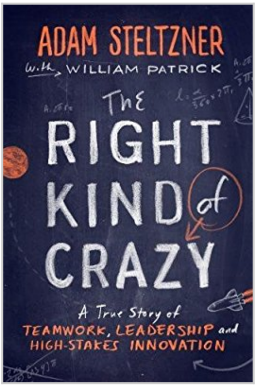

The Right Kind of Crazy: A True Story of Teamwork, Leadership, and High-Stakes Innovation

By Adam Steltzner, William Patrick

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At the helm of this effort was an unlikely rocket scientist and accidental leader, Adam Steltzner. After barely graduating from high school, he followed his curiosity to the local community college to find out why the stars moved. Soon he discovered an astonishing gift for math and physics. After getting his Ph.D. he ensconced himself within JPL, NASA's decidedly unbureaucratic cousin, where success in a mission is the only metric that matters.

The Right Kind of Crazy is a first-person account of innovation that is relevant to anyone working in science, art, or technology. For instance, Steltzner describes:

·How his team learned to switch from fear-based to curiosity-based decision making
·How to escape "The Dark Room"—the creative block caused by fear, uncertainty, and the lack of a clear path forward
·How to tell when we're too in love with our own ideas to be objective about them—and, conversely, when to fight for them
·How to foster mutual respect within teams while still bashing bad ideas

The Right Kind of Crazy is a book for anyone who wants to channel their craziness into creativity, balance discord and harmony, and find a signal in a flood of noise.

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Editorial Review

Review
"Steltzner's enthusiastic, passionately written memoir is an insider's guide to engineering wizardry and a testament to the effectiveness of team-minded engagement, rational problem-solving, and the concept of 'making ideas reality.' A motivational journey for armchair astronauts and readers fascinated by the unlimited wingspan of human potential."
- KIRKUS REVIEWS

"Steltzner is a genetic cross between Einstein and Elvis Costello who has mastered the art of managing complex tribes of humans. *The Right Kind of Crazy* is a fabulous—and ongoing—story."
—JUAN ENRIQUEZ, coauthor of *Evolving Ourselves*

"Crazy ideas stay crazy until they become reality. The problem is, it takes a lot of people working together to turn crazy into amazing. Adam Steltzner should know—he did it. In this book he shows us that doing what others think is impossible takes more than grit and courage. It takes the ability to inspire people . . . It takes leadership."
—SIMON SINEK, optimist and author of *Start with Why* and *Leaders Eat Last*

"Adam Steltzner not only does great engineering, he also teaches it and he can lead a great engineering team such as the one that landed *Curiosity* on Mars. All that embedded in a gaudy personality and astute observer makes for a book that is as delightful as it is instructive."
—STEWART BRAND, president, The Long Now Foundation

"How does a band of engineers get a 2,000 -pound robot to the surface of Mars? *The Right Kind of Crazy* is proof that with the right kind of leader, a team of determined dreamers can accomplish just about anything."
—BEN SILBERMANN, cofounder, Pinterest

"This book shares Adam's journey from juvenile delinquent to landing on Mars. In its pages you will enter the mind of a fearless genius rocket scientist and discover the power of intuition, and how creativity and courage are as important as math. It is a must-read for scientists and artists alike."
—TOM SACHS, artist

"A gripping account of the Curiosity mission, and some fascinating insights into the engineering principles and analytics involved."
– MICHIKO KAKUTANI, *The New York Times*

About the Author
ADAM STELTZNER is an engineer at the Jet Propulsion Laboratory. He worked on several flight missions, including *Galileo, Cassini,* and *Mars Pathfinder,* and the Mars Exploration Rover project. He was the phase lead and development manager for the *Mars Science Laboratory* and the *Curiosity* rover's Entry, Descent, and Landing phase; he also helped design, build, and test the Sky Crane landing system. He lives in Pasadena, California.

WILLIAM PATRICK has cowritten memoirs by Sidney Poitier, Larry Flynt, Tamara Mellon, Robert Schuller, and Amy Robach

Chapter 1

SINATRA, AND A LOT OF BRASS

I'm at the Jet Propulsion Laboratory in Pasadena, California, in the Cruise Mission Support Area, "mission control," hooking up my iPhone to the Voice Operational Communications Assembly (VOCA), getting ready to launch Ol' Blue Eyes singing Nelson Riddle's 1966 arrangement of "All or Nothing at All."

