HFACS Analysis of Military and Civilian Aviation Accidents: A North American Comparison

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HFACS ANALYSIS OF MILITARY AND CIVILIAN AVIATION ACCIDENTS: A NORTH AMERICAN COMPARISON

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Over the past several years, the Human Factors Analysis and Classification System (HFACS) has been used to analyze nearly a decade of accidents involving the U.S. military, U.S. scheduled and nonscheduled commercial air carriers, and U.S. general aviation (GA) aircraft. The results of these analyses have yet to directly compare the similarities and differences in human error trends across these seemingly diverse aviation communities. The purpose of this paper is to provide that comparison. A meta-analysis of over 16,000 accidents involving the U.S. Navy/Marine Corps (1990-1998), U.S. Air Force (1991-1997), U.S. Army (1992-1998), U.S. commercial air carriers (1990-1998) and U.S. general aviation aircraft (1990-1998) was conducted. Across all types of operations, skill-based errors were the primary human cause of these accidents, followed by decision errors, violations, and perceptual errors. Analyses revealed some differences between operation categories in terms of error trends across the years. This study provides the first ever comparison of human error causes of accidents across different types of U.S. aviation operations. These findings have direct implications for the development and sharing of safety programs that address specific types of human error in aviation.

INTRODUCTION

The last half-century has witnessed tremendous strides in aviation safety as technology and science have combined to dramatically reduce the rate of aviation accidents. However, over the last three decades that dramatic decline has slowed, reaching almost asymptotic levels. Some have even argued that the current rate of aviation accidents is “simply the cost of doing business.” To hear them describe it, perhaps what we are witnessing is a random accident rate that cannot be reduced constantly below current rates.

That being said, almost everyone agrees that somewhere between 70-80% of aviation accidents are attributed, at least in part, to human error (Wiegmann & Shappell, 2003). By definition then, human error is preventable and accident rates *can* be reduced still further. But how? What is that 70-80% of human error?

Since the mid-1990s we have examined the human causal factors associated with military and civilian aviation accidents (Wiegmann & Shappell, 2003). As part of that effort, we developed the Human Factors Analysis and Classification System (HFACS) to “put a face on human error.” The balance of this report will present our findings from the military and civilian aviation sectors in an attempt to determine the human causal factors associated with aviation accidents in the United States.

HFACS

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, 1980) axioms of industrial safety to 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 changed 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.

It wasn’t until Shappell and Wiegmann, (2000, 2001) developed a comprehensive human error framework, HFACS, that folded Reason’s ideas 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).

