NASA SP-4901

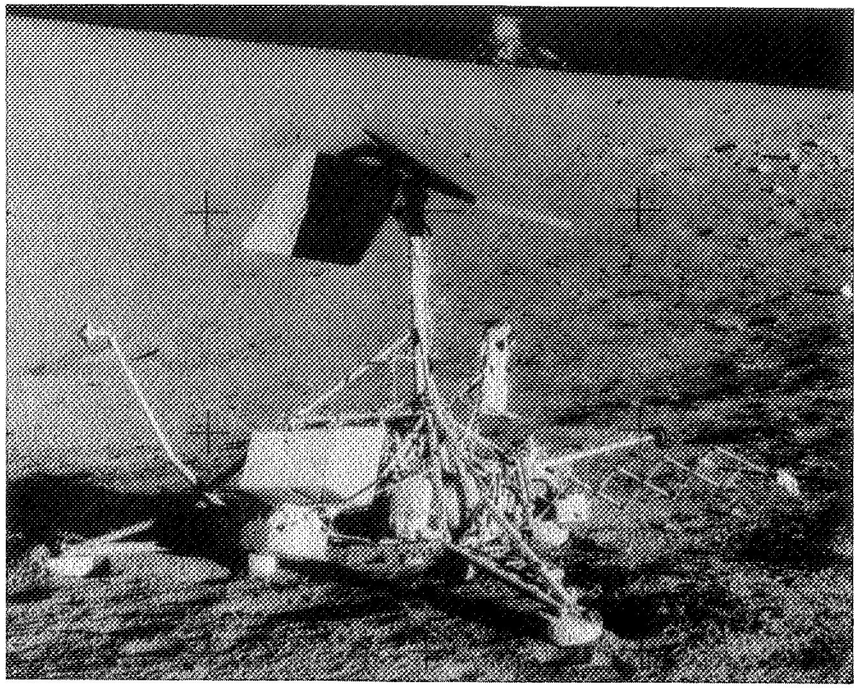
UNMANNED SPACE PROJECT MANAGEMENT

Surveyor and *Lunar Orbiter*

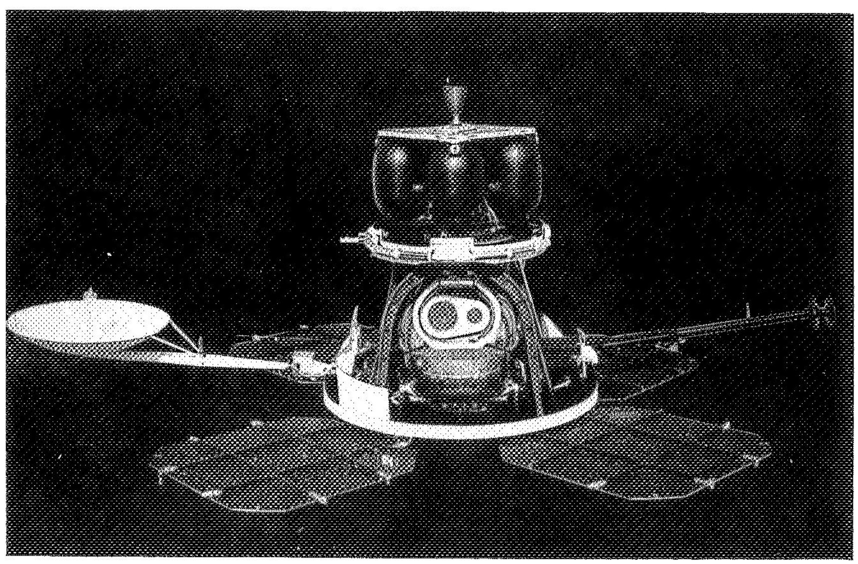
KLOMAN

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Unmanned Space Project Management



Surveyor



Lunar Orbiter

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Surveyor and *Lunar Orbiter*

By ERASMUS H. KLOMAN

National Academy of Public Administration

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FOREWORD

THE space program is, by nature, an activity that encompasses a number of discrete projects, each aimed toward achieving specific objectives within a finite period. Like many other advanced-technology enterprises, NASA has relied heavily on the techniques of organizing manpower and physical resources into project structures to achieve goals involving specified cost, schedule, and performance requirements.

In one sense, there is little new or unique about project management. Much that has been achieved in human progress has come by dedicating and organizing human energies and physical resources to meet specific goals. Modern industrialized society has become dependent on this type of management to a higher degree than ever before. Not only in the areas of hard sciences but also in the fields of social, economic, and political affairs, there is an increasing tendency to tackle problems through a project approach.

Despite the long history of project management, we still know relatively little about what might be called its human aspects—what kinds of people fit into a project organization, what effect project assignments have on professional development, how institutions and their employees are affected by the discontinuities that are a necessary concomitant of project management. We still have much to learn about how to make the most of the potential offered by project management while minimizing the side effects.

The following analysis seeks to draw some lessons from the experience gained in two NASA projects. There are inherent drawbacks to such an approach in that the events themselves are relatively recent; the perspective is therefore quite close, and dispassionate judgments are difficult to reach without the softening of time. There are, on the other hand, values to such an examination while memories are still fresh and source materials readily available. Inevitably, there are disagreements with the final results; in the evolution of programs and institutions, this can be healthy. The cause of learning is not best served by reporting only on successes; important contributions come from experience with difficulties and problems. Although there are obvious limits on the extent to which valid generalizations can be drawn from only two sets of experiences, this study represents a useful addition to a limited literature.

For readers familiar with aerospace programs, the study may provide a new look at familiar ground. For those from other fields, it may offer a bridge by which management experience from two aerospace projects can pass to their areas of specialization.

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Space Administration

ACKNOWLEDGMENTS

THIS analysis represents the distillation of extensive investigation of the management of two major NASA projects, Surveyor and Lunar Orbiter. In its present form, the report reflects the comments and criticism of many NASA officials who had responsibility for various aspects of these projects as well as the observations of many persons outside NASA who are knowledgeable about these two projects and the general field of project management. The number of people interviewed and consulted is far too great to permit individual acknowledgment. Seldom do so many contribute so much to a manuscript of such slender proportions.

The author owes special debts to James E. Webb, the Administrator of NASA when Surveyor and Lunar Orbiter projects were being conducted, whose perceptions of management and administration were an especially invaluable resource; to Dr. Homer E. Newell, Associate Administrator of NASA, who headed the Office of Space Science and Applications which was responsible for the projects; to David Williamson, Jr., Assistant Associate Administrator, whose thorough critiques served to illuminate and refine the manuscript throughout; to Benjamin Milwitzky, the former NASA program manager of Surveyor who devoted many hours to reconstructing the details concerning Surveyor; and to Captain Lee R. Scherer, the former Lunar Orbiter program manager. The Langley Research Center and the Jet Propulsion Laboratory facilitated the author's interviews at each of those locations as did the two prime contractor companies, The Boeing Co. and Hughes Aircraft Co. Colleagues on the staff of the National Academy of Public Administration who were particularly helpful in reviewing the many metamorphoses of this document include the Executive Director, George A. Graham; the Associate Executive Director, Roy W. Crawley; and two Senior Research Associates, Richard L. Chapman and Neil Hollander.

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I

INTRODUCTION

> The venture into space is meaningless unless it coincides with a certain interior expansion, an ever growing universe within, to correspond with the far flight of the galaxies our telescopes follow from without.
>
> Loren Eiseley
> *Unexpected Universe,* 1969

ONE of the valuable byproducts of the U.S. space program is the body of knowledge concerning management of large complex development project activities. The brief span of years since the formation of NASA has witnessed the rapid evolution of a variety of systems and techniques for directing the combined efforts of thousands of individuals cooperating in closeknit programs in which Government, university, and private industry play mutually reinforcing roles. Many of the major learning experiences, such as those in the Apollo management system, have been applied to other activities within NASA. There has been only limited effort, however, to distill the generalized management experience gained in other NASA projects for application outside the space agency itself.

In recognition of the need for continuous improvement and refinement of management techniques, NASA commissioned the National Academy of Public Administration to conduct a study of the management of the Surveyor and Lunar Orbiter projects, two of the major NASA precursors of the Apollo program. The study was designed to provide an analytical record supplementing the relatively limited case literature on the practical aspects of such management activity. An objective record of the significant milestones in the management of these two endeavors, it was felt, would help to inform both managers currently engaged in such activity and those who will assume such responsibilities in the future.

Much of what follows will appear as a statement of the rather obvious virtues of common sense. The history of Surveyor and Lunar

Orbiter, like most such studies, serves primarily as a confirmation of old truths about the so-called basic principles of management rather than a revelation of new ones. But the history brings out rather sharply that the application of basic principles may not always be a straightforward matter. It illustrates that what may be one man's basic principle may be another's shibboleth. Old truths are not always easily recognized or acknowledged. The aim of this study was, as Harold Orlans has written concerning the function of applied social research, "not to discover the truth (which historians will continue to debate for centuries), but rather to change the distribution of knowledge and opinion, informing a wider circle of what a few people already know and believe." [1]

In recapitulating the events of these two lunar exploration endeavors and trying to extrapolate from them the main object lessons, we should not make the mistake of dismissing the obvious as irrelevant. Even among the skilled and highly motivated professionals working toward common goals, as in the case of both Surveyor and Lunar Orbiter, the evidence suggests that no manager can definitely rely on his counterparts or colleagues to do the obvious. What seems obvious to one person may seem anything but obvious to others.

This survey reveals that the solutions to management problems which now seem so clear cut were not so apparent when, for example, the managers responsible for Surveyor were seeking to bring that program out of serious trouble. Indeed, many of Surveyor's early troubles stemmed from the difficulties in pinpointing some basic management problems, identifying their nature and causes, and facing up to the magnitude of necessary corrective measures.

Early NASA experience with advanced technological development confirmed what was already a well-known phenomenon: the more complex and ambitious an undertaking, the more liable it is to encounter delays and overruns. To make complex high technology undertakings more manageable, they can be broken down into smaller elements. NASA, like the Department of Defense and other mission agencies, has recognized the value of setting discrete limits on projects as a means of making them more "doable" and thus improving the record of success.

One of the fundamental distinctions between Surveyor and Lunar Orbiter, from a management viewpoint, is that the former was instituted as a NASA program whereas the latter was always a project. A "program," in NASA terminology, is a related series of undertakings normally continuing for years to accomplish broad scientific or technical goals. Within a program there may be one or more "projects," which are undertakings with a scheduled beginning and end involving the design, development,

[1] Harold Orlans, "Social Science Research Policies in the United States," *Minerva,* IX, (1) (Jan. 1971), 30.

and demonstration of major advanced hardware items such as launch vehicles or space vehicles. NASA program managers located in the major Headquarters program offices exercise a staff coordinating and control function over programs. In the field, project offices are located in NASA field centers under the direction of field managers.

As the time chart indicates, Surveyor origins trace back to 1959. At that time it was conceived as a large, ambitious, and almost open-ended undertaking devoted to the pursuit of lunar science and exploration. In the fourth year after its initiation and after a great deal of deliberation among opposing elements within NASA, Surveyor was curtailed to an Apollo-supporting project. Lunar Orbiter, on the other hand, was designated from the beginning as a single project to obtain data for Apollo.

