

DOT/FAA/AM-03/4

Office of Aerospace Medicine  
Washington, DC 20591

# **A Human Error Analysis of General Aviation Controlled Flight Into Terrain Accidents Occurring Between 1990-1998**

Scott A. Shappell  
Civil Aerospace Medical Institute  
Federal Aviation Administration  
Oklahoma City, OK 73125

Douglas A. Wiegmann  
University of Illinois at Urbana-Champaign  
Institute of Aviation  
Savoy, IL 61874

March 2003

Final Report

This document is available to the public  
through the National Technical Information  
Service, Springfield, Virginia 22161.



**U.S. Department  
of Transportation  
Federal Aviation  
Administration**

## **NOTICE**

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents thereof.

### Technical Report Documentation Page

1. Report No. DOT/FAA/AM-03/4	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle A Human Error Analysis of General Aviation Controlled Flight Into Terrain Accidents Occurring Between 1990-1998.		5. Report Date March 2003	
		6. Performing Organization Code	
7. Author(s) Shappell SA <sup>1</sup> and Wiegmann DA <sup>2</sup>		8. Performing Organization Report No.	
		10. Work Unit No. (TRAIS)	
9. Performing Organization Name and Address <sup>1</sup> FAA Civil Aerospace Medical Institute P. O. Box 25082 Oklahoma City, OK 73125 <sup>2</sup> University of Illinois at Urbana-Champaign, Institute of Aviation Savoy, Illinois 61874		11. Contract or Grant No.	
		13. Type of Report and Period Covered	
12. Sponsoring Agency name and Address Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., S. W. Washington, DC 20591		14. Sponsoring Agency Code	
		15. Supplemental Notes Work was accomplished under approved subtask HRR-521.	
16. Abstract Although all aviation accidents are of interest to the Federal Aviation Administration (FAA), perhaps none is more disconcerting than those in which a fully functioning aircraft is inexplicably flown into the ground. Referred to as controlled flight into terrain (CFIT), these accidents continue to be a major safety concern within aviation, in particular general aviation (GA). A previous study as part of the FAA's <i>Safer Skies</i> agenda examined 165 CFIT accidents using root cause analysis and developed 55 interventions to address their causes. While the study represented the work and opinions of several experts in the FAA and industry, the findings might have benefited from a more detailed human error analysis involving a larger number of accidents. In this study, five pilot-raters independently analyzed more than 16,500 GA accidents occurring between 1990-1998 using the Human Factors Analysis and Classification System (HFACS). Of the GA accidents examined, 1407 were identified as CFIT and compared with non-CFIT accidents using HFACS. The analysis revealed a number of differences in the pattern of human error associated with CFIT accidents. Findings from this study support many of the interventions identified by the CFIT Joint Safety Analysis Team (JSAT) and Joint Safety Implementation Team (JSIT), permitting safety professionals to better develop, refine, and track the effectiveness of selected intervention strategies.			
17. Key Words Human Error, Accident Investigation, Controlled Flight Into Terrain, HFACS		18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 25	22. Price



## **Acknowledgments**

The authors would like to express their thanks to Ms. Deborah Thompson, Mr. Dan Jack, Ms. Carrie Roberts, and Ms. Tara Bergsten for their tireless efforts managing and entering the data associated with these accidents. We also are indebted to Mr. Shawn Hoffman, Mr. Marshall Scott, Mr. Sean Sullivan, Mr. Robert Taylor, Mr. Joe Windes, Mr. Chris Yates, and Mr. Luis Gutierrez for their effort analyzing the thousands of general aviation accidents included in this study. Finally, we would be remiss if we did not gratefully acknowledge the editorial comments and support provided by Ms. Christy Detwiler and Mr. Michael Wayda during the writing and production of this manuscript.



---

# A HUMAN ERROR ANALYSIS OF GENERAL AVIATION CONTROLLED FLIGHT INTO TERRAIN ACCIDENTS OCCURRING BETWEEN 1990-1998

## INTRODUCTION

Aviation continues to be one of the safest forms of transportation, and with the help of modern technology, is enjoying its best years ever. Still, accidents do occur, leaving investigators with the unenviable and often difficult task of identifying the causes, in the hope that they might be prevented or mitigated in the future. Using sophisticated forensic techniques and deductive reasoning; the work of an accident investigator is much like a detective sifting through clues to solve a mystery. Yet, even the most skilled investigator is often at a loss when trying to explain how a pilot could inexplicably fly a functioning aircraft into the ground. These so-called controlled flight into terrain (CFIT) accidents continue to beleaguer both civilian and military aviation.

So, what is “controlled” flight into terrain? After all, it seems inconceivable that a pilot would fly an aircraft into the ground while it was still controllable. It should come as no surprise, then, that getting investigators and researchers to agree on what is, and more importantly, what is not CFIT, is difficult at best. Nevertheless, while individual definitions of CFIT may vary, most would agree at some level that CFIT occurs when an airworthy aircraft, under the control of a pilot, is flown into terrain (water or obstacles) with inadequate awareness on the part of the pilot of the impending disaster (FAA, 2000).

Regardless of the nuances of each investigator’s personal definition, no one would deny that CFIT is a serious issue facing aviation today. In fact, if one were to use the FAA’s definition (above), the U.S. Navy/Marine Corps alone lost an average of ten aircraft per year to CFIT between 1983 and 1995 (Shappell & Wiegmann, 1995, 1997b). Likewise, between 1990 and 1999, 25% of all fatal airline accidents and 32% of worldwide airline fatalities (2,111 lives lost) have been attributed to CFIT (Boeing, 2000). In fact, since 1990, no other type of accident has taken more lives in military or commercial aviation.

Given the accident data, no one would disagree that CFIT accidents in the military and commercial aviation warrant the attention they receive; but often forgotten are the even larger number of CFIT accidents that occur within general aviation (GA). To put it into perspective, while the U.S. Navy/Marine Corps lose on average 20-30 aircraft annually for a variety of reasons, there were nearly 20,000 GA accidents between 1990 and 1999

alone — including an average of almost 400 fatal accidents per year (NTSB, 2001). Unfortunately, neither the National Transportation Safety Board (NTSB), nor anyone else that we are aware of, has documented the number of CFIT accidents occurring in GA annually. But even if only 10% of the fatal GA accidents involved CFIT (well below the averages reported in commercial or military aviation), an alarming 40 fatal accidents per year could be attributed to this seemingly purest of human error accidents – and this does not even take into account those CFIT accidents in which a fatality did not occur.

### CFIT Joint Safety Analysis Team (JSAT)

On April 14, 1998, the FAA Administrator outlined the Agency’s safety agenda for GA, commercial aviation, and cabin safety. Referred to as *Safer Skies*, the goal for GA was to significantly reduce fatal accidents over a 11-year period from 1996 to 2007. To accomplish that goal, six focus areas were targeted, one of which was CFIT. Armed with this mandate, a unique team of industry and FAA safety professionals, the Joint Safety Analysis Team (JSAT), was formed in the fall of 1998 to “identify and implement a data driven, cost/benefit focused, safety enhancement program designed to reduce fatal general aviation accidents” (FAA, 2000, p.13) – in particular, those involving CFIT.

The team, using accidents identified by a previous study of CFIT performed by the Volpe Center (Volpe, 1997), examined 195 CFIT accidents that occurred between 1993 and 1994 under a variety of operations including: 14 CFR Part 91 (personal and business flying), 14 CFR Part 125 (privately operated transport aircraft), 14 CFR Part 133 (rotary wing external operations), 14 CFR Part 135 (air taxi), and 14 CFR Part 137 (agricultural aerial application) operations. Employing a root cause analysis approach, the CFIT JSAT conducted a detailed analysis of the CFIT accidents and identified 55 interventions aimed at addressing their causes. Ultimately, the team selected a set of ten interventions that would be the most effective and feasible to implement. In no particular order they included the following:

- Increase pilot awareness of accident causes.
- Improve the safety culture within the aviation community.
- Promote the development and use of low-cost terrain clearance and/or look ahead devices.

- Improve pilot training (i.e., weather briefing, equipment, decision-making, wire and tower avoidance, and human factors).
- Improve the quality and substance of weather briefs.
- Enhance the Biennial Flight Review (BFR) and/or instrument competency check.
- Develop and distribute mountain flying technique advisory material.
- Standardize and expand the use of markings for towers and wires.
- Use high-visibility paint and other visibility enhancing features on obstructions.
- Eliminate the pressure to complete the flight where continuing may compromise safety.

Even the best interventions are useless if a plan for implementing them is not drawn up. With that in mind, the FAA chartered a second team, including several members of the original CFIT JSAT, to develop an implementation plan for incorporating the recommendations of the CFIT JSAT into practice. The CFIT Joint Safety Implementation Team (JSIT) subsequently released a detailed implementation plan around eight areas that were in line with the original CFIT JSAT report (FAA, 2000). Included in their plan was an implementation strategy, the identification of responsible parties and resources, and a list of milestones/completions dates to monitor the program.

### **U.S. Navy/Marine Corps CFIT**

The military, like their civilian counterparts, has been confronted with CFIT almost since the inception of military aviation. Nevertheless, few studies have systematically examined the full spectrum of human error associated with these often fatal accidents. Shappell and Wiegmann (1997a) did conduct one such study, examining 144 U.S. Navy/Marine Corps Class A<sup>1</sup> accidents using an early version of the Human Factors Analysis and Classification System (Shappell & Wiegmann, 1997b). Their analyses revealed several findings applicable to the intervention of CFIT, some of which were unexpected, given conventional wisdom in the area. What was consistent with previous work, however, was that many of the U.S. Navy/Marine Corps CFIT accidents were associated with spatial disorientation and adverse mental states such as fatigue and the loss of situational awareness. In fact, to the extent that any particular causal category can be considered

characteristic of a particular type of accident, it would be adverse mental and physiological states with CFIT.

While the confirmation that spatial disorientation and adverse mental states contribute to CFIT was important, what was particularly revealing from the Navy study was the large number of CFIT accidents associated with the willful violation of the rules by aircrew—a surprising 40% of the CFIT accidents examined. Upon further review, it appears that whether the violations involved personal readiness (e.g., self-medicating or simply violating crew rest requirements) or unsafe act violations (e.g., flying into a cloud bank when authorized for visual flight rules only), they were often the seminal event in the tragic sequence of events that followed. This finding was particularly relevant because many of the interventions proposed to prevent CFIT involved terrain avoidance and ground proximity warning systems (GPWS) that would seemingly be of little help if aircrew were willing to violate established safety practices. In fact, it was felt that over-reliance on GPWS and other related terrain avoidance systems might actually increase the likelihood that aircrew will push altitude limits in an attempt to get an edge in training or combat.

Even more interesting than the relationship of violations with CFIT were the marked differences between the error patterns associated with CFIT occurring during the day versus night. Much to the surprise of many within Naval aviation, nearly half of all CFIT accidents occurred in broad daylight during visual meteorological conditions (VMC). After all, it had been generally thought that most, if not all, CFIT occurred during the night or when visual cues were otherwise impoverished during instrument meteorological conditions (IMC). It seemed reasonable therefore to ask whether any additional differences existed between day and night CFIT other than the obvious visual ones.

