Mars Spacecraft Failures – How and Why
(appendix to unpublished book on human Mars exploration)

The Russian novelist Leo Tolstoy once observed that "happy families are all happy in the same way, but unhappy families are all unhappy in different ways." The same can be said of Mars probes. When they work, it's because the same basic things are all done right. When they don't work, it's because one particular fatal flaw out of many possible hazards was allowed to reach a catastrophic level.

But it's not as hopeless as all that, because often the foundation of these flaws can be seen to stem from one of only a few basic philosophical or management errors.

Before human missions to Mars can be undertaken, the roots of these flaws must be ferociously assessed, and iron-clad countermeasures must be developed, validated, and implemented. And although the 1990's saw a number of impressively successful unmanned Mars missions, such as Mars Pathfinder and the Mars Global Surveyor, planners of future Mars missions need to pay at least as much attention to the US and Russian missions which failed, and to why they failed. The scary part is that often they failed due to avoidable mistakes, when engineers did things which in hindsight were clearly wrong.

Take the ill-fated Mars Observer, for example. Launched by a giant Titan-3 booster on September 25, 1992, it was to have been the first U.S. spacecraft to study Mars since the Viking missions 18 years earlier. But spacecraft fell silent on Aug. 21, 1993, just three days prior to entering orbit around Mars, following the pressurization of the rocket thruster fuel tanks to be used in the braking rocket burn.

The final report by the independent investigation board on the failure was delivered to NASA on January 5, 1994. The telemetry transmitted from the Observer had been commanded off because it was feared that the shocks of the rocket firing might break the heated cathode in the radio's amplifier. Subsequent efforts to locate or communicate with the spacecraft failed. So the board was unable to find conclusive evidence pointing to a particular event that caused the loss of the Observer.

However, after conducting extensive analyses, the board reported that the most probable cause of the loss of communications with the spacecraft was a rupture of the fuel (monomethyl hydrazine (MMH)) pressurization side of the spacecraft's propulsion system. This resulted in a pressurized leak of both helium gas and liquid MMH under the spacecraft's thermal blanket. The gas and liquid would most likely have leaked out from under the blanket in an unsymmetrical manner, resulting in a net spin rate. This high spin rate would cause the spacecraft to enter into the "contingency mode," which interrupted the stored command sequence and thus, did not turn the transmitter on. Additionally, this high spin rate precluded proper orientation of the solar arrays, resulting in discharge of the batteries.

However, NASA considered that the spin effect may have been academic, because the released MMH also would likely have attacked and damaged critical electrical circuits within the spacecraft. The spacecraft would have quickly died and then flown right past Mars to drift through interplanetary space.

The board's study concluded that the propulsion system failure most probably was caused by the inadvertent mixing and the reaction of nitrogen tetroxide (NTO) and MMH within titanium pressurization tubing, during the helium pressurization of the fuel tanks.

These two chemicals are 'hypergolic' propellants, designed to explode spontaneously when mixed in a rocket chamber. If mixed somewhere else, they explode with equal enthusiasm but very unhappy results. This reaction caused the tubing to rupture, resulting in helium and MMH being released from the tubing, thus forcing the spacecraft into a catastrophic spin and also damaging critical electrical circuits.

Based on tests performed at the Jet Propulsion Laboratory (JPL) Pasadena, Calif., the board concludes that "an energetically significant amount" (NASA talk for "enough to blow up") of NTO had gradually leaked through check valves and accumulated in the tubing during the spacecraft's eleven-month flight to Mars.

The report also listed other possible causes of the loss of the spacecraft. There might have been failure of the electrical power system, due to a regulated power bus short circuit. There could have been NTO tank over-pressurization and rupture due to pressurization regulator failure. Perhaps there had been an accidental high-speed ejection of a NASA standard initiator from a pyro valve into the MMH tank or other spacecraft system. But these were less likely failures.

As to contributing causes, the report cited the need to establish a policy to provide adequate telemetry data of all mission-critical events, which didn't happen on this mission. It pointed to the lack of post-assembly procedures for verifying the cleanliness and proper functioning of the propellant pressurization system. Also, engineers had made unwarranted assumptions based on a lack of understanding of the differences between the characteristics of European Space Agency and NASA pyro-initiators (explosive bolts), both kinds of which were installed on the spacecraft. The report also recommended more study of the potential for power bus short circuits, due to single component or insulation failure, and the potential for command and data handling control systems to be disabled by single-part failure. There were also deficiencies in systems engineering/flight rules, which hadn't been thoroughly developed due to inadequate time and inadequate experience on the part of the operations team.

