



Forty Years of Space Mission Management

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Over the past 40 years, APL has developed 58 satellites using the methodology currently captured by the phrase “faster, better, cheaper.” In so doing, a management culture evolved that allowed us to successfully meet technical requirements within short schedules, often below originally estimated costs. We present the basic guidelines used in our space mission management approach and illustrate how they can be applied effectively. (Keywords: Faster-better-cheaper, Management, Program Management.)

MANAGEMENT GUIDELINES

As described in the article by Bostrom, this issue (“Defining the Problem and Designing the Mission”), the Space Department came into being with the development of the Transit System. Within the incredibly short period of 4 years, APL turned the mission concept as described in an internal memorandum into a reality. The resulting small constellation of spacecraft consisted of four satellites orbiting at an altitude of about 1000 km and an inclination of 90°. This constellation was already providing navigation signals for ocean- and land-based users with a precision of about 1 km and repeat time of approximately 1.5 hours.

The remarkably short time between initial concept and operational availability was achieved by a dedicated group of scientists, engineers, and managers, all working together toward a common goal. In those early days of Transit, many of our basic management guidelines took root.

The paradigm for management for most of our programs throughout our history can be summarized by seven management guidelines.¹ We will discuss each guideline briefly and highlight its significance in terms of cost and performance.

1. *Limit the schedule from start to launch to ≤ 36 months.*

The 36-month period is based on the typical APL mission experience during the last 40 years. Most of our early programs were performed within time-critical schedules and were geared toward the operational needs of the Navy. Schedules will, of course, differ, depending on the mission. The primary issue is to fix the development phase such that the proper amount of time is allowed for study, design, fabrication, and test. Too much time in the study and design phase feeds the concept that “better is the enemy of good enough” and raises the cost of the product in terms of both time and money. Additional time in the later phases of development means that a “standing army” is being extended, which is very expensive and also tends to defocus the team.

2. *Establish a small, experienced technical team.*

The size of a development team is based on schedule and technical complexity. An experienced team starts with an understanding of the relationship of requirement to cost and schedule based on previous successful

missions. One important factor is to maintain a realistic challenge in design; that is, the manager should challenge the designers with an *achievable* schedule so that frustration does not replace the challenge. The manager must also bear in mind that only through an innovative approach, one that maintains the team's focus, can success be achieved.

Decisions must be made within the team whenever possible to foster team dynamics. In considering the experience level of the team, management must be part of the grooming process for future lead and system engineers. In addition, there needs to be an appreciable sprinkling of less experienced career staff behind each lead engineer. This is primarily the responsibility of a skill center supervisor, but the project manager must share in that responsibility for the improvement of the organization.

Independent review teams also support the development team. The manager plans a series of technical reviews to monitor and assess project progress, including a

- System requirements review coupled with a conceptual design review
- Preliminary design review
- Critical design review
- Pre-environmental review
- Pre-ship review
- Mission readiness review

Each review is conducted by an independent review board team that is drawn from within the Space Department, other APL staff, and external (primarily government) organizations to ensure coverage of various areas of expertise. The manager coordinates these reviews closely with the Space Department Chief Engineer (see the article by Ebert and Hoffman, this issue).

3. Design the spacecraft and instruments to cost.

At the onset of the development phase, a complete understanding of the mission requirements as viewed by the customer, science team, and spacecraft team is essential. Equally important are the derived requirements based on the mission requirements such as spacecraft pointing, data rates, processor architecture, etc. Again, there needs to be discussion and agreement that all mission requirements are achieved but not exceeded using the list of derived requirements.

Once the mission and derived requirements are in place, the cost of the project can be established. In cost-capped projects, the requirements may have to be adjusted, as cost is the fixed parameter. It is even more important that there be agreement between the customer and the development team over the resulting mission requirements. The single highest risk to managing a cost-capped program is "requirements creep."

From a management viewpoint, focus must be maintained on *everyone* involved, i.e., the customer, the science team, and the development team. As the development phase progresses, the customer will obviously want to obtain as much "mission" as can be acquired for the cost. The science team will assuredly desire the best possible instruments that money can't buy. Finally, all of the subsystem engineers developing the spacecraft are interested in the challenge—they are, after all, engineers.

Continued focus on the cost-capped design must be a part of all presentations, meetings, and discussions, again to prevent any creep in the original agreements. Once the various members of the development team recognize that the requirements are fixed—and that will take time—the job becomes easier. Conversely, if management shows signs of listening and perhaps even incorporating "better ideas," rest assured that a continued diet of better ideas will be on the plate and just as assuredly cause cost problems. Table 1 shows the cost performance of recent APL spacecraft buses.

4. Use the lead engineer method for each subsystem.

The APL Space Department is organized in matrix structure. The Project Office comprises a project manager, system engineer, and secretary. The staff are in skill centers such as telecommunications, mechanical, software, etc. At project start, the project manager and system engineer meet with the supervisor of each skill center and the lead engineer assigned by the skill center supervisor. Essentially, a contract is agreed upon between each skill center and the project. This contract includes technical requirements, schedule, and cost, and the lead engineer is then responsible for fulfilling the contract for all three issues. It is incumbent upon both the skill center supervisor and the project manager to periodically discuss the performance of the lead engineers.

