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Research and
Development Service
Washington, DC 20591

Workshop on Aeronautical Decision Making (ADM)

Vol. II—Plenary Session With Presentations and Proposed Action Plan

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NOV 20 1992

August 1992

Final Report

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1. Report No.	2. Government Access No.	3. Recipient's Catalog No.
DOT/FAA/RD-92/14, II		

4. Title and Subtitle	5. Report Date
Workshop on Aeronautical Decision Making (ADM) Vol. II - Plenary Session With Presentations and Proposed Action Plan	August 1992
	6. Performing Organization
7. Author (s) Richard J. Adams (AAC), Catherine A. Adams (AAC),	8. Performing Organization Report No.
	10. Work Unit No. (TRAIS)
9. Performing Organization Name and Address Advanced Aviation Concepts, Inc. 10356 Sandy Run Road Jupiter, FL 33478-9335	11. Contract or Grant No. DTFA01-90-C-00042
12. Sponsoring Organization Name and Address US Department of Transportation Federal Aviation Administration 800 Independence Avenue, S.W. Washington, DC 20591	13. Type Report and Period Covered Final Report
	14. Sponsoring Agency ARD-200

15. Supplementary Notes

ARD-200 Systems Technology Division

16. Abstract

This report analyzes the accomplishments and needs of ADM from the perspectives of the operators, researchers, the military and the FAA. Both the airplane and helicopter communitys' experiences are considered. The presentations and background material in this volume were a part of the Plenary Session conducted on the first day of the workshop. They were meant to provide a detailed understanding of the status and needs of ADM from both operational and research perspectives.

Problem areas identified by the workshop participants which defined the need for basic research included: Can we define what constitutes a "good decision"? Can we identify different decision "nodes" during a flight? What do we want to train? How do we want to train? This volume presents the participants perspectives on the behavioral psychology and human factors work that has been done in these areas as well as in the area of new decision making models and concepts.

Finally, the participants discussed the research required to sustain the progress achieved through ADM training to date. This lead to a critical analysis how training was being done today, what could be done to enhance basic ADM training, and what type of advanced or Expert Decision Making (EDM) training materials and methods could be developed. Part III of this volume translates the participants' responses to these future needs into a proposed action plan for use by all interested parties.

17. Key Words	18. Distribution Statement
Aeronautical Decision Making (ADM) Crew Resource Management (CRM) Advanced Qualification Program (AQP) Cognitive Task Analysis (CTA) Expert Decision Making (EDM)	This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	268	

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WORKSHOP ON AERONAUTICAL DECISION MAKING

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AERONAUTICAL DECISION MAKING WORKSHOP

PLENARY SESSION PRESENTATIONS

By: Advanced Aviation Concepts, Inc.
Jupiter, Florida

For: Federal Aviation Administration
Washington, DC

Denver, Colorado
May 6 and 7, 1992

PART I: OPERATIONAL ADM EXPERIENCE AND IMPACTS

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DOES COCKPIT MANAGEMENT TRAINING REDUCE AIRCREW ERROR?

Conclusion:

The results of six empirical and six operational evaluations provide strong evidence that these training programs can help reduce aircrew errors and thereby prevent accidents.

Paper Presented at the 22nd International Seminar
International Society of Air Safety Investigators
Canberra Australia, November 1991

DOES COCKPIT MANAGEMENT TRAINING REDUCE AIRCREW ERROR?

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Introduction

Human factors problems continue to be involved in majority of mishaps. Thus, the causes and cures for aircrew "error" are widely discussed topics. Several experts (e.g. Bruggink, 1978, Miller, 1979 and Nance, 1986) have noted that labels like pilot "error" are often misapplied in describing ergonomic, management, regulatory or systems design shortcomings. This paper uses the generic term "cockpit management" when referring to the wide variety of programs which are designed to reduce aircrew errors. In fact, recent evidence suggests Cockpit Resource Management (CRM) and Aeronautical Decisionmaking (ADM) training may help reduce aircrew error accident rates by as much as 81 percent.

These programs have only emerged in the last decade largely because of the fundamental problems associated with detecting and controlling human error. Many of us have lamented the greater difficulties of accurately documenting human vis-a-via mechanical failures, (e.g. mental fatigue is usually tougher to prove than metal fatigue). It is also often harder for us as air safety investigators to specify effective countermeasures in the human factors domain. Thus, some organizations unfortunately have assumed such errors are "the price of doing business."

In these times of tight budgets, management and government authorities can be expected to demand proof that preventive measures are in fact working. Here again, proving the effectiveness of human factors initiatives is very difficult, (e.g. crews can always comply with unpopular standard operating procedures during check-rides). Lastly, experts such as Dr. Clay Foushee (1987) have aptly noted that accidents, because of their relative infrequency, make poor scientific criteria. It is also axiomatic that proving the negative (accidents which were prevented) is even more difficult.

This paper addresses these issues by: 1) Examining the prevalence of major types of contemporary errors and reviewing the traditional methods which have been used to improve human reliability, 2) Discussing how innovative cockpit management training programs were developed and implemented, and 3) Describing the current evidence on the effectiveness of such programs.

Taxonomy of Errors

In their classic study, Jensen and Benel (1977) noted all aircrew errors could be classified into one of three major categories based on behavioral activities: Procedural, Perceptualmotor, and Decisional Tasks. Examples of procedural tasks include management of vehicle subsystems and configuration, while related errors would include retracting the landing gear instead of flaps or overlooking checklist items. Perceptualmotor tasks include manipulating flight controls and throttles, while errors would include over shooting a glide-slope indication or stalling the aircraft. Decisional tasks include flight planning and in-flight hazard evaluation, while errors would include failing to delegate tasks in an emergency situation or continuing flight into adverse weather. These researchers also noted while the term "judgment" is sometimes used with both perceptualmotor and decisional processes, it should be more closely associated with the complex cognitive processes involved in human decisionmaking.

They analyzed all US general aviation accidents occurring from 1970 to 1974 using the National Transportation Safety Board (NTSB) computerized data base. Their analysis of the fatal accidents involving pilot error indicated that 264 were procedural, 2496 were perceptualmotor, and 2940 were decisional in nature.

My recent paper (Diehl, 1991b) analyzed military and airline accident data, for comparison purposes, using the Jensen and Benel (1977) taxonomy. The NTSB computerized accident data base was examined for US airline (and scheduled airtaxi) accidents occurring during 1987, 1988, and 1989. This data indicated that 24 of the 28 major accidents (those resulting in destroyed aircraft and/or fatalities) involved aircrew error. In these accidents there were 16 procedural, 21 perceptualmotor, and 48 decisional errors. The relative percentages of these errors are depicted in Table 1, along with the previously discussed general aviation data and that of another study involving military accidents.

The computerized data base was examined for US Air Force (USAF) Class A flight mishaps. These were mishaps involving the destruction of the aircraft or over one-million dollars in damages and/or fatalities. The period reviewed included the data for fiscal years 1987, 1988 and 1989. Note US Government fiscal years begin on first day of October.

Here 113 of the 169 mishaps involved some type of aircrew error. Included were 32 procedural, 110 perceptualmotor, and 157 decisional errors. These types of errors were labeled "slips", "bungles" and "mistakes" respectively (Diehl, 1989). Thus, this data collectively reveals the significance of decisionmaking to all segments of aviation.

Table 1

Types of Aircrew Errors in Major Accidents

	Category of Error		
Kind of Operation	Procedural "Slips"	Perceptualmotor "Bungles"	Decisional "Mistakes"
General Aviation	5%	44%	52%
Airlines	19%	25%	56%
Military	11%	37%	53%

Improving Aircrew Reliability

Over the years great strides have been made in improving the mechanical reliability of aircraft and systems, while various means of enhancing human reliability have also been undertaken. Some concepts, designed to prevent aircrew error, were undertaken even before the phenomena was thoroughly understood. As noted above, oftentimes a priori scientific proof was unavailable. A proverbial "Catch 22" may have existed such as " We can't use it until we know it works, and we'll never know it works until we try it." Other times innovations may have just been institutionalized common sense, (e.g. the development of written checklists as aircraft became increasingly complex). Such countermeasures have focused on improving six human "faculties" fundamental to flying.

These faculties constitute the "right stuff" and include: 1) abilities, 2) motivations, 3) knowledge, 4) procedural techniques, 5) perceptualmotor skills, and 6) decisional judgment. As I recently noted, Diehl (1991b), these six items are part of a "Hierarchy of Aeronautical Faculties" with abilities on the base and decisional judgment at the apex, as the highest faculty. Figure 1 depicts this relationship along with the role played by traditional and modern preventative measures.

Obviously, the three categories of errors discussed above are failures associated with the three higher faculties (procedures, perceptualmotor, and judgment behaviors). While the other faculties (abilities, motivations, and knowledge) are enabling factors which underlie such behavioral tasks.

Interestingly, an individual student aviator generally undergoes screening and training processes which proceed systematically from the base to the apex of this hierarchy. Not surprisingly, this is also the fundamental sequence in which the aviation industry attacked the problems associated with human error.

Abilities: Medical screening tests were successfully used in the First World War. Early testing focused on easily measurable items such as cardiovascular health and visual acuity. Basic mental capacities were also measured. Such procedures were, of course, improved over the years by various military and civilian organizations.

Motivations: Mental tests for screening aviation candidates' personalities and interests have been widely used since the beginning of the Second World War. These psychological instruments, like the medical screening protocols, have been constantly refined. In addition, modern aviation organizations use a variety of measures such as employee assistance programs to enhance the physical and mental faculties of their employees.

Knowledge: In the post-Second World War era, greater emphasis was placed on screening the prospective airman's general knowledge, (e.g. a college degree became a pre-requisite for many military and commercial pilot training programs). Imparting the vast amounts of specialized knowledge (consisting of information and data as well as rules, concepts and principles) has been a major function of aviation training.

Great strides have been made in effectively imparting knowledge. For instance, standardized formats in flight manuals were in wide use by the 1950s. Instructional Systems Design concepts have been used since the 1960s to systematically identify "need-to-know" versus "nice-to-know" information. In recent years, computer based training applications have increased the efficiency of teaching aeronautical knowledge. This knowledge was always regarded as a prerequisite for learning procedures, skills, and judgment tasks.

Hierarchy of Aeronautical Faculties

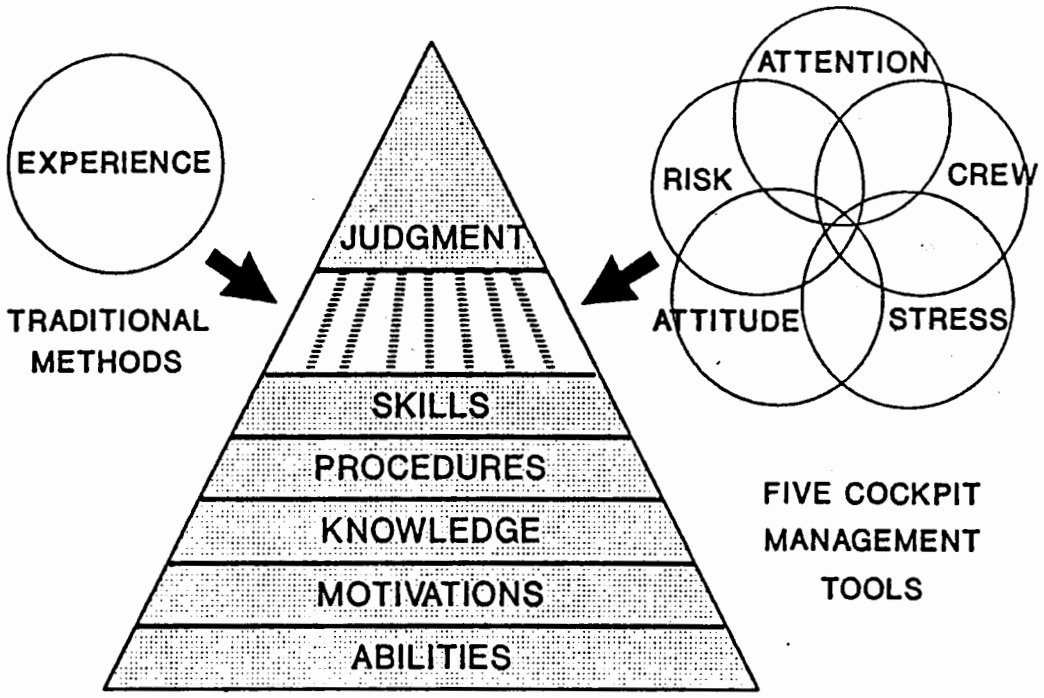

Figure 1

Procedural Techniques: These "finger faculties" were necessary to manipulate the switches, buttons, and knobs of aircraft subsystems. As on-board equipment became more complex, these techniques took on expanded importance. By the 1950s, cockpit design standards and crew checklists were in widespread use. The decades which followed saw increasing use of devices such as cockpit procedures trainers to enhance the mastery of such tasks.

Perceptualmotor Skills: The importance of these "stick-and-rudder" tasks have always been recognized. Good hand-eye coordination was a prerequisite for the timely maneuvering of an aircraft through three-dimensional space. Although, automation and stability augmentation systems have decreased somewhat the amount of time crewmembers now spend on basic aircraft control activities. Control-display integration and fused sensors have further decreased this type of workload. The use of modern digital simulators has facilitated the efficient acquisition of these skills, especially since the 1960s.

Decisional Judgment: "Headwork" or cognitive tasks were also regarded as vital. But such abilities were historically assumed to be a by-product of flying experience, or taught only informally. Little was known about this faculty until the 1970s. In that decade, cockpit voice and flight data recorders, as well as more systematic accident investigation methods, had revealed the magnitude of judgment, crew management and situational awareness problems. Moreover, human factors research began suggesting the possibility of formally teaching cockpit management tasks.

In that decade, the Federal Aviation Administration (FAA) had initiated the aforementioned study into potential methods of teaching judgment concepts to general aviation pilots (Jensen and Benel, 1977). At this time, USAF was examining methods to improve the workload management techniques of fighter pilots during emergencies (Thrope, Martin, Edwards and Eddowes, 1976). Meanwhile, the National Aeronautics and Space Administration (NASA) had simultaneously undertaken several comprehensive programs focusing on methods of reducing crew errors in transport aircraft (e.g. Ruffle-Smith, 1979). Several airlines were then in the process of developing important training innovations. Line Orientated Flight Training (LOFT) was pioneered by Northwest Airlines to improve crew coordination in simulators. United Airlines had also initiated simulator research into subtle incapacitation recognition, while KLM was developing a course to teach leadership skills of their line captains. The latter program was, of course, undertaken as a result of their 1977 Tenerife accident.

Implementing Cockpit Management Training

This then was the state of affairs in our industry when a United Airlines DC-8 crashed into a suburb of Portland Oregon on the evening of Dec 28, 1978. I was dispatched to this, now well-known, accident as the NTSB Human Factors Group Co-chairman. The circumstances of this mishap were quickly established: The highly experienced crew became distracted by a landing gear problem and ran out of fuel. After reviewing the reports of similar accidents and the existing research, I drafted the first recommendation calling for the operational implementation of cockpit resource management programs by US airlines (NTSB, 1979).

"Selling" this recommendation to the leadership of the NTSB was not difficult. For they were easily persuaded that CRM was "an idea whose time had come." These programs have gone into widespread use in the last dozen years. But, not without much debate about their effectiveness, which continues to this day.

Since writing that first CRM recommendation, I have found myself immersed in the continued advocacy, development, and evaluation of such programs. These endeavors have included helping extend the application of cockpit management concepts to general aviation and military users. For example, my first assignment after becoming the FAA Program Scientist for Human Performance was to monitor the initial experiments on the effectiveness of the prototype judgment training courses (Buch and Diehl, 1984). When the first airline accident occurred to a crew which had received CRM (NTSB, 1983), the FAA asked me to examine methods of improving the certification of these programs (Jensen, 1987). The USAF Inspection and Safety Center (now redesignated as the Safety Agency) recently tasked me with analyzing data on the effectiveness of civil and military cockpit management courses. The results of that research (Diehl, 1991b) will be discussed below.

This past year has seen a accelerating interest in such training. For instance, the NTSB as part of a major general aviation accident investigation, has recently recommended that Aeronautical Decisionmaking training be implemented among all categories of pilots in the civil aviation community (NTSB 1991). Similarly, all the USAF major commands now have adopted some type of cockpit management training program (Diehl, 1991a).

Components of Cockpit Management Training

Much has been written in recent years about methods for enhancing the collective decisionmaking in multi-place aircraft through the use of CRM techniques (Lauber, 1984, Nance, 1986, Alkov, 1988, Foushee and Helmreich, 1988, and Helmreich, 1991). In contrast, less information is available on programs aimed at improving the decisionmaking abilities of individual pilots (Buch and Diehl,

1984). Note that the term "aeronautical decisionmaking" (ADM) has become synonymous with "judgment training" in recent years. Furthermore, categorical distinctions between CRM and ADM are disappearing in that today most comprehensive versions of these programs have several common functional components dealing with: attention, crew, stress, mental attitude, and risk issues.

The role which the five components or "cockpit management tools" play in the hierarchy of aeronautical faculties is depicted in Figure 1. These tools may, in effect, provide "synthetic experience" for neophyte airman while offering a structured system for assisting the decisionmaking of their experienced counterparts. These five interrelated concept areas furnish "rules and tools" to help prevent common errors. For instance:

1. Attention management issues include understanding how distractions and "error chains" can be avoided.

2. Crew management issues teach the importance of proper communications, division of responsibilities, leadership, and teamwork.

3. Stress management concepts focus on understanding the effects of lifestress events as well as providing in-flight stress coping strategies.

4. Attitude management concepts describe the methods of recognizing and controlling certain hazardous attitudes and behavioral styles.

5. Risk management issues focus on the rational evaluation of qualitative and quantitative information related to operational hazards.

Cockpit Resource Management: Note that Crew Resource Management is another popular label for such courses. The conceptual basis of these programs was largely social psychology and management theory. Many of these programs were developed and refined with the data and expertise from NASA (Lauber, 1984, and Foushee and Helmreich, 1988).

Most contemporary CRM programs utilize training manuals, interactive classroom lectures, with audio-visual aids followed by LOFT sessions which are video taped for critique purposes. The courses provide a wealth of techniques to enhance flight deck communication. For example, avoid "excessive professional courtesy": If the captain is two dots low on the glide-slope, tell him so in unequivocal terms. Don't say, " You're a little low, Sir".

United Airlines has arguably fielded the most widely used of these courses, although KLM launched the first such course aimed at captains. Both airlines have successfully marketed their programs to other aviation organizations, and they continue to refine and enhance their respective programs (e.g. Freeman and Simmon, 1990 and Siemons, 1991). Other airlines (e.g. Quantas) have also independently developed highly innovative programs (Beaumont, 1989).

The USAF Military Airlift Command and the US Naval Safety Center have pioneered militarized CRM programs (Alkov, 1988), labeling them Aircrew Coordination Training (ACT). The USAF Strategic Air Command has recently fielded a very comprehensive CRM program under contract to Hernandez Engineering. This course has, in turn, been adapted for training USAF fighter crewmembers stationed in Europe.

The USAF Inspection and Safety Center initiated the development of a prototype course focused on single-seat fighters in 1990. It was intended to improve intercockpit as well as intracockpit decisionmaking. This program was a modified and enhanced version of the successful US Navy ACT program developed by CAE-Link. Units of the US Army have applied this same course to utility and attack helicopters. The USAF and USN training commands have also integrated these materials into their respective undergraduate pilot and navigator training. In 1992 the USAF T-1 "Jayhawk" trainer will become the first operational system procured with CRM specified in its design.

Aeronautical Decisionmaking: The conceptual basis of the ADM or judgement training programs was cognitive psychology, for this type of training was aimed at the attitudes and behavior of the individual pilot. Most of these programs originally focused on students pilots (Berlin, Gruber, Holms, Jensen, Lau, Mills and O'Kane, 1982), but the concepts were later applied to a advanced training including commercial, instrument, and helicopter pilots (Diehl and Buch, 1986). The FAA, Transport Canada, the Australian Aviation Department, and the USAF have sponsored the development and evaluation of ADM programs. These materials typically consist of training manuals and audio-visual products which explain fundamental concepts related to error causation and prevention.

The way these materials work is illustrated in Figure 2 from the student pilot training manual, (Diehl, Hwoschinsky, Lawton, and Livack, 1987). This figure depicts the decisionmaking process as a series of feedback loops in which the pilots must manage his/her attention in a timely manor and sequentially employ the other cockpit management tools (for controlling stress etc.). The text describes how one does these things. Interestingly while this figure is somewhat simplistic in comparison with flow charts in more sophisticated texts (e.g. Reason, 1990), it does comport with ideas on pilot information processing offered by experts like Lee (1990).

AERONAUTICAL DECISION MAKING PROCESS

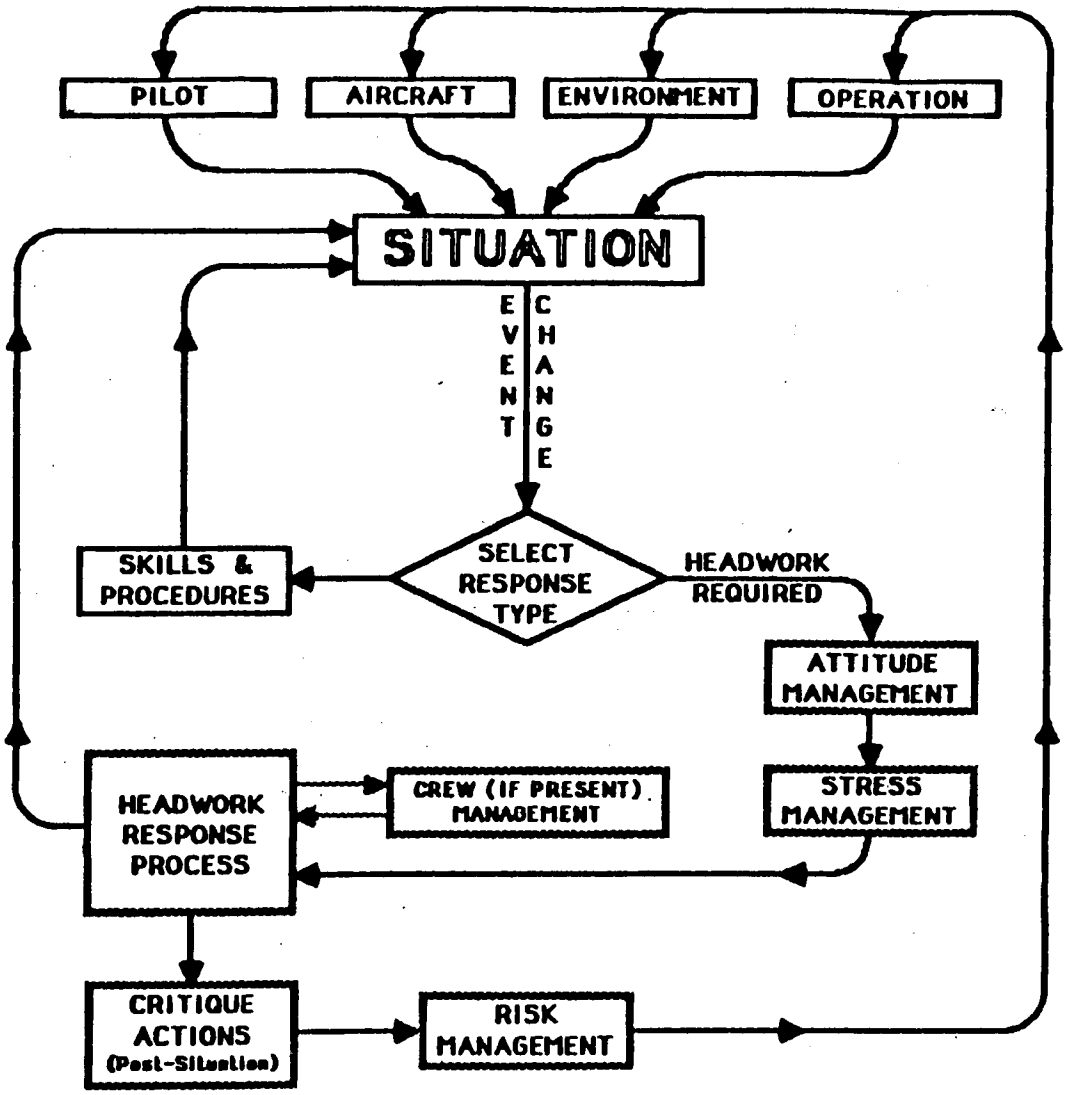

Figure 2

Situational Awareness: Other similar cockpit management training programs have focused on enhancing attention and task management issues. For instance, when the USAF began replacing its two-place F-4 with the single-seat F-15 in the 1970s, concerns were raised about pilot workload in emergencies. Situational Emergency Training was undertaken using cockpit procedure trainers. Thus, pilots could practice diagnosing typical emergencies, while maintaining aircraft control, rather than relying on memorized "bold face" procedures.

In the early 1980s, the US Air National Guard became concerned about the ability of their A-7 pilots to maintain proficiency in the low-altitude tactics. Their Low Altitude Training program was undertaken to teach pilots techniques for overcoming the unique hazards of operating in this highly dangerous and time critical environment (e.g. the tendency to fly lower over small desert bushes because, at high speed, they appear to be the same size as the larger trees which one is used to). This program included academics, simulator, and flight training.

Another important situational awareness training effort was just announced by the USAF Tactical Air Command. Their Aircrew Attention Awareness Management Program is designed to acquaint fighter pilots and weapon systems officers with physiological and psychological factors affecting their performance. These concepts are being taught in part by specially trained physiologists (familiar with CRM, ADM, etc.) who have been assigned to each fighter training unit.

Measuring Training Effectiveness

These training programs have all been generally well received by the individuals and organizations which have used them. Much contemporary research has described the improvement in the attitudes of people enrolled in such programs. But, for the reasons noted earlier, proving that the programs have prevented errors or reduced mishaps rates is difficult.

Fortunately, there is anecdotal information that such programs have helped prevent mishaps in a wide variety of civilian and military aircraft. For instance, a US Navy A-6 crew experienced a total hydraulics failure, but was able make a safe landing. The investigation concluded that this was a "first-ever" in that type aircraft, and their aircrew coordination training was a factor in this "save" (Alkov, 1991b). The NTSB came to basically the same conclusion regarding the value of CRM training in a similar incident involving the United Airlines DC-10 at Sioux City, Iowa (NTSB, 1990).

Preventing Error: One of the best methods of examining the effectiveness of training programs is to perform empirical tests to document whether crewmembers who receive such training make fewer errors. ADM programs have been extensively tested in this way. That was partly because, unlike CRM which was primarily employed for airline and military operations, ADM was initially applied to general aviation student training situations. The latter environment obviously involves relatively high error rates and low costs, thus permitting the use of controlled experiments.

Worldwide there have been six government sponsored, independent, evaluations of the ADM training programs. A detailed description of this research was recently completed (Diehl, 1990). These evaluations were performed to ascertain the effectiveness of such materials under differing conditions. The basic criteria were errors made during short, seemingly routine, crosscountry "observation flights." On these flights, specially trained observers surreptitiously placed subjects in a series of specific decision-making situations (e.g. rushing preflight inspections, or suggesting steep maneuvers at low altitudes). Observers then unobtrusively recorded the errors on these judgment items. In these rigorous "double-blind" experiments, the observers were not informed which subjects had received ADM training, while subjects were unaware of the real purpose of the flights beforehand (e.g. subjects might be lead to believe they would be evaluating new map designs).

As expected, the effectiveness of the ADM materials varied widely depending primarily upon the comprehensiveness of the training (see Table 2). For the six studies, the improvement ranged from 8% in a voluntary, minimally structured, situation to 46% for a well structured, comprehensive, ground school environment with simulator training. Note that all six tests were statistically significant at or beyond the .05 level of confidence.

Table 2

ADM Training Experimental Evaluations

Sponsor/Subjects	Methods	Results/Researchers
Australian Gov't. Private Pilots	Manuals, Lectures, Flight Training	8% fewer errors (Telfer and Ashman, 1986)
Transport Canada Private Pilots	Manuals only	9% fewer errors (Buch and Diehl, 1983)
US FAA Private Pilots	Manuals only	10% fewer errors (Diehl and Lester, 1987)
US FAA Student Pilots	Manuals, Lectures, Flight Training	17% fewer errors (Berlin, et al., 1982)
Transport Canada Civilian Cadets	Manuals, Lectures, Flight Training	40% fewer errors (Buch and Diehl, 1982)
USAF Instrument Students	Manuals, Lectures, Simulator Training	46% fewer errors (Connolly and Blackwell, 1987)

Preventing Accidents

These experimental evaluations provide strong statistical evidence such training can change behavior, and thereby reduce errors in low-time general aviation pilots. But the fundamental criteria for evaluating the effectiveness of cockpit management training programs is their ability to reduce the accident rates in the broader "operational world."

Airlines are obviously the most numerous users of these programs. But, their accidents occur very infrequently, (perhaps once every few years for a particular operator). Thus, it would be very difficult to prove that an individual airline, which had adopted CRM, in fact had experienced a significant decline in their aircrew error accident rate.

Fortunately, the FAA and Transport Canada have developed versions of the ADM training manuals for helicopter pilots (Adams and Thompson, 1987). This manual became widely used by a number of major rotorcraft organizations (Adams and Diehl, 1988). Because the accident rates for rotorcraft (and military aircraft) are normally orders of magnitude higher than those for airliners, one should be able to more easily detect improvement in their records. This was, in deed, the case.

Bell Helicopters Textron Inc. (BHTI): This major rotorcraft manufacturer provides extensive initial and recurrent training in both the US and abroad. They have utilized the ADM materials (Adams and Thompson, 1987) in their training programs since they were first published (Fox, 1991). BHTI particularly targeted their popular Bell Model 206 "Jetranger" because that craft generated about 46% of the total US civil helicopter flying hours.

They have also developed a "Cockpit Emergency Procedures Expert Trainer." Fox (1991) described this system as an artificial intelligence based software package which allows a pilot to use a personal computer as a decisionmaking simulator.

The results of BTHI ADM training efforts are impressive, especially when their accident rates are examined. Fox (1991) compared the 1983-1986 period (before training was begun) with the 1987-1990 period. The world-wide human error accident rate (per 100,000 hours) declined by 36% for the Jetranger. Note for comparison purposes, the rate for mechanically caused accidents declined by only 8%.

Fox (1991) also stated the US Jetranger human error accident rates declined by an even more impressive 48%. Here the comparison periods were 1984-1986 and 1987-1988. He notes that many Jetranger pilots attending their training also fly other single-engine helicopters, which may partly explain the more modest 25% improvement in those rates during this period.

Petroleum Helicopter Inc., (PHI): This organization is the largest commercial helicopter operator in the US with approximately 300 helicopters and fixed-wing aircraft. The company historically has had an excellent accident rate, well below the industry average. Their chief pilot (Mr Vern Albert) reported the results of the using of ADM/CRM training in Rotor & Wing International (1989), p. 65: "From 1980 through 1986, we had an accident rate of about 2.3 accidents per 100,000 flight hours. In mid-1986, we started ADM training, and the rate in 1987 was 1.86 and then dropped to 1.05 in 1988. The only thing we changed in our training syllabus was adding ADM and cockpit resources management." This translated to a 54% reduction in their overall accident rate.

US Navy: In 1986, the Naval Safety Center reviewed the CRM programs which were underway at several airlines and the USAF Military Airlift Command (Alkov, 1988). They began formal CRM training at all Navy and Marine Corps helicopter training units in 1987. CRM was then initiated in their A-6/EA-6 "Intruder" fighter-bomber training units in 1988. As noted earlier they labeled these CRM materials Aircrew Coordination Training.

Alkov (1991a), p. 25, stated "Aircrew error mishaps rates for helicopter and the A-6/EA-6 communities have declined dramatically since the introduction of Aircrew Coordination Training." Comparing the data for the fiscal year before the CRM training began with the most recent fiscal year data supports this statement. For these fighter-bombers, their 1990 aircrew error rate for all mishaps was of 1.43. Compared with their 1986 rate of 7.56, this represents an 81% improvement. Similarly, for their helicopters, the 1990 rate of 5.05 versus the 1986 rate of 7.01 represents a 28% improvement. Incidentally, their tentative figures for 1991 suggest that both helicopter and A-6 mishap rates continued to decline by another several percent (Alkov, 1991b).

USAF Military Airlift Command: In 1985, MAC became the first military organization to adopt CRM training. This program was initiated by the MAC Commander (General Thomas Ryan, Jr.) and labeled Aircrew Coordination Training. MAC has several thousand aircrewmembers who operate almost 1,000 transports and helicopters and fly approximately 700,000 hours annually. Thus it undoubtedly qualifies as one of the larger organizations to embrace CRM concepts. The CRM materials were developed by individual MAC units and several contractors including: United Training Systems, Flight Safety International, Hughes, and CAE-Link.

The MAC safety record for the five fiscal years before CRM (1981-1985) was compared with the five years (1986-1990) after they adopted this training. The total number of aircraft destroyed dropped from 21 to 10 (a 52% improvement). Similarly their Class A and B operations-related flight mishap rate dropped by 51% (from .679 to .333 per 100,000 hours). Note that these events currently include mishaps involving aircrew errors which the damages exceeded $200,000. These improvements far outpaced the rest of the USAF which saw the number of aircraft destroyed decrease by 18% while their aircrew error mishaps dropped by 21%.

This ten year period was relatively stable operationally, although longitudinal comparisons can be fraught with dangers. There obviously were a number of other training related developments occurring at this time (such as the simulator upgrades made throughout the USAF). However, the one major difference between MAC training and that of the other commands during this period was the use of CRM. It is also possible that the MAC Commander's bold decision to undertake this type training for all aircrewmembers produced other desirable side-effects.

The two earlier USAF situational awareness programs have also been found to work well. For instance, Situational Emergency Training was judged more effective than conventional training it replaced (Thorpe, et.al., 1976), while the manager of the Low Altitude Training program stated that of the approximately 400 graduates from their course, only one had been involved in a collision with the ground mishap (Thomae, 1991).

Table 3

ADM/CRM Operational Evaluations

Organization/Subjects	Materials	Accident Rates
Bell Helicopters Inc. Worldwide, Jetranger Pilots	ADM	36% Decrease
Bell Helicopters Inc. US Only, Jetranger Pilots	ADM	48% Decrease
Petroleum Helicopters Inc. Commercial Pilots	ADM & CRM	54% Decrease
US Navy All Helicopters, Crewmembers	CRM	28% Decrease
US Navy A-6 Intruder, Crewmembers	CRM	81% Decrease
US Air Force MAC Transports, Crewmembers	CRM	51% Decrease

Discussion

Table 3 summarizes the evidence reported to date on the effects of using ADM and CRM training by several large organizations. In all six instances, the use of the training was followed by major reductions in their accident rates. Collectively, these improvements were statistically significant at beyond the 0.02 level of confidence. These results agree with the six controlled experiments which focused on low-time general aviation pilots. Furthermore, this operational user data covers a large variety of civil and military flying from light helicopters, and medium fighter-bombers to heavy transports. It is, of course, impossible to conclude that CRM/ADM training was solely responsible for all the improvements observed. However, the inclusion of such training by management may act as a catalyst for other beneficial behaviors which, in turn, can reduce mishaps.

Povenmire et al. (1989), in their classic simulator study, noted that those crews who "innately" know how to use CRM-like techniques are more effective. Similarly Helmreich (1991) shows those who have had CRM training outperform their untrained counterparts. These innovative concepts have been endorsed by a host of prestigious organizations (e.g. Flight Safety Foundation, Aerospace Medical Association, Air Line Pilots Association). Furthermore, the International Civil Aviation Organization has recommended their use for training all newly licensed pilots, (ICAO, 1989). Ambitious research and development efforts are also underway at various organizations such as the US Naval Training Systems Center (Hartel, Smith, and Prince, 1991) and the FAA and NASA (Kayten and Foushee, 1991). This work will undoubted further enhance these programs.

These concepts may also have applications beyond flightcrew training, witness the fact that many airlines now include such materials in flight attendant courses. The FAA has also published decisionmaking materials for air ambulance program administrators (Rotor & Wing International, 1989), while Continental Airlines has applied the concepts to maintenance personnel, (Fotos, 1991). Not surprisingly, the US Army provides such training to their safety officers (Lofaro, 1990), while the US Pacific Air Forces now includes this training for new squadron commanders (Diehl, 1991a). Lastly, Kayten and Foushee (1991) correctly note the similarities between CRM and industrial total quality management programs.

New versions of this training have been labeled "third generation CRM programs" (Johnson, Shroyer, and Grew, 1991). In fact, I believe the more sophisticated programs have several characteristics: 1) focusing on enhanced effectiveness as well as safety, 2) targeting broader audiences (e.g. instructors, flight attendants, etc.), 3) having built-in update mechanisms, 4) using computer-based training, and 5) employing humor and aesthetics.

In the Air Line Pilots Association 1991 annual workshop it was interesting to hear candid discussions of still unresolved issues associated with cockpit management. It was reminiscent of my earlier concerns about how to evaluate or certify the people enrolled in such programs, as well as how to rehabilitate those crewmembers who reject or "fail" this training, or who have exhibited poor judgment in an incident, accident or violation (Diehl, 1982). I still feel that such issues may be more recalcitrant than our basic concerns about cockpit management education and training.

Conclusions

The results of these six empirical and six operational evaluations provide strong evidence that these training programs can help reduce aircrew errors and thereby prevent accidents. Furthermore, categorical distinctions between CRM and ADM training are becoming blurred in that most current versions of these programs have five common elements, which provide tools to deal with attention, crew, stress, attitude and risk management issues. While additional research and development continues there is a growing realization that these programs ideally need to be introduced early in flight training, reinforced during upgrade training, and reviewed during recurrent training.

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Footnote

Dr Diehl has been the Technical Advisor for Human Performance at the USAF Safety Agency since 1987. He has over twenty years professional experience with aircraft manufactures, the USN, NTSB and the FAA. He holds academic degrees in psychology, management and engineering, as well as an Airline Transport Pilot and Flight Instructors licenses. The views expressed in this article are those of the author and do not necessarily reflect the official policy or position of the Department of Defense or the US Government.

Dr. Alan E. Diehl U.S. Air Force Safety Agency

COCKPIT DECISION MAKING

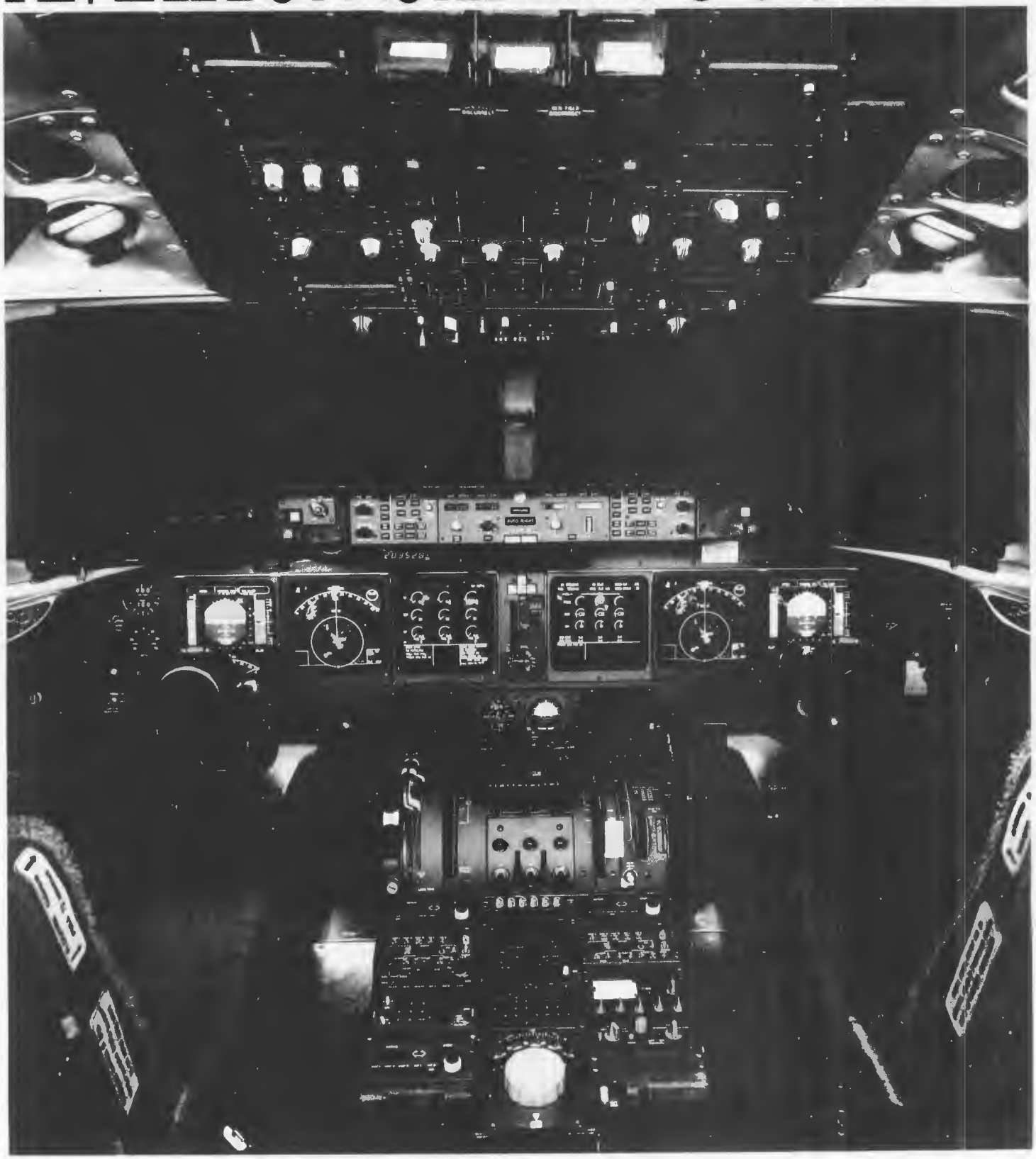
Conclusion:

Mishap rates associated with aircrew errors decreased dramatically in organizations that instituted ADM or CRM training programs. The amount of this improvement ranged from 28% to 81%. There is also evidence that such training can enhance effectiveness as well as safety.

FAA

FALL 1991, VOL. 1, NO. 4

AVIATION SAFETY JOURNAL



USAF AUDIO VISUAL SERVICE

Cockpit Decision Making

In the 5 years after MAC instituted CRM training, their mishap rate improved by 54 percent.

Aeronautical knowledge and "stick-and-rudder" skills have been the traditional focus of aviator training programs. Judgment and crew management tasks, in contrast, were largely regarded as by-products of flying experience or only taught informally. However, this situation has changed in recent decades.

By the sixties, cockpit voice recorders along with improved accident investigation methods revealed that crew coordination and decision-making problems were major causes of civilian and military mishaps. In the mid-seventies, this led to the development of realistic simulator programs such as the military Mission Oriented Simulation Training (MOST). Simultaneously, progressive airlines were incorporating similar Line Oriented Flight Training (LOFT), while judgment training concepts emerged for general aviation applications.

BOEING COMMERCIAL AIRPLANE GROUP

The eighties saw these concepts evolve into a number of elaborate programs designed to reduce "pilot error." Toward the end of that decade such programs were in widespread use in North America, Western Europe, Australia, and Japan. In fact, the International Civil Aviation Organization (ICAO) recently called for all newly licensed pilots to be trained in such concepts. Various U.S. military aviation organizations have now also implemented this type of training.

These human factors-oriented training programs are designated by a variety of labels including: "situational awareness," "crew resource management," "cockpit human factors," and "pilot decision making." They generally fall into one of two categories: programs designed for larger, multi-place aircraft and those intended for single-pilot operations.

Cockpit Resource Management

The most popular label for the multi-crew application is Cockpit Resource Management (CRM), although Crew Resource Management is also becoming a common title for these courses — reflecting the importance of the cabin as well as the flight deck crewmembers. Such programs stress the importance of proper communications, division of responsibilities, leadership, and teamwork. The conceptual basis of these programs was social psychology and management theory. These programs were developed and refined with data and expertise from NASA.

The Dutch airline, KLM, developed the first such course, while United Airlines has arguably fielded the most widely used of these courses. Both airlines have successfully marketed their respective programs to various aviation organizations, while other airlines have independently developed similar programs.

The U.S. Air Force Military Airlift Command (MAC) and the Naval Safety Center have pioneered militarized CRM programs, labeling them Aircrew Coordination Training (ACT). The Strategic Air Command (SAC) later adopted such training. Because of the strong need for this type of training in tactical aircraft and helicopters, the U.S. Air Force, Army and Navy are now using such courses to enhance teamwork in intercockpit as well as intracockpit tasks.

CRM programs generally use training manuals and interactive classroom lectures with audio-visual aids, followed by practice sessions in simulators. Ideally, video tapes are made to provide feedback to trainees on individual and crew performance during LOFT/MOST flight simulator training sessions. After the sessions are

critiqued, the tapes are normally erased to ensure future spontaneity, candor, and realism. The FAA issued an Advisory Circular on CRM in 1989.

Aeronautical Decision Making

The second general category of programs was formerly called "Judgment Training." The conceptual basis of Aeronautical Decision Making (ADM) programs was cognitive psychology, for this type of training is aimed at the attitudes and behavior of the individual pilot. Most of these programs originally focused on student pilots, but were later applied to advanced training including commercial, instrument, and helicopter pilots. The FAA, Transport Canada, the Australian Aviation Department, and the Air Force have sponsored the development and evaluation of ADM programs. These materials typically consist of training manuals and audio-visual materials which explain fundamental concepts related to error causation and prevention.

The FAA has been involved in CRM/ADM program development and research for a number of years. In 1987, the FAA began publishing manuals oriented to the decision making needs of various categories of pilots. These manuals provide information such as attitude modification, risk recognition, and stress management.

Common functional elements

The categorical distinctions between CRM and ADM are disappearing. Today, most comprehensive versions of these programs have several common functional, interrelated elements (Figure 1) dealing with attention, crew, stress, mental attitude, and risk issues.[1] The role which these five "cockpit management tools" play in the hierarchy of aeronautical faculties is depicted in Figure 1. They may in effect help provide "synthetic experience." These five interrelated concept areas furnish "rules and tools" to help prevent common errors. For instance:

1. Attention management issues include understanding how distractions and "error chains" can be avoided.
2. Crew management issues teach the importance of proper communications, division of responsibilities, leadership, and teamwork.
3. Stress management concepts focus on understanding the effects of life stress events, as well as providing in-flight stress coping strategies.
4. Attitude management concepts describe the methods of recognizing and controlling certain hazardous attitudes and behavioral styles.
5. Risk management issues focus on the rational evaluation of qualitative and quantitative information related to operational hazards.

Training effectiveness

CRM and ADM programs have been generally well received by the individuals and organizations that have used them. Furthermore, NASA and FAA research has documented changes in the attitudes of crewmembers.

There is also anecdotal information that programs have helped prevent certain mishaps. For instance, in 1989, a United Airlines DC-10 suffered an uncontained failure of the center engine and the total loss of flight control effectiveness. The crew manipulated the outboard engines to maintain enough control to allow an emergency landing at Sioux City, Iowa, in which most of the occupants survived. The National Traffic Safety Board concluded that CRM training was valuable in preventing what might have been an even more catastrophic accident.

Another method of examining the effectiveness of training programs is to perform controlled experiments to document whether crewmembers who receive such training make fewer errors. ADM programs have been extensively tested in this way. That was partly because, unlike CRM which was primarily employed for airline and military operations, ADM was initially applied to general aviation student training situations. The latter environment involves relatively high error rates and low costs, thus facilitating the use of experimental studies.

A recent paper summarizes the evidence regarding the effectiveness of such training.[2] In several controlled experiments, inexperienced pilots who were given judg-

Five Characteristics of New (Comprehensive) Programs

1. **Focus on enhanced effectiveness as well as safety**
2. **Target broader audiences (e.g., instructors, flight attendants, etc.)**
3. **Have built-in update mechanisms**
4. **Utilize computer-based training**
5. **Employ humor and aesthetics**

Table 1
Experimental Evaluations

Sponsor	Subjects/ Environments	Improvements
Australian Aviation Dept.	Private Pilots/ Light Airplanes	8% Error Decrease
Transport Canada	Private Pilots/ Light Airplanes	9% Error Decrease
U.S. FAA	Private Pilots/ Light Airplanes	10% Error Decrease
U.S. FAA	Student Pilots/ Light Airplanes	17% Error Decrease
Transport Canada	Civilian Cadets/ Light Airplanes	40% Error Decrease
USAF	Instrument Students/ Simulators	46% Error Decrease

[1]Diehl, A.E. "The Effectiveness of Training Programs for Preventing Aircrew 'Error.'" In Proceedings of the Sixth International Symposium of Aviation Psychology, Ohio State University, Columbus, Ohio, April 29 - May 2, 1991.

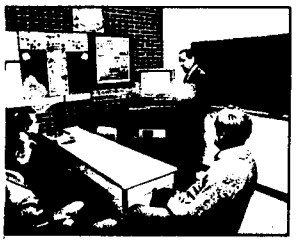
[2]Ibid.

Table 2
ADM/CRM Operational Evaluations

Organization/Subjects	Materials	Accident Rates
Petroleum Helicopter, Inc/ PHI Commercial Pilots	ADM & CRM	54% Decrease
Bell Helicopter/ Worldwide Jetranger Pilots	ADM	36% Decrease
Bell Helicopter/ U.S. Jetranger Pilots	ADM	48% Decrease
U.S. Navy/ Helicopter Crewmembers	CRM	28% Decrease
U.S. Navy/ A-6 Intruder Crewmembers	CRM	81% Decrease
U.S. Air Force/ MAC Transport Crewmembers	CRM	51% Decrease

ment training made 8 to 46 percent fewer errors than those who received conventional curricula (see Table 1). More importantly, other data has confirmed that mishap rates associated with aircrew errors decreased dramatically in organizations that instituted ADM or CRM training programs. The amount of this improvement ranged from 28 to 81 percent (see Table 2). For example, in the 5 years after MAC instituted this training, their rates improved by 51 percent, while those for the rest of the USAF improved only 21 percent. There is also evidence indicating that such techniques can enhance effectiveness as well as safety (e.g. B-52 bomb accuracy).

UNITED AIRLINES



Conclusions

The categorical distinctions between CRM and ADM training are becoming blurred. Most current versions of these programs have five common elements which deal with attention, crew, stress, attitude, and risk management issues. The results of six empirical and six operational evaluations (Tables 1 and 2) provide strong evidence that these training programs can help reduce aircrew errors and thereby prevent accidents. While additional research and development continues, there is a growing realization that these programs ideally need to be introduced early in flight training, reinforced during upgrade training, and reviewed during recurrent training and accident prevention seminars. ✈

by Dr. Alan E. Diehl.

Dr. Diehl is the Technical Advisor for Human Performance at the U.S. Air Force Safety Agency, Norton Air Force Base, California. He has over 20-years experience with aircraft manufacturers, the United States Navy, National Traffic Safety Board, and FAA. He holds academic degrees in psychology, management, and engineering, as well as Airline Transport Pilot and Certified Instructor licenses. Dr. Diehl drafted the first U.S. Government recommendation calling for the implementation of CRM programs and has been involved with the development of CRM and ADM concepts for civil and military applications. The views expressed herein are the author's and do not necessarily represent those of the USAF or any other governmental agency.

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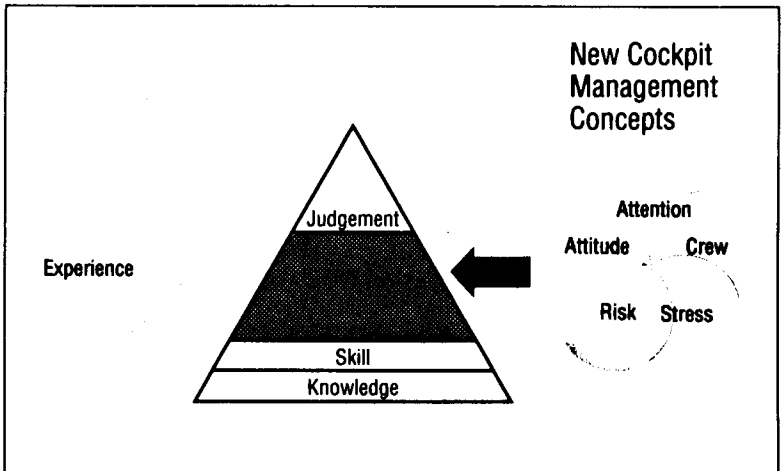


Figure 1. Hierarchy of Aeronautical Faculties

Captain Stephen E. Paul Delta Air Lines

DELTA AIR LINES

DECISION MAKING TRAINING

Conclusion:

Initially, CRM and ADM training was too academic and the operational impact was lost in "psychobable". Emphasis on operationally oriented training (i.e., experience based) creates the value or benefit first, which facilitates the pilot attitude changes required to change behavior.

DELTA AIR LINES

DECISION MAKING TRAINING

I. Introduction

- A. Initial CRM Training - Decision Dynamics - 2:45
- B. Transition - Problems, Solutions
- C. '92 Recurrent Training - 2:00

II. Decision Dynamics

- A. Sample decision problem
- B. P.A.S.S. Model
- C. Heuristics
  - 1. Shortcut
  - 2. Short circuit
  - 3. Types; operational examples; short circuit P.A.S.S.
    - a. Representativeness
    - b. Availability
    - c. Anchoring
    - d. Overconfidence
  - 4. Delta incidents
- D. Habitual routines
  - 1. Definition
  - 2. Disconnects
- E. Situational awareness
  - 1. Plan
  - 2. Communicate
  - 3. Critique
  - 4. Monitor

F. Better to disprove

III. Transition

A. Problem: Academic vs. Operational

1. Initial CRM too academic

2. Operational examples lost in "psychobabble"

3. Sequence and set-up more than total content

B. Solution: Operationally oriented training

1. Create value, get attitude & behavior shifts

2. Hangar talk - build consensus meaningful events "that could happen to me"

3. Support **THEIR** conclusions with academic research

IV. 1992 Recurrent Training - Total Crew Awareness

A. Incidents

1. Operational orientation - hangar talk

2. Recent, in-house

B. Crew Performance Categories - how we're evaluating

1. Systems Knowledge

2. Procedural Execution

3. Control Technique and Execution

4. Command Leadership

5. Crew Coordination

6. Management Skills

C. Demonstrated proficiency in Performance Categories

1. Blue Angel/Thunderbird video - why good

2. Airline operations - same/different

3. Being "predictable"

D. Total Crew Awareness

1. Def. Roles, Responsibilities, Expected Sequence of Events

2. Generic emergency - **BOLDFACE** - forced TCA

3. Gear problem after take-off - abnormal, create TCA

4. Video - AA 135

5. Routine arrival - plan? brief? incident

E. Creating TCA

1. Captains! what can F.O./S.O. do to create TCA?

2. F.O./S.O. what can Captain do to create TCA?

3. Anticipate, Plan, Communicate

F. Supporting research - NASA Ames; J. Orasanu

1. NASA Loft from hell

2. Characteristics of High Performance Crews

a. Anticipate difficulties early

b. Use low workload periods effectively

c. Talk less when workload high

d. Seek more information from others earlier

V. Q & A

Captain Kevin M. Smith United Air Lines

DECISION TASK ANALYSIS FOR THE AIR TRANSPORT PILOT

Conclusion:

Decision making is one of many demands on the crew system. ADM training should be based on the key decision points in the mission with special emphasis on those points that are clues to loss of situational awareness.

DECISION TASK ANALYSIS

FOR THE

AIR TRANSPORT MISSION

prepared for the

Aeronautical Decision Making Workshop

May 9-10, 1992

Denver, Colorado

prepared by

Kevin M. Smith

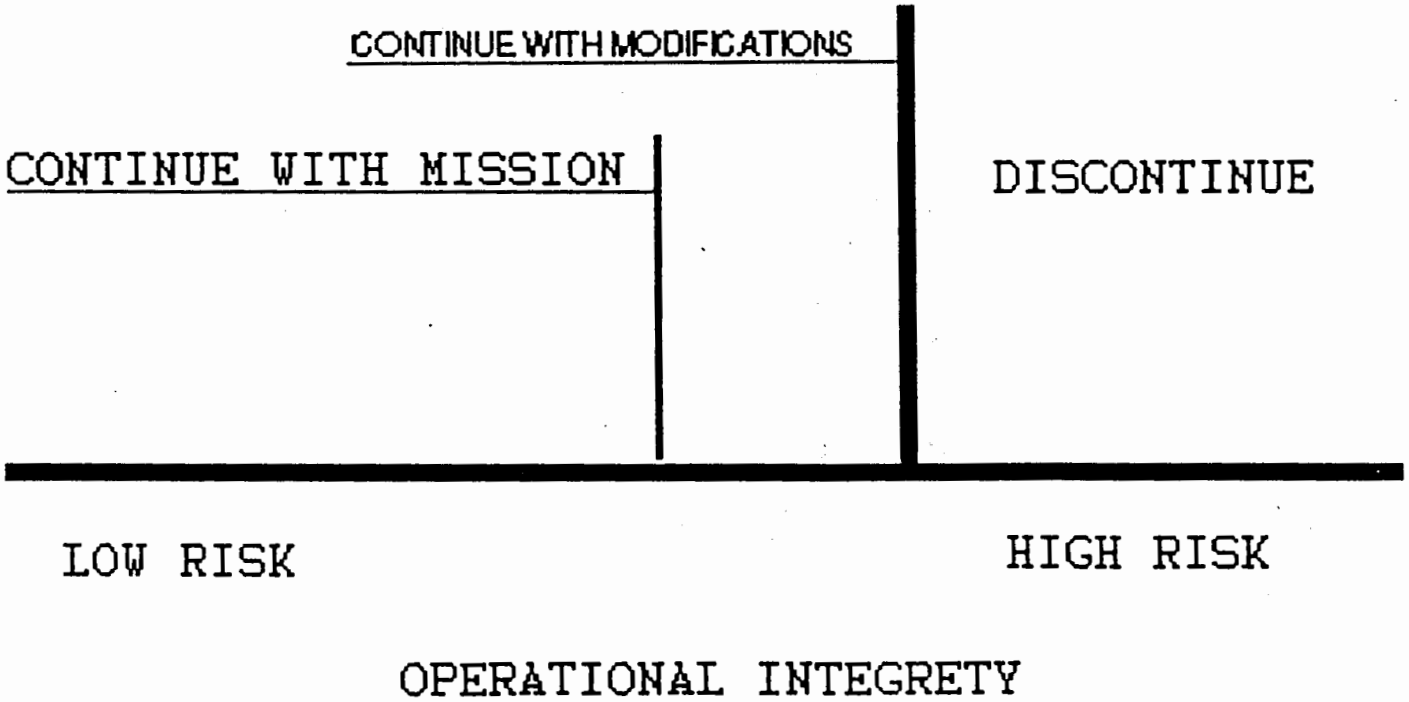
Opcon Corporation

5875 Olde Stage Road

Boulder, CO 80302

GENERAL DECISION OBJECTIVES WITH RESPECT TO RISK PROFILE

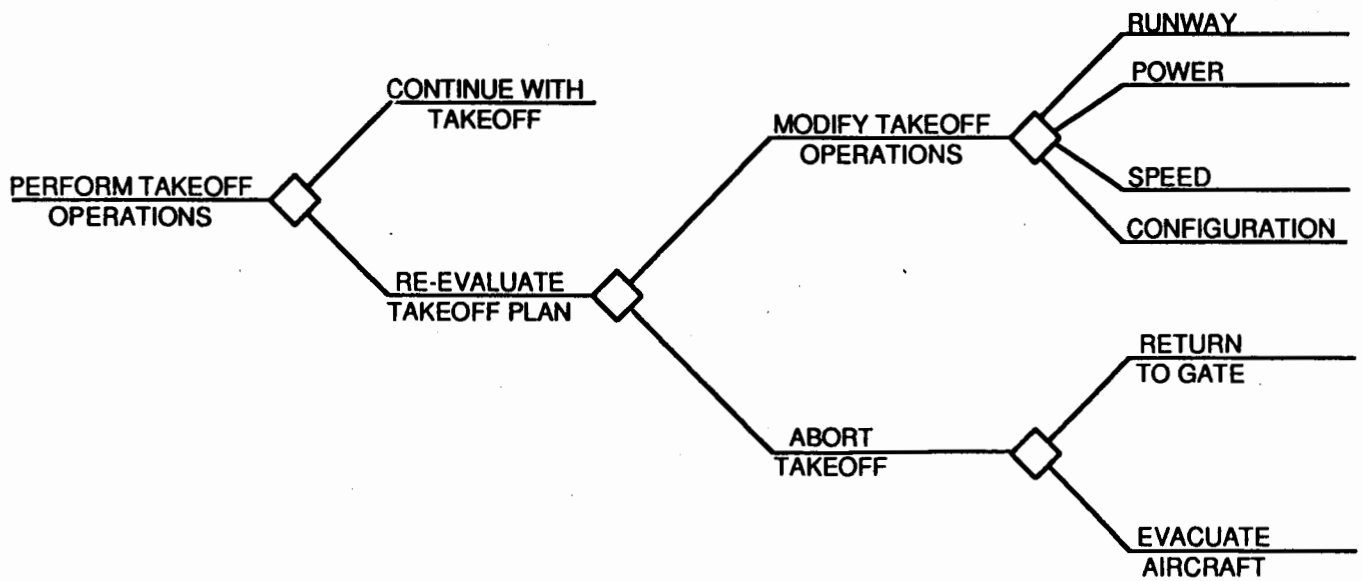
(OPERATIONAL INTEGRITY)



A

DECISION STRUCTURE

UNSTABLE



DECISION TASK: PERFORM TAKEOFF OPERATIONS

Primary Choice:	1. Continue takeoff as planned 2. Re-evaluate takeoff plan
Secondary Choice:	1. Modify takeoff operations 2. Abort takeoff
Tertiary Choice:	1. Return to gate 2. Evaluate aircraft

KEY

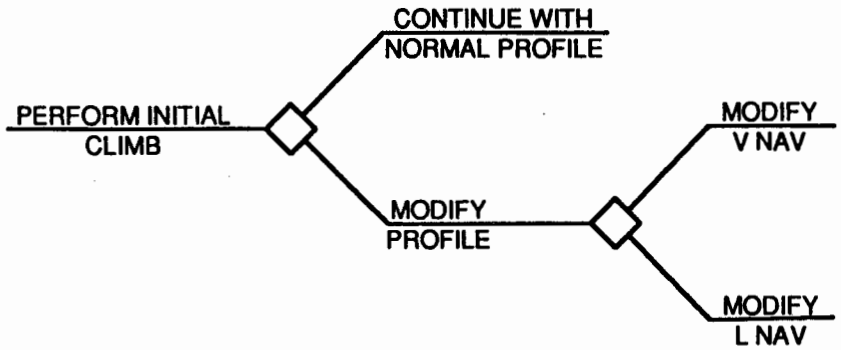
◇ = Decision Node

○ = Event Node

□ = Connector

B

DECISION STRUCTURE
STABLE



DECISION TASK: PERFORM INITIAL CLIMB

Choice:

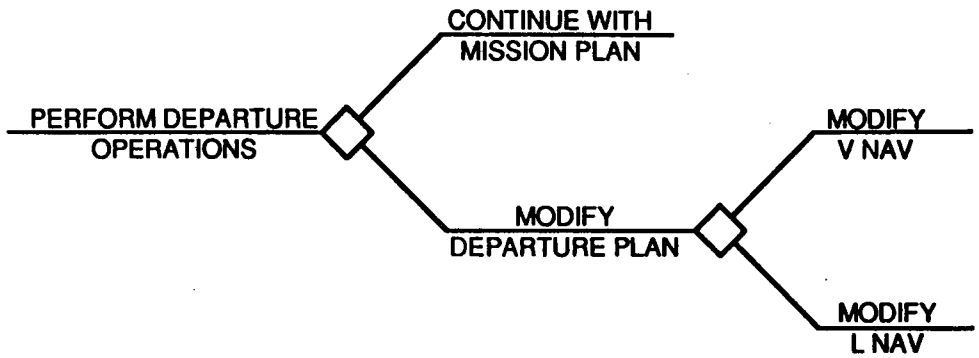
1. Continue with normal climb profile
2. Modify profile when operational conditions dictate
   - modify vertical nav to maintain safe energy level margins.
   - Modify L Nav to accommodate terrain/obstruction/weather.

