Project and Systems Management in the Apollo Program

by Dr. Eberhard Rees
Former Director of Marshall Space Flight Center
(adapted from a talk given at The World Management Congress in Munich, 1972)

Basically, project and systems management is nothing new. It is axiomatic that since the dawn of history there have been groups of human beings trying to achieve a common goal within a certain time span and with available resources. These project-oriented groups were immediately confronted with the problems of organizing and managing such efforts and resources in order to reach their goal on time and with minimum expenditure. In modern times we call the educational approach to such an undertaking "Project and Systems Management." Large projects of a scientific and technical nature generally involve:

- A multitude of government agencies, industrial firms and other organizations, sometimes on an international basis;
- Funds in the multimillion to billion dollar category;
- Complex technology sometimes reaching beyond the state of the art;
- Large forces of scientists, engineers, technicians and administrative personnel; and
- Construction of extensive and highly specialized facilities.

This type of project became more and more common in this century and especially in recent decades to solve problems of national and worldwide importance, to pursue large-scale scientific endeavors, to meet the needs created by a rapidly expanding world population, or to achieve other goals. It soon became evident that such projects, of great magnitude and complexity, had to be considered under the overall "systems" point of view continuously during execution. The alternative to such a concept leads inevitably to non-optimal technical solutions, cost overruns, and schedule slippages which would occur to the embarrassment of the responsible country, agency or firm. Therefore, terms like "Systems Management," "Systems Engineering," "Systems Planning," etc., were introduced to describe the systems aspects that had been emphasized as an inescapable necessity.

The management scheme that was developed and applied to the Apollo Program, a complex and technologically difficult program, is particularly interesting. It is now well-known that the technical complexities and the pioneering nature of this unprecedented undertaking were finally very successful, but the program was also accompanied by shortcomings, setbacks, and deficiencies during its execution -- all of which challenged the management system. It soon became clear that the project management had to be extremely flexible and capable of meeting unforeseen demands. It was also apparent that determination, resoluteness and faith would be vital if the goal were to be achieved.

To assure success of the Apollo Program, the first order of business was to minimize technical risks or actually mission risks as much as possible and, at the same time, to keep closely to the time schedule. Because of the rigid de-

mands of this time schedule, it was necessary wherever possible to engage in parallel rather than consecutive developments. In order to reduce technical risks, backup solutions in certain unprecedented areas, sometimes down to the component level, had to be concurrently pursued. For example, all possible abort schemes one could think of were considered and designed for, to provide the maximum possible safety. This concept is expensive, but it was accepted as an alternative to increased possibility of failure of the whole program.

Tight budget control and highest economy in expenditure were, of course, strong requirements but were subordinate to technical needs and the demands of the time schedule. Naturally, there is a trade-off between acceptable technical risks or product quality, time schedule and project cost. For instance, to eliminate the technical risk problem, frequently undue quality control or overtesting of hardware is applied which delays schedules and makes costs skyrocket. If the program management permits faulty components to enter the system -- due to lack of quality control and testing -- the components would only be detected in overall checkouts. And finally, unrealistically short time schedules endanger the quality of the product and cost control, whereas long, drawn-out time plans increase total project cost.

In summary, there has to be an optimum balance among technical performance, time schedule and cost. In the Apollo Program, this balance was deliberately shifted toward technical performance and time schedule. Depending on the nature of a project, such a balance could as well shift in the direction of economy and trade-in on technical performance.

Short Summary of the Apollo Program

For a better understanding of the management concept and of the problems confronting management, a brief history of the Apollo Program might be helpful. The mission as stated by the President of the United States and approved by the Congress was to land a man on the Moon in the decade of the 1960s and return him safely to Earth. During the excursion, scientific experiments were to be conducted for exploration of the Moon and its origin in order to provide a better understanding of the possible age and creation of the solar system. Also, other corollary research was to be undertaken.

It has been common practice in government circles to use the term "program" to describe a large, multimillion dollar undertaking. Within such a program, major elements have commonly been referred to as "projects." Thus, the lunar program in its entirety is referred to as "Apollo." The Saturn launch vehicle, an element of the total program, would properly be called a project. It is my understanding that in commercial or industrial practice, the term "project" is generally used rather than "program." For consistency, I shall use the term "program" for Apollo.

The program was started in 1961. Early snapshot estimates of cost were between $20 billion and $40 billion. After the program was laid out and firmly established, detailed calculations brought the estimates closer to $20 billion. Of this money, approximately 90 percent was spent in industry and 10 percent in government operations. During the peak of the effort, approximately 12,000 government employees and approximately 300,000 people in industry were employed. An investment of approximately $2.5 billion in new construction of facilities was made all over the United States at industry and government installations. These included the build-up of new government Centers; namely, the Manned Spacecraft Center at Houston, Texas, and the Kennedy Space Center at Cape Canaveral, Florida. It also comprised an expansion of the Marshall Space Flight Center at Huntsville, Alabama, including subsidiaries for production and testing at other locations.

