What went wrong with the Hubble Space Telescope (and what managers can learn from it)

NASA's former director of astrophysics, Charlie Pellerin, has learned a thing about leadership and project failure

Rohan Pearce (CIO) | **29 March, 2012 14:35**

Charles 'Charlie' Pellerin.

There's nothing unusual about having a bad day at the office. But some people have worse days than others, and in his time Charles (Charlie) Pellerin has had a few notable ones. Not many people find themselves having to explain why an organisation has invested a decade and half and in the vicinity of $3 billion on a project that has failed.

That's the position Pellerin found himself in as NASA's director of astrophysics in the wake of the 1990 launch of the Hubble Space Telescope, which had what appeared to be an unfixable flaw in its optical system.

It's difficult to overstate what a disaster this was and the humiliation faced by NASA; not just as an organisation but also the individuals who worked for the agency. A good friend of Pellerin who worked on the telescope fell ill in the wake of the launch and died. Two of Pellerin's senior staffers had to be removed from their offices by guards and taken to alcohol rehab facilities. "These are PhDs sitting at their desk getting drunk; this is how bad the stress was," says Pellerin.

Most people faced with a disaster on the scale of Hubble might want to either bury themselves under a blanket in bed for a decade or two, or try (no doubt unsuccessfully) to forget it ever happened. Instead Pellerin set out to try to fix Hubble — and succeeded, in the process winning NASA's Distinguished Service Medal, the highest honour conferred by the agency. And with a stubbornness that some people may consider verges on the perverse, set out to discover exactly what went wrong. The problem with Hubble, Pellerin concluded, wasn't merely a technical failure. It was a leadership failure and a product of the culture surrounding the project.

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His study of why projects fail also led him to draw links between Hubble and an earlier NASA disaster: The disintegration of Space Shuttle *Challenger* on January 28, 1986, which killed seven astronauts.

"In 1986 I drove into my parking place at NASA headquarters and my staff members are waiting for me there and it's very unusual," Pellerin says. "They ran up to me and said, 'Charlie, Charlie, *Challenger* exploded." Pellerin's division had the biggest payload on *Challenger*, and in the lead-up to the launch there had been a lot of cross-training between his division and the astronauts. "I had this sinking feeling that maybe my payload had come loose, because it was a very low cost effort and it was big and heavy and maybe it had broken through the cargo bay doors and caused this accident."

Pellerin watched the *Challenger* failure review closely. "I had good friends who I thought were good solid engineering managers who worked on the boosters so I'm trying to figure out what happened," he says.

"I saw this guy, Richard Feynman, who was a review board member, take a piece of rubber O-ring and put it in his icy water on television, and showed that it stiffened up. So immediately I said, 'Oh, that's the technical problem, they didn't do the O-ring well.'"

"That was nuts," Pellerin says. "These guys understood the O-ring, but I put that story in my head because technical people look for technical answers. I never read the conclusion of [the review board] report that said it was a social shortfall."

Four years after *Challenger* Pellerin was getting ready to launch Hubble and grappling with the difficulties of readying a telescope that wasn't intended for in-atmosphere operation. The advantage of a telescope in space is that light from stars won't be moved around by atmospheric incoherencies. No-one had attempted to design a telescope that would offer the accuracy promised by Hubble.

"So the question is, what are you going to tell people if someone asks you if it's going to work? What would you say? 'Of course.' It's the only answer right?" Pellerin says. "You spend 15 years and $3 billion or whatever, so of course it's going to work — there's no other answer.

"The head of NASA congressional appropriations asked me, 'Is it going to work?' And I said, 'Of course!' So she went and identified herself very closely with the project. So then we find it doesn't…"

The circumstances under which Pellerin discovered Hubble's flawed mirror were "awkward". There was a 'first light' event for the opening of Hubble's aperture door — "we call it the toilet seat," Pellerin says. The aperture door was opened, and a little spot of light appears — the first light from Hubble. "Everybody whoops and cheers," Pellerin says. But he noticed the spot of light was fuzzy. He was reassured by a colleague that it was nothing serious; Hubble's secondary mirror was attached to a stepping motor that would allow minor alterations to cope with dimensional changes brought about by the outgassing of water vapour in space.

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Pellerin went and spent a week in Japan during which he was out of contact with NASA. He was unprepared for what awaited him. "I land in St Louis airport and I made my first mistake: I called Washington," he says. His secretary asked him if he had spoken to his boss lately, and when he replied in the negative she put him straight through. "I'm thinking, 'What good news could this be?'" Pellerin recalls.

