Organizational Team Characteristics That Enable Successful Projects at NASA – A Framework for the Future

By

Timothy J. Flores

B.S. Aerospace Engineering, University of Texas at Arlington, 1990

Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Engineering and Business Management
At the
Massachusetts Institute of Technology

June 2001

Signature of Author________________________

Timothy J. Flores
System Design and Management Fellow
Mav 4. 2001

Certified by________________________

Paul R. Carlile
Assistant Professor of Management, Sloan School of Management
Thesis Supervisor

Accepted by__________

Stephen C. Graves
Abraham Siegel Professor of Management
LFM/SDM Co-Director

Accepted by____________

Paul A. Lagace
Professor of Aeronautics & Astronautics and Engineering Systems
LFM/SDM Co-Director

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Abstract

Teamwork within projects is held at the highest level of regard at the National Aeronautics and Space Administration (NASA) for project success. The intimate relationships between the workforce, customers, suppliers, management, industry and academia, have always been an important part of the success of the Agency. However, typical documented process and procedure guides at NASA do not address the fundamentals of teams and team building, yet we rely on their efficacy.

Personal and professional development of the workforce has always been a hallmark of the Agency. The Agency has a history of investment in its most endeared asset – its human capital. Even the NASA Strategic Plan professes, "Our greatest strength is our workforce." Additionally, the program and project leadership roles and responsibilities are documented in the NPG 7120.5a; that provide a framework for the individual's technical tasks for a successful project. The same could be said for the System Engineering Handbook. As a whole most literature and emphasis has focused on the individual rather than the team. Specifically, what has not been addressed is the project team development or the human resource management.

This research will explore the requirements, metrics, and management necessary for creating successful team characteristics that enhance a project's ability for success. Research was performed on team projects to uncover best practices and lessons learned. The analysis used a system level approach at breaking down the organization structure using a number of NASA space missions as case studies. The three lenses of organizational behavior (strategic design, political and cultural perspectives) were used to investigate the team characteristics within the organizations.

This research concludes with a discussion of the results and summary of predominate themes that made the most impact to the decisions, execution, and outcome of the projects studied.

Thesis Supervisor: Paul R. Carlile
Title: Assistant Professor of Management at the Sloan School of Management

Biography

The author, Tim Flores has been a key project manager and leader at NASA Ames Research Center for over 10 years. Previous to his acceptance in the Systems Design and Management Program at the Massachusetts Institute of Technology, he was the Activation Manager of the newly remodeled Unitary Plan Wind Tunnel; an $85M restoration program. Prior to this position he actively managed a variety of major projects including some of the most critical and high-risk at NASA Ames. He has received numerous service and performance awards while at NASA and has had the honor of being a distinguished nominee for TECHNiCA Magazine for the Hispanic Engineer National Achievement Awards. He is a current member of the American Institute of Aeronautics and Astronautics and the Society of Hispanic Professional Engineers.

Mr. Flores received a Bachelors of Science degree in Aerospace Engineering from the University of Texas at Arlington in May 1990 and will receive a Masters of Science degree in Engineering and Business Management from the Massachusetts Institute of Technology in June 2001.

Acknowledgements

First and foremost, I dedicate this thesis to the memory of my parents. My parents always taught me to work hard in life and if I did, good things would come. This degree represents an example of hard work and rewards. I don't believe that anyone could be more proud of me than my parents and I am saddened that they are no longer physically here to celebrate this accomplishment with me.

I want to thank my sponsoring agency, NASA Ames Research Center, for believing in my work and abilities and for allowing me to represent them in the System Design and Management Program here at the Massachusetts Institute of Technology. To my many mentors at NASA that push me to the top, I honestly could not have done it without your continued support and words of encouragement.

I want to thank my thesis advisor, Paul Carlile, Assistant Professor of Management, at the MIT Sloan School. Paul exemplifies the meaning of dedication and passion for teaching in the education field. His guidance and wisdom of this subject inspire me to no end.

I also want to give thanks to the many contributors at the NASA Jet Propulsion Laboratory in Pasadena, California, for taking time out of their busy schedule to assist me by sharing their knowledge and perspectives during numerous interviews for this research.

Finally, a special thank you to my small and very close family who supported me through the hard times my entire life, Linda, Gracie, Alisha, Marty, James, Steven and Dan.

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Acronyms

AMD	Angular Momentum De-saturation
DS2	Deep Space 2
DSN	Deep Space Network
EDL	Entry, Decent, and Landing
FBC	Faster, Better, Cheaper
GDS	Ground Data Systems
JPL	Jet Propulsion Laboratory
LIDAR	Light Detection and Ranging
LMA	Lockheed Martin Astronautics
MARDI	Mars Descent Imager
MCO	Mars Climate Orbiter
MGS	Mars Global Surveyor
MIB	Mission Investigation Board
MM	Martin Marietta
MO/GDS	Mission Operations/Ground Data Systems
MPF	Mars Pathfinder
MPL	Mars Polar Lander
MSOP	Mars Surveyor Operations Project
MSP '98	Mars Surveyor Project '98
MSP	Mars Surveyor Program
MVACS	Mars Volatiles and Climate Surveyor
NIAT	NASA Integrated Action Team
NASA	National Aeronautics and Space Administration
PM	Project Manager
SDM	Systems Design and Management
TMC	Total Mission Costs
UCLA	University of California at Los Angeles

Organizational Team Characteristics That Enable Successful Projects at NASA – A Framework for the Future

Chapter 1.0 Introduction

1.1 Problem Statement

1.1.1 Motivation

Teamwork within projects is held at the highest level of regard at the National Aeronautics and Space Administration (NASA) for project success. The intimate relationships between the workforce, customers, suppliers, management, industry and academia, have always been an important part of the success of the Agency.

> *However, typical documented process and procedure guides at NASA do not address the fundamentals of teams and team building, yet we rely on their efficacy!*

1.1.2 Current State

Personal and professional development of the workforce has always been a hallmark of the Agency. The Agency has a history of investment in its most endeared asset – its human capital. Even the NASA Strategic Plan professes, "our greatest strength is our workforce." Additionally, the program and project leadership roles and responsibilities are documented in the NPG 7120.5a; that provide a framework for the individual's technical tasks for a successful project. The same could be said for the System Engineering Handbook.

As a whole most literature and emphasis has focused on the individual rather than the team. Specifically, what has not been addressed is the project team development or the human resource management.

1.1.3 The Challenge

Most project life spans will encompass two, in most cases; entirely separate teams as they go through the development cycle to the operations cycle of evolution in a project. The two teams associated with development and operations usually possess entirely different sets of skills and the boundary between the two is typically not well defined. This is evident in the aerospace industry where large portions of the project development are sub-contracted, and responsibility for operations is held by a separate organization, as is typical in a NASA deep space mission. In addition to the prominent development to operations transitions there are a multitude of smaller no less significant transitions that occur throughout a project.

Recent studies have concluded that the team environment plays an important role in the success or failure of projects and the transitions within them. This research will attempt to uncover those characteristics that tend to most influence the decisions, execution and outcome.

Undefined boundaries at the interface between two teams are frequently the origin of obscurity and added complexity in the evolution of a project. Technical difficulties from lack of communication can cause extra or unnecessary stress on the project and can ultimately lead to a less than successful outcome, product, or project. In most cases it may be impractical to expect both sets of skills to reside on one team throughout the project's life span for cost purposes alone. The timing of the transition between the representative teams becomes one of the major issues when a decision maker makes tradeoffs between scheduling of resources and cost considerations.

This thesis will also look at the issues and barriers of communication in a large complex project going from development to operations and general transitions and provide metrics considered for being successful. The thesis will draw from best practices along with lessons learned to create a formula for future project success.

1.1.4 The Outcome

This research will explore the requirements, metrics, and management necessary for creating successful team characteristics that enhance a project's ability for success. Research was performed on team projects to uncover best practices and lessons learned. The analysis used a system level approach at breaking down the organization structure using a number of NASA space missions as case studies. The three lenses of organizational behavior (strategic design, political and cultural perspectives) were used to investigate the team characteristics within the organizations.

This research concludes with a discussion of the results and summary of predominate themes that made the most impact to the decisions, execution, and outcome of the projects studied.

1.2 Thesis Structure

This thesis is proposed to answer the implied questions in the problem statement. I have chose to focus this research in the area of space sciences at NASA where there have been numerous reports published addressing recent mission failures as well as addressing a mission that was considered extremely successful from all points-of-view. The research will draw from interviews with project personnel, project reports, and personal knowledge to determine best practice from successful attributes and attempt to uncover lessons learned from those unsuccessful.

Chapter 1.0 begins to describe the primary problem and the motivation for a solution. It defines the current state of the philosophy of individual versus team development at NASA. The challenge is presented by looking at a particular aspect of a project of team transitions. Then proposes the solution outcome of this research.

Chapter 2.0 provides a brief description of the programs that the projects involved in this research were apart of. The types of programs that these projects were apart of impart a great influence on their progression. Background information on each project is presented that provide the overarching principles that drove the mission either to success or in some cases failure. A description of the goals and mission of each program and project are included for understanding and to provide the right context for the reader. This section tries to establish the bigger picture for the reader.

Chapter 3.0 describes the research objectives and methodology used in the analysis. A description is provided that guides the reader through the thought process of data gathering and interviewing technique. The analysis framework of the three lenses of organizational behavior is described in detail.

Chapter 4.0 consolidates the data by project by first breaking it down through organization behavior lenses of strategic design, political, and cultural perspectives. This segmentation concentrates on key aspects of the organization and focuses on individual elements from three different points-of-view and attempts to capture a holistic view of the organization. This section also tries to capture the facts and the feelings of the personnel involved in the project cases studied.

Chapter 5.0 takes the data and provides a discussion of the results by segmenting them into key themes. An attempt was made to compare and contrast the decisions, execution, and outcomes to provide the reader with a pragmatic view of the projects. A holistic approach is taken through the use of system engineering tools and methods to provide an integrated effect of results.

Chapter 6.0 provides the conclusions based on the key themes that summarize the best practices and lessons learned drawn from the data. This research is concluded with a discussion of the results and summary of predominate themes that made the most impact to the decisions, execution, and outcome of the projects studied.

Chapter 2.0 Program/Project Descriptions

For hundreds of years the vast distance separating Earth from the red planet restricted our observations of Mars. About once every two years, at its closest approach (called opposition), Mars passes within about 55 million km of Earth and it is then that we are able to capture pictures of maximum resolution with earth-based telescopes. The Hubble Space Telescope now provides us with excellent views from earth-orbit, but until the launching of probes to Mars to collect and relay data back to Earth, much of what was "known" about Mars was based on fuzzy pictures which showed only large scale planetary features and events.

The earth-based observations of Mars paved the way for spacecraft exploration of the planet. So many questions had been raised about Mars and there were so few answers. Did life exist on Mars in the past or present? Was water present on the planet? If so, what form was it in? What was the atmosphere composed of and what were its dynamics? Could Mars be used to tell us more about the evolution of both Earth and our solar system? These were some of the questions, which captured the imaginations of scientists from many disciplines, and the answers could only be found by direct observation. Fueled by the curiosities of both the scientific community and the public, on November 28, 1964 at 9:22 EST Mariner 4 was launched and 228 days later it would become the first spacecraft ever to visit the red planet[1]. Soon there would be more and as years have pasted NASA has introduced programs that would explore the earth's closest neighbor. Two of those programs with independent missions will be discussed here. The Discovery and the Mars Surveyor Programs. A timeline of NASA missions to Mars are presented in **Figure 1**.

[1] The History of Mars Exploration; http://nssdc.gsfc.nasa.gov/planetary/mars/marshist.html

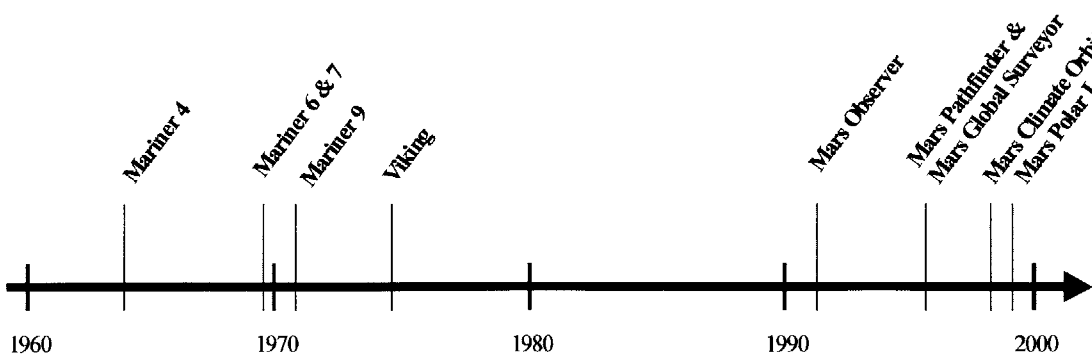


Figure 1: NASA Major Missions to Mars

2.1 Discovery Program

The primary goal of NASA's Discovery program is to conduct a series of frequent, highly focused, cost-effective missions to answer critical questions in solar system science. Formally started in 1994, the Discovery program features small planetary exploration spacecraft with focused science goals and can be built in 36 months or less, for less than $190 million in development costs, and for a total mission cost of less than $299 million. **Table 1** describes the projects and provides a brief description of each mission in the Discovery Program.

The program encourages the use of new technologies, the transfer of these new technologies to the private sector; increased participation of small and disadvantaged businesses; the pursuit of innovative ways of doing business; and the support of the nation's educational initiatives. The objective is to perform high-quality scientific investigations that will assure continuity in the U.S. solar system exploration program and enhance general public awareness of, and appreciation for, solar system exploration.[2]

[2] National Space Science Data Center website: http://nssdc.gsfc.nasa.gov/planetary/discovery.html

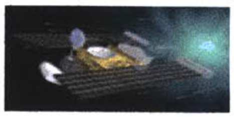
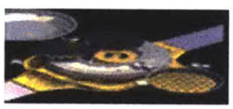
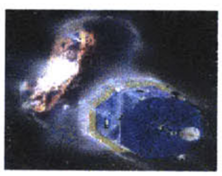
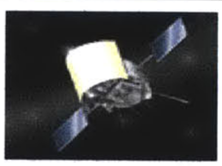
	On February 17, 1996, Near Earth Asteroid Rendezvous was the first Discovery Program spacecraft to be launched and is the first spacecraft ever to orbit and land on an asteroid.
	The Mars Pathfinder Mission is complete. The mission demonstrated a low cost method of delivering a set of science instruments and the Rover to the surface of Mars.
	The science data returned from Lunar Prospector has enabled scientists to create detailed maps of the gravity, magnetic properties and chemical composition of the Moon's entire surface.
	The Stardust spacecraft will collect comet dust and interstellar dust during a close encounter with Comet Wild 2 and return the particles to Earth for analysis by scientists worldwide.
	In July 2001, the Genesis spacecraft will journey a million miles sunward, unfold its collectors and "sunbathe" for two years, before returning in September 2004.
	The Comet Nucleus Tour, or CONTOUR, mission is timed to encounter and study two diverse comets as they make their periodic visits to the inner solar system.
	MESSENGER, (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) mission is a scientific investigation of the planet Mercury.
	The Deep Impact Mission will propel a large copper projectile into the surface of a comet, creating a huge crater.

