Pilot Competency and Capability

Responsibilities, Strategy and Command

Steven D. Green

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Pilot Competency and Capability presents strategies for the air carrier pilot-in-command operating complex engineered systems within a complex natural environment. It bridges the gap between academic books and practical application by providing real-world examples of how various safety and operational theories work in practice.

The book advises on how to develop concepts, strategies, and ways of thinking that integrate with existing structures and FAA regulations, while understanding how engineered systems and codified structures interface with complex natural environments. It considers how the prescribed safety margins function to manage emergent behaviors of both the natural environment and the engineered systems.

The book is intended for airline pilots, training captains, simulator instructors, and aviation students taking courses in aviation safety, risk management, and flight safety to improve in-flight decision-making, risk analysis, and strategic planning.

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For Lieutenant Thomas J. LeBel, USAF

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Preface

I started flying airplanes in 1971, at Palm Beach International Airport. I was fourteen years old. My first lesson was on January 30, the day before Apollo 14 lifted off from the Kennedy Space Center. I know that because the day after my best friend and I had taken our first flying lessons, we drove up the coast of Florida with our fathers to watch the launch. In two days' time, I was pretty sure I had arrived in the space age.

I am now retired, after forty-one years as a commercial airline pilot. Between that first day and today, I logged something north of 18,000 hours of flight time. As with almost any retired pilot, I could write a book about decades of truly amazing adventure and experience, flying all over the world. I wouldn't trade it for anything; not the airplanes, from Convair 240 to the L-1011, 727, MD-80, 757, and 737 Max, not the layovers, from Dayton to Paris, Cairo, Lima, and Barbados, and most certainly not the colorful, talented, and wonderfully eccentric characters that I flew with. But that is not this book.

On a single, radiant New England summer day, my career … my life … took an abrupt, brutal, and wrenchingly painful turn. On June 25, 1978, I crashed a Grumman Yankee trainer in the mountains just north of Lake Winnipesaukee, New Hampshire. The man with me was a close friend from high school and college; he had flown with me dozens of times during our college years. He had recently graduated and been commissioned in the US Air Force. At the end of the summer, he was destined for pilot training at Williams Air Force Base.

He was in the left seat. As a current and practicing flight instructor, I was giving him some basic instruction, mainly just because he was a very talented and capable individual with an amazing future ahead of him. We flew a practice approach to Moultonborough, then climbed to the north, turning east along one of my favorite ground reference paths across the hills to the north of the lake. We flew just a few hundred feet above the terrain, following the contours over to a point where a right turn southwest-bound would take us across a saddle in the rim on the north shore of the lake, back out across the water. I had done this many times.

At some point, something went very wrong. It seemed apparent that we would not clear the next ridge. I took control, added full power, and established a climb attitude. This did not seem to help. The terrain sloped down to the left, but a left turn would have taken us into the ridge before we could complete it. I rolled into a longer right turn, away from the ridge, intending to come all the way back around to the northwest, pointing downslope toward a different escape route. The last thing I remember was expressing profound shock that we were not going to make it.

Two days later, a US Air Force Huey crew extracted me from the forest. I was in very bad shape, with both ankles shattered and a crushed vertebra, along with a broken collarbone and numerous lacerations, as well as being seriously dehydrated. When the first PJ reached the ground, I was several yards away from the wreckage, intent on dragging myself to a stream nearby. I told the PJ that I thought my friend might still be alive and to go to him first. In an unforgettably compassionate act of honoring my dignity, given that I was pretty close to expiring myself, he complied. He returned shortly and carefully told me that my friend was gone. I had expected that, and of course, since that young airman had already been at the main wreckage, he already knew it. But hope had gotten me this far, and hope, however forlorn, must never be surrendered. My young rescuer chose to let my hope adjust slowly, rather than crush it.

The Safety Board, as far as I know, never went to the site but examined the wreckage after it had been airlifted out of the woods. They did visit the hospital and take my statement, and eventually decided that I had “failed to obtain/maintain airspeed”, made “improper in-flight decisions or planning”, and “continued flight over rugged terrain”. They also mentioned downdrafts as a weather factor, probably because I told them that’s what I thought had happened. They even threw in the entire section on mountain flying from the pilot’s operating handbook and added a statement that when the conditions were “right” in the area we were flying in, it was extremely turbulent with downdraft and heavy wind shear effect.

The problem with all of that is that it had been a beautiful summer evening. There was no significant wind at the surface and none aloft to speak of. The air had been smooth. In fact, the reason we flew the route we did is because it was such a perfect evening to do it. In the margin of my copy of the Board’s report, my father scribbled, “no indication of winds like this in the forecast, so what is the point I filling up this report with reprint?” Today, I still have no good idea why we were sinking in the first place. Or if we even were. I’ve looked at the weather data a thousand times and still don’t see where a downdraft sufficient to exceed to airplane’s climb capability would have come from. I’ll never know whether we could have successfully turned left; I didn’t think so at the time. I’ll never know if we actually would have cleared the ridge; I didn’t think we would. I’m pretty sure I got us into an accelerated stall during the turn, but I have no recollection of excessive bank. I will never know if a few degrees less of bank would have made a difference.

I realized a long time ago that I would never know what had happened.

There wasn’t enough of an investigation, yet in fact, the best investigation possible may just as well have found no more than this one. There simply was not enough factual evidence to work with. The phrases included in the accident report are nothing more than selections from a pull-down menu of factors designed to bend and fold the accident into a preconceived taxonomy. People don’t like uncertainty. They need a reason; they need to be able to organize events in their mind. The disconnect between what the actual weather was and all of the boilerplate pasted into the report unveils the true nature of our relationship with accidents. While phrases like “failed to obtain/maintain airspeed” can neatly pigeonhole an event and, by the way, create some distance between ourselves and the hapless pilots who failed to obtain/maintain airspeed, they obfuscate and erase for history the complicated, even byzantine web of nuance, variation, and complexity that creates a singularity of conditions for each and every accident. You have to wonder how many accident reports containing the phrase “failed to obtain/maintain airspeed” are similarly uncertain.

The one inescapable truth that I do know is that what happened was my responsibility to prevent.

So, I have spent the last forty years trying to understand more about the nature of accidents and to learn all I could about how to better execute that responsibility. That journey is what this book is about. I'm not going to follow a traditional path in describing this exploration. During my career, I have been involved in a number of major airline accident investigations, from AVAir 3378 to TWA 800 and several in between. I have participated in a number of safety initiatives, from the One Level of Safety effort in the early 90s that brought us Part 119 to the Commercial Airplane Certification Process Study in 2001. I have been a member of several rulemaking committees, most notably the years-long Ice Protection Harmonization Working Group. I had the privilege of being a part of building an entirely new and original airline. Along the way, I have attended more meetings, read more papers, and sat through more safety seminars and recurrent trainings than I really want to remember.

Most of that effort … not all, but most of it … has been very productive and meaningful. I think we've done a lot of good things; a lot of people have certainly worked very hard to do so. But none of it has really answered the mail, so-to-speak, from my perspective as an accident survivor, because none of it has ever really come to terms with the most fundamental truth about any accident. That truth is simply that you will never, ever, not in a million years, ever see the one coming that gets *you*.