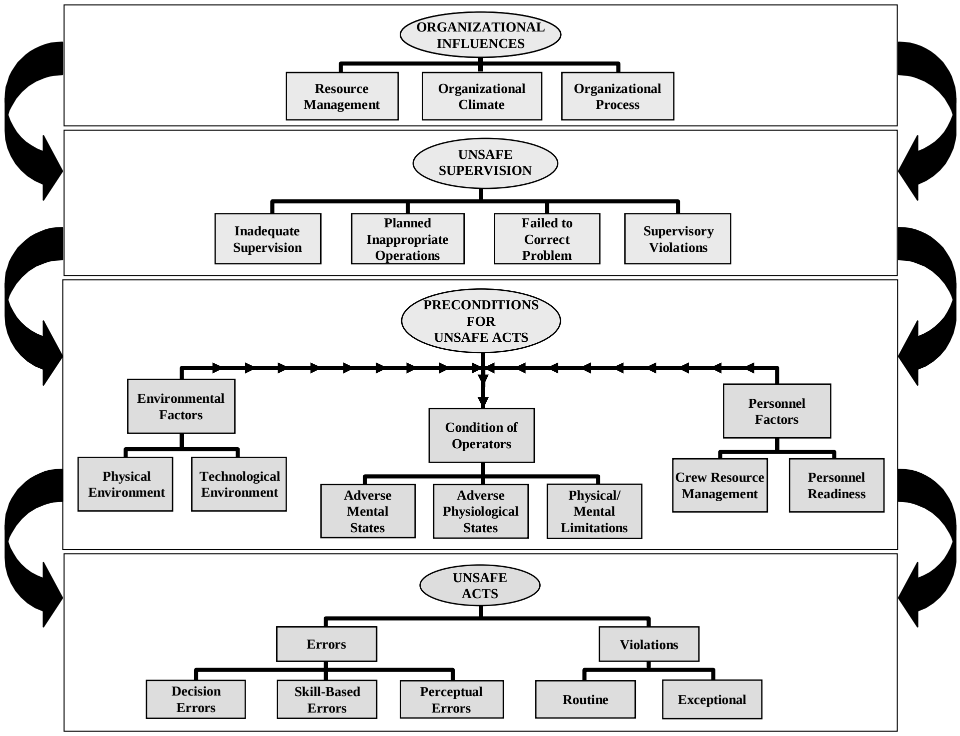

Figure 1. The HFACS framework.

Particularly germane to any examination of aviation accident data are the unsafe acts of aircrew. For that reason, we will briefly describe the causal categories associated with the unsafe acts of aircrew. A detailed discussion of the other tiers of HFACS (i.e., the preconditions for unsafe acts, unsafe supervision, and organizational influences) can be found elsewhere (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. 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, otherwise known as rule-based mistakes, 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, or knowledge-based mistakes, 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. 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 and inadvertent activation of controls. Likewise, memory failures such as omitted items in a checklist and forgotten intentions have adversely impacted the unsuspecting aircrew.

Equally compelling 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.

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, 1996).

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 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. Often referred to as "bending the rules," these violations are often tolerated and, in effect, sanctioned by authority.

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.

METHOD

Source of Data

Military and civilian data were obtained from the cognizant database repositories. Military data was obtained from the Navy, Army, and Air Force Safety Centers. For civilian aviation, data was obtained from databases maintained by the National Transportation Safety Board (NTSB) and the Federal Aviation Administration's (FAA) National Aviation Safety Data Analysis Center (NASDAC). In total, 16,077 aviation accidents associated with human error were extracted for analysis.

For comparison purposes the Navy/Marine Corps data was further divided into fixed-wing tactical (TACAIR) and rotary wing (helicopter) accidents.[1] In this way, USN/USMC TACAIR accident data could be compared to USAF TACAIR accident data, and USN/USMC helicopter accident data could be compared to U.S. Army helicopter accident data. A complete breakdown of the data is presented in Table 1.

Table 1. Accidents associated with human error

Type of operation	Frequency
USN/USMC TACAIR	138
USN/USMC Rotary Wing	60
U.S. Air Force TACAIR	72
U.S. Army Rotary Wing	62
14 CFR Part 121 & 135 - Scheduled Air Carrier	165
14 CFR Part 121 & 135 - Non-scheduled Air Carrier	452
14 CFR Part 91 – General Aviation	15,128
Totals	16,077

Data from these different sources have been presented elsewhere in a variety of forums, although never together and none has been published. Consequently, the years involved in the analysis varied depending on when the original analysis was conducted (note however, that the authors were involved in the analysis and collection of all the data reported in this study). Therefore, this report represents a meta-analysis of the military and civilian findings. The time frame of each set of data is presented in Table 2.

Table 2. Accident data time frame

Type of operation	Time Frame
USN/USMC TACAIR	FY 1990-98
USN/USMC Rotary Wing	FY 1990-98
U.S. Air Force TACAIR	FY 1991-97
U.S. Army Rotary Wing	FY 1992-98
14 CFR Part 121 & 135 Scheduled Air Carrier	CY 1990-98

[1] At the time of this writing, the civilian data were not broken out but will be for presentation purposes.

