Human Factors in Aviation Maintenance: A Look at the Fundamental Concepts

Robert Baron, Ph.D

The Aviation Consulting Group

Dr. Robert Baron is the President and Chief Consultant of The Aviation Consulting Group. He performs extensive work in his core specializations of Human Factors (HF), Safety Management Systems (SMS), Crew Resource Management (CRM), and Line Operations Safety Audit (LOSA). He consults with, and provides training to, hundreds of aviation organizations on a worldwide basis.

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Abstract

In 1988, Aloha Airlines Flight 243 had a large section of its fuselage separate from the aircraft at an altitude of 24,000 feet. While the aircraft did make a successful emergency landing, one flight attendant was fatally injured during the unfolding events. Aloha Flight 243 became the watershed event that would trigger the need to address human factors in aviation maintenance. This paper is intended to shed light on the fundamental concepts of human factors (HF). A brief history and overview is presented followed by a description of the elements that comprise an HF program.

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Introduction

> Flight 243 experienced an explosive decompression and structural failure at FL240 (24,000 ft.) while enroute from Hilo, HI, to Honolulu, HI. Approximately 18 ft. of cabin skin and structure aft of the cabin entrance door and above the passenger floorline separated from the aircraft. One flight attendant who was standing in the aisle was swept overboard. The flight diverted to Maui and a landing was accomplished. Examination of the aircraft revealed disbonding and fatigue damage which led to the failure of the lap joint AT S-10L and the separation of the fuselage upper skin between stations 360 and 540.
>
> **The National Transportation Safety Board determines the probable cause(s) of this accident as follows:**
>
> Fuselage, Attachment---Fatigue
>
> Fuselage, Attachment---Separation
>
> **Contributing Factors**
>
> Maintenance, Inspection---Improper---Company Maintenance Personnel
>
> Supervision---Inadequate---Company/Operator Management
>
> Inadequate Surveillance of Operation---FAA (Organization)
>
> Aircraft/Equipment, Inadequate Airframe---Manufacturer
>
> (NTSB/AAR-89/03, 1989)

This accident identified the need to address human factors in aviation maintenance. Specifically, the Aloha accident illuminated human performance deficiencies in visual inspections and the lack of recognition by management to identify limitations in work team performance. Much was learned from the NTSB (National Transportation Safety Board) investigation, including the fact that there is a fine line between 'technical proficiency' and 'person proficiency.' Because of this watershed event, as well as subsequent maintenance accidents due to human error, human factors training has now become widespread in the aviation maintenance domain; something unheard of just 10 years ago. But what is human factors and where did it come from?

Literature Review

Human factors, as a science, came of its own around the WWII period. Although there was other work conducted well before that time, such as DaVinci's work in the 1480s that included flight anatomy, physiology, mechanics, hydraulics, physics, philosophy, mathematics, writing engineering, orbital mechanics, botany, and optics (Bellis, n.d.), we will focus on the period from WWII forward.

The need to address human factors during WWII was made clear as more and more military plane crashes were being caused by a misfit between man and machine. In other words, early military aircraft were being designed without much insight about the humans that would be piloting them. Aircraft became more reliable and complex; unfortunately, the human operator was not well adapted to these designs and physical, physiological, and cognitive problems began to manifest as otherwise preventable crashes.

WWII resulted in aircraft that were of airspeeds four times as fast as those of WWI with altitude capabilities exceeding 30,000 ft. (Koonce, 1999, as cited in Garland, Wise, & Hopkin, 1999). While the aircraft designs had been rapidly advancing, the pilots were experiencing difficulties adapting to these higher speeds and altitudes. Higher speeds required faster cognitive processing times and higher altitudes required the pilots to fly in an environment that was louder, colder, and with less available oxygen than that found at lower altitudes. These, as well as other problems, resulted in pilots being forced to adapt to their machines as opposed to the other way around.

In an attempt to change this flawed philosophy, the Army Air Force Aviation Psychology Program was started. It focused on human limitations in the pilot selection process and is documented in a series of 17 "blue books" (Flanagan, 1947). Another program called

Aviator Selection 1917-1977 (North & Griffin, 1977) was used as a much broader knowledge base for information on pilot selection as it related to performance.

Following WW II, a major thrust was under way to take the knowledge gained from military aviator research and add to this knowledge for civil aviation applications as well. Some of the most prominent researchers included Alphonse Chapanis and colleagues for their early work that addressed the interface between man and machine (see Chapanis, Gardner, Morgan, & Sanford, 1947). Fitts (1947) conducted numerous experiments relating to psychological research on equipment design. In one study, addressing pilot error, it was found that 50% of errors in operating aircraft controls were choosing the wrong control (Fitts & Jones, 1947, as cited in Bainbridge 1995). Another study by Fitts and Jones (1947, as cited in Bainbridge, 1995) showed that in a sample of pilots' instrument reading errors, 22% of errors were either reversed spatial interpretations, or attitude illusions. Fitts was also responsible for changing the three pointer altimeter system to the two pointer systems by analyzing accident data that showed that pilots were having a difficult time discerning the actual altitude of the aircraft because of the complexity and attention drain required by the three pointer design.

