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

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The Human Factors Analysis and Classification System (HFACS) is a theoretically based tool for investigating and analyzing human error. The aim of this study was to extend previous examinations of aviation accidents to include specific aircrew, environmental, supervisory, and organizational factors associated with 14 CFR Part 121 (Air Carrier) and 14 CFR Part 135 (Commuter) accidents using HFACS. The majority of causal factors were attributed to the aircrew and the environment with decidedly fewer associated with supervisory and organizational causes. Recommendations were made based on the HFACS findings presented.

INTRODUCTION

While commercial[1] aviation accident rates have reached unprecedented levels of safety, little, if any, improvement has been realized over the last decade for either the air carrier or commuter/air taxi industry (Figure 1). Indeed, some have even suggested that the current accident rate is as good as it gets – or is it?

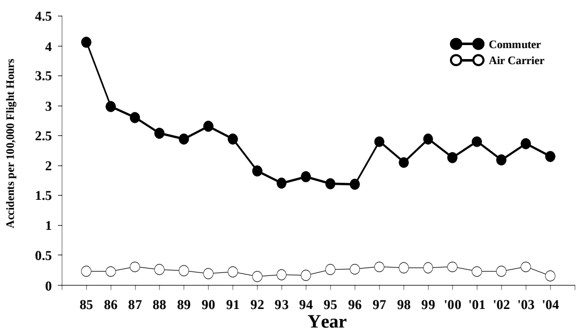

Figure 1. Air carrier and commuter/air taxi accident rates since 1985 (Source: NTSB).

The challenge for the Federal Aviation Administration (FAA) and other civil aviation safety organizations is to improve an already very safe industry. The question is where to start when most of the "low hanging fruit" (e.g., improved powerplant and airframe technology, advanced avionics, and the introduction of automation) have been "picked."

It is typically reported that somewhere between 60-80% of aviation accidents are due, at least in part, to human error (Shappell & Wiegmann, 1996). That being said, it may be surprising that with few exceptions (e.g., Billings & Reynard, 1984; Gaur, 2005; Li, Baker, Grabowski, & Rebok, 2001; Shappell & Wiegmann, 2003a, 2003b; Wiegmann & Shappell, 2003) most studies to date have focused on situational factors or pilot demographics, rather than the underlying human error causes of accidents.

Judging from current accident rates, situational and pilot demographic data alone have provided little in the way of preventing accidents, apart from identifying target populations for the dissemination of safety information. Given the multi-factorial nature of accidents (Baker, 1995), it may make more sense to examine these variables within the context of what we know about human error and accident causation.

HFACS

It is generally accepted that aviation accidents are typically the result of a chain of events that often culminate with the unsafe acts of operators (aircrew). The aviation industry is not alone in this belief, as the safety community has embraced a sequential theory of accident investigation since Heinrich first published his axioms of industrial safety in 1931 (Heinrich, Peterson, & Roos, 1931). When Reason published his "Swiss cheese" model of human error in 1990, the aviation community began a systematic examination of human error.

Drawing upon Reason's (1990) concept of latent and active failures, HFACS describes human error at each of four levels: 1) the unsafe acts of operators (e.g., aircrew, maintainers, air traffic controllers), 2) preconditions for unsafe acts, 3) unsafe supervision

[1] The FAA distinguishes between two types of commercial operations: those occurring under 14 CFR Part 121 – Air Carrier Operations and those occurring under CFR Part 135 commuter/air taxi operations.

(i.e., middle-management), and 4) organizational influences.[2]

Unsafe Acts of Operators

The unsafe acts of operators (aircrew) can be loosely classified into one of two categories: errors and violations (Reason, 1990). While both are common within most settings, they differ markedly when the rules and regulations of an organization are considered. Errors represent authorized behavior that fails to meet the desired outcome. Whereas, violations refer to the willful disregard of the rules and regulations. It is within these two overarching categories that HFACS describes three types of errors [decision (DE), skill-based (SBE), and perceptual (PE)] and two types of violations (V, routine and exceptional).

Preconditions for Unsafe Acts

Simply focusing on unsafe acts, however, is not enough. Investigators must dig more deeply into the preconditions for unsafe acts. Within HFACS, three major subdivisions are described: 1) condition of the operator, 2) personnel factors, and 3) environmental factors.

