References and Notes

1. G. A. Soffen and C. W. Snyder, *Science* **193**, 759 (1976).
2. H. P. Klein *et al.*, *ibid.* **194**, 99 (1976).
3. K. Biemann *et al.*, *ibid.*, p. 72.
4. P. Toulmin *et al.*, *ibid.*, p. 81.
5. The commanded locations of the GCMS sample and the biology sample were at the exact same position. It was believed that, after the first material was acquired, the trench would collapse enough for the small sample (100 mg) needed for the GCMS. In the photographs, the walls of the trench were seen to be very vertical. Very probably the sample collected was greater than 100 mg but not enough for the internal sensing system to determine a full condition.
6. R. W. Shorthill *et al.*, *Science* **194**, 91 (1976).
7. S. L. Hess *et al.*, *ibid.*, p. 78.
8. T. A. Mutch *et al.*, *ibid.*, p. 87.
9. Since most biologists have considered that the limiting substance for life on the planet is water, a great effort was made to determine the location of the most likely place for the existence of small amounts of anomalous liquid water. Because of the atmospheric pressure, there are no large bodies of water on Mars. It is now thought that water may possibly exist in the liquid form for brief periods when the pressure and temperature are just right. An alternative to this idea is that if the frozen water gets warm enough, it may become biologically available. Water exists in the polar regions as ice.
10. H. Masursky *et al.*, *Science* **194**, 62 (1976).
11. The Viking Mission is part of NASA's office of Space Science Planetary Exploration Program and is managed by the Langley Research Center. The orbiter was built by the Jet Propulsion Laboratory and its subcontractors; the lander by Martin Marietta Corporation and its subcontractors. I thank A. T. Young, J. Asnis, and P. Sakimoto for technical assistance.

2 September 1976

Mission Operations Strategy for Viking

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 have been conducted on Viking is 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 have been 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 requires 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 is 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 1 represents an abstract portrayal of the way that the MOS on Viking might appear to the scientist. The two major parameters of the diagram are freedom to change and time before commanding. The overall operational system has been so designed that virtually any single change in the mission can be accommodated if it is defined at least 16 days before desired implementation. This 16-day period is 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 proceeds 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 is these commands that represent the penultimate translation of the desired scientific sequence. The process next moves inexorably through its last step, where the spacecraft translates the coded message and performs the commanded sequence.

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

One last point should be mentioned before beginning a detailed explanation of the structure of the MOS. The strategy that has 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

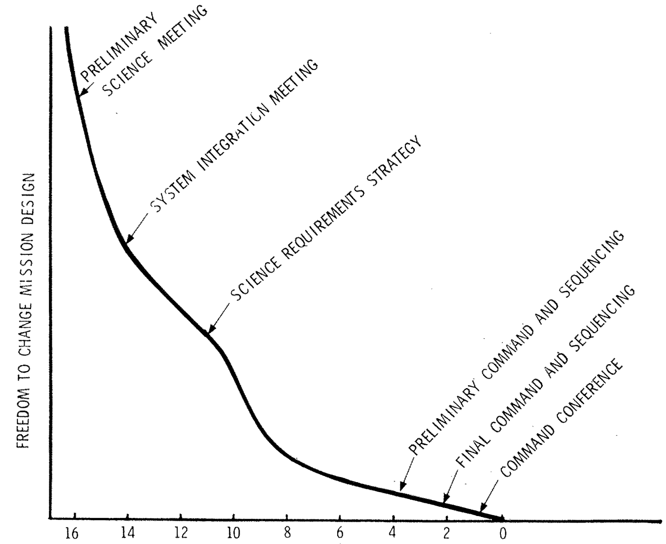

Fig. 1. Time ordinarily required (in days) to effect changes in sequence.

aspect of their involvement with Viking—the understanding of the scientific data returned from Mars.

