Chapter 4-1
Launch and the First Nine Hours of the Mission

Tuesday, January 6, through Early Morning, Wednesday January 7, 1998

–000/15:30 MET through –000/00:57 MET: Getting Ready

I woke up at about 4:00 AM and, after a coke and donut at the local Gilroy donut shop, I drove up to Mission Ops. I checked the Mission Profile for that evening's launch attempt, made copies of it, and put it next to the various computer consoles in Mission Ops. I checked with the Cape — the Athena II countdown, that had been recycled to T–24 hours the night before, was again progressing smoothly, but the weather was poor — it was raining. The tank pressure was 438 psi and the tank temperatures were all at 20° C and holding. The only concern was the weather.

Later in the morning, I did some TV interviews and waited for the morning to pass. Launch was at 6:28:43 PM PST, an hour later than the day before and we were going to start getting assembled in Mission Ops by early afternoon.

As everyone came in, I made sure they all had a copy of the correct Mission Profile. Then Dan, John, Paul, and I again settled into our Mission Ops chairs in front of our computers and brought up our spacecraft monitoring screens.

My Ames Nav Team, my Lockheed Engineering Support Team, and my Science Instrument Support Team again all took up their positions in front of the auxiliary computers outside the glassed-in Mission Ops room. Marcie, Dougherty, the rest of my controllers, and the other spectators slowly arrived for our second launch attempt.

We again checked our headphones and mikes. Dave and Ken again checked in with the Goddard Nav Team. Marcie and John again checked with JPL on the status of DSN and the ground communication network that linked us to JPL and the DSN, and I again checked the phone line between Kim at the Cape and me.

Finally, I was once again ready, with my red pen, to check off the events of the mission and to take command control of my spacecraft.

At 3:43 PM PST January 6 (23:43 GMT January 6 or –000/03:42 MET, or 2 hours and 45 minutes before launch), we started the first flight readiness poll.

–000/03:42 MET, I polled Mission Ops, Goddard, and JPL — red check.

–000/03:32 MET, Kim polled me — red check.

–000/03:27 MET, the Launch Director polled Kim — red check.

I again asked Kim what the tank pressure and temperatures were and he told me the pressure was 438.8 psi and temperatures were 20° C; I wrote those data in red on my Mission Profile. We again continued to sit, watching the launch preparations at the Cape on TV, and waited and listened.

Two hours before launch, there were concerns about thunderstorms that were over Tampa and that were moving towards the Cape. Range Safety rules dictate that you cannot launch if there are thunderstorms within 16 km of the launch pad. As the count continued, one such storm was moving directly towards Pad 46 and we held our breaths. However, the Gods on Mount Olympus smiled on the little rocket that was trying to send its small payload to one of their own, their Moon Goddess Diana, because half an hour before launch, the weather people said the storms were not going to interfere with the launch!

At 6:23 PM PST January 6 (02:23 GMT January 7, or –000/01:22 MET, or 0 hours and 25 minutes before launch), we started the critical GO/NO-GO poll.

–000/01:22 MET, I polled Mission Ops, Goddard, and JPL — red check.

–000/01:19 MET, Kim polled me — red check.

–000/01:16 MET, the Launch Director polled Kim — red check.

I again asked Kim what the tank pressure and temperatures were and he told me the pressure was 438.8 psi and temperatures were 20° C; I again wrote those data in red on my Mission Profile.

By then, we were less than 20 minutes to launch and the feeling in Mission Ops was that we were going to launch — no one doubted that in a few minutes, the Athena II was going to lift off Pad 46 and begin its maiden voyage into space, carrying in its shroud Lunar Prospector.

–000/00:57 MET through –000/00:15 MET: The Athena II Launch

At –000/00:57 MET, there were just 22 seconds to lift off. I reminded everyone that I wanted it quiet in Mission Ops — all of it — both inside the Glass Room and outside of it. There was to be no shouting, jumping around, and celebrating the launch — we were there to do a serious job and we had to concentrate on it and not act like a bunch of high school kids, as did the Mars Pathfinder Mission Ops Team when Mars Pathfinder successfully landed on Mars in July.

Then, as we watched the image of the Athena II on the TV screen, bathed in the glare of the launch-pad lights, the voice on the TV began calling out the final 10 seconds: 10-9-8-7-6-5-4-3-2-1-0.

Exactly on time, at T = 0, I saw a small bright light appear at the bottom of the Athena II — we had ignition; that was it — there was no more waiting, no more delays, we were irrevocably committed to launch. Once that 1st Stage Castor 120 started to burn, there was no going back and I was relieved. Good, bad, or indifferent, Lunar Prospector had started its journey to the Moon and there was nothing I could do to change the course of its fate for the next hour. Automatically, it would either get launched onto its proper translunar trajectory, or end up in the Atlantic, or burn up in the Earth's atmosphere after a failed TLI burn, or have such a bad launch that there was no way we could get it to the Moon — all that was out of my hands for a little more than an hour.

All that went through my mind at that instant of ignition. Then, in a fraction of a second, the small bright light grew to an ever increasingly brighter and larger exhaust plume as the Athena II lifted off Pad 46 and my thoughts turned to the acoustical waves that were assaulting my spacecraft. The noise that was being generated by the burning Castor 120, enhanced by its being reflected off the launch pad and back up the Athena II to the spacecraft, was so intense for the first few seconds of the launch that it could have damaged the science instruments and the delicate solar cells of the solar panels. Remembering that some of the delicate APS filters had been torn apart during our acoustic testing, I hoped — and expected — that they, and everything else on the spacecraft, would withstand their first acoustical assault of the launch.

Simultaneous with the initial acoustical assault on Lunar Prospector, the infamous pipe organ effect had also started its work of violently shaking the Athena II and Lunar Prospector — starting at 50 Hz. Though the amplitude of the pipe organ effect was large at the beginning of the burn, the amplitude decreased as the 1st Stage burn continued. Also, its effect was lessened because of the damping effects of the some 20 meters of rocket (the 2nd and 3rd Stages, the Orbit Adjustment Module or OAM, and the TLI Stage) between the top of the screaming 1st Stage Castor 120 and Lunar Prospector. I had little concern about the pipe organ vibrations during the 1st Stage burn, even though, as the burn continued, its frequency slowly increased towards its maximum of 60 Hz at the end of the 1st Stage burn, i.e., up towards the 65 to 70 Hz where the spacecraft did have some major resonances — but if we had done our work correctly, it would pose no problem.

In addition to the initial acoustical assault and the continuing pipe organ vibrations, the winds and the resistance of the Earth's atmosphere also buffeted the Athena II and Lunar Prospector as the rocket struggled to plow its way through the thick lower atmosphere. As the rocket's speed increased, the atmospheric buffeting increased until a crescendo was reached some 74 seconds after lift-off — when the Athena II passed through the sound barrier. As it did, the acoustical level, for the second time, reached an intensity that was great enough, for a few seconds, to damage the spacecraft. Finally, after passing through the sound barrier, the noise and atmospheric buffeting rapidly abated as the Athena II climbed out of the Earth's atmosphere, but the howling gasses inside the Castor 120 continued to shake the spacecraft. Finally, 89 seconds after lift-off, the 1st Stage burn came to its end and I hoped the spacecraft had survived the noise, the buffeting, and the howling of the 1st Stage burn. Also, during that 1½ minute, Athena Launch Control kept informing us, and the world, that the launch trajectory was near perfect!

As the 1st Stage burn trailed off, a sensor detected the end of the burn and sent a critical signal to ignite the Castor 120, 2nd Stage of the Athena II rocket. 2nd Stage ignition occurred while still attached to the 1st Stage. That "Fire in the Hole" ignition had never been done before and, while insuring that the Athena II was under positive attitude control during the transition between the 1st Stage and the 2nd Stage burns, it did pose some danger, since if the exhaust vents between the stages did not blast open at ignition, the back pressure of the igniting 2nd Stage could damage the engine bell and steering mechanism of the 2nd Stage.

Nevertheless, Athena Launch Control called out 1st Stage burnout and 2nd Stage ignition and we could plainly see on the TV screen that the bright exhaust plume (that was all one could see in the dark of the night) of the Athena II, suddenly and very briefly expanded as the exhaust of the burning 2nd Stage splashed off the top of the then dying and separated 1st Stage.