Unsafe Supervision

Clearly, aircrews are responsible for their actions and, as such, must be held accountable. However, in some instances, they are the unwitting inheritors of latent failures attributable to those who supervise them. To account for these, the overarching category of unsafe supervision was created within which four categories (inadequate supervision, planned inappropriate operations, failed to correct known problems, and supervisory violations) are included.

Organizational Influences

Where decisions and practices by front-line supervisors and middle-management can adversely impact aircrew performance, fallible decisions of upper-level management may directly affect supervisors and the personnel they manage. The HFACS framework describes three latent organizational failures: 1) resource management, 2) organizational climate, and 3) operational processes.

PURPOSE

The goal of the present study was twofold: 1) to extend our previous HFACS analyses beyond military and general aviation (GA) to include a comprehensive analysis of commercial aviation; and 2) to combine the power of a theoretically derived human error framework (i.e., HFACS) with traditional situational and demographic data from the accident records.

METHOD

Data

Commercial aviation accident data (i.e., 14 CFR Part 121 – air carrier; 14 CFR Part 135 – commuter) from calendar years 1990-2002 were obtained from databases maintained by the National Transportation Safety Board (NTSB) and the FAA's National Aviation Safety Data Analysis Center (NASDAC).

Eliminated from consideration were accidents that were classified as having "undetermined causes," and those that were attributed to sabotage, suicide, or criminal activity (e.g., stolen aircraft). The data were culled further to include accidents that involved aircrew or supervisory error. Of the remaining 1,020 accidents, 181 involved air carrier aircraft and 839 involved commuter aircraft.

Causal Factor Analysis Using HFACS

Six pilots served as subject matter experts (SMEs). All were certified flight instructors with a minimum of 1,000 flight hours at the time they were recruited.

Each pilot was provided roughly 16 hours of instruction on the HFACS framework. After training, the pilots were randomly assigned accidents such that at least two separate pilots independently analyzed each accident.

Using narrative and tabular data obtained from both the NTSB and the FAA NASDAC, the pilots classified each aircrew or supervisory causal factor identified by the NTSB using the HFACS framework. Where disagreements existed, the corresponding pilots were instructed to reconcile their differences. Overall, pilots agreed more than 85% of the time.

RESULTS

A summary of the HFACS analyses of commercial aviation accidents can be found in Table 1. The majority of human causal factors identified involved aircrew and their environment (i.e., *unsafe acts of operators* and *preconditions for unsafe acts*) rather than supervisory or organizational factors. Nevertheless, when organizational influences were observed they typically involved *operational processes* such as inadequate or non-existent procedures, directives, standards, and/or requirements or in the case of commuter operations, inadequate surveillance of operations. Unsafe supervision on the other hand, typically involved *inadequate supervision* in general or the failure to provide adequate training.

As anticipated, a large number of *environmental conditions* were identified within the commercial aviation database, particularly those associated with

[2] A complete description of all 19 HFACS causal categories is available elsewhere (see Wiegmann & Shappell, 2003)

aspects of the *physical environment* like weather and lighting. However they were not uniformly distributed across air carrier and commuter operations, as considerably more issues associated with the *physical environment* were observed during commuter (63%) than air carrier operations (37%). In contrast, the accident record revealed surprisingly few problems associated with the technological environment. Preconditions associated with aircrew were also frequently observed within the accident record. For instance, *crew resource management (CRM)* failures were identified in nearly one out of every five air carrier accidents examined. Even more interesting, the nature of the CRM failure differed between the two commercial operations. That is, while over 60% of the CRM failures associated with air carrier accidents involved "inflight" CRM failures (e.g., inflight crew coordination, communication, monitoring of activities, etc.), over 80% of the CRM failures observed during commuter operations involved "preflight" activities (such as planning and briefing).

As seen in other aviation operations (Shappell & Wiegmann, 1995, 1997, 2003a, 2003b, 2004; Wiegmann & Shappell, 1997, 2001a, 2001b, 2003) the majority of commercial aviation accident causal factors were found at the unsafe act level. Indeed, just over half of the accidents were associated with at least one SBE, followed by DEs (36.7%) and Vs of the rules and regulations (23.1%).

