Human Factors

Enhancing Pilot Performance

Dale Wilson

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by Dale Wilson

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Foreword

When Dale asked me to write the Foreword for his new textbook, *Human Factors: Enhancing Pilot Performance*, I was honored but not excited, because I have never had a good relationship with textbooks. I am a “get to the point and let’s move on” type of person, and most of the textbooks I have had the misfortune of being forced to read were not of that persuasion, as they often seemed to have little to do with reality and a lot to do with big words that normal people don’t use. I had a particularly rough time with accounting textbooks, as I really didn’t care at all what happened to the XYZ Corporation that seemed to be featured in all their examples.

This would be a particular challenge in a textbook about human factors, as the very word “human” means that it has to relate to people and their feelings and performance. I often fought this battle in my consulting with major corporations, as they usually wanted to count things. I kept stressing that human factors analysis requires human factors metrics, and that too much emphasis on numbers will scare people off and distract them from the truly important issues. This is why, in the many articles on human factors in aviation I wrote for *Flying* magazine, I always used stories other pilots could relate to, and terminology that would not send them to their computers to try to find out what something meant.

As I read Dale’s new book, I was happy to discover that he has the same philosophy that I have. He starts each chapter with a brief synopsis of several accidents caused by a lack of knowledge or application of the information in that chapter. This immediately pulls the reader into the topic and sets the scene for the factual information that follows, making it clear why this information is important to a pilot. Because it is a textbook, Dale does provide comprehensive coverage of each subject, but continually relates that information to actual accidents, thus always reinforcing the fact that a working knowledge of this topic could literally save the reader’s life.

If a pilot finds a particular topic especially interesting, Dale has included a “Helpful Resources” section at the end of each chapter, with up-to-date URLs and other information, along with extensive notes. Both include web addresses when those are available. The book also has an extensive Glossary and a list of Abbreviations and Acronyms making this an excellent reference tool.

While anyone interested in human factors in aviation could benefit from this book, Dale’s target audience are pilots attending a collegiate aviation program with a desire to fly professionally, and I feel that he has achieved a wonderful balance by providing a wealth of detailed information, while always relating that information to actual operational considerations. I care deeply about the safety of pilots in general, and especially those flying small aircraft, so I am relieved to know that such a comprehensive yet practical guide will be available to students in collegiate aviation programs and anyone else who seeks a deeper understanding and working knowledge of this important topic.

—*Jay Hopkins*
Founder and president of the Error Prevention Institute, Inc., and former contributing editor on Human Factors to *Flying* magazine

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It takes a team to publish a book like this. That is why I am extremely grateful for the contribution made by the following professionals who agreed to serve as its reviewers. Along with safety educators and experienced pilots representing several different airlines, these reviewers include experts in aerospace physiology, experimental psychology, cognitive psychology, advanced flight deck design, and human factors education. Their detailed feedback—especially within their areas of expertise—was invaluable and most of their suggestions were incorporated into the final manuscript.

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Bryce Hansen, M.D., Flight surgeon and civil aviation accident investigator (retired) and author of *Flying is Safe—Are You?*

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Thanks to Jackie Spanitz at Aviation Supplies and Academics, Inc., for taking on this project. A special thanks is due to Alex Lorden (Production Editor) and Kelly Burch (Graphic Designer) for their excellent work. I especially thank Jay Hopkins for providing valuable feedback and writing the foreword to this work. Jay is the founder and president of Error Prevention Institute, Inc., a two-decade writer of the *Human Factors* column for *Flying* magazine, an accomplished pilot (ATP, CFI), and one of the most down-to-earth and insightful flight-safety communicators I know. If you have read any of his more than 250 human factors articles in *Flying* magazine, I think you would agree.

My highest gratitude belongs to my family who have supported me in my career—my two wonderful adult children who I am very proud of, and my beautiful wife of more than 40 years whose support in my life and my work has been unwavering.

About the Author

Dale Wilson, M.S., is Emeritus Professor of Aviation at Central Washington University in Ellensburg, Washington, where he has taught courses in aviation weather, aerospace physiology and psychology, and threat and error management since 1996. He holds a master's degree in aviation safety from the University of Central Missouri and a bachelor's degree in psychology from Trinity Western University in British Columbia, Canada. Professor Wilson has been a pilot for 40 years, logging several thousand hours in single- and multi-engine airplanes in the United States and Canada. He holds several professional FAA pilot certifications, including Airline Transport Pilot, Certified Flight Instructor, Advanced Ground Instructor, and Instrument Ground Instructor. While in Canada, he held the Airline Transport Pilot License and Class 1 Flight Instructor Rating—the highest of four levels of flight instructor certification.

At Central Washington University, he received several awards for outstanding teaching and scholarship in the Department of Aviation, including the *Excellence in Teaching* award from the College of Education and Professional Studies. He was also nominated for the Central Washington University Faculty Senate *Distinguished Professor of Teaching* award. He earned the biennial *Master Flight Instructor* designation seven times (1999 through 2013), and the *Master Ground Instructor* from 2013 through 2017, from the National Association of Flight Instructors. He also served as an Aviation Safety Counselor and later as an FAA Safety Team Representative for the FAA's Spokane Flight Standards District Office.

His primary research interests include visual limitations of flight, pilot decision making, and VFR flight into instrument meteorological conditions. He has authored (or co-authored) more than 20 articles related to flight crew human factors in scholarly journals and professional aviation magazines, and has given numerous safety-related presentations at conferences and seminars in the U.S. and Canada. Published by ASA, Inc., in 2014, his co-authored book *Managing Risk: Best Practices for Pilots* describes many of the major threats to safe flight operations, offers insights on how and why pilots make errors that exacerbate them, and provides best practice countermeasures needed to successfully manage them (available at asa2fly.com). You can reach the author on *LinkedIn* or at Dale.Wilson@cwu.edu.

Introduction

It was after midnight when I got the call. Two of our school's airplanes were overdue. After daybreak, our worst fears were confirmed—both aircraft had collided in mountainous terrain south of our airport, killing all six occupants. As you can imagine, these deaths shattered the families of all those aboard—five aviation students and a flight instructor—and devastated the flight school staff and instructors who knew them.

The return from their multi-day trip had been delayed a couple of times because of weather. In fact, they were already late for the beginning of their spring semester at the college that housed our flight program. They resumed their trek when the weather cleared, and in spite of receiving information that indicated the weather would likely remain VFR conditions, as they neared our home airport they encountered unexpected deteriorating weather in the form of snow showers and clouds. They continued VFR flight, with the radar tapes indicating that one airplane followed the interstate highway, while the other stayed closer to a navigation (Victor) airway. However, the sun had set and it was very dark. Investigators determined that the cause of these accidents were the decisions by the pilots to continue VFR flight into instrument meteorological conditions and their failure to maintain proper altitude clearance from the mountainous terrain. Contributing factors were the darkness of night, adverse weather, and terrain conditions.

If you knew the pilots, you would know that they were not prone to risk-taking, nor were they incompetent. They progressed well in their flight training and were otherwise conscientious aviators. Neither of them suffered from any psychological disorders—they were normal people like you and me. A witness at a fixed base operator overheard one in their group say that they were not going to just sit around the airport waiting for a marginal weather report that would allow "scud running" to the next stopping point. So, rather than wasting their time at the airport waiting for the slightest hint of improvement that might tempt them to launch in questionable weather, they instead called it quits for the day and elected to go into town to participate in other recreational activities. The pilot-in-command of one of the flights was an experienced flight instructor who was providing instruction to his private-pilot student. One of my students was in the other airplane. She was a commercial pilot and I was teaching her how to be a flight instructor. Though she was not the pilot-in-command of the flight, she occupied the front right seat and, according to the accident report, was the designated safety pilot.