Table 1: Discovery Program Missions

Discovery missions will explore the planets, their moons and other small bodies within the solar system, either by traveling to them or by remote examination.[3]

[3] JPL Discovery Program website: http://discovery.jpl.nasa.gov/overview.html

NASA has adopted a streamlined program management structure for Discovery missions, with minimum oversight and reporting requirements to assure agreed-upon science return in compliance with committed cost, schedule, and performance requirements. Investigator teams are allowed to use their own processes, procedures, and methods to the fullest extent practical, but are encouraged to develop and implement new ways of doing business when cost, schedule, and technical improvements can be achieved. This new approach encourages teaming arrangements among industry, university, and government partners to optimize the talents of each group. The principal investigator who has the responsibility and accountability to accomplish the selected missions within the strict cost and schedule constraints of the program lead the teams. An investigation team needs to have clear lines of responsibility and accountability with good, open communication, a small, high-energy workforce, and an enhanced sense of teamwork.

Prior to the Discovery Program NASA announced plans to explore a certain planet or region of space and solicited independent bids for spacecraft, operations, and science investigations. These missions were very large in scope. They involved the transport of numerous science instruments, occupied large groups of people, took many years to organize, and often at a cost of more than one billion dollars. The philosophy of Discovery is to solicit proposals for an entire mission, put together by a team comprised of people from industry, small businesses, government laboratories, and universities. The goal is to launch many, smaller missions that do focused science with fast turn-around times. The intent is to have a mission launch every 12 to 24 months.[4]

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[4] JPL Discovery Program website: http://discovery.jpl.nasa.gov/overview.html

2.1.1 Mars Pathfinder

Mars Pathfinder was the first completed mission in NASA's Discovery Program of low-cost, rapidly developed planetary missions. It was also one of the first successful faster, better, cheaper philosophy missions. With a development time of only three years and a total cost of $265 million, Pathfinder was originally designed as a technology demonstration of a way to deliver an instrumented Lander and a free-ranging robotic rover to the surface of the red planet.

Mars Pathfinder was launched atop a Delta II-7925 launch vehicle from Cape Canaveral Air Station in Florida on December 4, 1996. The duration of the flight to Mars was a seven-month journey. Pathfinder used an innovative method of directly entering the Martian atmosphere, assisted by a parachute to slow its descent through the thin Martian atmosphere and a giant system of airbags to cushion the impact. It was the first time the airbag technique had been used. **Figure 2** illustrates the unique entry, decent, and landing (ED&L) phase of this mission.

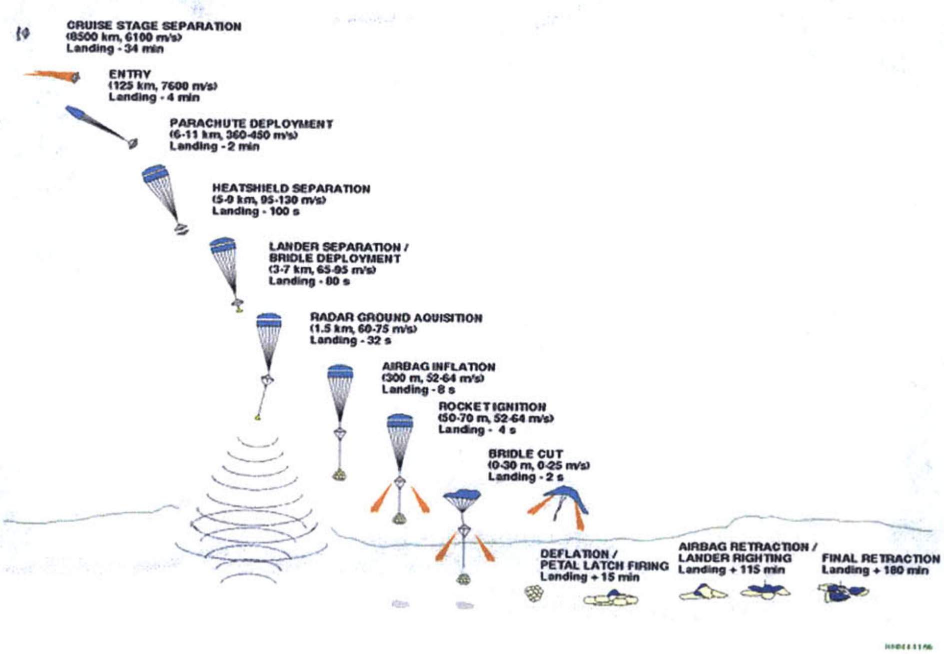


Figure 2: Pathfinder Entry, Decent, and Landing Sequence[5]

[5] Source: MPF ED&L web page: http://mars3.jpl.nasa.gov:80/MPF/mpf/edl/edl1.html

The airbag cushioned Lander hit the Martian soil on July 4, 1997, at a speed of 14 meters per second (31 miles per hour). Measuring 5.8 meters (19 feet) in diameter, it bounced like a giant beach ball about 15 times, as high as 15 meters (50 feet), before coming to rest 2-1/2 minutes later about 1 kilometer (six-tenths of a mile) from the point of initial impact.[6] After, the Lander's airbags deflated and were then retracted. Pathfinder opened its three metallic triangular solar panels (petals) 87 minutes after landing. The Lander's first transmitted signals received at Earth were of the engineering and atmospheric science data collected during entry and landing. The imaging system obtained views of the rover and its' immediate surroundings, and a panoramic view of the landing area, and transmitted this information to Earth. After some maneuvers to clear an airbag out of the way, ramps were deployed and the rover, stowed against one of the petals, rolled onto the surface on 6 July.[7] See **Figure 3,** for a collage of photos taken from the Lander of the rover deployment.

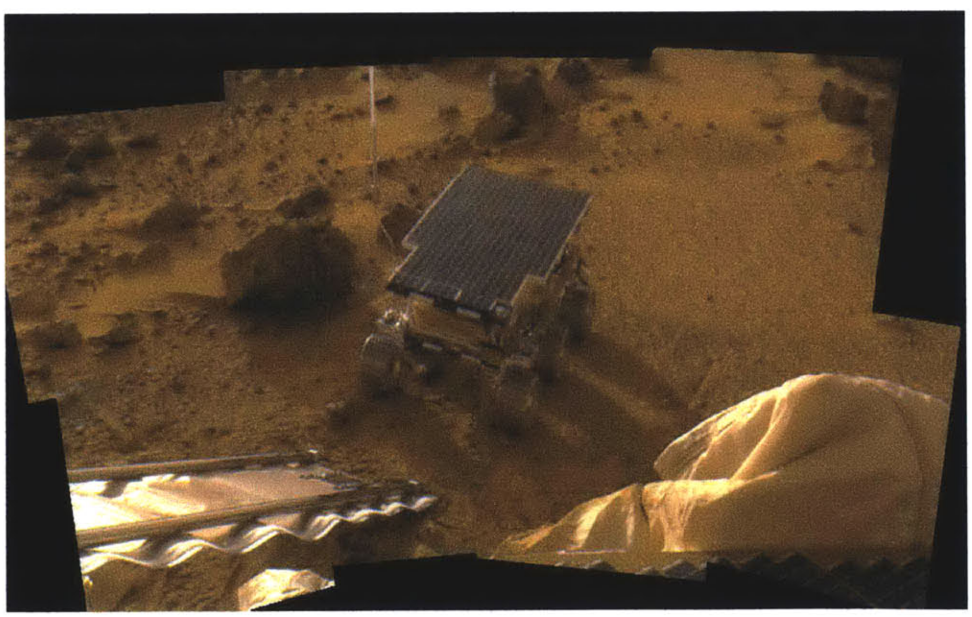


Figure 3: MPF Rover deployment from Lander[8]

[6] NASA Facts on the Mars Pathfinder
[7] National Space Science Data Center website: http://nssdc.gsfc.nasa.gov/nmc/tmp/1996-068A.html
[8] Source: General photo archive web page: http://mars.jpl.nasa.gov/MPF/ops/prm-thmb1.html

The Lander and the rover named Sojourner after American civil rights crusader Sojourner Truth, both outlived their design lives – the Lander by nearly three times, and the rover by 12 times.

From the landing on July 4, 1997, to the final data transmission on September 27, 1997, Mars Pathfinder returned 2.3 billion bits of information, including more than 16,500 images from the Lander and 550 images from the rover, as well as more than 15 chemical analysis of rocks and soil and extensive data on winds and other weather factors.[9]

2.2 Mars Surveyor Program

NASA's Mars Surveyor Program (MSP) began in 1994 with plans to send spacecraft to Mars every 26 months. Mars Global Surveyor (MGS), a global mapping mission, was launched in late 1996 as the first flight mission. **Table 2** describes the MSP projects and important mission facts. In 1995, two additional missions were identified for launch in late 1998/early 1999. The missions were the Mars Climate Obiter (MCO) and Mars Polar Lander (MPL). The two missions were designed to study the Martian weather, climate, and water and carbon dioxide budget, in order to understand the reservoirs, behavior, and atmospheric role of volatiles, and to search for evidence of long-term and episodic climate changes.

The combined development cost of MPL and MCO, including the cost of the two launch vehicles, was approximately the same as the development cost of the Mars Pathfinder mission, including the cost of its single launch vehicle.

[9] NASA Facts on the Mars Pathfinder

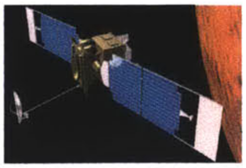
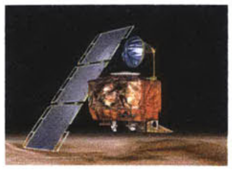
	The Mars Global Surveyor (MGS) mission is designed as a rapid, low-cost recovery of the Mars Observer mission objectives. Primary mapping mission and used as a data relay for later U.S. and international missions and is still flying today. Launched in 1996
	The Mars Climate Orbiter was destroyed when a navigation error caused it to miss its target altiude at Mars by 80 to 90 km, instead entering the martian atmosphere at an altitude of 57 km during the orbit insertion maneuver.
	The last telemetry from Mars Polar Lander was sent just prior to atmospheric entry on 3 December 1999. No further signals have been received from the lander, the cause of this loss of communication is not known.

Table 2: Mars Surveyor Program Missions

The Jet Propulsion Laboratory (JPL), a division of the California Institute of Technology, manages the Mars Surveyor Program for NASA's Office of Space Science. JPL created the Mars Surveyor Project '98 (MSP '98) office with the responsibility to define the missions, develop both MCO and MPL spacecraft and all payload elements, and integrate/test/launch both flight systems. In addition, the Program specified that the Mars Surveyor Operations Project (MSOP) would be responsible for conducting flight operations for MCO and MPL as well as the MGS. **Figure 4** provides a delineation of roles and responsibilities for each entity of the program.

The MSP '98 Development Project used a prime contract vehicle to support project implementation. Lockheed Martin Astronautics (LMA) of Denver, Colorado was selected as the prime contractor. LMA's contracted development responsibilities were to design and develop both spacecraft, lead flight system integration and test, and support launch operations. JPL retained responsibilities for overall project management, spacecraft and instrument development management, project system engineering, mission design, navigation design, mission operation system development, ground data system (GDS) development, and mission assurance. The MSP '98 project assigned the responsibility for mission operations/ground data systems (MOS/GDS) development to the MSOP, LMA provided support to MSOP for MOS/GDS development tasks related to spacecraft test and operations.