KEY
◇ = Decision Node
○ = Event Node
□ = Connector

92002

C

DECISION STRUCTURE
STABLE



DECISION TASK: PERFORM DEPARTURE OPERATIONS

Choice:

1. Continue with SID/Radar Vectors
2. Modify Departure profile when operational conditions dictate or when directed by ATC.

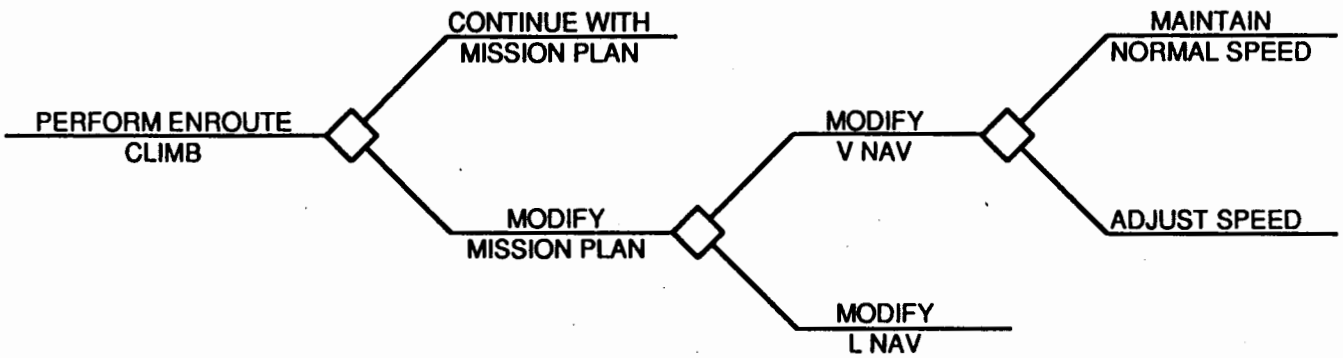
KEY
◇ = Decision Node
○ = Event Node
□ = Connector

EXAMPLE: Flying HKG ELATO ONE ALPHA proceeding to point Whiskey, ATC issues clearance to intercept and fly outbound CHEUNG CHAN 104° radial.

92003

D

DECISION STRUCTURE
STABLE



DECISION TASK: PERFORM ENROUTE CLIMB TO CRUISE ALTITUDE

Primary Choice:
1. Continue with mission plan
2. Modify mission plan. V Nav, L Nav.

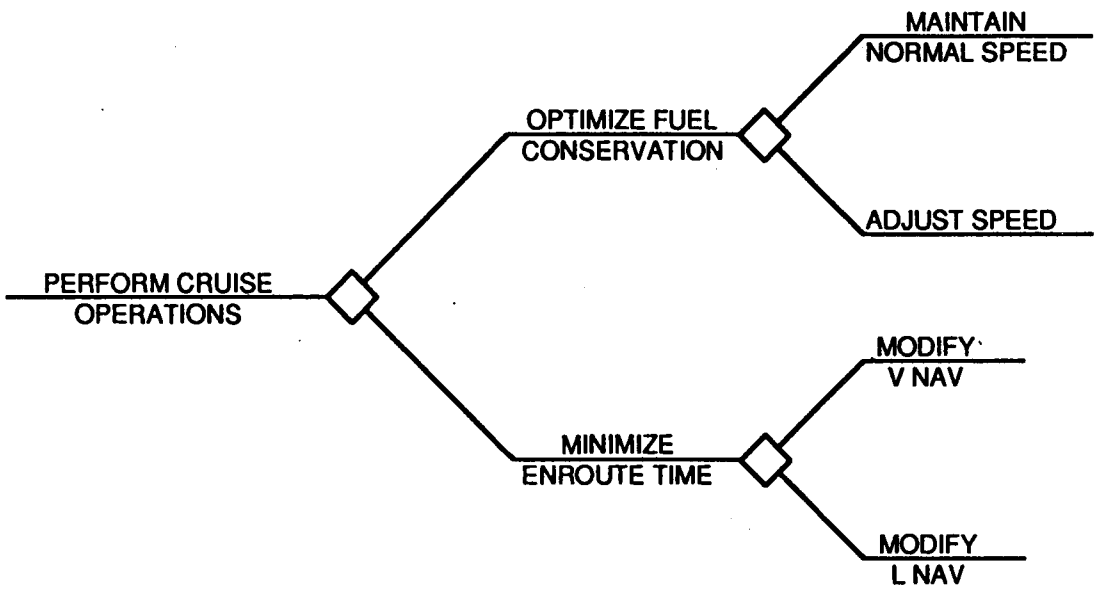
Secondary Choice:
1. Maintain normal (optimum) climb
2. Adjust speed to effectively deal with existing weather conditions.

KEY
◇ = Decision Node
○ = Event Node
□ = Connector

92004

E

DECISION STRUCTURE
MODERATELY STABLE



DECISION TASK: PERFORM CLIMB OPERATIONS

Primary Choice:

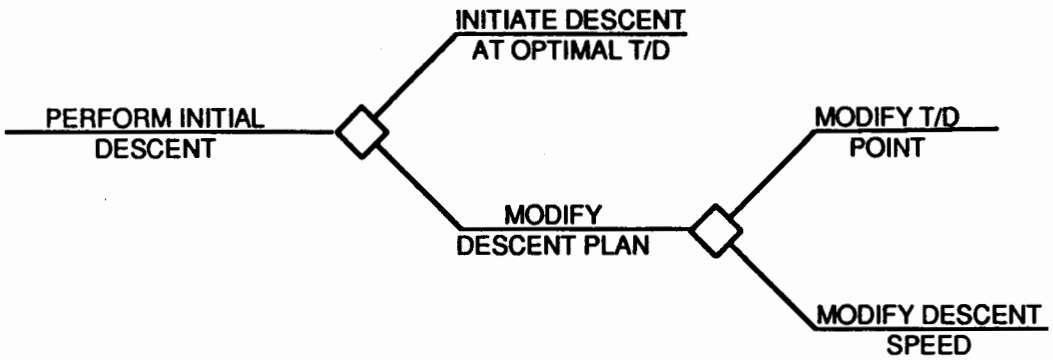
1. Optimize fuel conservation
2. Shorten enroute time to maintain integrity of the operation.

KEY
◇ = Decision Node
○ = Event Node
□ = Connector

92005

F

DECISION STRUCTURE
MOSTLY STABLE



DECISION TASK: PERFORM INITIAL DESCENT PLAN AND EXECUTE DESCENT AT MOST DESIRABLE POINT (T/D)

Choice:

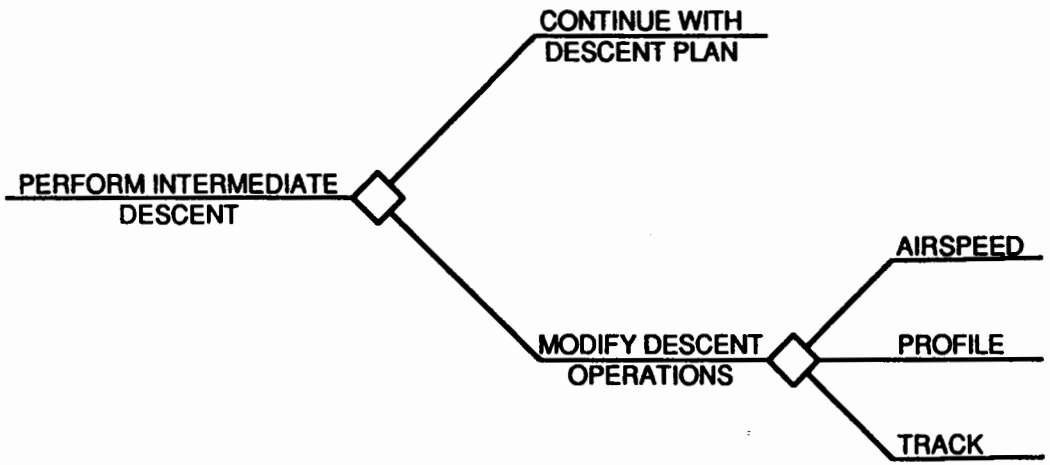
1. Initiate Descent at most fuel efficient T/D.
2. Modify descent plan to account for existing environmental/traffic conditions.

KEY
◇ = Decision Node
○ = Event Node
□ = Connector

92006

G

DECISION STRUCTURE
MOSTLY STABLE



DECISION TASK: PERFORM INTERMEDIATE DESCENT

Primary Choice:

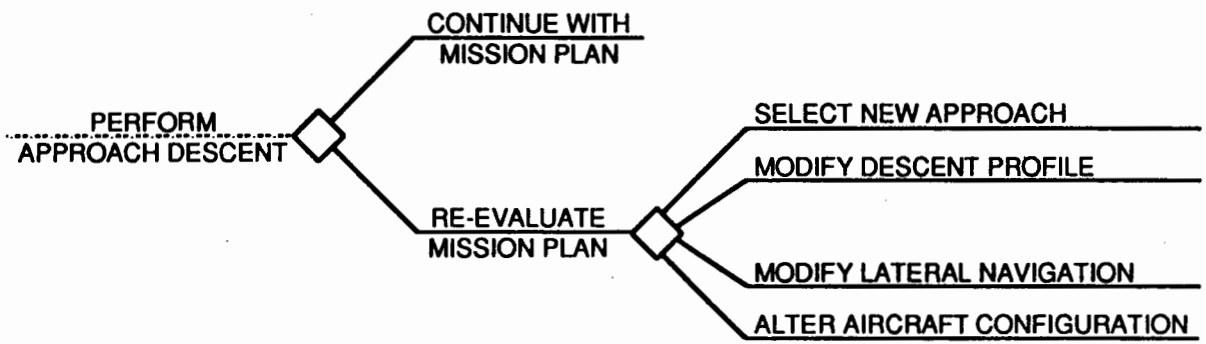
1. Continue with descent plan.
2. Modify descent parameters:
   Adjust airspeed, profile, or track.

KEY
◇ = Decision Node
○ = Event Node
□ = Connector

92007

H

DECISION STRUCTURE
MODERATELY UNSTABLE



DECISION TASK: PERFORM APPROACH DESCENT

Choice:

1. Continue with mission plan
2. Re-evaluate the mission plan

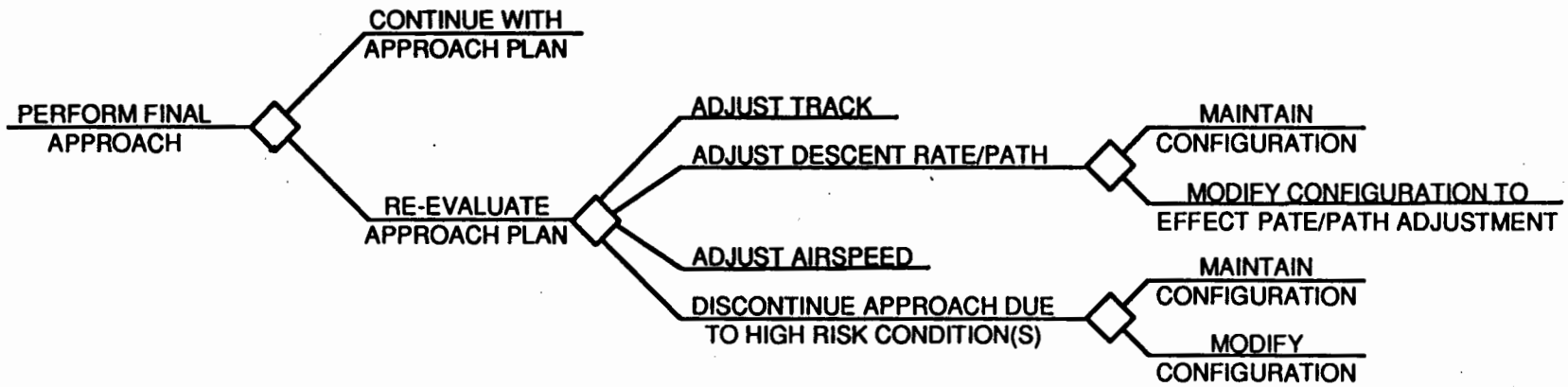
KEY
◇ = Decision Node
○ = Event Node
□ = Connector

92008

I

DECISION STRUCTURE

MODERATELY UNSTABLE



DECISION TASK: PERFORM FINAL APPROACH

Primary Choice:
1. Continue with approach.
2. Re-evaluate approach plan.

Secondary Choice:
1. Adjust approach parameters.
2. Execute go-around.

Tertiary Choice:
1. Maintain configuration.
2. modify configuration to optimize performance.

KEY

◇ = Decision Node

○ = Event Node

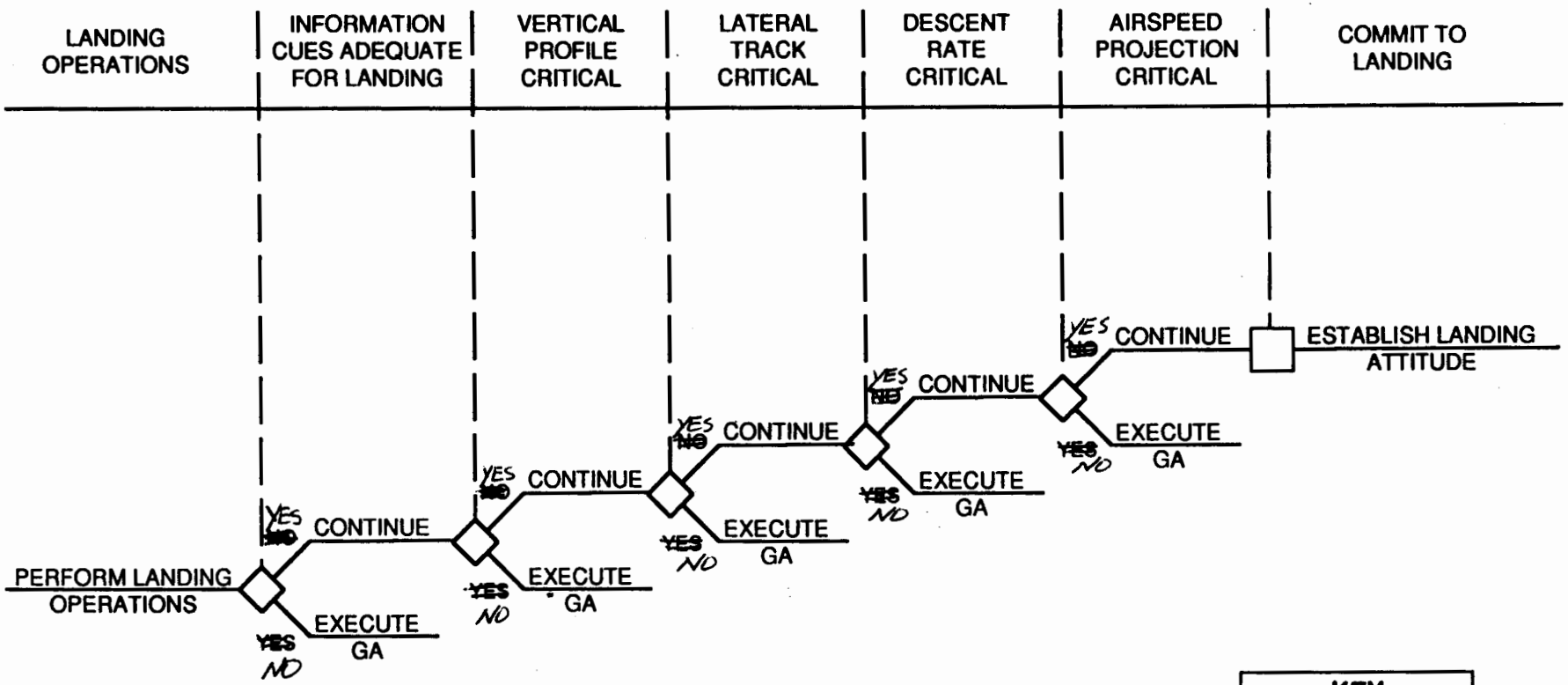
□ = Connector

92009

J

DECISION STRUCTURE

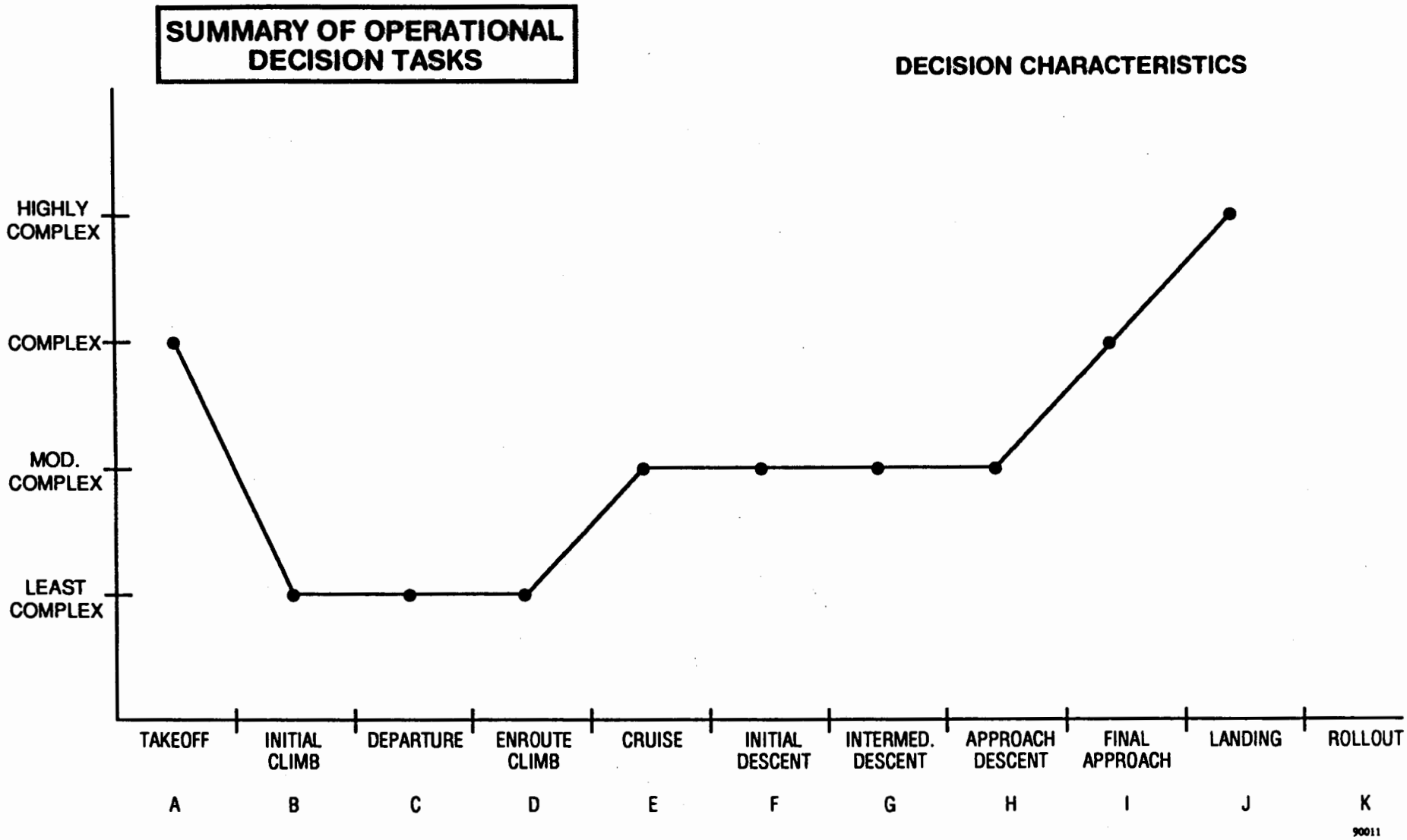
UNSTABLE



KEY

- ◇ = Decision Node
- ○ = Event Node
- □ = Connector

92010


SUMMARY OF OPERATIONAL DECISION TASKS
DECISION CHARACTERISTICS
HIGHLY COMPLEX
COMPLEX
MOD. COMPLEX
LEAST COMPLEX
TAKEOFF
INITIAL CLIMB
DEPARTURE
ENROUTE CLIMB
CRUISE
INITIAL DESCENT
INTERMED. DESCENT
APPROACH DESCENT
FINAL APPROACH
LANDING
ROLLOUT
A
B
C
D
E
F
G
H
I
J
K
90011

Captain James E. Irving United Air Lines

BOOTSTRAPPING EXPERTISE:

WHAT MAKES THE EXPERT PILOT DECISION MAKER EXPERT AND WHY ?

Conclusion:

It may not be possible or prudent to forge a program to train decision making skills if we have not derived the principles which allow us to answer these questions --

What is a good decision ?

How is it arrived at ?

BOOTSTRAPPING EXPERTISE:

What makes the expert pilot decision maker expert and why?

Jim Irving, Captain 737-30

(My views are my own and are not necessarily—and probably not—shared by my employer, United Airlines.)

(2) Defining the expert pilot decision maker

Traditional definitions of "expert" include

- **assumption that expertise is based on number of hours flown**
- **demonstration of exemplary knowledge in:**
  —SOPs
  —Systems
  —Flying (stick/rudder)
  —FARs
  —FOM
- **demonstration of skill**
  —in an emergency
  —in consistent safe completion of tasks
- **consensus of peers**
  —other pilots seek out the expert to ask questions

(3) Expert/Novice Distinctions

What does an expert have beyond average or novice ability? When faced with situations or problems requiring decision making for successful resolution

- **draws on a vast store of knowledge (of, e.g. FOM, FARs, systems) and experiences;**
- **is able to combine and apply that knowledge, while maintaining awareness of consequences of the decision beyond the immediate moment.**
  (flight attendant seat)
- **adapts existing procedures which only partially match a situation**
  (start valve opens in flight)
- **brings to bear the knowledge and experiences for successful resolution even when situation is not covered by any procedure or training**
  (loss of all three hydraulic systems on DC 10)

(4) Traditional Efforts to Bootstrap Expertise

- **SOPs**
- **Repetition during training**
- **Observation of more experienced crew members**
- **On-the-job training**

(5) What's wrong?

1. **Assumptions about level of experience**

   — system knowledge?

   —non-standard experiences?

   —decision making ability?

(6) What's wrong?

2 - SOPs

- **created by managers not always expert on aircraft**
- **SOPs have become hard and fast rules that must be followed**
  - —discourages the exploration of alternative ideas
  - —prevents development of new procedures by the operator
  - —constant increase in the number of procedures trying to cover every eventuality
- **obviate the need for pilot decision making**
  - —pattern recognition (EICAS annunciation is the procedure name)

What's wrong? cont.

(7) 3 - Training

- **doesn't come from experts**
  - —new hire instructors
  - —created by ISD experts with limited input from expert SMEs
  - —Capt/FO training is created using Second Officer SMEs (less experienced in decision making; concentration on rote memorization/motor skillss)
  - —Capt/FO SMEs are not used—too expensive
- **concentrates on motor skills, application of procedures, and "easily measurable" skills**
- **provides little or no training in data acquisition skills**
  - —match a pattern of warning lights with a procedure
  - —searching for secondary/confirming data not encouraged

(8) 4 - Practice

- on single problems, rather than complex, indeterminate or converging emergencies
- innovation and improvisation is discouraged
- mostly in motor skills (stick and rudder skills are primary)

(9) 5 - Over-reliance on observation time

Observation of experienced crews is diminishing as demographics change.

- Two person crews
  —No time as a Second officer
- Rapid promotion through seats
  —Less time to observe
  —6 years to Captain - 3 aircraft in that time; half of the 6 years spent learning own job
  —Most of time in seat is spent in learning duties of that seat.
- On the job training is restricted to normal occurrances
- Experience is random rather than structured
- Not formalized to ensure coverage of all important items

(10) Pilots Bootstrap their Decision Making Skills

Individuals exhibiting expertise (such as in emergencies and situations described in the beginning of this talk) have gained that expertise not by means of formal training, but rather in spite of it.

(11) Solutions?

Suggestions for a creating a program for training expert pilot decision makers

1 - Pretest trainees to determine existing knowledge level.

2 - Return the creation of procedures to "experts"

—experienced in aircraft, systems and line operations

3 - Adequate task analysis to reveal attendant decision tasks

—Define decision tasks required

—Analyze criticality of decision task

—Train decision tasks determined most critical (criticality index)

(12) Solutions? cont.

4 - Implementation of carefully crafted scenarios

—drawn from the observations of more experienced pilots

—training objectives established up front

—scenarios to practice decision making skills do not require simulators (not practicing motor skills)

—include full debriefing to structure the experience

(13) The Merits of "Hangar Flying"

- shared experiences
- review and critique of individual solutions
- allows practice in the process of evaluating solutions to a (possibly) dangerous situation

(14) What is a good decision?

How is it arrived at?

FINALE

It may not be possible or prudent to forge a program to train decision making skills if we have not derived the principles which will allow us to answer these questions.

Dr. Robert A. Alkov Naval Safety Center

TRANS-COCKPIT AUTHORITY GRADIENT IN NAVY/MARINE AIRCRAFT MISHAPS

Conclusion:

When helicopter pilots of unequal rank were paired, the potential for pilot error was increased over the potential for those crews who were equal in rank.

Trans-Cockpit Authority Gradient in Navy/Marine Aircraft Mishaps

Robert A. Alkov, Michael S. Borowsky, Dana W. Williamson, and David W. Yacavone

Naval Safety Center

NAS Norfolk, VA 23511-5796

Running Head: TRANS-COCKPIT AUTHORITY GRADIENT IN AIRCRAFT MISHAPS

Abstract

Navy and Marine Corps aircraft mishaps which had an aircrew causal factor assigned were analyzed to determine if the relative military rank of the pilot and copilot or Naval Flight Officer was associated with the rate of occurrence per 100,000 flight hours. All class A and B helicopter flight mishaps for the eleven calendar year period 1980-1990 were examined. Although statistically significant differences were not found, pairing helicopter pilots who were of equal rank yielded the lowest rate (2.81), seemingly refuting Elwyn Edward's notion that a flat "trans-cockpit authority gradient" may lead to greater problems in the cockpit than his hypothetical "optimum gradient". When there was one rank difference in the cockpit the rate was 3.40. When copilots flew with pilots who differed by two or more ranks, the largest pilot error rate (3.45) was revealed. These findings seem to support Edward's hypothesis that a steeper "trans-cockpit authority gradient" may be detrimental to helicopter flight safety.

Data from fighter and attack jet aircraft, where there is only one pilot flying with a radar intercept officer or a bombardier/navigator, were also studied for the calendar years 1986-91. It was discovered that the lowest aircrew error rate (1.80) occurred when the pilot and the other aircrew member differed by more than one rank. When the aircrew were of the same rank the rate was 3.51. For those crews in which there was a one rank difference the rate was 3.85. Reasons for these findings are discussed.

NOTE:

The opinions and interpretations expressed are those of the authors and should not be construed to be the official views, policies, endorsements or decisions of the Department of the Navy, the Department of Defense, or the government of the United States of America.

Trans-Cockpit Authority Gradient in Navy/Marine Aircraft Mishaps

When assessing cockpit performance in the areas of aeronautical decision making, cockpit resource management, and maintenance of situational awareness, interpersonal dynamics must be the leading factor studied. The dynamics of interaction between pilots in the cockpit have been characterized as the "trans-cockpit authority gradient" by Elwyn Edwards (1988). Edwards believes there is an optimum gradient to allow an effective interface between aviators. Although he does not provide a clear definition of this optimum, he does discuss instances where it is not achieved. A less than optimum gradient occurs when the pilot-in-command's role is either over-emphasized or underplayed. According to Hawkins (1987), Edwards feels this gradient may be too flat, as with two pilots of equal rank and qualifications, or too steep, where the pilot-in-command is a domineering senior with an unassertive copilot (or vice-versa). The steeper gradient can occur with the pairing of pilots with copilots of either higher or lower rank, experience, reputation, qualifications or ability. Edwards also reported that the chances of errors going undetected and uncorrected increase when this gradient is not optimized (1988). Breakdowns in aircrew communications leading to aircraft mishaps could occur as a result according to Foushee (1982). Hawkins (1987) says that a related problem occurs when the first officer advises the captain of an error but the captain fails to take action. According to Jensen and Biegelski (1989):

> ... a less technically competent crewmember may be highly defensive in order to preserve a competent self-image. This may result in the crewmember maintaining unrealistic and self-deceptive attitudes of personal competence, resistance to stress, and a lack of need for support from other crewmembers. This person may project an air of all-knowing confidence and independence when, in fact, the opposite is true. Such behavior may have a highly adverse effect on CRM. (page 177).

A study of 249 airline pilots in the United Kingdom revealed that 40 percent of the copilots admitted to having failed to communicate their doubts about the safety of the flight to their captains on several occasions. Their reasons for doing so ranged from a desire to avoid conflict to deference to the authority of their captains. In other instances the first officer clearly advised the captain who failed to respond or take action. The first officers found these captains to possess an arrogant and abrasive manner, with strong, intransigent attitudes, and a domineering style of work interaction (Wheale, 1983).

Data from the Naval Safety Center's files reveal that during the period from 1980-90 aircrew errors accounted for 58 percent (175 of

304) of the class A and B helicopter flight mishaps in the Navy and Marine Corps[1]. Of these aircrew error mishaps, 57 percent involved poor aircrew coordination or communication (100 of 175). Therefore 33 percent of all the helicopter mishaps studied involved poor aircrew coordination or communication. In order to expand our earlier study of helicopter pilots (Alkov, et. al., 1992) we also included fighter and attack jet aircraft that carry only one pilot, but with another non-pilot aircrew member who is a Naval Flight Officer (NFO). We focused on the F-14 and A-6 communities. Aircrew causal factors were present in 32 percent (103 of 323) of the mishaps for dual seated F-14 fighters and A-6 attack bombers during calendar years 1980-90. Poor aircrew coordination was a factor in 35 percent (36 of 103) of these aircrew caused mishaps.

The total of all Navy and Marine Corps helicopter aircrew error mishaps accounted for 218 fatalities and cost 414.7 million dollars during the 1980-90 period. There were 63 fatalities and costs of 1.19 billion dollars in the F-14 fighter and A-6 communities during this same period.

In order to determine if there is an optimum gradient of cockpit authority for safety in Naval aviation operations, we undertook an analysis of aircrew error mishaps. To ascertain the factors contributing to poor aircrew coordination in an attempt to propose remedial action to the Navy, we examined the mishap potential associated with the relative ranks of pilots and copilots or NFOs. We wanted to test Edwards (1988) assertion that the "trans-cockpit authority gradient" may be too flat or too steep. Therefore, the null hypothesis of this study was that pairings of pilots with copilots in helicopters and pilots with NFOs in dual seated jet aircraft would have the same aircrew caused mishap rates regardless of rank pairings.

METHOD

Navy and Marine Corps class A and B flight mishaps involving aircrew factors were analyzed in an attempt to refute or deny the hypothesis. The flying hours of Naval aircrews are not identified

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[1] A class A flight mishap, as defined by the Department of Defense, occurs when there is intent for flight and a fatality or permanent total disabling injury occurs; or the total cost of property damage is one million dollars or more; or an aircraft is destroyed. A class B flight mishap involves property damage less than a million dollars, but more than $200,000; or a permanent partial disabling injury; or the hospitalization of five or more persons. A class C flight mishap costs more than $10,000 or at least one lost workday due to injury.

as to the rank pairings of pilots and copilots or flight officers. However, aircraft mishap reports contain information on the ranks and flying hours of the aviators involved. In order to estimate the hours flown by specific pilot/copilot or pilot/flight officer rank combinations, the distribution of the rank combinations found in class A, B and C mishaps where there were no aircrew causal factors was used. This method enabled the flight hour estimates to be based upon the largest set of data reported to the Naval Safety Center. The study group consisted of aviators who were involved in the most serious aircrew-caused mishaps (class A and B). The data from 172 helicopter mishaps (3 of the original 175 lacked sufficient information for analysis) and 54 F-14 and A-6 mishaps in which aircrew error was assigned were analyzed to determine if the aircrew members were of equal rank, 1 rank removed or 2 or more ranks removed from each other. The number of serious mishaps involving each rank combination was then divided by the estimated flight hours per 100,000 for each combination to yield an aircrew error mishap rate for each category of rank pairing. Helicopter pilot pairings were placed into three categories, those of: (1) the same rank; (2) one rank different; and (3) two or more ranks different. For the fighter/attack crews the relative rank of pilot and NFO was also examined. Therefore, five combinations were examined for these aviators. These were (1) same rank; (2) one rank different, pilot senior; (3) one rank different, pilot junior; (4) more than one rank different, pilot senior; and (5) more than one rank different, pilot junior.

RESULTS

The aircrew error mishap rate for serious helicopter mishaps (class A or B) was 2.81 for the group of pilots and copilots who were equal in rank. When pilots and copilots differed by one rank the rate was higher (3.40). The mishap rate increased slightly (3.45) when pilots were flying together who were two or more ranks apart. The Poisson probability distribution did not reveal significant statistical differences, (but the combined rates for pilots who differed in rank was higher than the rate for the equal-in-rank group (see figure 1)). This finding would seem to be of practical importance.

Insert Figure 1 about here

As for the combinations of pilots with NFOs the Poisson Index of Dispersion revealed no statistically significant differences. However, it can be seen in figure 2 that when the pilot is senior by more than 1 rank, the aircrew error mishap rate is only 0.50. When the pilot is junior by more than 1 rank, this rate is 5.21. The other combinations yielded 3.51 for crewmen of the same rank,

3.75 when the pilot is one rank senior and 3.97 when the pilot is one rank junior to his NFO.

Insert Figure 2 about here

DISCUSSION

Is mishap potential associated with the ranks of helicopter pilots and copilots flying together? Perhaps. The theory that a steep trans-cockpit authority gradient can lead to poor aircrew coordination and aircraft mishaps may be upheld. However, although too flat a gradient may lead to problems, these problems do not occur as frequently as when there is a steeper gradient. Although there are documented cases of low ranking pilots flying together having mishaps due to misunderstanding as to who was in charge, these cases are rare. Apparently the competition factor among peers is not as significant to flight safety as is a steep gradient of authority. This is somewhat unexpected due to the aggressive and competitive nature of naval aviators.

The mishap rate of helicopter pilots who are paired with copilots whose ranks differ is greater than the rate for pilots who are paired with copilots of the same rank. According to Hawkins (1987), "When one crew member monitors or has reason to question the data used, the decision or performance of another, the effectivity of the monitoring depends on the response which it generates." Obviously, the personality of the senior is an important factor. If the response is to ignore the input, or worse, to react negatively, feedback from the junior will decrease. Hawkins goes on to say, "Leaders in all walks of life have a tendency to reject questioning by subordinates". This is especially true when the subordinates are low in the aviation hierarchy. Foushee (1982) found, in his research on aircrew interaction, that among airline pilots, subordinates often complain that captains can be so insensitive and intimidating that their subordinates are hesitant to speak up, even in potentially dangerous situations.

The most junior helicopter pilots are typically fresh from the Naval Air Training Command, where, as students they were required to defer to the authority of flight instructors who, for the most part were one to two ranks their senior. They were not encouraged to point out mistakes to these instructors, but to listen to criticisms of their own flying. Therefore, they are not very likely to be assertive in the cockpit when they arrive in the fleet. The airline pilot survey in the United Kingdom, referred to earlier, reported that captains found it difficult to work with

passive copilots (1983).

For the fighter/attack group of aviators, the low aircrew error mishap rate where the pilot is senior to the NFO by more than one rank is interesting. This fact and the higher rates that were found where the pilot is junior to the NFO by more than one rank may be reflecting the fact that pilots who are less experienced tend to have higher mishap potential than experienced pilots, regardless of whom they are crewed with.

CONCLUSIONS

When helicopter pilots of unequal rank were paired, the potential for pilot error is increased over the potential for those crews who were equal in rank. Senior aviators must be encouraged to seek feedback on flight safety information from their junior aircrewmembers, while juniors must be taught to be more assertive in the cockpit. The Naval Safety Center's Aircrew Coordination Training Program was designed to address these issues. A study we recently completed (Alkov & Gaynor, 1991) documents the success of this program in reducing aircrew coordination problems in naval aviation. Thus, although a less than optimum trans-cockpit authority gradient will continue to occur on the flight decks of military aircraft, it might be overcome through appropriate training.

These findings raise some interesting research questions. Is the deferral to a senior pilot caused by a sense of inferiority on the part of junior pilots when they are flying with seniors? Is there a lack of self confidence? Does the difference in rank obstruct their working as a team? Is this an inherent characteristic of military life? The answer to these questions must await the results of ongoing research.

On the other hand, when single-piloted tactical jet aircrews are examined, the relationships between the pilots and their non-pilot Naval Flight Officers reveal different dynamics. It is possible that senior pilots flying with juniors do not depend as heavily on these junior NFO's inputs for safety of flight information. They porbably depend on their NFOs primarily for mission performance. The more junior pilots are less experienced. Their higher mishap potential may reflect this lower level of experience. As the only aviator with flight controls available in the cockpit, the pilot is solely responsible for flying the aircraft. Thus the mishap rates of inexperienced pilots may be higher, regardless of the rank of their NFOs, because of their lower psychomotor skill levels.

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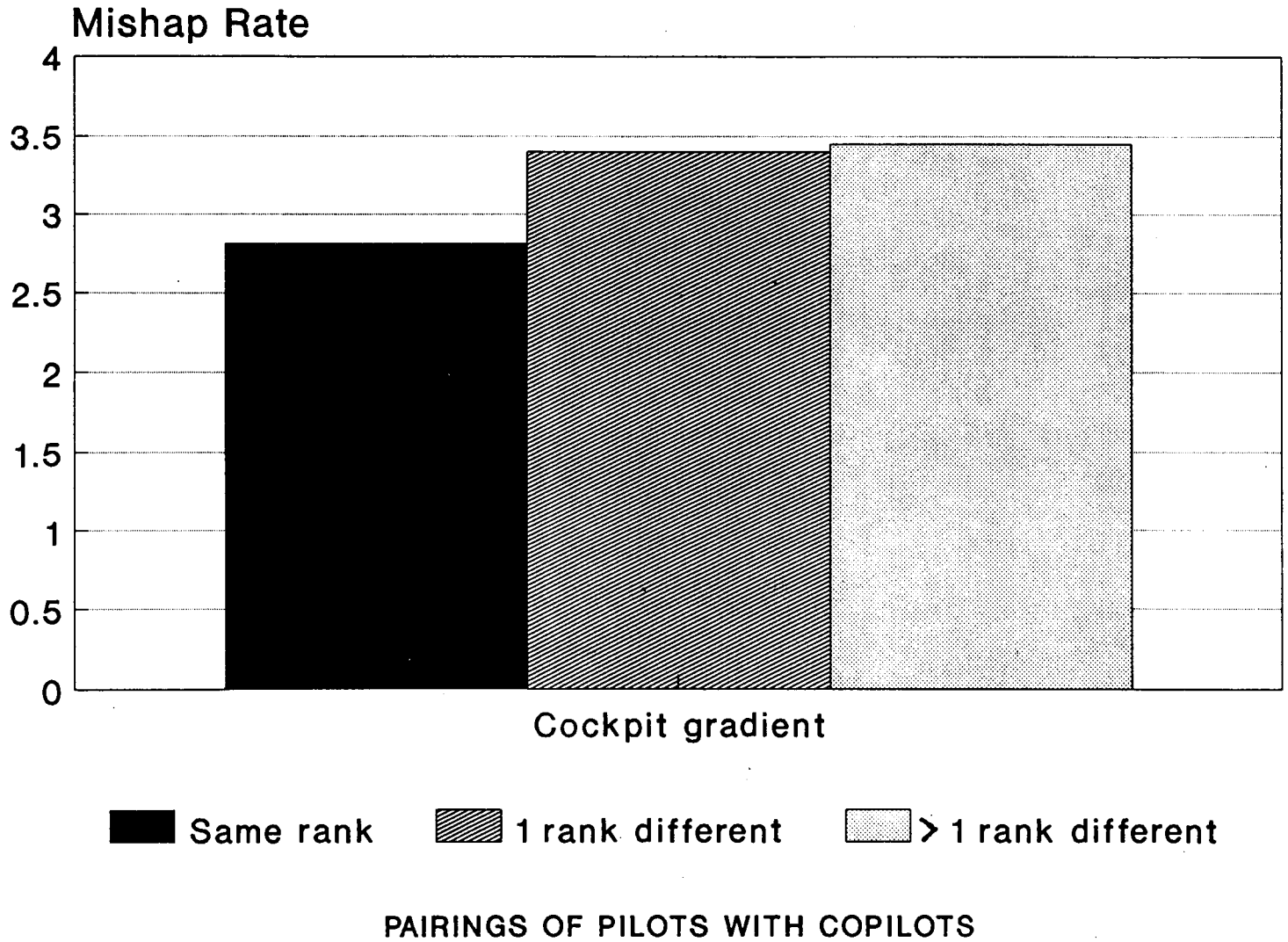
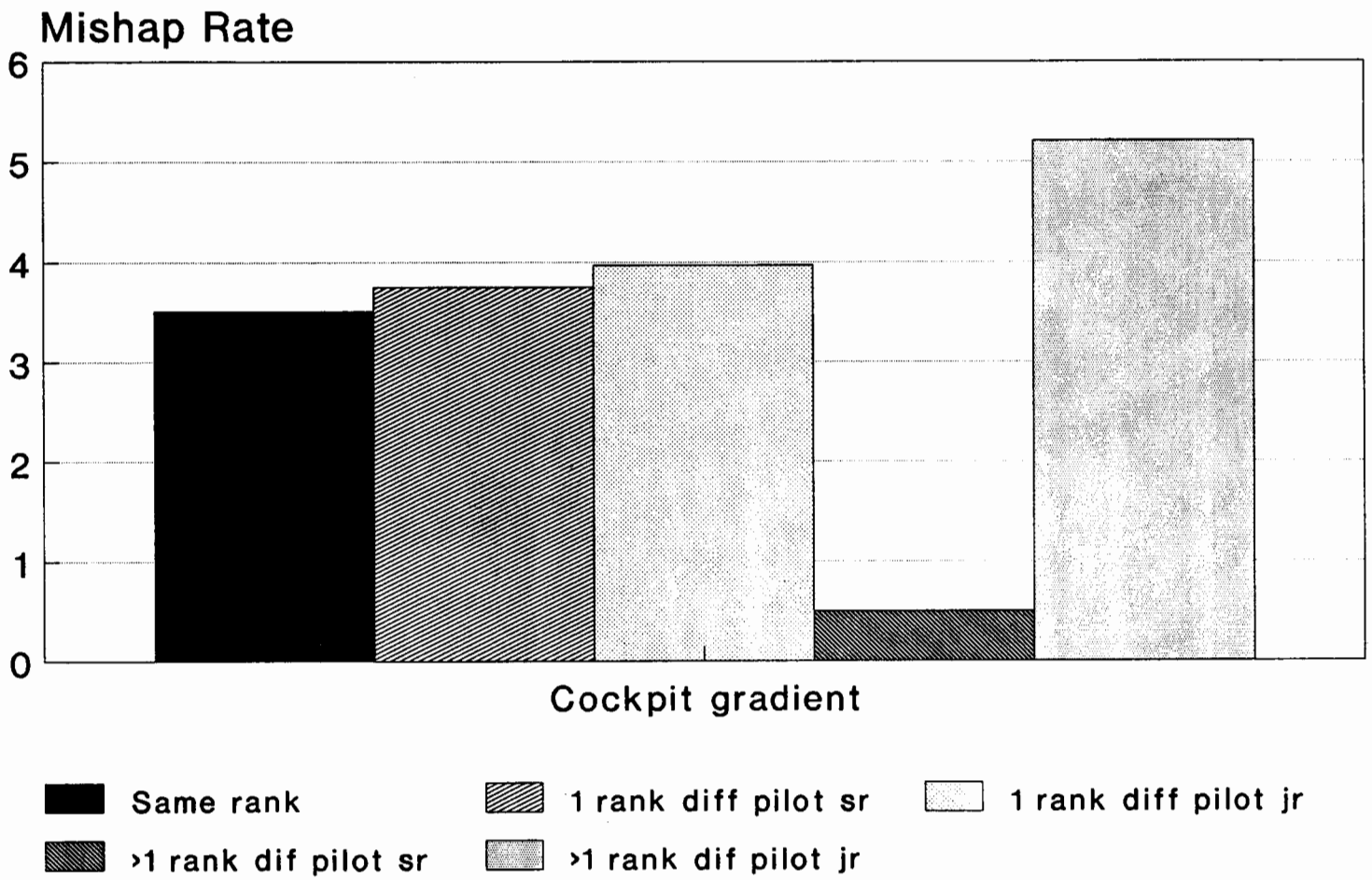
NAVY/MARINE HELO CLASS A/B FLIGHT MISHAP
AIRCREW FACTOR RATES/100,000 FLIGHT HRS.



NAVY/MARINE FIGHTER/ATTACK CLASS A/B
AIRCREW FACTOR MISHAPS/100,000 FLIGHT HR



PAIRINGS OF PILOTS WITH NFOS

PART II: RESEARCH PERSPECTIVES FOR THE NEXT GENERATION OF AERONAUTICAL DECISION MAKING

PRESENTATIONS BY:

SPEAKERS	AFFILIATION/TITLE	PAGE
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Dr. K. Anders Ericsson	Associate Professor, Psychology University of Colorado, Boulder	88
Dr. Gary A. Klein	Chairman, Chief Scientist Klein Associates, Inc.	129
Dr. John R. Bloomfield	Research Psychologist Honeywell Systems and Research Center	145,165
Dr. Judith Orasanu	Flight Human Factors Branch NASA-Ames Research Center	172
Roy G. Fox	Chief Safety Engineer Bell Helicopter Textron	182,231

Richard J. Adams

Sr. Human Factors Engineer
Advanced Aviation Concepts

HOW EXPERT PILOTS THINK

Conclusion:

Experts build a mental representation of meaningful relationships in a situation. These relationships are more than the cognitive knowledge perceived by novices in the same situation. Long familiarization in a specific field of knowledge transforms the experts mental representations into an accessible form of "synthetic global knowledge" which when applied to working situations has the characteristics of instantaneous insight or intuition.

Paper based on research supported by the U. S. Department of Transportation Federal Aviation Administration (Contract Number DTFA01-90-C-00042, Report Number DOT/FAA/RD-92/12)

HOW EXPERT PILOTS THINK

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Research on expertise and the differences between experts and novices is of great current interest and rapidly expanding into many areas within cognitive psychology and cognitive science (Gordon, 1990). Typically, the research approach has focused on expert performance in academic domains such as geometry, physics, engineering mechanics, etc. and employed psychometric testing methods to explore the different levels of cognitive processing. There is a real scarcity of information on outstanding individual performance or expertise in applied, real-world situations. Yet, this type of performance can be recognized in every day situations as diverse as financial markets (Wall Street decisions), emergency response medical teams (Chernobyl physicians) and aviation (the United Airlines flight 811 pilot/crew performance).

This paper provides an overview of the conceptual cognitive psychology research that defines and delineates the important characteristics of expertise. It is hoped that the understanding of the cognitive processes associated with "experts", will increase the awareness of these processes in the pilot training community. The importance of the attainment of a higher level of cognitive skills by pilots is the opportunity to enhance performance and further reduce human error accidents through improved decision making training.

Expertise

In virtually all arenas, a small group of individuals are recognized as exceptional performers. The abilities of these superior performers have historically been assumed to be the results of natural gifts or talent. Most of the research during the first half of the century (Guilford, 1967; Seashore, 1951 and Tyler, 1965) focused on the identification of these individuals with specific talents prior to the start of any long-term training. For most domains, this type of psychometric selection had very limited success in predicting which individuals would be superior or outstanding after training. Research in the last twenty years (Chase and Simon, 1974; Chi, Glaser and Farr, 1988; and Lesgold, 1984) has revealed that superior performance is mostly the result of **accumulated skill and experience**. The primary differences between a beginner and an expert, as well as skilled performance at different intermediate levels, can be attributed to **acquired knowledge** and problem solving skills: what we call expertise.

Expert performance can be generally defined as the selection of an appropriate response to situations or problems in a wide variety of domains. As illustrated in Table 1, these might include selecting the best move in a chess game, correctly diagnosing a medical problem, or using the proper emergency procedure in aviation. The relevant research supporting this claim has focused on the basic understanding of *knowing how* to respond to a situation rather than *knowing what* rule-guided response has worked in the past. Intuition or know-how refers to an understanding that effortlessly occurs due to discriminations resulting from previous experience. Intuition is the product of deep situational awareness and involvement quite distinct from the conscious application of abstract rules (Dreyfus and Dreyfus, 1986).

During the last decade, expertise has been studied in a wide range of domains including: medicine (Patel & Groen, 1991), physics (Anzai, 1991), sports (Allard & Starkes, 1991), music and competitive games (Sloboda, 1991) such as chess and bridge. From this extensive research, a number of theories of expertise have evolved (Adams & Ericsson, 1992)

The current theory of expertise is that a novice first solves problems by weak, domain general, heuristic methods (often working backwards from the goal); successful solutions (when repeated frequently) lead to the development of domain specific production rules and the beginnings of expertise; as these rules are used more and more often, and applied to many situations in a domain, they result in automatic generation of specialized productions which often use forward inferencing to progress from the initial problem state toward a solution or goal. Relative to the novice, the expert is able to reach the correct solution more quickly and efficiently.

Table 1 **EXPERT RESPONSES IN A VARIETY OF DOMAINS**

DOMAIN	SITUATION	EXPERT RESPONSE
Chess	A specific game pattern	Selection of the best move
Physics	A difficult problem	Solution generation
Medicine	Knowledge of a patient's symptoms and medical history	Correct diagnosis of the medical problem
Machine Repair	Description of equipment malfunction	Correct analysis & repair of the problem
Aviation	An impending emergency	Application of trained procedures or generation of appropriate response

Basic Traits of Experts

The status of the current theories of expertise are thoroughly summarized in "Thoughts on Expertise" and "On the Nature of Expertise" (Glaser 1986 & 1987). The latter reference, in particular, concludes with 24 "Summary Propositions" pertinent to this analysis. However, rather than simply restating this lengthy list or reviewing the entire two documents, the following summary of findings most relevant to aviation have been extracted.

1. Expert performance is characterized by **rapid access to a well organized body of conceptual and procedural knowledge.** Pilots are trained and tested in their ability to perform normal and "expected" emergency procedures. This training strengthens and expands their procedural knowledge base. High levels of competence result from the interaction between knowledge structure and processing abilities.

2. The organization of knowledge used by experts can be thought of as **schemata or a modifiable information structure based upon knowledge that is experienced.** This includes the interrelationships among objects, situations and events which individuals use to integrate and interpret instances of related knowledge. Schema theory assumes there are schemata for recurrent situations that expedite decisions in certain situations (e.g., the experienced pilot anticipating a thunderstorm by recognizing a threatening cloud formation, anticipating wind shear on landing, or anticipating in-flight icing conditions).

3. Expertise is domain specific. Within a domain, experts develop **the ability to perceive large meaningful patterns.** Furthermore, pattern recognition occurs so rapidly that it appears to take on the character of insight or intuition. This ability of experts appears to depend on the nature and organization of knowledge in existing memory which is directly related to training and experience. This is a partial explanation of how expertise, while domain specific, is characterized by the type of information processing of data within a domain.

4. Expert **knowledge is highly procedural and goal oriented.** Individuals with extensive domain knowledge are much better at relating events in cause-and-effect sequences that relate to the goals and subgoals of a problem solution.

5. The capability of experts to **fast-access** their knowledge facilitates problem perception in a way that leads to the **reduction of the role of memory search and general processing.** Although the novice and expert have equal capability for cognitive processing, novices typically use lots of search and processing in a less focused, more general manner. The outstanding performance of experts is derived from how their knowledge is structured for:

- Retrieval
- Pattern Recognition
- Inference

This expert capability is also referred to as "holistic discrimination and association". It manifests itself in the ability to intuitively respond to patterns without decomposing them into component features. This understanding occurs effortlessly due to discriminations resulting from prior, concrete experience.

6. Generalized thinking and problem solving skills may develop in individuals who acquire expertise in several domains (e. g., aeronautics, airplane systems, air traffic control procedures, emergency procedures, etc). **Continuous development of expertise in a field is based upon novel conditions that extend competence to novel situations.**

7. Experts develop specialized schemata that **match goals to demands of the problem.** Although both novices and experts can display good use of general problem solving process, experts use them primarily in unfamiliar situations.

8. The development of expertise is **influenced by task demands** encountered in the course of experience. In some domains, experts develop the capability for **opportunistic planning** which enables them to revise problem representations and to access multiple possible interpretations of a situation. These multiple patterns are quickly assessed and used to develop an "internal" visualization and then create a goal oriented scenario that can be played -- put in fine detail and in "slow-time" -- to a successful solution. In contrast, novices are less flexible and slower.

Experts build a mental representation of meaningful relationships in a situation. These relationships are more than the cognitive knowledge perceived by novices in the same situation. Long familiarization in a specific field of knowledge transforms the experts mental representations into an accessible form of **synthetic global knowledge** (Bastic 1982) which when applied to working situations has the characteristics of instantaneous insight or intuition.

9. Experts also possess metacognition abilities that are not present in less experienced decision makers. Experts develop **skilled self-regulatory processes** that free working memory for higher level conscious processing. These capabilities include: planning ahead, efficiently monitoring one's time and attentional resources, and monitoring and editing one's efforts to solve a problem. Self-regulatory activities become generalized cognitive processes. These generalized processes become important when an individual is confronted with problems in unfamiliar areas.

10. An important point of distinction is that there are both routine and adaptive experts. Either type is outstanding in terms of speed, accuracy, and automatic cognitive performance. Either type can construct mental models convenient for performing their tasks. While both adaptive and routine experts are very confident in the execution of their solutions, routine experts have somewhat limited capabilities in dealing with novel or new problems. Adaptive experts, on the other hand, possess **the ability to creatively respond** to novel situations and develop an appropriate response with some reasonable chance for a successful outcome.

Routine vs Adaptive Expertise

The distinction between routine and adaptive experts, points to an avenue for the next generation of expertise research; this research will be from a cognitive psychology perspective and will stress applications to real world problems like how aviators respond to untrainable emergencies. A broad distinction between two classes of expertise is that expert performance involves "the reliable attainment of specific goals within a specific domain" (Sloboda, 1991). A more demanding definition is that "an expert is someone who can make an appropriate response to a situation which contains a degree of unpredictability" (Sloboda, 1991). Perhaps the most apt general characterization suggested that an expert is **someone capable of doing the right thing at the right time.**

In general, an expert will have succeeded in adapting to the inherent constraints of the task. If the task can be done most efficiently by forward search, the expert will search forward; if backward search is better, the expert searches backward. If certain patterns of cues are crucial to performing the task well, the expert will likely perceive and remember them; if patterns are not so important, the expert will not selectively process them. The tendency of experts to adapt to task constraints would account for the fact that whereas novices differ widely in the way they organize domain relevant concepts, experts tend to resemble each other (and differ from novices) in their conceptual organizations.

Time Pressures

The adaptive experts ability to form a creative, complete and integrated representation of complex problems is critical in real-world situations. The standard experimental paradigm has been to present a situation, e. g., sheet of information on a medical patient, a chess position, a scene from a basketball game, an electronic circuit diagram, etc., for a few seconds and then have individuals with different levels of expertise attempt to recall as much as possible. Novices can recall only a small amount. The amount of recall increases with expertise even at very high levels of expertise. In many cases, the recall of the super-expert is virtually perfect. Expertise in sports (basketball, land hockey, etc.), in games (chess and bridge) and in computer science, electronics and medicine shows that the validity of the internal representation of the situation increases with expertise.

The ability to internally represent external situations appears to be related to the skill levels that experts develop to plan, i. e., mentally explore the consequences of potential sequences of actions even under extreme time pressures. There is a large body of informal evidence suggesting that this capability to plan increases with the acquisition of expertise. In domains where there is a pressure to respond rapidly often in response to dynamically changing situations, experts develop methods of coping with these demands.

The shortest possible reaction time to an external stimulus even after extensive training is about 200-250 milliseconds, and more complex reactions require between 500-1000 milliseconds. Research on elite tennis players, goal keepers in hockey and baseball players has shown that with increasing expertise, individuals dramatically improve their ability to correctly predict ball or puck trajectories relying on advanced cues. Similarly, typists, pianists playing from a score, and individuals reading text aloud are found to look ahead several characters, notes and words of material. This is referred to as eye-hand span. The size of the eye-hand span is closely related to level of expertise, such that expert performers have a long span and beginners or novices have essentially no span at all. The relevance of the eye-hand span in aviation is that it allows the expert pilot to scan the instruments while operating the aircraft controls, tuning radio frequencies, keying the microphone to talk to ATC, reading information off of charts, etc. In short, the expert pilot operates in an ultimate "multi-tasking" environment and needs highly developed eye-hand span capabilities in normal workload situations, and even more so in emergency situations.

These expertise domains which stress speed and solutions under time pressure may appear to always be driven by automatic responses to changes in the current situation. However the ability of experts to anticipate future conditions (such as the pilot's need to change aircraft heading or call ATC) and thereby reduce the need for responding to sudden changes in the situation implies an important role of an internal representation of the situation even in these types of expertise. Furthermore, the portion of the visual field that can be clearly seen at any given time is only a fraction (less than a thousandth) of the visual field, which means that monitoring the visual field and storing results in memory for later use and updating is a critical part of having an accurate description of the situation.