The report especially criticized NASA for too much reliance placed on the heritage of spacecraft hardware, software and procedures for near-Earth missions. To save money, NASA had tried to redesign a DoD spacecraft that had been built for launchings into the 24-hour 'geostatationary' orbit, a flight that lasted barely six hours, not the almost year-long cruise needed to get to Mars. This original mission was "fundamentally different from the interplanetary Mars Observer mission", the report noted in understatement. Also, the use of a firm fixed-price contract as a cost-saving gimmick restricted the cost-effective and timely development of the unique and highly specialized Mars Observer Spacecraft and failed to allow the original design deficiencies to be repaired.

In the final report, investigation team leader Dr. Timothy Coffey, Director of Research at the Naval Research Laboratory, Washington, D.C., noted, "We were challenged to conduct an extraordinarily complex investigation in which we had no hard evidence to examine nor communications with the spacecraft. However, after an extensive analysis covering every facet of the mission, operations and hardware, I believe that we are justified in arriving at the conclusions we have. If our findings will help to ensure that future missions won't suffer a similar fate, we feel we will have achieved our purpose."

"I commend Dr. Coffey and his team for the thoughtful and thorough research into the tragic loss of the Mars Observer," replied Dr. Wesley Huntress, Jr., Associate Administrator for NASA's Office of Space Science, Washington, D.C., when he accepted the report "Their work will help and guide us in formulating a corrective action plan to help ensure future success as we plan for recovering our Mars science exploration objectives." But the degree of NASA's success in learning from its mistakes would soon be subjected to severe doubt.

The double Mars disasters of 1999 saw one probe steered by mistake into hitting Mars, and the other one--Mars Polar Lander--vanish during the attempted soft landing near the south pole. During the descent, the vehicle was supposed to release a pair of microprobes that would hit the surface, penetrate the soil, analyze it, and then broadcast the results. NASA never heard from the microprobes or the Polar Lander again. The craft were not designed to communicate with Earth during the descent, so no one will ever know for sure what went wrong. The best guess was that the Lander turned off its braking rockets too early and slammed into the Martian surface.

On March 21, 2000, just days before NASA would release its formal investigation report, I wrote up an account of a version of the failure which I had learned from sources associated with the interplanetary program at JPL.

As a stringer for United Press International, I'd been breaking 'inside space stories' for months, using documents and off-the-record interviews provided by old friends and new friends. I'd been the first with reports of NASA's plans to deorbit the ailing Gamma Ray Observatory, first to disclose that NASA was adding a new maintenance mission to the International Space Station because of Russian delays and breakdowns. I also was first to confirm that Russia was going back on its promise to NASA to deorbit the old Mir space station in early 2000.

I first wrote about internal NASA documents downplaying the medical needs for an all-woman space shuttle crew, an option being considered to boost Democratic fortunes in the forthcoming presidential elections. I disclosed a secret NASA/Russia meeting on plans for a joint manned mission to Mars, and I reported on insider assessments of how the 'John Glenn Mission' hype on medical breakthroughs was all for show.

But this Mars crash story was a bombshell. And even though it was based on the same inside sources that had enabled me to write the December 1999 article on the 'Mars Climate Orbiter' loss (an article that received national press awards), as it turned out it wasn't entirely on target.

"The disappearance of NASA's Mars Polar Lander last December was no surprise to space officials," I wrote. "Prior to its arrival at Mars, a review board had already identified a fatal design flaw with the braking thrusters that doomed the mission, but NASA withheld this conclusion from the public."

The probable cause of the failure, I wrote, was the design of the descent engine. "As explained privately to UPI, the Mars Polar Lander vehicle's braking thrusters had failed acceptance testing during its construction," I had written. "But rather than begin an expensive and time-consuming redesign, an unnamed space official simply altered the conditions of the testing until the engine passed."

The Mars Polar Lander employed a bank of rocket engines which use hydrazine fuel. The fuel was passed through metal grates which caused it to decompose violently, creating the thrust used by the engines. These metal grates are called "catalyst beds," or "cat beds." Their purpose is to initiate the explosive chemical reaction in the hydrazine.

"They tested the cat bed ignition process at a temperature much higher than it would be in flight," I quoted my source as saying. This was done, he told me, because when the cat beds were first tested at the low temperatures predicted after the long cruise from Earth to Mars, the ignition failed or was too unstable to be controlled. So the test conditions were changed in order to certify the engine performance. But the conditions then no longer represented those most likely to occur on the real space flight.

