RD
92/
14, I

FAA WJH Technical Center
00093364

COPY 1

DOT/FAA/RD–92/14,I

Research and
Development Service
Washington, D.C. 20591

Workshop on Aeronautical Decision Making (ADM)

Vol. I—Executive Summary

Ronald John Lofaro, Ph.D.

Research and Development Service
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, DC 20591

FEDERAL AVIATION ADMINISTRATION

OCT 8 1992

TECHNICAL CENTER LIBRARY
ATLANTIC CITY INTL. AIRPORT NJ 08405

Richard J. Adams
Catherine A. Adams

Advanced Aviation Concept, Inc.
10356 Sandy Run Road
Jupiter, Florida 33478

August 1992

Final Report

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

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

This document is disseminated under the sponsorship of the U. S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

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

4. Title and Subtitle	5. Report Date
Workshop on Aeronautical Decision Making (ADM) Vol. I - Executive Summary	August 1992
	6. Performing Organization
7. Author (s) Richard J. Adams (AAC), Catherine A. Adams (AAC), Ronald John Lofaro, Ph.D. (FAA)	8. Performing Organization Report No.
9. Performing Organization Name and Address Advanced Aviation Concepts, Inc. 10356 Sandy Run Road Jupiter, FL 33478-9335	10. Work Unit No. (TRAIS)
	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 presents Aeronautical Decision Making (ADM) training accomplishments, limitations and future needs from the perspectives of commercial operators, general aviation, military aviation and research - development. A select group of experts on ADM was convened to share ideas, identify and explore future directions for advanced training. Cognitive training requirements based upon decision making task demands of both airplane and helicopter pilots and crews are analyzed. A major question which requires definitional research is: "What is a real aircrew/pilot decision?" -- that is, when does an event generate a true decisional opportunity for a pilot or crew versus a "one-path only" reaction, where the actual emphasis is not on cognitive decision making, but the application of procedures and basic airmanship. Going one step further, the group analyzed the decision making differences between expert and novice pilots when a real decision was required.

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	69	

AERONAUTICAL DECISION MAKING WORKSHOP PARTICIPANTS

NAME	ORGANIZATION/ADDRESS	TELEPHONE NUMBERS
Catherine A. Adams	Advanced Aviation Concepts, Inc. 10356 Sandy Run Road Jupiter, FL 33478	(407) 747-3414
Richard J. Adams	Advanced Aviation Concepts, Inc. 10356 Sandy Run Road Jupiter, FL 33478	(407) 747-3414
Dr. Robert A. Alkov	Naval Safety Center, Code 143 NAS Norfolk, VA 23511-5796	(804) 444-7341
Dr. John R. Bloomfield	Honeywell S. R. C. MN 65 - 2500 3660 Technology Drive Minneapolis, MN 55418	(612) 782-7674
Mr. Jan Demuth, AFS-210	Federal Aviation Administration 800 Independence Avenue, S. W. Washington, D. C. 20591	(202) 267-8922
Dr. Alan E. Diehl	USAF Safety Agency Norton AFB, CA 92409-7001	(714) 382-3458
Dr. Anders Ericsson	Department of Psychology, CU Campus Box 345 Boulder, CO 80309-0345	(303) 492-1492
Mr. Roy G. Fox	Bell Helicopter Textron, Inc., Dept. 81-16 P. O. Box 482 Fort Worth, TX 76101	(817) 280-5372
William Hamman, M. D.	United Airlines Flight Center Stapleton International Airport Denver, CO 80207	(303) 780-5512
Dr. Reid Hastie	University of Colorado Department of Psychology Center for Res. on Judgment & Policy Boulder, CO 80309-0344	(303) 492-8122
Dr. David Hunter, AAM-240	Federal Aviation Administration 800 Independence Ave. S. W. Washington, D. C. 20591	(202) 366-6935

AERONAUTICAL DECISION MAKING WORKSHOP PARTICIPANTS
(continued)

NAME	ORGANIZATION/ADDRESS	TELEPHONE NUMBERS
Mr. Peter V. Hwoschinsky ARD-30	Federal Aviation Administration 800 Independence Ave. S. W. Washington, D. C. 20591	(202) 267-8531
Captain James E. Irving	6305 Sunshine Canyon Boulder, CO 80302	(303) 444-9467
Sharon Irving	6305 Sunshine Canyon Boulder, CO 80302	(303) 444-9467
Dr. Ronald J. Lofaro, ARD-200	Federal Aviation Administration 800 Independence Avenue, S. W. Washington, D. C. 20591	(202) 267-8529
Dr. George Kaempf	Klein Associates Inc. 582 E. Dayton-Yellow Springs Rd. Fairborn, OH 45324	(513) 873-8166
Dr. Gary A. Klein	Klein Associates Inc. 582 E. Dayton-Yellow Springs Rd. Fairborn, OH 45324	(513) 873-8166
Dr. Judith Orasanu	NASA Ames Research Center MS: 262-5 Moffett Field, CA 94035	(415) 604-3404
Captain Stephen E. Paul	Human Factors/Delta Airlines 900 S. Pennsylvania St. Denver, CO 80209	(404) 725-1121
Dr. Carolyn Prince	NTSC, Code 262 12350 Research Parkway Orlando, FL 32826-3224	(404) 380-4831
Captain Kevin Smith	5875 Olde Stage Road Boulder, CO 80302	(303) 440-4292

WORKSHOP ON AERONAUTICAL DECISION MAKING

TABLE OF CONTENTS

SECTION	TITLE	PAGE
1.0	INTRODUCTION	1
	1.1 Objectives	1
	1.2 An Overview of Aeronautical Decision Making	2
2.0	THE ISSUES	5
3.0	THE NEED FOR A WORKSHOP	6
4.0	THE PROCESS	7
5.0	KEY CONCEPTS AND RECOMMENDATIONS	9
6.0	WORKING GROUP A: FUTURE CIVIL AVIATION RESEARCH AND TRAINING	13
	6.1 Introduction	13
	6.2 Problems and Needs	14
	6.3 Future Requirements and Recommendations	15
7.0	WORKING GROUP B: FUTURE MILITARY AVIATION RESEARCH AND TRAINING	16
	7.1 Introduction	16
	7.2 Problems and Needs	18
	7.3 Future Requirements and Recommendations	20
8.0	WORKING GROUP C: ADVANCED TRAINING AND EVALUATION METHODS	21
	8.1 Introduction	21
	8.2 Problems and Needs	22
	8.3 Advanced Training Requirements and Recommendations	23
9.0	CONCLUSIONS	27
References		29
Appendix A	Sample ADM Workshop Workbook	31
Appencix B	Workshop Presentation Topics and Authors	68

WORKSHOP ON AERONAUTICAL DECISION MAKING

LIST OF TABLES

NUMBER	TITLE	PAGE
1.	Advanced ADM Training Tools and Techniques	25
2.	ADM Value and Acceptance Areas to be Documented	26
3.	Recommended Advanced ADM Training and Methods	27

ACKNOWLEDGEMENTS

The material presented in this report is the result of a cooperative effort by a select group of participants recognized for their accomplishments and contributions over the past decade. The presentations on the first day of the workshop and the references sited provide a timely, accurate perception of how Aeronautical Decision Making (ADM) evolved, developed and has been used by the airlines, the military and general aviation. However, these key concepts, conclusions and recommendations would not have been possible without the contributions and tireless support of three individuals.

Mr. Jan Demuth of the FAA's Flight Standards Service, Air Carrier Training Branch has been working for the past several years in the development of the Crew Resource Management Advisory Circular and the development of the Advanced Qualification Program. He provide focused comments and guidance on the work needed to integrate ADM in the context of an overall training and qualification system.

William Hamman, MD, Manager of Recurrent Training for United Airlines provided guidance and knowledge on the practicalities of integrating ADM in the airline training environment. He was encouraging and helpful in identifying the basic work that needs to be done to define cognitive task demands during a flight.

Mr. Pete Hwoschinsky of the FAA's Vertical Flight Program Office participated in the early development and formulation of the workshop organization and format. His extensive human factors background, continual support of the FAA's ADM research, and active involvement in the development of rotary-wing ADM training materials provided a solid foundation and critical review of the focus and results of the workshop.

WORKSHOP ON AERONAUTICAL DECISION MAKING

1.0 INTRODUCTION

The 1992 FAA sponsored Aeronautical Decision Making Workshop was a part of a continuing effort to enhance safety by improving the operational capabilities of pilots and crews. The goal of the workshop was to bring together a small effective group of individuals from government, industry and academe; persons who were actively involved in the development and evaluation of decision making and resource management materials, courseware, simulator scenarios, or other products suitable for incorporation in the next generation of training. This concept, as well as the workshop, was enthusiastically supported by the participants from the U. S. Air Force, the U. S. Navy, several major airlines, the National Aeronautics and Space Administration, the Federal Aviation Administration, research companies and the University of Colorado. The workshop, held in Denver, Colorado on May 6,7, 1992, was organized and conducted by Advanced Aviation Concepts, Inc. as a part of FAA contract number DTFA01-90-C-00042.

This report is provided in order to document the background and the objectives, as well as the accomplishments, of the workshop. It is also designed to provide a rudimentary understanding of the proceedings of each Working Group convened at the workshop; the specific issues discussed; the results obtained; and, the recommendations provided. One other volume will be provided for those interested in a more complete description of the background research: Volume II provides the Workshop Presentations and the technical recommendations in the form of an Action Plan.

It is important to note that the workshop addressed the overall operations concept of Aeronautical Decision Making as an integral part of pilot/crew training. The training identified at the workshop as being needed immediately was derived from a value assessment and the realization that recognition of the value of ADM is critical to acceptance of the training by both pilots and management. The workshop participants identified the behavior and attitude elements which should be addressed in future training programs. Also, the diverse needs of these aviation communities were addressed: Federal Aviation Regulations (FAR) Part 121, Part 135 (for both airplanes & helicopters), Part 91 (airplanes and helicopters), general aviation and military.

1.1 Objectives

The major reason for convening this select group of experts on ADM was to share ideas, identify needs and explore future directions for research. The following objectives were established.

A. To discuss state-of-the-art knowledge and accomplishments in ADM from both operational and research perspectives.

B. To examine the decision making differences between expert and novice pilots by:

1. analyzing and discussing various old and new models of ADM and CRM, and

2. identifying differences in responses to novel cues, uses of automatic information processing, and their resistance to attitudinal or management style changes.

C. To form focus groups which would:

1. develop an initial consensus as to R&D and operational needs for near-term ADM efforts, and

2. define joint efforts/projects required for the next generation of ADM and consider integration in CRM/LOFT training programs.

1.2 An Overview of Aeronautical Decision-Making (ADM)

ADM training and Crew Resource Management (CRM) training (called Aircrew Coordination Training by the military) developed in parallel during the 1970s and 1980s. Today, there are still disagreements regarding the reality and size of the benefits for either pilots or management that came from the use of ADM and CRM training. Rather, individual users and developers of the training have gotten their motivation from their view of the safety and efficiency benefits from implementing and obtaining continuous support for these training programs. It is hoped that the following discussion will provide the common foundation necessary to begin building and documenting the value and benefits required to support continual and expanded use of ADM and CRM to improve safety through effective training and checking. This can only be done in the context of an overall training system which integrates technical, interpersonal and cognitive skills into one set of performance and behavioral criteria.

The following is provided as a frame of reference. By understanding this unofficial history, as well as the commonalities and differences between ADM and CRM, the user or researcher will be better equipped to evaluate the findings of the workshop participants.

A. <u>The 1970's and 1980's</u>

One thrust for the development of ADM training was similar to that for Crew Resource Management (CRM): A well-publicized series of fatal crashes which were attributed, in part, to poor crew coordination/communication and judgment. The other driver for ADM was, is and will be the need to provide skills through training which can be an initial substitute for those gained by flight experience. The reason here is three-fold.

1. While experience does teach, the cost of the lesson is often too high--and, the lesson is often not learned until after the experience. Sadly, some pilots are not alive after the experience. As has been said: "Experience is not a fair teacher; the test is given before the lesson is taught."

2. Also, experience can teach the wrong lesson, or teach a lesson wrongly. A poor or incorrect decision can be made and implemented which then actually works out "for all the wrong reasons". Since it turned out seemingly well, the likelihood of repeating, or trying to repeat, this poor choice and procedure (in a similar situation) is increased. All too often, the result is an accident or incident.

3. It has been found that there are levels of decisional skills and expertise. The characteristics of expert cognitive processes have been defined in many diverse fields such as music, medicine and athletics. The relationship between expertise and training or practice is also well defined in these fields. If methods could be found to teach "expert" pilot decision making skills to low and mid-time pilots, then they will be better equipped to make safe, effective decisions without needing to await high levels of flight time and experience.

However, no matter how one looks at ADM, the bottom line is a need to equip *all* pilots, especially the low-timers, with better ADM skills through training.