The total program consisted of the development and production of three types of launch vehicles; namely, Saturn, Saturn IB and Saturn V, and two types of spacecraft: a Command Service Module and a Lunar Landing Module. As a precursor, the Gemini Program was introduced. The special objectives were to improve life support systems and to develop docking processes, extravehicular activities and other techniques for Apollo.

Basic Principles Established in the Apollo Program Management System

After agreement had been reached on the method for traveling to the Moon and landing, and departure from the lunar surface for return to Earth, attention was turned toward establishing certain management basics to assure effective program execution. The size and complexity of the effort added an increased importance to such considerations.

First of all, there had to be "a superior planning effort." I venture to state that, without diligent planning -- especially systems planning -- right from the start, any project is doomed sooner or later to run into most serious difficulties. To recover from such planning failure costs large sums of money and time delays. It also brings a program into technical trouble which, as history has shown, could result even in cancellation.

Solid planning starts with master plans on hardware, software, and overall systems as to technical approaches; resources such as facilities, manpower and funds; and, finally, schedules. Important are detailed breakdowns of the overall job and the system into subsystems and what is called in Apollo "work packages." Then come the significant areas of planning of contracts and the contractor structure. This results in the determination of which packages to assign to prime contractors and, in special cases, to major subcontractors who are to be selected by Source Evaluation Boards. This selection is based on work statements, Requests for Proposals, and their submissions. The selected prime contractors have to be incorporated immediately into the planning activity.

It is strange that so few otherwise gifted managers and engineers do not see the significance and the great importance of proper planning. Such seems to be the case, however. It explains at least partially why we had great difficulties in finding technical experts who understood the value of planning. For the military, strategic planning is a matter of course. The same is true for any commercial undertaking where to neglect planning is to court bankruptcy. Why it is so hard to introduce proper planning into project and system management of projects of a more scientific nature is perplexing to me.

For success in any program or project, large or small, I consider it a dominant principle that management must have what we in the Apollo Program called "visibility." This means that the management at all levels should know almost in "real time" what is going on in the program: technical occurrences, schedule progress or delays, and financial status. From the outset of the program, proper and effective channels and ways of communication have to be established on the government side between upper and lower echelons of management. Similarly, the prime contractors must provide equally effective channels down to their respective subcontractors. Such an information system should not only depict the past and present status, but, more importantly, should also enable management -- again on all levels -- to predict trends in the progression of the program. The prediction of trends for some months ahead, or even longer, is vital for taking corrective steps before the program runs into impediments. The capability of management to foretell trouble and thus avoid it by appropriate actions was one of the major cornerstones of the Apollo success.

Next of importance was the establishment of certain "review milestones," that is, scheduled dates of management review between government and prime contractors. Such reviews are, for instance, in a chronological sequence:

Program Requirements Review	PRR
Preliminary Design Review	PDR
Critical Design Review	CDR
Design Certification Review	DCR
Pre-Delivery Turn-Over Review	PDTR
Flight Readiness Review	FRR
Countdown Demonstration Test and its review	CDDT

Figure 1 shows these reviews over the life of a program and the process applied to lead to a particular launching. Some indication of timing of the review span may be gained by noting that the Countdown Demonstration Test and review preceded an Apollo launching by five weeks.

In the Apollo Program there were many more reviews beyond those shown. They all served to critically examine and assess the project status, to affirm the quality of the product and its reliability, and to assure systems safety. Every review resulted in protocolled action items. As the resolution of problems raised at each of the reviews was completed, the contractor was authorized to go ahead with the next increment of the overall plan.

Also employed as an important management tool was the PERT, or Program Evaluation and Review Technique. This well-known approach needs no further elaboration.

