THE FASTER, BETTER, CHEAPER APPROACH TO SPACE MISSIONS: AN ENGINEERING MANAGEMENT ASSESSMENT

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Abstract

NASA was chartered as an independent civilian space agency in 1958 following the Soviet Union's dramatic launch of the Sputnik I (1957). In his state of the union address in May of 1961, President Kennedy issued to the fledging organization his famous challenge for a manned lunar mission by the end of the decade. The Mercury, Gemini and Apollo programs that followed put the utmost value on high quality, low risk (as low as possible within the context of space flight), quick results, all with little regard for cost. These circumstances essentially melded NASA's culture as an organization capable of great technological achievement but at extremely high cost. The Space Shuttle project, the next major agency endeavor, was put under severe annual budget constraints in the 1970's. NASA's response was to hold to the high quality standards, low risk and annual cost and let schedule suffer. The result was a significant delay in the introduction of the Shuttle as well as overall total cost growth. By the early 1990's, because NASA's budget was declining, the number of projects was also declining. Holding the same cost and schedule productivity levels as before was essentially causing NASA to price itself out of business. In 1992, the helm of NASA was turned over to a new Administrator. Dan Goldin's mantra was "faster, better, cheaper" and his enthusiasm and determination to change the NASA culture was not to be ignored. This research paper documents the various implementations of "faster, better, cheaper" that have been attempted, analyzes their impact and compares the cost performance of these new projects to previous NASA benchmarks. Fundamentally, many elements of "faster, better, cheaper" are found to be working well, especially on smaller projects. Some of the initiatives are found to apply only to smaller or experimental projects however, so that extrapolation to "flagship" projects may be problematic.

Background

In recent years the budgets for both NASA and the Department of Defense have been declining in constant dollars (Figure 1). These budget decreases have been due to efforts to reduce deficit spending and, in the case of Defense, due to the collapse of the Soviet Union and the end of the Cold War. At the same time, the global nature of the economy has forced the U.S. aerospace sector to look for ways to improve cost effectiveness and quality in the face of international competition.

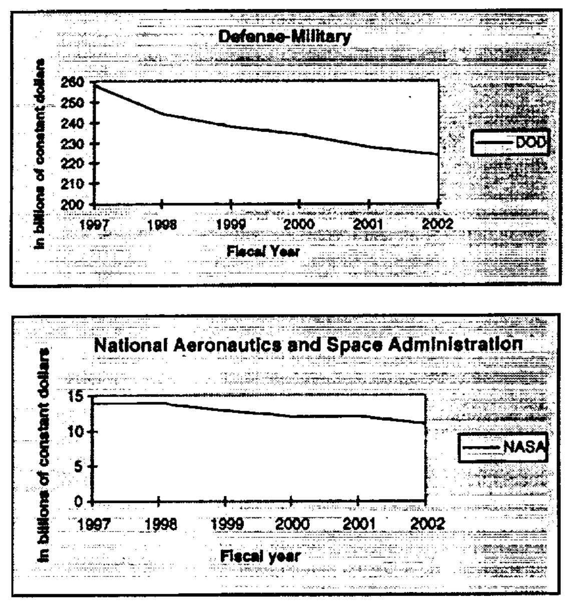

Figure 1

Decreases in purchasing power and increased competition obviously run counter with the continuation of the high historical cost levels of aerospace projects. Space programs have historically been costly for several basic reasons. First, the physical environment of space is very challenging. Low gravity makes fluid management difficult. The vacuum of space drives material costs and makes thermal control expensive. The radiation environment of space requires spacecraft electronics that are much more expensive than their terrestrial counterparts. Secondly, failure of a spacecraft generally means loss of the total mission due to the inability to retrieve or perform maintenance of hardware in space. Thirdly, the overall business base of the aerospace sector is very low when compared to most economic sectors. Automobiles, for example, have the luxury of amortizing non-recurring costs, fixed costs and support costs over hundreds of thousands of production units. Spacecraft production runs, in contrast, are usually only a handful of units. In addition, the number of suppliers of space products is relatively small and thus there is much less competition. A fourth driver has been the involvement of the government in most space projects which has induced changing requirements, detailed and extensive specifications, unstable budgets, and the cost plus fee environment. Finally, a fifth driver is the technological immaturity of many of the systems used in space projects, which rather routinely utilize systems with technology readiness level 4 to 6 (Figure 2). The commercial sector, on the other hand, generally tries to use technology readiness level 8 or 9 as a hurdle level.

Since about 1990, the aerospace industry has undertaken various concerted initiatives to improve the effectiveness of its projects. While policy level guidance has been provided by NASA and DOD, specific implementations have largely been the responsibility of individual projects. Many approaches have been attempted, some successful and some not. It is the intent of this research to examine the track record of these initiatives.

