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EDITORIAL

The Boundaries of Aviation Psychology, Human Factors, Aeronautical Decision Making, Situation Awareness, and Crew Resource Management

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Many new people are entering our field through the International Aviation Psychology Symposium door. We are delighted to have these new people because they bring fresh ideas and real problems to be solved. However, it is clear from some of their expressions (on the electronic networks which bridge both the Atlantic and the Pacific) that there are misunderstandings concerning the underpinnings, definitions, and boundaries of our field. I am particularly concerned with the synonymous use of the terms "CRM" and "human factors" and the use of "human factors" referring only to the human side of the operator–machine system.

Inasmuch as many have attempted to state the boundaries of human factors, aeronautical decision making (ADM) expertise, and crew resource management (CRM), as one who has convened nine International Symposia on Aviation Psychology over 18 years and served as editor of *The International Journal of Aviation Psychology* for 7 years, it seems good that I share my own views on this topic. This editorial is offered not to restrict zeal and creativity but to help all of us communicate better with one another, especially across the big oceans. Some of the ideas presented could be argued and my own bias is evident, but I hope this results in discussion that leads to clearer understanding.

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HUMAN FACTORS

Let us step right into the fire and offer that "human factors", "ergonomics", and "engineering psychology" are roughly equivalent terms for the field of science concerned with the optimization of the *relation between people and the machines* they operate through the systematic application of *human sciences* integrated within the framework of *systems engineering*. Whereas "human factors" has been more widely used in the USA, "ergonomics" has been more widely used outside of the USA. "Engineering psychology" has been more widely used in academia.

There are two major objectives of human factors. The primary objective is to design systems in the most optimum way to take advantage of the characteristics and abilities of the people who are expected to operate them. The second objective is to select and train the operators of these systems. Stated another way, human-factors people design systems to minimize the need for training, and training is used to complete the job left undone by the systems design (Roscoe, 1980). Thus, the first line of defense offered by the human factors engineer against the inevitable errors that the human operator(s) will make is system design. The design should minimize errors and it should clearly show when errors occur so that they will be noticed and corrected before they become catastrophic. The second line of defense is to select and train the operators to the point of expertise on the systems. Thus, all aspects of training system design, including evaluation, fall within the purview of human factors.

Human factors specialists also deal with physiological factors that could affect operator performance including workload, stress, vigilance, attention, pressure, sensory limitations, age, gender, *g* forces, oxygen deprivation, temperature, and many others. They also work with social factors including crew communication and teamwork, organizational influences, and cultural factors. To some extent, human factors specialists consider the impact of personality on performance. Finally, they work with cognitive factors including information processing, decision making, language, and memory. This is not an exhaustive list of areas covered by human factors but it is enough to show the breadth of the field and, to some extent, its boundaries.

AVIATION PSYCHOLOGY

Aviation psychology is simply the application of human factors to the aviation domain. Accordingly, the definition is "the optimization of the relation between aviation machines in the air and on the ground and the people who operate them." Figure 1 is a conceptual diagram showing the interaction that occurs between the cockpit crew and three major tools that human factors engineers have provided for controlling the aircraft (viz., displays, computers, and flight controls). The emphasis on the engineering aspect of human factors can be seen in the interaction of these systems. Obviously, aviation psychology goes far beyond the airborne system shown in Figure 1. It includes the air traffic controller (ATC), the dispatchers, the regulatory authorities, and the organizations backing the flights.

The two major objectives of human factors are clearly seen in the topics offered by the Aviation Psychology Symposium series that, every two years, serves to redefine the field of aviation psychology and describe its boundaries. In the Ninth Symposium, the largest number of papers were engineering in orientation, reflecting the need to first design systems properly. These included cockpit and ATC system design, automation, free flight, and so forth. Almost as many papers were offered under the general topic of training and particularly crew management training. Less coverage was offered to other topics such as perception, cognition, physiology, culture, and aircraft maintenance.

