GENERAL AVIATION MAINTENANCE ACCIDENTS:
AN ANALYSIS USING HFACS AND FOCUS GROUPS

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The Human Factors Analysis and Classification System (HFACS) was used to classify maintenance-related general aviation accidents in the United States from 1990 to 2000 inclusive. The analysis revealed that among the maintainers, skill-based errors were most frequent cause of accidents, followed by violations committed by both professional maintainers and owner-operators. Furthermore, violations committed by owner-operators were twice as likely to be associated with a fatality. In addition, focus groups comprised of professional airframe and powerplant mechanics in both Alaska and Oklahoma, provided valuable information to validate the accident analysis and describe the state of general aviation maintenance today.

INTRODUCTION

Commercial carriers have invested a great deal of financial and corporate resources to address human factors both on the flight deck and within maintenance. However, by comparison, general aviation (GA) has lagged somewhat behind. This is surprising when one considers that as much as 96% of active aviation in the United States involves either general or corporate aviation (Wells, 1996). For instance, Ropp and Lopp in 1998, found both general and corporate aviation lacking in any sort of structured safety management system for maintenance operations, in spite of the fact that maintenance related accidents comprised as much as 21.3% of the accidents occurring in 1997. This number is in stark contrast to the 9.7% of maintenance related accidents from 1987 to 1996 reported by Boeing (1997) for commercial aviation. In light of the fact that the accident rate for GA aircraft is five to seven times that of commercial air carriers, these percentages take on even more significance.

That is not to say that nothing has been done at all to address this concern. Indeed, an earlier study of maintenance-related GA accidents conducted by Goldman, Fiedler, & King, (2002) examined 1,503 National Transportation Safety Board (NTSB) accident reports spanning the years of 1988 to 1997. Their findings revealed that the most common accident cause factors involved installation errors, general maintenance, and maintenance inspection. Furthermore, they demonstrated that installation errors were often associated with severe accidents. In fact, their findings indicate that installation problems, general maintenance, and maintenance inspection accounted for over 50% of the fatalities in their sample. While these findings provide valuable evidence for the role of human error in GA maintenance, the results were limited in that the subject matter experts (SMEs) who evaluated the NTSB reports were actually GA pilots and not active aviation maintenance technicians (AMTs).

Likewise, one cannot study the types of errors associated with AMT performance in a vacuum. One must also bear in mind the environment within which the errors occur. For example, a majority of maintenance inspection is visual. This necessitates adequate lighting in the workplace, be that workplace indoors such as in a standing structure, or outdoors, where one may assume a fair portion of GA maintenance might occur. Indeed, AMTs are often required to work in less than optimal environments which may include one or some combination of unsafe noise levels, heat, cold, poor lighting and restricted workspace. Thus, one cannot exclude the environmental component associated with aircraft maintenance.

With this in mind, it makes sense to not only try to understand the errors made within the context of GA maintenance, but environmental factors as well. This line of reasoning has led experts and government agencies such as the Federal Aviation Administration (FAA) to examine not only the underlying factors involved in GA accidents, but to specifically target GA accidents in Alaska, a region known for its harsh climate and environmental conditions.

Consequently, the FY04 maintenance human factors effort at the Civil Aerospace Medical Institute (CAMI) had two purposes. One was to investigate human error associated with GA maintenance related accidents. The second purpose was to compare the errors made in Alaska (AK) with the rest of the United States (RoUS). To this end, not only were the maintenance factors associated with GA accidents investigated but focus group interviews of AMTs both in AK and in Oklahoma were conducted in an attempt to define issues faced by GA AMTs both in Alaska and at least one site in the contiguous 48 states.

HFACS

The entire HFACS framework includes a total of 19 causal categories within Reason's (1990) four levels of human failure. 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 the HFACS causal categories is therefore beyond the scope of this report and 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. 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.

Within HFACS, the category of errors was expanded to include three basic error types (decision, skill-based, and perceptual errors). In general, decision errors represent conscious decisions/choices made by an individual that are carried out as intended, but prove inadequate for the situation at hand. In contrast, skill-based behavior within the context of aviation is best described as "stick-and-rudder" or 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 as well as simple technique failures. Finally, 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.