Expertise and Training or Practice

At the most general level, expert performance and expertise involves the acquisition of encoding processes allowing the situation (problem) to be fully represented and integrated internally in such a way that relevant actions can be retrieved from memory. The internal representation of external situations is also critical to planning and evaluation of possible courses of action as well as a means to represent dynamically changing environment for the purposes of anticipation and prediction. The following paragraphs consider how this form of expertise can be attained and promoted by training and instructional activities.

As a first approximation, acquisition of expertise increases linearly in all relevant aspects of performance in a specific domain. The conventional use of categories to describe levels of expertise or phases of acquisition of expertise are shown in Table 2. Although knowledge about how experts acquire their expert performance is relatively limited, generally, the novice should have acquired all basic knowledge in less than one year. In parallel and continuing beyond this basic knowledge is the acquisition of problem solving skills where the knowledge is organized to effectively produce efficient performance. That is, there is an acquisition of the **procedural knowledge** of complex patterns occurring in specific domains. At this Intermediate level, differences in expertise appear to be related to the **cued recall** ability and the number and complexity of those patterns available for use.

Table 2 **PHASES AND CATEGORIES OF EXPERTISE**

PHASES OF EXPERTISE	CATEGORY OF EXPERT
Beginning Phase (Acquisition of declarative knowledge and domain general problem solving skills)	Beginner, Student, or Novice
About 1-2 years of active experience and training	Intermediate
Many years of active experience and training (Full time - 40-80 hours per week)	Routine Expert or Journeyman
More than 10 years of full time experience and training	Master or Adaptive Expert

Finally, in both the routine expert and adaptive expert categories, an accepted, domain specific vocabulary (or jargon) is developed to allow efficient communication among experts and masters in a given domain. This is obvious in medicine or law which also involve the use of Latin, French and to a lesser degree German. Similarly, in aircraft operations (from flight planning to air traffic control) experts have developed an extensive jargon which is formalized in the "Pilot-Controller Glossary" of the Airman's Information Manual. This manual is designed to promote efficient communications and a common understanding.

Most of our knowledge about how expert performance is attained comes from highly competitive domains with relatively vigorous evaluation procedures such as sports, games and music. Biographical analyses of the international level performers in these domains show that they start early. By the age of seven most of them are engaged in instruction and daily practice. The amount of practice is gradually increased to about two to four hours daily during the early to late teens respectively. During early adulthood, these individuals spend virtually all their time on activities related to their domain of expertise. This amount of practice appears to be the single most important variable in determining the attained level of performance in a given domain. Athletes and expert musicians clearly distinguish practice as the most important activity for further improving performance.

Pilots, on the other hand, must practice for events that most likely will never occur. This creates a different expert training or development scenario. For example, attainment of expert status in aviation and other domains such as architecture, engineering and medicine appears to be the result of a slow accumulation of experience in "on-the-job" environments. Given the relatively unstructured nature of this "practice" and the relative infrequency of objective evaluation of performance or guidance by a master instructor, **improved performance and expertise in these fields relies much more strongly on the motivations of the individual.**

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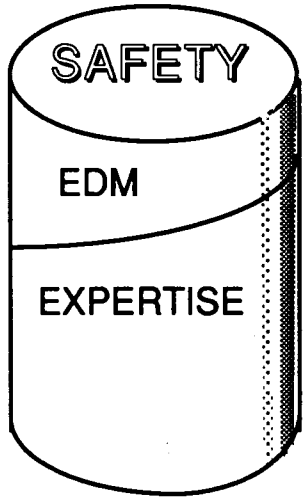
HOW EXPERT PILOTS THINK



MAY 1992

AAC

HISTORY

AERONAUTICAL DECISION MAKING (ADM)

- **Defined Judgment**
- **Identified hazardous attitudes**
- **Developed self-test**
- **Stressed situational awareness**
- **Utilized the "Decide" Model**

AAC

SUCCESSES

	HE REDUCTIONS
• 10 EXPERIMENTAL VALIDATIONS	8-46%
• WORLDWIDE CIVIL HELICOPTERS (B206)	
-- ALL H.E. ACCIDENTS	36%
-- WEATHER RELATED ACCIDENTS	72%
• U.S. CIVIL HELICOPTERS	
-- B206 ALL H.E. ACCIDENTS	48%
-- PHI ALL ACCIDENTS	54%
• U.S. MILITARY	
--USAF TRANSPORT CREWS	51%
--USN HELICOPTERS	28%
--USN AIRPLANES (A6 & EA6)	81%

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AERONAUTICAL DECISION MAKING

THE EXPERIENCE DILEMMA

- Error reductions occurred only in the inexperienced (< 5 years) pilots
- What are the differences in novice and experienced pilot decision making?
- Can we develop an expert level decision making training syllabus?

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AERONAUTICAL DECISION MAKING

EXPERTISE IN ACTION

DATE	LOCATION	AIRLINE	AIRCRAFT	TYPE
7-19-89	SIOUX CITY	UAL	DC-10-10	Eng. fail
2-24-89	HONOLULU	UAL	B-747-122	Cargo door
4-28-88	MAUI	ALOHA	B-737-200	Fuselage
7-23-83	GIMLI	Air Canada	B-767	Fuel Strv.
6-02-83	CINCINNATI	Air Canada	DC-9-32	Cabin Fire

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EXPERTISE IN ACTION

EXPERT CHARACTERISTICS

- INSTANTANEOUS RECALL OF TRAINING
- REVERSION TO BASIC AIRMANSHIP SKILLS
- REASONED APPROACH IN EMERGENCIES
- POSITIVE IN APPROACH & EXPECTATIONS
- SELF-ASSURED AND OPTIMISTIC

But, What is going on at the cognitive level???

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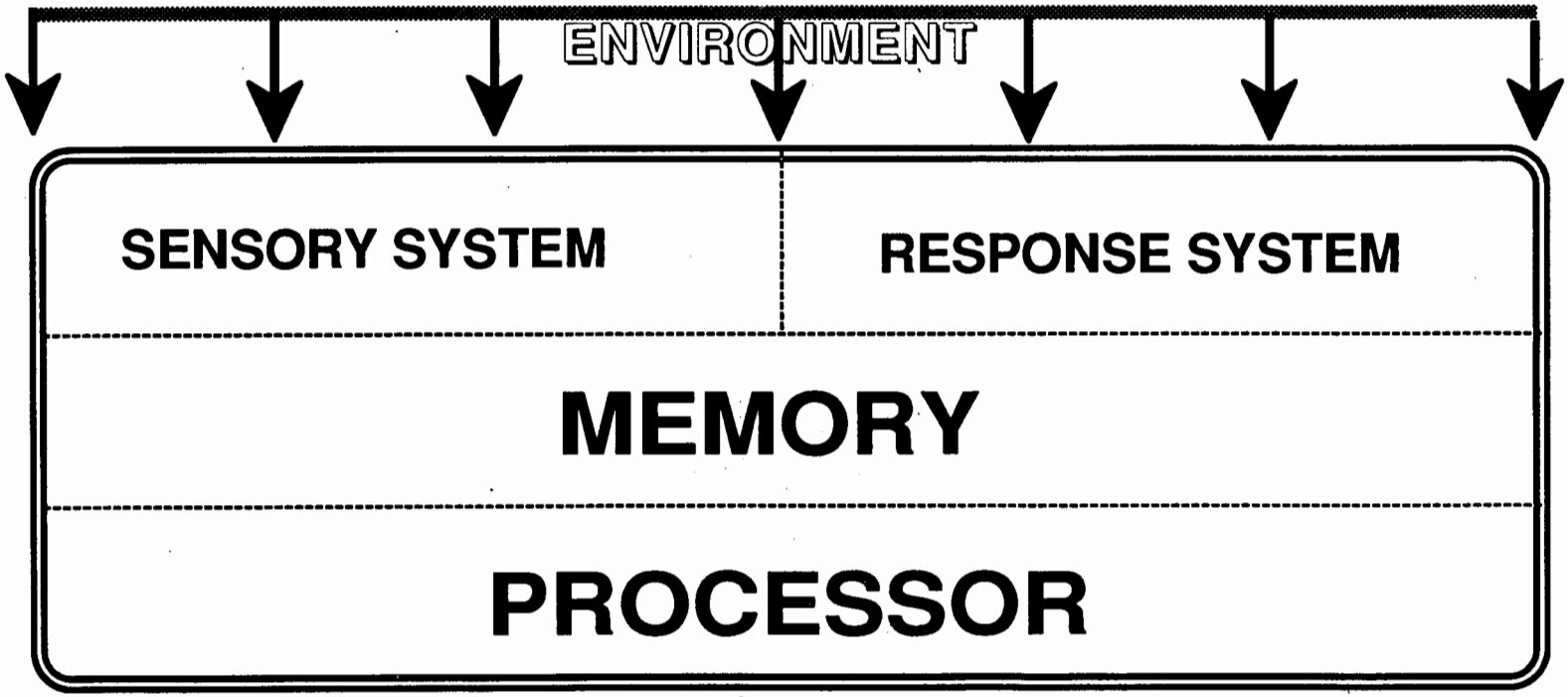
HUMAN INFORMATION PROCESSING (HIP)



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HIP -- SENSORY MEMORY

A lot of information received, a small amount "attended to" and remembered.

x	m	r	j
c	n	k	p
v	f	l	b

(3-6) vs (3/4) > 3 available

ATTENTION
- **Controlled (focused)**
- Automatic

PERCEPTION
- **Bottom-up**
- **Top-down (Context)**

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HIP -- WORKING MEMORY

A limited amount of information in a special "active" state available to be used.

- **Transient or Short term: 18 - 20 seconds**
- **7 ± 2 Items or "Chunks"**

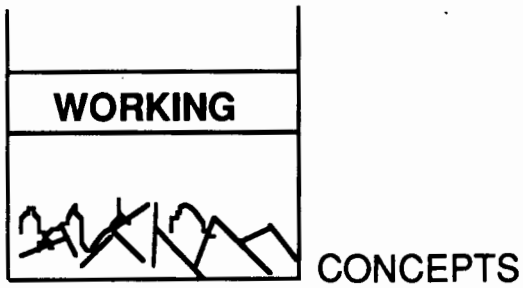
Chunks = Units stored in long term memory
e.g., 4 syllables (DAX, JIR, GOF, BIR)
6 words (TILE, LATE, ROAD,....)
3 four syl. words (CONSTITUTION, ...)
A 19 word sentence

HIP -- LONG TERM MEMORY

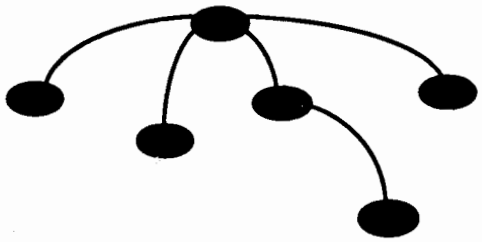
Not encyclopedic, but "reactivation and reconstruction".

- Recognition -- **Discriminate only**
- Recall -- **Generate and Discriminate**

fishnet theory



Schema



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HIP -- LONG TERM MEMORY

- ORGANIZATION AFFECTS BOTH R & R
- ELABORATIONS EXPEDITE RECALL
- INFERENCES AID ELABORATIONS & RECONSTRUCTION
- CUES & CONTEXT CAN MAKE RECALL EASIER THAN RECOGNITION

HIP -- PROBLEM SOLVING

Goal oriented cognitive behavior.

DECLARATIVE = "FACTS & THINGS"

PROCEDURAL = "COGNITIVE ACTIVITIES"

PROCESSOR → ALGORITHIMS

HUERISTICS

PRODUCTION RULES

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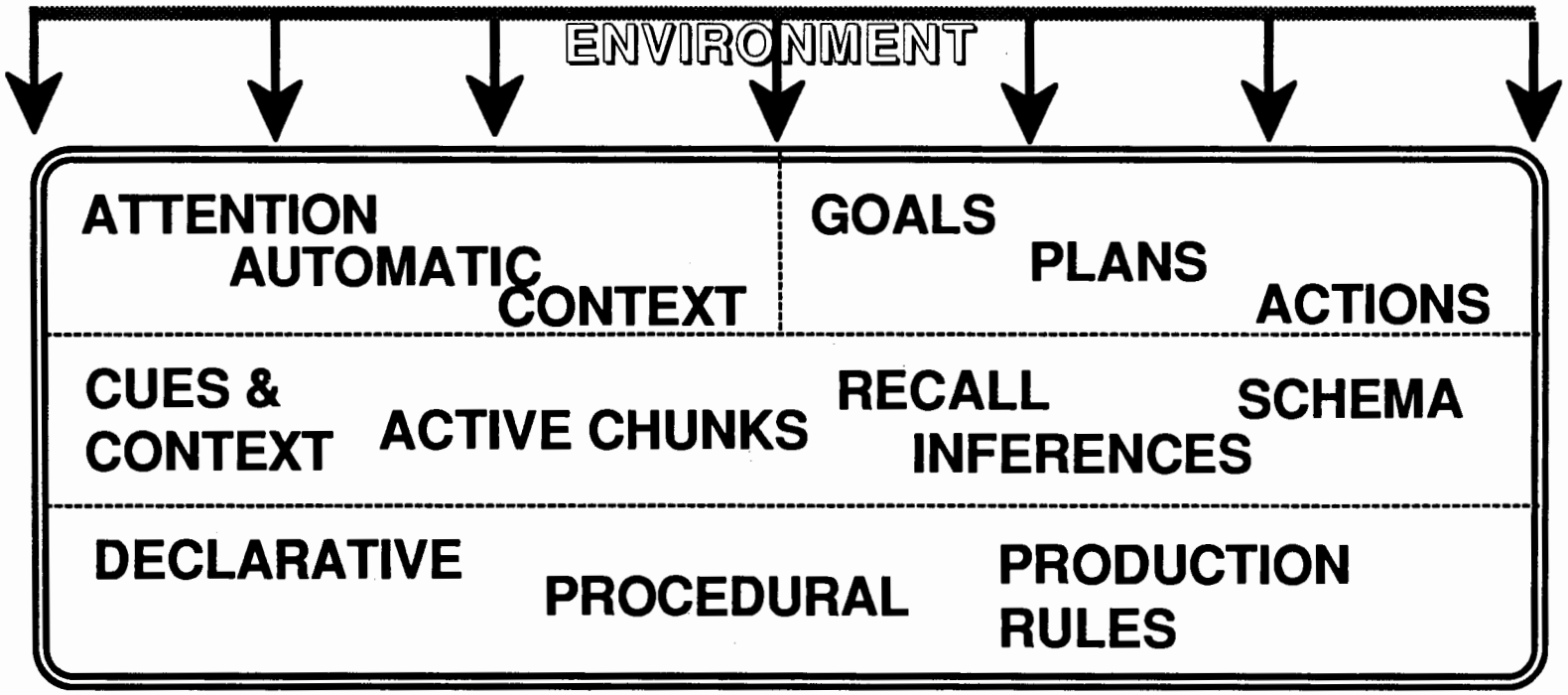
HUMAN INFORMATION PROCESSING (HIP)



AAC

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METHODOLOGY FOR STUDYING AND TRAINING EXPERTISE

Conclusion:

Expertise in aviation provides the ability to avoid emergency situations as well as the readiness to respond to both normal and abnormal situations rapidly. Realistic training scenario development to achieve these goals will require substantial adaptation and testing to yield effective results.

METHODOLOGY FOR STUDYING AND TRAINING EXPERTISE

by

Anders Ericsson, Institute of Cognitive Science
and Department of Psychology

University of Colorado at Boulder

I Brief Historical Background for the Study of Eminent People and Experts: Some Approaches and Issues

II The Study of Superior Expert Performance

III Sketch of a Proposal for Diagnosis and Training of Expert Decision-Making in Pilots

I Brief Historical Background for the Studyof Eminent People and Experts: Some Approaches and Issues

Eminent individuals and experts differ from average people in their abilities and achievements

- Identification of exceptional individuals using social criteria of success

Awards, Occupational status, salaries

Individual differences in basic capacities and characteristics

vs

Differences in acquired level of skill

Talent view

Avoid influence of experience

Expert Performance

Skill acquisition view

Maximum influence of experience

Basic processes

Speed of neural process (simple reaction time)

Characteristics of basic memory processes

Physical and anatomical characteristics
- compositions of muscles
- capillaries and hearts

Acquired characteristics

Speed of reacting in typical situation

Memory for representative stimuli

Individual differences in basic capacities

Conclusions:

- No reliable differences between Experts and Novices
  (Exception: height differences in sports)

- Attempts to predict ultimate performance
  <u>after</u> training have failed
  (less than 4% of variance accounted for)

- Large effects of training for performance
  on tasks measuring basic abilities.

- Superior reaction times and memory performance
  for tasks in the domain of their expertise.

Studying instances of superior achievements and performance

Situation & Individual --> Outstanding Achievement
Recency
Regularity
Reproducibility

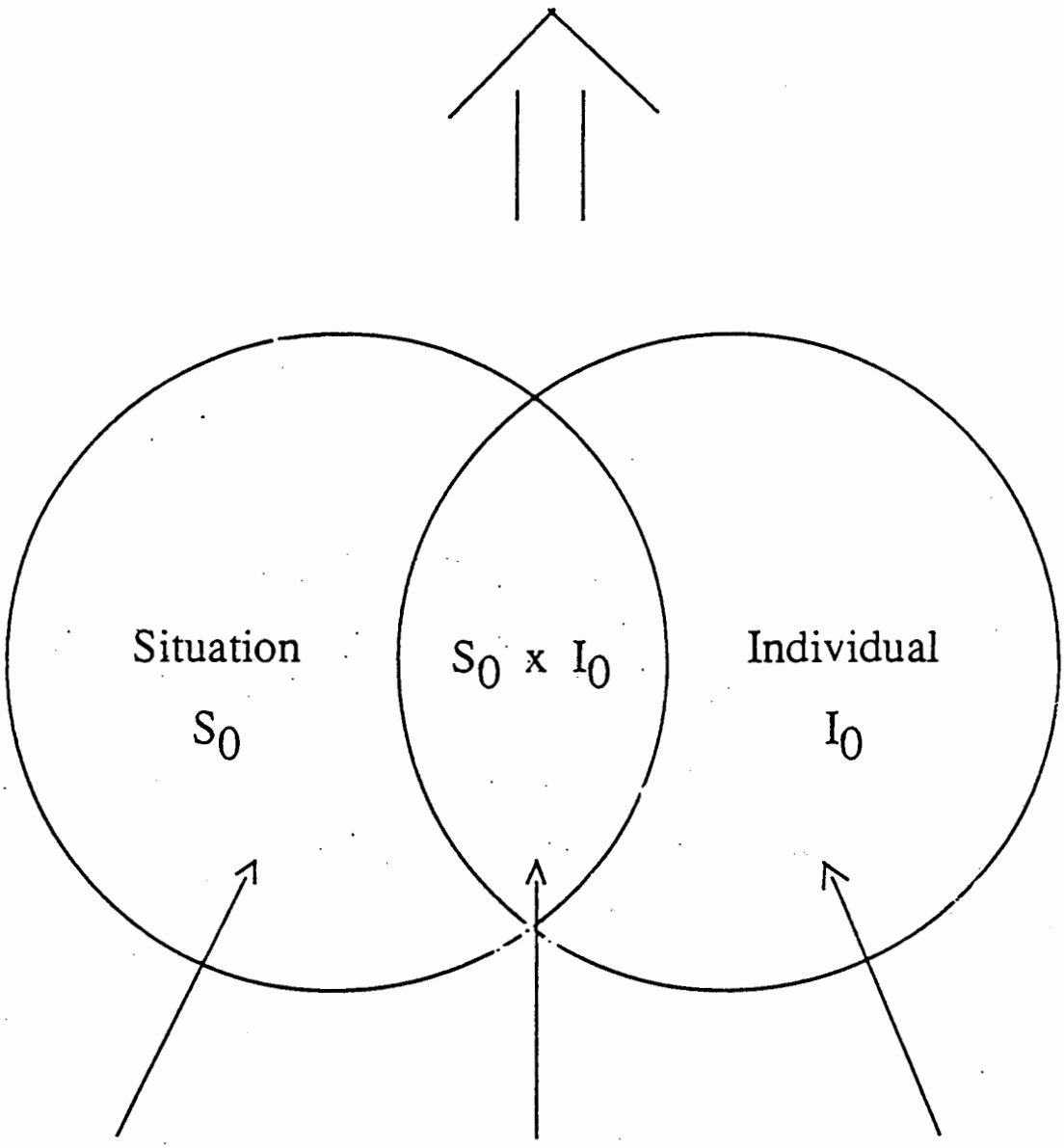
Standardized situations
Sports and other competitive events (chess, bridge)
Natural competition (stock market)

Conclusions

Some forms of expertise are difficult to measure and study

Expert status not always associated with superior performance
Computer programmers
Expert decision-making
Applied mathematicians

Outstanding Performance



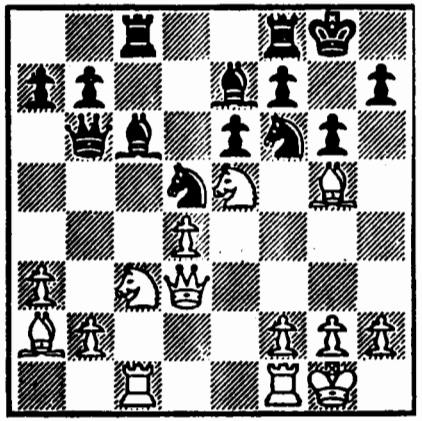
unique situation:	unique situation x individual interaction	unique individual:
discoveries military and political decisions	discoveries	winners of fair competitions

II The Study of Superior Expert Performance

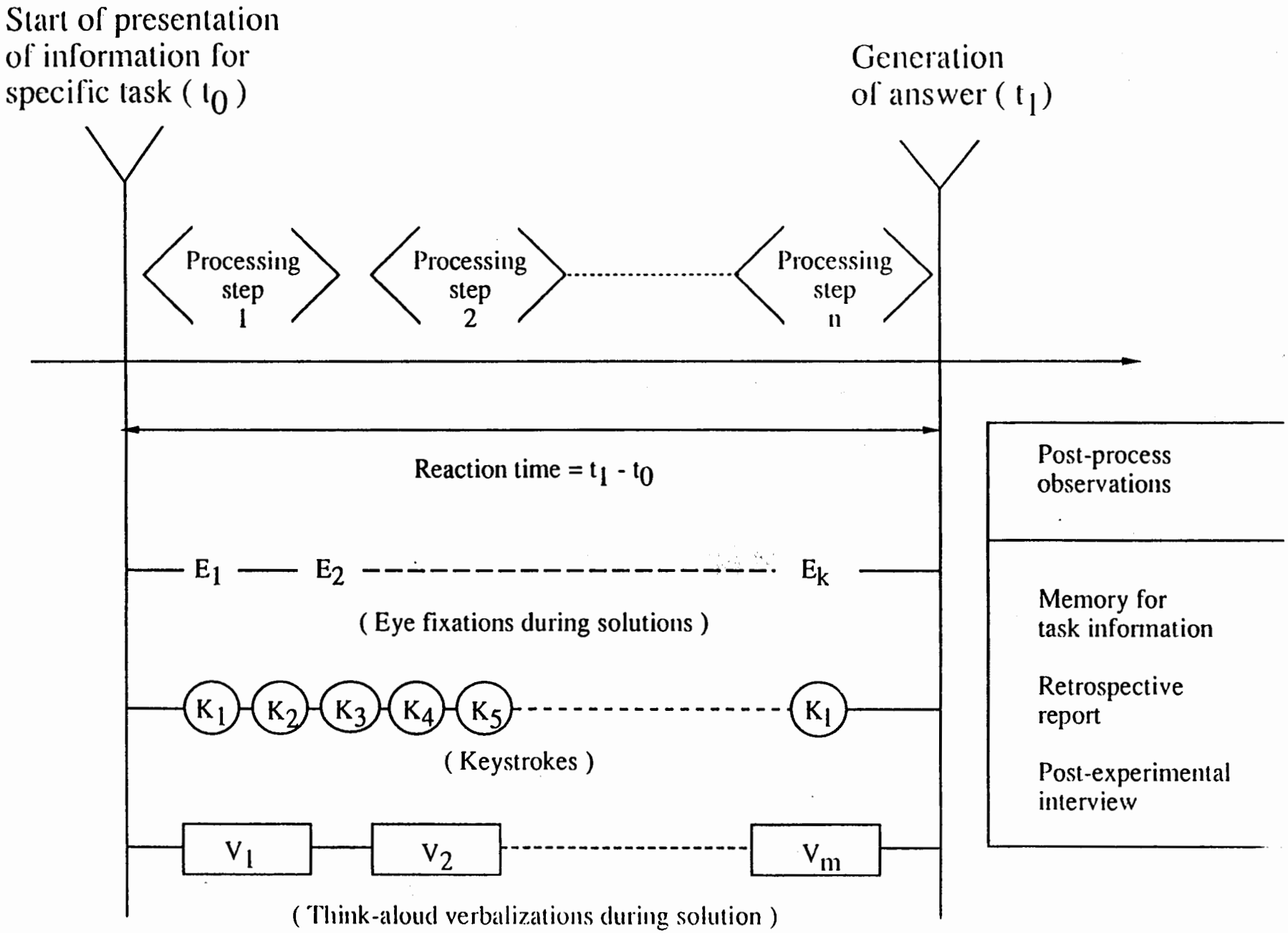
Capturing superior expert performance
- Essence of superior performance in a domain of critical tasks - Task analysis
- Laboratory analogues

Analysis of superior expert performance
- Process-tracing (verbal reports, reaction time)
- Experimental variation and analysis
- Findings: Rapid understanding & intuitive reactions
  - Slower systematic evaluation
  - Superior memory for relevant information

Analysis of acquisition and maintenance of expert performance
- Deliberate practice rather than experience
  - Necessary amounts of deliberate practice for attaining expert performance.
  - Constraints on daily and weekly amounts of deliberate practice
- Summary

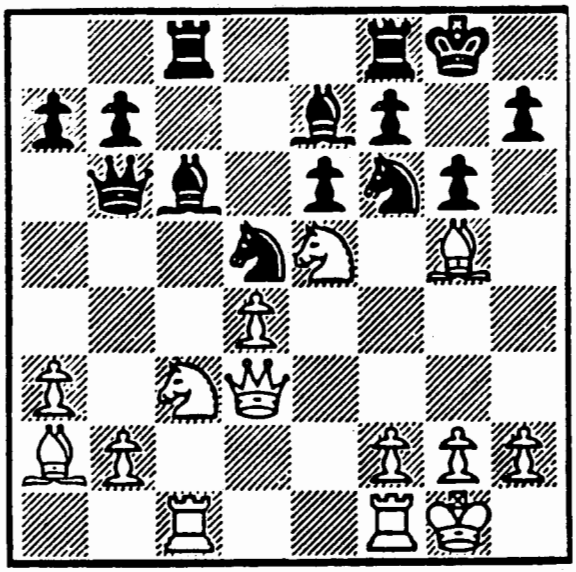
Domain	Presented Information	Task
Chess	 POSITION A *White on move*	Select the best chess move for this position
Medicine	<Description of a patient's medical symptoms>	Make and record accurate medical diagnosis of this patient
Sports	<A snap-shot of a tennis player serving a ball towards the camera>	Predict the place where the ball will land within the service area

Types of available observations on mediating cognitive processes



De Groot's Task:

Select the Best Move for a Given Chess Position while Thinking Aloud.

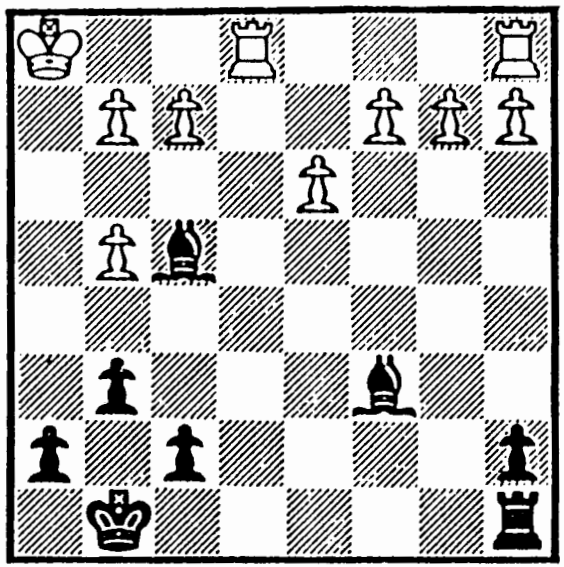


POSITION A

White on move

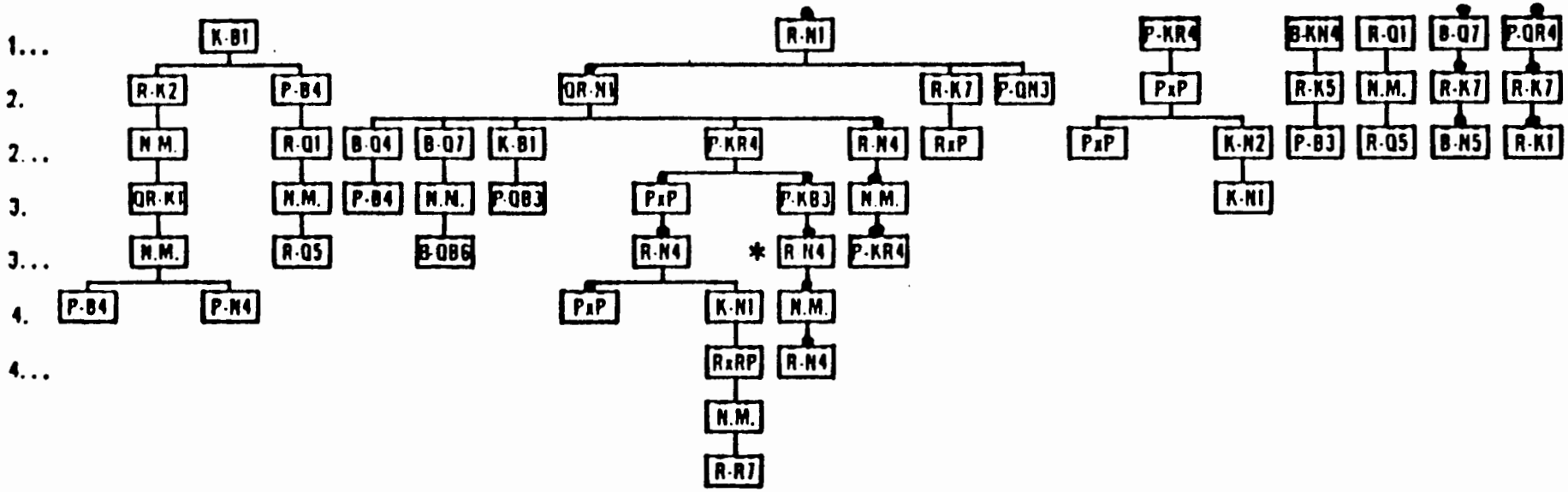
Phases of Think-Aloud Protocols

I. Initial Orientation
II. Exploration of Possibilities
III. Systematic Investigation
IV. Final Evaluation



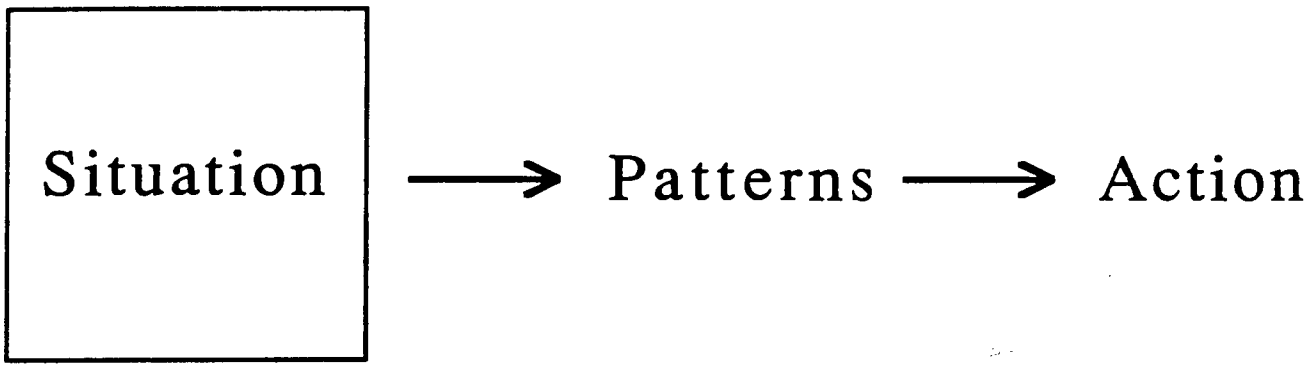
POSITION B

Black on move



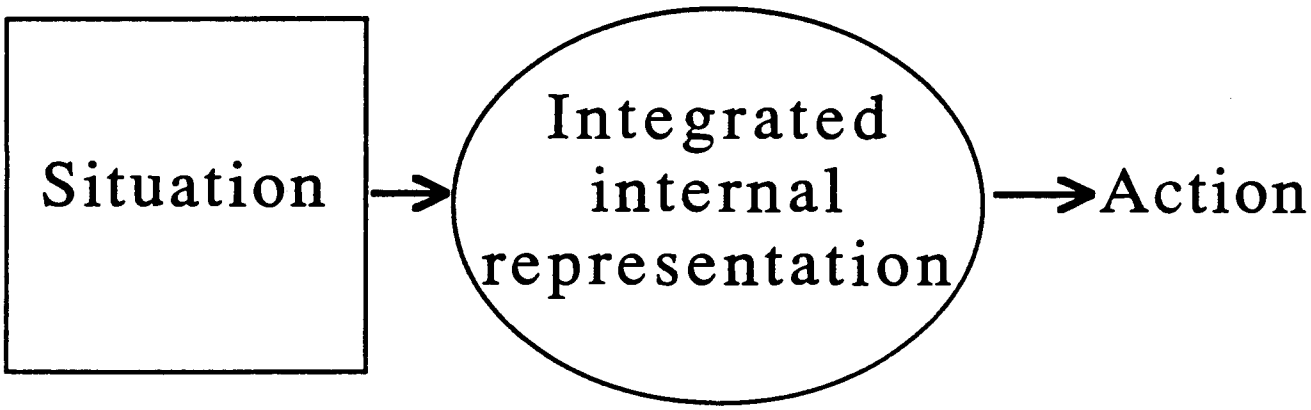
Organization of Expert Performance

I. Traditional View {Pattern → Action}



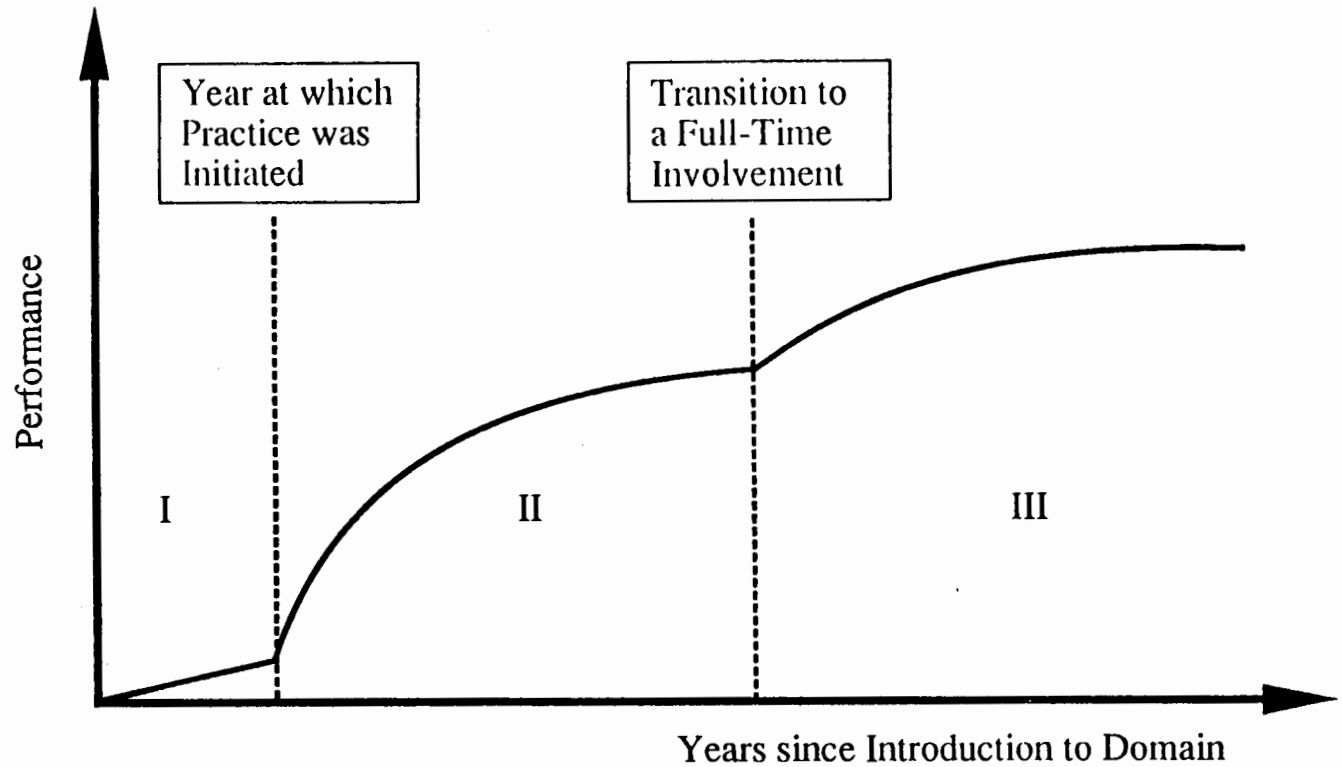
II. Revised View

- Memory for briefly presented information
- Mental exploration of possibilities (Planning)
- Evaluation and reasoning

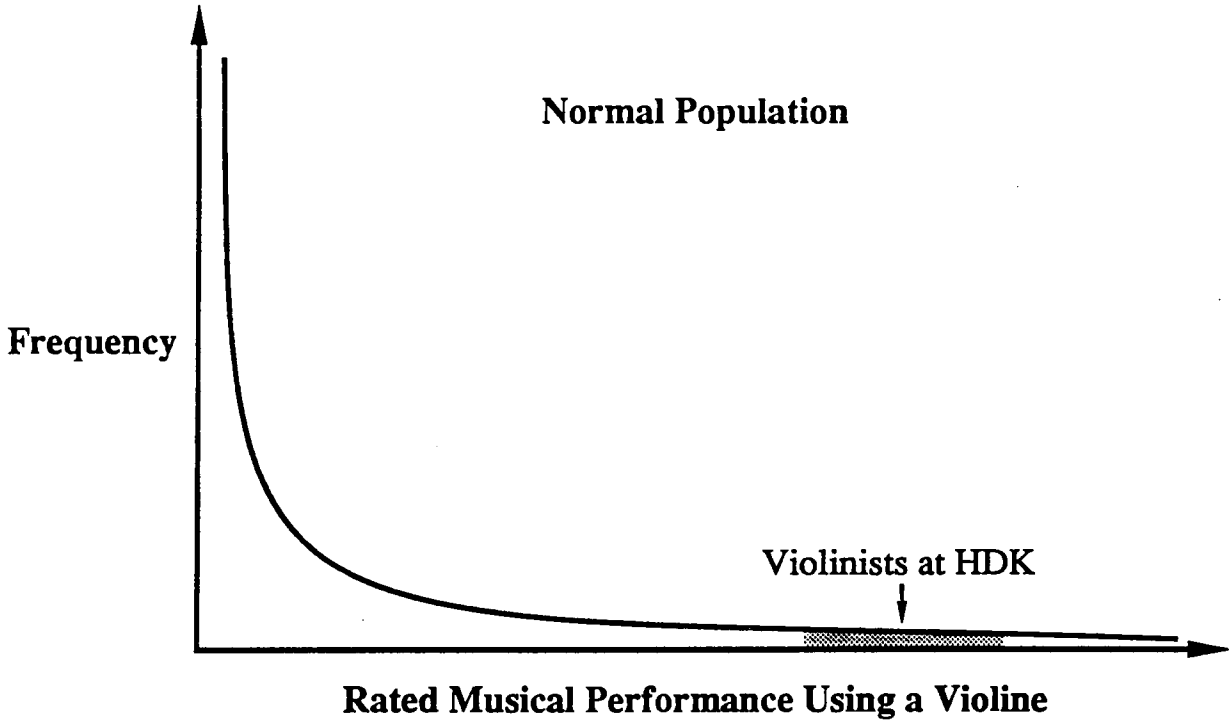


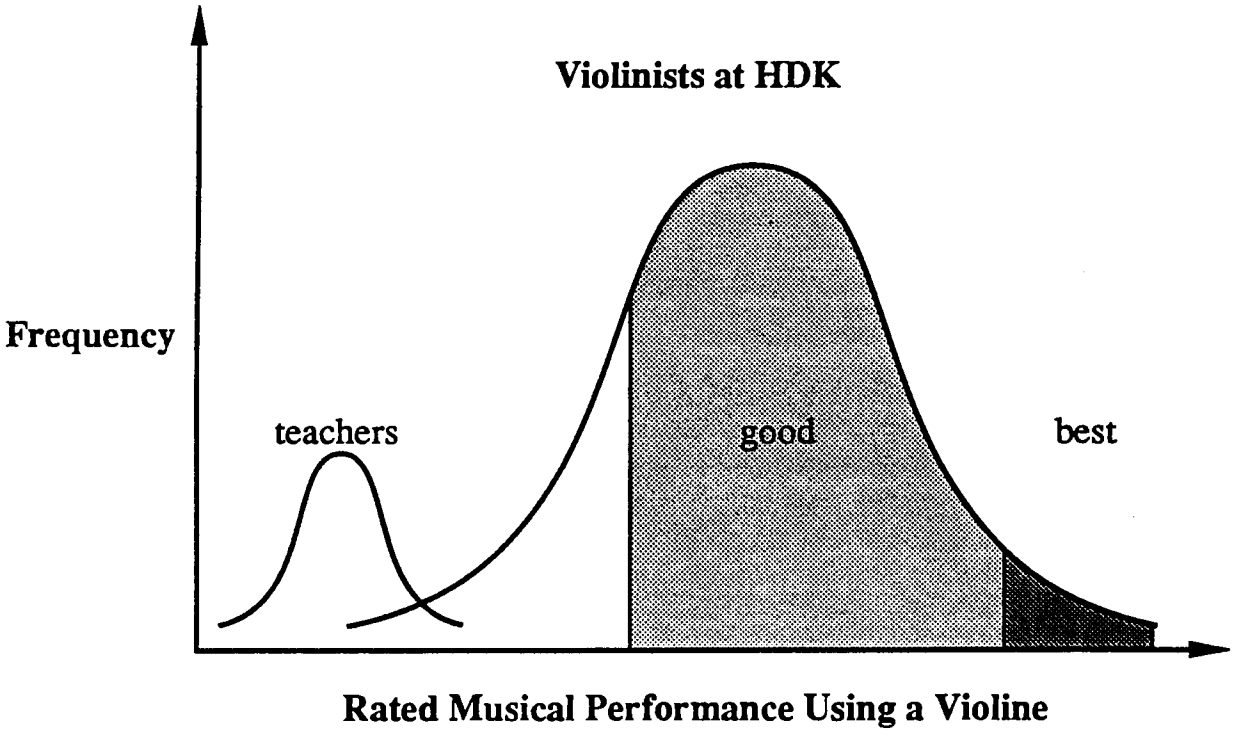
Different Types of Experience

	Deliberate Practice	Work	Play
Goal:	Improvement of Performance	Gaining external reward	Inherent enjoyment
Example Long-distance running	Internal training	Competition	Running with a group
Tennis	Repetitive practice with a coach on perfecting a specific shot	Competition	Recreational play



Design of Practice Activities	—	by Coach or Teacher	by the Master Teachers and the Individuals themselves
Allocation of Time and Energy for Practice	—	by Coach or Teacher and the Individuals themselves	by the Individuals themselves
Motivational Issues	Getting Started to Practice	Sustaining and Increasing the Level of Practice Restriction of Time for Leisure	Sustaining Analysis and Practice Restriction of Time and Effort for All Other Activities

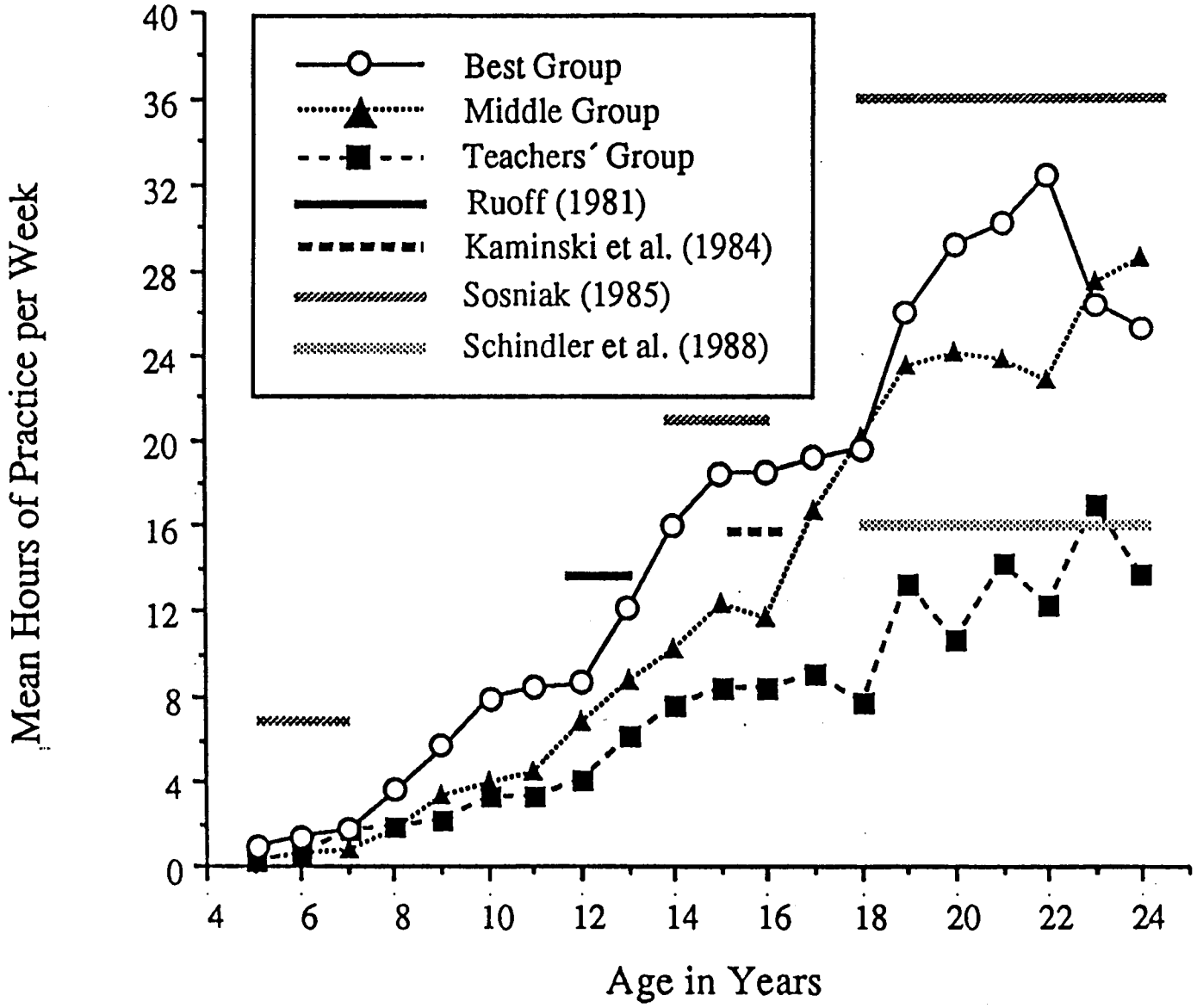

Normal Population
Frequency
Violinists at HDK
Rated Musical Performance Using a Violine

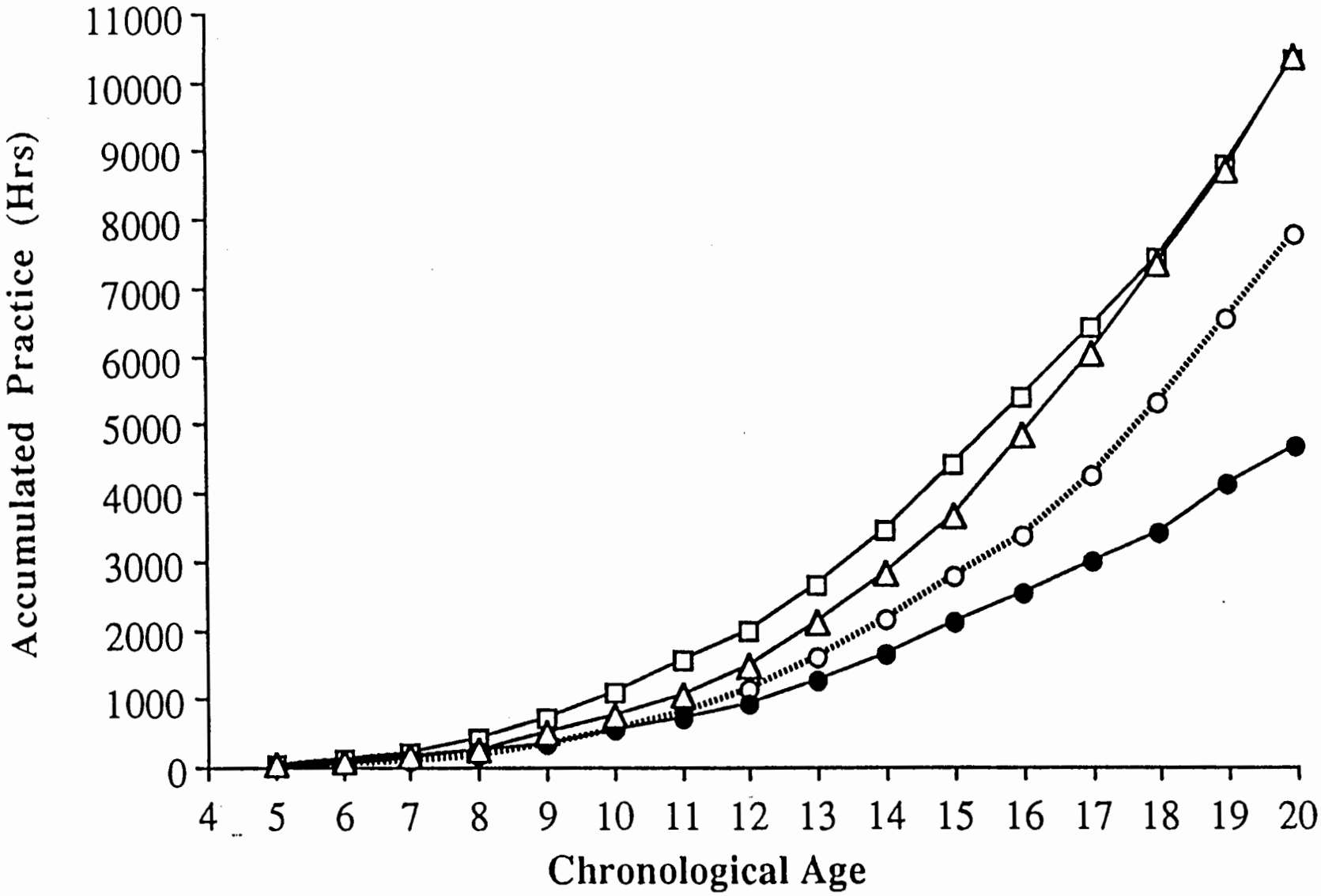

Violinists at HDK
Frequency
teachers
good
best
Rated Musical Performance Using a Violine

diary

Datum : 28.11.
SID Nr : 4.1

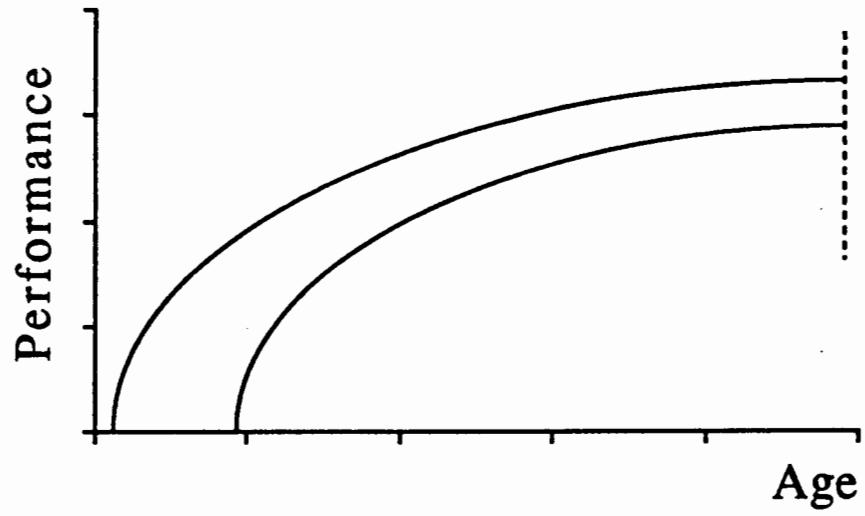
hour	minutes	mode of activity	
12	00-15	Ysaye	(practice alone)
	15-30		
	30-45		
	45-00	cooking	(housekeeping)
13	00-15	eating	(body-care)
	15-30	wash the dishes	(housekeeping)
	30-45		
	45-00		
14	00-15	sleep	(sleep)
	15-30		
	30-45		
	45-00		
15	00-15		
	15-30	packing things	(organisation & preparation)
	30-45	drinking coffee	(body-care)
	45-00	phonecall	(leisure)
16	00-15	play through Paganini	(practice alone)
	15-30		
	30-45	bike-riding to HdK (Miere)	(organisation & preparation)
	45-00		
17	00-15		
	15-30	presenting etudes	(solo-appearance)
	30-45		
	45-00		
18	00-15		
	15-30	bike-riding to HdK	(organisation & preparation)
	30-45	eating, unpack, warm-up	(body-care, organisation
	45-00		& preparation)
19	00-15		
	15-30		
	30-45		
	45-00		
20	00-15		
	15-30	Don Giovanni	(appearance with
	30-45		orchestra)
	45-00		
21	00-15		
	15-30		
	30-45		
	45-00		
22	00-15		
	15-30		
	30-45		
	45-00	pub	(leisure)
23	00-15		
	15-30		
	30-45	biking	(organisation & preparation)
	45-00	Bath, making the bed	(housekeeping, body-care)


Best Group
Middle Group
Teachers' Group
Ruoff (1981)
Kaminski et al. (1984)
Sosniak (1985)
Schindler et al. (1988)
Mean Hours of Practice per Week
0
4
8
12
16
20
24
28
32
36
40
4
6
8
10
12
14
16
18
20
22
24
Age in Years

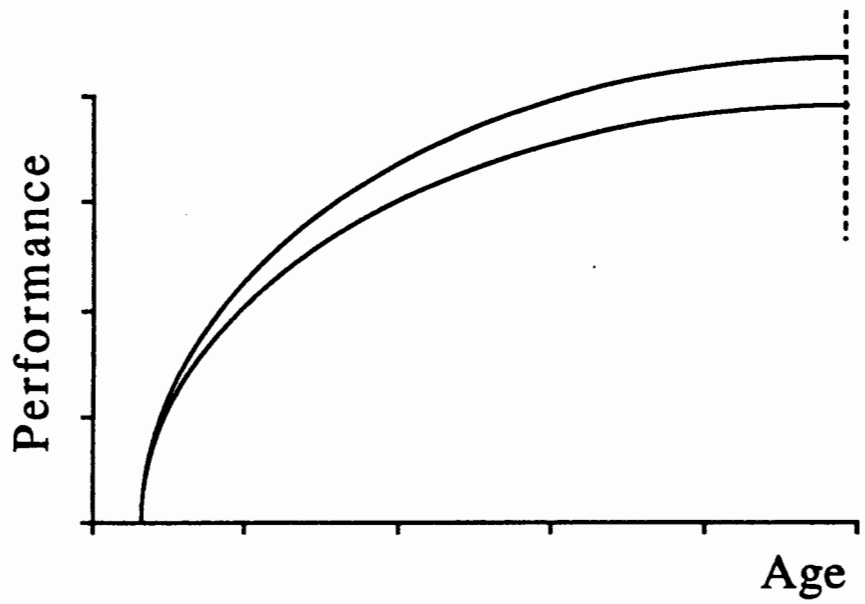

Accumulated Practice (Hrs)
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Chronological Age

Sports: Differences between athletes at different levels of performance

- Earlier ages for start of practice



- More weekly practice



Note: Similar amounts of daily practice for elite athletes and elite musicians

III Sketch of a Proposal for Diagnosis and Training of Expert Decision-Making in Pilots

Commercial flying vs. military combat

Expertise in commercial flying
- Readyness to respond to emergency situations
- Ability to avoid emergency situations

General design of tasks
- Relevant information about situation
- Perceptually available information

Presentation of information about emergency conditions
Timed generation of actions or plan for action
- Retrospective report
- Recall of all information about situation

Training of experts in other domains
- Chess & Bridge - Study of master games
- Medicine - Rounds, case conferences

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Sr. Human Factors Engineer
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ENHANCED ADM

TRAINING ALTERNATIVES

Conclusion:

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 when the situation requires such a response.

Paper based on research supported by the U. S. Department of Transportation Federal Aviation Administration (Contract Number DTFA01-90-C-00042, Report Number DPT/FAA/RD-92/12)

ENHANCED ADM TRAINING ALTERNATIVES

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The overview of this field of research has shown that the development of expertise relies heavily on training and requires considerable amounts of experience in a specific field. Furthermore, experts rely on a wide variety of different processing skills and unique problem solving capabilities. As summarized in Gordon (1990):

1. Experts have more detailed, better organized knowledge structures.
2. Experts perceive and organize problems on a more abstract level than novices.
3. Experts perceive problems in large meaningful patterns related to the context.
4. Experts are much faster than novices because of their use of procedural knowledge and forward inferencing techniques.

All of these characteristics are equally applicable in the expert pilot domain. At the same time, the past 15 years of aviation research in Aeronautical Decision Making (ADM) has developed training manuals which teach pilot judgment as a two step, linear process (Jensen and Benel, 1977):

• The ability to search for and establish the relevance of all available information about oneself, the aircraft, the environment, the flight situation; to specify alternative courses of action; and, to determine expected outcomes from each alternative.

• The motivation to choose and authoritatively execute a course of action which assures safety within the time frame permitted by the situation.

Although this ADM training program has been successful in decreasing the number of accidents and incidents in the inexperienced pilot group (less than five years), it has not been as successful with the more experienced, high time, expert pilot group (Albert 1989, Alkov 1991). That is, their accident rate (accidents per 100,000 flight hours) has not been affected. At least one reason for the apparent shortcomings of ADM training is that it teaches a linear, algorithmic process of controlled decision making that is not generally the way people make decisions, especially experts, and especially not in emergency or stressful situations.

In fact, a review of aviation examples (Adams & Ericsson, 1992) where expert pilots "saved the day" either in whole or in part, documented that pilot's making decisions under stress exhibit five basic characteristics shown in Table 1.

Table 1 **CHARACTERISTICS OF EXPERT PILOTS**

• REVERSION TO BASIC AIRMANSHIP SKILLS
• INSTANTANEOUS RECALL OF TRAINING
• REASONED APPROACH IN EMERGENCIES
• POSITIVE IN APPROACH & EXPECTATIONS
• SELF-ASSURED AND OPTIMISTIC

The following discussion explores the development of these expert pilot characteristics and attempts to relate that development to conventional training, experience, cognitive processing development and the new directions or innovations required for further improvements in decision making training.

Stages in Development of Pilot Cognitive Processes

For the purposes of the following discussion, it is important to note that human cognition is task dependent and purposeful (goal oriented). That is, humans use their knowledge, cognitive processing skills and the cues or stimuli of a situation or task to develop problem solving approaches. To accomplish this, two types of knowledge are used. These are declarative knowledge and procedural knowledge. Declarative knowledge consists of knowledge that can be verbalized, some call this knowledge about "facts and things". Procedural knowledge is knowledge about actions or how to perform various cognitive activities. These very often cannot be completely or adequately verbalized; for example, how to ride a bike could be broken down and described but the result would lose the essentials of the "how-to". However, procedural knowledge is the basis for development of specific steps (also called production rules) to be used in problem solving situations. As experience is gained, pilot's rely more and more on the use of procedural knowledge to solve problems. Furthermore they solve problems with increasing speed and accuracy using this type of knowledge as shown in Figure 1.