We are hamstrung, to a great extent, by the character of human cognition. We generally think of accidents in one of the two ways: we describe them through a story or we describe them as a statistic. Both of these approaches are powerful and useful tools, but both are frozen in time because they can only describe what has already happened. Any story is colored in by the language used and the meaning of that language. Words like "continued" are fairly black-and-white, describing a simple fact, but they can also imply additional meaning depending on context. A word like "failed" is also quite factual, but somewhat more prone to pejorative interpretation. But a word such as "improper" is designed to convert opinion into fact through unabashed pejorative judgment.

Furthermore, a story is built around a linear model of cause-and-effect. The effect is usually quite clear; the cause is more elusive. One way to backfill a story, beginning with the effect, and moving toward the cause, is through the aforementioned choices of language and the meaning therein. This gives the appearance of accounting for all of the detail and nuance, which promotes a sense of certainty. As history, the story can be deeply flawed for all of the reasons I have described. But the real problem with applying a story model to the future is that there is no story about an accident that has yet to occur because it hasn't actually happened. So, we are stuck with thousands of aimless causes and millions of meaningless details that cannot be linked to an effect because there is no effect. Not yet. We can guess, and if we guess well, there will be no accident. On the other hand, if we don't capture the nuance, don't see the patterns, then our guess, if we even think to make a guess, will miss the mark.

We can and do link causes and details statistically, but a statistical model is built from many, many stories, and a probability is created through a pretty binary, black-and-white assignment of value … pull-down menus … derived from the language we use to describe the stories. It is only as good as the stories, and the language, that it is built from. Even if we assume those stories to be watertight, we are still trapped by the very nature of a probability. In the end, all probabilities have a value of less than one, meaning that each data point represents a probability of something happening while simultaneously representing a probability of something not happening. None of them … none … have ever leapt out from under a bell curve and actually happened. This problem approaches the thought experiment of Schrodinger's cat, in which a cat is considered to be simultaneously alive and dead because the probability of a subatomic particle decaying and causing a poison to be released in the next hour is 50/50. When something does occur, when the particle does decay and release the poison, it suddenly has a probability of one, meaning that it is no longer a probability. And it is too late.

Statistical analysis is intended to quantify uncertainty, not to be used as a decision tool in the face of actual uncertainty. This conundrum demands that we think differently. Instead of anticipating certainty derived from historical models, we need to anticipate uncertainty, and in particular, a condition that I refer to as persistent vulnerability. There is not a single pilot involved in an accident who gets up that morning and sees someone in the mirror who, later in the day, will kill several hundred people. Not a single one of us can look in the mirror on any given morning and be certain.

So, while that is the last time I'll mention Schrodinger and his famous cat, I'm going to take a somewhat different path from that conventionally used. This book is a pretty deep dive into how we might think differently. I'm going to bring in a lot of thinking, some contemporary, some quite ancient, and hopefully show how it applies to what we actually do. The unwritten message that lies at the foot of human factors in aviation is that we are all human beings first and aviators second. Flying is a very singular, unique human endeavor, and we are not born to it nor can we be trained to it with any expectation of perfection. We must approach it not as procedurally programmed automatons but as human beings vested with the most profound responsibility in all of human endeavor.

Before launching into the text, a serious question might be asked: why? In the last several decades, commercial aviation safety has improved by whole orders of magnitude. Indeed, the first and most important consideration is that we must do no harm. We work in a well-designed, well-operated system that has yielded tremendous success. That success cannot be jeopardized.

Nevertheless, commercial aviation stands upon a precipice. The demand for new pilots is relentless. The path toward becoming a pilot has narrowed and become cost-prohibitive. The opportunities for gaining experience have diminished severely. At exactly the same time, the operational world of the commercial aviator has become vastly more digitized and nearly cybernetic. Such digitization is a powerful tool that has brought about significant improvement in standardization, consistent performance, and repeatability.

But human beings cannot be digitized. More importantly, we fly in an analog sky, a sky that really could not care less about binary code. There are analog lessons to be learned. My aim is to pass along as much of the analog world as I can, in the hope that new aviators, and some not-so-new aviators, can integrate it into the digital world of their future.

About the Author

Steven D. Green started flying at age fourteen and soloed on his sixteenth birthday in 1972. He began his airline career flying a Convair 240 for Providence Airlines around the Great Lakes, then flew Fairchild Metroliners up and down the east coast through the 1980s and then all over the world for TWA, Eos Airlines, and American. He holds a B.S. in Aviation from Louisiana Tech University. He also holds an Airline Transport Pilot license from the FAA with type ratings for the Boeing 767, 757, 737, MD-80, EMB-145, and the Fairchild SA-227, as well as a Flight Engineer license with a turbojet limitation. He flew professionally for forty-one years, operating at all levels of the industry including Part 135 commuter operations, Part 121 supplemental operations, and Part 121 flag operations. Beginning in 1986, he has participated in numerous aircraft accident inquiries and investigations as a representative of the ALPA including TWA 800, TWA 843, Business Express N811BA, Simmons 4184, Comair 3272, AVAir 3378, and AVAir 3464. He received his formal accident investigation training from the Transportation Safety Institute in Oklahoma City in 1993. For two years, he taught two segments of the ALPA's Basic Accident Investigator Course. He also participated in the FAA Commercial Airplane Certification Process Study in 2001–2002 and contributed to the drafting of the final report. Association with the 1994 Roselawn accident involving Simmons 4184 led to work with ALPA's Inflight Icing Certification Project, which included participation on the Ice Protection Harmonization Working Group ARAC. Since 1994, he has been actively involved with icing issues and has written a number of papers on the topic and delivered several oral presentations. Since 2004, he has actively consulted for both National Aeronautics and Space Administration and the FAA on the subject of airframe icing. He and his wife have lived in Vermont for thirty-three years and have two grown sons. He retired from American Airlines in 2021 as a Boeing 737 captain.

