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DEEP SPACE MISSION OPERATIONS: REALITY OR VISION?

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The deep space mission operations process has changed over the years, but mission operations are perceived to be overly expensive. But, costs have dropped in recent years, mainly due to improved approaches to missions.

Missions are experimental by nature, and science and engineering improvements have accommodated their increasing complexity. Operations has steadily evolved and kept pace. And the result is increased science return.

This paper discusses the new reality—operations must view each mission fresh, taking nothing for granted. Operations continually reviews mission plans' progress and anticipates problems, adjusting quickly so requirements are met on time.

This paper looks at operations' history, its present state, and advances new ideas so we in operations will better evolve and adapt, constantly increasing our efficiency to meet customers' ever more complex needs.

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1. Introduction

Over the years, Space Mission operations have changed from supporting quick short missions to longer, larger-scale ones. Recently, missions have become shorter and smaller, and like Spacecraft and Instrument Systems, operations have undergone major changes.

Why do mission operations seem overly expensive? Technology advancements, and missions' increasing complexity and size mean the supporting ground element has had to grow to keep up. We will explore a number of aspects about operations in an attempt to better understand what it was in the past, what we are dealing with today, and what it can be in the future.

An important aspect to consider is that operations is clearly a major and critical part of the exploration of space. Whether the process requires human intervention or is fully automated, it is a key part of the experiment. We gain knowledge by our actions—trial and sometimes error. We apply that knowledge to today's actions, and use it to plan the future.

Because of this, operations does a pretty good job of supporting our present missions. operations will always be a key part of space exploration. Can it be improved? Absolutely. We must take full advantage of advancing technology. In future, many of our tasks will be automated—some on the spacecraft, some on the ground. We must constantly maximize efficiencies while minimizing possible risks. Maintaining the delicate balance between the two while mining valuable knowledge is our most important task.

2. What is Space Flight Operations?

Flight operations is the after-launch period from initial acquisition by the Deep Space Network (DSN) until the defined End of Mission (EOM) is reached. In the project cost world, it is known as Phase E—the active, or execution phase of the mission. (operations really begins in the concept phase, since decisions made here and in the design phase largely determine how well the mission performs.)

Flight operations' real purpose is to follow the mission plan and provide the experimenters with the collected information.

The first step is to direct the spacecraft or instrument to obtain the desired data. In today's missions, this often means updating the spacecraft's instructions. Similarly, knowledge gained from the data returned to Earth may require operations to uplink new commands.

There are two reasons for this. The spacecraft or instrument is not operating as expected—i.e., it has a problem, or the science data does not agree with expectation and requires adjustment. This is the basic function of flight operations. Some of the how-to-do-it will be discussed later.

The point is that flight operations must be adaptive. Look at two extreme examples: the Lunar Prospector Discovery and Galileo Missions. Lunar Prospector's mission plan was followed, spacecraft and instruments performed exceptionally well, and its operations phase was completed with hardly any problems. Galileo, a much larger and longer mission, overcame several problems and changes in plan, but produced excellent results, and is now hailed as a most successful mission.

A number of factors make up a deep space mission, and they do affect a mission's operations phase. If there were little or no risk involved, a given mission's operations could be made highly efficient. But look at the mission's environment. Due to space missions' exploratory nature, data for analysis comes from a series of experiments. The truth is that no two missions are alike. Research and technology advances mean that supporting systems must be customized because the requirements are different. This paper's major point is flight operations must adapt to space exploration's experimental nature. This is why operations must be applied uniquely to each mission.

3. The Cost of Operations

Are operations really too expensive? Our customer's first requirement is always that the mission be successful, which means that it be risk free. On the other hand, we are told to launch increasingly complex spacecraft systems and their instruments on ever more intricate endeavors. Technology advancements and cost increases are driving this [1].

It is interesting to observe that in over 30 years of flight operations—from Mariner 64 through Cassini in 1997—operations cost grew about 1 percent per year on average, in constant year dollars. It wasn't an unreasonable build, but it was becoming more expensive in terms of exploration and data return. The advent of smaller, "faster, better, cheaper" missions lowered operations cost by about 50 percent. Over 5 years, as further improvements were made, this new class of missions' cost fell an additional 30 percent [4]. See Figure 1.