14 CFR Part 121 & 135 Non-scheduled Air Carrier	CY 1990-98
14 CFR Part 91 – General Aviation	CY 1990-2000

FY – Fiscal Year (October 01 – September 30)
CY – Calendar Year (January 01 – December 31)

Classification of accident causal factors using HFACS

The detail of the accident reports and manner in which causal factors were reported varied with the data sources. In addition, there were slight differences in the manner in which causal factors were coded within the HFACS framework. For instance, for all civilian accidents, GA and commercial aviation pilots were recruited from the Oklahoma City, Oklahoma and Urbana, Illinois area as subject-matter experts (SMEs). In the case of the military data, SMEs included a group of airframe rated pilots, flight surgeons, aerospace physiologists, and/or aerospace psychologists from the respective Services. All SMEs received training on the HFACS framework (roughly 16 hours) and were checked to ensure that a firm understanding of the HFACS causal categories was attained.

After training, SMEs were assigned accidents such that at least two separate SMEs analyzed each accident independently (typically more with the military data). Using narrative and tabular data obtained from the various safety centers, the SMEs were instructed to classify each human causal factor using the HFACS framework. Note, however, that only those causal factors identified within the accident reports were classified. That is, SMEs 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 SMEs made their initial classifications of the human causal factors (e.g., skill-based error, decision error, etc.), the independent ratings were compared. Where disagreements existed, the corresponding SMEs were instructed to reconcile their differences, and the consensus classification was included in the final database for further analysis. In the end, all human causal factors associated with both civilian and military data were reliably classified within the HFACS framework and the resulting consensus database was submitted to further analysis.

Inter-rater reliability averaged roughly 80% agreement with a Cohen's Kappa in the 70's. For a complete accounting of the reliability data, see (Wiegmann & Shappell, 2003). Regardless of inter-rater reliability however, all disagreements were resolved through consensus ratings.

RESULTS & DISCUSSION

Although the accidents were associated with causal factors at all levels of the HFACS framework, this examination of the data was limited to the unsafe acts of operators.

Analysis of skill-based errors

An analysis of the data revealed that, in general, the percentage of skill-based errors associated with GA and non-scheduled commercial operations were higher than all other types of aviation (Figure 2).[2] It was not surprising that the largest percentage of skill-based errors were associated with GA accidents given the relative amount of flight time and training logged by GA pilots. Indeed, while there are certainly exceptions, most would agree that the average GA pilot does not receive the same degree of recurrent training and/or annual flight hours that the typical commercial or military pilot receives.

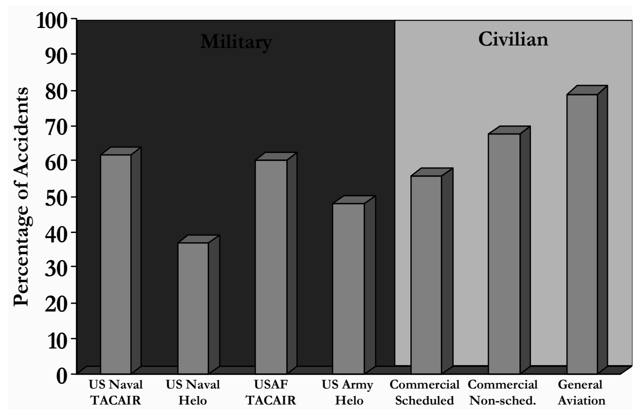

Figure 2. Percentage of military and civilian accidents associated with skill-based errors by type of operation.

It was also interesting that the percentage of skill-based errors associated with non-scheduled (also referred to as "on-demand") air carrier accidents were next highest among the aviation operations examined. One explanation for this finding may be the relative experience of these pilots as well. This is not to say that these pilots are inexperienced, just that relative to their military and scheduled air-carrier counterparts, there may be less opportunity to maintain proficiency or less overall experience. On the other hand, the increase in the percentage of skill-based errors may reflect inherent differences in the aircraft being flown, since many of these pilots fly smaller, less sophisticated aircraft than scheduled air carriers or the military.