List of Abbreviations

AC	alternating current
ACARS	Aircraft Communications Addressing and Reporting System
ADF	automatic direction finder
ADIRU	air data inertial reference unit
ADR	air data reference
AGL	above ground level
AIM	Airman's Information Manual
ALPA	Air Line Pilots Association
AoA	angle of attack
APU	auxiliary power unit
ARAC	Aviation Rulemaking Advisory Committee
ARFF	aircraft rescue and fire fighting
ARINC	Aeronautical Radio, Inc.
ATC	air traffic control
ATIS	automatic terminal information service
BTCU	borderline tolerated conditions of use
CAA	Civil Aeronautics Authority
CAVU	ceiling and visibility unlimited
CB	circuit breaker
CFR	crash fire rescue
CRM	crew resource management
CRT	cathode-ray tube
CSD	constant-speed drive
CVR	cockpit voice recorder
DME	distance measuring equipment
EASA	European Union Aviation Safety Agency
ECAM	electronic centralized aircraft monitor
EFIS	Electronic Flight Instrument System
EGPWS	Enhanced Ground Proximity Warning System
EICAS	Engine Indicating and Crew Alerting System
ELT	emergency locator transmitter
ETOPS	Extended-range Twin-engine Operations Performance Standards
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCPC	flight control primary computer
FMC	flight management computer
FMEA	failure modes and effects analysis
FMS	Flight Management System
FPM	feet per minute
GPWS	Ground Proximity Warning System
HF	high frequency
HRO	high-reliability organization

ICAO International Civil Aviation Organization
IAF initial approach fix
ILS Instrument Landing System
LOFT Line Oriented Flight Training
LORAN long range navigation
MAP missed approach point
MDA minimum descent altitude
MEL minimum equipment list
METAR meteorological aerodrome report
MORA minimum off-route altitude
NDB non-directional beacon
NOTAM notice to airmen
NTSB National Transportation Safety Board
PA public address
PBN performance-based navigation
PFD primary flight display
PJ para-rescue jumper
PRA Probailistic Risk Assessment
QRH Quick Reference Handbook
RNAV area navigation
RVR runway visual range
RVSM reduced vertical separation minimums
SAL Saharan Air Layer
SAFO Safety Alert for Operators
SB service bulletin
SFAR Special Federal Aviation Regulation
SOPs standard operating procedures
SSA System Safety Assessment
TAF Terminal Area Forecast
TALPA Takeoff and Landing Performance Assessment
TCAS Traffic Collision Avoidance System
TR transformer-rectifier
TWA Trans World Airlines
UPS United Parcel Service
UTC Coordinated Universal Time
VHF very high frequency
VNAV vertical navigation
VOR VHF omni range

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1 The Nature of Accidents

THE TENTH AXIOM

Among my collection of antiquarian aviation books and manuals, I have a copy of *Civil Aeronautics Bulletin No. 5, Flight Instructor's Manual*, published in June 1939. At the end of the manual are listed ten axioms for the pilot. My personal favorite is the tenth axiom, which says that "The capable and competent pilot will never allow an airplane to crack up …".[1] It then goes on to state that if a crash is inevitable, the pilot (apparently no longer classified as capable or competent) should maneuver the aircraft "in a manner to ensure that no injuries will result to himself or his passengers",[2] which, according to the manual, is almost always possible.

Most of us in the business of flying airplanes easily recognize the narrow-minded, myopic approach to safety that is captured here, and the historically aware might also recognize a Victorian tone that dates the original construction of this axiom back to World War I or slightly earlier. We could easily dismiss it as quaint. But I think that too quick a dismissal underestimates the impact that this axiom has had on the history of our own work in safety and the paradigms that go with that work. Rather, a careful unpacking of the axiom is worth taking some time to do.

There are probably some pretty deep cultural undercurrents at work in this axiom. It is hard to overlook that tone, which subtly flavors the accident as a fall from grace, suggesting that whether an airplane crashes or not is largely a matter of free will. Indeed, I suspect the axiom is rooted in the broader social and religious thinking of the era, which tended to emphasize the role of free will in overcoming inherent depravity. At the time, this thinking was being steadily challenged by accelerating technology, the science that lays behind that technology, and the increasingly irrefutable role of determinism in that science. The frequent failures of early technology presented powerful emotional trials to society … witness the crash of TWA 599 on March 31, 1931, which cost the life of Knute Rockne, among others … particularly since the deterministic aspect to causality made the control of that causality more and more complex.

Yet the accident reports of the same era do not consistently reflect the tenth axiom at all. In the Rockne crash, the investigation centered on poor glue application during the lamination process of a wooden wing spar and steered away from questions regarding the pilot's decision to depart, although that decision was debatable.[3] In other accident reports, there are as many references to poor judgment as there are to newly understood technical phenomena, such as icing, radio range failures, and weather conditions seriously different from those forecast. Indeed, there are even some rather fantastic technical explanations … one of my favorites was the DC-3 crash of Pennsylvania Central Airlines Flight 19 near Lovettsville, Virginia in 1940, in which one of the hypotheses suggested that the concussion resulting from a nearby lightning strike had "smashed in" the windshields.[4]

As it happened, a few years before my edition of the Flight Instructor's Manual came out, Jimmy Doolittle managed to destroy a brand-new Lockheed Vega after he

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had loaded it up with his family and all their worldly belongings and then attempted to take off, overweight, from the rutted frozen mud of Mitchell Field. Not too long afterward, he snapped the ailerons off of a highly modified Travel Air while tooling down the runway with more airspeed than altitude … the modifications were not as well thought out as they might have been … leading to yet another successful parachute deployment. Of course, both of these events took place sometime after his first parachute jump, made after he pulled the wings off of a Curtiss P-1 Hawk fighter when attempting an outside loop, a maneuver coincidentally prohibited by his commanding officer.[5] Although he himself made no excuses about these events in his autobiography, at the time he was considered rather capable and competent, having, after all, just demonstrated flight solely by reference to instruments. He had to have been something like that when he released the brakes on the lead B-25 off the deck of the Hornet.

Within two years of its publication in my copy of the manual, the tenth axiom was severely tested in the cauldron of World War II. Thousands of pilots, some perhaps marginally capable or even minimally competent, lost their lives making a somewhat more profound moral argument than one advocating the role of free will in preventing airplanes from "cracking up". In the meantime, on the home front, extensive research was being done to investigate such topics as pilot skill, judgment, and emotional control. In 1939, the Civil Aeronautics Authority was examining the relationship between breathing patterns and personality, with a view toward identifying the more extroverted candidates, characterized by one researcher as possessing "such features in their daily lives as simultaneous interests in a number of business enterprises, frequent entertainment, lack of interest in abstract thought, hearty dispositions and carefree attitudes",[6] a remarkably prescient description of an airline pilot if ever there was one. By 1943, the University of Rochester was researching "The Ability to Take It",[7] which has always seemed to me a bit of a Bogartian title for a research paper, but nonetheless consisted of evaluating several different techniques for measuring human resistance to pain and fatigue, among them a continuous electrical shock of increasing voltage or having a wedge slowly clamped down between one's knuckles. Eventually, the shock technique, along with a procedure for measuring how long a man could hold 60% of his maximum grip strength, was recommended for further study. The knuckle wedge idea was dropped.

A serious question might have been asked, and apparently was asked at some point, about how many of the fellows who were actually "taking it" in the skies over Europe and the Pacific at the time of this research would have passed the shock test. I suppose the grip test might have been useful for trying to figure out whether a pilot candidate would be able to hold onto the cockpit window frame while reaching back into a disintegrating B-17 to grab the parachute that he had overlooked when climbing out, as was claimed in at least one instance. No doubt the breathing patterns of pilots who were being shot at could be of interest, particularly the "unconscious vocalizations" that CAA researchers had earlier associated with the more "extroverted" research subjects.[8] I'd be willing to bet that some of the more introspective combat pilots, previously thought to be inclined toward a quieter form of "visual phantasy thinking",[9] may have exhibited a few unconscious vocalizations as well. In any event, these kinds of studies characterize the type of the shot-in-the-dark research done during the pre-war and war periods toward methods of identifying that select group of human beings who were more naturally inclined to never allow an airplane to crack up.