It's just before 8 p.m. on August 5, 2012, and we're nearing the climax of a massive team effort to land a rover the size of a MINI Cooper on Mars. The overall project, called *Mars Science Laboratory*, has taken ten years to reach this point. Before we're done tonight, we'll have set that rover down gently at our selected site, or we'll have made a smoking crater on the surface of Mars. Whichever way it goes, we won't even know for seven minutes. That's how long it takes data from Mars to reach us back on Earth.

Hunched over the desktop beside me, jamming his VOCA headset into the small iPhone speakers, is my good friend Miguel San Martin, who is also my deputy in managing our part of the project: the critical component known as Entry, Descent, and Landing (EDL).

The assignment we took on nearly a decade ago sounded straightforward enough: Design a way to deliver a 5,359-pound entry vehicle, which carries a 1,982-pound rover called *Curiosity*, into the Martian atmosphere without harm, then slow it down, guide it to the landing site, and put it down on the surface, safe and sound.

In just a couple of hours—10:32 p.m. Pacific time—we'll know how well we did. It's our all-or-nothing moment, the moment of truth.

As the engineer leading the EDL team, my main job tonight is to be on hand to accept praise or scorn on behalf of the team. Ours is perhaps the most treacherous part of this incredibly complex mission, and definitely the most visible. Like a flaming guitar solo in a stadium concert, EDL might not be the mission's most fundamental element but it is the part that everyone will remember, good or bad, the next day.

Thousands of people have spent a big hunk of their professional lives working fifty- to eighty-hour weeks on this mission; I have fifty colleagues in EDL alone. This is a complete team effort, and an effort of a truly remarkable team at that. But as my friend, mentor, and senior sage at the Jet Propulsion Laboratory (JPL), Gentry Lee, says, there has to be "one ass to kick," and that ass is mine.

At JPL there's a long tradition of playing a "wake up" song at the start of every new day on Mars. Most of the choices have been bright and chipper, like "Don't Worry, Be Happy." But Mig and I are in charge tonight, and the music's our call. As is our custom, we've tried to make a selection that speaks the truth of the situation we're in.

We flip the switch, and our little broadcast goes out through JPL's VOCA system to headsets all over the world. First comes some smooth and mellow brass—trombones, I guess—then a tease of muted trumpets, then more trombones, then another tease from the Hammond B-3, all riding atop that swinging drumbeat. And then the Voice with the Message: "All . . . or nothing at all . . ."

I take a moment to relish the sound, which is totally cinematic. You can see the helicopter shot over Mulholland Drive at sunset with the LA skyline below. Or maybe a '57 T-bird pulling into the Sands in Vegas with Deano at the wheel and Sammy Davis Jr. riding shotgun. It's a skinny-tie, dry-martini arrangement, perfect for a caper like *Ocean's Eleven*—the original, not the remake.

Listening alongside us in mission control are brass of another kind. The president of the California Institute of Technology is in the room, as is the head of JPL (which is an arm of Caltech), along with the head of NASA. Even the film director James Cameron is on hand to see what a real Mars landing looks like.

Since the space shuttle program was canceled in 2010, Mars has been the only game in town for NASA brass, and for space geeks this landing is the World Cup. A couple of large rooms manned by caterers and equipped with large fishbowl windows looking into the control room are filled with an assortment of governors and congressmen and other people wearing suits with flag lapel pins. At one point it looked as if the First Lady would attend, but something must have come up.

Our mission managers selected this date for the landing more than a year ago, based on celestial mechanics and the position of existing Mars orbiters that could photograph our descent and otherwise relay data. The rendezvous was set in motion last November, when the capsule carrying *Curiosity* was launched from the Kennedy Space Center aboard a $300 million Atlas V-51 rocket. This means that our spacecraft—the product of almost a decade of many of our lives and the result of more than ten thousand human years of effort—has been hurtling through interplanetary space toward the Red Planet at about 13,000 miles an hour for the past eight and a half months.

Getting a payload to Mars is hard. The target is anywhere from 40 million to 350 million miles away, depending on the alignment of the planets, and it's orbiting the sun at 24 kilometers a second, more than 50,000 miles per hour. Landing a rover full of delicate scientific instruments at a specific site—in this case the Gale Crater, near Mount Sharp, in the northwestern corner of the Aeolis quadrangle—and at precisely the right moment is harder still. Yet this was the objective of the team of engineers I had the privilege to lead.