In this kind of an analysis, one is confronted immediately with the question of what constitutes success in a program or project. There is no universally accepted set of criteria for measuring the success of research and development undertakings or the performance of those who manage them. Obviously a great deal hinges on such nonquantifiable factors as the degree of technical difficulty, the relative point in technological development at which a project is undertaken, the management philosophy guiding the sponsoring agency, and the overall environment in which a project operates. Comparisons based on the ratio of final costs to initial estimates are hazardous. There are many reasons both for and against overoptimism at the various levels where estimates are made, by the contractor, the field center, the NASA program office, or senior levels of NASA management. All such factors have a bearing on the reliability of cost estimates and should be taken into consideration when using costs as a measure of performance.

In these two projects, the United States acquired means of operating in space with both machines and men. The unmanned vehicles preceded the manned vehicles. Surveyor was the first long-lived NASA vehicle to land on and reduce uncertainties about the surface of a large body of matter other than the Earth. Within a few years of the first Surveyor landing, Dr. Frank Press, one of our country's most noted geologists, was willing to assert, "We have already learned more about the Earth by going to the Moon than we have by any other experiment performed on Earth." [2]

On the basis of the technological challenge involved, Surveyor and Lunar Orbiter rank as two of the outstanding accomplishments of NASA and the U.S. aerospace industry in preparing the way for Apollo. Surveyor's task was far more difficult and complex than that of Lunar Orbiter. One of the major technological hurdles that had to be overcome in accomplishing the Surveyor objectives was the development of a new

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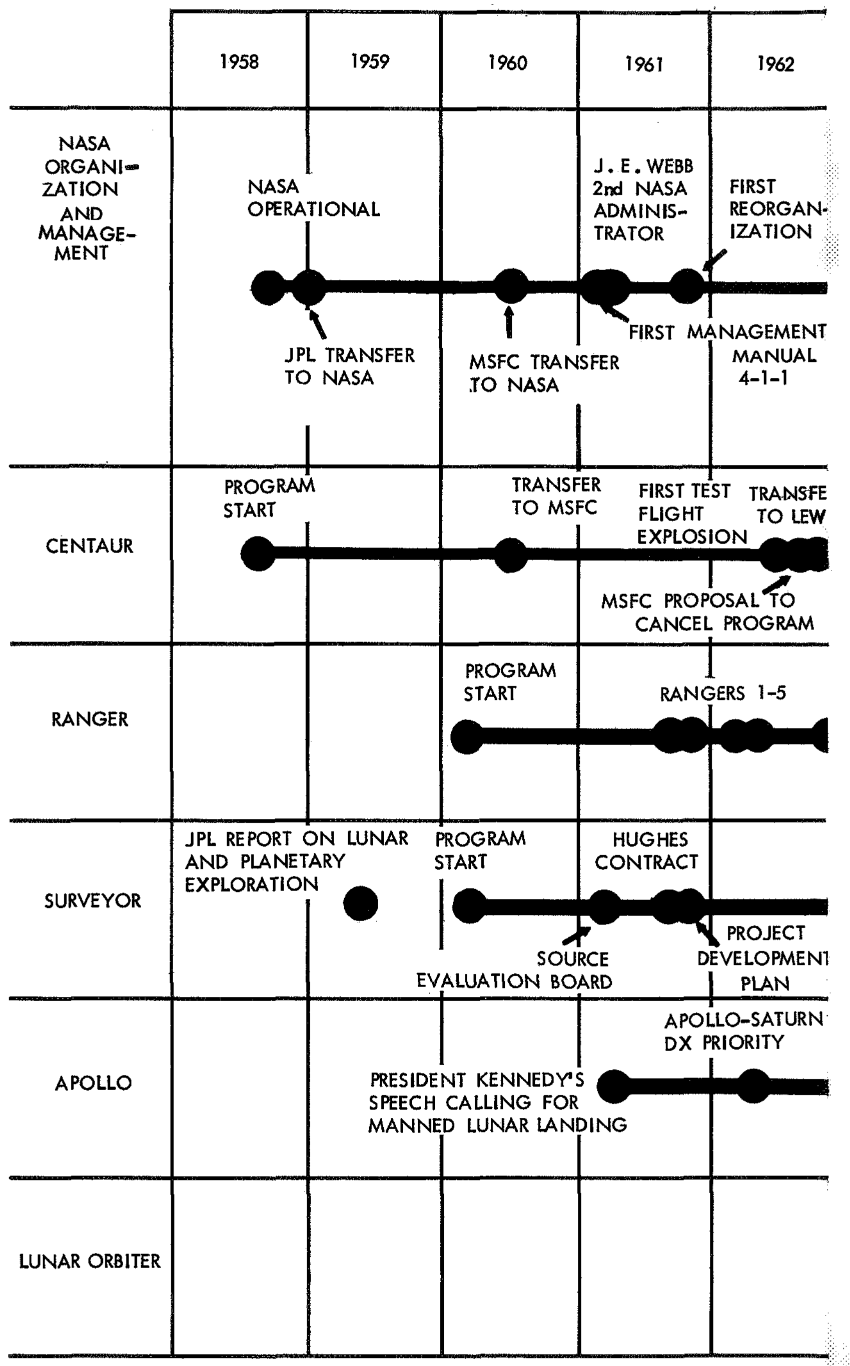
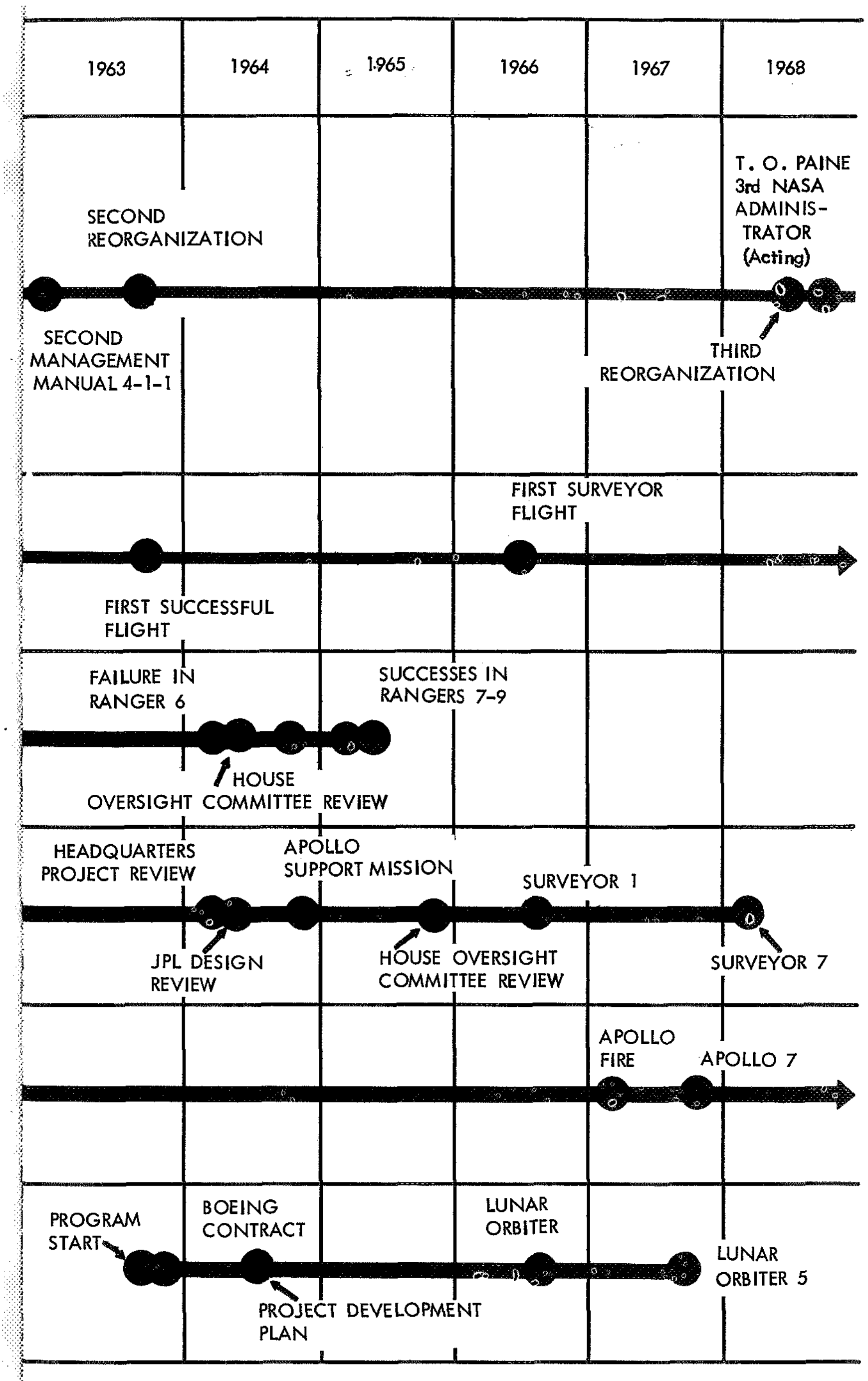
[2] Oran W. Nicks, ed., v. *This Island Earth,* NASA SP-250, 1970, p. 64.



Time chart of program events.


1963
1964
1965
1966
1967
1968
SECOND REORGANIZATION
T. O. PAINE 3rd NASA ADMINISTRATOR (Acting)
SECOND MANAGEMENT MANUAL 4-1-1
THIRD REORGANIZATION
FIRST SURVEYOR FLIGHT
FIRST SUCCESSFUL FLIGHT
FAILURE IN RANGER 6
SUCCESSES IN RANGERS 7-9
HOUSE OVERSIGHT COMMITTEE REVIEW
HEADQUARTERS PROJECT REVIEW
APOLLO SUPPORT MISSION
SURVEYOR 1
JPL DESIGN REVIEW
HOUSE OVERSIGHT COMMITTEE REVIEW
SURVEYOR 7
APOLLO FIRE
APOLLO 7
PROGRAM START
BOEING CONTRACT
LUNAR ORBITER
LUNAR ORBITER 5
PROJECT DEVELOPMENT PLAN

launch vehicle capability. The Centaur, based on a liquid-hydrogen/liquid-oxygen concept which had yet to be proven, was to be the second stage of the Surveyor launch vehicle. The eventual success of the Atlas/Centaur combination, although its many development problems adversely affected Surveyor, marked the achievement of a significant new propulsion capability serving the needs of a variety of space programs.

When this study was begun, the Apollo space spectaculars had already established new records and achievement in the organization and management of both programs and projects. But Apollo's success was dependent on technical data acquired through Surveyor and Lunar Orbiter, among other NASA precursors, and in no way diminishes their significance. Most of the technologies developed in the two projects have yet to be superseded in their respective fields. Moreover, in the area of systems management, the experience gained in these two endeavors promises to be prologue to the future management of similar endeavors.