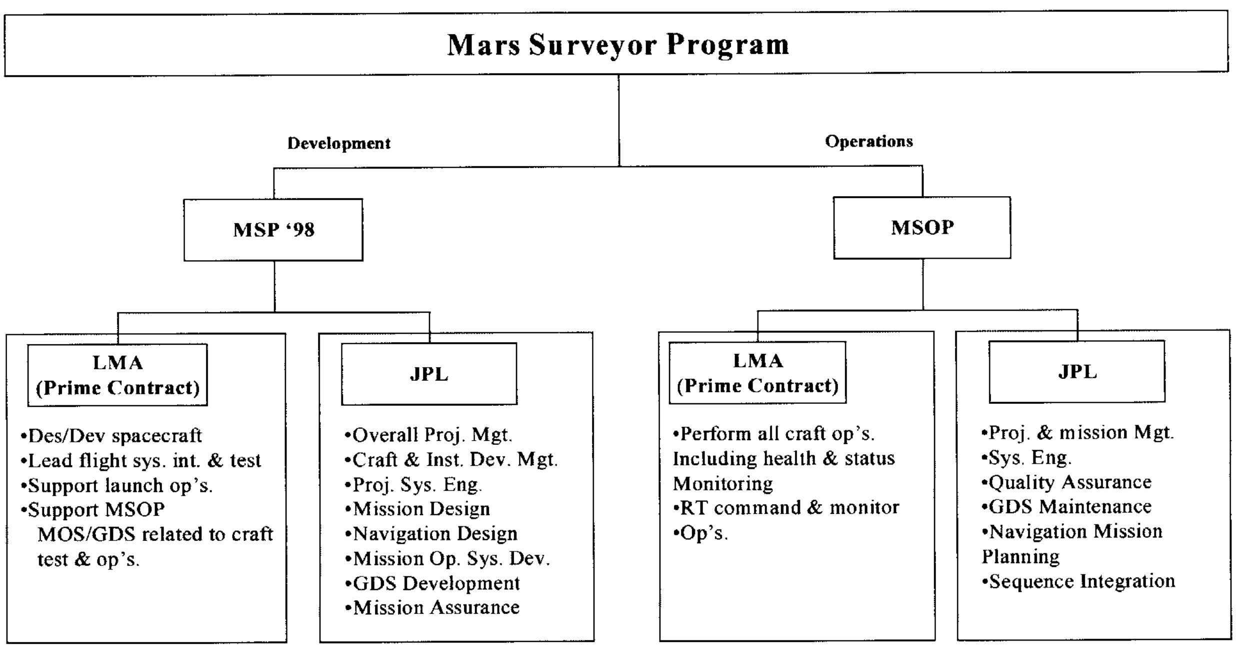


Figure 4: MSP Roles and Responsibilities

The MSOP assumed responsibility for both the MCO and the MPL at launch. The MSOP implemented a partnering mode in which distinct operations functions were performed by a geographically distributed set of partners. LMA performed all spacecraft operations functions, which included health and status monitoring, and spacecraft sequence development. In addition, LMA performed real time command and monitoring operations from their facility in Denver, Colorado. JPL was responsible for overall project and mission management, system engineering, quality assurance, GDS maintenance, navigation, mission planning, and sequence integration. Each of the science teams was responsible for planning and sequencing their instrument observations, processing and archiving the resulting data, and performing off line data analysis. These operations are typically performed at the Principal Investigator's home institution. The MSOP personnel also support MGS operations.[10]

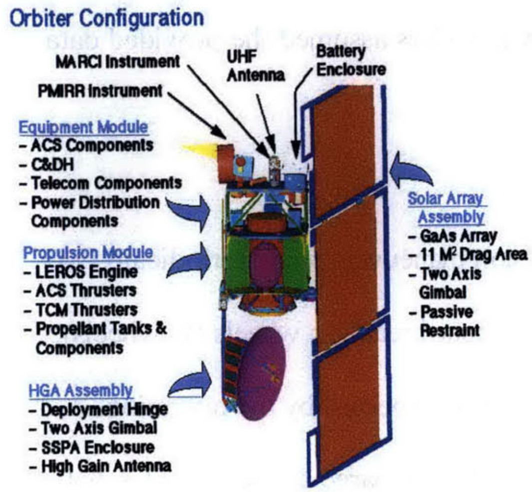
2.2.1 Mars Climate Orbiter

The Mars Climate Orbiter mission was conducted under NASA's "Faster, Better, Cheaper" philosophy, developed in recent years to enhance innovation, productivity and cost-effectiveness of America's space program. The "Faster, Better, Cheaper" paradigm has successfully challenged project teams to infuse new technologies and processes that allow NASA to do more with less.[11]

The MCO was launched on December 11, 1998 scheduled to arrive at Mars on September 23, 1999. MCO was launched atop a Delta II launch vehicle from Launch Complex 17A at Cape Canaveral Air Station, Florida. MCO's primary mission was to operate in a polar orbit for up to five years to study the weather and serve as a telecommunications relay link for the MPL that was due to reach Mars shortly thereafter, and other missions that would follow. **Figures 5 and 6** depict the Orbiters' configuration and mission overview respectively.

[10] Stephenson, Arthur G., et al; 1999
[11] Stephenson, Arthur G., et al; 2000

Figure 5: Mars Climate Orbiter Configuration



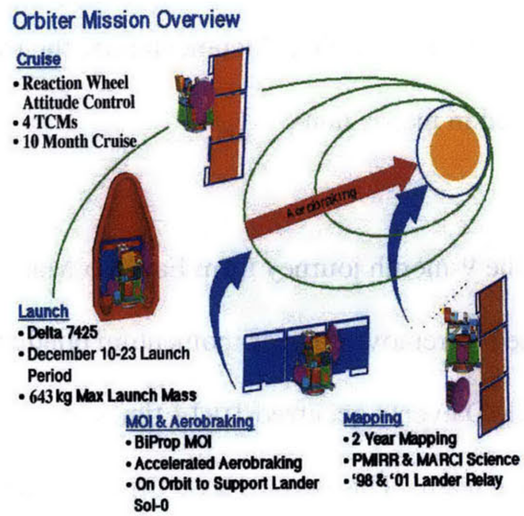


Figure 6: Mars Climate Orbiter Mission Overview

Nine and a half months after launch, in September 1999, MCO was to fire its main engine to achieve an elliptical orbit around Mars. The spacecraft was to then skim through Mars' upper atmosphere for several weeks in a technique called aero-braking to reduce velocity and move into a circular orbit. Friction against the spacecraft's single, 5.5-meter solar array was to have slowed the spacecraft as it dipped into the atmosphere each orbit, reducing its orbit period from more than 14 hours to 2 hours. On September 23, 1999 the MCO mission was lost when it entered the Martian atmosphere on a lower than expected trajectory.[12]

The MCO Mission Investigation Board (MIB) determined the root cause for the loss of the MCO spacecraft was the failure to use metric units in the coding of the ground software file, "Small Forces," used in trajectory models. Specifically, thruster performance data in English units instead of metric units was used in the software application code titled SM_FORCES (Small Forces). A file called Angular Momentum De-saturation (AMD) contained the output data from

[12] Stephenson, Arthur G., et al; 2000

the SM_FORCES software. As the data in the AMD file was required to be in metric units, per existing software interface documentation, the trajectory modelers assumed the provided data was indeed in metric units.

During the 9-month journey from Earth to Mars, propulsion maneuvers were periodically performed to remove angular momentum buildup in the onboard reaction wheels (flywheels). These AMD events occurred 10-14 times more often than was expected by the operations navigation team. This was because the MCO was asymmetric compared to the Mars Global Surveyor (MGS) with which the operations crew was familiar. The increased AMD events, coupled with the fact that the angular momentum (impulse) data was in English units rather than metric units, resulted in the introduction of small errors in the trajectory estimate over the course of the 9-month journey. At the time of Mars insertion, the spacecraft trajectory was approximately 170 kilometers lower than planned. See **Figure 7**. As a result, MCO either was destroyed in the atmosphere or re-entered heliocentric space after leaving Mars atmosphere.[13]

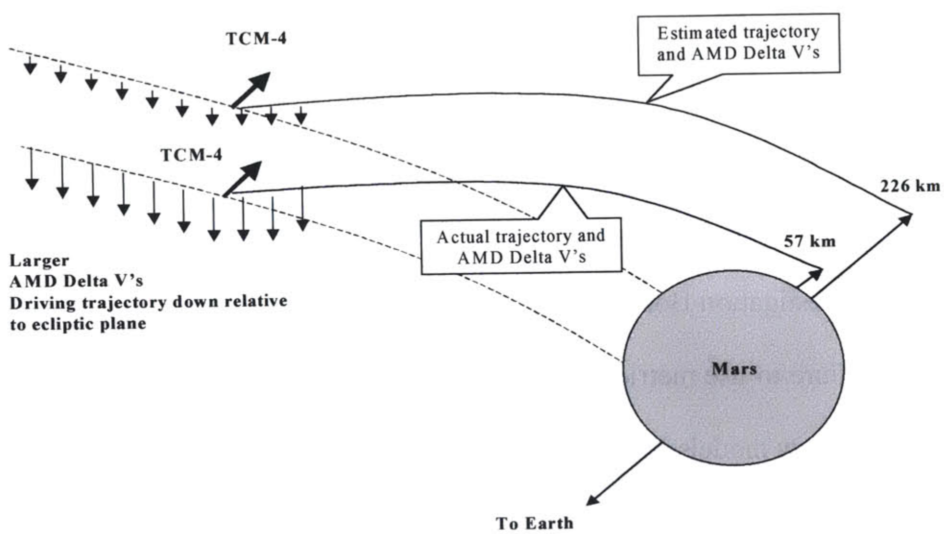


Figure 7: Mars Climate Orbiter Flight Path[14]

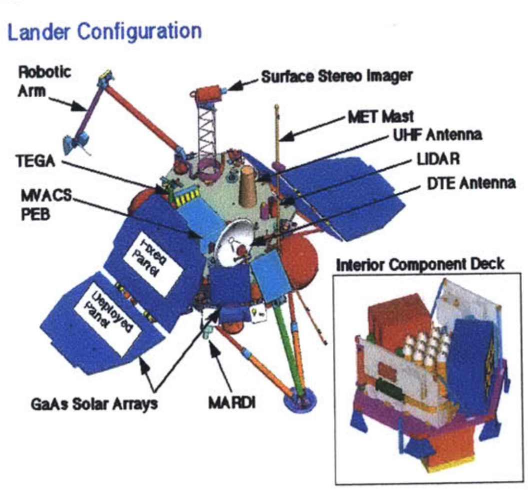
[13] Stephenson, Arthur G., et al; 1999
[14] Recreated from: Stephenson, Arthur G., et al; 1999

2.2.2 Mars Polar Lander

The MPL and two Deep Space 2 (DS2) probes were launched using a single Delta II launch vehicle from Kennedy Space Center on January 3, 1999. MPL was designed to study volatiles and climate history during its 90-day mission.[15]

Attached to the Lander spacecraft was a pair of small probes, the Deep Space 2 (DS2) Mars Microprobes, which were to be deployed to fall and penetrate beneath the Martian surface when the spacecraft reached Mars. Even though the two DS2 spacecraft were part of the entire mission they were disregarded in this analysis.[16] The Lander also carried three science investigations: the Mars Volatiles and Climate Surveyor (MVACS), the Mars Descent Imager (MARDI), and a Russian-provided light detection and ranging (LIDAR) instrument. **Figures 8 and 9** depict the MPL configuration and mission overview respectively.

Figure 8: Mars Polar Lander Configuration



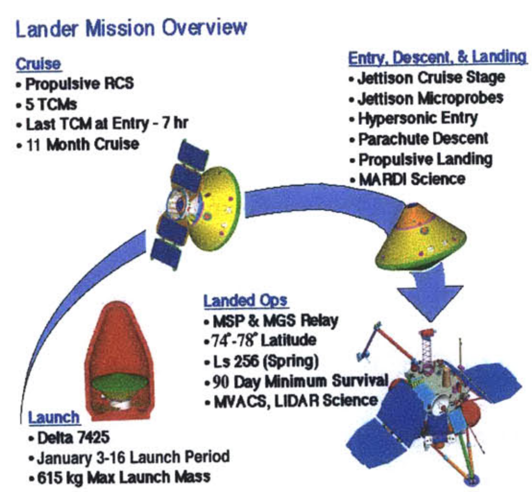


Figure 9: Mars Polar Lander Mission

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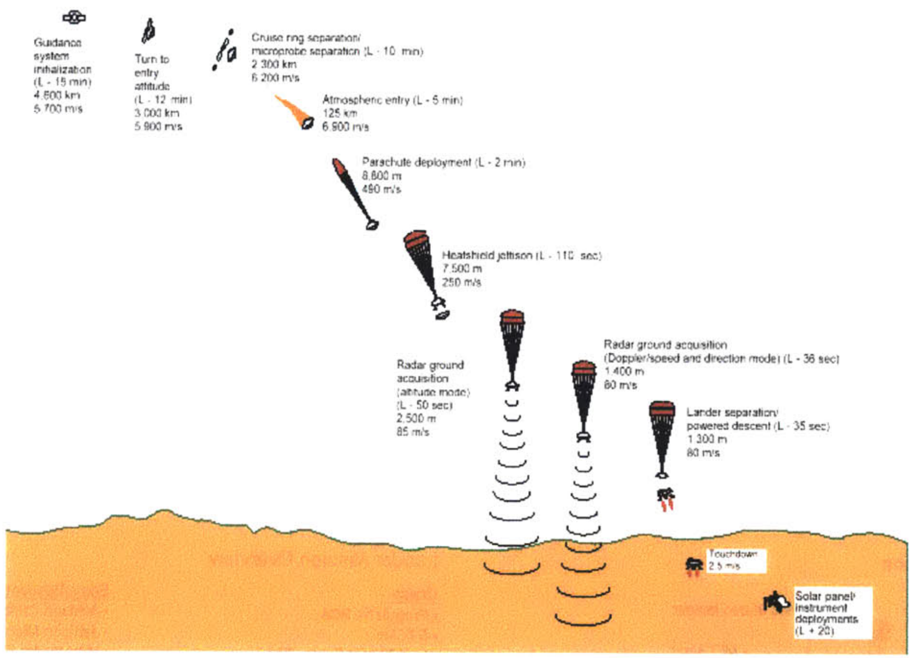
[15] Casani, John, et al; 2000

[16] The justification for their disregard is the same as with other science experiments included in the mission. There is an understanding that these additions add complexity however, they are trivial contributions to go into detail here.

After an 11-month cruise, the spacecraft arrived at Mars on 3 December 1999, targeted for a landing zone near the edge of the south polar-layered terrain.[17] Like Mars Pathfinder, MPL was to dive directly into the Martian atmosphere, using an aero shell and parachute, scaled down from Pathfinder's design, to slow its initial descent. **Figure 10** depicts the ED&L for this project. The smaller MPL did not use airbags but instead relied on onboard guidance, radar, and retro-rockets to land softly on the layered terrain.[18]



Entry, descent and landing

Figure 10: Mars Polar Lander Entry, Decent, and Landing Sequence

Upon arrival at Mars of the MPL and the 2 DS2's, communications with operations ended, according to plan, as the three spacecraft prepared to enter the Martian atmosphere. Communications were scheduled to resume after the Lander and the probes were on Mars' surface. Repeated efforts to contact the spacecraft for several weeks were unsuccessful.

[17] Casani, John, et al; 2000
[18] Stephenson, Arthur G., et al; 1999

Given the total absence of telemetry data and the lack of response to any of the attempted recovery actions, it was unlikely that a definitive cause, or causes, of failure could be determined.

Still, the most likely, or probable, cause for the loss of the MPL has been traced to a premature shutdown of the descent engines. This shutdown resulted from a vulnerability of the software to transient signals. Owing to the lack of data, other potential failure modes could not be positively ruled out.[19]

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[19] Casani, John, et al; 2000

Chapter 3.0 Research Objective and Methodology

3.1 Objectives

The main objective of this thesis was to identify best practices and lessons learned that would elevate the opportunity for projects to become successful. In order to answer the questions posed in the introductory chapters, appendix, and literature review, and, thus identify organizational characteristics that attribute to successful projects, it was necessary to review projects that were considered successful and some that were not.

