Lunar Prospector: Against All Odds

PREFACE

Purpose:

This book was written for several reasons. The first and foremost is to show the American taxpayer just how badly the national space program and the large aerospace companies, at least Lockheed, are run. While NASA and the aerospace industry use a carefully managed PR front to cover up their poor management, incompetence and lack of direction, many cracks have appeared in that façade over the past decades, cracks that have given the public a glimpse into the bungling NASA and aerospace bureaucracies, the most notable examples of which are:

The International Space Station, that was to have cost $8 billion of taxpayer's money and was to have been finished years ago - a poorly managed program that has already cost approximately $40 billion and will cost up to $80 billion by the time the "Core Space Station" (the Core is not the entire station, its just enough to make it look finished) is finished in a few years;

The January 1986 loss of the Challenger and its crew, because NASA managers and Morton Thiokol upper management would not listen to the Morton Thiokol engineers, who said that it was far too cold to launch the shuttle;

The incorrectly made mirror in the Hubble Telescope;

The loss of the Mars Observer (1993), the Mars Climate Observer (1999) and the Mars Polar Lander (1999) – all three failures were due to poor management and poor engineering.

The Lunar Prospector Mission was conceived as a mission to demonstrate to NASA, Congress and the American taxpayer how missions could be done inexpensively, efficiently and reliably, or as NASA puts it, "Faster, Better, Cheaper". This book gives the story of how the $65 million Lunar Prospector Mission was conceived by a small group of people outside of NASA and eventually brought to a successful conclusion eleven years later. It is meant to give the reader a detailed picture of just how the mission was accomplished, despite the bungling and mismanagement on the parts of NASA and Lockheed managers.

In addition, the book is meant to give the reader a first hand account of the personal side of the struggle that brought the mission from it fledgling start in late 1988, as a mission, to its triumphal conclusion at 2:52:00.8 AM PDT on July 31, 1999.

Finally, this book is meant to show the reader the technical side of the Lunar Prospector Mission - the technical challenges of designing, building, testing, launching and commanding the spacecraft on its way to the Moon and as it orbited the Moon 384,000 km from Earth - and how the technical decisions were made.

Viewpoint:

As the reader will quickly find out, this book is the highly personal tale of my role in the mission. The way I frequently and critically characterize some of the people, events, NASA and Lockheed throughout the book, reflect my own personal views of the individuals, events and institutions and may or may not be correct and may or may not be fair – but they are my views and, as such, they are subject to my personal biases and expectations. While I judge many people, NASA and Lockheed very harshly most of the time, I guarantee that if any of a number of managers in the NASA or the Lockheed bureaucracies had written this book instead of me, I would be the one characterized in a very harsh way. So, I leave it up to the reader to decide if I am the villain or not and/or if my critical judgments of the people, events and institutions involved are valid or not.

Historical Accuracy:

I have tried to make this history of the Lunar Prospector Program as accurate as possible. While I have an excellent memory for events, I am terrible at remembering dates and so, while the events are accurately described, there is some question about exactly when some of the events occurred. All stated dates are accurate, but there are a few periods of time when I could not determine the specific date on which an event occurred, but even in those cases, I have been able to place the event within a specific week or a specific month. Nevertheless, as detailed in the following, the availability of information giving the exact dates and the exact details of the various events depicted in this book is as follows:

Prolog – Most of the pre-Apollo and Apollo events described in the Prolog are derived from the open literature and are accurately dated. The accounts of the pre-Lunar Prospector activities at the Space Studies Institute and in the National Space Society were given to me by Gregg Maryniak and Peter Kokh, respectively, and are assumed to be accurate. The account of my pre-Lunar Prospector activities was derived from my memory and various documents.

Part 1 – The dating of the events during the "Early Years" of the project is checkered. The dating of events from late November 1988 through March 1989 is poor, since only a few of the events were recorded in documents. Once our Lunar Prospector Team started getting organized in March 1989, there are more dated records of events from then on through August 1989. Between October 1989 and November 1990, our Lunar Prospector newsletter and my monthly progress reports to Lockheed (which provided support for my work on Lunar Prospector during that period) provide accurate dates and information for essentially all events described. Unfortunately, from December 1990 through February 1995, when events in the development of the mission were few and far between, there are only occasional dated records, except for a few short periods

when Lockheed gave me support to work on the mission, periods of time that the reader will easily recognize.

Parts 2, 3 and 4 – Right after I was informed that Lunar Prospector had been selected for flight in February 1995, my sweet wife, Rebecca, insisted that I start recording the day's events on tape, so I would have accurate information for this book. So, from March 1995 to just after the end of the mission in July 1999, I recorded the day's events almost every night after work. In all, there are 44 tapes that my sweet wife laboriously transcribed and they served as the very accurate basis for dating and describing all the events in the bulk of the book. In addition, there are numerous documents, letters, reports, videos, newspaper articles, TV interviews, etc. from those periods of time, that add to the accuracy of the events described in Parts 2, 3 and 4.