In the Aviation Psychology Symposium we are continually seeking to stretch our thinking beyond our own boundaries when there are potential benefits for aviation. Thus, in the Eighth Symposium we shared research findings with the medical people who are concerned with teamwork in surgery rooms. In the Ninth Symposium we shared research findings with the Society for Human Performance in Extreme Environments, which includes space, underwater, and polar environments.

DESIGN OPTIMIZATION

Let us consider for a moment the current pressure to develop better situation awareness (SA) and CRM training. Why are we under such pressure? Could it be that our cockpit and ATC designs are no longer optimum for humans? Perhaps the

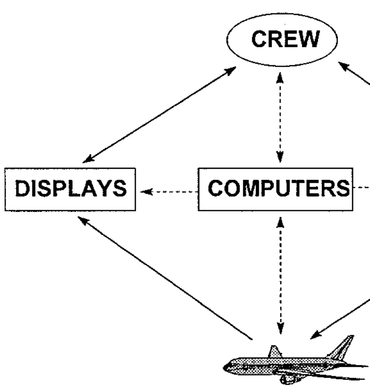

FIGURE 1 Conceptual diagram of crew interaction with aircraft systems.

many additional modes of operation have overstepped the human's capability to keep track. Perhaps we should be looking to the designers for better ways to present and control information rather than to look again to the training organizations to develop better ways to teach the pilots and controllers how to cope with these many new modes of operation.

AERONAUTICAL DECISION MAKING (ADM) EXPERTISE

As aviation psychologists think about how to complete the job left by the aircraft human factors engineer, an important question to answer is "What should the crew be like?" The answer requires a deep understanding of the "normal" persons assumed by the cockpit designer. It also requires the selection and training of those persons to the level of "expertise" expected of their passengers. So, we are faced with a series of questions including "What makes an expert pilot?" and "How can we distinguish between a competent pilot (as judged by the FAA in a flight test) and an expert pilot?" Finally, "Can we develop a training program that brings the competent pilot up to the level of the expert?"

The expertise literature indicates that the primary difference between a competent performer and an expert is judgment (Dreyfus & Dreyfus, 1986). In some aviation circles, the term Aeronautical Decision Making (ADM) has been used to refer to judgment. The expertise concepts have been confirmed in the aviation domain where most agree that many hours of flight does not an expert make, unless those hours include a variety of normal and abnormal experiences that lead to better judgment. Unfortunately, most student pilots do not receive structured decision or judgment training either in their initial or later flying experience. How can we expect them to reach above the level of competence if we do not teach judgment? We have assumed that they will learn judgment by their experience. Although a biennial flight review is required, many pilots keep repeating the same mistakes because they resist being evaluated in any meaningful way. Some may even resist continuing training for fear that some aspect of their flying will be deemed unsafe and that they may not be good enough to learn to do it right. These are the pilots who are now moving into airline positions where they must learn CRM and SA skills. Clearly, they could be better prepared for these skills with better ADM training in their early flying experience.

As a result of our research at The Ohio State University, we have concluded that there are five major components of expert aviator decision making expected by passengers of their pilots both in General Aviation (GA) and in the airlines. As shown in Figure 2, these five components are experience, risk management, dynamic problem solving, crew resource management, and attention control. Each of these components has subcomponents that should be addressed.

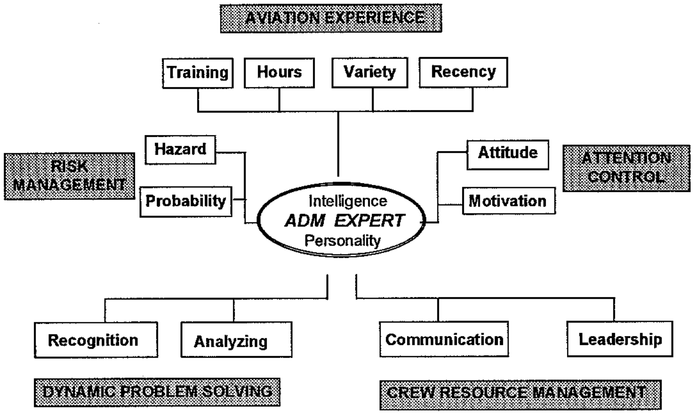

FIGURE 2 Ohio State University model of ADM expertise.