While errors occur when aircrews are behaving within the rules and regulations implemented by an organization, violations represent the willful disregard for the rules and regulations that govern safe flight. As with errors, there are many ways to distinguish between types of violations. However, two distinct forms are commonly referred to, based upon their etiology. The first, routine violations, tend to be habitual by nature and are often tolerated by the governing authority. The second type, exceptional violations, appear as isolated departures from authority not necessarily characteristic of an individual's behavior nor condoned by management.

METHODS

Data

The National Aviation Safety Data Analysis Center (NASDAC) and NTSB were utilized to identify maintenance related GA accidents. Two methods were used to select the maintenance factor sample. First, a sample of causal factors was selected from the years 1990-2000 based on NTSB personnel codes that identified the involvement of maintenance personnel (i.e., 4107 - Company Maintenance Personnel and 4108 - Other Maintenance Personnel). Second, NTSB "subject" codes were scanned to identify any accidents that involved maintenance causal factors (24100-24124). This latter method was used to ensure that all maintenance factors were captured, including those that were not attributed to a certified AMT or otherwise designated maintainer (e.g., an owner/operator).

Subject Matter Experts

The maintenance causal factors associated with each maintenance related accident were classified into HFACS categories independently by six certified, instructor level airframe and powerplant mechanics (A/P) who served as mechanic SMEs. The combined years in the aviation industry for the SMEs was 168 years with an average of 28 years. In addition, all were maintenance instructors at a local school. The span of instructor level teaching as aviation mechanics was 3 to 14 years with an average of 8 years.

SME Training

Training in HFACS for the mechanic SMEs was conducted in three phases.

Phase 1: An HFACS training session was conducted by the authors for the purpose of introducing the SMEs to the HFACS framework (Wiegmann and Shappell, 2001) and instructing them on how to use it. From the sample of maintenance related accidents (n=1935), a 10% random sample (n=194) was selected, resulting in 206 maintenance factors to be coded. Together, all six SMEs coded 59 factors from the first 50 accidents and discussed their codes in detail. In three subsequent meetings the remaining factors from the random sample were coded independently by all six SMEs. Initial coder agreement was not computed for this initial phase.

Phase 2: Maintenance factors from the years 1990-1991 were then randomly assigned to pairs of SMEs for coding. Using pairs of coders allowed for analysis of initial coder agreement. The SMEs coded their assigned factors independently. Codes were entered, discrepancy reports were generated, and initial coder agreement was computed. The SMEs agreed approximately 51% of the time during this second phase. Recall however, that there were 19 possible HFACS categories that the SMEs could place the causal factor in, which makes the percentage agreement appear more reasonable. Still, the inter-rater reliability is low when compared with the over 85% level of agreement seen with pilot SMEs coding aircrew errors associated with GA accidents (Wiegmann & Shappell, 2003). All the same, any factor for which the two SME coders had a discrepancy was discussed and resolved by all six SMEs as a group. These group discussions were also used to develop the exemplars within the causal categories associated with the HFACS framework.

Phase 3: This phase was initiated because of lower than anticipated initial coder agreement in Phase 2. Maintenance factors from the years 1999-2000 were coded and resolved using the same methodology as was used in Phase 2. Initial coder agreement increased to 59% for those years. However, it was determined that this percentage was still not high enough to justify the resolution of discrepancies with only two coders as was originally planned. It was therefore decided that the remaining data would be coded and resolved as they had been in Phases 2 and 3 of training, with two independent coders for each factor, and group resolution of discrepancies.

HFACS Coding

After completion of Phase 3 of training, the SMEs coded maintenance factors for the years 1992-1993. The necessity of meeting with all six SMEs to resolve discrepancies was timeconsuming and slowed the coding process considerably. It was decided, in the interest of time and completeness, that the remaining years of data (1994-1998) would be coded in two separate groups. This allowed a cross-section of data from all years to be analyzed before all of the coding was complete.