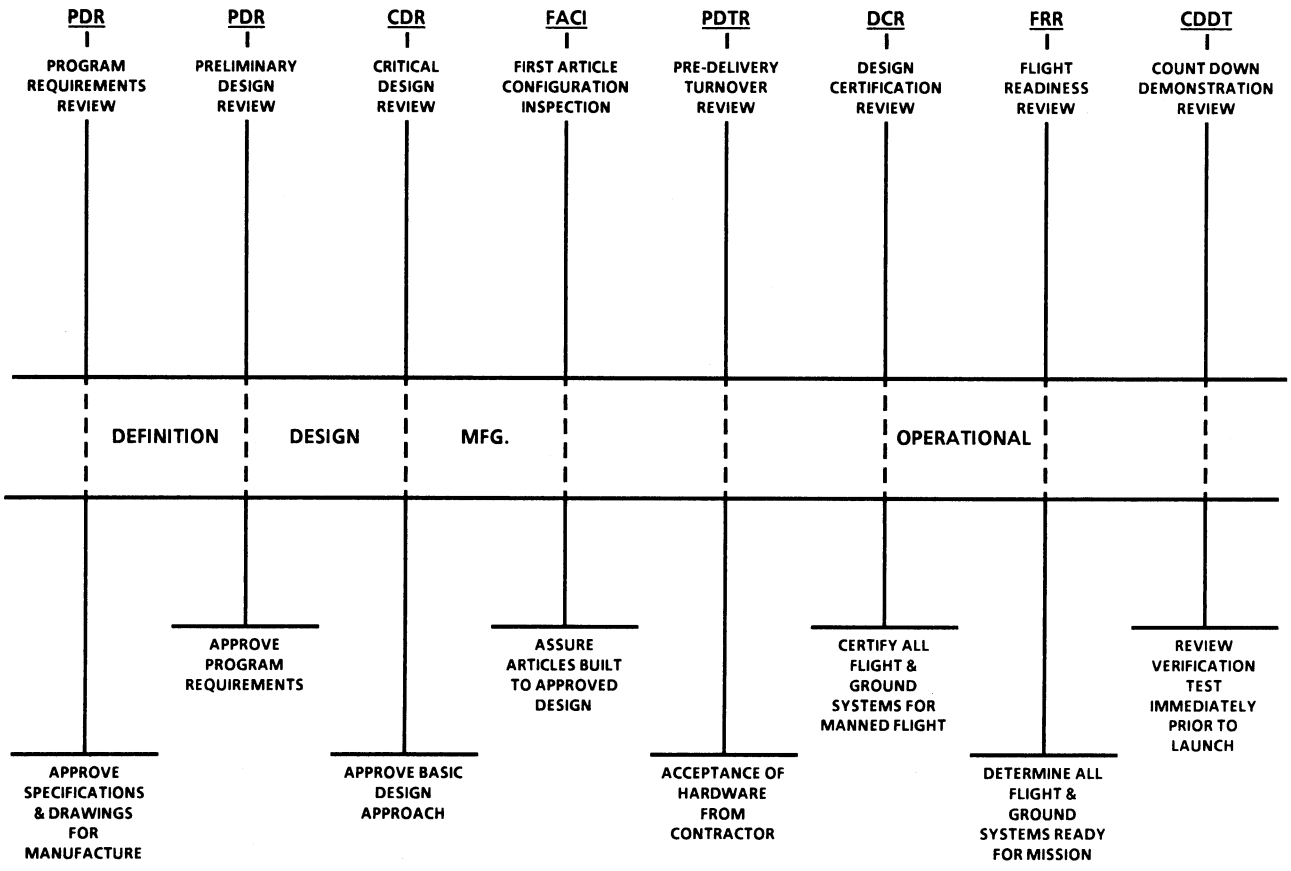

Figure 1. The Apollo Review Process.

Configuration control was another necessary management tool in the Apollo Program. This control scheme assured that:

- The contractor followed acceptable drawing room practice as to procedure and discipline;
- Design intentions were carried through manufacturing;
- Only mandatory changes were approved;
- The exact configuration, known down to the most minute detail, was delivered to the launching site; and
- Failures or unsuitable hardware or material could be traced down to the point of origin. Apollo management called this "traceability."

Configuration control carried out in a strict sense is very expensive. It is, therefore, vital that these controls not be overdone and that they are wisely introduced to prime contractors and subcontractors.

Application of the penetration principle did not stop at the government-contractor boundary. Instead, it permeated through the contractor organization to the subcontractor structure. Spawned by this approach, improved failure analysis appeared throughout the system; in-process inspection was maintained at a high level; and receiving inspection techniques and effectiveness were improved, among other benefits.

The application of the penetration approach resulted in a a vastly improved and effective communication channel with a host of side benefits. So while it might on the surface appear as an invasion of prerogative by the government, actually penetration should be looked upon as the close interaction of highly dedicated, competent technical and scientific personnel, all motivated by the impressive challenge of a huge complex program, no matter whether they are government or contractor employees. Most instrumental in this government-contractor relationship was the establishment of resident personnel in the prime contractor plants.

Another point basic to the management of the programs involves "contracting principles." Early in the Apollo Program, cost-plus-fixed-fee contracts were employed. The reason for using this contracting approach is rooted in the uncertainties of effective, close pricing in such a program with its many unknowns. Subsequently, the incentive fee contract was introduced. Essentially the fee applied consisted of two parts, one a base fee of modest proportions and the second a scaled or incentive segment. As the name implies, the amount of incentive fee awarded to a contractor in addition to the base fee was a direct result of success in meeting program product requirements for performance, cost, and time schedule. The incentive fee contract lends itself well to hardware contracts with reasonable, well-determined milestones, cost levels and schedule. (I should point out here that in several cases where contractors were experiencing troubles, effective management practice was considered in adjudging fee.)

