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

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A large effort has been expended over the last several decades to lower the military and commercial aviation accident rates. Unfortunately, until recently, a similar effort has not occurred within the general aviation (GA) community even though the total number of accidents is considerably greater. As part of the FAA's endeavor to better understand the etiology of GA accidents we previously analyzed eleven years (1990-2000) of GA accidents using the Human Factors Analysis and Classification System (HFACS). The findings, though significant, spawned additional questions regarding the nature of aircrew error associated with GA accidents. For instance, how often is each error type the "initiating" error in the causal chain of events and what are the exact types of errors committed within each error category? This brief report details the efforts made by the University of Illinois and the FAA Civil Aerospace Medical Institute to address these questions in FY 2003.

INTRODUCTION

It is generally accepted that like most accidents, those in aviation do not happen in isolation. Rather, they are often 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. 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. Included were: 1) Organizational influences, 2) Unsafe supervision, 3) Preconditions for unsafe acts, and 4) the Unsafe acts of operators. Unfortunately, while Reason's seminal work forever altered the way aviation and other accident investigators view human error; it did not provide the level of detail necessary to apply it in the real world.

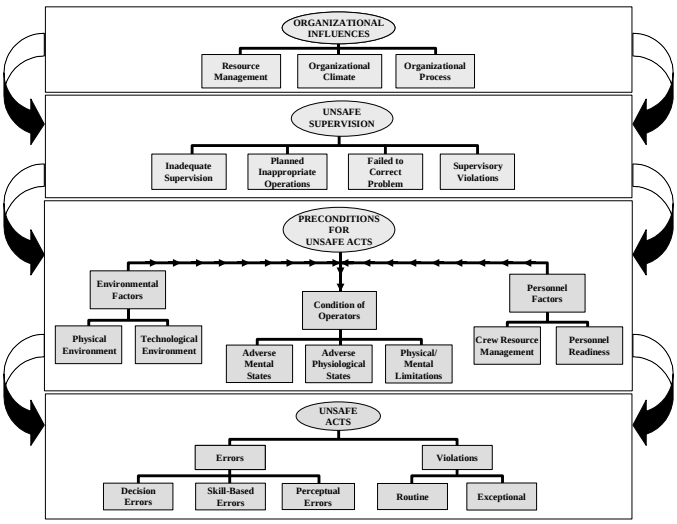

Figure 1. The HFACS framework.

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. The HFACS framework includes 19 causal categories within Reason's (1990) four levels of human failure (Figure 1). Unfortunately, a complete description of all 19 causal categories is beyond the scope of this brief report. It is however, available elsewhere (Wiegmann and Shappell, 2003).

HFACS

Particularly germane to any examination of GA accident data are the unsafe acts of aircrew – all the while keeping in mind that data from the preconditions for unsafe acts, and in some instances unsafe supervision and organizational influences, are important as well. For that reason, we will briefly describe the causal categories associated with the unsafe acts of GA aircrew.

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, on occasion these procedures are either 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 there is insufficient experience, time, or other outside pressures that 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.

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 ones 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 emergencies experienced in the air.

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 decent 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 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 (Shappell and Wiegmann, 1995).

Routine Violations. While there are many ways to distinguish between types of violations, two distinct forms have been identified, based on their etiology. The first, routine violations, tend to be habitual by nature and are often tolerated by the governing authority (Reason, 1990). Consider, for example, the individual who drives consistently 5-10 mph faster than allowed by law or someone who routinely flies in marginal weather when authorized for 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 nor condoned by management (Reason, 1990). For example, an isolated instance of driving 105 mph in a 55 mph zone is considered an exceptional violation. Likewise, flying under a bridge or engaging in other particularly dangerous and prohibited maneuvers would constitute an exceptional violation. However, it is important to note that, while most exceptional violations are indefensible, they are not considered exceptional because of their extreme nature. Rather, they are considered exceptional because they are neither typical of the individual nor condoned by authority. Unfortunately, the unexpected nature of exceptional violations makes them particularly difficult to predict and problematic for organizations to manage.