Research for this study placed a premium on the personal opinions of individual participants. We took a cue from the view advanced by Prof. Jay Forrester, of the Sloan School of Management that "snooping around can get you 100 times as much useful information as looking through official records."[3] Most of the management personnel who directed the two projects considered in this study were readily accessible and entirely sympathetic to the objectives of this study. More than 100 of these managers participated in interviews that probed their views on the significant lessons learned. In their individual careers, these two projects represented high-water marks of challenge and accomplishment.

Reporting the learning experience gained in these projects was complicated, nevertheless, by the fact that nearly all of the participating organizations and individuals continue to be actively engaged in similar activities. Analysis of current history always confronts the analyst with the difficulty of full, candid reporting of interpretations and opinions that may still be distorted by proximity and at the same time safeguarding the subject's right to privacy. In trying to strike the correct balance, the author's aim was a constructive brand of criticism which would not impair future relationships between individuals or institutions.

Sharp contrasts marked the environments in which Surveyor and Lunar Orbiter operated. Surveyor was begun at an early stage in the national space program *before* the commitment to a manned lunar landing. Lunar Orbiter, on the other hand, had the benefit of three critical years of experience after the initiation of Surveyor, and was designed to support Apollo from the beginning. The management styles exhibited under such dissimilar circumstances had to differ. But the contrast provides an

[3] George A. W. Boehm. "Inventor. Engineer. Heretic. Jay Forrester," *Think,* 36 (2) (Mar.-Apr. v. 1970), 18.

opportunity to test certain management lessons in two differing environments.

The two projects were paired together for this analysis largely because of the many sharp contrasts in their two histories. Surveyor's success depended upon overcoming many unforeseen technical problems of serious proportions. The endeavor eventually required a time-consuming and costly upgrading of organization and management to assure mission fulfillment. Lunar Orbiter, although it was by no means without its problems, progressed for the most part according to plan. Its objectives were achieved almost by "playing it by the book."

The differences in the two endeavors make a comparison in terms of any standard of success very difficult. For example, although the Lunar Orbiter project had a better record of vehicle successes and was operated with a substantially smaller cost escalation than the Surveyor program, it is true that Surveyor met all of its reduced level goals and was technically much more complex and ambitious. Thus, a conventional comparative approach was not useful for this study. Instead of comparing organizational behavior as determinants of program effectiveness, this study examined the range of interrelationships between organizational behavior and factors emanating from outside the project. Perhaps one of the most important lessons emerging from this investigation is, in fact, that management is only one of the ingredients that determine final results. Comparisons that fail to consider other factors can be misleading.

The 12 points discussed in the following pages represent a summation of the broad learning experiences gained. Each of the many individuals engaged in the two projects carried away his own personal collection of precepts. No two individuals would be likely to agree completely on a retrospective analysis of what was most important or significant.

When an outside observer looks at the two projects together, however, he is struck by the remarkable convergence in the lessons to be learned from two distinct sets of events. The implications of what emerges from looking at two quite dissimilar types of experience tend to be mutually reinforcing and corroborative. Whereas the Surveyor lessons include many illustrations of how "not to" set out on a project or how to correct for early misdirections, Lunar Orbiter shows how sound precepts and directions from the beginning can keep a project on track. One of the keys to the success of Lunar Orbiter was the learning experience gained from Surveyor.

Considerable attention has been given in recent years to the question of how NASA's collective management experience could be most effectively applied to tackling Earth problems. Many of the institutions and people engaged in Surveyor and Lunar Orbiter and other lunar and space exploration projects have moved into nonspace activities. So far, it has generally appeared easier to transfer technology than management. NASA, as an organization, has made extensive use of the project approach to getting jobs done. But many of today's big social problems are not and cannot be wrapped up in a single project package. When a problem is selected as appropriate for a project-type effort, the success of the endeavor will hinge a great deal on the sponsoring agency's maturity and sophistication in project organization and management. NASA and the aerospace industry have developed understanding and competence in project endeavors that are not necessarily duplicated in domestic agencies.

Furthermore, there is a limit to the potential of technical and technological competence in dealing with Earth problems. A demonstration model of an urban mass transit system, for example, can be designed and built to reduce substantially the transportation problems in a given community or type of community; but the determination of what system to build and how to go about developing it must take into account a wide range of social, political, and economic issues. Hardware oriented technicians cannot resolve these issues on their own. There must be an educational process in which the "hard" scientists and the social scientists learn to communicate in each other's languages, before the former's competence can be brought to bear on nonspace domestic problems.

The following pages demonstrate the importance of human aspects of management: relationships between individuals, compatibility, teamwork, and informal communications. When aerospace managers move into nonspace or civil activities, they must establish new sets of relationships with new people. Aerospace managers are accustomed to an environment in which decisions must be forced into go or no-go channels largely on the basis of measurable physical, financial, and time considerations. It is far more difficult to come by such hard quantitative measurements in social problem-solving activities. The aerospace manager may find it difficult to adjust to terrain that does not lend itself to precise measurement. Although the kinds of basic lessons to be learned from such projects as Surveyor and Lunar Orbiter are certainly not confined to the domain of the advanced-technology enterprise, it is essentially limited to project-type endeavors. What is most needed now is a means of expanding the area of common ground between the physical and the social sciences in which the project approach can be utilized to optimum effect.

II

Chronology

Surveyor

THE Surveyor program was an effort to explore the Moon with an automated, soft-landing spacecraft equipped to respond to commands from the Earth and transmit scientific and engineering data from the lunar surface. In addition to mastering the difficult techniques of making a soft landing, the overall objectives eventually included the acquisition of basic data to support the Apollo program and the performance of operations designed to contribute new scientific information about the Moon.

NASA Headquarters assigned the Surveyor program to the Jet Propulsion Laboratory of the California Institute of Technology (Caltech) in Pasadena in the spring of 1960. JPL had then been affiliated with NASA only a little more than a year, having been transferred to the space agency from the Department of the Army. Unlike NASA field centers, JPL was brought into association with NASA by means of a NASA contract with Caltech that included what came to be called a "mutuality clause" regarding the scope of the laboratory's activities.

During its 14-year relationship with the Department of the Army, JPL had concentrated on technical undertakings that were conducted largely in-house. It had managed two Army missile projects by means of industrial contracting, but nothing on the scale of Surveyor; and Headquarters favored contracting with industry for the development of the Surveyor spacecraft system. JPL conducted a study in 1960 to establish the overall objectives, feasibility, and design constraints applicable to the Surveyor mission. Pursuant to this study, JPL initiated requests from a large segment of industry with the intent of contracting for several funded preliminary design studies. A Source Evaluation Board was established to review these studies and select a spacecraft systems contractor. The JPL board recommended the selection of Hughes Aircraft Co. of Los Angeles, and NASA Headquarters concurred in this selection after its own review.

All through the first half of the Surveyor program, JPL was deeply involved in the Ranger project to launch a series of spacecraft for hard landings on the lunar surface. Overcoming problems that led to a series of failures in that project absorbed a large share of JPL's energies and resources. Eventually NASA Headquarters became deeply involved in Ranger through review boards and other efforts to instill engineering discipline in JPL. For JPL senior management, Surveyor created a troublesome conflict of priorities. Like NASA field centers, JPL operated under rigid manpower ceilings imposed by Headquarters. Even after NASA Headquarters had directed JPL to accord a high-priority status to Surveyor, the Laboratory continued to allocate limited manpower and support to the program. The senior administration of NASA Headquarters and the principal managers of the Office of Space Science and Applications, responsible for unmanned spaceflights including Surveyor, found it extremely difficult to deal with senior representatives of Caltech and JPL, who were considered unresponsive to Washington's directions.

Particularly critical to Surveyor was the need for concurrent innovation in the development of a new launch vehicle and a new spacecraft incorporating a highly sophisticated terminal descent guidance system. NASA consciously made Surveyor totally dependent on a highly advanced, yet-to-be-developed launch vehicle, the Atlas/Centaur, whose management was transferred to the space agency from the Department of Defense. Military and space mission requirements differed, and the Surveyor spacecraft would be Earth-bound if Centaur did not meet its performance requirements. When an open-ended project, such as Surveyor, was assigned to an open-ended launch vehicle, troubles were created for both. Centaur's development was greatly complicated by performance requirements on the booster that were incompatible with each other. From the viewpoint of the space program as a whole, the gamble paid off, but it greatly complicated and hindered development of Surveyor.

For the first half of the Surveyor program, serious doubts persisted about when, if ever, the Centaur booster would be ready to fly. Estimates of the weight-lifting capability of the launch vehicle fluctuated greatly, and mostly downward, despite pressures to push the spacecraft weight upward. The design of the Surveyor spacecraft and its payload had to be constantly modified. As it turned out, most of the Centaur weight-lifting projections were too conservative, and much of the time and expense involved in spacecraft weight-reduction programs could have been avoided.

Surveyor provided a forcing mechanism for the development of Centaur as part of the space agency's long-range launch vehicle program. Centaur has since proved a highly valuable propulsion vehicle for a number of U.S. space vehicles. However, this technique for forcing innovation stretched out timetables and increased expenditures for Surveyor.

Both the Surveyor and Centaur projects encountered technical and managerial problems of sufficient magnitude to become the subject of extensive congressional hearings. Each was subject to an exceptional degree of Headquarters intervention and involvement of representatives of senior management in day-to-day management of the project.

After beginning as an ambitious long-range science-oriented program, Surveyor was curtailed in the fall of 1964 to a discrete Apollo-support project. The first Surveyor spacecraft was launched on May 30, 1966. It made the first U.S. soft landing on the Moon and sent back photographs and other data from the lunar surface. Seven Surveyor spacecraft were launched over an 18-month period. Five successfully landed and returned engineering and scientific data essential for the first manned landing.

Lunar Orbiter

The Lunar Orbiter project was an element of NASA's Lunar and Planetary Program and was focused on the requirements for Apollo from its inception. Along with the Surveyor assignment, NASA had originally requested JPL to explore the possibility of a dual-mission project in which the Surveyor soft-landing vehicle and an orbiter would both use the Atlas/Centaur launch vehicle. At that time JPL's resources were so fully committed to Ranger, Surveyor, and in-house activity that it was unable to devote a great deal of time to an orbiter. Nevertheless, the orbiter mission studies conducted by JPL contributed significantly to the development of concepts that were ultimately adopted in the Lunar Orbiter design.

Senior management at NASA Headquarters debated at length whether an agency center rather than JPL should be assigned responsibility for management of a lunar project and the development of the specialized competence entailed. Recognizing that some duplication might be necessary and desirable, Headquarters authorized Langley Research Center in Hampton, Va., to investigate the feasibility of its undertaking a possible assignment from NASA of a major flight project of the scope of Lunar Orbiter. LaRC management deliberated carefully and concluded that it would be able to handle such a mission. The Center was very receptive to the challenge of its first spaceflight project. The objective was to carry out a series of five launches of lunar-orbiting spacecraft to be propelled not by the Atlas/Centaur but by the smaller and proven Atlas/Agena launch vehicle. The major goal was to photograph potential landing sites for Apollo.