The idiosyncrasies of Mars's dust-laden carbon dioxide atmosphere don't make the job any easier. The planet has one-third the gravity of Earth. Its atmosphere is so thin that the air offers little resistance to an object hurtling through it—but is still thick enough to cause tremendous heating when you show up going 13,000-some-odd miles an hour. You'll need to come equipped with both an outsize parachute to slow you down—one that can open while you're still going nearly twice the speed of sound—and a heat shield to keep you from bursting into flames as you enter.

Once that heat shield gets you in, you need to blow it off with pyrotechnics so your radar can see the surface, and then you need the usual rocket thrusters to slow you further and guide your descent. We have been to Mars before, and we have always used this approach. But here's the bummer: The long-legged landers we used for the *Viking* missions to Mars in the '70s could travel safely only to very flat places. We wanted *Curiosity* to follow the scientists' interests, which might take it across the slopes and boulders and surfaces that are endemic to Mars. And the air bags we'd used like industrial-strength Bubble Wrap to drop smaller payloads onto the surface on more recent missions, like *Mars Pathfinder* and Mars Exploration Rover, would only rip, deflate, and smash onto the ground under the weight of a spacecraft this massive.

The solution we came up with: the Sky Crane, an approach that resembled something Wile E. Coyote might rig up with ACME Company products. It certainly didn't inspire confidence on paper. On first hearing about it, Mike Griffin, then the top boss at NASA, memorably said, "I think this is crazy." We convinced him that it might just be the right kind of crazy, but we knew we were taking a risk.

Here's how we needed it to work:

After the nearly nine-month journey of 352 million miles, our work has barely begun. First we have to convert the spacecraft from an interplanetary probe to an atmosphere-tolerating "aircraft." We switch the lander's electrical power from solar to nuclear. The spacecraft must be aligned at the proper angle to withstand 15 g's in deceleration forces and temperatures of 3,800 degrees Fahrenheit when it smacks into the atmosphere of Mars. About 7 miles from the surface, friction with the atmosphere will have slowed the lander's speed from 13,000 miles per hour to roughly 1,000. That's when we pop the supersonic parachute. Twenty-four seconds later, we blow off the heat shield so the radar can see. A mile above the surface, we let go of our parachute and light our rockets to navigate to an altitude of 60 feet. Then—and here's the good part—comes the Sky Crane maneuver, in which the *Curiosity* rover is lowered out of its "rocket backpack" by a set of cables. The two objects, rover and backpack, separated by 25 feet of cable, then descend to the surface. We have to retract the cables right after touchdown, in real time, so they'll stay taut as the rocket backpack continues to descend at a little less than 2 miles an hour. At this point, small guillotines cut the cables, and our rocket backpack, its job complete, flies a safe distance away and crashes into the surface, leaving the rover all alone and (we hope) ready to roll.

If any part of this scheme goes wrong—and all it takes is one failure from among tens of thousands of components to cause catastrophic loss—we will all look like idiots, and I'll be at the head of the line.

So you can imagine that the entire EDL team was already pretty amped up and more than a little bit anxious well before we discovered the glitch.

• • •

It was Miguel San Martin who found it. In addition to helping me manage and lead the EDL team at a systems level, Mig served as chief engineer for Guidance, Navigation, and Control. About seventy-two hours ahead of entry, he discovered an error in our "center of navigation," a set of parameters meant to represent the dynamic heart of the spacecraft. The center of navigation is the point from which we make all measurements of dynamic motion. Our onboard computers conduct hundreds of thousands of calculations to determine just how fast the spacecraft is going and in exactly which direction, and they're all based on that agreed-upon starting point.

At JPL we test all our software over a variety of platforms, called test beds. They vary in level of sophistication, the most complete being a copy of *Curiosity*, unglamorously called VSTB (vehicle system test bed), that lives in what we call the Mars Yard, a tennis court–size area of Mars-like rocks and rubble on the JPL campus. But so many parts of the mission and different software developers and teams were constantly struggling for time on her that we made a couple of other versions, not quite as complete, named MSTB (mission system test bed) and FSTS (flight software test set). As we prepared for landing, we ran lots of tests in each of these venues. These test results had to be reconciled with one another and differences understood. As we cruised toward Mars, we also had the actual spacecraft, and we could look at measurements taken on the spacecraft and compare them with data generated within our test beds. They should have all lined up; they should have all matched. Some of them didn't. Mig noticed a tiny discrepancy in the measurements taken on the spacecraft from the value he expected. Which is not how it ought to be.