Previous Findings

Previous HFACS research performed at both the University of Illinois and the Civil Aerospace Medical Institute (CAMI) has shown that HFACS can be reliably used to analyze the underlying human factors causes of both commercial and GA accidents (Wiegmann & Shappell, 2001, 2003; Shappell & Wiegmann, 2003). Furthermore, these analyses have helped identify general trends in the types of human error that have contributed to civil aviation accidents.

When the GA accidents between 1990-2000 were examined using the HFACS framework; several heretofore unknown facts regarding GA aviation safety were revealed (Figure 2). For instance, it appears that safety efforts over the last several years have had little impact (flat trend lines) on any specific type of human error associated with GA accidents. If anything, they have had a ubiquitous impact – albeit unlikely. Equally

noteworthy, skill-based errors have contributed to GA accidents more than any other error form (roughly 80% of all GA accidents examined). Given that most of these skill-based errors were technique (stick-and-rudder) errors, it would seem to indicate that there may be a problem associated with current training and/or pilot currency/proficiency.

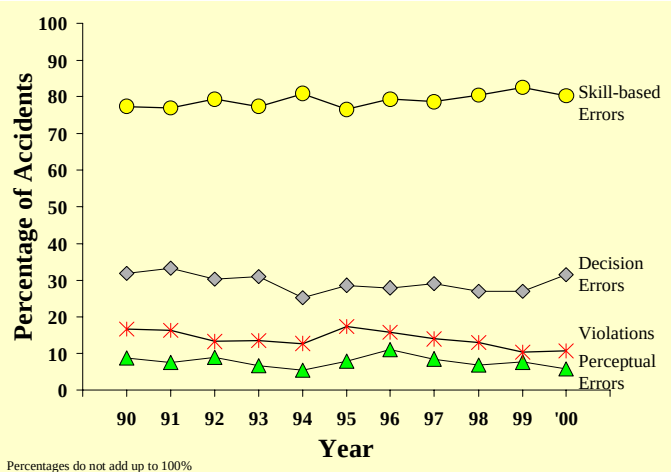

Figure 2. Overall percentage of GA accidents associated with at least one instance of a given unsafe act.

Furthermore, when the data are separated into fatal (Figure 3) and non-fatal (Figure 4) accidents, clear differences in the pattern of human error were noted. For example, while skill-based errors remained the predominant error form observed during both fatal and non-fatal accidents, violations of the rules were much more likely to occur during fatal than non-fatal GA accidents. The data also suggest that if a GA pilot elects to continue into IMC when he/she is VFR only (the predominant violation observed in the data), they are over 3 times more likely to die or kill someone else.

Although there was some variation, there were no significant differences observed between fatal and non-fatal accidents for decision or perceptual errors. That is, decision errors were observed in roughly 30% of the fatal and non-fatal accidents examined, while perceptual errors were associated with less than 10% of fatal and non-fatal accidents.

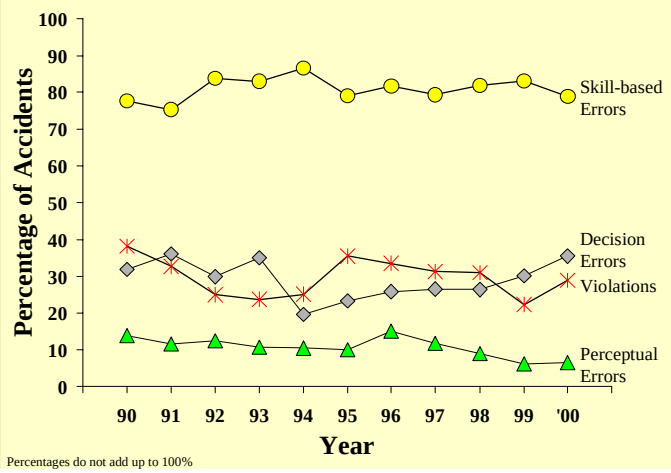

Figure 3. HFACS analysis of fatal GA accidents.