Unlike the 1st Stage burn, where the noise of lift-off, the breaking of the sound barrier, and the buffeting of the atmosphere presented dangers for the spacecraft, the only danger after 2nd Stage ignition was caused by the howling of the hot gasses inside the Castor 120, i.e., the pipe organ effect was at it again. However, unlike the 1st Stage burn, where there were 20 meters of rocket between the top of the burning stage and Lunar Prospector, Lunar Prospector was only 10 meters from the fiercely burning and howling Castor 120, 2nd Stage, so the howling was much more intense at the level of the spacecraft and certainly intense enough so that if there were an error in the design of Lunar Prospector, the consequences could have been serious. Regardless, the 2nd Stage burn began to die-out ninety-two seconds after 2nd Stage ignition or just three minutes and 1 second into the flight. As was the case for the 1st Stage burn, Launch Control kept reporting that we had a good launch trajectory — so far, so good.

After 2nd Stage burnout, the Athena II (minus the 1st Stage) coasted upwards for fifty-seven seconds, during which the shroud was to separate. Remembering that the shroud had failed to separate on the first LLV1 test launch and that the electrical connectors between the shroud and the adapter had had to be fixed by the launch preparation crew just two weeks before launch, I awaited shroud separation with some concern — for if it did not separate, the Lunar Prospector Mission would have, in effect, ended less than four minutes into its launch — the Athena II could not have even reached the parking orbit carrying along the heavy shroud, and even if it could have done so, the TLI Stage, and Lunar Prospector would have been destroyed as they tried to ram through the shroud at TLI Stage ignition. However, 52 seconds into the coast or 3 minutes and 53 seconds after launch, the shroud successfully separated and Launch Control announced the success of that critical event.

Five seconds later, at 3 minutes and 58 seconds into the flight, the two minute and 34 second burn of the Orbus solid fuel rocket 3rd Stage was to have begun. However, when that time came, no one at Athena Launch Control said a word about 3rd Stage ignition, so I thought it had failed to ignite! I immediately asked Kim what the status of the 3rd Stage burn was. It took two or three queries before Kim confirmed that the 3rd Stage was burning as planned — that was a relief! After the violent burns of the 1st and 2nd Stages, the 3rd Stage burn was relatively mild and posed no threat to the spacecraft. The worst of the launch was over. Finally, the Orbus burn came to its end and, throughout the 6½-minute launch, everyone had remained pretty quiet in the Mission Ops, as I had requested.

Immediately after the 3rd Stage burnout, the 7-minute burn of the OAM liquid fuel engines began. That very low thrust burn was made to correct all the errors in the trajectory caused by the relatively crude burns of the first three, solid fuel stages of the Athena II rocket and when the OAM burn was finished, the OAM, the TLI Stage, and Lunar Prospector would start their 42-minute coast in Earth parking orbit, a coast that would bring the stack over the NW coast of Australia to the exact point in time and space where the critical TLI burn was supposed to occur. About 45 seconds after the OAM began its corrective burn, it and the payload went over the horizon with respect to the tracking station and we had LOS (Loss Of Signal) at –000/00:49 MET, as planned. The next time we would hear from Lunar Prospector, it would be at turn-on, assuming it did turn on and assuming TDRS did pick it up.

Thus, we had a little over ¾ of an hour during which we would be in radio silence. I said to my Mission Ops Team and my Support Teams outside the Glass Room, that we had time to go to the bathroom, get a coke and a candy bar or whatever and get prepared for the post-TLI burn activities — our job was about to begin. I was at the head of the pack going downstairs to relieve and refresh ourselves and I went back to the Glass Room in a few short minutes — ready for the main event.

After sitting down at my console, I checked all my screens. The way the Oasis system worked, I could have as many graphs or data tables, each being about 8 cm or so in dimensions, active on my computer screen as I wanted and I could have any number of graphs or data tables activated and stored as little icons — to be called up at a moment's notice. Given the size of my computer screen, I could get 10 or so of the most important graphs on my screen and several others iconized all over the place.

The graphics I absolutely needed to be able to monitor the health of the spacecraft were the battery voltage and current, the load current, the solar array current and temperature, the tank pressure and the temperatures of the 3 tanks (all on one graphic), the temperature of the 6 engines on two different graphs (one from 0 to 150° C to monitor their normal temperatures and the second from 0 to 1300° C to measure their temperatures during the burns), one of two status tables that indicated which subsystems were turned on, and which were turned off, and a command table which told me the status of a command when I sent one.

The data on those graphics were also color coded: green meaning the data were within the normal operational range of the subsystem or it was turned on; yellow meaning the data were getting close to the upper or lower limits of the operational range; and red meaning the data were higher or lower than the operation limits of that subsystem or it was turned off.

The normal status table had the subsystem identified with dark letters, while the status words, On and Off, were in green or red, respectively. However, our SIM training had shown me that if the subsystem identifiers were also color coded, I would not waste precious time reading the table when the spacecraft was first turned on. In a special table — the "Acquisition Status Table" — all the engineering subsystems were written in green, since they were supposed to be turned on during the automatic spacecraft turn-on sequence initiated by the TLI timer and all the science instruments were written in red, since they were supposed to be off until I turned them on. Hence, all I had to do was to quickly glance at the Acquisition Status Table and see if every subsystem that was written in green had a green status word next to it and that each subsystem that was written in red had a red status word next to it — without actually reading any of the words. The Acquisition Status Table would be the first thing I would look at when we started getting data from the spacecraft.

Similarly, Dan was checking his numerous graphs, Paul had his uplink command screen up, and John had a little of everything on his computer screen. We were ready for turn–on.

–000/00:15 MET through +000/00:18 MET: TLI and Turn-On

Fifteen minutes before Turn-On, I polled my Command Team — Dan, Paul, and John; my Engineer Support Team; my Science Support Team; my Nav Team, TDRS, and the DSN to verify that they were all ready to support the mission at spacecraft acquisition and they all responded that they were GO.

At –000/00:10 MET, I issued my first command — though not a spacecraft command, it was the first command of the mission. I ordered the MAG/ER data line from Oasis to the MAG/ER console opened and had it verified 1 minute later.

At –000/00:05 MET, I ordered the Mission Ops recorder for the attitude data to be turned on and I had it verified 1 minute later.

Then, as we had practiced so many times during our Day 0 SIMs, I said to Dan, in a well-rehearsed way, "Dynamics, will you please take over the countdown to the TLI burn sequence?"

Dan answered, "Command, yes I will," and Dan started to count down to the TLI sequence of events that we expected would terminate with Lunar Prospector being inserted onto its Trans-Lunar Trajectory and being turned-on.

Though the Athena crew had wanted to have a tracking airplane flying over the NW coast of Australia and hence, under the TLI ignition point to monitor the final act of the OAM as it spun up our stack to 3.5 rpm, turned on our TLI timer, and separated itself from our stack, we had been told that was not going to happen. Also, when I asked them if the coast-time in the parking orbit was invariant, they had said, "Yes, it's constant." Hence, we expected the TLI events would occur exactly on time, since we had had an exactly on-time launch.

Dan began the count down to the initial spin-up (to 3.5 rpm), the separation of the stack from the OAM, the ignition of the spin-up rockets on the TLI Stage, and TLI Stage ignition, all of which would occur within 1 second of time! However, when Dan reached T minus 10 seconds, a voice came over the line from Athena Launch Control at the Cape saying, "Spin-up and OAM separation."

Dan stuttered and we looked at each other with surprised looks on our faces as we realized, a split second later, that the Athena team did have a tracking airplane under the TLI ignition point and that the coast-time was not invariant! The Athena crew had misinformed us about the launch right to the very last second of the their part of the launch — well, what could I say — well, how about, "Those bastards will never launch a spacecraft of mine again!"

Dan instantly recovered and counted down to the TLI burnout 1 minute later and the subsequent turn-on of Lunar Prospector. While he was doing so, the TLI Stage increased Lunar Prospector velocity by over 3 km/sec during its 1-minute burn!

As Dan was saying, "TLI burnout," the TLI Stage Timer was sending a signal to Lunar Prospector, thereby turning on the C&DH and the transponder's receiver — *after more than 9 years of work, the MET time was finally, 000/00:00!*

Six seconds later, the timer fired the explosive bolts that were holding the spacecraft and the TLI Stage together and essentially simultaneously opened the valves to the 3000 psi nitrogen tanks to blast the spent, but still chugging, TLI Stage safely away from Lunar Prospector. Lunar Prospector was finally free and on its way to the Moon.

