Deep Space 4/Champollion, 2nd Generation Cheaper, Better, Faster

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This paper summarizes actual key lessons learned that worked well on the Mars Pathfinder project under the constraints of cheaper, better, faster (CBF) and how these experiences are being carried forward into the New Millennium Program's Deep Space 4/Champollion mission. These lessons and practices will be discussed specifically in the context of the new business environment of the 21st century.

The Deep Space 4/Champollion mission is designed to test advanced technologies for landing on and analyzing in-situ small bodies in the solar system. Deep Space 4/Champollion will be launched in 2003 and, in early 2006, will rendezvous with the periodic Comet Tempel 1. This mission is one of the most complex missions ever attempted by NASA and will need to rely heavily on the experience of Mars Pathfinder to succeed in the environment of CBF.

Key Pathfinder success factors to be discussed will include: talent, trust, commitment, mission success criteria, hands-on leadership, organization structure, and risk management. A concept of Cheaper, Better, Less Heroic will be discussed and contrasted to Cheaper, Better, Faster. Major issues confronting 2nd generation missions will be discussed including interdependence, project size, and is cheaper, better, faster relative (and when is it relevant).

[1] The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. U.S. Government work not protected by U.S. copyright.

TABLE OF CONTENTS

1. MISSION OVERVIEW
2. IMPLEMENTATION APPROACH
3. APPLYING MARS PATHFINDER LESSONS
4. NEW CHALLENGES
5. GENERAL OBSERVATIONS OF CBF
6. CONCLUSION

1. MISSION OVERVIEW

The Deep Space 4/Champollion mission is being developed to demonstrate advanced technologies needed for landing on small bodies in the solar system, and for collecting samples of those bodies and for analyzing them in-situ. Elements associated with returning samples to Earth are also options.

The advanced technologies validated by the Deep Space 4/Champollion mission will be used in future NASA exploration missions throughout the solar system. These important technologies include:

- Advanced solar array using an inflatable, thermally rigidizing boom
- Multi-engine solar electric propulsion including feed system and light weight tank
- Integrated avionics and goal driven flight software
- Autonomous navigation and flight operations
- Miniature scanning laser altimeter
- Precision guidance and landing, including hazard avoidance
- Anchoring
- Sample acquisition, and delivery to instruments
- Bulk composition experiment

In addition to these technologies Deep Space 4/Champollion also carries a science payload. The payload consists of a descent camera, panorama and stereo cameras, near field cameras, microscope with visible and infrared detectors, gas chromatograph/mass
spectrometer, and physical properties experiment (surface strength and thermal conductivity).

Deep Space 4/Champollion is scheduled to be launched in April 2003 and, in early 2006, will rendezvous (match orbits) with the periodic (5.5 years) Comet Tempel 1. After several months mapping the cometary nucleus from orbit, Deep Space 4/Champollion will deploy a 125-kg spacecraft, the Champollion lander, that will attempt the first ever landing on the surface of a comet relying on its scanning laser altimeter for a completely autonomous flight and touchdown. Once landed and anchored (anchoring is required because of the negligible gravity), the lander will take high-resolution stereo images of the surface, and will drill up to one meter deep into the nucleus to collect samples of pristine cometary material. Over the 3 day surface mission, samples will be examined by the onboard instruments and the results transmitted back to Earth through the carrier spacecraft. The science team on the ground will assess the results and modify the experiments as appropriate, within the 3 day window. The 3 day lifetime is determined by the quantity of on-board primary batteries.

The estimates of the strength of the comet surface for anchoring range over 6 orders of magnitude, from cotton candy to concrete (light snow to hard ice). These unknowns must be accommodated in the robustness of the basic design.

This mission will provide unique new insights into the nature and behavior of comets and provide the first direct analysis of the comet surface and subsurface. A wealth of new information is expected about the physical and chemical state of the primordial solar nebula out of which the Sun and planets formed approximately 4.5 billion years ago.