It has been almost 30 years, and I have never gotten over these two accidents. Though I have a better understanding today of some of the causal factors involved in these types of accidents than I did back then, the unanswered questions still haunt me: Why didn't they turn around? Why did my flight-instructor colleague elect to fly lower when he was an accomplished instrument pilot and reportedly had the appropriate instrument charts on board his aircraft? What role did a rather somewhat optimistic weather forecast play in their decision making? For example, the accident report indicates that, with the exception of the possibility of marginal weather en route, about 40 minutes before these accidents a flight service specialist expressed doubt that the weather would drop below VFR conditions. Pilot witnesses reported unexpected local snow showers in the area that day and evening: How difficult was it for them to visually detect this weather at night, especially a dark one? Finally, what part did their previous delays play in their thinking? A witness for the fueling service company they used stated "everyone was most anxious to get going." Was it possible their desire to get home—with less than 25 miles to go—clouded their judgment?

Sadly, statistics indicate that the majority of aircraft accidents are caused by the actions of the pilots who fly them (*see* Chapters 1 and 2). After these two accidents, I changed the direction of my career and began a pursuit that was to occupy most of the remainder of my professional life: to discover *why* we pilots do the things we do. I reasoned that, just as we cannot prescribe a cure for an illness if we don't know its cause, we cannot reduce the incidence of flight crew errors if we don't know what causes them. Perhaps if I had a better idea, I might be able to help other pilots avoid the same fate.

Since the topics of visual perception, decision making, and human error—all apparent factors in these two accidents—fall primarily within the domain of cognitive psychology, I completed an undergraduate degree in psychology to better understand the limitations of human sensation, perception, attention, memory, and decision making. I also gained an appreciation for the subtle, yet profound, role that other people often play in our decision making. My graduate studies also helped me understand the risk management principles necessary to counter the threats and errors that are an inevitable aspect of everyday flight operations. Since then, I have spent thousands of hours in my teaching, speaking, and writing, helping pilots understand their "humanness," and how human "factors" pose an ever-present threat to safe flight operations.

A large body of research from several human-factors-related disciplines clearly indicates that we are subject to physiological, psychological, and psychosocial limitations when it comes to operating aircraft. For example, as pilots, not only do we experience physiological limitations common to most earth-bound individuals (illness, colds, sleep deprivation, fatigue, poor physical fitness, etc.), we are also subject to physiological threats that are unique to the flight environment. For example, when flying above altitudes as low as 10,000 feet, we will fall victim to hypoxia, a malady that causes us to become indifferent to our surroundings and that could lead to total incapacitation (Chapter 4). If we fly at high enough altitudes (in an unpressurized cabin), we will also experience what deep-sea divers do when they rise to the surface too quickly: decompression sickness, a condition that also physically incapacitates its victims (Chapter 5). Even though the human eye is equipped with a remarkable dual-visual system—one for day, the other for night—when flying in the dark or in poor visual conditions we may fail to detect adverse weather and/or terrain (Chapter 6). Alternatively, we may succumb to a visual illusion that tricks us into misperceiving the outside world (Chapters 12), or fall victim to a vestibular or somatosensory illusion that leads to spatial disorientation and possible loss of control of our aircraft (Chapter 9). In perfectly clear daylight conditions, we may think we are conducting an adequate visual lookout for other aircraft, when in fact we are not (Chapter 6).

Likewise, cognitive and social factors may impede our ability to make informed decisions on the flight deck. While paying attention to one aspect of the flight environment, we may completely miss another, such as the airspeed indicator, possibly leading to an unusual attitude or undesired aircraft state (Chapter 14). Similarly, distraction may keep us from monitoring the altimeter, resulting in overshooting our altitude assignment. Alternatively, we may accept a clearance intended for another aircraft that has a similar call sign as our aircraft, possibly leading to an incident or an accident (Chapter 7 and 13). Because human memory is not perfect, pilots forget things. In spite of injunctions to "not forget," pilots still do; like obtaining a clearance, or lowering the landing gear before landing, or forgetting to remove a myriad of things before flight such as control locks, pitot and static port covers, tow bars, and fuel caps (Chapter 16).

Many accidents are the result of pilots making wrong decisions. Unfortunately, research indicates that the complex process of decision making is often subject to error and bias (Chapter 17). For example, we may make an inappropriate decision to continue an approach-to-landing in the face of poor weather and attempt a landing with a tailwind, adverse crosswind, or in marginal visibility. Most pilots, even experienced ones, are reluctant to conduct a go-around when conditions clearly warrant it. As was the case with the two accidents previously discussed, sometimes VFR pilots decide to continue flying into less-than-VFR weather conditions, resulting in either loss of control in flight (LOC-I), due to spatial disorientation, or controlled flight into terrain (CFIT). Finally, other people—customers, supervisors, other pilots—sometimes have an influence on our decision making, even when we think they do not. This *social* influence can sometimes result in others making our decisions for us; in effect, *they* are flying our aircraft instead of us (Chapter 18).

Even though today's aviation industry enjoys a remarkable safety record—primarily because it has learned from the mistakes of its past—aircraft accidents, such as CFIT, LOC-I and loss of control on the ground, midair collisions, and other deadly accidents, still occur and the hazards of flight remain. Some aircraft accidents occur because of mechanical failure, improper maintenance or hazardous weather; but as this book attests to, the vast majority are caused by the actions (or inaction) of pilots who fly them. The majority of these are not intentional, nor are they the result of some psychological deficiency or mental disorder. Rather, most are caused by inadvertent errors made by pilots—errors that arise from normal physiological, psychological, and psychosocial limitations inherent in the human condition. For those who primarily move about on the earth's surface, the consequences of such human errors are often benign. For we who fly, these normal everyday human attributes operating in the non-normal environment of flight can be deadly. This book thoroughly explores the nature of these human limitations, describes how they often manifest themselves on the flight deck, and most importantly, provides best practice countermeasures designed to help you minimize their influence in your own flight performance.

This old adage is universal, applying to aviators everywhere: Learn from the mistakes of others; you will not live long enough to make them all yourself. This book is written to help you accomplish that learning. Whether you are a fair-weather private pilot, a new-hire first officer at a regional airline, or a seasoned pilot with thousands of hours under your belt, this book will help you better understand why we pilots make the mistakes we do. More importantly, it will arm you with the knowledge you need to successfully avoid or mitigate them.

This book is divided into four parts. Part I (Chapters 1–3) includes a discussion of the aircraft safety record, human error, and the discipline of human factors—all essential elements for the discussion of flight crew human factors that occupies the remainder of the book. Part II (Chapters 4–11) and Part III (Chapters 12–18) thoroughly explore the physiological and psychological aspects of pilot performance, respectively. Part IV (Chapters 19–20) concludes this book with a discussion of two major approaches used on today's flight deck for reducing or mitigating human error—crew resource management (CRM) and threat and error management (TEM).

Each topic is written not for the human factors or safety specialist, but for you, the pilot. While each chapter covers a topic in depth—so that you discover not only the *what* but the *why*—each also includes several examples of accidents or incidents that have occurred because of the human limitation or error discussed. Important terms are in highlighted in bold and are further defined in the extensive Glossary found in Appendix C. With the exception of two introductory chapters, each concludes with a "Helpful Resources" section that provides a list of web sites, videos, courses, documents, and other references for further study.

A Note About the Accident and Incident Citations in this Book

Numerous aircraft accident reports are used in this book to illustrate many of the human factors concepts discussed. These reports—primarily from the National Transportation Safety Board (NTSB) and the Transportation Safety Board of Canada (TSB), and incident reports from the National Aeronautics and Space Administration's (NASA) Aviation Safety Reporting System (ASRS)—contain a wealth of information about how and why accidents and incidents occur. NTSB and TSB reports can be accessed at www.ntsb.gov and www.bst-tsb.gc.ca, respectively, and ASRS incident reports can be accessed at asrs.arc.nasa.gov. The following are examples of typical accident and incident report citations used in this book and how they are coded:

NTSB/AAR-07/05
The fifth (05) major NTSB aircraft accident report (AAR) issued in 2007 (07).