One second after separation, the C&DH began its 23 second spacecraft turn-on sequence — safeing the engines and turning the rest of the engineering subsystems on, including the transponder's transmitter (at the 300 bps, engineering-data-only data rate) which immediately began sending Lunar Prospector's first signals — *Lunar Prospector's birth cry* — which were immediately picked up by TDRS!

TDRS immediately said, "We've picked up Lunar Prospector's signals, but we do not have a lock (TDRS could hear the spacecraft, but it could not receive data)."

Upon hearing TDRS's words, I, and everyone else in Mission Ops, knew Lunar Prospector had survived launch and was alive. I was relieved — I had a live spacecraft racing towards the Moon — at least I hoped so. Since Lunar Prospector had been turned on, none of us doubted that the entire TLI sequence had gone off like a charm. However, just hearing the spacecraft was no guarantee that the Star-37 had ignited and accelerated the spacecraft to TLI; we would know that for sure when and if TDRS got a good lock on the spacecraft or when we rose over the Goldstone tracking station 20 minutes later.

The fact that TDRS did not get a lock on the transponder and hence, that we could not get engineering data from the spacecraft, though disappointing, was not surprising, since it was an experiment. However, that minor disappointment was completely offset by my knowing Lunar Prospector was alive! We waited the twenty minutes for Goldstone rise, feeling very sure we had a good spacecraft on its way to the Moon.

As we waited for the spacecraft to rise over Goldstone, TDRS kept trying to get a two-way lock (a two-way lock is when the tracking station, in that case TDRS, sends a highly stable, reference signal to the spacecraft, which locks on the incoming signal and then, using that reference signal, transmits its data back to the tracking station, i.e., the signal goes both to and from the spacecraft) so we could get Doppler data to determine the spacecraft's velocity and to get downlinked data. Finally, I told them to just try to get a one-way lock (a one-way lock is when the tracking station just receives the signals being transmitted by the spacecraft without the use of a reference signal) and that didn't work either.

At 000/00:18 MET, as pre-planned as the spacecraft rose over Goldstone, I told TDRS to stop trying to lock-up on the spacecraft, because we were getting ready for Goldstone to pick us up.

000/00:18 MET through 000/01:10 MET: Goldstone and More Communications Problems

Very shortly after I told TDRS to cease operations, Goldstone, which was using both the 26-meter and the 34-meter antennas to track Lunar Prospector (to insure that we had coverage at the critical beginning of the mission), acquired Lunar Prospector. It was a little before 000/00:19 MET (the expected acquisition-time was 000/00:20 MET and was calculated on the assumption that the spacecraft had to rise a few degrees above the horizon to allow for the disturbing effects of the Earth's atmosphere, but they acquired Lunar Prospector very shortly after it had cleared the horizon). The fact that Goldstone had acquired Lunar Prospector just after it came over the horizon at the pre-calculated rise-time, said loud and clear that we had had a good TLI burn — if not, Lunar Prospector would not have been visible from Goldstone, period! The entire TLI sequence had worked as planned — what a relief!

At 000/00:21 MET, a couple of minutes after Goldstone had acquired Lunar Prospector, Goldstone got a two-way lock and the graphics on Dan's and my computer screens began to come live — Lunar Prospector was saying, *"Hello," to its masters!*

However, there were data dropouts and data spikes — the data were as erratic as hell! We didn't know what was going on, but we clearly had low signal strength and a poor link. The data on my screen were coming from the 34-meter antenna and Dan was getting his data via the 26-meter dish. Dan started getting readable data first, so I looked over at his screen and it was apparent the spacecraft was in good shape. The spin rate was about 51 rpm, instead of the expected 57±3 rpm, but that was OK. More importantly, there was only a small amount of Dan's dreaded nutation — proving that whole fiasco had been a waste of time, as I had always believed.

Then we both got some more data, though it was still sketchy, with all kinds of dropouts and data spikes. I saw that the engine temperatures were spiking — normally a sign of an inadvertent engine firing, but not in that case, since the temperatures dropped to normal just as suddenly as they would spike. Then I saw that the pressure in the fuel tanks was exactly 438 psi and the tank temperatures were 20° C, just as they were before launch. Finally, the colorful "Acquisition Status Table" came to life and, at a glance, I saw that each green subsystem word had a green status word next to it and each red subsystem word had a red status word next to it — the turn-on had been perfect, so I immediately deleted that critical table; having served its purpose, it was never to be seen again!

Much slower than I liked, we began to piece more and more data together and, though the data were very erratic, we could see that all the subsystems were in perfect shape.

Goddard reported, based on very preliminary Doppler data, that our TLI velocity error was an amazingly low +1±2 m/sec, which meant we had essentially a perfect launch, and that took off some of the pressure of our communications problem — we did not need do an emergency corrective burn, we were right on target trajectory-wise.

After just a few minutes, we knew the spacecraft was in excellent shape and we had had a near perfect launch. Both of those things were very good to know, since I could not start sending commands until we were getting reliable engineering data, i.e., I was not in a position to try to do the safe-engine-verification and PIV open sequences until we had a good communications link (or com-link). We had to find out what was wrong with our communications!

We knew, of course, that the spacecraft was in its TLI burn attitude and hence Goldstone was looking nearly up the butt of the spacecraft, where the omni antenna pattern had a null point, i.e., right then, we had a very bad communication aspect angle. Nevertheless, we still thought there should be enough signal coming from the back of the spacecraft to gives us a good link. Since the aspect angle would get worse for a while and then start to get better as Lunar Prospector rose higher above the Earth, we expected the signal strength would start to improve within an hour, if that were the cause of the com-problem. Since the spacecraft and the trajectory were both in excellent condition, there was no rush to start commanding — time was on our side.

However, as soon as I had seen the erratic link, I asked John to find out what was wrong. Shortly after Goldstone had acquired the spacecraft, John had heard someone say on the com-network (or com-net), "We have a good lock," and he had immediately reported to me when I asked about the link's status. Since we had a good lock, I assumed the com-problem might be in the ground lines between Goldstone, JPL, and us and I asked John to check that out. I also asked Marcie, who had more experience than John with the com-net and the DSN, to come into the Glass Room and assist John — and Dougherty, who was greatly concerned, trouped in with Marcie, uninvited. The three of them were trying to find out what was going wrong with our com-link.

Unfortunately, the person who had said on the com-net, "We have a good lock," was not from the DSN, rather from TDRS! Even though I had told TDRS to cease operations at Goldstone rise, they kept trying to establish a lock on Lunar Prospector, which they finally did after they widened their frequency sweep. They had been using too narrow a frequency sweep to acquire Lunar Prospector during the 20 minutes they were supposed to be on line and achieved lock only after it was too late and that had caused confusion on John's and my parts. Since we thought the DSN had said they had "a good lock," (the only logical conclusion, since TDRS was supposed to be off line), I made the logical conclusion that we had a ground line problem, so I sent Marcie and John off on a wild goose chase. Had I known that the DSN *did not* have a stable lock on Lunar Prospector, I might have started looking in the right place for the source of our com-problem, instead of thinking about bad ground lines and poor aspect angles.

As a result, as Marcie and John found there were no ground line problems and as the improvement in the communication aspect angle did not reduce the data dropouts to an acceptable level an hour into the mission, it was clear I had to try to take command control of the spacecraft, before Lunar Prospector's increasing distance from Earth made the com-problem even worse.

I said to my Ops Team, "OK, let's get ready to send the safe-engine-verification-sequence," and John made a brilliant suggestion, for which I will forever be thankful to him.

John said, "Why don't you try sending a NOOP Command first" (we had two commands that I could send to the spacecraft that did absolutely nothing, hence the name NOOP, which is short for No-Operation, and hence I could see if commands were getting to the spacecraft without risking anything unfortunate).

I said, "John, that's a great idea; thanks a million!"

I quickly looked up the NOOP1 Command, its hexadecimal identification number and its VCID number, added the new command sequence to my Mission Profile with the red pen I used to check off the Mission Profile events and to modify the Mission Profile in real-time. I then asked Dan and Paul to verify that I had the correct command and identifier (we always did at least a triple check on every command that we sent to the spacecraft) and they did. *I was ready to take command control of Lunar Prospector and send it its first command.*

Then I turned to Paul and said, "Uplink, please prepare the NOOP1 Command for uplink."