It is well known that when visual cues are limited, coordination among the crew and personnel external to the cockpit becomes paramount. It is not surprising then that the incidence of crew resource management failures was significantly higher among U.S. Navy/Marine Corps crews during night than during daytime CFIT accidents. Likewise, adverse physiological (e.g., spatial disorientation) and mental states (e.g., loss of situational awareness) were more prevalent at night than during the day. This was also anticipated, given that the lack of visual cues would presumably lead to spatial disorientation and the

---

<sup>1</sup> The U.S. Navy/Marine Corps considers an accident as Class A if the total cost of property damage (including all aircraft damage) is \$1,000,000 or greater; or a naval aircraft is destroyed or missing; or any fatality or permanent total disability occurs with direct involvement of naval aircraft.

loss of situational awareness. What was not expected was the rather large proportion of violations (nearly half of all the CFIT accidents examined) occurred mostly during the day. Given that violations almost invariably predicate other factors within the HFACS framework, this finding became a significant source of information for those designing systems to address CFIT in the U.S. Navy/Marine Corps.

### **A rationale for an HFACS analysis of GA accidents**

Without question, the work of the CFIT JSAT and JSIT represent a landmark effort within civil aviation. However, while the interventions identified by the CFIT JSAT represent the views and opinions of experts in industry and the FAA, their findings might have benefited from a more focused human error analysis like that used with the U.S. Navy/Marine Corps accidents – particularly one that was not constrained by a relatively small sample of accidents. This is not to imply that the CFIT JSAT study was flawed. Quite the contrary, the CFIT JSAT was working within the logistical and time constraints they were given. As a result, they based their conclusions on a relatively small subset of accidents from a variety of aircraft operations rather than GA alone. This was done primarily because no one had systematically examined the GA accident record for CFIT accidents, perhaps due to the general lack of agreement on what a CFIT accident is. Since the JSAT convened, however, a joint International Civil Aviation Organization (ICAO)/Commercial Aviation Safety Team (CAST) Common Taxonomy Team has published a definition of CFIT accepted by many in the field (including the National Transportation Safety Board in the United States and ICAO) similar to that used by the CFIT JSAT. Specifically, the ICAO/CAST defined CFIT as an “*inflight collision with terrain, water, or obstacle without indication of a loss of control.*”

The aim of this study therefore was to examine a large body of GA accidents using the CAST/ICAO criteria for CFIT. Then, after differentiating CFIT from non-CFIT accidents, a more detailed human error analysis could be performed. Given the success that the U.S. Navy/Marine Corps and other organizations have experienced using HFACS, it seemed reasonable to apply the HFACS framework to the GA accident database in the hope that similar results could be achieved. To familiarize the reader with the relevant aspects of the HFACS framework, it will be briefly reviewed here. Note however that a more complete description can be found elsewhere (Shappell & Wiegmann, 2001a).

## **HFACS**

It is generally accepted that aviation mishaps, like most accidents, do not happen in isolation. Rather, they are the result of a chain of events often culminating in the unsafe acts of aircrew. From Heinrich’s (Heinrich, Peterson, & Roos, 1931) axioms of industrial safety to Bird’s (1974) “Domino theory,” a sequential theory of accident causation has been embraced by many in the field. Particularly useful in this regard has been Reason’s (1990) relatively recent description of active and latent failures within the context of his “Swiss cheese” model of human error.

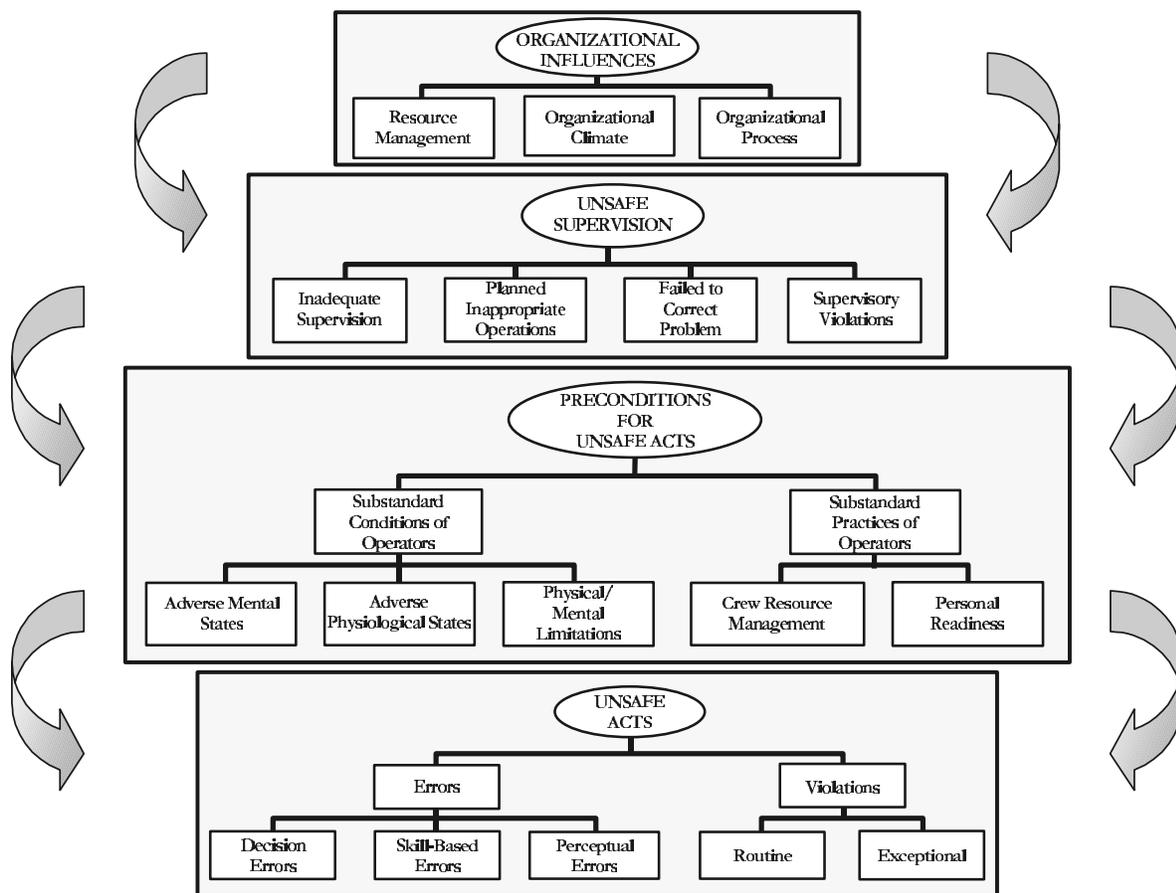
In general, Reason described four levels of human failure (organizational influences, unsafe supervision, preconditions for unsafe acts, and the unsafe acts of operators), each one affecting the next. To hear Reason explain it, many accidents have their roots high within the organization, at the level of the chief executive officer, president and vice-president(s). It is the decisions made by those at the top that often influence the middle managers and supervisors as they oversee the day-to-day operations of the organization. Ultimately, it is the operators at the “pointy end of the spear” who inherit all the baggage of the organization along with those that manage them as they perform their duties. Unfortunately, when the system breaks down and errors occur, accidents and incidents are the end result. So, if one wants to truly understand the causal genesis of an accident, they must peel the proverbial onion back, layer-by-layer, until the causal sequence of events is uncovered in its entirety.

Yet, even as Reason’s seminal work revolutionized the way we in aviation and other industrial settings view the human causes of accidents, it did not provide the level of detail necessary to apply it in the real world. Therefore, drawing upon Reason’s (1990) original work, the human factors analysis and classification system (HFACS) was developed to fill that need (Shappell & Wiegmann, 2000a, 2001a).

The HFACS framework describes 17 causal categories within Reason’s four levels of human failure (Figure 1). However, because our previous work (Shappell & Wiegmann, 2001b) using GA accidents has shown that the causal factors typically populate only the bottom two tiers of HFACS (the *preconditions for unsafe acts* and the *unsafe acts of operators*) we will limit our discussion to them. A complete description of all four tiers can be found elsewhere (Shappell & Wiegmann, 2000a, 2001a).

### **Unsafe Acts of Operators**

The first level of HFACS describes those unsafe acts of operators that can lead to an accident. Perhaps unfairly referred to in aviation as aircrew/pilot error since many



**Figure 1.** The Human Factors Analysis and Classification System.

unsafe acts do not involve aircrew, this level is where most accident investigations are focused and consequently, where the majority of causal factors are uncovered. The unsafe acts of operators can be loosely classified into one of two categories: errors and violations. While both are common within most settings, they differ markedly when the rules and regulations of an organization are considered. That is, errors can best be described as those activities that fail to achieve their intended outcome, while violations are commonly defined as behavior that represents the willful disregard for the rules and regulations. However, merely distinguishing between errors and violations does not provide the level of granularity required of most error analyses and accident investigations. Therefore, the categories of errors and violations were expanded here (Figure 1), as elsewhere (Reason, 1990; Rasmussen, 1982), to include three basic error types (decision, skill-based, and perceptual) and two forms of violations (routine and exceptional).

### Errors

**Decision Errors.** Perhaps the most heavily investigated of all error forms, decision errors represent intentional behavior that proceeds as intended, yet the plan proves

inadequate or inappropriate for the situation. Often referred to as “honest mistakes,” this type of error can generally be grouped into one of three categories: procedural errors, poor choices, and problem-solving errors (Table 1). Procedural decision errors (Orasanu, 1993), or rule-based mistakes (as described by Rasmussen, 1982), occur during highly structured tasks of the sorts, if A, then do B, then do C. Aviation, particularly within the military and commercial sectors, by its very nature is highly structured, and consequently, much of pilot decision-making is procedural. In fact, there are very explicit procedures to be performed in virtually all phases of flight. Still, errors can, and often do, occur when a situation is either not recognized or misdiagnosed and the wrong procedure is applied.

Even in aviation, however, not all situations have corresponding procedures that address them. Instead, many situations require that a choice be made among multiple response options. Consider, for instance, the pilot who unexpectedly confronts a line of thunderstorms directly along the intended flight path. He or she can choose to fly around the weather, divert to another field until the weather passes, or penetrate the weather hoping to quickly transition through it. When