The problem was, NASA denied ever making such a low-temperature test which failed and needed repeating at a higher temperature. Their proof was that they never performed ANY testing of the engines at ANY temperature. Instead, they later said, they simply assumed the engine would work because of 'similarity' with an engine used on another space vehicle. One top official, who called me despite being ordered not to, insisted, "If we're guilty of anything, it's stupidity, not fraud."

What I left out of the article--and got hammered for by some independent space experts--was reference to a NASA review two months before the landing attempt which had identified a cold cat bed engine as a potential hazard and had recommended countermeasures. My only excuse was that it was a newspaper article and was already much longer than is normally allowed.

Following the September 1999 loss of the first spacecraft, the MCO, due to management errors, NASA had initiated a crash review of the Mars Polar Lander to identify any similar oversights. According to my two sources, the flaws in the cat bed testing were uncovered only a few days before the landing was to occur on December 3. By then it was too late to do anything about it.

Garbled rumors of some temperature-related design flaw circulated in the days before the landing attempt. However, as in the September case when space officials possessed terrifying indications of imminent failure even before the arrival at Mars, NASA made no public disclosure of these expectations.

"The Mars Polar Lander investigation team has also reportedly identified a second fatal design flaw that would have doomed the probe even if the engines had functioned properly," I continued. "The three landing legs of the probe contain small microswitches which are triggered when the legs touch the surface. This signal commands the engines to cease firing. Post-accident tests have shown that when the legs are initially unfolded during the final descent, springs push them so hard that they 'bounce' and trigger the microswitches by accident. As a result, the computer receives what it believes are indications of a successful touchdown, and it shuts off the engines. Since this false signal actually occurs high in the air, the engine shutdown automatically leads to a free fall and destructive high-speed impact."

This part of the story was precisely on target, and a few days later, NASA announced exactly this theory as their leading guess as to what had gone wrong.

"Ground testing prior to launch apparently never detected this because each of the tests was performed in isolation from other tests," my UPI story explained, correctly as it would turn out. "One team verified that the legs unfolded properly. Another team verified that the microswitches functioned on landing. No integrated end-to-end test was performed due to budget and time constraints."

Perhaps by coincidence, in a safety memo to NASA employees distributed a week before my story appeared, NASA administrator Dan Goldin stressed "the importance of adequate testing." Reliability, he said, "requires well-thought-out verification and test activities."

Goldin explicitly described the adverse impact of "our difficulties with recent failures in late stages of development--such as system integration and testing--and during mission operations." The memo did not specifically attribute these problems to the Mars failures.

At the official press conference, I asked the NASA chief investigator how this microswitch error had been discovered, and when it had become known. He told me that it was not found by the pre-landing safety review, but had been discovered during more thorough acceptance testing of the next Mars lander spacecraft, which had been intended to follow the Mars Polar Lander two years later. This hadn't occurred until two months after the original MPL had crashed.

The Mars Polar Lander also deployed two small "penetrator" probes, both called Deep Space 2. They were designed to fall freely through the thin atmosphere, hit the ground at about 200 meters per second (400 miles per hour), and come to rest deep in the soil.

All attempts to pick up radio signals from these probes, relayed via another spacecraft already orbiting Mars, also failed. Reportedly, the review board believes that the probe radio equipment could not have survived the impact. "Nobody in the know really expected either of the penetrators to work," my primary source said, and NASA's official results confirmed this as well.

NASA went berserk over my UPI story. They gave me the singular honor of a press release which referred to me by name and called the theories 'whacko'.

A few hours after the story hit the wires, I talked to a very angry Bryan Welch, a top NASA HQ press official who had been a friend years before when he worked in Houston. He was particularly inflamed that the story appeared late in the afternoon on the day before Goldin was to testify before Congress. Since he had often manipulated the release time of NASA news for maximum press impact (or minimum, if he wanted to avoid attention), he interpreted the timing as a direct slap at his boss. I tried to assure him the story had been in work and under review for more than twenty four hours and we had no control over exactly when it finally was released, but he didn't want to believe it.

Welch also objected that I hadn't checked the story with him before releasing it. I pointed out to him that in fact I had called two of the probe's contractors, but officials told me they had been ordered by NASA not to talk to any journalists about the subject. I also told Welch that in my experience, when I checked with NASA's main press officials about a story I was working on that didn't cast a positive light on NASA, I often found that somebody at NASA--I never could say who--would call some more sympathetic newsmen (what we cynics call 'NASA's lapdog press', or the 'NASA PAO auxiliary') in order to break the story first with a more pro-NASA spin. Welch was outraged that I should 'accuse' anybody on his staff of such unprofessional behavior and he denied it ever happened (I knew better). As to his mistake about me not checking with press officials in advance, my correction was useless. Goldin made that same false assertion the following day as if it were factual.