Similar to other civil aviation accident data (Shappell & Wiegmann, 2003a, 2003b, 2004; Wiegmann & Shappell, 2003), there was little variation in the distribution of unsafe acts committed annually by aircrew flying either air carrier or commuter operations (Figure 2A & 2B). When accidents occurred in either type of commercial operation, they were typically associated with more SBEs followed by DEs, Vs, and PEs respectively. This was true even though the air carrier data had to be averaged over 3 or 4 year blocks due to the small number of accidents in the database (Figure 2A). Moreover, with the exception of the violations category which has shown a slight increase since the 1993-1995 time frame, the annualized data were relatively flat suggesting that there has been little impact on any specific type of human error over the last 13 years.

Table 1. Frequency and percentage of accidents associated with each HFACS causal category by type of operation.

HFACS Category	Air Carrier	Commuter	Total
Organizational Influences	**N (%)**	**N (%)**	**N (%)**
Resource Management	4 (2.2)	0 (0.0)	4 (0.4)
Organizational Climate	0 (0.0)	4 (0.5)	4 (0.4)
Operational Process	21 (11.6)	29 (3.5)	50 (4.9)
Unsafe Supervision			
Inadequate Supervision	15 (8.3)	21 (2.5)	36 (3.5)
Planned Inappropriate Operations	3 (1.7)	5 (0.6)	8 (0.8)
Failed to Correct Known Problems	0 (0.0)	0 (0.0)	0 (0.0)
Supervisory Violations	0 (0.0)	2 (0.2)	2 (0.2)
Preconditions of Unsafe Acts			
Environmental Conditions			
Technological Environment	11 (6.1)	4 (0.5)	15 (1.5)
Physical Environment	67 (37.0)	525 (62.6)	592 (58.0)
Conditions of the Operator			
Adverse Mental States	6 (3.3)	60 (7.2)	66 (6.5)
Adverse Physiological States	6 (3.3)	18 (2.1)	24 (2.4)
Physical/Mental Limitations	6 (3.3)	39 (4.6)	45 (4.4)
Personnel Factors			
Crew Resource Management	34 (18.8)	75 (8.9)	109 (10.7)
Personal Readiness	0 (0.0)	3 (0.4)	3 (0.3)
Unsafe Acts of the Operator			
Skill-based Errors	77 (42.5)	499 (59.5)	576 (56.5)
Decision Errors	71 (39.2)	303 (36.1)	374 (36.7)
Perceptual Errors	10 (5.5)	56 (6.7)	66 (6.5)
Violations	31 (17.1)	205 (24.4)	236 (23.1)

Note: Numbers in the table involve at least one instance of an HFACS category. For example 77 of the 181 air carrier accidents (77/181 or 42.5%) were associated with at least one skill-based error. Because accidents are generally associated with more than one causal factor, the percentages in the table do not add up to 100%.

14 CFR Part 135 - Commuter Operations

Because of the relatively small number of air carrier accidents in the database related to aircrew/supervisory error, additional fine-grained analyses of those data were not possible. However, more detailed analyses were conducted for commuter operations.

Visual Conditions. Given the relatively large percentage of accidents associated with physical conditions, in particular those associated with prevailing weather conditions and lighting, it seemed reasonable to begin with these two environmental causal factors. As can be seen in Figure 3A, just over 70% of the accidents occurred during visual meteorological conditions (VMC). Likewise, roughly 70% of the accidents occurred in broad daylight (Figure 3B).

In order to capitalize on the threat posed by both environmental causal factors, the two were combined to create a new variable. Specifically, two levels of visual conditions were created: 1) clear visual conditions which included accidents that occurred during VMC and daylight conditions, and 2) impoverished visual conditions that included accidents occurring during instrument meteorological conditions (IMC) or at twilight/night.

Unlike the results seen with weather and lighting conditions alone, the recombination of visual factors showed that the percentage of accidents occurring in clear visual conditions was only marginally higher than that occurring in visually impoverished conditions (Figure 3C). It would appear that while weather and lighting conditions are important factors in aviation, their impact is potentially magnified when a pilot's ability to see outside the aircraft is taken into consideration.