Experience

At the top is aviator experience. Although some have defined expertise as 10 years of full-time activity in a given field, we must differ at this point for the aviation domain. Our research indicates that each of four types of experience (viz., training, hours, recency, and variety) can compensate for less activity in other areas.

Training. There are two aspects of training that are important to ADM expertise. First, initial training can have an effect on certain aspects of flying that may carry throughout one's career (Tafliaferri, Wollard, Tigner, Guilkey, & Jensen, in preparation). Habits—including lack of flying discipline learned with one's first instructor—tend to remain and can be seen in flight test performance years later. On average, pilots who were initially trained in a Part 61 format do not perform as well, years later, as those who initially learned in a more disciplined Part 141 or University flying environment.

Second, a solid knowledge base, which is essential to ADM expertise, must be developed early, refreshed, and augmented periodically through self- and group study throughout one's flying career. Third, ADM, CRM, and SA skills need to be practiced repeatedly to be developed and to maintain expertise.

Hours. Number of flying hours is important and, by itself, is the single best experiential predictor of ADM performance, primarily because it indicates that the other subcomponents of experience are likely to be present. However, when the other components of experience (mentioned previously) are included, a more accurate picture is produced.

Variety. Ten years of flying in Ohio does not make an expert pilot in Colorado. In fact, experience flying in the mountains with a mountain flying expert can greatly improve one's Ohio flying performance. Furthermore, flying in various types of aircraft, in various weather, night, and airspace conditions, is essential to ADM expertise.

Recency. Clearly, recent flying experience is necessary to build and maintain ADM expertise. We forget over time. We forget procedures faster than we forget control functions. We may be able to make landings in normal conditions with no problem but we may forget, in a short time, how to tune the Global Positioning System (GPS) or how to do an emergency gear extension. ADM expertise is lost more from lack of attention than from lack of recent flying experience. Thus, most ADM expertise can be maintained through self-study and simulator work.

Risk Management

An essential second component of ADM expertise is risk management. Most accidents caused by pilots occur because the pilot did not manage the risks very well. In some cases the pilots did not know the risks involved; in others he or she ignored the risks. Risk management means being aware of the risks in all flying situations and being able to assess them, at least at the level of ranking them from least risky to most risky. Risk management means having a preestablished plan of action for as many flying situations as one can conceive and knowing the risks involved. Such safety plans are established by aviation operators as a precursor to the development of standard operating procedures for their pilots. Training in aviator risk management can take the form of reading case studies about accidents and incidents as well as studying the experiences of other pilots in abnormal situations. It can also take the form of the more formal "Personal Minimums" program (Jensen, Guilkey, & Hunter, in press) developed for general aviation pilots.

Dynamic Problem Solving

Pilots need to be able to solve problems in the dynamics of the in-flight environment. Usually, time is not severely limited, but it can be a factor. More important is the fact that the situation is changing and requires that pilots keep up with the changes to make the right decisions. If timing is very important, expert pilots may use a pattern matching technique such as Klein (1993) suggests in the Recognition Primed Decisionmaking (RPD) model. More typically, our research shows that when pilots have several minutes to more than an hour to make a decision, they will use more analytical techniques (Wiggins & Henley, 1997). At the very least, expert pilots will have defined strategies for solving problems that include information seeking, problem diagnosis, alternative generation, risk assessment, and decision making. They will follow a form of progressive decision making (Guilkey, Tigner, & Jensen, in press).

Crew Resource Management (CRM)

In the airline and upper-level corporate domain, CRM has become the primary new area of training for cockpit, cabin, dispatch and maintenance crews. CRM is defined as the effective management of all resources available to the operators. CRM is the application of ADM to multiperson flight crews. Therefore, CRM training includes interpersonal communication, group processes, team decision making, leadership, SA, conflict resolution, recognition of own behavioral styles, and recognition of other's behavioral styles. Many CRM courses offer other areas of content including management of automation, stress, and fatigue, but these are outside of the boundary of CRM unless they deal with interpersonal behavior. Expertise in ADM requires effective CRM techniques.

