## Title
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# DAWN DISCOVERY MISSION: LESSONS LEARNED

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## ABSTRACT

Dawn is a low-cost planetary mission with high heritage from Deep Space 1 and earlier missions. It uses ion propulsion to rendezvous with and orbit the two most massive asteroids in the main asteroid belt, 1 Ceres and 4 Vesta. The mission is well into its final year of development and will be launched in summer 2006. This paper shares lessons learned to date by the Dawn team.

## 1. INTRODUCTION

Dawn is NASA's ninth project in the Discovery program of low cost, Principal Investigator-led missions. The objective of the mission is to investigate the geophysical properties of the minor planets, 1 Ceres and 4 Vesta, by orbiting both successively. Dawn achieves this feat with ion propulsion powered by solar arrays. Its detailed science objectives have been described elsewhere [1]. An accompanying paper presents the status of the mission [2]. A contemporaneous paper prepared for the IAA/IAF meeting describes margin management during the development of an ion-propelled spacecraft [3]. The purpose of this paper is to list several of the lessons learned by the Dawn project team in the execution of the project. We prepare this report in the middle of the assembly, test and launch operations (ATLO) phase as the final assemblies are being installed. The payload is being delivered, and a fully functional, penultimate build of software is being installed.

Discovery missions are cost-capped and are selected to be executed in a limited period of time to minimize costs. The "time cap" is applied at selection but slips do occur and the time cap may be less of a constraint than the cost cap for which the rules are very strict. Cost-capped missions do get cancelled, and projects in the Discovery program must live constantly under the gun as they solve technical problems. Thus principal-investigator-led missions may be more difficult for project managers than strategic missions. This may be the first lesson learned on the Dawn project. From it derives a corollary. Experienced managers are essential in low-cost planetary projects. While training personnel is an important and worthwhile objective of these programs, this training should come through the explicit mentoring of the junior personnel, and key project positions, both management and technical, must be staffed by very experienced people.

The Dawn mission divides its prime responsibilities between the University of California Los Angeles (UCLA) the PI institution; the Jet Propulsion Laboratory (JPL), the project manager (PM) institution; and Orbital Sciences Corporation (Orbital), the industrial partner, where the spacecraft is assembled. UCLA manages the education and public outreach program, the science team and the Dawn Science Center. JPL provides project and systems management, delivery of some portions of the spacecraft, project systems engineering, mission design and mission operations. Orbital provides spacecraft development, integration, test, and launch operations.

As mentioned above the Discovery Program imposes a strict cost cap on the Dawn project. Less obvious, but as real, is the development-time cap imposed by the Discovery AO Guidelines and the usual fixed windows for planetary launches. Mass is also capped by the stricture that Delta II launch vehicles must be used. Fig. 1 (left) shows the front sides of the box in which a mission such as Dawn finds itself. The three visible sides represent the time, mass, and cost caps. There are three other sides of the box labeled "descopes" on the right. The pressure on the first three sides can be relieved by moving one or more of the other sides, the science operations of the mission (e.g. by shortening), the science payload (e.g. by demanifesting an instrument), and the data analysis, modeling, and other support of science (e.g. by cutting its level of activity). The scientific return is diminished if these sides move to accommodate pressure on the other three sides. Thus these descopes all come at a cost to the value of the mission. Another item in the trade space is risk. Initially Discovery missions were allowed to take greater risks than flagship missions. The logic was that they were much cheaper, and occasional failures would be acceptable. This paradigm has shifted to be much more risk adverse over the past few years. However, missions with operational phases of three years or less still have some flexibility in risk, e.g. flying single-string spacecraft electronics. Dawn which has a nearly