This mission raises the bar in terms of cheaper, better, faster. The technical challenges and programmatic constraints of this mission are no less daunting than for the Mars Pathfinder mission. In terms of cheaper, the development cost is currently estimated at between $161M and $171M real year dollars with the contributions from technology partners and from France not in that figure. The exact value of partner contributions has not been estimated yet. But the total development cost is below Pathfinder's $171M real year costs.

![Figure 1. Deep Space 4/Champollion Cruise Configuration](image)

Better, this is clearly a first of a kind mission, real Columbus or Lewis and Clark kind of exploration. The environment around and on the surface of a comet is largely unknown. In terms of faster, we're adopted a strategy that coins a new term, cheaper, better, less heroic. It was Dr. Wes Huntress, NASA Associate
Administrator for Space Science that voiced the "less heroic" phrase when our plan was presented to him. The plan is to use a small team of experienced individuals, working for a longer time in the formulation and implementation phases. This strategy, proposed by Flight System Manager, Dara Sabahi, appears to be working. The idea of taking a little more time (4 years vs 3 years), was the strongest recommendation of the presenters at the 1997 IEEE Aerospace Conference session on Cheaper, Better, Faster missions, to minimize burnout and maximize success.

2. IMPLEMENTATION APPROACH

The Deep Space 4/Champollion Project implementation approach will involve a combination of in-house, contracted and partnership relationships.

Deep Space 4/Champollion is actually two spacecraft, each with a separate and very distinct mission. These two spacecraft employ a number of new technologies to accomplish their missions. Figure 1 shows the cruise configuration featuring the large, 9kW inflatable solar array and 3 ion engines. Figure 2 shows the Champollion lander.

The nature of the DS4/Champollion spacecraft is that there are major new technologies spread throughout and integrated deeply into the system design. In other words, there is no "low tech" central bus that the advanced technologies hang off. Therefore, the basic implementation approach will capitalize on the skills of JPL and a number of industry teams to provide specific technologies which JPL will integrate into the flight system. For example, the inflatable solar array will be built by an industry team and integrated into the carrier structure and power bus. In the same way, the avionics, mostly provided by NASA's new Deep Space Systems technology program (whose first delivery is called X-2000) and running under new software utilizing the Mission Data System goal-based architecture will be integrated to the carrier on individual structural plates in a multi-functional structures concept.

We are partnered with the French Space Agency, CNES, in the areas of science, engineering and mission operations. France is currently planning on providing cameras for panoramic, stereo and descent imaging, gas chromatograph columns, the S-band telecommunications H/W between the lander and the carrier, and the lander's primary batteries.

NASA's Exploration Technology Program is providing advanced technology development, through engineering models of critical technologies including the scanning laser altimeter, anchoring, and sample acquisition and transfer mechanisms. As part of our pre-project effort we are already working with prototypes of each of these systems to verify basic performance.

Figure 2. Champollion Lander Configuration

The Air Force Research Labs and NASA Cross Cutting Technology program are participating in the advanced development of the >100w/kg inflatable solar array by supporting a flight experiment in 2000 on-board the shuttle. This flight experiment ahead of the mission is designed to reduce overall technical and programmatic risk of the critical development and to prove out various aspects of the technology including, packaging, deployment, rigidization, figure control, and deployed dynamics.

Any mission designed to land on the surface of a planet or small body carries with it higher inherent risk than a fly-by or an orbiting mission. The risk comes largely from the entry (assuming the target body has an atmosphere), descent, landing and surface operations.
phase where the complexities of the required hardware/software and the uncertainties in the environment (e.g. atmospheric density, orbiting hazards and landing site conditions) make such missions as challenging as they are interesting. On Pathfinder, we conducted an extensive entry, descent and landing test program using full scale and appropriately scaled hardware, testing multiple times and involving a wide variety of test conditions. We tied these tests together with a sophisticated set of Monte Carlo analyses. We will use the same basic approach on DS4/Champollion. Our plan is to conduct end-to-end hardware in the loop testing of the approach landing and surface sequences. We are planning to include full scale testing of the terminal landing including hazard avoidance with a remotely piloted vehicle on representative terrain.