**Table 1.** A partial listing of the unsafe acts of operators.

<u>Errors</u>	<u>Violations</u>
<p><b>Decision Errors</b> (“Honest mistakes,” occur when one does not have appropriate knowledge or made a poor choice, procedural error or problem-solving error)</p> <ul style="list-style-type: none"><li><input type="checkbox"/> Improper inflight planning</li><li><input type="checkbox"/> Improper altitude/clearance</li><li><input type="checkbox"/> Aborted takeoff/landing decision improper</li><li><input type="checkbox"/> Weather evaluation inadequate</li><li><input type="checkbox"/> Improper refueling decisions</li><li><input type="checkbox"/> Improper remedial action</li></ul>	<p><b>Routine Infractions</b> (“Bending” the rules tolerated by authority. Must look up the supervisory chain to identify those in authority who are not enforcing rules)</p> <ul style="list-style-type: none"><li><input type="checkbox"/> VFR flight into IMC (continued, performed, encountered)</li><li><input type="checkbox"/> Flight into adverse weather continued</li><li><input type="checkbox"/> IFR procedure not followed</li><li><input type="checkbox"/> Aircraft weight and balance improper</li><li><input type="checkbox"/> Procedures/directives not followed</li><li><input type="checkbox"/> Minimum descent altitude not maintained</li><li><input type="checkbox"/> Operation with known deficiency in equipment performed</li></ul>
<p><b>Skill-based Errors</b> (“Stick and rudder” and other basic flight skills that occur without significant conscious thought. Vulnerable to failures of attention, memory and/or technique)</p> <ul style="list-style-type: none"><li><input type="checkbox"/> Airspeed not maintained</li><li><input type="checkbox"/> Aircraft control inadequate<ul style="list-style-type: none"><li>• Abrupt</li><li>• Excessive</li><li>• Not maintained</li></ul></li><li><input type="checkbox"/> Stall spin inadvertent</li><li><input type="checkbox"/> Altitude improper/ not maintained</li><li><input type="checkbox"/> Clearance not maintained</li><li><input type="checkbox"/> Inadequate visual lookout</li><li><input type="checkbox"/> Poor emergency procedure</li><li><input type="checkbox"/> Proper glide path not maintained</li></ul>	<p><b>Exceptional</b> (Isolated deviation from the rules, but <u>not</u> tolerated by management. Difficult to predict, since not indicative of one’s behavior)</p> <ul style="list-style-type: none"><li><input type="checkbox"/> Low altitude flight/buzzing performed</li><li><input type="checkbox"/> Operation with known deficiency in equipment intentional</li><li><input type="checkbox"/> VFR flight into IMC intentional</li><li><input type="checkbox"/> Flight into adverse weather intentional</li><li><input type="checkbox"/> Design stress limits of aircraft exceeded</li><li><input type="checkbox"/> Aircraft weight and balance</li></ul>
<p><b>Perceptual Errors</b> (Errors due to erroneous response to illusions. Occur when sensory input is degraded)</p> <ul style="list-style-type: none"><li><input type="checkbox"/> Misjudged distance/Descent</li><li><input type="checkbox"/> Misjudged altitude</li><li><input type="checkbox"/> Misjudged maneuver/procedure</li><li><input type="checkbox"/> Clearance not maintained</li><li><input type="checkbox"/> Spatial disorientation/vertigo</li><li><input type="checkbox"/> Visual illusion</li></ul>	

confronted with situations such as these, choice decision errors (Orasanu, 1993), or knowledge-based mistakes as they are otherwise known (Rasmussen, 1982), may occur. This is particularly true when there is insufficient experience, time, or other outside pressures that may preclude correct decisions. Put simply, sometimes individuals chose well, and sometimes they don't.

Finally, there are occasions when a problem is not well understood and formal procedures or response options are not available. It is during these ill-defined situations that the construction of a novel solution is required. In a sense, individuals find themselves where no one has been before, and in many ways, must "fly by the seats of their pants." Individuals placed in this situation must resort to slow and effortful reasoning processes where time is a luxury rarely afforded. Consequently, while this type of decision-making is more infrequent than other types, the relative proportion of errors committed is markedly higher.

**Skill-based Errors.** In contrast to decision errors, the second error form, skill-based errors, occur with little or no conscious thought. Just as little thought goes into turning one's steering wheel or shifting gears in an automobile, basic flight skills such as stick and rudder movements and visual scanning often occur without conscious thought. The difficulty with these seemingly automatic behaviors is that they are particularly susceptible to attention and/or memory failures. In fact, attention failures have been linked to many skill-based errors such as the breakdown in visual scan patterns, task fixation, and the inadvertent activation of controls. Consider, for example, a crew that becomes so fixated on trouble-shooting a burned out warning light that they fail to monitor their altimeter and end up flying into the ground. Perhaps a bit closer to home, consider the hapless soul who locks himself out of the car or misses his exit while driving because he was either distracted, in a hurry, or daydreaming. These are both examples of attention failures that commonly occur during highly automatized behavior. While at home or driving around town, these attention failures may be frustrating, but in the air they can be catastrophic.

In contrast, memory failures often appear as omitted items in a checklist, place losing, or forgotten intentions. For example, many of us have forgotten to replace the gas cap after refueling the family car or failed to put the coffee in the coffeepot before turning it on. Likewise, it is not difficult to imagine that when under the stress of an inflight emergency, for example, or after a long, fatiguing flight, critical steps in a procedure can be missed. Yet, even when not particularly stressed, individuals have forgotten to set the flaps on approach or lower the landing gear.

Even the manner (or skill) with which one flies an aircraft (aggressive, tentative, or controlled) can affect safety. For example, two pilots with identical training,

flight grades, and experience may differ significantly in the way they fly. That is, some pilots may fly smooth and effortlessly, while others are more forceful and rough on the flight controls. Both may be safe and equally proficient in the air; however, given certain scenarios, the techniques they employ could set them up for failure. Likewise, there are some pilots who are very safe in daytime VMC conditions, but put them in a situation where they are flying at night or IMC and their skill quickly degrades to unsafe levels. In the end, such techniques are as much a factor of innate ability and aptitude as they are an overt expression of one's personality, making efforts at the prevention and mitigation of technique errors particularly difficult.

**Perceptual Errors.** While, decision and skill-based errors have dominated most accident databases and have therefore been included in most error frameworks, perceptual errors have received comparatively less attention. No less important, perceptual errors occur when sensory input is degraded or "unusual," as is often the case when flying at night, in the weather, or in other visually impoverished environments. Faced with acting on imperfect information, aircrew run the risk of misjudging distances, altitude, and decent rates, as well as a responding incorrectly to a variety of visual/vestibular illusions.

It is important to note, however, that it is not the illusion or disorientation that is classified as a perceptual error. Rather, it is the pilot's erroneous response to the illusion or disorientation that is captured here. For example, many pilots have experienced spatial disorientation (often referred to as the "leans") when flying in IMC. In instances such as these, pilots are taught to rely on their primary instruments, rather than their senses when controlling the aircraft. Still, some pilots fail to monitor their instruments when flying in adverse weather or at night, choosing instead to fly using fallible cues from their senses. Tragically, many of these aircrew and others who have been fooled by illusions and other disorientating flight regimes have wound up on the wrong end of the accident investigation.

## Violations

By definition, errors occur while aircrews are behaving within the rules and regulations implemented by an organization and typically dominate most accident databases. In contrast, violations represent the willful disregard for the rules and regulations that govern safe flight and, fortunately, occur much less frequently (Shappell & Wiegmann, 1995).

**Routine Violations.** While there are many ways to distinguish between types of violations, two distinct forms have been identified, based on their etiology. The first, routine violations, tend to be habitual by nature and are often tolerated by the governing authority (Reason, 1990). Consider, for example, the individual who drives consistently

5-10 mph faster than allowed by law or someone who routinely flies in marginal weather when authorized for visual meteorological conditions only. While both certainly violate governing regulations, many drivers or pilots do the same thing. Furthermore, people who regularly drive 64 mph in a 55-mph zone, almost always drive 64 in a 55-mph zone. That is, they *routinely* violate the speed limit.

Often referred to as “bending the rules,” these violations are often tolerated and, in effect, sanctioned by authority (i.e., you’re not likely to get a traffic citation until you exceed the posted speed limit by more than 10 mph). If, however, local authorities started handing out traffic citations for exceeding the speed limit on the highway by 9 mph or less, then it is less likely that individuals would violate the rules. By definition then, if a routine violation is identified, investigators must look further up the causal chain to identify those individuals in authority who are not enforcing the rules.

**Exceptional Violations.** In contrast, exceptional violations appear as isolated departures from authority, not necessarily characteristic of an individual’s behavior nor condoned by management (Reason, 1990). For example, an isolated instance of driving 105 mph in a 55-mph zone is considered an exceptional violation. Likewise, flying under a bridge or engaging in other particularly dangerous and prohibited maneuvers would constitute an exceptional violation. However, it is important to note that, while most exceptional violations are indefensible, they are not considered exceptional because of their extreme nature. Rather, they are considered exceptional because they are neither typical of the individual nor condoned by authority. Unfortunately, the unexpected nature of exceptional violations make them particularly difficult to predict and problematic for organizations to deal with.

### **Preconditions for Unsafe Acts**

Simply focusing on unsafe acts, however, is like focusing on a patient’s symptoms without understanding the underlying disease state that caused them. As such, what makes Reason’s (1990) “Swiss cheese” model particularly useful in accident investigation, is that it encourages investigators to address the latent failures within the causal sequence of events as well as the more obvious, active failures described above. As their name suggests, latent failures, unlike their active counterparts, may lie dormant or undetected for hours, days, weeks, or even longer, until one day they adversely affect the unsuspecting aircrew. Historically, such latent failures have often been overlooked by investigators, largely because the so-called “holes in the cheese” that adversely affect aircrew performance have not been clearly defined. To remedy this, HFACS describes two major subdivisions within the precondi-

tions for unsafe acts: Substandard conditions of operators and the substandard practices they commit (Figure 1).

### **Substandard Conditions of the Operators**

**Adverse Mental States.** Being prepared mentally is critical in nearly every endeavor, perhaps more so in aviation. With this in mind, the first of three categories, adverse mental states, was created to account for those mental conditions that adversely affect performance (Table 2). Principal among these are the loss of situational awareness, mental fatigue, and pernicious attitudes like overconfidence and complacency, which negatively affect decisions and contribute to unsafe acts.

Consider, for example, the individual who is mentally fatigued or suffering the effects of sleep loss. The likelihood that an error will occur given these preconditions becomes more predictable. In a similar manner, overconfidence and other pernicious attitudes such as arrogance and impulsivity influence the likelihood that a violation will be committed. Clearly then, any framework of human error must account for these preexisting adverse mental states if a thorough understanding of the causal chain of events is to be realized.

**Adverse Physiological States.** The second category, adverse physiological states, refers to those medical or physiological conditions that interfere with safe operations (Table 2). Particularly important to aviation are such conditions as visual illusions and spatial disorientation as described earlier, as well as physical fatigue and the myriad of pharmacological and medical abnormalities known to affect performance.

While the adverse effects associated with visual illusions and spatial disorientation are well known among those in aviation circles, the effects of simply being ill on aircrew performance are less well known and often overlooked. Consider the pilot suffering from the common head cold. Unfortunately, most aviators view a head cold as only a minor inconvenience that can be easily remedied using over-the-counter antihistamines, acetaminophen, and other non-prescription medications. However, it is not the overt symptoms of the cold that flight surgeons are concerned with. Rather, it is the accompanying ear infection and the increased likelihood of spatial disorientation when entering IMC that is alarming — not to mention the side-effects of antihistamines, fatigue, and sleep loss on pilot decision-making.