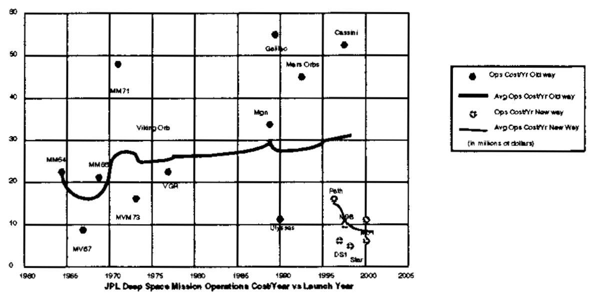

Figure 1 [4]

While technology was improving our missions, it made them larger. More instrumentation was included, complicating the operation. In order to cost effectively reduce the risk of spacecraft loss, two nearly identical spacecraft were launched. This doubled operations' workload, but because of the pair's similarity, the work was completed with efficiency.

Operations cost per science data bit is definitely cheaper than it was 30 years ago and continues to improve. This change had to occur, as the cost to operate—along with the overall mission cost—grew too large for NASA as well as Congress. Everything has contributed to this. Advancing technology has reduced both the size and risk of mission operations, and helps keep the cost in check. The instruments, spacecraft systems and ground systems have all evolved. Improvements have been big and small. It is estimated that in the next 10 years, ongoing electronics improvements will lower the cost per bit brought to the ground to below .001 millicents [1]. See Figure 2.

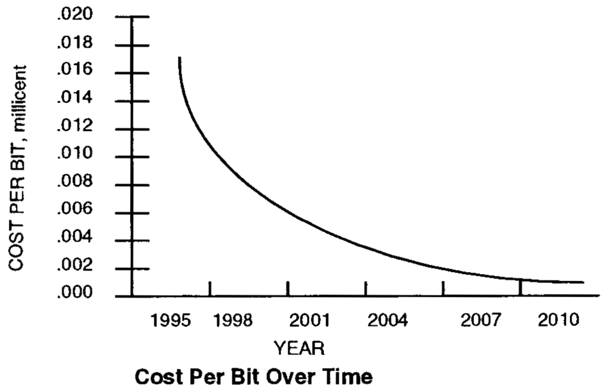

Figure 2 Cost per bit over time

The trend now is to design, build and launch more and more missions—but to do it while spending less and less money and time. And with less money to operate the mission, operations has had to work hard to make improvements just to keep up. We have greatly increased efficiency.

Consequently, the operations personnel ranks have shrunk. It is true that modern hardware and software now perform processes that used to require a number of peoples' efforts. But who is performing today's smaller mission tasks? A department, a system, or a subsystem team? No—only a single individual. But even that economy is not sufficient. Constraints require that the task be only one of several one person is assigned.

Figure 3 illustrates the old, and the new type organizations.

These kinds of improvements, which are also found in a mission's science and engineering areas, allow us to undertake increasingly more complex and exciting missions. The payoff: Increasingly better science returned to earth.

4. Operations in the Real World

Operations processes have steadily evolved over the years. Technology has greatly improved our view of the on-going process. Instead of analysts bending over line printers, looking for important information, our highly effective software immediately alerts us to significant subsystem data.