3.2 Interview Development

At this point the implied questions from Chapter 1.0 were expanded to the list presented in Appendix A, representing an initial list of interview questions. The series of questions in the appendix were documented prior to the interviews as a guide to systematically gather the same data from each individual. The questions were structured around the defined strategic, political and cultural perspectives and were reviewed by people in an attempt to remove any bias. Since the author had perceived notions from reading the numerous project reviews and literature this was an attempt to remove any leading questions. After the questions were reviewed by category they were reordered to provide a flowing conversation for the interviews.

3.3 Data Gathering

Because this research was a subjective exploration of projects, it was concluded that case studies derived through a series of interviews would be more insightful than using a standardized survey. Additionally, it would be difficult to collect a dataset from the aerospace industry large enough to warrant a statistical study; therefore, only qualitative results and conclusions are implied.

3.4 Project Selection

The next step was to select the projects to study as part of this thesis. The projects selected for analyses were chosen on the basis of three criteria, (1) budget size, (2) resource allocation, and (3) "perceived" complexity. All three are related as each affects the other in a significant way. All projects were chosen from a list of recent projects that were comparable on some datum (see **Table 3**). The decision to benchmark the Mars Pathfinder Project was made since there has been a general opinion that this project had been more than a successful mission exceeding all expectations. The Mars Climate Orbiter (MCO) and the Mars Polar Lander (MPL) were identified as two recent missions that were less than successful in that both spacecraft were lost prior to achieving mission objectives. The MCO and the MPL were essentially run as one project under the MSP and together were comparable to MPF in cost of development and total cost. All three projects were of comparable scope and these projects were run in succession under the philosophy of FBC. The MCO and the MPL have an abundance of literature in the form of mishap reports that assisted in the research.

3.5 Resource Selection

The individuals within each organization were selected for interviews based on their involvement in the project. A total of 8 people were interviewed – a breakdown of people interviewed per project is shown in **Appendix B**. More than one person from each organization was interviewed to improve reliability of the information, as well as increase the overall amount of information about a particular project. Also, acquiring many perspectives of the same subject matter helped remove the personal bias and alleviate the subjectivity.

Mission	Viking 1	Viking 2	MPF	MGS	MCO	MPL
Program			Discovery	Discovery	MSP	MSP
Launch	8/20/75	9/9/75	12/4/96	11/7/96	12/11/98	1/3/99
Arrival at Mars	6/19/76	8/7/76	7/4/97	9/12/97	9/23/99	12/3/99
Cruise Time (mths)	10	11	7	11	10	11
Mission Start Date	Jun-76	Aug-76	Jul-97	Mar-99	Sept-99	Dec-99
Estimated EOM	Aug-80	Jul-78	Aug-97	Jan-03	Dec-04	Mar-00
Lost Communication	11/13/82	4/11/80	9/27/97	N/A	9/23/99	12/3/99
Current Status	EOM	EOM	EOM	Functioning	Lost	Lost
Mass at Launch (kg)	3527	3527	894	1030.5	629	576
Mass upon Mars Arrival (kg)	1455	1455	584	767	338	494
Mass Lander (kg)	572	572	370	N/A	N/A	290
Mass Rover (kg)	N/A	N/A	10.5	N/A	N/A	N/A
Mass Orbiter (kg)	883	883	N/A	767	354	N/A
Development Cost ($M)			196	154	80	110
Launch Vehicle Cost ($M)			55	65	45	45
Operations Cost ($M)			15	20/yr	32	10
Total Cost ($M)	1600	1600	265	240	157	165
Science	Orbiter Cameras Infrared thermal mapping Radio science investigations Relay for Landers Lander Cameras Sampler arm Meteorology boom Seismometer Gas chromatograph mass spectrometer X-ray fluorescence spectrometer	Orbiter Cameras Infrared thermal mapping Radio science investigations Relay for Landers Lander Cameras Sampler arm Meteorology boom Seismometer Gas chromatograph mass spectrometer X-ray fluorescence spectrometer	IMP ASI/MET APXS	MOC TES MOLA RS MAG/ER Relay Experiment	MARCI PMIRR	Deep Space 2 MVACS MARDI LIDAR

Table 3: Mars Mission Comparison

3.6 Interviewing

Generally, the first interview with someone from an organization included questions on the strategic, political, and cultural perspectives drawn from the questionnaire in the appendix. Most interviews were recorded and later transcribed for future use. The interviews were long and ventured at times as an attempt was made to capture detail information of the subjects.

Additional interviews within the same organization focused first, on the strategic perspective and then on the political and cultural perspectives if time permitted. The first round of interviews were conducted at JPL during the fall of 2001 with each interview at least one hour in duration. In most cases, interviewees were contacted for second interviews in order to clarify and increase the depth of information about the respective organization. Either a telephone call or e-mail was used to perform the follow-up interviews. All of the data gathered on an organization was used to formulate its respective case study. Finished case studies were then sent back to the respective organizations where the interviewee provided feedback, corrections, and final approval for accuracy of the case study.

3.7 Case Study Development

3.7.1 The Three Lenses

These three lenses on organizational analysis and action have been developed over the years by researchers, teachers, consultants, and practitioners who study and participate in organizations.[20] The behavioral science perspective that has been used, builds on psychology, sociology, political science, and anthropology. Based on this foundation three lenses have been formulated and developed, the strategic design lens, the political lens, and the cultural lens. The three lenses were used in the analysis to breakdown the organization architecture from different perspectives. Using the three perspectives allowed for a thorough investigation of the project from various viewpoints and reduced the complexity.

The three lenses allow you to focus on an area or aspect of an organization one at a time. They are a way of breaking down a system into chunks, or subsystems, for analysis. The lenses also

[20] Ancona, et al. 1999

highlight very different aspects of organizational behavior. It is only through an understanding of all three that a complete organizational diagnosis can take place. The reassembly of the research back into a whole provides the benefit to the organization. Through each lens you observe slightly different features, e.g., the organizational structure, key stakeholders, goals, etc. Also, each lens focusing on one feature will reveal a different view from the others. An organizational chart will represent a system of grouping and linking critical tasks in one lens, a picture of the current power structure and dominant coalition in another. Like the analogy to a system, individual parts are incomplete without the other. In other words, no one perspective is sufficient to research or study an organization; rather all three provide the big picture.

3.7.2 Strategic Design Perspective Description

The strategic lens positions the organization as a goal-directed entity. As a change agent, this lens sets you up as an "organizational architect" improving the fit between the strategy and organization and cross-organizational components. It is based on an engineering approach that can be used to craft an organizational structure and system of rewards, careers, controls, and tasks that fit a given environment. This perspective looks at how the flow of tasks and information is designed. People are first sorted into roles; we then look at how the roles are related and how the organization can be rationally organized to accomplish its goals.

This is by far the dominant perspective. Organizations are typically viewed as strategic designs, that is, as systems deliberately set up to achieve certain strategic goals. This perspective asserts that by understanding basic principles of organizational design, by aligning the organization's design with its strategy, and by making sure that both strategy and design fit the environment in which the organization is operating, managers can make their organizations successful.[21] What does this understanding involve? The strategic design perspective sees three key elements of organizational design.

1. Strategic Grouping – The organizational units strategy should dictate the units grouping decisions. Grouping gathers together task, functions, and disciplines, and then separates them from others. It answers the question of what resources and what tasks should be clustered together. It can be looked to as "drawing the boxes" of the organizational design. Grouping decisions should also take into account the firms functional abilities, its' products produced, geographical considerations, and its' staffing restrictions.
2. Strategic Linking – Linking allows for formal and informal coordination to be maintained. It allows the mechanisms for strategic groups to be reunited for interdependent relationships. A growing challenge for organizations is to maintain linking throughout the organization particularly when barriers, such as geographical issues, are present. There are ranges of linking mechanisms on which organizations can draw. These mechanisms include, but are not limited to: formal reporting structures, liaison roles, integrator roles, information technology systems, etc.
3. Strategic Alignment – One of the several reasons for the failure of so many organizational redesign efforts, according to this perspective, is misaligned systems and processes; organizational patterns that pull groups and individuals to behavior that undermines the strategic intent or that pulls different groups in opposing directions.[22] Emphasis is on the metrics of organizational performance, the alignment of individual rewards and incentives with organizational strategy, and resource allocation.

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[21] Ancona, et al. 1999
[22] Ibid

3.7.3 Political Perspective Description[23]

The political lens views the organization and its environment as a set of changing interests and coalitions that are in conflict over scarce resources and thus, they negotiate agreements. This perspective casts one as a forger of coalitions and at the same time, a negotiator leveraging varying interests. The result is an organization consisting of multiple stakeholders and existing in a network of political relationships. This perspective looks at how power and influence are distributed and wielded; how multiple stakeholders express their different preferences and get involved in (or excluded from) decisions; and how conflicts can be resolved.

A political perspective views an organization as composed of multiple "stakeholders," i.e., individuals and groups who contribute important resources to an organization and depend on its success. In most cases, these individuals and groups will have different interests and goals, as well as different amounts and sources of power to bear in organizational interactions.[24]

There are three fundamental building blocks to understanding a political perspective. To use a political perspective you must first identify and map the relationships of the different stakeholders involved. Second, you must determine the interest and goals the different stakeholders bring to the interaction and the level of conflict or congruency that come with them. Finally, you must assess the amount and sources of power of the different stakeholders.[25] The political perspective sees three key elements of political interest.

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[23] Carlile, Paul; Organizational Behavior and Processes; Module 2 Part 3
[24] Freeman, 1984; Mitchell, et al., 1997; Kochan and Rubinstein, 1998
[25] Carlile, Paul; Organizational Behavior and Processes; Module 2 Part 3

1. Stakeholders – Today it is widely accepted that organizations consist of multiple stakeholders with varying interest. Stakeholder interests arise from a variety of sources. Some reflect the horizontal divisions of labor and organizational structures while others reflect one's vertical division of labor or hierarchy. All of these stakeholders have different goals and interests they are trying to maintain and expand.
2. Interest and Goals – One task for managers is to attempt to create is congruity among the numerous goals individuals and groups bring to an organization. However, the conflict of goals will not go away. Goal conflict is typically built into the design of most organizational interactions. For example, cross-functional teams are usually created to ensure that different requirements and knowledge bases are considered in a decision.
3. Power and Politics – A political perspective defines power as the ability to get things done when goals conflict.[26] Power can be categorized just as a negotiation can in that it does not have to be a zero-sum game. Just as in a negotiation when you align preferences to develop a win-win scenario, in power you find ways to align stakeholder interest or achieve solutions that produce joint gains for the different stakeholders. Some of the different bases or sources of power commonly found in any organizational interaction involving multiple stakeholders include:
    - Formal authority – position power
    - Control over scarce resources
    - Rules, structure, regulations, standard operating procedures
    - Information, knowledge, or specialized (scarce) skills
    - Control over decision process – access to decision making, etc.

[26] Dahl, 1957

3.7.4 Cultural Perspective Description

The cultural lens views the organization as a set of deeply held assumptions that are acquired early in a firm's history and are passed on through stories, symbols, myths, and socialization procedures. This perspective looks at how history has shaped the assumptions and meanings of different people, how certain practices take on special meaningfulness and even become rituals, and how stories and other artifacts shape the feel of an organization. These deeply held assumptions signal to people how to act and react to events around them. They may sabotage major change efforts because "that is simply not the way we do things around here."[27]

As a working definition for this thesis, consider culture to refer to the symbolic or expressive sides of human life-actions, objects, and ideas that stand for something else. Business organizations are social systems in which people must do things together, and therefore the management of meaning is as central to this collective task as is the management of money, production, and sales. As the definition implies this perspective is a broad one and covers much territory. This perspective will take five features under consideration as summarized below; taken from Ancona, et al. 1999.

1. Focusing on Symbols and Meaning – Taking a cultural perspective means trying to decipher what things mean to people in organizations.
2. Identifying Various Forms of Social Control – Organizations must develop the means to insure that employees act in ways that are more or less beneficial to the goals of the enterprise.

[27] Ancona, et al. 1999

3. Recognizing Subcultures – Homogeneous organizational cultures are probably quite rare and, when present, are typically found in a relatively small, closely held and highly focused firm.
4. Diagnosing Organizational Culture – Despite considerable subculture variation within large organizations, there is often a relatively small set of governing ideas or basic assumptions that members draw on to guide thought and action within the firm.
5. Looking Across Cultures – Strong cultural models claim that national, local, or firm-specific culture (or some combination) fully explains organizational behavior.

Chapter 4.0 Case Study Analysis

Based on the research it was determined that trying to separate the MCO and MPL, as separate projects were difficult. Actually they were run as a single project under the MSP '98 umbrella. They were run simultaneously under the identical management, organizational structure, incentives, and culture. In fact separation did not occur until close to launch when each were given separate names and an attempt was made to portray them as separate. Therefore throughout this analysis there will be reference to MSP '98 rather than the individual MCO and MPL project names. Occasionally there will be reference to the individual projects and will be noted as such.

The three-lens method of organizational behavior will be used to break down the organizational architecture for later discussion. Each project will be analyzed separately from the three perspectives with MCO and MPL being discussed together under the MSP '98 heading. This chapter consolidates the data by first breaking it down through lenses of strategic design, political, and cultural perspectives. This segmentation concentrates on key aspects of the organization and focuses on individual elements from three different points-of-view and attempts to capture a holistic view of the organization. This chapter also tries to capture the facts and the feelings of the personnel involved in the project cases studied without drawing conclusions.

4.1 Mars Pathfinder Case Study

4.1.1 Strategic Perspective

Strategic Grouping

JPL is organized as a matrix organization. The missions are separated as products (projects), and functional personnel are assigned to each project using the matrix technique as in **Figure 11**. As in all matrix organizations workers have two bosses, the project boss or manager and the functional line manager. This is sometimes considered a distraction when line management get involved in their employees work by requesting some degree of review or rigor in their work above and beyond the project requirements. However, this is considered a typical situation. In MPF the project dimension leadership was very powerful and experienced. That might have led to the line management decreased involvement in this project and the functional management allowing the team to become very isolated under project control. Workers referred to the project as having a "Skunk Works"[28] feel to it.