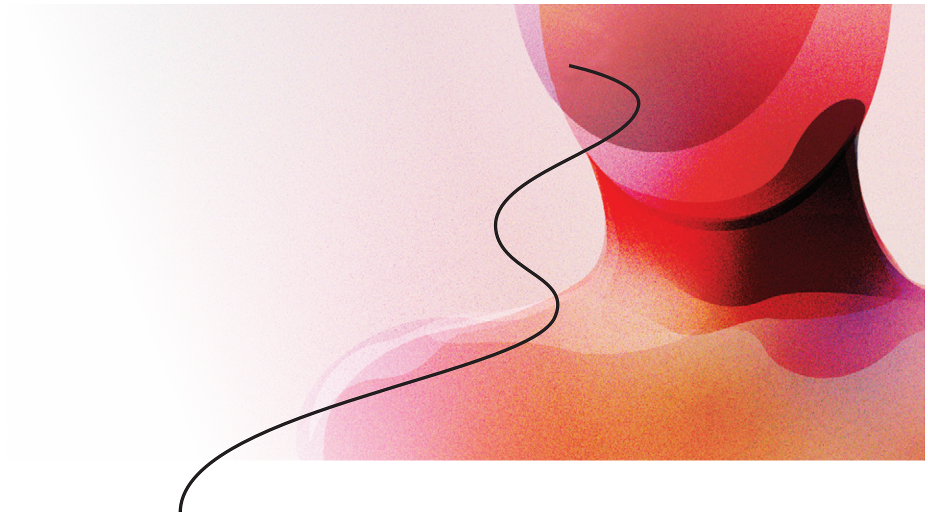
NTSB-AAR-75-9
The ninth (9) major NTSB aircraft accident report (AAR) issued in 1975 (75). Note: In 1983, the NTSB changed the report number format from hyphens (e.g., NTSB-AAR-82-16) to slash/hyphen/slash (e.g., NTSB/AAR-83/01). Both of these formats are used for major accidents published in Blue Cover Reports, so named because of their blue and white covers.

NTSB Identification No: LAX90LA116
The Los Angeles (LAX) NTSB office filed the accident report, which occurred during the 1990 fiscal year (90). It was a limited aviation accident investigation (LA), the 116th in fiscal year 1990. If the identification number is appended with a final letter, another aircraft was involved in the accident. All NTSB accidents are assigned an accident case number such as this one; however, most major aircraft accidents, especially those involving commercial flights carrying passengers, are identified using the format in the first example above and are published as Blue Cover Reports.

TSB Report No: A04Q0089
A TSB of Canada aviation (A) accident report from the year 2004 (04) in the Quebec (Q) region, which was the 89th accident or incident (0089) in fiscal year 2004.

ASRS Report No: 763177
The report ascension number (ACN) is 763177, which is the 736,177th incident report submitted to the National Aeronautics and Space Administration's (NASA) Aviation Safety Reporting System (ASRS) since the program began in 1976.

Part I
The Human in the Cockpit



1

Is flying safe?

The Aviation Safety Record

A friend of mine, who lived near Vancouver, Canada, often went on winter vacations to Disneyland in Southern California with his family during his children's Christmas break. If you thought he would choose to enjoy the three-hour journey southbound in the comfort of a modern Boeing passenger jetliner, you would be mistaken. Instead, he loaded up the minivan with his family and belongings and drove over 20 hours and more than 1,300 hundred miles at a time of year when winter road conditions could quickly become treacherous. Why did he do this? Because, according to him, it was safer than flying. What he didn't know was that, statistically, he and his family were at least 100 times more likely to die on the trip because he refused to go by air.

Before we thoroughly explore the main focus of this book—*human factors* and what they are in the aviation environment—it is important to first understand the safety context out of which the discipline arises. The first chapter of this book, therefore, compares the aviation safety record to other modes of transportation and between sectors within aviation, provides a brief overview of the various types of aircraft accidents that occur, and highlights some of the major causes of aircraft accidents.

Transportation Safety

The answer to the question in this chapter's title, "Is flying safe?" depends on how you define safe. Flight safety is defined differently by different people, as evidenced, for example, by our Disneyland traveler. If he defines it as the total absence of danger, then his assessment would be correct: flying is not safe. However, he, along with all of us, surely realizes that practically every human endeavor, let alone activities involving movement on the earth's surface—or above it—involves some degree of risk. For example, in the first decade of this millennium (2000 through 2009 inclusive), an average of 43,239 people died each year in transportation accidents (e.g., bicycles, cars, trucks, motorcycles, buses, aircraft, trains) in the United States making the annual risk of dying in a transportation accident about 1 in 6,800 per U.S. resident. In fact, transportation accidents are the number one cause (at almost 40 percent) of accidental deaths (often termed **unintended injury deaths**) in the United States, which is the equivalent to the number of people killed by falls and poisonings, the next two highest causes of accidental deaths.[1]

Compared to non-highway **transportation modes** (aviation, rail, maritime, etc.), road methods of human transport (cars, trucks, motorcycles, buses, bicycles, etc.) claimed by far the most lives during the 10-year period accounting for 95 percent of all transportation fatalities. Conversely, U.S. aircraft accidents claimed the lives of only 646 people annually during the period—less than 0.15 percent of all transportation deaths—with 85 percent of those occurring in the **general aviation (GA)** sector and the remaining 15 percent resulting mostly from only four scheduled **air carrier** (commercial airline) accidents during the entire decade.[2]

In fact, a look at the statistics clearly indicates that, in comparison to all other modes, commercial air-carrier flying is the safest mode of passenger transport in the United States. For example, if we compare the 0.07 passenger deaths per billion passenger-miles traveled[3] on commercial flights with passenger deaths on commuter trains, ferryboats, and cars and light trucks (*see* Table 1-1), we see the odds of dying when traveling using these modes increase by factors of more than 6 (.43/.07 = 6.14), 45, and 104, respectively. The odds of dying while riding a motorcycle are 29 times greater than riding in a car or light truck, and an astonishing 3,000 times greater than flying on a commercial air carrier!

Table 1-1. Passenger fatalities per billion passenger-miles for selected modes for ten year period 2000–2009.[4]

Transportation mode	Passenger fatalities per billion passenger-miles
Motorcycle	212.57
Car or light truck	7.28
Local ferryboat	3.17
Commuter rail and Amtrak	0.43
Urban mass transit rail (2002–2009)	0.24
Bus holding more than 10 passengers—transit, intercity, school, charter.	0.11
Commercial aviation	0.07

The good news for all U.S. travelers is that accidents and accident fatality rates for most modes of transportation—including aviation—have gradually trended downward over the past several decades. For example, highway fatalities per 100 million vehicle miles dropped from 3.35 in 1975 to 1.11 by 2010, a 300 percent improvement.[5] For large truck accident fatalities, the improvement was even better: fatalities per 100 million vehicle miles dropped from 5.51 in 1975 to 1.26 by 2008, more than a four-fold improvement. Other modes, such as railroad and maritime (both commercial vessels and recreational boating) have also seen significant fatality rate reductions over the years. But the fact still remains that the most dangerous part of the flight in a commercial air carrier is the drive to the airport, especially if you are on a motorcycle!

Aviation Operations

As noted, most U.S. **aircraft accident** fatalities (about 85 percent) during the ten-year period involved GA aircraft. Civil aviation is generally divided into two major groups: air carriers and GA.