This difference was reflected in the spinning centripetal acceleration—the acceleration that pulls you toward the outside of a merry-go-round. On the way to Mars our spacecraft spins like a top for stability. The measurements of that spinning acceleration were off by a tiny bit, around 150 micro-g's, or less than the 0.00015 of Earth's gravitational acceleration. It was the kind of discrepancy that another engineer might have blown off completely, but it nagged the hell out of Mig. In 1997 he'd been in charge of navigation and control on *Mars Pathfinder*, the mission that revitalized JPL and launched a new era in Mars exploration. After the spacecraft had landed safely, Mig discovered a time-tagging error in the data coming in from the radar. The discrepancy had not been large enough to endanger the mission, but it had been too close for comfort, and fifteen years later it still bothered him.

Mig's worries had a way of becoming my worries.

When you're leading even one component of a mission like this, you find yourself outwardly defending the reasonableness of your actions while, inside, you're criticizing the shit out of everything that's going down in order to find the one thing that can kill you. Even though I'd spent nine years of my life on this project, I'd always had a hard time imagining that it could work. The team had spent too many hours trying to anticipate all the ways it would *not* work. My thoughts in the months leading up to the landing were something like this: We are going ahead with this, and I can't imagine that it's going to work, and yet I can't think of a reason that it won't work, and for all I know it will work, but I've also seen it *not* work in other missions, and I know that we don't know everything about the spacecraft because we can't, because it is bigger than all of us.

When a space mission goes wrong, it is rarely the gut-wrenching disaster of *Challenger,* the shuttle that blew up on live television in 1986, killing all seven crew members on board. Everything we know about a mission's success or failure comes from radio signals sent from millions of miles away. If your telemetry goes dead, it might just be a temporary communication error. In the past we've lost contact with a space vehicle and had it come back. But we've also lost contact with space vehicles and never heard from them again, which is the most likely outcome if our craft goes silent during EDL. All we need to declare failure is a persistent lack of data confirming success.

Through most of the journey to Mars, the spacecraft's location is at best an estimate made by radio telescopes on Earth. As it draws closer to Mars, though, the planet's gravitational pull begins to remove uncertainty. We know where Mars is, we know the law of gravity, and this knowledge improves our understanding of where the spacecraft is, but only really toward the last minute (or the last few hours actually). If you've found something that doesn't add up, you have one last chance to make a change. It was in this time frame, this last getting-down-to-the-wire time frame, but completely independent of the Mars approach process, that Miguel found the problem.

After doggedly digging into the discrepancy he found between the spacecraft measurements and predictions, he got down to the essence of the problem, which consisted of three numbers representing the three axes that located the center of navigation. It turned out that when our supplier, Honeywell, delivered the inertial measurement unit—the heart of the guidance system—a JPL guy made a mistake logging in those three numbers. Rocket science is a high-tech world, but it's run by people, and people make mistakes.

During our spacecraft's long flight, we had regularly scheduled meetings to discuss software parameters we might want to tweak as we approached Mars, including trajectory parameters. Dust storms on Mars are a nightmare, and at all times we have a roomful of people obsessing over atmospheric updates, not just for the landing site but for the entire planet, in case we need to fine-tune the flight path we come in on. These types of parameters we had planned on changing, and we had structured the software to make it easy and safe to do so.

Parameters more at the core of our software, like the center of navigation numbers Mig was looking at, were not in that set. We could change them, sure, but it was a risky proposition. When you're a couple of days from the end of a nearly nine-month voyage, following nine years of development, you're not eager to tamper with anything unless there's a damn good reason. You certainly don't blithely rejigger vital software parameters, because tinkering with something as simple as the date or time might inadvertently alter one of the thirty thousand other parameters and cause a catastrophe.

But now Mars is looming large in our windshield. We've made it this far, and we've landed successfully in all the simulations that contained the error, so does that mean we should live with that error? Should we alter the parameters, or should we let it ride?

Mig found the error Wednesday and had confirmed it by late Thursday night, August 2. We immediately set up a "tiger team" of about twenty-five specialists to drop everything and launch a full investigation of the anomaly response—spacecraft ops–speak for "Look into this and get it un-fucked-up if possible." Folks from Guidance, Navigation, and Control, from software, and from trajectory simulations broke the problem into pieces so that subteams could pursue multiple lines of attack, and the subteams began pulling all-nighters. We ran trajectory simulations using both the correct parameters and the erroneous ones. When we compared the results, we couldn't find any differences. That didn't mean they weren't there. It just meant they didn't show up in our simulations. The software folks spent their efforts making sure we could fix the parameter error without upsetting the rest of the flight software. Everyone crammed furiously until 5 a.m. on Saturday, August 4, when we assembled, pencils down, for a come-to-Jesus session. Two hours later there would be a second meeting, with the project managers, to make the actual decision. Do we correct the error or not?