In contract arrangements where the parameters are not easily distinguished in advance, a variation known as award fee contracting is used. The contractor is adjudged on a more general basis; support service or engineering service contracts fall into this category. It may be seen rather clearly that this method of contracting is motivational in nature, thus fulfilling an important management requirement cited earlier.

Beyond the contracting device, additional and continuing motivational or inspirational techniques were used. While the award and incentive fee channel reached the interior of an organization through conventional management channels, there were others that appealed di-

rectly to the workforce of contractor and subcontractor. Located in the program and major project offices was a Manned Flight Awareness Office. The function of this office was to keep all program workers aware of the need for success by each individual. This was an effective technique that became tangible when merit awards and recognition were issued.

There are a number of other pertinent principles upon which the effectiveness of program management depends. Although they apply in other management schemes and in programs where the government is not involved, in a program-oriented structure, they are critical:

- Organize and motivate to achieve effective high morale in the workforce;
- Delegate authority clearly, concisely and positively to achieve timely decisions;
- Apply innovative concepts and techniques courageously;
- Keep objectives pointed toward the goal;
- Require continuing study and application of the systems engineering approach; and
- Relate actions to schedule and to budget continuously.

The Apollo Management System

In the actual managerial arrangement that used the principles I have mentioned to manage the program throughout its life, we did not enjoy any measure of managerial "genius" in running our changing, dynamic organization. On the contrary, our management system evolved after some painful experiences in the early days of Apollo. In fact, at the beginning of the program in 1961, there was no common system in existence within the rather young National Aeronautics and Space Administration. Then as the program gathered headway and matured, the management system became better defined, changing as necessary to keep pace with unfolding events. Early it was learned that in the environment of a big development project, there can be no static system. Change and evolution are inevitable.

Figure 2 is what we called the "Apollo Program Trend Chart." Management used this chart to follow the progress of every major component such as rocket stages, engines, spacecraft, etc. In this case it was employed as a master chart for predicting the landing date on the Moon. On the ordinate you see the planned launch date and on the abscissa the reporting date or the status. This visibility scheme was introduced in 1965 after the first lunar landing date, originally planned for the first half of 1967, slipped several times.

By 1962, after the decision on how to go to the Moon and after the introduction of the Gemini Project, the Apollo Program began to take shape rapidly. Budgets had increased decisively. American aerospace industries and universities were significantly expanding their involvement. Also, of course, by this time three sizable Centers were involved to capacity in the technical and managerial demands of their respective Apollo assignments. This involved multimillion dollar projects at each -- the command module, service module and lunar module at Houston; three stages and an instrument unit at the Marshall Space Flight Center in Huntsville; and assembly and launch operations at Cape Kennedy. Coupled with the national involvement of the industrial complex, the need for innovative overall management was clear. For this and other reasons, the Apollo Program management office in Washington, and the project management offices at the three field Centers, were thus restructured and strengthened to fulfill the vital role of the overall integration and management of all contractor, field Center and university efforts.

Figure 3 shows how the Apollo Program Office was placed in the complex of the Manned