Paul answered, "Yes Command." When he was ready, a few minutes before 000/01:08 MET, Paul said, "Command, I'm ready with NOOP1."

I said, "OK, send it on my mark in 20 seconds," and I began my well-practiced countdown, "20 seconds, 10, 5, 3, 1 and 0."

Paul immediately said, "Command away."

I watched the command table on my computer screen in anticipation of getting the echo of the command that the spacecraft would send back down to Earth after the C&DH had verified it was a valid command in its command table. The echo would appear in one or two data frames (32 or 64 seconds, depending on where the C&DH was in its 32 second frame cycle when it received the uplinked command). Then the hexadecimal numbers 640000 and 06 appeared on my screen and I said in my well-practiced way, "I have echo of 6-4-0-0-0-0, VCID of 0-6, both are correct for the NOOP1 Command. Paul, please execute the command on my mark at 000/01:08 MET."

Paul replied, "Affirmative."

At the appropriate time I began with, "20 seconds, 10, 5, 3, 1 and 0."

And Paul immediately said, "Command away."

A frame or two later I saw a CCA1F5 and 09 appear on my computer screen (the hexadecimal identifier and VCID of EXEC — the Execute Command) and I said, "I have Execute." Lunar Prospector had accepted, verified, and executed my first commands — I was ready to start taking control of the spacecraft, despite the numerous data dropouts. It was about 000/01:10 MET.

000/01:10 MET through 000/02:50 MET: The Initial Commanding and the Final Solution to the Communication Problem

Though we had the successful command test with the NOOP1 Command, I was in no rush to send the safe-engine-verification-sequence. We needed to be able to see if any of the engines heated up during the 5 seconds the PIV would be open during the tests, and the dropouts and data spikes were so numerous I could not be sure we could tell if we had a problem or not. We watched the data for another 10 minutes or so and then I told my Ops Team and the Engineering Support Team I was going to proceed with the engine test and I needed all eyes, especially Irv's eyes, on the engine temperature graphs to make sure we did not miss seeing an engine heat up amidst all the data spikes and data dropouts.

I then asked Paul to prepare to uplink the PIV Open Command and the file with EXEC, a 5 second wait, PIV Close, and an immediate EXEC. When Paul was ready, I had him uplink the PIV Open Command and I soon saw the command echoes, 5000AB and 06, on my screen, I read them off, verified them and then I said, "Send the file on my mark at 000/01:26 MET," and began my usual countdown.

Paul said, "Command away."

I watched for the echo of the EXEC and the moment I saw it, I said, "I have Execute — everybody watch the engine temperatures," and with one eye on the engine temperature graphic and the other on the command screen, I waited to see any rise in any engine temperature and for the echoes of the PIV Close Command and the EXEC. While those two echoes came very quickly, the engine temperatures remained constant, except for the dropouts and data spikes. We waited nearly twenty minutes to be sure we had not missed anything and/or for the com-link to get a little better (which it did not do) as the aspect angle continued to improve.

Finally, everyone agreed there were no engine leaks, so I prepared to open the PIV. I again asked everyone to watch the engine temperatures — even though the engine test had shown that none of the engines was fully on, one or more engines could have slow leaks that we would only notice after the PIV had been opened for several minutes, not just for 5 seconds. Then I had Paul uplink the PIV Open Command and, after having verified the echo, I had him uplink the EXEC at 000/1:46 MET. I saw and called out the Execute echo and watched the engine temperatures. Again the temperature remained normal. We were ready to reorient the spacecraft by 90°, to an SEA of –25°. Then the Earth would be in the best part of the omni antenna pattern — hopefully that would solve our com-problem — and the boom canisters could warm up in preparation for the critical boom deployment.

I told everyone we were going to do the 1st reor maneuver in the Mission Profile and I asked John to watch the downlink signal strength as we did the maneuver, expecting that our com-problem would cease once we got the spacecraft reoriented.

I asked Dan to select the appropriate pre-prepared reorientation maneuver file for the reor maneuver we had decided on. Given that there were not yet enough data for Dan to have determined the spacecraft's attitude accurately, that we had never fired the engines before, and that the file for this reor, by necessity, was pre-prepared, we did not expect, nor require, that the maneuver would be extremely accurate — all we needed was to get the spacecraft within a few degrees of the desired attitude.

After Dan selected the file, we started our formal burn parameter file verification routine we had developed during the SIMs. Dan re-checked the parameter file to be sure he had the correct one, then he called out its name and purpose and sent it to Paul's computer. Paul called the file up, read its name to Dan and me and asked if that was the correct file. Dan answered, "Yes." Then Paul opened the file, and with me watching over his shoulder and looking at my Mission Profile, Paul read the numbers in the four registers out loud to Dan and me and we checked the validity of each number (the four engine parameters were as follows: DELAYSUN, the time when the first engine [A1] fired after each Sun pulse was received by the C&DH from the Sun sensor [0.6817 sec]. SHORTDUR, the duration of the short burn pulses [0.167 sec]. HALFREV, the time after engine A1 fired, that engine A4 was to fire [0.4086 sec]. And DELAYNUM, this was two parameters in one; the first part [DELAY] was the time delay between the time the command was received by the C&DH and the execution of the burn [this could be up to 63.75 minutes, but was 0 seconds for all but 5 burns during the entire mission] and the second part [NUM] was the total number of pulses that were to be fired [230 pulses in the case of the 1st reor and 1 for long burns, i.e., 1 long pulse. It would take 9 minutes for all 230 pulses, 115 pulses on A1 and 115 pulses on A4, to fire and to reorient Lunar Prospector by the required 90°]).

When we were satisfied that the file and the parameters were correct, I asked Dan formally, "Are you ready to have the file loaded?"

Dan answered equally formally, "Yes, I am."

I told Paul to uplink the file, which he did on my usual time mark, "10, 5, 3, 1 and 0."

Paul said, "File away."

I watched my echo screen intently, waiting for the one or two 32-second data frames to pass and waiting to start our strict file uplink verification procedure with Dan — a procedure Dan and I had practiced over and over during the SIMs, so it was absolutely routine. Then, amidst the data dropouts and data spikes, I saw the first echo and I said, "I have echo of DELAYSUN of 3-1-0-2-9-D, VCID 0-6. Is that correct, Dan?"

Dan answered, "Yes it is."

The next frame appeared on my screen and I said, "I have echo of SHORTDUR of 3-1-0-1-2-C, VCID of 0-6. Is that correct, Dan?"

Dan answered, "Yes it is."

The next frame appeared and I said, "I have echo of HALFREV of 3-3-0-7-4-2, VCID of 0-6. Is that correct, Dan?"

Dan answered, "Yes it is."

The next frame appeared and I said, "I have echo of DELAYNUM of 3-0-0-1-4-0, VCID of 0-6. Is that correct, Dan?"

Dan answered, "Yes it is."

Having seen all four engine firing parameters correctly echoed back from the spacecraft, I then asked, "Dan, do you concur with the entire load?"

Dan answered, "Yes I do."

I asked Paul to send the Engine Selection Command for the A1 and A4 engine pair that I would use (and always did) for the reor maneuver. Then I told him to send it on my mark and then I waited for the echo. One or two frames passed and I said, "I have echo of 3-8-0-0-4-8, VCID 0-6, which is correct for the A1 and A4 engine selection." Then I again asked Dan, "Do you concur with the entire load (including the engine selection)?"

Dan answered, "Yes I do." We were ready, despite the data dropouts and data spikes that still plagued us.

I said to Paul, "Please send the Execute on my mark at 000/02:27 MET and have the Set Command Registers and Execute file (the SETCMDREG Command reset all the engine burn parameter registers to 0, so there could be no inadvertent engine firings when we were not looking) ready to send at the end of the burn."

Paul answered, "Affirmative."

And he waited until I said, "20 seconds, 10, 5, 3, 1 and 0."

Paul immediately said, "Command away."

We waited the one or two data frames for the verification that the silent fireworks had begun.

I saw the EXEC echo and started to say in my standard way, "I have Execute."