Navigation and control is not a trivial matter, and our center of navigation was off by about three inches. Was that enough of a discrepancy to slam us into the Martian atmosphere at the wrong angle and burn up the spacecraft? Was it enough to cause us to miss our landing site and put us down in mountainous terrain where we might smash into a mountain or topple over? Years of man-hours and billions of dollars were at stake.

Our Saturday-morning "What do we think?" discussion ran long. While everyone found the error unsettling, no one argued for taking the risk to correct it. It could mean nothing in the end, or it could poison us in a way that we could not imagine. But no one had isolated the one glaring truth that said this thing was going to kill us unless we fixed it.

We were still going around and around on the engineering analysis at 7 a.m. when the seven senior managers, all looking fresh and rested, showed up. The top dog for the mission was Pete Theisinger, silver haired and slight of build but a tough fighter. I told him I hadn't polled my team yet. "I'm happy to do it right now, in real time," I added.

Pete agreed, and so, with the senior decision makers looking on, we went around the table to get everyone's best judgment. The poll-taking would end up with me.

Everyone said, "Steady as she goes." Oddly enough, this included Miguel, who'd first spotted the problem and had obsessed about it until he got to the source.

Pete looked very relieved with our group's seeming endorsement of the status quo. He began to move the meeting toward closure. But then I stopped him.

"I said we'd poll the team," I said. "Unfortunately, the team's split . . . because I think we should make the change."

I could see the anxiety tighten his face, and then he settled back to consider his options. The whole EDL team has said that we're okay as is except for me, the guy in charge of that team, the guy specifically tasked with landing the spacecraft. I wasn't an unassailable authority, but I was the one ass to kick.

Pete then polled his colleagues—the rest of the senior management team, including engineering leadership. One after another they echoed the tiger team, somewhat sheepishly admitting that they would rather not make the change. This reluctant chorus of "steady as she goes" continued all around the room until we got to the last two guys: Richard Cook, the deputy project manager, and Rob Manning, the project chief engineer.

Richard said, "I agree with Adam. I think we have to make the change."

Then Pete turned his eyes to Rob. “What say you, chief engineer?”

“I’m with Adam and Richard. We’ve practiced making these kinds of changes. Let’s do what we’ve practiced and make this right.”

Pete drew in a long breath, as if absorbing all the data that had been crunched in the past thirty-six hours, along with all the opinions expressed, leavened with fifty years of life experience. Then he said, “We’ll make the change. Prepare the command for transmission, and radiate the command.”

So just before 9 a.m. Saturday, thirty-nine hours after we’d begun our assessment, we altered the three numbers that pinpoint the center of navigation. Fourteen minutes later—the time required for a round-trip transmission between Earth and near Mars—the spacecraft reported back that the change had been received and the update completed. At least as near as it could tell.

Had we just screwed the pooch, or had we averted an “O-ring moment” (the culprit behind the *Challenger* disaster) and saved the entire mission? There would be no way to know for thirty-six hours. During that time the spacecraft would have traveled 400,000 more miles and gone through the torturous seven minutes it would take for the rover to enter Mars’s atmosphere, descend to the surface, and land on the Red Planet safely—the Seven Minutes of Terror.

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Spoiler alert: We made it. When the seven minutes came and went and we heard that first ping back from *Curiosity*, we looked like geniuses and everybody loved us. (You can skip ahead to the last chapter if you want more detail on who cried, who cheered, and how we stormed the press conference.) Whether the last-minute change made the difference between a success and history’s most expensive pile of burning scrap metal, we may never know.

What we do know is that a roomful of the world’s best aerospace engineers couldn’t agree on whether it would make a difference. Engineers are supposed to be rational minimalists. Did each of us do a purely rational calculation and simply come up with different answers? Did we use our slide rules incorrectly? Were our calculators broken? Was it really just a question of math?

I don’t think so.