U.S. air carriers are commercial operators certificated under Parts 121 and 135 of Title 14 of the Code of Federal Regulations (14 CFR) to carry passengers or cargo for hire. In 2018 the U.S. air carrier fleet consisted of almost 7,500 airplanes (mostly turbofan-powered) used by mainline and regional passenger air carriers and cargo carriers, to transport passengers and cargo.[6] U.S. commercial carriers conducted more than nine million domestic and international flights, flew more than 17 million flight hours, carried a record 849 million passengers (called *enplanements*) and delivered more than 18 million tons of cargo in 2017. The U.S. commercial aviation industry directly employs more than 700,000 people and is responsible for creating over 10 million jobs (7.3 percent of U.S. jobs) and more than 5 percent of the gross domestic product in the United States.[7, 8, 9]

General aviation, or "gen av" as some call it, comprises all civilian flight operations other than scheduled commercial air carrier passenger and cargo service. With approximately 210,000 aircraft (more than 416,000 worldwide), GA accounts for more than 90 percent of the U.S. civil aircraft fleet and includes piston- and turbine-powered, single- and multi-engine airplanes (almost 80 percent of the GA fleet) and rotorcraft (e.g., helicopters), balloons, airships, and gliders. As you can imagine, GA does just about every type of flying there is, some of which includes: personal/recreational flights in piston-powered single-engine airplanes; instructional training flights (most U.S. commercial airline pilots learned to fly in GA); business and corporate transport in light, medium, or even heavy twin-engine jets; on-demand charter (air taxi) flights in piston- or turbine-powered airplanes; helicopter emergency medical (air ambulance) service; sight-seeing flights; and a variety of aerial observation/application flights, including highway traffic reporting, mapping, patrol, surveillance, search-and-rescue, crop production, and fire suppression. GA aircraft fly into more than 5,000 U.S. public-use airports (scheduled airlines fly to less than 400 U.S. airports), log more than 24 million hours per year—with about 65 percent conducted for business and public services—and transport an estimated 166 million passengers annually. The U.S. GA industry supports $219 billion of economic output and 1.1 million jobs. Of the almost 600,000 certified pilots in the United States, about 500,000 fly GA aircraft.[10, 11, 12]

Aviation Accidents

A distinction should be made between the *number* of accidents, or fatal accidents (in which at least one person died as a result of the accident), and the *rate* of accidents (or fatal accidents). For example, if the number of accidents in a given year dropped from the previous year you might conclude the safety record was improving. In one sense, that is certainly an improvement in safety because fewer unwanted outcomes—accidents and accidental deaths—occurred. But the improvement could have been because there were fewer aircraft operations. Let's say there were zero accidents because there was zero flying during a given time period. This tells us nothing about the safety of flying, only the safety of not flying. It's like having no private automobile accidents because everyone stopped driving their cars. What is needed, in order to determine and compare levels of flight safety (or highway, boating, or other modes of safety) over time and between aviation sectors, is some kind of rate. A rate is a ratio of the number of events compared to the exposure to them. You've already seen an example of rates in this chapter (*see* Table 1-1) expressed as the number of passenger fatalities per billion passenger-miles. Because these values are the easiest to obtain, it's common for the denominator in aviation accident rates to be the number of hours flown (e.g., x/million hours), the number of departures (e.g., x/100,000 departures), the number of aircraft-miles flown (e.g., x/million aircraft-miles), and the number of passenger-miles flown (e.g., x/million passenger-miles).

GA Accident Record

Looking at both the number and rate of accidents for the most recent available five-year period (2013 through 2017), you can see in Table 1-2 a stark difference between the safety record of Part 121 air carriers and GA.

Table 1-2. Number of accidents, fatal accidents and fatalities, and accident and fatal accident rates for U.S. GA aircraft and 14 CFR §121 air carriers for 2013 through 2017.[13]

		Number of accidents	Number of fatal accidents	Fatalities	Accident rate per 100,000 flight hours	Fatal accident rate per 100,000 flight hours
2017	GA	1,233	203	331	5.672	0.935
	Air carrier	32	0	0	0.172	0.00
2016	GA	1,267	213	386	5.934	0.984
	Air carrier	31	0	0	0.164	0.00
2015	GA	1,210	230	378	5.851	1.098
	Air carrier	30	0	0	0.162	0.00
2014	GA	1,223	257	424	6.230	1.300
	Air carrier	29	0	0	0.175	0.00
2013	GA	1,224	222	390	6.259	1.118
	Air carrier	23	2	9	0.129	0.011
Total	GA	6,157	1,125	1,909	--	--
	Air carrier	145	2	9	--	--
Yearly average	GA	1,231	225	382	5.989	1.087
	Air carrier	29	0.4	1.8	0.160	0.002

Notice that there were only two fatal Part 121 accidents resulting in nine fatalities over the five-year period. Compare that with the 1,125 fatal GA accidents that claimed the lives of 1,909 people during the same time frame. The average GA accident and fatal accident rates during the five years were 5.99 and 1.09 per 100,000 hours, respectively. Some improvement has occurred during the past two decades, but unfortunately, very little: the GA accident and fatal accident rates averaged 6.82 and 1.28 per 100,000 hours, respectively, for the 10 years from 2005 through 2014, and 7.04 and 1.27 per 100,000 hours, respectively, for the 10 years prior to that (1995 through 2004).[14]

The GA record is much the same in other countries. In Australia for example, 206 accidents in 2015 claimed the lives of 30 people in general- and recreational-aviation operations, while no lives in scheduled airline operations have been lost in that country since 1975.[15] In Canada, 31 people in 240 aircraft accidents in 2017 died, but only one of those deaths involved scheduled passenger airline operations. In fact, for the 11-year period between 2007 through 2017 inclusive, only two fatal accidents in commercial airline operations occurred in that country and, for the four-year period of 2014 through 2017 inclusive, no fatal commuter accidents occurred.[16]

Of course, you can probably think of several reasons why the GA sector has a higher accident rate than scheduled airline operations. Not only do airlines and commercial cargo operators use sophisticated multi-engine turbine-powered airplanes that are certified and typically maintained to the highest standards in the industry, but each airplane is piloted by at least two experienced crew members who are also highly trained and usually certified to the highest standards in the business. Crews also benefit from sophisticated (and expensive) life-saving technology, such as forward-looking Doppler weather radar inclusive of ground and in-flight wind shear detection, **terrain awareness and warning systems (TAWS)**, and **airborne collision avoidance systems (ACAS)**.

Airlines also operate in a stricter regulatory environment and enjoy a support system that is the envy of others in the business, including such benefits as company dispatch, weather and flight monitoring services, refueling and ground personnel, and air traffic control (ATC) services for almost all phases of flight. As part of their **safety management systems (SMS)**, airline safety departments also use a variety of organizational safety tools such as **aviation safety action programs (ASAP)**, **line operations safety audits (LOSA)** and **flight operational quality assurance (FOQA)** to help achieve their high levels of safety.[17]

However, in spite of these safety benefits, the airlines recognize that even experienced pilots sometimes make mistakes—they may get distracted and forget important items, they may execute the wrong action, or they may take the correct action too late. To compensate for these limitations, airline flight crews are trained to engage in best practice risk-reduction strategies during all flights. Some of these include adhering to **standard operating procedures (SOPs)** that are spelled out in detail for every phase of flight; conducting memorized procedural flow checks and using written checklists for normal, non-normal (abnormal), and emergency operations; verbalizing procedures—using callouts—during key points during their execution in order to reduce the possibility of miscommunication; complying with what is commonly called the **sterile cockpit rule** (14 CFR §§121.542 and 135.100) by avoiding nonessential activities (including extraneous conversations) that could distract them from completing the essential duties required for the safe operation of their aircraft during the critical phases of flight (generally below 10,000 feet); and practicing behaviors that are designed to effectively manage automation, distractions, and stress. These are effective tactics that professional and amateur pilots alike can use to avoid or mitigate errors on the flight deck. To help you effectively overcome the human limitations that are often involved in aircraft accidents, we will revisit some of these in greater depth, along with two other particularly effective strategies—crew resource management and threat and error management—in the last two chapters of this book.