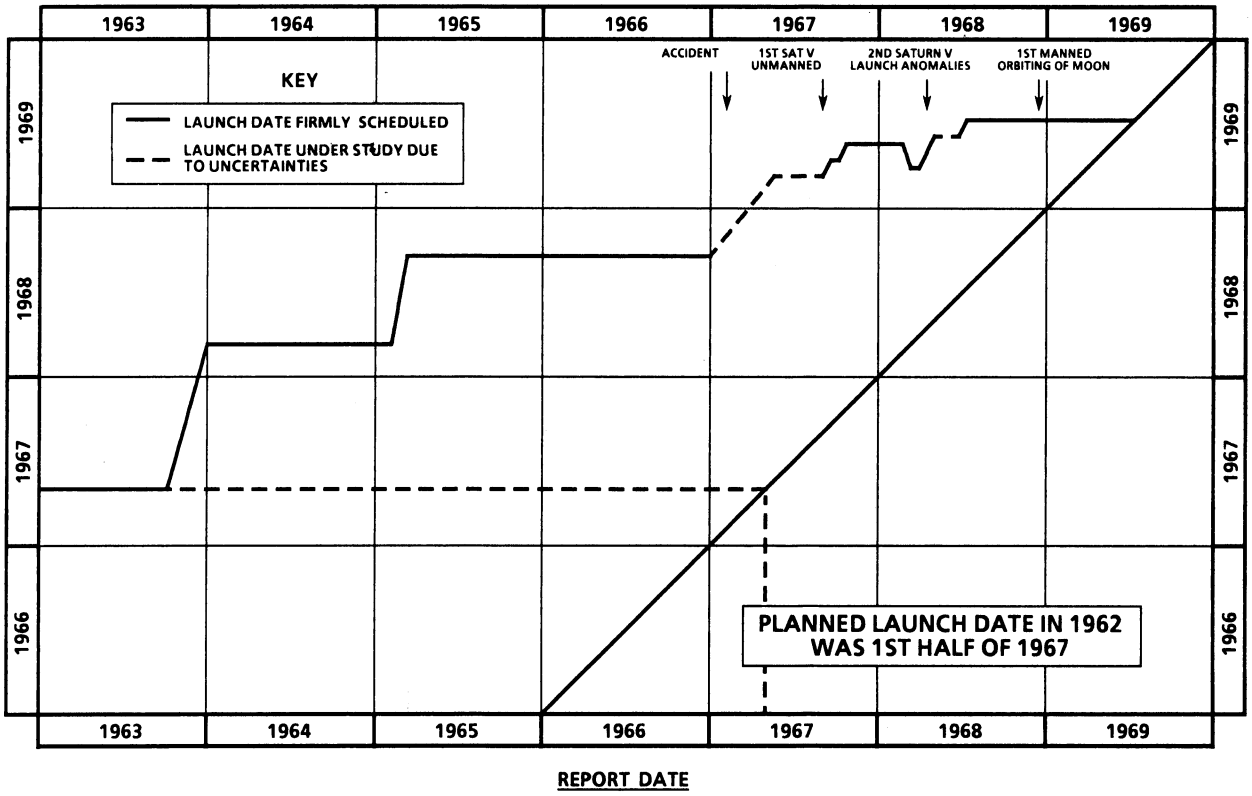

Figure 2. The Apollo Program Trend Chart.

Space Flight organization of NASA Headquarters. Note that the Apollo Program box appears in the NASA command structure just as any functional or institutional segment would appear, reporting to the Associate Administrator, who, in turn, reports directly to the NASA Administrator.

Figure 4 depicts the Apollo Program management structure. Some of its features require special attention in order to thoroughly understand the actual arrangement.

The Associate Administrator for Manned Space Flight at the same time chaired the Management Council. Its membership consisted of the Associate Administrator's deputies and the field Center directors with their deputies. Acting in a directive role, the Associate Administrator passed instructions to the field Center or to the Apollo Program Office. In turn, the Center director, through membership on the Management Council, had a direct voice in shaping the program direction which comes to the Center for execution. The Council met once a month or at the direction of the Associate Administrator, its Chairman. At these meetings, the Apollo Program Director in Washington and the project managers of the field Centers reported to the Council. The project managers included the Saturn V Manager from the Marshall Space Flight Center, the Apollo Spacecraft Manager from the Manned Spacecraft Center, and the Manager for Apollo launch preparation at the Kennedy Space Center.