Furious NASA managers passed around a distorted version of my story, telling outsiders that I had claimed that NASA knew before launch that the probe would fail, but launched anyway. Of course, what I'd really said was that NASA realized long after launch but before landing that the probe was almost certainly doomed by design flaws that weren't even realized until an experienced group of engineers studied the probe after its sister ship had crashed. I'm quite willing to concede that top NASA managers were confident the probe would succeed, because they were in a dream world that working level troops knew could be career-ending to disturb. I've been told that a technical review panel had glumly concluded there was a less than 5% chance of the probe overcoming the design flaws they had found and the myriad design flaws they knew must be out there but they hadn't found. But the panel chairman announced that a 5% success probability was an unacceptable answer, and he decided to put "50%" in the final report he sent up the chain of command. We'll return to the technical issues uncovered prior to the MPL landing attempt shortly.

Besides the accident investigations, NASA had also commissioned a panel to study the entire philosophy of 'faster-better-cheaper'. Early in 2000, NASA released the results of this general investigation. The report painted an ugly picture of an organization stripped of core expertise after years of budget cuts and a leader pushing a poorly defined and overambitious goal.

At the heart of the controversy was NASA's attempt to work more efficiently and effectively with less money. The man who has steered NASA through this change was Dan Goldin, previously an engineer and manager with the US aerospace company TRW, who took over as head of the space agency in 1992. Goldin inherited an organization still recovering from the Challenger disaster, growing frustrated with space station program delays, and suffering from low morale.

Goldin immediately identified an area for improvement. NASA spent too much on single missions and took too long to build them, he said, citing examples such as the $1 billion Galileo mission to Jupiter, which took more than a decade to design and build. Should a mission like this fail, Goldin argued, the loss is simply too great to bear.

As if to emphasize the point, in 1993 the $800 million Mars Observer spacecraft vanished without a trace as it was about to enter orbit around Mars. In future, said Goldin, NASA would spread the risk by building large numbers of smaller, cheaper spacecraft, so that losing one would be bearable. Goldin also argued that by working more efficiently it would be possible to build better spacecraft, more quickly and for less money. He dubbed this: the "faster, better, cheaper" philosophy.

The new approach led to a number of spectacular successes. In 1997, the Mars Pathfinder probe and its tiny rover generated worldwide interest for a cost of only $200 million. The Mars Global Surveyor, which has been in orbit around the Red Planet since 1997, cost about $250 million and continues to send back spectacular high-resolution images of the surface. But the two Mars disasters in 1999 told a different story. NASA did it cheaper and faster, said John Pike, then space policy director for the Federation of American Scientists, but the result was worse, not better.

The FBC philosophy was widely criticised even before problems surfaced in NASA's Mars program. Paul Pencikowski, a former "Top Gun" US Navy aviator and in 2000 a project manager for the Northrop Grumman aerospace corporation in California, had more than 20 years of experience in aerospace technology development. In association with a management consulting group called FasterBetterCheaper.com, he published a report in 2000 entitled "Faster, Better, Cheaper? A Critical View...." Pencikowski describes how the background of constant cost overruns in the aerospace industry created a demand for remedies. In the early 1980s, the phrase was "lightweight, low cost" and a few years later came "cost as an independent variable (CAIV)". "Following CAIV came literally dozens of platitudes-de-jour," Pencikowski says. "FBC is but the latest."

The FBC philosophy flies in the face of an old engineering proverb: "Faster, better, cheaper--choose two of the above." But for budget cutters, the notion that a smart enough engineer could have all three at once proved irresistible. Just how the new philosophy was supposed to be implemented was not so clear.

The causes of the 1999 Mars failures looked remarkably similar to the state of affairs that led up to the Challenger disaster in 1986. The accident occurred when seals in the shuttle's booster rockets failed. But the real cause lay deeper. Before the accident a number of engineers had become worried that the shuttle might not be safe. There were vague suspicions of undefinable problems, and engineers pointed out that the shuttle had not been tested at the low temperatures that prevailed on the day.

The disaster investigation discovered that shuttle managers had broken a fundamental rule of engineering. Every dictum of flight safety teaches that safety must be positively established--and reestablished if conditions change. Yet despite the engineers' warnings, NASA managers chose to cling to the assumption that the shuttle was safe, and challenged the engineers to prove that it wasn't. "Take off your engineering hat and put on your management hat," was the advice given to one wavering worker, who eventually went along with the launch decision.