Back in the early days of the American space program, the engineers on TV during the rocket launches and moon landings all sported white short-sleeved shirts and skinny ties with tie clips and nerd eyeglasses, all of which contributed to an “I am a robot” image that might have been meant to intimidate the Soviets. But engineers aren’t robots. Engineers are people, and no matter how carefully we pursue the truth of the physical universe as reflected in the hard data, our interpretation of the physical laws as applied to the business at hand is always going to be filtered through who we are as individuals. Any truth we arrive at, no matter how diligently we pursue it, is always going to be an approximation, a model of the universe and not the universe itself. When problems get thorny and the outcome or correct path is uncertain, as it was for the group contemplating changing software parameters at the last minute, human judgment and an appreciation of the limits of your understanding become paramount. This is true whether you are engineers building a spacecraft or software developers working on the next big iPhone app.

Beyond the importance of human judgment is the need to understand what makes other humans tick. The English word *engineer* comes from the Old French *engin*, meaning “skill or cleverness.” The act of engineering is to solve a problem by being clever and utilizing our understanding of the world around us. In an era of projects with billion-dollar budgets and head counts in the thousands, part of “the world around us” that needs to be understood is the people involved. If you're going to succeed in that kind of creative, collaborative environment, especially if you're going to lead and manage the development of something innovative, you need to engage a lot more of yourself than your knowledge of fluid dynamics or stress analysis.

As a practical enterprise, engineering is hugely dependent on honestly facing the hard data. If you pursue your own personal "truth," or if you settle for a partial or parochial truth, or if you deny the truth because it's awkward or inconvenient, your bridge falls down. Your cyclotron doesn't find any particles. You never get your spacecraft anywhere near Mars, much less safely on the surface.

But it's a mistake to assume—which plenty of folks, including engineers, often do—that the answers live in some preexisting space, that all you have to do is put the right equations on the table, that you don't have to use judgment or anything associated with the emotions to get to the solution. The best problems are simply too complicated to have a clean equation that describes them. In the real world of budgets and politics and the dynamics of large organizations, getting anything done is a no-holds-barred brawl, and as in any street fight, success or failure is a function of everything you bring to it: cleverness and intelligence, knowledge and technical prowess, charisma or awkwardness, shyness or the ability to persuade, self-confidence or self-doubt, self-awareness or denial.

On its face, this is the story of an audacious engineering project: the design and construction of a hugely complex rover and the innovative, "crazy" landing system that delivered that rover to Mars. But that's just the basic plot.

This is also a personal story about how I ended up at the Jet Propulsion Laboratory building spacecraft and how I learned from my time at the lab to lead an extremely talented team to solve impossible problems. It is a story about harnessing human curiosity to build something truly fantastic and about being honest enough about human nature to protect ourselves from self-deception on a scale that could bring disaster. And it's an exploration of the thought processes, leadership techniques, and problem-solving skills that went into making such an exceptional effort possible.

To the extent that my perspective might provide some insights, it is also going to be flawed. I'm going to present the story as honestly as I can, but my version is always going to be limited—colored by the lens of my perception.

Most, if not all, of the great works of our species have been team efforts. If we want to do great things—whether it's slow global warming, end malaria, or put a human on Mars—we can't rely on the lone genius working out of his garage. We need to figure out how to engage people of diverse talents, perspectives, and worldviews to come together to produce great work. My ultimate goal for this book is to provide a fresh perspective on how leaders can successfully engage smart people to build challenging, high-stakes, innovative projects. It's my hope that these observations and lessons are transferable to others' efforts in other fields.

Beyond that, I hope you will find a reflection of your own humanity in the story of the work that we do to explore our universe—the work of extending the edge of what we know and perhaps even who we are as a species.

Chapter 2

HOW CURIOSITY CHANGED MY LIFE

I sometimes joke that curiosity changed my life. But in some sense it is really true. I am very different from the man I could have been, and I think I might be better. I'm sharing this story not because I think it's unique but because I think it's not. There are scores of young people out there getting bad or conflicting advice, locked into what they think is the thing they are supposed to do and pushing themselves to perform. With those high standards frequently comes a crippling fear of failure. I was crippled by it, and if I hadn't been curious about the world, I would probably still be working in a health food store, dreaming of the day when my band would hit it big.

Yes, I have helped land robots on Mars, but I was not one of the math geniuses who carried a briefcase and won physics prizes in high school. I knew some of those guys, I liked them, but I was not part of their crowd. Some may consider it a miracle that I ever got my diploma. My only good subject was theater, and instead of studying, I smoked pot, rode mountain bikes, chased girls, and played gigs with my band. I had no real ambitions except perhaps to magically become Elvis Costello or Joe Jackson.

