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# THE PROJECT SCIENTIST'S ROLE IN SCIENTIFIC SPACECRAFT PROJECT MANAGEMENT

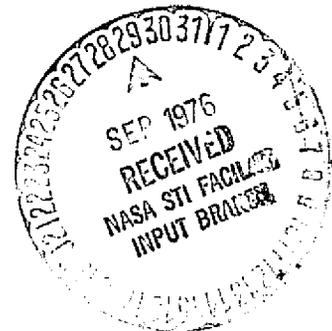
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EVAN LOGAN ELLER

JULY 1976



— GODDARD SPACE FLIGHT CENTER —  
GREENBELT, MARYLAND

THE PROJECT SCIENTIST'S ROLE  
IN SCIENTIFIC SPACECRAFT  
PROJECT MANAGEMENT

By

Evan Logan Eller  
B.S. June 1969, Virginia Polytechnic Institute

A Thesis submitted to  
The Faculty of  
The School of Engineering and Applied Science  
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July 1976

GODDARD SPACE FLIGHT CENTER  
Greenbelt, Maryland

# THE PROJECT SCIENTIST'S ROLE IN SCIENTIFIC SPACECRAFT PROJECT MANAGEMENT

Evan Logan Eller

## PREFACE

Casual observation reveals two features of the NASA project scientist position which are significant from an organizational planning point of view.

One is the diversity of activity and contact with many colleagues which characterizes the position. The project scientist contributes in many different ways to the mission's scientific success primarily through interaction and influence with many key people on the project. In addition, he conducts his own research activities, generally including an experiment on the same project. Accordingly, the project scientist may serve as a useful model for defining other research and development (R&D) positions.

The other aspect of the position concerns the management development of scientists. It has been found that temporary or part time managerial assignments are desirable as testing grounds for technical people who are potential managers. These positions provide a means for measuring both talent and disposition for managerial work. The functions of the project scientist appear to have a high managerial content, and, being a part time assignment, it may serve well as a management intern position.

Significant changes have occurred over the past ten years in the project scientists organizational environment at NASA. The purpose of this paper is to examine the role of the project scientist in order to measure how well it embodies the two features just described and how these environmental changes have affected those features.

In order to provide a basis for measurement, the results of behavioral studies and their organizational implications are given. A similar basis for measuring the project scientist's functions in terms of management development is supplied by presenting findings on the need for, and desirable characteristics of, such development programs in R&D organizations. A description of the organization of projects which are initiated from the Office of Space Sciences and executed at Goddard Space Flight Center will be given. The author believes that the project scientist's position is so characterized by its interaction with

project participants that it can only be understood in terms of its organizational context.

The data for this paper is supplied by interviews with project scientists and some of the principal people with whom they interact on the project. Half of the project scientists' interview is concerned with the nature of their project duties in comparison with their other work to see what professional development those duties supply. The purpose of the other half of their interview and those with other project members is to get a balanced view of the way projects are run. This should supply a more accurate description of the organizational environment in which the project scientists work and indicate the personal characteristics which are most important in filling the position.

This work is limited to projects which originated in the Office of Space Sciences and were managed from Goddard Space Flight Center. However, the author believes that the analysis has implications beyond this context to include federally-directed R&D efforts in general. It also does not include any cost analysis on the belief that long term overall cost effectiveness of research cannot be realized without careful position definition and personnel development.

The author would first like to thank those who agreed to take time from their busy work schedules to participate in the interviews. Their candidness is appreciated as it provides the mainstay of this paper. I would also like to thank Dr. Sam Rothman for guidance in the preparation of this thesis, Dr. Jacob Trombka, who gave me support and encouragement, and Dr. George Pieper, whose suggestion resulted in the topic chosen. Special thanks goes to my mother, Diane Eller, whose typing contributed to this paper's timely preparation.

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# THE PROJECT SCIENTIST'S ROLE IN SCIENTIFIC SPACECRAFT PROJECT MANAGEMENT

## I. INTRODUCTION

### Motivational Theory and Research

Research and development require individual initiative on the part of the scientist. For seeking a more accurate representation of the truth or designing a new measurement device, no external inducement alone can provide the motivation for the creativity which is necessary. No amount of organization, planning, or controls will succeed without this motivation. For this reason any discussion of scientific job definition must begin with motivational theory and research.

Motivation can be described in terms of satisfying needs. Maslow defined a hierarchy of needs which is given below, with clarifying subheadings.

#### Maslow's Hierarchy of Needs

1. Physical — physiological
2. Safety — survival
3. Social — fellowship
4. Ego — dignity
5. Self-actualization — sense of accomplishment

The title hierarchy refers to Maslow's assertion that the higher level needs become dominant as the lower (physical) ones are satisfied. What is significant about the higher level needs is that they are motivators which are intrinsic to the performance on the job itself. An occupation can supply needs away from work by providing wealth and status, but the ultimate motivation, especially for creative people, is the activity itself which is meaningful in terms of their own identity. Ideally this is the level on which scientists operate. However, the lower level needs must be reasonably satisfied in order for someone to effectively operate at this level. When the work climate motivates self-actualization — where a person can behave as much like the person he thinks he is — the scientist will voluntarily give his best and enjoy it. His creativity and productivity

will increase. When it prevents self-actualization, he will cooperate only as much as he must, and creativity will decline.<sup>1</sup>

Rathe and Irani describe four kinds of higher level needs which are important motivators for scientists and engineers. They are: recognition, growth, responsibility, and achievement. Achievement and recognition are related in that recognition should be self-earned. Growth is especially important, both in terms of professional and personal development. It is intrinsic to self-actualization, particularly for creative people. Such people are very sensitive to the difference between what is and what could be, even in themselves. Since a person's self-concept is constantly changing, growth is a never-satisfied motivator whose importance never disappears and whose absence can frustrate creativity. Growth can include increases in knowledge, responsibility, communication, breadth of viewpoint, activity, independence, range of perspective, and modes of behavior. Hence, there are many ways a job can satisfy this need. Varied activity is one way to experience growth; but for maximum motivation, that activity should lead to growth in the direction that the person feels is right for him. Responsibility encourages self-reliance and the feeling that one is contributing something of real value.<sup>2</sup>

The same study summarizes the guidance of technical people into three steps designed to satisfy those higher level needs: stimulation, challenging work situation, and personal and professional development.<sup>3</sup> The delegation of difficult tasks is a motivator of highest power, but the objective of the task must be clearly explained and feedback on performance is necessary so the individual knows how he is doing. The delegation contributes to growth and responsibility, and the feedback contributes a feeling of achievement. They also referred to management practices based on motivational theory as participation, job enlargement, and goal connecting. The essence of participation is that individuals have a meaningful hand in the management of the work. This is in some sense the delegation of managerial responsibilities. It is only limited by the time required, and the skill and attitudes of those involved. Job enlargement broadens the individual's functions and responsibilities, and makes his job's relationship to overall objectives clearer. This adds to his personal growth and his sense of achievement. By goal connecting, both the individual and the organization adjust their goals until the individual will reach his goals through working;

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<sup>1</sup>Alex W. Rathe and Dhun Irani, Scientists, Engineers and Managers – Partners in Space (New York: New York University Press, 1968), p. 32.

<sup>2</sup>Ibid., pp. 43-46.

<sup>3</sup>Ibid., pp. 113-118.

toward those of the organization.<sup>4</sup> This is growth in its most motivating form — self-actualization.

Pelz and Andrews performed a study which confirmed motivational theory in more specific terms and produced additional interesting findings. They correlated a number of personal characteristics and organizational situations with several measures of performance. These measures included numbers of papers or patents, rated scientific value and overall usefulness to the organization. While they made distinctions among several types of technical workers, only PhDs in government laboratories and non-PhDs in PhD-dominated laboratories are applicable to this paper. Most of their conclusions apply to all groups, though in some groups the implication is stronger than in others.<sup>5</sup>

They found the following qualities to be generally associated with the most effective scientists:

1. They were directed by their own ideas and valued freedom, but also interacted vigorously with their colleagues, allowing several other people a voice in shaping their directions.
2. They had diversified work, maintaining an interest in both applications and pure science.
3. They were not fully in agreement with their organizations in terms of their interests.
4. They had motivations similar to their colleagues, but differed in style and strategy with which they approached their work (e.g., abstract vs. concrete, broad vs. deep). This was particularly true for innovative scientists.
5. Effective older groups interacted vigorously, maintaining some tension through disagreement on technical strategies,<sup>6</sup>

These findings plus those correlating variations of performance with variations in climate or work environment resulted in the following conclusions and recommendations.

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<sup>4</sup>Ibid., pp. 53-60.

<sup>5</sup>Donald C. Pelz and Frank M. Andrews, Scientists in Organizations (New York: John Wiley and Sons, Inc., 1966) pp. 318.

<sup>6</sup>Ibid., p. 7.

A balance of freedom and coordination gives the most productive environment. Overall performance was actually lower where scientists had too much freedom.<sup>7</sup> The probable cause is lack of external stimulation, either interaction with diverse colleagues or a feeling of mutual influence with other echelons of the organization. Contacts with many colleagues both within and outside one's own group are beneficial, although less so for non-PhD scientists, and a large number of colleagues is best. The reason for this may be that they provide new ideas as well as a testing ground for the scientist's own ideas.<sup>8</sup>

Diversity is helpful, both in terms of developing several specialized technical fields and in mild exposure to administrative duties. Scientific review conferences where future directions are outlined are good means of managerial experience.<sup>9</sup>

Dedication to one's work enhances performance. What encourages dedication is more interesting: ability to influence others who have substantial weight over one's technical goals, and recognition of any kind.<sup>10</sup>

Inner motivation and interest in broad mapping of new areas were correlated with high performance. In agreement with Maslow, it was found that motivation should come from the job content which is challenging and with important chances for achievement. Consistent with this, extrinsic rewards (e.g., money or status) are considered unreliable motivators,<sup>11</sup> but must be awarded according to achievement, when it occurs.<sup>12</sup>

Creativity was found to be helpful as would be expected. This was particularly true for people working on a project or specializing in an area for a relatively short time; where coordination was not high; where there was influence with decision makers and a high level of communication. There was inconclusive evidence that creativity may hurt performance in restrictive situations.<sup>13</sup>

Investigators midway in their careers did best if they had broad interests. There tended to be a decline in the 40s of performance, but the strongly motivated

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<sup>7</sup>Ibid., 32.

<sup>8</sup>Ibid., pp. 51-53.

<sup>9</sup>Ibid., pp. 77-78.

<sup>10</sup>Ibid., p. 88.

<sup>11</sup>Ibid., pp. 108-110.