NASA Space Technology Readiness Levels

Level	Stage	Objective
1	Basic Technology	Observe and report basic principles
2	Feasibility Research	Formulate concept or application
3		Prove the concept through analysis or experiment
4	Technology Development	Validate the concept using components or breadboards in the laboratory
5	Technology Demonstration	Validate the component or breadboards in a relevant environment
6		Demonstrate a model or prototype in the relevant environment, ground or space
7	System/Subsystem Development	Demonstrate a prototype in the space environment
8	System Test, Launch and Operations	"Flight qualification" of the actual system through ground or space test
9		"Flight proven" through successful mission operations

Figure 2

This research surfaced three distinct eras of NASA engineering management philosophy as depicted in Table 1: (1) The newly formed NASA of the 1960's, (2) the maturing NASA of the 1970's through the 1980's and finally (3) the NASA of the 1990's attempting to restructure itself. For each of these era's, this study examined 21 separate engineering management criteria and characterized the NASA organization against these criteria.

1. Business Environment

In its infancy, the business environment of NASA was one of rapidly changing technology and very short development cycles for its projects.[33] Burns and Stalker describe this business environment as an innovative environment in which large changes are occurring rapidly in demand, products and services.[6] Organizations in this mode are dependent on R&D. They tend to be goal oriented versus task oriented just as NASA was oriented toward the goal of landing a man on the moon. Innovative environment organizations have flexible structures, intense communications and few rules—which to some extent represents the very early NASA. Due to declining budgets, a transition was made during the 1970's and 1980's to one of more stable technologies and much longer development cycles.[33] This corresponds to the first Burns and Stalker environment, the stable demand for the organization's services or products, the customers are constant and there is a low level of innovation. This reflects NASA in its former culture up through about 1990. In this mode the organization tends to have centralized decision-making, formal job descriptions, a rigorous chain of command and many rules. As part of its deliberate reengineering during the 1990's, NASA has returned to an environment of rapid technological change and short development cycles.[10] There are, however, marked differences this time in that the technologies are being matured in ground based research and experimental project demonstration projects prior to full-scale development. Also, the rise of a healthy commercial space industry pursing projects based on a profit motive versus the historical pattern of government sponsored space projects has made a dramatic contribution to the advancement of space technologies in the 1990's.

Strategies for managing change include changing the organizational structure, redesigning processes, utilizing technology, enhanced communications and improved training. NASA is utilizing each of these strategies. First, the current round of reorganization restructured the Agency into a much more product-oriented organization. Secondly, several process improvement teams were chartered to look at ways of improving the Task Agreement processes, implementing NASA program guidance policies, and improving the proposal preparation process, etc.

Another aspect of NASA's environment has been technology readiness. Because of NASA's original mandate to accomplish the moon mission in a short time beginning from a point of very immature space technology, the Agency had to begin full-scale development projects before the foundation technologies were mature. This was a very expensive practice. Several parallel technologies were often pursued simultaneously in the hope that at least one would work. The cost of projects escalated when certain systems were not ready at the time they were scheduled to be integrated into the next process step. As the budget and schedule criticality both diminished in the 1970's and 1980's, NASA's strategy turned more

