insertion, were employed to take pictures of a vast portion of Mars before a site was selected. As a result, far more of the early orbiter science measurements were aimed at supporting site certification than had originally been planned.

In addition, the beginning of the VO-1 walk around the planet was also delayed from 9/6 to 9/11, as is shown by the details in Figure 4. Because of the uncertainty in both the time and place of the VL-2 landing (a few days after MOI there were still multiple landing options with dates in the range September 3-6), and because of the desire not to send VO-1 away from VL-1 until it was confirmed that all was copasetic with VL-2, the start of the walk was delayed.

Later, an even more significant mission design change was made that significantly enhanced the orbiter science return. After the plane change on VO-2, the orbiter was gathering fantastic science data from all its instruments about the North Pole and the surrounding zones. Meanwhile, the relay link from VL-2 to VO-1 was holding at an exceptional value greater than all predictions, so the flood of lander data had continued while VO-2 was observing diurnal variations around the North Pole.

The decision was made to continue the desynchronous or walk period on VO-2. The engineering complement on the Viking Flight Team also saluted this decision, since there was only one Inertial Reference Unit left working and it was desirable to avoid propulsive maneuvers.

The lander mission designs for Viking underwent far more changes than one shown in the diagram. The times of surface sampling were changed to respond to both science surprises and engineering anomalies, the techniques used by the meteorology team to gather their data were drastically restructured based upon their receipt of the first data from Mars, and the lander imaging sequences were reorganized several times during each mission. All of these investigations owed a debt to the basic Viking *modus operandi* of "design for change". However, it was the two top priority investigations, the biology and the GCMS instruments, that benefitted the most from the adaptability.

After the landed mission had begun and the first puzzling results had been reported by biology, an elaborate logic tree was developed by the team that showed the kinds of future experiments that would be run as a function of the results of the intermediate experiments. A change in the way in which the biology instrument would be operated was implied for all major branches in the tree. Overlaid upon this overall investigation protocol were the procedures associated with the standard MOS. If there had been no complex operational architecture to accommodate mission design changes, many of the scientific deductions that were made, based upon the biology data, would have been impossible. Durations and temperatures for biology incubations were altered several times and this forced significant changes in the planning of other investigations. Figure 4 depicts graphically the resultant activity on the biology instrument. To understand the magnitude of the change, consider that four soil samples were analyzed on VL-1, for example, one of which was acquired after the touchdown of VL-2. This return to commanding VL-1, which required extensive replanning, was managed by not commanding the second lander for a few extra days.

The actual times of the organic analyses for the gas chromatograph - mass spectrometer (GCMS) shown in Figure 4 for the Viking mission bear little resemblance to those originally planned. It would be generally agreed that the instrument on Viking that used adaptability the most was the GCMS. On each spacecraft, to begin with, cruise tests indicated that one of the three GCMS ovens had failed. So a new strategy had to be developed that used only two ovens on each of the landers. On the surface of Mars, neither GCMS instrument received its soil at its first scheduled time and thus the operational strategy for the molecular analysis team had to be revised again. By the middle of the VL-2 mission, when it became obvious that the most important single discovery that *might* yet be made on Viking would be the discovery of organic material, the resources of the entire Viking Flight Team, now adept at handling even major changes, were martialed to maximize the probability of finding organics. Although ultimately no organic material was found, it was in the search for the elusive organics, that the Viking MOS had its "finest hour". Figure 4 shows that more organic analyses were done than were anticipated in the preflight mission design. This was due primarily to the increased relay data mentioned earlier, but, due to the late start, would not have been possible without the rapid responses provided for in the operational strategy.

V. Summary

In this paper the Viking mission designs, both preflight and after the actual mission, have been presented along with a description of the strategy used to change the mission design during the flight operations. The adaptability provided for in this Viking mission operations strategy was used to enhance significantly both the quality and the quantity of scientific data returned from Mars.