In his book *The Psychology of Flight*,[10] published in 1950, Alex Varney goes into exhaustive detail about the disastrous effects of unchecked emotion, describing a bevy of behaviors that, when read in a contemporary context, seem far more likely to appear in illegal street drag racing than aviation. I don't think he seriously believed that a pilot attempting to fly the Atlantic would actually start off in the opposite direction in order to buzz the blonde working in the cigar factory and then descend halfway across the ocean to circle a couple of icebergs, consequently running out of gas short of the destination. Nonetheless, examples of character weakness such as these, and his emphasis on the proper use of free will to overcome such weakness, continue to resemble an echo of that Victorian-era notion of depravity, perhaps now lightly salted with some of the Freudian fascination with the subconscious popular during the first half of the 20th century. Varney even revisits the ever-recurring notion of accident-proneness, a subset of ineptness containing those folks who, by virtue of clumsiness, absent-mindedness, and a general inability to navigate the more Hobbesian aspects of the day, are predicted to have regular accidents. On the other hand, he makes the case that a strong character is reflected by the disciplined control of emotional response and the "training" of "reflexes" so that the aerodynamically correct action is taken without thought when faced with debacle. From such ideas appeared iconic images of the era such as the comic strip hero Steve Canyon.

So, the tenth axiom persevered, appearing as late as 1958 in the Pilot Instruction Manual, having been slightly enhanced to state that "A capable and competent pilot will never allow an airplane to crack up out of control".[11] By this time, industrial process management, developing from roots in Frederic Taylor's planning rooms and time-motion studies, had begun to offer the certainty of mathematics to the management of human behavior within organizations. Herbert Simon, building ideas that would shortly introduce the notion of artificial intelligence, believed that human thought could be characterized by mathematically predictable patterns of information processing. Shortly after World War II, Simon had argued that

> Two persons, given the same skills, the same objectives and values, the same knowledge and information, can rationally decide only upon the same course of action. Hence, administrative theory must be interested in the factors that will determine with what skills, values, and knowledge the organization member undertakes his work.[12]

In other words, a flowchart could be drawn showing how a person would think in any particular situation and human performance could be predicted and modified deterministically, in much the same way as the operation of a machine might be. With this in mind, the capable and competent aviator could, in theory, be modeled. By carefully managing the aviator's skills and particularly by managing his knowledge and information, his decisions could be predicted and controlled. If accidents could not be eliminated through the autonomous pilot's proper application of free will, perhaps they could be eliminated through management systems that more or less dismissed the notion of free will altogether.

Just a few years after the improved 1958 edition, Chuck Yeager managed to “crack up” the Lockheed NF-104 at Edwards Air Force Base, dropping out of 100,000 plus feet about as out of control as could possibly be achieved. Perhaps a little too much free will pointed in one direction and not enough pointed in the other, and definitely a case of pretty skinny flight safety assessment; nevertheless, it would be hard to describe Yeager as anything but capable and competent. On the other hand, it is probably safe to say that Herbert Simon could have spent the rest of his life trying to model Yeager’s thought processes.

Which brings us to the beginning of the 21st century, in which James Reason, among many others, has argued tirelessly that human error is a universal condition. He has distinguished between the “person” approach to safety, which single out the errors of individuals, placing blame on them for mindlessness, ineptitude, or moral weakness, and the “system” approach to safety, which instead focuses on the environment within which individuals work and strives to create defenses that capture or prevent error and/or mitigate the effects of error.[13] In this latter approach, he disrupts Simon’s notion of consistent human behavior, departing from the attempt to create that predictable, repeatable working environment and instead striving to build a resilient environment which is capable of tolerating inadvertent deviation. In his 2000 essay for the British Medical Journal, *Human Error: Models and Management*, Reason explained that in particular, high-reliability organizations are persistently engaged with the possibility of failure,[14] which is the first of the five characteristics of a high-reliability organization cited by Karl Weick and Kathleen Sutcliffe in their pathfinding work on the subject.[15]

Yet today, we still borrow freely from the tenth axiom and some of the ideas Varney presented when we use terms such as “discipline” and “excellence” in opposition to words like “complacency” and “apathy”. On the other hand, we borrow from Simon and administrative theory as we simultaneously create structures designed to manage error, risk, and culture. Like many disciplines, we have become engaged, perhaps even a bit enthralled, with “big data”, and we struggle to understand the single catastrophic outlier that escapes statistical prediction. Events such as Asiana at San Francisco, or the Dreamlifter landing at the wrong airport in Wichita, get caught in the whirlpool between the notions of a capable and competent pilot as described by the Flight Instructor’s Manual and the contemporary systems management ideas that have evolved from Taylor, through Simon, and into the world of big data.

The whirlpool persists in part because the cultural argument over the primacy of either free will or determinism just won’t go away, no matter how progressive our analysis. The argument is nearly as old as dirt, and it remains hotly relevant today as neuroscience and other disciplines explain more and more of human behavior from a deterministic point of view, rendering the search for the source of free will even more problematic (though hardly pointless). The argument inevitably stalls on the issue of moral responsibility, and it is here that we debate the role of the system, complexity, and organizational behavior as explanatory in contrast to individual incompetence, willful violations, or the “bad apple” described by Sidney Dekker.[16] To veer too far toward a fully deterministic interpretation is to risk doing away with personal and moral responsibility altogether, dispersing into the so-called blunt end on a Simon-esque mission to preset the variables to fail-safe values, while inadvertently begging the question of where, along the continuum of systemic determinism, anyone will apply the free will required to effect the management of anything. Reason himself, in later work, has argued that the pendulum may have swung too far[17] and that a re-examination of the role of those people at the "sharp end" may be in order.

It is indeed hard to remember, after so many years of administrative theory and systems management, that our capable and competent aviator actually remains a fully autonomous actor in the whole scheme of things. The regulatory obligation is, and always has been, that the pilot is the final authority as to the operation of the aircraft and command of the crew, no matter how much a whole cast of corporate characters would like to water him down. That authority presupposes a role for free will and transcends the conditions of employment, making the pilot-employee something of a greased pig for all styles of management.