Epilog – The Epilog was written more or less as the events happened, thus the dating of the events in the Epilog is also very accurate.

Quotes – In an effort to keep the book lively, I have taken artistic license and written the essence of numerous conversations that occurred during the eleven years of the project as dialogue within quotation marks. However, with the exception of a few cases where the quotes are verbatim, as taken from videotapes of press conferences, the dialogues in the quotes are close approximations to the real conversations and, since I did record the day's events almost every night, the quoted dialogues are quite accurate, but, of course, not verbatim.

Have Fun:

Finally, as I told my Lockheed engineers at the beginning of the work on the final design, construction and testing of Lunar Prospector, "Lunar Prospector is supposed to be an interesting and fun program to work on. If you are not having fun, then go find another program to work on that is fun.", and they did have fun, as did I. In the same sense, this book is meant to let the reader share in the fun of the Lunar Prospector Mission. As the reader will see throughout the book, unlike NASA, I firmly believe that Lunar Prospector (and all space missions) belonged to the American taxpayer, who paid for it and thus you, the reader, the taxpayer, has the right to share in the fun of the mission. Thus, I wrote this book, in part, to give you that opportunity and to be able to say thank you for giving me the opportunity to do Lunar Prospector.

PROLOG: LUNAR PROSPECTOR'S PREHISTORY

1865 Through Late November 1988

Short discussion of historical background of mission and events that led up to it.

PART ONE: THE EARLY YEARS

Late November 1988 through February 23, 1995

Chapter 1-1: The Beginning

Houston Space Society (HSS), Space Studies Institute (SSI) and I join to start project as 1st non-NASA lunar mission. I am Project Scientist and define science payload and spacecraft. SSI has administrative lead.

Chapter 1-2: The Spring 89 Workshops

HSS and SSI host workshops to gain public support and financing. I put together Science Team and asked Preston Carter to be Project Engineer. SSI provides Project Manager.

Chapter 1-3: The RFP, LEI And The Proposals

Preston and I write Request For Proposals (RFP) for $75,000 Spacecraft Design Study; we build volunteer Spacecraft Engineer Team of 40 engineers and we start Lunar Exploration Inc. (LEI), which is responsible for science and engineering. SSI has main responsibility for solicitation of $10 million. SSI causes 1st major problem by delaying design study. We receive 3 proposals for design study and select OMNI Systems Inc. to do study.

Chapter 1-4: The Spacecraft Design Study

OMNI does design study and I take over as *de facto* Project Manager. Russia expresses interest in offering us a free launch! I start trying to solicit money and other support from Lockheed (Houston, TX, my employer) and other aerospace companies.

Chapter 1-5: Where's The Money

The design study is finished, but SSI had not even started to raise the $10 million needed for spacecraft construction! I was unsuccessful in my attempts to find major aerospace support. Project stalls, LEI takes *de facto* lead of project and LEI shrinks to a core of a few volunteers.

Chapter 1-6: To The Moon Using Pepsi And Pizza For Fuel?

We attempt to sell advertising rights of mission to Coke, Pepsi, Pizza Hut, etc.; Pepsi *almost* gives us $3 million. Project again stalls. Preston leaves project and SSI is on sidelines.

Chapter 1-7: The Political Approach

I try to get political support from Texas Congressmen and Senators to keep project alive.

Chapter 1-8: Lunar Prospector - The First SEI Mission

NASA appoints Mike Griffin to head President Bush's Space Exploration Initiative (SEI) to "Put man back on the Moon, permanently, and go on to Mars." Griffin wants Lunar Prospector to be 1st mission in SEI and asks for proposal! Griffin *accepts* our $16 millionproposal - a few days later he *rejects* it on political grounds!

Chapter 1-9: JSC To The Rescue, Again And Again

NASA Johnson Space Center's (JSC) Director, Arron Cohen, attempts to get Lunar Prospector funded, but Griffin blocks his efforts. Cohen tries to get LEI $10,000 to keep project alive and Griffin again blocks him. Griffin tries to force me to stop seeking a way of funding Lunar Prospector by threatening my LEI volunteers and me.

Chapter 1-10: Goldin Asks Lockheed To Do Lunar Prospector

New NASA Administrator, Dan Goldin, asks Lockheed to support my efforts to LEI get Lunar Prospector done. After a false start, Lockheed refuses.

Chapter 1-11: Keeping Lunar Prospector Alive And Keeping Gainfully Employed

JSC tries again to get me $10,000 to keep Lunar Prospector alive. I submit unsolicited proposal to NASA Headquarters, which rejects the proposal without even looking at it.

