Why Aren't We Teaching Aeronautical Decision Making?

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Abstract

Fifteen years of aviation research into the causes of human performance errors in aviation provided a basis for the current study. Detailed analyses of human performance error accidents produced the conclusion that approximately half of these accidents were decision related. Since traditional pilot training stressed aeronautical knowledge and flying skills while relying on experience to teach and practice decision making, an obvious question was: Can we teach decision making as a way to accelerate the normal learning based on experience and to reduce these accidents? This paper attempts to answer that question and to provide guidelines for both future research and the next generation of aeronautical decision making training materials.

Introduction

Extensive research and empirical testing in aeronautical decision making (ADM) produced a series of fifteen Federal Aviation Administration (FAA) manuals and reports on ADM (1986-1988) as shown in Table 1. These ADM training manuals covered the range of pilots from student private candidates to instrument-commercial pilots and crew resource management for multi-pilot operators, as well as reports devoted to helicopter pilots, emergency medical service (EMS) pilots, and natural resource pilots. In addition, ADM reports were developed for EMS operator risk management, hospital administrator ADM and air traffic controller decision making.

The work described in this paper was initiated in October 1990 with a Phase I study which investigated the differences between novice and expert pilot decision making from an information processing perspective (Adams & Ericsson, 1992). The Phase I report correlated the development of expert decision making with pilot training and experience, and reviewed accident scenarios which exemplified those processes.

Extensive experimental validations and empirical testing in both civil and military operational environments have documented that accident rate reductions of about 50% can be seen when comparing pilot groups with and without decision making training. Although it is difficult to accurately assess the impact of these manuals throughout aviation, significant reductions in human performance error (HPE) accidents have been demonstrated in the specific aviation applications shown in Table 2 which shows the worldwide civil and military safety improvements along with earlier FAA experimental results. The U.S. Air Force data reported by Diehl (1991) as shown in Table 2 and the U.S. Navy data (Alkov, 1991) further substantiate the validity and worth of the FAA research and ADM training.

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Table 1
Summary of ADM Training Materials

Report Number	Title
FAA/PM-86/41	ADM for Student and Private Pilots
FAA/PM-86/42	ADM for Commercial Pilots
FAA/PM-86/43	ADM for Instrument Pilots
FAA/PM-86/44	ADM Instructor Guide for Student and Private Pilots
FAA/PM-86/45	ADM for Helicopter Pilots
FAA/PM-86/46	ADM - Cockpit Resource Management
FAA/DS-88-5	Air Ambulance Helicopter Pilots-Learning from Past Mistakes
FAA/DS-88-6	Air Ambulance Helicopter Pilots-Situational Awareness Exercises
FAA/DS-88-7	Risk Management for Air Ambulance Helicopter Operators
FAA/DS-88-8	ADM for Air Ambulance Hospital Administrators
AC 60-22	ADM Advisory Circular
unassigned	Air Traffic Controller Decision Making Training Materials
unassigned	ADM Techniques for the Practical Test Guide
unassigned	Back to Basics Introduction to ADM
TE01P12	ADM for Natural Resource Pilots

Table 2
ADM Successes

Data sources	HPE reductions (%)
10 Experimental validations	8 - 46
World-wide civil helicopters (Bell 206)	
All HPE accidents	36
Weather related accidents	72
U.S. civil helicopters	
Bell 206 All HPE Accidents	48
Largest civil operator	54
U.S. military	
Air Force MAC transport crews	51
Navy helicopters	28
Navy airplanes (A-6 & EA-6)	81

This basic research defined judgment as: "the ability to stay on top of and control the flight situation, and the motivation to assure safety through timely decisions." ADM identified hazardous attitudes in flight operations and provided pilots with a self-assessment test with which to judge their own abilities. The method stressed situational awareness and a structured approach to decision making to enhance the pilot's application of conventional flight training, knowledge, skill and experience. The methods taught to accomplish good decision making stressed serial, deductive reasoning in a checklist form using the DECIDE model (Detect, Estimate, Choose, Identify, Do, Evaluate). This method is useful to novices, but not necessarily representative of the more advanced decision making abilities used by expert pilots.