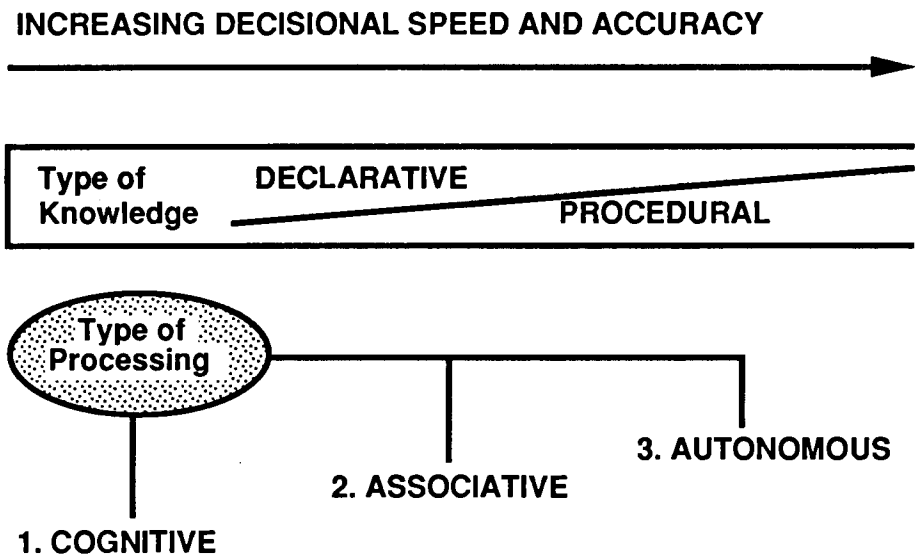

Figure 1 **EVOLUTION OF EXPERT KNOWLEDGE TYPES AND PROCESSING TYPES**

Cognitive psychology recognizes three stages in the development of expert problem solving skills (Anderson 1985) These are *cognitive, associative and autonomous* During the first, *cognitive* stage, pilots commit to memory a set of facts relevant to a desired skill. They typically rehearse these facts as they first perform the skill. For example, novice pilots learning stall recovery will memorize: recognize the stall, lower the nose, apply full power, level the wings and minimize altitude loss. In this stage, they are using their general aeronautics knowledge (domain-general) to guide their solution to loss of lift over one wing, and solve a domain specific problem, how to keep the aircraft flying. The problem solving capabilities and level of expertise in this stage are very basic. Novices spend a lot of time searching and moving around declarative knowledge.

The second, or *associative* stage, has two important characteristics. First, errors in the initial understanding and performance are detected and gradually eliminated. The novice pilot learns to coordinate the nose drop, power application and rudder application for a smooth stall recovery. Second, the connections between the various elements required for successful performance are strengthened. The pilot does not sit for a few seconds trying to decide which action to perform first after lowering the nose. Basically, the outcome of the *associative* stage is a learned procedure or production rule for performing a desired response to a known situation. In this stage, the declarative information is transformed and integrated into a procedural form. However, the procedural form does not necessarily replace the declarative knowledge. Rather the two forms coexist and are available when needed for the task. For example, the low time pilot can fly the airplane while simultaneously talking to ATC and navigating. All the while, he still remembers the rules of aerodynamics, the characteristics of a stall and the recovery process.

The third cognitive stage occurs when the problem solving procedures become faster and more automated. There is not necessarily any sharp distinction between the associative and *autonomous* stages of expertise. Rather, the *autonomous* stage evolves from the repeated application of known patterns and their associative use to achieve solutions. The use of declarative knowledge or "verbal mediation" often disappears during this stage of cognitive processing, at least for some tasks. In fact, the ability to verbalize knowledge of the procedure can be lost. Furthermore, expert cognitive process development appears to develop continually in a specific area or domain. Throughout the development, the skill gradually improves. **Ultimately, the skill can be extended to the ability to respond to cues not previously encountered and to develop new solutions or production rules applicable to novel situations.** The refinement of the expert pilot's cognitive processing and the characteristics associated with the three stages are illustrated in Figure 2.

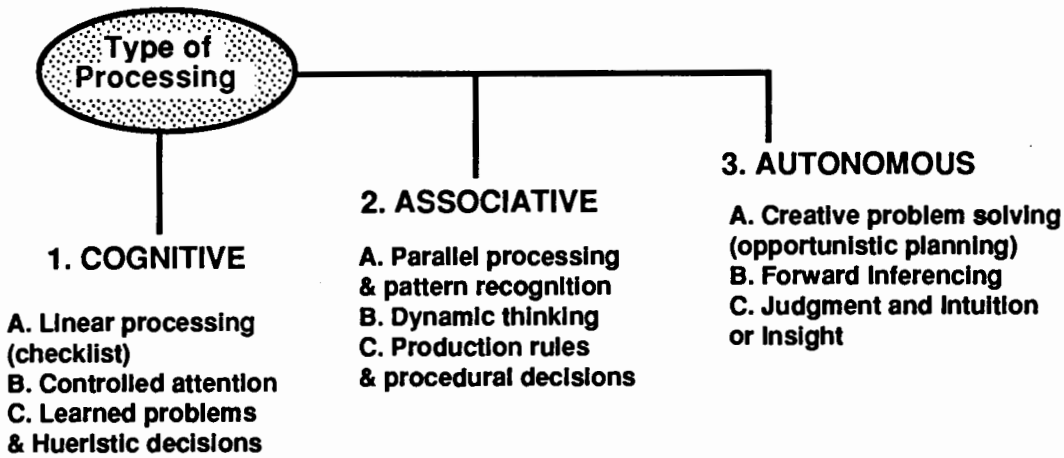

Figure 2 CHARACTERISTICS OF EXPERT COGNITIVE PROCESSES

Pilot Training and Information Processing

Conventional pilot training has been based upon this foundation: factual or declarative knowledge; flying procedures development; and, basic pilot skills or abilities as shown in Figure 3. The novice pilot, therefore, is expected to learn: aerodynamics, airplane performance capabilities and limitations, 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 a 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, judgment or 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. This provides the basis for the development of more sophisticated judgment as experience is gained.

In aviation, training is highly procedure oriented both in developing flying skills (psychomotor) and in decision making skills (cognitive and informational) for normal and emergency operation of the aircraft. These procedures and skills provide the foundation for the development of more sophisticated production rules (procedural knowledge) as experience is gained.

The newly qualified or low time aviator (100-1000 hours) develops his flying and decision making skills through 1 to 5 years of experience. This experience allows him to expand his procedural knowledge base using encounters with real-world problems and operational constraints. At the same time, his decision making ability and cognitive processing is strengthened by repeated use of trained patterns and expanded associative networks of experience patterns. The low time pilot is at the second stage of cognitive process development; he has begun to develop the speed and quality of processing of the Routine Expert.

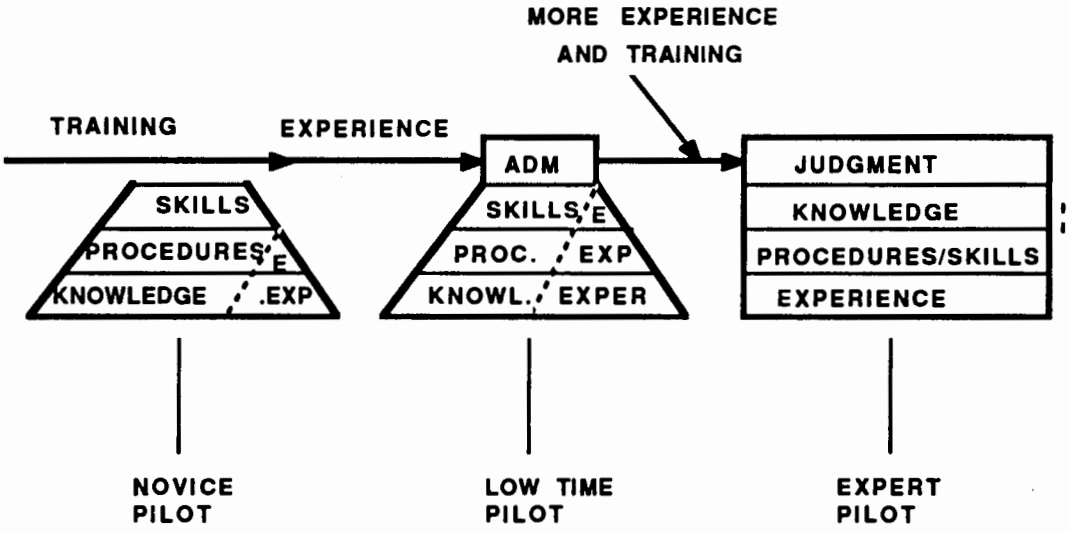

Figure 3 CONVENTIONAL PILOT JUDGMENT DEVELOPMENT

Finally, the Expert Pilot (1000-10,000+ hours) mainly relies on automatic cognitive processing abilities. Just as in the other domains of sports, games, music, and medicine, the Expert Pilot has achieved a tremendous base of procedural knowledge and skills applicable to normal day-to-day flying problems, trained emergencies (such as an engine failure) and novel or untrainable emergencies. He uses this procedural knowledge base for a very high percentage of his problem solving and decision making just as the Routine Expert in other domains. In addition, he has the similar routine ability to retrieve and integrate information from his declarative knowledge base, if the situation requires that action.

The review of the case studies of expert pilot performance presented in Adams & Ericsson, 1992 as well as NASA aviation research (Chappell 1991, Degani 1991) indicate that experienced pilots exhibit the "typical" characteristics of expert cognitive processes. Figure 4 illustrates the relationships between levels of pilot experience, types of knowledge used for problem solving and the three stages of development of cognitive processing ability.

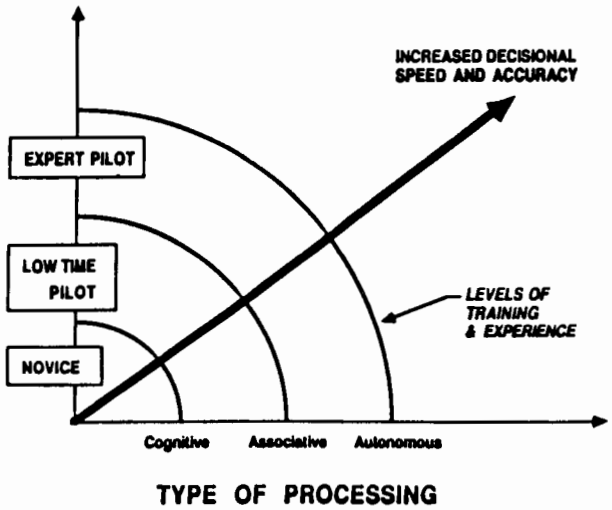

Figure 4 EXPERT PILOT JUDGMENT DEVELOPMENT

As shown in the figure, one main characteristic of the development of expert cognitive processes is the continual **increase in decisional speed and accuracy** as experience is gained in a specific area, e.g., aviation. In fact, these two characteristics are precisely the areas of decision making and problem solving most affected by experience and training or "practice".

The three types of cognitive processing in the development of the expert pilot correspond to an increased use of procedural knowledge gained from both experience and training. The expert's cognitive processing which relies on recognizing known patterns and solving problems with automatic use of production rules or procedural knowledge corresponds to the conventional development from novice, to low-time, to expert pilot from a flying skills and aviation procedures perspective. This is an extremely valuable finding since it facilitates the understanding of the developmental relationship of cognitive skills with the development of aeronautical or aviation skills. **In fact, it could be argued that pilot training has included "expert" cognitive process training all along simply as a result of the strong emphasis on aviator procedures.**

To summarize: the novice or ab initio pilot responds (cognitively) to stimuli or external cues based upon a thorough understanding of a complex, declarative knowledge base. His decisions, whether normal or critical, are typically based on a linear problem solving approach (some type of checklist or "DECIDE" type of model). His capabilities are generally limited to the procedures he has learned and expedited by the use of rules-of-thumb (or heuristics). This type of cognitive judgment is somewhat restrictive, but usually successful, in its application to familiar tasks or problems. The novice is aware of the situational demands and reacts or responds to them, but with limited cognitive and analytical resources.

The low time pilot or (associative problem solver) has the capability for an enhanced decision making. As a result of his experience, additional flight training and possibly a knowledge of ADM principles, the pilot develops a capacity for more dynamic cognitive processing. At the associative level, he stores information in terms of schemata which are modifiable information structures based upon experience. The associative pilot uses pattern recognition and dynamic interrelationships among objects, situations and events to integrate and interpret related knowledge instead of the static, linear thinking of the novice. This level of cognitive processing is characterized by the early development of the capabilities of a routine expert in that certain large patterns are spontaneously recognized rather than requiring a conscious search of declarative knowledge and a checklist review of alternative solutions. The associative thinker is in the process of evolving into an expert in the general sense of his procedural knowledge and use of production rules, and, as stated earlier, it is difficult to draw a specific line of demarcation between associative and automatic problem solving.

The Expert Pilot

The Expert Pilot is **"adaptive"**. In addition to having all the traits gained through experience and training, he can alter his procedures in real time (modify, delete or expand). He can create new rules and patterns based upon unique, previously unencountered problem characteristics. This capability to creatively respond to unique problems or novel task demands identifies the highest level of expert pilot cognitive processes. In fact, the expert pilot's ability to adapt to task demands, set goals and retrieve solutions from memory occurs so rapidly it appears to be intuitive problem solving in many instances.

This "adaptive" capability is referred to as "KNOWING WHEN" (Dreyfus and Dreyfus 1986). That is, **the Adaptive Expert Pilot perceives the necessity to alter ingrained procedures based upon the parameters and dynamics (or cues and context) of the problem or situation encountered.** It is believed that this "KNOWING WHEN" (an almost direct perception of the proper course of action) may provide the key to the next generation of ADM training. This would require a training environment or "situation" that provided the necessary cues and context to trigger the expert's adaptive processing mechanism. Replicating the inflight kinesthetic cues using a simulator and the pilot workload cues using typical emergencies or Line Oriented Flight Training (LOFT) scenarios may not be sufficient to trigger the associative mental "hooks" or adaptive cognitive process.

Since experts store information as schemas or organized sets of facts, relationships and perceptions, these same schemas are a "major mechanism" (Anderson 1985) for problem solving either in the simulator or inflight. Therefore, the retrieval of information and problem solving procedures will improve the more closely the cues and context during training match the real "experience". The expert pilot's perception of the whole situation involves a sense of relations that include physical, cognitive and internal effects which are used to both store and retrieve

knowledge. This is what is meant by the term "synthetic global knowledge" (Bastic 1982) used by experts for "opportunistic planning".

The coordinated use of cues and context with stored schema is believed to be a "major mechanism" used by experts to infer unobserved or unknown elements of a problem in "knowledge-lean" or "untrainable" novel situations. Delving into how experts develop insight into causal relationships in current situations by applying their global knowledge requires further understanding of the role of experience in cognitive processing skills development.

The Importance of Experience

Up to this point, the transition from novice to expert pilot has been shown to depend upon: the type of knowledge or knowledge structure; the type of processing that is used to effect a decision; and, the fast, accurate retrieval capability of proper actions. Specifically, high levels of cognitive processing, or expertise, were characterized by the predominant use of procedural knowledge and an autonomous processing ability. In addition, the performance of highly competent pilots indicates the ability to rapidly access and efficiently utilize their experienced based knowledge with marked increase in processing speed and accuracy, or appropriateness. These characteristics were seen to be based on an organized, modifiable knowledge structure (schemata) derived from experience, whereas, novice pilots can adequately perform using methodical, heuristic thinking, their cognitive performance is limited by their inability to infer additional knowledge from the specific stimuli or cues of a particular situation.

In contrast to novices, experienced pilots can generate inferences in new situations based upon the cues and context of the specific task at hand. This forward inferencing capability is based upon: the content of their aviation knowledge structure; the procedural organization that experience has developed; and, the ability to go between the two and apply the proper solution for the current problem. The documented performance of highly competent pilots with extensive aviation knowledge bases in emergency "saves" provides a snapshot of the powerful problem solving abilities of human experts. These pilots have demonstrated the unique ability to utilize a large knowledge base in an efficient, automatic manner while simultaneously tailoring their decisions to the situational demands. The expert's cognitive processing can accomplish this with minimum reliance on time consuming search of declarative knowledge and heuristics compared to the less experienced pilot decision making techniques. Furthermore, the expert pilot can develop effective solutions in a "knowledge-lean" situation with ambiguous or contradicting information and in the presence of novel cues or task demands never before experienced. Therefore, a significant focus for understanding and training expertise will require additional understanding of how experience influences knowledge structures that are acquired over long periods of time, how experts normally use that structure and how that use can be altered to "adapt" to new problems.

As stated above, experienced pilots use more global pattern recognition, retrieval and inferences. These cognitive processes free-up working memory and improve the pilot's capability to plan ahead, efficiently monitor his time and attention resources, carryout the normal "housekeeping" tasks (i.e., aviate, navigate and communicate), and still leave time for emergency or unexpected decision making.

These expert traits are very similar to what is currently termed "situational awareness" and "cockpit resource management". Such characteristics and processes are strived for in all pilot training, but "experts" have the additional capabilities of self-regulation and editing or evaluating the results of decision making. These traits become generalized cognitive processes after pilots use them repeatedly.

Experienced pilots are highly procedural and goal oriented. As a pilot's information processing skills become more and more automatic rather than a controlled cognitive function, they tend to "experience" a situation and react to it rather than consciously analyzing and deciding. **Because they have experienced large meaningful patterns during daily flying situations, they are much better at relating events in cause-and-effect sequences to achieve their goals.** In other words, experienced pilot cognitive processes are like expert processes in other fields, at least in the extremely small amount of cognitive attention and conscious processing required. Finally, these processes are fast, as the example accidents illustrated, and can be very effective in creating opportunistic solutions to new problems. Relationships are perceived, decisions made and actions taken so rapidly, that they take on the character of intuition.

Experiencing large global patterns repeatedly throughout an aviation career enhances a pilot's cognitive processing by providing redundancy or reinforcement of past similar situations, providing more associative paths to speed-up recall in new situations, and by providing elaborations or additional retrieval paths which can be used for both recall and

inference. However, experience is more than developing and storing cognitive knowledge in context. As a pilot faces each flight situation, he adopts an attitude toward it based upon a multitude of external and internal "states". **This reaction or psychophysiological attitude includes kinesthetic, affective and cognitive components which comprise the "experience", form the basis of the experts "global synthetic knowledge" and provide the context and meaning of the situation to be used as a "mental hook" when needed for later decision making or problem solving.**

Experience can also interfere with the perception of a situation and provide negative reinforcement for later use of bad decision making. This is the case for some of the classic aviation accident cause/factors such as: "ducking under" Decision Height or Minimum Descent Altitude; fuel starvation/mismanagement; inadvertent IMC; etc. In many of the accidents attributable to these causes, the pilot or crew had repeatedly "gotten-away-with" bad decisions and consequently formed them into a bad behavior pattern. Past experience can also interfere with the perception of a situation through job or personal stress, anxiety, fixation, emotional blocking, etc. so that the synthetic knowledge which is stored will not be representative of the situation.

Therefore, past experience that is intended to be used for expert pilot cognitive processing development must insure perception of the essential psychophysiological elements of the problem so that this experience can be brought to bear in a manner appropriate to successful problem solving in new situations. In particular the importance of "conditioning" i.e., associating these global patterns of experience with specific responses appropriate to new situations has been shown by modern "Activity Based Learning" techniques. These techniques stress kinesthetic experiences with structural apparatus associating ideas with experiences that can later be recalled and used "intuitively" Once again, the appropriateness of the synthetic experience will be critical to the subjective associations between the elements of the situation and the schema/global pattern used to hold the solution in mind for later use.

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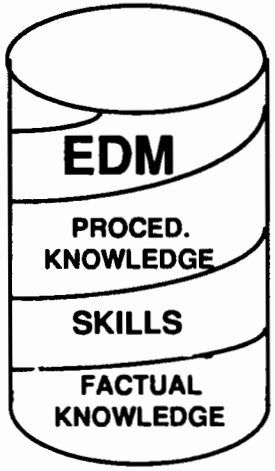


AAC

STAGES IN DEVELOPMENT OF EXPERTISE

1. COGNITIVE -- Accumulation of declarative knowledge.
   Perform tasks using domain general procedures.

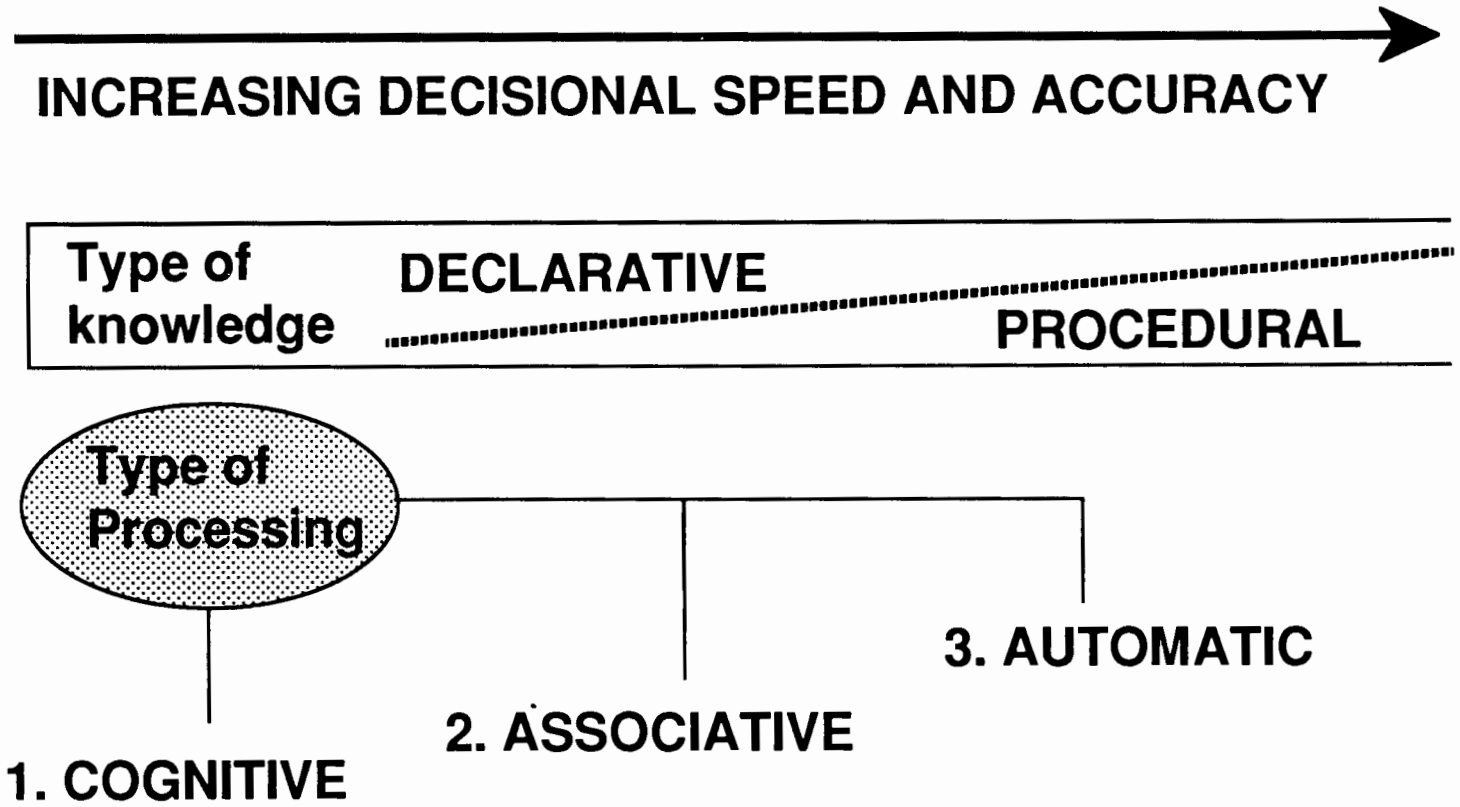
2. ASSOCIATIVE -- Form and store in memory domain specific procedures (also called production rules).

   -- Novices spend a lot of time moving around declarative knowledge.

3. AUTOMATIC -- Still relying on domain specific applications of procedural knowledge (IF __ , THEN __ .)

AAC

EVOLUTION OF EXPERT COGNITIVE PROCESSES



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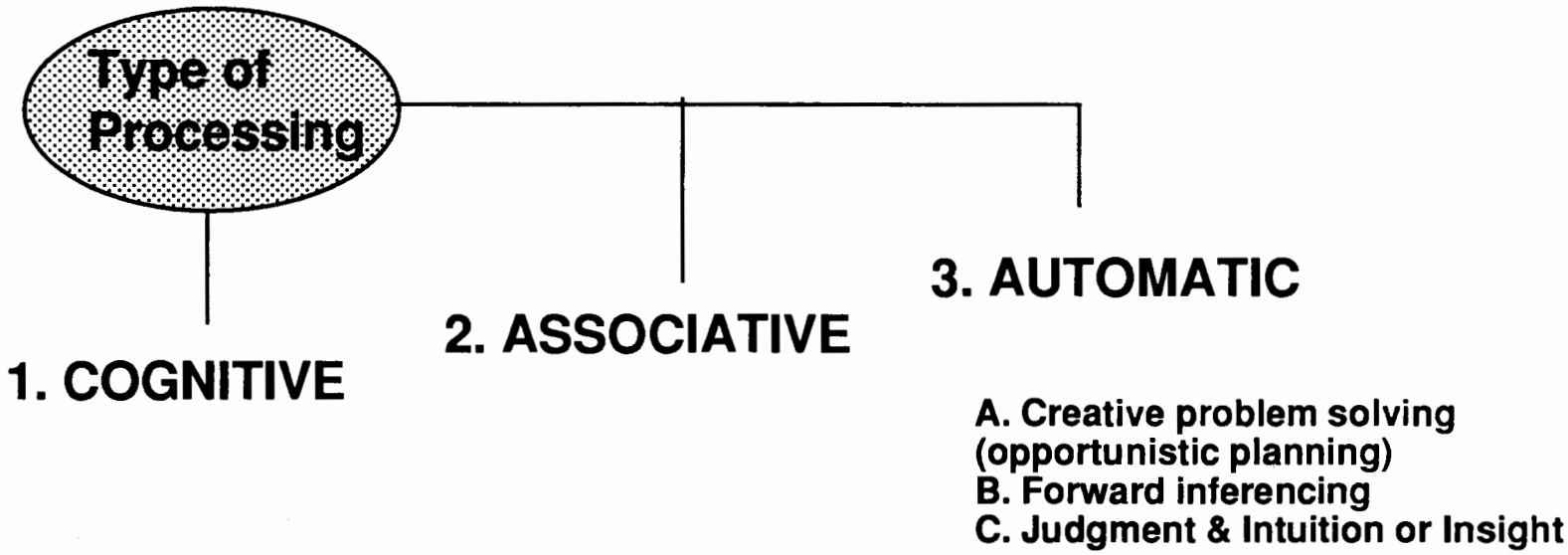
Type of Processing
1. COGNITIVE
2. ASSOCIATIVE
3. AUTOMATIC
A. Creative problem solving (opportunistic planning)
B. Forward inferencing
C. Judgment & Intuition or Insight
A. Parallel problem solving (pattern recognition)
B. Dynamic thinking
C. Production rules & procedural decisions
A. Serial problem solving (checklist)
B. Controlled attention
C. learned problems & hueristic decisions

AAC

IMPORTANCE OF EXPERIENCE

BASIC TRAITS OF EXPERTS :

1. **Schemata or modifiable information structure based on experience**

2. **Ability to perceive large, meaningful patterns**

3. **Fast access capability and the reduction of the role of memory search and general processing**

4. **Processing influenced by task demands and "opportunistic planning"**

5. **Routine and adaptive experts (increased decisional speed, accuracy and automaticity), but, the ability to creatively respond to novel cues identifies "knowing when"**

AAC

IMPORTANCE OF EXPERIENCE

THE ROLE OF EXPERIENCE :

- **Information processing based on context and training**
- **Capabilities based on knowledge content and structure**
- **Procedural, goal oriented organization and cognition**
- **effective in knowledge lean, ambiguous or contradicting situations**
- **Forward inferencing based upon novel cues or task demands**

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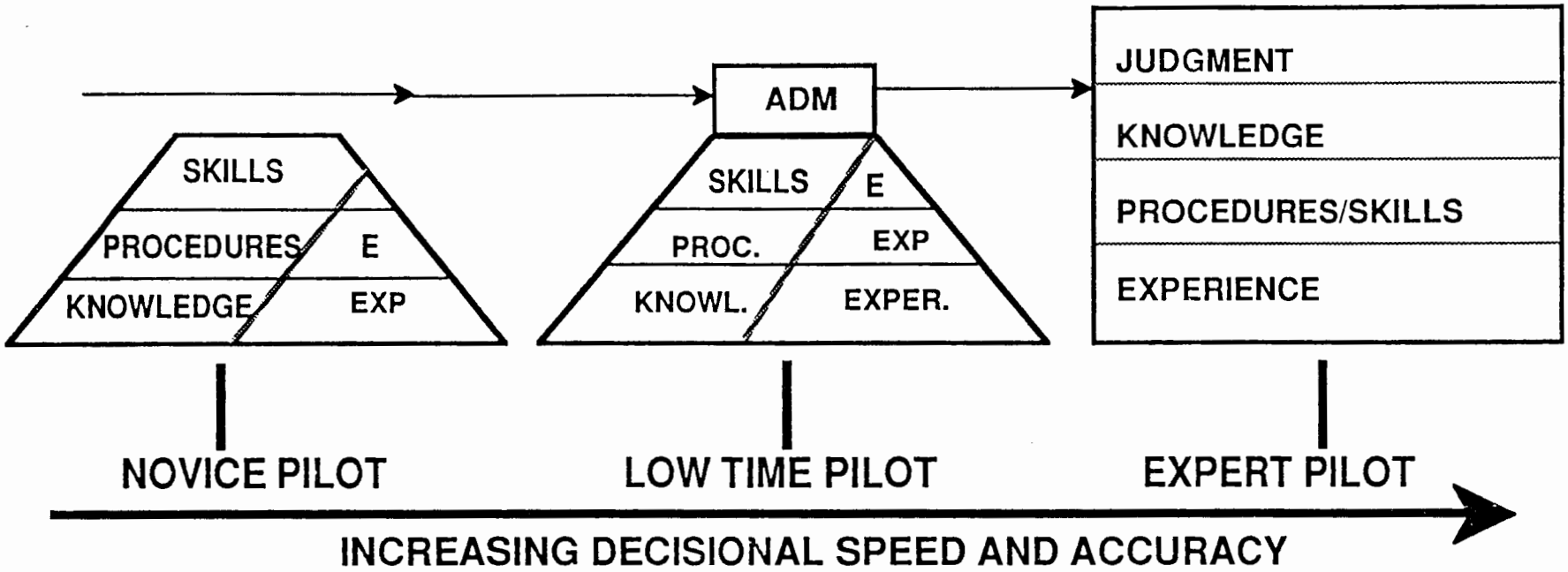
ENHANCED TRAINING TO REDUCE PILOT ERROR ACCIDENTS



KNOWING WHAT	KNOWING HOW	KNOWING WHEN
1) KNOWLEDGE BASE SEARCHING 2) DOMAIN GENERAL 3) TIME CONSUMING 4) ACCURATE	1) SCHEMA BASED PROCEDURES 2) DOMAIN SPECIFIC 3) FASTER 4) MOSTLY ACCURATE	1) CONTEXT DEPENDENT ACTION 2) EXPERIENCE BASED 3) INSTANTANEOUS 4) SELF-REGULATORY

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COGNITIVE TRAINING EXAMPLES

1. CENTER FOR STUDIES IN CREATIVITY, BUFFALO STATE COLLEGE & CENTER FOR CREATIVE LEADERSHIP, GREENSBORO, N.C.

   TYPE C -- CHAOS CHANGERS OR EXPERT PROBLEM SOLVERS

2. KREMLIN-BICETRE, PARIS -- BRAIN GYM

3. CENTER FOR DECISION RESEARCH, U. OF CHICAGO

   "THOUGHT TRIALS"

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ENHANCED TRAINING CONCEPTS

- NEW PARADIGMS FOR EXPERT DECISION MAKING
- CHAOTIC PROCESS MODELING AND NOVEL CUES
- APPLICATIONS OF ACTIVITY BASED LEARNING
- INTERACTIVE METHODS AND TOOLS

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EDM TRAINING OPTIONS

- MYERS ~ BRIGGS & HAZARDOUS ATTITUDES DERIVATIVE (SELF-ASSESSMENT TEST)
- CRM ~ ASSERTIVENESS MATRIX TYPE ANALYSIS
- CEPET ~ INTERACTIVE COMPUTER OR VIDEO TRAINING DEVICE
- VIGNETTES ~ SITUATIONAL AWARENES EXERCISES
- CRM OR LOS ~ COGNITIVE EFFECTIVENESS MARKERS

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EXPERTISE IN ACTION

What are the factors involved in the decisions that successful expert pilots execute?

"LUCK,
COMMUNICATIONS,
PREPARATION,
EXECUTION,
COOPERATION"

AAC

Captain Al Haynes, United Airlines

July 1989

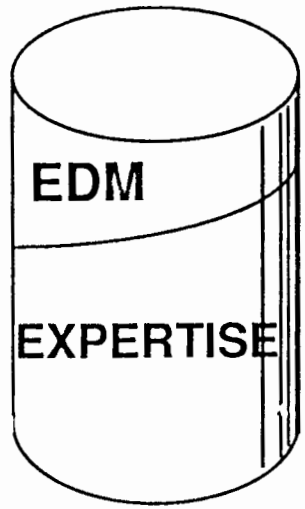
ADAPTABILITY & CREATIVITY

METACOGNITION

SCHEMATA

GOAL ORIENTED

SELF-REGULATORY



PROCEDURAL KNOWLEDGE

OPPORTUNISTIC PLANNING

FAST ACCESS

FORWARD INFERENCING

GLOBAL SYNTHETIC KNOWLEDGE

AAC

Dr. Gary A. Klein

Chief Scientist
Klein Associates, Inc.

A COGNITIVE MODEL FOR TRAINING DECISION MAKING IN AIRCREWS

Conclusion:

The Recognition Primed Decision model explains how people make decisions without having to compare options, not as an alternative to analytical decision making, but as one end of a continuum bounded by analytical decision strategies and recognition primed decisions.

A Cognitive Model for Training Decision Making in Aircrews

Gary Klein

Klein Associates Inc.
582 E. Dayton-Yellow Springs Rd.
Fairborn, OH 45324

Aeronautical Decision Making Workshop
Denver, CO

6 May 1992

KLEIN Associates Inc.

Prescriptions for Effective Decision Making (Janis & Mann, 1977)

Thoroughly canvas wide range of COAs

Survey full range of objectives

Carefully weigh costs, risks, and benefits of each COA

Intensively search for new information for evaluating COAs

Assimilate all new information

Re-examine positive and negative consequences of each COA

Carefully plan to include contingencies if various risks occur

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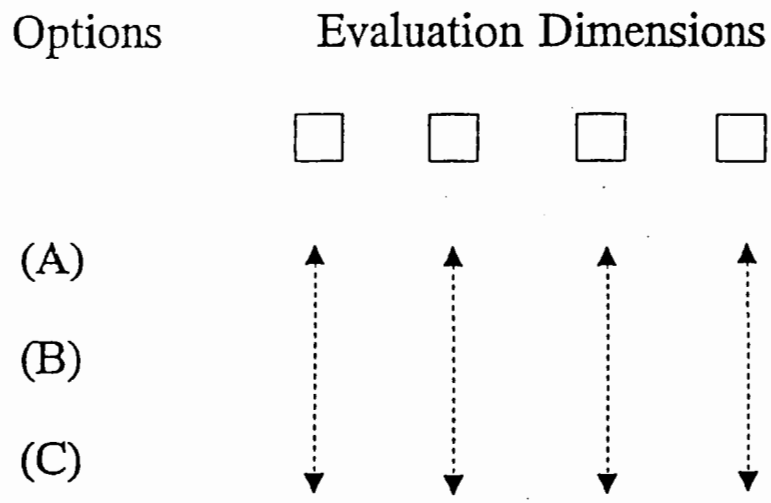
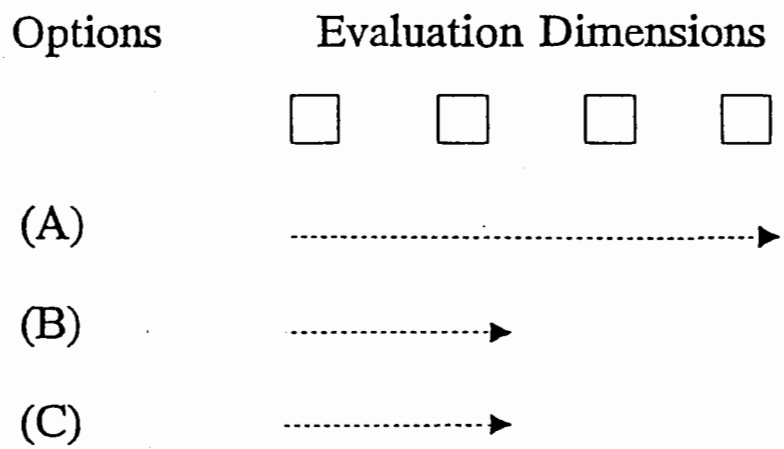
Serial vs. Concurrent Deliberation

Models of Option Evaluation

(A) Concurrent Evaluation - Vertical Model



(B) Serial Evaluation - Horizontal Model



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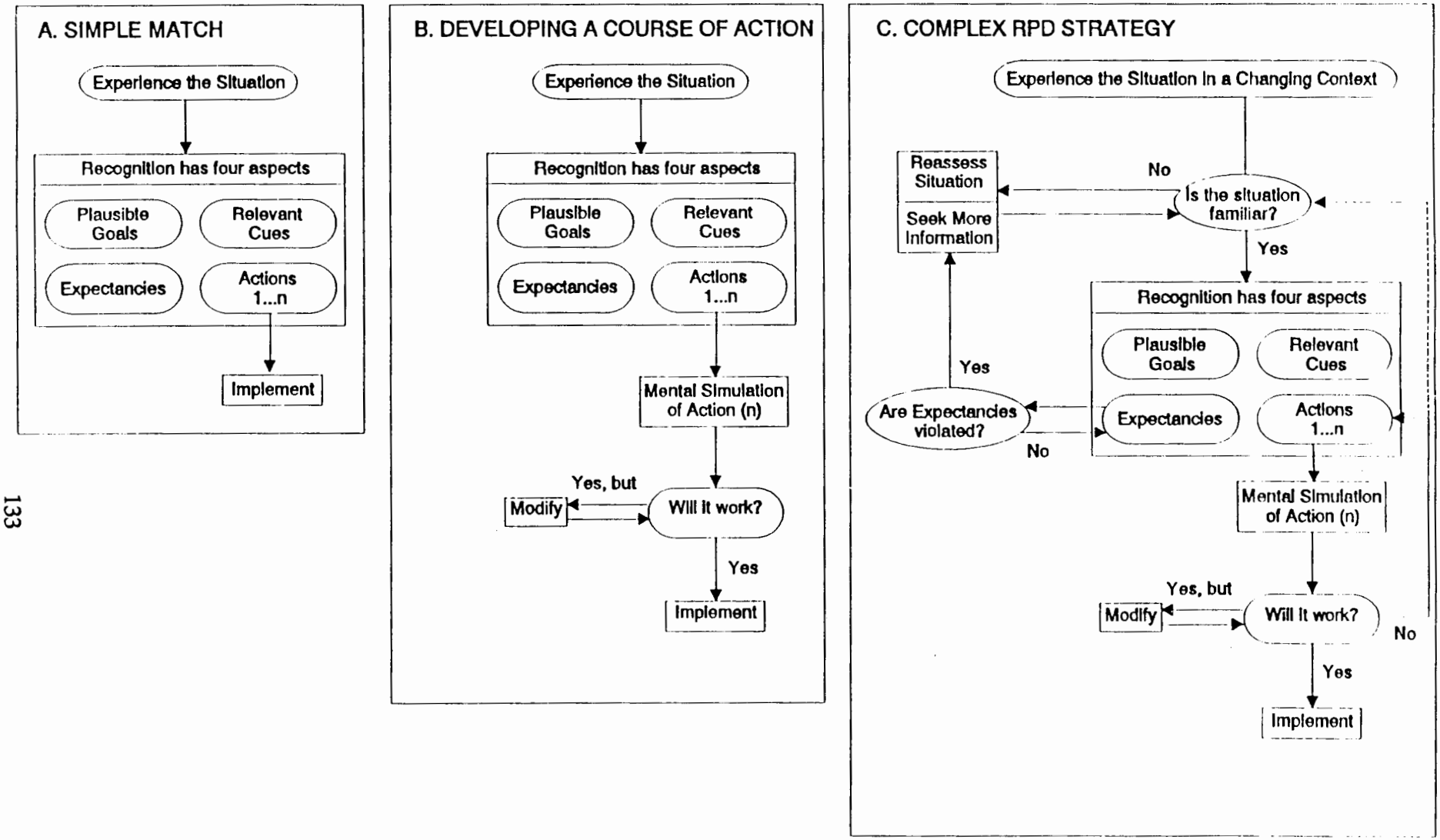

Recognition-Primed Decision Model

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Recognition-Primed Decision (RPD) Model

- Explains how people can make decisions without having to compare options
- Fuses two processes --
  situation assessment
  mental simulation
- Asserts that people use situation assessment to generate plausible COA and use mental simulation to evaluate COA

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Key Features of RPD Model

1. First option is usually workable
   Not random generation and selective retention
2. Serial generation/evaluation of options
   Not concurrent evaluation
3. Satisficing
   Not optimizing
4. Evaluation through mental simulation
   Not MAUA, Decision Analysis, or Bayesian statistics
5. Focus on elaborating and improving options
   Not choosing between options
6. Focus on situation assessment
   Not decision events
7. DM primed to act
   Not waiting to complete the analyses

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Factors Affecting the Use of Recognitional and Analytical Decisions

Factor	Probability of Recognitional Decisions
Time Pressure	Increased
Experience Level	Increased
Dynamic Conditions	Increased
Ill-Defined Goal	Increased
Abstract Data	Decreased
Justification	Decreased
Conflict Resolution	Decreased
Optimization	Decreased
Combinatorial Problem	Decreased

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Team Research and Observations

• Ft. Hood	Battalions
• Ft. Stewart	Battalions & Brigades
• Ft. Irwin	Battalions & Brigades
• Ft. Knox	Platoons
• National Defense University	Echelons above Corps
• Ft. Leavenworth	Divisions & Corps
• Central Training Academy	Emergency Operations Teams
• National Forest Service	Incident Command Teams
• U.S. Navy	Aegis Combat Information Center
• Hurlburt Field	Blue Flag
• Ft. Campbell	Helicopter Teams
• NASA/Ames	Airline Crews
• Industrial College of the Armed Forces	Echelons above Corps
• Air Force Institute of Technology	Management Teams

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Aspects of Teamwork

- Coordination
- Leadership
- Adaptation
- Assertiveness
- Communication
- Flexibility
- Decision Making
- Cooperation
- Morale
- Shared Mental Model
- Anticipation
- Conflict Management
- Stress Management
- Work Distribution
- Information Exchange
- Clarification
- Team Reinforcement
- Interactions
- Supportiveness
- Cohesiveness
- Power Distribution
- etc.

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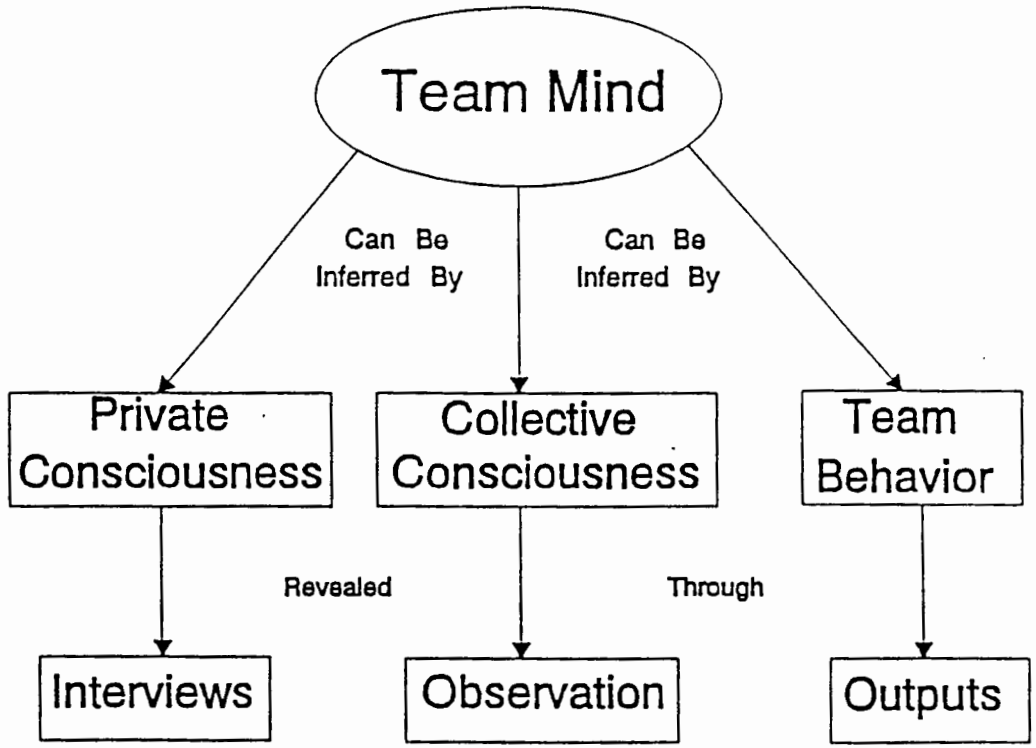

Understanding the team mind.

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Cognitive Process of Teams

- Selective attention
- Metacognition
- Memory (limited-capacity working memory; retrieval from long-term memory)
- Intentional behavior
- Mental simulation
- Reaction time

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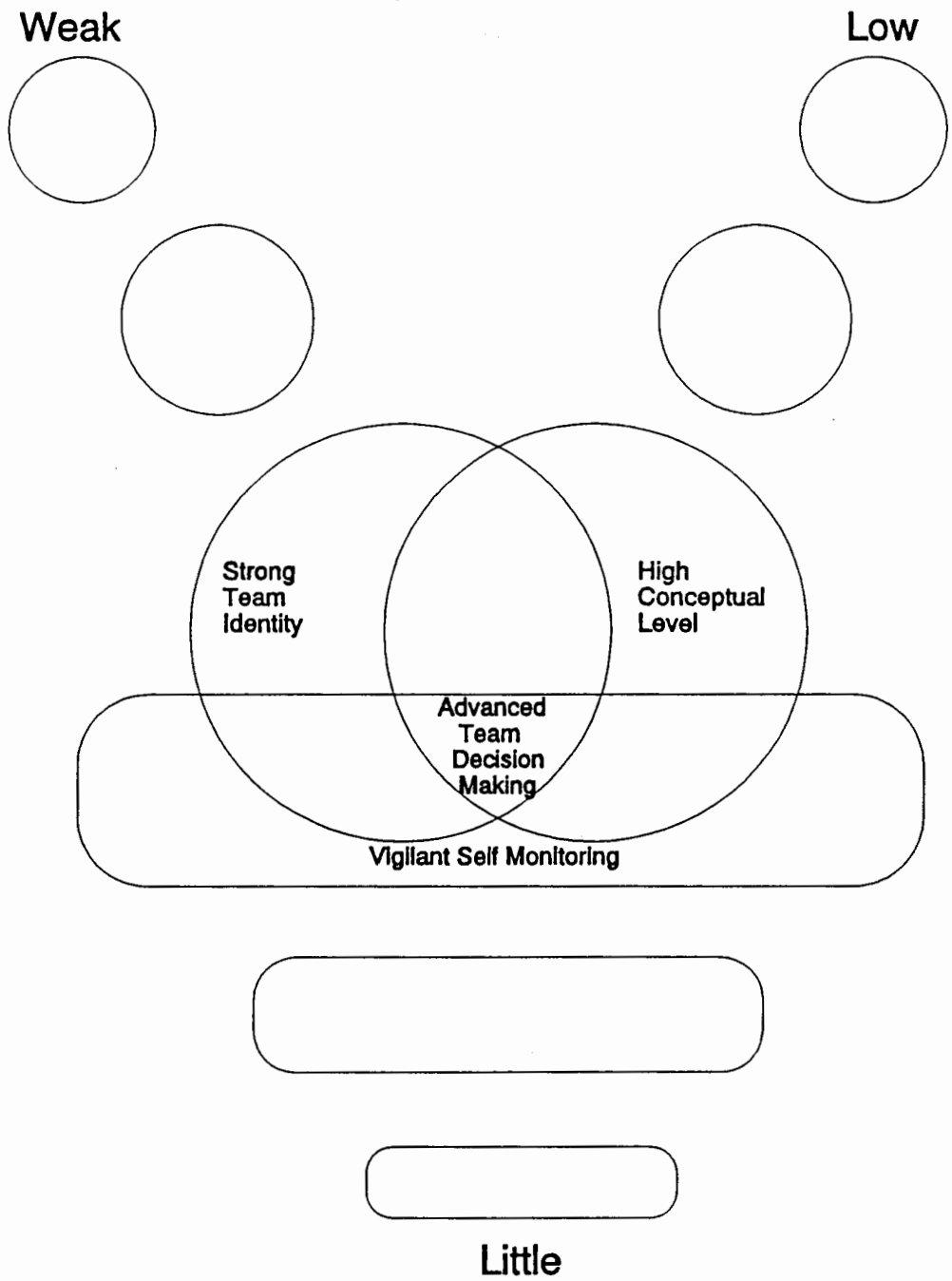
Advanced Team Decision Making:

A Developmental Model



6 May 1992

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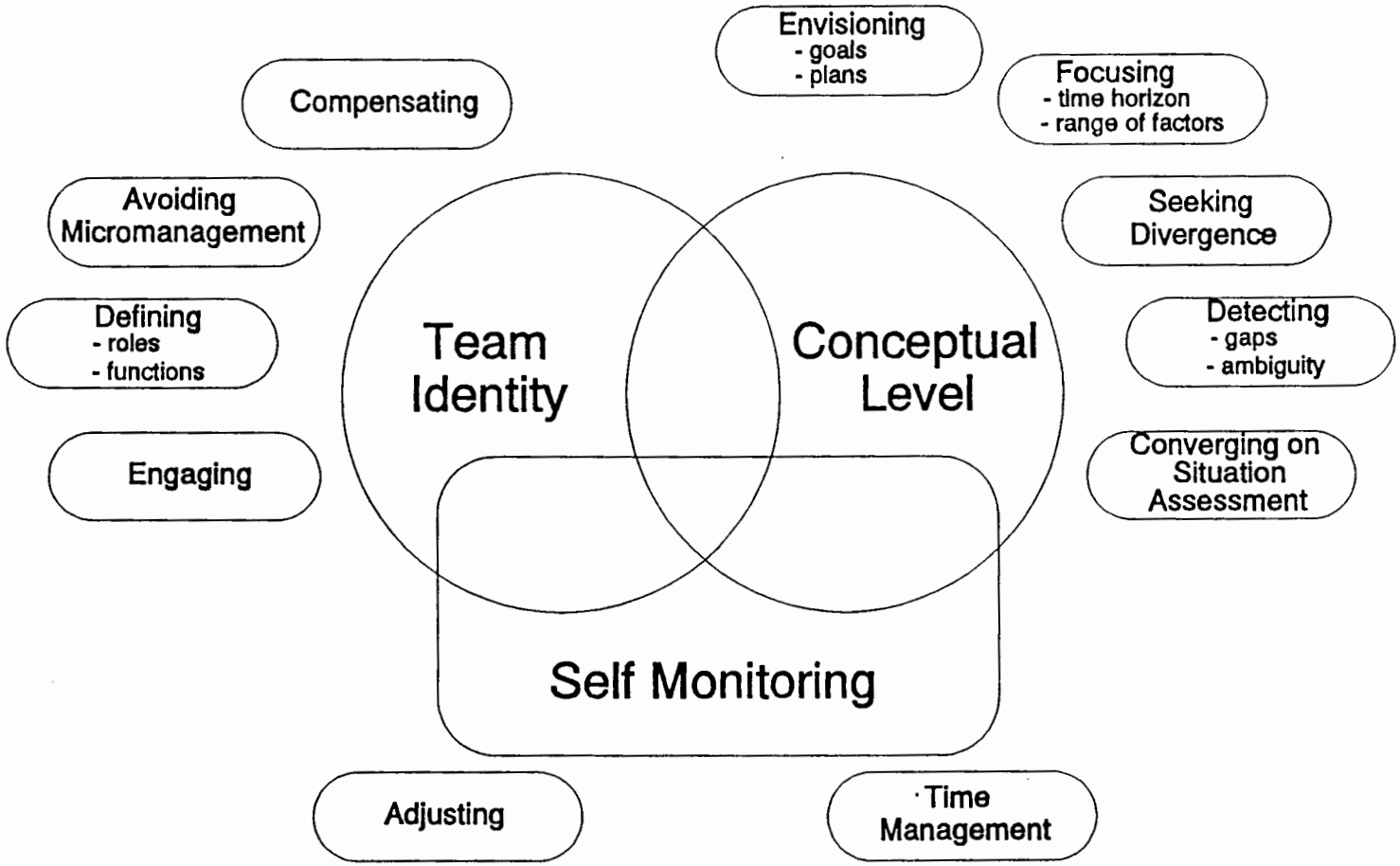
Key Features & Critical Processes of Decision Making Teams



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Myths about Team Decision Making

Exercises = Training

Instructors can → feedback

Team Decision Training is expensive

Team Decision Training must be streamlined

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Recommendations for Team Decision Training

Model-based approach
- Detect strengths
- Detect weaknesses
- Detect missing behaviors

Immediate feedback

Feedback around specific behaviors
- Generic feedback is less useful

On-line coaching

Incorporate Team Decision Training into exercises

Design exercises for Team Decision Training

KLEIN Associates Inc.

Dr. John R. Bloomfield

Research Psychologist
Honeywell, SRC

ELEMENTS OF A THEORY OF NATURAL DECISION MAKING

Conclusion:

The preliminary theory provides a framework that can incorporate a broad range of decisions and decision situations: ranging from the tightly-defined situations investigated by classical decision theorists all the way to complex real-world situations, involving proficient decision-makers, under a great deal of stress, and/or time pressure.

ELEMENTS OF A THEORY OF NATURAL DECISION MAKING

John R. Bloomfield

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Introduction

The preliminary decision theory presented here is in the process of being developed from the decision characterization framework presented to the Ergonomics Society in 1990 at the Leeds meeting (Bloomfield, 1990). It should perhaps be described as a theoretical framework.

There are many models and theories of decision making. Why do we need another one? Many theories are focussed narrowly on choice. Prescriptive theories, that deal with how choices should be made, suggest quite different mechanisms underlie choice than are suggested by descriptive theories, that are concerned with how choices are, in fact, made. And, the views of theorists who have conducted decision-making experiments in the laboratory often appear to be in conflict with the views of theorists who have observed decision makers in real-life stuations. However, when examined closely, it can be seen that these theories should not be directly compared: they deal with different types of decision, use different decision paradigms, and/or use decision makers of different skill levels.

The preliminary theory provides a framework that can incorporate a broad range of decisions and decision situations: ranging from the tightly-defined situations investigated by classical decision theorists, in which naive decision makers perform unfamiliar, highly-structured, context-limited, decision-making tasks, often without real-world constraints, all the way to complex real-world situations, involving proficient decision-makers, under a great deal of stress, and/or time pressure.

In the sections that follow, the elements of this theory are discussed. The theory takes a broad view of decision making, and includes some elements that are omitted in most other formal decision theories.

Types of Decision

Four types of decision can be isolated, mainly on the basis of their importance to the decision maker.

Consequential Decisions—The term "consequential decisions" was used by Janis and Mann (1977) to describe crucial decisions, that could have a great impact on the decision maker's life, such as decisions about whether to get married or divorced; whether to buy a new house or to have major surgery; whether to attack an approaching enemy aircraft; or whether to take off or abort when an aircraft faces adverse conditions.

Moderately Important Decisions—Moderately important decisions are out of the ordinary decisions about such things as whether to buy a compact disc player, or what to do on your next vacation.

Everyday Decisions—Examples of everyday decisions are: deciding what time to set the alarm clock for next morning, what to have for lunch, or whether to phone a colleague today.

Subordinate Decisions—A chain of subordinate decisions may be necessary: sometimes before a decision can be made (for example, in order to make a decision about what to do on vacation this year, you may have to decide when you can take time off from work, and how many days you can take, what you can afford to spend on a vacation, and whether or not you to take your children with you) and sometimes as a result of a decision being made (for example, after you make the decision to look for a new house, you may have to decide in which area of town should you search for a new house, what attributes the new house should have, and which estate agent you should employ to sell your current house).

The Decision Making Process

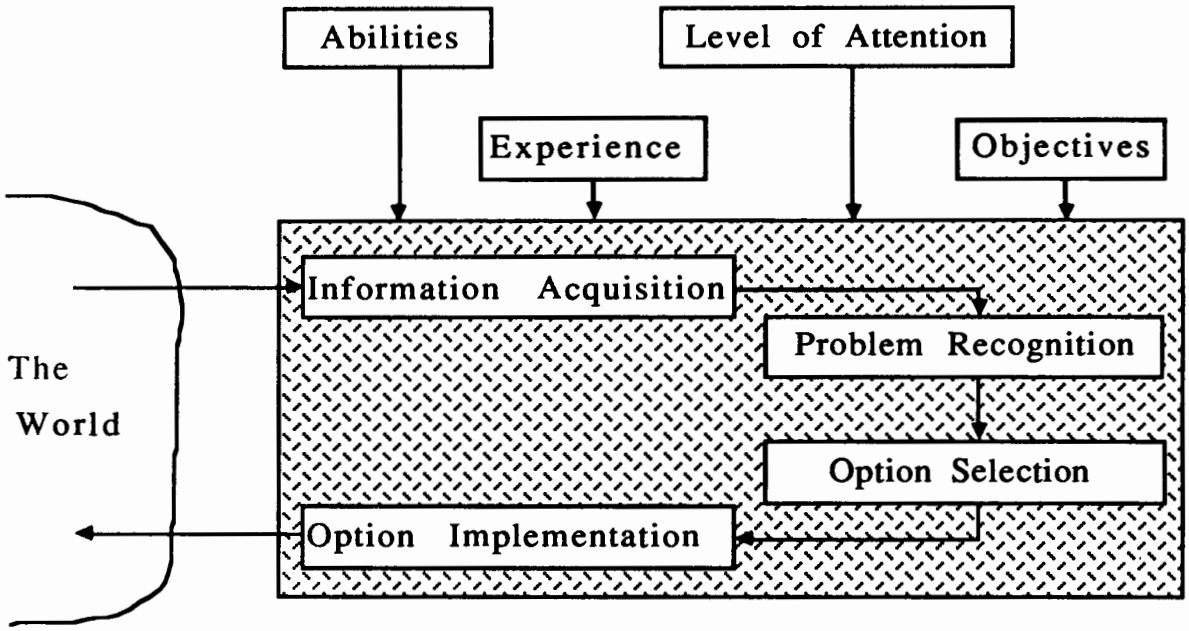

Figure 1: Model of the Decision Process

Wickens' (1991) model of the human infomation-processing system provided the basis for the preliminary model of the decision making process. An overview of the preliminary model is shown in Figure 1. As the figure shows, the process is influenced by the abilities, experience, level of attention, and objectives of the decision maker. The decision making process has four main elements or stages. In the first, information is acquired from the world. This information is passed on to the second stage, where the decision maker has to determine the nature of the problem. In the third stage, he/she selects a course of action. Then, in the fouth stage, this course of action is implemented.

The overview does not show the iterative loops in the model. These will be pointed out as we examine in more detail the various elements or stages of the model.

The Decision Maker

The decision maker's level of expertise will have a major effect on the decision making process. Each person's place on the continuum from novice to expert decision maker varies, to some extent, with the particular decision situation that he/she is facing: an expert in one situation, may be only a competent decision maker in a second situation, and a novice in a third. The decision maker's degree of expertise is a function of his/her ability and knowledge and experience. The quality of his/her decisions will also be affected by his/her level of attention and objectives.

Abilities—A number of abilities are of importance in carrying out decisions. They include the ability to acquire information, to process information, to interpret information, to assess decision situations, to select an approach to making a decision, to generate alternatives, to evaluate alternatives, to select among alternatives, and to implement alternatives. This list of abilities borrows some of the concepts suggested by Sternberg (1998) as knowledge-acquisition components, and metacomponents in his triarchical theory of intelligence.

Experience—Each individual's decision making experience will vary within a range. He/she may have previously encountered a specific decision situation, or situations similar to the current situation he/she faces, or decision situations in general, and he/she may have encountered them very frequently, quite often, sometimes, or very infrequently.

Attention—The extent to which a decision maker is able to attend to a particular decision, may affect the speed with which the decision making process is completed and/or the appropriateness of the outcome selected. When there are many competing sources of stimulation, and perhaps several decisions that simultaneously must be made, the allocation of sufficient attentional resources is difficult.

Objectives—The decision maker's objectives come from externally-imposed instructions and/or internally-derived desires; they may be explicit or implicit; and they may be clearly-defined, ambiguous, or even contradictory. Particular combinations of these qualities of the objectives may differentially affect the decision making process.