Curiously, the percentage of skill-based errors associated with USN/USMC and USAF TACAIR accidents were very similar to scheduled commercial air carriers accidents (albeit, the latter was slightly less). Exactly why that was the case is difficult to say. However, there were even fewer skill-based errors associated with

[2] Note that percentages within type of operation will not add up to 100% since accidents are typically associated with multiple causal factors. These data reflect the percentage of accidents associated with "at least" one instance of a particular HFACS causal category.

U.S. Naval and Army rotary wing accidents than in any other type of operation. While we have not fully explored this issue directly, it is interesting to note that most USN/USMC and U.S. Army helicopters are piloted by two pilots. Furthermore, all scheduled air carrier aircraft have at least two qualified pilots in the cockpit. Perhaps this can explain the lower percentage of skill-based errors in these communities as the second pilot can back-up the first – lending some credence to the view that "two sets of eyes are better than one."

Analysis of decision errors

The percentage of decision errors associated with each type of operation is presented in Figure 3. In general, fewer decision errors were associated with civilian aviation accidents than seen with military aviation accidents. What's more, there were only small differences observed between GA and both types of commercial operations. In contrast, there was wide variability associated with the different military operations examined.

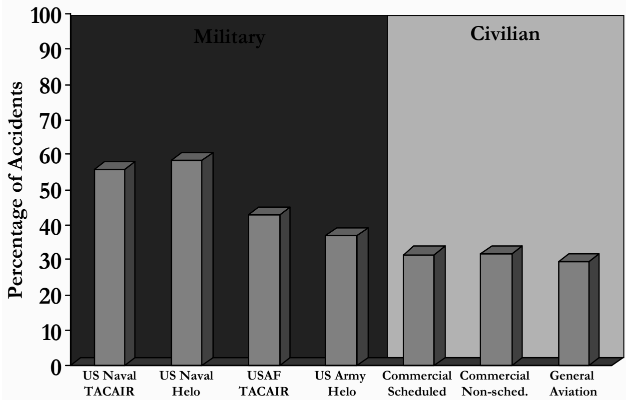

Figure 3. Percentage of military and civilian accidents associated with decision errors by type of operation.

One explanation why military accidents were more often associated with decision errors may be the relative number and type of decisions made in typical military operations. That is, while both military and civilian pilots have to make decisions regarding takeoff, landing, diverting to alternates, and other standard aviation decision-making, military pilots are also confronted with a variety of tactical decisions not seen in typical civilian aviation (e.g., low-level flight, high-G force maneuvering, etc.) thereby reducing the margin for error. This may artificially inflate the number of decision errors associated with military aviation accidents just by sheer exposure – something that is difficult, if not impossible, to control for in our data.

While it is somewhat understandable why military aviation in general is more often associated with decision errors, it is much less obvious why this difference is even more evident when USN/USMC aviation is considered. One explanation may be that many naval operations occur over water or at sea where options are limited if trouble arises and recovery from errors may be less likely. Indeed, aviation at sea is inherently more dangerous than flying ashore and much less forgiving. To some extent, this is borne out in the data as many of the decision errors observed in Navy/Marine Corps accidents occurred while operating at sea.

Analysis of perceptual errors

Upon examination of the data associated with perceptual errors (Figure 4), two things stand out. First, while perceptual errors appear rare within civilian aviation operations, within the military they continue to be a source for concern. Second, perceptual errors appear to be more prevalent among accidents involving helicopters, particularly within the U.S. Army.