The Project is working toward confirmation (approval to begin the implementation phase) in April, 1999. All subsystem and systems critical design reviews (CDR's) will be completed by September 2000. Assembly, test and launch operations of the lander will begin in September, 2001 with the carrier about 3 months behind. The two spacecraft will be integrated and tested at the system level at JPL and launched on-board a Delta II 7925 vehicle. Launch is scheduled for April, 2003.

3. APPLYING MARS PATHFINDER LESSONS

In November, 1993, NASA funded the Jet Propulsion Laboratory to undertake the Mars Pathfinder mission. Fundamentally different than past JPL planetary missions, both the budget and schedule were fixed. The Pathfinder development was fixed at $171 million, $25 million was allocated for development of a micro-rover, and the schedule was fixed at 3 years. Thus Mars Pathfinder became the poster child for “cheaper, better, faster”. The primary objectives of the Pathfinder mission was to enter, descent and land safely on the surface of Mars, deliver a rover onto the surface and take images and make scientific measurements of the landing site. Many skeptics thought Pathfinder would not even make it to the launch pad under these constraints. History records that on July 4, 1997 Mars Pathfinder landed successfully at Ares Valles, providing the existence proof that the principles of cheaper, better, faster were indeed applicable to deep space missions.

The following is a highly synthesized and bulletized summary of the key factors in the success of Pathfinder. Every one of these lessons will need to be applied for the development of Deep Space 4/Champollion to be successful. Some of the issues that make the implementation of these lessons more difficult are discussed in the next section.

The first set of lessons are those that apply best to the implementation team. Specific details supporting these “secrets” can be found in References 1, 2, & 3.

Cheaper, Better, Faster Secrets of the Mars Pathfinder Team

- Set goals that make you stretch
- Let limitations guide you to breakthroughs
- Deliberately choose to do things differently
- Invite different perspectives
Plan...and improvise

Proceed with optimism and a “can-do” spirit

Develop robust solutions

Maintain momentum

Be fully trustworthy

Take responsibility for communication

Demonstrate a passionate commitment to success

Complementary to the team “secrets” are a set of management practices specifically targeted at project leaders. These points are detailed in Reference 4.

Mars Pathfinder
Cheaper, Better, Faster Leadership Secrets

- The most important factor in the success of the Mars Pathfinder mission was THE TEAM!! Their Talent, Trust and Commitment!!

- “Take Risks, Don’t Fail”!! The key to taking risks and succeeding is doing things differently (e.g. make your own rules, work smarter, more efficiently).

- Hands-on management is essential for CBF projects. Microknowledge not micromanagement.

- Maximize communication. Collocate!!

- Develop and maintain an atmosphere of openness and honesty across the entire team.

- Treat contractors and support organizations as full members of the team.

- Develop and use generalists as the glue to hold the system together. They are the ones that will fill the inevitable vacuums that develop.

- Maintaining momentum is more important than being absolutely right all the time! (i.e. rapid decision making is critical)

- Don’t accept mediocrity in the team at any level. Weed out those who don’t belong.

- “Capabilities Driven” approach to system and subsystem designs was the culture; and it worked. Push back on “requirements” driving cost/risk/schedule

4. NEW CHALLENGES

When asked what I would do differently if I had Pathfinder to do over again, my answer is nothing; I’d like simply the opportunity to be able to it again the same way. But that is the problem, the rules and boundary conditions have changed such that cheaper, better, faster is even more difficult now than it was starting Pathfinder five years ago.

First and foremost we Project Managers are no longer masters of our own fate anymore. The era of interdependence is upon us. Previous Project Managers had a budget, which they controlled, which, within the agreed to scope should be sufficient to do the project. Today’s budget environment does not generally allow such independence. My definition of interdependence is the following: existence of a technical and/or programmatic relationship between two or more parties necessary for the pursuit (and hopefully success) of a project or goal. In other words, interdependence exists when two or more organizations, with independent resources, join together into a single project, to achieve an agreed to outcome. The term partnership is sometimes applied to the members of an interdependent venture. Many examples exist including, most notably, the International Space Station.