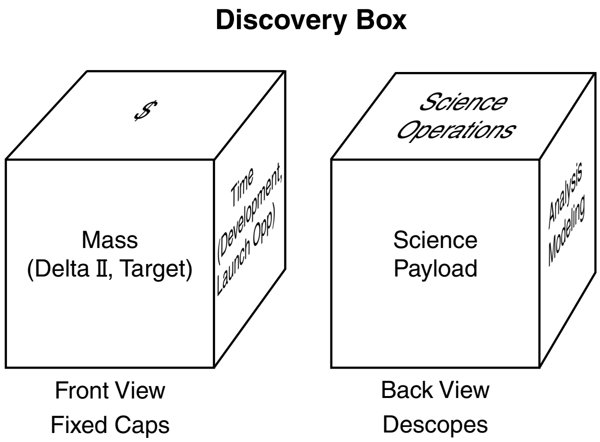


**Fig 1.** A visualization of the box in which a low-cost, planetary mission finds itself. Funding ($), mass and time are all capped. If these sides have to move they affect the other sides of the box that determine the science return or value of the mission: science payload, operations, and modeling and analysis.

10 year operations phase, does not have the luxury of trading risk for dollars. As such, risk is not in the Dawn trade space.

Missions are not developed instantaneously. They are implemented over many years, often 5 or more years from initial selection. (Dawn was selected in Step 1 in January 2001, and is scheduled for launch in mid-summer 2006). During such an extended period, the reporting structure evolves. New people rotate in. New ideas, responding to actual or perceived problems are introduced, and ground rules and the level of scrutiny changes. NASA's change in its risk posture for Discovery missions is an example of changing ground rules. The changing of ground rules only adds to the pressure the project personnel feel. While they solve the technical problems, they must worry about unknown unknowns of both a technical and managerial nature. Naturally tensions increase during a project as illustrated in Fig. 2. The project manager and his/her key personnel have to be aware of the increasing tension and mitigate it so that the team functions smoothly. This is not trivial since the project manager and his/her key personnel get caught up in the growing stress, and become contributors to the problem. This growing tension can and will lead to carelessness, that can lead to schedule delays and cost overruns. Good morale and mutual respect on a project are essential to success. It is imperative that the project manager step back and assess the morale and general attitude of his team. He/she needs to become part of the solution and not part of the problem.

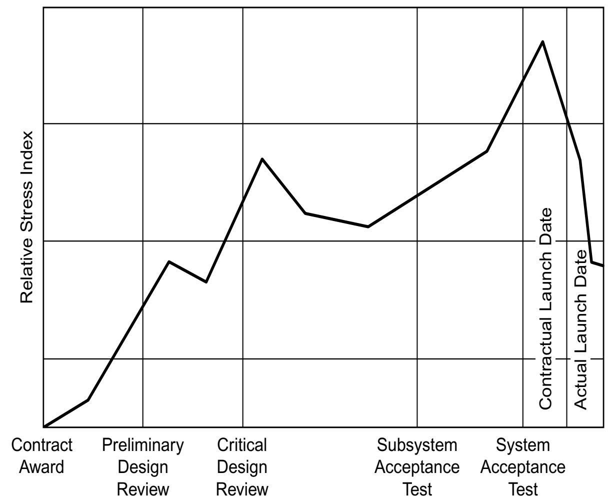


**Fig 2.** Changing morale during project development expressed as the relative stress index.

## 2. THE ROLE OF THE PRINCIPAL INVESTIGATOR

The Principal Investigator ensures and is ultimately responsible for the mission and science success. She or he is the primary spokesperson for the project to NASA Headquarters and external organizations. With the assistance of the science team, the PI develops the Level-1 requirements that are documented in the Discovery Program Plan. The PI has the authority to descope the science requirements from the approved baseline mission to the minimum mission, certifies the flight readiness of the mission, leads the science team, acts as the primary interface between the science and engineering teams, and ensures the successful and timely delivery of the science data products. The PI delegates project implementation to the Project Manager (PM).

## 3. THE ROLE OF THE PROJECT MANAGER

The Project Manager is responsible to the PI for the day-to-day implementation activities required for mission success. The PM develops project-implementation plans, schedules and budgets in accordance with project objectives and constraints, program constraints and other applicable institutional and agency policies and procedures. The PM maintains management oversight of all project activities and ensures the prevention or timely detection and correction of problems. He/she provides direct interface to the program managers and other external organizations on implementation status and issues. The PM reports regularly on the technical, schedule and financial status of the project to institutional program and agency officials.