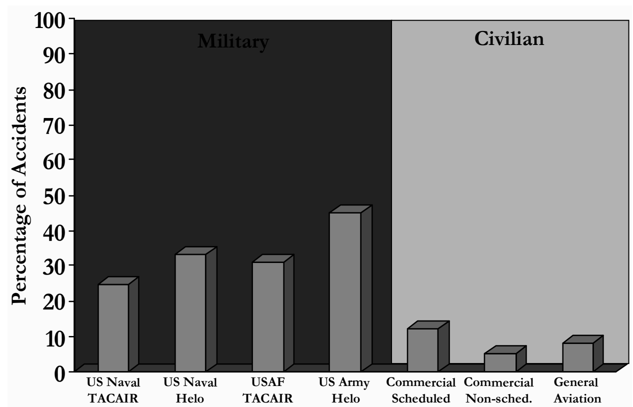

Figure 4. Percentage of military and civilian accidents associated with perceptual errors by type of operation.

It would appear then that at least for civilian operations that issues like spatial disorientation and visual illusions (although still common) are not as large a problem as they once were. Perhaps this is due to the enormous effort being put forth to educate civilian pilots about the hazards associated with flight into weather and other visually impoverished environments. On the other hand, the nature of civilian aviation, where most flying occurs in low-G environments and involve relatively less dynamic flight than seen in the military, may make perceptual errors less likely.

Within the military, perceptual errors continue to be associated with roughly 30% (on average) of all human error related aviation accidents. However, it appears to be more of a problem with the helicopter community – particularly the U.S. Army where nearly 50% of the accidents examined were associated with a perceptual error.

Upon closer inspection, most of the perceptual errors that involved military helicopters can be attributed to the effects of spatial disorientation and wire strikes. Given the latter, it is not surprising that the prevalence of perceptual errors is elevated among U.S. Army helicopter operations since many of their missions are flown at low levels (below 1500 ft AGL). In contrast, very few fixed-wing aircraft are routinely flown at these levels except during takeoff and landing. This may provide more time for TACAIR pilots to recover from spatial disorientation and thereby avoid an accident. This hypothesis is supported by the observation that when perceptual errors occur during TACAIR operations they typically occur while flying in visually impoverished environments or during occasional low-level, terrain-following evolutions.

Analysis of violations

Because it was particularly difficult to reliably classify causal factors *post hoc* as either routine or exceptional violations, we chose instead to analyze the parent category of violations. Anecdotally however, the majority of the violations observed in the accident data appeared to be routine violations (habitual departures from the rules/regulations condoned by management).

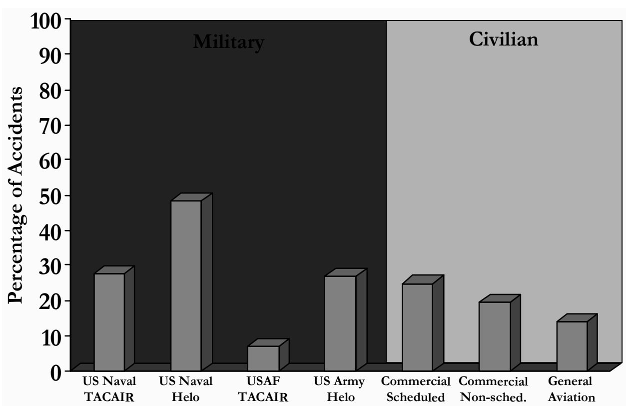

Figure 5. Percentage of military and civilian accidents associated with violations by type of operation.

The percentage of military and civilian aviation accidents associated with a willful disregard for the rules and regulations of aviation safety (i.e., violations) are presented in Figure 5. As can be seen, the percentages varied across all types of aviation operations examined ranging from a high of roughly 50% observed with USN/USMC helicopter operations to a low of less than 10% associated with USAF operations. It should also be noted that the percentage of violations associated with civilian aviation accidents declined consistently as one moved from scheduled air carrier accidents, to non-scheduled air carrier accidents and GA. This latter trend may be more a reflection of the fact that there are fewer rules and regulations governing GA than commercial flight and therefore may not represent a differential problem in commercial aviation.