<sup>12</sup>William W. Metz, Behavioral Science and Research and Development Management (Eglin Air Force Base, Fla., 1969), p. 44.

<sup>13</sup>Peiz and Andrews, Scientists in Organizations, p. 171.

individuals resisted this trend. Pelz and Andrew recommended mid-career switching from pure research to applied or more administrative roles as a means of reviving motivation. Alternatively, government senior scientists seemed perhaps too broad, too willing to change, and showed the sharpest decline in later years productivity. It was suggested that they should insist more on their own ideas and their personal growth.<sup>14</sup>

As the work environment becomes looser, a high level of either internal motivation or external stimulation is increasingly important for high achievement. Autonomy is most useful where coordination is fairly high.<sup>15</sup>

Basic research PhDs in particular benefit from high levels of communication, competition between groups, and new areas of research.<sup>16</sup>

Older research groups tended to be more relaxed, less talkative, less competitive, and more inclined to specialize. Those that resisted these tendencies were more likely to remain high performers. Older groups should not be allowed to become local "experts" on a given area, but rather should be assigned jobs outside their special field.<sup>17</sup>

Metz extracted some generalizations from these findings. Technical men were effective when their environment was challenging, in such ways as having associates with divergent views, and also when they had protection from external demands.<sup>18</sup> Influence with management is one form of self-protection from such demands. Such protection allows freedom of research and specialization by providing stability and security. This finding supports Maslow's theories on motivation, namely that higher level drives, which are necessary for creative research, can only be fully operative if the lower level drives are reasonably satisfied.

The root to all these findings can be found in individual growth and influence. Growth is achieved through increased and broadened responsibility, knowledge, skills, and equally importantly, influence. Growth may have to be encouraged, particularly in young scientists, by challenging assignments which require it. In senior scientists most often all that is needed is support, recognition, and the removal of barriers. Influence, both as input and output, is expressed in

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<sup>14</sup>Ibid., pp. 196-199.

<sup>15</sup>Ibid., p. 231.

<sup>16</sup>Ibid., p. 239.

<sup>17</sup>Ibid., p. 259-260.

<sup>18</sup>Metz, Behavioral Science and Research, p. 41.

such ways as determining one's own strategy, frequent interaction with colleagues, as well as ready access to higher-ups. Influence is the key element of the environment which allows both security and stimulation. The scientist has the security of knowing that arbitrary decisions will not be made about his research budget or objectives without being able to have an influencing input. Conversely the interests of upper management provide a stimulating influence against which he must argue for his chosen research objectives.

## II. ORGANIZATIONAL IMPLICATIONS FROM BEHAVIORAL FINDINGS

### General Implications

The implications for an organization suggested by Pelz and Andrews studies have been compiled by others:

1. Organizational structure should have fewer levels so that the individual can exert more influence.
2. Face-to-face interactions between scientists, engineers, and other significant people in R&D should be encouraged.
3. Broaden the channels of communication.
4. Establish study teams; pose problems which require consultation for solution.
5. Encourage groups and individuals to tackle both "pure" and "applied" problems.
6. Give scientists a share in the decision-making process, thereby getting them involved in, and committed to, the technical goals. Arbitrary decision making about funding with little control by the scientist is likely to breed cautious dependence, rather than the independent self-confidence which is necessary for creative performance.
7. Competition with other groups in the solution of technical problems can strengthen motivation and teamwork. Mild competition within a group can also be helpful; invite members of established groups to look for flaws in each other's presentation.
8. Form groups of diverse composition. where creativity is needed, to provide intellectual excitement. Periodically regroup teams, with the consent of the people involved.
9. Challenge expert groups by giving them a task outside their specialty.<sup>1</sup>

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<sup>1</sup>Metz, Behavioral Science and Research, pp. 41-45; Floyd C. Mann, "The Researcher and His Working Environment: Research Findings and Their Applications." U.S. Air Force Office of Scientific Research. Proceedings of Thirteenth Science Seminar (Albuquerque, N.M., 1968), p. 43.

A common thread through all these recommendations is that they encourage the scientists to have stimulating interaction with as many of the people who relate to his work as possible. These include scientists working in the same or related fields, engineers who are doing related development, or the managers who take part in determining objectives. In order for the interaction to have a motivating effect, it must be stimulating. This can be achieved if there is a high level of mutual influence. All parties anticipate that as a result of the encounter they will affect the subsequent actions of the other and will themselves be affected by them.

In the case of interactions with management, influence, decision-making and goal-setting has a synergistic effect both by bringing additional thought to bear on a decision and by increasing the motivation and performance of those involved. Hollingsworth asserts that the good researcher is most often right about the choice of projects; the higher up the choice is made in management, the more likely it will be wrong.<sup>2</sup> However, top management must set the overall goals, providing the criteria as to the areas in which not to work.<sup>3</sup> By bringing both into the decision process, the most satisfactory program can be designed.

By assigning tasks outside an expert group specialty, they are forced to learn from the experience of those already in that other specialty while contributing fresh ideas of their own.

Van Atta explained why research effort in a mission-oriented organization is more productive when it is combined with advanced development. The exchange between people doing research and those in development results in researchers becoming aware of basic problems and development men learning of opportunities for application.<sup>4</sup> For similar benefits within research, an adequate range of disciplines must be represented within the organization to cover a broad area of interest. Vollmer added another advantage. Information transfer from research to development is sometimes most easily accomplished by moving personnel, and such moves are facilitated by being within an organization.<sup>5</sup> Fortunately, that is the most often chosen move for technical people to make.<sup>6</sup>

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<sup>2</sup>Guilford L. Hollingsworth, "Planning Phenomena-Oriented Research in the Boeing Company," Center for Technology and Administration. Proceedings of Twelfth Institute on Research Administration (Washington, D.C., 1967), p. 8.

<sup>3</sup>John K. Galt, "Planning Phenomena-Oriented Research in the Bell Telephone Laboratory," Proceedings of Twelfth Institute on Research Administration (Washington, D.C., 1967), p. 11.

<sup>4</sup>Lester C. Van Atta, "Planning Phenomena-Oriented Research in NASA," Proceedings of Twelfth Institute on Research Administration (Washington, D.C., 1967), p. 23.

<sup>5</sup>Howard M. Vollmer, Center for Technology and Administration. Proceedings of Twelfth Institute on Research Administration (Washington, D.C., 1967), p. 29.

<sup>6</sup>Galt, Proceedings of Twelfth Institute on Research Administration, p. 29.

In experimental research, particularly of the type characterizing space research, communication not only enhances performance, it is a requirement. The success of an individual is dependent on meaningful cooperation with many other people. Communication affords opportunities for these necessary constructive relationships. The communications network should allow the flow of information of both internal and pertinent external events, and minimize "filters" which impede flow. Informal communication flow should be encouraged as it is usually faster than formal, and will help compensate for unavoidable shortcomings of the formal system.<sup>7</sup>

In general, less structured and more flexible arrangements have been found to be superior where the emphasis is on the individual's contribution. This is related to management by objectives. Within general policy restraints, the means of carrying out an assigned objective is left to the subordinate. The objective must be more clearly understood by all involved though, if this is to work. Furthermore, in making the objective understood, the same synergistic effect referred to previously occurs. Additional thought is applied to the decision and motivation is increased.

Prerequisites for research planning which are not directly related to communication and growth, but are based on motivational thinking are given by Van Atta. The research program must have a stable budget and be free from short-range engineering and mission responsibilities.<sup>8</sup> These are both examples of the need for security before higher level motivations can be effective.

### Projected Organization

Much of the research today is dependent upon large endeavors involving the building of very complex hardware. This is particularly true of space research in which information is gathered using instruments on spacecraft. In order to have the close communication and influence, as well as the control, which are necessary for the maximum return from these endeavors, the project organization evolved. Under this type of organization, responsibility for the execution of the project is concentrated in a separate group. The advantages of project organization are considerable. A table of the merits and problems of this system can be found in the references.<sup>9</sup> In short, it permits unified direction, control and dedicated effort on projects that require considerable accomplishments

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<sup>7</sup>Rathe and Irani, Scientists, Engineers and Managers, p. 86.

<sup>8</sup>Van Atta, Proceedings of Twelfth Institute on Research Administration, p. 25.

<sup>9</sup>Metz, Behavioral Science and Research, pp. 47-49; Rathe and Irani, Scientists, Engineers and Managers, p. 88.

within established schedules and costs. It embodies the essentials of delegation of authority (i.e., influence, participation) in that almost total responsibility for the project is delegated to the project personnel. Within the project the management style varies according to demands of the situation. During the early developmental stages, the style appropriate for research achieves the best results. As the project goes into implementation, and/or external variables such as external schedules affect the project, a more authoritarian hierarchical management achieves greater success.<sup>10</sup> It is still important, though, to rely on influence more than authority, to maintain mutual trust, and have a high level of communication between participants in the project.

Matrix organization is a variation of project organization with the advantage of more flexible use of personnel. Functional organizations are maintained where non-project work is performed more or less continuously. The project has a small central staff to maintain continuity within the project and scientists and engineers from the functional divisions participate in the project as they are needed.

Two aspects of project organization are relevant to scientists and management. It provides very broad management experience for those who participate in the project office, training them potentially for upper management positions. The environment, on the other hand, is quite different from that which is considered desirable for creative scientists. Accordingly, some feel that genuinely creative scientists, who exhibit the individualism of a fundamental researcher, are wasted in a project and will not contribute to its progress.<sup>11</sup>

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<sup>10</sup>T. Roger Manley, "The Project Manager's Lament: 'If Only...'", Institute of Electrical and Electronics Engineers, Inc. Proceedings of the National Aerospace Electronics Conference (Dayton, Ohio, 1973), p. 109.

<sup>11</sup>Robert H. McIntire, "The Engineer and Project Management," Institute of Electrical and Electronics Engineers, Inc. Proceedings of the National Aerospace Electronics Conference (Dayton, Ohio, 1973), p. 125.

### III. MANAGEMENT DEVELOPMENT OF ENGINEERS AND SCIENTISTS

In an organization in which attention is paid to the motivations of technical people, management development is a natural part of encouraging growth. When jobs are defined to include high levels of participation and influence, and technical people are allowed to manage their own work (management by objectives), then the manager's job does not seem so different from that of the scientist. The model in Figure 1 shows this relationship.