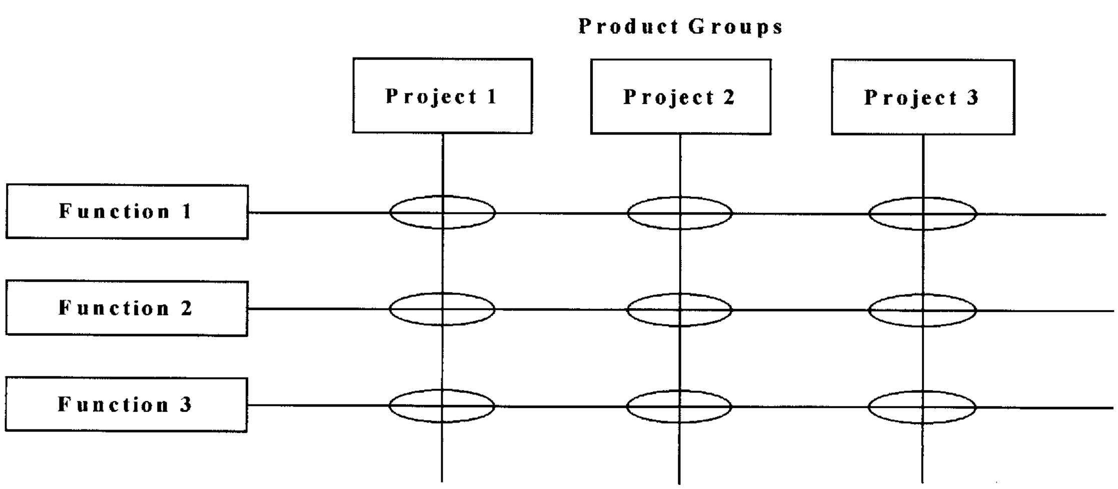

Figure 11: JPL Organizational Structure

[28] "Skunk Works" refers to secretive, isolated, and very famous Lockheed Advanced Development Company started in the 1940's in Burbank, CA. by Clarence "Kelly" Johnson. Skunk Works has been know for the development of such aircraft as the U-2 Spyplane and the SR-71 Blackbird

Many positive attributes came from isolation. With isolation came the autonomy that allowed the project to become very flat and flexible. Because they were so flat they developed very good relationships with one another, a certain camaraderie. They were also very flexible. The flexibility allowed managers to place people where they fit within the project using the individual skills that could add value to the project rather than stick strictly to job function classifications. In the words of Robert Manning, the Flight Systems Engineer, "we just did it, everyone understood the ultimate goal and we did what was necessary to accomplish that goal." The second benefit of flexibility came from, as certain job functions ended workers were allowed to transition based on where their individual skills could be used. That might make them cross boundaries of work in different areas. Robert Manning transitioned to the ED&L "czar" as he put it. Management also fostered system engineers; it was okay to be a generalist in this environment. Thus, the benefit was using workers across boundaries. Since people were allowed to fall where they fit, management also fostered a mechanism when people chose not to fit, in that case, a joint decision helped move them on. And finally, due to the flat organizational structure everyone was called upon to take extra responsibility and not a lot was made of standardized titles or job functions as in the example of the "ED&L czar" described above. Some people felt it was due to the personality of the PM's that allowed the project to evolve as it did. Tony Spear's management style was described as "managing by feel and trust." Trust seemed to be prevalent attribute associated with the environment.

Probably the most positive decision was the one made to use the entire team for development and operations. This so-called "cradle to grave" philosophy actually energized the team that they would design, build, and test the spacecraft; then they would fly it as well. This decision made sense for the type of mission it was; a Lander with a relatively short mission life and a fairly short cruise time to Mars. Development was 3 years and launch to landing was 7 months with 30-40 days planned on the surface.

Strategic Linking

As the MPF project was just getting started an opportunity presented itself to colocate. It was rather a coincidence that an entire floor in one building had opened up just in time that most of the MPF team could fit. Collocating brought out many favorable characteristics for the team. Because they were very flat and now they were colocated it was rather easy to talk to everyone in any functional area of the program no matter what level or authority you had on the organizational chart. Having everyone in one area seemed to blend the team or melt the boundaries between functions and hierarchical levels. The unofficial reporting process was to communicate with the one who needed to know. Since the navigation engineer may be sitting next to the propulsion engineer it just seemed natural to talk on an informal basis. A second benefit of colocation was that everyone stayed well connected. Being in such close proximity where issues are discussed freely it was very easy to overhear the issues of all the disciplines on a day-to-day basis, therefore giving each individual a better understanding of the big picture.

Strategically scheduled items were being moved to the left on the project schedule as much as possible. The feeling was that had to be done to integrate as many activities as quickly as possible. The PM's were given high credit by team members for laying out how they should operate together and when.

Since MPF was sparse on resources and they were a very close group they didn't have problems with organizational overlap, people welcomed support. Due to colocation everyone could see first-hand everyone else's issues and concerns allowing for a great medium for exchanging ideas. Colocation seemed to bring a sense of caring and respect for each counterpart since each had to be successful for the entire team to be successful.

Information flowed well in both directions creating a great benefit and unselfish attitude among the team. Every team member felt they understood the big picture even at the lowest levels. As an example, in many projects when equipment is needed the project pays for it, especially with computer equipment. However, since the entire team understood the cost constraints imposed on the mission a very unselfish attitude prevailed where black and white computer screens were used in place of purchasing new color monitors. One might think that the cost savings are insignificant compared to the project dollars yet that's exactly what allowed a project like this to work. This was just one example of the many stories of the entire team understanding the "big picture."

Even though the project seemed isolated they built a lot of partnerships, "we had to rely on the institution for some things, rather than isolate ourselves." A lot of people thought they isolated themselves but they really didn't. Ironically they were physically isolated yet they took advantage of institutional capabilities and personnel. An example was that they used the Cassini project to purchase parts from thus lowering their costs. They also took advantage of institutional expertise for review boards.

Strategic Alignment

The new philosophy of FBC posed a great challenge to the environment that coincided with the thrill of the return to Mars. NASA had not been to Mars since the mid-seventies and there was a great deal of interest to get back to the red planet. The consequence of these plus others like colocation presented the alignment for a great team effort. As one team member put it, "we knew we were on a Superbowl team[29] from the very start, everything was just lined up." The corollary of these challenges was an "esprit-de-core" that was felt on the project. It was a very good working environment and very challenging. Considering the difference in budgets from the Viking days MPF had less than ¼ the budget and in FY2000 dollars an order of magnitude difference. This major discrepancy led many to believe outside the project that it couldn't be done for that price; and that only fueled the teams' motivation to succeed. Everything was aligned to bring out a great team effort. All management had to do was not undermine the internal drive that had surfaced.

4.1.2 Political Perspective

Stakeholders

There were many factors that affected the participation of the stakeholders in this project. The stakeholders that it had did not get involved. The program office at NASA Headquarters was going through an evolution of change and management was cycling through at such a fast rate that there were no single program manager at Headquarters that had time to get involved in what was going on at JPL. Colocation allowed the team to be rather secluded from their functional organizations and due to the strength of the project leadership the team felt that line management did little to interfere with their work. There was no vehicle prime contract thus eliminating a

[29] Reference to Pro Footballs elite teams

major hurdle that is usually present in most projects. The team also used internal support for supplies and had very little sub-contracts. The outcome was an intense focus with very little distraction. The primary stakeholders are presented in **Figure 12**.

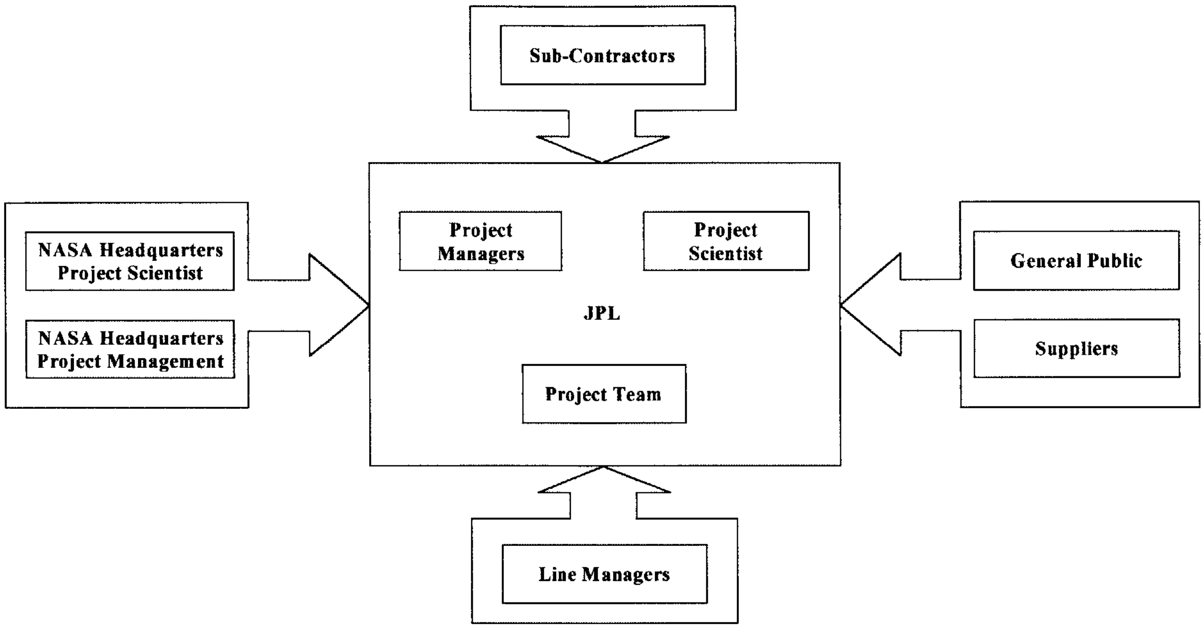

Figure 12: Mars Pathfinder Primary Stakeholders

<u>Interest and Goals</u>

In every mission there is a conflict in interest between the project scientist and the project management. The project scientists always want to get all the science they can, and the engineering team needs to make the spacecraft with the science for the allotted funds. It's the PM's job to provide a balance. In MPF there was a feeling that the collaboration and interaction between the science community and engineering was seamless. According to Dr. Mathew Golombek, "at the start of the mission the science was poorly defined, the project was mostly ED&L. Science objectives were not even in the goals statement for the mission. MPF became a science mission also, through the efforts and collaboration during development, because of the relationship with the engineering team, since we both had the same ultimate goal. Science was allowed to be added since the engineers also wanted a mission that would do as much as it could do."

The project mission and goals were purposely kept as simple as possible. The management wanted the overarching goals to fit on one piece of paper and be known by everyone. To communicate the project goals and to assure the entire team shared the same common vision the management set up a so called "war room" where most formal and informal meetings and discussions took place. The "war room" included the mission objectives that were posted on the wall. "Land and operate for one month for the Lander, and for the rover get a panorama and a soil sample and we are done!" Team members remarked that project goals are usually very elusive to the workers. One team member put it this way, "usually every manager that you talk to gives you a different answer to what's important, in this case everyone knew the project goals by heart."

Power and Politics

The typical sources of power were not wielded in the MPF project. MPF project managers had many years of experience and were very hands off. Tony Spear's approach to management was described, as "he would look you in the eye when he talked to you and if he trusted you he would let you do your work without a lot of oversight. If he felt he could not trust you or you weren't sure what you were doing, he defaulted to a process leadership until trust was established between the two." There did not appear to be a lot of mistrust on this project and those that did not fit the team were by joint decision moved elsewhere. The lack of hierarchical power resulted in a very "esprit-de core" team effort. Most found the working conditions loose and comfortable yet a high sense of diligence and thoroughness.

The cooperative nature of the project management and lack of any power struggle led to decision making that (1) got the job done, (2) collectively lowered the cost, and (3) reduced the risk. The management gave people responsibility to do a job then let them do it. Workers were allowed to make the decisions that were necessary however they were responsible for their actions. Major reviews were held only twice a year yet they took advantage of continually reviewing things internally amongst themselves. They attempted to turn everything into working group activities that gave total involvement across the project. Risk were only taken where appropriate such as when it was determined that 1000 hours of testing was required on the electronics yet no funds were available to run them 24/7 with a full team. The decision was made to let the ground system run the test craft off-hours with only one person as a "fire-watch" to alert people of issues or alarms. Thus, reducing risk and allowing the job to get done within budget.

Another source of power that was not used was the use of standard operating procedures and long paper trails. Due to the nature of the pressure put on this project there was a decision to forego some processes to get the job done. If it was determined that any process that was felt by an individual to not carry a "value added" identity, it was cut. This was a decision that the team felt really allowed them to be creative and work without a lot of "red tape." There was a realization from the MPF team that this was taken to an extreme and probably the pattern has swung to the other end in today's missions. One of the factors contributing to the new philosophy was at that time NASA project guidelines were in flux so management was able to let people work without having to manage a long paper trail. As one of the key team members put it "sometimes you spend a lot of time and effort on processes that their only value is convincing others that a system will or will not work. These tools only add value if you have time and money which the MPF did not have. We worked on proving to ourselves that it would work."

4.1.3 Cultural Perspective

Starting around 1993 JPL was undergoing a cultural change to a "process-based management" with a desire for a broad application to flight projects and institutional functions. The MPF management took this the other direction. With the autonomy of colocation management took an undefined FBC philosophy and made it work with what it had in terms of resources and budget. They developed their own culture by letting the team members define what processes were relevant and had a "hands off" style of management to let the team, work. Since there were no preset FBC guidelines and MPF was one of the first projects to be restricted by this philosophy they were free to describe what it meant to them. The FBC philosophy allowed the team to change the institutional rules as they saw fit and in some cases that meant cutting formal processes as mentioned above.

The MPF team was defining it's own culture, in one team members words the culture was described as a "cult-like environment." Workers enjoyed the benefits of getting in a room, deliberating the issues, and making decisions without having to write justifications with sign-off documentation before proceeding. They were able to make decision, handshake an agreement and get back to work, all with the backing of senior management. This type of process or lack of it went over well with the workers and sent a clear message that was disseminated from the top down. Allow the team to work and define the proper process and they will get the job done.

4.2 Mars Climate Orbiter and Mars Polar Lander Case Study

4.2.1 Strategic Perspective

Strategic Grouping

The primary strategic design was to try incorporating as much commonality as possible both philosophically, technically, and organizationally in the way MCO and MPL would be built and flown. Therefore, a lot of common component subsystem level hardware and software were intentionally designed in. Not only in development but operations processes were also treated the same, such as course corrections and command sequence development were standardized between both missions due to costs. "There was a need to be as efficient as possible," said John McNamee, development project manager. "We were given a pot of money equivalent to approximately the Mars Pathfinder budget to do two missions." A popular project description was "two for the price of one" by project team members. The project management team knew up front that they would have to cut things to the bone and definitely could not support a standing army. Heavy cost constraints and repeatedly told of the fixed budget if exceeded, the missions would be cancelled created elevated levels of stress. The good news is both missions met their budget targets.