Engineering Management Criteria	NASA (1960-1970)	NASA (1970-1990)	NASA (1990-Current)
1. Business Environment	Rapidly changing technology, short cycles; technology push during development project; response time fast but only with heavy use of overtime; major projects took 5-7 years.	Stable technologies (due to declining budgets) and long cycles; less technology push and technology harvesting; response time slow; major projects tool 8-10 years.	Return to rapidly changing technology, short cycles; use of precursor ground based and X vehicle technology maturation; response time more rapid; major projects take 3-5 years; small projects in <3 years.
2. Organizational Form	Functional, specialized, mechanistic and centralized	Functional, specialized, mechanistic and centralized; matrix approach attempted to increase responsiveness	Functional fortresses much reduced; much less use of matrix; reorganized into project oriented teams
Use of Teams	Teams used but inefficient implementation	Team efficiency increased	Product development teams initiated
Team classification	Working Groups	Pseudo teams	Potential/real teams
Size	Much larger than 2 to 12	Much larger than 2 to 12	Approximately 5 to 20 typical
Diversity	Little diversity	Token diversity	Noticeably more diversity
Volunteer or Draft	Appointed	Appointed	Appointees and volunteers
Team Leader	Project manager typically	Project manager typically	Team lead(non supervisor)
Training	No team training	No team training	Team training
Performance evaluation	Project level eval., not team	Project level, not team	Some team performance eval.
3. Management Process, Decision Making, Vision and Values	Top management and project managers made decisions; nationally mandated goal used as vision	Top management and project managers made decisions and dictate direction with little emphasis on vision and values	Teams and team leads generate many solutions; management tends to policy issues much more
4. Chain of Command and Communications	Formal vertical, top down; freedon of information often restrictive, proprietary; need to know only	Mostly vertical, top down but with some bottom to top, some horizontal cross functional communications; freedom of information more open but still a need to know mentality	Significant autonomy granted; vertical channels augmented by horizontal cross functional communications, more communication with customer; heavy use of intranet and internal freedom of information much more open but still pockets of need to know mentality
5. Job Descriptions	Detailed prescriptions	Detailed but with some flexibility	Less detail, more responsibility and authority given to employee
6. Span of Control/Support	7 employees for each supervisor (span of control)	10 employees for each supervisor (span of control)	14 employees for each supervisor (more span of support approach)
7. Valued Skills	Specialists	Specialists	More fostering of generalists
8. Training	Moderate quantity but mostly technical	High quantity, technical and management subjects	High quantity, adding diversity, safety, team building
9. Motivation and Awards	Formal, by quota, very delayed	Formal, by quota, very delayed	More team awards and more use of on the spot awards
10. Performance Appraisal	Tied to job description	Complicated system; tied to job description	Relatively simple paperwork; performance tied to organizational strategic plan
11. Policies, Procedures and Specifications	Inherited military systems which were extensive	Extensive policies and procedures tailored to NASA	Significantly rolled back
12. Supplier & Contractors	To be controlled	To be controlled	Frequently a partner
13. Customer Focus	Early customer focus on the Executive and Legislative branches of government and effective public relations with the taxpayer; success criteria includes performance, schedule (r variables) and reliability (p variable)	Same customer focus continued; success criteria include performance, cost control (r variables and reliability (p variable); quality circles attempted.	Consistent with TQM, much more importance put on internal, intermediate customers; success criteria include performance, cost control (r variables), reliability but also customer satisfaction and retention, morale, rewards (p variables); product development teams with QA providing support training; heavy emphasis on ISO 9000.

Table 1

toward reuse of existing technologies. In the 1990's, NASA has policies in place, which direct that technology is to be matured in the laboratory setting and in experimental programs. Only when a technology has been matured to Technology Readiness Level 6 (Figure 2), is it allowed to be used in a full-scale development project. This is proving to be a very effective approach to controlling cost and schedule growth **(See recommendation 1)**.

A final metric of the NASA business environment is response time. NASA was initially charged with landing a man on the moon in under a decade. Thus one of the characteristics of the Agency in the 1960's was the ability to perform technically and managerially complicated projects quickly. In the 1960's it was usual for major projects such a spacecraft to be developed and flown in 5 to 7 years. Following the success of the Apollo program, NASA budget and priority status with the Congress and the Executive Branch declined. By the 1980's, NASA's response time as measured by project development timelines had expanded to 8 to 10 years or more.[33] A major tenet of NASA's ongoing reinvention of itself into the faster, better, cheaper is the ability to accomplish projects with a much improved response time. Numerous projects have been accomplished in the 1990's with development templates of 3 to 5 years. One of the major contributing factors which has allowed this is the faster work that can be done in the concurrent engineering environment of teams **(See recommendation 2)**.

2. Organizational Form

Within 5 years of being chartered in 1958, NASA had established most of the field center organizations that still exist today and had to a large measure also institutionalized similar organizational forms within these field centers. Much of the organizational structure was inherited from the military commands from which many NASA centers were derived. The organizations tended to utilize divisions or laboratories that were functionally ordered (typically against the standard spacecraft systems and functions of structures, propulsion, avionics, test, manufacturing, systems engineering, etc.). Within these functional fortresses, engineers and technicians worked their specialist disciplines and passed the completed work on to the next function.[4]

This early NASA is a classic example of what the German writer Max Weber defined as a bureaucracy. According to Weber, a bureaucracy has such characteristics as:[38]

- Organization of official function bound by rules
- A sphere of competence with knowledgeable managers having the authority for making decisions
- A strict chain of command
- Regulation by technical rules and norms

NASA also was characterized by the division of labor into functional organizations, the centralization of authority, narrow job descriptions and large staffs that are all characteristic of a bureaucracy. This all worked acceptably well as long as NASA had the stability that it had in the 1960's with one single, focused mission. As the business environment changed in the 1970's and 1980's, NASA was hamstrung by the bureaucracy's slow response time to react to change.[4]