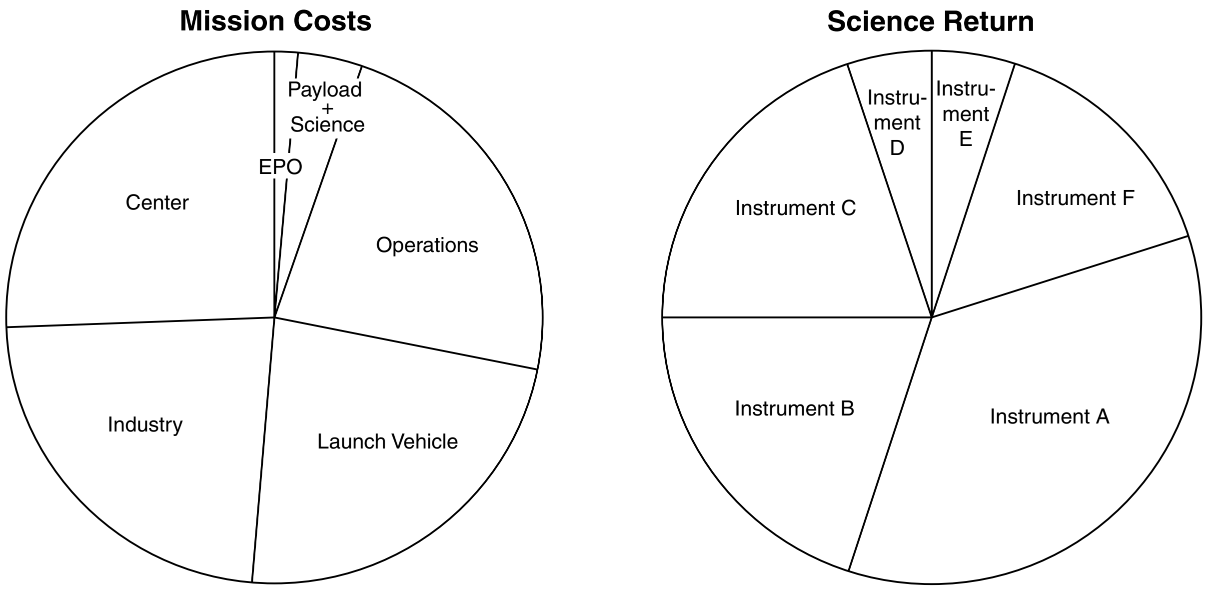


**Fig. 3.** Comparison of mission costs and science return that determine the value of the mission. Only a small portion of the funding is expended on the scientific payload. Even though the science return of each instrument may be different descoping any one makes a large change in the value of the mission, much greater than the cost saving accrued. Thus descoping of payloads should be avoided.

## 4. LESSONS LEARNED

### 4.1 Cost versus value

When cost savings need to be made, the value (loss of scientific return) of any descope must be considered. In planetary programs, generally only a small fraction of the cost of a mission is expended on the science payload. Major cost savings must come from areas of greatest expenditure such as in management activities at the center or in the flight system at the industrial partner. There is often great pressure to choose science descopes over technical or managerial descopes. Some potential descopes affect the science return greatly for very little cost savings as illustrated in Fig. 3. This is most evident in the case of the scientific payload. Dawn demanifested two scientific instruments, resulting in a measurable loss of science, at a time when the project was under pressure to increase its cost reserves from those it had at selection. The attempt to recover some of the lost science has increased operational complexity. The net result has been to transfer costs from Phase B/C/D to Phase E, as well as diminish the science return. For details on the originally proposed Dawn mission see the Proceedings of the 2002 ACM Symposium [4].