There is always a delicate tension between engineers in aerospace projects and their managers, many of whom are former engineers themselves. The pressure to finish a project on time and within budget, the managers' responsibility, must be balanced against the need to test the system thoroughly, a task that falls to the engineers. In theory, tests can go on forever as engineers find out how a spacecraft is affected by changes in temperature, g-forces and radiation, to name only a few parameters. But at some point, the decision to go ahead has to be taken and in the Challenger disaster, the pressure to launch had become so great that this balance was lost.

Many observers remarked on these disturbing parallels between the Challenger disaster and the loss of the Mars Climate Orbiter. The Young report pointed out that the pressures on NASA managers were huge since there is a relatively small launch window for missions to Mars and these occur only once every 18 months. The report stated that when the goals of the project, its budget and its launch date are all fixed, the only option for managers when things start going wrong is to accept more risk. In practice, accepting more risk means carrying out fewer tests so that mistakes are more likely to slip through.

Some former NASA space managers have said they have been warning NASA about problems with FBC for years but have been ignored. Donna Shirley worked on the highly-successful Mars Pathfinder mission and became the first project manager for the Mars Polar Lander. But after thirty years in the space business, she chose to retire instead of seeing the project though to its conclusion.

Her departure was a direct result of NASA not responding to her concerns. "They kept adding to the project and not putting more money into it," said Shirley, who became assistant dean of engineering at the University of Oklahoma. "I couldn't persuade them that they were going too far with 'better, faster, cheaper'," she said. "I told them everything was going to fail."

Shirley concluded that her resources were spread too thinly. "There was no one to check and double check, and when you have complicated and complex missions you are going to make mistakes that need catching."

"I couldn't stop the train," Shirley lamented. "I was afraid something like this was going to happen and I couldn't do anything about it. Why stay there and suffer?"

Hindsight, along with NASA's recent studies, fully confirmed Shirley's warnings, and raised the unanswered question of why her warnings--and those from others inside and outside NASA--went unheeded for so long.

The special post-1999-Mars-debacles FBC re-assessment team was headed by Anthony Spear, a retired space manager. In a report released early in March 2000, Spear's panel of space experts told NASA the FBC approach wasn't working and needed major changes.

"The current mission failure rate is too high and must be reduced," the report stated. "Most failures over the past decade can be attributed to poor communication and mistakes in engineering and management," it explained. "Failing due to mistakes is not tolerable."

The original FBC theory was that there would be some failures due to trying more difficult missions and to using more advanced technologies. Such failures were to be expected and tolerated. But, the report explained, mission failure due to avoidable mistakes "was NOT what was meant when Dan Goldin said, 'It's OK to fail'."

"We need to slow down some, not rush too quickly into important programs and projects," the report advised. It strongly implied that previous programs had not been planned and implemented with sufficient care, and had been too fixated on cost containment and short-term goals.

One critical problem which the Spear report highlighted was that there was no authoritative definition of what FBC really is. "Everyone had his or her pet definition, and it was difficult to get consensus," the report stated. "In all our sessions, the ones defining FBC were the most animated."

"FBC is simply attempting to improve performance by being more efficient and innovative," it concluded. There is also "an intangible element", it added, "a team spirit associated with doing FBC." This principle was often violated, the report noted, in overzealous cost-cutting campaigns. "Some FBC Teams reported that the fun had gone away after having their resources cut too deeply."

"In our zeal to do FBC," it continued, "the challenge bar was raised too high. The cost cap challenges were made too great, along with a mix of unstable funding and escalating requirements." The report stressed that "it takes a Project Manager with good judgment and courage to declare under pressure that the Project is not doable for the available resources." And at Goldin's NASA, managers were never allowed to do that.

The FBC approach did have some notable successes in the 1990s. They ranged from the Pentagon's "Clementine" lunar probe, to deep space probes such as Lunar Prospector, Deep Space 1, Stardust, and the NEAR-Shoemaker satellite now circling the asteroid Eros. The most spectacular FBC success story is the Mars Pathfinder, which used parachutes and airbags to bounce safely onto the Martian surface in 1997. It deployed a cigar-box-sized 'Sojourner' wheeled rover to move across the nearby landscape.

Deep within the Spear report, after enthusiastic tributes to current NASA leadership ("Dan Goldin is right on with his FBC thrust--he set the stage, created the environment"), there are hints of what had been wrong from the start. "This requires unprecedented teaming and open, candid communications," the report stated. "No one person has the answer. It takes a lot of debate and evolution of ideas to get there. It takes courage to admit a wrong path and the need to move in another direction."

This is where Goldin, who championed an approach the report explains was already "crystallizing" within the space industry in the early 1990s, is widely considered to be at odds with the prescribed solutions. By all accounts of those close to him, he is a leader with the confidence that he does have all the answers, and reportedly he has little tolerance for debate or for questioning his judgment.