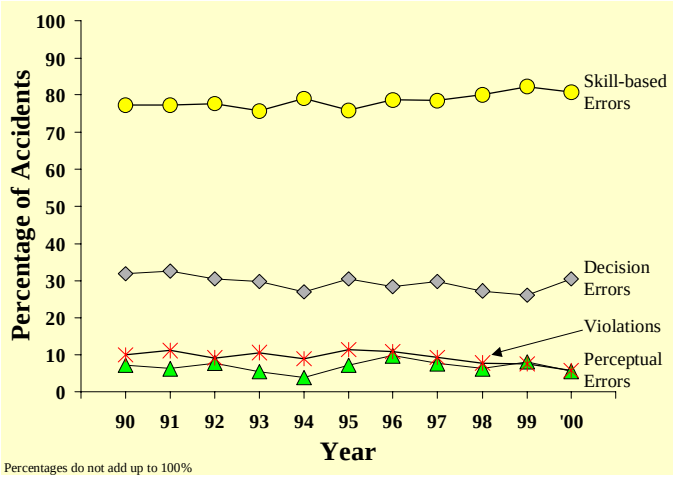

Figure 4. HFACS analysis of non-fatal GA accidents.

FY03 Research Effort

Key members of the FAA (e.g., AFS-800) and several committees chartered to address GA safety (e.g., Aeronautical Decision Making (ADM) JSAT and the General Aviation Data Improvement Team (GADIT)) have acknowledged the added value and insights gleaned from the HFACS analyses. However, these individuals and committees have requested that additional analyses be done to answer specific questions regarding the nature of the human errors identified within the context of GA. For instance:

- How important is each error type? That is, how often is each error type the "primary" cause of an accident? For example, 80% of accidents might be associated with skill-based errors; but how often are they the "initiating" error or simply the "consequence" of another type of error, such as decision errors?
- What are the exact types of errors committed within each error category? In other words, how often do skill-based errors involve stick-and-rudder errors, verses attention failures (slips) or memory failures (lapses) and what are those errors specifically?

Answers to these questions were not available in the database, as it currently existed. Therefore, additional fine-grained analyses of the specific human error categories within HFACS were needed to answer these and other questions that have arisen, and to target problem areas within GA for future interventions. A new requirement was therefore initiated in 2002 to address these questions. CAMI and the University of Illinois are now midway through the second year of a three-year effort to perform a fine-grained HFACS analysis of the individual human causal factors associated with fatal GA accidents and to assist in the generation of possible intervention programs.

METHOD

Data

As with the previous studies (above), GA accident data from calendar years 1990-2000 was obtained from databases maintained by the NTSB and the FAA's National Aviation Safety Data Analysis Center (NASDAC). In total, 20,797 GA accidents were extracted for analysis. These so-called "GA" accidents actually included a variety of aircraft being flown under several different operating rules: 1) 14 CFR Part 91 – Civil

aircraft other than moored balloons, kites, unmanned rockets, and unmanned free balloons; 2) 14 CFR Part 91F – Large and turbine-powered multiengine airplanes; 3) 14 CFR Part 103 – Ultralight vehicles; 4) 14 CFR Part 125 – Airplanes with seating capacity of 20 or more passengers or a maximum payload capacity of 6,000 pounds or more; 5) 14 CFR Part 133 – Rotorcraft external-load operations; 6) 14 CFR Part 137 – Agricultural aircraft operations. In addition, the database contained several accidents involving public use aircraft (i.e., law enforcement, state owned aircraft, etc.) and a few midair accidents involving military aircraft.