Information Acquisition

Figure 2 shows how incoming data is acquired from the world by the senses, then passes on to be processed. The decision maker then interprets the resultant information. After this, if the decision maker does not have a clear picture of the situation, more data processing may be required, or he/she may have to go back further in the chain to acquire more data. On the other hand, if a clear enough picture has emerged, the information developed in this stage moves on to the Problem Recognition stage.

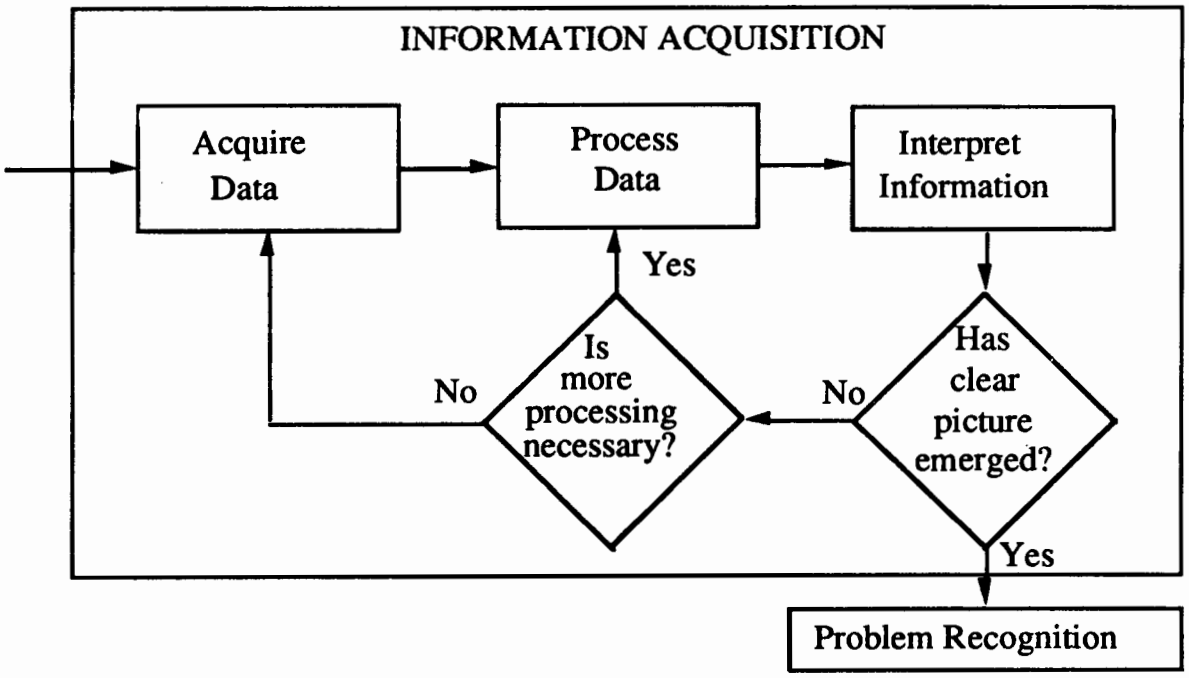

Figure 2: The Information Acquisition Stage

Problem Recognition

As Figure 3 shows, at the beginning of the Problem Recognition stage, the decision maker must determine whether a decision is required. There are three possible responses to this question. First, if a decision is not required, the incoming information still has to be processed and may require a response, but the way in which all this is achieved is outside the concerns of the decision model. Second, if the determination as to whether a decision is required cannot be made, because the available information is insufficient, the decision maker will need to return to the Information Acquisition stage. And third, if a decision is required, the next step for the decision maker is to assess the decision situation.

Bloomfield (1990) suggested that the decision maker assesses the situation in terms of a number of attributes. If the he/she is proficient, the assessment is likely to be carried out in a comprehensive, accurate, and efficient way. On the other hand, if he/she is a novice, it may be only partially carried out, and it may be done inadequately, and/or inefficiently.

The attribute suggested by Bloomfield are as follows:

Decision Type—Is the choice to be made one of selecting among alternatives, or one of selecting the time and/or the location in which to initiate an already-chosen course of action?

Familiarity—Is the a situation a familiar one, either because the decision maker has encountered it frequently before, or because he/she can match it to expectations derived from training, briefing or some other form of prior knowledge?

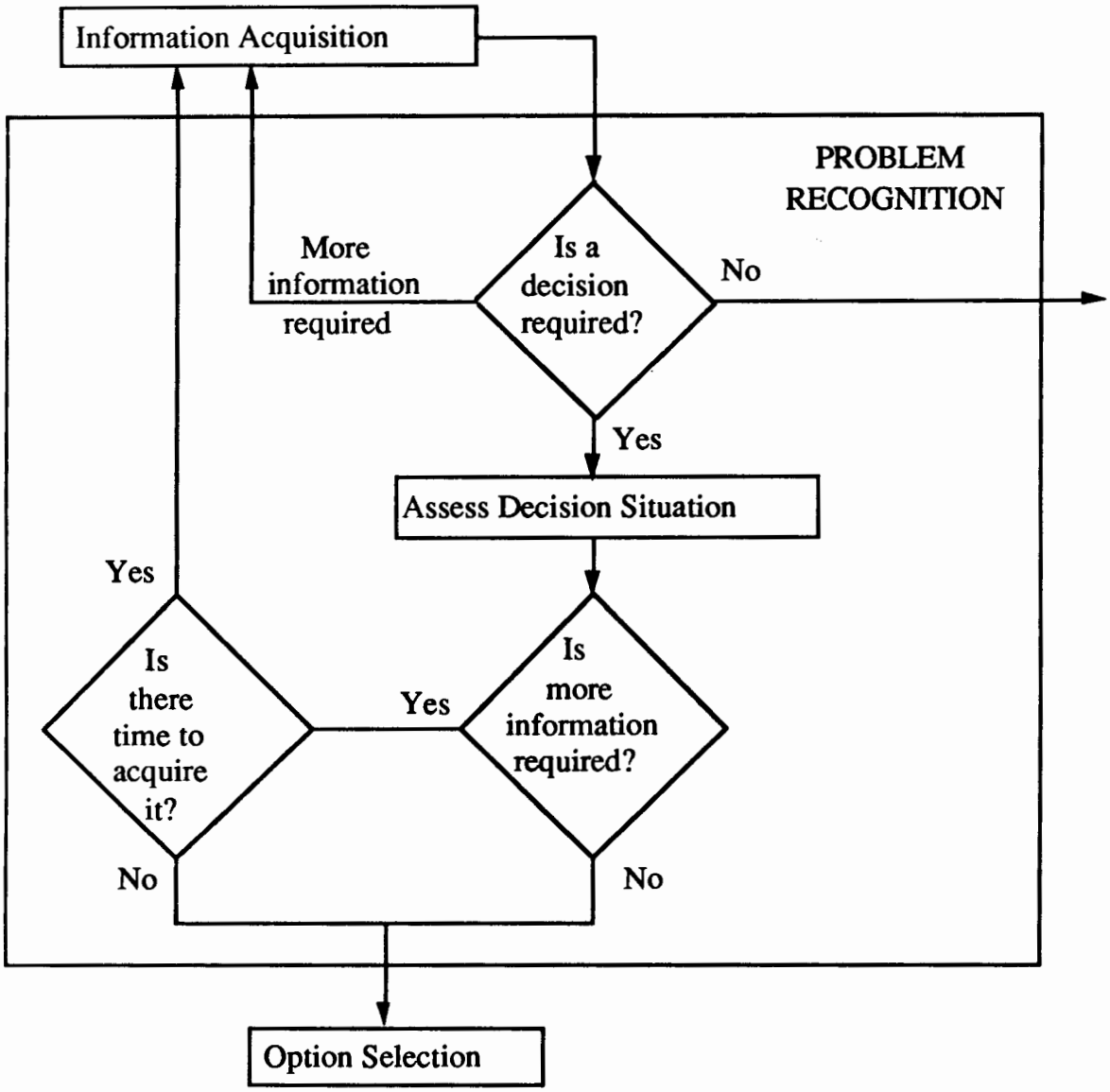

Figure 3: The Problem Recognition Stage

Static or Dynamic—Is the decision to be made in a situation which is static — so that the conditions do not change as a function of time — or in a situation which is changing dynamically?

Time-Relaxed or Time-Pressured—Is the decision to be made under time-relaxed or time-pressured conditions?

Degree of Ambiguity—Is the situation one that is well-defined, or is it ambiguous and difficult to interpret?

Information Rate—Is there a high or low rate of incoming information?

Interference—Is there interference from any source, or sources, of irrelevant stimulation?

After assessing the situation, the decision maker determines whether more information is required. If it is required, he/she must determine whether there time to acquire this information? If there is time, then he/she moves back to the Information Acquisition stage; on the other hand, if there is insufficient time, then he/she moves to the next stage, Option Selection. If the decision maker already has enough information he/she also moves on to the Option Selection stage.

Option Selection

As Figure 4 shows, the decision maker's first step in Option Selection is to determine whether any alternative courses of action are available. If the situation is very familiar, and the decision maker is proficient, the generation process may seem effortless as a number of possible options spring readily to the decision maker's mind, allowing him/her to move quickly to the Option Evaluation stage. However, if the situation is unfamiliar, and/or if the decision maker is a novice, it is less likely that there will be any readily-available options: instead, he/she may need to develop alternative courses of action. There are also other circumstances under which it may be necessary to develop new options: for example, even if the situation is familiar, there may be occasions when all the readily-available options prove to be unacceptable, so that the decision maker must generate new possibilities before moving on to the next step, which is to evaluate options.

The process by which the decision maker evaluates options is likely to vary with the circumstances surrounding each decision that is made. Many evaluation processes have been suggested. Several of them are included in Figure 4 and listed below:

Optimizing—The prescriptive, classical decision theory approach, stemming from the work of von Neumann and Morgenstern (1947) and Ward Edwards (1954, 1961), suggests that a decision maker should take account of the probabilities of all possible consequences of each alternative that could be selected, compare each alternative with all other alternatives on all dimensions, and then select the alternative that would produce the optimal outcome. In practice, i.e. outside of the laboratories of classical decision theorists, it is hard to find many situations in which decision makers actually use, or even attempt to use, an optimizing rule—two situations in which they may in fact use them are (1) when trying to select winners at the race track, and (2) in some instances in the domain of health care. There are several problems with using an optimizing approach successfully: unless he/she faces a simple well-defined situation, the decision maker does not have enough processing capacity to be able to compare all the options on all the dimensions; humans are poor at assessing probabilities; there may be insufficient time to use an optimizing technique and, as Miller and Starr (1967) pointed out, even when there is enough time, the optimal strategy may not be to use an optimizing rule—sometimes the "optimal" outcome it would produce would not be cost effective, because of the high cost of actually using such a rule in considering and comparing all the alternatives.

Suboptimizing—Because of these problems, Janis and Mann (1977) suggested that a decision maker who tries to use an optimizing rule may end up with a suboptimizing rule instead, where he/she maximizes some utilities that he/she expected to gain at the expense of losing other utilities. Whether the decision maker is satisfied or dissatisfied with the resultant outcome will depend on the relative importance of the lost utilities.

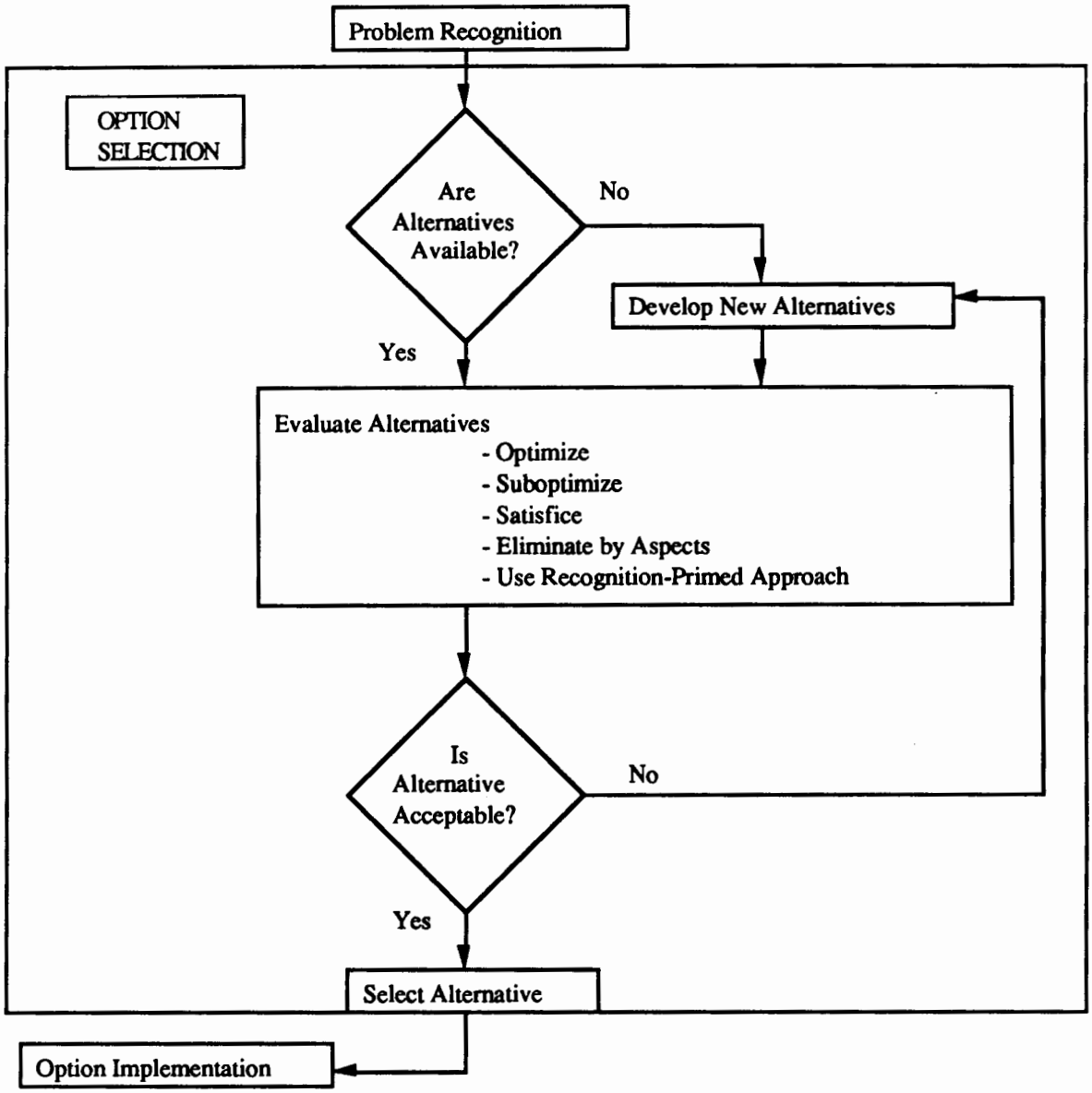

Figure 4: The Option Selection Stage

Saticficing—In many situations, Simon (1955) suggested that the decision maker does not try to optimize, but instead uses a satisficing strategy, in which he/she considers alternatives sequentially, selecting the first alternative that is good enough.

Elimination By Aspects—Tversky (1972) suggested another alternative to optimizing: with it, the decision maker essentially uses a sequential narrowing-down process, in which the possible alternatives are compared on one dimension at a time. The decision maker first determines which alternatives are able to satisfy his/her most important requirement, discarding those alternatives that do not meet it, then moves on to the next most important requirement.

For example, when buying a car, price might be the decision maker's most important consideration, and all cars that cost more than, say $15,000, would be eliminated. Having high gas mileage might be the next most important consideration, and those cars not meeting this requirement would be the next to be eliminated. This procedure would continue, with requirements that were progressively less important, until only one alternative remained.

Recognition-primed approach—Gary Klein (1989) used Simon's satisficing suggestion in developing a detailed account of proficient decision making. Klein suggested that, when considering the available alternatives sequentially, the proficient decision maker uses mental simulation to assess the likely outcome of employing each alternative. As soon as he/she finds an alternative that will lead to an acceptable outcome, he/she stops the assessment process and moves to the Option Implementation stage. Often, the decision maker only needs to assess one alternative—his/her expertise in the decision situation assessment step of the Problem Recognition stage enabling him/her to produce, an alternative that is acceptable immediately.

Evidence to supports Klein's recognition-primed model has been obtained in a number of studies in which information was gathered from expert decision makers, including fire ground commanders (Klein, Calderwood, and Clinton-Cirocco, 1986), tank platoon leaders (Brezovic, Klein, and Thordsen, 1987), combat pilots (Bloomfield, Peio, Lehman, Masters, and Boettcher, 1989), and business executives (Sherwood-Jones, 1989).

When a decision maker faces an unfamiliar situation, in which he/she does not know how to produce an acceptable outcome, he/she is likely to attempt to use a criterion of optimality, since selection of the optimal course of action should guarantee an acceptable outcome, unless, of course, no solution would have been acceptable.

Option Implementation

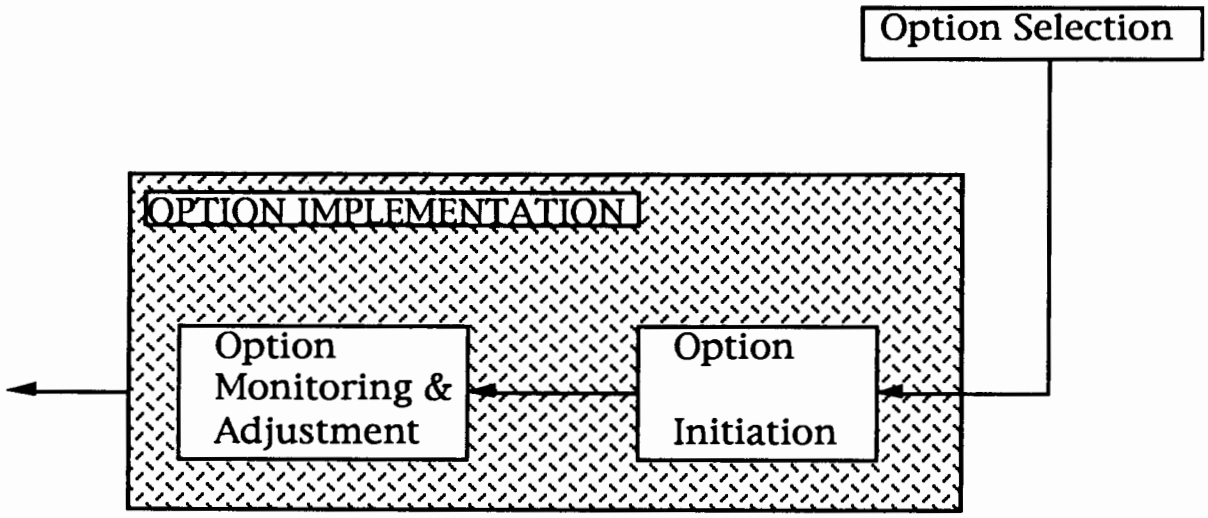

Figure 5. The Option Implementation Stage

Figure 5 shows the final decision making stage, Option Implementation. It always involves the first of the two steps shown in the figure, and often requires the second as well.

Option Initiation—Once it is selected, the decision maker must initiate an option, either manually or vocally.

Option Monitoring and Adjustment—In some cases, the decision maker needs to monitor the selected course of action, and to make appropriate adjustments to ensure that it is implemented properly: for example, after carrying out the decision to fire a weapon, an operator may need to monitor and adjust the flight path of the munition until it locks on to its target.

Connolly and Wagner (1988) suggest an alternative form of option monitoring and adjustment, with the decision maker making an incremental commitment and testing a choice by experiencing its effects in a limited and non-binding way: for example, by taking out a trial subscription for a journal.

A second incremental approach to decision making, identified by Lindblom and his co-workers (e.g. Braybrooke and Lindblom, 1963) makes use of monitoring and adjustment in a different way: that is, to gain acceptance of other people. In this case, the decision maker, implements the selected course of action by making a series of adjustments, that he/she hopes are each small enough to be acceptable to others. With this approach, which is sometimes used by politicians, the decision maker may implement a series of small adjustments that all go in a consistent direction, eventually producing a substantial change.

Future Directions

At present, the preliminary model outlined above deals with a range of diverse decision situations, from the highly-structured, unfamiliar laboratory decision task faced by a novice decision maker, to the dangerous and stressful situation faced by a proficient decision maker. It also includes timing decisions in dynamic situations, where the decision maker has already selected a course of action, but has to decide when the conditions are favorable for implementation, and it suggests how different mechanisms of selecting alternatives might be used in diverse decision situations.

The next step in developing this model is to determine whether four other theoretical formulations can be incorporated into it. The first of these is Montgomery's (1983,1989) idea that decision making involves the search for a dominance structure, with the decision maker moving backwards and forwards between possible alternatives and desired attributes—at the very least more feedback loops will be needed in the model, if this idea is to be incorporated. The second is Janis and Mann's (1977) conflict-theory decision making model, which suggests how differences in the circumstances might lead a decision maker to react to a threatening situation, sometimes successfully, sometimes not, in a variety of ways, including ignoring it, responding to it rapidly (and, maybe, inappropriately), attempting to avoid it, panicking, or evaluating it carefully. The third is Rasmussen's (1983) ruled-based, knowledge-based, skill-based trichotomous account of performance. And the fourth is Pennington and Hastie's (in press) account of explanation-based decision making.

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Elements of a Theory of Natural Decision Making

by

John Bloomfield

Honeywell Systems and Research Center

Minneapolis, Minnesota

Types of Decision

Consequential

Moderately Important

Everyday

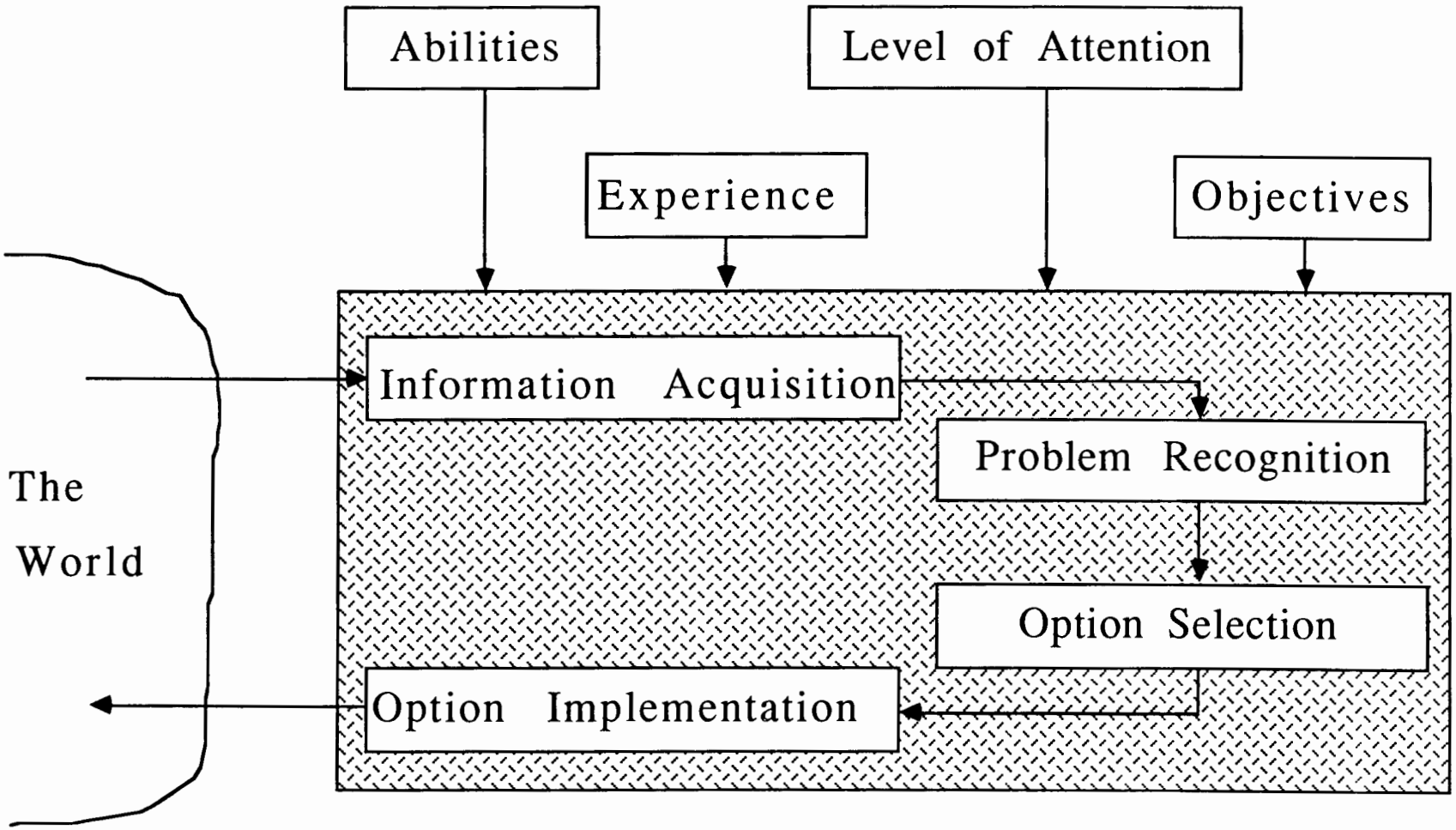
Subordinate

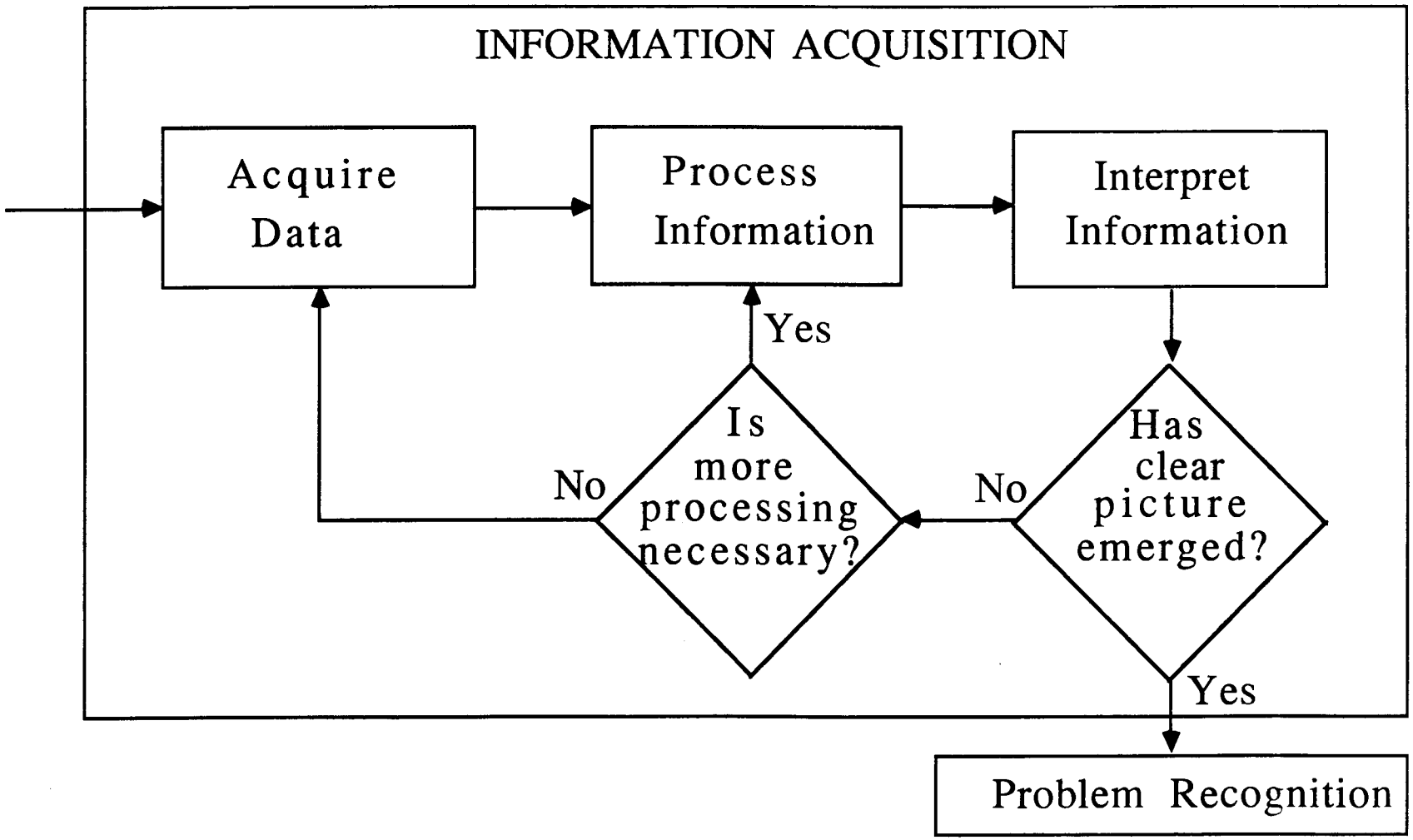
Decision Maker

Ability

Experience

Objectives


Abilities
Level of Attention
Experience
Objectives
The World
Information Acquisition
Problem Recognition
Option Selection
Option Implementation


INFORMATION ACQUISITION
Acquire Data
Process Information
Interpret Information
Yes
Is more processing necessary?
No
Has clear picture emerged?
No
Yes
Problem Recognition

Decision Situation Attributes

Decision Type - Selection &/or Timing

Familiarity

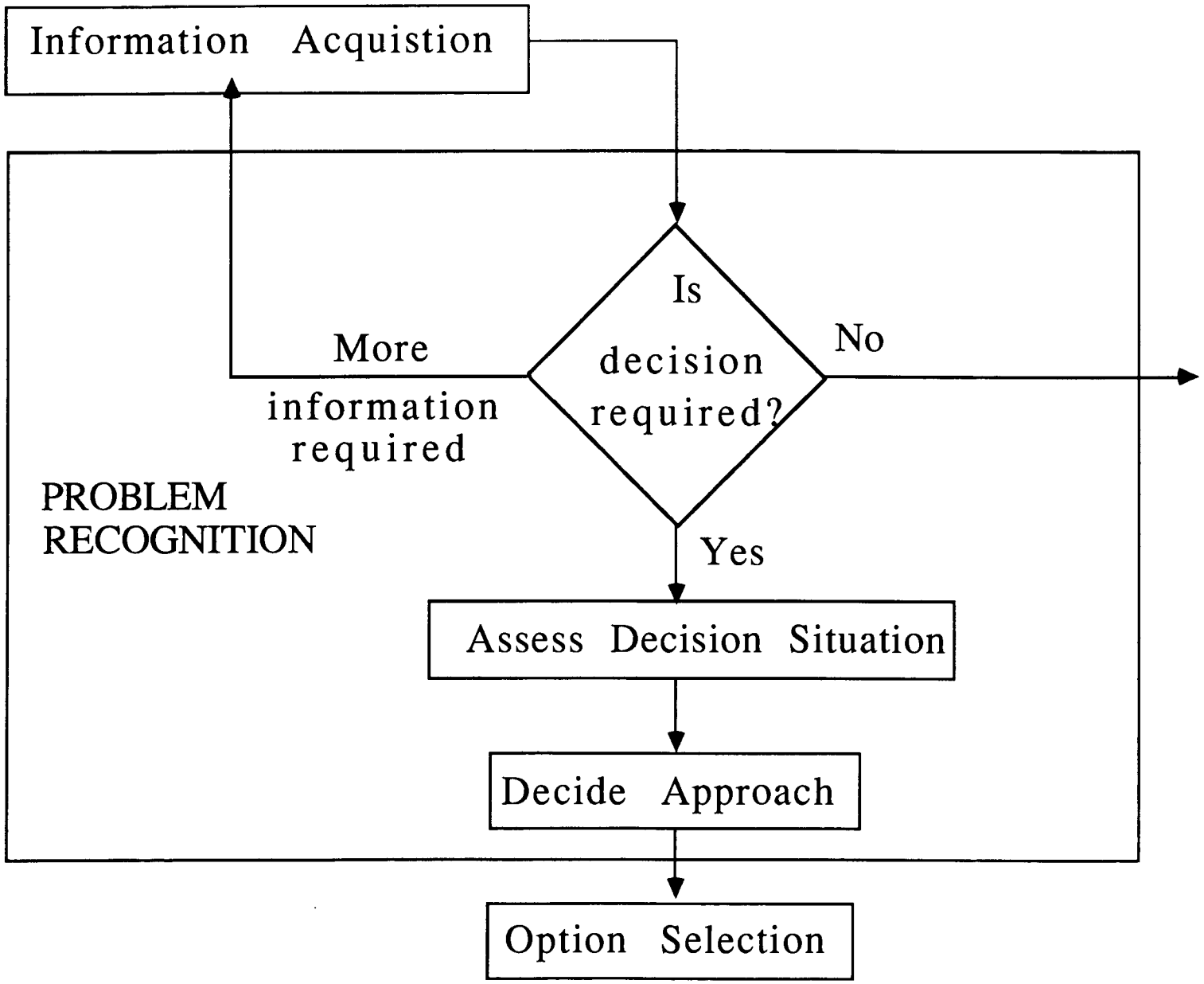
Static/Dynamic

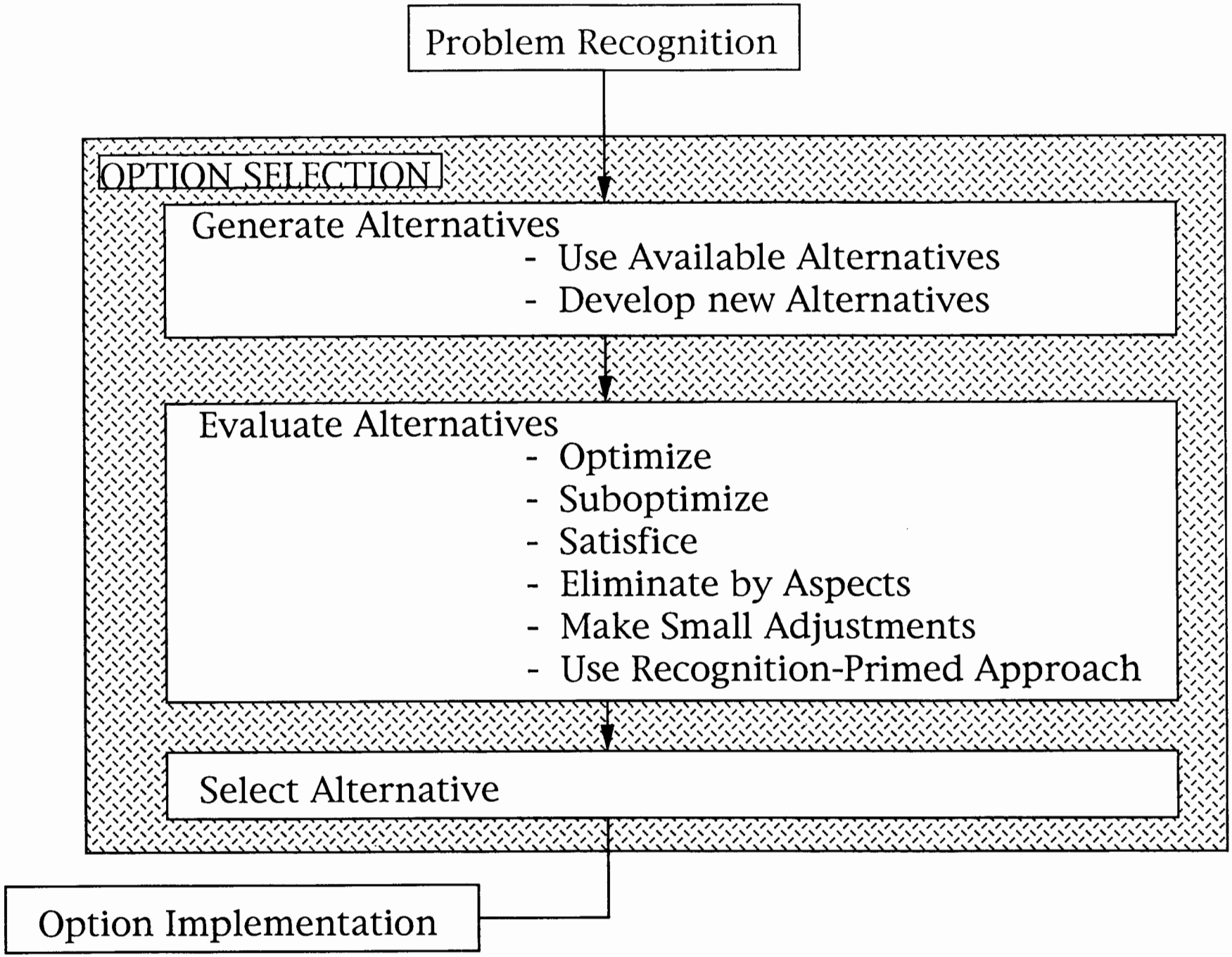
Time Relaxed - Time Pressured

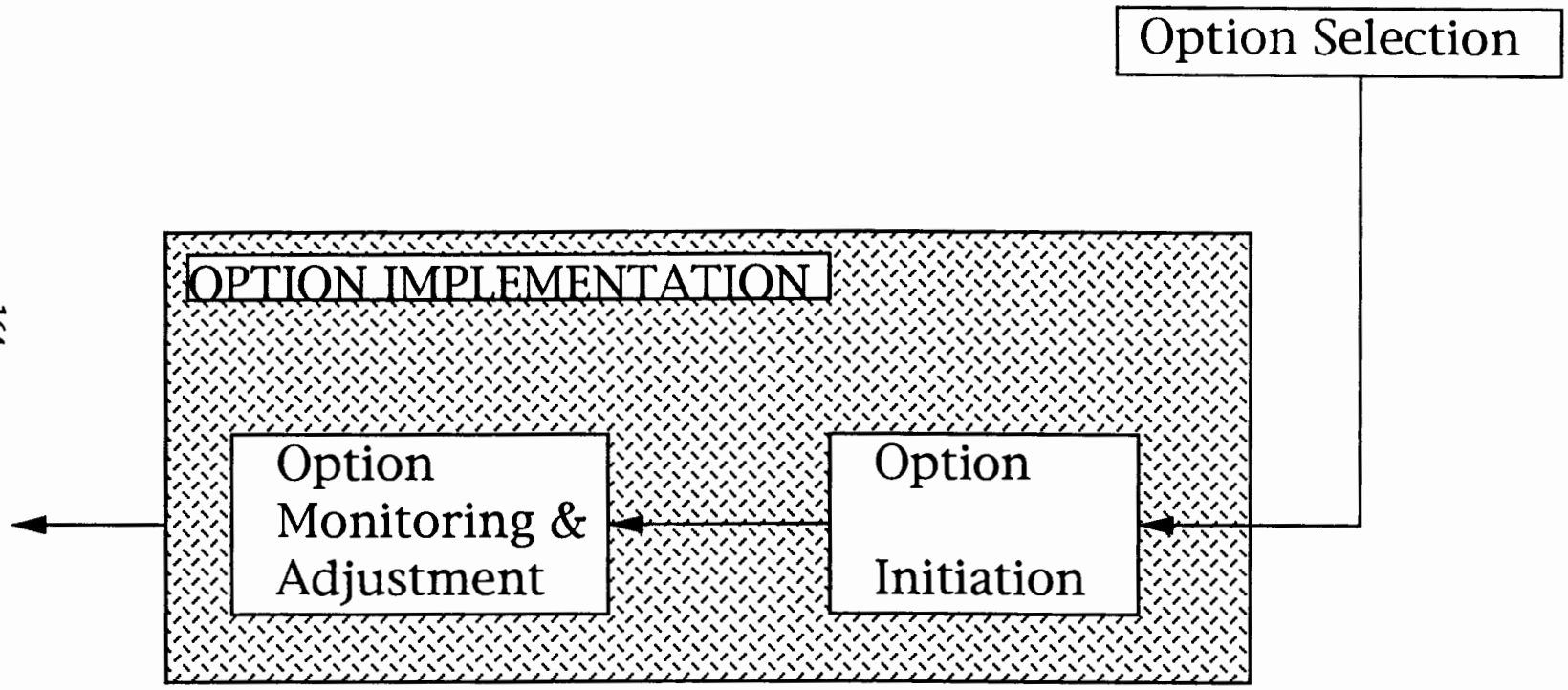
Degree of Ambiguity

Information Rate

Interference


Information Acquistion
Is decision required?
More information required
No
PROBLEM RECOGNITION
Yes
Assess Decision Situation
Decide Approach
Option Selection


Problem Recognition
OPTION SELECTION
Generate Alternatives
- Use Available Alternatives
- Develop new Alternatives
Evaluate Alternatives
- Optimize
- Suboptimize
- Satisfice
- Eliminate by Aspects
- Make Small Adjustments
- Use Recognition-Primed Approach
Select Alternative
Option Implementation


Option Selection
OPTION IMPLEMENTATION
Option Monitoring & Adjustment
Option Initiation

Dr. John R. Bloomfield

Research Psychologist
Honeywell, SRC

TAXONOMY OF FLIGHT VARIABLES

Conclusion:

The taxonomy developed for Controlled Flight Into Terrain accidents and incidents will also be of use in considering other air accidents and as a strawman taxonomy of flight operations in general.

TAXONOMY OF FLIGHT VARIABLES

John R. Bloomfield*, Lee Levitan*, Barry Cooper+,
Elizabeth A. Lyall+, and Eleana Edens•

Introduction

Under FAA Contract #DTFA01-91-C-00040, we are currently investigating Controlled Flight Into Terrain (CFIT) accidents and Controlled Flight Toward Terrain (CFTT) incidents, particularly those that occur when the flight crew believe that the autopilot, flight director, and/or flight management system is in use.

Our first step was to develop a taxonomy of flight variables. Currently, we are using this taxonomy to review CFIT accidents and CFTT incidents.

We believe the taxonomy will also be of use in considering other air accidents, and that it will be a useful strawman taxonomy of flight operations in general. The taxonomy has seven major categories. They are:

1. Flight Variables
2. Aircraft Equipment Variables
3. Visibility Variables
4. Pilot Variables
5. Air Traffic Control Variables
6. Airport Variables
7. Airline Procedures Variables

A detailed listing of the flight variables organized into these categories is provided below. We would welcome any comments on items that should be modified, or on any variables that have been omitted, or any suggestions of how the variables might be better organized.

---

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• Federal Aviation Administration, 800 Independence Ave. S.W., Washington, DC 20591

Taxonomy Of Flight Variables

1. Flight Variables—

- Length
  - -short haul (under 45 min)/
    medium haul (45 min to 3 hr)/
    long haul (over 3 hr)
- Schedule
  - -late/ontime departure
  - -early/ontime/late ETA
- Direction of flight
  - -east/west bound
- Local time of day
- Local time of year
- Other segments scheduled
  - -before/after
    segment in which CFIT/CFTT occurs

2. Aircraft Equipment Variables—

- Control display unit
  - -installed/not installed
  - -used/not used
  - -programmed correctly/incorrectly
- Map mode
  - -installed/not installed
  - -used/not used
- Landing lights
  - -on/off
- Localizer/glideslope
  - -connected/not connected
- Hard copy charts
  - -brand
  - -quality
  - -location in flightdeck
  - -current chart used/not used
  - -correct chart used/not used
  - -used by both/one/neither pilot
- Radar altimeter data
  - -available/not available
- Barometric altimeter type
- Weather radar
  - -in use/not in use
- Mode/automation level
  - -understood/not understood
- Electronic Flight Instrument System
  - -installed/not installed

- Flight director -used/not used
- Autopilot -used/not used
- Windscreen wipers -in use/not in use
- Approach mode -vertical speed/glideslope/other
  -engaged correctly/incorrectly
  -understood/not understood
- Navaid -which type
  -engaged/not engaged
  -programmed correctly/incorrectly
  -pilot knew/did not know which navaid was in use
- Autothrottle -installed/not installed
  -in use/not in use
- Ground Proximity Warning System
  -installed/not installed
  -active/inhibited
  -sounded warning/did not sound warning
  -warning heeded/warning not heeded
- Aircraft configuration at CFIT site
- Minimum Equipment List items
- Malfunctions while in flight

3. Visibility Variables—

- Visibility -at CFIT/CFTT site
  -reported at destination
- Sun -crew looking into/not looking into
- Time of day -day/dusk/night
- Meteorological conditions
  -enroute
  -at destination
  -at CFIT/CFTT site

4. Pilot Variables—
(These apply to both the pilot flying and the pilot not-flying)

- Age
- Experience -total flying hours
  -flying hours with particular aircraft

-experience with destination airport
-experience with precision approaches
-experience with nonprecision approaches
-experience with hilly/mountainous terrain
-experience with flat terrain

- Seat position
- Degree of fatigue -low/medium/high
- Amount of stress -low/medium/high
- Medical issues
- Crew member familiarity with each other
- Intercrew communications
  -poor/good
- Interpersonal issues between crew members
  -good/neutral/bad
- Distractions

5. Air Traffic Control Variables—

- Crew-expected and actual ATC instructions
  -matched/did not match
- Controller attention to involved aircraft
  -yes/no
- Vectoring -none/some/much
  -early/late
- Speed change requests to aircrew
  -no request/increase/hold /decrease speed
- Controller workload -low/medium/high
- Controller degree of fatigue
  -low/medium/high
- Interpersonal issues between ATC and flight crew
  -existed/did not exist
  -nature of issues
- Communication misunderstandings between ATC and flight crew
  -existed/did not exist
  -nature of misunderstanding

- Did ATC detect some problem with the involved aircraft?
  - -no
  - /yes, but not reported to crew
  - /yes, and was reported to crew
  - -content of report

- Minimum Safe Altitude Warning
  - -installed/not installed
  - -operating/not operating
  - -did/did not sound warning to ATC
  - -ATC did/did not issue warning to flight crew

- Altitude clearance instructions
  - -nature of instructions
  - -when issued

- Aircraft cleared for approach
  - -no/yes
  - -if yes at what point in flight
  - -type of approach

- Communications frequency
  - -congested/not congested
  - -blocked/not blocked

- Controller experience -low/medium/high

- ATC anomalies

6. Airport Variables—

- Physical features -runway length and width

- Lighting types
  - -runway lights
  - -approach lights
  - -approach slope indicator
    - /no approach slope indicator
  - -airport environment lights
  - -nearby lighting
  - -freeway, other

- Lighting
  - -visible/not visible to crew
  - -used/not used for vertical guidance

- Navigation aids
  - -type
  - -location
  - -quality
  - -Radio Magnetic Indicator indicating navaid
    - /RMI not indicating navaid
  - -pilot did/did not select correct navaid
  - -pilot confused/not confused about navaid
  - -navaid does/does not
    - give distance information

- Approach -visual/nonprecision/precision
- Terrain at and just preceding CFIT/CFTT site
  -hilly/mountainous/flat/water

7. Airline Procedures Variables—

To date, we have not developed this category. Airline procedures may play a role in some CFIT accidents and CFTT incidents. As we review the CFIT/CFTT literature, we will record any indications that these procedures did play a role.

Dr. Judith Orasanu

Flight Human Factors Branch
NASA-Ames Research Center

SHARED MENTAL MODELS AND CREW DECISION MAKING

Conclusion:

The model implies that effective crew decision making training would include different foci such as Situational Awareness, Planning, Communication, Resource Assessment and Prioritizing. This research also raises the research issues: What can be trained? and How?

SHARED MENTAL MODELS AND CREW DECISION MAKING

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FAA/AAC WORKSHOP ON
AERONAUTICAL DECISION MAKING

Denver, CO
May 5-8, 1992

OUTLINE FOR PRESENTATION AT FAA/AAC WORKSHOP ON AERONAUTICAL DECISION MAKING, Denver, May 5-8, 1992

SHARED MENTAL MODELS AND CREW DECISION MAKING

Judith Orasanu

NASA-Ames Research Center

I. Structure of decisions tasks in the cockpit and their cognitive requriements

A. Rule-Based Decisions
   Go/No Go Decisions
   Recognition-primed Decisions

B. Knowledge-based decisions - WELL-structured problems
   Choice Decisions
   Scheduling Decisions

C. Knowledge-based decisions - ILL-Structured problems
   Procedural Management Decisions
   Creative Problem Solving

RESEARCH ISSUES: Is this the right taxonomy?
What kinds of decision tasks are found in the cockpit?
What cognitive processes are required for each?
What are their weak links?

II. What is known about effective crew decision making?

A. Criteria for evaluating crew decisions?
   Outcomes vs. Performance

B. Process variables that affect performance
   Good situation awareness
   Planfulness
   Communicate to build shared mental models
   Resource management

RESEARCH ISSUES: What are appropriate CRITERIA for evaluating aero DM?
Are normative criteria relevant? For which types of decisions?

III. Implications for training ADM

A. Implications from analysis of decision types

B. Implications from 4 process factors

RESEARCH ISSUES: What should/can be trained? HOW?

OVERVIEW

1. What is the structure of decision tasks in the aeronautical environment?

2. What is known about effective crew decision making?

3. What are the criteria for judging aeronautical decisions?

4. What are the implications of 1. and 2. for training ADM?

WHAT IS THE STRUCTURE OF DECISION TASKS IN THE AERONAUTICAL ENVIRONMENT?

1. Rule [redacted]-Based Decisions

   -- Go-No Go Decisions
   -- Recognition-Primed Decisions

2. Knowledge-based Decisions
   -- WELL-STRUCTURED PROBLEMS

   -- Response selection decisions
   -- Scheduling decisions

3. Knowledge-based Decisions
   -- ILL-STRUCTURED PROBLEMS

   -- Procedural management decisions
   -- Creative problem solving

RESEARCH ISSUES:

1. Is this the right taxonomy?

2. What cognitive processes are required by each type of decision?

3. What are their weak links?

WHAT IS KNOWN ABOUT EFFECTIVE CREW DECISION MAKING?

1. What CRITERIA should be used to judge decision quality?

   Outcomes vs. Performance

2. PROCESS variables that affect performance

   -- Situation awareness

   -- Metacognitive skills

   -- Shared mental models

   -- Resource management

RESEARCH ISSUES:

1. Are different criteria appropriate for different types of decisions?

2. Are normative criteria ever relevant?

   -- For which types of decisions?

3. How do we know if crew decision performance has improved?

IMPLICATIONS FOR TRAINING ADM

1. 6 decision types require different skills:

   -- perceptual pattern matching
   -- situation assessment
   -- risk assessment
   -- scheduling
   -- option selection heuristics
   -- problem diagnosis
   -- creative problem solving.

2. Model of effective crew decision making implies different training foci:

   -- situation assessment
   -- planning
   -- communicating (within cockpit and with ground -- ATC and dispatch)
   -- resource assessment and prioritizing

RESEARCH ISSUES:

1. What can/should be trained?

2. HOW?

Roy G. Fox

Chief Safety Engineer
Bell Helicopter Textron

EMBEDDED ADM REDUCES HELICOPTER HUMAN ERROR ACCIDENTS

Conclusion:

Judgment Training (e.g., PDM or ADM) has more safety improvement potential than the total elimination of all airworthiness failure causes (a primary goal since the start of aviation).

HELIPROPS

EMBEDED ADM REDUCES HELICOPTER HUMAN ERROR ACCIDENTS

Roy G. Fox

BELL'S APPROACH

NEED TO REDUCE ACCIDENT RATES

IR&D: SAFETY RESEARCH TO IDENTIFY ROOT CAUSES OF HUMAN ERROR ACCIDENT:

DEVELOP & IMPLEMENT SAFETY TRAINING

1987 SAFETY/JUDGMENT TRAINING STARTED

WHAT DID NOT WORK :

TALKING DIRECTLY TO THE SUBJECT

PILOT CAUSES 2 OUT OF 3 ACCIDENTS

LET'S TALK ABOUT PILOT ERROR

OH NO ! NOT ANOTHER SAFETY MEETING !

DON'T DO THAT !

>>>PROBLEM :

- PILOT'S RESISTANCE & FEELING OF BEING ATTACKED.

ADM3

APPROACH THAT WORKS: KEYS

1. TALK TO AUDIENCE LEVEL & SIMPLIFY FURTHER
2. GAIN GROUP'S TRUST EARLY (SINCERITY)
3. GROUP'S PARTICIPATION/QUESTIONS
   - USE "INTEREST HOOKS" & OBJECT TOUCHING
   - TALK ABOUT THINGS THAT WORRY HUMANS
4. HUMOR : MORBIDITY RELIEF & MEMORY AID
5. TOPIC SEQUENCING & VARIETY OF SUBJECTS
6. EMBED JUDGMENT TRAINING
7. GIVE INFO TO HELP HIM/HER UNDERSTAND SELF
8. PROVIDE FORMAL ADM INTRODUCTION
9. SHOW THAT HELIPROPS IS WORKING
10. FUTURE TECHNOLOGY: PC DECISION-MAKING SIMULATOR

MESSAGE RECEIVED

1. INDUSTRY CARES FOR ME, THE PILOT
2. I CAN BE A "PROFESSIONAL PILOT"
   (HERE ARE SOME TRICKS TO HELP)
3. I CAN RESIST INTERNAL/EXTERNAL PRESSURES
4. ALERT & THINKING PILOTS DON'T HAVE ACCIDENTS
5. ADM (JUDGMENT TRAINING) IS KEY
6. I CAN PROTECT MYSELF IF I DO CRASH
7. MY RISK OF SERIOUS INJURY IS VERY REMOTE

The basic outline of this brief:

1. WHO IS RESPONSIBLE FOR SAFETY?

2. MEASURING RISK

   - Accident rates
   - Configurate effects
   - Accident rates by causes
   - Single vs twin comparisons
   - Individual risk of serious injury
   - Injuries by accident cause differences

3. MEANS OF REDUCING RISK

   - Accident Prevention vs Injury Prevention

4. CRASH SURVIVAL

   - What is needed to survive a crash
   - Injury distributions
   - Restraints used and effects
   - Human tolerances
   - Mechanics of a crash
   - Crash energy management (energy attenuation)
   - Post Crash Fires & Crash Resistant Fuel Systems

5. ACCIDENT CAUSES - 2/3 ARE HUMAN

- What is human error
- Root causes of human error (worldwide study)
- Experience effects on human error accidents
- Nutrition effects on human error accidents
- Stress (stressors)

6. JUDGMENT TRAINING

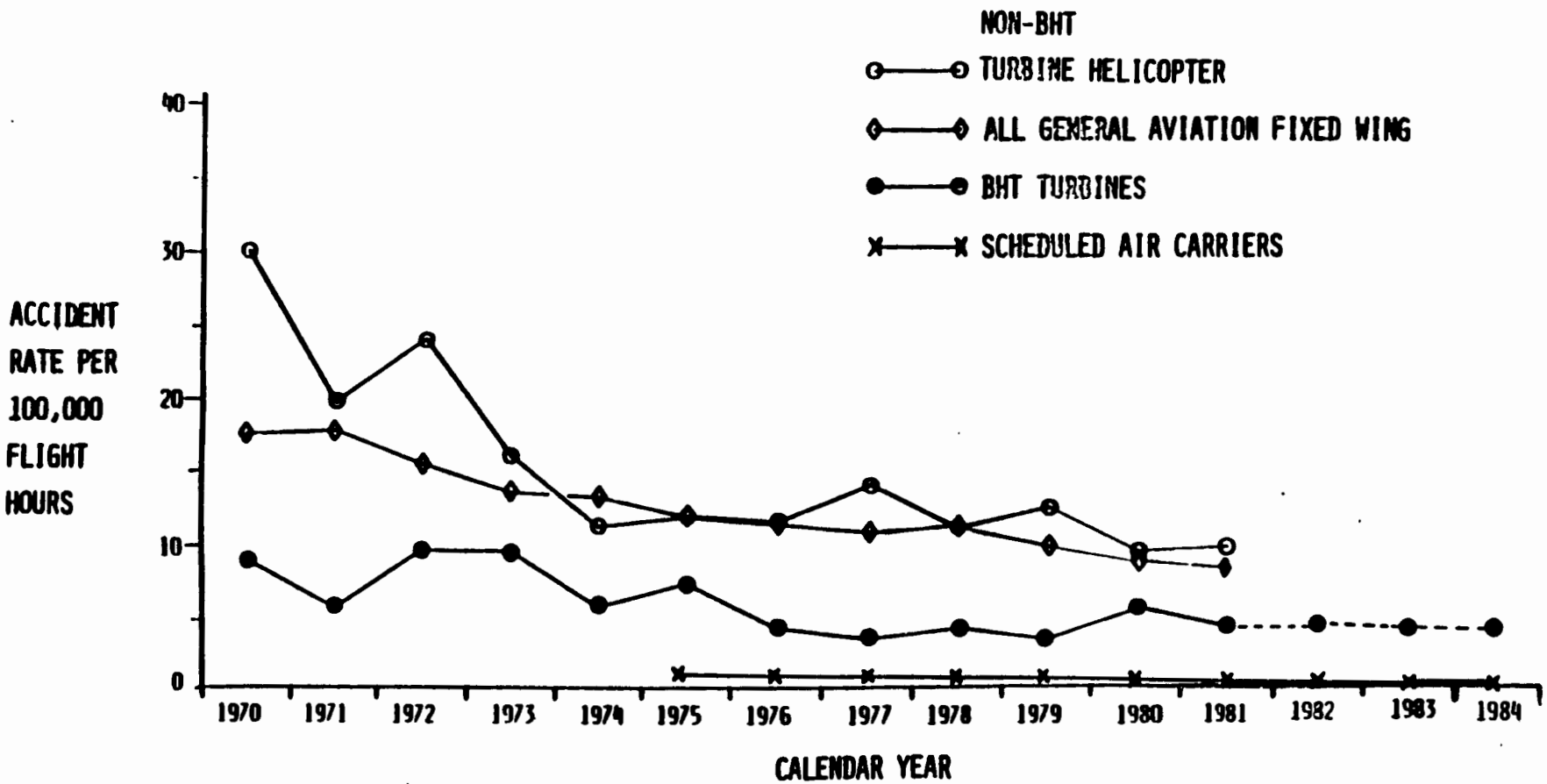
- Aeronautical Decision Making (ADM)
- Hazardous attitudes
- Responses and self-monitoring
- CEPET (Cockpit Emergency Procedures Expert Trainer), a PC based decision-making simulator.

7. HELIPROPS EFFECTS ON 206 HUMAN ERROR ACCIDENT RATES

- Worldwide human error accident rate reduced by 36%
- U.S. human error accident reduced by 48%
- Largest civil helicopter operator overall accident rate down 54%
- Human error related to weather decisions reduced 72%.

AVIATION ACCIDENT RATES

U.S. REGISTERED AIRCRAFT, NTSB DATA



Bell Helicopter TEXTRON
Division of Textron Inc

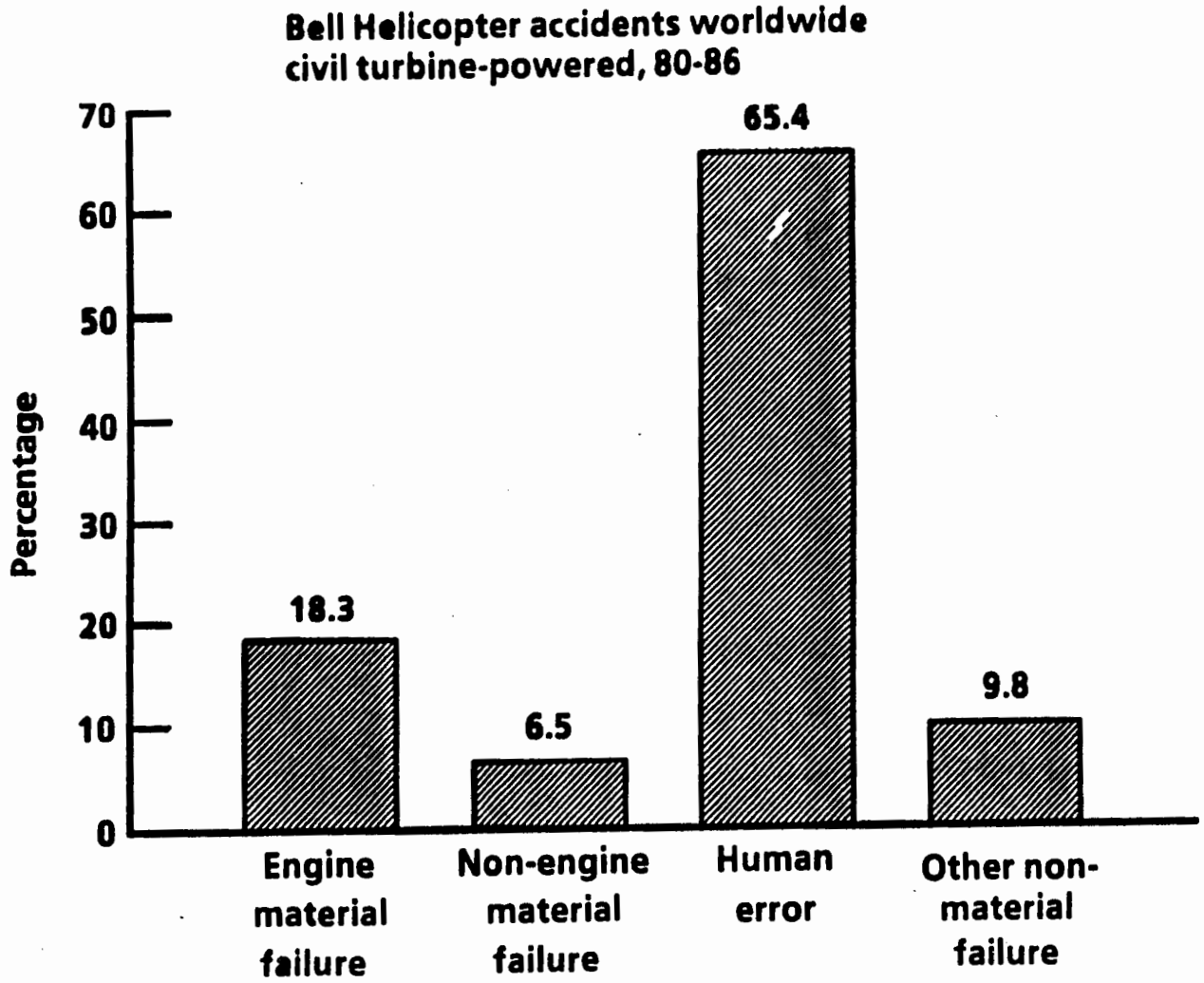


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Fig. 4. Known accident causes.