Viking flight team organization. Before describing the way in which the science sequences for Viking are 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] is represented on Viking by a team. This team, which is managed by one of the scientists, consists of a blend of scientific and engineering personnel.

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

The two science groups, which contain all the scientists on the project, belong to the science analysis and mission planning directorate (SAMPD) along with 30 or so persons in the mission planning group whose specialty is trajectories, celestial mechanics, and the design of the mission sequences to meet the scientific objectives. The SAMPD is one of three operational directorates on the VFT. The other two are the mission control directorate (MCD), which integrates and schedules the activities of the entire VFT and conducts real-time operations, and the spacecraft performance and flight path analysis directorate (SPFPAD), which is responsible for all the spacecraft hardware except lander science instruments, performs all the navigation work, and provides 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 is 800. The three directors report to the Viking mission director, who in turn reports to the Viking project manager.

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

The PSSM is the first of a sequence of meetings that are clearly defined in the Viking procedures. Sixteen days after the PSSM, the first commands to the lander that orginated from ideas discussed at the PSSM will reach the spacecraft. In between, these ideas will have undergone considerable transformation, from science concept to mission time line to detailed sequence of events to coded commands, and will 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 increase, changes become more and more difficult to make. In other words, the inventory of possible changes in the science sequences continues to decrease. At the front end (the PSSM) of the process, the system can accommodate virtually any single change. By the time of the command conference just before the commands are 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 Fig. 2. At each of the defined "ports," a management meeting is held to review the progress of the design. In between these meetings all the detailed work is done. After the PSSM, for example, representatives of the mission planning group and the lander science sequencing team work 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 have been done, and possible options for the 6 days under question are presented. Since the experiments all use the same data and communication systems, the scientific desires of the different teams are often in conflict and these conflicts must be resolved. At the SINT meeting, not only are the major science options for the 6-day cycle laid out before the project management, but also the representatives from the SPFPAD and MCD report 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 meets for a science requirements strategy (SRS) meeting. It is now 11 days before the first command resulting from this cycle will be implemented. By the time of the SRS, a detailed science time line to roughly 1-hour intervals has been developed for all the spacecraft. A preliminary system assessment has also been made to determine that the command loads are within the size constraints, that there is sufficient room on the tape recorders to acquire all the data, and that there is 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 are formally closed. After the SRS, there is a significant change in the nature of the uplink process. Prior to the SRS the effort is expended trying to figure out how best to meet the scientific objectives. After the SRS, the principal function of the VFT is to implement the science contained in the SRS manifest that is the formal product of the SRS meeting.

From the PSSM through the SRS, the design process treats a 6-day portion, or cycle, of the mission. After the SRS, the detailed design begins, and each separate uplink to the spacecraft follows its own time line. For the Viking lander, as mentioned earlier, there are 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 Fig. 2, 7 days elapse. It is during this period that lander personnel expert in command and sequencing take 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) are resolved at the working level by engineers who understand the science intent in the SRS. As the sequence becomes developed in more detail and the investment in personnel resources increases, the science changes that can be accommodated necessarily decrease. At the time of the SINT, for example, all that is known is the total science data allocation for all the lander instruments. By the time of the SRS this has been subdivided among the instruments and cannot be changed. By the time of the PC&S, even the specific data distributions, including the times of day that the data are acquired, are not allowed to change.

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

The final activity in the uplink process is the command conference. Except for cases where special approval has been granted for what are called "late adaptive" science changes, the command conferences are not concerned with the science content of the commands. The focus of the command conference is 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 Fig. 2 define the baseline uplink process that is incorporated in the Viking MOS. Its purpose is to provide a balance between flexibility and safety in the sequences transmitted to the spacecraft. There have been times when events have required more rapid response than the normal process allows. These necessary deviations have been accommodated on Viking primarily because of the familiarity that all the participants, both scientist and engineer, have with the structure of the underlying process.