Unlike the MPF the MSP '98 had a vehicle prime contract. The relationship was described as "difficult at best." The original prime contractor for the spacecraft was Martin Marietta (MM) in Denver Colorado. Martin Marietta was acquired by LMA in March of 1995 a few months afterward. The contract was not a fixed price contract as usual instead it was a cost-plus award fee contract. Based on a handshake agreement between JPL and Martin Marietta early in the contract part of the award fee could be used if needed to "get things done." Therefore under certain circumstances the award fee was used and subsequently very little award fee was left at the end of the project. After the acquisition of MM by LMA and the new President took over, the award fee usage became a critical issue of contention however he eventually relinquished his dissention based on the early agreement.

In MSP '98 the decision was made that one organization MSOP would be a multi-mission project and handle flight operations for all active Mars missions. This organizational design was to develop a single "specialty" organization that could focus on only one area (operations) and proficiency and efficiency should increase. The primary driver for the decision to have only one operations team for all MSP '98 missions was motivated by cost. With a single operations team that functionally supported all projects you could avoid having to build dedicated command telemetry teams and ground systems teams for each project and ultimately save money.

Strategic Linking

The MSOP was actually the MGS operations team that had taken the MGS spacecraft from development to operations. When the MSOP inherited the MCO operations it already had responsibility for the MGS. In addition, the new MCO mission manager would now step in to lead that team for operations of the MCO. The intent of MSOP was new missions would essentially enter as older missions were nearing their terminal life with less oversight required. However, MGS had a solar panel problem after launch with a latching pin malfunction. The solar panels are used as wings in a maneuver called aero-braking that use atmospheric drag on the panels to slow the spacecraft and put it into the right orbit. With a malfunctioned solar panel the operations crew had to be less aggressive with aero-braking and more nurturing to the spacecraft. Due to the solar panels the actual mapping mission was delayed by one year to March of 1999. This delay pushed the tedious MGS operations to overlap the early operations of MCO and MPL. The MGS team like most teams that work together from beginning to end of a mission developed a sense of ownership for that spacecraft and would now have a second mission responsibility that needed just as much care and attention that was being applied to MGS yet required the team to do both with no emotional attachment to the MCO. This eventually led to a feeling that there was not the required dedication and more specifically the right team environment to nurture the MCO mission operations.

The success of product development teams has long been tied to the communication of critical information and its flow across cross-functional boundaries in the team.[30] Communication with LMA went very well considering the geographical separation. LMA knew exactly the circumstance that JPL was in with funds and understood where every penny went during development. However, day to day conversations were lacking that were needed to convey the urgency of some issues. As Dougherty[31] points out communications in product development settings are not straightforward because their content is subject to different interpretations. With LMA in Denver Colorado there was a persistent roadblock due to the distance between team members for daily communication. Communication was enhanced with the use of Docushare© developed by Xerox that allow sharing of presentations that can be seen remotely in real-time.

[30] Carlile, Paul; Lucas, William A.; 2001
[31] Dougherty, D.; 1992

Members of the team felt that this is still in its infancy and very archaic substitute for face-to-face involvement. They also developed a very formal process environment with the use of formal requirements documents with change controls in place to transmit information. However, this type of communication created time lags when mailing documents back and forth for review and approvals. There were also internal JPL communication problems. There were personality conflicts that created barriers that were never resolved. The outcome was that certain things either weren't done well or didn't get done at all such as pre-launch testing with end-to-end systems. There were enough issues between development and operations that hindered success without the addition of personal conflicts that were also allowed to get in the way of thoroughness.

It was very clear that the lack of colocation with the prime contractor hindered communication efforts and hurt the overall effort to succeed. In hindsight it was also clear that there were many personality differences, along with differences in strategic philosophies internal and external to JPL. With MCO even with occasional face-to-face meetings it was felt that LMA never understood the urgency brought forth by the chief navigator at JPL to the attitude control team at LMA. "There was definitely a lack of inquisitiveness on the LMA side" as one member at JPL put it. There was not only the external problem, the same issues were prevalent internal as well. Internal reviews had team members in navigations proclaiming there were no issues, when in fact they were fighting all sorts of problems. There were internal technical communication issues during MPL as well. As one example, there was an issue with the temperature of the propellant. The propulsion engineers and the thermal engineers did not cross boundaries enough to allow the other to understand the requirements or the other did not transmit the requirements satisfactorily.

Strategic Alignment

JPL has made a major advancement in their rewards and recognition program. They offer incentives for both individual excellence and teamwork. The only drawback is in the area of job classification. Since the MCO project appeared understaffed, responsibility was pushed downward. Another way of looking at it is some positions took on responsibility one or two levels above their immediate position. In this case, acquiring an increased classification that mirrored the job responsibilities and perhaps adding perks, was not authorized.

Software development was an issue and ultimately led to both failures. LMA was always behind said one team member. The first year of the project JPL management felt that LMA had someone in software that was not getting the job done. Even though JPL hesitates to dictate personnel to LMA they insisted this person be replaced. LMA took one year for the replacement and essentially started from scratch at that point. As a result the software was behind schedule and in the end software testing was not carried out to its fullest extent.

The organizational structure for MSP'98 appears to be poorly suited for the nature of the jobs and that added to the stress of the project personnel. It was noted that there were people sleeping at work many times due to the multiple pressures that were enhanced from planning efforts being considered too ambitious. The largest issue was the mismatch between scope and ambition laid out for Mars '98 in development and operations. There were reported 100-hour workweeks for people at LMA in Denver. Environments of extreme pressure incubate personnel conflicts that were prevalent in this project.

4.2.2 Political Perspective

Stakeholders

Even though there were only a few more stakeholders in MSP '98 than in MPF there was one major difference. In MSP '98 most of the stakeholders were very involved. After the loss of the MCO a lot of attention was put on the MPL to succeed. There was pressure to succeed even from the public since the media had exploited the MCO unit's error. Therefore the mission was very much in the public eye.

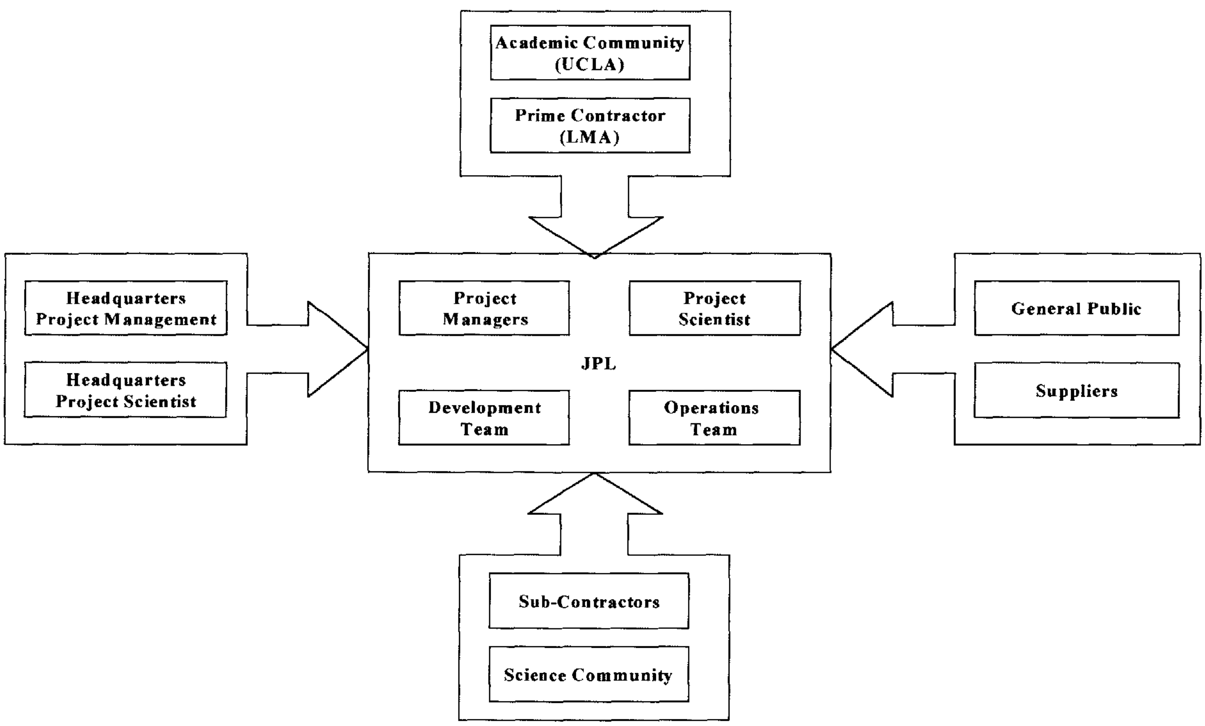

Figure 13: MSP '98 Primary Stakeholders

Interest and Goals

Having multiple stakeholders with sometimes conflicting goals led to an escalation of internal and external conflicts. There are several sources that point out the influence of external (organizational) factors that influence team performance.[32] There were two primary types of conflicts that appeared in some opinions more than normal. The two types most common were money issues and credit/visibility. The over ambitious project goals led to continuous development issues since money was tight. LMA was sometimes very argumentative due to the fact that the contract was written in a way that money normally used for award fee could be used to cover cost overruns if certain conditions were met. JPL went through many disputes with LMA over the interpretation of the contract. For LMA a priority was making a profit for the corporate headquarters in Maryland. Profit and being thorough for a successful mission had little or no intersection viewed by all partners. In addition the science community in general always chaffed heavily at the cost constraints, creating a lot of pressure. They always pushed for the best performance of science, which is understandable. However, due to the extreme budget pressure this led to elevated problems with LMA. Typically the prime contractor will be conservative and want to minimize the scope and objectives of the mission in order to maximize the chance given the resources the have, they can build vehicles that work.

During operations an issue of credit or visibility of the project surfaced between partners. The University of California at Los Angeles (UCLA) and JPL struggled with how the mission was portrayed to the public. UCLA and the team associated with the mission were after a combination of good science with visibility and recognition that can come with it. JPL and UCLA argued even what location press conferences to the public would be delivered from.

[32] Barthelemy, Jean-Francois, et al. 1998

Ultimately, the visibility and recognition issues were worked out, however not without bad feelings. The resolution was that mission centered press conferences were presented from JPL and science issues or statements, were delivered from UCLA.

Power and Politics

Mars '98 projects due to the schedule did not develop dispute or conflict resolution processes up front, most issues were handled as they occurred (reactive). They used a very process oriented and change controlled environment. Because MSP '98 budget was thin, resources were short and probably too short. Decision-making was driven down many levels. At LMA this process was not dealt with as easily since on this project LMA had a more traditional Project Manager (PM) as the key decision maker and decisions were still made at that level. JPL felt that this should have been changed. However, JPL felt it was not their place to tell LMA how to run their side of the project. After the MCO was lost at JPL the MPL received much greater scrutiny and involvement from above as the decision process migrated upward.

4.2.3 Cultural Perspective

An area that had to be addressed for doing a mission under the MSP was the issue surrounding historical legacy. Resource constraints and FBC forced the management team to attempt to do things differently, particularly with the prime contractor LMA. It could not be business as usual. Philosophically, what makes the most sense to do or what is the right thing to do as compared to what can we do with this budget were constantly challenged. Due to the circumstances behind doing more with less, management handled historical legacy very well. They would not accept status quo and challenged everything. An example was when a mid-course maneuver was proposed by LMA to take three weeks long since that is the way it was always done. With a strong objection from management to status quo, the maneuver was reduced to five days ultimately lowering risk and saving money. The difficulty that was put on management was that they repeatedly had to push the cost savings that eventually wore on the team members. The cost pressure from FBC was in constant conflict between resources and philosophically the right way to do things. The project personnel compensated for lack of resources by attempting to ignore the fact that it was a FBC mission. They took the view that it had to work and they would do whatever was right and has the best possible chance to work therefore, cost would not be used as an excuse for not doing a good job. The consequence from that was everyone worked 80 hours a week to compensate.

Chapter 5.0 Discussion of Results

In this chapter the key themes are presented that reassemble the previous organizational behavior breakdown. The key themes present a framework for discussion of best practice and lessons learned from the project analysis by using a direct comparison between the two. They first present the facts and opinions associated with the feelings towards the decisions made that influenced the outcomes. An attempt was made to compare and contrast the decisions, execution, and outcomes to provide the reader with a pragmatic view of the projects. Each section is followed by the author's admonition and/or observation.

5.1 Theme I – Development of the Organizational Structure

Organizational Design

Other than the prime system contract, organizationally MPF and Mars '98 projects were almost identical. Both were run by JPL with sub-contracted independent science on each. Each had a few of the top managers selected for those positions and the rest of the team assigned from functional organizations that matrix out their workforce. However, internally they had one difference. That difference was MPF planned that almost the entire team would make the transition from development to operations. In contrast, the MSP '98 planned that only a minimum amount of people would make that transition. One of the positions that did not transition was the PM whose role ended at launch plus 30 days for each mission. It was a totally different philosophy of running a space mission and was being driven by budget. The MCO and MPL combined had the budget of the MPF and it seemed justified by MSP '98 to have a single team be responsible for all operations from a cost point-of-view.