During the 1970's and 1980's, the functional approach was modified slightly by the addition of the matrix philosophy as a strategy toward increasing responsiveness to project manager customers.[4] Of course, the matrix adaptation brought a new set of problems associated with the "two boss problem" of functional managers and a project manager. *The Fifth Discipline* councils about two learning disabilities that NASA suffered from in its old culture.[35] One is the "I am my position" syndrome in which employees narrowly focus on their sphere of influence. In this mode of thinking, they do not feel responsible for helping solve problems that are "over there". A second learning disability is "the enemy is out there" in which functional organizations look at other functional organizations not as member of the same team but rather as an outsider. Thus marketing does not communicate with engineering or design does not communicate with production. By the 1990's, most NASA field centers were reorganizing to reduce functional fortresses and the use of the matrix system in favor of product oriented organizations with a cross-functional makeup.[34]

A team is a group working synergistically toward common goals with mutual accountability. Interviews with employees who were charter members of the NASA organization or who were at least hired during the 1960's, [Personal communication with ASTP staff, 1999; LFBB staff, 1999; RLV staff, 1999; Provence, 1999] revealed that teams were a part of the early NASA. However, the implementation of the use of teams was not very efficient. The teams actually tended to be working groups as defined by Katzenback and Smith.[13] They tended to be much too large for efficiency. Most of the team members were white male engineers and thus were not equipped to take advantage of the original solutions sets that a truly diverse team can achieve. The team makeup was almost always by management appointment as opposed to volunteerism.

Team leadership was provided either by the project manager delegated to a lower level supervisor. No evidence was uncovered that there was any training on working in teams. Performance was evaluated at the individual employee level instead of assessing the performance of the team as a whole.

During the 1970's and 1980's, NASA's implementation of the team approach took several turns for the better, rising perhaps to the Katzenbach and Smith level of pseudo teams.[13] Some token examples of diversity were becoming noticeable—race and sexual diversity due to the equal opportunity legislation rules mandated by law and educational background diversity by the addition of non engineers to many teams including procurement and business specialists, lawyers, public affairs professionals, computer systems analysts and other disciplines. [Provence, 1999] This increased range of cultural background undoubtedly increased the range of opinions of solutions to problems that were at least considered by the teams though most evidence suggests that the engineering opinion still dominated **(See recommendation 3)**.

By the 1990's, thanks to the increasing engineering management literature and university training emphasis on the value of teams, NASA had begun a dramatic implementation of the team approach. The TQM initiative, especially with its advocacy of a participatory culture, led NASA to explore the use of teams. Frequently termed, "product development teams", the transition is being made to a much more effective level of efficiency, probably equivalent to the Katzenback and Smith potential or real team level. The average team size is being decreased to about 5 to 20 people and diversity has increased in another step function to the point where the level of diversity of the team is essentially equal to the overall labor pool of the NASA field centers. Frequently, teams are staffed at least partly by volunteers who have enthusiasm and experience for tackling the problem at hand. Team leads are now routinely selected by the team itself and need not be supervisors—indeed examples abound of team leads who are actually a lower grade level than some the team members they are leading. And the measure of success or failure is increasingly being focused on the performance of the team as a whole as opposed to individual performance [Parks, 1999] **(See recommendation 4)**.

The use of teams in NASA has enhanced performance through obtaining buy-in from the team members at project initiation and the synergy of the team dynamics in problem solving which leads to better decisions. Teams are being given autonomy, as recommended in *Search of Excellence*.[30] There has been some resistance to teams, usually in the form of employees thinking it is the fad of the month and the normal resistance to change. The early resistance to teams was also due to lack of training [Provence, 1999] **(See recommendation 5)**.

Besides the other obvious advantages, the widespread use of teams in an organization such as NASA also has the benefit of increasing employee feelings of well being. The psychologist Abraham Maslow maintained that humans have physiological, safety, membership, self-esteem and self-actualization needs.[9] At least three of these needs are addressed by teams: (1) the need for membership in the team, (2) the need for self esteem from achievement, reputation and recognition from the team and (3) the need to strive for self actualization by becoming what one is capable of becoming which can be enhanced by the overall high performance of teams.

3. Management Process, Decision Making, Vision and Values

NASA was established in 1959 and set its initial culture in a time when the rational model of management thinking was still very much evident. In the rational model, decisions are the responsibility of management, order and control is highly valued and organizations are normally thought of as functional layouts. As part of its cultural change, NASA is moving toward a more social organization structure in which the responsibility for detailed technical decisions are the responsibility of teams which are usually much closer to the problem and are best equipped to make decisions.

Throughout the 1960's and 1970's, NASA project managers and top management had has been viewed as having major responsibility for all decisions.[4] This is what the behavioral theorist Douglas McGregor termed a Theory X view.[21] The Theory X view is an operating assumption that employees are not necessarily motivated to do what is right but instead must be directed and controlled. The use of teams and the change to decentralized organizational forms in the 1990's has begun a transition to more of what McGregor termed a Theory Y mentality in which employees are given much more credit for the ability to use self direction in problem solving.