The source evaluation process for Lunar Orbiter led to selection of a design proposed by The Boeing Co. of Seattle, Wash. Although this choice was criticized because it involved a relatively complex and costly camera and spacecraft configuration, NASA Headquarters was convinced that the Boeing design was the one that would best assure fulfillment of the mission. The selection was justified in the ultimate performance of the Lunar Orbiter spacecraft.

The first of the five successful Lunar Orbiters was launched in August 1966, only two months later than the original target date. All of the photographic requirements for Apollo were essentially satisfied in the first three Lunar Orbiter missions, and missions four and five were reoriented to acquire other photography desired by the scientific community.

III

Summary

THE following summary represents the principal findings emerging from the analysis of the management of the two projects.

Environment

The environment in which a project operates is not separable from the project but an integral part of it. Ability to understand and operate under changing environmental factors is a critical element of project management. Managers at all organizations involved in a project must be highly sensitive to environmental factors and able to adapt to the fast pace of environmental change. Within their respective organizations, project managers must make correct judgments on such delicate questions as when to work through the established chain of command and when to go outside channels for specific objectives.

Role of Individuals

The choice of individuals to head programs or projects is of critical importance. Individual managers serve as the principal conduits of previous learning experience. It is difficult to specify precisely the types of qualifications that are most important in the makeup of individual managers. Differing types of management styles can work equally well in directing a project team. However, both the Surveyor and Lunar Orbiter experiences, from two very different angles, strongly underline the importance of human skills, interpersonal compatibility, and relationships based on mutual respect and confidence. Project organization places a premium on top-level leadership. But there is also a premium on reciprocation of trust both vertically and laterally throughout the organization.

Teamwork

Teamwork is a vital ingredient in the conduct of programs and projects. Lunar Orbiter benefited from a strong sense of teamwork within both the customer and contractor organizations and in their relations with each other. Surveyor was handicapped by the lack of an equivalent sense of teamwork, particularly in the early years of the program. Senior management was committed to full support of the Lunar Orbiter project and was personally involved in overall direction at both the NASA field center and in the prime contractor's organization. There was far less support and involvement in the case of Surveyor.

Definition of Roles and Missions

Although clear definition of the respective roles and missions of organizations participating in a given undertaking is conducive to smooth operation, it is not likely that such roles and missions will remain constant or static. Good project management will be responsive to the need for some latitude in modifying roles and missions and supplementing prescribed formal relationships by informal links.

Maintaining Original Objectives

The Lunar Orbiter experience bears out the positive value of commitment throughout all organizations involved in a project to fulfilling objectives within a set time and specified resource limits. Lunar Orbiter managers were dedicated to building and flying the original hardware design while restricting change to the minimum. The Surveyor and Centaur experiences, conversely, illustrate that if you do not control change, you can expect schedule delays and cost escalation.

Organization

The Surveyor and Lunar Orbiter undertakings with project-type organizations, although they were very different, both bear out the importance of the right mix of managerial and technical competence at top project management levels. Each experience confirms the importance of adequate support from the matrix organization within which the project operates. Locating project staff together in a central facility proved to be highly beneficial from the outset in the Lunar Orbiter offices at Langley Research Center and the Boeing Co. Similar benefits were derived when Surveyor project offices were collocated at the Jet Propulsion Laboratory and Hughes Aircraft Co.

Systems Capability

A strong systems management capability at the top levels of a project office is a critical element of project staffing. Those who manage a project need the kind of understanding and perspective that permits them to see the interrelationships between the various elements of a project and the impact that change in one system has on other systems.

Management Systems

Careful consideration should be given at the outset of a technical development undertaking to the adoption of workable management systems based on a well-defined work breakdown structure mutually agreed upon between the customer and the contractor. The customer should not impose systems that are beyond the ability of a contractor to follow. Care should be taken to avoid unnecessary redundancy. Although effective reliability and failure reporting systems are important, no formal communications systems will replace the dynamic system of personal and informal relations between key members of a project team.

Role of Headquarters

Relatively few NASA projects have been subject to the depth of Headquarters intervention that was felt necessary in Surveyor and Centaur to resolve problems encountered in those two related undertakings. In both cases, Headquarters decisions contributed to many of the basic difficulties that had to be overcome, and therefore only Headquarters intervention could have effected the necessary redirection of the projects. The Lunar Orbiter experience, on the other hand, demonstrated how well the NASA Headquarters-field center-contractor relationship can work under the most favorable circumstances.

Incentive Contracting

Both Surveyor and Lunar Orbiter contracting broke new ground for NASA in experimenting with contract incentives. Administration of the Surveyor contract was greatly complicated by the many changes in the scope of the project and specific missions assigned to the spacecraft. Converting the contract from a cost-plus-fixed-fee to a cost-plus-incentive-fee basis at a late date in the project, although it involved a massive conversion effort, greatly facilitated effective administration of the contract. The Lunar Orbiter contract was the first major NASA flight project contract to be awarded on an incentive basis. It gave the agency some useful insights on the merits as well as the limitations of this type of contract.

Cost Performance

Total Surveyor project costs finally came to about four times the original estimate while the Lunar Orbiter final costs were about twice the initial projection. Surveyor took two years longer to complete than originally planned, whereas Lunar Orbiter was completed within two months of schedule. The wide differences in the environments surrounding the two projects and the much more difficult technical challenge involved in Surveyor account for much of the difference in cost performance.

SCIENCE/ENGINEERING RELATIONS

NASA Headquarters allowed the Surveyor science payload to be subject to major change in composition and configuration until a late state in the project. This caused problems for the Jet Propulsion Laboratory and Hughes Aircraft Co. Scientists and engineers were intentionally kept at arms length from each other in the early stages of Surveyor. When, later, they formed closer working relationships, they had more success in finding solutions to problems in science experiment design. Lunar Orbiter, as an Apollo-support project, involved relatively little science except that which was added on the last two flights. There was therefore far less potential for trouble in the science/engineering interface.

IV

Analysis

Environment

FROM a management viewpoint, the greatest contrast between the Surveyor and Lunar Orbiter projects was the nature of the relationships of participating organizations, or what might be called the institutional environment. For Surveyor, there was an unusual degree of conflict and friction between Headquarters, JPL, and the prime contractor. For Lunar Orbiter, harmony and teamwork prevailed. Institutions and people worked together in a spirit of mutual respect.

Obviously one cannot generalize from these two experiences on whether harmony or disharmony is more conducive to innovation and the successful management of complex technical projects. What does emerge from the Surveyor and other similar undertakings is that, once engendered, mistrust lingers, coloring the relationships between organizations well after a project has been completed. The manner in which Headquarters, JPL, Hughes, Langley, and Boeing perceive each other still reflects to a considerable degree the impact of the Surveyor and Lunar Orbiter experiences.

The differences in the institutional environment of Surveyor and Lunar Orbiter trace back to the different origins of the two centers and the two prime contractors engaged. Each pair of organizers was characterized by distinctive institutional personalities which influenced relations with their outside worlds.

The Jet Propulsion Laboratory, having entered into its contractual relationship with NASA only a short time before the assignment of Surveyor, was still new to the ways of the space agency. Langley Research Center, on the other hand, was the oldest of the field centers affiliated with NASA's predecessor organization, the National Advisory Committee for Aeronautics. LaRC had been the leading U.S. center for aeronautical research since its formation only 14 years after the Wright brothers' flight. Its senior managers had established close and effective working relationships with their counterparts in nearby Washington, and NASA had given Langley a mission of basic and applied research encompassing the entire range of aerospace programs, both manned and unmanned.

JPL was a leading research and development center in rocketry and missile systems. As it moved into unmanned space exploration, JPL had the difficult task of converting its capabilities to the complex multisystem requirements for space hardware development. The conversion involved major manpower training and redirection.

JPL was accustomed to a high degree of autonomy. Its professional preeminence had bred a strongly independent attitude and a good deal of skepticism concerning more recently formed organizations, including NASA. Its management was quite understandably intent on preserving the scientific and engineering creativity and the independence of its talented staff.

Like the Army Ballistic Missile Agency (ABMA) headed by Dr. Wernher von Braun at Huntsville, Ala., JPL was oriented toward the "in-house" approach to development. JPL and ABMA (which became the Marshall Space Flight Center) enjoyed good working relationships with each other, developed largely through their association as the Army team responsible for the first U.S. satellite, *Explorer* 1, launched in 1958. The two centers had come to share a certain antipathy toward Air Force and Navy approaches to missile development which relied heavily on industrial contracting. Although the high degree of technological innovation needed in Surveyor development appealed to JPL's interest in pushing the state of the art, serving as a monitor of an industrial contract weakened JPL's enthusiasm for the program.

Relations between NASA Headquarters and JPL at the senior administration levels were strained from the beginning. In the early 1960's, Administrator Webb and his principal associates, Dr. Hugh L. Dryden and Dr. Robert C. Seamans, Jr., became deeply concerned about failures on Ranger, the JPL in-house project for a hard-landing lunar probe. A congressional inquiry into Ranger, following two high-level NASA reviews, spotlighted some basic weaknesses, including an inadequate system of preflight testing, a reflection on past technical judgments. By the spring of 1964, when NASA instituted an intensive review of Surveyor, Headquarters/JPL relations were under severe stress.

The more Headquarters increased its monitoring of JPL projects, the more JPL resented what it regarded as an intrusion on its professional independence. The Headquarters outlook toward JPL was anything but homogeneous because of the differing views at differing levels—the Administrator and his associates and the program offices, particularly the Office of Space Science and Applications and its subdivisions having special responsibility for Surveyor. Headquarters did not present a single institutional front in its relationship with the field, and it was difficult for the field to sort out what seemed quite often to be rather wide divergences. Differences between JPL and Headquarters, moreover, were accentuated as Headquarters began increasingly to concentrate interest and resources on manned flight and the Apollo program. This emphasis was not easily reconciled with the long-standing Caltech/JPL commitment to unmanned space exploration. Such environmental influences operated against good communications and teamwork on the Surveyor project.

A very different situation prevailed in the case of Lunar Orbiter. LaRC is close to Washington, and person-to-person communications between Lunar Orbiter personnel in Headquarters and the field center could be maintained with relative ease. LaRC's managers looked long and hard at the Lunar Orbiter program before they undertook it. They accepted the assignment with full commitment and a determination to make it succeed. The management placed great store in its reputation for fulfilling every mission it set out to accomplish. In reporting to the Headquarters Office of Space Science and Applications, LaRC made no effort to hold back information concerning problems that arose. OSSA reciprocated with full cooperation and support. For all of these reasons, the institutional environment surrounding Lunar Orbiter was favorable to teamwork.

Just as there were marked differences between the Jet Propulsion Laboratory and Langley Research Center, two very distinctive types of corporations served as prime contractors for the respective programs—Hughes Aircraft Co. for Surveyor and the Boeing Company for Lunar Orbiter. The overall experience of Hughes was, in many respects, more relevant to a spacecraft development project than that of Boeing. Hughes' design engineers were recognized for their highly creative talents. But the newly formed Aerospace Group, in which a skeletal Surveyor project staff was located, had limited experience in the management of a complex systems undertaking or in production techniques. For the first several years Hughes Surveyor managers found it difficult to obtain the degree of support and assistance that the project required from other Hughes divisions.