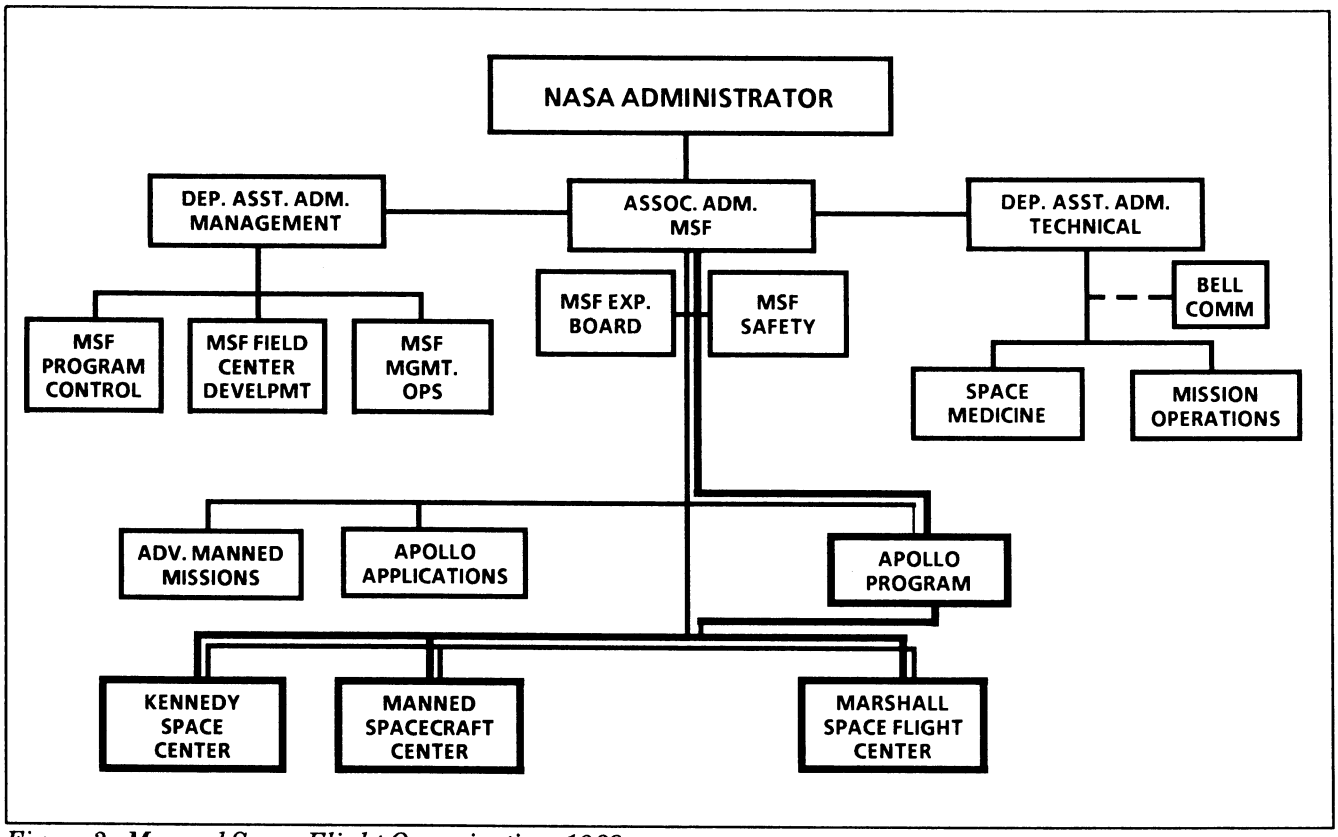

Figure 3. Manned Space Flight Organization, 1968.

The topic of these presentations covered, among others, the following principal areas:

- Where did the money go and can we manage with the allotted funds remaining?
- What planned tasks have been accomplished and can we meet the projected schedule?
- What are our major technical and programmatic problems and what previously unforeseen actions must be taken to overcome them?
- What are our motivational problems?

The Design Certification Review (DCR) was part of the Management Council meetings and the certification was signed by the Chairman and the three Center directors.

Five organizational segments reported directly to the Apollo Program Office. They were the major units through which the program director managed the program. Corresponding to this organization was the field Center's organization with exactly the same segments. The names of the boxes are self-explanatory. A similar organizational structure was set up at the prime contractors, to the extent that such was necessary.

Figure 5 indicates the manner in which the contractors, prime and sub, may relate to a project. The diagram in this case pertains to the Saturn Project at the Marshall Space Flight Center and the corresponding contractor structure. Of particular interest here is the relationship between the institutional technical capability and the project manager on the one hand, and this capability and the contractor on the other.