The seminal FAA study (Jensen and Benel, 1977) documented the need for ADM training to reduce "pilot error" accidents. The authors identified the need for (what was then called) pilot judgment training <u>and</u> concluded that judgment skills could indeed be taught. During the remainder of the 1970's and through most of the 1980's, materials and programs were developed in pilot judgment training (PDM); many of these had R&D aspects. As a result of this work, PDM materials became available to the aviation community in the USA, Canada and Australia. These materials took the form of manuals published by *Transport Canada, Australian Department of Aviation, Aircraft Owners and Pilots Association,* and the *Helicopter Association International.* Additionally, a series of twelve FAA training manuals were published covering such topics as helicopter ADM, Instrument flight, EMS operations, administrative risk management and more (DOT/FAA,

1986-1991 inclusive).

During this same time frame, much, if not all, of the ADM R&D and publications were aimed at single pilot, general and corporate aviation operations. FAR Part 121 carriers were developing ADM training primarily as a part of their CRM training programs.

In retrospect, this era resulted in quite a good deal of research and materials but did have some lack of cooperative efforts, data sharing and common target groups. There were (and still are) some basic questions which needed answers, as well as some basic differences of opinion on what constituted ADM and its place in a training curriculum.

B. The 1990's

ADM, along with "situational awareness", has again become a topic of discussion and limited R&D. Some operational personnel and research personnel share the view that there are still basics (definitions, concepts, etc.) which either are not resolved or are totally unaddressed. Additionally, advances in CRM have begun to resurrect some old concerns about ADM and CRM. These CRM advances, in concepts and in measurement, also led to a feeling among some people that an ADM breakthrough was now possible. Put idiomatically, perhaps we finally know what we didn't know and now can proceed from there.

C. ADM and CRM: Ties, Similarities, Differences

A long-standing question has been: Is ADM part of CRM or a result of CRM? (or vice versa!). Is a good crew decision the result of CRM skills, if indeed not a major goal of CRM, or are CRM skills a *sine qua non* for a good crew decision?

These two questions suggest that CRM and ADM have long been tied together. There are successful ADM programs and successful CRM programs. ADM modules are often parts of CRM training and ADM (Leadership and Decision-Making) aspects are called out as CRM behavioral/performance markers in the FAA's CRM Advisory Circular 120-51A. ADM, more than CRM, currently needs research attention and development work.

One basic similarity of ADM and CRM (R&D and training) is their mutual goal of a safe, efficient mission. Another similarity is that ADM is also poised to make major advances, due in part to advances in CRM. The five primary cockpit management tools which have been taught in both ADM and CRM: attention, attitude, crew management, risk management and stress management will expedite the achievement of these major advances.

The basic difference between ADM and CRM is that CRM has already taken some significant strides in the early 90's; strides in identification and assessment of discrete skills and behaviors which make up "good" CRM, and in developing a 3-tier, or phased model of training: awareness, indoctrination and recurrency. (Helmreich & Foushee, 1986, Helmreich & Wilhelm, 1990). On the other hand, ADM is now in a position to take new strides and make advances -- and ADM needs to make these advances. In short, ADM needs work, through new R&D.

The question of whether CRM is part of ADM, or the reverse, now seems academic. Both are vital components of mission safety and mission performance; both offer vital information and understanding to the other; both must continue to be stressed, expanded and refined; and, both must become transparently embedded in flight training and openly integrated with the technical (flight control) skills of which they are truly a part.

[Aside: A major area where CRM and ADM can immediately work together is in the development of better (LOFT) scenarios. Improved LOFTs can be developed based on focused training requirements for CRM, ADM, normal/abnormal/emergency procedures, motor skills, etc. Better understanding and use of ADM events in a LOFT can enable better scenario design and better pilot/crew assessment.]

2.0 THE ISSUES

A. ADM has not yet developed a well-defined and comprehensive set of constructs and a theory of its own (Maher, 1991). Rather, general decision-making theory was applied and/or modified for ADM. The results were predictable: a simplification process whereby a linear model (e.g., PASS, SAFE, DECIDE) was used. Such models are time-consuming, cumbersome and inadequate to the dynamic, often time-compressed, decisional situations that aviators face when flying. In point of fact, it seems fairly accurate to say if a linear model was taught on the ground, it was rarely used aloft.

Part of this issue was that most decision-making theories began with how or why people make errors. Al to often the result of the decision-making process was to prevent errors, especially catastrophic ones. However, the problem of how to identify the elements of a good decision, and of how to enhance both the capability and the probability of making one were not adequately addressed. There was an assumption that error elimination was equivalent to good decision-making. A major player in this school of thought was the linear, causal chain of event concept of accidents, where the goal is breaking the causal chain and the assumption is that breaking the chain precluded an accident (Diehl, 1990). New findings on the multi-dimensional, multi-"layered" processes which people actually use to make decisions -- often projecting forward <u>and</u> backward in time in their thinking -- have

shown an insufficiency in the linear models of decision-making. A view that ADM was too complex, contained too many variables, and was too dynamic for any one model to capture also existed. An offshoot of this view was that, while no training would be truly complete and adequate, *any* training was better than none at all. This view was complementary to the use of linear models and reinforced teaching them.

B. Very recently, several new models and concepts of how people actually make decisions, rather than how they make errors, have been developed (Klein & Klinger, 1991, Orasanu & Salas, Orasanu). Another advance has been in the area of team decisional processes, especially in naturalistic (i.e., on the job) settings, rather than in an artificial laboratory-like experimental setting.

C. The final issue, or perhaps driver, is the new efforts which explore Expert Decision Making (EDM) in operational settings by researchers in and out of the Government (Adams & Ericsson, 1992, Ericsson & Smith, 1991, Bloomfield, 1992, Bloomfield, Edens, et. al., 1992) and, to a lesser degree, by some major air carriers.

The sum of A,B,C (above) was the authors' realization that a series of ADM workshops, bringing together the operational "users", the researchers and the FAA was timely and appropriate.

3.0 THE NEED FOR A WORKSHOP

A. The rationale is simple enough and is actually contained in the two preceding sections. Historically, the time was right to begin new, coordinated ADM R&D work. First there were new findings, new interests, new needs and basic issues which still had not been answered and which needed to be resolved. Second, there was a growing realization that ADM was in real need of new models and materials which accurately identified, defined, and enhanced ADM skills. Third, the past two years of FAA-sponsored research on the cognitive processes of expert pilots has reached a level of maturity which suggested that a broader exposure and use was possible.

B. There were also certain things which had occurred in CRM and other aviation R&D areas which the ADM workshop sought not only to correct but also to preclude in the future. The workshop was designed to bring together a diverse group of experts who were doing or had done work in decision making, from a variety of perspectives. In this way, there would be an initial cross-pollination which could be built upon and expanded in later workshops and projects. The workshop also was an effort to preclude a premature "standardization" of ADM at a time when new concepts and development, not codification, are needed. ADM needs to be an open and expanding discipline, not the domain of any

"in-group". The workshop was a step toward opening ADM to all by evaluating the merits of their concepts on scientific, logical grounds.

4.0 THE PROCESS

A. Preparation

The workshop was conceived in mid-1991 because the authors' interest and work in ADM, input from aircrew training officers at several major air carriers, and with coordination with NASA, private and academic researchers.

During February 1992, an initial list of participants and a preliminary set of objectives and agenda was prepared. Each potential participant was mailed the rough-cut objectives and draft agenda, as well as a cover letter and other materials. This package solicited the participant's preferences for possible meeting sites and offered a tentative May time-frame. The personnel receiving this package were encouraged to indicate their willingness to attend/present, and their choice of workshop site was solicited.

Based on the responses received to this initial mailing, a second letter was prepared, some new participants targeted, and others deleted [by their choice], from the initial roster. It should be noted that, throughout this process of planning and arranging the workshop, both Rich Adams and Ron Lofaro had numerous telephone conversations with the proposed/actual participants, explaining details and goals.

In April, a final package containing a revised set of objectives, agenda, requests for biographies and hard copies of their presentations, choice of conference site. The details on travel and hotel accommodations also were mailed to the participants at this time.

Advanced Aviation Concepts, Inc. prepared a workshop workbook which was given to the participants on Day I. Major features of the workbook were a brief resume of the presenters and the use of formatted areas where notes and questions concerning each briefing could be recorded and later used in group discussions as well as referenced after the conference. It included papers on EDM (Adams and Lofaro, 1992), as well as on CRM (Lofaro, 1992). The same workbook format was included to aid the participants in recording working group discussions, conclusions and recommendations. A sample copy (edited for space requirements) of this workbook along with pre-defined goals and objectives is provided in Appendix A.

B. **Day I**

Ron Lofaro welcomed the 20 participants and briefly discussed ADM ("How it got to be where it is"), the rationale for the Workshop, and provided a brief discussion of the variety of approaches to CRM/ADM, simulator usage and the existence of substantial experience which has produced the following set of programs, regulations and advisory guidelines.

1. Existing Training Programs:

   a. LOS - Line Oriented Simulation

   b. LOFT - Line Oriented Flight Training

2. AQP - Advanced Qualification Program (SFAR[1] 58)

3. CRM - Crew Resource Management (new AC 120-51A)

4. ADM - Aeronautical Decision Making (AC 60-22)

Rich Adams of AAC then reviewed the objectives, processes and organization of the Workshop. For the remainder of the day (0830 - 1730), nine (9) people made presentations, with Q&A sessions immediately following each presentation. It was a mark of the skill of the presenters and the relevancy of their presentations that this very long first day did not have any "drop-outs" either by any presenter or because of lack of sufficient time. It is a more significant mark that, while the participants all agreed it was a long day, they also agreed it was a day well spent and they had retained their interest throughout. The high levels of interest were further reflected in an informal "mixer", wherein further questions and discussions flowed for over two hours.

C. **Day II**

There was one final presenter. After this presentation, Ron Lofaro reviewed the working group objectives; Rich Adams dealt with the structure of each work group and the proposed outputs. The working groups then convened in individual, separate work areas. After some 3 1/2 hours, all participants re-assembled in the main conference room to hear the 3 working groups present their discussions and recommendations.

---

[1] SFAR -- Special Federal Aviation Regulation

After this time was given to an examination of similarities and differences across the working groups and a short discussion of possible actions and projects in ADM. Ron Lofaro and Rich Adams did a brief processing-out and delivered closing comments and thanks.

Again, a benchmark of the level of participant interest and involvement was that, after another long day and after the workshop had been closed, the participants remained to discuss issues and plans informally for well over another hour.

5.0 KEY CONCEPTS AND RECOMMENDATIONS

This workshop took ADM several steps forward, produced several seminal concepts and one major re-look/re-questioning at ADM. Appendix B provides a summary of the specific technical contributions of the eleven presenters at the workshop. There was an extraordinary similarity among the issues, discussions, and conclusions across the 3 work groups even though one purpose of the 3 work groups was to provide the structure for diversity and differentiation.

The working groups had different foci: Future Civil Aviation Research & Training; Future Military Aviation Research and Training; and, Advanced Training & Evaluation Methods. Each work group analyzed ADM problems and needs within its area of emphasis. However, the commonality of concern and conclusions across the groups is a significant indicator of a generic quality to ADM, a set of similarities which exist in all aviation flight operations, be it military private or commercial. At the same time, ADM also was seen as very specific to, and conditional upon, both the type of aircraft and the mission being flown. The outputs of the working groups are presented in Sections 6.0, 7.0, and 8.0; these contain fairly complete records of the discussion topics and results of the deliberations for each group.

The general conclusions reached by the participants, both in their work groups and in the intact, entire group can be briefly summarized by these statements.

A. ADM, like CRM, must be embedded in all levels of an organization. Without real "buy-in" and training for *all* organizational units, ADM will not have the operational impact it can engender: increased safety and increased crew performance and effectiveness.

B. This workshop should be the first step in a new awareness period for aviation of the status, promise, prior work and future efforts/goals of ADM and EDM.

C. This workshop demonstrated a truly remarkable convergence and "match" between

the operational community and the R&D community as to the status, goals and needs of ADM.

D. There already is some application and extension of such research-generated concepts and techniques as Naturalistic Team Decision-Making and Expert Decision-Making in the Aviation arena.

E. There is a major question to be answered, which requires an accurate re-look and re-definition: "What is a *real* aircrew/pilot decision?" -- that is to say, when does an event generate a true decisional opportunity for a pilot/crew versus a "one-path only" reaction, where the real emphasis is not on decisional aspects but procedures. A new term for this "real" decision was suggested, "operational decision"; one which places decisional demands on the flight crew and flight system to resolve an ambiguous situation.

F. Stemming from, and interlocked with (4) above, was an initial proposal that 3 classes of aeronautical decisions exist. These are:

1. **Binary** Decision Making: A simple "go/no go" call, one where there are only two paths open. This was referred to as somewhat of a lower powered cognitive task where the actual issues were timely response and using correct technique in a situation which actually had only one correct response. "Correct" here is used in the sense of the alternate response leading to an accident or incident; a response which could only lead to failure. The level of cognitive processing required to make the decision is the main discriminator. The binary decisions are often made at such a low level that the person making the decision is virtually unaware a decision has been made. There is a high level of automaticity, due to training, to the pilot/crew response in this class of decisions.