But the whirlpool may also persist because of the structure of thought itself, particularly the ways in which we are constrained to think about accidents as distinguished from how they actually occur. Part of that constraint is obscured by the clarity of hindsight, which we regularly recognize but then just as regularly marginalize, on the notion that it is a previously stipulated, universally recognized condition … "hindsight is twenty-twenty" … or words to that effect. But the impact of hindsight on our interpretation can scarcely be overstated, for the simple reason that, in all cases, you cannot think of a thought until you think of it. This is a genuine conundrum, conditionally but nonetheless thoroughly overwritten by hindsight. We then tend to marginalize this idea as well, while routinely attempting to out-flank it, under the nearly unconscious assumption that the particular thought must actually exist somewhere and is simply not being acquired, usually through a lack of diligence, foresight, or will. Sidney Dekker refers to this as a

> … naive Newtonian scientism: total knowledge of the world is achievable; the world is "out there" as an object entirely separable from observers. People will know the truth if they are fully rational, once the correspondence between the picture in their mind and reality in the world is perfect.[18]

THE MODES OF HUMAN THOUGHT

The psychologist Jerome Bruner, in his book *Actual Minds, Possible Worlds*, describes what he believes are the two principal modes of human thought: the narrative and the paradigmatic. The paradigmatic mode is a rigorous, mathematical description and explanation.[19] It is the language of logical argument. The narrative mode, on the other hand, describes human intention and action, including the changes in circumstance, modifications, and consequences of such actions.[20] A good narrative begins with the ordinary, the routine, and then features a sudden reversal of circumstances, often referred to in literature as a peripeteia. The peripeteia is the occurrence or development that disrupts the ordinary and puts it at risk. In his paper, *Culture and Human Development: A New Look*, Bruner argues that "These narratives typically depict a canonical state of things and a deviation from that state. Stories are means for making these deviations comprehensible, if not acceptable".[21]

Bruner makes the case that a story has a skeleton, shown as a sketch in Figure 1.1. It begins with the canonical, ordinary state of things, experiences the peripeteia, and

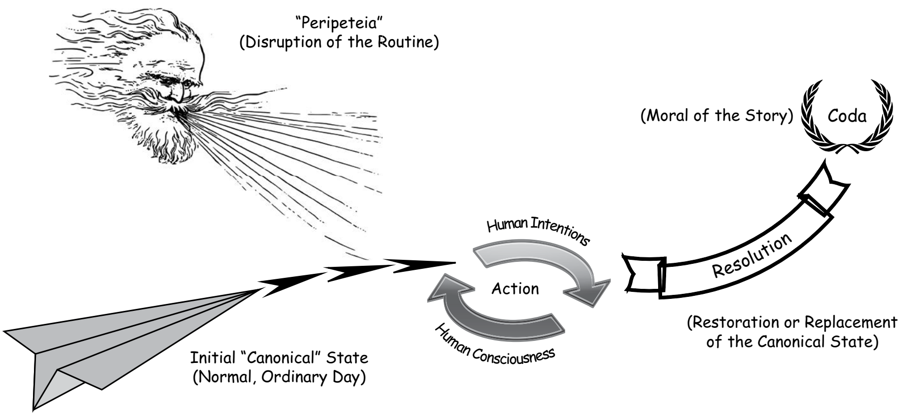

FIGURE 1.1 The narrative skeleton, the way stories are told.

this is followed by an action or series of actions, an attempt to undo the peripeteia. The action is followed by a resolution, either the restoration of the canonical state or its replacement by another canonical state. Finally, the story contains a coda or a discourse in the lessons learned. Returning to *Culture and Human Development*, Bruner says that "narrative seeks to render the ordinary as if it were not only majoritarian but also obligatory, whereas the ultra-ordinary is made to seem optional and subject to choice".[22]

Herein lies the actual constraint on how we think about accidents. The management of risk, error, and safety culture, essentially the entire system approach to safety, is organized and executed within the paradigmatic mode of thought, as illustrated in Figure 1.2. In the accident investigation discipline, we make a dedicated effort to produce a paradigmatic description of the accident, in order to identify and control the variables that have conspired to align the holes in Reason's cheese. We commit a lot of ink to investigations into oversight, culture, training, and even more specific aspects such as operational control and the approval of supplemental-type certificates. Nevertheless, one way or another, we always make time to stop and visit issues of character, as reflected by the flight crew's behavior. It is virtually impossible to separate the details of the accident paradigmatically from the human intentions and actions and the resulting changes in circumstance, modifications, and consequences that result. There is a story there, waiting to be told. The accident is clearly differentiated from routine operations by a peripeteia, a deviation from a canonical state. Our capable and competent aviator is a protagonist, or perhaps an antagonist, depending on one's point of view, in a story that is inescapably interpreted through the narrative mode of thought. There will be a resolution, either a recovery from the disrupted flight or a somber change in procedures or training resulting from what was learned. And there is always a coda, a moral of the story, usually embedded in the probable cause statement.

Both the paradigmatic and the narrative modes of thought work to create certainty where none exists, either a calculated, repeatable certainty or a certainty derived from comprehensibility, from knowing the whole story from beginning to end.

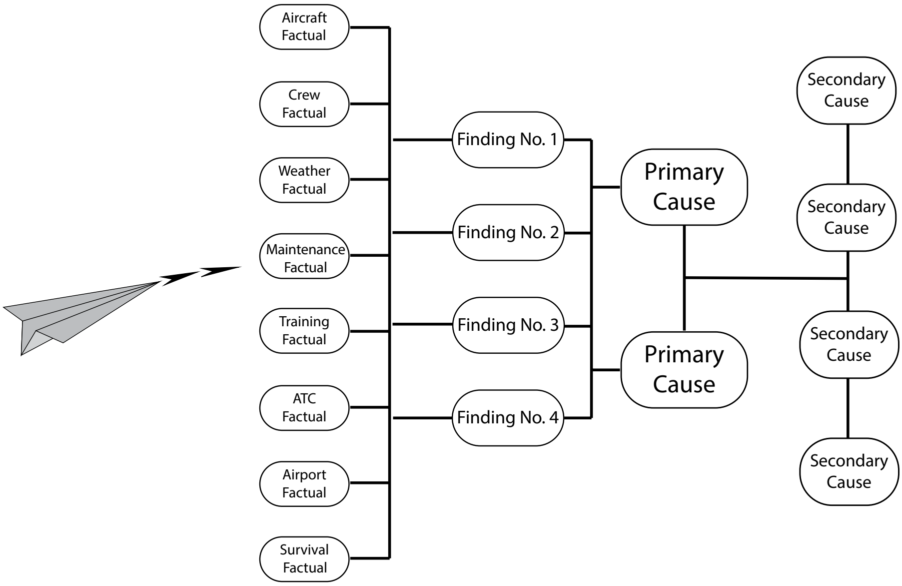

FIGURE 1.2 The paradigmatic approach to an accident report.

We have a strong need to trust the day … the sun comes up, the sun goes down … and the overwhelming sense of deceit experienced through proximity to a serious accident or its immediate aftermath is demoralizing, heartbreaking, and completely fractures any trust in the day that we might have had at breakfast. Such feelings create a powerful incentive to put as much emotional distance between ourselves and the breakdown of certainty as we possibly can. One way of doing that is to isolate the event, place it under a glass case, and stare at it from the outside, while developing a narrative structured to remove the sense of deceit, the apparent unpredictability, as well as the irrevocable impossibility of a second chance, and replace them with a mechanical, structured comprehensibility that offers the hope of a sort of do-over, as in I'll never let that happen to me, thereby reinstating trust in the day.

