DOT/FAA/AM-05/24
Office of Aerospace Medicine
Washington, DC 20591

Human Error and General Aviation Accidents: A Comprehensive, Fine-Grained Analysis Using HFACS

Douglas Wiegmann
Troy Faaborg
University of Illinois
Institute of Aviation
Savoy, IL 61874

Albert Boquet
Cristy Detwiler
Kali Holcomb
Scott Shappell
Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

December 2005

Final Report

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/AM-05/24	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Human Error and General Aviation Accidents: A Comprehensive, Fine-Grained Analysis Using HFACS		5. Report Date December 2005 6. Performing Organization Code
7. Author(s) Wiegmann D,[1] Faaborg T,[1] Boquet A,[2] Detwiler C,[2] Holcomb K,[2] Shappell S[2]		8. Performing Organization Report No.
9. Performing Organization Name and Address [1]University of Illinois Institute of Aviation Savoy, IL 61874	[2]FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency name and Address Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, DC 20591		13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplemental Notes

Work was accomplished under approved task AM-B-05-HRR-521.

16. Abstract

The Human Factors Analysis and Classification System (HFACS) is a theoretically based tool for investigating and analyzing human error associated with accidents and incidents. Previous research performed at both the University of Illinois and the Civil Aerospace Medical Institute has successfully shown that HFACS can be reliably used to analyze the underlying human causes of both commercial and general aviation (GA) accidents. These analyses have helped identify general trends in the types of human factors issues and aircrew errors that have contributed to civil aviation accidents. The next step was to identify the exact nature of the human errors identified. The purpose of this research effort therefore, was to address these questions by performing a fine-grained HFACS analysis of the individual human causal factors associated with GA accidents and to assist in the generation of intervention programs. This report details those findings and offers an approach for developing interventions to address them.

17. Key Words HFACS, Human Error, General Aviation, Aviation Accidents		18. Distribution Statement Document is available to the public through the Defense Technical Information Center, Ft. Belvior, VA 22060; and the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 22	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

HUMAN ERROR AND GENERAL AVIATION ACCIDENTS: A COMPREHENSIVE, FINE-GRAINED ANALYSIS USING HFACS

INTRODUCTION

It is generally accepted that like most accidents, those in aviation do not happen in isolation. Rather, they are the result of a chain of events often culminating with the unsafe acts of aircrew. Indeed, from Heinrich's (Heinrich, Peterson, & Roos, 1931) axioms of industrial safety, to Bird's (1974) "Domino theory" and Reason's (1990) "Swiss cheese" model of human error, a sequential theory of accident causation has been consistently embraced by most in the field of human error (Wiegmann & Shappell, 2001c). Particularly useful in this regard has been Reason's (1990) description of active and latent failures within the context of his "Swiss cheese" model of human error.

In his model, Reason describes four levels of human failure, each one influencing the next. To hear Reason and others describe it, *organizational influences* often lead to instances of *unsafe supervision* which in turn lead to *preconditions for unsafe acts* and ultimately the *unsafe acts of operators*. It is at this latter level, the unsafe acts of operators, that most accident investigations are focused upon.

Unfortunately, while Reason's seminal work forever changed the way aviation and other accident investigators view human error, it was largely theoretical and did not provide the level of detail necessary to apply it in the real world. It wasn't until Shappell and Wiegmann (2000, 2001) developed a comprehensive human error framework — the Human Factors Analysis and Classification System (HFACS) — that Reason's ideas were folded into the applied setting.

HFACS

The entire HFACS framework includes a total of 19 causal categories within Reason's (1990) four levels of human failure (Figure 1). While in many ways, all of the causal categories are equally important; particularly germane to any examination of GA accident data are the unsafe acts of aircrew. For that reason, we have elected to restrict this analysis to only those causal categories associated with the unsafe acts of GA aircrew. A complete description of all 19 HFACS causal categories is available elsewhere (i.e., Wiegmann & Shappell, 2003).

Unsafe Acts of Operators

In general, the unsafe acts of operators (in the case of aviation, the aircrew) can be loosely classified as either errors or violations (Reason, 1990). Errors represent the mental or physical activities of individuals that fail to achieve their intended outcome. Not surprising, given the fact that human beings, by their very nature, make errors, these unsafe acts dominate most accident databases. Violations, on the other hand, are much less common and refer to the willful disregard for the rules and regulations that govern the safety of flight.

Errors

Within HFACS, the category of errors was expanded to include three basic error types (decision, skill-based, and perceptual errors).

Decision Errors. Decision-making and decision errors have been studied, debated, and reported extensively in the literature. In general, however, decision errors can be grouped into one of three categories: procedural errors, poor choices, and problem-solving errors. Procedural decision errors (Orasanu, 1993) or rule-based mistakes, as referred to by Rasmussen (1982), occur during highly structured tasks of the sorts, if X, then do Y. Aviation is highly structured, and consequently, much of pilot decision-making is procedural. That is, there are very explicit procedures to be performed at virtually all phases of flight. Unfortunately, these procedures are occasionally misapplied or inappropriate for the circumstances, often culminating in an accident.

However, even in aviation, not all situations have corresponding procedures to manage them. Therefore, many situations require that a choice be made among multiple response options. This is particularly true when insufficient experience, time, or other outside pressures may preclude a correct decision. Put simply, sometimes we chose well, and sometimes we do not. The resultant choice decision errors (Orasanu, 1993) or knowledge-based mistakes (Rasmussen, 1982) have been of particular interest to aviation psychologists over the last several decades.

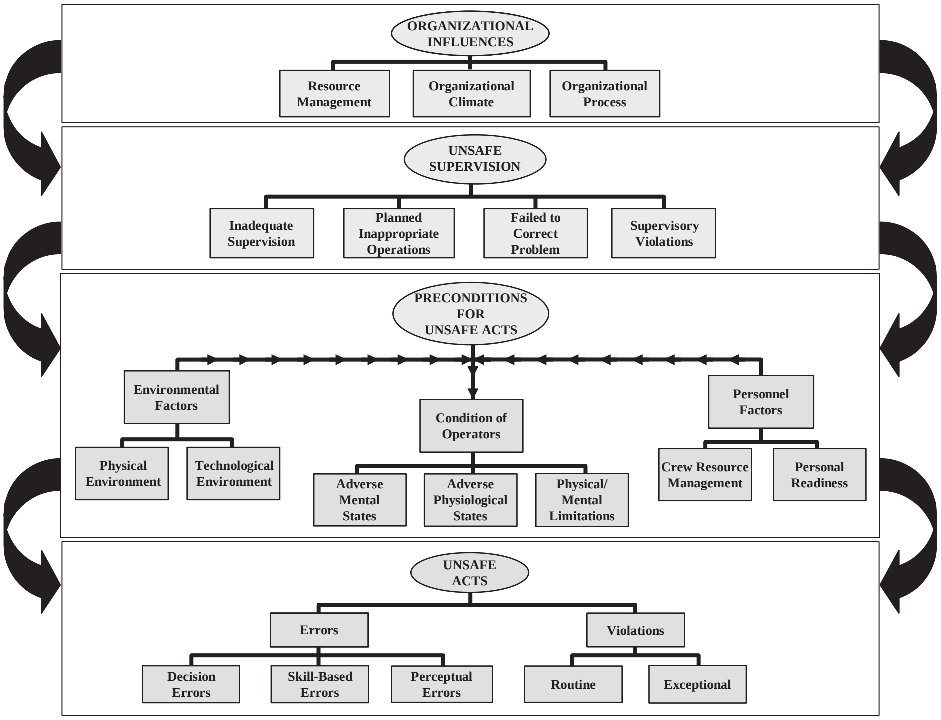

Figure 1. The HFACS framework

Finally, there are instances when a problem is not well understood, and formal procedures and response options are not available. In effect, aircrew find themselves where they have not been before and textbook answers are nowhere to be found. It is during these times that the invention of a novel solution is required. Unfortunately, individuals in these situations must resort to slow and effortful reasoning processes – a luxury rarely afforded in an aviation emergency – particularly in general aviation.

Skill-based Errors. Skill-based behavior within the context of aviation is best described as "stick-and-rudder" and other basic flight skills that occur without significant conscious thought. As a result, these skill-based actions are particularly vulnerable to failures of attention and/or memory. In fact, attention failures have been linked to many skill-based errors such as the breakdown in visual scan patterns, inadvertent activation of controls, and the misordering of steps in procedures. Likewise, memory failures such as omitted items in a checklist, place losing, or forgotten intentions have adversely impacted the unsuspecting aircrew.

Equally compelling, yet not always considered by investigators, is the manner or technique one uses when flying an aircraft. Regardless of one's training, experience, and educational background, pilots vary greatly in the way in which they control their aircraft. Arguably, such techniques are as much an overt expression of one's personality as they are a factor of innate ability and aptitude. More important, however, these techniques can interfere with the safety of flight or may exacerbate seemingly minor flying emergencies.