**Physical/Mental Limitations.** The final class of substandard conditions involves individual physical/mental limitations (Table 2). Specifically, this category refers to those instances when mission requirements exceed the capabilities of the individual at the controls. For example, the human visual system is severely limited at

**Table 2.** A partial listing of the preconditions for unsafe acts.

<u>Substandard Conditions of Operators</u>	<u>Substandard Practices of Operators</u>
<p><b><i>Adverse Mental States</i></b> (Mental conditions that affect performance)</p> <ul style="list-style-type: none"><li><input type="checkbox"/> Impairment – alcohol/drugs</li><li><input type="checkbox"/> Fatigue: lack of sleep, flight schedule</li><li><input type="checkbox"/> Excessive workload</li><li><input type="checkbox"/> Overconfidence in personal abilities</li><li><input type="checkbox"/> Overconfidence in aircraft capabilities</li><li><input type="checkbox"/> Complacency</li><li><input type="checkbox"/> Diverted attention</li><li><input type="checkbox"/> Circadian dysrhythmia</li><li><input type="checkbox"/> Pressure induced by conditions/events</li></ul>	<p><b><i>Crew Resource Management</i></b> (Poor communication/coordination among personnel)</p> <ul style="list-style-type: none"><li><input type="checkbox"/> Preflight planning preparation inadequate</li><li><input type="checkbox"/> Aircraft preflight inadequate</li><li><input type="checkbox"/> Crew group coordination inadequate</li><li><input type="checkbox"/> Poor communication/coordination within and between aircraft, ATC, etc.</li><li><input type="checkbox"/> Failure of leadership</li></ul>
<p><b><i>Adverse Physiological States</i></b> (Medical/physiological conditions that preclude safe operations)</p> <ul style="list-style-type: none"><li><input type="checkbox"/> Spatial disorientation</li><li><input type="checkbox"/> Impairment due to illness</li><li><input type="checkbox"/> Incapacitation/loss of consciousness</li><li><input type="checkbox"/> Physical impairment</li><li><input type="checkbox"/> Hypoxia</li><li><input type="checkbox"/> Motion sickness</li><li><input type="checkbox"/> Illness</li></ul>	<p><b><i>Personal Readiness</i></b> (Failure to prepare mentally or physically for duty)</p> <ul style="list-style-type: none"><li><input type="checkbox"/> Failure to adhere to crew rest requirements</li><li><input type="checkbox"/> Self-medicating</li><li><input type="checkbox"/> Overexertion while off duty</li><li><input type="checkbox"/> Poor dietary practices</li><li><input type="checkbox"/> Failure to adhere to bottle-to-brief rules</li></ul>
<p><b><i>Physical/Mental Limitations</i></b> (Situation exceeds the capabilities of the operator)</p> <ul style="list-style-type: none"><li><input type="checkbox"/> Lack of recent/total instrument time</li><li><input type="checkbox"/> Visual look out not possible</li><li><input type="checkbox"/> Lack of recent/total experience</li><li><input type="checkbox"/> Physical impairment visual deficiency</li><li><input type="checkbox"/> Lack of familiarity with geographical area</li><li><input type="checkbox"/> Lack of familiarity with aircraft</li></ul>	

night; yet, when driving an automobile, many drivers do not necessarily slow down or take additional precautions. Likewise, in aviation, while slowing down is not necessarily an option, increasing one's vigilance for other aircraft or obstacles whose size or contrast interferes with their detection will often increase the safety margin.

Similarly, there are occasions when the time required to complete a task or maneuver exceeds an individual's capacity. That is, while good pilots are typically noted for their ability to react quickly and accurately, individuals vary widely in their ability to process and respond to information. Still, even given individual differences, if any operator or pilot is required to respond quickly (as is the case in many aviation emergencies), the probability of making an error will likely increase.

In addition to the basic sensory and information processing limitations described above, there are at least two

additional instances of physical/mental limitations that need to be addressed, albeit often overlooked by most safety professionals. These limitations involve individuals who simply are not compatible with aviation, because they are either physically unsuited or do not possess the aptitude to fly. For example, some individuals simply do not have the physical strength or dexterity to operate in the unique aviation environment, or for anthropometric reasons, simply have difficulty reaching the controls. In other words, cockpits have traditionally not been designed with all shapes, sizes, and physical abilities in mind.

Likewise, not everyone has the mental ability or aptitude for flying aircraft. Just as not all of us can be concert pianists or NFL linebackers, not everyone has the innate ability to pilot an aircraft – a vocation that requires the unique ability to make decisions quickly and respond accurately in life-threatening situations.

The difficult task for the safety professional is identifying whether physical abilities or aptitude might have contributed to the accident causal sequence.

### Substandard Practices of the Operator

Clearly, then, numerous substandard conditions of operators can, and do, lead to the commission of unsafe acts. Nevertheless, there are a number of things that individuals do to themselves that set up these substandard conditions. Generally speaking, the substandard practices of operators can be summed up in two categories: crew resource management and personal readiness.

**Crew Resource Management.** Good communication skills and team coordination have been the mantra of industrial/organizational and personnel psychologists for decades. As one might expect, crew resource management has been a cornerstone of many aviation safety programs as well (Helmreich & Foushee, 1993; Wiegmann & Shappell, 1999). As a result, the category of crew resource mismanagement was created to account for occurrences of poor coordination among personnel. Within the context of aviation, this includes coordination both within and between aircraft, with air traffic control personnel and maintenance control, as well as with facility and other support personnel as necessary. Likewise, good crew resource management includes coordination before and after the flight in the form of pre-flight briefings and debriefings as necessary.

**Personnel Readiness.** In aviation, or for that matter in any occupational setting, individuals are expected to show up for work ready to perform at optimal levels. However, in aviation as in other professions, individuals have been known to report for duty ill prepared, having violated crew rest requirements, bottle-to-brief rules, and rules associated with self-medicating. For example, when individuals violate crew rest requirements, they run the risk of mental fatigue and other adverse mental states that may ultimately lead to errors and accidents<sup>2</sup>.

Still, not all personal readiness failures occur because of violations of governing rules or regulations. For instance, running 10 miles before piloting an aircraft may not be against any existing regulations, yet it may impair the physical and mental capabilities of the individual enough to degrade performance and elicit unsafe acts. Likewise, the traditional “candy bar and coke” lunch of the modern businessman might be common but may not be sufficient to sustain performance in the often complex and demanding

environment of aviation. While there may be no rules governing such behavior, pilots must use good judgment when deciding whether they are ready and “fit” to fly.

## METHOD

### Data

General aviation accident data from calendar years 1990-98 was obtained from databases maintained by the NTSB and the FAA's National Aviation Safety Data Analysis Center (NASDAC). In total, 17,994 GA accidents were extracted for analysis. These so-called “GA” accidents actually included a variety of aircraft being flown under several different operating rules: 1) 14 CFR Part 91 – Civil aircraft other than moored balloons, kites, unmanned rockets, and unmanned free balloons; 2) 14 CFR Part 91F – Large and turbine-powered multiengine airplanes; 3) 14 CFR Part 103 – Ultralight vehicles; 4) 14 CFR Part 125 – Airplanes with seating capacity of 20 or more passengers or a maximum payload capacity of 6,000 pounds or more; 5) 14 CFR Part 133 – Rotorcraft external-load operations; 6) 14 CFR Part 137 – Agricultural aircraft operations. In addition, the database contained several accidents involving public use aircraft (i.e., law enforcement, state owned aircraft, etc.) and some midair accidents involving military aircraft. The distribution of each of these accident categories within the NTSB/NASDC databases is presented in Table 3.

Of the 17,994 accidents listed in Table 3, 157 investigations still remained incomplete at the time of this analysis and were eliminated from further consideration<sup>3</sup>. An additional 1,168 accidents were classified as due to undetermined causes and were also eliminated from the analysis. In addition, we were concerned with the apparent heterogeneity of the accident sample as depicted in Table 3 even though all of the accidents listed can be found within the NTSB under the heading of “general aviation.” However, we were only interested in those accidents involving aircraft operating under 14 CFR Part 91. After all, it is difficult to envision that large commercial aircraft being ferried from one airport to the next (operating under 14 CFR Part 91F) or aircraft being used to spread chemicals on a field (operating under 14 CFR Part 137) can be equated with small private aircraft being flown for personal or recreational purposes (operating under 14 CFR Part 91). This left us with 16,510 accidents in the database. Next, the accidents were examined for

---

<sup>2</sup>Note that violations that affect personal readiness are not considered “unsafe act, violations” since they typically do not happen in the cockpit, nor are they necessarily active failures with direct and immediate consequences.

<sup>3</sup>The NTSB classifies the results of accident investigations as either “preliminary” or “final” within their database. Only those designated as final by the NTSB as of May 30, 2002 were used in this study.

**Table 3.** Distribution of accidents using the NTSB and FAA NASDAC general aviation databases.<sup>1</sup>

Type of operation	Frequency
14 CFR Part 91	16,510
14 CFR Part 91F	8
14 CFR Part 103	11
14 CFR Part 125	2
14 CFR Part 133	124
14 CFR Part 137	1,288
Public Use	51
Totals	17,994

<sup>1</sup> Note that midair or other accidents involving multiple aircraft were counted only as a single accident although they appear in the NTSB and FAA NASDAC databases as multiple entries with a suffix of A, B, etc. denoting each aircraft involved.

aircrew-related causal factors. Again, we were only interested in those involving aircrew error, not those accidents that were purely mechanical in nature or those with other human involvement. This does not mean that mechanical failures or other sources of human error did not exist in the final database, only that some form of aircrew error was also involved in each of the accidents included in the final database. In the end, 14,086 accidents involving 31,491 aircrew causal factors were included and submitted to further analyses using the HFACS framework.

### Causal Factor Classification using HFACS

Five GA pilots were recruited from the Oklahoma City area as subject matter experts and received roughly 16 hours of training on the HFACS framework. All five were certified flight instructors with a minimum of 1,000 flight hours in GA aircraft (mean = 3,530 flight hours) as of June 1999 when the study began. After training, the five GA pilot-raters were randomly assigned accidents so at least two separate pilot-raters analyzed each accident independently. Using narrative and tabular data obtained from both the NTSB and the FAA NASDAC, the pilot-raters were instructed to classify each human causal factor using the HFACS framework. Note, however, that only those causal factors identified by the NTSB were classified. That is, the pilot-raters were instructed not to introduce additional casual factors that were not identified by the original investigation. To do so would be presumptuous and only infuse additional opinion, conjecture, and guesswork into the analysis process.

After our pilot-raters made their initial classifications of the human causal factors (i.e., skill-based error, decision-error, etc.), the two independent ratings were compared. Where disagreements existed, the corresponding pilot-raters were called into the laboratory to reconcile their differences and the consensus classification was included in the database for further analysis. Overall, pilot-raters agreed on the classification of causal factors within the HFACS framework more than 85% of the time (29,534 agreements; 4519 disagreements), an excellent level of agreement considering that this was, in effect, a decision-making task.<sup>4</sup>

### CFIT analysis

In addition to the analysis of human causal factors using HFACS, the five pilot-raters were instructed to independently classify each accident as CFIT or non-CFIT using the definition provided by the ICAO/CAST Common Taxonomy Team that defined CFIT as the “**in-flight collision with terrain, water, or obstacle without indication of a loss of control.**” Accompanying the definition were a series of usage notes that further defined the accident category. They included the following:

- CFIT is used only for accidents occurring during airborne phases of flight.
- CFIT includes collisions with those objects extending above the surface (for example: towers).
- CFIT can occur during either Instrument Meteorological Conditions (IMC) or Visual Meteorological Conditions (VMC).
- This category includes instances when the aircrew is affected by visual illusions (e.g., black hole approaches) that result in the aircraft being flown under control into terrain, water, or obstacles.
- If control of the aircraft is lost (induced by crew, weather, or equipment failure), do not use this category.
- Do not use this category for occurrences involving intentional flight into terrain (i.e., suicide).
- Do not use this category for occurrences involving runway undershoot/overshoot.

Finally, there was some concern that intrinsic differences between controlled flight into “terrain” (water or the ground) and controlled flight into “obstacles” (e.g., telephone wires, buildings, or other man-made structures) might exist. For this reason, pilot-raters were also instructed to differentiate CFIT accidents along this dimension as well.

<sup>4</sup> The measure of agreement was a combined analysis of all accidents coded under the NTSB classification of “general aviation” and therefore includes accidents other than 14 CFR Part 91 as described above. A breakout by 14 CFR Part 91 alone was not possible at this time but there is no reason to believe that the level of agreement would change appreciably.