Upon completion of the first group for years 1994-1998, the SMEs raised concerns about the reliability and validity of the data obtained from Phases 1 and 2 of training. Therefore, the data coded in these phases were eliminated from the analysis, and were re-coded by the SMEs. Maintenance factors from the years 1990-1991 were also separated into two groups to be coded again. To date, 1263 maintenance causal factors associated with 1133 accidents have been coded (*note: the aircrew and other human causal factors have been coded and reported in previous reports – for a summary see the HFACS FY04 Annual Report).*

GA Maintenance Focus Group

In order to better understand the issues facing maintenance providers in Alaska today, and to validate the HFACS analysis, a series of focus groups were conducted at selected maintenance sites throughout Alaska. These focus groups were composed of personnel at maintenance facilities located in Anchorage, Nome, Fairbanks, Juneau, and Barrow, Alaska. The results of these interviews were then compared with focus group interviews made up of the SMEs in Oklahoma City, OK.

RESULTS

HFACS Analysis

Similar to other areas of aviation, skill-based errors (SBEs) were associated with the largest percentage of maintenance related accidents (Wiegmann & Shappell, 2003; Figure 1). These types of errors were followed by violations committed by AMTs (VMAINT) at 23.9%, violations by owner/operators (VOO) at 12.1% and decision errors (DE) at 8.2%. Of note, no perceptual errors were reported by the SMEs for maintenance related data.

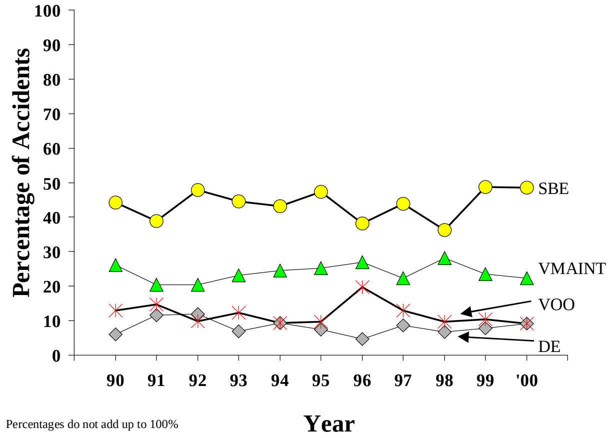

Figure 1. Overall accident rate by year and unsafe act.

Fine-Grained Analysis

In order to gain a better understanding of the specific types of errors committed, a fine-grained analysis was conducted for each of the unsafe acts reported above. Those errors, which comprised at least 5% of the unsafe acts within each HFACS error category, were reported. A brief summary of those results follows:

Decision Errors. The most common decision error was the failure to comply with a service bulletin or letter. This comprised 35.2% of the decision errors in the sample. These decision errors were followed by maintenance overhaul (11.2%), and replacement of parts (8.0%).

Skill-Based Errors. The fine-grained analysis revealed that the most common skill-based error was installation, which accounted for 29.3%, followed by inspection errors accounting for 16.7%.

Aviation Maintenance Technician Violations. Violations attributed to AMTs were similar to skill-based errors in that the most common violation involved installation (16.7%), while the failure to follow procedures and directives were the second highest violation committed by an AMT at 12.6%.

Owner/Operator Violations. Violations committed by owner-operators performing their own maintenance were somewhat different from those committed by AMTs. The most common violation in this case was the failure to obtain an annual inspection (18.2%). Following that, aircraft service and maintenance represented the next highest percentage of violations seen with owner/operators (10.6% each). Improper installation resulted in 10.9% of the violations, and unauthorized design change, modifications, and non-compliance with airmen's directives each accounted for 5.2% of violations observed in this causal category.

Comparison between Alaska and the Rest of the U.S.

Because of the disparity in total events between AK and the RoUS, the comparison between the two will reflect aggregate numbers collapsed across the 10-year period rather than an annual comparison. This was done to account for the relatively small cell sizes found in the AK data.

The percentage of skill-based errors associated with maintenance related accidents for AK and the RoUS were essentially the same (AK=43.4%; RoUS=46.7%). Similar patterns were noted for decision errors with 8.1% of the maintenance-related accidents in AK associated with decision errors versus 11.2% in the RoUS. Likewise, violations for both AMTs and owner-operators revealed almost identical patterns whether they occurred in AK or the RoUS (AK = 23.9%, RoUS = 22.2% and AK = 12.1%, RoUS = 13.3%).

Fatal Events Related to Maintenance Unsafe Acts

In an effort to quantify a worst-case scenario of maintenance-related accidents, the unsafe acts were examined with respect to the degree that they factored into a fatal event.