I grew up in the sixties and seventies, mostly in Sausalito, just north of San Francisco, with parents who were very much in tune with the time and the place. My mother was a true free spirit. She lied about her age to serve in the Women's Army Auxiliary Corps during World War II and afterward was a bit of a beatnik in San Francisco, managing nightclubs and dating influential female artists of the time. Her intelligence and independence aside, she still preferred to sit in the passenger seat when there was a man to drive. She met my father when, fresh from Army service, he stopped for a drink at the bar of a hotel she managed in the foothills of eastern California's Sierra Nevada. Sparks flew, and he stayed four days, leaving my mother with the address of an accountant in Piedmont to whom the bill should be sent.

My parents, my brother, and I lived an almost comfortable existence on what was left of my father's family inheritance. My father was a great reader, knowledgeable on subjects ranging from the aerodynamics of laminar airfoils to the artificial insemination of sheep, but he never showed much interest in earning a living. Work meant struggle, struggle meant the possibility of failure, and failure was simply unacceptable.

As the family wealth dwindled, denial hung over us all like a cloud. My father dealt with it by drinking heavily. I coped by becoming a human projectile.

At a very early age, I pursued every form of physical recklessness, from skateboarding in traffic to biking down steep mountain roads at race-car speeds. I was the kid who climbed every fence and leapt off every ledge. In retrospect, I think I was trying to escape the fear that seemed to cage my father, or to suspend it via an act of will and perhaps grab on to something real and true. But mostly I broke bones—thirty-two in all before I was grown.

The closest thing to a hint of a future career in space exploration was my daydreams, which dealt with spatial reasoning. My number one alternate reality was a weird game in which gravity would turn off, then turn on in a different direction. I would be left trying to understand this new force field and the trajectories that objects, especially myself, would now take through space. Sometimes gravity ran sideways and, in my imagination, would slam me into a corner of the room. I would have to grab a windowsill or try to avoid a column.

Meanwhile, in my waking life, there was no such thing as following the customary path from point A to point B in the neighborhood. One game was to follow a straight line no matter how many obstacles were in my way, refusing to bend my will to the designs and will of "the man." Did I have to climb three 8-foot-high fences and make my way through a couple of industrial yards on my way to get a candy bar? So much the better. Climb along the 25-foot-high peak of a roofline? No problem. Property owners would put axle grease on their fences and catwalks to keep me off, but that just increased the appeal. Let's see if I can now jump off that roof to that gate and walk along the top of it to the fence without touching the grease. “Get off the roof, Adam!” was a common cry from the neighbors. And “Hello again, Adam,” a common greeting in the ER.

By the time I reached high school, it had become abundantly clear that I was not “college material.” My parents sent me to therapy to explore my combination of extreme risk taking and minimal consciousness in school, but I don’t think my behavior was really all that great a mystery. I was simply acting out a challenge to my dad. I could see what fear had done to him, and I was having none of it. And if he didn’t have to go to a job and work hard, why should I? I’d also internalized the message from my dad that trying to do anything seriously was pointless, even dangerous, because absolute perfection was required, and absolute perfection was unattainable.

After I barely managed to graduate from high school, I moved to Mill Valley, took a day job at a health food store, and started playing bass in a kind of rock-jazz-punk fusion band called Exit.

One night I had a gig at a club in Corte Madera, on the way up to Larkspur, so early in the evening I was driving up Highway 101, heading for our sound check, and I noticed the constellation Orion over my right shoulder, meaning that it was in the eastern sky, looking toward Point Richmond. After midnight, when I was driving home, there it was again over my right shoulder, meaning that now it was in the western sky, looking toward Stinson Beach. I’d never taken an astronomy course, but for some reason this intrigued me. We see the stars “moving,” but I knew that what’s actually happening is that *we’re* moving, riding on the surface of the Earth as it rotates on its axis and orbits the sun—or did I? Was that what was really happening? How does all that shit really work?

As I drove on home that night, I kept thinking about this movement in the sky—what I’d now call celestial mechanics—and for the first time in a long, long while, I was deeply curious about something. And that curiosity changed my life.