## RESULTS

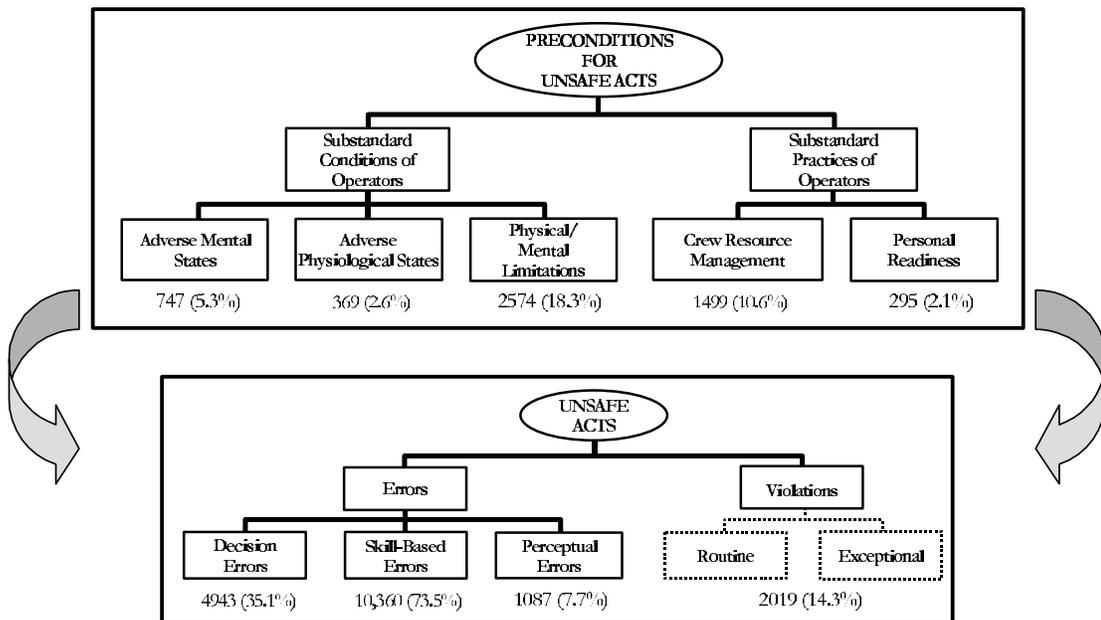
The GA data were initially examined to determine the extent to which each HFACS causal category contributed to GA accidents overall. To accomplish this, the frequency and percentage of GA accidents associated with each HFACS causal category were calculated. However, to avoid over-representation by any single accident, each causal category was counted a maximum of one time per accident. In this way, the count acted as an indicator of the presence or absence of a particular HFACS causal category for a given accident. The data were calculated in this manner with the knowledge that most aviation accidents are associated with multiple causal factors, including on some occasions, multiple instances of the same HFACS causal category (e.g., multiple decision errors may have been committed). However, only by analyzing the data in this way could a true representation of the percentage of accidents associated with each causal category be obtained.

The number and percentage of accidents associated with at least one instance of a particular HFACS causal category can be found in Figure 2, with one notable exception. As with post-hoc data examined in other venues (e.g., the U.S. Navy/Marine Corps, U.S. Army, U.S. Air Force, etc.), it proved too difficult to differentiate between routine and exceptional violations using narrative data from the NTSB and NASDAC. As a result, pilot-raters

were instructed to use the parent causal category of “violations,” rather than distinguish between the two types.

The overall analysis of 14 CFR Part 91 accidents revealed a picture of human error within GA that was not possible before the development of HFACS. For instance, the data indicate that skill-based errors (73.5% of the 14,086 GA accidents) were the most frequently cited unsafe act committed by aircrew, followed by decision errors (35.1%), violations (14.3%), and perceptual errors (7.7%). The finding that the unsafe acts of operators accounted for the majority of causal factors in the database was anticipated, given the emphasis of most investigations. However, the preconditions for unsafe acts were no less important. In fact, physical/mental limitations were among the most prevalent of all the HFACS causal categories cited, contributing to 18.3% of the accidents examined. The remaining preconditions for unsafe acts, in order of prevalence, were CRM failures (10.6%), adverse mental states (5.3%), adverse physiological states (2.6%), and personal readiness failures (2.1%).

The preceding analysis of the data represents a “quick look” at the human error issues facing GA. Yet, alone it provides little insight into the pattern of errors associated with any specific type of accident, like CFIT. The next step, therefore was to investigate what differences, if any, existed in the type and frequency of errors committed by aircrew involved in CFIT versus those observed in other



**Figure 2.** The number and percentage of GA accidents (N=14,086) associated with each HFACS causal category. (Note that percentages will not add up to 100% because each accident is typically associated with multiple causal factors across several causal categories.)

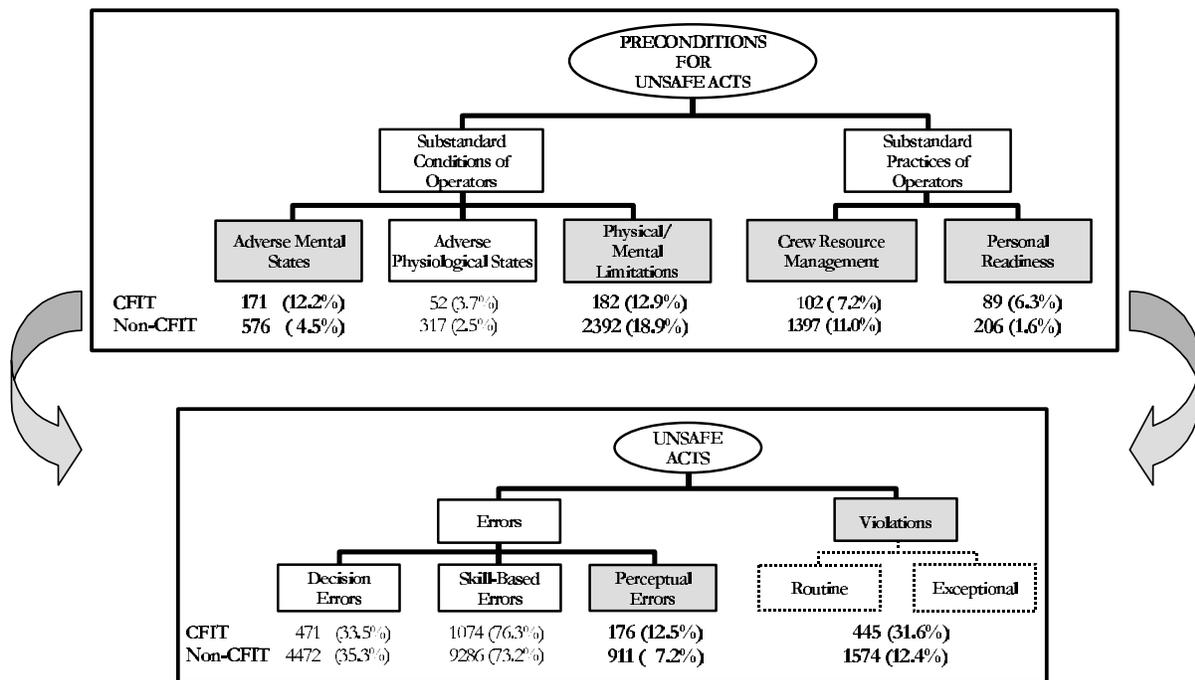
types of accidents. An examination of the GA accidents revealed that 1,407 (roughly 10 percent), of the 14,086 accidents were classified as CFIT by our pilot-raters using the criteria established by the CAST/ICAO Common Taxonomy Team. While the actual number and percentage of accidents associated with CFIT is a new and important finding in and of itself, the larger question was whether there were any differences in the pattern of errors associated with CFIT and the 12,679 non-CFIT accidents.

An inspection of Figure 3 reveals that the proportion of accidents associated with each HFACS causal category varied markedly between CFIT and non-CFIT accidents. The difficulty was in determining which differences, if any, were actually significant, and more importantly, which were meaningful. Traditionally, nonparametric statistics, like Chi-square, are used to measure the association between two nominal (indicator) variables. However, Chi-square, like many other non-parametric statistics, are fraught with problems where large data sets are involved. That is, as the sample size increases, the more likely it is to find significance where only small, perhaps trivial, differences actually exist.

One option is to use a measure of association that is not affected by sample size, like the odds ratio. Commonly

used in epidemiology, the odds ratio is typically used to measure the *degree* of the association between two variables or the ratio of the odds of suffering some particular fate given certain characteristics. Consider, for example, the odds of surviving an automobile accident with or without using a seatbelt<sup>5</sup>. If drivers suffer fatal injuries 20% of the time when they use their seatbelts, the odds of dying in a car accident while wearing a seatbelt are 0.25 (0.2 die with their seatbelt on / 0.8 survive with their seatbelt on). In contrast, 35% of drivers not wearing seatbelts die in automobile accidents, giving odds of 0.538 (0.35 die with their seatbelt off / 0.65 live with their seatbelt off). Thus, the odds ratio is 0.465 (0.25/ 0.538). In other words, you have a 0.465 times higher chance of dying in an automobile accident with your seatbelt on than without it. Arguably, this is hard to interpret, so with numbers of less than one we typically calculate the inverse of the odds ratio, which in this case equals 2.15 (1/0.465). This means that you would be 2.15 times more likely to die in an automobile accident if you did not wear your seatbelt than if you had worn it.

Another option is to dispense with traditional non-parametric statistics altogether, and compare the differences observed in the percentage data associated with



**Figure 3.** Number and percentage of CFIT and non-CFIT accidents associated with at least one instance of each particular causal category. Statistics associated with violations have been collapsed across the type of violation committed. Significant differences ( $p < .001$ ) are represented by shaded boxes.

<sup>5</sup> These data are hypothetical and for illustrative purposes only. They are not the official statistics of the NTSB or Bureau of Transportation Statistics.

each HFACS causal category for CFIT and non-CFIT accidents against some preset level considered “operationally relevant.” But, who is to say which differences are operationally relevant, and which are not? After all, is a difference between CFIT and non-CFIT accidents of five percentage points more operationally relevant than say three or four percent — or perhaps, one should use a larger percentage like 10 percent? In the end, the decision is subjective and often left to the researcher to defend.

Regardless of whether one uses traditional statistics or simply chooses an operationally relevant difference, there really is no right or wrong answer. Therefore, left without a clear-cut option, we chose to use the more objective approach of nonparametric statistics (Chi square and odds ratios) but with a considerably more conservative *p* value (*p*<.001) than is typically reported in other studies (*p*<.05 is generally regarded as acceptable within the psychological literature). Our intention was to capitalize on the objective power of statistics while minimizing the problems associated with potentially inconsequential findings.

Using this approach, the results of the Chi-square analysis are presented for each HFACS causal category in Table 4. Also included are the corresponding odds ratios with a 95% confidence interval as a measure of the relative risk of CFIT given a particular causal category. For illustrative purposes, the results of the analyses in Table 4 have been translated into Figure 3 by shading the corresponding HFACS causal categories where significant differences existed.

In some ways, the pattern of human error was similar for CFIT and non-CFIT accidents, as skill-based and decision errors were the most frequently cited causes of both. However, important differences did exist. For instance, almost one-third of all CFIT accidents were associated with violations of the rules compared with just over 12% for non-CFIT accidents, yielding an odds ratio of 3.264. Likewise, personal readiness failures (e.g., failing to obtain adequate rest, self medicating, etc.), arguably another type of violation only occurring external to the cockpit, were over four times more likely during CFIT accidents. Adverse mental states (odds ratio = 2.907) and perceptual errors (odds ratio = 1.847) were also more prevalent during CFIT than non-CFIT accidents. In contrast, physical/mental limitations (e.g., the inability to maintain control of the aircraft) and failures of crew resource management were more likely to occur during non-CFIT than CFIT accidents<sup>6</sup>.