The specific shortcomings of this approach included (a) the great difficulty in carrying out the linear analysis under conditions of time pressure, (b) the difficulty in applying it to problems with incomplete information or ambiguous data, and (c) that it was not representative of documented differences between novice and expert decision makers in other fields (Chi & Glaser, 1988).

All of these shortcomings lead the industry to come back to the FAA with a request for additional training material for use in training of novice pilots and for use in both initial and recurrency training with more experienced pilots.

Expert Decision Making (EDM)

Developing EDM training involves unraveling the relationships between cognition (how pilots think in operational situations) and training. Conventional pilot training has been based upon a foundation of skill-based, rule-based and knowledge-based tasks. That is, pilots are taught conceptual knowledge; flying procedures; and, basic pilot skills, while leaving the development of decision making to the realm of experience. The novice pilot, therefore, is expected to learn aerodynamics, airplane performance, electrical and hydraulic systems, Federal Aviation Regulations, etc. He is then trained in aircraft control and operation for both normal and emergency situations. This training includes procedures development for preflight, takeoff, cruise, approach and landing phases of flight. Through this training, the novice develops and improves his basic psychomotor abilities and hones his flying skills.

At this stage, decision making is only taught informally through training session debriefs, hangar flying, analyses of other pilots' experiences and the limited flight experience gained in preparation for an airman certification test. After successfully passing the test, the novice pilot is expected to cautiously begin developing good decision making and judgment skills as he gains experience. Because of the emphasis of aviation on procedure oriented training, both in developing flying skills and in decision making skills, training lays the foundation for the development of more sophisticated decision making as experience is gained.

Common characteristics of expert decision making have been observed in the fields of mathematics, physics, medicine, music, sports and aviation (Ericsson, 1991). In fact, individuals with expert thinking ability have been identified as a new personality type. First the classic Type A and B personalities were identified, individuals who respond dramatically differently to stressful situations. Then the Type T or thrill-seeking personalities, those who seek out the "edge-of-the-envelope" and enjoy the challenge of overcoming dangerous situations was recognized. Now psychologists have identified the Type C personality style as chaos changing individuals who are expert problem solvers. Type C individuals have a tolerance for ambiguity, can see solutions in unfamiliar and information lean environments, and develop action plans even in time compressed situations (Buffington, 1989).

The most dramatic examples of how Type C pilots and crews apply their expert thinking skills have occurred in several airline accidents listed Table 3.

Table 3
Expertise in Action

Date	Location	Airline	Aircraft	Type
7-19-89	Sioux City	United	DC-10-10	Engine failure
2-24-89	Honolulu	United	B-747-122	Cargo door
4-25-88	Maui	Aloha	B-737-200	Fuselage
7-23-83	Gimli	Air Canada	B-767	Fuel starvation
6-02-83	Cincinnati	Air Canada	DC-9-32	Cabin fire

The catastrophic engine failure and subsequent total failure of the triply redundant flight control system of a United Air Lines DC-10 (Flight 232), the failure of a cargo door and explosive decompression of another United B-747 (Flight 811), and the fuselage separation of an Aloha Air Lines B-737 (Flight 243) are three prime examples of abnormal situations in which Type C problem solving abilities were used to overcome chaotic situations for which there were no specified procedures, no previous simulator training, and certainly no past experience. The event histories of these accidents were analyzed during Phase I of this project to provide specific examples of how expert pilots think (Adams & Ericsson, 1992). For ease of reference, the expert pilot decision making process demonstrated by Captain Al Haynes of United Flight 232 will be reviewed here.