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 conditions. Faced with acting on inadequate information, aircrew run the risk of misjudging distances, altitude, and descent rates, as well as 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 when flying in instrument meteorological conditions (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 visual/vestibular illusions 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. In contrast, violations represent the willful disregard for the rules and regulations that govern safe flight and, fortunately, occur much less frequently.

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 (VMC) only. While both certainly violate governing regulations, many drivers or pilots do the same thing. Furthermore, people who 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 or 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 makes them particularly difficult to predict and problematic for organizations to manage.

PURPOSE

The HFACS framework was originally developed for the U.S. Navy and Marine Corps as an accident investigation and data analysis tool (Shappell & Wiegmann, 2000; 2001; Wiegmann & Shappell, 2003). Since its development, other organizations such as the FAA have explored the use of HFACS as a complement to preexisting systems within civil aviation in an attempt to capitalize on gains realized by the military. These initial attempts, performed at both the University of Illinois and the Civil Aerospace Medical Institute (CAMI) have been highly successful and have shown that HFACS can be reliably and effectively used to analyze the underlying human causes of both commercial and general aviation accidents (Wiegmann & Shappell, 2003). Furthermore, these analyses have helped identify general trends in the types of human factors issues and aircrew errors that have contributed to civil aviation accidents (Shappell & Wiegmann, 2003; Wiegmann & Shappell, 2001a; 2001b).

Indeed, the FAA's General Aviation & Commercial Division (AFS-800) within the Flight Standards Service and the Small Airplane Directorate (ACE-100) have acknowledged the added value and insights gleaned from these HFACS analyses. Likewise, HFACS was cited by the Aeronautical Decision Making (ADM) Joint Safety Analysis Team (JSAT) and the General Aviation Data Improvement Team (GADIT) as being particularly useful in identifying the human error component of aviation accidents.

To date, however, these initial analyses using HFACS have only been performed on a limited set of accident data within the context of civil aviation. Furthermore, these analyses have generally been performed at a global level, leaving several questions unanswered concerning the underlying nature and prevalence of different error types. As a result, AFS-800, ACE-100, the ADM JSAT, and the GADIT committees have directly requested that additional analyses be conducted to answer specific questions about the exact nature of the human errors identified, particularly within the context of GA. Those specific questions include:

> ***Question 1:*** *Which unsafe acts are associated with the largest percentage of accidents across the entire decade of the 1990s (the 11 years from 1990 through 2000)?* The answer to this question will provide insight into the types of human errors associated with GA accidents from a global perspective.
>
> ***Question 2:*** *Has the percentage of accidents associated with each unsafe act changed over the years?* This question addresses whether any interventions implemented over the past 11 years have been successful in reducing

accidents caused by specific types of human error. It also provides information as to whether any particular error form has been increasing in occurrence and would therefore pose serious safety concerns in the future, if not addressed today.

Question 3: *Does the pattern of unsafe acts differ across fatal and non-fatal accidents?* Previous research in other aviation venues (e.g., military aviation) has shown that violations of the rules tend to be associated with a larger portion of fatal accidents (Shappell & Wiegmann, 1995, 1997; Wiegmann & Shappell, 1995). Will this same pattern exist in GA accidents, or will other errors more readily distinguish fatal from non-fatal accidents? This question also directly addresses Objective 2 of the FAA Flight Plan that states, "*Reduce the number of fatal accidents in general aviation.*"

Question 4: *Do the patterns of unsafe acts for fatal and non-fatal accidents differ across years?* Similar to question two, this question addresses any increasing or decreasing trends in the specific types of errors across the years, particular as they relate to accident severity.

Question 5: *How often is each error type the "primary" or seminal cause of an accident?* Answers to the previous questions will highlight how often a particular error type is associated with GA accidents. What they do not answer is how often each type of error (e.g., skill-based) is the "initiating" error or simply the "consequence" of another error form (e.g., decision errors). To answer this question, we will examine the seminal unsafe act associated with each accident. Seminal events in this study were defined as the first human error cited within the sequence of events in an accident. Ultimately, information regarding seminal errors will help safety managers within the FAA to refine and/or target intervention strategies so that they can have a greater impact on GA safety.

Question 6: *Do seminal unsafe acts differ across years?* Similar to questions 2 and 4, answers to this question will provide insight into potential trends that will affect efforts aimed at reducing accidents and incidents among GA.

Question 7: *Do seminal unsafe acts differ as a function of accident severity (fatal vs. non-fatal)?* Like question 3, an answer to this question could indicate which seminal errors are most important for preventing fatal aviation accidents.

Question 8: *What are the exact types of errors committed within each error category?* Just knowing that certain types of errors (e.g., skill-based errors) are of major concern typically does not provide enough detail to do anything about it. What we would like to know, for example, is exactly what are the skill-based errors we should focus our safety programs on? A more fine-grained analysis of the specific types of errors within each unsafe act causal category will be conducted to answer this question.

Question 9: *Do the types of errors committed within each error category differ across accident severity?* Like questions 3 and 7, the answer to this question could indicate which specific type of error within each category poses the greatest threat to safety.

Question 10: *Do the types of errors committed within each error category differ between seminal vs. non-seminal unsafe acts?* This question addresses whether there are differences in the specific types of errors within each category that are more likely to initiate the sequence of events. After all, a given causal factor may be the most frequently cited error form but may not be the most frequently cited initiating event. If the goal is to intervene before the accident chain of events is set in motion, this question will determine where to focus safety resources.

Ultimately, answers to these questions will provide us with an unprecedented glimpse into the face of human error within general aviation. The results of these analyses can then be used to map intervention strategies onto different error categories, enabling safety professionals to determine plausible prevention programs for reducing GA accidents. Essentially, this project represents the next step in the development of a larger civil aviation safety program whose ultimate goal is to reduce the aviation accident rate through systematic, data-driven intervention strategies and the objective evaluation of intervention programs.

METHOD

Data

General aviation accident data from calendar years 1990-2000 were obtained from databases maintained by the National Transportation Safety Board (NTSB) and the FAA's National Aviation Safety Data Analysis Center (NASDAC). For analysis purposes, we selected only accident reports that were classified "final" at the time this report was written. The NTSB reports two levels of investigation: factual and final. The factual investigation is a preliminary report that only includes demographic information associated with the accident such as the location of the accident and severity of injuries but no causal factors. Only the final report that contains the causal factors associated with the accident was of interest in this study.

We further eliminated from consideration those accidents that were classified as having "undetermined causes," and those that were attributed to sabotage, suicide, or criminal activity (e.g., stolen aircraft). When the data were parsed in this manner, we were left with only those GA "accidents" for which causal factors had been "determined" and released by the NTSB.

The data were culled further to include only those accidents that involved powered GA aircraft (i.e., airplanes, helicopters, and gyrocopters), thereby excluding blimps, balloons, gliders, and ultra-light aircraft from the analysis. Although the latter is arguably a powered aircraft, ultralights were considered sufficiently different from other powered aircraft to warrant exclusion. Finally, since we were interested in aircrew error, we excluded accidents in which no aircrew-related unsafe act was considered causal or contributory to the accident. In the end, 14,436 accidents involving over 25,000 aircrew causal factors were included and submitted to further analyses using the HFACS framework.

Causal Factor Classification Using HFACS

Seven GA pilots were recruited from the Oklahoma City area as subject matter experts (SMEs). All were certified flight instructors with a minimum of 1,000 flight hours in GA aircraft at the time they were recruited.

Each pilot was provided roughly 16 hours of training on the HFACS framework, which included didactic lecture and practice (with feedback) applying the HFACS framework to accident reports. After training, the seven 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 identified by the NTSB using the HFACS framework. Note, however, that only those causal and contributory 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.

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, an excellent level of agreement considering that this was, in effect, a decision-making task.

Human Factors Quality Assurance

The data used in this study were drawn from NTSB investigation reports that are often highly technical in nature, requiring a fundamental understanding of specific terms, flight conditions, and the overall domain of aviation to be effectively classified and coded. As aviation SMEs, the pilot-coders were able to clearly understand each component of the investigation reports studied. What's more, the pilot-coders represent the end users of improved error analysis methods for conducting accident investigations (i.e., aviation experts typically investigate aviation accidents). Therefore, they were considered the appropriate personnel for conducting the overall HFACS analysis of the GA accident reports.

General aviation pilots, however, are not SMEs in the domains of psychology or human factors, and therefore, they may not fully understand the theoretical underpinnings associated with the various error types within the HFACS framework. Hence, pilots might classify human error data somewhat differently than SMEs in human factors. Still, pilots in this study were trained on HFACS, which did give them some level of expertise when assessing human error. In fact, an earlier study addressed this issue by comparing the coded database of a commercial pilot rater to that of a psychologist and found the data to be reliable (Wiegmann & Shappell, 2001a; 2001b).