The Boeing Company's organizational approach to the Lunar Orbiter project was quite different. It had accumulated years of experience as a major contractor for production of airplanes and aeronautical equipment. It was familiar with the exacting requirements of systems development. Corporate management was highly sensitive and responsive to requirements imposed by the contractual relationship with a Federal Government agency.

When Surveyor was undertaken, the U.S. space program was still a very young enterprise. Soviet successes in space, beginning with *Sputnik*

1 in October 1957, had produced strong pressures in Washington to demonstrate American technological ability to catch up with and surpass the U.S.S.R. The Surveyor program felt the direct impact of these pressures.

It meant many different things to different people. Almost everyone involved, however, saw it as a major program stretching out over a long period and involving several blocks of spacecraft, each for increasingly complex and difficult missions. Managing the program was greatly complicated by the various mutations through which Surveyor passed as it was stripped down to a discrete project dedicated to the support of Apollo.

During the three critical years between the startup of Surveyor and the startup of Lunar Orbiter, the U.S. space program matured and settled down somewhat. NASA Headquarters/field center relationships went through two major reorganizations. The Lunar Orbiter project was the beneficiary of a tremendous effort on the part of NASA Headquarters to develop organizational forms and machinery conducive to effective management. Lunar Orbiter managers could take advantage of what had been learned from Surveyor about techniques and systems of project management. Both NASA Headquarters and the field center applied directly the lessons from Surveyor to the management of Lunar Orbiter.

As an agency, NASA has striven to overcome the temptation to filter the feedback of critical information on past performance. Openness to constructive criticism was espoused. As James E. Webb has observed on the basis of his experience as NASA Administrator, the management of today's large-scale enterprises places a premium on flexibility and adaptation. A continuous and often turbulent process of interaction between a large-scale enterprise and its environment is to be expected, and flexibility in organizational structure is necessary to ride out environmental disturbances. Effective adaptation, in turn, depends upon the effectiveness of the feedback process.[4]

Environment is not something apart from, but an integral part of, a project. An effective manager needs to be sensitive and responsive to change in the environment, particularly the kinds of change that alter existing organizational relationships or the relationship between one project and another.

Although the individual manager who moves from one project to another serves as the most efficient carrier of learning experience, NASA fosters the feedback process through manuals and guidelines reflecting past experience. Emerging from both the Surveyor and Lunar Orbiter projects were a number of documents and reports applicable to future project

[4] James E. Webb, *Space Age Management: The Large Scale Approach,* McKinsey Foundation Lecture Series, sponsored by the Graduate School of Business, Columbia Univ. (McGraw-Hill, 1969), pp. 142-146.

activity. These included NASA publications such as a report on the Surveyor failure reporting system, an article on technology transfer in the Surveyor project by the JPL project manager, and numerous reports and papers on various aspects of Lunar Orbiter.

At the conclusion of a project, contractor organizations often conduct critiques of their own performance. Although such critiques may contain a high degree of proprietary content, it would be beneficial to the feedback process if such reports, or at least modified versions of them, were made available to NASA upon completion of a project. After the conclusion of Lunar Orbiter, the prime contractor and one of the major subcontractors made such critiques available to NASA, but the Surveyor prime contractor chose not to release to NASA its own internal critical analysis.

Role of Individuals

All the principal managers in NASA's Office of Space Science and Applications with responsibility for Lunar Orbiter had also been involved in the management of Surveyor. Perhaps the most significant transfer of learning experience took place among those individuals. At the Jet Propulsion Laboratory, a number of key managers of the Space Flight Operations Facility, and the Deep Space Instrumentation Facility for Lunar Orbiter, were also able to make direct use of what had been learned from Surveyor. Langley Research Center management learned vicariously from the Surveyor experience. The Boeing Co., the prime contractor for the Lunar Orbiter spacecraft, was responsive to suggestions from the Government agency and sought to avoid repetition of mistakes.

In effecting a transfer of learning experience, there is no substitute for an individual manager as a conduit. He carries in his head what he has learned from one experience to another. The individual style and characteristics of managers selected to take on new assignments obviously have a great deal to do with how projects will be conducted. But it is difficult for those administering advanced-technology organizations to determine how managers can best be selected, trained, and rotated.

Management analysts have yet to identify the qualifications that distinguish the ideal candidate for project management assignments from other types of managers. Indeed, a recently completed National Academy of Public Administration study [5] found that extensive research and interviews provided no scientific basis for drawing conclusions on the kinds of characteristics, skills, or management styles that best lend themselves to

[5] Richard L. Chapman, with the assistance of Robert H. Pontious and Lewis B. Barnes, *Project and Program Management in NASA: The System and the Men,* National Academy of Public Administration (Washington, 1971), pp. 165-168.

the responsibilities of program or project management. There is even more reason for caution in generalizing on such an issue on the basis of findings in only two undertakings.

The Surveyor and Lunar Orbiter experience might be considered to lend support to the findings of the broader Academy study concerning the difficulty of reconciling different criteria and viewpoints in assessing the qualifications for project management. The Surveyor and Lunar Orbiter findings also support the conclusion of the broader study that individual personal qualities and management capabilities can at times be a determining influence in overall project performance. Most specifically, they conform with that study's emphasis upon "human skills" as the most important of the principal project manager skills. The human skills, which center on the ability to work with others, outranked managerial, conceptual, and technical skills.

Human skills and the ability to stimulate effective working relationships between people came much more into play in Lunar Orbiter than Surveyor. The latter, in fact, seems almost to have created an environment of its own which put relations between individuals to the severest test. The pressures and constraints upon Surveyor managers were hardly likely to foster easy cooperation and good working relationships between counterparts. Three-way friction between Headquarters, the field center, and the contractor posed a barrier to good interpersonal relationships.

The impact of the personalities of managers is evident in interrelationships with both peers and subordinates. Managers undoubtedly can adopt many different styles to stimulate others to perform. In the Surveyor and Lunar Orbiter experience, assuring that things got done seemed to depend greatly on the power to persuade and a certain ability to "wheel and deal." This was particularly true in the case of the Headquarters program managers. Because they are nominally staff rather than line officials, these managers operate with a somewhat ill-defined authority base. They do not have what NASA calls "directive control" and must confine their role to advisory and monitoring functions while somehow assuring that the program or projects for which they are responsible proceed on target. Although a field center project manager has line responsibility, his real ability to control, like the Headquarters program manager's, is heavily dependent upon his persuasive powers. Those powers need to be brought into play with great skill in the coordination of the activities of other field centers and organizations responsible for various subsystems.

The compatibility of the Headquarters program manager with the field center project managers can be critical to the success of an endeavor. In recent years many of the NASA field centers have come to recognize the importance of this relationship and take it into account in the selection of managers. Headquarters and its field centers now make a joint effort to match the personalities of the two sets of counterparts.

Both Langley Research Center and the Boeing Co. were able to assign managers to Lunar Orbiter who were experienced in prior project activity. The top project managers at Headquarters, the field center, and the prime contractor organization developed smooth-working relationships and highly effective communications with each other. It should be noted again, however, that Lunar Orbiter's discretely defined and technically feasible goals subjected the institutional interfaces of that project to far less strain than was encountered on Surveyor. The smooth-working relationships among various levels of top managers on Lunar Orbiter should probably be regarded as both contributing to and a consequence of successful technical performance. Lunar Orbiter had the advantage of second-generation developments in the three years after the start of the Surveyor program; this also contributed significantly to the high standards set by Lunar Orbiter.

Teamwork

The question of how to achieve good teamwork in project activity involves many intangibles and unquantifiable elements. The difficulty of identifying and measuring the ingredients of teamwork, however, in no way reduces the importance of the concept. Almost all of the Lunar Orbiter managers regarded teamwork as an important aspect of the successful management of that project. In headquarters, the field center, and the prime contractor organization, project personnel regarded their project counterparts with respect and trust. Within both the customer and contractor organizations, moreover, the history of the project was marked by high morale and good teamwork.

Although some sense of teamwork developed in the course of the Surveyor program, it grew slowly and fitfully, spurred by a sense of shared anxiety and concern. The many changes during the project's early years, the basic question whether a launch vehicle would be ready to fly the spacecraft, and concomitant uncertainties about the project's future, were hardly conducive to smooth interinstitutional relations.

The positive attitude and enthusiasm of top management were contagious and infected the Lunar Orbiter project staffs. Some of Langley Research Center's top talents had sought assignment on the project, considering it a career plus. The Lunar Orbiter project organizations at both LaRC and the Boeing Co. were tightly knit cohesive units, yet they operated with full support of and in close communication with functional divisions.

The conditions that prevailed for Surveyor were less favorable. The attitude of most JPL personnel toward a project assignment, particularly one based on contract monitoring, reflected a concern for any diversion from recognized paths of career advancement. There was no doubt about the feasibility of achieving the technical objectives, but the difficulties were tremendous and the Surveyor project was isolated from the mainstream of JPL activity. These factors mitigated against recruitment for the Surveyor project office of some of the best qualified and most talented persons.

The early Hughes organization for Surveyor was highly diffused throughout 13 operating divisions loosely tied to the project office. That office was at a level below many of the divisions on which it was dependent, and the Surveyor manager encountered great difficulty in influencing or controlling all project-related personnel. Senior Hughes management was not sufficiently involved in the project to take steps necessary to assure the responsiveness of divisions to project requirements. This was hardly an environment calculated to evoke a strong sense of unity and project commitment. Hughes undertook a major reorganization after Surveyor, to consolidate many activities needing to be under one organizational roof for managing space project activity.

Given the inadequacies in structural formation of the project offices in the Jet Propulsion Laboratory and Hughes Aircraft Co. on top of all the major technical problems besetting the program, it was not surprising that a reciprocal sense of teamwork was slow to develop. Nevertheless, as counterparts worked together, strong ties were forged. For example, the contract manager at JPL and his counterpart at Hughes eventually developed a very effective working relationship. In time, individuals on each side of the fence came to recognize each other's technical competence and skill. With the strengthening of the project organization and the upgrading of management enforced mainly by Headquarters during the latter half of the program, customer/contractor relations improved and a team spirit began to develop.

DEFINITON OF ROLES AND MISSIONS

A good deal of the theory discussed in management literature and a good deal of practical effort to systematize management procedures has been centered on early definition of various roles, missions, and responsibilities. Although a period of planning and project definition preceded Surveyor, efforts to carry out the plan ran afoul of many unforeseen contingencies. External influences forced the program to go through fundamental changes in organizational roles and relationships which somewhat vitiated the value of advanced planning.

Quite a few observers have come to believe that a good deal of uncertainty is endemic to research and development activity and that efforts to pin down organizational roles and conform with rigid phasing can be counterproductive. It is argued that too much mechanical effort to build in order and harmony is dysfunctional. In fact, no NASA programs have strictly followed the Phased Project Planning Guidelines issued by Headquarters in 1968. The value of guidelines rests in their utility as points of reference rather than as inflexible standards.