The percentage of fatal and non-fatal maintenance related accidents associated with each of the unsafe acts is presented in Figure 2. What is evident is that skill-based errors are least likely to be associated with fatal accidents while violations attributed to owner/operators were most often associated with fatal accidents by an almost 3 to 1 margin. Indeed, nearly 1/3 of the accidents attributed in part to a maintenance violation committed by an owner/operator were associated with fatalities. Decidedly, fewer fatalities were attributed to violations committed by AMTs, although even they were twice as likely to result in fatalities when compared with skill-based errors.

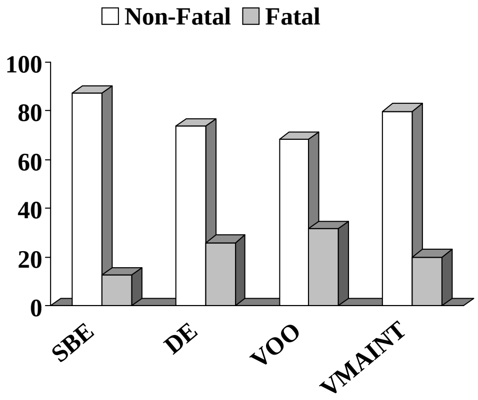

Figure 2. Percentage of maintenance related unsafe acts associated with fatal and non-fatal accidents.

Maintenance Focus Group Analysis

In an effort to understand the issues facing AMTs in today's GA environment, a series of focus group surveys were carried out both in AK and in OK. Although far from complete, this initial effort was initiated to get a better understanding of those areas of GA maintenance that need to be addressed both from a regulatory, as well as from a maintenance/system safety, standpoint. Further interviews are planned for other regions of the U.S. in FY05.

That being said, the data obtained from Alaska and Oklahoma were revealing and will be briefly summarized here.

Alaska. A number of problems were mentioned by the Alaskan focus groups, ranging from training programs to oversight (or lack thereof) by regulatory agencies. One area of concern mentioned by our focus group members was licensing. Separate licensing for large aircraft, GA, and rotorcraft, in addition to doing away with endorsements was one possible remedy mentioned. Presumably, this would open the door for advanced training and recognize maintainers for the professionals that they are, not just technicians.

Also obtained from the focus groups was the apparent lack of qualified maintenance personnel in Alaska. A number of reasons were cited for this with the distinct lack of training facilities topping the list. Poor remuneration for GA maintenance personnel also makes retention difficult. Also of concern was the fact that training beyond certification is hard to come by in Alaska, not to mention expensive. Lack of training in basic mechanics in technical programs was also cited as a problem. Finally, the focus groups suggested that the pressure to graduate students from programs results in teaching to certification exams, rather than focusing on core subject matter.

Oklahoma. The focus group established in the Oklahoma City area echoed many of the same sentiments of the Alaska focus groups. For instance, the group was unanimous in their assertion that there were not enough qualified GA mechanics to meet industry demands. Furthermore, they also cited training as a major shortcoming in the industry. Specifically, a lack of training facilities and lack of ongoing training and certification opportunities in the GA sector were a major concern.

Oversight by the FAA was also voiced as a concern by the Oklahoma focus group. In addition, follow-up on manuals once they are submitted, surveillance of pilots performing their own maintenance, and oversight of maintenance performed on weekends and after hours were all cited as issues. Finally, they were concerned that pay rates for GA mechanics were too low, which might make it difficult to keep people in the field.

DISCUSSION

A number of errors were classified using the HFACS framework including not only AMTs, but also owner-operators performing their own maintenance. Perhaps most notable were violations. For instance, violations committed by AMTs represent an inordinately high percentage of the unsafe acts when compared to violations committed by flight crews (Shappell & Wiegmann, 2003). Moreover, owner-operator violations proved to be an even greater problem in GA maintenance. This observation is supported by the fact that accidents, which were associated with owner-operator violations, were three times more likely to involve a fatality than accidents involving skill-based errors. The data for violations committed by AMTs did not prove to be much better, revealing a two-fold increase in the likelihood of a fatality.