"He says, 'What do you know about spherical aberration?' I said all I know is that when amateurs build mirrors and do it sloppily they get what's called a downturned edge, and on different radii of the mirror it focuses the light on different parts of the optical axis and it's physically impossible to ever focus a telescope; they're useless."

Pellerin's boss responded: "Well you launched Hubble Space Telescope with a spherically aberrated mirror."

"This was two PhDs and this was the maturity of the conversation," Pellerin says: "I said, 'Did not.' He said, 'Did so.' 'Did not.' 'Did so.' 'Did not.' 'Did so.'" Finally his boss told him to go and pick up a national newspaper and read out loud the front page headline above the fold.

"So I find the *St. Louis Post Dispatch* and I bring it back and I pick up the phone and I read it. It says 'National disaster: Hubble launched with flawed mirror'. So he said to me, 'Now what do you say?' And I said — 'You guys are too much; how'd you get a fake newspaper printed in this airport lounge?'"

Pellerin returned to Washington DC for a crisis meeting with NASA's top administrators. What followed were congressional hearings into the disaster. "It's a misnomer," Pellerin says. "There's no-body hearing at congressional hearings; they should be called congressional browbeatings or congressional yelling sessions."

Pellerin was appointed NASA liaison to the failure review board that was formed. The mirror was fabricated in 1977 and he didn't take his position until 1982, so "the thinking was I could have had nothing to do with whatever problem the mirror had. It turns out that was wrong."

The technical error related to the null corrector used to test Hubble's aspheric mirror. Using a null corrector, imperfections in a mirror can be found and fixed by the person fabricating it. The mirror was balanced on what NASA described as a 'bed of nails': A series of steel pins with little springs that maintained the mirror in the shape that it would have in zero gravity. NASA built a reflective null corrector, because even optical glass has inhomogeneities that can cause refraction; this isn't a problem with a mirror. "Looked foolproof," Pellerin says. The null corrector was used first used to build a 60-inch mirror. NASA tested the mirror extensively. "It's just a throwaway mirror, we did everything to it. Perfect mirror."

After that, to build the telescope's 96-inch mirror "all you had to do was respace and put a new field lens on [the null corrector], which is really simple. But because we're building the world's most perfect mirror we didn't use a more normal process like micrometers or something." Instead, they obtained precise metering bars from the US National Bureau of Standards (now called the National Institute of Standards and Technology). The metering bars were used to respace the reflective null corrector's two mirrors to produce the larger flight mirror.

NASA's *Hubble Space Telescope Optical Systems Failure Report* (known as the "Allen report", after Lew Allen, director NASA's Jet Propulsion Laboratory who headed the review in Hubble) states: "The ends of the metering rods were rounded and polished because the very precise positioning of the optics in the RNC [reflective null corrector] used an interferometer, rather than a mechanical measurement. This procedure involved auto-reflecting a focused beam of light off the end of a rod and observing an interference pattern from the beam that came back on itself. Centering the light beam on the rod end was essential for the measurement.

"To prevent the metering rod from being misaligned laterally with respect to the interferometer axis [*so that the light hit the precise centre of the rod's curved end — RP*], P-E decided to attach 'field caps' to one end of the rod… The field caps were fitted over the rod ends and had a small aperture in the center to ensure centering of the rod on the beam."

"The instructions were take the cap and spray paint it," Pellerin says.

"The guy was working under great stress because we were angry about costly delays, and were threatening to put Kodak's mirror in the telescope, which would have been humiliating for our contractor [Perkin-Elmer Corporation was responsible for the mirror]. So he's working, he's really hurrying, he can't find the spray paint. So instead he puts black tape on [the cap] and he takes his X-Acto knife and cuts a hole. He doesn't notice he made a shiny little burr. So he puts the thing on, the light hits the burr and goes back up.

"His instructions were to move the thing in every direction to see if the intensity of the light went down. So he moves it. Light goes onto the black tape, onto the black tape, onto the black tape, down the hole [in the field cap]. He assumes he got it centred."

However, the light had hit the burr instead of the top of the rod, which led to a gross misplacing of the two mirrors.

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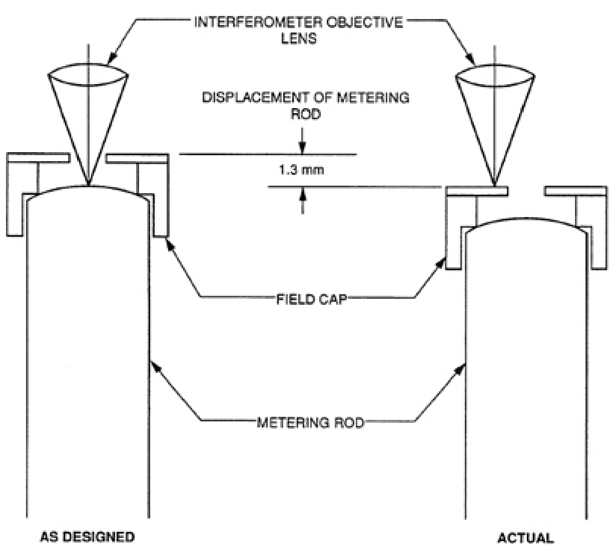

Diagram from the Allen report.