In a speech on January 26, 1991, Captain Haynes reported that the transition from a normal, uneventful takeoff and climb to 37,000 feet to a "nearly uncontrollable" aircraft occurred in about 15 seconds. His first response was reverting to basic airmanship skills (i.e., figuring out how to fly the airplane). His ingrained training in crew resource management was evident by (a) his immediate decision to use the abilities of a check airman to operate the throttles and maintain heading with differential thrust, (b) his utilization of the second officer for damage assessment, (c) his concern for he passengers and coordination with the flight attendant and, (d) his professional communication with the air traffic controller. (Haynes, 1991)

Captain Haynes' behavior clearly show the expert pilot's ability to assimilate data and impressions quickly, formulate a solution, and carry it out while maintaining mental composure under extreme time pressures. However, even with complete utilization of his expertise and all available personnel, pitch oscillations (60 second phugoids) and roll reversals (from 4-28 degrees of bank) were as stable an approach as the aircraft could make. Nonetheless, Captain Haynes reported that he was always "confident of getting the aircraft on the ground." This expert thinking -- knowing what to do and when to do it -- and the taming of a chaotic situation is the real mark of the Type C decision maker. After the accident, Captain Haynes stated that five factors were instrumental in his ability to land the aircraft and save as many lives as he did. They were luck, communications, preparation, execution and cooperation.

The focus of this report is on the preparation and execution aspects of how expert pilots think. Since the way these tasks are performed in practice strongly affects how they will be performed during an emergency, these areas offer the greatest potential for improved training. The factors and processes involved in these two critical decision making areas include: **S**ensing, **O**rganizing, **A**nalyzing and **R**esponding to the cues and contexts of the situation. The Type C behavior documented by Captain Haynes, his crew and the crews of the other "aviation saves" is referred to herein as Cognitive SOARing to recognize the special level of expertise required for abnormal emergencies.

Cognitive SOARing: Sensing, Organizing, Analyzing and Responding

The study of cognition over the past 40 years has identified the importance of four systems used in thinking, or "information processing." Basically, the human information processing system includes (a) the sensory systems (visual, auditory, seat-of-the-pants, etc.), (b) the memory systems (long term, short term and sensory memory), (c) the processor, and (d) the response systems (motor events, communications, etc.). These four systems incorporate the basic characteristic concepts which contribute to the individual's cognitive **SOAR**ing capabilities.

Sensing is the first preparation step involved in decision making. Pilots vary in the way they perceive (recognize and sort) information from the cues and context of a situation. Sensory memory provides enough retention to allow a reasoned response to each situation. The basic characteristic of sensory memory that is important for pilots to be aware of is that a lot of information is "sensed" or received, but only a small amount is "attended to." Dedicated time spent focusing on individual cues and responding is time taken away from situation monitoring or passive situation assessment.

Since the amount of time pilots spend actively attending to sensory inputs versus passively monitoring the cues and context of a situation varies directly with knowledge, training, experience and currency, each of these elements impact the pilots ability to respond in a timely fashion to specific situations. Consequently, attention is one of the differentiators which can be used to identify experts vs. novices. Attention training can, therefore, provide the first part of a program designed to lessen the reliance on experience as the only means of attaining expert performance.

Organizing involves filtering, prioritizing and structuring sensed information. During this step, short term and long term memory resources are used to identify the most important information and develop an understanding of the situation or problem. This understanding is formulated into a group of related facts, data, results and procedures, that is, a pattern which characterizes the current situation and can be used to retrieve related information from short and long term memory. Although the novice and expert pilot have equal capability for cognitive processing, novices typically use lots of search and processing time in a less focused and more general manner. The outstanding performance of experts is derived from how their knowledge is structured in short and long term memory for retrieval, pattern recognition and inference. Memory training should be the second part of an EDM program.

Short term memory and long term memory should not be thought of as different places pilots "put" facts or procedures. Rather, the differences in these two memory systems are based upon the "operational readiness" of the knowledge at any given time. Short term memory provides active, usable chunks of information in a state of readiness to be used. The precise content, organization and usability of each chunk is tied directly to exposure and practice. Therefore, pilot training and especially decision-making training could benefit by re-examining the criticality of information chunking and train novice pilots earlier in the necessary short term memory skills.

Long term memory provides stored information including factual, procedural, experiential, and emotional knowledge. Pilots have stored this knowledge in related groups or schema and must reactivate it based upon the specific situation. Reactivation can be initiated by the cues (mental or physical), the context of a situation (normal or emergency procedure) and the pilot's abilities to make associations between current and previous patterns. Long term memory, then, depends on the pilot's ability to respond to new demands for information through his abilities of recognition and recall.