Nonetheless, to be doubly sure that the pilot coders had grasped the psychological aspects underlying human error and HFACS, three additional SMEs with expertise in human factors/aviation psychology examined each HFACS classification that the pilot SMEs had assigned to a given human cause factor. Essentially, the human factors SMEs were ensuring that the pilots understood the error analysis process and did not code causal factors like spatial disorientation as a decision error, or exhibit any other such blatant misunderstandings of the HFACS model. To aid in the process, descriptive statistics were used to identify outliers in the data, after which the corresponding NTSB report was obtained. The reports were then independently reviewed by a minimum of two human factors SMEs for agreement with the previous codes. After the human factors SMEs came to a consensus, the codes were either changed in the database or left as the pilot SMEs originally coded them. In the end, less than 4% of all causal factors were modified during the human factors quality assurance process.

RESULTS

The results of this research project will be presented in a manner that addresses each of the specific questions raised earlier. Each section will begin by restating the question of interest, followed by a description of the findings pertaining to it.

Question 1: Which unsafe acts are associated with the largest percentage of accidents?

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 percentages 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. For example, regardless of whether a given accident was associated with one or more skill-based error, the presence of a skill-based error for that accident was only counted once. 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 occasion, multiple instances of the same HFACS causal category. 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 – routine and exceptional violations. 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 obtained from the NTSB and NASDAC. As a result, the pilot-raters were instructed to use the parent causal category of "violations," rather than distinguish between the two types.

The overall analysis of GA accidents revealed a picture of human error within GA that was not possible before the development of HFACS (Figure 2). Specifically, the data indicate that skill-based errors were associated with the largest portion of GA accidents (79.2% of the 14,436 GA accidents), followed by decision errors (29.7%), violations (13.7%), and perceptual errors (5.7%). Note that many of the accidents were associated with multiple HFACS causal categories. In other words, an accident could have been associated with a skill-based error, decision error, perceptual error, and violation, or any other combination. Therefore, percentages of accidents do not total 100%. Additionally, each accident may be associated with multiple instances of the same type of unsafe act. However, as stated previously, the findings presented here are for those accidents that involve at least one instance of a particular unsafe act category.

Question 2: Has the percentage of accidents associated with each unsafe act changed over the years?

Analysis of the data on a year-by-year basis reveals that the proportion of accidents associated with at least one instance of each unsafe act category remained relatively unchanged over the 11-year period examined in this study (Figure 3). This would seem to suggest that safety efforts directed at GA over the last several years have had little effect on any specific type of human error. If anything, there may have been a general, across-the-board effect, although this seems unlikely, given the safety initiatives employed. The only exceptions seemed to be a small dip in the percentage of accidents associated with decision errors in 1994, a gradual decline in violations observed from 1991 to 1994, and then again from 1995 to 2000. With decision errors, however, the trend quickly re-established itself at levels consistent with the overall average.

Question 3: Does the pattern of unsafe acts differ across fatal and non-fatal accidents?

Figure 4 presents the percentage of fatal (n = 3,256) and non-fatal (n = 11,180) accidents associated with each type of unsafe act. From the graph in Figure 4, some important observations can be made. For instance, it may surprise some that skill-based errors, not decision errors, were the number-one type of human error associated with fatal GA accidents. In fact, fatal accidents associated with skill-based errors (averaging roughly 80.6% across the years of the study) more than doubled the percentage of accidents seen with decision errors (29.5%) and the willful violation of the rules (30.5%). Even perceptual errors, the focus of a great deal of interest over the years, were associated with less than 4% of all fatal accidents. In fact, the proportion of accidents associated with skill-based errors was greater than the three other error types combined.

Upon closer examination, it appears that the percentage of fatal and non-fatal accidents with skill-based, decision, and perceptual errors, was relatively equal (Figure 4). However, as expected, the proportion of accidents associated with violations was considerably higher for fatal than non-fatal accidents. In fact, using a common estimate of risk (known as the odds ratio), fatal accidents were more than four times more likely to be associated with violations than non-fatal accidents (odds ratio = 4.547; 95% confidence interval = 4.11 to 5.021, Mantel-Haenszel

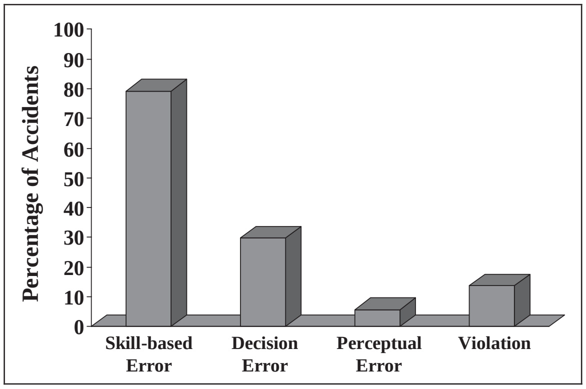

Figure 2. *Percentage of aircrew-related accidents by unsafe act category.*

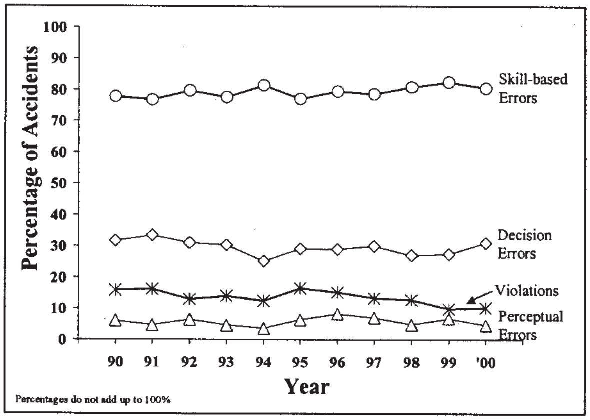

Figure 3. *Percentage of accidents by error category by year.*

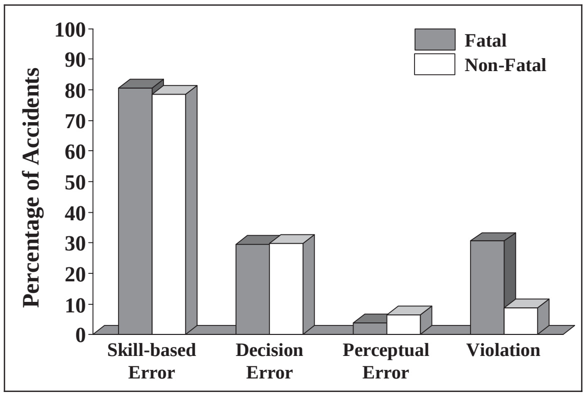

Figure 4. *Percentage of fatal and non-fatal GA accidents associated with each unsafe act.*

test for homogeneity = 1002.358, p<.001). Put simply, if a violation of the rules results in an accident, the pilot is more likely to die or kill someone else than to get up and walk away.

Question 4: Do the patterns of unsafe acts for fatal and non-fatal accidents differ across years?

As with the overall analysis, an examination of the 3,256 fatal accidents on a year-by-year basis revealed that the proportion of accidents associated with at least one instance of each unsafe act category remained relatively stable over the 11-year period examined in the study (Figure 5). As before, there appears to have been a slight downward trend in both decision errors and violations during the early part of the 1990s. However, these trends reversed direction and generally increased during the later half of the decade.

While this is certainly important information, some may wonder how these findings compare with the 11,180 non-fatal accidents. As can be seen in Figure 6, the above results were strikingly similar to those associated with fatalities. Again, the trends across the years were relatively flat, and as with fatal accidents, skill-based errors were associated with more non-fatal accidents than any other error type, followed by decision errors. The percentage of non-fatal accidents associated with violations and perceptual errors were relatively equal across the years. In fact, the only real difference in the pattern of human error seen with fatal and non-fatal GA accidents was with the percentage of accidents attributable, in part, to violations of the rules (Figure 7).

Question 5: How often is each error type the "primary" cause of an accident?

The previous analyses have indicated that, overall, roughly 80% of GA accidents are associated with skill-based errors. More important, however, is how often skill-based errors are the "initiating" error or simply the "consequence" of another type of error, such as decision errors. Consider, for instance, a pilot who knowingly takes off into a forecasted thunderstorm without an instrument rating. Such a choice would be considered a *decision error* within the HFACS framework. Later in the flight, the pilot may be faced with either turning around or flying through the weather (flying in instrument meteorological conditions – IMC) when he/she is authorized for only visual flight rules (VFR) flight. If the pilot willfully penetrates IMC, a *violation* would be committed. This might lead to spatial disorientation (*adverse physiological state*), which, in turn, might lead to a misperception in the aircraft's attitude (*perceptual error*), and ultimately the loss of control of the aircraft (*skill-based error*) resulting in an accident. Given such a scenario, some would argue that the first error in the chain of events is more important than the skill-based error committed well down the error chain.