Although all 20,797 accidents obtained can be found within the NTSB under the heading of "general aviation," we were only interested in those accidents involving aircraft operating under 14 CFR Part 91. After all, it is difficult to envision that large commercial aircraft being ferried from one airport to the next (operating under 14 CFR Part 91F) or aircraft being used to spread chemicals on a field (operating under 14 CFR Part 137) can be equated with small private aircraft being flown for personal or recreational purposes (operating under 14 CFR Part 91). This left us with 19,147 accidents in the database.

For this analysis we were primarily concerned with powered aircraft and therefore conducted another reduction of the data to include only accidents involving powered fixed-wing aircraft (i.e., no gliders, ultra-lights, balloons, or blimps), helicopters, and gyrocopters. The remaining 18,531 accidents were then examined for aircrew-related causal factors. Since we were only interested in those involving aircrew error, not those accidents that were purely mechanical in nature or those solely attributable to other human involvement, a final reduction of the data was conducted. Note, this does not mean that mechanical failures or other sources of human error did not exist in the final database, only that some form of aircrew error was also involved in each of the accidents included. In the end, 14,631 accidents were included in the database and submitted to further analyses using the HFACS framework.

Causal Factor Classification using HFACS

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

After our pilot-raters made their initial classifications of the human causal factors (i.e., skill-based error, decision-error, etc.) the two independent ratings were compared. Where disagreements existed, the corresponding pilot-raters were called into the laboratory to reconcile their differences and the consensus classification was included in the database for further analysis. Overall, pilot-raters agreed on the classification of causal factors within the HFACS framework more than 85% of the time (29,676 agreements; 4,474 disagreements).

RESULTS

Unlike our previous studies where we were interested in the percentage of accidents associated with at least one instance of a given unsafe act, our focus this FY has been on identifying the seminal (precipitating) aircrew unsafe act. That is, what percentage of the time are skill-based errors, decision errors, perceptual errors, and violations the first unsafe act committed by the aircrew in the chain of events leading to an accident. The results were very similar to those seen in our previous studies.

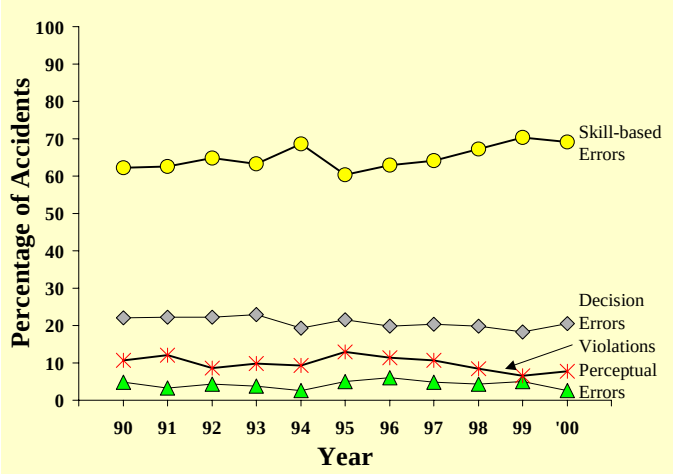

Figure 5. Seminal HFACS analysis of GA accidents.

An examination of the overall seminal HFACS analysis (Figure 5) revealed that, as before, skill-based errors were the most frequently cited seminal unsafe act by an almost 3 to 1 margin. These were followed by decision errors, violations, and perceptual errors in that order. Note that unlike the data from the previous studies, the percentages here do add up to 100% since there is only one seminal (precipitating) error per accident.