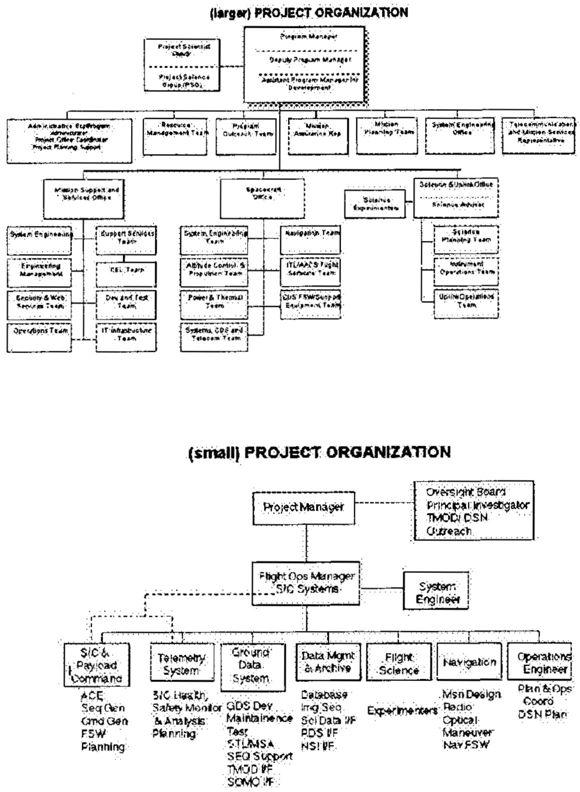

Figure 3. Project Operations Organizations

Today spacecraft are smarter, and so is their supporting ground system, which allows operations personnel to do more. Our sphere of knowledge is greater, so our decisions are broader in scope. Instead of teams of specialists reporting up through a chain of command, a few specialists handle it in a flat, more effective organization. Individuals, not teams, make decisions. Risk and stress are higher. When everything works right—or nearly so—missions are highly successful.

In the exploration of space, things do go wrong, and it is operations' responsibility to sort things out. What is most important is to get things back on track, determine the cause of the problem, and take steps to ensure it never happens again.

When it involves the ground, problems can be fixed fairly quickly. Problems aboard spacecraft are more difficult. Redundant systems and fault protection software usually keep spacecraft safe until the ground sets things right.

Most missions experience these events. Major problems sometimes require major fixes. For example, the Galileo spacecraft could not fully deploy its high gain antenna, but our workarounds helped make it a highly successful mission. Another example is NEAR, the probe that missed an encounter with the asteroid Eros in early 1999, but is expected to successfully rendezvous with it later this year.

In a mission's life cycle we identify the transfer point where Development hands off responsibility to operations. But in the space exploration business there is never a complete transfer. Throughout the mission adjustments are continuously made, from concept to the last science data analysis. It is important that a few key personnel remain with the mission all the way from pre-launch assembly and testing right through, well into operations because they know how it works and can prevent human errors from happening.

When a real problem arises, we speak to the experts who designed, assembled and tested the systems because it is from them we learn how to fix it. Also helpful to recovery is a spare or test unit, as well as documentation—especially if the experts are not available.

Today we have more missions, sporting better technology, launching in shorter timeframes—but chancing higher risks. Despite accelerated schedules, we are expected to obtain more and better science. The high price paid for improved products comes out of our hides. We must recognize the fact that higher stress and job burnout is increasing steadily. Management has become aware of the problem, but has yet to solve it.

5. Improving Operations

One operations area in need of technological improvement is unique. Because of their life cycle, instruments and spacecraft take advantage of major improvements. Mission designers specify the latest, usually proven technology. But operations are more restricted because of the nature of the supporting ground system.

Generally, the Ground Data System (GDS) supports multiple missions, and each is usually in a different stage of development. GDS upgrades missions' technologies and makes a variety of improvements, but overall speed suffers as new missions are added.

A major reason for this is the system must continue to support older missions still in operations. Upgrades work both ways in this case. On-going missions accept some, those they can afford in terms of what matching changes they must make to their own spacecraft and ground interfaces. But the GDS must also accommodate older systems that cannot be changed. This prevents or complicates GDS improvements.

There have been proposals to make a breakthrough in operations. Most of them appear valid and helpful.

One idea that has worked well and proved effective is multi-mission operations [2] [3]. We've proven that multiple projects can be operated effectively in the Telecommunications and Mission operations Directorate (TMOD), Deep Space Network (DSN), and in related data processing and distribution.

As the process moves deeper into a project, uniqueness makes function sharing more difficult. Institutional support has yet to form a backbone of operational functions. Multi-mission operations has worked to a degree for image processing [3]. It has worked fairly well to support downlink functions—returning and processing data. Completing these tasks in conjunction with other missions is efficient and involves little or no risk. But fearing risk, project teams are reluctant to share command and control or uplink functions.