Chapter 1-12: Galvan, ISE And Goldin

Israel Galvan sets up meeting with NASA Administrator Goldin for International Space Enterprises (ISE) and me. Goldin agrees to support Lunar Prospector, but as we leave meeting, the Deputy Associate Administrator (AA) for Space Sciences (Code S) tells me he will not follow Goldin's directive!

Chapter 1-13: Rebecca, Sam Venneri and Code C

After Code S rejected his directive, Goldin suggests that I ask Sam Venneri (AA for Commercial Space [Code C]) for support, to no avail. I met my future wife Rebecca.

Chapter 1-14: "*…what have you got to lose?*"

NASA announces the Discovery Program of inexpensive missions, in which "the Principle Investigator is solely responsible for the success of his mission". Given all the rejection from NASA, I see no reason to try, until a JSC colleague asks, "*...what have you got to lose?*" I ask Lockheed (Sunnyvale, CA) to support my proposal. Lockheed agrees.

Chapter 1-15: The Proposal

I go to Sunnyvale and write proposal during grueling 8 week period, during which I get a few to zero hours of sleep/night. Total mission cost: $63 million, compared to $250 million maximum allowed. Deliver proposal just before deadline after very eventful last 24 hours. My proposal is 1 of 28!

Chapter 1-16: The Wait

Rebecca and I marry and wait for word from NASA.

PART TWO: SUCCESS AT LAST

February 24, 1995 Through September 7, 1995

Chapter 2-1: The Call

NASA Headquarters calls to tell me that Lunar Prospector was selected for flight – SUCCESS AT LAST.

Chapter 2-2: The News Conference

I go to Headquarters to participate in Discovery Announcement News Conference to tell world that Lunar Prospector is going to the Moon.

Chapter 2-3: On To Sunnyvale

I fly to Lockheed (Sunnyvale) to start administrative processes of my being hired there and to start Phase B (final spacecraft design) activities.

Chapter 2-4: Trouble In Sun City

A week after NASA News Conference, Congressman Sensenbrenner refuses to allow new program starts, because NASA did not provided Congress with 5-year budget – so Lunar Prospector might be stillborn! Lockheed and I start Lunar Prospector contract negations with NASA/Ames - expect contract in 30 days. Sensenbrenner crisis passes.

Chapter 2-5: Back To Houston

I returned to Houston to present Lunar Prospector at annual *Lunar and Planetary Science Conference* and to prepare for my permanent move to Sunnyvale.

Chapter 2-6: Off To California (Via Arizona)

Rebecca and I drive to California with my car loaded with minimum. I need to live in motel until Lockheed (Sunnyvale) hires me and she and our household goods are moved to CA.

Chapter 2-7: Trying To Getting Started

Rebecca and I rent home in Gilroy. Lockheed (Sunnyvale dragging it feet in hiring me! We get slowly started on Phase B work.

Chapter 2-8: The Fee Crisis And The NASA Contract

NASA and Lockheed battle for a week (!) over the $4 million fee Lockheed expects beyond $63 million cost of program - NASA is ready to cancel program before ink is dry on contract! NASA yields!

Chapter 2-9: Getting Started At Last

With Sensenbrenner and fee crises behind us and with the main contract (in which it states that "*all work is to be done under the direction of the Principal investigator*") finally signed, we start seriously working on Phase B. 6 weeks (!) after I started to work at Lockheed (Sunnyvale), I'm finally hired, but forced to do so at ¾ of salary that was written in proposal, since Lockheed knows that I would accept rather than lose my mission - the 1st of numerous Lockheed stabs-in-the-back.

Chapter 2-10: Grinding Through Phase B

Serious work begins on the Phase B design of the spacecraft.

Chapter 2-11: Too Much Of Dom

It becomes clear that Dominick Tenerelli, Lockheed's Project Manager, is sabotaging design work in effort to take control of the mission for his personal gain. After discussing situation with NASA/Ames Project Manager, Scott Hubbard, we consider having Dom replaced, but first I confront Dom in effort to correct situation.

Chapter 2-12: Lunar Prospector Facing Cancellation, The End Of Dom

Due to Tenerelli's counterproductive activities, it is clear to NASA, Lockheed and me that Dom has to be replaced or project will be cancelled.

Chapter 2-13: Exit Dom, Enter Tom

Tom Dougherty, the new Lockheed Project Manager, replaces Dom Tenerelli.

Chapter 2-14: Trying To Save Lunar Prospector

It is clear that Dom had destroyed the program and Tom and I set out to save Lunar Prospector 3 weeks before NASA Technical Design Review (TDR) that would seal fate of project. LLV1 test launch fails, sending NASA into a tizzy about our launching on an untried LLV2 (the big 3-stage brother to the smaller 2-stage LLV1).