   This type of decision may be typified best by an engine out at V_1. The issue here is not so much what to do--the pilot/crew are trained to respond to this event--but the timely, accurate, skillful application of the techniques necessary for rotation and an immediate landing at the airport; along with any other procedures required by the terrain and weather for accomplishing the safe landing. This type of decision represents a simple cognitive effort and requires less time than the more complex classes (B. and C. below) which may require significant cognitive workload and processing time.

2. **Rule Based** decision making: A decisional class where there must be some planning and problem-solving. In this class, the decision was more complex, but still could end up as a "go/no go" type. There still was some emphasis on accurate and quick recognition with the response to be mainly the application of correct procedures.

   However, in this class of decisions, the complexity of the environment and conditions led to more actual problem-solving and decisional strategies than in the first class.

3. **Adaptive** decision making: The third type of decision has so much ambiguity embedded in it--conditions, causes, differing possible courses of action--that it requires all the skills needed for classes 1 and 2, plus a high-level of diagnostic skill and team work. This type of ADM is best typified by United Flights' 232 and 811. It is this type of decision which needs new emphasis and needs the most supporting R&D to identify, understand, and integrate the condition sets, operational demands, and decisional strategies with successful outcome behaviors and performances.

<u>NOTE</u>: The participants recognized that overlap exists among these three aeronautical decision classes. A major R&D effort would be to define/refine all of these three classes.

G. Again, stemming from and interlocked with both (4) and (5) is the consensus that, in order to do (4) and (5), several R&D products are absolutely essential. These are:

1. Accomplishing what was termed a "cognitive task analysis" (CTA), broken out by phases of flight in a mission. This analysis must embed the cues, conditions, environment and mission goals.

2. Developing a taxonomy and classification schema of decisional events (this will define what is "real" aeronautical decision making) and decisional strategies.

3. Identifying and articulating how to use the Cognitive Task Analysis and Decision Making Taxonomy in the development of pilot/crew training, and especially in the development of expert LOFT training scenarios based on actual decisional events.

FAA WJH Technical Center
00093364

H. Finally, there was the strong recognition that ADM R&D and strategies, while having similar aspects and components, were differentiated by aircraft type and mission. It was hoped that generic ADM materials, methods and tools could be developed as well as paradigms for extending generic findings/components to specific aircraft and missions.

Let us look once again at the three proposed classes of decisions. There was a group recognition that not only are there three classes of crew/pilot decisions, but that differential conditions--such as mission (long; medium; short-haul) and aircraft type (automated versus non-automated) lead to different decisional needs and processes. Cues (availability, type, recognition) and conditions (context, environment, phase of flight), along with time pressures, are the drivers for all types of decisional processes. The type of flight operations (normal, abnormal, emergency) is significantly related to the class of decision. In the first type, we are usually looking at normal operations, with the emphasis on procedures, sequencing of responses and prioritization/timing. While not quite as simple as a "go/no go", this first class of decision has fewer crew decisional needs for cues. It also has fewer conditions.

The second class of decision has multiple alternatives which are usually known. Time, not timing, is a factor and the thrust is on finding the right procedure(s) and implementing it rapidly and precisely. These are usually abnormal operations. If the decision maker has learned the procedures, he/she will know what to do after reaching a level of situational awareness. The ambiguity lies in assessing the situation. This is particularly true in time-compressed situations. The final decisional type features ambiguity and previously un-encountered circumstances, where all aspects of the first two types are present and the focus is on the diagnostic skills needed to use the cues and conditions, usually in a time-compressed situation. This is usually an emergency situation. These circumstances require the expert's ability to recognize and combine patterns from previous individual, related situations, reason forward and backward to come up with a new procedure or plan while continually monitoring the performance and outcome of the plan. A key point is that both class 2 and 3 decisions can be "reduced", i.e., the decisional skills and processes of the crew/pilot, can make the decisions abnormal or, in some cases, normal operational decisions.

6.0 WORKING GROUP A: FUTURE CIVIL AVIATION RESEARCH & TRAINING

This group was tasked with analyzing the status, accomplishments and shortcomings of ADM in the civil aviation environment. Emphasis was placed on the commercial service training of Part 121 and Part 135 pilots and crews. The group chairman was Dr. Ronald John Lofaro of the FAA's Research and Development Service, Systems Technology Division, ARD-200 (202) 267-8529. The industry co-chair was Catherine A. Adams of Advanced Aviation Concepts, Inc. (407) 747-3414. The subject matter experts and technical support staff were:

Mr. Jan Demuth	FAA Air Carrier Training	(202) 267-8922
Dr. David Hunter	FAA Aviation Medicine	(202) 366-6935
Dr. John Bloomfield	Honeywell S. R. C.	(612) 782-7674
Dr. Gary A. Klein	Klein Associates, Inc.	(513) 873-8166
Mr. James E. Irving	Captain, United Airlines	(303) 444-9467

6.1 Introduction

The group discussion was based on the identification of problems and immediate needs in ADM and some effort at finding paths to resolving the problems. Initial group discussion centered around what was perceived as barriers to new ADM training being implemented by major air carriers and various ways to approach this. This initial discussion lead to the following points and concepts, built around this 3-part premise:

Air carriers will see any "new" training as adding to the overall cost of, and subtracting from the bottom-line, profit. What, then, can be done to combat and nullify this? ADM training must not be seen, presented, or become another add-on piece of training: as a band-aid for some set of problems. Rather it must become an integral, necessary part of a comprehensive successful program. Suggestions were made during the dialogue of the participants in light of the premise.

A. ADM, perhaps, can be integrated into flight training, as the FAA's AQP (Advanced Qualification Program) SFAR 58 (Special Federal Aviation Regulation number 58) calls for CRM to be integrated into the technical aspects of flight training.

B. ADM must be transparent - it must be so finely interwoven in the fabric of training that it is not perceived as add-on material or a separate module.

C. ADM training for airline "new hires" may be the initial thrust, followed by making ADM a part of a pilot's career education progression--"a career-long event".

D. Senior airline captains should be key participants and called upon to formulate parts of this initial thrust, giving a simultaneous top-down and bottom-up approach.

E. An "ADM awareness" program, both within air carriers and in the aviation community, needs to be started to develop an awareness of the value and benefits of ADM to pilots and management. (This is not to be confused with the Awareness Phase of CRM training.)

F. ADM can be introduced by using it as an analytic tool on operational procedures, by and across fleets. For example, analysis and discussion of decisional strategies and styles in current situations or scenarios could establish linkages to training and training needs. This, then provides a rationale for the development and inclusion of ADM in flightcrew training.

6.2 Problems and Needs

There were two major problem (need)-areas agreed on by this workgroup. Both of these are contained in the previous portion of the Key Concepts and Recommendations section. However, it may be instructive to state these as the working group, rather than the entire Workshop, formulated them.

The first issue was the immediate need to begin R&D on a common and basic classification schema with a taxonomy for aeronautical decision-making with validation. This could be developed in part from the initial work in #6 above. Parallel and interlocked with this effort was the need for (what was termed) a cognitive task analysis (CTA). In this CTA, attention should be given to classes of decisions; node points in an event where information is absolutely needed by the crew; identification of what information is needed; specification of the rationale for what information management strategies would be effective. Embedded in the task analysis and taxonomy work would be an identification of *where* the operational impact of R&D work would occur--training design, materials and procedures; SOP's; other.

Finally, the CTA needs to provide a paradigm for further, differential CTAs -- CTAs which are to be aircraft specific and can drive specific areas of training development.

6.3 Future Requirements and Recommendations

The two problem areas addressed by this group define the need for basic research in the ADM domain. For example, can we define what constitutes a "good decision" and can we identify who good decision makers are? The thrust of the group's recommendation in these basic areas was to examine these questions in the context of the operational cognitive task demands for each flight phase.

The recommended form and substance for this analysis included:

A. Cognitive Task Analysis & Evaluation for normal, emergency and abnormal procedures

B. Simulator scenario generation

C. Subject pilot test and evaluation

D. Debrief and re-analysis of cognitive nodes and decisions (good vs. bad) and decision maker's performance (good vs. bad qualities)

Due to the sophistication, cost and complexity of this research, the group suggested a joint government/industry effort with the FAA and NASA developing the program goals and objectives, providing technical direction and monitoring outputs. R & D support from the airlines, and researchers from both industry and academe would be used to spread the workload and expedite the data collection and interpretation from an operational perspective.

7.0 WORKING GROUP B: MILITARY AVIATION RESEARCH & TRAINING

This group was tasked with analyzing the similarities and differences between ADM in the military and civil aviation environments. Emphasis was placed on the analysis of ADM in high and low workload military missions, relating decision making training needs to specific tasks in those environments, and defining training strategies applicable to those tasks in both military and civil aviation. The group chairman was Dr. Alan E. Diehl of the USAF Safety Agency (714) 382-3458. The co-chair was Sharon Irving of the University of Colorado at Boulder (303) 444-9467. Subject matter experts and technical support staff were:

Dr. Robert A. Alkov	Naval Safety Center	(804) 444-7341
Dr. Carolyn Prince	Naval Training Sys. Ctr.	(407) 380-4831
Dr. Reid Hastie	Univ. of Colorado	(303) 492-8122
Dr. George Kaempf	Klein Associates, Inc.	(513) 873-8166

7.1 Introduction

A. The Military Aviation working group based their discussions on the following observations.

1. The military has these unique capabilities:

   a. access to large quantities of data and information not otherwise available.

   b. LOFT scenarios tied to demographic data.

   c. a captive group of subjects (time and cooperation is insured).

   d. a highly structured, controlled training process.

2. Although civilian aviation has been very active and collected a great deal of ADM/CRM data using airline pilot/crew volunteers, the results obtained may not be completely representative of "typical" line pilots due to the predisposition of the volunteers to support and use ADM/CRM.

3. Accident events (because of the relative infrequency and often missing data) are not always the best source of information for training purposes.

4. The military training and laboratory environments can often provide more controlled test situations.

5. There is a safety-driven need to determine a way for the FAA's National Plan for Human Factors to utilize these resources.

6. The tactical and mission requirements of military flying provide an extremely rich environment for studying pilot decision making under time-compressed and stressful conditions.

B. Using these basic observations, the group set out to develop an analysis of future ADM research and training requirements based on military needs but with generalized applicability to the civil environment. They wanted to avoid spending several man-hours (actually about a combined half-manweek was available) creating a wish list of dream projects. Therefore, the problems were framed in a systematic approach to develop specific training needs. The military helicopter and transport operations environments were selected to represent high and low decision making environments respectively.

The group used the information from the presentations on the first day of the workshop (see Volume I Appendix B and Volume II for presentation material indicated in parenthesis) as a foundation and frame of reference in the following manner:

1. The ADM Effectiveness Overview (Diehl) and Trans-Cockpit Authority Gradient (Alkov) discussions were used to formulate the macro environment.

2. The Recognition Primed (Klein) and Natural (Bloomfield) decision making models provided two theoretical methods for analyzing the process occurring in the cockpit.

3. The transition between the theoretical and the operational was based upon the Bootstrapping Experience (Irving), Shared Mental Models (Orasanu) and How Experts Think (Adams) presentations.

4. The springboard for developing advanced training were the presentations on Decision Making in Operational Systems (Smith) and the Methodology for Training Expertise (Ericsson).

C. The group concentrated their work in these four areas.

1. Identifying and defining decision making tasks (The work group felt that aeronautical decision making is not yet clearly understood or defined)

2. Determining Training Objectives

3. Developing Training Strategies

4. Evaluating Training Effectiveness

7.2 Problems and Needs

The approach selected by this group recognized that there is a great deal of basic research that is necessary, including: defining the concept of ADM and distinguishing it from other concepts; classifying decisions; learning how crews deal effectively with decisions; determining how this can be trained; and evaluating the training itself. This approach resulted in the identification of four problem areas requiring future R&D work. It also led the group to an examination of not only what needed to be done, but also who would be affected, who should be tasked to perform the necessary research or training development, and the time frame within which it might be targeted for completion. The following pages present a brief summary of the analyses performed and the products anticipated.

A. Identifying and defining decision making tasks

The goal in this area is to identify decision tasks and how decisions are made in as many environments (civil, military and general aviation) and as many mission types as would be practical and meaningful. The problem statement is to determine the various methods and models that could be used to identify decision making tasks. The work required would be to identify how the decisions are made, the cues used, the goals, the expectancies, etc. Once we know how experts do it, then we can develop training objectives for the novices. The work required would explicitly include review of existing models such as those presented by Bloomfield, Klein, Orasanu and Smith for applicability. Further work would include the specification of the need for, and possibly the types of, models that may need to be generated in the future.

The products of this analysis of decision tasks and applicable methods of decision making for both high and low workload tasks would be a specification of a generalized methodology and documentation of the taxonomy of decision making tasks across different environments or mission types. The methodology would be suitable for use both by training departments and by pilots in their day-to-day decision making. The applicability of these results would be across the user communities and include a range of aircraft and mission types.

The team proposed to accomplish this work would include the military and NASA laboratories/simulator facilities augmented by academic and industry subject matter experts

and working under the supervision of an FAA Project Manager and Technical Monitor.