A couple of days later, I decided to drop by College of Marin, the local community college, to see about signing up for an astronomy class. Coincidentally, it was the day of the next semester’s course registration, and sign-up sheets covered the walls of the gym. I grazed the offerings until I saw what I was looking for: Introduction to Astronomy. But then I read the fine print. To take the course, you had to have taken the prerequisite: Physics 10. I signed up for both, hoping we could work out some sort of deal. As it turned out, the joke was on me, because not enough people signed up for the astronomy course, so it was canceled, and there I was in a physics course I’d had no intention of taking. I decided to stick it out because, deep down, I craved a new experience. That and the fact that one of my classmates was a high school buddy I used to race mountain bikes with.

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I didn’t have a particular game plan. I was simply following my curiosity. I had let go of any expectation about where my efforts might take me. I certainly had no expectation of great success. I wasn’t waiting to become Elvis Costello anymore. I was simply doing my best to learn about my world and the universe around me. In some sense I was starting small, starting at the ground floor with the bedrock truth of the physical universe and hoping to build up from there.

I was also experiencing what my friend Miguel calls a “constructive interference of personality disorders,” which he claims is the secret of success for most people who get anywhere. But be that as it may, at College of Marin math and physics opened up to me a shiny new world of precision and clarity and absolute honesty. The idea that there were laws that governed this confusing universe we inhabit was a huge turn-on.

I'd taken elementary algebra and geometry (twice) in high school, passing with an F+. I'd done whatever the minimum requirement was to graduate, but anything I'd learned had gone in one ear and out the other, leaving no trace. Luckily, Physics 10 was "physics for poets," which meant there was basically no math, so I thought that maybe I could survive.

The larger stroke of luck was that the man teaching the course, Stephen Prata, had the gift of being able to share with his students his passion for understanding the universe. When Dr. Prata took a piece of chalk and scrawled F = MA on the blackboard, it seemed to me like an incantation, making mass (M) and acceleration (A) transmute and reveal their nature. I'd experienced the force (F) he was talking about riding skateboards, so I understood in my gut what the equation was saying. Now I could see how that fact of nature could be analyzed abstractly. You could make a model, and then you could use that model to make predictions. And then you could use those predictions to make stuff or to make stuff happen. You might even use them to explore outer space.

To me this manipulation of equations that represented the functions of the universe was not only magic but a thing of intense beauty. It seemed to speak the hard truth that I had been looking for when I was slamming myself against the world and breaking all those bones. But I was so far behind in my education that I would have a long, long way to go before I could approach the truth in the form of an equation.

I worked hard to catch up, entering a monkish phase during which I let go of music and buzzed off all my hair. I kept my apartment and my day job at Living Foods in Mill Valley, and I rode my mountain bike back and forth over Mount Tamalpais to attend class. It was what a Jungian shrink might call a time of ashes, when you go down to get real in order to go back up. But I never really saw it that way. I was simply saving my life and the lives of everyone to follow in my lineage, hell-bent on not repeating the mistakes of my father.

I did well at Marin—the feeling that you're playing out a family curse if you don't stick with something is excellent motivation—and it awakened a dormant competitiveness within me. I started working harder to see just how well I could do.

After a few years, I transferred to the University of California, Davis, where I majored in mechanical engineering and design. The way I looked at it, being an engineer was like being a physicist, only you could count on getting paid. But what appealed to me most was the focus on fearlessly seeking out the truth of a situation, being objective and empirical. It would take a while to realize that there was a lot more to getting engineering done than a firm grasp of objective truth.

Three years later I graduated and gave the valedictory address for the College of Engineering. I was offered a full ride for graduate school from all the right places—Stanford, Caltech, MIT—but when I visited Caltech, in Pasadena, they seemed focused on the work more than on their prestige, and it scared the crap out of me. These guys were *serious*! I chose Caltech. For someone with decent math skills and something to prove, entering the California Institute of Technology was like joining the Navy SEALs.

In fact, I had no burning desire to do research, and I didn't even have a particular field that I wanted to explore. I was driven simply by curiosity and the need to overcome my insecurities.

I never found a professor I clicked with or research that excited me, and with a vague dissatisfaction bubbling up, I went to see a former student give a seminar on his work at Orbital Sciences Corporation in Maryland. They'd developed the Pegasus launch vehicle, designed to carry small satellites into space and also designed to be launched from an L-1011 airliner at 30,000 feet or so to bypass the denser parts of Earth's atmosphere.

My work at Caltech up to that point had been theoretical and abstract. Until I saw the talk from the guy from Orbital, I hadn't realized how hungry I was for the hands-on application of engineering training. I wanted to get my hands dirty. I wanted to build something. By the end of the summer, I'd made up my mind to move on.

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