Airline Accident Record

The safety record in scheduled commercial airline flying has not always been stellar and accidents still occur both at home and abroad. Boeing compiles a yearly accident *Statistical Summary* that includes the worldwide fleet of commercial turbojet airplanes—made by Boeing and other manufacturers—that have a maximum certificated takeoff weight of more than 60,000 pounds. Their analysis, therefore, excludes all commercial operations using lighter turboprop and piston-engine airplanes, a segment responsible for most accidents in commercial aviation.[18] According to Boeing, 41 accidents involving commercial jet airplanes worldwide took the lives of 304 people in 2018, with 301 of the 304 lost in two major scheduled passenger airline flights; one involving the loss of all but one occupant of a Boeing B-737-200 that crashed after takeoff from Cuba's José Martí International Airport and the other involving the loss of all crew and passengers on board Lion Air Flight 610, a Boeing B-737-8 MAX, that crashed shortly after takeoff from Soekarno-Hatta International Airport, near Jakarta, Indonesia. Between 1959 and 2018, the worldwide fleet experienced 2,030 accidents, 632 fatal accidents, 30,330 onboard fatalities, and 1,255 external fatalities. External fatalities refer to people on the ground or from another aircraft that were also involved in the accident. During the same time period, U.S. and Canadian operators experienced 590 accidents, 183 fatal accidents, and 6,584 total onboard and external fatalities.[19]

The safety record has significantly improved for the worldwide commercial fleet since 1959. Boeing's *Statistical Summary* indicates that the percentage of accidents that involve fatalities (the **lethality rate**) was 35 percent between 1959 and 2018 but averaged only 13 percent for the 2009–2018 decade—a more than 60 percent drop.

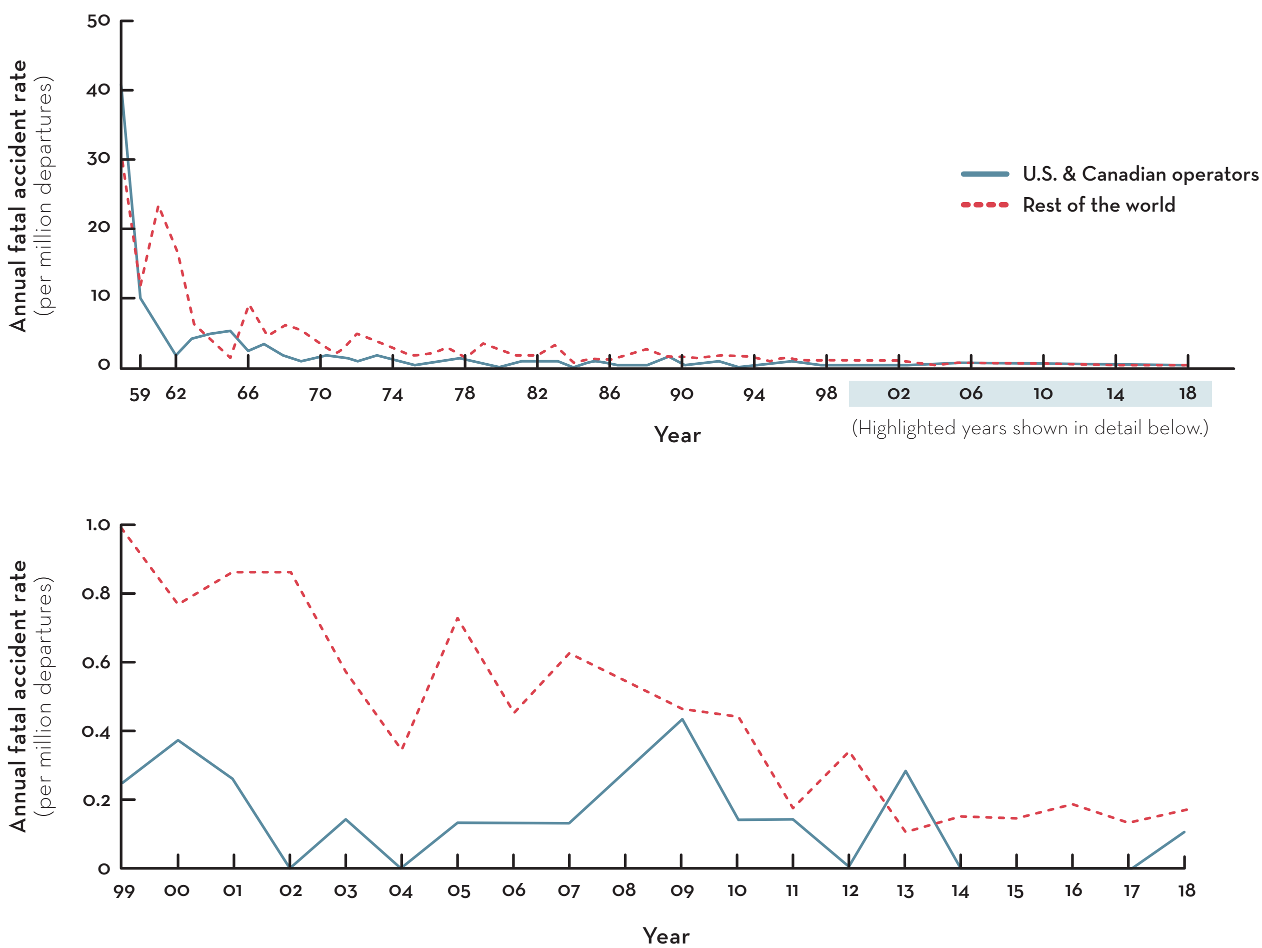


Fig 1-1.

American and Canadian commercial jet fatal accident rate (per million departures) compared to the rest of the world for the periods 1959 to 2018 and 1999 to 2018.[20]

The average U.S. air carrier accident rate and fatal accident rate over the most recent 10 years where complete data are available (2008 through 2017), were 0.31 and 0.007 per 100,000 departures (takeoffs), respectively. This represents a 21 percent drop in the accident rate and a 65 percent drop in the fatal accident rate over the previous 10 years (1998 through 2007) where it was 0.39 and 0.02 per 100,000 departures, respectively.[21]

Types and Causes of Aircraft Accidents

Accident data reveal relatively predictable types and causes of both GA and airline accidents. The U.S. National Transportation Safety Board (NTSB) often uses one event, called the **defining event**, to describe the type or category of accident that occurred. Some examples of defining events are loss of control in flight, controlled flight into terrain, and fuel related. The NTSB also identifies the probable cause or causes of an accident and its contributing factors—those situations or circumstances that are central to the accident cause.[22]

From 2008 through 2017, most U.S. GA accidents—at just over 80 percent—involved personal flight operations (flying for pleasure, recreation, or other personal reasons) and instructional flights. Personal flights accounted for 67 percent of all GA accidents and 63 percent of fatal accidents, and instructional flights accounted for 13 percent and 6 percent of all GA accidents and fatal accidents, respectively. This was followed by aerial applications, and depending on the year, positioning, public use, business, aerial observations, flight tests, skydiving, banner towing, air race/show, external load, ferrying, glider towing, executive/corporate, and unknown.[23]

An earlier U.S. Government Accountability Office (GAO) analysis for the 12 years between 1999 to 2010 found the percentage of fatal accidents involving personal flying was disproportionate to the number of hours it was responsible for—it accounted for only an estimated 40 percent of GA activity yet was responsible for 77 percent of the accidents. Similarly, the GAO noted an estimated 14 percent of GA flight hours involved corporate flight operations, a GA sector that was responsible for less than 1 percent of fatal accidents.[24] Corporate flight departments often make use of airline-type flight crew training, require annual or semi-annual recurrent training in simulators, possess greater levels of operational support, and conform to a variety of safe operating practices that are often required by their respective insurance companies.

According to a recent U.S. Federal Aviation Administration (FAA) GA Safety *Fact Sheet*, the following are the five leading defining events involved in fatal U.S. GA accidents over the past several years. The acronyms that accompany these aviation **occurrence**[25] categories were developed by the Commercial Aviation Safety Team (CAST)/International Civil Aviation Organization (ICAO) Common Taxonomy Team (CICTT). The taxonomy consists of common definitions designed to assist the world's aviation safety community by using standard definitions to classify accidents and **aircraft incidents**. A list of these categories (defining events) and their definitions is included in Appendix B.

1. Loss of aircraft control in flight (LOC-I).
2. Controlled flight into terrain (CFIT).
3. System/component failure—powerplant (SCF-PP).
4. Fuel related (FUEL).
5. Unknown or undetermined (UNK).