### 4.2 Cost Reserves

Funding is generally available to a project at a rate determined by outside factors, a rate that may not be optimum for a project. Moreover, costs are not always predictable and projects are essentially self-insured through unallocated funds known as cost reserves. These publicly known reserves become a target for everyone who has a problem to solve. It is the project's responsibility to mitigate risk and to maximize the efficiency of the team by the judicious expenditure of the reserves. It is almost a tautology that reserves will be spent by the end of a project as there is always risk that can be further mitigated or greater efficiency that can be obtained by the expenditure of reserves. Ultimately increasing reserves simply leads to increased costs. An alternative strategy is to allow projects a modest level of reserves with which to solve problems and manage a larger pool of reserves at the program level where the granting of reserves obtains greater scrutiny and is not assured. The problem with this approach is that when a project needs to tap into these reserves, they may not be available. Other projects or institutional funding problems may consume these reserves, leaving the project with serious financial problems.

Managing reserves is very difficult since every cost account manager looks to them to solve any problems they encounter. It is always easier to ask for additional funding than trying to solve problems within allocated resources. This is a typical issue that project managers face. Usually the project manager is not made aware of the problem until it is too late to correct by any other means than applying additional dollars. While technical problems are known early, the types of problems that consume reserves are more often the timely availability of people, tools, and facilities, and/or poor management of the cost account. These problems do not bubble up to project management in a timely fashion. Fortunately there is a tool called Earned Value Management (EVM) that does gives early warning of such issues to the project manager, and if used properly can significantly reduce the wasting of cost reserves. This is discussed in more detail below in the paragraph on EVM.

### 4.3 Schedule Reserves

Adequate schedule reserves must be in the mission plan, and the costs included for them. The schedule reserves must be costed at the peak expenditure rate. Many projects cost schedule reserves at zero or at a much reduced burn rate. All of the schedule reserves will be spent and it will be spent at the peak burn rate. If it is not put into the cost estimate, it will be come a real lien against the cost reserves.

### 4.4 Technical Margin Management

On an ion-propulsion mission, power and mass are closely coupled and can be interchanged. An additional complexity is that on an ion-propulsion spacecraft the power is overwhelmingly used by the ion propulsion system for which margin management may be different than for payload and subsystems. Thus the usual design principles that apply to chemically-propelled missions need not apply to ion propulsion missions. Appropriate design principles need to be developed. The coupling of technical margins on Dawn is discussed in a contemporaneous IAF/IAA paper [3].

### 4.5 Level of Difficulty of Low Cost Missions

Low cost missions, especially low cost planetary missions, are as difficult and maybe more difficult to successfully execute than "strategic" missions. Project teams are thin due to a limitation of funding. Therefore, project leadership and system engineers make many more decisions with fewer or no people to consult. Development schedules are very short and cost caps and planetary windows require quick and effective decision making. There is neither time nor money to recover from a bad decision. Good decision making requires considerable experience on the part of project leadership. In a larger mission the more sizeable teams can have considerable depth. This depth of experience combined with longer schedules allows a more thorough decision making process. Thus, while personnel may be mentored in junior positions on a low cost project, leadership positions need to be staffed with experienced personnel. Additionally, a small project cannot tolerate "underachievers". Project leadership must act quickly to remove poor performers. Just as harmful is the temptation to transfer out key experienced personnel to new projects prior to launch. On a small low cost project it is important to maintain the core team all the way through launch plus 30 days.

### 4.6 Communication

Good communication is paramount. Everyone working the project must feel they are part of the total mission, not just a provider of a small piece of it. They must take pride and ownership in mission success. For this to happen, people need to understand what the mission is planning to do, and the value of its science return. While project managers tend to assume that team members know what the mission is all about, in fact >50% do not. Manufacturing people in particular know nothing about the missions they work on. Hold regular all-hands meetings to keep the entire team up to date with project status. Develop and give project overview presentations, including science and engineering details, to the entire team, particularly the manufacturing people, so they understand how what they are working on fits into the mission, and that their contribution is important.

Email messages are a most unreliable form of communication as they may not be read or given the attention they deserve. As such, one should not rely on them. This is particularly important when developing interface documents between two suppliers. Nothing is better than face-to-face communications. If this is not practical on a regular basis, then telephone conversations are required as follow up to email communication and documentation exchanges.