B. Determining Training Objectives

The problem statement in this area is to address the specific decision making training needs for each aircraft type or fleet. What the military has to offer in this area is diversity in crew experience, in crew size, in crew tasking, and in some of the decisions they face. The target groups postulated at this time were air transport operations and helicopter operations training. What the military also has to offer is more access to crews for research than is possible in the airline communities, and its on-going training programs at multiple levels that provide research opportunities. The spectrum of pilot decision making training needs from ab initio and undergraduate through recurrent training could be analyzed. The products of this work would be Training Objectives and Lesson Plans for each of the target groups. This research, 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, so that he/she is given appropriate training that will build as professional skills are built.

C. Developing Training Strategies

The objective of this research would be to identify a spectrum of training strategies utilizing appropriate media and methods for the target user groups (civil, military and general aviation). A team of researchers, instructional design and media specialists was proposed to develop a variety of training materials. Examples of the proposed products included the following:

1. Desktop decisional aids (PC-based with software modifications for each target group)

2. Computer-based training devices (interactive video disk)

3. Virtual reality technology for out-of-cockpit decision making exercises (Emergency Medical Service helicopters, tower cab, maintenance, etc.)

4. LOFT scenarios across target groups

5. Procedural changes to aid decision making tasks

6. Audio-visual training aids

7. Tailored manuals with task specific ADM training

D. <u>Evaluating Training Effectiveness</u>

The objective in this area is to evaluate the effectiveness of training strategies to meet the training objectives, using appropriate training instruments for each of the user groups. This would require the development of necessary experiments, execution of the experiments, data collection and analysis. Essential to this task is the development of an acceptable measure or "marker" of cognitive performance changes pre- and post-ADM training. This type of cognitive performance evaluation tool requires further research and development of its own. In particular, the use of appropriate cognitive markers for specific task demands identified during a flight (see Cognitive Task Analysis discussion from Working Group A) needs to be defined and tested.

7.3 Future Requirements and Recommendations

Two of the major areas addressed by this group were defining the concepts and developing the methods for examining ADM, such as developing a taxonomy, etc. Some examples are: How are decisions quantified? What is the process? If the process is good, can the decision be poor? Can the process be measured, or just the outcome? What techniques are available for that?

The major output from Working Group B was the specification of a "strawman" five-year plan to accomplish the work outlined. The group's estimate of the task required to analyze each problem area adequately were as follows:

Problem Area	Description	Tasks	
A.	Identify ADM Processes	1. Define Methodology 2. Develop taxonomy	
B.	Define ADM Objectives	1. Transport aircraft	2. Ab initio/UPT 3. Helicopters
C.	Develop Training Strategies	1. Military 2. Commercial Operators 3. General Aviation	
D.	Evaluate Training Effectiveness	1. Define Cognitive Tasks 2. Develop Perf. Markers 3. Perform Experiments	

8.0 WORKING GROUP C: ADVANCED TRAINING & EVALUATION METHODS

This group was asked to assess the need for advanced ADM training based upon the problems and issues identified during the first day's presentations and their combined research and operational experience. The group chairman was Richard J. Adams of Advanced Aviation Concepts, Inc. (407) 747-3414. The co-chair was Dr. Anders Ericsson of the University of Colorado (303) 492-1492. The subject matter experts and technical support staff were:

Mr. Roy G. Fox	Bell Helicopter Textron	(817) 280-2676
Mr. Pete Hwoschinsky	FAA Vertical Flight Prog	(202) 267-8531
Dr. Judith Orasanu	NASA Ames Research Ctr.	(415) 604-3404
Mr. Steve Paul	Captain, Delta Airlines	(404) 715-1121

8.1 Introduction

The deliberations of this working group were based upon an assessment of the deficiencies and problems of current pilot/crew ADM training. Although the interface between the pilots and air traffic controllers in the decision making process was included in this analysis, the explicit consideration of the need for controller decision making training, the anticipated problems and research required for ATC were outside the scope of this workshop.

A. The purpose of the current discussions was to identify and plan the future work required to address these problems. The group discussion was expedited and focused by the use of a three step process.

1. Identified ADM problems and needs in a "shopping list" format and then selected the top three for more detailed analysis.

2. Developed problem statements for the issues including what needed to be done and which user group was affected.

3. Identified the kinds of training products needed and categorized the products suitable for each user group.

B. This analysis included discussion of operational decision making objectives and whether or not they varied by type of operation or user group, i.e., Commercial, Military or General Aviation. The discussion within each of these groups addressed different types of decisions required by different aircraft types (helicopter vs. fixed wing, piston vs. turbine, single vs. multi-engine, etc.). The needs of both airplane and helicopter pilots and

crews were explicitly addressed - where they were common and where they were different.

Topics that could be classified as the "structure of decision making tasks" were discussed at length. These included: the need to match or tailor decision making training to key decision points in an operation or mission; the desire to identify expert decision making characteristics to match these varying task/situation demands; the type of decision making aiding that could be developed to reduce the demands on the crews/pilots; and, the need to alleviate the cognitive dissonance and "boomerang" effects of ADM/CRM training currently observed by both researchers and operators.

The need to match or tailor decision making training to key decision points in an operation or mission was considered to be a worthwhile future effort and it was integrated into the advanced training proposed. (Note: Working Group A discussed this in greater detail as a Cognitive Task Analysis.) In addition, the need to develop expert decision making training to meet the needs of critical tasks was recognized as a priority activity.

C. Finally, the type of future ADM training desired was discussed. The group agreed that the training needed to be context based. Such training could be subdivided into decision making training with differing emphasis: either to anticipate, or to avoid, or to respond to the task demands of any normal or emergency situation. The consensus was that the historical focus of ADM and CRM training courseware and simulator scenarios dealt with how to respond to specific circumstances or problems. The group felt that future training should be designed as follows:

1. Pro-Active

    a. Anticipating decision making tasks and alternatives

    b. Avoiding decision making situations (where possible) which involve undue risk

2. Reactive: responding to tasks or situations requiring decisions after they occur

Analyzing decision making task demands in this manner should expedite identification and characterization of the differences between expert and novice pilot decision strategies and styles. This knowledge can then be used by teams of senior captains, training officers and researchers to develop expert training materials and scenarios.

8.2 Problems and Needs

There was significant discussion (in both content and time) about the primary problems with

ADM training and, in particular, with the ordering or prioritizing of those problems. Six systemic ADM problems were identified. Within these six, two types of problems or issues emerged. The first type (problems 1, 2, and 3) addressed issues that needed to be addressed near term to ensure the integration and success of ADM training. The second type (problems 4, 5, and 6) addressed the future of ADM programs from the perspective of critical areas in need of additional research. The specific problems in each category were:

A. The need to change attitudes and value acceptance of ADM by both pilots and management

B. The need to tailor ADM training to the non-homogeneous pilot community requiring different solutions.

C. The lack of explicit ADM training in most operations (many Part 121, most Part 135, majority Part 91) and in pilot certification criteria of Part 61.

D. How to maximize decision making information and training to the pilot community. Probably less than 5% of the pilot community is being reached.

E. How to develop and implement programs to train the ADM instructors and evaluators. Small general aviation fixed base operators involved in training were of particular concern.

F. How to evaluate the impact of ADM training experimentally and operationally using:

1. controlled assessments (before and after simulator sessions);

2. principled criteria (i.e., theory grounded); and

3. behavior assessment pre-and post-ADM or during an evaluation by a check airman.

The proposed work will support the seventh objective of the FAA's National Plan for Aviation Human Factors which is: "to develop enhanced methods of training and selection for aviation system personnel".[16] FAA policy now recognizes the need for CRM training for multi-pilot aircraft operations and there may very well be applications of the suggested research for air traffic controller's as well.

8.3 Advanced Training Requirements and Recommendations

The group then discussed the requirements for sustaining the progress achieved through ADM thus far. This lead the group to a critical analysis of its future requirements to

enhance decision making training. As often occurs, the use of ADM has reached a plateau where the training community and the pilots are asking questions such as: What do we do the next time around? (next recurrency training), and Can we develop a second generation, advanced or expert decision making curriculum? The group's response to these questions covered three primary areas.

A. The first area addressed the question: What can we do beyond what is being done today for decision making? The requirements that need to be investigated in this area included those of commercial air carrier (Part 121), commuter (Part 135), corporate (Part 91) and general aviation. Each of the last three categories need to define the varying needs of both airplane and helicopter ADM. The decision was made to continue the discussion of advanced training needs by defining the components of the training material to be included, and the appropriate training approaches.

B. The second area of importance to the group was centered on the definition of the framework for problem solving. The group answered the question: What do we want to train? A consensus answer was achieved that the four areas of attitudinal training, knowledge, procedural skills and process skills (including the effects of time pressure) should form the basis for the framework of advanced ADM. Although each of these areas have been historically addressed (both before and after formal ADM training existed), a more refined or focused decision making approach was suggested. For example, the following "advances" were proposed as potential fertile ground for the next step in ADM training using aircraft simulators, interactive video, computer based training, classroom training, or other advanced decision making training methods and tools.

1. **Attitudes** -- Analyze and develop training required to resolve difficulties experienced with acceptance by some, resistance by others and rejection by a few (i.e., cognitive dissonance and boomerang effects). This will require an analysis of possible differences in expert and novice psychophysiological attitudes including kinesthetic, affective and cognitive components, as well as exploring the role of ego in decision making.

2. **Knowledge** -- Pilot training should include an expanded knowledge of the importance of decision making, the types of decisions, styles of decision making and the characteristics that have been recognized as "expert" in normal, emergency and novel situations.

3. **Procedural Skills** -- Advanced ADM training should provide an understanding of the different types of cognitive skills required and used to satisfy various task demands. The difference between analytical reasoning and procedural knowledge based decision making should be taught, as well as, the need for adaptive decision making in situations with novel cues or

contexts (e.g., UAL 232 catastrophic failure accident).

4. **Process Skills** -- The attention, memory, recognition and recall skills necessary to anticipate, avoid or respond to inflight situations should be incorporated in advanced or expert decision making training. Specifically the way experts combine factual knowledge, procedural skills and experience into the problem-solving process to develop adaptive plans needs to be understood. This should explicitly address the successful means of responding within the time frame required, that is, how to attain the fast, accurate decision making skills characteristic of experts.

C. The third area included in this analysis of advanced training requirements addressed the question: How do we want to train decision making -- for both individual and full crew ADM (training materials and techniques)? The response to this query was to develop a comprehensive list of training methods and tools (listed in Table 1) which could be used to train and evaluate pilot/crew decisional skills.

Table 1 ADVANCED ADM TRAINING TOOLS AND TECHNIQUES

TYPE OF TRAINING		MATERIALS AND METHODS
Individual Study	1.	Manuals and Self-tests
	2.	Other ADM publications (APS pubs, HELIPROPS, VORTEX)
Training Syllabi	1.	Student
	2.	Instructor
	3.	Evaluator
Context Based	1.	Classroom Vignettes (structured hangar flying)
	2.	Library of Videos
Experience Transfer	1.	Grand Rounds (Mentor) Concept
	2.	Peer Training (alternate roles)
Activity Based	1.	Computer-based Training (Knowledge based expert system)
	2.	Interactive video disk
Simulator Scenarios	1.	Normal Procedures (based on Cognitive Task Analysis)
	2.	Emergency and Novel Situations

The development of this type of ADM training methods and tools will support the National Plan for Aviation Human Factors "Flightdeck Environment" requirements which include: "the development of computer-based models of flightcrew decision- making and other cognitive processes to serve as a basis for the design of new systems".
The Advanced ADM Recommendations resulting from these detailed discussions (and debates) was concisely summarized by the two primary recommendations of the group:

1. the number one priority of future efforts should be to create the value and acceptance of ADM.

2. advanced training must specifically address the diverse communities involved.

The areas needing attention in order to effect the first recommendation include developing, documenting and disseminating the benefits of ADM for both pilots and management. The proposed Cognitive Task Analysis and decision making taxonomy will facilitate this understanding, without creating the need for entirely new or different training syllabi. Using these analytical techniques, will allow the training community to express and articulate both individual and crew cognitive behavior and performance in an analogous manner to psychomotor flying skills. Table 2 summarizes the recommended benefit areas that should comprise this future work as a minimum.

Table 2 ADM VALUE AND ACCEPTANCE AREAS TO BE DOCUMENTED

COMMUNITY	BENEFITS TO BE QUANTIFIED
Pilots	Longevity/Livelihood/Quality of Life
Management	Reduced Accident Rates/Reduced Insurance Costs/Improved Public Image/Improved Operating Benefit/Cost Ratios

In considering the specific work that needs to be developed to effect the second recommendation, we concentrated on the type of training needed for each of the user communities. The advanced ADM training requirements were categorized according to the work generally needed by all groups, the areas needing customized attention, and the appropriate tools that should be considered for each community. Table 3 presents the consensus of the working group for satisfying these needs.