As human factors research progressed from the wartime era up to the present time, there have been, and currently are, numerous other studies that have been adding significantly to the literature. As can be discerned from the discussion so far, the initial "push" for human factors was aimed primarily at the interface between pilots and their aircraft. However, it wasn't until the 1990s that maintenance errors and their relationship to human factors began to be studied in detail. One of the first significant studies, conducted by Marx and Graeber (1994), showed that maintenance and inspection deficiencies were accountable for 12% of 93 major airline accidents. One of the most salient points of their findings was that, after pilot error (the number one cause of accidents), maintenance deficiencies was number two on the list. Further analysis showed that *incorrect installation of components* was the most problematic and pervasive occurrence in maintenance procedures. These results were also validated in a study by Goldman, Fiedler, and King (2002) who found that, in a study of NTSB general aviation accidents occurring between

1988 and 1997 with at least one maintenance-related issue as a cause or factor in the accident, *installation errors* were the leading maintenance-related cause or factor involved with the accidents. The authors also found that *reversed installation* and *wrong part* were the two installation errors most likely to cause death or injury in general aviation accident aircraft. Now that this information was quantified, the next question that logically needed to be answered was why?

The maintenance environment can be considered the "perfect storm of error-provoking conditions." There are extensive cognitive and physical demands that are placed on maintenance technicians. The environment consists of, among others, loud noises, extreme temperatures, shiftwork, fatigue, time pressure, stress, inadequate lighting, working at height, poor physical access to components, and distractions. Just one of these can cause a "normal" person to commit an error; in multiple combinations the probability of errors increases significantly.

The Aloha Airlines case cited in the beginning of this paper showed, in its purest form, the perfect storm of error-provoking behavior. The NTSB accident investigation revealed that, among others, the following maintenance antecedents were causal to the accident:

1. Inspection of the rivets required inspectors to climb on scaffolding and move along the upper fuselage carrying a bright light with them.
2. If an eddy current inspection was required, the inspectors needed a probe, a meter, and a light.
3. At times, the inspector needed ropes attached to the rafters of the hangar to prevent falling from the airplane when it was necessary to inspect rivet lines on top of the fuselage.
4. Even if the temperatures were comfortable and the lighting was good, the task of examining the area around one rivet after another for signs of minute cracks while standing on scaffolding or on top of the fuselage is very tedious.

5. After examining more and more rivets and finding no cracks, it is natural to begin to expect that cracks will not be found.
6. Aloha's maintenance was conducted at night and there was pressure to complete maintenance tasks and inspections quickly in order to get the aircraft back on line to generate revenue as quickly as possible.
7. The lack of management involvement in monitoring team performance allowed for less than adequate team performance to occur.

   (NTSB/AAR-89/03, 1989)

The Aloha case points to a few salient examples of limitations in human performance. First, it shows how poor physical access to a worksite can create unnatural and uncomfortable working conditions (this can also be viewed from the related field of ergonomics). Second, it shows how lengthy and repetitive procedures can lead to complacency. Third, it shows how "expectancy" can effect a decrease in an otherwise meticulous inspection. In other words, a maintainer may believe that if dozens of rivets were inspected and no cracks were found, then there is a very good possibility that other rivets will be free of defects as well. This is related to the *see what you want to see syndrome*, where humans are so accustomed to seeing a switch, a light, or perhaps a gauge in a certain position, that they tend to see what they want to see even if it is completely opposite of what is being seen. Fourth, working under extreme pressure will be conducive to corner cutting, oversights, and general sloppiness. Fifth, from the organizational perspective it was apparent that Aloha management was not aware of, or chose not to adequately address, the aforementioned limitations of human performance.

The Aloha accident was the first in which the NTSB began to specifically address human performance limitations in maintenance tasks. Since that time, there has been a sharp increase in the amount of research being conducted. This research has concentrated primarily on human error in maintenance tasks. Since human factors is a multidisciplinary field, there are numerous hypotheses that can be postulated. For instance, Drury and Ma (2003; n.d.) investigated the effects of language barriers on maintenance errors. The authors hypothesized that maintenance and inspection personnel whose native language was not English would be more susceptible to errors due to language barriers. In their two part study, the authors did find varying amounts of communication deficiencies in both synchronous (verbal and informal) and asynchronous (written and formal) communication. The implications of their findings are very salient due to the fact that a large amount of maintenance is now being outsourced to foreign facilities; a trend that is likely to increase. This, coupled with domestic maintenance facilities where a fair amount of employees may not speak English as their native language, raises some critical safety concerns.