Bell Helicopter TEXTRON
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BELL SAFETY TRAINING IS REDUCING HUMAN ERROR: HELIPROPS

HELICOPTER PROFESSIONAL PILOTS SAFETY PROGRAM, HELIPROPS (BELL-FUNDED), TO REDUCE HUMAN ERROR ACCIDENTS

- SHORT TERM
  - SYSTEM SAFETY DEVELOPED / GIVES TRAINING BRIEF
    - WEEKLY 206 PILOT GROUND SCHOOL
    - REGIONAL / CUSTOMER SAFETY MEETINGS
  - FULL TIME HELIPROPS ADMINISTRATOR
    - REGIONAL / CUSTOMER SAFETY MEETINGS
    - PUBLISH HUMAN AD MAGAZINE
- LONG TERM
  - HUMAN FACTORS ENGINEERING DEVELOPED CEPET (COCKPIT EMERGENCY PROCEDURE EXPERT TRAINING)
  - USES ARTIFICIAL-INTELLIGENCE-BASED SOFTWARE
  - PC BECOMES A DECISION-MAKING SIMULATOR
  - AIMED AT INDIVIDUAL PILOT TRAINING AROUND WORLD
  - AVAILABLE ON MODELS 206B3, 206L3, AND 412 / 212

2 B649

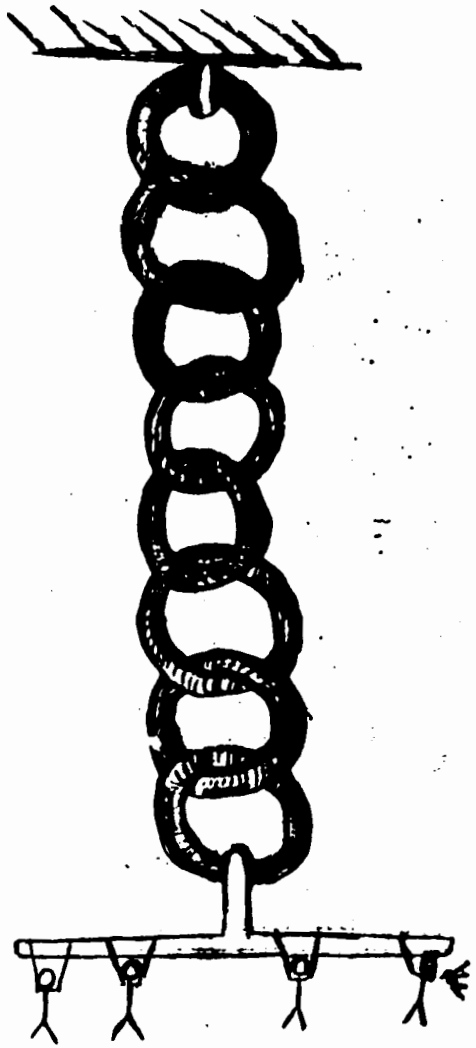
HELIPROPS

(HELicopter PROfessional Pilot Safety) program

SAFETY ENGINEERING VIEW

Roy G. Fox

SAFETY RESPONSIBILITY CHAIN



FAA

AIRCRAFT MANUFACTURER

PART SUPPLIER

MAINTAINER

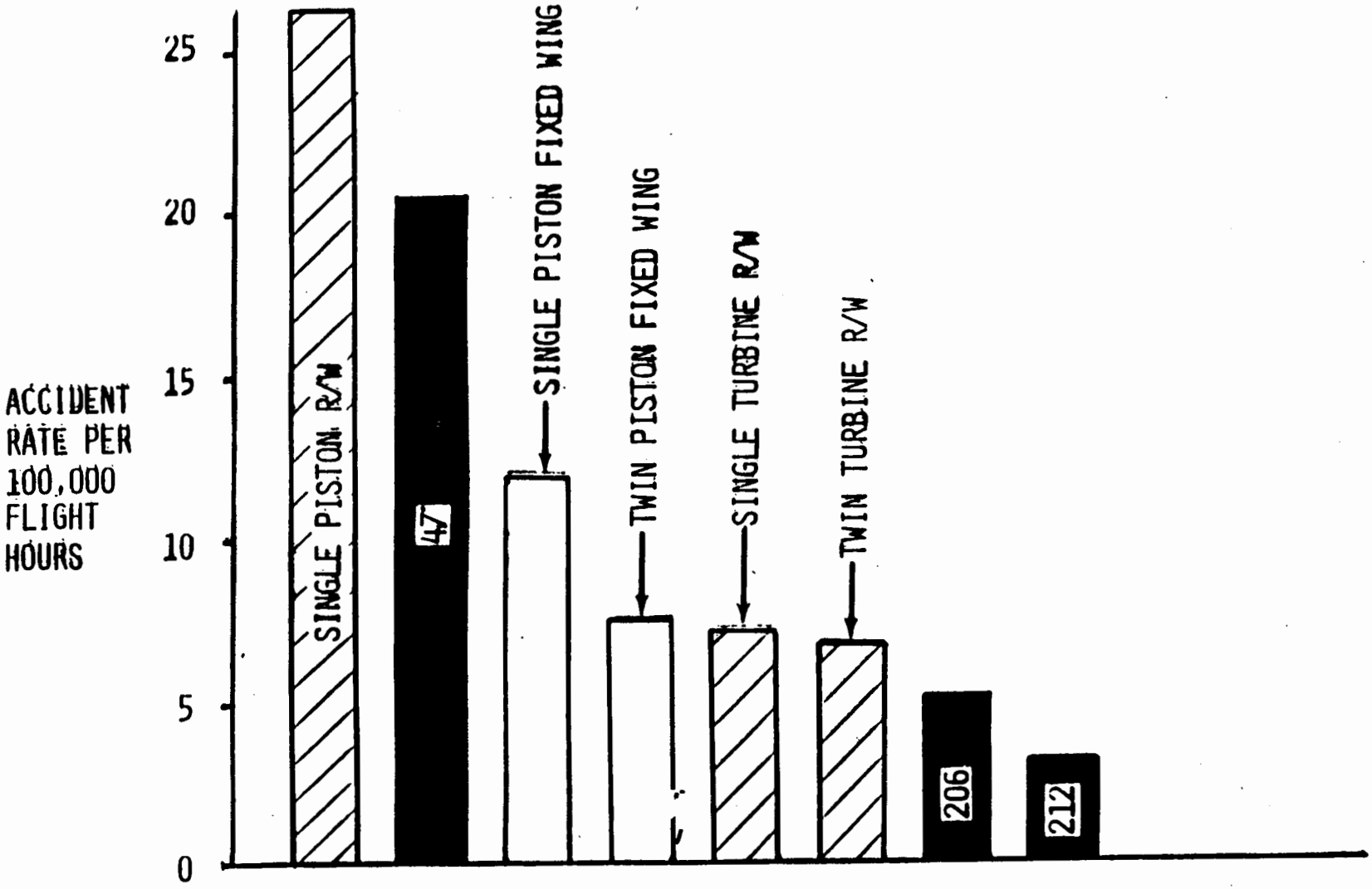
CUSTOMER DEMANDS

COMPANY ADMINISTRATION

CHIEF PILOT

PILOT

U.S. GENERAL AVIATION ACCIDENT RATES
(1975 - 1979)



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ICAO ANNEX 6, PART III, AMENDMENT 1

COMMERCIAL AIR TRANSPORT & GENERAL AVIATION

PERFORMANCE CLASSES BASED ON ONE ENGINE INOP (OEI)

1 - CONTINUE FLIGHT, REGARDLESS OF WHEN ENGINE FAILED
2 - CONTINUE FLIGHT EXCEPT DURING TAKEOFF TO DEFINED POINT AND FROM DEFINED POINT TO LANDING
3 - FORCED LANDING (I.E. SINGLE ENGINE HELICOPTER)

ICAO PROHIBITIONS

1 - NO CLASS 2 & 3 OPERATIONS FROM ELEVATED STRUCTURES IN CONGESTED AREAS
2 - CLASS 3 (SINGLE ENGINE) OPERATIONS:
- OUT OF SIGHT OF SURFACE
- AT NIGHT
- CLOUD CEILINGS LESS THAN 180 M (600 FT)

SINGLE ENGINE PROHIBITIONS NOT CONSISTENT WITH ACCIDENT EXPERIENCES

2 B390

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CIVIL HELICOPTER EXPOSURE

USA, UK, AND CANADA CIVIL HELICOPTERS BY ENGINE TYPE (FLIGHT - HOURS FLOWN)

ENGINE TYPE	USA (84 - 88)	UK (80 - 87)	CANADA (82 - 87)	USA / UK / CANADA COMBINED	%
SINGLE PISTON	2,961,252	91,737	190,894	3,243,883	21.3
SINGLE TURBINE	7,035,846	239,548	2,078,376	9,353,770	61.5
TWIN TURBINE	1,442,116	932,474	242,696	2,617,286	17.2
TOTAL HELICOPTERS	11,439,214	1,263,759	2,511,966	15,214,939	100
MOST COMMON	5,215,001	155,648	1,471,675	6,842,324	45.0

AIRCRAFT: 206 SINGLE TURBINE

2 B289

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USA - REGISTERED HELICOPTER ACCIDENT RATES

(SOURCES: NTSB / FAA FOR 1984 THROUGH 1988) (ACCIDENTS PER 100,000 FLIGHT - HOURS)

TYPE OF HELICOPTER	ENGINE - ONLY AIRWORTHINESS	NON - ENGINE AIRWORTHINESS	ALL AIRWORTHINESS	ALL CAUSES
ALL HELICOPTERS	1.22	1.08	2.30	8.54
SINGLE PISTON	1.99	2.09	4.09	17.83
TWIN TURBINE	0.35	1.25	1.59	4.37
SINGLE TURBINE (ALL)	1.08	0.61	1.69	5.49
206 SINGLE TURBINE	0.88	0.17	1.05	4.28

2 B292

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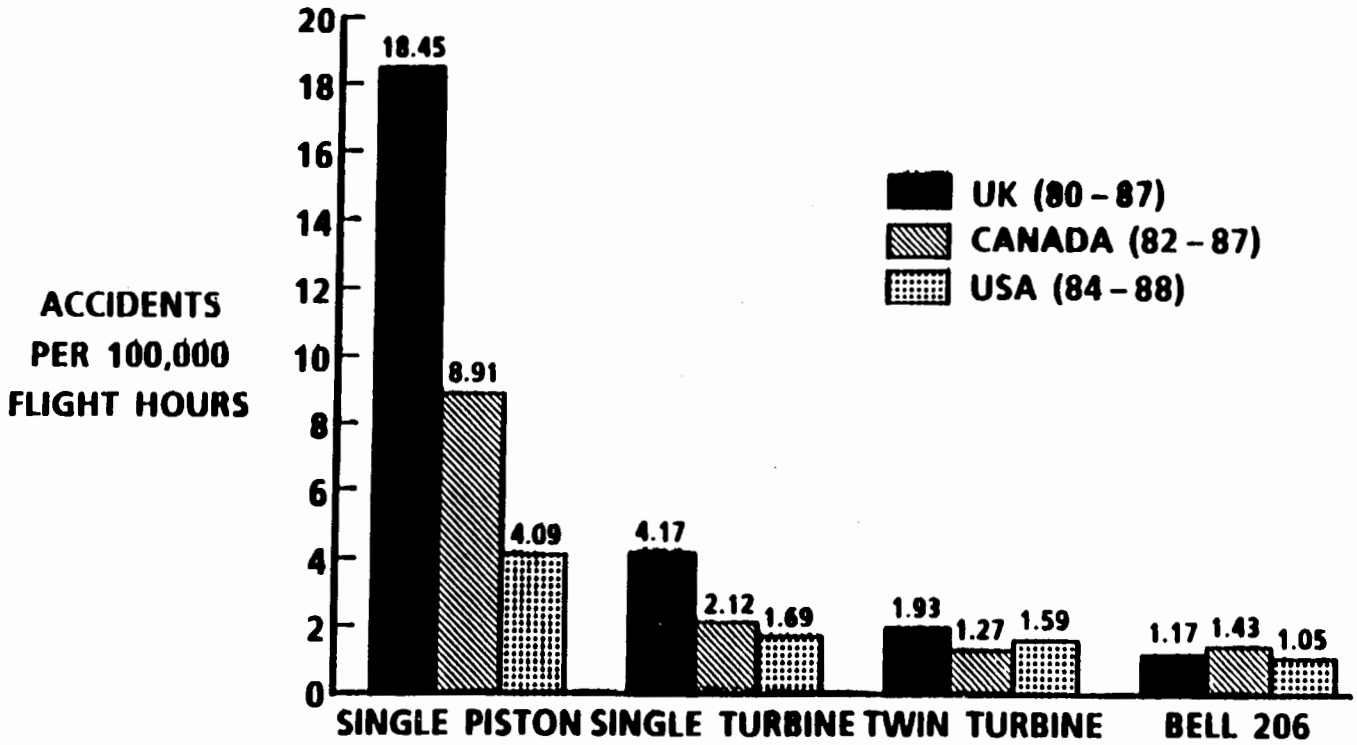
AIRWORTHINESS FAILURE ACCIDENT RATES



AIRWORTHINESS FAILURE ACCIDENT RATES FOR UK, USA, AND CANADA IN THE 1980'S

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TIME TRAVEL EQUIVALENT: AROUND-THE-WORLD TRIPS

- MEAN TIME BETWEEN ACCIDENT (MTBA): ALL AIRWORTHINESS CAUSES
  - TWIN TURBINE — 1 IN 62,893 FLT HOURS
  - 206 — 1 IN 95,283 FLT HOURS
- AROUND-THE-WORLD TRIPS AT 130 MPH (113 KNOTS)
  - TWIN TURBINE — 327 TRIPS
  - 206 — 495 TRIPS
- ONE AIRCRAFT, FLYING CONTINUOUSLY 24 HR / DAY
  - TWIN TURBINE — 7.2 YEARS
  - 206 — 10.9 YEARS

NO SAFETY JUSTIFICATION TO PROHIBIT SINGLES OR TWINS FROM FLYING OVER CONGESTED AREAS OR HOSTILE-EARTH SURFACES.

SAFETY IS RISK MANAGEMENT

RISK (RSI) = PROBABILITY OF AN ACCIDENT X PROBABILITY OF SERIOUS INJURY

$$\text{RISK} = \frac{\text{NUMBER OF ACCIDENTS}}{\text{FLIGHT-HOURS FLOWN}} \times \frac{\text{NUMBER PEOPLE FATAL/SERIOUSLY INJURED}}{\text{TOTAL NUMBER OF PEOPLE ON BOARD}}$$

ACCIDENT PREVENTION PROGRAM

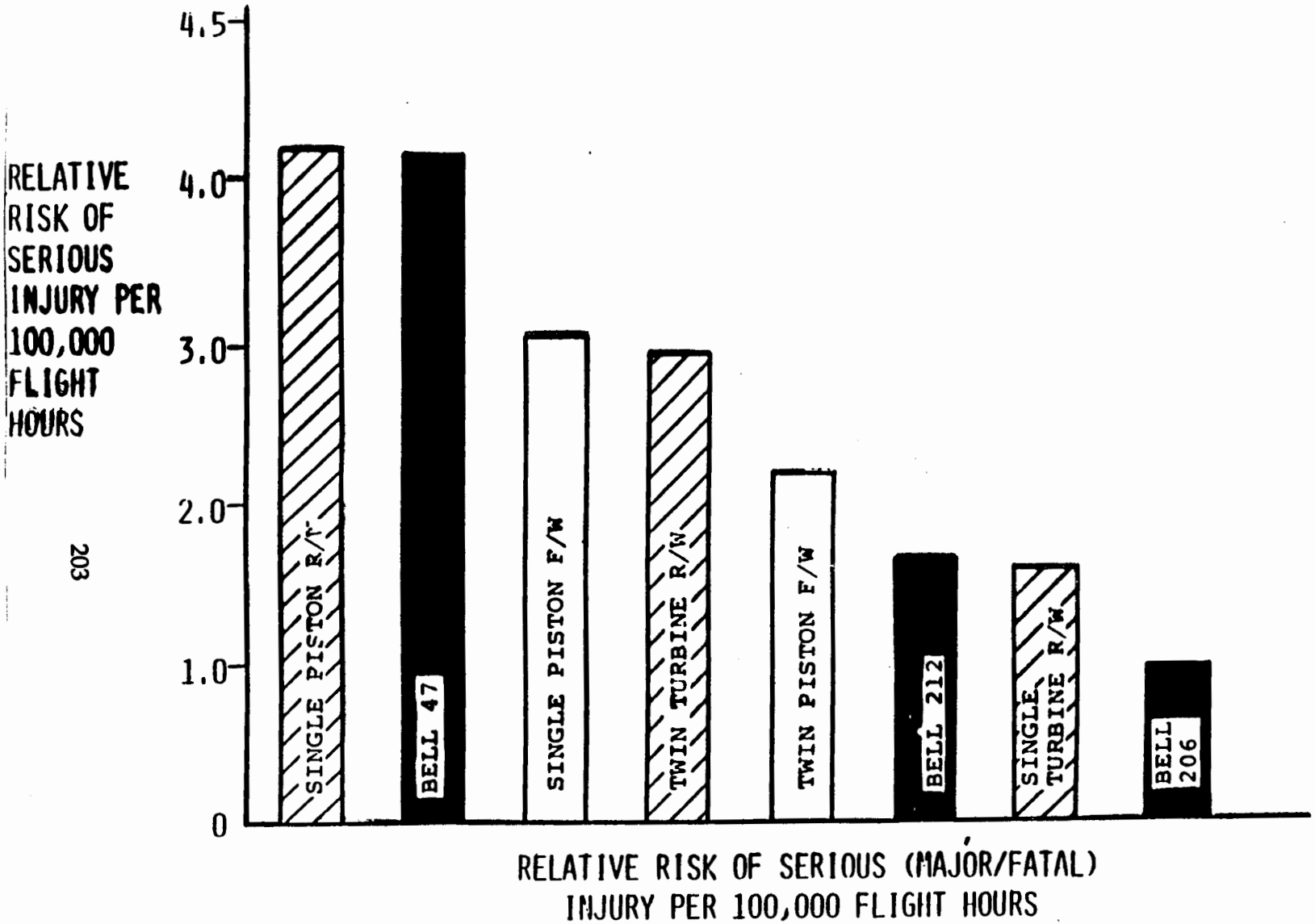
- AIRCRAFT DESIGN
- STANDARDIZATION
- REGULATIONS
- TRAINING

INJURY PREVENTION PROGRAM

- AIRCRAFT CRASH SAFETY FEATURES
- SURVIVAL TRAINING
- POPOUT FLOATS
- FLIGHT FOLLOWING
- ACCIDENT RESPONSE PLAN

CAN NOT IGNORE EITHER PROBABILITY

RELATIVE RISK OF SERIOUS INJURY IN GENERAL AVIATION



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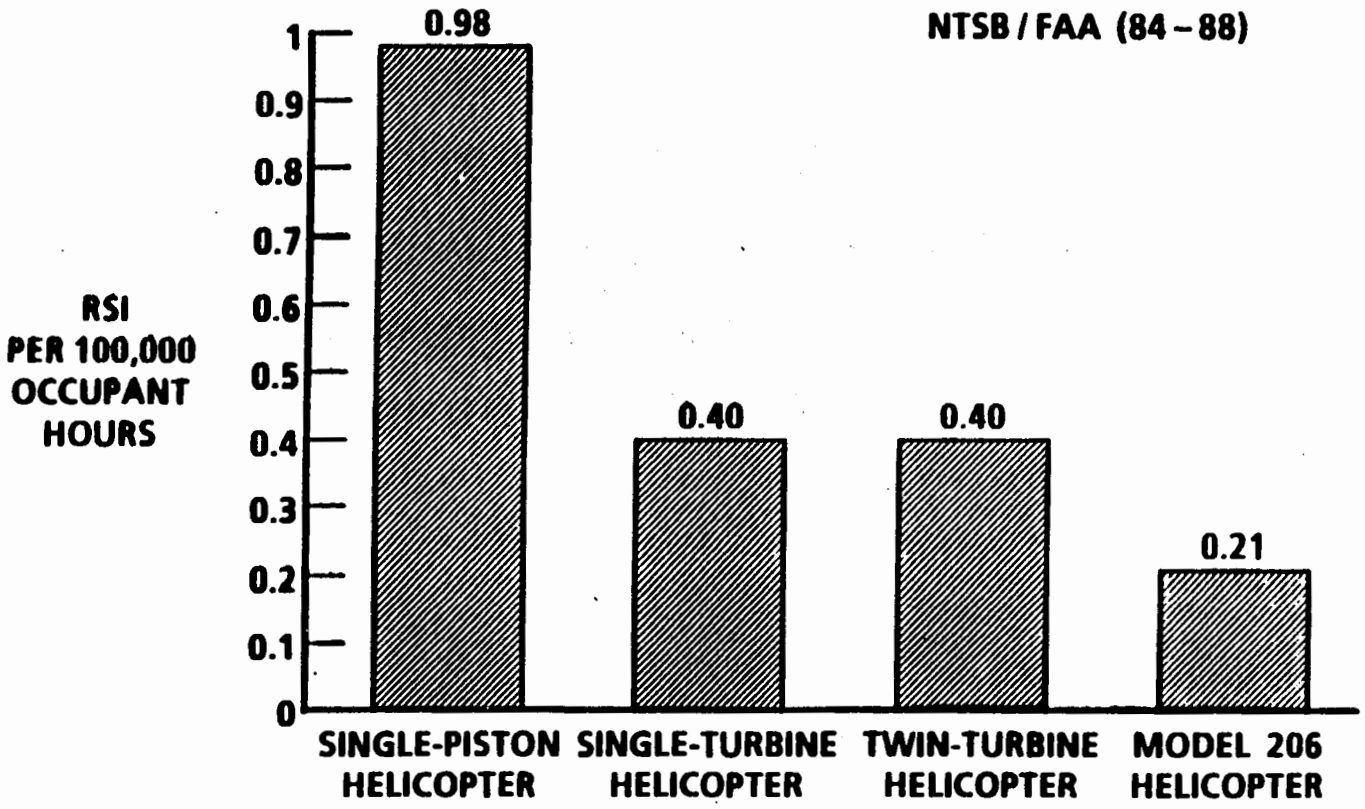
RSI



RSI FROM AIRWORTHINESS FAILURES

2 B205

CRASH SURVIVAL REQUIREMENTS

- MAINTAIN A LIVABLE VOLUME
- RESTRAIN THE OCCUPANT
- KEEP CRASH LOADS WITHIN HUMAN TOLERANCE
- PROVIDE TIME/MEANS OF ESCAPE

FAA CIVIL HELICOPTER CRASH SCENARIO STUDY

SIX MOST SIGNIFICANT HAZARDS:

1. BURNS - POST CRASH FIRE
2. SPINAL INJURIES - EXCESSIVE VERTICAL LOADING
3. ALL TYPE INJURIES - WIRE STRIKES
4. HEAD/UPPER TORSO IMPACTS - RESTRAINTS PROBLEM/CLEARANCE
5. SECONDARY IMPACT - LACK OF UPPER TORSO RESTRAINTS
6. DROWNED - INJURIES PREVENTED ESCAPE

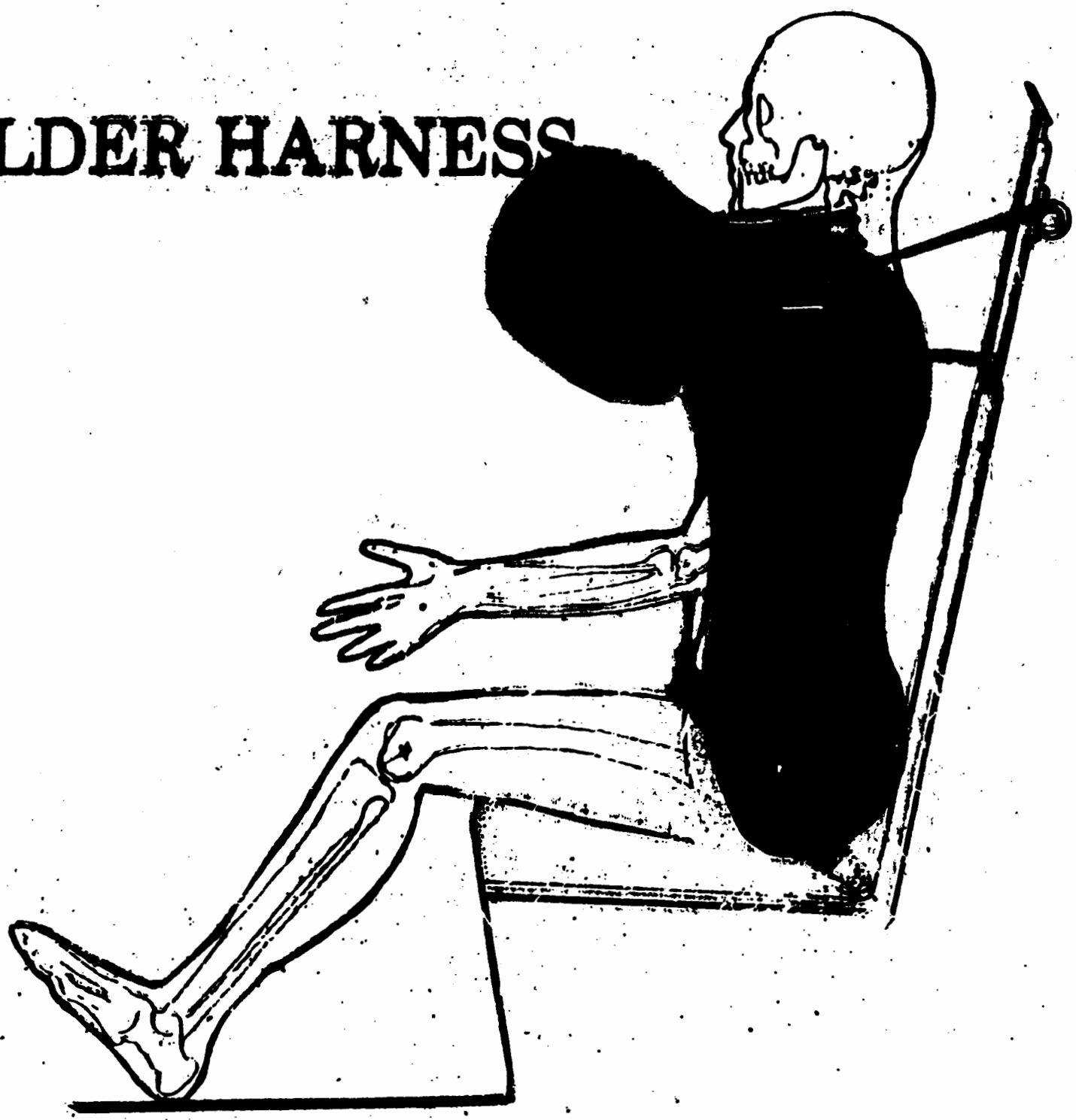
BEST HUMAN TOLERANCE RELATIVE TO RESTRAINT

	HUMAN TOLERANCE (UNINJURED)	
	LAP BELT ONLY *	HARNESS & LAP BELT **
LONGITUDINAL (- G_X)	15 G (0.002 SEC)	45 G (0.1 SEC) 25 G (0.2 SEC)
VERTICAL (+ G_Z)	4 G (INJURED)	25 G (0.1 SEC)
LATERAL (± G_Y)	11 G (0.1 SEC)	20 G (0.1 SEC)

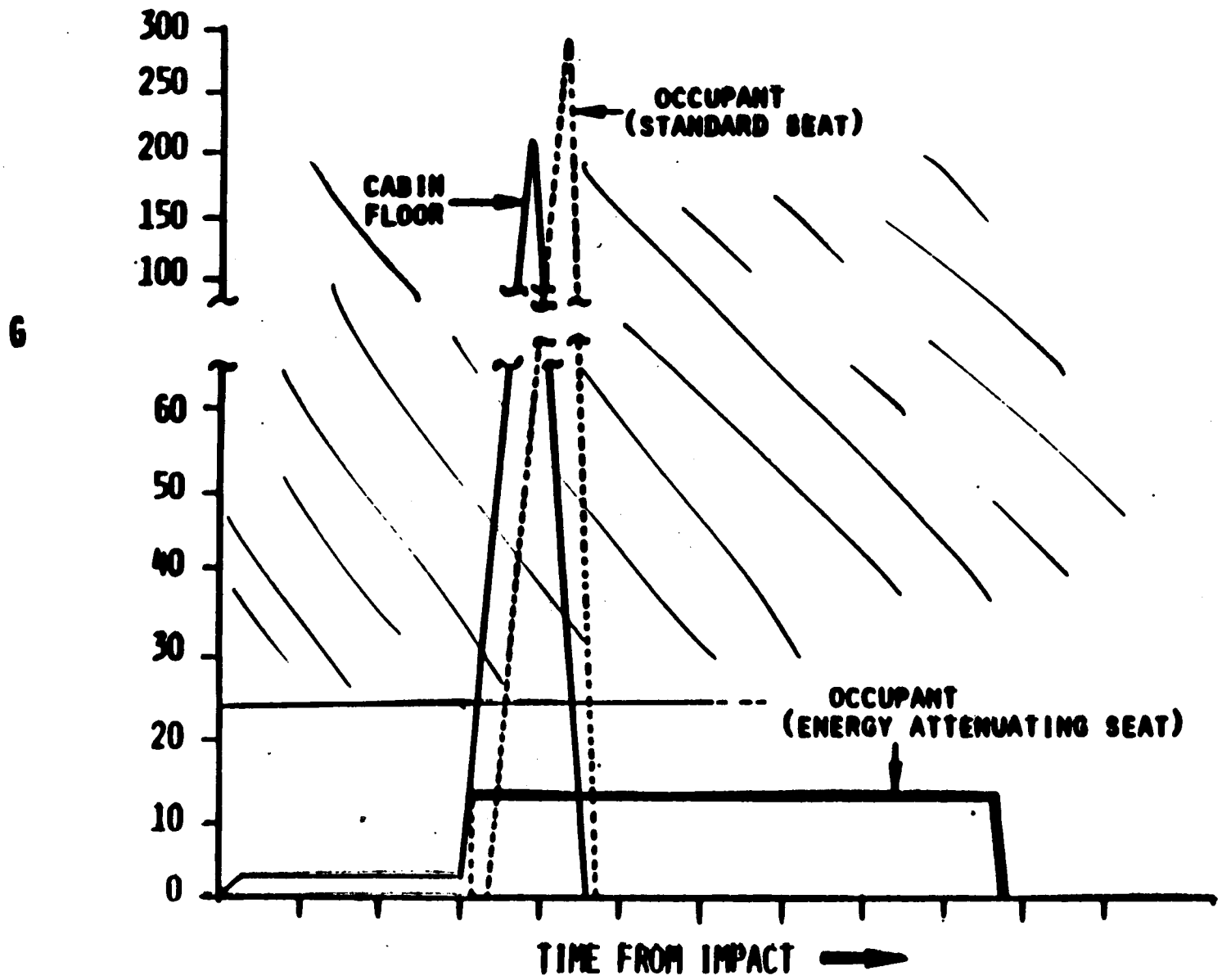
*EIBAND, NASA MEMORANDUM 5-19-59E

**USARTL-TR-79-22

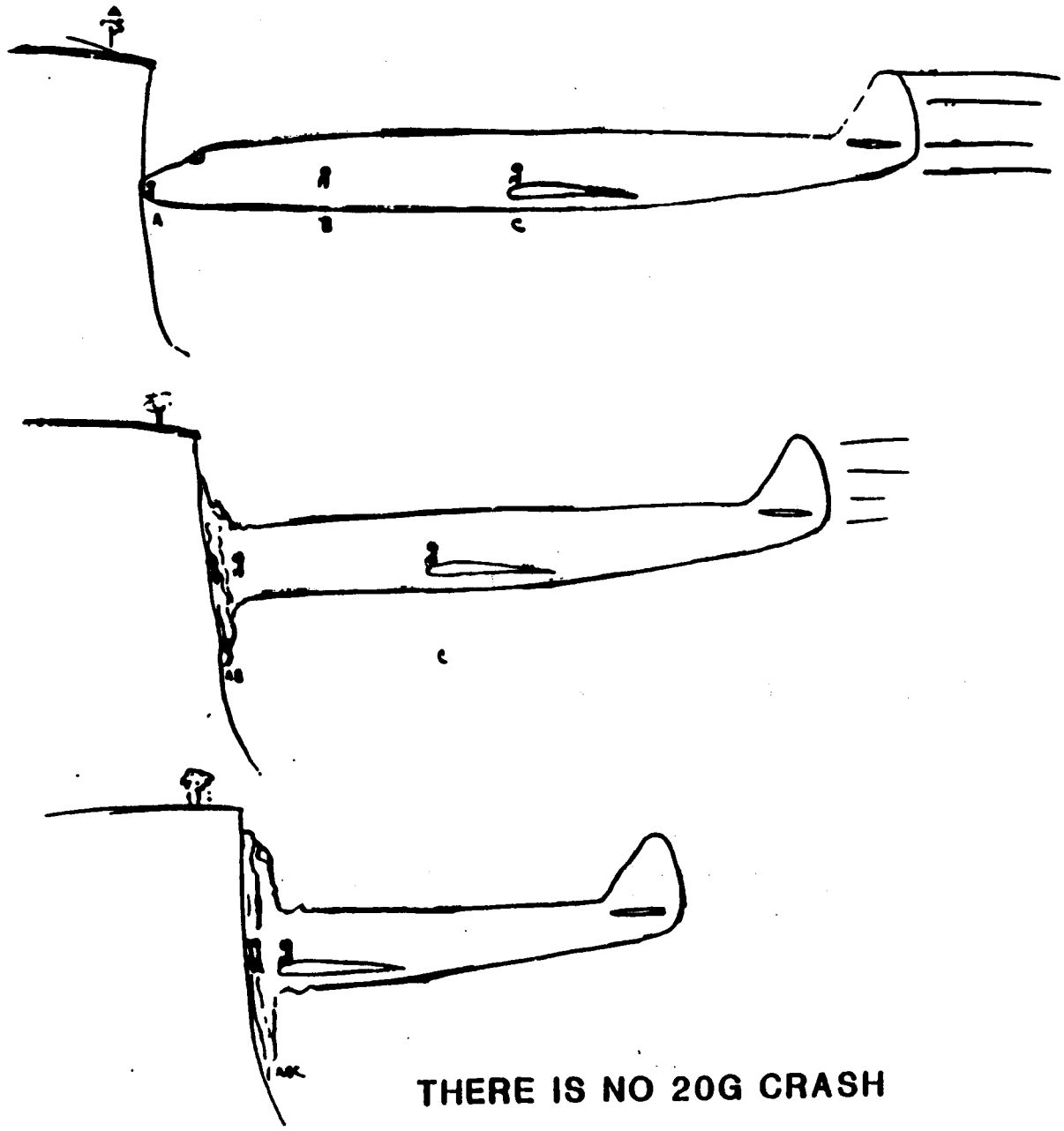
SHOULDER HARNESS



G's APPLIED TO OCCUPANT IN CRASH

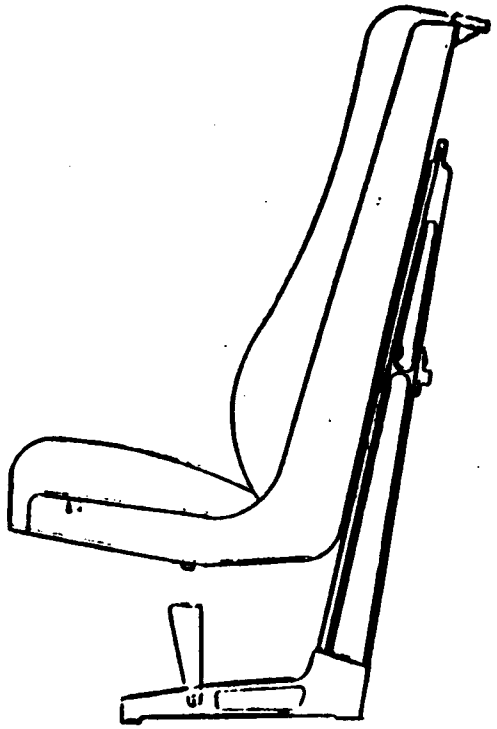


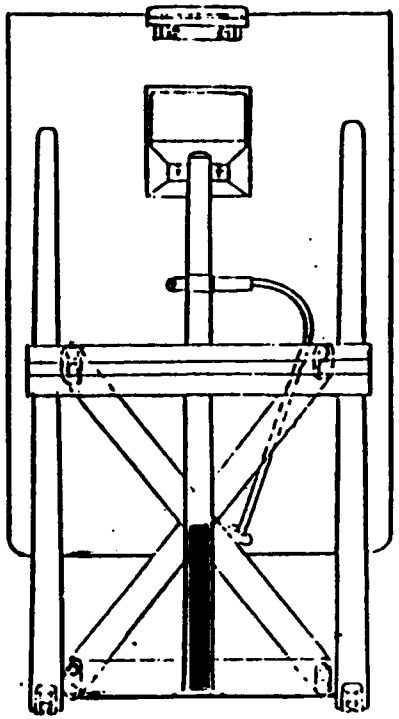
G LOAD VARIANCES



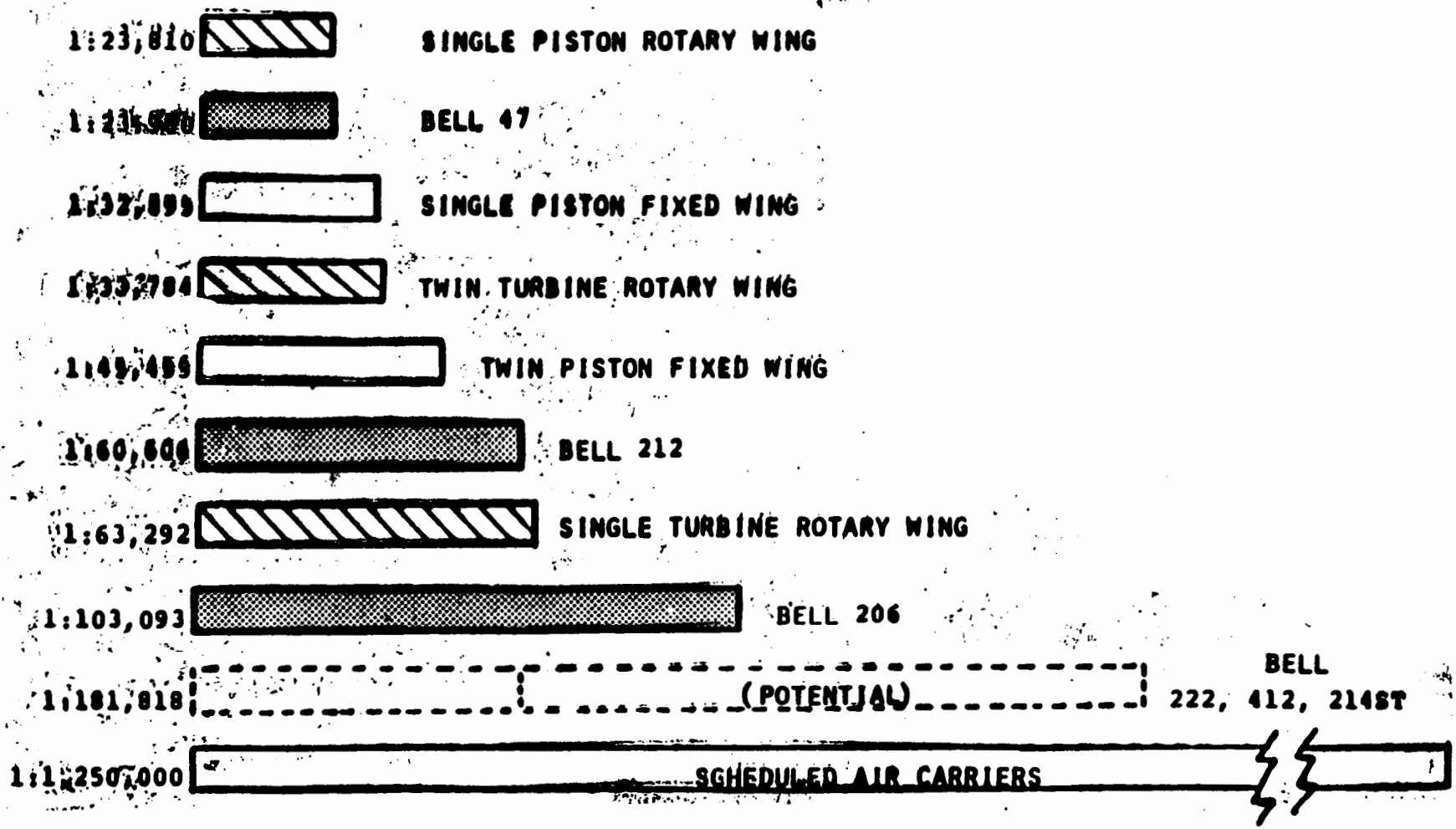
THERE IS NO 20G CRASH

214ST/412 CREW SEAT





MEAN TIME BETWEEN SERIOUS INJURY (HOURS)
(1975-1979)



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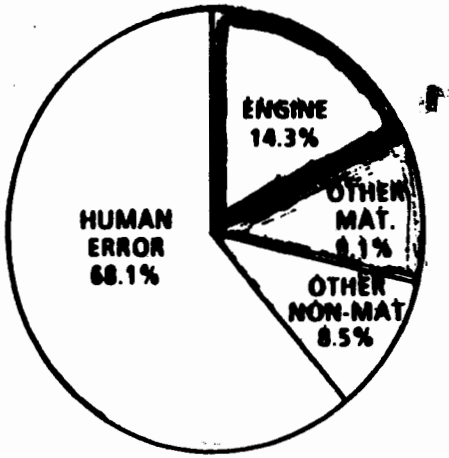
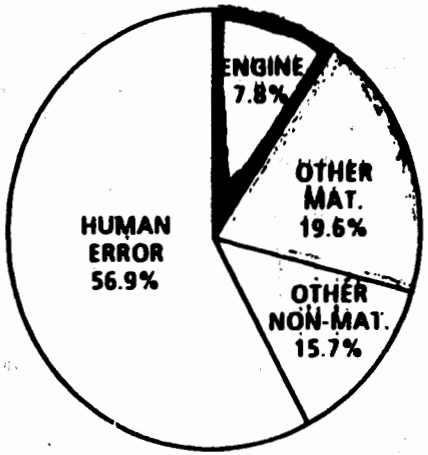
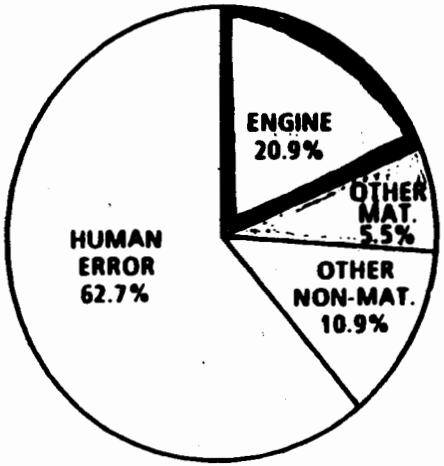
PERCENTAGE OF KNOWN CAUSES
NTSB/FAA (1982 - 1985)



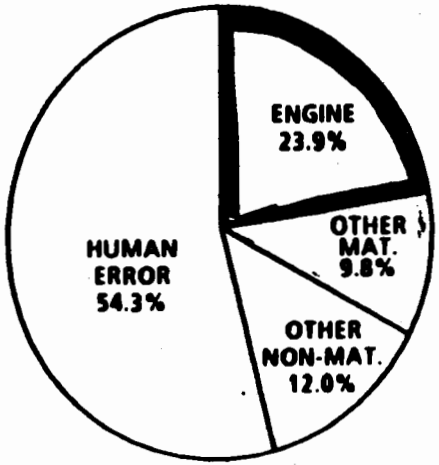
SINGLE PISTON



TWIN TURBINE



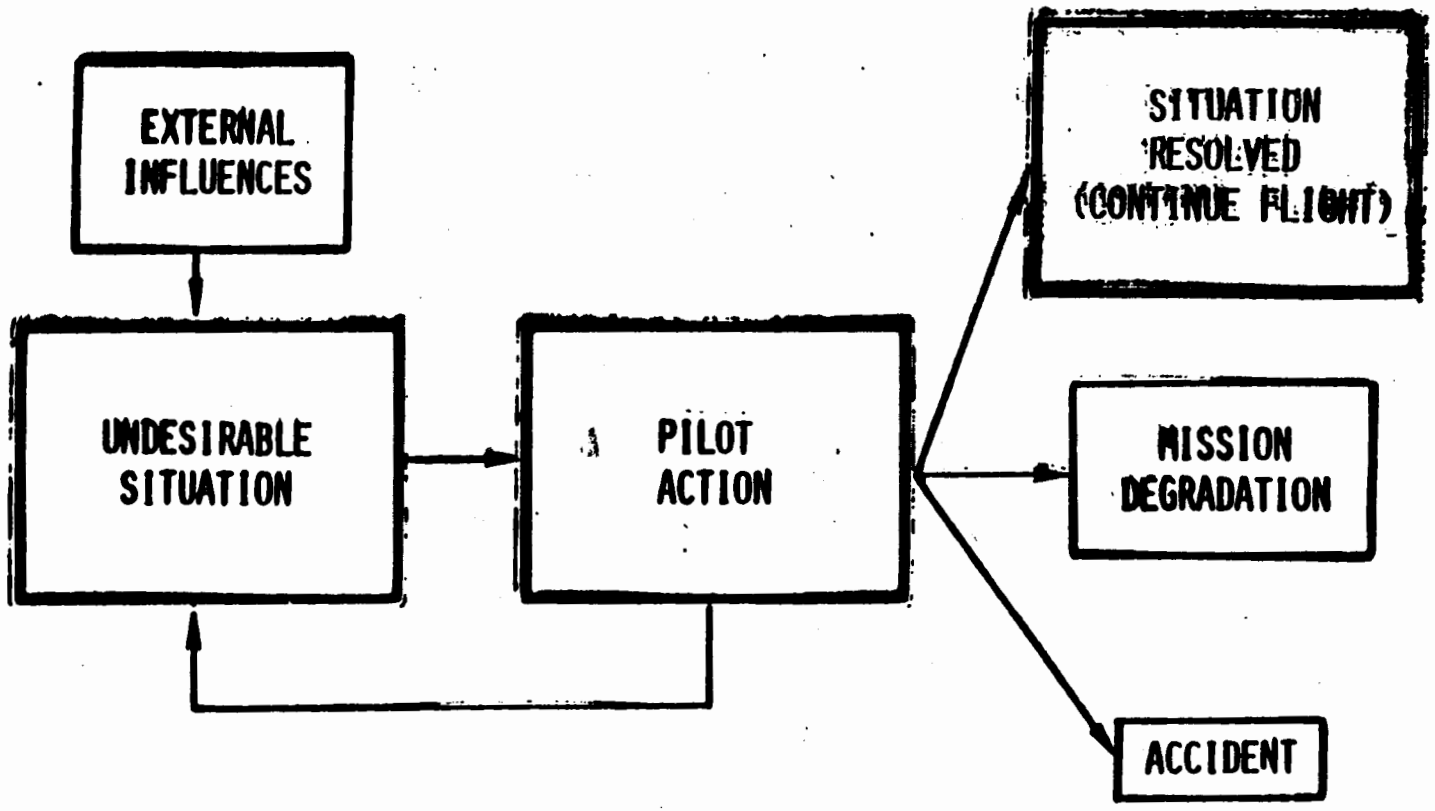
206



SINGLE TURBINE

HUMAN ERROR

MISJUDGEMENTS, INATTENTION, OR IMPROPER ACTIONS IN CERTAIN SITUATIONS THAT EITHER PRODUCE AN ACCIDENT OR CONTRIBUTE TO ITS SEVERITY. FEW HUMAN ERRORS RESULT IN AN ACCIDENT.

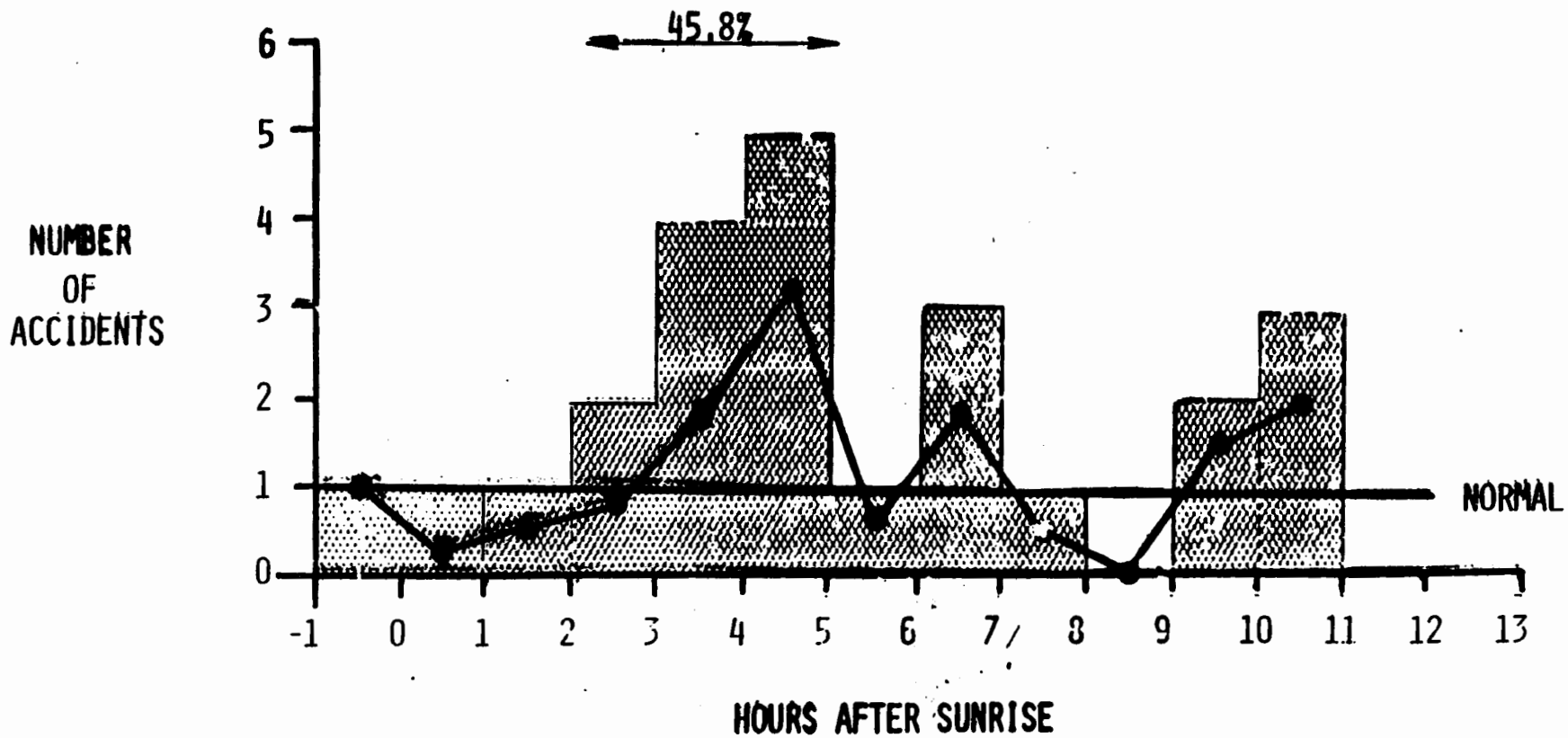


HELICOPTER ACCIDENT CAUSES

NTSB (1982 - 1985)

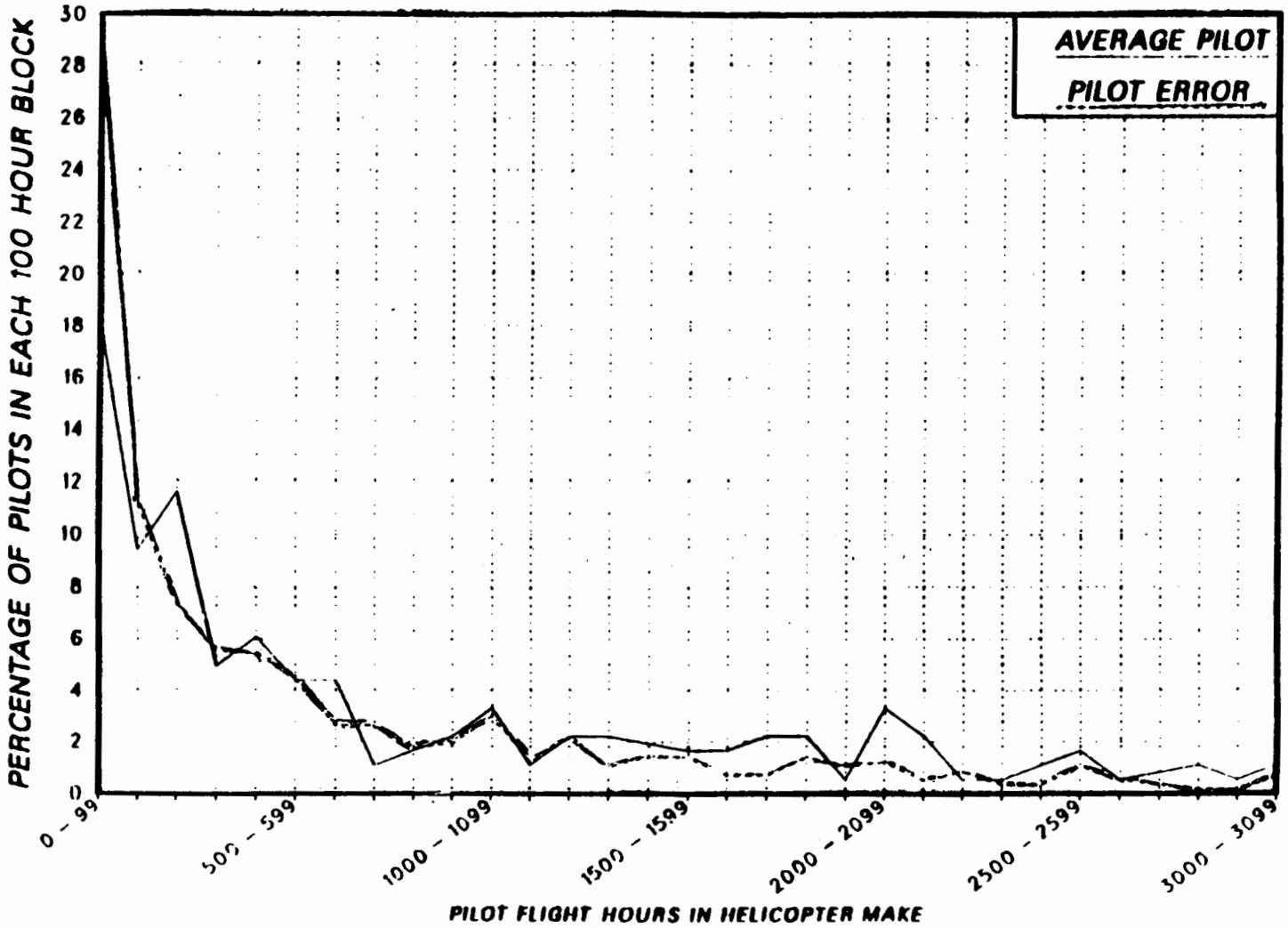
Pilot	**63.5%**	**Pilot (Continued)**	
Weather	9.0%	Intoxication	0.5%
Loss of Control	8.6%	A/C Struck Water	0.5%
Fuel Exhaust	6.0%	A/C Struck Other	0.4%
Wire Strike	5.8%	Power Loss	0.4%
Settled	4.0%	Helipad/LZ	0.4%
Hard Landing	3.8%	Ground Fires	0.3%
Dropped RPM	3.5%		
Rollover	3.4%	**Other Non-Material**	**6.9%**
Miscellaneous	2.8%	Maint. Error	4.5%
M/R Strike	2.3%	Person Into T/R	1.4%
T/R Strike	2.2%	Other Personnel	1.4%
Caught Skid	2.0%		
Fuel Contamination	1.9%	**Material**	**29.6%**
Whiteout	1.2%	Powerplant	19.3%
A/C Struck Trees	1.2%	M/R & Drive	3.5%
Inadequate Preflight	1.1%	Miscellaneous	3.0%
A/C Struck Ground	1.0%	T/R Drive	2.9%
Midair	0.8%	Fixed Controls	0.5%

PILOT ERROR ACCIDENTS (GULF)
HOURS AFTER SUNRISE
ALL HELICOPTER TYPES
(24 ACCIDENTS)
1975 THRU JULY 1981



Bell Helicopter TEXTRON

FLIGHT - HOUR EXPERIENCE OF PILOTS IN HELICOPTER MODEL FOR PILOT ERROR ACCIDENTS VS. AVERAGE PILOT (BASED ON NSTB DATA)



How Close to the Edge Are You?

At the University of Washington Medical School in Seattle, Drs. Thomas H. Holmes and Richard H. Rahe devised a "Social Readjustment Rating Scale" test, which lists forty-two common life changes in the order in which they found them to be important as precursors of illness. Oddly enough, an outstanding personal achievement can often lead to disease. When Astronaut Edwin "Buzz" Aldrin Jr., the second man on the moon, returned to earth he committed himself to a psychiatric hospital. He said: "None of us knew how to handle it."

The test is widely used now, especially in the armed forces, to determine how susceptible you are to disease. If you have a score of less than 150 within a period of a year you have only a 37 percent chance of getting sick within the next two years. Should your score be between 150 and 300, your chances of an illness increase to 51 percent. But if you score over 300, you are in serious danger, for the odds are 80 percent that you will have sickness within the next two years.

Dr. Holmes, a man with a wry sense of humor, says: "If you have more than 300 life-change units and get sick, the probability is you will have cancer, a heart attack, or manic-depressive psychosis rather than warts and menstrual irregularities." On the other hand, he adds, "There are worse things in this life than illness. It is worse to go on in an intolerable, dull, or demeaning situation."

Life, as we know, represents growth and change. Change causes stress. You can help yourself by keeping things in perspective and realizing just what sort of stress you are under. That will help you live longer, happier and healthier.