Table 3 RECOMMENDED ADVANCED ADM TRAINING AND METHODS

USER GROUP	COMMON NEEDS (Reference Table 1)	CUSTOM NEEDS	RECOMMENDED TOOLS
Part 121			B3, C1, E1, F1 & F2
Part 135	**ATTITUDES**	**KNOWLEDGE**	A1, B2 & B3 E1 & D2
Part 91	**AND**	**AND**	A1, A2, B2, C1 & D2
(incl. helos)	**PROCESS**	**TAILORED**	
Gen. Aviation	**KNOWLEDGE**	**SKILLS**	A1, A2, B1, B2 & C1
(incl. helos)			
Military			A1, B3, C1, D1, E2, F1 & F2

9.0 CONCLUSIONS

To return to the focus of ADM and CRM, their similarities and differences, it should be noted that there was and is ADM "stand- alone" training; there was and is CRM with ADM as a part of it; all current CRM does have ADM as a component. But, ADM is the piece of current CRM training which now needs a renewed emphasis, and this will occur through new, joint FAA/NASA/Industry/Academe research and development efforts.

As with CRM, ADM is a growing, evolutionary field. As with CRM, the early years failed to produce a well-defined core set of principles and practices. ADM, like CRM, had some unanswered questions and differing "camps" of thought. As with CRM, ADM was, and still is, in need of the development of crew performance/behavior markers (or evaluation measures) to be embedded in a new paradigm which focuses on the reality of operational requirements.

In the past 3 years CRM has begun to consensually develop and articulate accepted core principles and practices. It has a set of CRM performance markers, developed by Dr. Robert Helmreich and used by many air carriers. CRM researchers and users are evaluating at least one new paradigm which does use the mission as the framework for the analysis and evaluation of crew performance requirements.

ADM, by using what has been learned in CRM and by beginning with the CRM behavioral/ performance markers entitled "Decision Making" and "Leadership", can step off now into developing its own taxonomy via a Cognitive Task Analysis (CTA). The CTA will allow effective pilot/crew behavior to be expressed in terms of cognitive and motor skills as well as attitudes. The resultant would be a new ADM paradigm on which to build advanced or expert training requirements and procedures.

ADM R&D, and the resultant insights and materials from joint Government/Industry/

Research Community efforts, needs to provide future contributions in 3 major aviation areas:

A. There will be **changes in operational procedures**. As understanding of the aircrew/airman decisional needs and processes grows, new light will be shed on what procedures are/aren't truly safe and efficient--and why.

B. There will be great **changes in training**: requirements, actual training, evaluation strategies and procedures. There will be emphasis on new paradigms of ADM. These will lead to new training techniques; to recognition of the need for new requirements for providing crews/pilots with the tools and skills they need for differential decisions; to new ADM training; and, to new ways to evaluate crew decisional needs, strategies.

C. Finally, there will be **new insights into hardware design**, especially cockpit and ground automation, resulting from ADM R&D. As more is learned about the decisional processes and conditions, this knowledge can be translated into truly user friendly designs/technology/hardware that both enables and actively assists in ADM.

ADM materials and training, with CRM, hold the promise for **the** major human factors contribution to aviation safety in the flightcrew training and assessment areas.

"LEARN FROM THE MISTAKES OF OTHERS; YOU'LL NEVER LIVE LONG ENOUGH TO MAKE THEM ALL YOURSELF".....Ralph Waldo Emerson

REFERENCES

Adams, R. J., & Ericsson, K. A. (1992). *Introduction to Cognitive Processes of Expert Pilots* (Rep. No. DOT/FAA/RD-92/12). Washington, DC: Federal Aviation Administration.

Adams, R. J., & Lofaro, R. J. (1992). *Training Considerations for Expert Pilot Decision Making*. Collegiate Aviation Review, in press.

Bloomfield, J. R. (1992). *Elements of a Theory of Natural Decision Making*. Honeywell Systems Research Center. Minneapolis, MN.

Bloomfield, J. R., Levitan, L., Cooper, B., Lyall, E. A., & Edens, E. (1992). *Taxonomy of Flight Variables* (Contract No. DTFA01-91-C-00040). Washington, DC: Federal Aviation Administration.

Diehl, A. E., (1990). *An Overview of Cockpit Resource Management and Aeronautical Decision Making* (paper presented at the Second Department of Defense Technical Training Group Meeting). Orlando, FL: USAF Safety Center.

DOT/FAA, (1986). *ADM for Student Pilots* (Rep. No. DOT/FAA/PM-86/41). Washington, DC: Federal Aviation Administration.

DOT/FAA, (1986). *ADM for Commercial Pilots* (Rep. No. DOT/FAA/PM-86/42). Washington, DC: Federal Aviation Administration.

DOT/FAA, (1986). *ADM for Instrument Pilots* (Rep. No. DOT/FAA/PM-86/43). Washington, DC: Federal Aviation Administration.

DOT/FAA, (1986). *ADM Instructor Guide for Student and Private Pilots* (Rep. No. DOT/FAA/PM-86/44). Washington, DC: Federal Aviation Administration.

DOT/FAA, (1986). *ADM for Helicopter Pilots* (Rep. No. DOT/FAA/PM-86/45). Washington, DC: Federal Aviation Administration.

DOT/FAA, (1986). *ADM -Cockpit Resource Management* (Rep. No. DOT/FAA/PM-86/46). Washington, DC: Federal Aviation Administration.

DOT/FAA, (1988). *ADM for Air Ambulance Helicopter Pilots-Learning from Past Mistakes* (DOT/FAA/PM-88-5). Washington, DC: Federal Aviation Administration.

DOT/FAA, (1988). *ADM for Air Ambulance Helicopter Pilots-Situational Awareness Exercises* (DOT/FAA/PM-88-6). Washington, DC: Federal Aviation Administration.

DOT/FAA, (1988). *Risk Management for Air Ambulance Helicopter Operators* (Rep. No.

DOT/FAA/PM-7). Washington, DC: Federal Aviation Administration.

DOT/FAA, (1988). *ADM for Air Ambulance Hospital Administrators* (Rep. No. DOT/FAA/PM-88-8). Washington, DC: Federal Aviation Administration.

DOT/FAA, (1990). *The National Plan for Aviation Human Factors*. Washington. DC: Federal Aviation Administration.

DOT/FAA, (1991). *ADM Advisory Circular* (Rep. No. AC 60-22). Washington, DC: Federal Aviation Administration.

Ericsson, K. A. & Smith, J., (1991). *Toward a General Theory of Expertise*. Cambridge: Cambridge University Press.

Helmreich, R. L., Foushee, H. C., et. al. (1986). *Cockpit Management Attitudes: Exploring the attitude-performance linkage*. Aviation, Space and Environmental Medicine, 57, 1198-1200.

Helmreich, R. L., Wilhelm, J. A., et. al., (1990). *Reinforcing and Evaluation Crew Resource Management Training: Performance Ratings of Flightcrews*. Paper for the Sixth International Symposium on Aviation Psychology. Columbus, OH: The Ohio State University.

Jensen, R. S. & Benel, R. A., (1977). *Judgment Evaluation and Instruction in Civil Pilot Training* (Rep. No. DOT/FAA-RD/78.24). Washington, DC: Federal Aviation Administration.

Klein, G. & Klinger, D., (1991). *Naturalistic Decision Making*. Cseriac Gateway, Volume II: Number 1, 1-4.

Lofaro, R. J. *Crew Resource Management: Past, Present and Future*. The Journal of Aviation/Aerospace Education & Research, in press.

Maher, J. W., (1991). *Why Pilots are Least Likely to get Good Decision Making Precisely When They Need it Most*. Paper for the Sixth International Symposium on Aviation Psychology. Columbus, OH: The Ohio State University.

Orasanu, J., *Decision Making in the Cockpit*. In E. Wiener, B. Kanki & R. Helmreich (Eds.). Cockpit Resource Management. New York: Academic Press, in press.

Orasanu, J. & Salas, E. *Team Decision Making in Complex Environments*. In G. Klein, J. Orasanu, R. Calderwood & C. Zsambok (Eds.). Decision Making in Action: Models and Methods. Norwood, New Jersey: Ablex, in press.

APPENDIX A

SAMPLE ADM WORKSHOP WORKBOOK

BACKGROUND

The workshop workbook was prepared and distributed for three reasons. First to provide each participant with a bound notebook to encourage recording of their perspectives of ADM problems, issues, requirements, opinions, etc. for use throughout the workshop. Second, to provide a common background knowledge of the expertise and interests of the presenters. Third, to provide a basic foundation of the current FAA research and publications in the areas of Expert Pilot Decision Making and Crew Resource Management.

PURPOSE

This appendix is provided in a "short" or sample form of what was provided the workshop participants. It is intended to acquaint the reader with the overall thrust of the workshop (see Section I - Objectives and Products), as well as the detailed organization and contents of the agenda (see Section II).

PRESENTERS

Section III of this appendix is an abbreviated version of the pages provided the participants. A biographical sketch of each presenter was included (see Section 7a. page 7 - Dr. Ronald J. Lofaro) along with three sections of mostly blank note taking space (see Section 7b. pages 8,9 - Dr. Alan E. Diehl) which gave the participants an organized and lasting place to record: Presentation Notes, Questions and Issues, and Future Required Activities. As shown on the Agenda (pages 4,5) the discussions of the participants views and ideas in these three areas were solicited after about every 2 or 3 speakers.

REFERENCES

Two background papers were provided as a bare minimum of common knowledge to establish a starting point for discussion and elicit comments/critiques from each participant's perspective regarding operational status and research needs in the areas of expert decision making and crew resource management.

AERONAUTICAL DECISION MAKING WORKSHOP

Workbook

By: Advanced Aviation Concepts, Inc.
Jupiter, Florida
for:

Federal Aviation Administration
Washington, DC

Denver, Colorado
May 6 and 7, 1992

Table of Contents

I.	Objectives and Products		3
II.	Agenda		4, 5
III.	Presenters		
	a.	Dr. Ronald J. Lofaro	7
	b.	Dr. Alan E. Diehl	8
	c.	Steve Paul	10
	d.	Kevin Smith	12
	e.	James E. Irving	14
	f.	Dr. Robert Alkov	16
	g.	Richard J. Adams	18
	h.	Dr. K. Anders Ericsson	21
	i.	Dr. Gary Klein	23
	j.	Dr. John Bloomfield	25
	k.	Dr. Judith Orasanu	27
	l.	Roy Fox	29
IV.	Working Group Goals and Action Items		
	a.	Working Group A	31
	b.	Working Group B	32
	c.	Working Group C	33
V.	Proposed Projects, Products & Plans		34
VI.	References		35
	a.	Training Considerations For Expert Pilot Decision Making	Adams/Lofaro
	b.	Crew Resource Management: Past, Present and Future	Lofaro

AERONAUTICAL DECISION MAKING WORKSHOP

MAY 6th and 7th 1992

A CONVENING OF A SELECT GROUP OF EXPERTS AND OPERATIONAL PERSONNEL ON AERONAUTICAL DECISION MAKING (ADM) FOR THE PURPOSE OF SHARING IDEAS AND IDENTIFICATION/EXPLORATION OF FUTURE PROJECTS

THE
MARRIOTT
COURTYARD INN
DENVER AIRPORT

OBJECTIVES:

1. TO DISCUSS STATE-OF-THE-ART KNOWLEDGE AND ACCOMPLISHMENTS IN ADM FROM BOTH OPERATIONAL AND RESEARCH PERSPECTIVES.

2. TO EXAMINE THE DECISION MAKING DIFFERENCES BETWEEN EXPERT AND NOVICE PILOTS ESPECIALLY THEIR RESPONSES TO NOVEL CUES, USE OF AUTOMATIC INFORMATION PROCESSING AND THEIR RESISTANCE TO ATTITUDINAL OR MANAGEMENT STYLE CHANGES.

3. TO FORM FOCUS GROUPS FOR FOLLOW-ON JOINT PROJECTS IN THE NEXT GENERATION OF ADM AND CONSIDER INTEGRATION IN CRM/LOFT TRAINING.

PROPOSED OUTPUTS:

- INITIAL SPECIFICATION OF THE CONTENTS AND FORMAT FOR THE NEXT GENERATION OF ADM TRAINING.
- INITIAL SPECIFICATION OF THE VALIDATION METHODS AND EVALUATIONS NEEDED TO INSURE EFFECTIVENESS OF FUTURE TRAINING.
- INITIAL DEFINITION OF AN ACTION PLAN -- INCLUDING AREAS OF RESPONSIBILITY FOR THE CONTINUED ENHANCEMENT OF ADM TRAINING.