On a more cognitive level, other studies have been conducted to look at the associations between errors and contributing factors in aircraft maintenance (Hobbs & Williamson, 2003). The authors suggested that the preponderance of cognitive error models allude to a string of contributing factors; however, there is a lack of published information on possible links between specific errors and contributing factors. A total of 619 safety occurrences involving aircraft maintenance were reported using a self-completed questionnaire. Of these occurrences, 96% were related to the actions of maintenance personnel. The associations revealed that there were links between memory lapses and fatigue and between rule violations and time pressure. This may not be surprising given the environment that maintenance personnel must perform within. Based on the results, the authors recommend a proactive approach to recognizing these factors, including the designation of accident prevention programs. This author agrees with these recommendations as it is clear that these error-inducing cognitive factors cannot be eliminated and therefore must at least be recognized, addressed, and mitigated to the best extent possible.

Do HF programs work? In order to determine if HF programs are effective, management needs to incorporate valid measuring systems. Just teaching an HF class to a group of maintenance technicians and assuming the results will lead to a reduction in errors and associated costs is a hard sell to management. Adding to this is the "fact or fantasy?" dilemma posited by Johnson (2001). Johnson suggests that many maintenance organizations claim to have an HF program in place when in fact they do not. This then begs to ask the question: What is a human factors program and what should it be doing for the organization? According to Johnson (p.1), "A human factors program for a maintenance organization is a means to identify, understand, and mitigate the characteristics of the human to the system interaction that may lead to sub optimal performance." To that end, "A human factors program should reduce the likelihood of error, contribute to worker and product safety, and ensure continuing efficient and effective maintenance work" (p.1). So how does management know whether its HF program is simply lip service or not? Let's take a brief look at the methods.

There are ways to quantify the effects of human factors training. Behavioral quantification can be in the form of attitude surveys, tests, and rating scales, just to name a few (see Drury, Ma, & Woodcock, 2002). In terms of financial quantification, Johnson, Sian, and Watson (2000) discuss the need for establishing an ROI analysis because human factors interventions compete for resources in an airline environment. The fine line between investment in safety and profitability can sometimes become blurred as managers have difficulty seeing HF training as a worthwhile investment. Indeed, trying to put HF programs into an investment frame can be difficult to say the least. Fortunately, the FAA has recently addressed this issue.

In a recent publication by the FAA that offers guidance on human factors program design and evaluation, a section is included that specifically addresses ROI (FAA, 2005, p.20). A simple formula is provided to compute the ROI of an HF program. The benefit of this simple formula is that one does not have to be an economist or mathematician to perform the calculations. The downside is that there will be certain limitations and constraints to absolutely precise calculations, due to the imprecise measurement of HF interventions. Overall, however, the formula does offer a simplistic and relatively accurate depiction of the investments and returns that are possible within the company's HF program. This is critical information when safety managers are trying to persuade upper-level management to buy into an HF program.

Research has been but one prong in a two pronged attack in addressing maintenance human factors. There has been a slow, but steady, adaptation of human factors training programs by maintenance organizations as well. In fact, as of 2006, the FAA (2006) is mandating that all Part 145 maintenance repair facilities have a formal human factors training program in place. Additionally, EASA (European Aviation Safety Agency) (2006) is requiring that all U.S. maintenance facilities that conduct work on foreign aircraft become human factors compliant in 2006. Either way, human factors training in maintenance will now be mandated in an effort to reduce errors in what had been a virtually ignored domain only a few years ago.

Discussion/Summary

This literature review looked at the history of aviation human factors, from its roots in World War II, to the "big push" to improve the interface between the aircraft and pilot, to the current requirement to address human factors in the maintenance domain. This historical timeline was by no means exhaustive and in fact was very basic. More detailed information can be found in the reference list at the end of this paper.

In summary, this author believes that the mandatory incorporation of human factors programs in maintenance facilities will have a positive and measurable affect on flight safety. Expected results may not come immediately. In fact it might be a few years before significant and measurable changes can be observed. This is due mostly to the large number of maintenance technicians that will be receiving HF training for the very first time (industry-wide training will require some time). Additionally, reinforcing concepts (such as annual refresher training) will likely need to complete a few cycles to ensure that the concepts of HF are firmly implanted.

Finally, for those who may not be involved in the aviation maintenance business, you might be interested in knowing what types of HF subjects are being taught to maintenance technicians in an attempt to make your flight as safe as possible. The following list, although not exhaustive and subject to modification, covers the basic subjects, as required or recommended by various aviation authorities that oversee HF compliance.

- **Human Performance and Limitations** (including vision, hearing, information processing, claustrophobia, physical access, and fear of heights).
- **Social Psychology** (including group and individual responsibility, motivation, peer pressure, culture issues, teamwork, management, supervision, and leadership)
- **Factors Affecting Performance** (including fitness and health, stress, time pressure, deadlines, workload, sleep, fatigue, shiftwork, alcohol, medication, and drugs).
- **Physical Environment** (including noise, fumes, illumination, climate, temperature, motion and vibration, confined spaces, and work environment).
- **Tasks** (including physical work, repetitive tasks, visual inspection, and complex systems).
- **Communication** (including interpersonal and intrapersonal communication, work logging and recording, currency, and dissemination of information).
- **Human Error** (including error models and theories, types of errors in maintenance tasks, implications of errors, and threat and error management).
- **Hazard in the Workplace** (including the recognition and avoidance of hazards).
  (CAA, 2002)

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