### The Effect of Visual Conditions on CFIT

When discussing CFIT, many safety professionals have suggested that these accidents typically occur at night or in adverse weather when pilots simply may not be able to see their impending collision with the terrain or obstacles. However, it now appears that more of these accidents occur during VMC (n=867; 61.6%) than IMC (n=501; 35.6%)<sup>7</sup>, although the percentage that occurred in VMC was considerably less than that observed for non-CFIT

**Table 4.** Chi-square and odds ratio for CFIT for each HFACS causal category.

HFACS Causal Category	Chi-square		Odds Ratio	95% Confidence Interval		
				Lower	Upper	
Unsafe Acts of Operators						
Decision Errors	1.792	ns	0.923	0.822	1.038	ns
Skill-based Errors	6.229	ns	1.178	1.036	1.341	ns
Perceptual Errors	50.404	<i>p</i> <.001	1.847	1.555	2.193	<i>p</i> <.001
Violations	380.748	<i>p</i> <.001	3.264	2.883	3.695	<i>p</i> <.001
Substandard Conditions of Operators						
Adverse Mental States	146.069	<i>p</i> <.001	2.907	2.427	3.482	<i>p</i> <.001
Adverse Physiological States	7.097	ns	1.497	1.110	2.017	ns
Physical/Mental Limitations	29.826	<i>p</i> <.001	0.639	0.543	0.751	<i>p</i> <.001
Crew Resource Management	18.916	<i>p</i> <.001	0.631	0.512	0.778	<i>p</i> <.001
Personal Readiness	136.486	<i>p</i> <.001	4.089	3.168	5.276	<i>p</i> <.001

<sup>6</sup>When interpreting an odds ratio of less than 1, the inverse of the ratio is calculated. For example, the odds ratio associated with physical/mental limitations was 0.639, indicating that physical/mental limitations were 1/0.639, or roughly 1.5 times more likely to occur during non-CFIT than CFIT accidents.

<sup>7</sup>The weather conditions at the time of the accident were unknown for 39 (2.8%) CFIT accidents and 62 (0.5%) non-CFIT accidents, while the lighting conditions were unknown for two (0.1%) CFIT and four (0.003%) non-CFIT accidents. Weather and lighting combined were used to identify visual conditions (impaired versus clear). When the data were examined in this manner, visual conditions were completely unknown for 27 (1.9%) CFIT and 43 (0.3%) non-CFIT accidents. Percentages reported in the text and Figure 5 reflect these data.

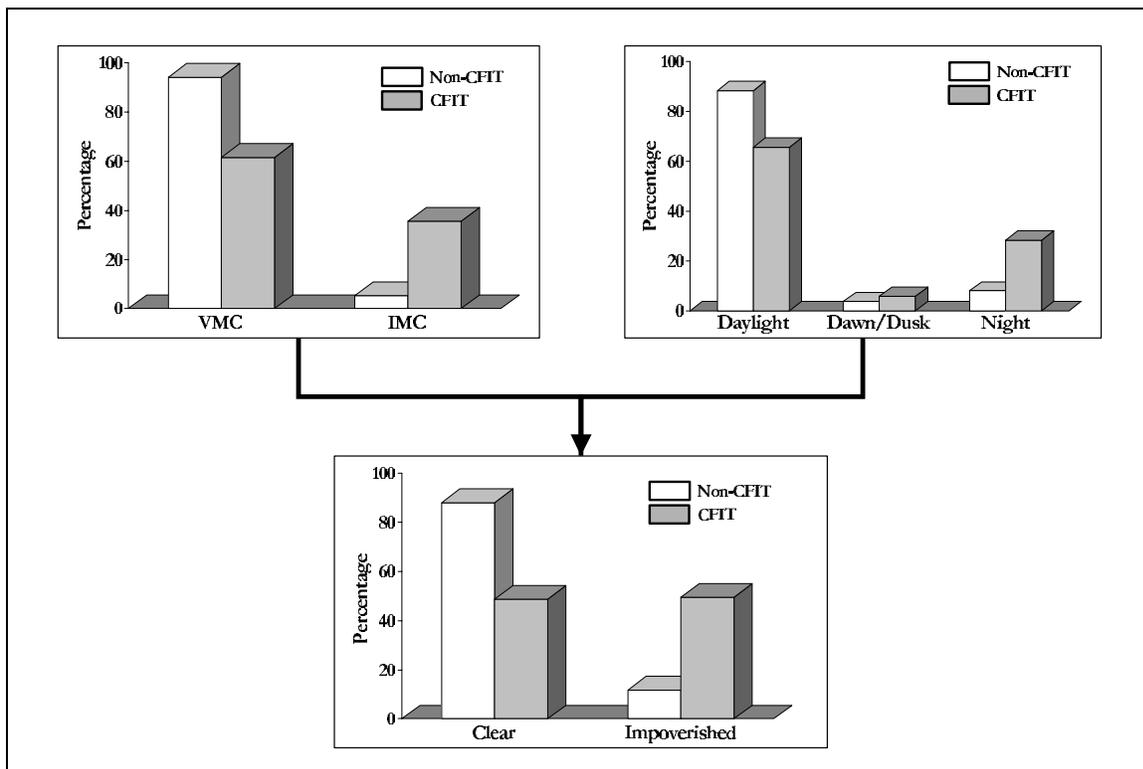
accidents (Figure 4, upper left). Furthermore, it appears that a greater percentage of CFIT accidents occur during the day (n=923; 65.6%) than at dawn or dusk (n=82; 5.8%) or even at night (n=400; 28.4%; Figure 4, upper right).

However, simply looking at lighting conditions without considering the weather, or vice-versa, really only presents part of the picture. Therefore, we combined the weather with the lighting information and examined the percentage of CFIT and non-CFIT accidents occurring during visually impoverished (i.e., accidents occurring either at night or in IMC) and clear daytime conditions. Yet, even when the data were examined in this way (Figure 4, lower panel), nearly as many CFIT accidents occurred in clear daytime conditions (n=685; 48.7%) as during visually impoverished conditions (n=695; 49.4%). While this finding might not have been predicted by those in the GA community, it was not unprecedented given the previous findings of Shappell and Wiegmann (1997a) using U.S. Navy/Marine Corps accident data. In contrast, considerably more non-CFIT accidents occurred in clear conditions.

Although there appears to be very little difference in the number of accidents that occurred during clear and visually impoverished conditions, the question remains whether the pattern of human error differed appreciably for the different visual conditions. Indeed, the data presented in Figure 5 suggest that in some ways the underlying

causes are intrinsically different. For instance, those CFIT accidents that occurred during visually impoverished conditions were more often associated with violations of the rules, adverse physiological states, physical/mental limitations, and poor crew resource management (Table 5). Perhaps not surprising, aircrew involved in a CFIT accident during visually impoverished conditions were well over six times more likely to have committed a violation of the rules. They were also five times more likely to have been affected by adverse physiological states (e.g., misjudging altitude and spatial disorientation) and more likely to mismanage their resources (e.g., failing to obtain an adequate preflight weather brief or update prior to departure). Indeed, one could almost envision a crew that fails to obtain a weather update prior to takeoff (crew resource management) and then encounters weather enroute. Then, after choosing to continue into IMC when VFR only (violation), they end up misjudging their altitude (adverse physiological state) and collide with the terrain.

In contrast to visually impoverished conditions, trying to understand why a pilot would collide with terrain in clear daytime conditions is somewhat more puzzling. However, the odds ratio data may provide a clue. It appears that pilots involved with CFIT in clear daytime conditions are well over two times more likely ( $1/0.436 = 2.29$ ) to have committed a skill-based



**Figure 4.** The percentage of CFIT and non-CFIT GA accidents that occurred during selected weather (upper left), lighting (upper right), and visual conditions (lower).

error than those involved in other types of accidents. Given that skill-based behavior is often the result of inattention and simple stick-and-rudder skills, perhaps they were either not proficient or simply preoccupied with other things. In either event, the human errors associated with CFIT in clear and visually impoverished conditions are fundamentally different with regard to the types of human error more often associated with it.

### Collision With “Terrain/water” Versus Collision With “Obstacles”

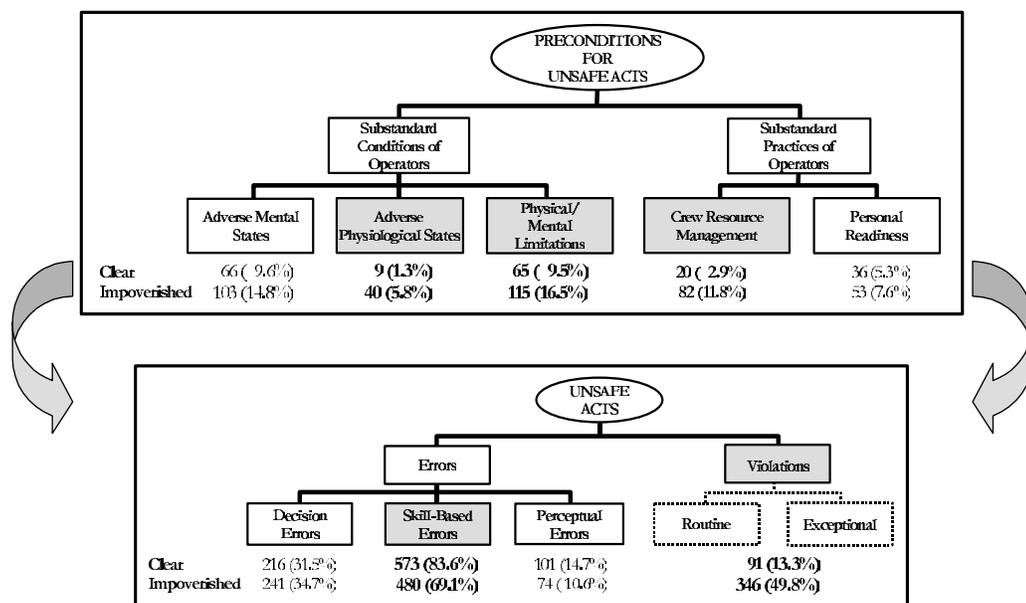
There was some concern that a definition of CFIT that equates collision with terrain/water with collision with obstacles might be akin to “comparing apples and oranges,” at least from a human factors perspective. To address this concern, we examined the pattern of human errors associated with collision with terrain/water (n=826) and that with obstacles (n=581). An inspection of Figure 6 revealed very few differences between the two types of CFIT, including no differences among the preconditions for unsafe acts. In fact, the only differences were among skill-based and perceptual errors (Table 6). Specifically, skill-based errors were nearly two times more likely (odds ratio = 1.759) when the collision was with the terrain/water. In contrast, collision with obstacles was more often associated with perceptual errors (odds ratio = 1/0.574 or 1.74).

## DISCUSSION

Accidents and the tragic loss of life that often accompany them have confronted aviation since the first flights of the Wright Brothers. Still, when a healthy pilot flies a perfectly good aircraft into the ground, the pundits grow eerily quiet. Of all the ways one can crash an aircraft, controlled flight into terrain (CFIT) is arguably the hardest to explain and therefore begs the question, “*Why would an experienced aviator fly a perfectly good aircraft into the ground?*” (Shappell & Wiegmann, 1995, 1997a)?