AERONAUTICAL DECISION MAKING WORKSHOP

AGENDA

Wednesday May 6th	TOPICS	SPEAKER	ORG.
7:30 - 8:00	Continental Breakfast		
8:00 - 8:15	Welcome and Introduction	Dr. Ronald J. Lofaro	FAA
8:15 - 8:30	Workshop Organization and Objectives	Richard J. Adams	AAC
Morning	**OPERATIONAL ADM EXPERIENCES & IMPACTS**		
8:30 - 9:00	Overview of ADM Effectiveness	Dr. Alan E. Diehl	USAF
9.00 - 9:30	Decision Making Training Methods at Delta	Steve Paul	Delta
9:30 - 10:00	Decision Making in Operational Systems	Kevin Smith	Opcon
10:00 - 10:30	Problems, Issues & Requirements Development	Group Discussion	
10:30 - 10:45	BREAK		
10:45 - 11:15	Bootstrapping Experience: What Makes the Expert Pilot Decision Maker Expert and Why?	James E. Irving	United
11:15 - 11:45	The Effect of Trans-Cockpit Authority Gradient on Navy & Marine Aircraft Mishaps	Dr. Robert A. Alkov	USN
11:45 - 12:15	Problems, Issues & Requirements Development	Group Discussion	
12:15 - 1:15	LUNCH (on your own)		
Afternoon	**RESEARCH PERSPECTIVES FOR THE NEXT GENERATION ADM**		
1:15 - 1:30	How Expert Pilots Think	Rich Adams	AAC
1:30 - 2:00	Methodology for Studying and Training Expertise	Dr. K. Anders Ericsson	U of CO
2:00 - 2:15	Enhanced ADM Training Alternatives	Rich Adams	AAC
2:15 - 2:45	Problems, Issues & Requirements Development	Group Discussion	
2:45 - 3:00	BREAK		
3:00 - 3:30	A Cognitive Model for Training Decision Making in Aircrews	Dr. Gary A. Klein	Klein Ass.
3:30 - 4:00	Elements of a Theory of Natural Decision Making	Dr. John Bloomfield	Honeywell
4:00 - 4:30	Shared Mental Models in Crew Decision Making	Dr. Judith Orasanu	NASA
4:30 - 5:00	Problems, Issues & Requirements Development	Group Discussion	

AERONAUTICAL DECISION MAKING WORKSHOP

AGENDA

Thursday May 7th	ACTIVITY	MODERATOR
7:30 - 8:00	Continental Breakfast	
8:00 - 8:30	Heliprops, Embedded ADM to Reduce Human Error Accidents in Helicopters	Roy Fox
8:30 - 9:00	Working Group Organization & Activities	Ron Lofaro
9:00 - 9:30	Goals and Proposed Outputs	Rich Adams
9:30 - 12:30	Working Groups Convene	see below

Morning **NEXT GENERATION "ADM" DIRECTIONS**

Group A	Group B	Group C
FUTURE CIVIL AVIATION RESEARCH & TRAINING	FUTURE MILITARY AVIATION RESEARCH & TRAINING	ADVANCED TRAINING & EVALUATION METHODS
MOD.: Ron Lofaro	MOD.: Al Diehl	MOD.: Rich Adams

12:00 - 1:00 LUNCH (on your own)

Afternoon **ADVANCED RESEARCH & TRAINING PROJECTS & PLANS**

1:00 - 1:30	Working Group A Goals & Action Items	Ron Lofaro
1:30 - 2:00	Working Group B Goals & Action Items	Al Diehl
2:30 - 3:00	Working Group C Goals & Action Items	Rich Adams
3:00 - 3:15	BREAK	
3:15 - 4:00	Proposed Projects, Products & Plans	Ron Lofaro & Rich Adams

PRESENTERS

Dr. Ronald J. Lofaro

Aviation Psychologist/Project Manager
Federal Aviation Administration (FAA)

Dr. Lofaro has been with the FAA at their national headquarters (HQ) since 1989 as an aviation Psychologist/Project Manager for Human Factors research and development in aviation safety. He is working on such issues as evaluation techniques for cockpit resource management (CRM) and line oriented simulation/line oriented flight training (LOS/LOFT); the integration and assessment of CRM and Flight Control Skills, the identification and training of Expert Pilot Decision Making (EDM); air traffic controller selection/screening and circadian dysrhythmia/desynchronosis issues in both long and short-haul flying.

Prior to coming to the FAA, Dr. Lofaro was with the Army Research Institute's (ARI) Aviation R&D Unit at the Army's Aviation Center in Alabama. He focused on various aspects of aviation safety and training including: aviator candidate classification and Selection; air-to-air combat human factors; aviation accident investigation/analysis.

Previous to ARI, he was involved in human resources with the FAA's Eastern Region, as a personnel Psychologist for the Army's Training and Doctrine Command, involved in test development and evaluation and served as a clinical psychologist at Walson Army Hospital. Dr. Lofaro spent twelve years as a university professor after serving in the US Air Force from 1960 to 1965.

Dr. Lofaro earned his PhD. from the New York University. He is widely published in aviation psychology including the *Human Factors Society Journal and Bulletin* and *the International Journal of Aviation Psychology*. He is a member of the SAE Human Behavior Technology Committee.

Dr. Alan E. Diehl **Human Performance Technical Advisor**
U.S. Air Force Safety Agency

Dr. Alan E. Diehl has been the Human Performance Technical Advisor for the US Air Force Safety Agency since 1987. He holds academic degrees in psychology, management and engineer and holds Airline Transport Pilot and Flight Instructor ratings. He has several important accomplishments and distinctions resulting from his twenty years of professional experience with US aircraft industry and government agencies.

At **LTV** Electrosystems, Dr. Diehl assisted in the design of Project "Redflame," one of the first lasers to be used in combat. With **Cessna Aircraft** , his responsibilities included flight deck design on the Citation business jet. He later won the esteemed **Collier Trophy** for the Citation's outstanding safety record.

As an Aviation Research Psychologist for the **Naval Training Systems Center** , Dr. Diehl developed innovative methods for evaluating simulator training programs. Joining the NTSB HQ staff in 1977, he was the first Human Performance Scientist/Air Safety Investigator, helping to expand the scope and effectiveness of investigations and to better document the underlying causes of human error. He drafted the first recommendation calling for operational implementation of Cockpit Resource Management (CRM).

He became the Program Scientist for Human Performance at **FAA HQ** in 1980, directing research into pilot judgment training, monitoring ongoing work in CRM and initiating development of several training manuals and audio-visual programs related to cockpit management and aeronautical decision making (ADM). Dr. Diehl received two special achievement awards for his work with the FAA.

Since transferring to the USAF, he continues to serve as a consultant to mishap investigation boards. He has helped various commands select and/or develop cockpit management programs. He has also served as a consultant to other important safety efforts such as ICAO, Flight Safety and Human Factors Study Group, and the DOD Air Carrier Analysis System.

Presentation: "Overview of ADM Effectiveness"

Presentation Notes:

Questions/Issues:

Future Required Activities:

Capt. Steve Paul **Senior Facilitator, Program Developer**
Delta Airlines

Captain Steve Paul is currently a senior facilitator and program developer for Delta Airlines. His responsibilities include developing programs for check airmen, training and initial Captain upgrade training. This includes assisting with the development for recurrent training and facilitator training. Facilitation activities include check airmen, recurrent and various co-facilitated flight attendant training.

Captain Paul graduated from the University of Colorado in 1966 with a major in Psychology. He served in the US Navy as a pilot as a T-39 NATOPS instructor and check airman. As a pilot for Delta, he has flown the 727 as both Second and First Officer (SO & FO respectively); the DC-8 as SO; DC-9 as FO; the L1011 as FO and the 737 as Captain. He was a CRM facilitator from 1989 to 1990.

Presentation: Decision Making Training Methods at Delta

Presentation Notes:
Questions/Issues:
Future Required Activities:

Kevin Smith **Captain**
United Air Lines

Kevin Smith is currently a captain on the 737/300 and a First Officer on the 747/400. He served two years at the United Air Lines Training Center working on CRM and AQP and was a member of the Air Transport Association (ATA) Committee on CRM/AQP/LOS. He has coordinated and worked with Dr. Helmreich and the FAA Flight Standards and R& D.

Captain Smith served as a Navy pilot flying the F111B Tiger and has extensive experience with both military and civil operations analysis.

Presentation: Decision Making In Operational Systems

Presentation Notes:
Questions/Issues:
Future Required Activities:

James E. Irving **Captain**
United Air Lines

Captain Jim Irving flew with the US Navy for five years in helicopters and multi-engine patrol aircraft as well as jet fighters. As in instructor pilot for Lockheed Commercial Aircraft on the L1011, he developed classroom training and performed simulator and aircraft training for airlines all over the world.

Capt. Irving was director of Learjet training at Martin Aviation in Santa Ana, California, one of the largest Learjet training facilities in the United States. During this period he also developed and managed the ground school.

Jim has been flying with United Air Lines for eighteen (18) years and is currently a Captain with United Airlines flying a Boeing 737/300. His experience includes pilotage in captain, first and second officer positions in half a dozen aircraft types he has been training check airman.

Capt. Irving is keenly interested in the problems of training commercial airline pilots, in the particular problems presented by advanced automated aircraft, and is providing subject matter "expertise" to a team at the University of Colorado studying part-task training.

Presentation: Bootstrapping Experience: What Makes the Expert Pilot Decision Maker Expert and Why

---

Presentation Notes:
Questions/Issues:
Future Required Activities:

Dr. Robert Alkov **Research Psychologist**
Naval Safety Center

Robert A. Alkov received a PhD. in Experimental Psychology from Florida State University in 1965. He worked as an aviation psychologist for George Washington University (HumRRO) under contract to the US Army for aviation training research at Ft. Rucker, Alabama in the mid 1960s. he has been employed at the Naval Safety Center as a research psychologist for the past 25 years.

Bob is a retired Naval Reserve Aviator, a Fellow of the Aerospace Medical Association and past president of both the Association of Aviation Psychologists, and the Tidewater chapter of the Human Factors Society. He teaches graduate courses for Embry-Riddle aeronautical University.

Since 1987, Dr. Alkov has been working to introduce aircrew coordination training into US Navy aviation training squadrons and units. he has been employed at the Naval Safety Center as a research psychologist for the past 25 years.

Bob is a retired Naval Reserve Aviator, a Fellow of the Aerospace Medical Association and past president of both the Association of Aviation Psychologists, and the Tidewater chapter of the Human Factors Society. He teaches graduate courses for Embry-Riddle aeronautical University.

Since 1987, Dr. Alkov has been working to introduce aircrew coordination training into US Navy aviation training squadrons and units.

Presentation: The Effect of Trans-Cockpit authority Gradient on Navy & Marine Aircraft Mishaps

---

Presentation Notes:
Questions/Issues:
Future Required Activities:

Richard J. Adams **Vice President**
Advanced Aviation Concepts, Inc.

Mr. Adams received his B.S. in Aeronautical and Astronautical Engineering from the University of Illinois in 1965 and his M.S. in Mechanical Engineering from the University of Florida in 1968. Mr. Adams is a registered Professional Engineer in Mechanical Engineering in the State of Florida and a private pilot. Mr. Adams has been involved in civil aviation research and development for over 27 years. He has authored over sixty (80) technical reports, articles and papers in the fields of pilot training, pilot workload, accident data analysis, avionics, area navigation, aircraft energy conservation, air traffic management, propulsion and controls. From 1974 to 1984 Mr. Adams specialized in the technical and operational problems of the civil helicopter operator. Since 1985, he has supported the FAA's Aeronautical Decision Making research in the development of decision making training manuals for private, commercial, instrument and instructor pilots, emergency medical service operators and hospital administrators. He has investigated accident trends to determine where training can be enhanced and recommend ways of changing pilot attitudes to improve safety.

Presentation: How Expert Pilots Think

Presentation Notes:
Questions/Issues:
Future Required Activities:

Richard J. Adams (Continued)

Presentation: Enhanced ADM Training Alternatives

Presentation Notes:
Questions/Issues:
Future Required Activities:

Dr. K. Anders Ericsson

Associate Professor, Psychology
University of Colorado, Boulder

K. Anders Ericsson received his Ph.D. in Cognitive Psychology in 1976 from the University of Stockholm (Sweden). For two years he headed a group in Human Factors at the Institute of Aviation Medicine in Linköping, Sweden, where he was involved in task analysis and cockpit design for the next generation of light-attack airplanes for the Swedish Airforce. During 1977 to 1980 he was a post-doctoral fellow at Carnegie-Mellon University in Pittsburgh, working with Professor Herbert Simon (Nobel Prize 1978).

He has served as Assistant Professor of Psychology at the University of Colorado and the Max-Planck Institute for Human Development and Education, West Berlin. He recently accepted the position of Conradi Eminent Scholar Chair of Psychology in January 1993 at the Florida State University to develop research on the study of expert performance. His current research interest concerns the study of expert performance-its structure and acquisition. Dr. Ericsson is widely published including books with: Herbert Simon, "Protocol analysis: Verbal Reports as Data;" and Jacqui Smith, "Toward A General Theory of Expertise: Prospects and Limits."

Presentation: Methodology for Studying and Training Expertise

Presentation Notes:
Questions/Issues:
Future Required Activities

Dr. Gary A. Klein **Chairman, Chief Scientist**
Klein Associates Inc.

Dr. Klein received his Ph.D. in experimental psychology from the University of Pittsburgh in 1969 and served as an Assistant Professor of Psychology at Oakland University until 1973. As a research psychologist at the Air Force Human Resources Laboratory from 1974 to 1978, he was a member of the team that investigated the use of functional requirements to design aircrew simulators.

In 1978, Dr. Klein formed Klein Associates conducting studies of naturalistic decision making at both the levels of individual and team decision making. He has developed methods of cognitive task analysis for use in conducting research and in developing training materials. Additional applications of this work include the development of storyboards for man-machine interfaces and knowledge elicitation for market research of consumer decision making. He has developed the Recognition-Primed Decision Model which describes how people make rapid decisions in a domain with which they have experience.