During one famous incident involving schedule slips on the International Space Station, one speaker tried to describe a backup plan in case a Russian module turned out to be late (as indeed it later did). Reportedly, Goldin was so enraged by the disagreement that he picked up the viewgraph projector and threw it at the screen. In another case, Goldin reacted to being told he was wrong in one of his assessments by storming out of the meeting and sulking in his office for an hour before returning.

With Goldin's leadership so closely tied with the FBC philosophy, whatever it really means, disagreements with FBC was widely interpreted within NASA leadership as criticism of Goldin himself. Such ideas were not tolerated. As a result, experienced and talented managers such as Shirley left the program. This Spear report recognized the problem but not all of the causes, when it wrote, "There is a talent drain due to retirement, downsizing, and loss of people to industry." It recommended that NASA "develop incentives for attracting good people and well-respected leaders to come to work for NASA."

In light of the failures, Dan Goldin's leadership of NASA began to attract harsh criticism. Goldin responded to the rash of accidents with a series of safety and reliability messages--and they enraged some NASA workers. One, called "Fault Tree Analysis", published in January 2000, spelled out what Goldin believed NASA had been doing wrong. "In our work," Goldin wrote, "we often focus on ways to make things 'go right'. This confident optimism is an important characteristic that helps us pursue the challenges of invention and exploration." Goldin's message went on: "To make things 'go right', we also need to understand and control the things that can 'go wrong'. This beneficial pessimism is sometimes a bit more difficult to apply to our own creations," he admitted, "but it is needed to increase the likelihood of future successes." Goldin ended by saying: "Therefore, I ask that we put more effort into analysing 'what can go wrong'."

The message hit a raw nerve among space workers who felt that Goldin was accusing them of not understanding fault tree analysis, a basic tenet of engineering. "It's scary to hear him talking like that," says Ed Hanna, an aerospace management consultant with FasterBetterCheaper.com. "Discovering 'fault tree analysis' like it was new--it makes you wonder."

The Young report on the MPL failure, however, put the blame elsewhere. It pointed out that the combined cost of the two failed missions was less than the price of the successful Mars Pathfinder project, even though these missions were more ambitious.

"It was underfunded by at least 30 per cent," says the report, a huge margin in aerospace terms. One consequence of this underfunding was that the teams did not effectively test their spacecraft. In particular, the report says the two microprobes carried by the Polar Lander had not been tested properly and were not ready to be launched.

Young and his team also pointed out that NASA did not have enough experienced scientists and engineers capable of managing the dramatically increased number of space missions it was planning. The lack of experienced oversight was a serious contributing factor in the failures, said Young.

Throughout the 1990's, the American space industry suffered continual cutbacks and the decline in government aerospace budgets led to the number of workers employed in aerospace being cut in half. The most expensive workers tend to be older and more experienced, and they had been the primary target of cost-conscious lay-offs. Hanna believed that these older, more experienced workers had tended to be replaced with younger people. "And that's related to a loss of quality," he said. Since the fourth quarter of 1992, more than 4500 scientists and engineers had left NASA, of whom only 1000 were younger than 40.

Other experts agreed. When a board appointed by the White House to investigate a number of recent launch accidents released its report early in December 1999, it said that the main causes were connected with engineering and fabrication flaws during the assembly of the boosters. This stemmed from a lack of adequate management attention, possibly caused by the loss of the most experienced employees to retirement, lay-offs and higher salaries elsewhere. "We have started seeing the results of the cutbacks in the knowledge of the people and the morale, particularly down at the Cape," said Seymour Himmel, a retired NASA official and an aerospace expert who was a member of the White House panel.

After the release of the Young report, Goldin stood up and shouldered the blame. He admitted pushing the FBC philosophy too hard and said it was time to rethink. NASA then cancelled all but one of its planned flights to Mars. The question became whether this will be enough. The gradual loss of expertise and reduced budgets influenced every aspect of NASA's work, not just the Mars program. The biggest fear was that other projects were also likely to fail.

In the months that followed, Goldin proved how he still "didn't get it". In a begging-for-forgiveness appeal before a congressional committee, Goldin proclaimed that "people were talking, but I just wasn't listening." But they weren't. People with disturbingly bad news had been bullied or bluffed into silence (they were NOT talking at all) out of fear for their jobs by Goldin's management style, so the bad news never got to him. It wasn't even a case of him not wanting to know bad news, it was far worse: he wanted NOT to know any news that detracted from the way he was sure things were going.