Historically, several explanations for CFIT have been offered such as the loss of visual cues at night or during IMC, inattention or distraction during periods of high workload, or simply poor aviation skills. In response, civilian and military organizations have instituted more conservative altitude restrictions, provided additional safety awareness training, and employed the use of altitude and ground proximity warning systems (GPWS).

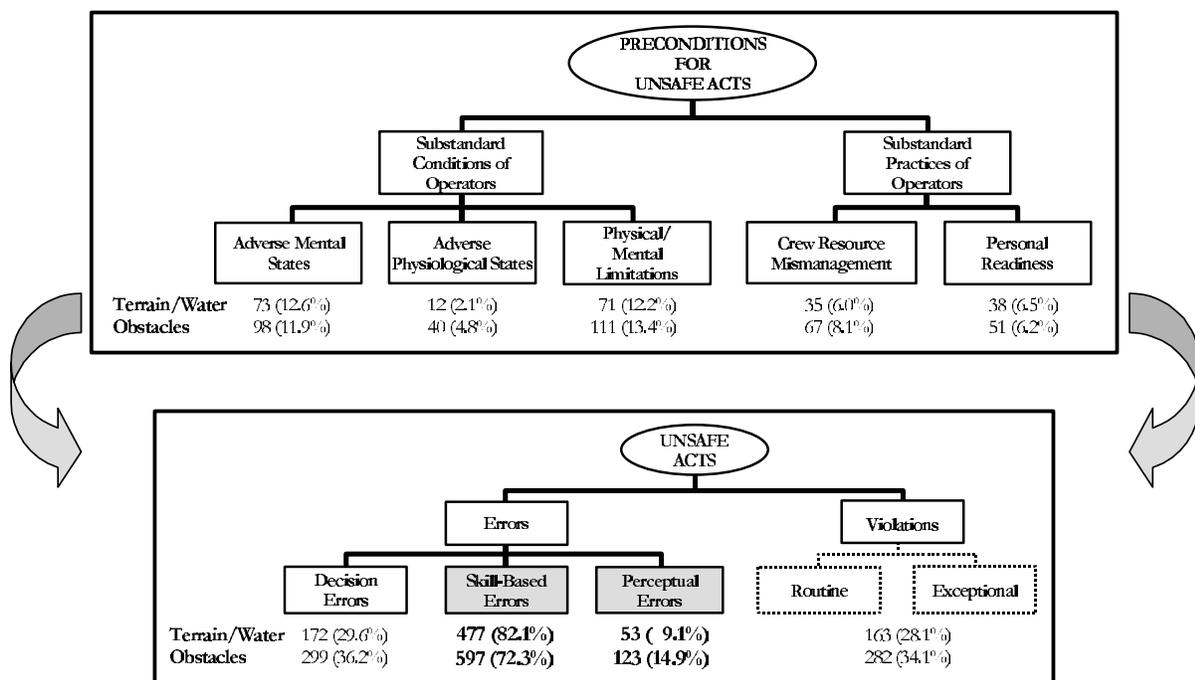
Undeniably, these intervention strategies have helped save many lives by either requiring aircrews to maintain greater separation from hazardous terrain or by alerting flight crews to an impending collision with the terrain. However, their utility in the realm of general aviation varies dramatically from that of their military or commercial aviation counterparts. For instance, most GA enthusiasts



**Figure 5.** Percentage of CFIT accidents occurring in clear versus visually impoverished conditions associated with at least one instance of each particular causal category. Statistics associated with violations have been collapsed across type of violation committed. Significant differences ( $p < .001$ ) are represented by shaded boxes.

**Table 5.** Chi-square and odds ratio for CFIT occurring during clear versus visually impoverished conditions for each HFACS causal category.

HFACS Causal Category	Chi-square		Odds Ratio	95% Confidence Interval		
<b>Unsafe Acts of Operators</b>						
Decision Errors	1.539	ns	1.153	0.921	1.443	ns
Skill-based Errors	40.587	p<.001	0.436	0.337	0.565	p<.001
Perceptual Errors	5.230	ns	0.689	0.500	0.949	ns
Violations	212.391	p<.001	6.471	4.960	8.444	p<.001
<b>Substandard Conditions of Operators</b>						
Adverse Mental States	8.631	ns	1.632	1.174	2.267	ns
Adverse Physiological States	19.872	p<.001	4.587	2.208	9.528	p<.001
Physical/Mental Limitations	15.151	p<.001	1.891	1.367	2.616	p<.001
Crew Resource Management	39.732	p<.001	4.448	2.695	7.340	p<.001
Personal Readiness	3.213	ns	1.488	0.961	2.304	ns



**Figure 6.** Percentage of collisions with obstacles versus terrain/water associated with the specific unsafe acts of aircrew.

**Table 6.** Chi-square and odds ratio for type of CFIT for each HFACS causal category.

HFACS Causal Category	Chi-square		Odds Ratio	95% Confidence Interval		
				Upper	Lower	
Unsafe Acts of Operators						
Decision Errors	6.660	ns	0.741	0.931	0.590	ns
Skill-based Errors	18.221	.001	1.759	2.284	1.355	.001
Perceptual Errors	10.372	.001	0.574	0.807	0.408	.001
Violations	5.841	ns	0.752	0.948	0.597	ns
Substandard Conditions of Operators						
Adverse Mental States	0.157	ns	1.067	1.475	0.772	ns
Adverse Physiological States	7.391	ns	0.414	0.797	0.215	ns
Physical/Mental Limitations	0.449	ns	0.897	1.233	0.652	ns
Crew Resource Management	2.210	ns	0.726	1.109	0.476	ns
Personal Readiness	0.077	ns	1.063	1.642	0.689	ns

do not have the monetary resources of the military or commercial sector, making many new technologies such as GPWS difficult to afford. Simply enforcing existing Federal Air Regulations is likely not the answer either. After all, there are more GA aircraft in the U.S. than there are military and commercial aircraft combined; not to mention, many of these GA aircraft fly in unrestricted airspace, making enforcement a difficult prospect, indeed. So, if the availability of terrain warnings or the enforcement of more conservative altitude restrictions alone are not likely to have a significant affect on GA CFIT, what is the answer?

A major step in addressing this challenge was taken by the GA CFIT JSAT and JSIT. In their final report to the Joint Steering Committee, the CFIT JSAT identified 55 intervention strategies, finally settling on a “top 10” that were submitted to the CFIT JSIT. The primary goal of the CFIT JSIT was to develop an implementation strategy that identified the resources, responsible parties, milestones for implementing the interventions, as well as metrics for tracking their success. In the end, the CFIT JSIT produced a detailed and prioritized implementation plan<sup>8</sup> with the following components:

1. **Streamline equipment installation.** Terrain avoidance and other equipment have been available for some time within military and commercial aviation. However, for many GA pilots, such technology is out of reach due to cost concerns and the simple fact that in many cases new technology in use within military and commercial aviation has not been modified for GA aircraft. Given “low cost” displays that enhance terrain awareness and reduce pilot workload are being developed, perhaps the process for certifying the new

technology can be streamlined within the FAA.

2. **Enhance pilot training for CFIT awareness and prevention.** Specifically, the JSIT recommended that Practical Test Standards, Knowledge Tests, and other training materials be modified to include knowledge of how CFIT occurs and how to prevent it.
3. **Establish a General Aviation Safety Council.** The idea was to establish a council of safety experts from the government (FAA, NTSB, and NASA) and industry to act as a vehicle for launching safety-related programs and distributing information to the GA community in a more expeditious and efficient manner.
4. **Increase pilot awareness on CFIT accident causes.** The JSIT proposed establishing a Web page on the FAA’s Internet site that would increase pilot awareness of the causes of CFIT and relay first-person accounts of “near-CFIT” accidents. Also included here was a recommendation for the NTSB to begin classifying accidents as CFIT or non-CFIT within their accident reports to track trends in the data and facilitate future analyses.
5. **Develop education, awareness, and training modules for CFIT prevention.** This area focuses on the development of several training modules centered about CFIT awareness and risk-taking behavior similar to the widely disseminated personal minimums checklist.
6. **Standardize and expand requirements for enhancing the visibility and detection of wires, support structures, and towers.** Surprisingly, there are no standardized criteria for the marking of obstacles or hazards. Therefore, it was proposed that a national standard for marking wires and towers be developed, as well as

<sup>8</sup>For a more thorough discussion of each of these components, see Federal Aviation Administration (2000). General aviation controlled flight into terrain Joint Safety Implementation Team: Final Report.

a passive (e.g., visual markings) and active (e.g., avionics equipment capable of sensing obstacles) means of detecting wires, towers and other obstacles.

7. **Develop routes for GPS waypoints for mountain passes.** While somewhat controversial, it was recommended that with the advent of GPS, that waypoints for safely flying through mountain passes could be made available. Some have argued, though, that this would only convey a false sense of ease to pilots attempting the complex and often demanding task of traversing through high-altitude mountain passes.
8. **Enhance digital user access terminals (DUATS) to provide density altitude advisories.** In particular, pilots would receive a density altitude advisory at both the departure and destination airports, as well as areas along their intended route.

Given the scope and detail of the analyses conducted in this study using the HFACS framework with a considerably larger pool of accidents, it seemed reasonable to examine which of the interventions identified by the CFIT JSAT and JSIT would address the human error associated with CFIT. Recall that, in the analysis of all GA accidents occurring between 1990-98, skill-based errors were associated with nearly 3/4 of all the accidents, regardless of whether they were CFIT or not. Skill-based errors were followed by decision errors (35.1%), physical/mental limitations (18.3%), and violations of the rules (14.3%). It should come as no surprise then, that skill-based errors (76.3%) and decision errors (33.5%) were also the most frequently cited form of human errors associated with CFIT accidents as well. More interesting, however, were those human errors that differentiated CFIT from non-CFIT accidents. For instance, while violations and perceptual errors contributed to only 12.4% and 7.2% of the non-CFIT accidents, respectively, they contributed to 31.6% (violations) and 12.5% (perceptual errors) of CFIT accidents. Likewise, adverse mental states and personal readiness failures were more likely to occur during CFIT than non-CFIT accidents. In fact, CFIT accidents were over four times more likely to involve a personal readiness failure and three times more likely to involve at least one violation of the rules.

So, how do these findings reconcile with the interventions and implementation plan proposed by the CFIT JSAT and JSIT? First, it is hard to overlook the fact that three out of four CFIT and non-CFIT accidents were associated with skill-based errors, even though there were no real differences between the two. Certainly then, improving basic flight skills through improved primary flight and recurrent training would likely have an impact on all types of accidents, including CFIT. But, in many instances, skill-based errors are that last

fatal flaw before impacting the ground – particularly among CFIT accidents. The real culprit in CFIT typically lies farther upstream in the causal chain of events among areas like violations of the rules, perceptual errors, adverse mental states, and personal readiness failures.

An examination of the CFIT JSIT's implementation plan reveals that many of the recommendations map very well onto these four human error causal categories. For instance, it is quite likely that simply by increasing a pilot's awareness of the hazards of excessive risk-taking and other causes of CFIT (numbers 2, 4, and 5 above) we can begin to reduce the number of violations and personal readiness failures committed by GA pilots. Perhaps this is where the establishment of a General Aviation Safety Council could help as well by organizing the distribution of training and informational materials directed at improving pilot awareness of the issues surrounding CFIT. Indeed, if we could somehow convince GA pilots that they are four times more likely to die if they continue into IMC when they are rated for VFR flight only, a significant reduction in the number of fatal accidents might be realized (Shappell & Wiegmann, 2002). Perhaps then, they might think twice before taking the chance of having an accident. In much the same way, we can provide actual data, rather than anecdotes and opinions, regarding the hazards of flying without adequate rest or when tired and fatigued. Indeed, while an individual GA pilots may ignore anecdotes as rare events that only happen to the other guy, the statistics may convince them otherwise.