In conforming with the Headquarters policy, both the Jet Propulsion Laboratory and Headquarters seem to have operated on the assumption that the designation of a spacecraft systems contractor implied turning over much of the technical direction of the program to the contractor, and Hughes found that they were not receiving what they regarded as adequate technical guidance from JPL. As the program encountered increasingly serious trouble, Headquarters actively intervened in its management. JPL was compelled to assign a very large monitoring staff to on-site direction of the program. The initially minimal technical direction was replaced by a massive supervisory force. Thus, in the program's latter years, the responsibility for overall spacecraft development was gradually retrieved from Hughes by JPL, thereby altering significantly the respective roles of the field center and the spacecraft systems contractor.

Somewhat parallel changes took place in the management of the Centaur program. General Dynamics Corp., the prime contractor for that program, was originally left very much on its own with a loose monitoring rein. When field center responsibility for the management of the program was assigned to Lewis Research Center in the hopes of pulling Centaur out of serious trouble, Lewis established firm technical control over the contractor; this was a major factor contributing to the successful development of the Centaur vehicle. Another major change in the Centaur program that greatly improved its prospects was the removal of requirements for missions other than Surveyor in the development of the booster capability. The initial decision by NASA Headquarters to assign such an open-ended project as Surveyor to an open-ended launch vehicle made for many complications in both spacecraft and booster development.

Both the Surveyor and Centaur experiences suggest that, during an extended program, roles and responsibilities are not likely to remain fixed or permanent. Arrangements between customer and contractor should be sufficiently flexible to permit each to take advantage of its special strengths and abilities. Adaptive mechanisms to redefine roles and responsibilities at various stages of a program are more likely to result in high standards of performance than rigid adherence to a preset pattern.

The Lunar Orbiter experience also demonstrates the positive values of interorganizational flexibility. Informal organizational relationships in the customer/contractor relationships supplemented prescribed formal links. Although Langley Research Center's Lunar Orbiter project office had formal responsibility for "project-wide systems integration," the Boeing

Co. played an important auxiliary role. With LaRC's tacit approval, Boeing maintained an active monitoring role as a link with the several NASA field centers having a system responsibility in the program.

Maintaining Original Objectives

Those who managed Lunar Orbiter at Headquarters, LaRC, and Boeing agreed fully on the importance of adhering to the original objectives. The Surveyor and other space and defense programs offered visible evidence of the risks inherent in changing objectives. The clear lesson was that if you change direction, you will pay for it. The basic objectives of Lunar Orbiter, to obtain data to support the Apollo program for landing men on the lunar surface, remained almost static. As it turned out, the first three Lunar Orbiter missions returned all the data necessary for this set of objectives, and it was possible to add a quest for data sought by the scientific community to the last two flights of Lunar Orbiter spacecraft.

The important consideration from a management viewpoint, however, is that work on the design and development of Lunar Orbiter systems and subsystems was not interrupted by a change in objectives. In the case of Surveyor, the composition of the science experiment payload had been allowed to remain open-ended until late in the program's development stage. In retrospect, it now appears that the uncertainty concerning the number of experiments, their weight and configuration proved to be one of the most serious distractions in the management of that program. Lunar Orbiter managers were careful to avoid this mistake. The Lunar Orbiter Headquarters program manager assured adherence to the principle of minimum change by requiring that his office give prior approval to negotiation of any major change affecting spacecraft design and overall performance.

To reinforce the basic commitment to hold Lunar Orbiter changes to the minimum, management in both the customer and contractor organizations adhered to rigid design review and configuration control programs. After hardware and equipment passed through the critical design review, change was restricted to absolute essentials. Early establishment of a baseline mission for hardware design, worked out between the Boeing Co. and Langley Research Center, greatly facilitated evaluation of the effect of a change. A change board, with representation from each major area involved in a proposed change, reviewed all proposals to assure that only the essentials were authorized. Even before referral to the board, the program manager or the engineering manager had to pass on the submission of the proposed change to the board. These management techniques, together with the basic commitment to make maximum use of "space proven" hardware, made it possible to develop a spacecraft that resembled very closely the design of the original mock-up submitted with the Boeing proposal to NASA.

ORGANIZATION

The major strengthening of organization midway in both the Surveyor and Centaur projects resulted largely from increasing the project staff. In both cases, it had been assumed that the contractor could be given greater systems responsibility than it could exercise. In each case the customer and contractor organizations had started out with small staffs heavily dependent on their respective matrix organizations for technical support. Eventually, more highly "projectized" organizations incorporating all the necessary support functions were developed.

The internal structure of both the customer and contractor organizations for Surveyor went through numerous changes in form and composition. At Hughes Aircraft Co., a major reorganization occurred on the average of every six months. Keeping the interface between structures of the customer and contractor organizations compatible required concerted effort. On both sides, the need for a clear-cut counterpart relationship between key men for every major element of project activity came to be recognized.

At both JPL and Hughes the early Surveyor organizations suffered from the physical dispersion of the activities. Marked improvement came in both project organizations when project personnel were collocated in central facilities at JPL in Pasadena and Hughes in Los Angeles.

The organizational forms used at Langley Research Center and at the Boeing Co. for the Lunar Orbiter program were well suited at all stages to the task at hand. LaRC adhered to its basic philosophy of starting out with a lean organization, essentially as Surveyor began at JPL. But LaRC, unlike JPL, was prepared to supplement the initial project staff, as needed, while also providing full support from other divisions of the center.

The Boeing organization for Lunar Orbiter was highly project oriented from the beginning. Boeing's management had considerable experience in organizing for project activity and was fully prepared to bring together all the manpower necessary for the Lunar Orbiter assignment. The tight schedule for the project placed a premium on efficient movement from one phase to the other and for adequate staffing of each phase. Personnel administration provided for timely transition of personnel from design to test and later operational phases. Test and operations teams worked with each spacecraft from final assembly through launch.

The Lunar Orbiter project offices at both Langley Research Center in Hampton, Va., and Boeing, in Seattle, were located from the outset in central facilities where project personnel could work closely together. Close continuing communication both within the two project organizations and between them was a major factor contributing to the success of the program.

There are no firm standards that dictate how far an organization should go in forming project staffs for specific undertakings. The eventual buildup of a very sizable Jet Propulsion Laboratory Surveyor project staff represented a measure that compensated for understaffing in the first half of the program. But the shift is open to the criticism of being an overcompensation, wasteful of scarce manpower. LaRC's organization for Lunar Orbiter, on the other hand, remained lean and relied heavily on the divisional structure. Environmental considerations such as other projects with which participating organizations are involved, the stage of development of an organization, and the availability of the right types of project personnel influence significantly the effectiveness of any form of project organization. The evidence of Surveyor and Lunar Orbiter suggests that gradual restructuring and administrative flexibility are necessary to adapt to changing stages. The question of how organizational boxes are arranged, although important and even sometimes determining, is closely tied, of course, to the question of the kind of people who fill the boxes and, particularly, the availability of competent systems managers.

The Hughes experience with Surveyor was one factor leading to a corporate reorganization in 1970. The Surveyor project organization had been located within the Space Systems Division of the Hughes Aerospace Group. Formed in 1961, the division also managed the Syncom communications satellite project. Although the division included many of the technical and managerial elements necessary for managing space projects, it relied on laboratories centered in other divisions of the group for a number of technical requirements. By 1970 the division had established a firm business base. A special predominance in communications satellites had led into other aspects of space communications. The technology and systems management resources were then separated from the Aerospace Group and combined to form a new operational group, Space and Communications, to develop and manage programs in research and applications of space technology. It was designed to comprise virtually all the resources necessary, both technical and business, to conduct these programs.

Systems Capability

Systems management capability was scarce when Surveyor was initiated, and few systems managers were available in either the customer or contractor organizations. The real strengths of both the Jet Propulsion

Laboratory and the Hughes Space Systems Division resided in creative engineering design talent and researchers in various aerospace specialties.

Systems managers are trained and skilled in supervising the diverse sub-systems of a project in accordance with a schedule to assure integration of the various parts of the project as it moves toward mission fulfillment. A systems manager must have the peripheral vision needed to see the totality of a program, and he cannot afford to focus his attention too long on indepth examination of special areas. He must be able to delegate to specialists in such a way as to assure the highest possible levels of performance in their respective technical areas. Two recognized specialists on systems management, David I. Cleland and William R. King, describe the systems manager as

> that individual who is appointed to accomplish the task of integrating functional and extraorganizational efforts directed toward the development and acquisition of a specific project. The systems manager is confronted with a unique set of circumstances and forces with each project, and these circumstances and forces channel his thought and behavior into somewhat singular patterns of response.[6]

Surveyor was a training ground for the development of a sizable number of systems managers highly qualified to apply this skill to future tasks. The structures of the project offices at both JPL and Hughes were significantly altered during the later half of the program to permit more effective execution of the systems management function. This strengthening of the systems function provided better overall integration and represented a major element of the general upgrading of project organization.

When Lunar Orbiter was initiated, more than three years after Surveyor, both Langley Research Center and the Boeing Co. were fully conscious of the importance of systems management. Their project organizations included highly qualified systems managers located at the right levels. Boeing was able to assign many of the personnel from two recently concluded projects to Lunar Orbiter, including several highly qualified systems managers; these personnel contributed greatly to the successful management of the program.

Management Systems

In preparing to undertake a complex technical project, a sponsoring agency faces some critical questions concerning the kinds of formal reporting and control systems to apply. How extensive and how detailed should

[6] David I. Cleland and William R. King, *Systems Analysis and Project Management* (McGraw-Hill, 1968), p. 12.

these systems be? How much information is needed at various levels of management?

Everyone recognizes in principle that systematic reporting and control mechanisms are necessary to maintain the discipline required for advanced-technology projects. It is also widely recognized that beyond a certain level, formal reporting systems are wasteful, and that they are counter-productive when they curtail qualified managers' freedom to make decisions. Many good managers insist on being able to make "seat of the pants" judgments without being bound by documents resulting from some formal reporting system.

The Surveyor experience represents an example of an effort begun with too little attention at the outset to the management systems that would be appropriate and the measures necessary to indoctrinate and train personnel in their use. PERT, for example, was introduced several months after the project had started. PERT reporting was handicapped not only by its delayed introduction but also by the fact that the prime contractor, the Jet Propulsion Laboratory, and NASA Headquarters all had had insufficient experience in its use. Hughes Aircraft Co. was not prepared to give up other familiar systems altogether. Although PERT was useful, particularly in the program's early stages, Hughes never fully relied on it for project evaluation and control. Much of the PERT reporting represented more *pro forma* compliance with NASA requirements than effective utilization of a reporting system for project management.

Surveyor's difficulties stemmed from very fundamental causes such as the changes in the initial program's nature and content and the difficult and complex technical requirements for all major systems, including the launch vehicle. No formal reporting and control systems, however effective, could have overcome the technical difficulties. But, as technical problems were solved and the prospects for meeting all the requirements began to appear reasonable, the management systems required a massive upgrading. Such a substantial overhaul was necessary to assure the degree of rigor and discipline essential to fulfillment of the mission. The upgrading of these systems resulted largely from NASA Headquarters' direct intervention. The Headquarters program manager played a major role in this process.