The downlink process. The data management scheme that will determine when the Viking scientific data will reach Earth is of course defined as part of the uplink process. These data are 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 are processed into separate packages by a complex set of computer software that prepares 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 is used in operational decisions, the computer software that does at least first-order analysis of the science data resides on the operational computers at JPL. Detailed scheduling of the flight operations indicates to each of the science teams on a daily basis when their data files will be ready for their software to process. If special data are needed in a timely manner to support a quick operational decision, these data are marked as URSA (urgent response science analysis) data and hurried through the system by the flight controllers.

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

The strategy at work. During the early

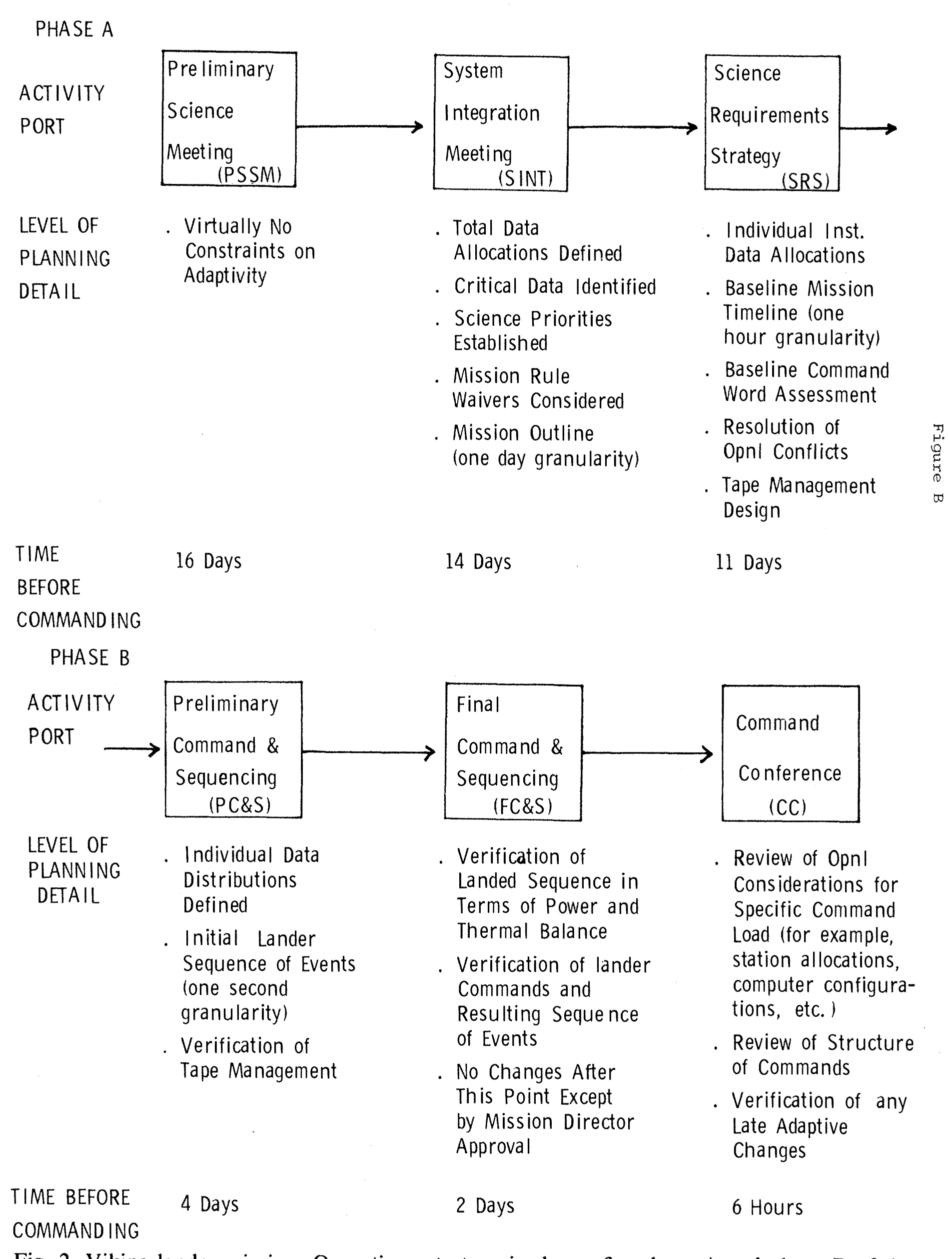

Fig. 2. Viking lander mission. Operations strategy is shown for phase A and phase B of the sequence development process.

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. Since that time, further insights into the process have streamlined the strategy even more.

The most impressive credentials that the Viking MOS can proffer are the extensive changes that have been made in the Viking mission design as a result of the feedback from the scientific data that have been acquired. Most of these changes have been made in a way that is consistent with the strategy. However, and this is an important point, because the strategy has been working so effectively, time and energy have been available to make changes that are scientifically important but cannot 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. 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 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 has met the response requirements. The evolution of both the biology and GCMS instrument strategies has been significantly influenced by the acquired data. The strategy changes are not only in the Viking 1 mission design but also extend 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 has altered its strategy in a similar manner on the basis of early scientific results.

The Viking MOS was designed to be adaptive so that the totality of the Viking scientific contribution would not be limited by those ideas about Mars that were prevalent before beginning the in situ investigations. The exciting and surprising results from Mars, plus the resultant alteration of the experiments to expand upon these results, has proved not only that the MOS design was sound, but also that the time and effort spent in constructing and testing the adaptive operational architecture were justified.