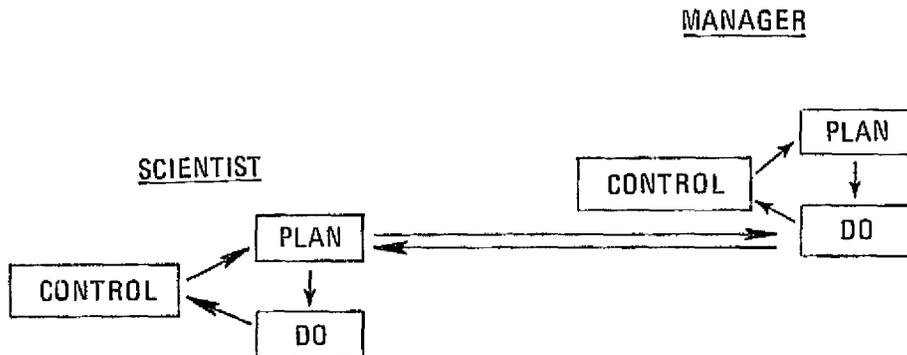


Figure 1. Model of the Manager-Scientist Relationship

The form of each job is the same. The content of each block within the job is different.<sup>1</sup> In the case of the lower level supervisory type management positions, the content difference may itself be small. Supervisory positions often evolve as a natural consequence of one's technical growth, or the size and scope of the job that is being managed.

It is the non-supervisory type management positions, where one is not directly leading technical work but is more involved with project or program direction, that may require training for those filling them.

Management development is generally more difficult for scientists than for engineers. Because development is usually more closely connected to the organizational goals than the science that preceded it, and involves more managerial consideration such as schedule and cost than does research, engineers' goals

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<sup>1</sup>J. C. Sawatsky, "Theory of Managing Scientific and Professional Personnel," Journal of the Canadian Aeronautics and Space Institute, XV (February, 1969), p. 38.

usually are more closely aligned with those of the organization.<sup>2</sup> Engineers generally measure success against internal organizational standards. It is not surprising then that most engineers initially aspire to positions in management, while most scientists have extremely negative feelings toward it as a profession.<sup>3</sup>

The typical relationships between science, engineering and upper management is depicted by the model in Figure 2.<sup>4</sup>

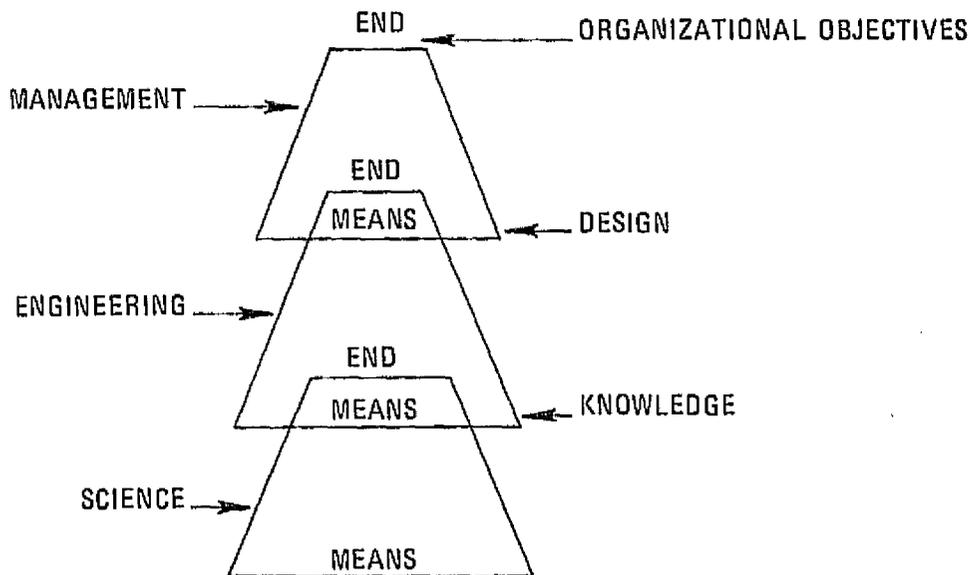


Figure 2. Model of the Means-End Relationships Between Science, Engineering and Management

However, in an organization such as the Office of Space Science, the overall objectives are themselves primarily scientific. It is important then that people who hold responsible positions have at least enough scientific background to be able to understand those objectives. Furthermore, basic knowledge is required

<sup>2</sup>Todd R. LaPorte, "Technical Professionals in Complex Research Organizations – A Structure Process Perspective, Part 1" (internal working paper 75, Space Sciences Laboratory, University of California, Berkeley, Nov. 1967), p. 19.

<sup>3</sup>Vladimir V. Berniklau, "Management Development of Scientists and Engineers in the Federal Government: An Analysis of Basic Behavioral and Systems Considerations" (unpublished Masters thesis, University of New Mexico, 1970), p. 29.

<sup>4</sup>Rathe and Irani, Scientists, Engineers and Managers, p. 19.

at all levels to ask the right questions of the specialist,<sup>5</sup> to be competent to evaluate technical performance, and to judge what attributes are required for conducting research in large organizations. It would weaken the organization by increasing the strain between the scientists and management if the managers lacked these capabilities. Unable to use professional influence, they would have to use authority alone in giving direction to the scientists.<sup>6</sup>

These assertions are supported by findings, listed below, about the supervisors of effective work units.

1. They were similar in age and educational achievement with the scientists in the section.
2. They identified the professional colleagues in their part of the agency as their most important reference group.
3. They tended to attach high importance to those work goals that are characteristic of the scientific professional.
4. They saw R&D efforts as being crucial to their agency's basic mission.<sup>7</sup>

It is important then to develop scientists from within the organization to be able to fill managerial positions. Scientists do have some traits which are useful for the managerial role: objectivity in solving problems, planning ability, motivation toward higher productivity, intellectual curiosity, perseverance, and the mathematical background to handle new management techniques.<sup>8</sup>

However, there are problems to be overcome in transforming scientists to managers. One obstacle is the value divergence between science and management previously referred to. This can cause problems for the scientist when he begins working in a managerial position. Sources of conflict that management may present for the technical man include: emphasis on people rather than things; uncertain criteria for making decisions; the necessity of basing decisions on conditions which seem contrary to rigorous technical theories; problems which have several acceptable solutions rather than one correct one. He loses direct control of the technical work and now must accomplish it through other people, and he is afraid of losing his image as a scientist with those

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<sup>5</sup>Berniklau, "Management Development of Scientists," p. 77.

<sup>6</sup>LaPorte, "Technical Professionals in Complex Organizations," p. 28.

<sup>7</sup>Mann, "The Research and His Working Environment," pp. 35-36.

<sup>8</sup>Berniklau, "Management Development of Scientists," p. 25.

people.<sup>9</sup> In addition, the person may have some inner conflicts as to whether he wants to make the change or not. He may not know if he really wants to do managerial work or if he actually has talent for it. He may lack confidence because he has little training for managerial work. By contrast he has many years training in his scientific field. There may be conflicts between his perceptions of his ability, interests, and the reward system that is important for him. He does not know which combination of them will best lead him to a satisfying situation several years later, and it may be difficult to return to research after a few years.<sup>10</sup> Considering all the potential problems, it may be necessary in some instances to compromise scientific ability to get the equally important managerial skills.

The decision is eased somewhat in many organizations by establishing a "dual ladder approach" to advancement. NASA uses this approach which in theory allows advancement through non-managerial positions comparable in level to most management levels. The transition from one column of advancement to the other can be made at any level<sup>11</sup> so the individual is less likely to feel pressure about making an irreversible decision.

To facilitate the transition, training needs to focus not only on the skills required but also on the areas of difficulty given above, namely, human relations and changing attitudes. At least at higher levels, managerial performance is as much a matter of attitudes as of knowledge and skills. New attitudes are learned either through identification or internalization. Identification occurs when someone is coached into a new job or learns by being an assistant to someone. Internalization occurs when new attitudes are demanded to solve problems in a particular environment.<sup>12</sup>

A description given as the only complete way to achieve internalization sounds suspiciously like brainwashing. It begins with unfreezing, whereby all support is removed for the old attitudes and the environment is saturated with the ones to be acquired under conditions of minimal threat and maximum support for changes in the right direction. For these conditions training should take place away from work. Refreezing is the integration of the new attitudes into the individuals personality, through superior and peer support, so that he becomes aligned with the new group norms.<sup>13</sup>

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<sup>9</sup>Ibid., pp. 21-26.

<sup>10</sup>Rathe and Irani, Scientists, Engineers and Managers, p. 29.

<sup>11</sup>Ibid., pp. 27-28.

<sup>12</sup>Berniklau, "Management Development of Scientists," pp. 48-49.

<sup>13</sup>Ibid., pp. 50-52.

Such methods do not seem appropriate for most senior level scientists, whose value system would not be conducive to the success of such a program. For attitudes to be adopted requires that the individual feels a need for the change stronger than the need supporting the old attitudes. External inducements alone will not result in any real or continuing attitude change.<sup>14</sup> This suggests that a training program which includes identification or coaching may be the most useful.

A study of the transformation of scientists and engineers into managers was done for NASA by Bayton and Chapman of the National Academy of Public Administration, and published as a NASA document in 1972. They interviewed scientists and engineers at both NASA and the National Institute of Health (NIH) who were now working at various administrative levels within those organizations, including non-managerial, supervisory, non-supervisory managerial, and senior managerial positions. They analyzed management according to three dimensions: the component functions or tasks to be performed; the skills and abilities used in performing the tasks; and the motives which give positive or negative meaning to participation in the managerial role.<sup>15</sup>

Their questions on the functions of management confirmed that "bench" scientists and engineers do perform them. However, the frequency and breadth of their performance of these functions increased as they moved into managerial positions. Those functions showing the most frequent increase were: budgeting, staffing, supervising, policy-making, representing the organization, and program assessment. For NASA "bench" scientists, who as a group reported the lowest frequency of management functions, planning and reporting can be added. Most respondents at all levels said that none of the functions were especially difficult to perform. Approximately 40 percent of the bench respondents said none of the functions was particularly important in the work of a manager, confirming the negative feelings of technical people toward management.<sup>16</sup>

Out of a list of sixteen skills used in management, ten were considered to increase in importance: operating within the organizational system, operating within the financial system, operating within the personnel system, recognizing and coping with environmental factors, working with diverse people, coordinating group effort, leadership style, generation of confidence of superiors, integrative ability, and decision making. NASA management also perceived communication

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<sup>14</sup> Ibid., p. 53.

<sup>15</sup> James A. Bayton and Richard L. Chapman, Transformation of Scientists and Engineers into Managers (Washington, D.C.: National Aeronautics and Space Administration, 1972), p. 1.

<sup>16</sup> Ibid., pp. 27-48.

of ideas as increasing in importance. Fundamental technology and application of techniques decreased in importance, and scientist-managers saw creative thinking as decreasing in importance. The reasons for difficulty with the first seven skills listed above were the same for all of them: lack of training, need to define problems and solutions within the organizational framework, broader scope of the work, responsibility for coordination of programs, new and different goals and objectives, conflict of self-interest with organizational interest, change from an introspective climate to an extroverted one, responsibility for the production of others, and considerations of political expediency.