As a result of intensive and laborious effort, the Surveyor management reporting systems became a true reflection of the state of the project, providing checks in great detail. A trouble and failure reporting system provided not only complete coverage of the technical aspects under review but clear identification of each individual responsible for technical requirements. In the revised reporting systems, heavy emphasis was placed on pinpointing individual responsibility as a stimulus to improving performance. Ultimately, as a result of this type of visibility, a high degree of rigor and discipline was injected into management systems that had previously been too lax and unsystematic.

By the time Lunar Orbiter was started, NASA had made a good deal of progress in refining and standardizing formal reporting and control systems. The issuance of a revised General Management Instruction 4-1-1 in March 1963 clarified the entire field of project organization and management within the space agency.[7]

Langley Research Center and the Boeing Co. both gave careful initial attention to the adaptation of reporting annd control systems to the project. In contrast to Hughes' resistance to PERT, for example, Boeing accepted the requirement and relied on it as the reporting and control system for all of its work on Lunar Orbiter. Even so, Boeing's Lunar Orbiter program manager made little use of PERT in his decisionmaking. But the system was effective, on the whole, as a device for recording and tracking the status of the project.

Having a great deal of experience in Government contracting that required extensive formal reporting and control, Boeing management sought from the beginning of Lunar Orbiter to keep the volume of reporting from becoming excessive and the reported information from being unnecessarily redundant. Yet NASA reporting requirements for the project exceeded what Boeing considered the optimum level of detail. Midway in the project, Boeing was able to convince LaRC that some of the reporting requirements could be discontinued, thereby reducing the cost.

Both LaRC and Boeing took care to assure that management reporting systems were updated and well maintained. Boeing sought to make the reports true and meaningful indicators of the state of the program. By keeping the reporting systems in good repair, those responsible for Lunar Orbiter were able to avoid the need for a massive upgrading. Lunar Orbiter managers made information systems come close to serving the basic purpose for which they were intended—to communicate the essential information on the state of a project to all those who needed to know in both the customer's and the contractor's organizations.

What stands out in the Lunar Orbiter experience, however, is not the overriding importance of formal reporting but the optimal use of informal person-to-person communications. Lunar Orbiter experience corroborates the conclusion reached in Richard Chapman's study: "No formal arrangement can replace the dynamic system of personal and informal relations developed by key members of the project team to meet that project's

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[7] NASA Management Manual, *General Management Instructions Number 4-1-1*, subject: Planning and implementation of NASA Projects (Mar. 8, 1963). This instruction replaced GMI 4-1-1 of Jan. 18, 1961.

particular needs." [8] The compatibility of individual managers serving the customer and the contractor helped greatly to assure Lunar Orbiter's success.

Role of Headquarters

Only rarely does a program require the extent and depth of intervention by Headquarters that occurred in the case of Surveyor. Both the Surveyor spacecraft and the Centaur on which it depended faced such serious troubles that the highest levels of Headquarters management felt compelled to intervene. The story of Centaur demonstrates the importance of decisionmaking at the Headquarters level.

Marshall Space Flight Center was the first NASA field center to be assigned responsibility for Centaur after the transfer of the program in 1959 from the Air Force. Many factors worked against the interests of Centaur at MSFC. Senior management at MSFC focused its attention mainly on the development of the powerful Saturn launch vehicle for Apollo, and the demanding responsibilities for Saturn left somewhat limited technical and managerial resources available for Centaur.

Before being assigned to MSFC, Centaur had gone through numerous changes and shifts in objectives, and there were numerous technical conflicts in the propulsion requirements represented by several different potential customers for a single launch vehicle. Advent, a military communications satellite project, imposed demands on Centaur that were incompatible with the Surveyor requirements, and a year elapsed before the Advent mission was deleted.

Even after Centaur was transferred to MSFC, the Air Force retained responsibility for monitoring the prime contractor. In the face of many serious technical difficulties associated with Centaur development, MSFC's top management concluded that it would not be feasible to meet the minimum weight-lifting requirements of Surveyor and that the program should be cancelled in favor of a Saturn C-1/Agena combination. The Jet Propulsion Laboratory concurred in the MSFC recommendation.

Headquarters, after carefully reviewing the situation, confirmed its position that the Centaur concept was both technically feasible and essential to the launch vehicle program for the space effort. It thus rejected the recommendation of senior management at MSFC and JPL. Responsibility for Centaur was transferred abruptly then to Lewis Research Center. This was interpreted as a rebuke to MSFC and a signal to the other centers that they could not back out of major development commitments assigned by Headquarters.

On numerous occasions Headquarters felt compelled to intervene in Surveyor. For example, a major Headquarters investigation of the pro-

[8] *Op. cit.*

gram in early 1964 uncovered many serious weaknesses in both technical and managerial aspects of the project and led to a series of correctional moves. The Headquarters review contained detailed proposals for tightening and upgrading project organization and management both at JPL and at Hughes. Headquarters urged JPL to appoint a Deputy Director who could help in JPL administration and management while keeping an eye on Surveyor. A former general manager of the Atomic Energy Commission was designated by JPL to serve in a similar capacity. He instituted significant changes in the business administration and management practices of JPL in general and Surveyor in particular.

This appointment was highly charged with internal political overtones. Headquarters senior administrators were dissatisfied with the general management at JPL and saw the difficulties encountered in Surveyor as an opportunity to force a change. JPL senior administrators, on the other hand, were skeptical of any organizational or personnel changes inspired by NASA. Thus, despite the new deputy's substantial contributions to improved management, he left JPL and accepted a position outside NASA before the seven Surveyor flights were completed.

In several instances, difficulties within the Surveyor and Centaur project organizations became so serious that representatives of general management were designated to assume direct day-to-day responsibility for management. A representative of JPL's senior management served as Surveyor project manager for a critical period: the Deputy Associate Administrator in Headquarters Office of Space Science and Applications acted in the capacity of Surveyor program manager; and, for several months, the Director of the Lewis Research Center was project manager of Centaur. Ideally, a project, once assigned to a responsible field center, would not require such penetrating intervention by Headquarters. Only a monitoring function was needed on Lunar Orbiter.

In view of the eventual success of Surveyor and more than a dozen other projects that were simultaneously sponsored in the area of space science and applications, the overall record is impressive. Cost escalations, however, were not uncommon and many projects slipped behind schedules.

By intervening in Surveyor, Headquarters helped reduce constraints for which it shared a considerable degree of responsibility. The original underestimation of the complexity of the Surveyor program, the imposition of manpower and financial ceilings, prolonged insistence on an unreasonably open-ended combination of scientific experiments for the payload, the many changes in scope and objectives of the program, and the tying of Surveyor to an unproven launch vehicle were all problem-causing factors that were attributable to decisions made by Headquarters. Only Headquarters could effectively ameliorate them.

The Jet Propulsion Laboratory, as the responsible management center, was slow to accord the Surveyor project the priority that Headquarters wanted it to receive. The deep concern of top JPL management caused by the series of troubles encountered in the Ranger project and the requirements for other in-house projects limited JPL's efforts on Surveyor. It took a major Headquarters review and persistent Headquarters directives, both orally and in writing, to bring JPL management to improve the Surveyor project organization.

The Headquarters review in the spring of 1964 also pinpointed a number of deficiencies in the Hughes Aircraft Co. organization. Headquarters instituted a direct watch over Hughes operations to assure that more support was being given to the project and that more attention was being given from senior levels of Hughes management. Headquarters continued to be dissatisfied with aspects of Hughes management and technical performance well into the operational phase of the project.

When all the demanding tasks involved in the Surveyor lunar landing missions were complete, the aftermath was characterized by institutional friction. In each of the three principal organizations involved in the project—NASA Headquarters, the Jet Propulsion Laboratory, and Hughes—the Surveyor personnel tended to view their own organization's contribution as the critical key to success. For the record, each organization has formally acknowledged that team effort was essential to ultimate success. But among Surveyor personnel in the three participating organizations there is far less willingness to acknowledge the contribution of other groups and individuals than there is among the participants in the Lunar Oribiter project.

Incentive Contracting

The Surveyor spacecraft systems contract was awarded on the basis of a source evaluation by JPL, and JPL negotiated the contract with Hughes. The contract was written as the cost-plus-fixed-fee (CPFF) type, and was converted to an incentive basis quite late in the program—on the day before the launch of the first Surveyor spacecraft. JPL's administration of the CPFF contract failed to keep pace with the many change orders and modifications, and fell far behind in its accounting of the financial status of the project. About a year of intensive work in the Surveyor contract office was needed to upgrade contract records. At about the same time, JPL, in response to Headquarters direction, began efforts to persuade Hughes to convert to an incentive contract. Although Hughes at first resisted, strong Headquarters insistence induced Hughes management to accept the new contract. When the project was completed, the company earned fees totaling several million dollars more than their minimal expectations under the CPFF contract.

Both customer and contractor management then regarded conversion of the contract as a highly beneficial administrative measure well worth the massive effort entailed. The entire work breakdown structure and financial reporting system had to be revised as part of the total conversion process. After the conversion, however, it was possible for the first time in several years for customer and contractor to operate on the basis of mutual agreement on the status of the contract.

More important, the incentives had a highly beneficial impact on Hughes' performance. The prospect of earning fees tied to specified and realistic cost and schedule targets motivated all levels of personnel. General management at Hughes had played an active role in negotiating the contract conversion and took steps to assure that the entire project received full support. An award fee in the new contract provided additional incentives for high standards of performance in the management and operation of the project. This fee stimulated maximum effort in all areas of project management over and above those that had a direct relationship to costs and schedules.

The original negotiated cost of the Hughes contract for seven spacecraft was $67 million. Final Hughes contract costs came to $365 million, over a fivefold increase. For Lunar Orbiter, the original negotiated cost of the spacecraft contract was $84 million and the estimated final contract costs at $144 million represented less than a twofold increase. There is no incontrovertible method of correlating the cost performance on Lunar Orbiter with the fact that it was the first major NASA flight program to be undertaken on the basis of an incentive contract. Although the incentive fees were generally regarded as a positive feature in the contractual relationship between customer and contractor, the Boeing Co. representatives attribute less significance to incentives than to the strong corporate determination to achieve success in their first spaceflight project.

The Boeing contract for Lunar Orbiter was cost plus incentive fee, whereas the two major subcontracts with Eastman Kodak and RCA were CPFF. Boeing's management had anticipated that, once having negotiated the prime contract, they would be able to persuade the two subcontractor firms of the advantages of an incentive form of contract. Both Eastman and RCA held out firmly against what they considered an untested and risky method of contracting. The absence of incentives in the two major subcontracts tended to undercut the impact of the incentives in the overall spacecraft system development.

As the first major NASA project to be awarded on an incentive basis, Lunar Orbiter broke important new ground in the development of standards for determining and administering fee awards. Both Lunar Orbiter and Surveyor experiences attest to the positive value of incentives. NASA's early favorable experience with incentive contracting on such projects as Lunar Orbiter led the agency to increase the use of this type of contract to the point where it represented 68 percent of total award obligations for external research and development in 1968.