MPF was considered a short mission, 3 years development; 7 months cruise to Mars; then 30-40 days of planned operations on the surface. The decision was made from the start that one team would design, build, test, and fly the spacecraft. Because this mission was relatively short, team members bought into the strategy of "cradle to grave" in a timeframe that allowed them to not tie up too much of their careers with one mission. This may only be relevant to Lander missions that usually have relatively short mission operations as compared to orbiting missions (days or months of operations compared to years). There was also a sense of ownership developed knowing it was your craft from beginning to end. This sense of ownership played an important role in the teaming aspect to be discussed later. Mars '98 developed a different strategy. They developed the MSOP to handle all flight operations for all active Mars missions. The MGS operation team, being the first MSP project, took over as the MSOP and would inherit all future Mars mission operations with MCO being the first inherited mission. The intent of MSOP was that one mission would be ending while a new mission was beginning and missions would flow through the process. What were not considered were implications of delays. The MGS had a failed solar array at launch and required more attention than usual. The mission was delayed by one year due to issues like not being able to be as aggressive with aero-braking as they could with a fully functional solar array. Therefore, when operations for MCO were required the MSOP team was still fully immersed in operations for MGS. This led to a feeling from the MCO team that their spacecraft was not getting the attention it deserved. There was not only divided attention but there was also a bias toward the spacecraft that the operations team had grown up with. There were examples that showed this lack of involvement or attention. In the MCO cruise to Mars residuals between the expected and observed Doppler signature of the more frequent AMD events were noted but only informally reported. Doppler and range solutions were compared to those computed using only Doppler or range data. The Doppler-only solutions consistently indicated a flight path insertion closer to the planet. These discrepancies were never verified. It is not clear that if more of the development team in MSP '98 made the transition each MSP '98 spacecraft would not have been lost but more attention would undoubtedly been paid to these discrepancies. MSOP was badly understaffed for the circumstance that they were presented, with a spacecraft that needed nurturing and the added responsibility of other mission operations. The original intent of missions cycling through the MSOP had been challenged from the start.

Admonition and/or Observation - For MSP '98 the structure was poorly suited to the nature of the jobs and that made the jobs harder. It is not evident that the entire team always needs to make the transition from development to operations but there should be a better mix of multi-mission functional teams that support all missions and some personnel dedicated to each spacecraft. Some jobs in a multi-mission organization like Deep Space Network (DSN) make sense. Command and sequence development are types that require intimate knowledge that should go with the spacecraft. Development to operations transitions need to have a core group that passes through the boundary and need to have the appropriate skill mix to make the transition smooth. This strategy helps the issue of ownership since some follow the spacecraft and keep the knowledge legacy and attention high.

<u>Resource Distribution</u>

Up to this point we have only talked about transitioning from development to operations. Looking at it from another point-of-view you can have operations personnel reside on the development team where appropriate. Due to cost constraints however, the practicality of having the entire operations team during development is unlikely. However it is also impractical to expect only one person to disseminate information from development to operations as the MSP '98 tried to do. MSP '98 had the MSOP mission operations manager fully participate during development and history has proven that it is inadequate or looked at another way it is irresponsible to expect that amount of information to be distributed months down the line to an entire operations team by one person. One example was that critical information on the control and de-saturation of the MCO momentum was not passed on to the operations navigation team.

Admonition and/or Observation - During development each functional area in operations should be represented during formal reviews. The downside is you take away from the immediate job that the operations crew is doing. However, the operations navigation team must be involved during development to gain familiarity with the spacecraft. The operations navigation team for MCO did not participate in any of the testing of the ground software nor did they participate in the preliminary design review or critical design review process.

Colocation

There are obvious benefits of being in close proximity of team members however; proximity does not always mean increased communication. Literature supports the increased frequency of communication as it relates to team performance and that information gets distorted when communicating across boundaries.[33] The convergence of these two links the frequency of communications with how communications are enabled or distorted across organizational boundaries. MSP '98 had communication problems even at the top levels of management that

[33] Carlile, Paul; Lucas, William A.; 2001

worked together on a continuous basis. Colocation is just one enabler of potential increased communication. What colocation did do for MPF was enhanced the opportunity for relationships to develop. Being allowed to locate most of the team on one floor certainly increased information flow. Team members spoke of being able to understand other functional group issues just from overhearing conversations. As Reinertsen points out, by clustering people together we get a dramatic improvement in communications on teams.[34] The general feeling was colocation was the first step in many positive developments. First the team became very close from working on a daily basis under stressful conditions. Second, there was a lack of hierarchy from the fact that it was easier to talk to the one that needed the information than to go through the normal rank and file. And finally, it reduced the bases of power because everyone seemed to be on the same level with no real titles or hierarchy, just people working jobs that needed to be done in an even mix. The obvious difference with MSP '98 was they had to deal with a prime contractor in another state. As Allen pointed out back in 1977, where he discovered a dramatic decrease in technical organizations communication as a function of distance.[35] This may seem like common sense yet organizations fail to address this beyond fundamental needs. There was no easy solution for dealing with a geographical separation. They used real-time document sharing software and a very time-consuming process documentation that were mailed back and forth. However, everyone agreed that there could be no replacement for face-to-face involvement at least not with existing technology.

Admonition and/or Observation - In appreciation for that fact, a good idea might be to set aside a significant amount of the budget to make sure certain members of the team meet periodically

[34] Reinertsen, Donald G.; 1997
[35] Allen, Thomas J.; 1977

whether they think it necessary or not. It is especially critical for virtual teams to gather face-to-face time early in the project that will allow them to build relationships and mutual understandings of their common purpose.

5.2 Theme II – Developing and Supporting Exceptional People and Teams

Leadership

Kotter makes a distinction between management and leadership.[36] He defines management as coping with complexity and leadership, by contrast, is about coping with change. MSP '98 management attempted to assure the accomplishment of the mission plan by controlling and problem solving. What seemed to be missing was the leadership required to achieve the vision that required motivating and inspiring the workforce. It is typical of a project to take on the personality of its senior management. If the senior management is strict, hierarchical, play by the rules, or process oriented, the project will inherit those attributes. Typical management cultures emphasize rationality and control. However, when the organization is flat, and the atmosphere is very trusting an entirely different attitude prevails. These were the two prevalent descriptions of the organizational management of MPF and MSP '98 respectively and are obviously in sharp contrast. Leaders tend to keep people moving in the right direction, despite major obstacles, by appealing to basic human needs, values and emotions.

Admonition and/or Observation - Trust seemed to be a word that was used to describe the environment of MPF and is prevalent attribute of strong leaders. There was a general feeling that senior management in MPF trusted them to get the job done. The lack of interference was an indicator of the trust that they felt compelled to deliver to. However, a note of caution, in the

[36] Kotter, John P.; 1990

workplace it can sometimes be dangerous to blindly trust people to get the job done, there must be a balance. Managers/leaders should find the right balance between giving people independence to accomplish great things and providing the guidance, or even guidelines, to help them do it.

Performance and Reward

Not enough research was done in this area to draw many conclusions. However, one area that there could be improvement is the area of rewarding people for the actual work they do not the work assignment they fill. MSP '98 was so scraped for dollars that most personnel were doing two or three jobs and usually one or two levels work above them. Most personnel were given higher levels of responsibility and were not given equivalent job classifications, such as from senior engineers to first tier managers that would have allowed perhaps higher pay. Second, was I heard of no incentive to contribute to teamwork? This is the phenomenon discussed by Kerr of "On the Folly of Rewarding A, While Hoping for B."[37] This phenomenon has been widely discussed in literature where the tendency is to reward individual performance while the true success comes from team success. Looking at it from the perspective that success of the whole can only be achieved by the success of the individual parts should be challenged.

Admonition and/or Observation - More in depth analysis should look at the level workers are being asked to work in these small ambitious projects. How can rewards be more in tune with what they actually do as opposed to what their functional job classification is? Overall at JPL when teams are successful they usually receive team awards, however before they are completed

[37] Kerr, Steven; 1975, 1989

there are no rewards for contributing to a team effort. The incentive to contribute to the team appears to be missing.

Enabling Team Competency

There were many challenges put on the MPF team from different directions that had positive influence. Among those were the first return to Mars in twenty years, the new FBC philosophy of projects, and the thrill of a good challenge laid out by those who thought it could not be done. Remember there were an order of magnitude difference in budget from the 1970's Viking missions and the MPF. There was a feeling that people are not challenged enough and most people are looking for opportunities to excel and be noticed. Every person interviewed said the MPF had a great team. But how was the team created and how did they create such value? Great teams have people that like what they are doing and the people they are doing it with. Management made the first step and created a trusting environment that was a critical element. People felt comfortable with the environment and the people they were working with. The atmosphere brought out a strong performance ethic and the relentless desire to accomplish the mission.

In contrast, the MSP '98 teams had only partial fulfillment of these attributes. The challenge was presented with a negative connotation of "it couldn't be done" rather than "lets see if we can do it." In addition overcompensation might have crept into the equation by people being overworked and stressed due to under-experienced workforce that can contribute to errors. In light of the budget issues everything was questioned over and over to continuously strive to meet the budget yet the consequence is it can appear to be a very untrusting environment when every move you make is questioned. There are also the effects of constant threat of cancellation if the budget is exceeded. Even the managers in MSP '98 admitted that it was hard to constantly threaten the same issues on budget.

Admonition and/or Observation - The messages that we can take away from this are to develop people to their full potential by challenging them; it has been written that most companies leave a tremendous amount of human potential untapped.[38] *Leadership should build the capacity to achieve results with well-placed challenges, knowing that you unleash the talents and work ethic of the people. And also, MSP '98 never overcame the obstacles that were presented to them, where the more successful teams manage to turn the negatives into positive motivational factors.*

Developing Teamwork

One key to project success is the need for someone who builds teams and enables teamwork. Organizational leaders can foster team performance best by building a strong performance ethic rather than by establishing a team-promoting environment alone. The MPF had a defined clarity of the purpose and goals of the mission. The performance results were a balance of the customer or product needs with the employees or stakeholder needs.

Another attribute of effective teams is diversity among team members, which helps keep ideas fresh. "We had a good mix of old experienced people and young people with a lot of energy" was the description of the MPF team. Diversity, if properly managed, can increase creativity and innovation in organizations as well as improve decision making by providing different perspectives on problems. As Robbins, points out, when diversity is not managed properly, there

[38] Katzenbach, Jon R., Smith, Douglas K.; 1999

is a potential for difficult communication and more interpersonal conflicts.[39] "We gave people responsibility and let them do their jobs, and did not constantly interfere with them," was how managers described their influence on MPF. They did not try to review in success, using formal reviews. "Very few review boards actually review the details of the analysis, it is like a business plan to a venture capitalist. They care that you did it is all." "We did not smother ourselves with a paper process that would take all the resources in the project to manage; we let the people really work."

Probably the single most significant decision for the MPF management team that developed teamwork was the decision to colocate. The proximity of everyone produced an endogenous esprit-de-core and allowed the team to develop. There were many other reasons that contributed to the camaraderie, e.g. selection of a July 4th landing date, the excitement of the return to Mars after 20 years, etc. Everyone felt a sense of ownership and they understood the big picture by sharing resources. An example of the shared resources is that the solar panels were paid for by the grounds system budget. This is considered very rare since the solar panels are a spacecraft element that is usually covered by the development budget, especially rare when development has the majority of the budget anyway. That type of attitude prevailed throughout the project signifying that management was seeing the big picture and committed.

Admonition and/or Observation - Some messages to take away from this are that management can enable success but cannot create it; people make success and that is where leadership for enabling teamwork is important. MPF had continuous peer reviews going all the time to convince themselves that they were doing the right thing as they changed the process as well as

[39] Robbins, Stephen P.; 1998

the culture of running projects. And finally, with management making decision that were very team oriented it created a vision of success from the top down. Once the team shared this same vision an exceptional team had developed. As Senge points out in The Fifth Discipline, team learning is the process of aligning and developing the capacity of a team to create the results its members truly desire. It builds on the discipline of developing a shared vision.[40] *There is also a tradeoff with the sheer numbers of resources that allow such a close bond with the people. You must be careful as to the number of resources that you throw at a project because the larger the project the harder it is to gain the team relationships.*

5.3 Theme III – Mitigating Risk

Mission Planning

Over the last 30 years budgets have been drastically cut due to the pressure put on the Agency to reduce spending. Budget cuts are part of the design of the FBC philosophy in that large projects are broke down into many smaller more manageable projects. In doing so budgets for similar missions went from over $3 billion in today's dollars for Viking to $300 million for MPF and finally down to $300 million for the MCO and the MPL combined. Such drastic cuts in the budget allow no room for surplus staffing, testing, hardware redundancy, etc. Everything must be cut to the bare minimum. One important consistency across the MPF and the MSP '98 projects is the scope remained about the same. Perhaps the budget was cut too thin for the desired projects, maybe not? One thing that has changed is that the next mission that will send two rovers to Mars has an estimated budget of $600 million, more than doubling MSP '98.

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[40] Senge, Peter M.; 1990

Admonition and/or Observation - There may have been a bad mismatch between scope and ambition laid out for MSP '98 in development and operations. The resource envelope in terms of money and people did not meet the scope and ambition of the job. The risk associated with trying to do too much with too little permeated through the team from the start of the MSP '98. The phrase of "two for the price of one" was coined from the start that leaves a clear message that people felt they had inadequate resources.

Validation and Testing

The MSP '98 team voiced their concerns of "two for the price of one" why then didn't the MPF team have the same attitude when the budget was cut by an order of magnitude from the Viking missions of the 1970's? Maybe it was the difference of focus that the team initiated. The MPF team focused on testing whereas MSP '98 emphasized cost reduction and let testing fall off the table in some instances. For example, when software problems continued to fall behind schedule they let the schedule and resources dictate the amount of testing that could be done with the software. Obvious errors in the software went unnoticed and eventually caused the loss of both spacecraft. Software testing may have wrung out some of the problems that MSP '98 had. In contrast MPF pushed everything as far as possible to the left on the schedule to make sure there was extra time for testing. "Almost as soon as the project started we had a ground system up and running supporting test of the software that the flight people were developing," claimed the PM. Since most of the redundancy had to be scraped due to the budget, the MPF team felt that the only way to reduce risk and verify that the spacecraft could accomplish the mission was through testing. "You can't be as rigorous or thorough as you want to be however you have to establish your priorities." MPF put this priority on the ED&L phase. They spent the most part of 1995 testing for ED&L and the test crew described it as "rigorous" and "fun." Testing turned out to be a key during flight operations. An example was when the Lander airbags did not fully retract and partially covered the rovers deploying ramp. The team had seen this during testing and knew exactly how to circumvent the problem. Operational decisions were made quickly from the teams' familiarity with the spacecraft from testing.

Admonition and/or Observation - Too often testing is viewed as a necessary evil in the development process. It only exists because we make mistakes. We should spend our time and effort designing in quality instead of finding defects by testing. Without tests however we are operating in the abstract world of theory. The mismatch between the physical world and the world of theory is often unexpected.