Within the military, the percentage of accidents associated with violations is a mixture of good and bad news. On the bad side of the coin, nearly 50% of all U.S. Navy/Marine Corps accidents were associated with at least one violation of the rules. This was particularly alarming to the Navy and Marine Corps when this problem first surfaced in the late 1990's. Later it was revealed that the problem was largely the result of a small subset of naval aviation that has since been addressed (Wiegmann & Shappell, 2003). The good news is just that. Since our initial report of the violation data associated with USN/USMC aviation, accidents associated with this particular unsafe act have been reduced across the board to less than 15% in 2002 (Webster & White, 2004).

Further good news is seen in the low percentage of accidents associated with violations in the USAF. Some have argued that this may reflect an under-reporting of violations by the USAF. However, this argument was not supported by the data we examined. More likely, the lower percentage of accidents associated with violations reflects a policy within the USAF of zero tolerance for violations of the rules and regulations of safety.

CONCLUSION

In some ways, these data lend support to previous beliefs, while in others it has provided new information. For instance, it has long been held that GA pilots receive less training and therefore may not be as proficient or skilled as their commercial and military counterparts. To the extent that the accident data reflect the state of GA in the U.S., such beliefs appear to be warranted. That is, more GA accidents are associated with skill-based errors than any other type of aircraft operation.

But why would a comparison between GA, commercial, and military aviation accidents be important? Consider this, prior to the late 1980's and early 1990's most commercial aviation pilots were recruited from the U.S. military that was actively downsizing after the Cold War. However, with recent global events, recruitment bonuses, and longer commitments after initial flight training, fewer military pilots are leaving the service for the lure of commercial aviation.

So if not the military, where are commercial aviation pilots coming from? Increasingly, today's commercial aviation pilots are receiving their training from within the GA sector. The question is how this will impact commercial aviation safety. Or perhaps the better question is, "Does commercial aviation resemble GA where skill-based errors are elevated, or does it look more like military aviation?" In fact, given that many of the decision errors seen in military aviation are specific to military operations and perceptual errors are inflated due to the dynamic flight seen in the military, would you rather have commercial aviation look more like the military or GA?

Regardless of your answer, the truth is that human errors associated with commercial aviation look more like GA than the military (Figure 6). As a result, it is now more important than ever to address human error associated with GA, particularly that associated with basic flight skills. These data should prove as a foundation for addressing those concerns.

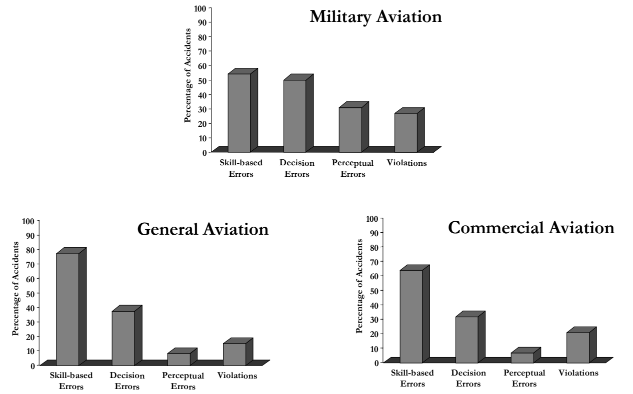

Figure 6. Comparison of the percentage of accidents associated with the unsafe acts of operators by type of operation.

At a minimum however, these data represent the first time that commercial and military data has been compared beyond simply reporting overall accident rates or the overall percentage of accidents associated with human error. The HFACS framework provides a reliable and valid means to compare human error associated with seemingly disparate aviation communities. Notably, this analysis did not require major changes within any of the communities involved. That is, all the aviation communities still have their separate means of investigating accidents and corresponding databases. To date, only the U.S. Navy/Marine Corps utilize HFACS to actually conduct the original accident investigation. However, that is currently under revision as the U.S. Department of Defense is currently considering requiring a modified version of HFACS for use during accident investigation and analysis throughout all branches of the service.

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