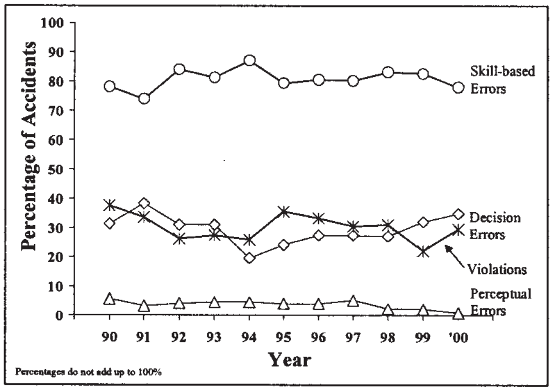

Figure 5. *Percentage of fatal GA accidents associated with each unsafe act across years.*

To resolve this potential issue, we examined the seminal unsafe act associated with each accident, the results of which are presented in Figure 8. As can be seen from the figure, the pattern of unsafe acts was similar to that seen in the overall analysis above (see Figure 2). The only difference is that these percentages will add up to 100%, since there can only be one "seminal" human causal factor. Still, nearly 61% (n = 8,838) of all accidents began with a skill-based error. In contrast, roughly 19% (n = 2,729) began with a decision error, 8% (n = 1,180) began with a violation, and only 4% (n = 564) began with a perceptual error. The remaining 8% (n = 1,125) were associated with a seminal event other than an unsafe act (e.g., a precondition for an unsafe act, such as an adverse physiological state).

Questions 6 and 7: Do seminal unsafe acts differ across years or as a function of accident severity (fatal vs. non-fatal).

Let's begin with accident severity. As depicted in Figure 9, seminal skill-based errors were associated with the largest proportion of both fatal and non-fatal accidents. However, the percentage of non-fatal accidents associated with seminal skill-based errors was somewhat higher than for fatal accidents. In contrast, seminal violations continued to be associated with a much larger percentage of fatal accidents than non-fatal accidents. Percentages of fatal and non-fatal accidents associated with seminal decision errors were equivalent, as they were for perceptual errors. Worth noting, the latter (perceptual errors) were practically non-existent for both fatal and non-fatal accidents. This finding was not surprising given that most perceptual errors occur later in the chain of events; after an individual has committed a violation or following a decision error.

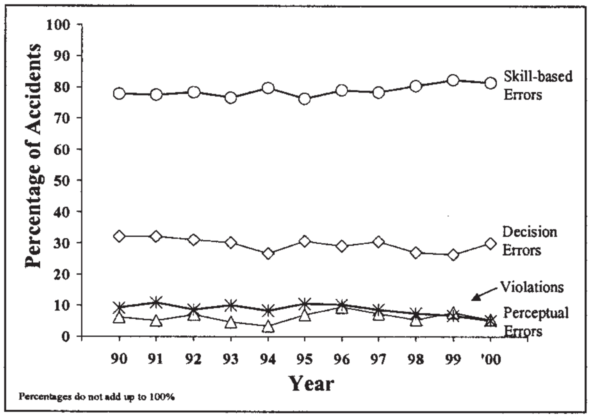

Figure 6. *Percentage of non-fatal GA accidents associated with each unsafe act across years.*

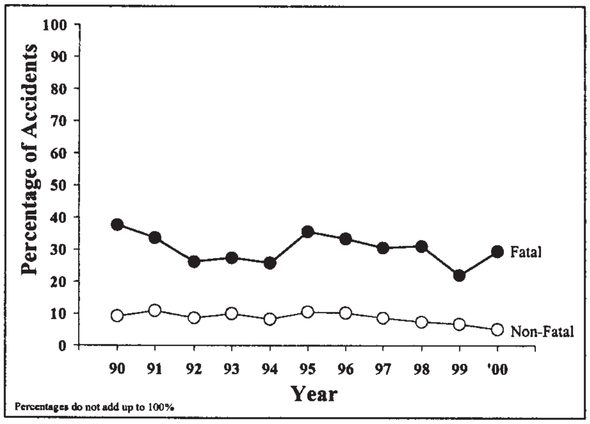

Figure 7. *Percentage of fatal (closed circles) and non-fatal (open circles) GA accidents associated with violations across years.*

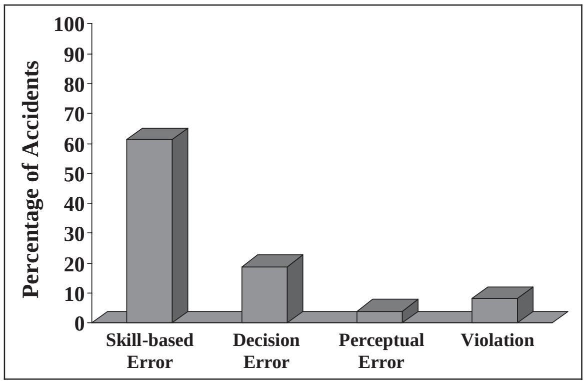

Figure 8. *Percentage of accidents in which each unsafe act was the first (seminal) human error in the accident sequence.*

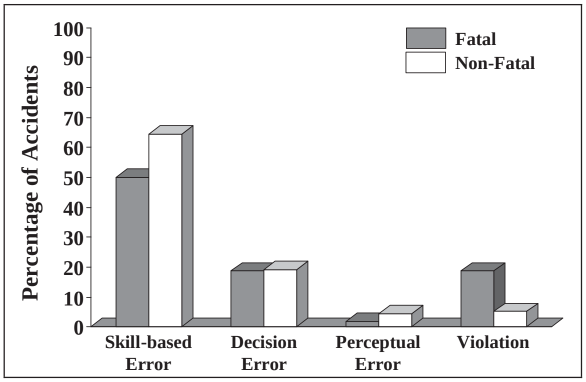

Figure 9. *Percentage of fatal and non-fatal accidents associated with each seminal error category.*

Figures 10 and 11 illustrate the percentage of fatal and non-fatal accidents associated with each seminal error across the 11-year period examined in this study. In general, the patterns of errors across the years were virtually the same as those observed for the overall error trends (see Figures 5 and 6). That is, skill-based errors were consistently the most frequent cause of both fatal and non-fatal accidents, followed by decision errors, violations, and perceptual errors.

What differences did occur between fatal and non-fatal seminal errors (i.e., skill-based and violations) remained relatively constant across the years of this study (Figure 12). Furthermore, the differences were in opposite directions, with a higher percentage of fatal than non-fatal accidents associated with violations and a higher percentage of non-fatal than fatal accidents associated with skill-based errors.

Questions 8, 9, and 10: What are the exact types of errors committed within each error category (question 8) and do these types of errors committed within each error category differ across accident severity (question 9) or seminal events (question 10)?

Just knowing that skill-based errors (or any other type of error) are a major concern does not provide safety professionals sufficient detail to do anything about it. What is needed is a fine-grained analysis of the specific types of errors within each HFACS causal category so that targeted interventions can be developed. With this in mind, we compared each HFACS classification with the NTSB's causal factor designation.

Contained within the NTSB database are three codes (subject, modifier, and person code) associated with each cause/factor for a given accident. For instance, an accident cause may be stated as "VFR flight into IMC" (subject), "continued" (modifier), "pilot in command" (person code). Another might be classified as "directional control" (subject), "not maintained" (modifier), "copilot/second pilot" (person code).

Because all causal factors identified in this analysis involved aircrew, we did not need to differentiate the person code. Of the two remaining codes, the subject code provided the most information. Although the modifier code provided additional clarity, including it at this time would have left us with a list of potential human causal factors well beyond the scope of this study (the list of subject-modifier combinations far exceeds 500). Consequently, we restricted our initial analysis to only the subject codes.

Of note, many of the NTSB subject codes were similar, with only subtle semantic or behavioral differences among them (e.g., stall, stall/mush, stall/spin, and tailplane stall). Where similarities occurred among NTSB causal factors, the descriptions were grouped according to their similar nature. This reduced the number of unsafe act exemplars to a manageable number.

To aid in the presentation of the data, we will examine the fine-grained analysis for each type of unsafe act separately. Included in the results will be the "*top 5*" human causal factors overall, across accident severity and seminal events.

Skill-based errors. The most frequently occurring human error categories within skill-based errors are presented in Table 1. As can be seen, nearly 12% of all skill-based errors involved errors in maintaining direction control, followed by airspeed (10.63%), stall/spin (7.77%), aircraft control (7.62%), and errors associated with compensating for wind conditions (6.18%). Together, these five cause factors accounted for nearly one-half of all the skill-based errors in the database. For clarification, "directional control" typically refers to control of the aircraft on the ground, while "aircraft control" refers to control of the aircraft in-flight.