During the early days of NASA there was the nationally mandated vision associated with the moon project that unified NASA employees. During the 1970's and 1980's, top management tended to dictate direction with little emphasis on vision or values. This also has changed in the 1990's with the advent of teams. While not all projects are utilizing teams to the extent they should, those that are now tend to leave more detailed technical decisions up to the team. This has led to managers using more of their time with the proper role of policy making and providing the support that teams need to function. *In Search of Excellence* advises that organizations should be "hands-on, value-driven" meaning that management should be proactive in directing the company by way of establishing and clearly communicating the underlying values of the organization. NASA has implemented this by way of developing an Agency level strategic plan and then flowing down this to a center level strategic plan for each field center.[9] Another tenant of ISOE is that of using stories and legends to foster an appreciation of the values of the organization in employees. NASA, perhaps more than most organizations, has an abundance of lore from the Mercury, Gemini, Apollo, Skylab and Shuttle histories. This could be the basis for teaching values but is not being particularly utilized **(See recommendation 6)**.

These changes are consistent with the third discipline in Senge's *The Fifth Discipline*, which is mental models. Where the old mental model valued managing, organizing and controlling, the new mental model values vision and values to guide decision-making. Much of the culture change is consistent with some of the other major tenants of *The Fifth Discipline*. For example, there is increased emphasis in NASA, especially since the arrival of Dan Goldin as NASA Administrator in 1992, on building a shared vision across the Agency team. Also there is the recognition that some of today's problems came from yesterday's solutions. For NASA this can be said to be the case in the sense that the Agency's first big assignment to "land a man on the moon and return him safely to earth" was to be done by the end of the decade and at all cost. Thus NASA's culture was established at the outset to be one which valued speed and technical success with little regard for how much it cost. This culture, while very successful for the Apollo Program, was distinctly not very appropriate for the post Apollo 1970's and 1980's when NASA's budget was substantially lower in real terms. It has been very problematical for NASA to break with this old culture and move into a more cost-effective mode of operation (See **recommendation 7**).

Another concept, which can be usefully employed to analyze NASA's management process, is that of the Managerial Grid developed by Blake and Mouton.[5] The Managerial Grid is a measure of management's concern for production versus its concern for people. Both axes of the grid are divided into three zones: 1 for low, 5 for medium and 9 for high. Thus rankings can be made along the following scheme:

- 1,1 = low concern for production, low concern for people
- 1,5 = low concern for production, medium concern for people
- 1,9 = low concern for production, high concern for people
- 5,1 = medium concern for production, low concern for people
- 5,5 = medium concern for production, medium concern for people
- 5,9 = medium concern for production, high concern for people
- 9,1 = high concern for production, low concern for people
- 9,5 = high concern for production, medium concern for people
- 9,9 = high concern for production, high concern for people

In its early days, NASA was a 9,1 organization, [Parks, 1998] with a high focus on production (the mandate to land a man on the moon) and little in the way of systems or management philosophy regarding people other than as a resource. During the 1970's and 1980's, NASA migrated to more of a 5,5 organization, with relatively less emphasis on program (production) and relatively more concern for people. A Managerial Grid rating of 5,5 for NASA, with a compromising, intermediate level of concern for both production and people is consistent with several of the other assessments made in this study such a soft Theory X rating on McGregor's operating assumption and the level 3 membership needs level of Maslow. We shall also see consistency later with theories by David McClelland and Frederick Herzburg's.

NASA in the 1990's is attempting to move toward a 9,9 on the Managerial Grid, which corresponds, to a high regard for both production and people. To achieve 9,9, NASA would have to have the ability to integrate production concerns and people concerns together, to use more fully use teams for decision-making and conflict resolution, and have effective two way communications between employees and management **(See recommendation 8)**.

4. Chain of Command and Communications

Based on the military model, NASA began life with a chain of command that was very formal and vertical. This rigidity was relaxed only slightly during the 1970's and 1980's, though still with very little decision making power delegated downward. In the 1990's, largely because of the advent of teams, NASA management has delegated some autonomy for technical decisions to the product development team level. [22]

In Search of Excellence discusses the advantages of "simultaneous loose-tight" policy in the realm of chain of command, advocating only a loose implementation of the formal chain of command in order to maintain a flexibility within the organization to respond to changing environments, customer needs and so on. NASA, in the installation of the product development team approach, has certainly loosened reliance on strict adherence to the chain of command but needs to move further in this (**See recommendation 9**).