Significant ground system improvements have gone largely unnoticed. TMOD's ground systems multi-mission program has saved missions—especially smaller ones—large amounts of money. In the early days, each mission usually provided its own ground-processing system, but shared the multi-mission tracking network, and the ground communication system. TMOD has combined the DSN processing with a central processing, data management and distribution system that can handle the needs of all users. As a result, new missions pay only to adapt and maintain the system.

Data handling is where operations has made the most significant technology improvements. Data is converted into information, which is translated into knowledge. In future, that knowledge becomes the basis for us to automate more and more tasks. More and more, automation is being used on the ground, and beginning to be integrated into spacecraft and instruments.

Automation reduces the number of decisions required in real-time, but it doesn't stop there. With knowledge-based systems, only select data bits need to be returned. This is especially important for outer-heliosphere and beyond missions where the communications link is the limiting factor. The key operations' consideration here is that while many bits are collected, only significant ones need to be downlinked. This is especially useful for anomaly resolution. Reducing data volume is more efficient and permits more distant, complex space explorations.

6. Future Operations

What is operations' mission? It must continue to evolve and adapt.

Some call for revolution—or breakthroughs—in operations. Okay, but at what risk? Improvements must maintain their course. Operation's most promising new technology is the continuing automation of processes to facilitate new explorations with widening scope. We are already looking for ways to add knowledge-based decision making to the new automation. It will then become feasible to do in-situ and farther distant exploration. We must always be able to emulate on the ground what the instrument and the spacecraft experience in order to test and verify, but still allow the investigator to control his or her experiments.

Information technology is causing big changes, and operations is developing and deliverying a large portion of them.

At the same time, research continues to study and develop future technology to aid exploration in coming decades. It is vital that operations be aware of and participate in these studies. Serious efforts are being made in miniaturization, telecommunications bandwidth, advanced propulsion, and spacecraft power sources. Operations will be ready to support the new missions flying these innovative new ideas. To become ever more efficient, we shall blend our technological innovations with the breakthroughs of others in order to best meet our customers' new mission needs.

7. Conclusion

Deep Space Missions must refocus on operations, where the fruits of our experiments are seen. It is the most important phase of a mission because it is where knowledge is acquired and we must be able to make adjustments based on that knowledge. It is especially important to NASA and to space research that the taxpayer—our real customer—participate in this exciting phase.

There are challenges in the future, but it is here in the present that we must make our preparations and plans.

Operations must become more interactive with pre-launch testing. Each mission is unique, so it is mandatory that a few key personnel continue to work with operations because they understand the mission's unique features.

In order to plan for the future, operations must continue to improve its process, with more emphasis on design and development.

A multi-mission approach is necessary wherever practical. Whenever common tasks are similar, missions must share resources such as common tools, processes, documentation and personnel.

We must never forget that the first cardinal rule is: each mission is unique, and we must be adaptable or the mission may not be operated in the best possible way. As we move into the future, we must never forget this.

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Robert Ryan *has been associated with deep space mission operations for over 30 years. An employee of the Jet Propulsion Laboratory since 1956, he was involved in missile and early spacecraft design for almost 10 years. He became active with operations shortly after the Pioneer 6 launch in late 1965, and has coordinated operations for all subsequent Pioneer spacecraft. As a supervisor of the Flight Mission Control Teams for the Voyager spacecraft, Helios, AMPTE, Galileo, Magellan, Ulysses, and TOPEX, he helped form and guide those teams. He led the development and demonstration of a Multimission Control Team that was based on Magellan operations and served the Voyager spacecraft, and, briefly, Ulysses. He has participated in various proposal and study efforts, representing operations. He was a member of the successful Stardust Discovery Proposal Team, and was a member of the Lunar Prospector Discovery mission team. He is currently the Deputy Flight Operations Manager for Stardust, and is involved in the development of new concepts of mission operations.*

Robert Warzynski has been involved in mission operations for over 16 years. An employee of the Jet Propulsion Laboratory since 1979, he was involved in deep space mission operations planning, and Space Shuttle payload operations planning. He was the Galileo Mission Control Team Chief for seven years. For the past six years, he has been involved with developing software to assist projects schedule DSN tacking coverage.

9. Acknowledgment

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