The superiors of the lower level managers generally agreed that their subordinates had difficulty operating within the organizational system and also tended to view working with diverse people, leadership style and generation of confidence of superiors as being sources of difficulty in their subordinates.<sup>17</sup>

Concerning motivations, first line managers and specialists were in general agreement. The satisfaction potential of the following motivations were thought to increase when one moved into management: being a leader, liking to do detailed planning, contributing to the organization's goals, helping one's colleagues, seeking the support of others, exercising authority, and risk taking in decision making. The satisfaction potential of these motivations tend to decrease: making direct attack on problems, being independent, being recognized for accomplishments, and using technical knowledge and skills.

The system of rewards for scientists and engineers was found to be mainly within the profession. The system for managers was found to be mainly oriented toward scope of operation and exercise of authority. Both were said to contain achievement satisfactions and status satisfaction, though the context was different. There was more emphasis on financial reward in the managers reward system. About half of the NASA managers said that the only path to salary advancement was through management. This opinion was even more prevalent among non-managerial scientists, less with senior managers. All agreed that skill in a technical field should carry with it financial reward.<sup>18</sup>

As a result of this study, an Advisory Panel made recommendations for improving the transition of technical people into management.

1. Greater emphasis should be given to criteria other than technical competence in selecting potential managers. In particular, the selection

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<sup>17</sup>Ibid., pp. 53-70.

<sup>18</sup>Ibid., pp. 77-95.

process should provide evaluation of motivations, as well as other elements of managerial potential. To aid in this evaluation, potential managers should be assigned to ad hoc tasks which involve many management functions, such as temporary assignments to task forces or committee responsibility, where the individual must work with a wide variety of people in a way which requires more than technical skill.

2. The key training need is in the area of personal skills required to perform the managerial role. The main skills which need enhancing are the ability to cope with the organizational system and dealing with a broader cross-section of people, and a few specific management functions such as budgeting.
3. Lectures and reading are insufficient training. Intern-type assignments for new or potential managers should have wider use, as these tend to expose the individual directly to the organizational systems involved. Participation in these assignments should not jeopardize the individual in any way.
4. Senior level supervisors who are particularly knowledgeable of the organizational and operational subtleties should be identified to serve as an informal advisor to whom new managers can turn.<sup>19</sup>

Project work supplies many positions for engineers which can serve as trial or management development positions. There is a progression of jobs, independent of the functional areas, which give exposure to, or experience in, the broad management functions of projects. These are considered excellent preparation for upper management positions. It seems reasonable to expect that similar project positions could be made available for scientists, if they do not already exist. In order to determine this, it is necessary first to understand the way projects are run at the Office of Space Sciences at NASA.

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<sup>19</sup>Ibid., pp. 1-4.

#### IV. NASA'S ORGANIZATION FOR PROJECTS IN THE OFFICE OF SPACE SCIENCE

A brief description of the essential elements of project management at NASA will be given as background to the interview results which are to follow. Most of the information given in this chapter is taken from Project Management in NASA, NASA-SP-324, though minor updating has been necessary because of reorganizations since its publication. The reader is referred to that document, which is still essentially accurate, for a more detailed description of this subject.<sup>1</sup>

That NASA has incorporated modern behavioral and management research is reflected by this statement:

"The NASA concept of project management is based upon a philosophy of integrating the technical and managerial competence of industry, NASA laboratories, and university scientists within a system that could best be called one of participative responsibility."<sup>2</sup>

No single company, it is believed, has all the skills and experience required for the execution of a large space flight project. NASA uses its in-house management and technical competence to monitor closely, and to work with, the contractor, retaining the authority to use outside technical help in order to overcome problems. Organizational boundaries are not to interfere with the application of needed talent.<sup>3</sup>

NASA has incorporated project management into its overall organization. Headquarters is divided into program offices, including the Office of Space Sciences (OSS), each of which is responsible for many programs. A program continues over several years and usually includes several related projects which share common broad scientific goals. A project is an undertaking, within a program, with a scheduled beginning and ending. It normally involves the construction and operation of one or more space vehicles and ground support facilities in order to accomplish a scientific or technical objective. It is considered one of the strengths of NASA management that the general organizational structure, both at headquarters and at the centers, supports project type management.<sup>4</sup>

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<sup>1</sup>Richard L. Chapman, Project Management in NASA: The System and the Men (Washington, D.C., National Aeronautics and Space Administration, 1973), pp. 1-37.

<sup>2</sup>Ibid., p. 4.

<sup>3</sup>Ibid., p. 5.

<sup>4</sup>Ibid., p. 9.

Both programs and projects have managers who have the responsibility of executing them. A program manager is the senior person responsible for developing and administering the Headquarters guidelines under which the projects within the program are conducted. He is to balance project requirements with overall organizational requirements. The project manager is the senior official at the NASA field installation who controls the execution of the project.<sup>5</sup>

A typical project management structure for projects at the Goddard Space Flight Center (GSFC) originating out of OSS is shown in Figure 3. Though the line of authority is drawn from OSS, in practice it is delegated to the operating division for programs falling within their jurisdiction. The program manager is the principal staff man to the director of the program office, and will usually exert a substantial and perhaps determining influence on decisions. He receives support from a program scientist who is skilled in the discipline related to the principal scientific objectives of his program. Though no formal link is shown between the project and program managers, most information between them flows directly, rather than through the formal system.<sup>6</sup>

GSFC uses a modified matrix system for large projects. The project manager and his deputies for engineering and resources are assigned to the project office; some personnel remain assigned to the operating divisions, but are co-located with the project staff; others remain located with their respective divisions, but are assigned subsystems or major components for which they monitor and manage contractor execution.<sup>7</sup>

Figure 4 shows a simplified GSFC project organization. In reference to this figure is the only mention of the project scientist in this NASA document.

"The project scientist is a member of the Space Sciences Directorate. He provides the principal scientific guidance to the project manager, and formally is viewed as co-equal with the project manager. The project scientist is not located in the project office and he does not report to the project manager. Many project managers see his function as purely advisory, though he makes important contributions during the development of the Project Plan and technical specifications for the contract."<sup>8</sup>

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<sup>5</sup> Ibid., pp. 9-10.

<sup>6</sup> Ibid., pp. 22-24.

<sup>7</sup> Ibid., pp. 48-49.

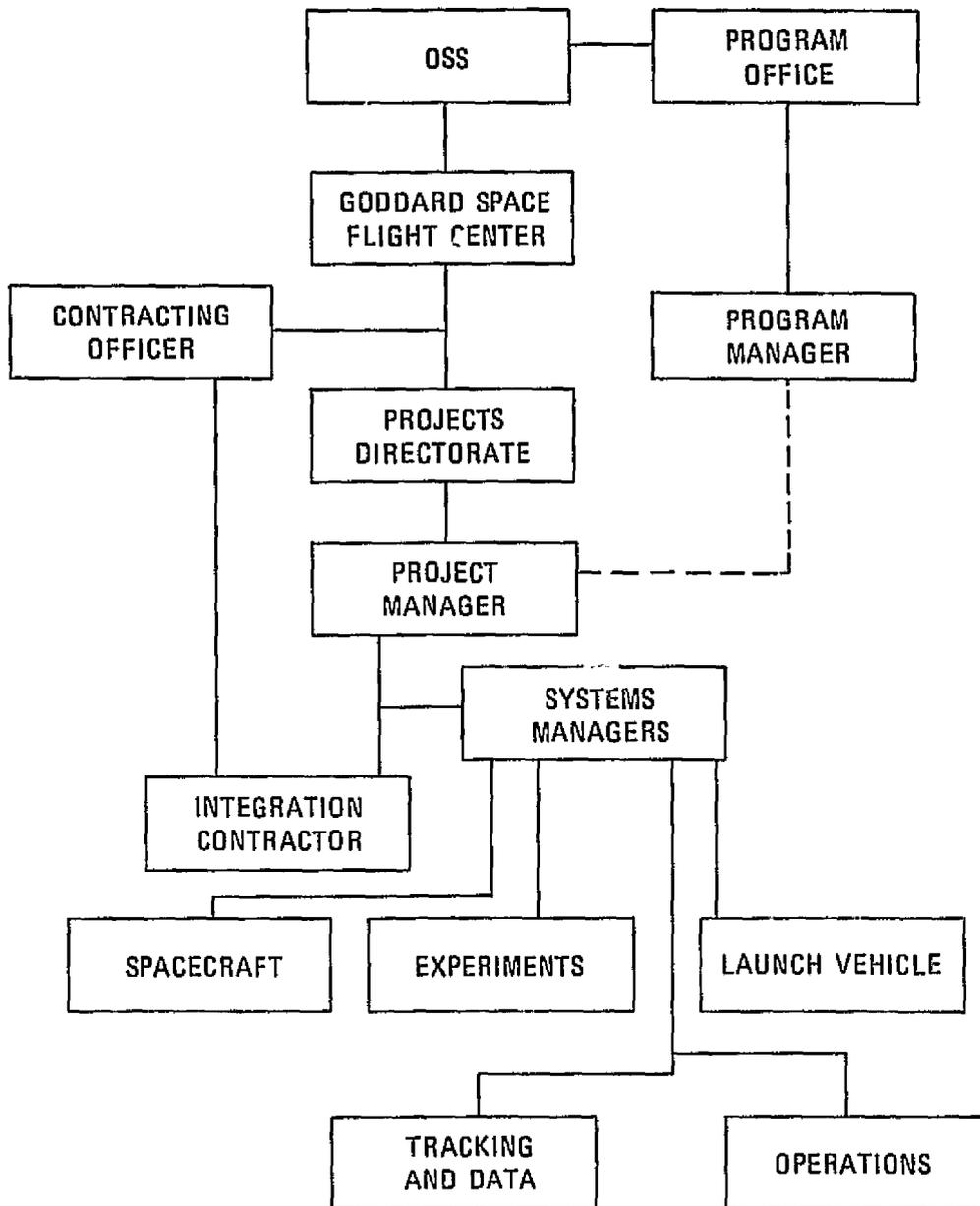


Figure 3. A Typical OSS Program and Project Management Structure

Accordingly, the project scientist is generally shown on project charts as he is shown in Figure 4; as being an advisor, not directly involved with the course of the project. By contrast, the broad responsibility of the project manager in NASA is clearly emphasized and is considered an important element in the success of space flight projects.