Communications in the early NASA was typically vertical from top to bottom. Major policy and mission plans were produced by top management and these were directed downward in the organization. By the 1970's and 1980's, with the rudimentary beginnings of the use of teams, significant bottom to top and some horizontal cross functional information flow was in use. In the 1990's, with product development teams very much the norm, cross-functional communication is quite heavy by the very nature of the concurrent engineering process being used. Most product development activities also include a representative of the customer on the team. Communications improvement actually started in 1986 after the Challenger accident when lack of communication was cited as a contributing cause. Communications has been improved through the use of more emphasis on supervisor to employee staff meetings, occasional "all hands" meetings and probably most effective, much more use of internet and intranet electronic communications. The use of Intranets and the Internet are now very common at all NASA installations, which have significantly aided communications in all directions.

NASA was a mainly a functional organization in the beginning and information flow across functional boundaries tended to be restricted and treated on a proprietary basis. While not a ubiquitous practice, it was widespread enough that it was often very difficult for a person or organization outside a particular project to obtain information about the project if they could not clearly demonstrate a need to know. This practice loosened some during the 1970's and 1980's but, even today, here are still pockets of the organization that is resistant to completely open information flow across the organizations (**See recommendation 10**).

5. Span of Control (Support)

The span of control that can be derived from the number of employees divided by the number of supervisors from 1960's NASA personnel data yields a ratio of about 7 employees to each supervisor (30,000 personnel, 4,000 supervisors). The span of control is the focus of functional organizations. However, according to Dr. Dawn Utley of the University of Alabama in Huntsville, the focus should be on *the span of support* (i.e. how many employees can one manager support). The span of control thinking persisted throughout the 1970's and the 1980's, though the ratio did increase to something like 10 employees for each supervisor. Starting in the 1990's, NASA made a purposeful decision to increase this ratio even more. Most NASA centers have established a goal of 14 to 1 in the current round of reorganizations.[29] Wide spans of support force communications to be more employee driven. Geographical proximity is another strategy to facilitate larger span ratios because it aids communication. Geographical proximity, however, is not quite as necessary today as it was a few years ago due to the increasing use of intranets for team communications. Moving from control to support implies that the role of managers changes as discussed by Warren Bennis.[3] He writes that managers need to become leaders, moving from an old style manager's short term focus on allocating scarce resources, organizing and scheduling to a leadership long term focus on establishing vision and values and motivating through empowerment. And to a beginning extent, again due to the advent of teams, supervisors are finding themselves acting more in mold of Dr. Utley's span of support role, providing policy guidance, training, and other support to their employees who are daily working in a team environment.

6. Job Descriptions

The NASA job descriptions of the 1960's were very detailed and highly specialized prescriptions for work written by management without employee input [Provence, 1999]. Most of these very same job descriptions were held over into the 1970's and 1980's, with some flexibility inserted here and there and with a minor amount of employee input on occasion. A dramatic change has been made in job descriptions over the past 10 years. They tend now to be much shorter, more general, and give much more authority to the employee. Though not yet to the point where they read, "do what you think is right" most NASA job descriptions are much improved over their forerunners.

In Search Of Excellence maintains that formal job descriptions actually inhibit employee creativity. ISOE also advocates that organizations remain flexible in assigning employees and should not be hesitant to shift employees around to enhance organizational productivity. While NASA has not limited job descriptions or adopted quite the level of employee assignment flexibility that *In Search Of Excellence* counsels, the movement is at least in that direction.

7. Valued Skills

The young NASA of the 1960's installed a cadre of specialists to develop the systems necessary for the Mercury, Gemini and Apollo programs. These were very much the valued skills that the Agency sought to solve quickly the complex problems associated with a fairly narrow mission assignment. This mentality of valuing specialists continued unabated through the 1970's and 1980's. Finally, in the 1990's, an entirely new set of missions came along. Projects such as the International Space Station are very complicated and depend upon the cooperation of a very diverse set of international countries. The Reusable Launch Vehicle project is a partnership between the government and industry and depends upon the ability of the team to craft a program, which is win-win for both sides. In this environment, NASA is beginning to realize the value of teams populated by employees with "big picture" viewpoints and employees with generalist's skills **(See recommendation 11).**

8. Training

During the 1960's, NASA training programs were focused mainly on improving the employees' technical performance. Due to the large amount of overtime that was being worked during the projects of that decade, there was only a limited amount of time available for training. The 1970's and 1980's had more time available for training and the amount of training was increased. Though still focused in the main on technical subjects, management and other topics were also offered. The level of training has increased even more in the 1990's and the subject list has expanded to include quality improvement, team building, customer satisfaction, safety, cultural diversity, and similar topics.[1]