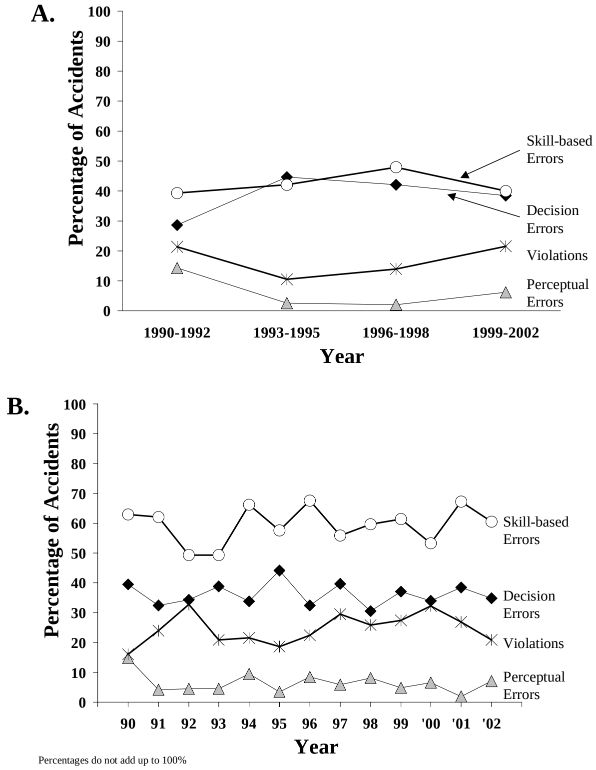

Figure 2. Percentage of unsafe acts committed by aircrew during air carrier (Panel A) and commuter (Panel B) operations by year.

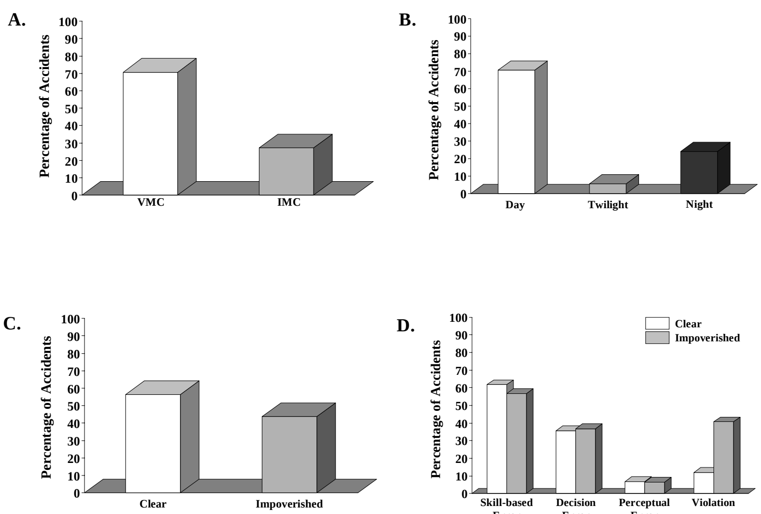

Figure 3. Percentage of commuter accidents by weather conditions (Panel A), lighting conditions (Panel B), visual conditions (Panel C) and visual conditions by unsafe acts (Panel D).

Naturally, one would expect the pattern of human error to be different during accidents in clear versus visually impoverished conditions. Indeed, when visual conditions were compared across the unsafe acts of aircrew (Figure 3D), an interesting pattern of human error emerged. While SBEs were the most common error form observed during accidents in clear and impoverished conditions, Vs were five times more likely to be attributed to accidents in visually impoverished conditions (X^2 = 92,322, p<.001; odds ratio = 5.077).

Upon closer examination, intentional flight into IMC while operating under visual flight rules (i.e., VFR flight into IMC) accounted for nearly 1/3 of the Vs observed during impoverished visual conditions. In addition, the failure to adhere to procedures/directives (V), poor in-flight planning/decision making (DE), the loss of control in-flight (SBE), and the failure to maintain sufficient airspeed (SBE) all were commonly cited as causes during accidents in visually impoverished conditions.

The failure to adhere to procedures/directives (V) was also frequently seen among accidents in clear conditions as was poor in-flight planning/decision-making (DE). However, unlike impoverished visual conditions, commuter accidents occurring in the clear were often associated with the selection of unsuitable terrain (DE) and the inability to compensate for winds (SBE).

Injury Severity. Previous investigations of GA accidents have shown distinct differences in the pattern of human error associated with fatal and non-fatal aviation accidents (Shappell & Wiegmann, 2003a, 2003b; Wiegmann & Shappell, 2003). A similar examination of commuter accidents revealed that roughly 30% of all commuter accidents resulted in at least one fatality.

As with the findings regarding visual conditions, SBEs were associated with the majority of fatal and non-fatal accidents followed by DEs, Vs, and PEs. Of note however, Vs were more than three times as likely to be associated with fatal accidents (X^2 = 48.239, p<.001; odds ratio = 3.145).