But in the world of cheaper, better faster, interdependence brings major challenges. The ability to apply the Pathfinder lessons learned is greatly hampered, particularly the hands-on micro-understanding style of leadership. I believe very strongly that the success of interdependencies depends on all parties being fully competent to carry out their roles (not always a foregone conclusion or something easily verifiable), and even more importantly, that they share a common commitment to the success of the project. Since management is no longer in full control of the project’s fate, without both competency and commitment, interdependent relationships can be a source of constant concern and potential disaster.

We are learning about how to manage interdependence on DS4/Champollion, through teaming with other projects and technology programs within JPL for hardware and software, and with the French space agency for engineering and scientific hardware. In both cases, the “partners” are using their own money to develop and deliver flight-ready systems. To date, establishing a clear relationship with CNES has worked very well, largely because CNES has a clear plan of their total scope of participation.
In addition, we've moved into the era of ISO 9000. Documentation is now required to show: "say what you do, do what you say, and prove it." In general, Pathfinder followed this process, but without a lot of formality. But we also invented many new processes as we went along. Being creative with one's development approach is an essential element of operating in the cheaper, better, faster paradigm. It is not clear how you do that and be ISO 9000 compliant. Stay tuned.

Lastly, there is an ever more serious need for employees to be able to "multi-task" between the technology side and the business side—engineers learning to understand, plan and present the business equation for their projects, and business people reaching a heightened comfort level in grasping the intricacies and market significance of their organization's technologies. Both sides of this multi-tasking relationship were in evidence on Pathfinder and will need to be further developed and strengthened on DS4/Champollion. To that end I now employ a "business manager," one of whose jobs is to set the example for this bridging.

5. GENERAL OBSERVATIONS ON CBF

Mars Pathfinder provided extravagant proof that cheaper, better, faster can work, yet it would be dangerous to suggest it should be the answer to every situation. When misused or misapplied, CBF can be more harmful than beneficial. A few caveats are in order.

At its peak around the time that assembly and testing began, about 250 people were working full time on Pathfinder, plus another 150 dividing their time between our project and others. No one yet knows what the maximum size is for a CBF project, but it seems clear there is a maximum. It would be particularly foolhardy for an organization of 10,000 people to think of trying to perform an enterprise-wide cheaper, better, faster project—the group is simply too large for rapid, nimble movement.

But certainly, even large companies or projects can put CBF to work within individual units or departments, or on individual projects elements. A good rule of thumb for the time being: a cheaper, better, faster effort should be of a scope that can be within the span of control of a single leader or tight-knit leadership team (but recognizing that span of control is a function of the people themselves—some can handle a broader span than others). If the leadership can stay hands-on with most activities, and the decision-making process is fast enough to meet the project or task goals, then CBF should be viable. And once the lessons of CBF are learned on a small scale, those lessons can begin to infiltrate the larger organization. Efficiencies identified, applied and validated by a CBF team can be adopted by larger groups.

Yet one of the troublesome problems organizations face today, and JPL is a case in point, is the shortage of experienced leaders. That leaves the temptation for upper management to put an under-experienced person in charge of a CBF team. This does an enormous disservice to the team, particularly the people right below the leader. Everyone needs to carry their own weight as well as support each other, especially the boss.

There's a caution here for new CBF managers as well. First take a hard look at the resources, scope, and degrees of freedom. If upper management is eyeing CBF, but has no experience with what a project of this kind really means, they will likely saddle it with truly unreachable goals or truly impossible constraints. When the parameters don't fit the pattern for cheaper, better, faster, a manager must have the guts to say "No." Taking on a project labeled Cheaper, Better, Faster but without the resources and the freedom needed to succeed, is not a sound career decision.

The right reasons to adopt CBF have to do with a stretch goal that represents an urgent or enterprise-critical effort, important enough that the project leaders will be given the latitude to recruit from other parts of the organization, operate in a more free-wheeling manner than would otherwise be acceptable, and have the authority, responsibility and license to invent processes that offer the opportunity of grasping success. If an organization isn't willing to bestow that kind of latitude on the project leaders, then it isn't serious about doing things cheaper, better, faster.