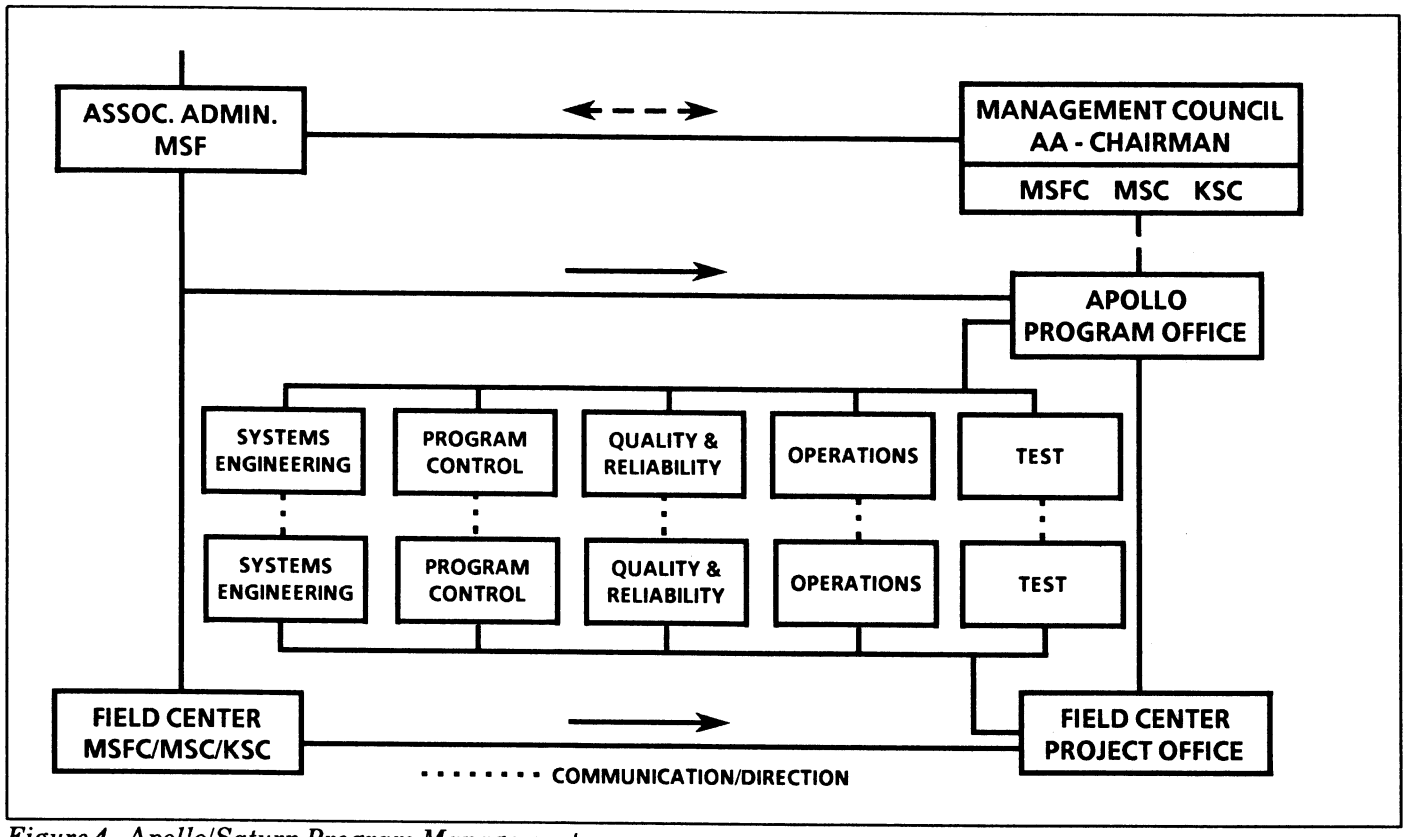

Figure 4. Apollo/Saturn Program Management.

The ready access that the project director had to the engineering expertise of the Center was of particular importance in maintaining real-time project visibility and control. For maximum effectiveness, the institutional capability must respond to specific requests and maintain continuing surveillance, thus exposing unsatisfactory technical trends early enough to allow preventive measures. As an additional contribution, the in-house technical capability may and frequently did respond to requests from the prime contractor.

Other areas of the Apollo Program that were of great significance to the program management are:

- The system logistics: that is, transportation of hardware from manufacturer to launching site, supply of propellants, pressurants, spare parts, etc.;
- The safety and security system;
- Astronaut training with all the training hardware and simulators;
- The medical aspects of the expedition;
- The organization and management of the scientific endeavor;
- The determination of the landing sites on the Moon;
- The ground organization and the worldwide network for tracking and data acquisition during a mission. Sixteen stations distributed around the Earth had to be operated, many in foreign countries; and
- Finally, the planning of the mission operation and the mission operation itself.