Just how MPL failed will probably never be known, but the frightening part was that the investigators uncovered literally dozens of ways it could have. At the official NASA press conference on the MPL investigation results, Dr. Thomas Young, director of the accident investigation team, announced that the probe had been almost certainly doomed by a software error. The "most probable cause of loss of mission", according to Young, was premature shutdown of the probe's braking rockets as it neared the surface.

The design flaw was not caught before launch, Young's team discovered, because other hardware errors masked it during tests.

In all, the report analyzed 31 different "plausible failure modes". They also included loss of control, a parachute draped over the probe on the surface, and a non-survivable landing site. The report also confirmed in part my earlier notorious UPI story on propulsion problems. "Major errors in the propulsion thermal design went undetected until after launch," the report stated. The designs "did contain four potentially serious, if not catastrophic, weaknesses." However, the report described in detail the development of a workaround procedure for this problem which was thoroughly tested and implemented before the landing attempt.

Along with the MPL, a pair of small "penetrator" probes deployed from MPL also vanished without a trace. Young's review found so many inadequacies in their construction that it concluded it was a waste of time to even launch them. This, too, confirmed another aspect of my 'whacko' story.

Young's report detailed the management flaws which had led to these failures. In hindsight, he said, NASA had tried "to do the impossible". By holding costs, schedules, and science requirements fixed, Young noted, NASA created a situation where risk was the only variable.

The report noted other contributors to the failures. There had been inadequate staffing at NASA, and inadequate consultations with experienced NASA experts. Testing and analysis at Lockheed Martin, where the probes were built, was deficient. Operational experts were not adequately involved in the probe design and testing. And program management had been split between different officials who also had other responsibilities.

The problems could be fixed in time for new launchings to Mars in 2001. "While the flaws are serious, they are correctable," Young's report said.

Dr. Ed Weiler, NASA's Associate Administrator for Space Science, presented a list of procedural improvements. They dealt with improved communication, improved training, and more strict reviews and oversight. Weiler's announced intent "to learn from these failures" was received with some skepticism from reporters. "Look at these mistakes," one demanded. "They're STUPID mistakes." Weiler appeared unapologetic. "In hindsight," he pointed out, "all mistakes are stupid."

Weiler described how NASA had intended to "make a revolution" in flying missions based on the "faster-better-cheaper" philosophy. To do so, they had to keep pushing the boundary of what was possible. "We found the boundary," he admitted, "and we're stepping back from it. You've got to get to the boundary to know you've found it."

Young described in detail how the "one most probable cause" of MPL's failure was able to happen. The MPL probe was supposed to descend slowly using braking rockets, until its three landing legs touched the ground. At that point, a signal from a switch on any of the three legs would have told the computer to switch off the rockets. But this same switch was also accidentally triggered when the legs first folded open, high above the surface.

The MPL's computer started monitoring for this indicator when it dropped below 130 ft, as measured by its landing radar. The fatal error, according to Young, was that the computer's software never cleared out the indicators just in case of such a premature false signal. The very first time the software looked at the indicators, it would have seen the flag 'set' and decided that landing had already occurred.

The engines would then have been turned off in midair. Falling from that height, the probe would have hit the ground at about 50 mph, ten times its planned touchdown speed. If the probe even got this far, said Young, "this is undoubtedly the cause of the failure."

The inadequate testing and monitoring of the failed probes was attributed directly to financial limitations. In 1996-7, NASA had performed two successful missions to Mars at a cost of about $250 million each. Buoyed by this success, they next planned to fly four missions in 1999 for less than the cost of one of the 1997 probes.

"[These probes] did not have adequate margins," the report stated. "The project was significantly underfunded from the start." This budget shortfall was at least 30%, the report estimated. "We could probably have pulled these missions off if we had done them a little less cheap," said Weiler in agreement.

Further, said Young's report, "[the 1997 mission] success can be directly attributed to the experienced project managers and their effective use of expertise from numerous sources." The projects also showed a "sensible application of innovative technology and processes."

NASA managers were understandably frustrated and embarrassed by these failures, which goes a long way in explaining (but not excusing) their ferocity in attacking me over the UPI story. But workers within the program also took me to task, quietly and out of sight of their bosses, about what they saw as my worst misunderstanding. The phrase I kept hearing was "hadn't done your homework."

There were two issues related to the cat beds. First was the lack of any acceptance testing, and second was the emergency procedure implemented prior to landing when a review board discovered that the cat beds would be so cold they probably would indeed blow up when ignited.

The engine design was never tested, the Young Report states, because they were validated 'by similarity' to an engine which had already been flown in space without problems. You'd think it would be simple to find out on which spacecraft this engine design had previously been used, but it wasn't. NASA and the engine vendor refused all inquiries about this, underscoring how sensitive they were--and still are--to the public finding out.