Consistent with previous work in the area (Jensen & Benel, 1977; Hunter, 2002; O'Hare, 1990), the data presented here suggest that any training aimed at the reduction of CFIT should also focus on adverse mental states like overconfidence, self-induced pressure, and a variety of other hazardous attitudes – particularly when adverse mental states were nearly three times more likely to be associated with CFIT than non-CFIT accidents. Furthermore, because violations and personal readiness failures are often associated with adverse mental states, one would expect that many of the same interventions would be effective in combating adverse mental states as well. Consider, for example, the pilot who first learns to fly. It's very unlikely that a pilot with less than 100 hours total flight time would press through the weather or try flying through a mountain pass. But give that same pilot three or four hundred hours in the aircraft and the confidence will build to a point where they might be more likely to take risks not previously considered. The difficulty is teasing apart skill from overconfidence, because as skill improves overconfidence will likely increase as well. The unfortunate thing is that a pilot's overconfidence may lead them into a situation that their current skill set cannot get them out of. Now, if we could somehow

control that pilot's overconfidence either through enhanced training or increased awareness of the hazards associated with excessive risk taking (see numbers 2, 4, and 5 above) then maybe we can reduce the number of violations and personal readiness failures committed by GA pilots. Ultimately, this would have the effect of driving down the number of CFIT accidents in general aviation.

So, how will the interventions developed by the CFIT JSAT affect those CFIT accidents associated with perceptual errors and adverse mental states? Arguably, the small percentage of CFIT accidents associated with these two error forms was unexpected. After all, in many corners, CFIT has often been attributed to spatial disorientation and visual illusions that occur during visually impoverished environments such as those experienced during IMC or at night. Nevertheless, only 12.5% of the CFIT accidents examined occurred as the result of perceptual errors. In fact, our analyses revealed that nearly as many CFIT accidents occurred during daytime VMC as did those occurring in visually impoverished conditions (i.e., during IMC or at night). It is unclear then, to what extent using technology such as a GPWS or other terrain avoidance technology (number 1, above) would help. While it can be reasonably argued that terrain displays and other warning systems would address some of the problems associated with spatial disorientation at night or in the weather, there were only 74 (10.6%) CFIT accidents in which a perceptual error was committed in visually impoverished conditions. Another 101 or 14.7% of the perceptual errors occurred during broad daylight where presumably the errors were simply misjudging airspeed and altitude or simply not seeing obstacles due to inherent limitations in the visual system. What may help in these instances would be the use of high visibility paint and other enhancing features on obstructions (number 6, above) combined with improved visual scan and safety awareness. Nevertheless, the development of a low-cost terrain clearance or "look ahead" device (number 1, above) may be worth examining.

It should also be noted that, although crew resource management failures were infrequent, when they were associated with CFIT accidents they were more than four times more likely to occur during visually impoverished conditions than during daytime VMC. Upon closer inspection, these failures were often the result of GA pilots not taking advantage of all the resources at their disposal prior to departing or while en route rather than the traditional crew resource management failures associated with communication among multi-place crews. Indeed, many of these failures were the result of not getting an adequate weather update prior to departing or in the air. While none of the CFIT JSIT's eight areas specifically deal with this particular issue (albeit, number 8 above, does address the need to provide density altitude infor-

mation), it would not be difficult to emphasize the need for frequent weather updates and encourage the use of Flight Service Stations while en route within the training recommended to address CFIT. Indeed, the CFIT JSAT did include improving the quality and substance of weather briefs in their "top-10" list of interventions, but it did not make the final list published by the CFIT JSIT. Perhaps if they had the information presented here, it might have been included in the final report.

Finally, the CFIT JSAT recommended the development of mountain flying advisory materials. While on the surface this makes sense (i.e., the perception that pilots are simply flying into mountains), not all CFIT occur in mountainous terrain. For that matter, a number of accidents are not even controlled flight into "terrain" in the classical sense. That is, 581 (41%) were actually controlled flight into "obstacles." Arguably, there were very few differences in the pattern of human error associated with each, with the noted exception of skill-based errors that were more likely during collision with terrain/water and perceptual errors that were more likely during collision with obstacles (presumably because the pilot could not perceive them). In both cases, however, the odds ratios were not large (i.e., they were less than 2). Perhaps the plan to develop routes for GPS waypoints for mountain passes (number 7, above) was driven more by the sample of accidents the CFIT JSAT examined, since roughly 50% of those occurred in the mountains. Certainly, if that were to be true for our larger sample of 1407 CFIT accidents, it would warrant the emphasis the CFIT JSAT and JSIT placed on it by including the development of routes for GPS waypoints in mountain passes. Unfortunately, that data have yet to be examined fully.

## CONCLUSIONS

Regardless of how one examines the data, using root cause analysis or a human error framework like HFACS, no single intervention will eliminate GA CFIT accidents. What is needed is a strategy that combines several interventions into a concerted effort. More important, a means to track intervention strategies is required to assess the viability of each recommended intervention on specific error forms – a proven quality of the HFACS framework.

It appears from our analysis that many, if not all, of the interventions developed by the CFIT JSAT and the accompanying implementation plan proposed by the CFIT JSIT will address many of the human error causal factors associated with GA CFIT accidents. If nothing else, this analysis provides further validation of the efforts of the two teams. Beyond simple validation, however, HFACS provides a means to track specific types of human error. What the CFIT JSAT and JSIT were unable to provide

is a listing of the specific types of human error committed by aircrew involved in CFIT. This analysis provides a benchmark of sorts that will enable the FAA and other safety organizations to track the effectiveness of these interventions on very specific error forms. If for instance, we do not see a significant trend downward in the number and percentage of CFIT accidents attributable to violations and personal readiness failures, we can re-evaluate the effectiveness of the targeted intervention and modify it as needed. Better yet, rather than rely on an overall accident rate that is affected by a variety of things other than the specific interventions put in place to address CFIT, we can now focus specifically on CFIT accidents and those human errors most prevalent within the causal chain of events.

In summary, the analysis presented here represents a first look at the human error associated with GA CFIT accidents and is not the final word. While it does validate the findings of the GA CFIT JSAT and JSIT, it provides much more. In a sense, it puts a face on human error, particularly human error associated with CFIT that we simply did not have prior to the HFACS analysis. Now that we know what it looks like, we are in a better position to find it and cut it off at its roots.

## REFERENCES

- Bird, F. (1974). *Management guide to loss control*. Atlanta, GA: Institute Press.
- Boeing (2000). *Statistical summary of commercial jet airplane accidents: Worldwide operations 1959-1999*. [On-line]. Available: [www.boeing.com/news/techissues/pdf/1999\\_statsum.pdf](http://www.boeing.com/news/techissues/pdf/1999_statsum.pdf).
- Federal Aviation Administration (2000). *General aviation controlled flight into terrain Joint Safety Implementation Team: Final Report*.
- Heinrich, H., Petersen, D., & Roos, N. (1931). *Industrial accident prevention: A safety management approach* (1<sup>st</sup> ed.). New York: McGraw-Hill.
- Helmreich, R.L., & Foushee, H.C. (1993). Why crew resource management? Empirical and theoretical bases of human factors training in aviation. In E. L. Wiener, B. G. Kanki, & R. L. Helmreich (Eds.), *Cockpit resource management* (pp. 3-45). San Diego: Academic Press.
- Hunter, D. (2002). *Risk perception and risk tolerance in aircraft pilots*. (DOT/FAA/AM-02/17). Washington, DC: Federal Aviation Administration, Office of Aerospace Medicine<sup>9</sup>.
- Jensen, R. & Benel, R. (1977). *Judgement evaluation and instruction in civil pilot training*. (NTIS No. AD-A057-440). Washington, DC: Federal Aviation Administration.
- National Transportation Safety Board. *Aviation accident statistics (2001)*. [On-line]. Available: [www.nts.gov/aviation/stats.htm](http://www.nts.gov/aviation/stats.htm).
- O'Hare, D. (1990). Pilots' perception of risks and hazards in general aviation. *Aviation, Space, and Environmental Medicine*, 61(7), 599-603.
- Orasanu, J.M. (1993). Decision-making in the cockpit. In E. L. Wiener, B. G. Kanki, and R. L. Helmreich (Eds.), *Cockpit resource management* (pp. 137-72). San Diego: Academic Press.
- Rasmussen, J. (1982). Human errors: A taxonomy for describing human malfunction in industrial installations. *Journal of Occupational Accidents*, 4, 311-33.
- Reason, J. (1990). *Human Error*. New York: Cambridge University Press.
- Shappell, S. & Wiegmann, D. (1995). Controlled flight into terrain: The utility of models of information processing and human error in aviation safety. *Proceedings of the Eighth Symposium on Aviation Psychology, Columbus, OH, Vol. 2*, 1300-6.
- Shappell, S. & Wiegmann, D. (1997a). Why would an experienced aviator fly a perfectly good aircraft into the ground? *Proceedings of the Ninth Symposium on Aviation Psychology, Columbus, OH, Vol. 1*, 26-32.
- Shappell, S. & Wiegmann, D. (1997b). A human error approach to accident investigation: the taxonomy of unsafe operations. *The International Journal of Aviation Psychology*, 7, 269-91.
- Shappell, S. & Wiegmann, D. (2000a). *The Human Factors Analysis and Classification System (HFACS)*. (DOT/FAA/AM-00/7). Washington, DC: Federal Aviation Administration, Office of Aviation Medicine<sup>9</sup>.
- Shappell, S., Wiegmann, D., Fraser, J., Kinsey, P. & Reddix, M. (2000b). Tracking aircrew error trends in naval aviation mishaps using HFACS [Abstract]. *Aviation, Space, and Environmental Medicine*, 71(3), 328.

<sup>9</sup>All Office of Aerospace Medicine technical reports are available in full-text from the Civil Aerospace Medical Institute's publication Web site: [http://www.cami.jcabi.gov/aam-400A/Abstracts/Tech\\_Rep.htm](http://www.cami.jcabi.gov/aam-400A/Abstracts/Tech_Rep.htm).

- Shappell, S. & Wiegmann, D. (2001a). Applying reason: the human factors analysis and classification system (HFACS). *Human Factors and Aerospace Safety*, 1(1), 59-86.
- Shappell, S. & Wiegmann, D. (2001b). Unraveling the mystery of general aviation controlled flight into terrain accidents using HFACS. *Proceedings of the Eleventh Symposium on Aviation Psychology, Columbus, OH*, 1-6.
- Shappell, S.A., & Wiegmann, D.A. (2002). HFACS analysis of general aviation data 1990-98: Implications for training and safety [Abstract]. *Aviation, Space, and Environmental Medicine*, 73(3), 297.
- U.S. Department of Transportation, Volpe National Transportation Systems Center. (1997). General aviation accidents, 1983-1994; Identification of factors related to controlled flight into terrain (CFIT) accidents. Cambridge, MA.
- Wiegmann, D.A. & Shappell, S.A. (1999). Human error and crew resource management failures in naval aviation mishaps: A review of U.S. Naval Safety Center data, 1990-96. *Aviation, Space, and Environmental Medicine*, 70(12), 1147-51.