Fundamentally, CBF is about doing things differently, smarter and more efficiently. If the upper management isn't willing to do what they must do, any attempt at CBF will likely be doomed from the outset.

In one respect, being the first to do a cheaper, better, faster deep space project made our job easier. Pathfinder proved that a planetary mission was possible for a fraction of the cost, but in the process we set the bar demandingly high, and that bar keeps getting raised. For all those missions coming after Pathfinder, it grows tougher, and DS4/Champollion is no exception. Pathfinder has now become the standard by
which other projects are judged, and being faster, better or cheaper than Pathfinder won't be easy.

There is no universal definition of CBF and like so many things its meaning lies in the eye of the beholder, but it is and always will be a relative concept. The first CBF project in an organization will, if effectively managed, be ground-breaking. It will inevitably be in some ways revolutionary, defying and at the same time defining procedures, structures, relationships and traditional ways of doing things.

But what about the next one, and the next? It would be a mistake to think that cheaper, better, faster means that every CBF project in the organization has to be revolutionary in being faster, better, and cheaper than the preceding project. That way lies failure. Sooner or later.

Rather, I see CBF as a way of operating. The early efforts will set new patterns for carrying out projects in the organization. Subsequent projects will adopt these new patterns, these new ways of organizational behavior. The goal will not be the clearly impossible one of always setting new records for lower budget, shorter time, better results; instead, success will be measured by how well the project applies the practices of CBF as proven within the organization.

Along the way, there's a particularly hazardous pitfall to avoid. It's the natural inclination of leaders to see something that works well and try to bottle it—capture it, codify it—and require everyone to apply the process. But this is the antithesis of cheaper, better, faster, which at root is the opposite of formulaic. What is inherently a dynamic, creative process dies when an organization or a manager attempts to codify and forcibly apply it.

Within the Jet Propulsion Lab, while there is a commitment to the principles of cheaper, better, faster, we're still struggling to understand it's meaning in the diverse environment in which we work. One CBF project does not, cannot remake an organization; it will only be through a series of projects that we finally grasp what CBF means to JPL.

But changing our ways of doing business, adopting CBF, is necessary to keep JPL alive and thriving.

The key to JPL's success, as I've said many times to the Lab's management, is in its hands-on people—people trained and developed through being personally involved in the design, building, testing and flying of real spacecraft on challenging missions.

6. CONCLUSION

The Deep Space 4/Champollion mission is the embodiment of 2\textsuperscript{nd} generation cheaper, better, faster (less heroic). In order to be successful within the constraints of this mission, DS4/Champollion will need to develop and implement a design that inherently takes risk without significantly increasing the likelihood of failure. In order to do this we will build on the experience of Pathfinder and also find ways to do many things differently, particularly in accommodating the challenges of interdependence.

The primary key to success for DS4/Champollion will be, as it was on Mars Pathfinder, the talent, trust and commitment of the team assembled to perform this challenging mission, including JPL, NASA, industry, academia and our European partners.

REFERENCES


BIOGRAPHY

Brian Muirhead has worked on various spacecraft, science instrument and technology projects at JPL, including Galileo, CRAF/Cassini, Mars Rover Sample Return. He managed the Advanced Spacecraft Development Group and the Mechanical Systems Integration Section. He has led two CBF developments at JPL: the SIR-C Antenna Mechanical System (which flew on STS 59 and 68) and the MSTI I Mechanical Subsystems, launched in 1992. He was the Flight System Manager for Mars Pathfinder with the responsibility for the design, development, test and launch of the Pathfinder spacecraft. He was appointed Project Manager after the successful landing of Pathfinder. He is now the Project Manager of the Deep Space 4/Champollion mission to develop the first ever mission to rendezvous with, land on, and analyze
in situ an active comet. He has a BSME from the University of New Mexico and an MSAE from Caltech.