But Bruner goes on to point out that authentic narrative also contains two different landscapes: the landscape of action, in which the participants are the origin of actions, intentions, and goals, and the landscape of consciousness, which describes the participant's thoughts, knowledge, and feelings, or perhaps more importantly, what they do not think, know, or feel.[23] Consciousness does not lend itself easily to paradigmatic investigation; thus, an accident report is typically pretty long on the landscape of action and somewhat short on the landscape of consciousness. The initial story will usually be rather flat and may not do much to assuage our need for comprehensibility. What we can discern about the participant's state of consciousness may be incomplete, truncated, or worse but still offer absolutely no precursory perceptions that might serve to warn of what we already know about the rest of the accident.

Where was the flaw in the knowledge or thought processes that led to an undesirable aircraft state? Surely there must have been a flaw. What kinds of signposts in those thought processes should we be looking for that will forewarn of such a catastrophic outcome? We'll never know of course, since the crew have ended up, in the memorable words of the fictional Squadron Leader Colin Harvey from the movie "Battle of Britain", "spread from one end of this field to the other like strawberry jam" … and to make matters worse, they foolishly failed to vocalize their entire day's thinking for posterity on the cockpit voice recorder.

But since the tenth axiom, and similar tropes, can introduce an element of presupposition into the narrative, voids in the landscape of consciousness can easily be backfilled to make the narrative work, to make the "deviations comprehensible, if not acceptable".[24] We backfill the landscape of consciousness with what we believe the consciousness must have been and what the participants must have known or felt, and these beliefs are constructed almost entirely from our knowledge of the outcome and from an instinctual suspicion that the crew, in one sense or another, must have fallen from grace.

The subtle, quiet effect of backfilling the landscape of consciousness is that we never doubt our own grip on comprehensibility. We are not in the least bit inclined to consider possibilities that remain incomprehensible, at least to the extent of the available knowledge. It is as though we expect to be able to invert the narrative, casually walk around to the other end of the lens through which we view the past, and look forward into the future, fully anticipating that the lens works both ways. It doesn't; it never has. The morning of the day of the accident looks the same as any other morning; the evening looks like no other evening at all.

THE HIDDEN AXIOM

In 1978, I was working as a flight instructor in central New Hampshire. On a warm, cloudless, and quite calm summer evening, a friend of many years and I were flying a Grumman trainer a few hundred feet above the terrain to the north of Lake Winnipesaukee, having just flown a practice approach at Moultonborough. We were following a route that would take us to the east of the hills on the north shore of the lake and point us back toward Laconia.

At some point, something went terribly wrong. Despite the absence of any surface winds or forecast winds aloft, I had a strong sensation that we were starting to sink and it did not appear that we would clear the next ridge. I took control of the airplane, applied full power, and established a climb attitude. This did not appear to help the situation, and I began a long turn to the right, upslope initially but away from the most proximate terrain, with the intention of turning approximately one hundred eighty degrees to a downslope route.

I was not successful. The airplane clipped the trees and came to rest deep in the forest, hardly breaking a branch as it fell. The following evening, the ELT was picked up by a passing SAS DC-8, and the next afternoon, after about forty-three hours, we were located by a USAF UH-1 Huey, which dropped in a couple of PJs to initiate a rescue. By that time, my friend had passed away. I was in rather serious condition, with shattered ankles and a crushed vertebra as well as serious lacerations, a broken collarbone, and a collapsed lung … but, thanks to something like six or seven combined tours dropping out of similar helicopters into the Vietnamese jungle, I was successfully packaged up, lifted through the forest canopy into the old Huey, and flown to the hospital to begin a lengthy recovery.

To this day, over forty years later, I still do not know what actually happened. My perception was that we had encountered a downdraft, as I had experienced that before, but I have never understood how that energetic a downdraft would have occurred on such a calm summer afternoon. I suspect that, in the turn, I managed to induce an accelerated stall. The official investigation did not bother with any of those questions, or tear down the engine, or even visit the crash site. They were content with my hospital bed interview and the popular accident report refrain of "failed to maintain flying speed". No kidding.

The narrative mode of thought is dependent on the landscape of consciousness, but the landscape of consciousness will not actually respond to naive Newtonian scientism. Backfill after the fact as we may, the entire frame of thought is hostage to the hidden axiom, so to speak, the axiom that more or less plays the joker in the deck of axioms, trumping all the rest. That axiom says that you will never, ever, not even in a million years, see the one coming that gets you.

Of course you won't. If you saw it coming, you wouldn't let it get you.

This is a pretty unsettling proposition; it has unsettled me for decades. It is a corollary to the idea that you cannot think of a thought until you think of it. The accident cannot be experienced in the narrative mode of thought because actual comprehensibility is not possible until the narrative is complete, at which point it is obviously too late. The only way we can interpret experience in real time is by correlating a developing sequence of events with one or more known narratives, in order to identify a likely comprehensibility, but to do this, we must still make an educated guess as to the outcome. The probability of accurately guessing the outcome improves with experience and education, but it will always require us to make the correct correlation with known narratives, and it will always require us to assume a conclusion not yet in evidence. Acting on that conclusion before it has manifested requires an acceptance of persistent vulnerability, the opposite of certainty, and persistent vulnerability has no place in either the tenth axiom or administrative behavior … or, for that matter, to anyone's trust in the day.

Yet the term "will never" in the tenth axiom is an absolute term, addressing all which has not yet happened, leaving no room whatsoever for errors of perception, presumptively requiring that the aviator, by virtue of being capable and competent, will always see the accident coming, as if he could just eyeball a line of holes right through Reason's cheese. This is the net effect of a lifetime of trust in hindsight of an entire body of experience built from comprehensibility. In fact, the aviator who actually has the accident, regardless of whether he is capable or competent, is never going to know what hit him.

Herein lies the fundamental flaw contained within the tenth axiom. By creating the impression that the capable and competent pilot will always see the crack-up coming, it also promotes the contrapositive idea. The contrapositive says that, if you reside within the set of capable and competent pilots, then the threats that you see, that you become aware of and can identify, are the only threats that exist. This is precisely what Dekker means by naive Newtonian scientism. Total knowledge of the world is achievable … people will know the truth if they are fully rational … ergo, if you are fully rational, thus capable and competent, then you will see all possible threats.

Yet if the hidden axiom is true … if you really won't ever see the one coming that gets you … then why would that particular shortcoming be limited to the single threat that manifests into an accident? Is that the only threat that you won't see? Is it possible for threats to remain unseen while never manifesting into anything at all? If you won't see the one coming that gets you, is it also possible that you may not see dozens, hundreds, of "ones" coming that go right by you? And if that is true, how can our capable and competent aviator ever hope to apply free will in any way to manage such unseen threats?

A DIFFERENT WAY OF THINKING ABOUT ACCIDENT PREVENTION

One way to do so is by creating, updating, and executing a strategy that diverges from a focus on what goes wrong and instead concentrates on ensuring that things go right. The strategy begins with what we know works, remains proactive and anticipatory, and is constructed to tolerate variability in performance and adapt to modification in the operating environment. The key to tolerating performance variability and modifications to the environment is to protect the margins.