Systems leads must make regular trips to suppliers to insure adequate and proper communications takes place. Foreign partners may not understand what you said or meant so you must verify all communications. In fact even industrial and government partners from the same country may use a different vocabulary. At the end of every communication one should make sure that everyone is on the same page.

### 4.7 Receivables, Deliverables

Maintaining a list of all receivables and deliverables, particularly between institutions, is very important. This list should include all items, including documentation, hardware and software to be delivered from one institution to another. Even the most insignificant item like a simple bracket can cause a large schedule hit if it is not delivered on time. Both the deliverer and the receiver need to agree on the dates on this list. Then the status of the list must be reviewed often. A status review once a month is fine for deliverables six or more months in the future. A weekly status review is necessary for items three months or less from delivery.

### 4.8 Earned Value Management (EVM)

EVM is an extremely valuable tool for project managers. Problems can be seen in the first month and it shows trends within two months of its initiation. For it to be of value one must do more than report the trends, one must act them. A manager should be assigned whose only job is to work with cost account managers at the lead institution and subcontractors with negative trends, and see that they are turned around. This activity must begin with the first month of EVM data. The longer one waits the less chance one has of completing that effort on cost and schedule. One cannot assume that people know how to plan their work. Cost account managers often get in trouble because they are given the job based on their technical skills and not their management skills. As such, many cannot adequately plan the work they are responsible for. Further, good plans are not always executed well, and not all people are good at developing effective work around plans once they are in trouble. More project reserves are wasted due to poor planning and execution at the cost account level than due to technical problems and underestimated costs combined.

### 4.9 Tailored Metrics

There are numerous metrics available for tracking performance. It is important to remember that one size does not fit all. Metrics should be selected to best fit a project's needs, and they should be tailored to optimize their usefulness.

### 4.10 Risk Management

Risk management is a powerful tool for decision making on a project. Many times very costly decisions are made that add little value. A very simple test for all decisions is to ask what are the cost, schedule, and mission success risk if it is not implemented. If the risk is low and the implementation cost is high, the decision should not be implemented. Maintaining and regularly monitoring a list of all the projects significant risks and mitigations insures that they get the necessary attention. It is very easy to lose sight of a significant risk when you are in the heart of the implementation phase. If mitigations are not pursued early in development, they will be very costly to implement later.

### 4.11 Requirements Flow Down

Early development of requirements and effectively managing them is crucial for any project, but with the short development times of Discovery missions it is imperative. Because of the small system engineering staff, a tool to manage requirements is very important. Dawn chose the DOORS tool, and has had considerable success with its usage.

### 4.12 Unfunded Mandates

Unfunded mandates are exactly like creeping requirements, except they come from your institution or your sponsor rather than from within the project. These mandates do not increase the science return from the mission. Rather science must be traded to pay for them. If new requirements are imposed in the form of unfunded mandates, make sure the institution and sponsor know they are changing the "deal", and provide them with a bill to implement them.

### 4.13 Sub-tier Contractors

One should not assume that sub-tier contractors have good processes in place. Trust but verify. Ensure that they are making progress. Make sure that excellent contract technical managers are assigned and that they have the training to thoroughly probe performance on a weekly basis. The contractors should be visited regularly. Their recent delivery experience for other projects should be a guide. The worse their past experience, the more attention they will need.

## 5. CONCLUDING REMARKS

Dawn is a low-cost planetary mission with high heritage and a purposefully simple design. Nevertheless, such a mission is challenging because of the rigidity of the cost cap, the short development time and the intense scrutiny such missions endure. The mission's financial reserves are expected to cover all unforeseen costs. A fixed development time for Discovery missions is a one-size fits all approach that may not be applicable when complex missions are selected. The multi-layer scrutiny that has evolved is an expensive cost and time burden that a low cost project cannot afford and whose true costs are seldom appreciated. Excellent technical and management staff are the keys to mission success. Ensuring future success demands that the leaders of the next generation be mentored in the projects of today, but experienced personnel must be at the helm. Dawn uses DOORS to manage requirements flow down and earned value to manage schedule and cost, but tailored metrics for managing software development, action items, and similar liens on readiness for launch, are also important management tools.

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