# INSERTING NEW TECHNOLOGY INTO SMALL MISSIONS

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## ABSTRACT

Part of what makes small missions small is that they have less money. Executing missions at low cost implies extensive use of cost sharing with other missions or use of existing solutions. However, in order to create many small missions, new technology must be developed, applied, and assimilated. These statements seem to contradict one another. Luckily, there are methods for creating new technology and inserting it into faster-better-cheaper (FBC) missions. NASA has invested in many processes for technology development and infusion. Each of these has had successes and has also uncovered areas for improvement. Understanding the technology lifecycle and how capabilities progress within it is critical to maintaining strong and successful technology development programs.

## 1. INTRODUCTION

NASA remains committed to the philosophy of “faster-better-cheaper” (FBC.) Recent mission failures were not a result of FBC – these missions were designed before FBC. In fact, the causes for some failures emphasize the need to adopt FBC concepts, including increased reliance on “just-in-time” new technology.

I have presented data showing a dramatic increase in the number of NASA missions [1]. This increase has not occurred at the predicted rate – but there has still been a noticeable increase. The new projects tend to be smaller and have considerably less funding. The FBC processes are meant for them.

In the old days, there were only a few deep space missions developed, about one every two to three years. These missions consisted of large spacecraft and large budgets. These large missions developed whatever technology they needed. This does not work in the FBC era since no mission has enough discretionary investment capability to pursue an intensive development program.

FBC requires that the latest breakthrough technology be used to increase performance while at the same time reducing cost – hence the “better” and “cheaper” components of FBC. Infusion must take place quickly so that we also reduce the time it takes to design, assemble, test, and launch the mission. This results in the “faster” part of FBC. Infusion times have been coming down at JPL. It now takes about three years to move a newly proven technology into flight. This is still not good enough. Programmatic changes and the need to

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[*] The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration.

change missions due to new scientific results both have time constants less than three years.

Technology must be acquired from all sources. In the old days, JPL could do most of its own technology development. Today, we need to assimilate technology from other NASA centers, US Government agencies, other countries, industry, and universities. Each of these has its own distinct challenges.

The methods we use to get new technology into smaller missions have been many and varied. Some have worked better than others. In the remainder of this paper, I will discuss these methods, give examples of technologies that have gone through these paths, and make some recommendations on which ways may have the most merit for the future.

## 2. THE TECHNOLOGY LIFECYCLE

It takes a great deal of time and effort for a technology to progress from an idea to application in a flight mission. It is beneficial to talk about four distinct epochs as shown in Figure 2.1.

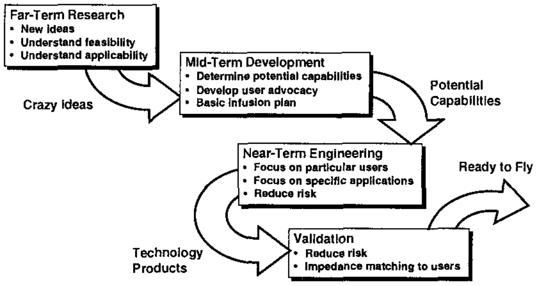

Figure 2.1
Model of technology life cycle

"Long-term research" is the epoch in which a new idea is developed to the stage of understanding its basic feasibility and applicability. We start with only an inkling of how flight missions might use it, and how long it might take to develop. These "crazy ideas" often have the most profound impact on the design and execution of small satellites.

"Mid-term development" is the epoch that turns the crazy idea into a potential capability with advocacy from the user community and at least a basic plan for eventual infusion.

"Near-term engineering" is the epoch in which development is focused on a particular set of users and applications. Problems are solved that reduce the risk of infusing the technology. The output of this phase is often a physical or software product that has the form fit and function of the capability required for a flight customer.

The "validation epoch" is the ultimate for reducing risk for the flight customers. This is also by far the most expensive epoch so we can only use this in selected situations.

Dividing technology development into these epochs makes it possible to talk about various approaches that work well in each. However, ensuring a smooth transition between epochs is equally important.

## 3. FAR TERM RESEARCH

Crazy ideas are not usually tied to particular missions so their funding needs to be institutional. NASA business is divided into Enterprises (e.g. Space Science and Earth Science.) Far-term programs are either funded within Enterprises or are "Cross-Enterprise."

The Telecommunications and Mission Operations Technology (TMOT) program that supports NASA's deep space com-

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munications infrastructure is an example of an Enterprise program. Since TMOT also includes mid and near-term technology, there is little problem in transition between epochs – but there is a challenge to insure a proper investment balance among epochs. TMOT has been extremely successful in infusion. NASA error-correcting codes [2] and compression algorithms [3] have come out of this program.

The NASA "Space Base Technology" program is Cross-Enterprise. It makes a majority of its investment decisions through open U.S. competition (including universities and industry.) This increases the range of new ideas, but also may have a negative impact on creativity at the NASA centers. This program has had mixed success with infusion, partially because of the interface to the next epoch. However, there have been a number of very important successes. NASA's optical interferometry capability came out of this program and has enabled most of the Origins Program. This technology will someday allow us to image and study Earth-like planets orbiting other stars.

## 4. MID-TERM DEVELOPMENT

Although technologies at this level already have some user advocacy, there is generally not enough of a business case for direct project funding. Hence, these tend to be institutionally funded within single Enterprises. The System on a Chip (SOAC) program at JPL is a good example. Figure 4.1 shows an example of the work coming out of the SOAC program. The X2000 Future Deliveries program is designed to pick up these technologies and develop them through the next epoch. At the moment, X2000 is not funded adequately to make this happen – a potential problem. An example of work within SOAC is a capability for integrated sensor, power, and processing chips [4].