Margins are typically understood by pilots within the context of aircraft performance. We evaluate performance margins every day, from net vs. gross takeoff performance, through 1.3 g cruise altitude capability all the way to 167% of the landing distance … margins are our daily bread. Yet the concept of margins is much broader than aircraft performance. The most fundamental margins we protect on every flight are aerodynamic margins … angle of attack, bank angle, and g-loading … and altitude margins … minimum enroute altitudes, driftdown capability, grid MORAs, minimum crossing altitudes, and approach minimums. We protect margins of aircraft configuration and system functionality, such as single pack altitude limits and single generator diversion requirements. Figures 1.3 and 1.4 provide a couple of common examples of margins.

At a different level, we protect margins of human performance. Early in the post-war research done on human factors in aviation, Stanley Roscoe identified the concept of residual attention. He said that, "During routine flight operations a pilot's attention capacity exceeds the moment-to-moment demand by varying amounts …".[25] He then explained that "a blunder occurs because the perceptual, judgmental, and motor demands of the moment exceed a pilot's momentary attention capacity".[26] Protecting the margin of residual attention is critical and is precisely what rules pertaining to such things as a sterile cockpit are aiming at.

Rene Amalberti, the original head of human factors and flight safety at the European Joint Aviation Authorities, has pointed out that workers must execute their jobs within an envelope of possible choices and actions, and that the envelope is continuously influenced by much broader organizational and social forces and factors.[27] This idea is shown graphically in Figure 1.5. The capable and competent aviator of today is suspended somewhere between the Tayloristic, one-best-way prescribed procedures, a need for efficient, expeditious application of labor, and the struggle, in a proceduralized world, to retain an identity of craftsmanship, of artisanship really,

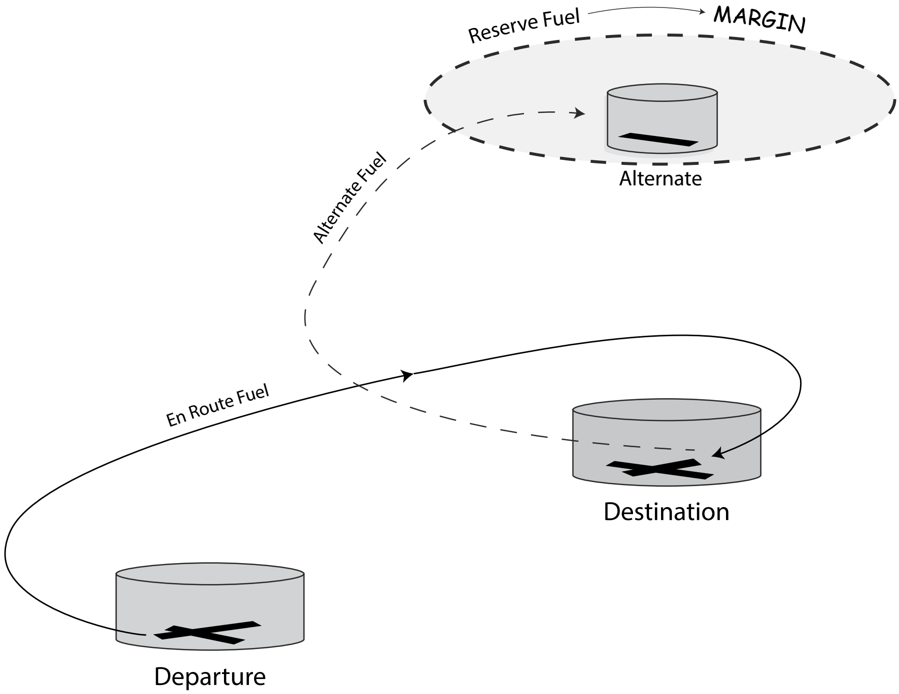

FIGURE 1.3 Reserve fuel is a margin.

through the application of free will. From a utilitarian perspective, it can be very easy to conflate economic efficiency and expeditious labor with craftsmanship, but this is misleading; the former is simply one of several outcomes resulting from the latter. Further, the "lack of interest in abstract thought, hearty dispositions and care-free attitudes"[28] noted by the CAA in 1939 can promote an almost Yeager-esque, right-stuff understatement of risk. The tension between these three ideas creates a drift, beginning at what Amalberti calls the "initial safe space of action", and migrating toward the "borderline tolerated conditions of use",[29] the absolute edge, a position which appears to optimize efficiency and economic benefit while retaining an acceptable level of risk, but beyond which there is no further margin, no safe space of operation at all. This natural drift is facilitated by the normalization of deviance. Conveniently, these days the drift toward borderline tolerated conditions of use is monitored by flight operations quality assurance (FOQA) programs … but a FOQA flag comes to this point rather late in the game. It is the drift that must be constrained from the outset, indeed zeroed out to the extent possible, in order to protect the margins intrinsic to the initial space of safe operation.

Amalberti describes the initial space of safe operation as designed around rules and procedures, including various constraints and fail-safe procedures, all of which are intended to serve as defenses against human error and constrain possible human actions.[30] Standard operating procedures are designed to protect margins that can absorb variation in external influences, random deviations, and normal

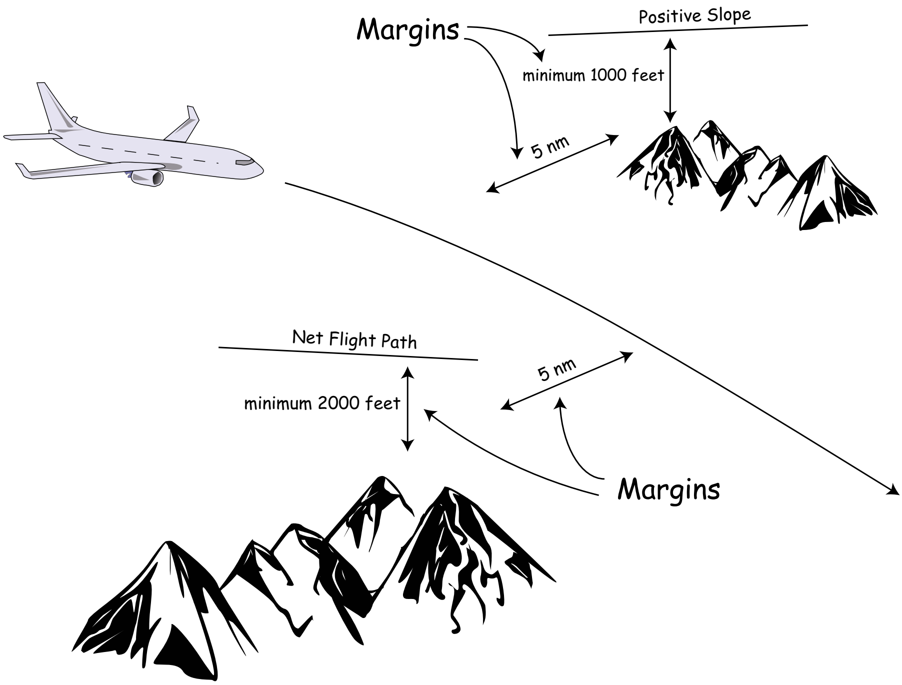

FIGURE 1.4 FAR 121.191 enroute driftdown margins.

imprecision. Well-designed procedures are constructed with carefully crafted constraints and error traps built into them; these error traps are intended to capture the inadvertent excursions into the margins, first arresting and then ejecting human error harmlessly over the side.