HOLMES-RAHE STRESS TEST

RANK	EVENT	VALUE	YOUR SCORE
1.	Death of spouse	100	
2.	Divorce	73	73
3.	Marital separation	65	
4.	Jail term	63	
5.	Death of close family member	63	
6.	Personal injury or illness	53	
7.	Marriage	50	
8.	Fired from work	47	
9.	Marital reconciliation	45	
10.	Retirement	45	
11.	Change in family member's health	44	
12.	Pregnancy	40	40
13.	Sex difficulties	39	
14.	Addition to family	39	
15.	Business readjustment	39	
16.	Change in financial status	38	
17.	Death of close friend	37	
18.	Change in number of marital arguments	35	
19.	Mortgage or loan over $10,000	31	
20.	Foreclosure of mortgage or loan	30	
21.	Change in work responsibilities	29	
22.	Son or daughter leaving home	29	29
23.	Trouble with in-laws	29	
24.	Outstanding personal achievement	28	28
25.	Spouse begins or starts work	26	
26.	Starting or finishing school	26	
27.	Change in living conditions	25	
28.	Revision of personal habits	24	
29.	Trouble with boss	23	
30.	Change in work hours, conditions	20	
31.	Change in residence	20	
32.	Change in schools	20	
33.	Change in recreational habits	19	
34.	Change in church activities	19	
35.	Change in social activities	18	
36.	Mortgage or loan under $10,000	18	
37.	Change in sleeping habits	16	
38.	Change in number of family gatherings	15	
39.	Change in eating habits	15	
40.	Vacation	13	
41.	Christmas season	12	
42.	Minor violation of the law	11	
	TOTAL		

#18. Change to different line of work

ROOT CAUSES OF HUMAN ERROR ACCIDENTS

BHTI CIVIL HELICOPTERS - WORLDWIDE

1. JUDGMENT
2. MINDSET
3A. STRESS (PHYSIOLOGICAL)
   - HEALTH
   - WORKLOAD
   - FATIGUE
   - MEDICATION
   - SUBSTANCE/INJURY ABUSE
3B. STRESS (PSYCHOLOGICAL)
   - EMOTIONAL
   - ADMINSTRATIVE
4. SENSORY INPUT
5. CULTURAL BACKGROUND
6. TRAINING FUNCTIONS
   - FLIGHT PROCEDURES IN TYPE
   - TIME SINCE UPDATE IN TYPE
   - FLIGHT & PROCEDURES IN OTHER TYPE ROTARY WING
   - FLIGHT & PROCEDURES IN FIXED WING, ETC.
7. PERSONALITY FUNCTIONS
   - RISKTAKER/NONCONFORMIST
   - PREVIOUS ACCIDENT/MISHAPS
8. PREOCCUPATION

POOR JUDGMENT WAS COMMON FACTOR IN ALL HUMAN ERRORS

HEI

AERONAUTICAL DECISION MAKING FOR HELICOPTER PILOTS

DOT/FAA/PM-86/45

Program Engineering
and Maintenance Service
Washington, D.C. 20591

Richard Adams
Jack Thompson

Systems Control Technology, Inc.
1611 North Kent Street, Suite 905
Arlington, Virginia 22209

U.S. Department of Transportation
Federal Aviation Administration

February 1987
Training Manual

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

87ORG00281M

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JUDGMENT TRAINING

E.G. ADM & PDM

JUDGMENT TRAINING HAS MORE

POTENTIAL SAFETY IMPROVEMENT

THAN THE TOTAL ELIMINATION OF

ALL AIRWORTHINESS FAILURES

2 B391

THOUGHT PATTERNS

HAZARDOUS ATTITUDE → *REPLACE WITH* →	ANTIDOTE
ANTI-AUTHORITY: "Don't tell me"	"Follow the rules. They are usually right."
IMPULSIVITY: "Do something - quickly!"	"Not so fast. Think first."
INVULNERABILITY: "It won't happen to me."	"It could happen to me."
MACHO: "I can do it."	"Taking chances is foolish."
RESIGNATION: "What's the use?"	"I'm not helpless. I can make a difference."

87FORG0024LM

JUDGMENT EXAMPLE 2

- YOU HAVE GET-HOME-ITIS
- NO PREFLIGHT; TIRED OF BEING TOLD WHAT TO DO
- T/O WITH REFUELING NOZZLE STILL IN HELICOPTER
- TRY TWO OR THREE PROCEDURES; CAN'T RECALL SEQUENCE - GIVE UP AND LAND HARD WITH SUBSTANTIAL DAMAGE

☐ ANTI-AUTHORITY ☐ IMPULSIVITY ☐ INVULNERABILITY ☐ MACHO ☐ RESIGNATION

Table 14. Worldwide Bell turbine accident rates (Rates per 100,000 flight-hours)

Aircraft and Period	Flight-hours	Causes of Accidents		
		Human Error	Non-Human and Unknown	All Causes
Model 206				
1983 - 1986	7,903,072	3.90	2.05	5.95
1987 - 1990	9,341,573	2.49	1.89	4.38
Percent change		−36.2%	−7.8%	−26.3%
Bell Mediums				
1983 - 1986	2,438,515	2.62	2.01	4.63
1987 - 1990	2,472,091	2.31	2.39	4.69
Percent change		−11.8%	+18.9%	+1.3%

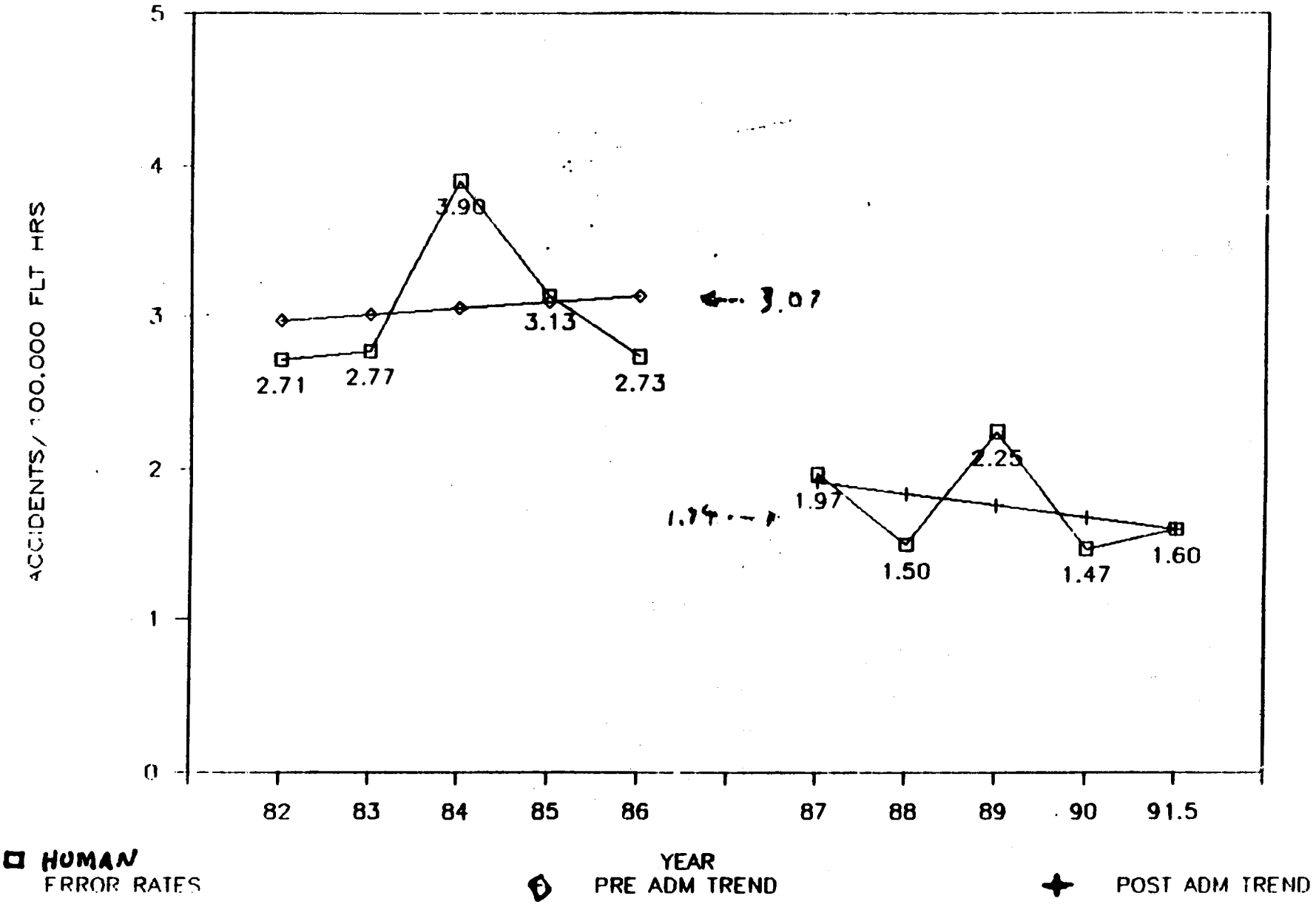
Table 15. Safety education effects on human error accident rates NTSB/FAA (USA-Registered)

Type of Helicopter	Rate* Before (84 - 86)	Rate* Since (87 & 88)	Percent Changes
Single piston	11.16	10.92	−2.2%
Non-206 single turbine	4.11	3.07	−25.3%
Twin turbine	2.56	1.61	−37.1%
206 single turbine**	3.40	1.76	−48.2%

*Human error accidents per 100,000 hours
**Concentrated HELIPROPS safety education

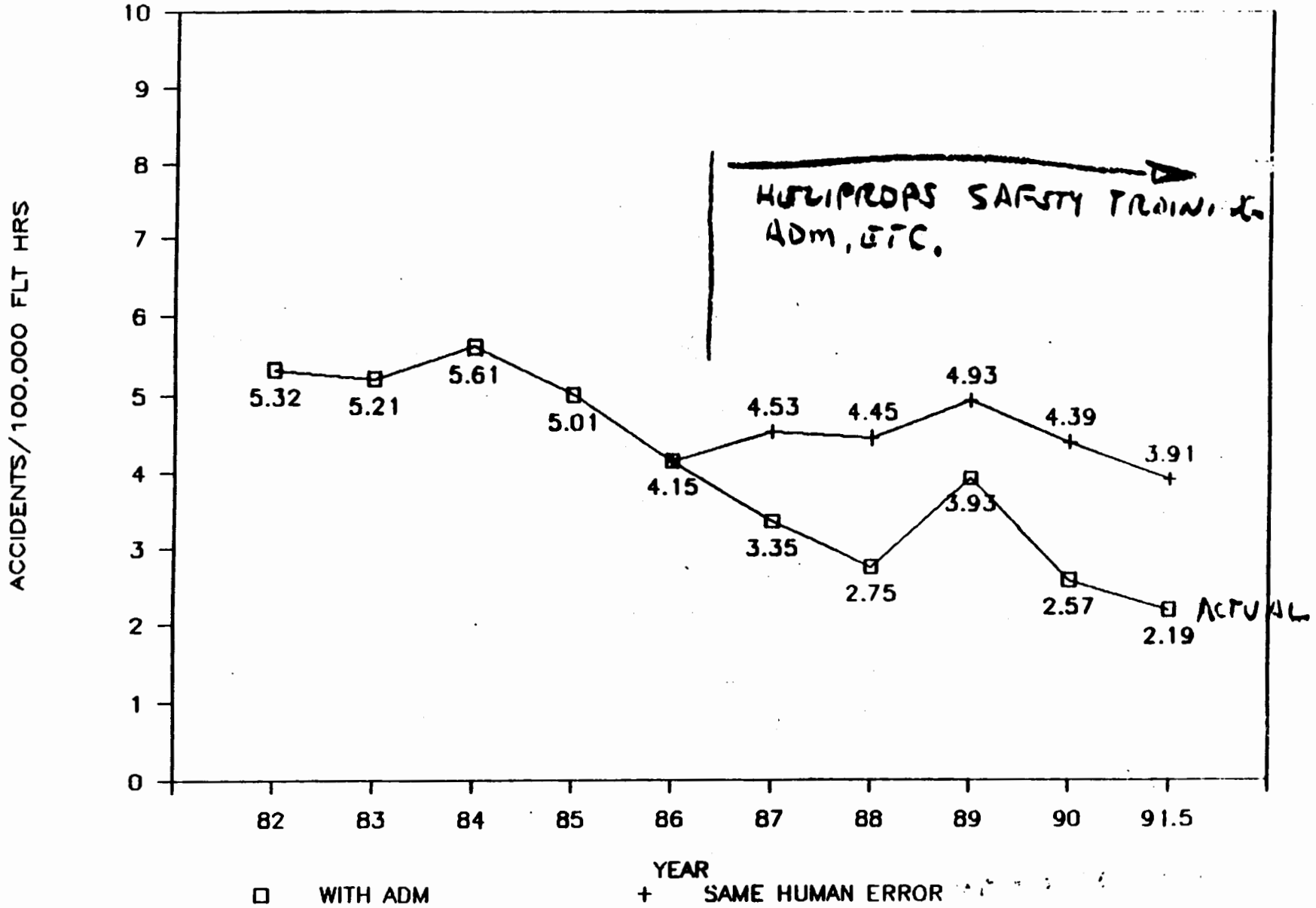
206 HUMAN ERROR ACCIDENT RATES

USA, 1982 TO JUNE 1991



206 ACCIDENTS RATE WITH & WITHOUT ADM

USA, 1982 TO JUNE 1991



CEPET

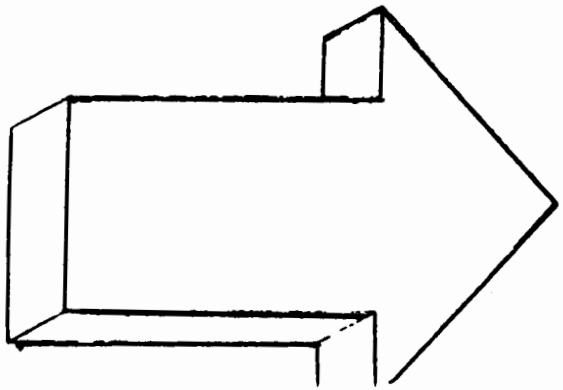
Cockpit Emergency Procedures Expert Trainer

PERSONAL COMPUTER (3.5" & 5.25")

DECISION MAKING SIMULATOR

SEGMENTS
- -EMERGENCY PROCEDURES
- -DECISION MAKING IN SCENARIOS
- -ASK QUESTIONS OF AN EXPERT

AVAILABLE ON MODELS
- 206BIII
- 206L-3
- 212/412



JUDGMENT TRAINING

Roy G. Fox

Chief Safety Engineer
Bell Helicopter Textron

MEASURING RISK IN SINGLE-ENGINE AND TWIN-ENGINE HELICOPTERS

Conclusion:

The human error accident rate for Bell 206 pilots receiving ADM training from 1987 to 1991 was significantly different from the human error rate for Bell 206 pilots from 1982 to 1986 to a significance level of 0.05.

MEASURING RISK IN SINGLE- AND TWIN-ENGINE HELICOPTERS

ROY G. FOX

BELL HELICOPTER TEXTRON, INC.

January 1992

Reprint of article presented at the 2nd Asian Vertiflite Seminar, sponsored by the American Helicopter Society, Singapore, February 24, 1992

Bell Helicopter TEXTRON

A Subsidiary of Textron Inc.

MEASURING RISK IN SINGLE- AND TWIN-ENGINE HELICOPTERS

Roy G. Fox
Chief Safety Engineer
Bell Helicopter Texton, Inc., Fort Worth, Texas

ABSTRACT

Safety is the management of risk. Many decisions are made by businesses, government agencies and individuals using their perceptions of an aircraft's safety. Public perception of safety can deny the introduction or expansion of aviation in specific areas. Decisions to buy, use, repair, install improvements, insure, sell, and replace aircraft are all related to perceived safety. Likewise, governmental restrictions and rule-making are based on the perceived deterioration of safety, as in the proposed single-engine helicopter restrictions of ICAO Annex 6. Accurate aircraft safety measurements are thus essential to bring perceived and actual safety together. Such accuracy also provides realistic corrective actions for safety problems and evaluation of desirable and undesirable aspects of different aircraft configurations, as well as allowing individuals to determine their risk in flying in specific types of aircraft. Existing safety measuring methods are discussed, along with the advantages, disadvantages, and correctness of each method. Recent safety training and its effects are discussed, related to improved pilot judgment and significant reductions in accident rates--without any regulatory changes.

INTRODUCTION

Safety has always been a paramount concern in aviation. Safety is not an absolute; rather, it is a relative measure of the risk involved when flying in an aircraft. Several methods are used by publications that attempt to measure safety. Some of these methods are misleading and inaccurate, and create the perception of a low level of safety in helicopters. Misconceptions about helicopter safety can cause overly restrictive regulations and prohibit the use of safe aircraft. Thus, accurate measuring of helicopter safety is crucial to the helicopter operators and the flying public.

Presented at the 2nd AsianVertiflite Seminar, sponsored by the American Helicopter Society, Singapore, 24 February 1992.

There is a continuing question of whether an occupant is safer in a single-engine helicopter or a twin-engine helicopter. Some proponents say that two engines must be better than one. Others say, "We have two engines in commercial fixed-wing airplanes; therefore, helicopters also need two engines." However, facts do not support application of "fixed-wing thinking" to helicopters. Helicopters have unique uses and designs and are operated in difficult environments. Thus, helicopters are different from fixed-wing airplanes. One must look at all causes of accidents and injuries, not just at components like engines or tail rotor blades. This paper addresses the safety issues for both single-engine and twin-engine helicopters.

Accident data from the United States of America (USA), the United Kingdom (UK), and Canada were analyzed to determine the risk to occupants of single- and twin-engine powered helicopters. These three nations (States) account for about 82% of all known (non-Soviet bloc) civil helicopters. Although the subject of this paper is rotary wing aircraft, the methodology is equally applicable to fixed-wing airplanes.

WHY MEASURE SAFETY?

Many important decisions made by businesses, government agencies, and individuals are based on the perceived safety of an aircraft. Decisions to buy, use, fix, improve, insure, and sell or replace an aircraft are related to perceived safety. Likewise, government operational prohibitions are based on the perceived deterioration of safety. For example, the recent Amendment 1 to International Civil Aviation Organization (ICAO) Annex 6, Part III (Ref. 1) establishes three categories of helicopter performance and recommends certain operational limitations. The categories are

Performance Class 1. Includes multiengine helicopters that are capable of continuing normal operations with one engine inoperative, regardless of when the engine fails.

Performance Class 2. Includes multiengine helicopters that are capable of continuing flight after one engine fails, except that a forced landing would be required following an engine failure between takeoff and a specific point and between a specific point and landing.

Performance Class 3. Refers to single-engine helicopter operations; a forced landing would be required after an engine failure.

Amendment 1 to ICAO Annex 6, Part III recommends prohibition of the use of Performance Class 3 single-engine helicopters for instrument flight rule (IFR) flights, night flying, flights out of sight of the earth's surface, flights with cloud ceilings of less than 600 feet or visibility less than 1,500 meters, and flights to elevated structures (heliport). ICAO itself does not regulate world standards; however, it recommends that individual member states adopt its criteria into their own regulations. The United States and many other countries have not adopted the recent recommendations of ICAO Amendment 1 to Annex 6, Part III.

Since single-engine helicopters account for three out of four helicopters in the world, adoption of this amendment would have a drastic effect on the helicopter community and on the public benefit derived from helicopter use. Some single-engine helicopter operations will no longer be performed, due to the higher costs involved, if twin-engine helicopters are mandated. Most multiengine helicopter operations are conducted in Performance Class 2. Since the accident data do not discriminate between performance classes, the safety comparisons of Performance Classes 2 and 3 from the available data is accomplished in this paper by looking at the differences between single-engine (Performance Class 3) and multiengine (Performance Class 2) operations. The performance class restrictions on helicopter operations in accordance with the ICAO Amendment 1 change includes the prohibition of single-engine helicopter operations involving transport of passengers, cargo, or mail for remuneration or hire, and general aviation uses. This prohibition is based on a perceived belief that twin-engine helicopters are always safer than single-engine helicopters in all environments. Thus, accurate helicopter safety measurements are critical to ensure that perceived safety and actual safety may be similar. Such accuracy also allows prioritized correction of safety problems and the evaluation of desirable and undesirable aspects of different aircraft configurations. This is of personal importance to an individual, allowing a person to determine his risk when flying in a specific type of aircraft.

Why Worry about Safety?

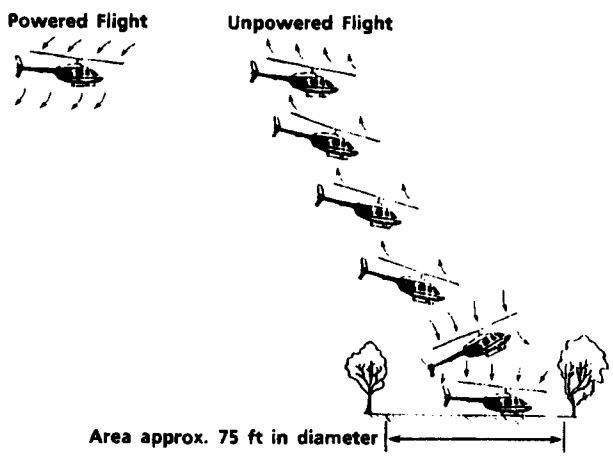
Why do people worry about safety in the first place? The primary reason is that no one wants to get hurt or die. Since none of us wants to think about our own death or injury, we tend to tell ourselves "I am never going to be in an accident, therefore I won't have to worry about being injured or killed." The next step in this internal stress coping action is to assume that all that is needed to accomplish the goal is to prevent all accidents. This internal protection mechanism helps each of us go through all of the stresses of each day. Aviation accident prevention is based on this concept: "If I can prevent the emergency, I won't have to worry about my pain and my death." This human coping mechanism works well for the average individual; but management (aviation and regulatory) must go beyond to first determine the actual risk and subsequently manage the risk to an acceptable level. *Safety is the management of risk.*

HELICOPTERS AND AIRPLANES RESPOND DIFFERENTLY TO POWER LOSS

If a power loss occurs, the resulting emergency landings are significantly different for airplanes than for helicopters. To maintain control of an airplane, its airspeed must stay above wing stall speeds until ground contact. This means the airplane airspeed at ground contact will be typically 60 to 100 knots. This high speed requires a shallow approach angle and a long cleared landing site. Any obstructions (e.g., trees, buildings, fences, or ground irregularities) will be impacted with significant crash forces and resulting injuries.

Conversely, all helicopters have a safety feature capability to make an unpowered, controlled landing, called "autorotation." Figure 1 shows the airflow during this emergency procedure. The pilot controls the pitch of the main rotor blades at all times. In normal flight under power, the air is pulled through the main rotor disc and thrust downward, providing lift to hold the helicopter in the air and controlling the aircraft. In unpowered flight or an emergency descent, the pilot enters autorotation and changes the pitch on the main rotor blades to allow the air to come upward through the main rotor disc as the helicopter is descending. This airflow turns the main

rotor blades like the wind turns a windmill. The pilot prevents overspeeding of the main rotor by converting some of this energy being gained to lift. Thus, the spinning main rotor acts like a parachute and a near-constant descent rate is maintained. The main rotor blade structure/weights store this rotational energy in a manner similar to a giant flywheel. Since the helicopter is fully under control, the aircraft can be maneuvered to the best landing site, allowing a steep approach into a confined area. Upon approaching the selected landing site, the pilot flares (aircraft nose is pitched up) to reduce the airspeed for a slow touchdown. The pilot then converts the stored rotational energy in the spinning main rotor back to lift and gently lands the helicopter. The typical autorotation rate of descent at touchdown is lower than a normal landing of a scheduled airline landing on the runway. The helicopter forward airspeed at touchdown will typically vary from 0 to 5 knots, so emergency landings can and have been achieved in very small spaces.



1-N109

Fig. 1. Helicopter autorotation.

Helicopters Have Different Missions and Uses

Using National Transportation Safety Board (NTSB) accident data for 1982 through 1985 for USA-registered helicopters, the type of mission underway at the time of accident was determined (Ref. 2). As shown in Table 1, single-piston, single-turbine, and twin-turbine helicopters are used in the same missions but in varying degrees. Single-piston helicopters have a concentration in relatively high risk areas of flight training, personal use, and agricultural work, where relative low cost is a driving factor. These types of usage are major contributors to the safety record for single-piston helicopters. If twin-turbine helicopters performed similar missions and were operated like the single-piston helicopters, the twin-turbine helicopter accident rate would rise significantly.

Table 1. Helicopter missions at accident NTSB data 1982 - 1985 (% of accidents)

Type of Operations	Single Piston	Single Turbine	Twin Turbine	All Helicopters
Personal	26.2	24.4	16.0	24.9
Business	9.4	23.6	32.0	14.9
Instruction	21.3	2.0	8.0	14.4
Executive/ corporate	0	5.6	16.0	2.4
Agricultural	29.8	8.8	4.0	21.9
Observation/ survey	5.1	5.2	0	5.0
Public use	1.1	4.0	8.0	2.3
Ferry/ Positioning	2.3	4.8	16.0	3.6
Other work	4.8	21.6	0	10.6

Helicopter Fleet Is a Mixed Fleet

The U. S. FAA Civil Aircraft Registry for August 1990 shows the following distribution of helicopters (Table 2). The 34 military surplus twin-piston helicopters on the Registry were not included. However, the numbers of aircraft on the Registry can be misleading, because it includes many aircraft that are wrecked, being salvaged for parts, under repair, stored, or used as static (nonflying) aircraft. Thus flight hours are a better indicator of actual aircraft usage. Flight hours by model series were extracted from the U. S. Federal Aviation Administration (FAA) General Aviation Activities and Avionic Survey annual reports for the same time period. If the FAA estimated flight hours for a model for two or more years of the 5-year period, those flight hours were used. The accidents of that model series were used if flight hours occurred in the year of the accident. If no hours or one year of flight hours were estimated by the FAA reports, the accidents and flights hours for those affected models were deleted from the study. The author considers this data to be the best available and therefore has used it in this

Table 2. USA-registered helicopters by engine type (FAA data)

Type of Engine	Number of Helicopters (11-31-90 Registry)	Flight-hours flown 1984 – 1988	Flight-hours (%)
Single piston	5,371	2,961,252	25.9
Single turbine	3,642	7,035,846	61.5
Twin turbine	1,108	1,442,116	12.6
Total helicopters	10,121	11,439,214	100
Aircraft with most flight-hours: 206 single turbine only	2,092	5,215,001	45.6

paper. The usable models with flight hours were then arranged in groups: single-piston, single-turbine, and twin-turbine helicopters, and the most common helicopter, the Model 206. The Model 206 flew 45% of all helicopter flight hours during the 1984 through 1988 time period. The Model 206 is the most prominent model and is used as a standard by which other helicopters are typically compared. The single-turbine engine Model 206 will be shown by itself as well as being in the generic single-turbine fleet throughout this paper.

The Canadian, UK, and USA helicopter fleet flight-hours shown in Table 3 indicate that these helicopter fleets are also varied. The Canadian accident and flight hour data from the Transportation Safety Board of Canada and Canadian Aviation Statistics Centre were for the period 1982 through 1987. The United Kingdom accident data and flight hours from the Civil Aviation Agency were for the period 1980 through 1987. The mixture of the UK fleet flying is significantly different from that in Canada and the USA. This helps to explain why attitudes and helicopter usages vary among ICAO States. The most common helicopter flying in the UK was the S-61 twin turbine, which accounted for 28.2% of the UK flight-hours whereas the Model 206 made up 12.3%.

Disregarding home-built and experimental helicopters, it is estimated that of approximately 15,200 rotorcraft in the world (excluding the Soviet bloc states) that 12,511, or 82%, of these rotorcraft are in the USA, the UK, and Canada. Thus the conclusions from these data should be applicable to the remaining helicopters in the non-Soviet-bloc world. The helicopter data are presented by configuration groups of single piston (SP), single turbine (ST), and twin turbine (TT).

MEASURING SAFETY

Now that we have some indication of the helicopter activities, the next step is to measure safety or determine relative risk. There are various methods used; some are useful and others are misleading. Using the total number of accidents that have

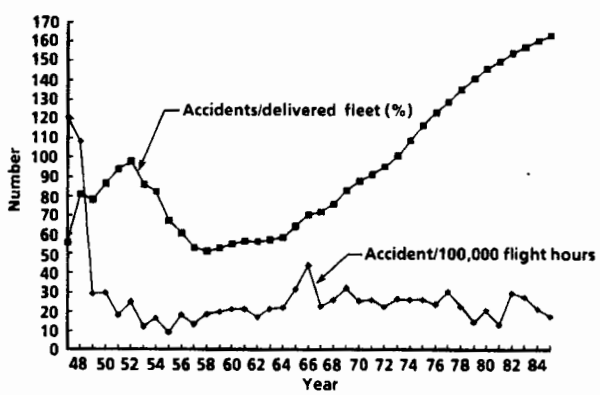
Table 3. USA, UK, and Canada civil helicopters by engine type (flight-hours flown)

Engine Type	USA (84 - 88)	UK (80 - 87)	Canada (82 - 87)	USA /UK / Canada Combined	%
Single piston	2,961,252	91,737	190,894	3,243,883	21.3
Single turbine	7,035,846	239,548	2,078,376	9,353,770	61.5
Twin turbine	1,442,116	932,474	242,696	2,617,286	17.2
Total helicopters	11,439,214	1,263,759	2,511,966	15,214,939	100
Most common aircraft: 206 single turbine	5,215,001	155,648	1,471,675	6,842,324	45.0

occurred for a model is probably the most misleading method. This primitive method does not account for fleet size and subsequent usage/exposure over the years and should be avoided. Accident-per-amount-of-exposure methods are more appropriate.

Accidents per Fleet Ratio

One attempt to address the effects of fleet size is to determine the ratio of accidents to the size of fleet in existence at the time of comparison. This approach is only slightly better than counting accidents. The ratio is determined by counting the number of accidents that have occurred on a specific model in the USA since its introduction. The total accident history number is then divided by the latest "estimated" number of active helicopters of that model in the USA. The ratio technique is inaccurate and misleading because it (1) disregards the changing fleet size over the years, by only using the latest year's "active" fleet, (2) looks at models in different periods of their service life, and (3) disregards the different amount of flying done by various models. Also, the number of accidents will increase as a model fleet continues in use. In Figure 2, the Model 47, which is the oldest civil helicopter model, suggests what may happen to all other models as they mature in the future. The number of accidents from 1958 through 1963 were estimated from accident trends before and after that period. Since the number of "active" helicopters are seldom known, the actual numbers of civil aircraft delivered with a U.S. Registry number were used. Note that the last Model 47 was delivered in 1973 in the USA. The total number of accidents grows each year and far exceeds the number of aircraft delivered. Obviously, the ratio of total accidents to an existing fleet is going to be different depending on when that ratio is calculated. If the ratio



1-N110

Fig. 2. Model 47 accident/fleet ratio.

is determined within two years of model introduction, the ratio will probably be low. Five, ten, fifteen years later, the ratio continues to increase regardless of the true model safety. Also shown in Figure 2 is the annual accident rate per 100,000 flight hours. Note that the accident ratio continues to climb to about 160% as of 1985 even though the accident rate is basically decreasing over the last three years. This disparity will be present for all other models and is dependent on when in the model's life cycle the ratio is computed.

Accidents per Departure

When comparing vastly different types of aircraft, it was apparent that some types spent the majority of their flight time in the more hazardous flight phases of takeoffs and landings. Thus the accident rate per departure (or mission) was used. This approach answers the question "Is the likelihood of this mission failing greater or lesser for Means A vs. Means B?" but is not concerned with how long Means A or Means B takes to accomplish the mission. For example, if the mission is to get a person from Point X to Point Y, the following means of travel can qualify for the task:

- -Rocket
- -Jet airplane
- -Helicopter
- -Train
- -Automobile
- -Boat
- -Balloon
- -Walking.

The number of accidents that occurred from the time of departing Point X and arriving at Point Y would then be determined for each means of travel. When divided by the number of missions attempted, this becomes the accident rate per departure.

Helicopters can perform some missions which no other transportation means can achieve. These unique missions, involving hovering or very slow flight, cause very short flight times, and result in a large number of takeoffs and landings. Since large airplanes spend the vast majority of their flight time in cruise rather than in takeoff/landings, comparisons with helicopters are somewhat biased. A study in 1981 included a look at Part 135 unscheduled air-taxi helicopter safety related to airplane air carriers (Ref. 3). The helicopter operators surveyed flew 603 single- and twin-turbine helicopters during the

subject period (1977 through 1979). The percentage of singles vs. twins is no longer available; however, the percentage of single turbines vs. twin turbines is available for 1983, which is the nearest period. The 1983 U.S. Registry indicates a mix of 83% single turbines and 17% twin turbines. The mix in the helicopter survey group should have been similar. The accident rate per flight hour for the combined turbine helicopter fleet compared to the air carriers is shown in Figure 3A. This shows that the helicopter accident rate per flight hour was slightly better than that of commuter (regional) air carriers. To account for time spent in the more hazardous phases of flight (i.e., takeoff and approach/landing), the accident frequency is based on number of departures (i.e., takeoffs). The helicopter accident rate per 100,000 departures was 73% lower than commuter air carriers, as shown in Figure 3B. The helicopter rate was much closer to the rate for the large certificated air carriers. Figure 3C, fatal accident

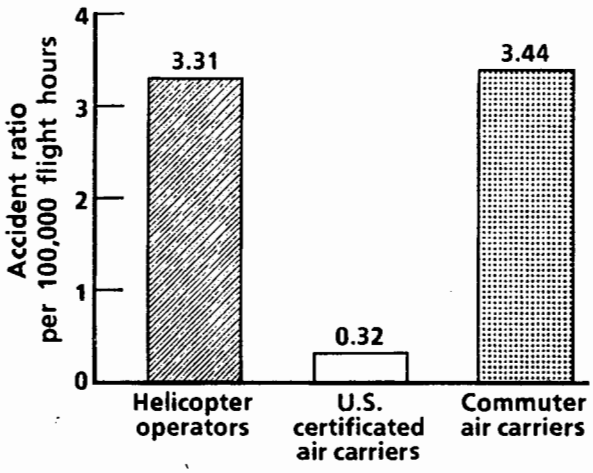


Fig 3A. **Accident rate per flight hour (all causes).**

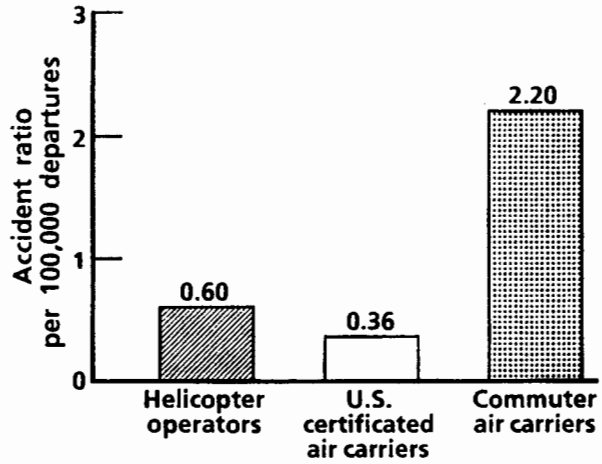


Fig 3B. **Accident rate per departure (all causes).**

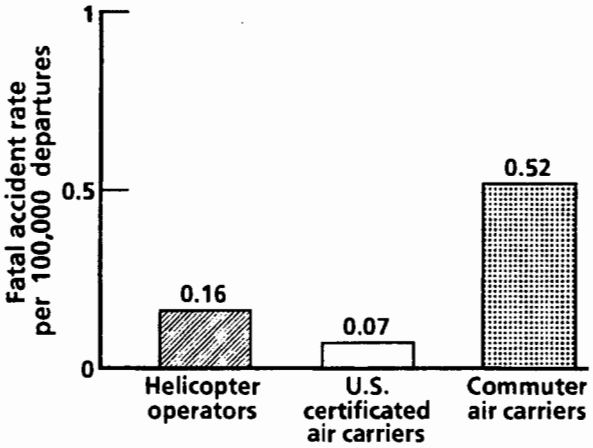


Fig 3C. **Fatal accident rate per departure (all causes).**

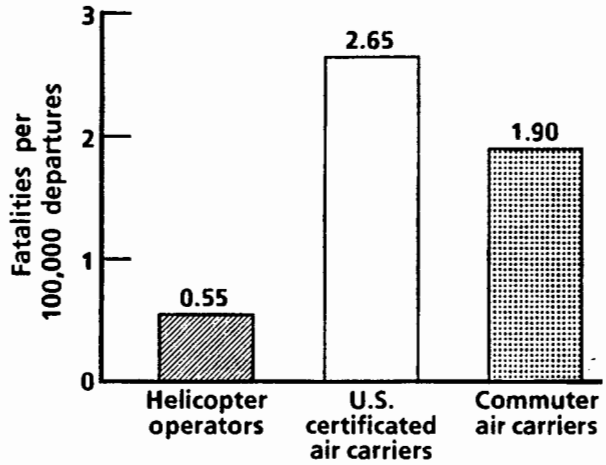


Fig 3D. **Number of fatalities per departure (all causes).**

* Part 135 helicopter operators survey.

** National Transportation Safety Board, Special Study, *Commuter Airline Safety* (Reference 4).

1-N111

Fig. 3. Accident and fatality rate comparison (1977 – 1979).

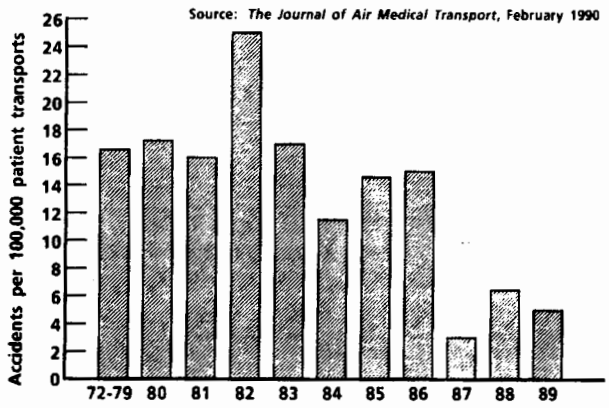
rate per departure, shows that the helicopter rate was 69% lower than the commuter air carriers. Figure 3D shows comparable data for fatalities per departure. In this case, the helicopter rate is 71% lower than commuter air carriers and 79% lower than certificated air carriers. The helicopter industry in general is safer than perceived by those outside of this industry, considering the amount of time spent in hazardous phases of flight. This also indicates the variability of potential safety perceptions, depending on the method of measurement.

The offshore oil industry in the Gulf of Mexico gives a good indication of the safe operation of turbine helicopters (Table 4). In 1990, there were 1,855,345 takeoffs and landings. About 1,500,000 of these takeoffs and landings were at offshore platforms. There were 3,958,525 passengers moved by helicopter. Of the 619 helicopters in the Gulf of Mexico, 138 (22%) are IFR equipped. Single-turbine helicopters account for 349 (56%) of the total helicopter fleet. This significant usage of single-turbine helicopters indicates that single turbines are being operated safely from elevated platforms and over water.

This method based on departure exposure is accurate for determining the risk to mission accomplishment, but is not accurate for determining safety. Safety is related to "freedom from harm, injury, or loss and should be counted in terms of time of individual occupant exposure.

Accidents per Patient Transport

This recent safety measurement variation is used by the emergency medical services (EMS) community. This accident rate is the number of EMS aircraft accidents that occur divided by the number of patients transported during the same time period. This unique approach uses the EMS primary function of "moving patients" as the basis for comparison with the safety of other modes of "moving patients." This approach is appropriate for only that medical transport mission comparison of mission completion, not safety of the crew and patient. Figure 4 (from Ref. 5) shows the annual EMS helicopter accident rates per 100,000 patients transported. It cannot be used to compare with "non-patient-carrying" aircraft. Since many of the EMS helicopter accidents occurred without a patient onboard (e.g., en route to pickup, returning after transport, or repositioning), this is a mission-oriented measurement (similar to "per departure"), rather than "per human" exposure.



1-N112
Fig. 4. EMS accidents per patient transport operation.

Accidents per Passenger Mile

Accidents per passenger mile is another "per mission" measurement, with an adjustment for the distance traveled. Fixed-wing scheduled air carriers and fixed- and rotary-wing air taxi operators have

Table 4. Gulf of Mexico helicopter safety data

Year	Fleet Size	No. of Accidents	Flight-hours	Departures	Accidents per 100,000 Departures	Accidents per 100,000 Flight-hours
1987	708	17	691,655	2,101,850	0.80	2.46
1988	599	10	455,330	1,384,000	0.65	2.20
1989	608	9	515,770	1,885,571	0.48	1.74
1990	619	9	533,761	1,855,345	0.49	1.69

passenger-carried information from revenue flights; but General Aviation and helicopters, in general, do not. Thus comparisons are seldom made in this area. Limitations of "per mission" measurement are easily noted by comparing the safety of an 80-knot aircraft with a 400-knot aircraft, both having the same number of passengers and accidents per passenger mile. Some people try to interpret this as the same level of occupant safety. However, the slower machine is in the air five times as long as the faster aircraft for the same distance. Therefore, the slower aircraft must have only one fifth of the accident rate per flight hour of the faster aircraft. This dichotomy is due to the primary concern being "per mission" and not related to "per human"or occupant safety. Accident per passenger mile is only meaningful if your primary concern is mission completion of moving a passenger a given distance, not the safety of the occupants.

Accidents per Flight-hours

The most common method presently used is "accident rate per 100,000 flight hours." This accident rate per hour is the number of accidents of a model for a specific period of time divided by the hours flown by those aircraft over the same time period. This accident rate per 100,000 flight hours is an good method to determine the aircraft damage cost expected in a model fleet or the likelihood of aircraft damage. Table 5 shows the accident rates per 100,000 flight hours for USA General Aviation fixed-wing and rotary-wing aircraft in descending order.

Helicopter accident rates for the 1980s from the USA, the UK, and Canada for the time periods of Table 3 are shown in Table 6.

AIRWORTHINESS VS. OPERATIONAL ISSUES

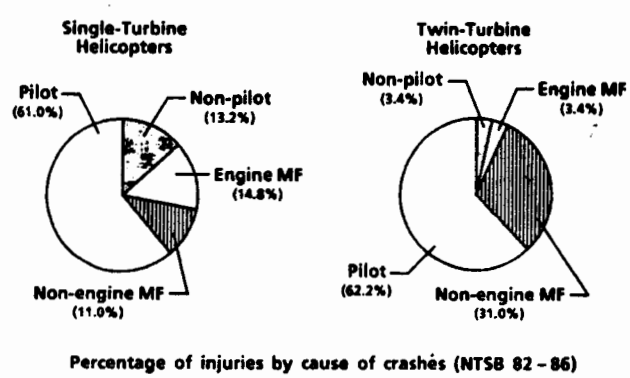
The causes of accidents resulting in serious (major/fatal) occupant injury were determined (Ref. 6) using NTSB data from 1982 through 1986 for single-turbine and twin-turbine civil helicopters, as shown in Figure 5. Engine material failure (MF) initiated the crashes that caused 14.8% of the serious injuries to occupants of single-turbine helicopters, as compared to only 3.4% for the serious injuries to occupants of twin-turbine helicopter accidents. If you stop here with only this one piece of information, the obvious conclusion is that two is better than one. However, consider only material failures other-

Table 5. USA-registered general aviation accident rates (NTSB/FAA data 1984 - 1988)

Type of Aircraft	Accidents per 100,000 flight-hours
Single-piston helicopter	17.83
Single-piston airplane	8.55
Single-turbine helicopter (all)	5.49
Twin-piston airplane	5.12
Twin-turbine helicopter	4.37
Bell Model 206 single-turbine helicopter	4.28

Table 6. 1980s USA, UK, and Canadian accident rates (all causes) (accidents per 100,000 flight-hours)

Type of helicopter	Canada (82 - 87)	United Kingdom (80 - 87)	United States of America (84 - 88)
Single piston	33.53	73.79	17.83
Single turbine (all)	9.86	17.12	5.49
Twin turbine	4.67	4.83	4.37
Model 206 single turbine	8.70	14.07	4.28



1-N113
Fig. 5. Seriously injured occupants by accident cause.

than-engine or non-engine MF. Only 11.0% of the seriously injured occupants were in single-turbine helicopter crashes initiated by non-engine material

failures as compared with 31.0% in twin-turbine helicopter crashes. This is an indicator of the detrimental effects of complexity and more parts. If you were to consider only this last piece of information, the obvious approach should be to ban all twin-turbine helicopters and only use single-turbine helicopters. Actually, the total material failures, engine and non-engine, should be considered together, which yields percentages of seriously injured occupants due to all types of MF-caused accidents of 25.8% for occupants in single turbines and 34.4% for occupants in twins. This is consistent with the greater number of parts and increased complexity present in twins. Since deaths or injuries do not only occur as a result of engine-related factors, it is essential that all other factors be considered as well, both material failure and nonmaterial failure (i.e., human error). The accident rates for the combined U.S. helicopter fleet (all helicopters) and the individual types are shown in Table 7.

Engine material failures are just one of the material failures (also called airworthiness failures) that cause accidents; the remaining non-engine material failures that caused accidents are also shown in Table 7. The single-piston accident rate per 100,000 flight-hours for non-engine material failure accidents is the highest rate, followed by twin turbines, all single turbines, and (with the lowest rate) the Model 206 single turbine. Table 7 shows the combined engine and non-engine material failures (e.g., all airworthiness failures), and indicates that the accident rate for all airworthiness failures in twin turbines is significantly lower than for single pistons, and slightly lower than for all single turbines, but still 51.4% higher than the single-turbine 206 rate. From an overall airworthiness standpoint, there is no justification to require twin-turbine engines on *ALL* helicopters for *ALL* mission applications.

Statistical Significance

Individual yearly airworthiness failure accident rates will vary from year to year due to the random natures of rare events like accidents, as shown for turbine helicopters in Table 8. The statistical significance of the single- and twin-turbine helicopter accident rates was used to determine if the rates for all their accidents due to airworthiness failures were significantly different or not. The statistical method used for this determination, "Student T," utilized a level of significance of 0.05. This technique can determine the likelihood that the two sets of data (i.e., accident rates of singles vs. twins) will be from the same group (i.e., not of significant difference), with the observed rate varying only due to chance. A level of significance of 0.05 indicates that

Table 7. USA-registered helicopter accident rates (Sources: NTSB/FAA for 1984 through 1988) (Accidents per 100,000 flight-hours)

Type of Helicopter	Engine-only Airworthiness	Non-engine Airworthiness	All Airworthiness	All Causes
All helicopters	1.22	1.08	2.30	8.54
Single piston	1.99	2.09	4.09	17.83
Twin turbine	0.35	1.25	1.59	4.37
Single turbine (all)	1.08	0.61	1.69	5.49
206 single turbine	0.88	0.17	1.05	4.28

Table 8. USA turbine helicopter fleet airworthiness-failure annual accident rates (NTSB/FAA data for 1984–88) (Accidents per 100,000 flight-hours)

Type of Helicopter	1984	1985	1986	1987	1988	Average (84 – 88)
Single-turbine helicopter (all)	1.65	1.95	2.04	1.59	1.30	1.69
Twin-turbine helicopter	1.76	0.95	2.14	1.92	0.98	1.59
Bell Model206 single-turbine helicopter	0.95	1.46	1.21	0.79	0.92	1.05

the statement being made will be wrong no more than 5 times out of 100. In other words, the statement being made will be correct 95 times out of 100. *The airworthiness-failure accident rates of singles and twins are not significantly different 95 times out of 100.*

Comparing the all-airworthiness-failure accident rates of the three ICAO States (the USA., the UK, and Canada) are Table 9 and Figure 6, which show the variability that is a function of the mix of aircraft models within a type and how they are used in the different ICAO States. The rates of twin turbines and Model 206s appear to be quite consistent. It is interesting to note that the single-turbine Model 206 has the lowest airworthiness accident rate in two of the three ICAO States and second lowest in the remaining State. *These data do not justify the ICAO Annex 6, Amendment 1 prohibition of single-engine helicopters.*

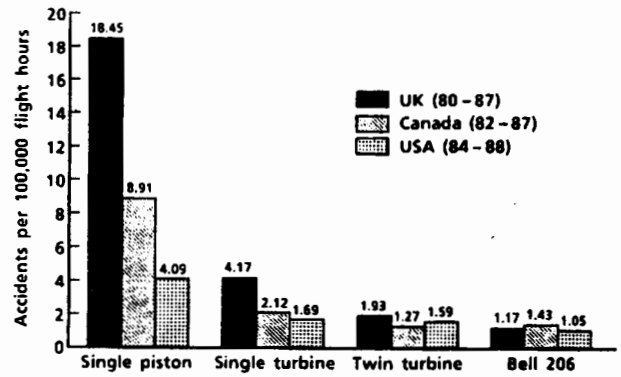
Table 9. 1980s USA, UK, and Canadian airworthiness-failure accident rates (Accidents per 100,000 flight-hours)

Type	Canada (82 - 87)	United Kingdom (80 - 87)	United States of America (84 - 88)
Single piston	8.91	18.45	4.09
Single turbine (all)	2.12	4.17	1.69
Twin turbine	1.27	1.93	1.59
Bell 206 single turbine	1.43	1.17	1.05

Time-Exposed Comparisons

Accidents are quite rare events. A trip around the world at the equator would take about 192.3 hours for a turbine helicopter flown at an average cruise speed of 130 miles per hour (113 kn) Thus, a comparison of the mean-time-between-accidents (MTBA) can be expressed in an exposure-time equivalent of around-the-world trips. The MTBA is the number of hours flown by an aircraft type divided by the number of accidents (e.g., the inverse of the accident rate).

The around-the-world trip equivalent for the Model 206 and twin-turbine helicopters shows the



1-N114
Fig. 6. Airworthiness failure accident rates for UK, USA, and Canada in the 1980's.

remoteness of accidents from all airworthiness failures (both engine and non-engine). Using the data from Table 7, the MTBA for the Model 206 and a twin-turbine helicopter can be derived as 95,283 hours and 62,893 hours, respectively. Thus, on the average, the expectancy of an accident due to airworthiness failure was equivalent to 495 trips and 327 trips for the Model 206 and for twin-turbine aircraft, respectively. Likewise, the number of years for one aircraft to fly those around-the-world trips, without landing (i.e., continuous 24-hr/day flying) would be about 10.9 years and 7.2 years for the Model 206 and a twin-turbine helicopter, respectively. The chance of an accident, for both types, is extremely remote. *There is no safety justification for prohibiting single-engine or twin-engine helicopters from flying over congested areas or hostile-earth surfaces.*

Accident Site Surface

A failure of the engine does not automatically mean that an accident will occur. The type of terrain can influence whether the results of autorotation will be merely a forced landing or an accident with damage. If the engine fails over terrain hospitable to an emergency landing, such as prepared hard surfaces, unprepared ground, soil, fields, open terrain, or helipads, then autorotation is possible without further damage, and no accident occurs. If the helicopter is equipped with an aircraft flotation system, an emergency landing can be made on water. Such a water landing is not considered an accident unless significant aircraft damage or an injury occurs; with significant damage or injury, it is considered an accident. If the terrain is inhospitable (e.g., covered with trees, swamps, or walls), the emergency landing may result in an accident.

The known impact surfaces for all U.S. civil helicopter accidents from 1984 through 1988 are shown in Table 10. Accidents from all causes are included. Unknown site surfaces, inflight breakups, midair collisions, and unknown types of ground surfaces, accounting for about 28% of the accidents, were deleted as nonusable. The surface category "Trees/swamp/wall" includes terrain where a successful emergency landing without damage is not likely after a power loss or any other immediately required emergency landing. This was the surface for 10.5%, 10.7%, and 8.8% of the impacts for twin turbines, single turbines, and the Model 206, respectively. Thus, the accident history for impacts into trees (inhospitable sites) has not been different for twin-turbine than for single-turbine helicopters. Care should be taken in reading Table 10, as the exposure over these surfaces has not been the same for each type of aircraft. The value of many helicopter jobs over inhospitable terrain cannot justify the use of an expensive helicopter, and therefore a small, less expensive helicopter is often used. The table is indicative of how aircraft are being used, rather than pointing out relative danger of impact sites. For example, the twin-turbine helicopter had 33.3% of its known-site accidents in the "Prepared surface/pad" category, which is the least dangerous impact site. Overall, the table shows that basically all types of impact sites have occurred with all types of helicopters.

Table 10. Known accident impact sites

Type of Impact Surface	Model 206 Single Turbine (%)	All Single Turbines (%)	Twin Turbines (%)
Clearing/ brush/burm	6.4	5.4	0
Rough ground/ rocks	11.1	10.7	0
Ground/soil/ unprepared	23.4	31.9	12.3
Prepared surface/pad	19.3	17.1	33.3
Trees/swamp/ wall	8.8	10.7	10.5
Buildings	1.2	1.0	3.5
Auto/boat/ railroad	0.6	0.6	3.5
Snow/ice	2.9	3.7	1.8
Water	24.0	17.4	29.8
Rig	2.3	1.3	5.3

Fatal Accidents per Flight-hours

Safety is typically defined as a condition of freedom from harm, injury, or loss. Thus, measurement of those accidents involving fatal injuries is relevant to the relationship of safety to human suffering. A fatal accident is an accident in which at least one person is fatally injured. A fatal accident rate is the number of fatal accidents per 100,000 flight hours. Table 11 shows the fatal accident rate for the three types of helicopters in the USA. These aircraft types have about the same fatal accident rate. This method is still inaccurate, as it does not account for the number of people onboard that had the chance of being fatally injured. For example, for a twenty-place helicopter with ten people onboard, there is five times the chance of someone being killed as for a five-place helicopter with two people onboard. This is due to the difference in ten people impacting the ground in one airframe vs. two people in the other airframe. Obviously, the number of helicopter seats is not important; but the number of people onboard *is* important. Thus, fatal accident rates are misleading when they are related to aircraft airframe accidents, not to the occupants. Fatal accident rates should not be used to measure safety.

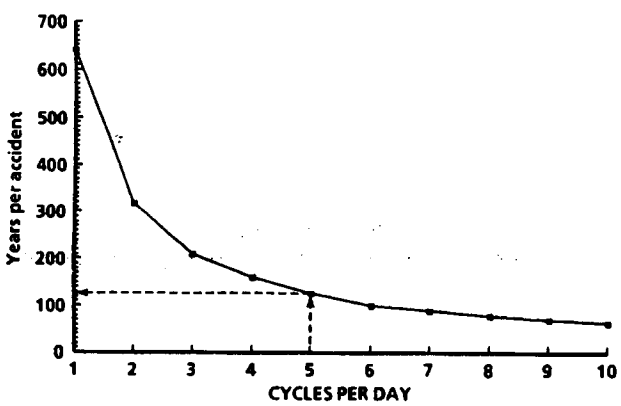
Table 11. USA helicopter fatal accident rates (NTSB/FAA 1984 - 1988)

Type of Helicopter	Fatal accidents per 100,000 flight-hours
Single piston	1.89
Twin turbine	1.10
Single turbine	1.08

Risk around Heliports

Some neighbors around heliports have voiced concern about safety of helicopters approaching or leaving a heliport. These concerns are unfounded. The actual risk to the neighborhood from helicopters was analyzed (Ref. 7) to determine the likelihood of a helicopter accident in a 0.8-km (1/2-mile) radius of the heliport/airport using NTSB/FAA data for the

period of 1975 through 1978. This analysis was based on the Model 206 accident rate of 4.33/100,000 flight-hours. A 3-minute time period spent over the 0.8-km (1/2-mile) radius for an approach or landing was used to be conservative. One can then calculate the likelihood of an accident within the 0.8-km (1/2-mile) radius which becomes a function of how many takeoffs and landings are made. The term "cycle" is used for the combination of a takeoff and landing (e.g., 6 minutes over the 0.8-km [1/2-mile] zone). Using the average number of cycles per day for a year, the average number of years between accidents can be determined using Figure 7. For example, for a busy heliport conducting 5 cycles per day (182.6 hours per year over the 0.8-km [1/2-mile] zone), the expected average of years between accidents should be 128 years. One accident in 128 years is an extremely remote possibility.

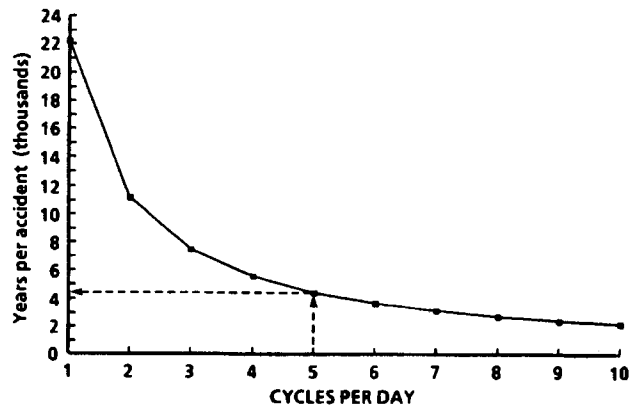


1-N115

Fig. 7. Helicopter accidents within 0.8 km (1/2 mile).

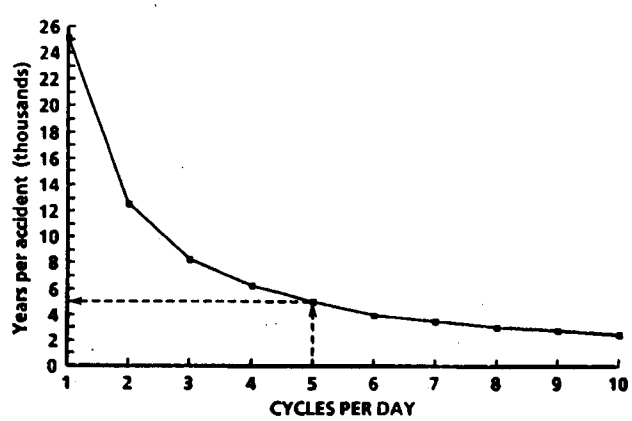
Likewise, the likelihood of a helicopter striking a residence or building within a 0.8-km (1/2-mile) radius of a heliport can be estimated using Figure 8. The accident frequency used was for all helicopter accidents (i.e., single piston, single turbine, and twin turbine) involved in striking a residence or building. For the 5-cycle-per-day case, a helicopter striking a building/residence is estimated, on average, once every 4,000 years. This is extremely remote. Figure 9 shows the likelihood of an on-the-ground person (i.e., not a crewman or passenger) being injured within this 0.8-km (1/2-mile) radius. For the 5-cycle-per-day case, this shows that the average number of years between injuries to be about 5,000 years. This is likewise extremely remote.

The heliport operating at 5 cycles per day over a one-year period is an extremely busy heliport. For a



1-N116

Fig. 8. Helicopter strikes residence or building (within 0.8-km radius).



1-N117

Fig. 9. On-the-ground personal injury (within 0.8-km radius).

private heliport or limited use that averages less than 1 cycle per day over each year period, the risk is significantly lower. Using 1 cycle per day average, the likelihood of an accident in the 0.8-km (1/2-mile) area, the likelihood of striking a residence/building, and the likelihood of an on-the-ground person being injured are once in 635 years, 22,400 years, and 25,000 years, respectively. These average year values in themselves are not important but their magnitudes indicate the extremely remote threat due to helicopters operating over a congested area.

If only airworthiness-failures-caused accidents are considered using the Model 206 and twin-turbine helicopter rates of Table 7, a comparison of the likelihood of an airworthiness-caused accident over the neighborhood can be made. For a constant usage of 5 cycles per day, the expected accident frequency within the 0.8-km (1/2-mile) radius of the heliport is

an accident once in 34.4 and 52.2 years for a twin-turbine helicopter and Model 206 single-turbine helicopter, respectively. Thus one should expect the Model 206 accident significantly less often than the twin-turbine helicopter accident. The likelihood for both helicopter types is extremely remote. *There is no more justification to prohibit twin-turbine helicopters than there is to prohibit a Model 206 from flying over congested (e.g., populated) areas.*

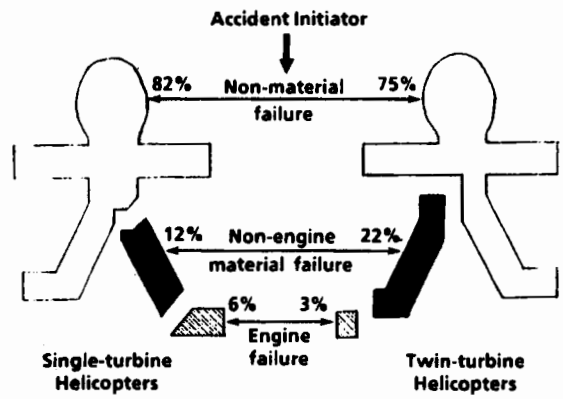
Causes of Accidents Resulting in Fatalities

A study of Bell civil and military turbine-powered helicopter accidents around the world was conducted to determine the accident causes that resulted in fatalities. The period of time was January 1970 through March 1987. The size of the Bell turbine fleet delivered at the time was approximately 19,700 single-turbine aircraft and 1,800 twin-turbine aircraft. An engine failure was the initiating cause that resulted in 6% of all fatalities in single-turbine helicopter accidents and 3% of all fatalities in twin-turbine helicopter accidents as shown in Figure 10. However, the percentage of fatalities due to remaining airworthiness failures (non-engine material failures) was 12% and 22% for single-turbine and twin-turbine helicopters, respectively. Thus the total percentage of fatalities for all airworthiness failures was 18% for single-turbine helicopters and 25% for twin-turbine helicopters. It is apparent that more complex twin-turbine helicopters will have a higher total number of material failures (engine and non-engine) with a corresponding higher total number of fatal injuries than a simpler single-turbine helicopter.

OCCUPANT RISK

Relative Risk of Serious Injury

Accident rates compare the frequency of aircraft being damaged to such an extent that it must be reported as an accident. In the majority of accidents, there is no serious injury, so the accident reporting is basically an aircraft damage mishap frequency. This information is useful in forecasting the number of aircraft expected to be damaged, repaired, replaced, or other activities based on aircraft damage. It does not address the safety of the occupant. A person's safety is a personal issue, applied on an individual basis, not an aircraft basis. Risk must be limited to an individual occupant to be meaningful. Occupant safety must be determined for each individual occupant based on his individual exposure.