Presentation: A Cognitive Model for Training Decision Making in Aircrews

---

Presentation Notes:
Questions/Issues:
Future Required Activities:

Dr. John Bloomfield **Honeywell Systems and Research Center**

Dr. John Bloomfield was educated in England, obtaining a B.A., in Psychology from the University of Hull and a PhD in Psychology from the University of Nottingham. In 1972, he moved to the United States to carry out post-doctoral research at the Ohio State University Research Foundation, and then joined Honeywell two years later. Dr. Bloomfield is interested in natural decision making and knowledge acquisition techniques. he developed a flight decision taxonomy, while working on a Wright-Patterson AFB program, then used this as the basis for a more-generally applicable Decision Categorization Framework. Also, he has developed an advanced knowledge acquisition technique, Knowledge-Sensitive Task manipulation, and demonstrated its use of acquiring specific detailed, tacit knowledge from commercial airline pilot training instructors flying a motion-based flight simulator. Currently, Dr. Bloomfield is Principal Investigator on an FAA's program, the objective of which is to investigate Controlled Flight Into Terrain (CFIT) air accidents. In addition to his work at Honeywell, Dr. Bloomfield is an Adjunct Professor at the University of St Thomas and at Hamline University.

Presentation: Elements of a Theory of Natural Decision Making

Presentation Notes:
Questions/Issues:
Future Required Activities:

Dr. Judith Orasanu

Flight Human Factors Branch
NASA-Ames Research Center

Dr. Orasanu received her PhD in Experimental Psychology from Adelphi University in 1975 and was awarded a Postdoctoral Fellowship at Rockefeller University. As a Research Associate at Rockefeller she focused on cognitive processes in comprehension. Dr. Orasanu joined the Crew Factors Group at NASA-Ames Research Center in 1991 where she is conducting research on crew problem solving and decision making. She went to NASA after six years with the US Army Research Institute's Basic Research Office. In that position she developed a program on Planning, Problem Solving and Decision Making that examined reasoning in everyday settings. Her involvement with that program laid the foundation for research on crew communication and problem solving, initiated when she was a visiting Fellow at Princeton University (1989-1990). Prior to joining ARI, Dr. Orasanu was a Senior Research Associate at the National Institute of Education managing research on literacy and bilingualism from 1979 to 1983.

Dr. Orasanu is widely published in the areas of CRM, stress and performance and decision making. She edits a series on Cognition and Literacy for Ablex Publishers.

Presentation: Shared Mental Models in Crew Decision Making

Presentation Notes:
Questions/Issues:
Future Required Activities:

Roy G. Fox

Chief Safety Engineer,
Bell Helicopter Textron

Mr. Fox started the Systems Safety Engineering Group at Bell and still directs that effort. In addition to Safety Engineering, he is deeply involved in crash survival of helicopters. This includes military and civil helicopters. Mr. Fox has chaired the helicopter industry AIA (Aerospace Industries Association) Crashworthiness Project Group, member of General

Aviation Safety Panel for seats and post crash fire protection, and member of SAE (Society of Automotive Engineers) committees on aircraft seats and occupant restraints. he also lectures on crash survival and human performance at the Bell pilot training school and the FAA Helicopter Safety and Accident Investigation Course. He also provides HELIPROPS safety briefings at regional safety seminars.

In 1989, Mr. Fox received the AHS (American Helicopter Society) Harry T. Jensen award for significant improvements in reliability, maintainability, or safety due to his crash survival efforts that are becoming mandatory FAA rules. In 1990, Mr. Fox received the FSF (Flight Safety Foundation) Business Aviation Meritorious Award for his crash survival efforts and teaching efforts that are resulting in improved safety in business aviation.

Presentation: "Heliprops, Embedded ADM to Reduce Human Error Accidents in Helicopters"

Presentation Notes:
Questions/Issues:
Future Required Activities:

Working Group Goals and Action Items
Working Group A-Notes/Issues

Working Group Goals and Action Items
Working Group B-Notes/Issues

Working Group Goals and Action Items
Working Group C-Notes/Issues

Proposed Projects, Products & Plans
Notes/Issues

REFERENCES

TRAINING CONSIDERATIONS FOR EXPERT PILOT DECISION MAKING

By:

Richard J. Adams
Advanced Aviation Concepts, Inc.
Jupiter, Florida

and

Ronald John Lofaro, Ph.D.
Federal Aviation Administration
Washington, D. C.

March 1992

Note: This report is based, in part, on research supported by the U. S. Department of Transportation Federal Aviation Administration Contract Number DTFA01-90-C-00042, on which the first author was the principal investigator. The second author was the project manager, coordinator and technical monitor for this research. The information, analysis and content of this report reflect the views of the authors and not necessarily those of the FAA or any of its organizational entities.

TRAINING CONSIDERATIONS FOR EXPERT PILOT DECISION MAKING

Decision making training has made a significant impact on safety by reducing the human performance error related accidents in both civil and military aviation. Accident rate reductions of about 50% can be seen when comparing pilot groups with and without decision making training. Yet, these large safety improvements have not reached the entire pilot community. In particular, there is a lack of acceptance of the linear decision making model by the more experienced pilots, a resistance to change in interpersonal skills in the multicrew environment and even a "boomerang" effect where the attitude toward the use of all crew resources deteriorates after training.

Extensive research and empirical testing in Aeronautical Decision Making (ADM) produced a series of ten Federal Aviation Administration manuals and reports on ADM (1986-1988). Although it is admittedly difficult to accurately assess the impact of all of the manuals throughout aviation, **significant reductions in human performance error (HPE) accidents have been documented in specific areas:**

- A 36% reduction in all HPE accidents for the *worldwide* B206 fleet (Fox 1991).
- A 72% reduction in weather related HPE accidents for the *worldwide* B206 fleet.
- A 48% reduction in all HPE accidents for the U. S. B206 fleet.
- A 54% reduction in HPE accidents for the largest U. S. civil helicopter operator (more than two million takeoffs and landings annually)
- A 51% reduction in accidents/100,000 hours for USAF MAC crews (Diehl 1991).
- A 20% reduction in USN helicopter air crew mishap rate and an 81% reduction by A6 and EA6 airplane pilots (Alkov 1991)

These findings generated a request from many in the aviation community for advanced decision making and crew resource management material. They also have led the National Transportation Safety Board to recommend that the FAA pursue the implementation of ADM more vigorously following a fatal 1991 accident involving an airplane and a helicopter (NTSB 1991) However, as dramatic as the examples of improvements were, a more detailed examination of the accident rate reduction data disclosed that the major positive impact has been on the less experienced pilots. This finding led to two questions: Can we achieve the same impact in human error reduction with more experienced pilots? And, how can this be done?

The current research effort attempts to respond to these questions, questions which industry has also asked. The research is based upon parallel events occurring in the air carrier industry during the 1983-1989 timeframe. During this period, there were several extraordinary accidents involving multiple engine failures, explosive decompressions caused by structural failures, fuel starvation and in-flight fires. In each of these accidents, experienced pilots quickly responded to emergencies for which there was no handbook procedure or previous training. They assessed the situation and <u>integrated</u> airmanship skills, trained procedures and aeronautical knowledge into a quick, effective decision making process. Such dynamic cognitive behavior was in direct contrast to the more basic ADM training which stressed a linear, measured approach to situation analysis.

EXPERT COGNITIVE PROCESSES

Research in the last twenty years has revealed that superior performance is most often the result of the interaction between **accumulated skill and experience.** The primary differences between a beginner and an expert can be attributed to **acquired knowledge** and problem solving skills: what we call *expertise* and which is demonstrated through performance. Expert performance can be defined as the selection of an appropriate response to situations or problems in a wide variety of domains. These 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 on expert performance has focused on the basic understanding of *knowing how* to do something well rather than *knowing what* the underlying mechanism was for superior performance. Complex problem solving research assumed that the integration of the basic **human information processing** skills was required. This included the processes

of **perception, memory, attention, and reasoning.** This research had real-world importance since performance/expertise obviously depended on learning how to do something well.

All human cognition is task dependent and purposeful (goal oriented). 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 say knowledge about "facts and things". Procedural knowledge is knowledge about actions or how to perform various cognitive activities. These ordinarily cannot be completely or adequately verbalized, for example, how to ride a bike. Procedural knowledge is the basis for development of specific steps (also called production rules) to be used in problem solving situations. The study of **procedural learning** became a crucial area to be understood. The current (general) theory of acquiring expertise includes the following three stages:

1. Novice's solve problems by weak, domain general, heuristic methods (often working backwards from the goal).

2. Successful solutions (when repeated frequently) lead to the development of domain specific procedures or production rules. These rules specify actions that will achieve goals under particular conditions. Production rules form the beginnings of expertise.

3. As these rules are used more and more often, and applied to many situations in a domain, they result in fairly automatic generation of specialized productions which often use forward inferencing to progress from the initial problem state toward a solution or goal. Thus, relative to the novice, the expert is able to reach the correct solution more quickly and efficiently.

The status of these theories of expertise are presented in two references which provide 24 "Summary Propositions" pertinent aviation. *Thoughts on Expertise* (Glaser 1987) and *On the Nature of Expertis* (Glaser and Chi 1988) provide the following relevant findings:

1. Expert performance is characterized by **rapid access to a well organized body of conceptual and procedural knowledge.** 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.** Schema theory assumes there are schemata for recurrent situations that expedite decisions in certain situations.

3. Expertise is domain specific. Within a domain, experts develop **the ability to perceive large meaningful patterns.** Furthermore, the expert's pattern recognition occurs so rapidly that it appears to take on the character of insight or intuition.

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.** The outstanding performance of experts is derived from how their knowledge is structured to accomplish: *Retrieval, Pattern Recognition, and Inference.*

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.

9. Experts also develop types of metacognition or self-regulatory capabilities that are not present in less experienced decision makers. Experts' **skilled self-regulatory processes** free their working memory for higher level conscious processing. These include: planning ahead, efficiently monitoring one's time and attentional resources, and monitoring and editing one's efforts to solve a problem.

10. An important point of distinction is that there are both routine and adaptive experts. Adaptive experts possess **the ability to creatively respond** to novel situations and develop an appropriate response with some reasonable chance for a successful outcome.

This distinction between routine and adaptive experts leads to the threshold of the next generation of expertise theory which relies on a cognitive psychology perspective. The current FAA sponsored R&D will examine applications to real world problems and the focus will be on *how* aviators respond to untrainable emergencies. A broad distinction between two classes of expertise is suggested in Sloboda, (1991). His definition is that expert performance involves "the reliable attainment of specific goals within a specific domain". An extended definition is that "an expert is someone who can make an appropriate response to a situation which contains a degree of unpredictability".

In general, an expert will succeed in identifying and 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.

EXPERTISE AND TRAINING OR PRACTICE

Initially, expert performance and expertise involves the development of encoding processes which allow the situation to be fully represented and integrated cognitively. In this way, 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 a dynamically changing environment for the purposes of anticipation and prediction.

It seems that acquisition of expertise can be increased for most, if not all, relevant aspects of performance. Table 2 shows a phase, or stage, view of differing levels of expertise.

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

At this time, knowledge about how experts attain the base for their expert performance is relatively limited. Generally speaking, the current view is that the novice should have acquired all basic knowledge in less than one year. Continuing beyond this basic knowledge leads to 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 situations. 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. 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 aircraft operations (from flight planning to air traffic control) where experts have developed an extensive jargon which is formalized in the "Pilot-Controller Glossary" of the Airman's Information Manual.

PILOT COGNITION & INFORMATION PROCESSING

Thus far, we have characterized the performance of experts from a cognitive psychology perspective. We have tried to show that the development of expertise relies heavily on training and requires considerable amounts of experience in a specific field. Further, experts rely on a wide variety of different processing skills and unique problem solving capabilities. As summarized in Gordon (1990):

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

These characteristics are equally applicable to the expert pilot domain and all have been observed and documented. We will now attempt to show how the cognitive psychology perspectives and understanting of the development of expertise apply to pilot development, training and aeronautical decision making.

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 factual knowledge.

The second, or *associative* stage, has two important characteristics. First, errors in the initial understanding and performance are detected and gradually eliminated. That is, 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 for performing a desired response to a known situation.

The third cognitive stage occurs when the problem solving procedures become faster and more automatic. 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. Expert cognitive process development gradually improves in a specific area or domain. 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.

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 novice aviator (100 - 1000 hours) develops his flying and decision making skills through 1-5 years of experience. This experience allows him to expand his procedural knowledge base using encounters with real-world problems and operational constraints. The low time (1000 - 3000 hours) 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. Finally, the Expert Pilot (1000 - 10,000+ hours) mainly relies on his 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.