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Notes

1. The strategy outlined in this paper was developed over a long period and many people made major contributions to it. Among those whose efforts warrant mention by name are O. L. Butler, C. G. Cooley, N. G. Freeman, R. T. Gamber, M. M. Grogan, S. Z. Gunter, J. P. Hardy, H. M. Holt, J. K. Kerekes, D. W. Marquet, J. F. Newcomb, J. D. Porter, D. G. Roos, P. S. Stafford, and H. N. Zeiner. Special thanks go both to the Viking project management, who understood from the beginning that scientific adaptability was the sine qua non of the flight operations, and to the Viking scientists, who saw that the strategy was being developed for them and participated actively in the somewhat painful stages of the design.

2 September 1976

Search for the Viking 2 Landing Site

Abstract. *The search for the landing site of Viking 2 was more extensive than the search for the Viking 1 site. Seven times as much area (4.5 million square kilometers) was examined as for Viking 1. Cydonia (B1) and Capri (C1) sites were examined with the Viking 1 orbiter. The B latitude band (40° to 50°N) was selected before the final midcourse maneuver of Viking 2 because of its high scientific interest (that is, high atmospheric water content, surface temperature, possible near-surface permafrost, and a different geological domain). The Viking 1 orbiter continued photographing the Cydonia (B1) site to search for an area large and smooth enough on which to land (three-sigma ellipse; 100 by 260 kilometers); such an area was not found. The second spacecraft photographed and made infrared measurements in large areas in Arcadia (B2) and Utopia Planitia (B3). Both areas are highly textured, mottled cratered plains with abundant impact craters like Cydonia (B1), but smaller sectors in each area are partially mantled by wind-formed deposits. The thermal inertia, from which the grain size of surface material can be computed, and atmospheric water content were determined from the infrared observations. A region in Utopia Planitia, west of the crater Mie, was selected: the landing took place successfully on 3 September 1976 at 3:58:20 p.m. Pacific Daylight Time, earth received time.*

An earlier report (*1*) described the successful search for the Viking 1 landing site. Even before the successful landing of Viking 1, the Viking 1 orbiter was used to obtain pictures of the Cydonia (B1) and Capri (C1) candidate landing sites, located at 44°N and 5°S (Fig. 1). Typical pictures of the B1 area are