Chapter 2-15: The Technical Design Review - The Gate

Despite Tenerelli's squandering 5 months of time and $1.7 million, we pass NASA TDR.

PART THREE: BUILDING LUNAR PROSPECTOR

September 8, 1995 Through January 5, 1998

Chapter 3-1: Getting Ready For Phase C/D

Having passed TDR, we enter Phase C/D (Construction and Testing), but thanks to Tenerelli, we still have to finish the spacecraft design. Government shuts down, so we cannot get the $20 million Phase C/D money needed to keep project alive! Engineers bring up potential fatal problem of nutation (wobbling) of spacecraft during Translunar Injection (TLI) burn. Lockheed Launch Vehicle (LLV) staff reneges on $25 million

launch agreement; LLV2 launch conditions are so bad that they could destroy spacecraft; I start looking for a way to get a Taurus rocket from Orbital Science.

Chapter 3-2: Phase C/D Draft Letters

We get unofficial NASA letter telling us to start Phase C/D, but we still have no money because of government shutdown. Dougherty gets Lockheed to loan us money to keep project alive. I start critical and unending battle with engineers to keep spacecraft's mass down.

Chapter 3-3: Trying To Get A Taurus

I fly to Washington DC to try to get our money and to talk with Orbital Sciences behind Lockheed's back; Orbital will do entire launch for $23 million! Meet with Lockheed manager Henshaw; told him about LLV problems and Orbital's excellent offer; Henshaw raises hell with LLV.

Chapter 3-4: LLV2 Or Nothing, Power Problems And A Second Fee Crisis

Told by Lockheed upper management that I use LLV2 or nothing. Designed solar array will not produce enough power; need budget busting expensive solar cells or bigger array that won't fit in rocked shroud! LLV moves to Denver; I meet with new LLV team. Lockheed and NASA *again* battle about Lockheed $4 million fee; NASA *again* threatens to cancel project; NASA *again* backs down.

Chapter 3-5: Officially Starting Phase C/D

With fee crises solved and Phase C/D contract signed, we get official OK to start Phase C/D; much-needed NASA money finally starts to flow, over 3 weeks late, but design work gets into high gear.

Chapter 3-6: Pushing For A Taurus

Launch vibrations of the LLV2 rocket are reported to be worse that we had been told, so much so that Lockheed has to let Dougherty and me visit Orbital to talk about a Taurus launch. LLV Denver wants extra $9 million for TLI stage (!), money we don't have. NASA seems to push for Taurus launch, but backdoor dealings keeps LLV2 in picture.

Chapter 3-7: The Rocket Mess Continues

Lockheed does not want Orbital Science to launch Lunar Prospector - NASA does not want Lunar Prospector launched on unproven LLV2 - so around and around we go.

Chapter 3-8: Blue Moon, Boom Problems And More Rocket Mess

US Air Force Academy Aerospace class wants to launch small lunar satellite "Blue Moon" and asks my help in return for USAF helping track Lunar Prospector. Science booms have resonance problem and might break during engine firings. The LLV2/Taurus mess continues to boil over; I write formal request to NASA to force Lockheed to allow me to use $5 million cheaper and much safer Taurus.

Chapter 3-9: Doing The Launch Vehicle Two Step

Headquarters will enforce no-first-launch-rule, eliminating LLV2 from question, unless Lunar Prospector is launched on LLV2 after Lockheed's commercial satellite "CRSS" is launched in December 1997 on 1st LLV2, i.e., we delay our launch a few months until CRSS has been launched. However, if I don't get launched by January 1998, I lose more and more of my 19 month mapping mission as each month goes by - worse, *Lockheed is lying to NASA* about CRSS' readiness to launch (it launched 16 months late!).

Chapter 3-10: The End Of Taurus

NASA and Lockheed upper management conspire (?) to get Taurus out of picture – NASA adds $6 million of NASA oversight costs to Taurus' $23 million price! I can no longer afford a Taurus – dirty pool! I'm stuck with LLV2.

Chapter 3-11: Completing The Spacecraft Design

Spacecraft's design is complete and we start construction.

Chapter 3-12: Where Can We Buy Some Solar Cells?

Ready to start solar array development, but no vendor has any solar cells for sale! LLV has not even started construction of our LLV2 (!), so LLV mess continues; I blow my top at their incompetence. Mark Sanders of Headquarters thinks Lockheed is hiding bad information about project (not true) and *again* wants to cancel project.

Chapter 3-13: A Simple Change Makes Major Differences

I make change to magnetics experiment boom configuration that solves concern about post-launch nutation dangers and makes solar array more efficient, thereby greatly reducing spacecraft power problem. As result, we can use high efficiency solar cells from Japan for solar array; cells are finally ordered and arrive.

Chapter 3-14: Moving Towards Assembly

Most spacecraft components are delivered and we get started on assembling spacecraft. More of LLV2's unending problems.