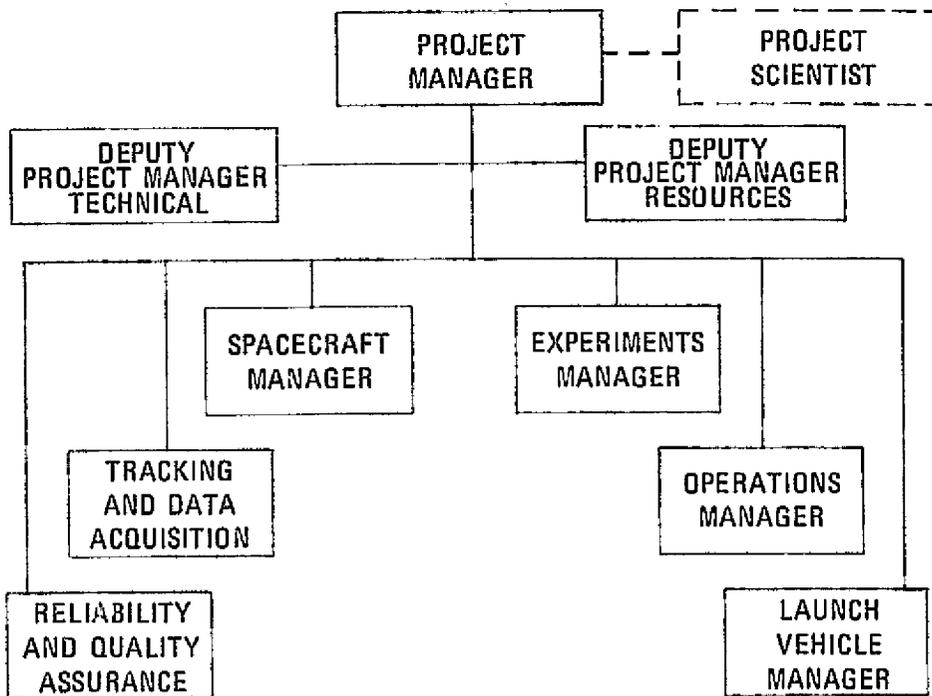


Figure 4. GSFC Project Organization. (Dotted lines denote a project function that is performed by a group outside the project manager's direct control.)

"The NASA project manager, unlike his industrial counterpart, carries the management responsibility for all aspects of his project from its planning through the fabrication and integration of the spacecraft and its experiments, to the successful launch into the desired orbit, the subsequent acquisition of data from the experiments and ultimate disposition or use of that data."<sup>9</sup>

In order to understand the roles of the participants, one must be familiar with the life cycle of space flight projects in OSS. A project passes through stepped phases, each defining it in greater detail than the previous one. In order to avoid premature commitment of resources to a particular course of action, one phase is not approved until the completion of the previous one.

Some members of the scientific community at a field center such as Goddard are interested in pursuing analysis which is compatible with the goals of a

<sup>9</sup>Ibid., p. 18.

particular program office. As a result of discussions between Headquarters and Goddard, the director of the programs office involved asks the center management to undertake a preliminary analysis (Phase A) of how NASA might, through a space flight project, conduct a scientific investigation. A group of scientists and engineers are assigned to do the study, including the scientists who completed the earlier theoretical work and a study manager who may be selected to lead the project, should the effort advance that far. At the same time, a liaison officer at Headquarters is chosen who may eventually become the program manager.

If the analysis proves favorable, a project proposal to establish a project formally and proceed to Phase B may be approved. Phase B is the definition stage, and includes detailed study, comparative analysis and preliminary systems design. As initiation of this phase, a Project Approval Document (PAD) is written and approved by Associate Administrators in OSS and Organization and Management. This is the written authorization to begin the new project. It outlines the resources assigned, specifies the field installation, defines the number of spacecraft and type of launch vehicle, and defines the plan for the allocation of funds and manpower. This PAD is for Phase B only, and gets reviewed annually. A project manager is now assigned. The Phase B analysis includes estimated schedules and resources through total project completion, and results in a detailed Project Implementation Plan.

A new PAD is written to include approval of technical, schedule, managerial and resource changes made during Phase B. It may include authorization only for Phase C (design) or for both Phase C and Phase D (development and operations). More contractor personnel are now involved in the detailed engineering design and development of specifications on all the major systems of the spacecraft. During Phase B, OSS solicited and selected, through competition, experiments appropriate for flight. The design phase includes more detailed design and integration studies of the selected experiments. Upon completion of the design stage, the project team develops a Request for Proposal (RFP) which prescribes the performance specifications for contractor proposals to undertake final hardware design and development, fabrication, test, and project operations.

The project team depicted in Figure 4 has been assembled by the beginning of the design phase. It includes the experiments manager who facilitates coordination between the project and the experimenters, including both those inside and outside the NASA laboratories.

During fabrication of the spacecraft, the project manager and systems managers take part in design and test reviews, visits to contractors plants, and conferences dealing with problems uncovered by quality assurance checking, component

testing, and systems integration. There are reviews prior to each level of integration including that with the launch vehicle to assure that the assembly preceding that level is within specifications.<sup>10</sup>

Throughout the performance of the project, certain elements are emphasized which contribute to its success. One is that decisions are made incrementally as new information from the series of reviews is obtained. All elements remain open for review. Decisions about one aspect of the project also consider the impact on other elements, and all interested parties have an opportunity to argue their point of view. Broad participation is inherent in the decision process because the project manager, though the focus of project responsibility, shares authority for major decisions with systems managers, experimenters, functional managers, and Headquarters representatives. This makes reviews and negotiations between the participants necessary. The competitive atmosphere of integrating the often conflicting requirements of various systems keeps the participants alert in order that they can put forth their best arguments in support of their requirements.<sup>11</sup>

The project manager is expected to maintain a constant open flow of communications by instituting informal communications links to supplement the formal channels. Hiding problems is considered worse than the failure to solve a problem.<sup>12</sup>

The project organization is kept flexible enough to be suited to tasks of many different kinds. It relies on the cooperation of the managers which comes from a common commitment to the project goals, with resource control being the major tool of the project manager for asserting direction.<sup>13</sup>

From the considerations involved, it is evident that NASA has very heavily applied behavioral considerations in organizing space flight projects. However, the NASA report deals almost entirely with the project and program managers. The project scientist's role in project management is minimized. His role and the potential effect of that role on his career is the subject of the interviews in the next chapter.

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<sup>10</sup>Ibid., pp. 13-18.

<sup>11</sup>Ibid., p. 52.

<sup>12</sup>Ibid., p. 53.

<sup>13</sup>Ibid., pp. 109-116.

## V. THE INTERVIEWS

Interviews were conducted in March 1976 and included project managers, program managers, and experimenters, in addition to project scientists. The questionnaires, which were used as guides in these interviews, are shown in the Appendices. The reasons for interviewing other members of the project are twofold: 1) to see how much agreement there was within the project on the role of the project scientists; and 2) to provide a balanced view of the way projects are run.

Six projects were selected by the criteria that they should be primarily scientific, be currently active, have experimenters other than the project scientist (and at least some from outside NASA), and be managed by Goddard Space Flight Center. All but one of the projects were an operating spacecraft. That remaining one was in the implementation phase. The number of projects studied eliminates the applicability of statistical analysis; however, one should be able to infer trends. All the project personnel listed above for each project were interviewed except two. Five experimenters, in addition to the project scientists, were interviewed including three outside NASA.

An interview format was chosen, rather than written questionnaires, because candid opinions about the way projects are run were sought, and it was believed that verbalization would allow a free flow of thought than written answers. It can be seen from the description of projects that fairly subtle relationships are involved. The questions were used in some cases as starting points for discussions between the subject and the interviewer to clarify some of these subtleties. Clarification on the questions themselves was often needed from the interviewer.

In addition to questions pertaining directly to the project, the project scientists, were asked questions pertaining to their views on the nature of their work in general, and the relative qualities of project scientist work and their other work. The objective was to understand the value of the experience of being project scientist. Résumés of the project scientists were also obtained in order to understand their background as a group and to evaluate differences. Unlike the other interviews, these sessions were taped (except one) in order to reduce the time needed to take notes. These interviews tended to be an hour or more, and the interviewer felt that an overly long interview might be tiresome and affect the quality of the answers.

The interviews, particularly those with the project scientists, were structured to start with fairly explicit questions calling for answers which involved ordering things or rating them according to a scale. These were followed by questions which called for more free discussion on the part of the respondent. This order

was chosen on the belief that many of the participants, particularly the scientists, may not have given much conscious thought to the considerations involved. The more explicit questions would, in those cases, help prepare their thinking for the later questions.

### The Project Scientists and Their Work

As can be expected, each project scientist, or the project involved, is distinctive in a way which means that some significant information is lost in treating them as a group. For example, two of the scientists had considerable engineering background which probably increased their involvement with the details of the spacecraft design. However, the only distinction which will be treated is that between the projects in which the satellites are already in orbit and the one which is still in its early implementation phase. There are two reasons for this: the project scientist in the latter case is much younger and less experienced than the others; and this project should more nearly reflect the way projects are run in recent years, which is somewhat different to that of several years ago.

All the project scientists with spacecraft now orbiting have impressive indications of performance. All have received at least two major NASA achievement awards. They average 70 publications each, and 56 publications each since 1965. They list on their résumés an average of four research areas, showing much breadth of interest within the space program. Three have been project scientists on five or more missions, and all have been involved in some capacity with nine or more spacecraft. All have line authority at branch level or above. The remaining project scientist, while having not yet developed as impressive a résumé, has published at a high rate and has experience on previous spacecraft experiments.

The results which follow give the arithmetic mean of their responses about the nature of project scientist work and that of their other work. The range of all responses is also given in parentheses.

Table 1 gives the estimated fraction of time spent on technical versus managerial activities within the role of project scientist (P.S.) compared to non-project scientist work (N.P.S.).

The technical work in each class is also characterized separately in Table 2.

The role of Project Scientist has a much lower technical content than their work in their functional area, and the nature of the technical work itself was different; being more involved with other people's work indirectly. The 23% in the "Other"

Table 1

Estimated Time Spent on Technical Versus Managerial Activities

	P.S.	N.P.S.
Technical	37% (0-80)	66% (50-80)
Administrative	63% (20-100)	34% (20-50)

Table 2

Technical Work in Each Class Compared

	P.S.	N.P.S.
Research	0	61% (0-100)
Development	21% (0-100)	30% (0-80)
Consultation	56% (0-100)	6% (0-25)
Other	23% (0-100)	3% (0-20)

category for project scientist work may be partly due to differences in interpretation of the categories.

Table 3 gives a rating of the enthusiasm for various types of work, where five was labeled as "continuously exciting" and one was "painful". In all ratings of this kind, five is the maximum.