This approach provides a sense of ownership and responsibility in the lead engineer, who also usually stays with the project through concept, development, fabrication, test, and launch. A significant amount of documentation is eliminated as well, since paperwork is generated only because there are several handoffs when this approach is not followed.

5. Design in reliability and redundancy at the outset.

Discussions are necessary in the early phase of a mission design among the customer, the science team, and the implementing agency (contractor) to establish the reliability requirements with respect to the spacecraft, instruments, and overall mission. These discussions allow the necessary redundancy to be "designed in" and not added at a later date, thereby adding additional expense. Often, functional redundancy can be attained at a lower cost than "block" redundancy (i.e.,

Table 1. Spacecraft bus cost performance history.

Program	Sponsor	Weight (kg, dry mass)	Launch	Duration (months)	Constant FY97 ^a (\$M)	Cost growth ^b (%)
Magsat	NASA/GSFC	158	1979	24	26.3	8
AMPTE	NASA/GSFC	156	1984	36	27.0	0
Geosat-A	Navy	543	1985	37	33.2	7
Polar BEAR	USAF	94	1986	24	18.0	-5
Delta 180	SDIO	323	1986	12	20.6	-3
Delta 181	SDIO	1081	1988	17	114.7	-1
Delta 183	SDIO	253	1989	13	21.8	8
NEAR	NASA/HQ	429	1996	26	71.9	-7
MSX ^c	BMDO	1449	1996	40	112.0	13
ACE	NASA/GSFC	590	1997	47	48.8	-10

^aCost at project completion (launch +30 days) in constant fiscal year (FY) dollars.

^bPercent cost growth from initial cost estimate at start of Phase C/D.

^cCost adjusted for 3.5 years of program schedule slip, e.g., funding shortfall, government-furnished instrument delays, programmatic delays, etc.

the duplication and necessary cross-strapping of a module).

Two examples of functional redundancy were used on the Near Earth Asteroid Rendezvous (NEAR) Program. In one, the imaging instrument, the MultiSpectral Imager, was planned as a backup for the onboard single-string star camera. Although there would be a slight but tolerable degradation in pointing, early discussions allowed this trade-off to be manageable. A second example is the functional redundancy between the reaction wheels and the attitude control propulsion system on NEAR. The inherent redundancy was considered in the design and cost of both subsystems. Early recognition that block redundancy would optimize reliability allowed for a proper harness design in case cross-strapping was needed.

6. *Integrate the product assurance engineer into the program.*

Many organizations structure the reliability and quality assurance component outside the program so that it reports through the line organization to upper management. APL takes a different approach and integrates this element into the development team in the form of a “product assurance” (PA) engineer. With this approach the “cop on the beat” atmosphere is lessened; the PA engineer has a product to deliver as do all other subsystem engineers. Communication is stronger, and the discussion of problems that do occur is more open. If the project manager does not address a particular issue appropriately, the PA engineer has a secondary path through the line organization to upper

management. Rarely, however, is this path taken.

7. *Assign a single agency manager to interface with the development team.*

This guideline differs from the rest in that it affects the customer’s organization. The rationale for this guideline will be illustrated by a hypothetical but possible example.

Suppose APL begins a project for NASA, but more than one of NASA’s field centers are involved, each with slightly varying requirements (e.g., product assurance). What may appear to be slight variation within NASA could have potential cost and schedule impact on the implementing team. It is therefore essential to establish a lead center as the interface. If this does not occur,

an agreed-upon set of rules for all issues must be established at the outset. The time to discuss rules is *not* after development is under way, mainly because the interfaces are then between engineers or scientists who typically do not set policy and may make agreements that impact schedule or cost.

As already noted, this guideline, although not one over which we may have much control, should be brought to the customer’s attention early.

THE FUTURE

Space missions have changed radically over the past 40 years since the Space Department’s first entry into the early days of space exploration. Our government (military and civilian) systems are far more complex, the expense involved in any space mission is much higher, and decisions to approve a mission (military or civilian) are far more involved. But as much as things have changed, some things have remained the same. The capability to conceive and implement space missions within a given schedule and cost is still highly valued. In the future, our management practices will need to continue to be responsive to customer needs, but at our core is a proven method for meeting mission goals within cost and schedule. More automated tools and commercial off-the-shelf hardware will have to be incorporated in our mission concepts and managed effectively and efficiently to ensure that implementation is successful. At the same time, new development is necessary to accomplish many of the missions envisioned for the future. Management of development is far more complex

than management of “production” work, and this is an area in which the Space Department has had much success. We are looking forward to the challenges of balancing these aspects into the next century.

REFERENCE

- ¹Krimigis, S. M., “Practices for Inexpensive, Short-Development Cycle Spacecraft à la APL,” in *Microspacecraft for Planetary Exploration Workshop*, B. Murray and L. Friedman (eds.), Pasadena, CA (1992).

THE AUTHORS



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