Responsibility and Experience: Resource Loading

It has already been pointed out there were reported 80 to 100 hour work weeks reported during MSP '98. People slept at work from the added pressure of doing an equivalent project scope with half the budget. That shows the tremendous internal drive, heart and dedication of a team that attempted to beat the odds. It is unfortunate that their hard work went unappreciated. The fact is there is a danger of, people working long enough and hard enough even the best people will make mistakes because they are under stress, they are tired, and it starts to get to them thus increasing risk. It was also pointed out that responsibility was being pushed down and there may not have been enough experience in the resources to accomplish the mission. This is a real risk when implementing FBC.

Admonition and/or Observation - NASA has recognized that this is the case for experienced project managers now that we run many more projects than before. I want to point out that this permeates at all levels and is no less significant. In small ambitious projects resources are obviously scarce and job responsibility get pushed downward. Careful controls should be in place that junior engineers are ready for the increased responsibility. We have the potential for many more mistakes with inexperienced engineers gaining more responsibility then their experience warrant.

5.4 Theme IV – Improving Communication

Knowledge Management

This discussion deals with knowledge management at the project level. Thus, in this context knowledge management means the management of the historical legacy of knowledge that comes from the project evolution and not just information. As Carlile points out, you must make the distinction of the tacit knowledge that is more difficult to transfer than pure information.[41] Starting from one extreme the MPF organizational design of one team end-to-end allows for the retention of knowledge including tacit, yet this organizational design seems to be the exception to the rule. What do you do when you have transitions? The two primary aspects of knowledge management are knowledge capture and dissemination. MSP '98 did not sufficiently address these issues when only the operations mission manager crossed the forward boundary of operations to development. If the intent were that all knowledge would be captured and disseminated there were inadequate tools to enable him to succeed. Clearly on these missions the operations team were missing mission critical information. For example, originally the MCO spacecraft was going to be rotated to relieve the angular momentum buildup during the cruise to

[41] Carlile, Paul; 2000

Mars. Later, systems engineering determined that this was not necessary and scraped the rotation. Unfortunately, this decision was not communicated to the navigation team and the AMD events occurred more than anticipated.

Admonition and/or Observation - NASA has recognized the importance of managing its corporate knowledge and has placed it among the highest priorities in recent years. The NASA Integrated Action Team (NIAT) report published in December 2000, points out a number of initiatives that are now under development to manage corporate knowledge. NASA has developed these new programs to attempt to strengthen the knowledge management within the Agency.

The best way of passing tacit knowledge and lessons learned insights is through people before any kind of document center. Face to face communication is the key to being successful at transferring tacit knowledge. However, information can be communicated in many ways as will be discussed later. NASA must ensure that the proper tools are in place to facilitate the capture and dissemination of this information. Having someone from operations involved during development was a great foresight for representation and to address future needs however, dissemination or knowledge transfer was not addressed in this case. In a project where operations members need to be intimately familiar with the spacecraft there is a need for their presence early at critical reviews and stages of development.

Transition Metrics from Development to Operations

Not every mission can afford to take the entire team from development to operations as MPF did. Some missions like orbiter missions, may even be impractical due to the length of the missions. If you cannot transition the whole team or the majority, some metrics should be set to establish a successful transition. In MSP '98 a process could have been established for transitioning requirements and information from one organization to another. The description below is how MSP '98 personnel believed they could have carried out the transition successfully.

Admonition and/or Observation - Prior to the transition there should be a set of operational readiness test that the operations side proposes. The development personnel involved in the testing should provide a description of the test. The criteria for passing and failing should be established by the operations team in a very formal structure and agreed to by the development team and their management. This process should be run from the operations side to make sure the team have been passed and possess all the data, files, and any other necessary information that allow them to understand the mission. The development team should be the ones that say yes the criteria was met, and serve as a check on the operations organization. The justification is that the development has to police this since it's their craft otherwise they should not sign off.

Project Element Communication

Once again we come back to colocation this time as the enabler to cross-functional communication. Earlier the lack of communication was addressed with an example that occurred across the transition from development to operations during the MCO mission. Here we will discuss the communication across cross-functional elements within the project. Research has supported such as Brown and Eisenhart's product development review distinguished communications and boundaries as the two most critical issues in the product development literature.[42] There was evidence that during MSP '98 that there were many barriers to communication between project elements including senior level managers, development and operations teams, operations and navigation, etc. Personalities seemed to play an important role as barriers since at times there appeared to be no concrete reason for insufficient communication.

There should also be adequate systems engineering solutions in place that do not allow assumptions to misguide information exchange. For example, the navigations team assumed that the MCO was similar to the MGS and therefore acquired insufficient technical knowledge of the spacecraft. Reinertsen, point out that if we recognize the lessons of system theory, we will look for the value of the organization in its interfaces between elements, not on just its components.[43]

Admonition and/or Observation - Management must find a way to separate personalities from the equation and keep defensive mechanisms from inhibiting progress. With relationships stressed even at the senior management positions they set the tone for the relationships beneath them. Team leaders are expected to be the communicators of the team goals and vision. They are looked upon to set the example for the team to follow. Also, management should increase the amount of face-to-face communication with all team elements. This may mean that management must set aside part of the budget to assure these teams meet on a regular basis if they do not reside in close proximity geographically.

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[42] Brown, Shona L.; Eisenhart, Kathleen M.; 1995
[43] Reinertsen, Ronald G.; 1997

Chapter 6.0 Conclusions

NASA has not adequately included the human resource management into the Agency's strategy. As a consequence, there is an inconsistency on project philosophy's, strategic designs, and culture created from project to project. Hence, NASA and the project management have not determined the appropriate number of resources and competencies needed to carry out its strategic goals and objectives for its programs. This research illustrates some of the fundamental characteristics that should be addressed as the underlying principles to human resource management and the building blocks of team development. Chapter 5, attempted to provide high-level observations with minor admonitions for project manager practitioners.

First, a word should be said about the distinction between success and failure in deep space missions. The difference between them can often be very small. As we learned, one critical error could rescind the effort of an entire hard working team. The MSP '98 projects did an incredible job and more than anyone thought possible with very little. The unfortunate part was one mistake on each and the mission was lost. Credit must be given however to the team since they almost pulled it off. In hindsight there is much to be learned from both the MSP '98 and MPF missions. In all fairness to this comparison many things fell into place for the MPF and the following attempt to summarize key aspects of the intangibles and rare circumstances that were encountered that cannot always be planned.

- At JPL where physical space is a commodity an entire floor in one building became available just as the MPF team was being assembled thus enabling colocation of almost the entire team.

- There was no prime contractor for the spacecraft it was built in-house.
- No one knew what faster, better, cheaper meant. This project was one of the first FBC missions and the bar of success had not been set.
- There was the challenge of a return to Mars after 20 years.
- The type of mission, being a Lander mission allowed for a short timeframe that allowed the team to take the spacecraft from "cradle to grave."
- There was very little "interference" from Headquarters and line management.

Alternatively, I would like to point out the issues and circumstances that describe the MSP '98 projects that could have been addressed and were not.

- From the beginning of the project there were personality conflicts that went uncontested. These conflicts existed at all levels of the project and were allowed to influence the outcome.
- The decision to run all operations out of MSOP lacked the foresight of the implications of preoccupation with MGS with later missions.
- There was a negative connotation that went with the phrase "two for the price of one," that was popular from the start of these projects.
- The goals of different stakeholders were never controlled allowing credit and monetary conflicts between stakeholders to become issues.
- Risk reduction was not properly addressed when software testing was allowed to fall off the table.

An interesting note is that the MPF and MSP '98 had many things in common as well as differences, both affecting the outcome in different ways. A direct comparison of these projects provides the key similarities and differences.

Similarities

- Each project was heavily influenced by temperament and personality of individuals in key positions.
- Each project was in a fast-paced, demanding, stressful environment due to the relatively small size of the development teams.
- The cost and schedule constraints were strong drivers on both technical and programmatic decision-making processes that developed.

Differences

- Colocation versus decentralized teams resulted in substantial differences in speed and dynamics of decision-making.
- MPF team became very cohesive with strong "esprit de corps" with a heavy reliance on personal communication for success.
- MSP '98 developed strong cohesiveness in selected pockets, but lacked the necessary political relationships between different organizations.
- There was generally more emphasis on regimented processes in MSP '98 that became very difficult when participants had little direct interaction.

The overall objective of this research was to identify best practices and use lessons learned from past missions to develop a framework for future mission success. **Table 4** below summarizes some of the non-technical observations and recommendations that were determined to enhance opportunities and create successful environments. The table is organized by the three lens framework presented in chapters 3 and 4.

Performance of teams is a critical issue in making organizations work effectively. If a manager is to influence work behavior and performance, he or she must have an understanding of motivation and the factors which influence the individual and the team to come to work, to work hard, and to work well together.

Strategic	Grouping	* Create a flat and flexible organization. * Let team members fall where they fit not necessarily having to fill functional slots. * Allow the team to follow through the entire project where practical. * Use common groups cautiously and make sure they acquire the required information to get the job done.
	Linking	* Collocate as much of the team as possible. * Open informal communication links that don't necessarily have to follow the hierarchial chain of command. * Allow for information exchange between functional groups for problem solving. * Create an environment that information flows both up and down the chain. * Use organizational expertise and partner wherever possible. * Never underestimate the power of face-to-face communication. * Never let personalities influence the amount of communications.
	Alignment	* Create a challenging environment. * Establish a esprit-de-core among team members if possible. * Reward teamwork as well as individual efforts. * Facilitate resource sharing among functional groups. * Make resource replacements quickly and efficiently.
Political	Stakeholders	* Establish clear and well understood stakeholder roles & responsibilities. * Manage stakeholder influence and participation.
	Interest & Goals	* Communicate the mission goals and objectives to the entire team. * Manage the differences between the goals of each stakeholder. * Balance realistic expectations of faster, better, cheaper.
	Power & Politics	* Create a trusting work environment. * Distribute the decision making as far down as possible. * Use constant peer reviews within the team. * Adopt tools that create added value to the project, question everything else.
Culture		* Establish a people first environment. * Create an environment where the culture can be created to accomplish the mission. * Adopt formal risk management practices.

Table 4: Summary of Observations

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Appendix A: Interview Questionnaire

Acronym: Definition

SG: Strategic Grouping; SL: Strategic Linking; SA: Strategic Alignment; ST: Stakeholders; IG: Interest and Goals; PP: Power and Politics; CP: Cultural Perspective

1. What is your full name?
2. What was your title for this project?
3. Give a brief description of your job responsibilities?
4. What was the relative size of this project in dollars? In resources?
5. Where did you enter this project on the timeline? Were you part of the development or operational team? Or both?
6. What went well on this project?
7. Who did you report to officially? Unofficially? SG
8. What is the formal reporting process? Is it the same as the organization chart? SL
9. What type of organizational structure did the project have (i.e. functional, product, matrix,...)? SG
10. Does information flow both ways in the information exchange? Do you always feel you have the information you need from above? SL
11. What are the formal procedures for selecting team members and team leaders? SG
12. In your opinion were the right people in the right positions? SG
13. Does the choice of team structure fit well with the conditions and demands of the organization's environment? SG

14. Who does the performance reviews and when (i.e. yearly or project based)? SA
15. What does the reward system look like? SA
16. Have team-level rewards been created as incentives for team-level collaboration and the fulfillment of team-level goals (not just individual goals and rewards)? SA
17. Does the elimination of individual recognition for team members unintentionally make people feel more depersonalized and powerless, instead of making the team feel more collaborative and less competitive, as intended? CP
18. Do any artifacts exist such as employee of the month? Are they joked about? CP
19. Do the units created by the strategic grouping process have the resources they need to achieve their goals (i.e. money, people, equipment)? SA
20. Who are the internal and external stakeholders (i.e. scientific community, public, researchers, managers, headquarters, etc)? S
21. What kinds of disputes arise most commonly? PP
22. Are processes in place to resolve disputes among team members or groups? PP
23. Are the needed policies in place to support effective negotiations, problem solving, and if necessary, conflict resolution? PP
24. Who has the power to make critical decisions? PP
25. Is critical information shared with those who need it to make decisions? Or is information hoarded as a resource that confers power? PP
26. How is historical legacy handled (i.e. that's the way we always do it)? CP
27. What does it mean to be a part of the team? Are development and operations both part of that team or is it us and them? CP

28. Are there important positions that were present before FBC that were meaningful features to the project before and have been eliminated? CP
29. How has FBC affected decisions? CP
30. Do you feel that you had a good understanding of the goals of the project and <u>your responsibility</u> within that framework? IG
31. Are the goals of each stakeholder aligned with each other? IG
32. Are the goals of individual groups within a team well known throughout the project? IG
33. Are there adequate safeguards to protect the interest of the least powerful individual or groups involved in conflict or decisions? IG
34. What are metrics for successful handoffs between development and operations? IG
35. Is it easy to add people to the project or do cost of resources have an affect on the project decisions? IG
36. How does the timing of the handoff affect the cost and scheduling of resources? IG
37. What are the stage gates that a project like this goes through? SL
38. How often did the team have unscheduled and informal conversations about the project? SL
39. How is the operations team linked to development during the development phase of the project? Do the operations crew attend all reviews? SL
40. What are the key barriers to communication that hinder effective between development and operations? SL
41. How does team location help or hinder communication between teams? SL
42. Who play the formal integration roll through the entire evolution of the project? SL
43. How has technology affected information exchange? Can you have too much/little information? SL

44. What types of tools are being used for knowledge sharing? SL

45. What skills or knowledge are gained or lost with job rotation? SL

46. How are technical requirements adhered to, across the boundary of development and operations? SL

Appendix B: Interview List

Name	Project (s)	Dev.	Op's.	Primary Job Description
Dr. Sam Thurman	MCO/MPL	Y	Y	Flight Operations Manager & Mission Manager Project Engineer - Dev.
John McNamee	MCO/MPL	Y	N	Project Manager up to launch for both spacecraft
Dr. Richard Zurek	MCO/MPL	Y	Y	Project Scientist
Robert Manning	MPF	Y	Y	Flight Systems Chief Engineer & Entry, Decent & Landing Manager
Alan Sacks	MPF	Y	Y	Ground and Systems Manager
Dr. Matt Golombek	MPF	Y	Y	Project Scientist
Sam Thurman	MPF	Y	Y	Landing Systems Engineer
Brian Muirhead	MPF	Y	Y	Flight Systems Manager & Project Manager
Jennifer Harris	MPF	Y	Y	AIMS subsystem Manager -Dev. Flight Director - Op's.