The types and frequencies of skill-based errors coded as fatal/non fatal and seminal events are also shown in Table 1. As can be seen from this table, the percentage of skill-based errors involving stall/spin, airspeed, and aircraft control was greater for fatal than non-fatal accidents. In fact, causal factors such as directional control and compensation for wind conditions were rarely associated with fatal accidents. This pattern was similar whether one compared fatal and non-fatal accidents, overall, or only within accidents in which a skill-based error was the seminal event.

Such findings make sense when one considers that errors leading to a stall/spin, as well as airspeed and control of the aircraft in the air typically happen at altitude, making survival less likely. In contrast, errors controlling the aircraft on the ground (such as ground loops) and compensation for winds (typically seen during cross-wind landings), while dangerous, do not necessarily result in fatalities.

Decision Errors. Table 2 presents the most frequently occurring decision errors. Improper in-flight planning tops the list, contributing to roughly 18% of all decision errors. Errors categorized as in-flight planning refer to planning or plan revisions performed after the aircraft has taken off and are often studied as plan continuation errors (Orasanu, 1993; Burian, Orasanu, & Hitt, 2000; Wiegmann, Goh, & O'Hare, 2002; Muthard & Wickens, 2003). The remaining decision errors, such as preflight planning/decision errors (8.94%), fuel management (8.73%), poor selection of terrain for takeoff/landing/taxi (7.85%), and go-around decision (6.03) all occurred at

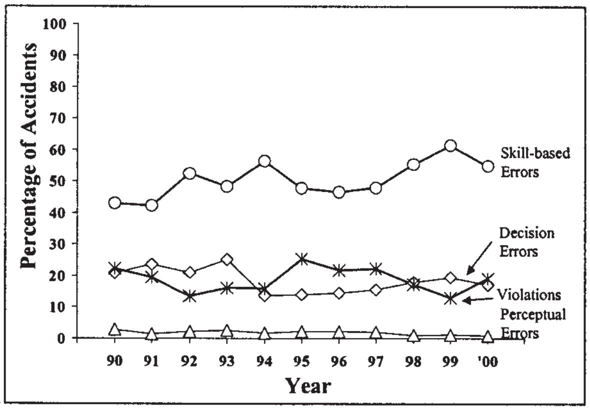

Figure 10. *Percentage of fatal accidents associated with each seminal error category across years.*

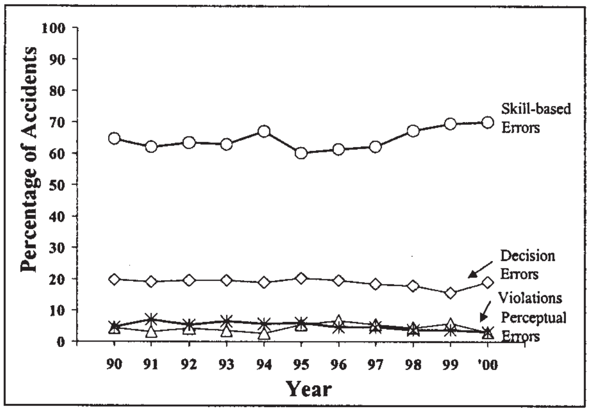

Figure 11. *Percentage of non-fatal accidents associated with each seminal error category across years.*

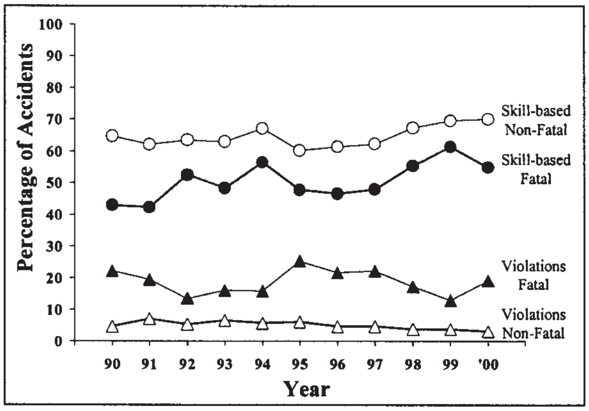

Figure 12. *Percentage of fatal (filled symbols) and non-fatal (open symbols) accidents associated with skill-based errors (circles) and violations (triangles) across years.*

Table 1. *Five Most Frequent Skill-based Error Categories for Fatal and Non-fatal Accidents.*

ERROR CATEGORY	OVERALL Frequency (%) Fatal	Non-fatal	Total	SEMINAL Frequency (%) Fatal	Non-fatal	Total
Directional Control	20 (0.50)	2018 (15.2)	2038 (11.8)	9 (0.57)	1326 (17.5)	1335 (14.6)
Airspeed	713 (17.9)	1127 (8.5)	1840 (10.6)	302 (19.2)	605 (8.0)	907 (9.9)
Stall/Spin	592 (14.9)	753 (5.7)	1345 (7.8)	84 (5.3)	144 (1.9)	228 (2.5)
Aircraft Control	654 (16.5)	665 (5.0)	1319 (7.6)	311 (19.8)	429 (5.7)	740 (8.1)
Compensation for winds	23 (0.6)	1046 (6.2)	1069 (6.2)	12 (0.8	859 (11.4)	871 (9.5)

Table 2. *Five Most Frequent Decision Error Categories for Fatal and Non-fatal Accidents.*

ERROR CATEGORY	OVERALL Frequency (%) Fatal	Non-fatal	Total	SEMINAL Frequency (%) Fatal	Non-fatal	Total
In-flight Planning	268 (22.9)	683 (17.0)	951 (18.3)	133 (22.6)	427 (19.8)	560 (20.4)
Planning/Decision-making on the Ground	115 (9.8)	349 (8.7)	464 (8.9)	89 (15.1)	284 (13.1)	373 (13.6)
Fuel Management	40 (3.4)	413 (10.3)	453 (8.7)	20 (3.4)	252 (11.7)	272 (9.9)
Unsuitable Terrain Selection	16 (1.4)	391 (9.8)	407 (7.8)	5 (.85)	284 (13.1)	289 (10.5)
Go Around	22 (1.9)	291 (7.3)	313 (6.0)	5 (.85)	70 (3.2)	75 (2.7)

Table 3. *Five Most Frequent Perceptual Error Categories for Fatal and Non-fatal Accidents.*

ERROR CATEGORY	**OVERALL**			**SEMINAL**		
	Frequency (%)			**Frequency (%)**		
	Fatal	**Non-fatal**	**Total**	**Fatal**	**Non-fatal**	**Total**
Distance	26 (17.8)	233 (27.7)	259 (26.4)	23 (33.8)	135 (26.5)	158 (27.4)
Flare	5 (3.4)	217 (25.8)	222 (22.5)	4 (5.9)	163 (32.0)	167 (28.9)
Altitude	22 (15.1)	91 (10.8)	113 (11.4)	9 (13.2)	51 (10.0)	60 (10.4)
Clearance	18 (12.3)	51 (6.1)	69 (7.0)	14 (20.6)	41 (8.1)	55 (9.5)
Visual/Aural Perception	15 (9.6)	36 (4.2)	50 (5.1)	3 (4.4)	5 (1.0)	8 (1.4)

Table 4. *Five Most Frequent Violations for Fatal and Non-fatal Accidents.*

ERROR CATEGORY	**OVERALL**			**SEMINAL**		
	Frequency (%)			**Frequency (%)**		
	Fatal	**Non-fatal**	**Total**	**Fatal**	**Non-fatal**	**Total**
VFR Flight into IMC	305 (25.8)	53 (4.7)	358 (15.5)	182 (30.5)	29 (5.2)	211 (25.8)
Procedures/Directives Not Followed	75 (6.3)	176 (15.6)	251 (10.9)	37 (6.2)	109 (19.6)	146 (12.7)
Operating Aircraft with Known Deficiencies	61 (5.2)	168 (14.9)	229 (9.9)	27 (4.5)	97 (17.4)	124 (10.8)
Hazardous Maneuver	154 (13.0)	47 (4.2)	201 (8.7)	83 (13.9)	24 (13.9)	107 (9.3)
Flight into Known Adverse Weather	135 (11.4)	61 (5.4)	196 (8.5)	85 (14.3)	41 (7.4)	126 (10.9)

approximately the same frequencies. Combined, these five causal categories accounted for roughly half (49.89%) of all decision errors in the database. It should be noted that individual factors related to weather-related decision making did not reach the top of the list (e.g., weather evaluation, flight into adverse weather, and inadvertent VFR flight into IMC). However, when combined, they did constitute a significant portion of the factors related to decision- making (6%).