Even more important is determining why the higher percentages of violations occurred in the first place. For the owner-operators, the two most common violations were the failure to obtain an annual inspection and aircraft service/maintenance. Thus, for the owner, it may be the expense of obtaining an inspection and servicing the aircraft, which may cause the owner to delay these services. This makes sense when one considers scheduled maintenance for the family automobile. It's quite likely that manufacturer scheduled maintenance is either not followed to the letter or ignored entirely by those who simply can't afford it. However, as an individual's income improves later in life, so to does the frequency of scheduled maintenance on the family car.

On the other hand, violations attributable to AMTs tended to reflect the business of actually maintaining the aircraft. Specifically, the two most common violations for AMTs were installation and failure to follow procedures and directives.

The fix for this may involve finding a different way to perform certain tasks, which differ from protocols laid out in service manuals or bulletins. The "I know best" mentality may work well in some instances, but has the potential for catastrophe as demonstrated by the data reported here.

Similar to other areas of aviation, the most common unsafe act seen in the maintenance data was skill-based errors. This remains a consistent finding in the analysis of accidents using the HFACS framework, and more than likely is explained by the fact that even in complex environments, the bulk of the behaviors performed by operators tend to be low processing, highly automatized behaviors. However, these findings differ in that there were decidedly fewer skill-based errors noted in the maintenance data than is typically seen in other industrial settings such as aviation and mining. In fact, when one surveys the literature regarding flight crews, the percentage for skill-based errors is approximately double that noted here (Shappell & Wiegmann, 2003). Exactly why this would be the case is hard to say. However, it may be inherent to the job of the AMT where one would expect to find less routine behavior than in the cockpit.

For skill-based errors, both focus groups mentioned a number of interventions that may prove beneficial when addressing the errors and violations observed in our data. For instance, something as simple as ensuring that AMTs have the proper tools to perform tasks would likely enhance technical applications. Training in shift scheduling and the importance of sleep requirements might also help to combat fatigue and related mistakes. Finally, proper lighting and organization of the workspace has been shown to be effective in improving proficiency.

Dealing with violations may prove to be the most difficult of the unsafe acts to address. First, this in not an error *per se*, but willful behavior that is committed by the person charged with insuring that the aircraft is safe to fly. Thus, the same interventions that may prove useful in mitigating human error, don't really apply here. This is perhaps where regulatory agencies may play the most important role. Fair and consistent punitive actions taken against those individuals who violate the rules have been shown to be successful amongst pilots in the U.S. Navy and Marine Corps (Shappell, Wiegmann, Fraser, Gregory, Kinsey, and Squier, 1999). Although policing maintenance operations may prove difficult for any one entity to do, (e.g., the FAA); consistent enforcement may help to send the message that the regulatory agency takes violations as a serious affront to aviation safety.

However, one must also question the safety culture in which these violations occur. Just as GA pilots must be made part of a culture of safe flight, so must those individuals who choose to maintain their aircraft. This culture or attitude of safety begins with the first day of training and should be stressed throughout one's career. In effect, safety begins with the AMT, long before any pilot leaves the ground. So shouldn't the same emphasis be placed on ensuing safety in maintenance operations as is seen in the cockpit?

When comparing the responses of the focus groups, there were far more similarities than differences. In fact, for both groups, the chief complaints were lack of pay, which causes a shortage of personnel in the field. Both groups also cited poor training programs, both for certification and for supplementary training following licensure. Until these issues are addressed, it will be difficult to address any other problems from the AMT side of the equation. Finally, while there was consensus between the focus groups, it should be noted that there were only two regions surveyed. Future work will involve regional focus groups from the rest of the United States.

These data suggest that rather than using a blanket, one-size fits all approach to rectifying these problems, targeted interventions should be employed that will be most effective in reducing the specific types of errors seen here. For example, decision errors, especially those that are knowledge-based, would benefit most from additional on-going training. Furthermore, stressing the importance of following service bulletins and manufacturers maintenance recommendations may influence decision making in the right direction. In fact, by making service bulletins a requirement, would remove the decision-making from the maintainer altogether.

Nevertheless, while interventions and recommendations can be talked about and instituted by employers and regulatory agencies, ultimately, the person holding the wrench has to want to be safe. Only then will they invest themselves in their work and in the safety of the planes that we fly.

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