Perhaps here's why: I've been told that the engine was previously used on the MIRV bus of an intercontinental ballistic missile. It would fire to precisely aim and deploy a sequence of nuclear warheads. But that space mission lasted only half an hour, and started in a warm missile silo, not after a year of cold-soaking in deep space. If this story is true, it's the Mars Observer debacle all over again, flaw for flaw and misjudgment for misjudgment.

When engineers realized that the cat beds were too cold to fire safely, they developed a plan to turn on spacecraft heaters and raise the cat bed temperatures. NASA's story is that this procedure, implemented just prior to the landing attempt, adequately nullified this threat. It's this procedure that I got hammered on for not describing in my original article.

But I'm not ready to concede on this one, either. Again based on conversations with space engineers disgusted by what they see as a continued damage-limitation spin from space program management, the effectiveness of that procedure may be questionable.

First, it would have been hard to heat the cat beds because the heaters were on the fuel valves leading from the fuel tanks, and in order to keep the fuel lines from getting overheated by the engine firings, the lines themselves were insulated from the cat beds. And although NASA says that the planned pre-landing four-hour heater run was deemed adequate, my same sources tell me that in fact four hours was the maximum time the heaters could run without totally draining the spacecraft batteries. Even with that duration, which was the maximum they could possibly get out of their system, the batteries were so drained that the spacecraft would need to recharge them with its solar panels after landing. This means that it would have been impossible to get any more than the four hours of heating out of the system. Whether it proved adequate or not, it was the best they could do, and was a reasonable precaution.

Chauncey Uphoff, a 40-year veteran of the space program, was one of the men who told me that he had heard rumors from multiple independent sources of incompetence in the testing of the thrusters of the MPL spacecraft. Uphoff was the only one who gave permission to have his name used, since others were fearful of NASA retribution (a curious policy if the rumors were untrue). Even Uphoff was told by NASA associates that he was 'toast' for having discussed the subject, and a top NASA manager and lifelong friend of Uphoff's asked him how much he'd been bribed by the press to make such statements.

Specifically, Uphoff said that he had heard a story that the MPL landing thrusters had been qualified without proper disclosure of the qualification tests to the project. This statement turned out to be quite correct as evidenced by investigator John Casani's letter to Dr. Weiler dated March 30, 2000. In that letter, it was stated that the descent thrusters were "qualified by similarity" and that "unfortunately, a formal 'qualification by similarity' report was not generated and the qualification process lacked the full formality and rigor that would have been desirable."

Uphoff's information (as relayed to me for my story) was exactly correct; the qualification tests were done at ambient temperature, were not properly reported to the project, and there were no thermal analyses, available at launch, to show that the MPL propulsion would be successful in landing the spacecraft on the surface of Mars. Later, and principally because of the failure in September of the MCO (Mars Climate Orbiter), a more thorough analysis of the thermal continuity of the spacecraft showed that the MPL spacecraft would not have landed successfully because of the deep cold the system had been exposed to. A fix for the problem was developed, with suggestions from a review team, that involved turning on the propellant tank heaters several hours before the time originally planned.

Later, when Uphoff was asked if he knew of deliberate altering of records, he said "Absolutely not; no one in the space program would phony up records if they knew it would endanger the mission. This looks like incompetence to me, and poor communication within the project. I don't know how this project ever made it past CDR (Critical Design Review)."

In a telephone interview with UPI's Marc Borbely, Uphoff was asked if he still thought MPL blew up. "I'm not so sure as I was when I made that statement," Uphoff said. "I didn't know about the landing leg switch problem then and I hear there were 29 other possibilities I didn't know about. The landing leg switch sounds like a very credible failure mode. But some analysts in the propulsion business still think there's a high probability that one or more of the cat beds cracked on ignition.

"I think Jim's (Oberg's) article was speculative and had some distorted rumors in it" said Uphoff, "But he couldn't get anyone who really knew what happened to tell him, and the rumors were remarkably consistent and independent." Uphoff concluded, "In my experience, Oberg's speculations, e.g. his December 1999 report in SPECTRUM on the MCO failure, are often closer to the truth than the official NASA reports. In this case, I think he was given some exaggerated rumors, but I don't know and I can't find out."

Whatever the truth of these unconfirmed allegations, NASA's bitter experience with the 1999 Mars twin disasters shows that too much please-the-boss make-believe and too many spineless bureaucrats are death on Mars missions. A ferocious, fearless passion for the whole truth is at the top of the list of the things you need to get to Mars.