It was a misalignment of about 1.3mm. "Holy Christ," says Pellerin. "In an optical system this is like missing by a thousand miles."

The review board had considered three possibilities when it came to the null corrector, according to the Allen report:

"(1) The field lens was inserted backward.

"(2) The index of refraction of the field lens was incorrect (i.e., the wrong glass was used).

"(3) The optical elements were incorrectly spaced (a circumstance that seemed highly unlikely because of the method used to set the lens spacings)."

After an analysis of the null corrector, which had been stored by the contractor after the mirror was finished, number three turned out to be the culprit,"

"So the next thing that happened was really kind of interesting," Pellerin says.

"Being a technically trained person and completely unaware of the power of social constructs, I thought 'Great it's a technical failure.' I mean it's not my fault, I wasn't even there. I'm off the hook — that's what I'm thinking. Because these things are usually unpleasant when you're responsible for them."

But the chair of the failure review board wanted to look into it further. What he found was that when the mirror was removed from the bed of nails and put in its three point mount, it was tested again. "We tested that mirror over and over and over with a different kind of device, the old style refractive null corrector," Pellerin says.

The results? "Half wave of error, half wave of error, half wave of error."

"So some people sat down and said, 'What's going on?" Pellerin recalls. "The mindset was that the mirror can not be other than perfect. So something else is happening. They concluded that the mirror was sagging under the force of gravity in the three point mount rather than being on the bed of nails by half a wave.

"Well it turned out that was wrong. But they rationalised, rationalised, rationalised. What kind of minds does a project like Hubble attract? The best. So [Allen] said, 'I want to understand why the smart guys working on it didn't go dig in and find out what's going on.'"

The project had suffered other challenges beyond fabricating and mounting the mirror; staff were being "hammered" all the time, Pellerin says. In addition there was constant angst about how far the project had gone over budget. "Hubble's initial budget was $434 million we closed it at $1.8 billion just for the flight segment; big overruns."

"So the way it works is you tend to blame the people doing the work," Pellerin says. "So we're hammering on them, hammering on them so they had no free time or no inclination to track down anything that wasn't a critical problem because we have other critical problems. Difficult technical things that we couldn't solve yet."

The review board also found that a hostile environment had been created for the contactor, which meant "they told us about any problem at their peril," Pellerin says.

When the board's findings were reported to Congress, it was found that the question of leadership had been at the centre of the project's failure. "Now you might have thought that would have heaped criticism on me, but everybody else around me is technical too. The whole NASA management chain is technical people. They all did just like I did with *Challenger*: They heard that but it didn't register, didn't register on me."

In the wake of the Hubble disaster, Pellerin found himself in the office of the congresswoman who headed NASA appropriations. She wasn't happy. "When she got through throwing newspapers, she's screaming at me and there's spittle collecting on my glasses. We just stood there and she puts her finger in my chest and says this is done. We're going to forget this ever happened. You've humiliated me with this, you've made me look like an idiot with what you've done. And so there will not be any servicing for [Hubble]. Ever."

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"I left the room and I thought about two things," Pellerin says. "All the trauma that was around this, and it wasn't going away. I mean the international partners are mad at us, NASA looks bad to the whole world, the US looks bad." Pellerin says that he realised he was the one person in the world that had the ability to salvage the Hubble project.

"I had a big budget for astrophysics programs. I had $2 billion or $3 billion a year to spend on various things. And I had the motivation and I had the team that knew how to do it because we built the thing in the first place," he says.

"So I quietly, and perhaps illegally, scrounged up $60 million and started a servicing mission. When I started we didn't know how to do it."

However, "it turned out that the nature of the error was a good thing," he says. The mirror was flawed but not in an irregular manner. "We built the perfect mirror to the wrong prescription."

His team worked out that removing one set of instruments — "one of them wasn't that important; it was a photometer" — they could insert another mirror in Hubble that was deformed proportionally to the telescope's flawed mirror, which would allow the half a wavefront error to be corrected by the time it hit the telescope's instruments.

"Once we had everything in hand and knew how to do it and showed people we knew how to do it, everybody forgot about the fact that

I had started this thing against the wishes of the most powerful person in the world for NASA's budget. They ignored all that and nobody thought much about the leadership failure.