9. Motivation and Awards

The psychologist Frederick Herzberg, who has done important work on motivation, identified two distinct types of motivators.[10] First, the set Herzberg termed "hygiene factors" are thought by many managers to be positive motivators but are really negative motivators. Hygiene factors include such things as salary, time off awards, employee counseling, improved working conditions, changes in company policy, relations with peers and supervisors—all of these need to be satisfactory for an employee but do not really motivate beyond the break-even point (i.e., their absence is a de-motivator but their presence is only expected and does not cause an employee to perform better). Rather, Herzberg identified the real motivating factors as achievement, recognition for achievement, the work itself, responsibility, growth and advancement. These findings by Herzberg would probably not be intuitive to the average NASA manager. Many of Herzberg's hygiene factors are still thought of as motivators in NASA, especially such things as reserved parking, time off and bonuses **(See recommendation 12).**

Similarly, the psychologist David McClelland has identified two types of broad groups, the minority who are challenged by opportunity to work hard for achievement, and the majority who are not greatly motivated to achieve results.[20] He believed that those not so motivated can be taught to become achievers and that it is the organization's responsibility to train employees to achieve and to structure the organization in such a way that this outcome is encouraged. The lesson for NASA here is to recognize that while the organization may be mainly populated by the majority type, these employees can be turned into achievers by giving them challenges, setting stretch goals and giving them decision-making power **(See recommendation 13).**

10. Performance Appraisal

Early NASA performance appraisals were relatively simple affairs, usually a check off system on one page [Parks, 1998]. They were, however, very narrowly tied to the job description of the employee. During the 1980's the government was vastly complicated in a misguided effort to use the performance appraisal system as a cure to improve productivity. Thankfully, this system was scrapped in the late 1980's and replaced with a streamlined system that also took steps toward aligning the performance appraisal system with the strategic plans of the organization.

11. Policies, Procedures and Specifications

Along with the people, facilities and programs that NASA inherited from the military in the 1960's, the Agency also adopted most of the Department of Defense policies and procedures regarding engineering and management. Only in the 1970's and 1980's did NASA tailor the military specifications to its unique needs. By the end of the 1980's the Defense Department had begun to dismantle its government guidelines in favor of using commercial specification practices. NASA has also adopted this practice, reasoning that it is more cost efficient to simply specify in contracts the top level performance and quality requirements for a system and allow the contractor community to utilize its own internal procedures to assure that the delivered product meets requirements.

A good example of this is the increasing practice in NASA to use performance specifications for new projects. In this practice, management only gives broad performance guidelines called performance specifications. These guidelines only specify the top level function that is desired for a given project (e.g. the X-33 performance specification was a system capable of achieving a certain Mach number, a certain altitude and range and a particular turnaround time). The detailed decisions of exactly how to achieve the performance spec is left up to the creativity of the team. One problem with such an approach is that sometimes the specification is essentially impossible to achieve. For example, the Bantam Project has been given a performance specification of launching a 150-kg payload for a total cost of $1.5 million per flight. Despite the fact that the Bantam team has been working on this problem for well over a year, no design has been generated that comes close to meeting the requirement.

In Search Of Excellence promotes what is termed "simultaneous loose-tight" policy in which the organization is loose in using formal control and policies but tight on using the company wide communication of values to equip each employee with the value driven philosophy needed to make decisions. NASA has moved in this direction first by establishing values through its strategic planning as previously discussed and by advertising to its employees that they are empowered to make decisions based on what they think is right.[9] The extent to which individual employees have embraced this is still somewhat problematical (**See recommendation 14**).

12. Supplier and Contractors

NASA's mentality toward its contractors and suppliers was constant throughout the 1960's up until fairly recently. Contractors were to be controlled with tightly written contractual documents and significant engineering management oversight. At times, NASA has almost viewed the contractor community as the enemy that must be controlled using whatever constraints were available. Concurrent with NASA and Defense's roll back of dictated procedures, NASA has changed the way it operates in regards to the contractor community. Several NASA projects in the 1990's have seen NASA and industry partner on projects (the X-33 and RLV programs are good examples). Even the Shuttle program is slowly morphing to a joint government and industry operation with plans to turn the entire process over to industry.[23]

13. Customer Focus

As a government agency, NASA has traditionally had the Executive and Legislative branches of government as its immediate customer. However, NASA early on understood that the ultimate customer of its projects was the American people. Consequently, NASA institutionalized a fairly effective public relations activity to educate the taxpayer on the benefits of the space program and to appeal to the exploration spirit of the citizenry with its portrayal of the excitement of its projects. This policy basically continued until the ascendancy of TQM in the 1980's and its broader emphasis on the voice of the customer. By the 1990's, NASA was placing much more importance on the internal and intermediate customers at all levels of the organization.[17]