Upon closer examination, it appears that causal factors such as intentional VFR flight into IMC (V), poor in-flight planning/decision making (DE), and control of the aircraft and airspeed (SBE) were the most frequently cited aircrew errors associated with fatal accidents. In contrast, non-fatal accidents appear to be more closely associated with the failure to compensate for winds (SBE), loss of directional control on the ground (SBE), selection of unsuitable terrain (DE), poor in-flight planning/decision-making (DE), and the failure to follow procedures/directives (V).

Given the similarity in the pattern of human errors associated with visual conditions and injury severity (fatal vs. non-fatal), it made sense to examine the combination of the two variables. The largest percentage of fatal commuter accidents occurred in visually impoverished conditions. In contrast, when the accident occurred in clear visual conditions, a much smaller percentage resulted in fatalities. Indeed, commuter accidents were over four times more likely to result in fatalities if they occurred in visually impoverished conditions (X^2 = 83.978, p<.001; odds ratio = 4.256).

Fully one half of the fatal accidents occurring in visually impoverished conditions involved at least one V – often intentional VFR flight into IMC. Not surprisingly, given the environmental conditions at the time, poor in-flight planning (DE) was also commonly cited among this subset of the data.

DISCUSSION

Generally speaking, nearly 70% of the "commercial" aviation accidents occurring between 1990 and 2002 were associated with some manner of aircrew or supervisory error. However, the percentage varied slightly when air carrier (45%) and commuter (75%) aviation accidents were considered separately. This finding is consistent with results reported elsewhere (Li, Baker, Grabowski, & Rebok, 2001).

Organizational Influences and Unsafe Supervision

Consistent with previous work (Wiegmann & Shappell, 2001a), comparatively few commercial aviation accidents were associated with organizational and/or supervisory causal factors - particularly within the commuter aviation industry. In spite of this, a relatively large proportion of accidents involved issues related to *operational processes*. Causal factors associated with the remaining HFACS organizational causal categories, *resource management* and *organizational climate*, were rarely observed in the data.

A closer inspection revealed that the particular type of *operational process* cited appeared to be dependent on the type of operation involved. Namely, air carrier accidents were typically associated with the manner in which procedures or directives were communicated assuming they existed at all. In contrast, commuter accidents were more often associated with a lack of organizational oversight. Exactly why this difference might exist requires a more in-depth investigation than what was performed here.

Preconditions for Unsafe Acts (Aircrew)

With a couple of notable exceptions causal categories within the preconditions for unsafe acts were also lightly populated. One of those exceptions was the large proportion of accidents (particularly among commuter aviation) influenced by prevailing weather conditions and reduced visibility. This was not particularly surprising since studies like the one conducted by Baker, Lamb, Li, and Dodd (1993) reported similar results in their examination of commuter accidents between 1983 and 1988.

While previous efforts suggested that factors associated with the *physical environment* and *CRM* would be identified among the commercial data, it was surprising that other areas, in particular the *condition of the operator (aircrew)*, were not identified in the accident record more often. The exception involved commuter aviation accidents, where a number of *adverse mental states* (64 out of 839 accidents or 7.2%) and *physical/mental limitations* (43 out of 839 or 4.6%) were observed.

In some ways the fact that many commuter aviation operations are single-piloted may explain why *adverse mental states* played a more prominent role among these accidents. For instance, without a second set of eyes in the cockpit any distraction would likely be exacerbated and distract the pilot from the task at hand – flying the aircraft.

Perhaps more disconcerting than the issue of attention was the large number of commuter aviation accidents associated with the pilot's lack of experience – something rarely seen among the air carrier accidents examined. Whether this represents a lack of flight hours or merely inexperience with a particular operational setting or aircraft remains to be determined. Still, flight hours alone may not be sufficient to overcome the lack of experience observed here. After all, flying straight and level in VMC will not prepare a pilot for the complexities of instrument flight or the dangers of flying in other potentially hazardous environments.

Unsafe Acts of Operators (Aircrew)

As with our previous efforts involving civil and military aviation (Wiegmann & Shappell, 1997, 1999, 2001a, 2001b), SBEs were the most prevalent form of aircrew error among the commercial aviation accidents examined. Particularly widespread were technique errors associated with handling or controlling the aircraft. More important, when the commercial data reported here were combined with our previous investigations of GA accidents (Wiegmann, Shappell, Boquet, Detwiler, Holcomb, Faaborg, in press; Detwiler, Hackworth, Holcomb, Boquet, Pfleiderer, Wiegmann, and Shappell, in review) an interesting finding emerged. It appears that the percentage of SBEs associated with accidents increases systematically as one moves from air carrier (43%) to commuter (60%) to GA (73%) operations.