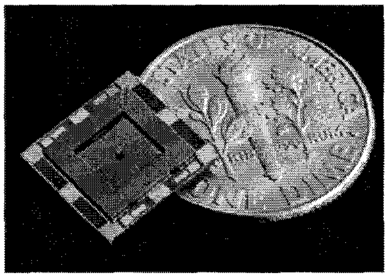

Figure 4.1
MEMS Microgyro developed in NASA's SOAC program

TMOT has work at this epoch, including optical communications development [5].

## 5. NEAR-TERM ENGINEERING

Most NASA work in this epoch is funded by single projects, programs (sets of related projects) or consortia (sets of unrelated projects.)

The Mars Focused Technology Program is a good example of funding by a flight program. Technologies developed in this program benefit multiple related Mars missions. By careful engineering, there is potential for great cost savings. Mars rover development is done this way and has led to common solutions for several Mars missions.

X2000 First Delivery began as a focused activity to provide next generation avionics for NASA's outer planet missions. With the recent restructuring of NASA's outer planets program, X2000 has only a single near-term customer: Europa Orbiter. Hence, X2000 is becoming

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a development funded by a single project. Despite this, many other missions will likely adopt the miniature, modular, radiation-hard avionics developed by X2000.

Consortia of unrelated projects have been quite successful in this area. An example of a capability developed this way is the current NASA deep space transponder [6] shown in Figure 5.1. Although this component would benefit many missions, none of these had sufficient funding to create the transponder on its own. Today, this transponder is standard on all JPL deep space missions.

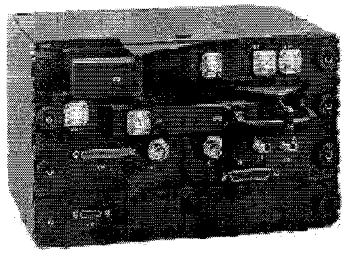

Figure 5.1
Small Deep Space Transponder

## 6. VALIDATION

Validation of technology in a flight environment is both costly and difficult to do quickly. For this reason, investments are carefully chosen. Not all technology needs this validation.

NASA's New Millennium Program (NMP) is an institutional program for flight validation. It has been extremely successful in reducing risk and encouraging infusion of critical technologies including the ion engine [7] and autonomous on-board navigation [8]. Figure 6.1 shows a test firing of the ion engine that flew on the NMP's Deep Space 1 mission.

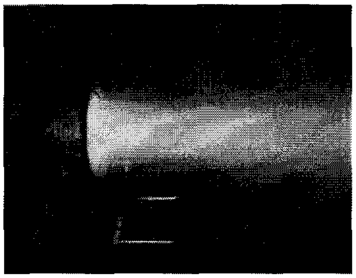

Figure 6.1
Ion Engine validated for Deep Space 1

Often, technology experiments are flown on operational missions. This require spare mass and power on the spacecraft, a situation that is getting less likely with small missions. Even though NASA's Mars Observer spacecraft failed, it's Ka-band communication experiment functioned throughout the journey to Mars and provided useful validation.

TMOT does validation of ground systems using a dedicated 34m ground station [9] shown in Figure 6.1. This ground station, DSS13, has special equipment to allow it to support multiple simultaneous experiments in an operation-like environment. It can also be wired into the NASA Deep Space Network.

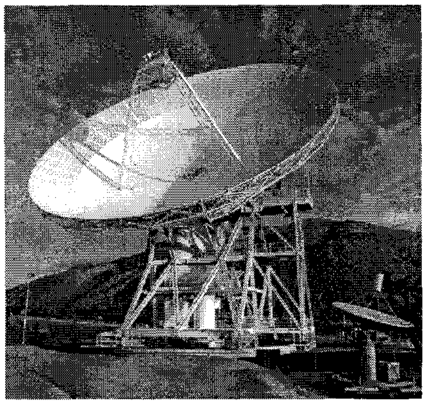

Figure 6.1
DSS13 dedicated R&D ground station

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## 7. TRANSITION BETWEEN EPOCHS

The TMOT program contains all epochs so it has very smooth transitions. Infusion is also very smooth since a dedicated multimission engineering office picks up most TMOT capabilities. The engineering office concept might also work with flight capabilities and the concept deserves further consideration.

For most other technology programs, epoch transition is the major challenge. It is never too early to plan a path for infusion and, in fact, people that begin thinking about this in the first epoch tend to be the most successful. A good understanding of the potential applications of the new capability, together with an intimate understanding of real mission problems, is crucial. The best technology programs promote this thinking in all epochs.

Close coordination among programs in different epochs is mandatory. NASA has begun to deal with this by establishing a technology councils and boards. Also, some NASA Enterprises and centers have formal technology integration activities.

## 8. CONCLUSIONS, WHAT HAS TENDED TO WORK SO FAR

We at NASA have not found the perfect solution yet. However, some processes have proven themselves to be successful and we will continue along these paths.

Solid, stable investment is required at all epochs of technology development. There needs to be a strong mechanism for capturing the best crazy ideas from all sources, without negatively impacting inhouse NASA creativity. Alignment with and advocacy from potential flight users is critical. Transitions between epochs and infusion to flight missions need to be planned early.

These observations should hold for other space faring entities as well.

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