Attention Control

It is vitally important for pilots to maintain control over their attention (Gopher, 1982). Pilots must be able to focus attention on the most important task at hand but also be able to shift the focus of their attention when priorities change. Pilots are constantly facing challenges to their attention to the flight task in many forms, including social pressure, goal conflicts, and passenger requirements. Pilots are faced with perceptual errors and cognitive biases that can rob them of rational thought. There are at least five aspects to attention that, when brought under control, can contribute to ADM expertise; these include motivation, attitude, perception, expectations, and adaptability.

Attention control is seen in one's strength of character, will power, and integrity. It represents all of the positives that oppose the hazardous attitudes found, to some extent, in all of us. In another sense, it represents an internal locus of control, meaning that the person attributes success or failure to his or her own abilities. In another sense it represents task orientation. It is shown by the pilot who has the courage to decide to ground a questionable airplane against the demands of passengers and superiors. It may be measured by observing pilot reactions to ethical choice dilemmas around flying decisions (e.g., safety vs commitment). Does the pilot have the will power to go against social pressures to do the less-than-safe thing? Risk assessment requires knowledge and SA. Attention control requires the mental strength to avoid those situations that push risk.

Motivation. There are two aspects to motivation that are important. On the one hand, *intensity* or zeal to observe, organize, control, and stay aware of the situation in flight and to continuously learn more about aviation and safety away from flight are vitally important to ADM expertise. On the other hand, *direction* is equally important. Motivation should be directed to safety, as opposed to other goals including commitment to the flight, adventure, peer admiration, and so forth.

Attitude. Five or six hazardous attitudes have been identified, studied, taught, and evaluated over the past several years. These are *anti-authority, invulnerability, impulsivity, machoism,* and *resignation* (Berlin et al., 1982). Pilots who will not admit to any of these hazardous attitudes have the sixth attitude, *denial.* The results of fairly extensive research show that, when pilots are taught to recognize and avoid these hazardous attitudes, decision making and safety improves (Buch & Diehl, 1984; Jensen, 1995).

THE CHALLENGE: AVIATION SAFETY

It is important for all of us to present a message to the world upon which we can roughly agree. As we have seen previously, human factors is a field of science dealing with the operator–machine interface that is bounded by design at the beginning and training at the end, not the reverse. The challenge that I have faced from the beginning of the Symposium series is to convince the world, including the media, that "Aviation Psychology" is first and foremost "engineering" from the cockpit door forward. It is only after that human engineering effort is complete that the other parts of the field of aviation psychology–flight skill training, ADM, SA, CRM, fatigue, physiology, workload, and so forth–come into play.

Our theme for the Ninth Symposium focused on human error in the aviation system. We must agree that our first line of defense against flight crew error is not to look at the flight crew but to look at the design of the system. Unless we get this straight among ourselves, our message to the public—and especially to politicians who control our research budgets—will be clouded, and the importance of what we do will be diminished in their minds. The biggest potential loser is the public, whose safety would be compromised. Let us work together across the oceans as engineers, psychologists, scientists, training specialists, medical doctors, pilots, regulators, and flight program administrators, to reduce the impact of human error and improve safety in the worldwide aviation system.

ACKNOWLEDGMENTS

In this editorial, I speak for myself but credit for clearing my thinking goes to the OSU Aviation Research Team (consisting of faculty, staff, and students in the Aviation Program and other departments at The Ohio State University) and to David

Hunter, FAA Contract Technical Monitor in the FAA Office of Aviation Medicine—although all ideas are my own and not necessarily those of our research sponsor. The OSU research has included: national pilot surveys; interviews with hundreds of pilots; structured, think-aloud flying problem simulations with pilots and pilot examiners; line-oriented flight simulator studies; computer-based training program development; collaborative work with academics in New Zealand and Australia; and an extensive simulator and flight test of pilots with varying levels of flying experience—all in an attempt to better understand pilots and to make them safer.

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