Chapter 3-15: The C&DH Turns On

Lunar Prospector's central brain, the Command & Data Handling Unit (C&DH) is turned on for 1st time. Headquarters *again* raises concerns about LLV2 and *again* wants us to wait for CRSS to launch – also wants me to add bigger battery so I can fly full mission after waiting for CRSS. That would cause a redesign of spacecraft and cost several million dollars that neither we, nor NASA has, so NASA *again* backs down. *Lockheed continues to lie to NASA* about CRSS' major schedule slips. Construction of Lunar Prospector starts to seriously slip, but Dougherty won't admit that to NASA in order to protect Lockheed.

Chapter 3-16: Getting Way Behind Schedule

The construction schedule slip gets more serious, but Dougherty keeps denying it to protect Lockheed. LLV continues to cause problems with our LLV2 launch vehicle. Software engineers resist doing necessary work on ground system.

Chapter 3-17: A Major Thermal Modeling Error

Thermal Engineer discovers major error in thermal calculation, error causes major redesign of thermal subsystem and means that Gamma Ray Spectrometer won't get as cold as planned so its data will be degraded somewhat. Despite our several month schedule slip, Lockheed pulls most of my engineers off project to work on another proposal (!); I protest to no avail.

Chapter 3-18: Static Testing

Static test of spacecraft structure shows that we have to strengthen side panels, but structure is basically OK.

Chapter 3-19: The Delivery Of The Engines And The Tanks

Fuel tanks and engines delivered. I go to Headquarters with LLV Chief Engineer and convince Headquarters that we can launch on LLV2's 1st launch, i.e., not wait for CRSS, if the next LLV1 launch is successful!

Chapter 3-20: A Major Power Crisis

New thermal calculations show that solar array will be hotter than expected, so power will be lower – *another power crises*. Solar array engineers want bigger battery that would add 20 kg to spacecrafts mass; I say, "NO". I show that solar array heating is not as bad as calculated and Power Engineer and I add 5 cm to solar array to finish solving power crises.

Chapter 3-21: Drop Test, Pyro Tests And Boom Shake Test

We test pyro-separation of spacecraft from Trans-Lunar Injection (TLI) Stage (drop test). First signs that NASA manager Scott Hubbard is trying to take over project for his personal gain. We conduct pyro-shock test to see if separation pyro explosions will damage spacecraft; make minor modification to spacecraft as result of test. I go to southern California to watch shake tests of science booms assembly; booms pass test.

Chapter 3-22: Shake Testing The Spacecraft Structure – A 57 Hz Resonance!

We do shake testing of spacecraft structures and find 57 Hz resonance – right in middle of the 50 to 60 Hz vibrations of the LLV2. We modify structures to move resonance out of harm's way - well above 60 Hz. NASA agrees to a September 24, 1997 launch of Lunar Prospector on 1st LLV2 launch. Scott Hubbard gets put in his place by Congressman Sensenbrenner regarding the release of the data to the public.

Chapter 3-23: The 57 Hz And TLI Burn Issues Solved

After modifying the structure, retest on the shake stand shows that the resonance is at 70 Hz - well above the danger frequency range. After considerable effort concerning possible problems cause by nutation during the TLI burn, I'm finally able to prove to engineers that there is no problem and we tell Thiokol how much fuel to load into the Star 37 motor of TLI Stage.

Chapter 3-24: Starting Plumbing The Spacecraft

Technicians begin installing and welding tanks, fuel lines and engines in the spacecraft, only to be held up by incorrectly made connectors to engines; this increases our serious schedule slip, so much so, that I start discussing with NASA/Ames Deputy Project Manager the possible need to replace Dougherty as the Lockheed Project Manager, since he is doing nothing about serious schedule slips.

Chapter 3-25: The Official Beginning Of Testing

We pass NASA Test Readiness Review and prepare for next phase of spacecraft construction and major testing of completed spacecraft. Headquarters *again* worries about LLV1 and LLV2 launch vehicles and considers Launching Lunar Prospector on Boeing Delta rocket as secondary payload; but we would have to spend several million dollars modifying spacecraft to launch on Delta, money that NASA does not have. So *again* headquarters backs down and accepts LLV2 launch for Lunar Prospector! We receive 3 of science instruments, but have to send them back to Los Alamos National Labs (LANL), because *Lockheed cannot provide for their safekeeping until they are mounted on spacecraft*!

Chapter 3-26: Finally Moving Beyond The Plumbing

Plumbing of propulsion subsystem finished weeks late. Science Instruments are taken back to LANL for safekeeping! Little work is done on spacecraft and schedule slip increase, but after New Years, spacecraft is ready for mounting of electronic units and for wiring.

Chapter 3-27: Wiring The Spacecraft

Wiring of spacecraft finally begins, but very slowly and schedule slip grows.