Table 3

Rating of Enthusiasm for Various Types of Work

	Enthusiasm
P.S.	4 (4)
N.P.S.	4-1/2 (4-5)
Technical	4-1/3 (4-5)
Managerial	2-2/3 (1-4)

The inference which can be made here is that these people find the project scientist role slightly less enjoyable than their other work because of its lower technical content. There is also a large variation among the scientists in their enjoyment of management.

As an indication of the impact of project duties on their other work, the percent of their total worktime during the various project phases spent doing project scientist work was polled. This is given in Table 4.

Table 4  
Project Scientist Percent of Total Worktime

	Percent Time
Preliminary Study	15% (0-30)
Definition	17% (10-30)
Design	12.5% (5-20)
Development and Operations	16% (5-35)
Data Analysis	8% (0-15)

The average level of effort indicated is fairly flat throughout at about fifteen percent. However, some reported a peak during the planning phases, while others reported a peak during development. This may indicate adjustments of the job to fit the talents of the individuals. When asked if they reduced their research activity on becoming a project scientist, half said they had not, the rest said they had slightly.

Table 5 gives ratings on three criteria for judging functions performed as project scientist.<sup>1</sup>

A reason given for the importance of planning was that it determines all the important aspects of the mission. It is clearly also the most enjoyable. This may be because it has the highest technical content and because planning is a relatively creative process.

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<sup>1</sup>For clarification of these functions, see Appendix 1, question 5.

Table 5  
**Functions Rated by Project Scientists as to Importance,  
 Enjoyment and Difficulty**

	Importance	Enjoyment	Difficulty
Project Planning	4-2/3 (3-5)	4 (3-5)	2-1/3 (1-4)
Project Information & Control	3 (1-5)	2-1/3 (1-4)	2-1/6 (1-4)
Science Team	3-2/3 (2-5)	3-1/2 (3-4)	1-5/6 (1-3)
Consultation	4-1/6 (3-5)	3*	2 (1-4)
Data Management	3-2/3 (2-5)	2-2/3 (2-4)	2-2/3 (1-4)

\*All gave 3s except the least experienced who gave a range because of disliking Headquarters presentations.

It is also interesting to note that the project scientist on the most recent mission gave a rating of five for the importance of all the functions.

Difficulty was generally considered low, similar to the earlier NASA study findings on management functions. Ratings of difficulty anticorrelated with experience. A particular sharp distinction occurred for data management between the two most experienced participants and the rest. This may in part be explained by the fact that they were both project scientists on a number of similar spacecraft where data management may have become routine.

The perceived importance of four skill types are compared for both roles in Table 6.<sup>2</sup>

Table 6  
**Importance of Four Skill Types Compared**

	P.S.	N.P.S.
Technical	4-1/2 (3-5)	4-5/6 (4-5)
Managerial	3-1/3 (2-5)	3-2/3 (2-5)
Human	4-1/2 (3-1/2-5)	3-5/6 (3-4)
Conceptual	4 (3-5)	4-5/6 (4-5)

<sup>2</sup>For clarification of these skills, see Appendix I, question 7.

The differences are small; however, project scientist work has almost a full point higher need for human skills (e.g., communicating, motivating, coordinating) than does the scientist's other work. Conversely, conceptual skills (e.g., integration, evaluation, problem solving, creativity) dropped almost a full point. Also perhaps significant is that the project scientist on the most recent project gave technical skill the lowest rating, stating that a minimum level was required, but that less was needed than project scientists generally had, if other skills were also present.

Most felt there was little difficulty associated with the skills required on becoming project scientist. Of the difficulties reported, human skills were referred to most often because the job required them to deal with a broader range of people. Skill was required particularly in working with the project manager to resolve conflicts. Technical skills were also mentioned because they had to be broadened.

The criteria given for selection as project scientist were: motivation to do the job (usually through a commitment to the importance of the project), and sufficient technical background to understand the mission and the hardware involved.

All the project scientists described their careers in terms of a series of opportunities to engage in activities they enjoy. The youngest one also indicated some motivation toward advancement within the organization. This is perhaps to be expected since his organizational stature is currently less than the others, who have already satisfied their need for it. They all generally wanted to continue in their present positions. None wanted to take a position at headquarters within the next five years. Some specifically mentioned refusing such an offer.

All but one agreed that being a project scientist increased their research capability, usually by broadening their technical knowledge to include related disciplines and related experiments. Also mentioned were learning about problems associated with satellite projects and having the opportunity to meet the researchers in related fields. All but two said that their project scientist experience had increased the importance of management in their estimation. Two referred to a changing situation which required more management than in the past.

Two of those interviewed had been among the first project scientists in NASA and so had no training opportunities for the position. Two had worked with project scientists as experimenters, thereby being oriented to the job by observation and related activity. Two had actually worked as assistant project scientists prior to being chosen for the position.

All had received assistance informally in carrying out project duties and preferred it to having a formal assistant. They mostly sought expert advice in areas where they lacked background. One also mentioned using project office personnel as substitutes in meetings when he was busy.

Most of the satisfaction of being a project scientist comes from a sense of achievement; of being involved with the project from conception through receiving the data; of contributing in a key way, not available to experimenters, to the success of the mission. The learning (growth) involved was also satisfying.

Management red tape was the biggest source of frustration in the form of counterproductive requirements imposed on the project from upper management. Lack of support for future missions and for missions after launch, and the incompetence of some of the management outside the project were also cited as frustrating.

The strongest impression made by the interview was that all of them considered themselves primarily experimentalists. The duties of project scientist, while interesting, were performed out of obligation to NASA as employees. A less certain impression is that the two scientists with the longest records as project scientists actually found the duties rather boring.

#### Project Organization and the Role of the Project Scientist

The role of the project scientist is described in the execution phase project plan for each project.

1. He is responsible for assuring coordination between and satisfactory accomplishment of the scientific objectives of the mission and its individual experiments.
2. He reviews the implementation of individual experiments to ensure that their objectives are consistent with the proposal upon which the selection was based.
3. He reviews the spacecraft weight, power, space, and telemetry assignments among experiments, operations plans, and data acquisition and processing requirements to ensure that the total system plan is consistent with the overall scientific objectives.
4. He provides leadership in assuring that the experiment data are effectively used and that the scientific results of the mission are expeditiously produced.

5. He evaluates all scientific requirements placed on the project and provides scientific guidance to the project manager and others involved in the program.<sup>3</sup>

When asked to describe the project scientist's functions, everyone interviewed included Item 1. People in general tended to mention those items which furthered their own objectives. For instance, experimenters generally said something similar to Item 5, which in part involves telling the project manager their requirements. Some also stated that he was chairman of the investigators team, holding meetings for the exchange of information between investigators and to inform them of any changes in project direction.

The project scientists were asked to fill in their position on a simplified project chart and show both formal and informal connections using solid and broken lines respectively with the positions shown. The vertical location selected should indicate their perceived level of authority. The solid lines should indicate a channel of authority, and the broken lines should show where there is mutual influence. This chart is shown in Figure 5, with the most typical connection made by the project scientists. The location is co-equal with the project manager as shown on official project charts. The other solid lines probably refer to their function of allocating spacecraft resources among the experiments and the recourse of taking issues all the way to the director of Goddard for arbitration with the project manager, if necessary. The communication with the program office, being indicated more frequently than that with the program manager, is interpreted as being with the program scientists. The experiments manager is naturally interacted with concerning experiment execution. The other systems managers were also indicated, as the project scientists had to confer on the capabilities of the spacecraft and telemetry systems. It is very clear from this diagram that the project scientist does a lot of interfacing, and that there is much exchange of influence with other project members.

The frequency of communication during project execution averaged according to the list below, which indicates a high level of involvement with the activities of the project office.

Project manager	2/week
Experiments manager	1.5/week
Experimenters	1/2 week per experiment
Program office	1/month

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<sup>3</sup>Execution Phase Project Plan for Small Astronomy Satellite (SAS-C) (Greenbelt, Md., Goddard Space Flight Center, 1970), p. 56; Execution Phase Project Plan for International Sun-Earth Explorers (ISEE-A/B and C) (Greenbelt, Md., Goddard Space Flight Center, 1975), p. 103.

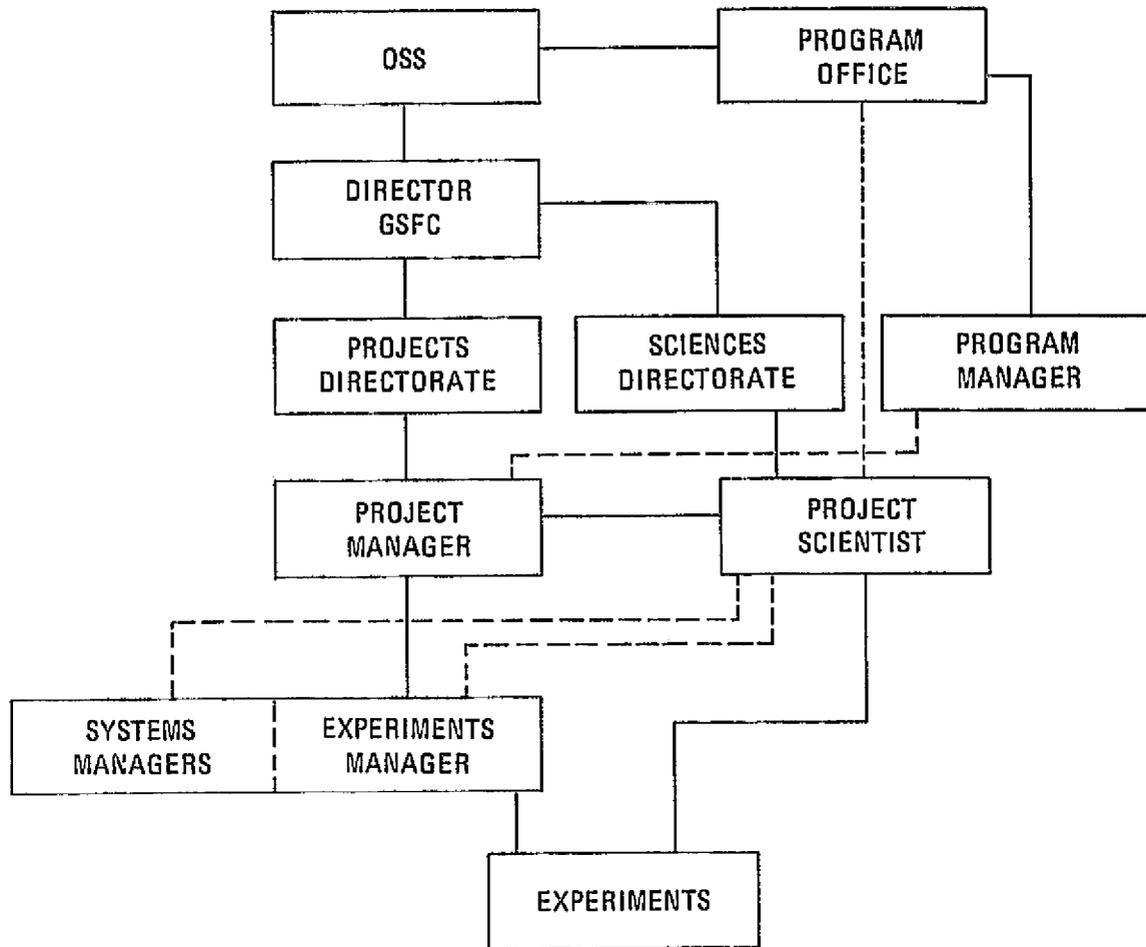


Figure 5. The Project Scientists' Self-Placement in Project Organization

To see if project communication significantly increased their colleague contact, they were asked how many colleagues they contacted regularly outside their project scientist role. All said about ten or significantly more. Three said that the number was much larger than on the project.