Table 2 also presents the types and frequencies of decision errors for fatal/non fatal and seminal events. As indicated, the categories *in-flight planning* and *planning/decision making on the ground* tended to be associated more often with fatal than non-fatal accidents. Whereas the categories *unsuitable terrain*, *go around*, and *fuel management* were associated more often with non-fatal accidents. This pattern was generally consistent for the overall data, as well as within seminal events.

Perceptual errors. A review of accident causes and factors coded as perceptual errors revealed that *misjudging distance* was the most common, accounting for over a quarter of all perceptual errors (26.4%; see Table 3). The next highest was flare (22.5%), followed by misperceiving altitude (11.4%), misjudging clearance (7.0%) and visual/aural perception (5.1%). Together, these errors accounted for nearly three-quarters of all perceptual errors in the database.

The types and frequencies of perceptual errors as they occurred within fatal/non-fatal accidents are also shown in Table 3. As can be seen from this table, there is very little difference in the percentage of fatal and non-fatal accidents associated with any particular type of perceptual error. The only exception appears to be perceptual errors related to performing the flare, which, in most cases, was associated more with non-fatal than fatal accidents.

Violations. The *top five* violations are presented in Table 4. Analysis of the fundamental types of unsafe acts that are included within the violations categories reveals that the most common violation involved visual flight rules (VFR) flight into instrument meteorological conditions (IMC) (15.5%) and not following known procedures or directives (10.9%). The remaining top violations included operating aircraft with known deficiencies (9.9%), performing hazardous maneuvers such as low-altitude flight or buzzing (8.7%), and flight into adverse weather (8.5%). Together, these five variables accounted for more than half of all violations in the database.

The types and frequencies of violations for fatal/non-fatal and seminal events are also presented in Table 4. As indicated, the categories VFR flight into IMC, hazardous maneuver, and flight into known adverse weather were much more likely to be fatal than non-fatal, both overall and for seminal events only. This pattern is consistent with the observation that accidents involving violations of the rules are, in general, more likely to be fatal.

DISCUSSION

The present study of GA accidents examined literally thousands of unsafe acts committed by pilots, perhaps suggesting that, correspondingly, there are literally thousands of unique ways to crash an airplane. The results of this study, however, demonstrate that accidents that may appear to be unique can be reliably grouped, based upon underlying cognitive mechanisms of pilot errors. By applying HFACS, a theoretically based model of human error, we were able to highlight several human error trends and identify the categories of unsafe acts that contribute to both fatal and non-fatal GA accidents.

While there are many ways to describe the accident data, perhaps the best way is to discuss the findings in the order of their relative contributions to the accidents examined, beginning with skill-based errors.

Skill-Based Errors

By far, skill-based errors were the most common type of error in the accident database as nearly 80% of all GA accidents were associated with at least one skill-based error. Of these, roughly half were the first human causal factor in the chain of events.

The most common skill-based errors among more than 17,000 identified in this study included: control or handling of the aircraft on the ground and in the air, improperly maintaining airspeed, the occurrence of a stall or spin, and compensating for wind. Notably, these skill-based errors occurred more often than any other error category across all types of unsafe acts – not just the skill-based error category.

These findings are not without precedent in aviation. In fact, our previous work has shown that skill-based errors are the most prevalent form of aircrew error in commercial and military aviation accidents as well (Wiegmann & Shappell, 1997; Wiegmann & Shappell, 1999; Wiegmann & Shappell, 2001a, 2001b). Still, the percentages reported here were generally higher than those found in our other investigations, suggesting that skill-based errors are even more prevalent in GA than in other domains.

So, what caused these skill-based errors in the first place? Historically, these types of errors are often attributed to failures of the pilot to monitor crucial flight parameters, a fundamental aspect of cockpit task management (Funk, 1991). For instance, if interrupted or distracted by a situation or event, a pilot can quickly become sidetracked from the primary task of flying the airplane. Furthermore, individuals are more susceptible to distraction during low processing tasks. Ultimately, these intrusions, uncertainties, and general distractions may keep the pilot from effectively monitoring the aircraft's airspeed and altitude as well as other parameters critical to the flight. As a result, a skill-based error is committed that may lead to an incident/accident.

Another possibility is that the lower levels of experience and training obtained by GA pilots may account for the larger proportion of accidents involving skill-based errors than those observed in military and commercial aviation. Presumably, GA pilots fly less frequently than their military or commercial counterparts do, such that recency of experience is less. Herein lies the rub. According to models by Reason (1990) and Rasmussen (1982), skill-based errors, by definition, occur during the execution of routine events. Furthermore, once a particular skill is developed, it must be maintained through repetition and experience. Given that many GA pilots fly less and typically participate in less recurrent training than commercial and military pilots, it stands to reason that their proficiency would be degraded. In turn, this lack of proficiency may explain the increase in skill-based errors evident in the accident data.

Indeed, one can imagine a situation where increased workload in-flight (e.g., while flying in IMC or adverse weather) quickly overcomes an inexperienced pilot and diminishes the capacity to monitor altitude, fuel state, visual clearances, communication, or directional control. Furthermore, the inattention that results from a high workload situation could manifest as failing to monitor critical flight instruments, the failure to accomplish required in-flight checklist items, or the gradual, inadvertent loss of airspeed, all of which would appear in the present study as skill-based errors.

The real question is, "How do you go about reducing skill-based errors?" Perhaps the obvious answer is through experience and effective training. In that way, pilots are able to increase their familiarity with the rules governing flight and increase their knowledge of all aspects of their domain, improve their overall proficiency, and become less prone to attention slips or memory lapses due to high workload or distractions. However, that may not be the only answer. Other proposed ways to manage pilot workload include detailed checklists (Degani & Wiener, 1993), automation such as auditory reminders of critical tasks (Norman, 1988), and task or workload management training (Wiener, Kanki, & Helmreich, 1993). Whether these or any other interventions can be effectively integrated into the GA environment remains to be determined.

Violations

Violations are the classic glass half-empty, glass half-full conundrum. On the one hand, GA accidents associated with at least one violation were present in "only" 14% of the data (i.e., glass half-full). On the other hand, GA accidents associated with violations were second only to skill-based errors when fatalities were involved (glass half-empty). The latter is of more concern to the FAA.

As stated previously, this finding indicates that if a pilot breaks a rule that results in an accident, he or she is much more likely to perish than if the accident was due to some other (non-rule breaking) action. These results are similar to those observed in the military and commercial aviation domains (Wiegmann & Shappell, 2001a, 2001b).

Many of the violations cited in the database involved weather-related factors, including VFR flight into IMC. The question remains, however, as to why a pilot would willfully fly into such dangerous weather conditions. Goh and Wiegmann (2002), along with O'Hare and Smitheram (1995) found that social pressures often contribute to continued flight into adverse weather. For example, Goh and Wiegmann reported that GA accidents resulting from VFR flight into IMC were more likely to have passengers on board than any other type of accident. Furthermore, in a study of weather-related decision-making, Holbrook, Orasanu, and McCoy (2003) found that "systemic pressures" to fly, such as those from passengers or other pilots, may "contribute to pilots' decisions to continue flight despite cues suggesting they should do otherwise" (p. 581). Further analysis is needed, however, to determine the extent to which these factors contribute to accidents within the present database.

Beyond social pressures previously addressed, O'Hare and his colleagues (O'Hare & Owen, 1999; O'Hare & Smitheram, 1995) have explored this question by investigating how pilots frame the situation of continuing or discontinuing flight into adverse weather. They found that pilots who framed diverting from a flight plan as a loss (e.g., loss of time, economic loss, or expense of effort) tend to continue flight into adverse weather; whereas those who frame a diverting decision as a gain (e.g., in personal safety) tend to divert more.

Some research (i.e., O'Hare, 1990; Goh & Wiegmann, 2002) suggests that pilot overconfidence and a limited appreciation of the risks involved with flight into adverse weather may also contribute to weather-related violations. Others contend that there are GA pilots who "simply do not mind taking risks and yet who also either lack the experience to assess those risks, or perhaps have just enough experience to overestimate their own abilities" (Knecht, Harris, & Shappell, 2003; p.673).

While the percentage of accidents involving violations shows no appreciable decline over the years studied, the simplest way to reduce the occurrence of violations is through continually and consistently enforcing the rules. Unfortunately, simply enforcing rules more effectively is extremely difficult within GA due to its organizational structure. Since it is often not clear exactly whose authority GA pilots fly under (as compared with military and commercial pilots), it becomes very difficult to police the GA system.

As a result, other interventions have been proposed to reduce the occurrence of violations, such as the education of GA pilots on the extent of the real risks of violating established rules and regulations. Another proposal involves simulator training of difficult tasks such as emergencies or risky situations to directly demonstrate the hazards associated with violating rules (Knecht et al., 2003).