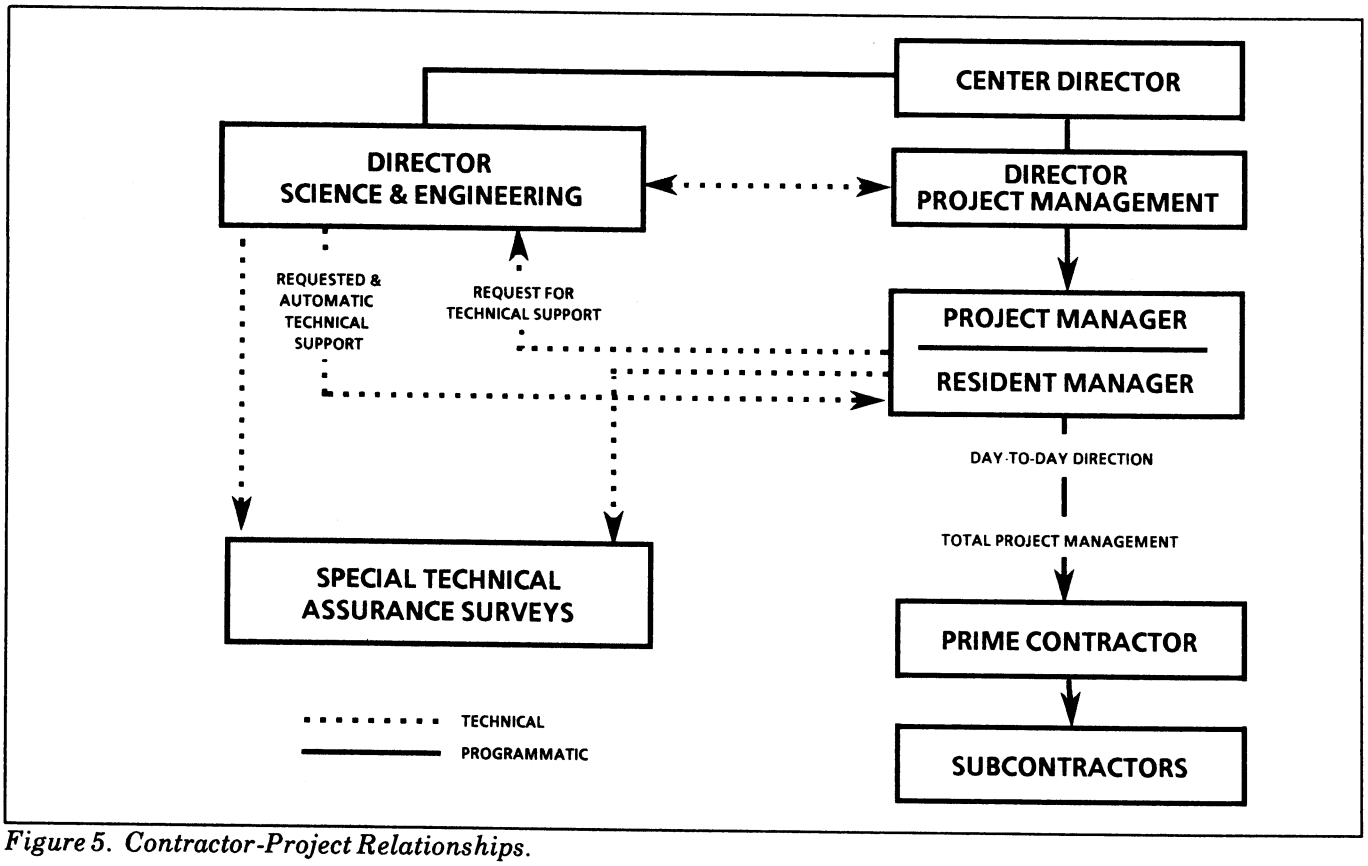

Figure 5. Contractor-Project Relationships.

All these subjects comprise major activities which had to be integrated into an overall management system. In order to provide maximum control and visibility of the system and of all occurrences in the program, a system of control rooms was established. These rooms contained up-to-date information and displays and were located at the Apollo Program Director's Office in Washington and at the three Manned Space Flight Centers and at each prime contractor. Each control room was equipped to permit conference calls between Headquarters and the Centers. This communication system furnished a means for greatly accelerating the decision-making process.

I should now like to explain the matter of integrating the project office, the functional elements of the institutional organization, and the contractor. Three categories of concern emerge. First, there are the hardware, systems and subsystems specialists who devote attention to the delivery of items that are technically adequate and qualified for mission performance. Second, there are the specialists who approach the project from the point of view of controlling costs and schedules. As the third organizational element in the grouping, there is the on-site resident management office. Staffing this latter element were specialists located at the contractor's facility to assure that project management interests were advanced and that decisions were made and implemented within the designated scope of authority of the resident group.

This resident element proved to be a most important link between government and contractor activities. To expedite decisions, the resident manager required functional support, which was provided by specialized, on-site contract administration and technical engineering staff. These support personnel were assigned from parent functional organizations of the responsible Center. Within well-established limits, these people could make decisions "on the spot" or commit the parent office or function at the Center. The result was

to speed the project management process and to provide a dynamic interface with the contractor on a continuing day-to-day basis. It was in this relatively small unit that the relationship of project management and functional discipline was most clearly mirrored; where the integration of technical and managerial personnel became most apparent. This unit also provided a mechanism for tempering the varying emphasis on government project and functional groups in the contractor organization. For example, the technical functions tend to strive primarily toward perfection to a degree that possibly inhibits adequate attention to manufacturing and launch schedules or cost. The contractor could well be oriented toward schedule, costs and profits, whereas the project manager might weigh concern more heavily on schedule and costs. Through the office of the resident manager, an automatic system of checks and balances developed to the end that each consideration received its appropriate share of attention.

Conclusion

A number of the points I have raised offer a high potential for solving difficult problems. One of these is the technique of contractor penetration to obtain visibility. There is an understandably strong desire on the part of industry to take the control and the funding and to do the job with but minor government intervention. However, there have been too many cases of severe program impacts when this alternative to close contractor surveillance has been permitted. The restiveness that stemmed from such close control gradually dissipated early in the Apollo Program as the benefits accruing from the industry-government teams approach were revealed.

In forming the project or program offices, it is clear that the manager must have control of competent technical and administrative staff in order to conduct activities efficiently. In the event that such competence is not available, a vital principle would be jeopardized -- that of responsibility requiring adequate authority. Competent staff members must be drawn from the functionally oriented disciplines.

Yet another aspect of personnel concerns the disposition of people upon termination or completion of a program. It is not sufficient to relegate them to positions formerly held, particularly in the case of technical persons. If a new program is forthcoming, the problem is eased somewhat, although it is highly likely that retraining or refresher education will be required. In any event, the transition from program management status back to a technical activity in a laboratory can indeed be traumatic. It is here that the institutional leadership must be asserted on the highest plane.

While centralized program management has many values, of prime importance is the assignment of all responsibility to single organizational management structures, pyramiding into a single strong personality. This prevents fragmenting vital responsibility among numerous individuals with subsequent loss in time, money, manpower and technical progress. Of course with the responsibility, the manager must have commensurate authority to resolve technical, financial, production and other problems that otherwise require coordination and approval in separate channels at different echelons. And the manager must have clear, concise communications flowing in all directions.

With these tools, program management can apply all the capabilities -- technological, sociological, economic, or whatever -- to any project and systems problem, however large or complex it might be.