Both the project scientists and project managers were asked to rank certain key participants in the project by their influence in determining final mission objectives. What was to be determined here was who was most influential in setting the objectives of the project, and how much those objectives were changed during the execution phase by the project office. The results are given in Table 7.

Table 7

## Influence of Key Participants in Setting Objectives of the Project

	P.S.	P.M.
Experimenters	1	2 (1-5)
Project scientist	2	1 (1-4)
Project manager	3	2 (1-4)
Program scientist	4	4 (2-6)
Program managers	5	5 (3-5)
Center management	6	6 (3-6)
Other colleagues	6	6 (3-6)
Experiments manager	6	7 (7)

The order of the averages is very much the same, but the variation was much greater with the project managers. The experimenters dropped from first on the project managers' list because of a five given them for a project which was not originated by the science. Otherwise it was remarkable how consistently the emphasis was placed on them in determining objectives. All participants when asked to do a similar ranking said that the scientific community had the most influence on objectives. Consistent with this ranking was the generally held view that relatively small changes are made in the objectives during execution. The project scientists felt they had a lot of influence, and this view was confirmed by the project managers, but not so strongly by the other participants. The most interesting aspect of this question, though, was the difficulty with which most people answered it. The mutual influence in determining the objectives and the number of iterations on those objectives were so great that it was hard for most people to separate individual influence. In addition, different people's main influence occurred during different phases, so that it was difficult to compare.

The project scientists on average felt that they had almost as much influence on the execution of the project as the project manager, and more than the experiments manager. The basis for this feeling is the conviction that the spacecraft is designed around the scientific objectives. The project managers said the project scientists' influence on execution was about half his own, and the experiments managers said that the project scientists had none at all, principally on the basis that he did not get involved with the details of execution.

Both the project and non-project environments were described as being moderately coordinated, while the project scientists generally saw themselves as being highly autonomous. They had much more freedom than most project members — a high performance position as found by the behavioral research described in earlier chapters.

The only conflicts reported by the project scientists were with the project manager. These were mostly direct results of their respective roles (i.e., resources vs. science) and all agreed that they should not be avoided as they contributed to the overall success of the mission.

Most project managers felt that the project scientists interviewed had performed excellently. One expressed a wish that the project scientist had more time to guide other experimenters, especially those at Goddard. The experiments managers and experimenters similarly thought that he was effective. Some of them also felt that he should have more time to devote to the functions as project scientist; that his performance had suffered because he was primarily concerned with his own experiment.

For the projects studied there apparently were no serious experiment cost overruns caused by the shortcomings of the investigator's management of his experiment. In general, however, the only influence the project scientist has on overruns is technical; by spotting the need for changes in an experiment early he can conceivably avoid additional costs. If cuts in the experiment complement are needed in order for the mission to stay within its budget, he can recommend to the project manager where they will make the least impact on the science.

All the scientists interviewed, including the project scientist, agreed that the project scientist should be an experimenter on the mission. He should be an active space scientist which necessitates that the job be a part time one. In order for him to be motivated to put enough effort into the job, he must have a personal interest in the success of the mission. Most felt there was little danger of conflict of interest. Most project scientists kept a balanced view, and peer pressure tended to keep them honest.

All the participants were reasonably satisfied with the way projects were organized; in particular with the role of the project scientist. They could not suggest a better alternative. There was general agreement, including among project management, that the strong project scientist was best for the project, and that he contributed significantly to overall mission success. He should participate as actively in the project as possible.

## VI. CONCLUSIONS AND RECOMMENDATIONS

The hypothesis that the project scientist is in a position which rates very high in terms of behavioral study recommendations has been confirmed.<sup>1</sup> He does have frequent stimulating interactions with most of the key people involved with the project. He believes that he exerts much influence over the objectives and execution of the project; and in terms of motivation, his beliefs are the most important. His influence over objectives is generally considered to be important. He is highly autonomous in a moderately coordinated environment. He has diverse managerial and technical functions and the performance of these functions require him to grow beyond his role as an experimenter.

However, the position within the line organization for those interviewed is also very stimulating, rating almost as high by the same criteria. The functions of that line position occupy most of his time, and actually are preferred somewhat to those of the project scientist position. Therefore, the role of project scientist may not be the dominant means of professional growth for the experienced scientific investigators. Furthermore, the influence which the project scientist exerts on the project and the stimulation of that position for him are determined largely by his position outside the defined project scientist role. The role of the project scientist is changing because the environment of those who become project scientists is changing.

Much of this external effect can be found in the phasing of projects. Project positions are not officially assigned until a project is an approved flight mission. This is evident in that the project plan in which the roles are defined is not written until the beginning of the execution phase. Yet the most important phase for scientists is the planning or the preliminary study and definition phases. Very little is changed concerning objectives after the definition phase.

There are three principal ways that a project can be initiated. One is an unsolicited proposal from a scientist who has a concept for a new mission. Another is a mission concept developed at Headquarters using informal communications with certain members of the scientific community. The third way is for Headquarters to announce a planning opportunity in order to establish formal communication with the scientific community in defining potential new missions.

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<sup>1</sup>Most of the information in this chapter concerning project execution has been assembled from discussions during the interviews.

In the first case, the individual scientist, who has the concept, dominates the development of the spacecraft and generally becomes the project scientist. His experiment determines the principal objectives of the spacecraft and dominates its design. Other experiments added during definition are secondary. In the second case, Headquarters scientists and program managers dominate the definition of the spacecraft. In the third, the scientific community as a whole has increased influence. The growth of space science during the sixties has tended to shift the initiation process from the first type to the second and third, and with that shift the scientific influence of the project scientist has declined.

In the early sixties the state of knowledge and technology was such that relatively simple experiments made major breakthroughs. Also, very few scientists knew how to propose a workable spacecraft. Many of the scientists who did were located at the NASA centers, partly because they had access to the engineering capability there. Because so little was known, it was an inherently risky endeavor and, because funding was high, NASA was willing to take those risks. These factors made it relatively easy for an experienced NASA scientist with the help of a key engineer to shape a mission around his own interests and convince Headquarters to support it. Then, as project scientist, he primarily made sure that those who built the spacecraft executed his objectives. In this role, especially in terms of management by objectives, he acted much like upper management to the project office.

In the seventies, technology and knowledge have advanced to the point where very many people are capable of proposing reasonable experiments with high assurance of returning new knowledge. These experiments have advanced in complexity and cost and often involve several investigators. In the meantime money has become available for fewer new missions. As a result, there are many more potentially good missions than can be funded. Under these circumstances the best way to maximize scientific return is to maximize the influence of the scientific community by bringing them into the decision process early, as in initiation type three.

However, the relative influence of the project scientist is much reduced. He has little more weight in determining mission objectives than any other experimenter, as he is often chosen from among them after the experiment selection process. His dual capacity as liaison between the scientists and project management and as coordinator of the scientific team has become a much more dominant part of the position.

Since the number and complexity of the experiments increase per spacecraft, the coordination and liaison functions of the project scientist have also become more demanding. Simultaneously NASA's budget tightening has required much

closer budgeting for experimenters. While this is facilitated by increased study prior to flight approval, both experimenters and project scientists must have much greater management skills than previously. To be an effective advisor to the project manager, the project scientist must now be more aware of cost-benefit trade-offs.

The tighter budget control by Headquarters results in reduced self-determination and influence over the project by the center project participants. Contingencies funds in everyone's budget are smaller so that changes which could once be approved within the project now must go back to Headquarters for approval. Considering the behavioral research results presented earlier, this change is in the direction of encouraging cautious dependence on the part of the project members, including the project scientist. The effect on performance in this case may not be severe, but certainly decisions on budgetary control should consider project motivation as a parameter. Tighter budget control permits more missions. It may not necessarily result in more science.

The NASA report on project management concluded with:

"The driving force was the excitement of the particular task at hand, its importance and innovative nature. It is true that NASA was able to appoint extraordinarily capable men as project and program managers, but none could claim all the virtues usually listed as necessary. For the most part they led teams whose members were highly committed to the project and who derived great satisfaction from selflessly contributing to the team's purpose. The project was the focus — organizational lines and personal ambitions were submerged in the common effort by contractors, Headquarters and installation officials, university experimenters, and project staff. This was the driving force of NASA's success.<sup>2</sup>

Tighter Headquarters control requires tighter organization, and as one project scientist noted, too much organization removes the dedication to, and excitement of, the challenge.

The project scientist's stature in the scientific community and at the center are two other external parameters which affect his project performance. As it has been said, influence is more effective than authority as a motivator, and scientific stature gives the project scientist the acceptance of the other experimenters whose requirements he is coordinating. Conversely, the experimenters

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<sup>2</sup>Chapman, Project Management in NASA: The System and the Men, pp. 119, 120.

are very much self-motivated in developing their instruments, and do not need additional motivation from the project scientist. His role among them is primarily the distribution of spacecraft resources. He must be influenced by them, but may be able to rely somewhat on his authority in arriving at agreed allotments. He may gain the respect of the experimenters if he has the skills (technical, managerial, human, and conceptual) and motivation necessary to do the job well. This does require that he have sufficiently broad technical knowledge to apply good judgment in his project decisions.

Stature at the center can help him get the cooperation of the project office, though this was generally not a problem. It is especially important that he have these kinds of influence if one of the principal investigators is prominent and forceful enough to otherwise dominate the experiments group and, in the case of a Goddard scientist, unbalance demands on center resources.