Analyzing (or information processing and evaluation) is the third critical step in pilot thinking. This step relies on the type of knowledge stored and how it can be retrieved. Once again, expert pilots have developed superior long term memory organizational capabilities which facilitate recognition and recall. Experts use schema, pattern recognition, associative reasoning, elaborations and inferences to interpret the cues and context of a new situation based upon their related knowledge. This expert capability manifests itself in the ability to intuitively respond to patterns without decomposing them into component features or problem elements. An example of these abilities would be the expert's ability to respond to loss of an engine on takeoff without consciously "thinking through" the engine out procedure. This understanding occurs effortlessly due to the expert's knowledge structure.

The expert's ability to fast access their schema (concepts or patterns) of aviation knowledge is expedited by the associations with cues and context of new situations which stimulate the recall process. Although the associations (or concept elaborations) are predominantly based upon experience today, training aimed at replicating this ability is not an unreasonable goal. In addition to the elaborations, the expert's ability to use inferences to aid reconstruction of similar problems and solutions could also comprise part of this training.

Responding is the most critical step of the EDM process. This step requires that the pilot take some action to alter or control the situation and then monitor the effectiveness of that action. Responding involves the use of conceptual and procedural knowledge. Since aviation training is highly procedural both in developing flying skills (psychomotor) and in problem solving for normal and emergency situations, pilots are provided the foundation for more sophisticated problem solving using production rules. Production rules consist of conceptual knowledge combined with general problem solving procedures (i.e., heuristics, algorithms, working backward from a goal, etc.) to create new, problem specific procedures. This ability marks the early beginnings of how expert pilots think. As these rules are used more and more often, and applied to many situations, they result in autonomous generation of specialized production rules which often use forward inferencing to progress from the initial problem toward a solution or goal.

The captain of the UAL Flight 232 (used as an example of successful decision making and problem solving in chaotic, multiple failures) expressed the opinion that preparation and execution were critical factors involved in his decision making and problem solving. For this analysis the preparation factor was limited to the cognitive aspects of **S**ensing and **O**rganizing information. The EXECUTION factor was similarly limited to the cognitive aspects of **A**nalyzing and **R**esponding to the needs of the situation.

Conclusions

This paper has presented a unique view of how pilots think based upon expertise, information processing and problem solving processes. This analysis of the mental aspects of preparation and execution lead to the coining of the term cognitive SOARing for the "taming of the chaotic situation" demonstrated in several of the recent air carrier accident "saves." This type of problem solving behavior has been recognized and identified in the psychology field as Type C behavior where solutions are developed under time pressured, information lean, ambiguous circumstances. Successful training of Type C problem solving behavior has been demonstrated in other fields. The transfer of this training to aviation offers potential enhanced decision making training for pilots and should be addressed in future research. The following general conclusions can be drawn from the analysis presented:

1. Aeronautical decision making can be taught both in a classroom and a simulator environment. The principles and concepts of ADM have been accepted and used by a wide variety of civil and military aircraft users performing a multitude of missions. All formalized ADM training implemented to date improves safety through significant reductions in human performance error accident rates.

2. Expert cognitive performance is characterized by rapid access to a well organized body of conceptual and procedural knowledge. This is a modifiable information structure based upon knowledge that is experienced. This experience allows the perception of large meaningful patterns in familiar and new situations which help the expert match goals to task demands. This means they can respond creatively or with opportunistic solutions based upon a global perception of the meaningful relationships in a situation.

3. Experienced pilots have exhibited expert cognitive performance through keen, quick, confident decisions and almost a direct perception of the proper course of action. These decisions which occur so rapidly it appears to be a cognitive process and behavioral resultant based upon

insight or intuition. This intuitive performance is based upon: experience (cognitive and sensory, internal and external); the cues and context of the situation; and, the experts ability to identify causal relationships in a situation.

4. Experience or training that is intended to be used for the development of expert pilot cognitive processing development must insure the perception of the essential psychophysiological elements of the problem. The appropriateness of the experience will be critical to the subjective associations and stored knowledge patterns that will be used in new situations.

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