System/component failure—non-powerplant (SCF-NP), unintended flight in **instrument meteorological conditions (IMC)**, **midair collisions (MAC)**, low-altitude operations, and other (OTHR)—in that order—are the remaining five types of GA accidents.[26]

The top five accident categories (or defining events) are responsible for the majority of fatal accidents in GA, especially in the highest risk category of personal flight operations. In 2015, for example, they were responsible for 44 percent of all U.S. GA fatal accidents and 74 percent of all fatal accidents involving personal flying operations.[27]

GA Safety Alerts

Concerned about the more than 1,400 GA accidents per year in which more than 400 passengers and pilots died annually, the NTSB—for the first time ever—listed the entire GA sector on its **Most Wanted List of Transportation Safety Improvements** in 2011. They also, for the first time, began addressing some of the major safety issues associated with GA flight operations by publishing safety alerts that were historically published primarily for commercial flight operations. The first few GA safety alerts[28] were published in 2013 and targeted the top three types of fatal GA accidents: loss of aircraft control in flight, controlled flight into terrain, and system/component failure—powerplant.

Loss of control in flight (LOC-I) involves an unintended departure of an aircraft from controlled flight. Since LOC-I is the most common defining event for fatal GA accidents, the NTSB Safety Alert SA-019, *Prevent Aerodynamic Stalls at Low Altitude*, addresses a major cause of LOC-I accidents. According to the safety alert, accident pilots typically fail to avoid the conditions that lead to an aerodynamic stall, to recognize the symptoms of an approaching stall and to use proper stall-recovery procedures.

The safety alert also reveals that these types of accidents arise from a variety of circumstances that tend to repeat themselves in GA flight operations—becoming distracted while maneuvering in the traffic pattern (*circuit* in Canada), fixating on ground objects, and coping with emergencies. For example, applying excessive rudder after overshooting the extended runway centerline while turning base to final, attempting a 180 degree turn back to the runway after losing engine power at low altitude, and losing control when distracted by a spectator while conducting a low altitude pass over the ground.

Another NTSB safety alert, *Reduced Visual References Require Vigilance* (SA-020), underscores the threat of reduced visual references, a condition that has contributed to fatal commercial and military accidents but is particularly problematic among GA flights, many of which are conducted under **visual flight rules (VFR)**. Outside visual references (e.g., horizon, terrain) needed to safely fly under VFR are diminished when visibility is near or below **visual meteorological conditions (VMC)** and during dark-night conditions (overcast and/or moonless). The NTSB says that accidents involving reduced visual references generally are involved in GA's two biggest killers—LOC-I and **controlled flight into terrain (CFIT)**. The safety alert highlights typical scenarios: VFR pilots fly into IMC and either collide with nearby terrain or lose control of their aircraft due to spatial disorientation (SD); instrument-rated pilots experience SD (discussed in Chapter 9) while flying in IMC; and pilots lose control of their aircraft as a result of SD or are involved in a CFIT accident as a result of a visual illusion while attempting to rely on inadequate outside visual references during dark-night conditions.

The good news is the rate of GA CFIT accidents has decreased in recent years, and the General Aviation Joint Steering Committee, an FAA/Industry program, speculates that this may be due to the proliferation in GA aircraft of moving map displays in avionics and **electronic flight bags (EFB)**.[29]

System/component failure-powerplant (SCF-PP) is generally the third most common type of fatal GA accident, but in 2015 it crept ahead of CFIT to second place behind LOC-I. The GA sector relies heavily on the use of single-engine piston-powered airplanes (over 80 percent of the U.S. GA fleet), and piston engines are generally less reliable than turbine engines. The fastest growing segment of the GA fleet—experimental-amateur built (E-AB) aircraft (often called "homebuilts")—is responsible for a disproportionate share of accidents (4 percent of fight hours, 21 percent of fatal accidents), in part because "most E-ABs are simple aircraft that may incorporate previously untested systems and modified airframes and instruments."[30]

NTSB safety alerts *Is Your Aircraft Talking to You? Listen!* (SA-021), addressed to pilots, and *Mechanics: Manage Risks to Ensure Safety* (SA-022), appropriately targeting aircraft maintenance personnel, indicate that the circumstances involved in fatal accidents involving system or component failures are "remarkably similar to those of previous accidents" and that pilots and mechanics are not taking advantage of the lessons learned from previous accidents. For example, too often pilots attempt a flight even though they are aware that something is not quite right mechanically with their aircraft.

Finally, according to Safety Alert SA-067, *Flying on Empty*, there was a yearly average of 50 GA fuel mismanagement accidents (FUEL) between 2011 and 2015. Fuel exhaustion (the aircraft completely runs out of fuel) and fuel starvation (fuel is present but isn't delivered to the engine) accounted for more than 90 percent of all fuel-related accidents. Fuel system malfunctions were cited in less than 5 percent of these accidents—pilot inexperience, complacency, overestimation of flying abilities, and improper operation of fuel systems caused, or were contributing factors, in over 95 percent of fuel-related accidents.

Causes of and Contributing Factors to GA Accidents

As with fuel-related accidents, most GA accidents are caused by some type of pilot error. In fact, the Aircraft Owners and Pilots Association (AOPA) concluded that the "overwhelming cause of accidents is pilot error, which has consistently caused 75 percent of accidents for decades."[31] Pilots, like all humans, are prone to error and mistakes. Some of these involve, at least in part, errors of skill as witnessed by the fact that the highest number of pilot-caused accidents occur during landings. Fortunately—as indicated in AOPA's Air Safety Institute's recent *Joseph T. Nall Report* and seen in Figure 1-2—these also involve the fewest fatalities: there were 262 landing accidents involving U.S. GA aircraft in 2015, but only three resulted in fatalities.

Also seen in Figure 1-3, the most common type of landing accident involves loss of directional control suggesting that they are caused, or at least partially caused, by skill errors. There were 115 landing accidents in 2015 involving loss of control, one of which involved a fatality. Other likely skill-related causes include airspeed control issues, stalls, and landing short or long on the runway.

Fig 1-2.

Types of pilot-related GA accidents, including number of accidents and fatal accidents for each type in 2015.[32]

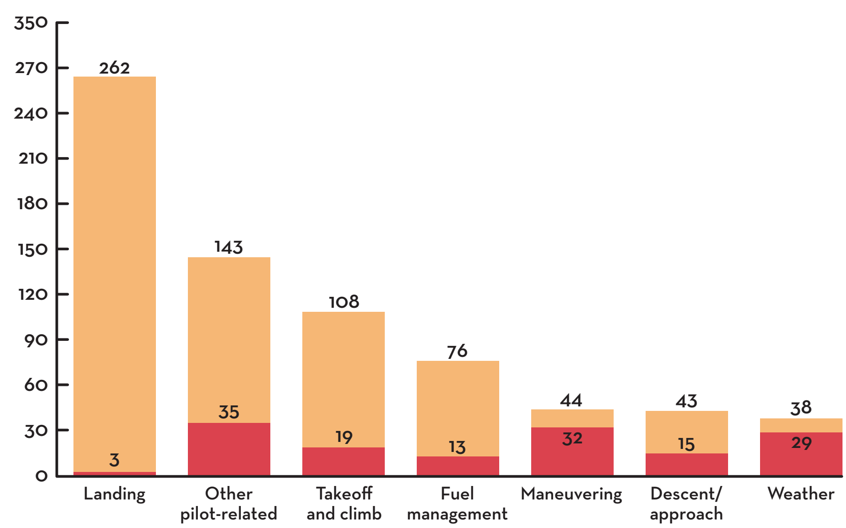
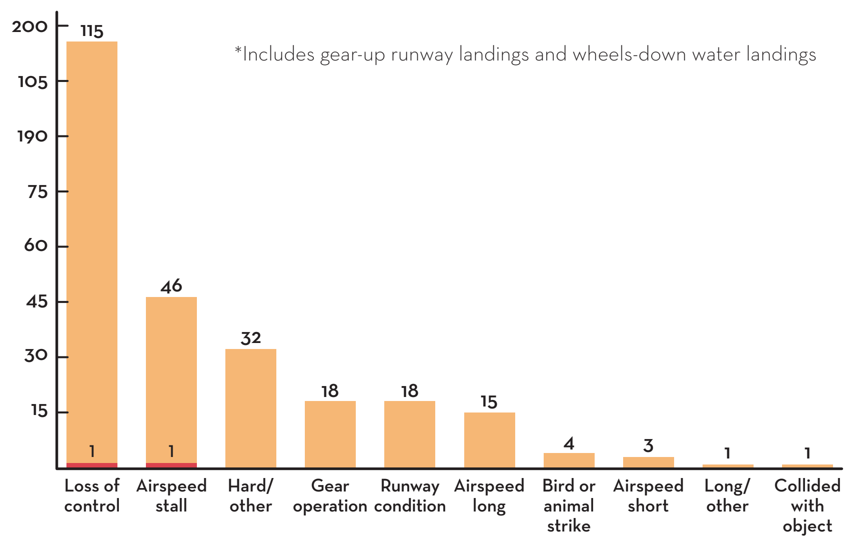


Fig 1-3.