Chapter 3-28: Another Launch Vehicle Crisis

Headquarters *again* decides that we cannot launch on 1st LLV2 and have to wait for CRSS launch. *Lockheed and Dougherty continue to lie to NASA* about the major CRSS slips and say that CRSS will launch in December 1997. Headquarters *again* insists that we add bigger battery so we can launch after CRSS. Since spacecraft is almost finished, that would mean redesign and rebuild of entire spacecraft at cost of up to $15 million and delay of year or more. After considerable debate, NASA *again* agrees that it does not have extra to $15 million for and drops its idiotic request *again*! Launch issue still hinges on successful launch of next LLV1 – a launch that is slipping seriously!

Chapter 3-29: Finally Finishing the Spacecraft

Wiring is finally finished –2 months late - and after I discover that a high-voltage cable to Neutron Spectrometer is missing. But finally spacecraft is finished!

Chapter 3-30: Turning On Lunar Prospector

We begin slow and careful process of turning on spacecraft and finding and fixing various wiring errors and problems with electronic units. After 3 weeks work, all spacecraft systems, as well as the Science Instruments are turned on.

Chapter 3-31: Functional Testing

Science Instruments tested, we have to replace defective high-voltage cable to Neutron Spectrometer (NS). Instead of using very expensive helium sniffer to test engines, I test them by putting inexpensive rubber gloves on each engine and watch to see if helium pressurant (no fuel, just pressurant) blows up rubber gloves like balloons when engine valves are opened. Similarly, instead of using expensive test equipment, we use engineer's wife's iron as infrared (IR) heat source to test IR limb-crossing sensor and flash camera to simulate Sun to test Sun sensor! We complete full Function Testing. We do Science Instrument boom deployment test perfectly, except one of booms has a cracked longeron that must be replaced. Happily it is NS boom that has to be removed to replace the defective NS high-voltage cable anyway. Function testing completed.

Chapter 3-32: Thermal-Vac Testing – The Big One

All-important Thermal-Vacuum testing set up with 2 cold soak and to hot soak test cycles over 10 day period, , because spacecraft *never, ever* get through Thermal-Vac testing on 1st, and frequently not even 2nd try, test engineers reserved big Lockheed test chamber for 3 weeks. *After just 7 days and on 1st try, Lunar Prospector passes Thermal-Vac test; that is 1st time that has ever happened in Lockheed's history. I have just proven that my method of designing and building spacecraft - the KISS (Keep It Simple Stupid) principle, works and I have just proven that "Faster, Better, Cheaper" works when a scientist runs program, rather that a NASA bureaucrat or an Aerospace Company Project Manager.*

Chapter 3-33: The Interlude Between Thermal-Vac and Acoustic Testing

More problems with Denver LLV staff concerning launch trajectory! We pass formal Ground Segment Review - NASA accepts our plan for running spacecraft and setting up Mission Operation Center. We start work on computer model of spacecraft, with which we will do our training to fly spacecraft. I start to prepare to retire from Lockheed and go into my non-profit company, Lunar Research Institute (LRI), from which I will finish mission.

Chapter 3-34: Acoustic And Pyro-Shock Testing And Mission Training

Spacecraft passes final big test – Acoustic Testing – with only minor problems. We do Pyro-Shock Test and complete testing. My Mission Operations (Mission Ops) Team and I (Mission Director) start our training simulations, or SIM's, to practice flying spacecraft with just 4 months to September launch.

Chapter 3-35: Going Through Hell To Get Out Of Lockheed

Though Lockheed resents my being in charge of the mission and does not want me in company, Lockheed makes it as hard as possible for me to leave Lockheed and run mission from LRI - Lockheed wants to keep mission looking like Lockheed endeavor. Headquarters wants to delay launch and have 6 months of reviews of LLV1 and LLV2 rockets before LLV1 launch of Lewis satellite and LLV2 launch of Lunar Prospector! After much difficulty, Lockheed begins to agree to a contract for LRI so I can leave Lockheed, but Lockheed will not pay LRI enough money so I can do my job as Principal

Investigator and Mission Director! LLV say that they can't make September launch - we slip into October!

Chapter 3-36: Another Lockheed Stab In The Back

Lockheed delay and stalls LRI contract negotiations and puts so many financial restrictions on LRI that I would not be able to carryout mission duties! LLV1 Lewis launch is *again* delayed to August! More SIM's, more contract negotiation BS, more launch vehicle BS, more frustration, but finally, barely acceptable contract offer from Lockheed.

Chapter 3-37: LRI Becomes A Reality

August 8, 1997, I'm free of Lockheed and start working at LRI. Lewis gets delayed *again* and we get delayed *again,* until November. More SIM's.