A problem area for NASA, especially in the 1970's and 1980's after the down turn form the Apollo program, was the loss of focus on its basic mission. During that timeframe, NASA embarked on several endeavors, which really did not mesh with its basic capabilities and interests. Several energy projects were begun in the 1970's such as solar heating and cooling and coal gasification. Satellite communications programs were attempted in the 1980's, which were better, left to private industry. The attempt to commercialize the Shuttle and to fly teachers in space in the 1980's was ill conceived. All of these thrusts, which were mainly inspired by a desire to keep the workforce from declining in times of budget reductions, were basically examples of not doing what *In Search of Excellence* calls "sticking to the knitting." More recently, in the 1990's, using its strategic plan and flow down of that plan to roles and missions for each field center, NASA has done a much better job of channeling the Agency's efforts toward a more tightly focused set of objectives.

The Fifth Discipline recommends not just focusing on the linear cause and effect relationships that drive cost for example, but instead using systems thinking to focus on the cures such as improving the process, training, enhancing customer focus. In NASA's case, the Agency should perhaps concentrate on improving productivity so that more projects are accomplished for the same level budget. That is, for the same $13 billion dollars, NASA could challenge themselves to accomplish twice or three times as many space projects (**See recommendation 15**).

While the responsibility for quality has always flowed down to individual employees, most NASA field centers have utilized a Quality Assurance organization in a checking role. During the 1970's and 1980's, Quality Circles were attempted without lasting success. With the advent of product development teams in the 1990's, the teams have been given the responsibility of insuring that quality is designed into the systems from the outset. While quality is the responsibility of all team members, there is usually a representative of the QA organization on the team. The QA organization is generally also given the responsibility of providing support such as quality training to the entire organization as well. NASA has also adopted the ISO 9000 program and each NASA field center is required to become certified in ISO 9000. Regular internal and external ISO audits are being performed.

Recommendations

1. Mature technologies in ground based research and flight demonstration projects prior to the use in full-scale development. Also, make maximum use of commercially developed technology.
2. Utilize concurrent engineering in a team environment to improve response time of the organization.
3. Encourage diversity in teams and utilize the results range of opinions to identify better solutions.
4. Measure the performance of teams as a whole, not the individual performance of team members.
5. Provide teams with professional training on team building and working in teams.
6. Make use of NASA lore from past success stories to transmit the values of the organization to employees.
7. Recognize that NASA culture was set up originally in an era of unlimited budgets and work to communicate that such a culture no longer exists.
8. Demonstrate concern for both production issues and people issues, using teams for decisions and improving communications between management and employees.
9. Loosen the reliance on a strict chain of command and allow employees to communicate horizontally.
10. Demand open information flow throughout the organization without insisting on "need to know."
11. Cultivate employees with generalist skills and the ability to see the "big picture."
12. Use positive motivators (versus hygiene factors) such as achievement, recognition for achievement, the work itself, responsibility, growth and advancement. Remove controls, increase the employee's accountability and authority and enable people to become experts.
13. Encourage employees to achieve by giving them challenges, setting stretch goals and giving them decisions-making power.
14. Educate employees on the strategic values of the organization and empower them to make decisions based on these values.
15. Focus on productivity improvements (rather than budget availability) in order to equip the workforce to accomplish more projects for a given budget level.

Concluding Observations

The analysis enumerated many faster, better, cheaper initiatives that have been undertaken by the aerospace community. In the area of improved engineering processes, the underlying initiative was seen to be the increasing utilization of a team approach and the complementary movements toward more effective organizational forms that are flatter, more fluid and product oriented and are working closer with both customers and suppliers. Simultaneously, these teams are being given improved tools and are being imbued with an increasing awareness of empowerment to control costs. They are working in environments with fewer restrictions involving specifications and a reduced requirement for non-contributing documentation and oversight. And they are making more intelligent use of technology, harvesting only mature technological systems for use in flight projects. In the area of improved business processes, procurements are being streamlined and more effective partnering arrangements are being used. At times, industry is being relied upon to develop products and services needed by government customers on a commercial basis. Government labs are being used in new and more effective ways and the government organizations are increasing their efficiency through the use of better accounting systems to identify costs and more rigorous process procedures such as ISO 9000. Finally, outsourcing is being utilized to provide services to organizations without diluting their focus on their core business operations.

In all of this there is considerable optimism and anecdotal evidence that the basic engineering management culture of the aerospace sector is improving. While the industry will, for the foreseeable future, remain a more expensive environment in which to do business because of inherent characteristics having to do with space, there is considerable optimism and more than a little evidence that the overall engineering management effectiveness of the nation's space endeavors are improving.