More recent years have brought a shift away from incentives, down to a level of 46 percent in 1970. This shift reflects growing awareness that dollar profits may be less of a motivating force in a private organization's performance than the impetus to hold a place in a growth market or the need to assure corporate survival. Despite this decline in the relative importance of incentives, Lunar Orbiter contracting experience was worth while because it helped to inform NASA about effective approaches to research and development procurement.

Cost Performance

Analysis and interpretation of cost data relating to space projects is a complex task involving many variables. Assuring complete objectivity is difficult. From the viewpoint of achieving the goals of the national space program, what matters is essentially the ratio of costs to the amount of scientific and space engineering information produced in each project. Did the spacecraft send back the kind of data that it had been designed to retrieve? Were the data useful to the scientific community and to engineers and technicians engaged in other ongoing space activities? Measuring by these criteria almost inevitably involves subjective judgments concerning the utility of the data returned.

NASA's original estimated total cost of the Surveyor project was $125 million whereas the final costs came to $469 million, somewhat less than a fourfold increase. Lunar Orbiter costs were first estimated at $77 million and wound up at $163 million, or slightly more than a twofold increase. To gage these two records of cost performance, it is useful to compare them with other NASA projects in unmanned space exploration. An analysis of 16 research and development projects being conducted by OSSA during the sixties indicates that the average final costs were somewhat less than three and a half times the initial estimate.[9] Extended delays in several of the early OSSA projects as well as increases in the number of spacecraft flown contributed to substantial cost escalations in several of the earlier projects .

Costs, of course, are in considerable part a function of time. The nearly fourfold increase in the total cost of Surveyor over the original estimate reflects the fact that the project took more than two years longer than originally estimated. Previous discussion has brought out many factors contributing to delays in Surveyor. The early planning for Surveyor

[9] Final cost estimates for 16 OSSA projects totaled approximately $2.5 billion in comparison with original estimates of about $784 million. (From Memorandum from Assistant Administrator for Program Plans and Analysis to the Administrator, subject: NASA Project Cost Projections (Apr. 10, 1969).)

was highly unrealistic and vastly underestimated the complexity of the task.

Lunar Orbiter final costs, in contrast, were only slightly more than double the original schedule, the first launch being made within two months of the initial target date. The preceding analysis discloses how Lunar Orbiter managers took advantage of the three years of learning experience that elapsed between the start of the Surveyor program and the initiation of their project. The Lunar Orbiter record compares favorably with the overall OSSA performance.

Both Surveyor and Lunar Orbiter were highly successful from the viewpoint of gathering scientific and engineering data essential to the Apollo program and future lunar exploration. The data on the chemical composition, density, and bearing strength of the lunar surface acquired by means of Surveyor's instruments were essential to the planning of Apollo landings. The photographic data acquired from both Surveyor and Lunar Orbiter formed the essential basis for selection of initial Apollo landing sites. The acquisition of these data and their systematic exploitation called for an effective relationship between the hundreds of consulting scientists, engineers, and technicians engaged in the projects. The manner in which this relationship evolved is discussed in the following section.

Science/Engineering Relations

Meshing the interests of scientists and engineers in the Surveyor program was a real challenge and the source of much management difficulty.

Communications barriers between scientists and engineers reflect the differing motivations and orientations of the two disciplines. The scientist tends by and large to be interested in acquiring knowledge about his special field. For him, the mechanical means for attaining that knowledge may be of only incidental interest. The engineer or technician, on the other hand, is likely to be primarily interested in the mechanics of an instrument problem. In a gross sense, he focuses his interests on the "how to do" rather than the "what to do." Though he wants and needs to know enough about the scientific objectives of an experiment to do his engineering work satisfactorily, he is essentially concerned with the very practical issues of what will work.

There are also likely to be wide divergences among scientists seeking data from a spacecraft. One scientist does not necessarily have much interest in the work of other scientists whose experiments may be riding on the same space "bus" as his. Only in the later phases of the Surveyor program were the principal investigators and other science advisors for Surveyor brought into full realization of the interdependence of the various experiments.

NASA Headquarters, where the selections of scientific experiments for Surveyor were made, was pressed by the scientific community to pursue many different lines of investigation via Surveyor. These pressures made Headquarters reluctant to narrow the options for change. Indeed, in the early years when Surveyor was conceived as a three-block program, there was good reason to plan for a broad and diverse science program. But it now appears to have been quite unreasonable for Headquarters to have insisted that the design of the spacecraft be such as to accommodate any combination of some 30 science experiments, particularly when most of the experiments were also continually being changed.

To avoid some science/engineering problems, the Jet Propulsion Laboratory kept the Surveyor science investigator teams somewhat removed from the technicians and engineers responsible for instrument design. JPL was concerned that scientists might disrupt the work of the engineers and that some engineers might become overly committed to perfecting a scientist's pet experiment. In time, the need for such concern diminished. But in the early years of Surveyor, the slight concern of the scientific investigators for the impact of their experiments on spacecraft performance caused trouble for project managers.

Whenever science is an important aspect of an engineering task, the scientific objectives must be clearly recognized at the outset. Special management attention should be given to those levels of the engineering organization at which the science inputs are made to be sure that they are properly incorporated in the payload. The scientists responsible for the experiments must work closely with the engineers responsible for the basic assembly on which the experiments will ride.

The photographs and other data on the lunar surface returned by Surveyor aroused great interest in the scientific community. NASA Headquarters and the Jet Propulsion Laboratory developed highly effective machinery for collecting, analyzing, and widely disseminating scientific data. Thus the Surveyor data served the interests of both those responsible for planning the Apollo landings and the growing ranks of scientists interested in information on the Moon.

Lunar Orbiter had no major science objectives until they were added for the last two flights. The U.S. Geological Survey was the only outside group involved, and Langley Research Center needed only a small science complement. The Lunar Orbiter consequently had fewer problems than Surveyor and less need for the elaborate organizational structure that was established for Surveyor, a project in which more than 100 outside scientists and a highly sophisticated science division at the responsible field center were involved. Nevertheless, the photographs returned from Lunar Orbiter and the data collected on the last two flights provided a rich store of information that is still being widely studied and analyzed by lunar and other scientists.

V

Synthesis

WHAT is the essence of the management learning experience gained in the Surveyor and Lunar Orbiter undertakings? Can this experience be synthesized into meaningful and significant concepts relevant to the management of future undertakings? How important is the "management" of the project relative to other factors such as environment and the state of the technology? Are there apparent means suggested by Surveyor and Lunar Orbiter for transfer of learning experience? Is the experience applicable exclusively to similar advanced-technology research and development projects, or can there be lateral transference to the broader field of management in general?

What emerges perhaps most forcefully from a broad retrospective view is the importance of the human aspects of organization and management. Both projects demonstrated the critical nature of human skills, interpersonal relations, compatibility between individual managers, and teamwork. The Surveyor experience brought out these lessons, for the most part, by demonstrating the effects of gaps or barriers in the total web of managerial relationships. Many of the difficulties of the Surveyor project can be traced to individual and institutional discords that stood in the way of communication and agreement based on mutual interest in resolving project problems. Despite all the formal reporting systems, communications in the early stages of Surveyor were generally inadequate, both within and between the participating organizations. Individual managers in the various customer and contractor organizations were often surprised by a failure of their counterparts to follow what seemed to be the obvious course to get the job done.

Lunar Orbiter demonstrated the importance of leadership commitment to a project. When all levels of management fully support an endeavor, the odds for its successful completion obviously improve. In an environment marked by mutual respect and confidence of all participating organizations, Lunar Orbiter maintained its schedules and avoided many of the kinds of trouble that beset advanced research and development projects.

Surveyor demonstrated the depth of trouble a project can encounter when the full column of management support is incomplete. The general management structure of the Surveyor project at both the Jet Propulsion Laboratory and Hughes Aircraft Co. tended to be too removed from the project and too little committed to its necessary priorities. As one of the consequences, a multiple tier of suspicion and mistrust developed among the participants. Midway in the project, massive corrective measures, sometimes to the point of overcompensation, had to be instituted to assure the success of the Surveyor missions. Surveyor managers applied elaborate, detailed, and costly formal reporting systems in their attempts to keep the project on track. Lunar Orbiter managers, by contrast, had learned to reduce the amount of formal reporting and maximize the value of the informal links between project counterparts.

People make organizations; different kinds of people make different kinds of organizations. The field center personnel assigned to Surveyor were, by dint of circumstances of the time, very different from the kinds assigned to Lunar Orbiter. There was considerable reluctance at JPL to jeopardize professional careers in a project assignment. The professional staff charged with responsibility for Surveyor tended to be highly specialized in various research fields of science or engineering. The professional staff from which the Lunar Orbiter team was selected was eager to accept the challenge of the first spaceflight project assigned to them. Whereas the best talents were not applied to Surveyor until relatively late in the project's development, some of the best talents were assigned to Lunar Orbiter at the outset.

As between the prime contractors, the differences in makeup of Surveyor and Lunar Orbiter personnel were mainly in the degree of prior project experience. Personnel assigned to Surveyor were, for the most part, not trained in that type of project activity and few had the systems management capability needed. For Lunar Orbiter, large numbers of qualified technicians and managerial personnel who had worked with each other on prior projects were available. They began, moreover, with three years' more learning experience.

The different attitudes of Surveyor and Lunar Orbiter personnel upon the completion of their respective projects is significant. Some personnel at JPL still tended to regard their Surveyor experience as a sidetrack in their career advancement. Some felt that not enough effort had been made to apply their experience effectively in new assignments. Among Lunar Orbiter personnel, on the contrary, there was almost universal feeling that this project involvement had been a net plus in their careers.

Association with a successful undertaking breeds pride and confidence. Lunar Orbiter teams acquired a positive outlook almost from the beginning. For years Surveyor teams were harassed by serious technical problems, doubts about the technical feasibility of the entire undertaking, and second-class citizenship within their immediate environment.

The lesson here is obviously not that technical organizations should limit new undertakings to the least risky or demanding enterprises. Tough technical challenges must continue to be accepted by organizations aspiring to lead in technical endeavor. Perhaps the lesson centers on how the requirer and the producer reach agreement on their contract. General management of customer and contractor organizations must agree beforehand on the method of dealing with questions posed by sometimes conflicting priorities in allocating manpower and resources. Although it is far easier to make such a general observation in hindsight than to deal with such issues in practice, the assignment of priorities and allocation of resources by general management undoubtedly may be a determining factor in a project's outcome.

Many of the organizations and individuals engaged in spaceflight projects such as Surveyor and Lunar Orbiter have now moved on to work in non-space-related fields. Despite the differences in technologies or differing environments surrounding their new enterprises, what they have learned about managing projects is still broadly applicable to their new ventures. The management skills represented in organizing and directing a space exploration project are not *sui generis*. Rather, they are a combination of common sense, managerial sensitivity, and technical competence adaptable to rapidly changing situations.

Although each manager setting out on a new task may view his assignment as a completely new departure, he is actually part of a continuum. Just as he brings to his task his own past knowledge and experience, so his colleagues bring theirs. The successful project manager is one who is able to provide the kind of leadership that effectively taps this experience, focusing a common effort upon common goals through a progression of commonly accepted intermediary steps.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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