Dan said simultaneously, "NUMTIME, 229 (the spacecraft had fired the first [230th] pulse and was counting-down the number of pulses remaining, i.e., Dan was reading the second part of DELAYNUM which we called NUMTIME)." That was our first indication that our first burn was underway! A data frame later I saw that the A1 and A4 engine temperatures had jumped to several hundred degrees. Dan periodically read off the remaining number of pulses, the slight amount of nutation caused by the shaking of the spacecraft by the pulses, and the slowly decreasing SEA as Lunar Prospector was slowly reorienting itself towards the target SEA of –25°. Simultaneously, I read out the A1 and A4 engine temperatures, which had reached equilibrium at just under 1000° C after several frames, the periodic increases in the load current as the engines fired and the slight decrease in the tank pressure as we used the small amount of fuel required for the reor maneuver.

The burn was going well and it looked like we were going to end up with a SEA of about –20°, which would be OK. However, we still had numerous data dropouts and John saw only a modest improvement in the downlink signal strength! Slowly, the nine minutes passed and Dan finally said, "Burn time up." The burn was over.

Almost immediately I saw that the temperatures of the A1 and A4 engines begin to drop — the first positive sign that the engines had stopped pulse firing and I said, "A1 and A4 temperatures are dropping; the burn is over."

I had Paul uplink the SETCMDREG and EXEC file that was executed at 000/02:43 MET and we saw all the parameter registers go to 0. *Our first burn maneuver was completely finished!* However, we still had data dropouts and data spikes, not as bad as before, but still quite bad! We were sure that the reorientation of the spacecraft to the optimum aspect angle would have fixed our com problem, but it did not!

The next command in the Mission Profile was the command to change the downlink rate from the engineering-data-only, 300 bps to the science and engineering data rate of 3.6 kbps. Then it dawned on me — I remembered the trouble we had getting a good link at the 300 bps data rate during the RF Testing (July 10, 1997) and during the End-to-End Testing at the Cape (December 6, 1997) and I said to Dan, "Remember the trouble we had linking up at 300 bps during testing? I'll bet that what's causing the com-problem. I'm going to proceed with the changeover (from 300 to 3600 bps) and see what happens." Then I told John to tell the DSN that we were switching from 300 bps to 3600 bps at 6:14 GMT (000/02:49 MET) and I told Paul to prepare the T3600 Command for uplink. Paul did and I had him uplink it to the spacecraft. After receiving the echo and verifying it, I said, "Uplink, send the Execute at 000/02:49 (MET) on my mark. 20 seconds, 10, 5, 3, 1 and 0."

Paul said, "Command away."

A frame later, I saw the EXEC echo and a 3600 replace the 300 on the data rate indicator on my screen and I said, "I have Execute, the data rate has changed from 300 to 3600 bps." Immediately the data dropouts and data spikes ceased! Cautiously, I said, "Well, it looks like that did it," and we watched for a few more frames and the data were absolutely clean. The com-problem was gone and I again remembered that during the RF Testing (July 10, 1997), I had considered changing the initialization sequence so it turned on the 3.6 kbps data rate instead of the 300 bps data rate and, for all the right reasons, Tim Bridges had talked me out of it. I thought, *crap, I wish I hadn't listened to Tim* (he could not have anticipated that we would have trouble with the 300 bps link) *and I had changed the initialization sequence, or at least, I had recognized that the bad link was due to the 300 bps and switched immediately to 3.6 kbps. If I had done either of those things, I wouldn't have the com-mess I've had for the last two hours. Oh, well, hindsight is always better than foresight.*

Though slightly aggravating and though I had to completely change the Mission Profile around to makeup for the lost time, the com-mess had not really put us in danger. I redlined my Mission Profile to account for the many changes needed to get us back on track — the main change was shifting the 1st midcourse maneuver (MCM) from 000/04:30 MET to 000/08:30 MET to allow me to get the booms deployed as soon as possible, to do the initial science instrument turn-on sequence, and, just as important, to allow the Nav guys to get some good data, since their Doppler tracking data were also compromised by the poor com-link.

I told everyone how I was changing the Mission Profile and said, "I'll follow the redlined version starting with the despin maneuver that was originally scheduled for 1:09 (000/01:09 MET) and that will now be executed as soon as I can, but I want to get back to the original schedule, with the normal verification periods between events, as soon as I can."

000/2:50 MET through 000/04:30 MET: Boom Deployment and Back On Track

From about 000/02:50 MET on, everything was just like a SIM, so much so that sometime after boom deployment, I turned to Dan and said, "Man, this is just like a SIM."

Dan replied, "It sure is!"

Though we were nearly two hours behind the timeline of the Mission Profile, the spacecraft was still quite warm, about 10° C higher than expected, but Jim said the temperatures were slowly coming down to the levels he had expected, just more slowly than he expected. Apparently, the spacecraft was warmer at launch than it was supposed to have been and the cooling times were longer than Jim calculated. All that was very good, since the boom canisters were still warm. Dougherty, Steve Honodel, Jim, Dan, and I discussed the boom deployment and we all agreed that the canister temperatures were high enough for us to proceed.

The first step in the boom deployment sequence was the despin maneuver. The spacecraft was spinning at 51 rpm and we had to decrease it to 30 rpm for boom deployment. Taking into consideration the tank pressure and amount of fuel remaining, Dan and I each calculated the required burn time on the T1 engine. Dan did it using his program on his Mission Ops console computer, on which he automatically developed the burn parameter file, and I did it on my laptop computer, sitting next to my computer console. As was our practice, we compared our answers and had essentially the same result — a 6.09 second burn. Since there was no discrepancy (outside the very small differences due to the different ways we each had interpolated the test data on the engines Olin had provided), I said, "I accept your value (as I always did, if the results were essentially the same, since his values went directly into the burn parameter file in his computer and mine did not). Please prepare the burn file and send it to Uplink."

As soon as Dan did that, we went through our standard burn parameter file cross checks and read backs. When we were satisfied that the file was correct, I asked Paul to uplink the file on my mark. Then, as the echo of each of the four parameters plus the engine selection (T1), appeared on my screen, I read it, verified it, and asked Dan if it was correct. When all four parameters and the engine selection had been again verified, I asked Dan my standard question, "Dan, do you concur with the entire load?"

Dan answered, "Yes I do."

I said to Paul, "Please send the Execute and Engine Safeing File (burn Execute, wait 32 seconds, STOPFIRE [a backup Engine-Off Command just in case the engine did not shut off as planned in 6.09 seconds], SETCMDREG, and Execute) on my mark at 000/03:05 MET."

And Paul answered, "Affirmative."

And we waited until I said, "20 seconds, 10, 5, 3, 1 and 0."

Paul immediately said, "File away."

After the usual delay, I saw the EXEC echo and started to say my standard, "I have Execute."

Dan simultaneously said, "NUMTIME, 0."

A data frame later I saw that the T1 engine temperature jumped to several hundred degrees, the tank pressure dropped from its static value of 431 psi to its lower, dynamic value of 426 psi and the load current jumped by about 1 amp — all as expected. By the next frame (32 seconds), the 6.09 second burn was long over, the T1 temperature had started to drop, the load current had dropped back an amp, and the tank pressure had returned to its static value and I said, "T1 temperature is dropping, load current is again 5 amps, and the pressure is 431 psi — the burn is over," and I saw and called out the echoes of the STOPFIRE, SETCMDREG, and EXEC, and added, "The T1 engine is safed."

Dan had to wait a little while longer to call out the new spin rate, since at spin rates higher than about 20 rpm, the Sun pulses were coming so fast that the C&DH had to buffer the data and spit out the new spin rate when it had had time to get through its data overload. Finally Dan said, "The spin rate is 31 rpm." Which was 1 rpm high, but well within what was acceptable for boom deployment.

I called Dave Curtis into the Glass Room and he took his seat in front of the MAG/ER console. When Dave was ready, I had Paul uplink the command to turn on the MAG. After I verified the echo (2400D4, 06) and after Dave verified the command on his screen, I had Paul uplink the EXEC at 000/03:11 MET and a frame or two later, I saw and called the EXEC echo (CCA1F5, 09) and saw on my status table that the MAG/ER change from off (red) to on (green) and my MAG/ER plots come alive with the engineering data (voltages, currents, and temperatures).