While many cases of flight into adverse weather are rightfully coded as violations, there are many that may not represent a willful departure from established procedures and are instead the result of the misdiagnosis of weather conditions, improper planning, or a decision not to use preflight briefing service information. Rather than coding them as willful violations, these errors represent a breakdown in the decision-making process and are thus captured within the next category to be addressed — decision errors.

Decision Errors

Decision errors were present in roughly one-third of all accidents, which is also consistent with proportions observed within other aviation domains (O'Hare, Wiggins, Batt, & Morrison, 1994; Murray, 1997; Shappell & Wiegmann, 2001; Wiegmann & Shappell, 2001a, 2001b). These percentages were roughly equivalent for both fatal and non-fatal accidents, even when only seminal decision errors were examined.

Upon closer examination, it appears that many of the decision errors involved planning, both in-flight and on the ground, as well as issues related to weather evaluation. Recently, Burian, Orasanu, and Hitt (2000) found that 28% of accidents involving weather events involved plan continuation errors, and suggest that pilots with less experience may "not trust what their eyes are telling them and so proceed on blindly" (p. 25). Wiegmann, Goh, and O'Hare (2002) also studied the occurrence of plan continuation errors of VFR flight into IMC and presented findings that suggest that under certain conditions these errors are more often attributable to poor situation assessment (early stages of information processing) than to motivational judgment. In either case, however, proper planning, both in the air and on the ground, is a critical component of flight safety.

Proposals for ways of improving pilots' judgment often involve training in aeronautical decision-making. It is generally believed that novices may lack a full understanding of the significance of some weather-related cues. Therefore, by examining techniques used by expert pilots to assess situations and solve problems, a better training method may be developed. For example, Wiggins and O'Hare (2003) recently developed a program for the FAA that uses static weather images and short video clips to help teach pilots how to more effectively identify critical weather cues. Based on initial evaluations, the computer-based training program shows positive effects on aeronautical decision-making.

Another method of assisting pilot decision-making is the implementation of planning aids. Layton, Smith, and McCoy (1994) evaluated the effectiveness of three different planning aid (cooperative) systems and demonstrated that different system design concepts can strongly influence the cognitive processes and resultant performance. Through their findings, the researchers recommended further research into better information displays, geographical interfaces of alternative route manipulation, access to more complete and accurate weather and traffic information, and optimization technologies to assist users in generating alternative plans. Others have encouraged further study of the improved design of displays that present critical data such as weather, traffic, and other environmental information (Wickens & Hollands, 2000).

Finally, scenario-based training has been shown to be an effective technique for improving decision-making in a variety of domains. The training method involves embedding decision-making tasks within a "real world" context, similar to those in an operational setting. This is in contrast to traditional training methods that compartmentalize or modularize training, teaching decision strategies in isolation or independently from a particular context. Indeed, the FAA's General Aviation & Commercial Division (AFS-800) has recently introduced the FAA/Industry Training Standards (FITS) program aimed at improving GA flight training using scenario-based training and other technologies. While the program is currently focusing on "personal or professionally flown single-pilot aircraft for transportation with new technologies" (Glista, 2003), there is no reason to believe that FITS will not benefit the light-sport and recreational pilots as well.

Perceptual Errors

Not surprisingly, perceptual errors contribute to the smallest percentage of accidents within the present analysis (5.7%), a percentage that is much lower than that found in military research (Wiegmann & Shappell, 2003). Given the non-tactical, non-aerobatic nature of GA flight, spatial disorientation and difficulties in perception are expected to occur at a lower frequency than is found within military aviation, particularly within the dynamic domains of fighter, tactical, aerobatic, or night operating aircraft.

Furthermore, due to the relatively small numbers of perceptual errors coded within the GA accidents studied, it is difficult to draw any conclusions. Nevertheless, it is reasonably clear that errors involving misjudging information comprise the majority of perceptual errors and represent misperception, as opposed to non-detection. Analogous to other errors made in the presence of correct and adequate information, misperception errors are disheartening, as pilots inaccurately code or improperly process accurate cues from the environment. Ultimately, this leads to the misjudging of altitude, distance, or descent, which encompass a large proportion of the perceptual errors cited within the present database.

That being said, one may wonder why spatial disorientation did not make the *top 5* of the perceptual error list. Spatial disorientation, although often leading to perceptual errors (e.g., misjudging altitude/attitude), is not considered an error. Rather, it is considered a physiological state that cannot be controlled by the individual. That is, you are either disoriented or you are not and more important, not every instance of spatial disorientation leads to a perceptual error (e.g., Type 1 – recognized spatial disorientation, otherwise referred to as the "leans").

Consequently, our SMEs classified instances of spatial disorientation within the HFACS category of *adverse physiological states*. Unfortunately, when NTSB investigators did identify spatial disorientation (an *adverse physiological state* using HFACS) they often did not identify the resultant perceptual error when reporting the causes/factors associated with an accident. Hence, perceptual errors were under-reported here. For completeness, there were 279 accidents out of the 14,436 we examined (1.9%) associated with spatial disorientation, of which all but 34 involved fatalities.

Perceptual errors, whether caused by spatial disorientation or other factors, are much like skill-based errors and can degrade due to lack of recency, experience, or training. However, in addition to training and practice, other interventions such as enhanced displays may improve the veridical nature of pilots' perceptions. For example, such technologies as radar altimeters, angle-of-attack indicators, or other such displays may ultimately reduce accidents due to perceptual errors.

Additional Issues

As previously described, the present study examined only those causes or contributing factors that were classified as unsafe acts by the aircrew. There are a number of other accident cause factors that involve humans that are not unsafe acts. For instance, in addition to spatial disorientation, a breakdown in communication is another example of a human error that is not considered an unsafe act within HFACS. Rather, the category of crew resource management (CRM) captures errors of communication between pilots and their crew, other pilots, and air traffic controllers, and is classified under the "preconditions for unsafe acts" within HFACS (Shappell & Wiegmann, 2000, 2001; Wiegmann & Shappell, 2003).

Many other potentially important human factors related accident causes are also captured within other levels of analysis such as fatigue, alcohol use, self medication (use of over-the-counter medications), workload, medical history, and work environment. While important human factors, these are also not considered to be unsafe acts and were not examined within the present study.

Nevertheless, such causal factors were rarely cited in the NTSB database. In fact, analysis of all seminal events indicated that less than 8% of all seminal cause factors were anything other than an unsafe act by the aircrew. So, although we can all agree that such factors as spatial disorientation, self-medication, and poor CRM are important issues (and HFACS does account for these as preconditions), they were virtually non-existent in the general aviation database.

Such limited information concerning pre-conditions for unsafe acts does result in only a partial picture of the entire sequence of events that contributed to the accident. However, the present study represents the most comprehensive human error analysis of GA data ever conducted and provides useful information for understanding the immediate causes of accidents. Furthermore, the absence of critical preconditions in the database clearly indicates a need to improve the accident investigation process so that more in-depth information concerning the causes of aircrew error can be identified. Indeed, HFACS provides an effective tool for improving this process (Shappell & Wiegmann, 2003).

CONCLUSIONS

The high level of safety currently achieved within aviation should not obscure the fact that many aviation accidents are preventable. It is important to realize that safety measures and defenses currently in place in GA may be inadequate, circumvented, or perhaps ignored, and that the intervention strategies aimed at reducing the occurrence or consequences of human error may not be as effective as possible.

Even though the results of the present study point to several ways to reduce the rate of GA fatalities, there may be several more and far better solutions that have yet to be identified.

Historically, accident and incident interventions have been generated by the NTSB in the form of recommendations or have come from experts in the government (FAA, NASA, etc.), military, or other aviation organizations. As a result, they tend to focus on the prevention of specific types of accidents such as those related to loss of control in flight or controlled flight into terrain, rather than specific types of human error per se. What's more, the interventions tend to be rather narrow in scope, often emphasizing only changes to the aircraft in the form of automation and displays or simply recommending changes to existing policies or regulations. Even when attempts are made to address specific types of human error, the emphasis has traditionally been placed on pilot decision-making, which accounts for just over 30% of the GA accidents that occur annually.

What is needed is a systematic approach to generating intervention/prevention strategies that can tie into the HFACS framework that has proven success with civilian aviation accident and incident data. Within epidemiology, one such approach, the Haddon matrix, was developed to address injuries sustained as the result of automobile accidents (Haddon, 1980). Haddon's argument was that we often overlook potentially useful interventions by not considering all aspects of the accident/incident. In fact, when one examines the typical interventions recommended by the NTSB and others following an accident, they typically focus on only a few areas rather than the gamut of intervention possibilities.