At first glance, this would appear to suggest that pilot skill and proficiency is best among the air carrier industry and becomes progressively more suspect within commuter and GA. Recall that SBEs, by definition, occur during the execution of routine events (Reason, 1990; Rasmussen, 1982). Furthermore, once a particular skill is developed, it must be maintained through repetition and experience. That being said, most people would agree that GA pilots fly less and participate in fewer recurrent training sessions than their commercial counterparts. It stands to reason that their proficiency would be less than their commercial counterparts and may explain why SBEs are more prevalent among GA accidents.

DEs were observed in roughly four out of every ten commercial aviation accidents while Vs and PEs were observed in 23% and 7% of the accidents, respectively. Some have even argued that DEs and Vs are of the same ilk (i.e., both involve decisions by aircrew that go awry) and should actually be combined in the HFACS framework. If this were true, the combined causal category of DE/V would be roughly equivalent to that seen with SBEs.

Scenario-based training, in-flight planning aids, and education may improve pilot decision-making; however, these approaches have been largely ineffective in stemming Vs. Instead, enforcing current standards and increasing accountability in the cockpit may be the only effective means to reduce violations of the rules – a tactic that is often difficult to employ in civil aviation. As a result, the FAA and the commercial aviation industry may have to look to other avenues to reduce Vs such as the use of flight simulators that can demonstrate the hazards associated with violating the rules (Knecht, Harris, & Shappell, 2003).

REFERENCES

Baker, S. (1995). Putting "human error" into perspective. *Aviation, Space, and Environmental Medicine, 66*, 521.

Baker, S., Lamb, M., Li, G., & Dodd, R. (1993). Human factors in crashes of commuter airplanes. *Aviation, Space, and Environmental Medicine, 64*, 63-68.

Billings, C. & Reynard, W. (1984). Human factors in aircraft incidents: Results of a 7-year study. *Aviation, Space, and Environmental Medicine, 55*, 960-965.

Detwiler, C., Hackworth, C., Holcomb, K., Boquet, A., Pfleiderer, E., Wiegmann, D., & Shappell, S. (in review). Beneath the tip of the iceberg: A human factors analysis of general aviation accidents in Alaska verses the rest of the United States. Federal Aviation Administration, Office of Aerospace Medicine Technical Report No. DOT/FAA/AM-05/xx. Office of Aerospace Medicine: Washington, DC.

Gaur, D. (2005). Human factors analysis and classification system applied to civil aircraft accidents in India. *Aviation, Space, and Environmental Medicine, 76*, 501-505.

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

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.

Li, G., Baker, S., Grabowski., J., & Rebok, G. (2001). Factors associated with pilot error in aviation crashes. *Aviation, Space, and Environmental Medicine*, *72*, 52-58.

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, 1300-06.

Shappell, S. & Wiegmann, D. (1996). U.S. naval aviation mishaps 1977-92: Differences between single- and dual-piloted aircraft. *Aviation, Space, and Environmental Medicine, 67*(1), 65-69.

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. (2003a). 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.

Shappell, S. & Wiegmann, D. (2003b). Reshaping the way we look at general aviation accidents using the human factors analysis and classification system. *Proceedings of the Twelfth International Symposium on Aviation Psychology*, Dayton, Ohio.

Shappell, S. & Wiegmann, D. (2004). HFACS Analysis of Military and Civilian Aviation Accidents: A North American Comparison. *Proceedings of the Annual Meeting of the International Society of Air Safety Investigators*, Gold Coast, Australia.

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.

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). *Aviation, Space and Environmental Medicine, 72*, 1006-16.

Wiegmann, D. & Shappell, S. (2001b). 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.

Wiegmann, D., Shappell, S., Boquet, A., Detwiler, C., Holcomb, K., & Faaborg, T. (in press). Human error and general aviation accidents: A comprehensive, fine-grained analysis using HFACS. Federal Aviation Administration, Office of Aerospace Medicine Technical Report No. DOT/FAA/AM-05/xx. Office of Aerospace Medicine: Washington, DC.