Simultaneously, Dave said, "I'm getting data" (at that point in time, the spacecraft was still deep in the Earth's magnetic field, so we began to get the desired MAG calibration data in the well known geomagnetic field). *I had just turned on Lunar Prospector's first science instrument and we were getting the first science data of the mission!*

I asked Dave what the spin rate was according to the MAG data and he said, after a short pause, "31 rpm," which was correct (that was important since I would have to rely on Dave's determination of the spacecraft's spin rate, using the MAG data, during the first part of the boom deployment — when there was the delay in getting the spin rate from the Sun pulse data due to its being buffered as a result of the high spin rates).

I asked Dave if he was ready for me to pop the MAG extension boom and he answered, "Yes." I told Paul to uplink the MAGBOOM Command, which he did on my usual mark. Before issuing the EXEC, I reminded Dave to announce the apparent 100° rotation of the Earth's magnetic field and the decrease in the spacecraft's spin rate as the little boom deployed, and I reminded Dan to call out the increase in the spacecraft's nutation, the change in its attitude, and the decrease in its spin rate after deployment.

At 000/03:15 MET, I had Paul uplink the EXEC and out there, deep in space, the two little wire-cutter-pyros silently popped and the little boom swung out. Shortly thereafter, I saw the echo and I said, "I have Execute."

Dave said, "The magnetic field has rotated 100° and the spin rate has decreased by 0.6 rpm."

Shortly thereafter, Dan confirmed the decrease in the spin rate and added, "I have a degree or two of nutation and the SEA is now –19°." The deployment of the MAG extension boom went perfectly and we were ready for the critical deployment of the main booms.

I asked Steve to come into the Glass Room to prepare for boom deployment. Steve was nervous, as usual. I asked him if he was ready to support the deployment and he answered, "Yes." I told Steve what the bus voltage was and what the temperature of the viscous damper was and asked him to calculate how long I should command the paraffin actuator heater on. Steve calculated an on-time of 135 seconds, but said it should pop in about 70 seconds. Then I asked Paul to insert the on-time into the boom release command (RELBOOMS), which he did and then Dan, Steve, and I verified it.

Before I had Paul uplink the RELBOOMS Command, I reminded Dave to call out, "First motion," the instant when he saw from the MAG data that the booms had been released and then to call out each apparent quarter revolution of the Earth's magnetic field (as the booms uncoiled and rotated 4 times during the deployment), the decrease in the spacecraft's spin rate, and the final snap-over when the booms were fully deployed and locked into position. Then I reminded Dan to call out the decrease in the spin rate derived from the Sun pulse data, the nutation, and any change in the SEA (if the booms were not deploying evenly, the SEA would change and the nutation would increase dramatically). Finally, I asked Dan, Dave, and Steve if they were ready to support the deployment and each answered, "Yes," and then I asked Paul to call out the time every 10 seconds since heater turn-on.

Paul said, "Affirmative."

Finally, everything was ready and I told Paul to uplink RELBOOMS on my mark and I began my count down, "20 seconds, 10, 5, 3, 1 and 0."

Paul said, "Command away."

A frame later I had the echo and I called out, "I have echo of 2-7-0-5-4-6, VCID 0-6, which is correct for boom release." Then I said, "Send the Execute on my mark at 000/03:44 MET," and I again began my count down, "20 seconds, 10, 5, 3, 1 and 0."

Paul again said, "Command away."

Then I saw the EXEC echo and said, "I have Execute," and I saw the expected increase of 0.8 amps in the load current, indicating that the paraffin actuator heater had turned on.

Then we waited. Slowly, as Paul called out the time, the viscous damper's temperature began to increase a few degrees, indicating that the heater was heating the paraffin actuator, and we waited. Paul said, "10 seconds . . . 60 seconds, 70 seconds, 80 seconds."

At about 87 seconds, Dave said, "I have first motion!" — up in space, the paraffin had melted and forced the plunger of the actuator out; the plunger had tripped the release mechanism, which had caused the 3 latching pins on each of the three booms to disengage, releasing the three booms; instantly, the booms had jumped out about a centimeter and rotated a few degrees — *first motion* had occurred and it was faithfully detected in the MAG data by David. The critical boom deployment was underway.

Dave called out the first quarter revolution of the Earth's Magnetic field (and hence of the MAG/ER boom) and the corresponding decrease in the spin rate of the spacecraft. The buffered Sun pulse data started to yield spin rate data and Dan also called out the decreasing spin rate and the fact that, except for the small increase in the spacecraft's nutation caused by the jolt as the booms released, the nutation was not increasing. All were good signs we had had a simultaneous release of all three booms and they were deploying uniformly.

Dave kept calling out the quarter revolutions of the booms and the decreasing spin rate, followed 10 to 15 seconds later by Dan's confirmation of the decreasing spin rate and the steadiness of the nutation. After a few minutes, it was clear the spacecraft spin-down was following the expected curve as a function of the number of boom revolutions called out by Dave. The booms were deploying evenly and correctly. As the process continued, it got slower and slower as expected. Finally, after about 20 minutes, Dave called out, "Four revs and snap over!" Boom deployment had been successfully completed!

Dan and Dave both reported that the spin rate was 6.825 rpm and Dan said, "The snap-over caused a slight increase in the nutation, as expected, and the SEA has changed slightly to –20°!" We had had a perfect boom deployment! At that point, *Lunar Prospector was in its final flight configuration in terms of all of its engineering subsystems!*

We watched the spin rate and the MAG data for a few minutes to be sure everything was holding steady — and they were. Then I said formally, "We have successfully deployed the science booms and I will proceed on the redlined timeline of the Mission Profile." Then I said to Steve, "Thank you for giving me three good booms. Please say thanks to Able for the great booms and the great deployment. Now I would like you to leave Mission Ops."

Steve said, "Thanks and I'll thank Able for you, and boy, am I relived," and then he gratefully left the Glass Room.

Then, while Dave continued to monitor the MAG data (I still needed him in the Glass Room for the rest of the MAG/ER turn-on and the calibration test I would command in a little while), I got prepared for the final step in the boom release sequence — the spin-up to our operational spin rate of 12.0±0.7 rpm.

Dan and I made our respective calculations of the spin-up burn on engine T2 and came to the conclusion that we needed a 6.58 second burn. Dan prepared the burn parameter file; we verified it; he sent it to Paul; Paul, Dan, and I verified it; then we did the read-back check and when we were all satisfied everything was correct, I had Paul prepare the standard EXEC and Engine Safeing File. When Paul was finished, I had him uplink the burn parameter file on my mark. Then, as the echoes of the burn parameters and the engine selection came back, I read them off and had Dan confirm each one. Then I asked, "Dan, do you concur with the entire file."

Dan answered, "Yes, I do."

I told Paul I would execute the file at 000/04:21 MET and started my countdown. At "0," Paul uplinked the file and soon Dan and I were calling out our standard burn comments as we watched the echoes and data come in. Then the engines were safed and Dan called out that our spin rate as 11.2 rpm, 0.1 rpm less than the minimum we had shot for, but it was still OK. We would make the final correction to the spin rate after the 1st MCM in a little over 4 hours.

Then Woody, after having watched the battery's performance for the previous couple of hours, recommended I change the battery charge rate from VT2 to VT4 (VT meaning Voltage/Temperature curve). I redlined my Mission Profile and had Paul prepare a command file containing the VT4 Command. Then I had him uplink it and, after verifying its echo, I had him execute it and I watched my console for its echo and the change from VT2 to VT4. It was 000/04:30 MET when that was finished.

000/4:30 MET through 000/07:00 MET: Finishing the Initial Science Instrument Turn-On Sequence and the Reor to Cruise Attitude

After having changed the VT curve for Woody, I was ready to proceed with the rest of the science instrument turn-on sequence and the reor to cruise attitude. By that time it was clear the spacecraft and my Ops Team were both performing flawlessly — we knew we could run the spacecraft and it did what we asked it to do. ***It truly was just like a SIM, though much better — it was the real thing!***

According to the Mission Profile, I was to do a two-step MAG calibration sequence and turn-on the ER. I told David to get ready to observe the test and to verify the commands at his console after I had verified them on my console. The MAG calibration sequence started at 000/04:32 MET and was finished, on time, at 000/04:36 MET. It showed the MAG was performing perfectly. Then I went through the normal command and verification sequence with Paul and Dave to turn on the ER's low-voltage, so it could start its degassing process that would allow me to turn on its high-voltage the next evening. The ER was turned on at 000/04:42 MET. Since there was more MAG/ER testing to be done in a little more than an hour, I allowed Dave to stay in the Glass Room to watch the MAG data until we would proceed with the MAG/ER tests.