Along these lines, Wiegmann and Rantanen (2002) examined over 75 intervention strategies identified by NASA for use within U.S. civilian aviation using a similar matrix. In that study, the vast majority of the interventions were technologically oriented, leaving one to believe that a variety of other potentially useful strategies had been left on the drawing board or not even considered. Ideally, a similar matrix using HFACS causal categories could be developed that would be both manageable and effective at generating putative intervention strategies and assessing their impact prior to deployment.

It is apparent from the current study that human error associated with GA accidents is multi-faceted. Specifically, our analyses have revealed that the largest percentage of accidents is associated with skill-based errors, followed by decision errors, violations of the rules and regulations, and perceptual errors. While individual interventions may address one error form more than another, a true intervention "strategy" will identify a variety of interventions targeted at all four error forms. The next step in this research effort will be the development of the Human Factors Intervention Matrix (HFIX) that pits the unsafe acts of operators (i.e., skill-based errors, decision errors, perceptual errors, and violations) against several putative intervention approaches (e.g., organizational, human-centered, technology, task, and environment; Figure 13). In addition, other features will be integrated into the model/matrix such as feasibility, efficacy, and acceptance.

	Organizational/ Administrative	Human/ Crew	Technology/ Engineering	Task/ Mission	Operational/ Physical Environment
Decision Errors					
Skill-based Errors					
Perceptual Errors					
Violations					

Figure 13. *The Human Factors Intervention Matrix (HFIX).*

Once developed, HFIX will be validated and assessed using intervention programs currently in use and planned within the Small Airplane Directorate (ACE-100), the General Aviation & Commercial Division (AFS-800), Alaska Region (AAL), and other FAA offices.

Ultimately, the systematic application of HFACS, coupled with the methodical utilization of HFIX (once fully developed) to generate intervention solutions, should ensure that the aviation industry's personnel and monetary resources are utilized wisely. This should occur because such efforts will be needs-based and data-driven. Together, these tools will allow the true effectiveness of intervention programs to be objectively and impartially evaluated so that they can be either modified or reinforced to improve system performance. Only then can any great strides in improving the GA accident rate be achieved.

REFERENCES

Bird, F. (1974). Management guide to loss control. Atlanta, GA: Institute Press.

Burian, B., Orasanu, J., & Hitt, J. (2000). Weather-related decision errors: differences across flight types. Proceedings of the XIVth triennial Congress of the International Ergonomics Association/44th annual meeting of the Human Factors and Ergonomics Society. 22-4.

Degani, A. & Wiener, E. (1993). Cockpit checklists: Concepts, design, and use. *Human Factors*, 35(4), 345-60.

Funk, K. (1991). Cockpit task management: Preliminary definitions, normative theory, error taxonomy, and design recommendations. *The International Journal of Aviation Psychology*, 1(4), 271-85.

Glista, T. (2003). FAA/Industry Training Standards (FITS): Times (and training requirements are a changing). *FAA Aviation News*, 42(4), 1-6.

Goh, J. & Wiegmann, D. (2002). Human error analysis of accidents involving visual flight rules flight into adverse weather. *Aviation, Space, and Environmental Medicine*, 78(8), 817-22.

Haddon, W. (1980). Options for the prevention of motor vehicle crash injury. *Israeli Medical Journal*, 16, 45-65.

Heinrich, H., Petersen, D., & Roos, N. (1931). Industrial accident prevention: A safety management approach (1st ed.). New York, NY: McGraw-Hill.

Holbrook, J., Orasanu, J., & McCoy, C., (2003). Weather-related decision making by aviators in Alaska. Proceedings of the 12th International Symposium on Aviation Psychology, 576-81.

Knecht, W., Harris, H., & Shappell, S. (2003). Effects of visibility, cloud ceiling and financial incentive on general aviation voluntary takeoff into adverse weather. Proceedings of the 12th International Symposium on Aviation Psychology, 669-73.

Layton, C., Smith, P., & McCoy, E. (1994). Design of a cooperative problem-solving system for en-route flight planning: An empirical evaluation. *Human Factors*, *36*(1), 94-119.

Murray, S. (1997). Deliberate decision making by aircraft pilots: A simple reminder to avoid decision making under panic. *The International Journal of Aviation Psychology*, *7*(1), 83-100.

Muthard, E., & Wickens, C. (2003). Factors that mediate flight plan monitoring and errors in plan revision: Planning under automated and high workload conditions. Proceedings of the 12th International Symposium on Aviation Psychology, 857-62.

Norman, D. (1988). The Psychology of Everyday Things. New York: Basic Books.

O'Hare, D. (1990). Pilots' perception of risks and hazards in general aviation. *Aviation, Space, and Environmental Medicine*, *61*, 599-603.

O'Hare, D., Wiggins, M., Batt, R., & Morrison, D. (1994). Cognitive failure analysis for aircraft accident investigation. *Ergonomics*, 37(11), 1855-69.

O'Hare, D., & Owen, D. (1999). Continued VFR into IMC: An empirical investigation of the possible causes: Final report on preliminary study. Unpublished manuscript. University of Otago, Dunedin, New Zealand.

O'Hare, D., & Smitheram, T. (1995). "Pressing on" into deteriorating conditions: An application of behavioral decision theory to pilot decision making. *International Journal of Aviation Psychology, 5*, 351-70.

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, CA: 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 an information processing approach to mishap causal factors. Proceedings of the Eighth International Symposium on Aviation Psychology, The Ohio State University, 1300-6.

Shappell, S. & Wiegmann, D. (1997). Why would and experienced aviator fly a perfectly good aircraft into the ground? Proceedings of the Ninth International Symposium on Aviation Psychology, The Ohio State University, 26-32.

Shappell, S. & Wiegmann, D. (2000). The Human Factors Analysis and Classification System (HFACS). Federal Aviation Administration, Office of Aviation Medicine Report No. DOT/FAA/AM-00/7. Office of Aviation Medicine: Washington, DC.[1]

Shappell, S. & Wiegmann, D. (2001). Applying Reason: the human factors analysis and classification system (HFACS). *Human Factors and Aerospace Safety, 1*, 59-86.

Shappell, S. & Wiegmann, D. (2003). A human error analysis of general aviation controlled flight into terrain (CFIT) accidents occurring between 1990-1998. Federal Aviation Administration, Office of Aerospace Medicine Technical Report No. DOT/FAA/AM-03/4. Office of Aerospace Medicine: Washington, DC.[1]

Wickens, C., & Hollands, J. (2000). Engineering psychology and human performance. Upper-Saddle River, NJ: Prentice-Hall.

Wiegmann, D., Goh, J., & O'Hare, D. (2002). The role of situation assessment and flight experience in pilots' decisions to continue visual flight rules flight into adverse weather. *Human Factors*, *44*(2), 189-97.

Wiegmann, D. & Rantanen, E. (2002). Defining the Relationship Between Human Error Classes and Technology Intervention Strategies (Technical Report ARL-02-1/NASA-02-1). Savoy, IL: University of Illinois, Aviation Research Lab.

Wiegmann, D & Shappell, S. (1995). Human factors in U.S. naval aviation mishaps: An information processing approach. Proceedings of the Eighth International Symposium on Aviation Psychology, The Ohio State University, 1295-99.

Wiegmann, D., & Shappell, S. (1997). Human factors analysis of post-accident data: Applying theoretical taxonomies of human error. *The International Journal of Aviation Psychology*, *7*(1), 67-81.

---

[1] This publication and all Office of Aerospace Medicine technical reports are available in full-text from the Civil Aerospace Medical Institute's publications Web site: www.faa.gov/library/reports/medical/oamtechreports/index.cfm

Wiegmann, D., & Shappell, S. (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.

Wiegmann, D. & Shappell, S. (2001a). Human error analysis of commercial aviation accidents: Application of the Human Factors Analysis and Classification System (HFACS). *Proceedings of the Eleventh International Symposium on Aviation Psychology*, The Ohio State University.

Wiegmann, D. & Shappell, S. (2001b). Human error analysis of commercial aviation accidents: Application of the Human Factors Analysis and Classification System (HFACS). *Aviation, Space and Environmental Medicine*, *72*, 1006-16.

Wiegmann, D., & Shappell, S. (2001c). Human error perspectives in aviation. *International Journal of Aviation Psychology, 11*(4), 341-57.

Wiegmann, D. & Shappell, S. (2003). A human error approach to aviation accident analysis: The human factors analysis and classification system. Burlington, VT: Ashgate

Wiener, E., Kanki, B., & Helmreich, R. (Eds.) (1993). Cockpit resource management. San Diego, CA: Academic Press.

Wiggins, M., & O'Hare, D. (2003). Expert and novice pilot perceptions of static in-flight images of weather. *The International Journal of Aviation Psychology*, *13*(2), 173-87.