Chapter 3-38: Finally - Cleared To Launch And Ready To Launch

Lewis finally launched, but satellite dies within a day! Nevertheless, we are cleared for launch November, but then I'm asked for acceptable launch dates in January! We continue training and doing emergency procedure SIM's.

Chapter 3-39: SIM's, SIM's And More SIM's

The Chapter Title tells it all. Lockheed delays paying LRI!

Chapter 3-40: The Second Lockout

In fit of childish rage, because I was on TV and he was not, NASA Project Manager Scott Hubbard starts chain of events that get me locked out of Lockheed like common criminal for 7 days. I decide to ask Headquarters to replace Scott as Project Manager as soon as spacecraft is safely in lunar orbit.

Chapter 3-41: Delayed Until January

NASA officially delays us to January launch! If I get delayed further, I will start losing mission duration and science. We start preparing to send Lunar Prospector to Cape Canaveral to start preparing for launch.

Chapter 3-42: Steven's Boom Canister Crisis

As we are preparing everything to go to the Cape, Steve Honodel, the science boom engineer, gets concerned that boom will not deploy. Though I show that his concerns are not valid and tests show that I am correct, Steve keeps Dougherty in uproar and we waste time on baseless crisis just before shipment to Cape!

Chapter 3-43: Preparing Lunar Prospector For Launch

My engineering crew and I go to Cape for 4 weeks to prepare Lunar Prospector for launch. We conduct final pre-launch test, fuel spacecraft, mount it on LTI stage, spin balance the TLI Stage/Spacecraft stack and mount stack on LLV2 adapter. We take stack to launch pad 46 where LLV2 is waiting for its payload. Preparations are finished and I go back to CA on Christmas Day to make final Mission Ops preparations for launch and flight.

Chapter 3-44: Waiting To Launch

We get prepared for launch and flight.

Chapter 3-45: Launch Day

After perfect 29-hour countdown on evening of January 5, 1998, a Range Safety Radar breaks down and we are scrubbed for 24 hours!

PART FOUR: THE LUNAR PROSPECTOR MISSION

January 6, 1998 Through July 31, 1999

Chapter 4-1: Launch And The First Nine Hours Of The Mission

Lunar Prospector successfully launched on 1st flight of LLV2 (now called Athena 2) and injected into Trans-Lunar trajectory. After initial communication difficulties, I take command control over spacecraft, despin it, reorient it, deploy the science booms, re-spin it up, do the initial turn-on of all the Science Instruments, do 1st Mid-Course Maneuver (MCM). At end of first 9 hours, I have healthy, happy spacecraft heading to Moon.

Chapter 4-2: The Translunar Coast

The next evening I finish turning on Science Instruments and conduct 2nd MCM, after which our trajectory is near perfect and I cancel 3rd MCM. We coast to Moon.

Chapter 4-3: LOI – Lunar Orbit Insertion

After 105 hour Tran-Lunar Flight, I perform critical 1st LOI burn by firing engines for 32 minutes and put Lunar Prospector into 12-hr capture orbit – had burn not occurred, spacecraft would have flown past Moon and mission would have been lost. 24 hours later I performed 2nd LOI burn and reduce orbit to one with 3.55 hr period. 24 hours later, and after Lockheed, out of fear that we could hit Moon if I burned all the way down to 100-km altitude-mapping orbit, tried to stop me from during full burn. After compromising, to lessen their fears, I agreed to 3% underburn and I put spacecraft in 91x153 km, initial mapping orbit. Two days later I corrected orbit and placed spacecraft in 100 km altitude-mapping orbit. Mapping mission began.

Chapter 4-4: The Letter, The Confrontation And The Gravity Map

Having reached mapping orbit, I send letter to Headquarters demanding Scott Hubbard's removal from project and, upon delivering copy of letter to Scott, I confronted him regarding all the backstabbing and self-serving activities he conducted over past many months. Two weeks of achieving mapping orbit, we have 1st complete gravity map of Moon that allowed us to finally plan the rest of mapping mission.

Chapter 4-5: Water, Water Everywhere, But…?

Six weeks after arriving in lunar orbit, we discover that Moon has deposits of water ice near each pole – a significant find for future exploration, colonization and utilization of Moon. We hold press conference announcing gravity mapping and water ice

discovery. Protecting its own, NASA refuses to remove Scott from the project, but – because of all his other duties – Scott turns over NASA management activities to his deputy, Sylvia Cox, who did all the work anyway.

Chapter 4-6: PR, Reor Maneuver Problems And The LPS Conference

Minor spacecraft reorientation maneuvers that we periodically do seem to go wrong; my dynamics engineer, Dan Swanson, starts looking into problem. My Science Team and I present our result at Lunar and Planetary Science Conference. Dan finds source of errors in reorientation maneuvers.