I was ready to start the initial turn-on sequence for the spectrometers, so I called Bill Feldman into the Glass Room. Unlike Dave, who is always calm and collected, Bill was excited and slightly nervous — as Bill usually is at such times. As was Dave's job during the MAG/ER turn-on, Bill's job was to monitor the spectrometer commands and data as I commanded the spectrometers on and went through my command verification procedures. As always, every command was checked, at least twice, first by me at my command console and then by Bill at the spectrometer console, before I sent the EXEC for that command. Because Bill is somewhat excitable, and even though he had participated in turn-on SIMs, I carefully reviewed with him what I wanted him to do.

I had Paul uplink the command to turn on the Spectrometer Electronics System (SES). I executed that command at 000/04:45 MET and after seeing the SES had turned on according to my status screen and after seeing the expected changes in the load currents and voltages, I asked Paul to route the spectrometer data from Oasis to the spectrometer console and Bill began to see the engineering data on his screen and verified it for me. Then, on three minute intervals, between 000/04:58 MET and 000/05:04 MET, I commanded the low voltages on for the NS, GRS, and the APS. While I would have to wait for the NS and the GRS to degas before turning on their high-voltage supplies the following evening, the APS was fully operational, though I had to do an APS test sequence after turning on the A1 and A4 engine heater in preparation for our next reor burn. Nevertheless, at that point in time, I had *two of my five science instruments, the MAG and the APS, fully turned on* and they were providing data in a known environment so we could calibrate them before we reached the Moon.

According to the original Mission Profile, I would then have done a series of tests on the APS to fully check it out. However, because of the delays due to the initial com-problem and the resulting need to put the spacecraft in a negative attitude to warm the boom canisters in preparation for the critical boom deployment, I needed to get the spacecraft into its normal cruise attitude. Because time was of the essence until the booms were deployed (even under normal conditions and especially after the com-delays), I had not (nor had I planned to do so in the original Mission Profile) pre-heated the A1 and A4 engines before firing them for the first reor, nor the T1 engine before the first spin-down burn, nor the T2 before the first spin-up burn. Though the engines can be fired cold a few times without problems, they need to be pre-heated to prolong their lifetimes. When I inserted a reor burn to get the spacecraft into its nominal cruise attitude in the redlined Mission Profile, Irv strongly recommended I pre-heat the A1 and A4 engines. Since time was no longer a problem, I followed Irv's recommendation and redlined a standard A1 and A4 heater turn-on sequence into the Mission Profile and asked Paul to prepare that file for uplink.

Paul got the file ready, we verified it and then, on my mark, he uplinked it. Shortly thereafter, I got and verified the echo for the A1 heater, which was executed at 000/05:10 MET, and then I got the echo for the A4 heater, which was executed at 000/05:11 MET. I saw the expected 0.2 amp increase in the load current when each heater turned on, and after a few data frames, the A1 engine temperature started to climb, followed shortly by the A4 engine temperature. Having successfully turned on the heaters for the first time, I returned my attention to finishing the APS and MAG/ER testing that was part of the initial science turn-on sequence — but I kept my eye on the increasing temperatures of the A1 and A4 engines.

Following the Mission Profile, I started the test of the APS with Bill and it ran from 000/05:13 MET to 000/05:35 MET, which just happened to be the time needed for the engines to heat up! During the test, I first shut off the detectors on all five faces of the APS and then turned on the detectors, one face at time, so Bill could check out each face's performance. Faces 1, 2, 3, and 4 were perfect, but Face 5 looked a little funny — Face 5 was the –Z facing Face I was concerned about when I saw where the APS was located with respect to one of the TLI Stage spin-up rockets back in June (June 27, 1997) and with respect to one of the nitrogen jets of the collision avoidance system when we were doing the spin balancing at Astro Tech (December 13, 1997). Bill said he would have to monitor the Face 5 data, with the APS fully on, for a while to see if anything was really wrong with it. We finished the APS test and I turned all five faces back on and asked Bill to leave the Glass Room, since I was about to do the reor-maneuver.

Also, by that time, over 5½ hours into the mission and just after 1:00 PM, Goddard Nav informed us that their original estimate of the TLI velocity error of +1±2 m/sec, which was based on the poor Doppler data yielded by our poor com-link, was off. The real ΔV error was about –10 m/sec, which would require about a 60 m/sec MCM burn at the new burn time of 000/08:30 MET. That was OK, since I had allocated 80 m/sec of ΔV for all three MCM burns, but the delay in the 1st burn was going to cost me an extra 20 m/sec of ΔV. Also, I remembered the Athena crew had told us the Athena was going to give us a 7 m/sec over-burn after we had stacked the payload on the rocket, so I had had Kim add ballasting to the TLI Stage to compensate for the over-burn (December 26 through 28, 1997). Had they not made that mistake, our TLI velocity error would have been just –3 m/sec, instead of –10 m/sec — one last blow from the Athena crowd!

While I was busy commanding the last of the initial science instruments turn-on sequence and testing, Dan was busy getting his first good solution for the spacecraft's attitude using the Sun sensor and Earth/Moon (EM) limb-crossing sensor data and preparing the file for our up-coming reor to the cruise attitude. With that file prepared and with the A1 and A4 engines hot, we began our standard and careful series of checks on the file and its burn parameters. Then I had Paul send up the file and I carefully read off the echoes, asking Dan if each parameter was correct and then asking him if he concurred with the entire file. When all the checks and rechecks were finished, I then had Paul uplink the EXEC Command at 000/05:58 MET. Shortly thereafter, I called out the Execute echo and Dan and I then called out the events of the reor burn. The reor maneuver took 8 minutes to complete, consisted of 45 pulses on the A1 and A4 engines, and changed the attitude by 21.2°. We then had the spacecraft in its nominal cruise attitude. At 000/06:07 MET, I had Paul uplink the Engine Safeing Command — our second reor-maneuver of the mission was finished.

Finally, I was at the place in my redlined Mission Profile where I would finish the initial turn-on and testing of the MAG/ER with Dave, who had been sitting at the MAG/ER console, watching the MAG data roll in and, when we did the 21.2° reor, he had noted the corresponding 21.2° rotation of the Earth's magnetic field. I told Dave I was ready to proceed and I first opened the ER cover (000/06:20 MET) and then we went through a 13 Step ER Pulser Test that started at 000/06:23 MET and ended at 000/06:45 MET. When we were finished, the ER was ready to go as soon as I turned on its high-voltage the following evening. With the end of that test, I was finished with the initial turn-on sequence of the science instruments and it was just after 3:00 in the morning.

Since the science instrument work was done for the night, Dave and Bill decided it was time to turn in, and, along with the few visitors who had not already left, they left Mission Ops. The only people who were left were my Mission Ops Team, the Ames Nav Team, Marcie, Dougherty, and the rest of the Lockheed support engineers and the Mission Controllers who would take over watching the spacecraft when my Command Team and I finished our first command session.

000/07:00 MET through 000/11:00 MET: The 1st MCM

The final event of our planned Day 0, post-launch, turn-on activities was our 1st MCM. By that time, Goddard Nav had the velocity vector data for the MCM. We had to do a 12.97 m/sec continuous burn on axial engines A1 and A2 and a 48.6 m/sec pulsed burn on tangential engines T1 and T2. Dan and I checked the Goddard data and we each calculated the burn durations. We independently calculated that the axial burn would last 55.5 seconds and the tangential pulsed burn would consist of 276 pulses and hence, had to be broken down into two burn files, the first with the maximum number of pulses we could put in a file, i.e., 255, and 21 pulses in the second file. The pulsed burns would last some 23 minutes, plus the few minutes we would need to uplink the second pulsed burn file. The whole 1st MCM would last about ½ hour.

Once Dan and I had made and compared our calculation for the burns, we had a conference with the Goddard Nav Team and our Ames Nav Team (Dave Lozier and Ken Galal), and with Marcie, who stuck her nose in. Though we had done two reor burns and two spin adjustment burns already, the 1st MCM maneuver was our first major ΔV maneuver and we could not afford to make a mistake. Finally we all agreed we had everything right and Dan prepared the three burn files and sent them to Paul. Then we began our careful checking and verification procedure. The files were correct and I was ready to begin the commanding sequence.