Types of GA landing accidents, including number of accidents and fatal accidents for each type in 2015.[33]



Of course there are other types of errors, besides stick-and-rudder skill errors, that contribute to landing accidents. The *Nall Report* highlights two major types of errors that GA pilots consistently make: flight planning errors and decision-making errors. These higher level cognitive errors can also lead to landing accidents if a pilot makes a decision to attempt a landing in weather conditions (crosswind, tailwind, turbulence, poor visibility) or runway conditions (short or downsloped runway, or water, snow, ice contamination) that exceed her or his skill level.

One particularly vexing decision error involves pilots' decisions to continue **VFR flight into IMC**. Notice in Figure 1-2 that the lowest number of accidents in 2015 were weather-related accidents, yet they involved the highest proportion of fatal accidents—29 out of 38—producing a lethality rate of 76 percent. That's because the majority of these fatal accidents involved attempted VFR flight into IMC. (The others involved thunderstorms, airframe icing, poor instrument flying technique and turbulence.) In these accidents, VFR pilots either depart into existing adverse weather or, more typically, continue VFR flight into gradually deteriorating weather, and while attempting to make it to their destination they inadvertently fly into IMC (weather conditions below VFR weather minimums) and lose sight of their outside visual references. If they are VFR-only pilots, or pilots with inadequate instrument flying skills, as pointed out previously in NTSB Safety Alert SA-020, pilots either fly under controlled flight into nearby terrain (CFIT) or experience SD and lose control of their aircraft (LOC-I). The latter results in **uncontrolled flight into terrain (UFIT)** or in-flight structural failure due to the pilot overstressing the aircraft while recovering from an unusual attitude. In fact, a study conducted by the University of Illinois in the 1950s found that pilots who lack sufficient instrument flying ability lose control of their airplane in an average of only 178 seconds once they lose outside visual references.[34] It's no wonder that 95 percent of these types of accidents in 2015, like most previous years, were fatal.[35]

Types of Air Carrier Accidents

Figure 1-4 portrays the most common CAST/ICAO CICTT accident categories and associated fatalities from 2009 through 2018 for the worldwide commercial jet fleet.

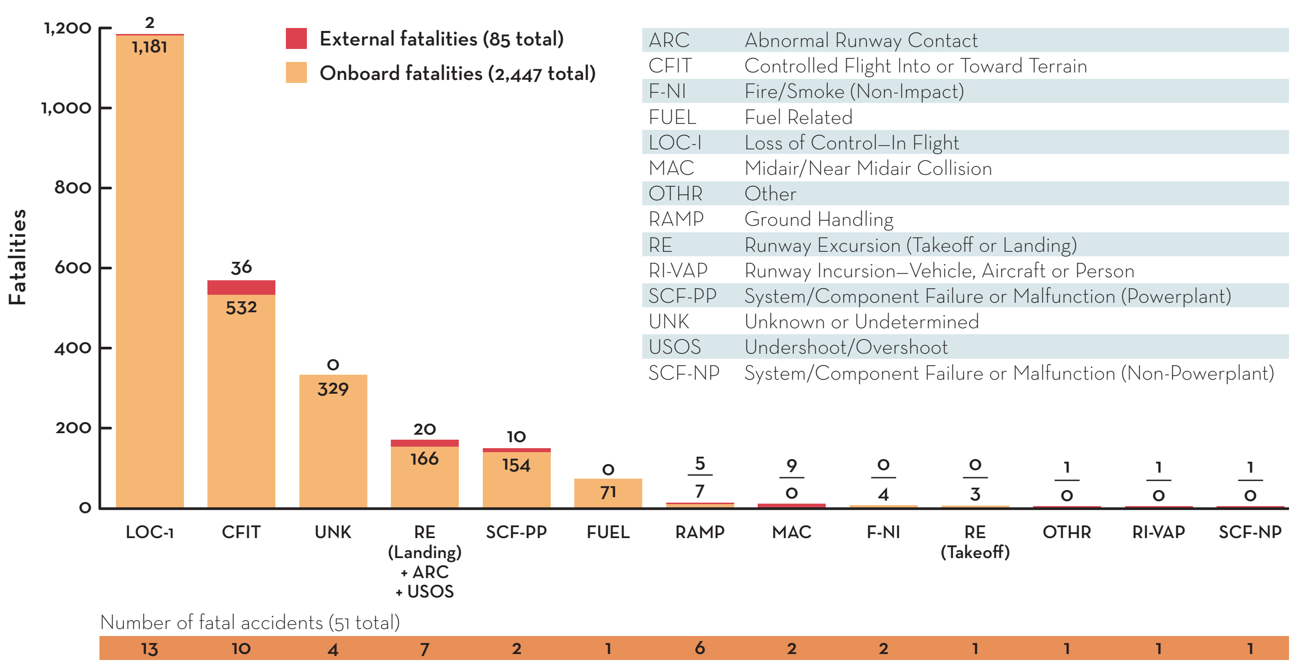


Fig 1-4.

CAST/ICAO CICTT accident categories (defining events) and fatalities for worldwide commercial jet fleet, 2009 through 2018.[36]

Loss of Control in Flight

Like GA, the biggest killer for air carriers was LOC-I at 1,183 deaths for the 10-year period. According to the International Air Transport Association, worldwide, LOC-I was responsible for less than 10 percent of commercial jet and turboprop aircraft accidents from 2011 through 2015, yet was responsible for 45 percent of all fatal accidents.[37] That's because LOC-I in airline operations, as for GA flights, are fatal 90 percent of the time.[38] In-flight LOC has held the top spot since 2006 where its 10-year average first overtook CFIT as the leading cause of fatalities in the worldwide commercial jet airplane fleet.

Similar to GA accidents, CFIT, SCF-PP, FUEL, and UNK occupy the remaining top categories or defining events for fatal accidents.

Controlled Flight into Terrain

Worldwide, CFIT is currently responsible for only 5 percent of airline accidents, yet 16 percent of all fatalities.[39] CFIT has historically been the number one cause of aviation fatalities in commercial airline accidents. A study conducted in the 1990s found that it had claimed the lives of more than 9,000 passengers and airline crew members since commercial passenger jet operations began in the mid-1950s.[40] CFIT was still the leading cause of worldwide airline fatalities between 1987 and 2005—responsible for the loss of 3,735 lives[41]—but since then the number of fatalities has been gradually decreasing, coming second only to LOC-I thanks in large part to improved education, better awareness, and the use of improved CFIT-avoidance technology (e.g., TAWS).