The position of project scientist as management development for scientists has some contradictions. It certainly requires skills which are useful to NASA managers: coordinating, communicating with many different types of people, familiarization with space flight requirements, and understanding project organization. While not having any direct financial responsibility as project scientist, he is exposed to the concerns of the project manager, and as an experimenter is financially responsible for his own instrument. Program managers indicated that project scientists have just the sort of experience that Headquarters looks for in selecting for management positions. However, the project scientist's attitudes were still primarily those of the researcher, and none were interested in taking positions of greater management responsibility. A program manager confirmed that sometimes several people turned down a management opening before it was filled.

The changing environment has decreased the appeal of being project scientist to many of the experimenters. It has somewhat less scientific influence and more demanding management functions which tend to take time from the experimenter's main interests. However, some of those interviewed agreed that on complex spacecraft missions involving many experiments requiring the work of many coinvestigators and key people, a willing member of this team might be selected to aid in the more managerial functions of the project scientist. This could serve as both experience and testing ground for potential scientific managers. At the same time the more disagreeable aspects of the project duties would be removed for the project scientists. Few project scientists expressed an interest in having an assistant. Often such positions create more problems than they solve. To avoid this, care would have to be taken to select someone compatible with the project scientist.

A more satisfactory solution might be to select a project scientist who is properly motivated for the position as it now functions. Dedication to the science is still important as in the past, but interest in management is more important than it used to be. Compromising on the need for scientific prominence makes it easier to find someone with both of these motivations. It was generally agreed that project scientists should have a background of planning and executing space flight experiments. That experience need only be with a very few experiments and not necessarily be as a principal investigator, as long as he was deeply involved with many aspects of the experiments. Usually many of the people who participate in the experiments on a project meet this criterion. The project scientist should be selected from those who express an interest in managerial functions and whose experience shows an aptitude for them. Such a person should find the position both stimulating and a valuable background for later advancement.

It should be noted that these are only recommendations. In endeavors which are as complex as scientific spacecraft projects, rules are seldom appropriate. What is appropriate is the direction of consideration to all the important aspects of the project. In the selection of project scientists, consideration should be given not only to the scientist's technical qualifications, but also to his managerial aptitudes and to the later utilization within NASA of his project experience.

APPENDIX I

PROJECT SCIENTIST INTERVIEW

HOW YOU SEE YOUR OWN JOB

1. What portion of your work time, project scientist work and other work considered separately, is spent on the following types of activities?

<u>Project Scientist</u>	<u>Non-Project</u>	
		A. Technical (including supervisory, research, consultation, etc.)
		B. Administrative (reporting, controlling)

2. What portion of your technical work is spent on the following activities for each work area?

<u>Project Scientist</u>	<u>Non-Project</u>	
		A. Basic or Applied Research
		B. Development or Invention
		C. Technical services (testing, consulting)
		D. Other

3. Rate your enthusiasm for the following types of work.  
(5 = continually exciting; 3 = somewhat interesting; 1 = painful)

- A. Project scientist work
- B. Non-project work
- C. Technical work
- D. Managerial work

4. What percent of your time was spent as project scientist during the various phases of the project?

- A. Preliminary study
- B. Definition (preliminary system design)
- C. Design
- D. Development and Operations
- E. Data Analysis

5. What are the relative importance, enjoyment, and difficulty in terms of your participation as project scientist of the following project functions?

<u>Importance</u>	<u>Enjoyment</u>	<u>Difficulty</u>	
			A. Project planning (technical specifications, science mission requirements, etc.)
			B. Project information and control (contract negotiation, reviews)
			C. Science team (organize, represent, define interfaces)
			D. Consultation (science advisor, spokesman)
			E. Data management

6. On becoming a project scientist, did you reduce your own research activity? How?

7. What is the relative importance to you as a project scientist of the following skills? On non-project work? (5 = extremely important; 1 = unimportant)

<u>Project Scientist</u>	<u>Non-Project</u>	
		A. Technical (fundamental knowledge, applying it, breadth)
		B. Managerial (organizing, controlling, finance, contracting)
		C. Human (communication, motivation)
		D. Conceptual (integrative, evaluation, problem solving, creativity)

8. Were any of these skills sources of difficulty on becoming a project scientist?

9. Would you describe your scientific motivations as (a) broad, mapping of new areas, or (b) probing deeply into a specific area. 1 = all(a) to 5 = all(b).

10. What are the most important criteria for selection as project scientist?

11. Do you think of your career as (a) a series of opportunities to engage in activities you enjoy, or (b) a progression up one or more organizational ladders? 1 = all(a) to 5 = all(b)

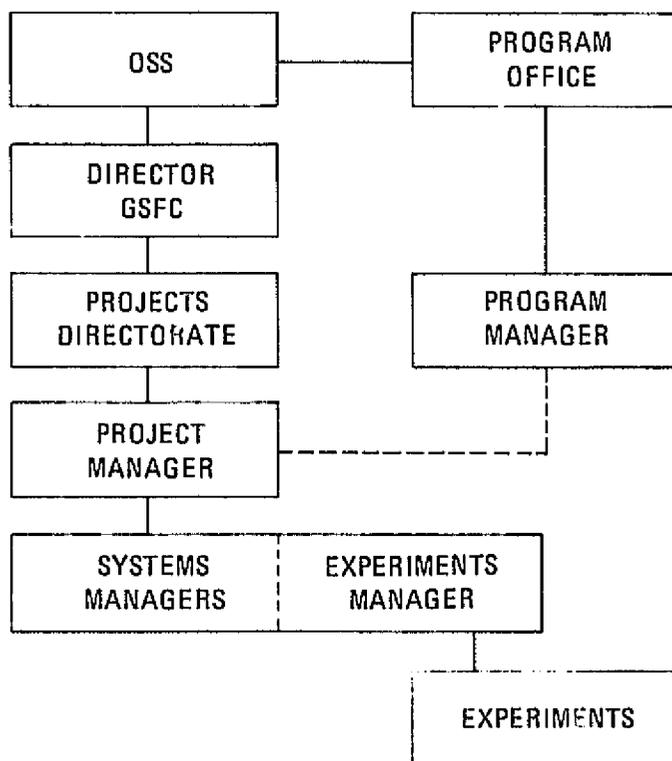
12. Has your experience as a project scientist increased your capability as a researcher? If yes, how?

13. What would you want to be doing in five years?

14. Has your perception of the importance of managerial functions changed since you have been a project scientist? If yes, how?
15. Prior to becoming a project scientist had you worked with a project scientist in some way which helped train you for the position?
16. During any phases of the project, would you welcome assistance in performing project scientist duties? If so, what kind?
17. Have you either formally or informally received such assistance? How much?
18. What do you find most enjoyable or satisfying about being a project scientist? Most frustrating?

#### PROJECT ORGANIZATION

1. Locate the project scientist and investigators on this simplified project chart. Include informal relationships with broken lines.



2. How frequently do you communicate with the:

Project manager?  
Experimenters?  
Experiments manager?  
Program office?

3. In your non-project work, how many colleagues do you have frequent contact with?

4. Rank the following people by their influence in determining final mission objectives?

Project scientist  
Program scientists  
Experimenters (collectively)  
Program manager  
Project manager  
Center management  
Other colleagues

5. How much influence do you exert over the execution of the project relative to the project manager? (Project manager influence = 5) Put Experiments manager and principal investigators on the same scale.

6. How restrictive are the project and non-project environments? 1 = very loose, 5 = highly coordinated.

Project  
Non-project

7. How autonomous are you as a project scientist? (5 = totally independent)

8a. What conflicts, if any, tend to occur with the project manager? How might they be alleviated?

8b. With the experiments manager?

8c. With the experimenters?

9. Has your experience with non-NASA experimenters been different than with NASA experimenters?

10. How open were (are) your communications with the project office? With the experimenters? 1 = minimum formal communication, 5 = completely open.
11. Was there a significant experiment package overrun? What was the primary cause?
12. Rate the overall success of the project on a scale from 1 to 5. 1 = total failure, 5 = all potential results realized.
13. In general, how well do you think project management performs their jobs? 1 = not well at all, 5 = excellently.
14. Do you think that the project scientist should be an investigator on the project? What danger of conflict of interest?
15. How would you, if at all, change the organization of flight projects, including all phases, to increase overall performance?

## APPENDIX II

### COLLEAGUE INTERVIEWS

#### PROJECT MANAGER INTERVIEW

1. What are the primary functions of the project scientist?
2. Rank by the relative influence in deciding final mission objectives, the:
  - Project manager
  - Program manager
  - Experiments manager
  - Project scientist
  - Program scientist
  - Principal investigators (collectively)
  - Center management
3. Was there a significant experiment package overrun? If so, what was the primary cause? Could the project scientist have done anything to reduce it?
4. When there are many experimenters, would it be helpful to the project if the project scientist used assistants to maintain closer contact with individual experimenters?
5. How much influence does the project scientist exert over the execution of the project relative to yourself? (Your own influence = 5)
6. What conflicts tend to occur with project scientists? How might they be alleviated?
7. How might the project scientist perform his functions more effectively?
8. In what ways would you redefine the position of project scientists?
9. Other comments?

#### EXPERIMENTS MANAGER INTERVIEW

1. What are the primary functions of the project scientist?

2. Rank by the relative influence in deciding final mission objectives,

Project manager  
Experiments manager  
Project scientist  
Principal investigators

3. Was there a significant overrun in experiment package cost? If so, what was the primary cause. Could the project scientist have done anything to prevent or reduce the overrun?
4. How much influence does the project scientist exert over the execution of the experiments package relative to yourself? (Your own influence = 5)
5. What conflicts tend to occur with the project scientist? How might they be alleviated?
6. How might the project scientist perform his function more effectively?
7. In what ways would you redefine the position of project scientist?
8. Other comments?

#### PROGRAM MANAGER INTERVIEW

1. What are the principal functions of the project scientist?
2. Who were the key participants, by position, in the initiation and preliminary study phase of the project?
3. Rank by relative influence in deciding final project objectives,

Program manager  
Project manager  
Program scientists  
Project scientists  
Principal investigators

4. How do you see project scientist work in terms of management development of scientists?
5. Other comments?

## PRINCIPAL INVESTIGATOR INTERVIEW

1. What are the primary functions of the project scientist?
2. Rank by relative influence in deciding final mission objectives,  
  
Principal investigators  
Project scientist  
Project manager  
Experiments manager
3. Was there a significant overrun in the cost of your experiment? If so, what was the primary cause? Could the project scientist have done anything to reduce it?
4. What conflicts tend to occur with the project scientist? How might they be alleviated?
5. How might the project scientist perform his functions more effectively?
6. In what ways would you redefine the position of project scientist?
7. Were there significant differences between your relationships with project scientists on different projects?
8. Other comments?

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