First, I had Paul prepare the standard A1, A2, T1, and T2 heater turn-on file, we checked it, Paul uplinked it on my mark, and then as I saw the first echo, I said, "I have echo of 2-E-0-0-2-A, VCID 0-6, that is correct for the A1 heater," then at 000/07:36 MET, the first EXEC went up and I soon said "I have Execute." Then in succession, the remaining three heater echoes and their Executes appeared on my screen and I methodically read each off and verified it. By the time the entire heater turn-on file had been uplinked, i.e., at 000/07:39 MET, the load current had increased the expected 0.8 amps and I saw the A1 temperature was already beginning to rise. Within a few minutes, all four engines were heating up towards their 120 to 140° C pre-burn temperatures.

As the engines were heating up, I asked Paul to call up the burn parameter file for the axial burn. He did and then Dan, Paul, and I checked and verified the file and when we were satisfied, I had Paul uplink it and I read and verified, with Dan, that each of the four burn parameters and the A1 and A2 engine selection were all correct as their echoes came back from the spacecraft. When we were finished, I asked, "Dan, do you concur with the entire load?"

Dan answered, "Yes I do."

I turned to Paul and said, "Please Execute the file on my mark at 000/08:30 MET."

Paul said, "Affirmative." Soon I was counting down in my standard way and when I hit "0," Paul said. "Execute away."

As I said, "I have echo of Execute."

Dan said, "NUMTIME 0."

I saw the A1 and then the A2 temperatures jump several hundred degrees, the load current jump an amp and the tank pressure drop by 17 psi from its static value (428 psi) to its dynamic value (411 psi). The axial burn was under way. The engine temperatures continued to rise for two frames and the pressure began to drop as fuel was being used. Then the 55 second burn was over, the load current dropped by nearly 2 amps as the engines shut off, the tank pressure jumped back up to its static value and the A1 and A2 engines began to cool off.

Then we verified, uplinked, verified via the echoes, and then executed the first burn file for the first 255 pulsed burns on the tangential engines. I watched the T1 and T2 engine temperatures, the tank pressure, and the load current for the usual signs of the burn's beginning and ending, while Dan called out the number of pulses remaining and the very slight spin-up and very slight reor of the spacecraft caused by the very slight misalignments and the slight differences in the thrust levels of the engines. We knew that both of those things would happen, but we did not know if the spacecraft would spin-up or spin-down during the burns and how much reor would occur. We were beginning to learn those things during that first really long set of burns (as it turned out, no matter which set of engines we used, the spacecraft always spun up a little during each burn — statistically we expected that some set of engines would have despun the spacecraft, but it just so happened that the slight misalignments and slightly different thrust levels of the engines all resulted in spin-ups).

As soon as I called out, "Engine stop," we quickly verified, uplinked, verified and executed the second file with the final 21 pulses of the tangential engines. When those 21 pulses were finished, I had Paul send up the Engine Safeing Command and suddenly we were completely done with the Day 0, post-launch commanding session — it was 000/09:05 MET or 4:30 AM Wednesday, January 7, 1998. We had been in Mission Ops for 14 or 15 hours and I had been up for some 24 hours, but my fuel tank was filled with adrenaline and though I could feel the fatigue in my body, I was not tired — *who could be with a perfect spacecraft racing towards the Moon!*

Speaking of which, Goddard Nav reported their preliminary evaluation of our 1st MCM burn was that we had over-burned by a whole 0.2 m/sec! That was an error of 0.3% on engines that were rated with a 1% uncertainty! What could one say about my simple little spacecraft after such an astounding 9 hours of operations, during which we had sent 130 commands without error — a dumb little spacecraft with no computer that was run by four people on the ground?

The only thing that I was concerned about was the temperature of the GRS, which had been dropping steadily from its launch temperature of about 20° C towards its operational temperature of –28 to –29° C, increased a few degrees during the pulsed burns of the tangential engines during the MCM. The reason was clear — because the two tangential engines pointed in the same direction as the GRS boom and the GRS was only about 3.3 m from those two engines, the GRS was enveloped in the hot gas plumes of the tangential engines during the pulsed burns. Jim Schirle was initially concerned that the plumes had degraded the thermal shield of the GRS and that the GRS would not cool completely down to its operational temperature. However, after the burn, we saw that the GRS temperature again began to decrease and it looked like it would probably be OK, but I would take a closer look at the GRS temperature as soon as I got back to Mission Ops after a few hours of sleep.

Even though we were finished with the first, critical commanding activities, we all stayed and monitored the spacecraft and the GRS temperature for more than an hour. While all the visitors had drifted away during the long night, my Engineering Support Team Members and Dougherty were still there, so I thanked them for their support and for helping me build such a perfect little spacecraft and then they drifted off.

Finally, I turned Mission Ops and my spacecraft over to the next shift of controllers that was led by Ric Campo and told them to call me at the motel across the street if anything at all looked funny. Then Dan, Paul, John, and I left to get some rest at about 6:00 AM or 000/10:30 MET.

As I walked the few blocks to my motel room, I was very pleased. Lunar Prospector had performed flawlessly — even when we had the damned com-difficulties because of the 300 bps data rate early in the flight — and my Ops Team and I had also performed flawlessly — all those SIMs paid off handsomely, as did my having a very simple spacecraft that was very easy to run. *My dream had come true.*

As I was about to go to bed for what I expected would be, at most, a couple of hours of sleep, I thought both about the question someone had asked me just before launch, if I was nervous and my answer, "No, there's nothing I can do about the launch, either the Athena works or it doesn't, and I completely trust my spacecraft and my Mission Ops crew. If we get launched, we will do our jobs. Also, if I were nervous, I would have no business being the Mission Director and the PI."

Chapter 4-2
The Translunar Coast

Wednesday, January 7, through Early Morning, Thursday, January 8, 1998

000/14:00 MET through 001/06:00 MET: High-Voltage Turn-on and the 2nd MCM

Technically, the translunar coast began at the end of the TLI burn (at 000/000:00 MET), since Lunar Prospector coasted most of the rest of the 105 hours it took to get to the Moon (except for the short periods of acceleration during the MCM burns). However, in practice, the coast began when we finished commanding the spacecraft at the end of the initial commanding session at 000/09:05 MET. By the time I had slept almost 3 hours and had returned to Mission Ops (at about 10:00 AM on the 7th), some four hours after having left it, the translunar coast was well under way. When I arrived at Mission Ops, I looked at my computer screen and Lunar Prospector was functioning perfectly.

I looked at the GRS cooling curve. The GRS had reached its operational range and was varying between –27.8 to –29.5° C, as planned. The GRS, like everything else on the spacecraft, had come to thermal equilibrium and all the subsystem temperatures were well within their expected ranges.

The only problem we had was with Face 5 of the APS. Bill still did not know why, but its detectors had lost sensitivity. In an effort to try to understand what was wrong with it, Bill asked me to set the detection threshold to zero. I redlined the necessary commands into my Mission Profile, checked them with Bill and Ric Campo, who was the Uplink Controller for that shift, and then commanded the APS detection threshold to zero at 000/16:21 MET or at 11:46 AM. If Bill could not figure out how to correct the problem with Face 5, that would mean the APS field of view would be asymmetric, but that couldn't be helped and it would not pose a serious problem for the mapping.

After finishing the APS commanding and since I had not eaten after I got up, Bill and I went out for a Mexican lunch and then came back to Mission Ops to continue monitoring the spacecraft and to prepare for the evening's commanding session, i.e., turning on the high-voltages of the GRS, NS, and ER and doing the 2nd MCM.

Rebecca arrived at the San Jose Airport (from the Cape) early Wednesday evening, while I was busy preparing for the commanding session. Thus she took a cab to our motel room and called me at Mission Ops. I picked her up and brought her to Mission Ops so she could watch the evening's commanding activities.

Rebecca told me that right after launch, when we were just taking control of the spacecraft and everyone wanted to know its status, NASA and Lockheed held their post-launch news conference to congratulate themselves on the successful Athena II launch and to announce that Gene Shoemaker's ashes were on board Lunar Prospector! There was no mention of the spacecraft's condition, the quality of the trajectory or anything about the critical commanding activities that were going on in Mission Ops! The only indication that Mission Ops even existed was via a TV screen behind the seated NASA and Lockheed bigwigs that showed a view of the backs of our heads as we sat at our computer consoles in Mission Ops! Rebecca said she and others were trying to find out