But the margins exist independently of procedures, and it is the margins that bound the safe operating space. We track the centerline of the runway for a reason. While nothing particularly bad will happen simply by landing with the right main wheels to the left of the centerline, something rather different may occur when the left main tires and/or brakes fail, which of course, we will have no reason to see coming, or perhaps a wind gust combines with less-than-stellar tire friction and directional control. We track the centerline to remain centered within the safe operating space and protect the seventy-five feet between where we are and the rather pronounced end of that margin … the edge of the pavement.

The margins, when they are engaged, function more or less in the dark, which is not the same thing as saying they function in a vacuum. This is a real fly in the ointment for the bean-counting population, themselves stuck in a paradigmatic mode of thought, their own version of “naive Newtonian scientism”, because they cannot measure the success of safety, or the value of the investment in safety, without being able to “see” at least a representative sampling of these unfulfilled catastrophes. Pilots, too, can easily misinterpret excursions into the margins, beginning with the premise that any landing you can walk away from is a good one.

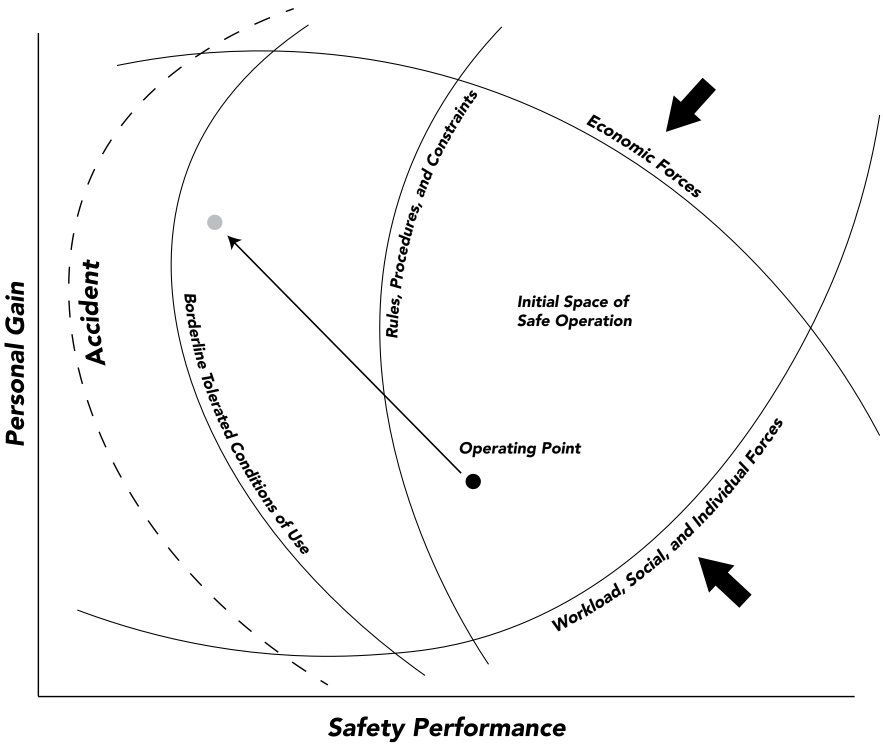

FIGURE 1.5 Amalberti's envelope of possible actions.

Procedures are, of course, eminently malleable, and thus become irresistible to management as tools for the exertion of control over employees, obfuscating the true role procedures play in the work of constructing and protecting the margins. The almost reflexive response to a mishap in an audit-centered universe is to install one more line of code, still banking on Simon's premise of tweaking "the same knowledge and information" so that "Two persons … can rationally decide only upon the same course of action".[31]

On the other hand, a willful imposition of drift toward the borderline conditions can be used as a means of usurping top-down control and preserving an identity of craftsmanship. In conventional human factors parlance, this willful imposition of drift is made up of routine and optimizing violations. In fact, rather than demonstrating craftsmanship by artfully bending and folding procedures, the craftsmanship inherent in professional airmanship actually lies with the skill used to protect the margins and remain squarely within the safe operating space when organizational and social forces exert strong pressure to drift over somewhere near the edge, the borderline tolerated conditions of use.

Strategy is always anticipatory, always dynamic, and never assured. But for the simple reason that you cannot think of a thought until you think of it, strategy operates in a kind of bilateral reciprocity with the concept of resilient performance. Resilient performance is the anti-matter to persistent vulnerability, wild enough to trump the joker. In his work on high-reliability organizations, Karl Weick has defined resilience, at the organizational level, as the organization's "capability to investigate, learn, and act *without* knowing in advance what they will be called to act upon".[32] This definition is easily migrated from an organizational level to the individual and crew levels. Weick expands his definition to say that resilience is the "capacity to do quick study, to develop swift trust, to engage in just-in-time learning, to imagine detailed next steps, and to recombine fragments of potentially relevant past experience".[33]

Strategy and resilience are embodied in the concept of prudence. Neither function independently, and both require that we replace the misinterpretation of experience with mindfulness, as well as anticipate the threat posed by the normalization of deviance. Every flight will be different, and every flight will experience variability in human performance as well as an open environment subject to considerable modification.

When I'm having a particularly irreverent day, I've always thought that the real goal of a professional pilot is to arrive at the Pearly Gates, checking in for eternity, and find yourself standing in line just ahead of one of those bean-counters. The fellow at the desk checks off your name, and as you are about to step through the Gate, he says, "Hey, hang on a minute. We've got something for you …". He reaches into a cabinet behind his desk, pulls out a fat roll of newsprint, reaches across the desk to hand it to you, inadvertently clubbing the bean-counter in the back of the head as he does so. The roll of newsprint turns out to be about a hundred yards long, containing line after line of ten-point font, each line a description of every disaster that did not happen because of your lifetime of meticulous airmanship.

Alas, in the earthly scheme of things, a more practical axiom, one that we could use to replace the classic tenth axiom, may be that suggested by Karl Weick, when he said that reliability is a dynamic non-event.[34] We have to be careful not to confuse reliability with safety; they are not necessarily the same thing. However, insofar as safety is the non-occurrence of an unsafe event, a non-event, we get a much more meaningful axiom if we say that *safety is a dynamic non-event*.

So how does our meticulous pilot facilitate a dynamic non-event? Start by not misreading James Reason. We work with a structurally deterministic system in a highly complex environment, while remaining entrusted with an almost completely autonomous free will. A system approach does not obviate the pilot's singular responsibility as the final authority over the operation of the aircraft. As a first guideline, we can use that authority in a manner to protect the margins. We can leverage human adaptability to ensure that we remain well inside the space of safe operation. We can construct and modify a strategy aimed at ensuring that what can go right, does go right.

But we must also integrate within the strategy an awareness of mistakes that we do not want to make. From the outset, we must anchor the execution of the authority vested in the pilot-in-command by understanding when, and how, to say no.

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