BHTI turbine helicopters 1970 – Mar 87

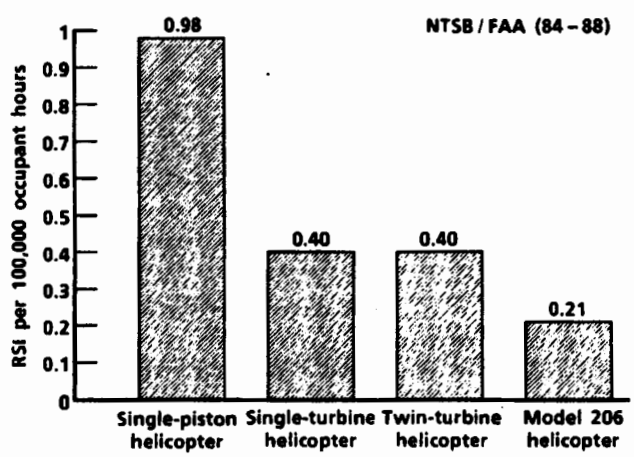
1-N118

Fig. 10. Percentage of fatalities by accident initiator.

This is done with Relative Risk of Serious Injury (RSI). RSI is the probability of an accident occurring times the probability of serious (e.g., major or fatal) injury. The RSI is calculated by

$$\text{RSI} = \frac{\text{Number of accidents}}{\text{Flight-hours flown}} \times \frac{\text{Number of people with major or fatal injury}}{\text{Total number of people on board in accidents}}$$

The RSI or an individual occupant risk of serious injury for every 100,000 occupant-hours of exposure is shown in Figure 11 for all airworthiness-failure causes. This is the true measure of occupant safety related to the aircraft design.



1-N119

Fig. 11. RSI from airworthiness failures.

Thus an occupant's risk of a serious injury due to accidents caused by all airworthiness failures is the same in the generic single-turbine and the twin-turbine helicopters. An occupant's risk in a Model

206 single-turbine helicopter is nearly half that of being in a twin-turbine helicopter. *Based on the risk to helicopter occupants, there is no justification to prohibit the use of single-turbine helicopters.* The reasons that risks are generally higher in twins than singles are

1. More parts and increased complexity yield more non-engine material failures, causing accidents.
2. There are more freestanding passenger seats and resulting seat failures in twins.
3. There are more passenger seats without shoulder harnesses.
4. More fuel cells leads to increased likelihood of post-crash fires.

The introduction of passenger shoulder harnesses, energy-attenuating seats for all occupants, and the Crash Resistant Fuel Systems may lower the RSI. FAA Amendments* will require shoulder harness and dynamically tested energy-attenuating seats for all occupants in future helicopter designs. A shoulder harness is required for all seat locations in all helicopters manufactured in the USA or for use in the USA after September 16, 1992.** FAA Notice of Proposed Rule Making (NPRM) 90-24 in progress is addressing a requirement to include a Crash Resistant Fuel System in large and small helicopters to minimize thermal injuries due to post crash fires. Thus occupants of future helicopter designs may have even lower risk of serious injury, regardless of what causes the accidents.

A study (Ref. 8) of U.S. Army helicopter accidents and injuries found similar results to the risk in civil helicopters. Table 12 shows the RSI for the four Army helicopters in the study. The UH-60 is the twin-turbine helicopter and the remainder are single-turbine powered. The risk of injury was lower in the single-turbine helicopters than in the twin turbine. There are several reasons for this; two of these are the greater complexity of the UH-60 and its higher impact speeds. Again, one must be careful to evaluate all aspects of an aviation system since improvements in one area can have detrimental effects in another area. One of safety's goals is to strive for the best mix to get the lowest risk.

*FAA Amendments 27-25 and 29-29 of November 13, 1989.
**FAA Amendments 21-69, 27-28, 29-32, and 91-223.

Table 12. Relative risk of serious injury (RSI) in Army helicopters (Class A & B)

Type of Helicopter	RSI / 100,000 occupant hours
UH-60	5.11
AH-1	4.13
OH-58	2.91
UH-1	1.36

Safety Is Risk Management

To manage your risk, you must first understand your total risk. Prudent risk management will reduce both probabilities in the RSI formula (probability of an accident times probability of a serious injury) and achieve the lowest possible risk. Accident prevention programs attempt to reduce the probability of an accident. Training, standardization, equipment, maintenance, and positive management attitude toward safety are key factors in reducing the probability of an accident occurring. This important effort must continue. Pre-accident planning, flight following, aircraft/occupant survival gear and training, and aircraft crashworthiness features address the reduction of the probability of serious injury. This important effort must also continue. To believe that you can prevent all accidents is analogous to a baseball team made up of only a pitcher and a catcher. The other baseball team members will not be needed, because the pitcher will always strike out the batter. Totally effective accident prevention is a worthwhile goal, but realistically, it is doubtful that it will ever happen. The aviation community must work to reduce both probabilities.

UNIQUE SAFETY ENVIRONMENTS

Australian CAA Study of Single vs. Twin Helicopter Transfer of Marine Pilots

The Australian Civil Aviation Authority (CAA) conducted a study (Ref. 9) in September 1989 to respond to a recommendation to mandate twin-engine helicopters be used rather than single-engine helicopters for marine pilot transfers. A marine pilot is a special ship pilot that boards the ship and brings that ship into a harbor. He likewise will pilot a ship out of a harbor to open sea after which he is returned to land. A single-engine helicopter is used for this

transfer to and from the ship. A recommendation had been made to mandate the use of only twin-turbine helicopters. The study looked at accident data from around the world. Applicable paragraphs from the study findings and conclusions are quoted below:

> "The CAA believes that greater weight should be given to actual accident performance figures (where these are available) than to theoretical assumptions about fatal accident rates derived from, say, engine shutdown. For example, it would fail to account for the trade-off between the extra reliability from having a second engine and the lower reliability of the more complex helicopter system. . . ."
>
> "Informal advice from the industry suggest that it would approximately double the cost of transferring marine pilots by helicopter if twin-engine helicopters were made compulsory. . . .
>
> "This report does not pursue costing further because of the lack of conclusive evidence of twin-engined helicopters leading to lower fatal accident rates. . . .
>
> "Marine Authorities have indicated that in some cases the higher cost of twin-engined helicopters could lead to them reverting to launches to transfer pilots, which these authorities have stated is less safe than transfer by helicopter. . . .
>
> "CONCLUSION
>
> "The CAA believes the proposal to regulate to make it compulsory to use twin-engined helicopters for the transfer of marine pilots to and from ships should be shelved at this time. The CAA concludes that the proposal should be shelved because the present very low engine-failure accident rate is acceptable, and because there is no conclusive evidence that using twins would result in a lower fatal accident rate."

This Australian study is a good example of the importance of analyzing accident data for factual information considering all aspects.

Helicopter Accidents at Elevated Structures

The accident histories of turbine-powered helicopters at elevated structural platforms were compared to determine if the ICAO Annex 6 prohibition of single-engine helicopter operation from elevated structures was justified. The USA accidents from NTSB for 1984 through 1988 were used. There were no distinctions made between type of operations being conducted such as air transport vs. aerial work. Since the vast majority of helicopter uses are for hire or remuneration in some aspect, it is not possible to use the ICAO definitions. Many helicopter operations in the USA are not clearly within the ICAO definitions and also can change categories of work several times in a day. For example, a helicopter used for emergency medical services (EMS) can fall in the operational categories of business, unscheduled air taxi, and other work. If the owner is a government/ municipality entity or the civil operators contract with a government agency for helicopter services, the same helicopter can also be considered to be in the category of "public use." The accident data should be considered in its entirety to be consistent with flight hours.

Each NTSB helicopter accident narrative for the latest available data (1984 through 1988) was used to determine all accidents that occurred on an elevated landing site or approaching/departing the elevated structure. A key word search was used for the following words in the NTSB accident narratives. These key words were

Elevated	Helipad	Net
Structure	Helideck	Rail
Platform	Heliport	Pad
Rig	Hospital	Raised
Roof	Building	Deck

The resulting accidents were then separated into movable landing structures or stationary landing structures. Accidents at movable landing structures of landing dollies, trailers, trucks, boats, barges, and portable landing structures were eliminated as not being applicable to the safety history of helicopters operating on an elevated structure. The stationary elevated structure accidents are those that were at rooftops or offshore platforms. There were no single-piston helicopter accidents related to stationary elevated platform structures, but some were on movable landing structures.

There were fifteen single-turbine helicopter accidents at stationary elevated platform structures. Twelve were at offshore platforms and three at a rooftop. Of the fifteen accidents, there were four power losses reported. There were no material failures found during the investigation of two of these power losses. The remaining eleven clearly resulted from human causes as follows:

Takeoff with aircraft tied down
Landing gear caught on safety net
Landing gear caught on deck obstruction
Main rotor blade strike
Blown off platform during engine start by wind
Elevator cover not removed prior to flight

There were thirteen twin-turbine helicopter accidents at elevated platform structures. Nine were at offshore platforms and four were at rooftops. Of the nine offshore platform accidents, two were due to material failures of tail rotor drive shafts and one pylon mounting failure allowing ground resonance. The remaining seven offshore platform accidents were human caused as follows:

Tail or tail rotor strike
Main rotor strike
Flight controls restricted (maintenance error)
Takeoff with wheel in safety net
Flight control loss

Of the four rooftop accidents, two were power losses due to fuel exhaustion. A tail rotor strike and a flight controls restricted (loose object in cockpit) made up the two remaining accident causes. Two of these twin-turbine helicopter accidents on stationary elevated structures were deleted prior to the accident rate calculation as no FAA flight-hours were available for the year of the accidents. These accidents were two twin-turbine SA-330J helicopters which were included above to show the types of accidents (i.e., 13 accidents) but are deleted in Table 13 when accident rates are used (i.e., 11 accidents). All single-turbine accidents (which were Model 206s) on stationary elevated structures were usable accidents.

Table 13 shows the USA elevated structure helicopter accident history for 1984 through 1988. This table also identifies the stationary elevated structure accidents that were related to power losses. For all accidents at elevated structures, the accident rates for the single-turbine and twin-turbine helicopters were 0.21 and 0.76 per 100,000 flight-hours, respectively. Thus the single-turbine rate was 72.4% lower than the rate for twin-turbine helicopters. Considering only those related to power losses, the single-turbine and twin-turbine helicopter accident rates were 0.071 and 0.139 per 100,000 flight-hours, respectively. The single-turbine rate for power loss accidents was 48.9% lower than the twin-turbine

Table 13. USA elevated structure turbine helicopter accident history (1984-1988)

Type of Aircraft	Fleet Flight-hours	All Accidents	All Causes Rate*	Power-Loss Accidents	Power-Loss Accident Rate*
Single	7,035,846	15	0.21	5	0.071
Twin	1,442,116	11	0.76	2	0.139
Using hours of aircraft models involved in accidents:					
Single					
206	5,215,001	15	0.29	5	0.096
Twin					
222	932,438	11	1.18	2	0.214
AS355					
B0105					
S58T					
S76					

*Accidents per 100,000 flight-hours

rate. The second part of Table 10 is similar, except the fleet flight-hours used were for only the models that were involved in elevated structure accidents. In this analysis, the single-turbine and twin-turbine accident rates for all causes were 0.29 and 1.18 per 100,000 flight-hours, respectively. The single-turbine rate was 75.4% lower than the twin-turbine rate. Considering the power loss accidents, the single-turbine and twin-turbine accident rates are 0.096 and 0.214 per 100,000 flight hours, respectively. The single-turbine rate for power-loss accidents was 55.1% lower than the twin-turbine rate. Thus, the actual helicopter accident experience related to helicopter operations at a stationary elevated structure does not justify the prohibition of single-engine helicopters.

Offshore Helicopter Operator Experience

Petroleum Helicopters, Incorporated (PHI) is the largest commercial helicopter operator in the world. Most of their flying is offshore oil support and as such provides an excellent example of safe helicopter operations in a difficult environment. The latest PHI-furnished flight-hour information and NTSB accident data on PHI helicopters from 1984 through 1988 indicate that single-turbine helicopters can be and are operated safely over water and onto elevated platforms. PHI flight hours in Table 14 show that 66.1% of their flying was in single-turbine helicopters. Table 15 compares the PHI accident rates for all causes with the U.S. civil helicopter fleet rates for all causes. PHI accident rate for single-turbine helicopters was 65.8% and 62.2% lower than the general U.S. single-turbine and twin-turbine helicopter rates, respectively. This shows that a safe operation can be and is being conducted using single-turbine helicopters without severe operational regulations like the recent ICAO Annex 6, Amendment 1 change.

Table 14. Petroleum Helicopter, Inc (PHI) flight-hours (1984 through 1988)

Type of Aircraft	Flight-hours	Percentage of Total
Single turbine	1,064,439	66.1%
Twin turbine	545,670	33.9%
Total	1,610,117	100%
206 only	982,611	61.0%

Table 15. PHI vs. USA helicopter accident rates (Accidents from NTSB, Hours from FAA and PHI, 84 - 88)

Type of Aircraft	US (NTSB/FAA)	PHI (NTSB/PHI)
Single turbine	5.49	1.88
Twin turbine	4.37	1.65
206 only	4.28	1.73

*Accidents per 100,000 flight-hours

Time of Accident, Day vs. Night

Since the actual flight hours flown at different times of the 24-hour day are not know, it is difficult to determine relative safety of night flight vs. daylight flight. However, it is possible to approximate the distribution of flying at night by considering the random nature of material failures. For the period of 1982 through 1988, the USA distribution of accidents (all causes) by the time of day from NTSB data is shown in Figure 12. The breakpoints between light and dark were assumed to be 0600 and 1959 hours. This distribution of accidents should be conservative, as most flying is done during the summer months when the length of daylight is highest. This indicates that 91.8% and 82.8% of all single-turbine and twin-turbine helicopter accidents, respectively, occurred during daylight hours. Figure 13 shows the time of accident distribution of airworthiness-failure accidents (all material failures including the engine). For all airworthiness-failure accidents, 98.2% and 94.1% of single-turbine and twin-turbine helicopter accidents, respectively, are occurring in daylight hours. The two figures have similar distribution; thus accidents due to material failures do not appear to be adversely affected by lighting, and

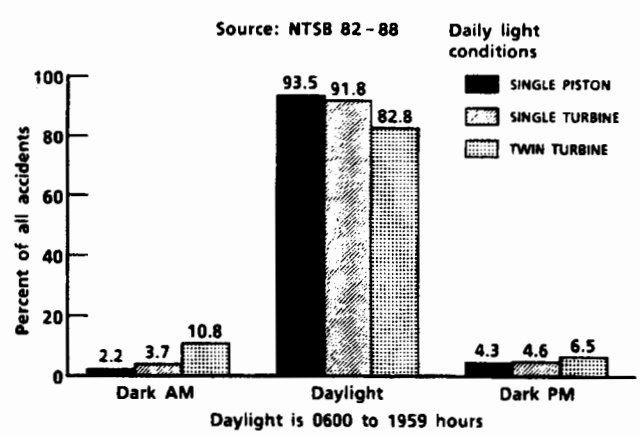


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Fig. 12. Time of accidents due to all causes.

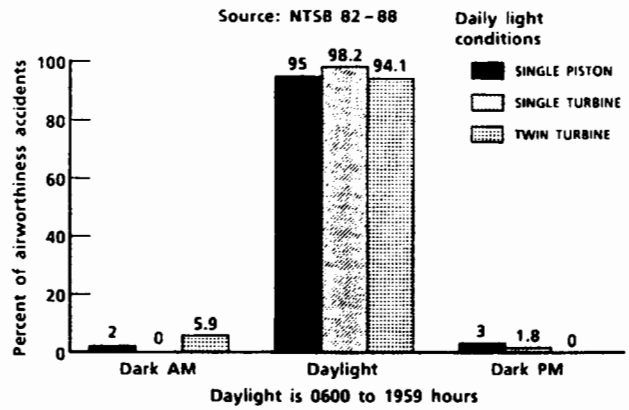

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Fig. 13. Time of accidents due to airworthiness failures.

therefore, there is no rationale to prohibit single-engine helicopters from flying at night.

The big difference in helicopter and fixed-wing aircraft emergency landings is that the fixed-wing aircraft requirement for a long cleared landing site increases the likelihood of injury during the final phase of the emergency. Conversely, a helicopter (regardless of the number of engines) can use a landing site that is quite small in comparison to the fixed-wing aircraft needs. Likewise, visibility at night is not as critical in a helicopter as in a fixed-wing airplane due to the helicopter's lower speed and greater maneuverability during autorotation.

Likelihood of Material Failure Accident at Night

Assuming a Model 206 and a twin-turbine helicopter flew 10 hours of darkness every night throughout one full year, each helicopter would fly 3,652.5 hours each year. Using the NTSB/FAA accident data for 1984 through 1988 (Table 7), the likelihood of an accident due to a material failure (which includes engine) for the twin-turbine helicopter is estimated at once in 17.2 years whereas the 206 likelihood is estimated at once in 26.1 years. Both of these likelihoods are extremely remote. Thus the likelihood of any material-failure-caused accident is 51.4% higher in a twin-turbine helicopter than in the single-turbine Model 206. Again, there is no rationale that supports the prohibition of night flights of single-engine helicopters.

BELL'S SAFETY TRAINING APPROACH

Accident data analyses can be used to determine if safety programs or other factors are making a change in the accident frequencies. Two out of three accidents are not caused by airworthiness failure but are basically due to human error. This is not a "pilot" problem, but a human problem (i.e., the problem is not merely related to the process of piloting, but to the larger problem of human limitations). Accidents caused by human error (generally called pilot error) are an extremely complex problem with a large number of root causes and an even larger number of potential solutions. Engineers and regulatory agencies are comfortable working on physical parts as their performance and failure modes are fairly predictable. Thus aviation safety efforts in the past have made significant gains in minimizing airworthiness failures. More attention is now being made toward understanding and eventual reduction of human error accidents. An engineering study in 1985 and 1986 into worldwide human error accidents of Bell civil helicopter models found that poor judgment was the common factor in all of these accidents (Ref. 2). Two directions of concentrated effort at Bell were launched in 1987 to aggressively attack the complex human error problem, with the emphasis on Judgment Training.

Individual Judgment Training Aid

Human Factors Engineering's approach was to develop an artificial-intelligence based software which would allow a pilot to use a personal computer (PC) as a judgment (decision-making) simulator. This is roughly a decision-making simulator equivalent of the present-day six-axis motion simulators that allow the pilot to test his motor skills without endangering his aircraft or his life. This program, called Cockpit Emergency Procedures Expert Trainer (CEPET), also includes emergency procedures training. A CEPET was developed for the Bell JetRanger (206BIII) and LongRanger (206L-3), with one for the 212/412 completed late in 1990. The CEPET is a long-term effort where an individual pilot can use the CEPET software and a PC to improve his safe decision-making skills. A CEPET package is provided with each new aircraft delivery starting in 1991. Pilots can also purchase a separate CEPET package.

Group Safety Training

The other direction was concentrated safety education. System Safety Engineering developed a 3-hour safety briefing for immediate use with groups of pilots/managers. This safety briefing presented by the Chief Safety Engineer includes how to measure

one's risk, what happens in a crash, how one can improve his chances of survival, causes of accidents, root causes of human error, and Judgment Training. Judgment Training emphasizes the use of all resources available to the pilot and is something of a single-pilot version of the Cockpit Resource Management (CRM) used in crew-served airplanes. Judgment Training emphasis is on situational awareness and internal pilot monitoring rather than crew interactions of CRM. Judgment Training is also called Pilot Decision Making (PDM) and Aeronautical Decision Making (ADM). Portions of the FAA study, DOT/FAA/PM-86/45, Aeronautical Decision Making for Helicopter Pilots (Ref. 10) are used in this safety briefing and the FAA report is given to the student for further self study. This safety brief is given at operator's and regional safety seminars and is included in Bell's weekly 206 pilot's ground school as part of the Helicopter Professional Pilots Safety (HELIPROPS) program.

Bell's Chief Training Pilot also conducts customer HELIPROPS safety briefings on safety awareness, professionalism, and management's role in safety. These safety briefings are held at Bell, customer sites, and regional safety seminars. In 1988, Bell's Customer Support and Service Department (CSSD) initiated the HELIPROPS program to add continuity and coordination of these safety education efforts. A HELIPROPS Administrator was assigned full time for coordination and to also conduct customer site and regional safety seminars. The HELIPROPS effort was spread to the other helicopter manufacturers with three companies trained in the techniques that were working for Bell. These companies then started their own safety training version of HELIPROPS.

The worldwide effects of this 4-year safety education effort on the human error accident rate since the Model 206 effort was fielded in 1987 is shown in Table 16. There have been over 5,000 Model 206 series helicopters produced or 70% of Bell's entire civil turbine helicopter model fleet. Bell also conducts pilot flight training in Model 206s. Based on these two factors, the concentrated safety education effort has been directed at Model 206 pilots. For comparison, the same worldwide data for Bell's medium civil helicopters models (i.e., 204B, 205A1, 214B, 212, 214ST, 222, and 412) are also shown in Table 16. These medium helicopter data indicate some reductions in human error causes but were offset with non-human-error causes; thus the accident rate for all causes was basically the same over the two 4-year periods. Conversely, accident rates due to human error in a 206 for the 4-year period before the initiation of this safety effort (1983-1986) and the four-year period since (1987-1990), show a 36.2% reduction. This is a significant safety improvement since we have covered only a portion of all Model 206 pilots in the world thus far. The overall (all causes) Model 206 accident rate is now reduced by 26.3%. Since many pilots fly helicopters in addition to the Bell Model 206, we can expect some spillover of the

Table 16. Worldwide Bell turbine accident rates (Rates per 100,000 flight-hours)

		Causes of Accidents		
Aircraft and Period	Flight-hours	Human Error	Non-Human and Unknown	All Causes
Model 206				
1983 - 1986	7,903,072	3.90	2.05	5.95
1987 - 1990	9,341,573	2.49	1.89	4.38
Percent change		−36.2%	−7.8%	−26.3%
Bell Mediums				
1983 - 1986	2,438,515	2.62	2.01	4.63
1987 - 1990	2,472,091	2.31	2.39	4.69
Percent change		−11.8%	+18.9%	+1.3%

Table 17. USA human error accidents involving weather

	Single Piston	Single Turbine	Twin Turbine	206 Single Turbine
Flight-hours				
84 - 86	1,899,081	4,167,156	821,679	2,997,911
87 - 88	1,062,171	2,868,690	620,437	2,217,090
HE WX Accidents				
84 - 86	26	40	7	25
87 - 88	8	8	2	5
HE WX Accidents per 100,000 flight-hours				
84 - 86	1.37	0.96	0.85	0.83
87 - 88	0.75	0.28	0.32	0.23
HE WX Rate Reduction	−45.3%	−70.8%	−62.4%	−72.3%

beneficial effects of Judgment Training (ADM), which should affect the overall helicopter-industry accident rate. Further, since the Model 206 flies most of the helicopter fleet hours, the industry accident rates will be lower.

Analysis of human error accidents involving weather shows a changing trend in the USA. NTSB accident data and FAA flight hours for 1984 through 1988 were divided, with an early period of 1984 through 1986 compared to the later period of 1987 and 1988. The results are Table 17. The year 1987 was the beginning of Bell's concentrated safety training programs to reduce human error accidents as discussed above. Thus the range of human error accident rate reductions due to poor weather decisions in the most recent time period has been significantly reduced between 45% and 72%. This reduction is due to safety training, not mandatory regulations.

The annual human error accident rates in the Model 206 were determined for the period of 1982 to mid-1991 to check the statistical significance at even longer periods. The FAA flight-hours for 1982 through 1989 were used. The flight-hours for 1990 and 1991 (through June 30) were forecast, using the trend of the previous 8 years of FAA data. The accidents used were from NTSB data (1982 through 1988, the latest available). The accidents occurring from 1989 through June 30, 1991 were estimated from Bell information. Figure 14 shows the Model 206 accident rates due to human error for the accident data period 1982 through 1987 (i.e., prior to the introduction of safety training) and the period 1987 through June 30, 1991 (with concentrated Model 206 safety training, including ADM). *The human error accident rate for the ADM safety training period (since 1987) is significantly different from the previous period 95 times out of 100. This reduction in accident rate has occurred with no changes to regulatory restrictions.* As a further check, the accident rate of the Model 206 for all causes was determined with and without the ADM safety training, as shown in Fig. 15. Curve A is the actual accident rate for the Model 206, with the ADM training effects since 1987. Curve B is the estimated accident rate for the Model 206 with a continuation of the consistent human error accident rate trend of 1982 through 1986 extended throughout the remaining years. The trend of the accident rates without ADM is consistent with historical accident rates. *The actual accident rates with ADM safety training (Curve A) are significantly different from that normally expected without ADM training (Curve B) to a significance level of 0.05.* In other words, 95 times out of 100, the two curves are significantly different.

The Canadian government is starting to integrate PDM into their pilot training requirements as of 1991. PHI, the largest U.S. helicopter operator, introduced Judgment Training as an integral part of their internal training which has subsequently cut their accident rates in half. Bell looks for further accident rate reductions as we continue this worthwhile effort. *Judgment Training (e.g., PDM or*

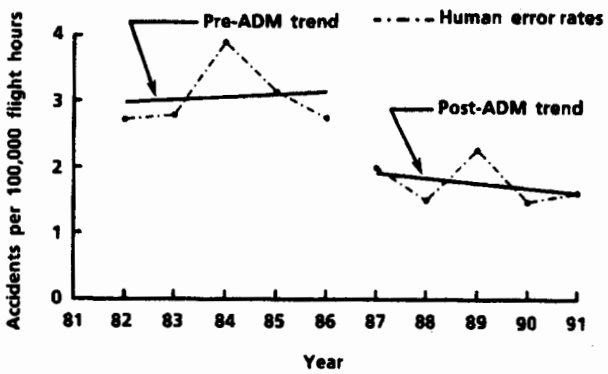

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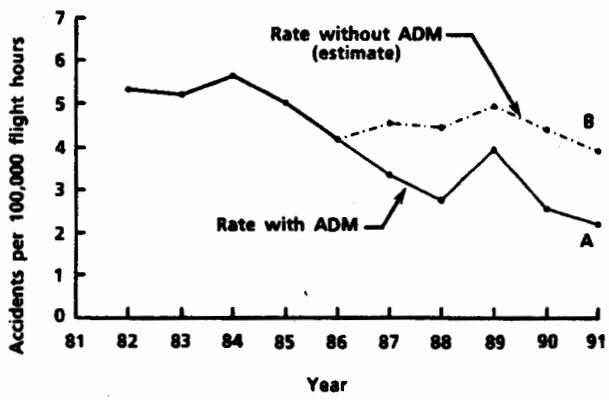
Fig. 14. Model 206 human error accident rates (USA, 1982 to mid-1991)



1-n123
Fig. 15. Model 206 accident rate with and without ADM (USA, 1982 to mid-1991).

ADM) has more safety improvement potential that the total elimination of all airworthiness failure causes (a primary goal since the start of aviation).

Consideration of the safety education effects of several manufacturers efforts on the human error accident rates of the types of helicopters in the USA is found in Table 18. This shows a significant reduction in human error accident rates in the turbine helicopter fleet. More work is needed in the single-piston fleet. Since safety education is an ongoing effort, it will take several years to reach all helicopter pilots.

CONCLUSIONS

Helicopters are not fixed-wing aircraft and therefore behave differently when undergoing any engine failure. The helicopter's ability to autorotate allows a low speed emergency landing from an engine failure and the selection of suitable landing sites. One should not make safety decisions on any one helicopter part without considering the safety aspects of all other parts and the human causes. Considering all airworthiness failures (all material failures including the engine), the twin-turbine helicopter accident rate is 1.5 times higher than in the single-turbine 206. Considering all accident causes, the twin-turbine helicopter accident rate is close to, but still higher than, the Model 206 rate. *Mandating twin engines does not reduce the likelihood of a material-failure-caused accident, but merely changes the types of failures that cause accidents.* Single-turbine accident experience related to elevated structures is better than for twin turbines. The risk to the neighborhood around a heliport from an airworthiness-failure-caused accident is lower for the single-turbine Model 206 than for twin-turbine helicopters. Mandatory use of twin-engine helicopters around the world does not make sense from a safety point of view. In some specific harsh environments such as the North Sea, the twin-turbine helicopter is, and should be, used. However, there are many environments and uses where the twin-turbine helicopter is not the best choice.

Table 18. Safety education effects on human error accident rates NTSB/FAA (USA-registered)

Type of Helicopter	Rate* Before (84 - 86)	Rate* Since (87 & 88)	Percent Changes
Single piston	11.16	10.92	−2.2%
Non-206 single turbine	4.11	3.07	−25.3%
Twin turbine	2.56	1.61	−37.1%
206 single turbine**	3.40	1.76	−48.2%

*Human error accidents per 100,000 hours
**Concentrated HELIPROPS safety education

Based on the preceding analyses, there are no statistically significant differences between Performance Class 2 (twin-turbine engine) and Performance Class 3 (single-turbine engine) accident rates, and therefore the restrictions placed on Performance Class 3 operations are unwarranted from a safety standpoint. Additionally, these restrictions can impose severe humanitarian and economic hardships by denying the less costly services that could be provided by a simpler and less restrictive Performance Class 3 single-engine helicopter.

The safety measurement method that should be used is strictly determined by the subject of primary concern. The denominator of the frequency rate will include this primary concern. If aircraft damage frequency is your primary concern, then an accident per aircraft flight-hour method is appropriate. If the mission is the primary concern, then the accidents per mission (e.g., launch, departure, takeoff, flight, trip, passenger mile or patient transport) method is appropriate. If the primary concern is the risk of an accident in a neighborhood without regard to the aircraft occupants, then years-between-accidents measurement for that specific neighborhood exposure is appropriate. With the safety of the aircraft occupant as the primary concern, measuring relative risk of serious injury per occupant flight-hour is the best method.

The recent concentrated Judgment Training/ADM/PDM efforts of manufacturers, operators, and regulatory agencies have made a significant reduction in human error accidents. This major reduction has occurred without any regulatory changes or limitations. Major improvements in helicopter safety for the future require the continuation and refinement of these safety efforts. Occupant risk in a helicopter is low now but the aviation community can, and must, reduce it further.

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PART III: PROPOSED ACTION PLAN TO IMPROVE ADM EFFECTIVENESS

DEVELOPING A NEW ADM PARADIGM ON WHICH TO BUILD

ADVANCED OR EXPERT

DECISION MAKING TRAINING

August 7, 1992

PROPOSED ACTION PLAN TO IMPROVE ADM EFFECTIVENESS

1.0 INTRODUCTION

ADM training benefits in terms of reducing human error accident rates were documented during the presentations at the workshop. Basic research needs, training implementation problems and the need for additional modeling work were also identified. This document provides the aviation industry and the FAA with a suggested roadmap to assist in the development of improved ADM concepts and training methods. The basic questions that will be addressed are:

- Can decision making tasks be identified and defined?
- What are the training objectives?
- What are the appropriate training strategies?
- How can the training effectiveness be evaluated?

2.0 GOALS

The central goal of this proposed plan is to provide a coordinated workplan which can be used to make the significant step from current ADM training to an enhanced, integrated ADM/CRM/AQP flight training concept. Although ADM is only one part of this overall system, it has been identified by the participants (operators, regulators and researchers) as the part which currently needs attention and development work. This goal supports the user's desire to avoid "add-on" material which increases training time and cost.

3.0 NEEDS

The proposed research supports the FAA's *National Plan for Aviation Human Factors* (NPAHF). The seventh objective of the NPAHF is: "to develop enhanced methods of training and selection for aviation system personnel". The NPAHF recognizes the need for realistic training in crew coordination, judgment and decision making in flight operations. The development of the proposed ADM training methods and models will provide critical input to specific "Flightdeck Environment" requirements of the National Plan in three areas:

1. The development and demonstration of an intelligent "human centered" advanced technology flightdeck.

2. The development of computer-based models of flightcrew decision making and other cognitive processes to serve as the basis for the design of new systems.

3. The development of new technologies for flightcrew performance measurement to answer questions about in-flight performance of both individual pilots and crews.

4.0 PROPOSED ACTION PLAN

This detailed Action Plan presents the work necessary to develop advanced ADM training programs. It includes tasks which should be started as early as possible because of the need for basic information as recommended by the participants at the workshop . It also includes a presentation of all subtasks necessary, as a minimum, to address the cognitive and decision demands required by different aircraft types, different missions and pilots/crews with different levels of experience.

Sections 6.3, 7.3 and 8.3 of Volume I of this report provided technical recommendations from the participants for future research and development requirements from commercial, military and general aviation perspectives. These recommendations were used along with the Key Concepts (Section 5.0) and Conclusions (Section 9.0) of Volume I as a basis for developing the following tasks.

Task 1 -- Defining the Structure of Decision Making Tasks
Task 2 -- Developing Training Requirements
Task 3 -- Specifying Training Strategies
Task 4 -- Evaluating Training Effectiveness

The basic work to be performed, the expected outputs and the flow of information are represented in Figure 1. An overview description of the four primary Action Plan tasks follows the figure. The specific analytical elements and subtask details of each task are described in Sections 4.1, 4.2, 4.3 and 4.4.

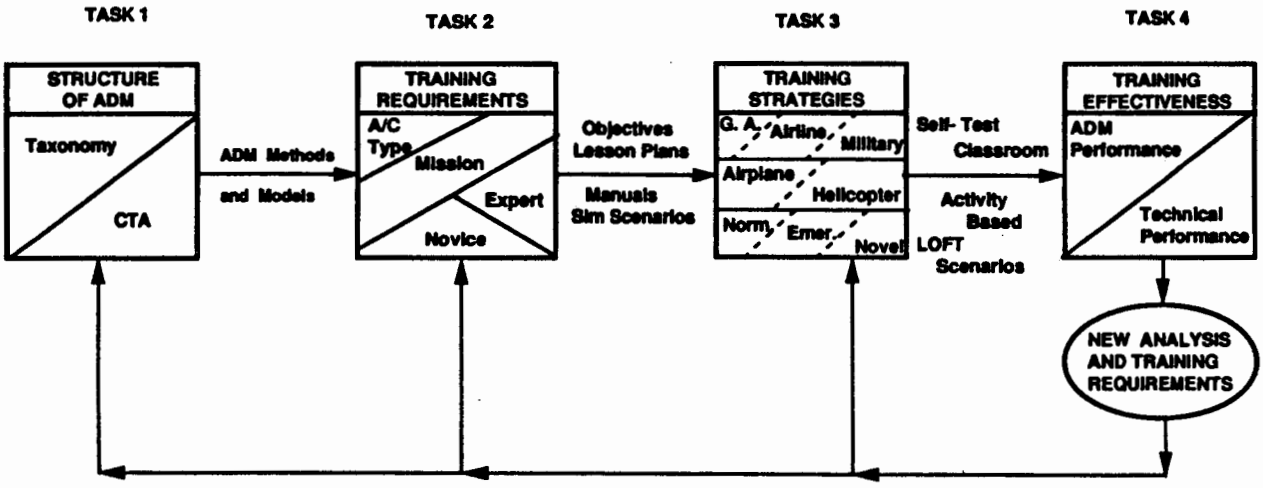

Figure 1 ADM TRAINING PROGRAM DEVELOPMENT TASKS

As shown in the figure, the first task is comprised of developing an ADM specific taxonomy and performing a comprehensive operational analysis of cognitive task demands (termed a Cognitive Task Analysis - CTA- by the participants). The primary outputs of Task 1 are expected to be the identification and definition of generalized ADM methods and models including: decision types, decision making styles and decision making capabilities (novice vs. expert). These outputs will be refined to formulate and develop ADM specific models for use throughout the training development process. The understanding and knowledge gained during the performance of Task 1 will also be used to specify preliminary training objectives.

Task 2 will begin the development of training requirements for the various training environments. These will include: aircraft type (airplane vs. helicopter and automated vs. non-automated flightdeck); type of operation (mission); single pilot vs. multi-crew; and, level of expertise (novice to expert). As proposed at the workshop, the initial work in developing training requirements might be limited to high and low workload missions such as the airline, air transport mission (low workload) and offshore, helicopter, single pilot IFR mission (high workload). The spectrum of experience from ab initio to ATP rated pilots should eventually be evaluated from a cognitive training needs viewpoint. However, this analysis could begin with the novice vs. recurrent training requirements specification since these are the two largest target audiences and also represent two extremes of the ADM spectrum. The outputs from this task are expected to be a refined set of training objectives. The analysis can then proceed to develop lesson plans and manuals to be used in an evaluation of alternative training strategies.

Task 3 will involve tailoring the training strategies to the spectrum of candidate training audiences. The different needs of general aviation, the airlines and the military will be considered. The large differences in availability of training facilities for centralized vs. de-centralized audiences (i. e., military vs. private pilots) and the affordability of the training will be the primary considerations in developing alternative materials, methods and tools. Expected outputs include individual study and self test manuals, context based classroom instruction, interactive training devices (computer based and interactive video) and simulator scenarios suitable for the LOFT environment.

Task 4 will evaluate the ADM taxonomy, models, training objectives, and training strategies in an integrated Training Effectiveness program. The scope and duration of this program is difficult to speculate on at this time. However, each training test plan will require the use of cognitive and skill performance measures. These are currently referred to as Behavioral and Technical "markers" in the CRM Advisory Circular. These markers require further R.D.T. & E. themselves, but some type of objective measures will be required to adequately assess whether or not the ADM training is operationally meaningful. The outputs from this task are expected to be refined training plans, strategies and methods. There will be some iteration between the initial evaluation outputs and each of the first three tasks.

4.1 Task 1 -- Defining the Structure of Decision Making

The basic work required in Task 1 of the analysis was generated from the workshop participants' expressed need for a better understanding and definition of aeronautical decision making. This includes the immediate need to begin R & D on a basic classification taxonomy for aeronautical decision making. The taxonomy development should be done in parallel with a detailed analysis of cognitive task demands by phase of flight. These definitional analyses would include both single pilot general aviation and commercial air transport mission or flight scenarios. They would also explicitly consider the differences between helicopter and airplane workloads and decision making demands. Figure 2 illustrates the steps involved in this task.

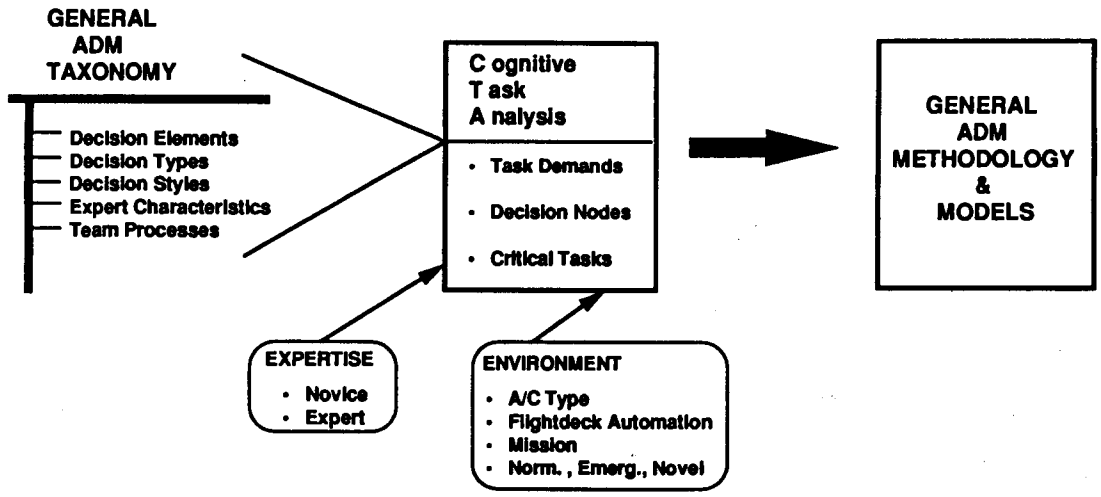

Figure 2 DEFINING GENERAL ADM METHODS AND MODELS

4.1.1 Technical Subtasks

As shown in Figure 1, the development of an ADM specific **taxonomy** and classification schema will include five subtasks:

1. Identifying the elements of a good decision (normal, emergency and novel situations should be considered)
2. Identifying, defining and developing types of decisions (initial group efforts identified Binary, Rule Based and Adaptive types. See Volume I Section 8.3)
3. Identifying decisional styles under various situations and task demands
4. Defining characteristics of expert decision makers
5. Identifying individual vs. team decisional processes (single pilot vs. crew)

The **Cognitive Task Analysis** will require selection of operational environments to be analyzed (e. g., air transport operations) and performing a detailed task demand

analysis for each flight phase (takeoff, climb, departure enroute climb, cruise, etc.). The decision making demands for each phase should be analyzed for complexity (high, medium, low) and the most complex decisional demands prioritized for more detailed analyses of the effects of expertise (novice vs. expert) and environment (automated vs. non-automated flighdeck).

The results of the taxonomy and CTA analyses will be used to characterize situation specific Aeronautical Decision Making. The spectrum from classical analytical decision making to the more recent naturalistic decision making paradigms will be analyzed for applicability. Appropriate ADM methods will be defined within this spectrum as a function of cognitive task demands. The goal of this analysis is to produce a compendium of tailored ADM methodologies and models for the variety of task demands and environments typically encountered by each type of operator. From this understanding of the decision making processes across environments, advanced ADM training materials, methods and models will be developed.

4.1.2 Applicable Resources

The performance of the proposed task should capitalize to the greatest extent possible on related research which has been completed or is still underway. Participants at the Workshop from the FAA, NASA, NTSC, the airlines and research companies are all currently involved in directly related basic research. In addition, the University of Colorado at Boulder (a participant), the University of Texas, the University of Illinois, Massey University in New Zealand and others are actively developing and testing the types of methods and tools which may need to be integrated in the proposed task. What is needed is the establishment of an ADM development project with centralized oversight and a core group of Subject Matter Experts (SMEs). This will help ensure the achievement of all specific objectives. The oversight should be in the form of a Technical Monitor who would act as an integrator and facilitator between other research efforts as well as establish the statement of need for additional research to support the tasks described. The FAA is the logical agency to provide this function due to the fact that it is the only central agency that has supported and directed research in ADM, CRM, EDM and AQP. The FAA Technical Monitor could, perhaps, be supported by Technical Representatives from NASA, NTSC, USAF, etc. Table 1 was prepared to illustrate the responsibility of the Technical Monitor and indicates the FAA in this role as an example. The areas of known expertise and expressed interest/capabilities are indicated as applicable resources for each subtask. This analysis may be incomplete, but it is important as a first step in illiciting comments and action on the proposed work.

4.1.3 Proposed Scope

A one year initial project effort is proposed culminating with a second ADM workshop to report on research findings, status and future directions. A one to three year continuing effort may be required to attain the desired general ADM methodology and tailored models, training objectives and select target groups.

Table 1 RESEARCH RESOURCES AVAILABLE FOR DEFINING THE STRUCTURE OF ADM

	GOVERNMENT				INDUSTRY		
SUBTASKS	FAA	NASA	AFSC	NTSC	AIRLINES	UNIVER-SITIES	CORPOR-ATIONS
Technical Project Management	√						
1. Identify decision elements		√				√	√
2. Identify decision types		√				√	√
3. Identify decision styles		√			√		√
4. I.D. Expert Characteristics		√			√	√	
5. I.D. Team Processes		√	√	√	√		

4.2 Task 2 -- Developing Training Requirements

This task will begin with the general decision making methods and models identified in Task 1 and develop alternative training strategies for a variety of user operations based upon realistic context and cues. The realism will be developed from specific analyses of relevant situations of varying workload for a number of aircraft types and for varying levels of pilot/crew expertise. As specified by the workshop participants (Section 7.3 B Volume I), this task will provide information on decision making when crews have multiple tasking and provide guidance on how training can be developed for different levels of an aviator's career. Figure 3 illustrates the subtasks required to support this analysis and their relationship.

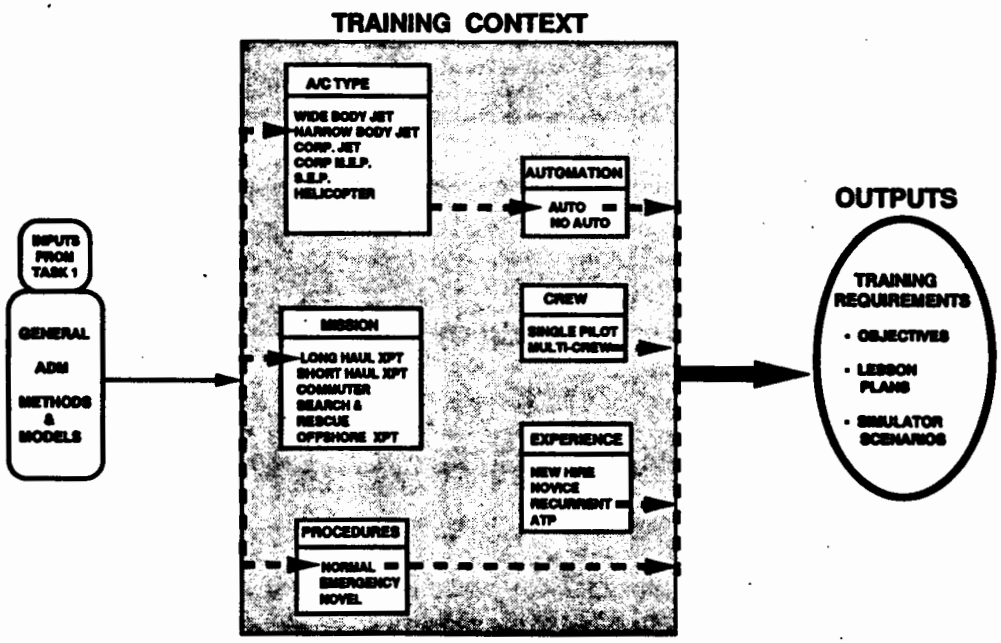

Figure 3 DEVELOPING TRAINING OBJECTIVES AND PLANS

4.2.1 Technical Subtasks

As shown in Figure 3, the development of tailored ADM training objectives and plans requires consideration of the following:

1. Applying the general methods and models from Task 1 to the operational environment and situation (i.e., context) to be trained.

2. Specifying the preliminary cognitive training objectives and the type of ADM to be trained.

3. Developing the training context and cue environment (A/C type, workload, procedures, level of automation, etc.

4. Defining specific training requirements and objectives.

5. Developing lesson plans and simulator scenarios as required to attain objectives.

The **heavy dashed** lines in Figure 3 provide one example of the training requirements development process. As indicated, a narrow bodied, air transport aircraft with an automated flightdeck is selected as the training environment. A long haul mission with normal procedures is the specified workload or task demand. This training session will involve a mult-crew circumstance because of the aircraft type selected. The target crew would be undergoing recurrency training. Based on these parameters, specific training requirements in terms of session objectives, a lesson plan for the crew to exercise their ADM capabilities, the instructors training syllabi, and if desired, a simulator scenario (an alternate would be a classroom or video tape training session).

The results of Task 1 could be used repeatedly in the manner illustrated in this example to generate a complete set of ADM training and evaluation lessons for each of the desired Training Contexts. Again, the participants suggested that the initial emphasis be on low workload air transport operations and high workload helicopter single pilot IFR operations as two extremes. The goal of Task 2 is to develop Training Requirements that can be used to evaluate various training strategies as well as a range of ADM skills. The performance of this task will require several iterations and refinements for each operation type (mission) and workload level desired. However, completion of this task for each combination should result in a reasonable number of usable, realistic training requirements by operation type (e.g., short-haul air transport).

4.2.2 Applicable Resources

The development of meaningful training objectives will require a cooperative and iterative effort between government and industry resources. However, the general flow of this development is from NASA, University and Corporate researchers to the Air Force, Navy, Airline and General aviation user communities. Therefore, Table 2 was prepared as a strawman resource application exercise. As shown in the table, the FAA Technical Monitor would rely on Subject Matter Experts (SMEs) from the other user communities throughout this task. NASA would be expected to take the early lead in applying the generalized ADM methodology and models developed in Task 1. NASA could use University and Corporate decision making researcher's as resources throughout subtasks 1, 2, and 3. However, the user communities (AFSC, NTSC and the Airlines) would become heavily involved during the development of the training context options of subtasks 3, 4, 5 and the University/Corporate resources become less-and-less involved as the training requirements development emphasis switched from applying theories and models to developing realistic training contexts and scenarios. As in Task 1, exceptions to this general flow of work would be made based upon expressed interest, demonstrated capabilities and expertise.

Table 2 RESEARCH RESOURCES AVAILABLE FOR DEVELOPING TRAINING REQUIREMENTS

	GOVERNMENT				INDUSTRY		
SUBTASKS	FAA	NASA	AFSC	NTSC	AIRLINES	UNIVER-SITIES	CORPOR-ATIONS
Technical Project Management	√	SME	SME	SME	SME		
1. Applying methods & models		√				√	√
2. Specifying ADM type		√				√	√
3. Developing training context		√	√	√	√	√	√
4. Specifying tailored objectives			√	√	√		
5. Developing plans/scenarios			√	√	√		

4.2.3 Proposed Scope

The Training Requirements task could actually begin during the last six months or 3 months of the Task 1 effort. As in Task 1, a one year initial effort is proposed as a trial period. It is recommended that a small number of training plans and scenarios be targeted for completion in the first six months as a calibration on progress, problems and possible redirection. After the initial 12 months, the outputs should include training requirements specification (objectives & plans) for at least one user from each of the three communities -- airline, military and general aviation.

4.3 Task 3 -- Specifying Training Strategies

The work required in this task will focus on applying various training strategies and alternatives to the outputs from Task 2. That is, the training requirements will be transformed into meaningful, cost effective training materials, tools and techniques. The alternatives to be considered were summarized in Volume I Section 8.3 but are repeated in Table 3 for ease of reference .

Table 3 ADVANCED ADM TRAINING TOOLS AND TECHNIQUES

TYPE OF TRAINING	MATERIALS AND METHODS
A. Individual Study	1. Manuals and Self-tests 2. Other ADM publications
B. Training Syllabi	1. Student 2. Instructor 3. Evaluator
C. Context Based	1. Classroom Vignettes (structured hangar flying) 2. Library of Videos
D. Experience Transfer	1. Grand Rounds (Mentor) concept 2. Peer Training (alternate instructor roles)
E. Activity Based	1. Computer Based Training (expert system) 2. Interactive video disk
F. Simulator Scenarios	1. Normal procedures (based on CTA) 2. Emergency and Novel situations

The application of each of these alternatives would require analysis of the needs and capabilities of the user communities. Figure 4 depicts the process involved.

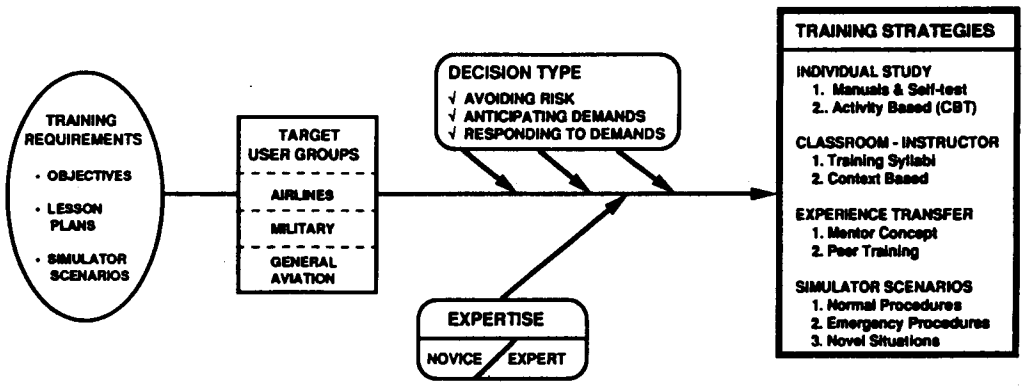

Figure 4 ANALYZING APPROPRIATE TRAINING STRATEGIES

4.3.1 Technical Subtasks

As shown in Figure 4, the basic process required to select appropriate training alternatives has one primary and two secondary subtasks. First, the Target User Group must be defined: General Aviation, Airlines or Military. Then the selection of Decision Type to be trained and the level of Expertise of the trainee group defined. At this point, the alternative training objectives and plans from Task 2 can be reviewed vs. the various implementation strategies from Table 3. The primary consideration for selecting the appropriate training strategy (methods and tools) should be the ability to train-to-objective at minimum cost in terms of both training time and initial investment. Obviously there is a broad range of capabilities between the user groups that will influence the strategy selected. The primary outputs of this analysis should be the specification of training strategies suitable for all three user groups. Tailored training manuals, classroom vignettes, interactive videos, computer based training, and simulator scenarios should be developed for evaluation in the next task.

4.3.2 Applicable Resources

At this point in the development of advanced ADM training methods the available resources will have to be selected and used based upon the specific strategies which are to be developed and evaluated. That is, it is difficult to speculatively specify resources for unknown strategies. However, past experience and available capabilities suggest that the FAA might take the lead in developing general aviation and helicopter training strategies. These may include selections from Table 3 training types A., B., C., and E. The airlines and NASA may choose to work independently or in consort to develop the more complex and costly strategies in training types D. and F. as well as considering applications of the other strategies for the more sophisticated users. Precise selection and tasking of resources will require further consideration prior to completion of this task.

4.3.3 Proposed Scope

The scope of this effort is somewhat evolutionary in nature. However, if realistic training requirements are developed in Task 2 for a limited set of target groups, then some advanced training strategies (manuals, videos, CBT devices, and simulator scenarios) should be able to be developed within two years of the concept specification. Based upon the postulated scopes of Tasks 1 and 2, this would mean some limited strategies could be fielded in two and one-half to three and one-half years after initiation of Task 1.

4.4 Task 4 -- Evaluating Training Effectiveness

This task will evaluate the ADM taxonomy, models, training objectives and training strategies developed in the three previous tasks. The basic work required was generated from the participants strong recommendation regarding the importance

of the validation step. The specific design of the work performed in this task will depend upon the number and types of training strategies developed in Task 3 as will the duration and cost of this task. However, three basic subtasks and the overall scope of this task is illustrated in Figure 5. The general type of work involved for evaluating each training module is described in the next section.

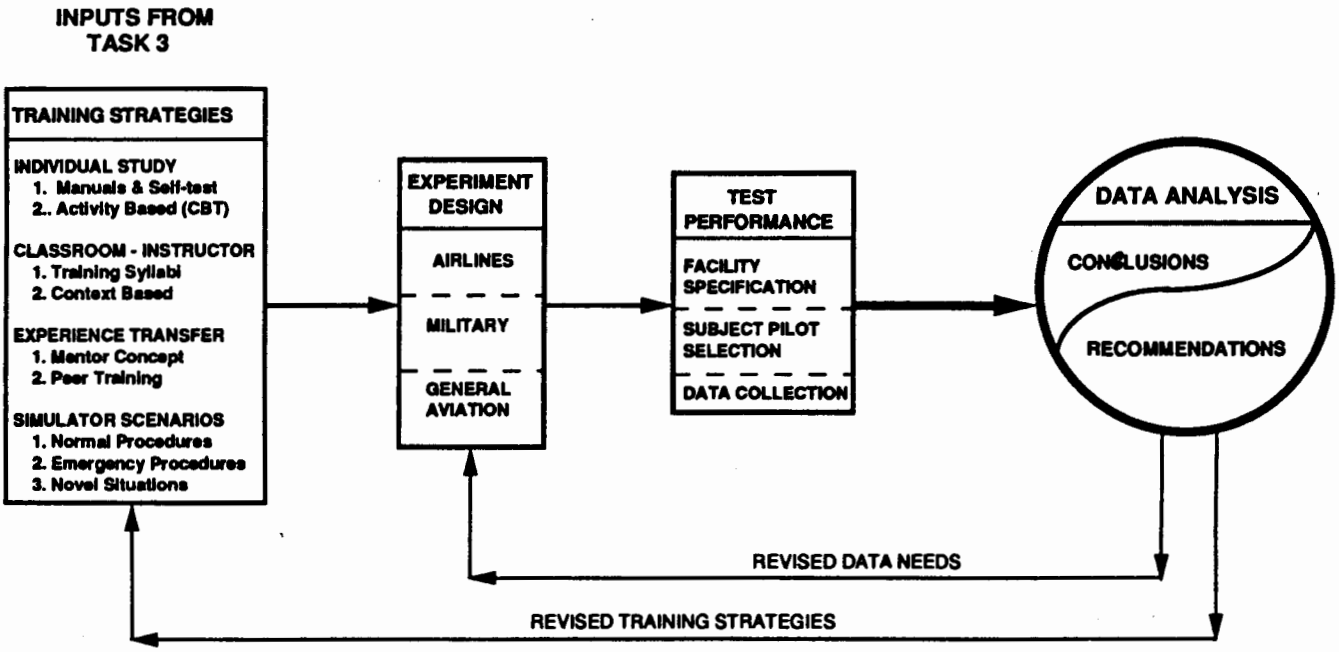

Figure 5 EVALUATING TRAINING EFFECTIVENESS OF ADVANCED ADM STRATEGIES

4.4.1 Technical Subtasks

The performance of each training effectiveness evaluation will require three subtasks as a minimum:

1. Test plan development
2. Test performance and data collection
3. Data analysis and development of conclusions/recommendations.

The test plan development will include experiment design, resource specification test group selection, pilot/crew subject selection, data collection specification and data analysis technique proposals. The resource specification will entail a coordinated evaluation of the specific user communities to be evaluated and the typical training resources they would use. The analysis would then proceed to match experimental resource capabilities to meet those typical needs. For example, Flight Safety International may be used to evaluate the training effectiveness of new ADM training scenarios for multi-crew, corporate helicopter operators since they are a typical resource for that user group.

The test performance, data collection and data analysis subtasks would also require a coordinated industry/government effort. NASA, military and FAA personnel and facilities would be required to support the effectiveness evaluation tests. In addition, University and industry research teams would be required to provide members of the analysis team.

4.4.2 Applicable Resources

The performance of the required training effectiveness evaluation should utilize, to the greatest extent possible, civil and military simulator and training facilities. The test subject pilots should also include both civil and military pilots at the appropriate experience levels. There are two reasons for this strategy. First, the government facilities offer access to sophisticated facilities with data collection and information not otherwise available. Second, the results of training strategy development research using these resources, although not focused solely on the commercial cockpit, may provide information on decision making when the crews have multiple tasking (which is standard for military aircrews) and may give guidance on how training can be developed for different levels of an aviator's career. In addition, the captive group of subjects in a highly controlled environment offers an initial opportunity to test the viability of the training in a timely manner. Table 4 provides initial guidance on the use of these resources along with industry and university support for the evaluation of the training strategy alternatives.

Table 4 RESOURCES AVAILABLE FOR EVALUATING TRAINING EFFECTIVENESS

	GOVERNMENT				INDUSTRY		
SUBTASKS	FAA	NASA	AFSC	NTSC	AIRLINES	UNIVER-SITIES	CORPOR-ATIONS
Technical Project Management	√						
1. Test Plan Development		√				√	√
2. Testing and Data Collection		√	√	√	√		
3. Analysis, Conclusions & Rec.		√	√	√	√		

4.4.3 Proposed Scope

Test design and facility evaluation/selection could begin as soon as prototype training strategies have been developed for the three audiences: airlines, military and general aviation. This could occur approximately three and one-half years after the start of the Advanced ADM Training project. However, due to the other commitments of both facilities and personnel involved, the detailed availability, schedule and use of these facilities will require a much closer examination as the need develops. Estimates of a one to two year data collection and analysis period were made for the training effectiveness evaluation by the participants at the workshop. This would have completion of the evaluation between four and one-half and five years after the start of the project.

5.0 PROPOSED OVERALL SCHEDULE

The following overall schedule was compiled to provide a snapshot of the task duration and overlap envisioned at this time. It is provided as guidance for discussion and comment. The actual generation of a more meaningful schedule will require actual interest in, and initiation of, the proposed Action Plan by the key participants indicated.

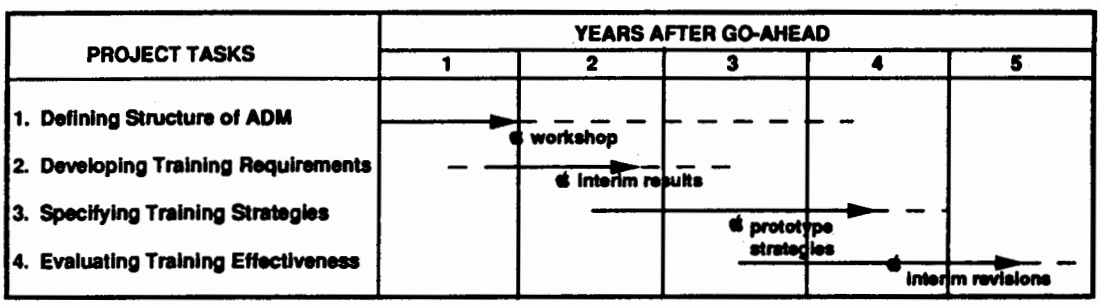

Figure 6 PROPOSED OVERALL SCHEDULE