Runway Excursions

A category that you might expect for large, heavy, and fast airplanes, that are required to take off and land on runways with limited lengths, are **runway excursions (RE)**. An RE occurs when an aircraft departs the end (overrun) or the side (veers off) of the runway during a takeoff or landing. A Flight Safety Foundation study discovered that 29 percent of 1,429 major and substantial damage accidents involving worldwide turboprop and turbojet commercial transport aircraft from 1995 through 2008, were REs.[42] For a recent five-year period (2012 through 2016) they were the number one cause of worldwide commercial air transport turbojet and turboprop accidents—responsible for 26 percent of all accidents. The good news is they accounted for only 6 percent of fatal accidents and less than 1 percent of all fatalities.[43]

From 2009 through 2018, 98 percent of airline REs occurred during landing. As for GA accident statistics—where landing accidents are the number one type of accident—landing excursions point out a major fact of piloting an aircraft: no matter how experienced a pilot you are, the approach and landing are the most difficult phases of flight to safely accomplish. The aircraft must be correctly aligned—both laterally and vertically—and at the correct speed, configuration and position at the touchdown zone in order for a successful landing to occur. In addition, proper control inputs during landing are needed to compensate for runway conditions such as crosswinds or runway surface contamination; otherwise the consequences could be catastrophic.

The elevated level of risk during the approach and landing is visibly illustrated in Figure 1-5 which reveals that just under one-half of the world's fatal commercial jet airplane accidents between 2009 and 2018 occurred during the final approach and landing phases of flight—phases that occupied only about 4 percent of flight time! In fact, 61 percent of fatal accidents and 43 percent of all fatalities for Western-built commercial turbojet aircraft occurred during takeoff, initial climb, final approach, and landing—phases which occupy only 6 percent of flight time. These 10-year average figures have remained relatively the same for decades.

The statistics reveal another aspect of safety we haven't yet discussed. The last two columns in Table 1-2 indicate the disparity between U.S. air carrier and GA accident and fatal accident rates. For example, U.S. passenger air carriers and cargo operators in 2013—the only year during the five-year period that their fatal accident rate was greater than zero—recorded a fatal accident rate of .011 per 100,000 flight hours and GA experienced a fatal accident rate of 1.118 per 100,000 flight hours—more than 100 times the air carrier rate. However, these figures may belie the true difference between them because the denominator used to measure accident rates is number of hours, instead of departures. It can be argued that if the latter was used, the disparity between the two sectors would be reduced. The reasoning goes like this: Larger scheduled commercial airplanes typically fly for a longer duration each flight than do smaller GA aircraft. Consequently, for a given flight time period—let's say four hours—a typical light GA aircraft may actually accomplish several flights (takeoffs and landings) for each flight a commercial airliner does. Therefore, since smaller GA aircraft are exposed to the riskiest stages of flight—takeoff, initial climb, final approach, and landing—more often per given flight-hour, then measuring fatal accidents per departures would narrow the gap slightly between the airline and GA safety record because each departure has the same exposure to these risky phases. Unfortunately, accurate departure statistics for GA aircraft are impossible to obtain, so the FAA, NTSB, and other organizations use information they can obtain: the number of flight hours.

Causes of and Contributing Factors to Airline Accidents

As is true in GA, the majority of airline accidents result from errors committed by the flight crew. Estimates vary widely, depending on what sector, time frame, or region being measured. For example, an evaluation of 329 major U.S. airline accidents and 1,627 commuter/air taxi crashes for the 14 years from 1983 through 1996, found that pilot error was a probable cause in 38 percent of the major airline accidents and 74 percent of commuter/air taxi accidents.[45] However, statistics compiled by Boeing found that flight crew errors were the primary cause of 66 percent of worldwide commercial jet accidents from 1991 through 2000. This was followed by airplane malfunctions (13 percent), adverse weather (8 percent), mainte-

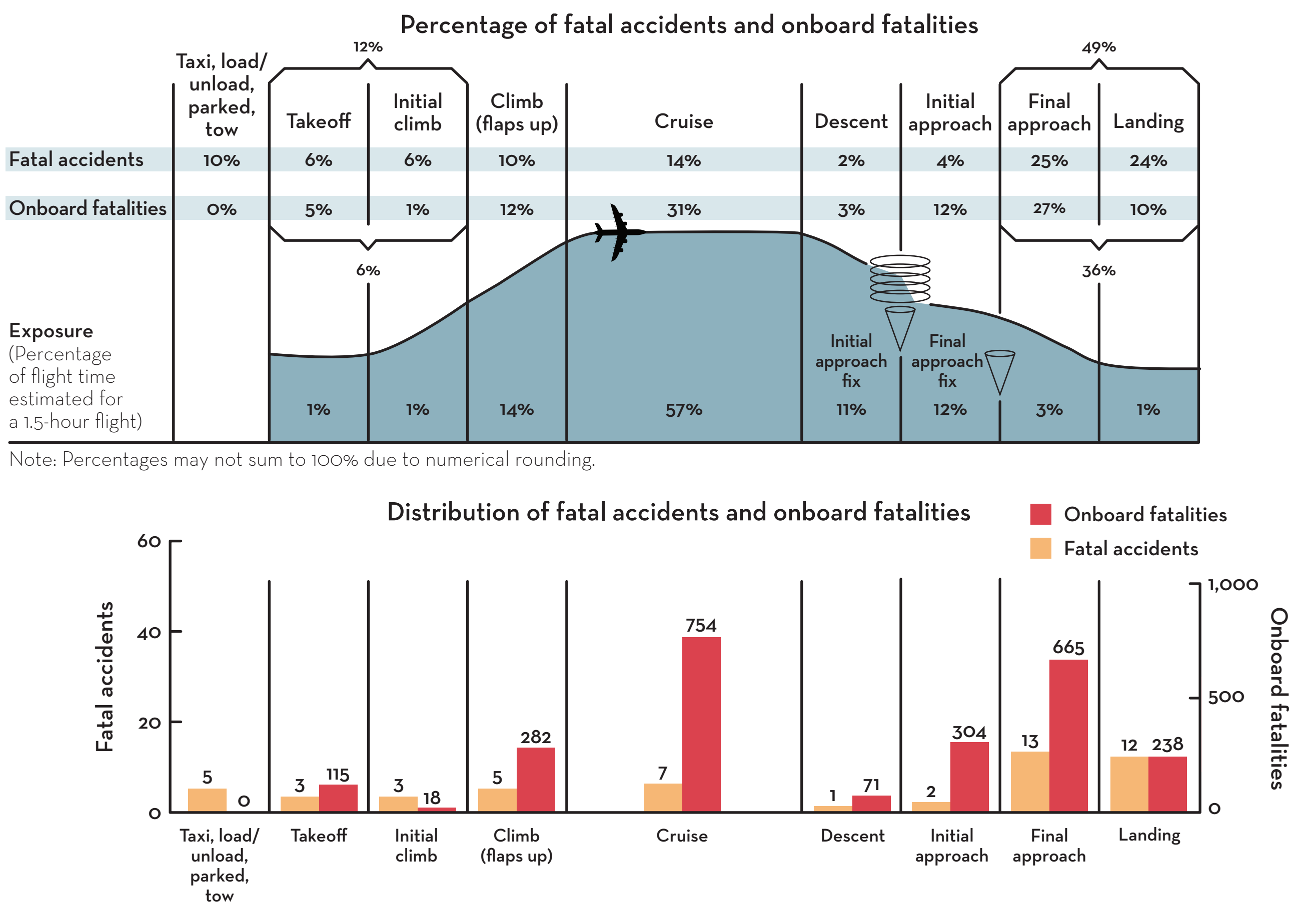


Fig 1-5.

Fatal accidents and onboard fatalities by phase of flight for worldwide commercial jet fleet, 2009 through 2018.[44]

HumanFactors

Enhancing Pilot Performance

Dale Wilson

Today's aviation industry enjoys a remarkable safety record, primarily because it has learned from the mistakes of its past. Through the study of aviation accidents, most of the risks of flying have been identified and the threats they pose to safety can be managed. However, aircraft accidents, such as controlled flight into terrain, loss of control, runway excursions and incursions, and midair collisions still occur, and the hazards of flight remain.

Some accidents happen due to mechanical failure, improper maintenance, or hazardous weather—but the vast majority are caused by pilot action (or inaction). Pilots can commit errors and make decisions that lead to tragic outcomes. Most accidents are not intentional; inadvertent errors made by flight crews arise from normal human physiological, psychological, and psychosocial limitations.

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