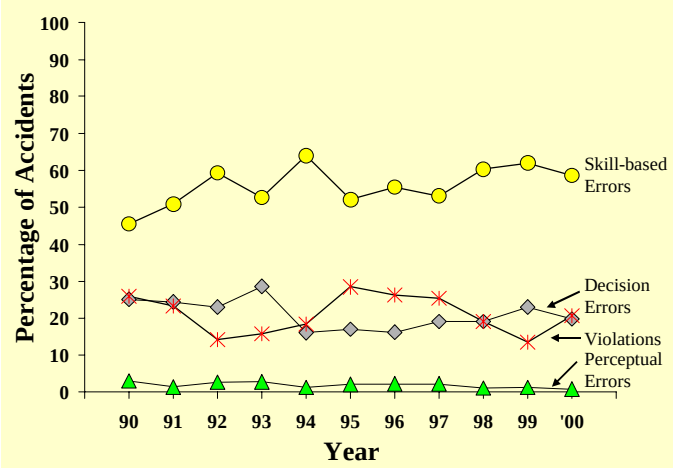

Figure 6. Seminal HFACS analysis of fatal GA accidents.

Even when the data are analyzed separately for fatal (Figure 6) and non-fatal GA accidents (Figure 7), the pattern of errors remained essentially unchanged. That is, skill-based errors were the most frequently cited seminal unsafe act. The only notable

difference was that considerably more violations were seminal in the chain of events leading up to a fatal accident when compared to non-fatal accidents.

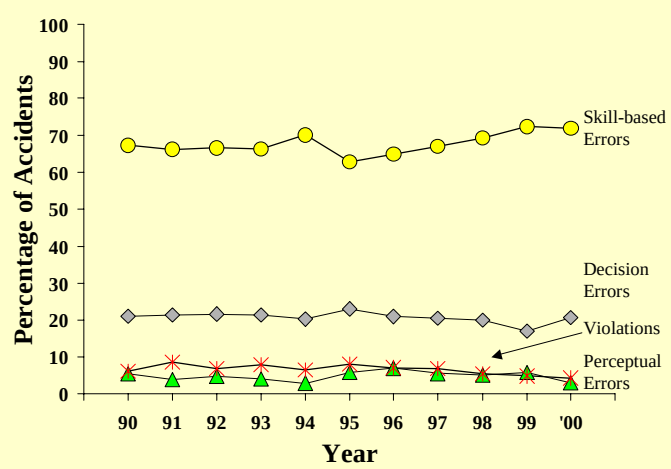

Figure 7. Seminal HFACS analysis of non-fatal GA accidents.

DISCUSSION

It would appear from our fine-grained analyses that it doesn't matter whether one examines the percentage of accidents associated with at least one instance of a given unsafe act or the seminal unsafe act, the pattern of human error observed among GA accidents remains essentially the same. That is, skill-based errors are consistently the most common error leading to a GA accident and in most cases is the seminal error form as well. Furthermore, when violations are associated with GA accidents they are much more likely to result in a fatality than if a violation is not committed. It is also noteworthy that while a great deal of effort has been expended to inform pilots of the hazards of spatial disorientation and visual illusions, it does not appear to have been done in vane since perceptual errors are the least common among all four categories of unsafe acts.

With the issue of seminal (precipitating) causal factors seemingly answered (i.e., the pattern of human error did not change appreciably from that previously reported looking at all aircrew errors), our work can now turn toward an examination of the specific types of skill-based errors, decision errors, perceptual errors, and violations that are most predominant among the unsafe acts. To give the reader a sense of what that analysis will look like, a preliminary analysis of the seminal skill-based errors was conducted and the results presented in Table 1.

Table 1. Top Five Seminal Skill-based Errors

Directional control	1357
Airspeed	1045
Compensation for winds	867
Aircraft control	809
Visual lookout	365

It is clear from the table that the top five types of skill-based errors all involve technique (stick-and-rudder/basic flight skills) errors rather than errors due to failures of attention or memory. This is important since it suggests that improved or additional training (both *ab initio* and recurrent) is needed to prevent or mitigate these types of errors.

The good news is that AFS-800 has recently introduced the FAA/Industry Training Standards (FITS) program aimed at improving GA flight training. 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. Furthermore, data from the HFACS analysis will provide valuable information for the FAA and other civilian organizations as they develop data-driven intervention and prevention strategies for the GA community.

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