"So I actually got promoted twice to the top of NASA. I didn't like it up there. I like being close to hardware, scientists, technical problems. It is all politics up there; it's dealing with the White House, the Congress."

After 10 years of director of astrophysics, he decided to call it quits. It was time to do something else. "Probably a good idea to let somebody else do it anyway after 10 years," he says.

He decided to he wanted to get to grips with the concept of leadership; "Whatever it is, it trumped the best technical minds in the world." He got a professorship at the University of Colorado business school and began teaching a course called '21st Century Leadership'. As part of studying leadership, he took another look at the lessons that could be learned from the *Challenger* disaster and discovered a book by Diane Vaughan called *The Challenger Launch Decision*.

"What she said is, the real question is not the technical question. The real question is, why did they continue with the launch when all the data said they shouldn't? She said that there are social forces at play that are forever invisible and unmanageable. And it's most unfortunate she said… She named the phenomenon normalisation of deviance.

"It's for things that are deviant if you step back from them become okay locally. What happened with the *Challenger* launch is that under the pressure from Washington to launch, launch, launch, the technical people at Marshall [Space Flight Center] drifted unnoticeably into a place where it required a much more powerful technical argument to delay a launch than to continue. I looked at that and I said, 'By god it's the same thing that happened with Hubble.'"

As part of his study of leadership he began to look for other cases of the phenomenon. One powerful example he came across was the rash of crashes suffered by Korean Air Lines in the 1990s.

"Korean Air Lines in the 1990s was crashing at seventeen times the international average," Pellerin says. "It got so bad the president of Korea would not fly on Korean Air Lines. What's interesting about it is it went on for four years. Why did that happen?"

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Pellerin says it's because people make a fundamental error when addressing questions of failure and leadership: "That this stuff is about individual abilities."

As with *Challenger* and Hubble, they were good technical people at KAL. "They kept testing the pilots… they're as good as pilots any place." Finally Boeing subsidiary Alteon put observers in the cockpits of KAL jets to find out what was happening. What they discovered, Pellerin says, was that the social context in which pilots were operating was having an impact on safety.

"There's only two people sitting there [in the cockpit]. The captain starts to make small mistakes and [because of the airline's internal hierarchy] the first officer is embarrassed to correct him, so he doesn't say anything cause it's considered impolite. Most of the time it doesn't matter. But as this goes on and on, the first officers just want to tune out. So they're reading magazines while the plane's flying and the captain is all by himself screwing things up. And you know, modern jets are designed to be flown by two people working as a team… so they figured out the problem fixed it and the safety record immediately went back to international standards."

This question of the emphasis on individual abilities versus the context in which individuals and teams operate is something that has consumed Pellerin's energies in his time since leaving NASA, and is the foundation of the training system used by the company he founded, 4-D Systems.

"There's a bunch of research I've come across in this work, where people say that the social context is a 78-80 per cent determinant of performance; individual abilities are 10 per cent. So why do we make this mistake? Because we spend all of these years in higher education being trained that it's about individual abilities."

Thanks to happenstance (three CEOS of Fortune 500 companies heard a talk by one of his students), Pellerin ended up converting the course he was teaching into a leadership workshop for corporations.

His starting point, he says, was Vaughan's assertions that the destruction of *Challenger* was a product of "invisible forces and therefore unmeasurable and therefore unmanageable". Unmeasurable and unmanageable didn't sit well with Pellerin. He studied the question, and, he says, "a voice comes to my head from undergraduate days that said the right coordinate system can turn an impossible problem into two really hard problems." He devised a matrix system used in 4-D training that he says looks at the kind of behaviours and needs that can help strengthen teams. "If I meet people's needs, we're going to be improving performance," he says. The needs include things like "Mutual respect, enjoyable work", "Authentic, aligned, efficient action" while behaviours cover such points as

"Express authentic appreciation" and "Appropriately include others".

His training focuses on questions of the social context in which a team operates, rather than just looking at a team as a group of atomised individuals. In a twist, Pellerin found himself working for NASA again on a contract to deliver his training.

"I went and met one day with the guy who worries about team development and risk management at NASA and I showed him what I got… So they give me a small contract and I use all the money up. They give me a contract that I thought would be big enough for my whole life. This thing gets so popular in NASA of all places! Technical people don't usually gravitate to this kind of thing. If you want to really scare a technical person, put deep fear into them, just say something 'touchy feely' and watch while they run.

"So what I've done is I've taken social constructs and I've described them in metaphors that they understand through technical analogies. So how do I get them to understand the social forces? I tell them about *Challenger*. I talk about Hubble."

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