Chapter 4-7: Routine Mission Activities And The Data Reduction Money Issue

Mission becomes routine and, *after spending $63 million on the mission, NASA begins to look for ways to avoid giving my Science Team and I the $4 million we need to get data reduced to forms so scientists and the public can use the Lunar Prospector data!* My team and I go to Headquarters and demonstrate that our data are of very high quality and that NASA must give us money for data reduction program! We force NASA to agree.

Chapter 4-8: Planning For The Extended Mission, The Flip, The Leonids And Eclipses

NASA grants us 7-month extended mission to map Moon from 30-km altitude orbit. We plan to perform 180° flip of spacecraft halfway through mission, so we can calibrate out any asymmetries in instrument responses. As expected, spacecraft easily survives worst partial lunar eclipse of nominal mission. We plan how to protect spacecraft from meteoroid hits during upcoming Leonid Meteor Shower in November.

Chapter 4-9: The Degrading Battery

Due to aging, battery has difficulty in getting fully charged after nighttime passes when high-wattage, fuel tank heaters are on. We start turning off transmitter during critical nighttime passes –process that no one likes, when something is shut off on a spacecraft, it might not come back on!

Chapter 4-10: The Flip

Over 3-days, I command spacecraft to reorient itself by 90°, leave it in that attitude to collect calibration data for 2 full days; then I finish the flip with second 90° maneuver and leave spacecraft "upside-down" for second half of the mission – except during Leonid Meteor Shower.

Chapter 4-11: The Leonid Meteor Shower And The End Of The Nominal Mission

I reorient the spacecraft by 78°, so *insensitive* bottom of spacecraft is facing incoming meteoroids; I spend 20 hr/day over the next 4 days watching spacecraft so I'm ready to save spacecraft in case it get hit. After uneventful meteor shower, I reorient spacecraft back into its "flipped" attitude.

Chapter 4-12: Transition To The Extended Mission And A Critical Penumbral Eclipse

On December 19, I lower spacecraft's orbit from 100 km to 40 km, ending nominal mission and beginning transition to 30 km altitude orbit of extended mission. On January 28, 1999 I lower orbit's mean altitude to 30 km and at time, spacecraft is within 5 km of the Moon's peaks. On January 31 spacecraft survives worst possible lunar partial lunar eclipse – the worst that it was designed to survive!

Chapter 4-13: The Extended Mission Becomes Routine

Despite fears of NASA and Lockheed that low altitude mapping could lead to disaster, extended mission runs smoothly, though I spend more time at Mission Ops checking on battery as it continues to degrade. University of Texas engineers ask if I could crash spacecraft at end of mission into a crater where we found evidence of water ice, in expectation that impact would throw up cloud of water vapor that could be detected with Hubble Space Telescope and Earth telescopes and I answer, "Yes."

Chapter 4-14: The Eternal Question – Who Is In Charge?

The eternal problem as to who is really in charge of mission - NASA, Lockheed or me (the Principal Investigator) - boiled over, as it had done several times during past 4 years. After series of meetings and, as always, I win *again*, but that problem is a source of constant aggravation. For 1st time in mission, we have problems commanding spacecraft; we determine that cause is that signals sent to spacecraft reach it directly and indirectly, after being reflected off Moon's surface - causing interference.

Chapter 4-15: The Tank Heater Event/Battery Problem

As battery continues to degrade, we have more problems with battery charging during tank heater events. I continue trying to convince NASA and Congress that they should fund $300 million/year lunar data purchase program and turn lunar exploration over to commercial world - to companies like my 2nd company, Lunar Exploration Inc.

Chapter 4-16: Transitioning

We prepare for end of the mission on July 31, when I will impact spacecraft into a crater near lunar South Pole in the hopes of carrying out impact experiment set up by University of Texas scientists and engineers. First, we have to survive total lunar eclipse that spacecraft was not designed to survive and was supposed to cause end of mission. My wife and I prepare to leave California and move to Tucson after end of the mission.

Chapter 4-17: The Last 75 Hours Of The Mission

Thought it is touch and go, my Operation Team and I successfully get spacecraft through "killer" lunar eclipse and on morning of July 31. At 1:52:00.8 PDT Lunar Prospector impacts on Moon, ending completely successful 19-month mission, proving that "Faster, Better, Cheaper" really works and proving viability of lunar mission as commercial ventures.

EPILOG: THE LUNAR PROSPECTOR AFTERMATH AND PAYOFF

July 31, 1999 And Beyond

We set up LRI in Tucson and after usual NASA delays, we start getting money to numerically reduce Lunar Prospector data. I'm asked by Congress to testify to Space Science Committee about "Faster, Better, Cheaper" that is under attack after twin Mars Mission failures in fall of 1999. I continue my quest to get Congress and NASA to start commercial based lunar exploration program. All data are reduced by the end of 2001, thus successfully completely entire 12-year effort.