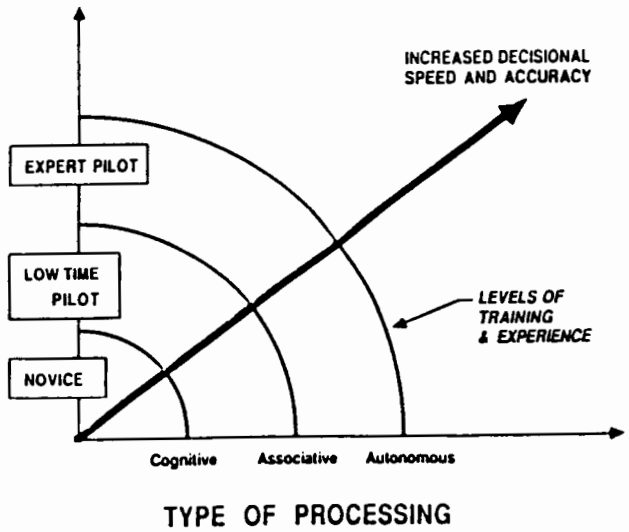


Figure 1 EXPERT PILOT JUDGMENT DEVELOPMENT

Figure 1 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.
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".

To summarize, the novice or *ab initio* pilot responds (cognitively) to stimuli or external cues based upon an 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). His capabilities are generally limited to the procedures he has learned and expedited by the use of rules-of-thumb (or heuristics). The intermediate pilot is becoming an associative problem solver. He has the capability for an enhanced decision making. As a result of his experience and additional flight training, he has the 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. This "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 pilot's level of cognitive processing is in the process of evolving into a Routine expert.

In addition to having all the decision making skills gained through experience and training, the Expert Pilot is **"adaptive"**. 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.

This "adaptive" capability is referred to as "KNOWING WHEN" (Dreyfus and Dreyfus 1986). That is, the Adaptive Expert Pilot can perceive the necessity to alter ingrained procedures based upon the parameters and dynamics of the problem or situation encountered. When necessary, he is able to plan and set goals required to accomplish a successful solution. 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. As in the general field of expertise, isolating and quantifying the cues that experts use to either trigger a routine response or the mechanism to adapt remains a challenge.

TRAINING CONSIDERATIONS

Two issues must be considered when teaching decision making to experienced pilots. These are non-linear decision making and cognitive dissonance.

Non Linear Decision Making: Currently there are a large number of both competing and complementary decision making models and procedures. A few of these either were aviation developed, modified for aviation use or applied to aviation. These include the DECIDE model; the PASS model; and, the SAFE model. However, no definitive research exists which allows for the identification of one optimum decision making theory -- either for the pilot or crew. All theories have positive aspects and drawbacks; all have difficulty in meeting all the unique and stringent requirements that aviation imposes. However, **a great deal is known about establishing and promoting a set of environmental conditions which foster optimal crew decisional processes and strategies (Lofaro 1992).**

One of the newest areas that holds promise for the development of ADM comes from Mathematics/Artificial Intelligence; it is Chaos theory. All current models of ADM are essentially linear. Some models have branching (decisional "trees") aspects, but all involve a linear series of steps/choices. The causal chain model used in accident analysis is an example of an essentially linear view of a complex event. It is true that a linear chain of prior events can be reconstructed for an accident. But, such a chain is not sensitive to the fact that small changes (in the environment, in time-pressure, in the crew composition, etc.) can make large--and unpredictable by any linear model--- differences in the actions and consequences as time passes.

Since many ADM models are based on accident analysis (on breaking the causal chain), once again the linear DM paradigm is used. It is becoming apparent that, especially under time pressure, we make decisions in a non-linear fashion; this holds also for group decisions (Lofaro 1991). Another short-fall of ADM models based on accident data is that they rely on an analysis of one (or a statistical representation of many) prior event(s). They then are either so general as to not be helpful in a particular situation or so complex and specific that they only apply to one situation which will never re-occur in exactly the same way. Chaos theory deals with non-linear systems and the corresponding beginnings of the realization that the human mind does not typically use linear steps to decide. Rather, cognitive processes go forward and backward, sideward and into many layers simultaneously. Insight and direction for expert decision making training may be available from this field.

Cognitive Dissonance: The psychological phenomena of cognitive dissonance may, in part, help to explain why some high-time aviators show less acceptance of ADM --- as well as less attitudinal change after exposure to ADM and/or CRM training materials. An analogy may clarify this statement:

> *Consider if you will the baseball, a small hard core wrapped with layers of varying types of twine and covered with an outer shell of stitched-on horschide. The core is well protected by the layers of twine and the cover. The twine layers themselves are of different strength and they may be wound or wrapped with more or less tension. The core can be considered our basic, deepest values and beliefs; the twine windings are less tightly held beliefs and attitudes; and, the cover is what holds it all together and what must be penetrated to access the interior of the baseball--- the biases and slants and filters by which we initially process new data.*

Following this analogy, it would seem that the attitudes and beliefs of high time aviators are closer to the core and therefore less amenable to change. Or, looked at another way, their flying habits and attitudes are more embedded, therefore, challenges may trigger a cognitive dissonance based

"protection". The initial reaction of such pilots to ADM information and strategies which run counter to their own are typical cognitive dissonance mechanisms by which people do not change their attitudes and beliefs when confronted with new, unsettling data.

Typically, the person experiencing cognitive dissonance responds by challenging or rejecting the data which has caused the dissonance. This is done by forgetting it, by questioning the source, and/or by finding others of similar beliefs and attitudes. This serves to reinforce the original beliefs and attitudes of all concerned. This can be a partial explanation of what Dr. Robert Helmreich has found in some CRM trainees and what he terms the "boomerang effect" (Helmreich 1989). Dr. Helmreich has found that some pilots receiving CRM training not only resist attitudinal change, but also experience either a hardening or "negative increase" of their initial attitudes, as well as sometimes attempting to proselytize others in the CRM class.

CONCLUSIONS

A review of aviation examples where expert pilots "saved the day" either in whole or in part, documented that pilot's making decisions under stress exhibit five basic characteristics (Adams and Ericcson 1992)

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

This research effort has identified the characteristics of expert pilot decision making and identified the differences between expert and novice pilot cognitive processing skills. This is the initial step in the development of expert pilot decision making training. However, additional research is required in three areas to further our understanding of the how the adaptive expert pilot functions and how to train novice and intermediate pilots this "adaptiveness".

The first area is to acquire a better understanding of the adaptive expert's perception of information and his decision related actions. This can be done by analysis of the different interpretations of task demands between novice and expert pilot's when faced with the same cues and context, i. e., their sensing and filtering cognitive processes. This analysis should also include a more detailed examination of differences between novice and expert pilot's in setting goals and taking action on the available information.

The second task should be a closer examination of how experienced pilot's have applied their cognitive abilities in both trainable and untrainable emergency situations. This empirical data base coupled with current efforts in modeling chaotic systems and the importance of knowing <u>when</u> to "adapt" cognitive processing to meet novel task demands may provide enough information to postulate an initial expert pilot decision making model.

The third area to explore is the importance and impact of cognitive dissonance in experienced pilot decision making training. An analysis of the possible differences in the expert and novice psychophysiological attitudes including kinesthetic, affective and cognitive components should be performed. The importance of affective components and characteristics in problem solving should be analyzed to determine what relationships might exist between these characteristics and decision making. These issues should be addressed in expert decision making training which provides analogous affective states to reinforce the development of analytical relations between the training environment and what is perceived as the operational environment.

If a new level of understanding of expert pilot cognitive processes in these three areas can be achieved, then safety could be further improved through more advanced, tailored training. Again, teaching judgment or decision making skills (of a more advanced nature) to avoid the pitfalls of learning totally from the expensive school of accident/incident experience.

REFERENCES

Adams, R. J. and Ericsson, K. A., "Cognitive Processes in Expert Pilot Decision Making", Advanced Aviation Concepts, Inc., for the Federal Aviation Administration, Report No. DOT/FAA-PM/XX (in press).

Adams, R. J. and Weiss, R. W. (1991). Enhanced training to reduce pilot errors. 46th Annual Forum Proceedings. American Helicopter Society.

Alkov, Robert A., "U. S. Navy Air Crew Coordination Training - A Progress Report", U. S. Naval Safety Center for the Sixth International Symposium on Aviation Psychology, The Ohio State University, April 1991.

Anderson, J. R. (1985). Cognitive psychology and its implications. W. H. Freeman and Company, New York.

Chi, M., Glaser, R., & Farr M. (eds.) (1988). On the nature of expertise. Hillsdale, NJ: Erlbaum.

Diehl, A. E., "The Effectiveness of Training Programs for Preventing Aircrew Error", U. S. Air Force Inspection and Safety Center for the Sixth International Symposium on Aviation Psychology, The Ohio State University, April 1991.

Dreyfus, H. L. and Dreyfus, S. E. (1986). Mind Over Machine. The Free Press, New York, N. Y.

Fox, Roy G., "Measuring Safety in Single-and Twin-Engine Helicopters", Bell Helicopter Textron, Inc. for publication by the Flight Safety Foundation in the Flight Safety Digest, July 1991.

Glaser, R. (1987). "Thoughts on Expertise", In C. Schooler & W. Schaie (eds.), Cognitive functioning and social structure over the life course (pp. 81-94). Norwood, NJ: Ablex Publishing Corp.

Gordon, S. E. (1990). Implications of cognitive theory for knowledge acquisition. Chapter to be published in - The cognition of experts: Psychological research and empirical AI. Hoffman, R. (ed.).

Helmreich, R. L. and Welhelm, J. A., "When Training Boomerangs: Negative Outcomes Associated with CRM Programs" Proceedings of the Fifth International Symposium on Aviation Psychology, The Ohio State University Press, Columbus, Ohio, April 1989.

Lofaro, R. J. (1992). "Crew Resource Management: 1991 and Beyond", Society of Automotive Engineers, Inc. Aviation Behaivoral Technology committee meeting minutes, Warrendale, Pennsylvania.

Lofaro, R. J. (1991). "Crew Resource Management Integration", presentation at the joint ATA/FAA Workshop on Integrated CRM, Washington, D. C., 19-21 November 1991.

National Transportation Safety Board, "Aviation Accident Summary Report -- Mid-Air Collision between a Lycoming Air Services Piper Aerostar and a Sun Oil Company Bell 412", Marion, Pennsylvania, April 1991, NTSB 91-XXX.

Sloboda, J. (1991). Musical expertise. In K. A. Ericsson and J. Smith (eds.) Toward a general theory of expertise: Prospects and limits. New York: John Wiley.

Crew Resource Management: Past, Present and Future

Dr. Ronald J. Lofaro
Federal Aviation Administration
Systems Technology Division
Flight Crew Systems Research Branch
Washington, DC

December 1991

INTRODUCTION

The years 1991 and 1992 will mark the third watershed in the history of what is now termed Crew Resource Management (CRM). The first two watersheds had their impetus come from large-scale conferences on Cockpit Resource Management issues and training (Cooper, White and Lauber, 1979; Orlady and Foushee, 1986). Present efforts are and will be driven by a constellation of break-throughs in the understanding, use and assessment of CRM.

HISTORICAL OVERVIEW: CRM I AND II

In the late 1970s, there was the initial recognition that human factors such as crew interaction and coordination, communication, leadership styles were causal factors in a series of fatal commercial crashes. At that time, several seminal, outstanding efforts to develop aircrew training which addressed these human factors issues were developed and implemented in commercial and military aviation. This training was centered around what was then termed "Cockpit Resource Management." Such efforts and programs serve as the foundation from which today's CRM springs--and can be seen historically as "CRM I."

During this same time-frame, and extending to the present, NASA Ames and The University of Texas at Austin instituted an extensive CRM and CRM training research program. This research was led at NASA-Ames by Dr. Clay Foushee and Dr. John Lauber with Dr. Robert Helmreich of UTA. (NOTE: Results realized by these researchers and their associates generated many papers and publications. What follows is only a small sampling; Foushee and Manos, 1981; Foushee, 1984; Helmreich, 1984; Helmreich and Wilhelm, 1988; Helmreich, Foushee, Benson and Russini, 1986; Gregorich, Helmreich and Wilhelm and Chidester, 1989; Lauber and Foushee, 1981; Lauber, 1884).

There was a proliferation of CRM in a great variety of commercial and military training programs. The Federal Aviation Administration (FAA) accepted the value of CRM training by allowing a recurrent training waiver to be granted if a CRM course was taken. This eight to nine year period (c.1979 - c.1988) also brought out and clarified many issues which needed resolution. Paramount among these were *how* to identify and evaluate skills resulting from CRM training and how/if CRM skills were related to the more traditional flight control ("stick and rudder") skills. There were, and still are to some degree, differing schools of thought on these issues. This period can be referred to as "CRM II." As with "CRM I", it is a part of the foundation and genesis of today's work. CRM I and II should not be viewed as separate phases, but as part of a seamless chain; a process which is still occurring and parts of which are, and will be, with us (see Figure I).

[INSERT FIGURE I ABOUT HERE]

THE PRESENT

Currently, (1992), CRM is taking great strides. This is the time of *crew/team* resource management; a time when cabin crew, dispatch and air traffic are being included as parts of the team which ensures a safe and efficient flight. The four drivers for the leap forward that CRM is now taking are:

1. The development of a set of observable, assessable performances (called "behavioral performance markers") by Helmreich, which capture the specific actions that make up CRM skills.

2. The initial demonstrations of what many had long-believed, that CRM skills and technical/flight control skills are interrelated and interdependent. These skills could be "broken apart" for analyses, but in actual flightcrew performance, they were both simultaneous and embedded in each other. This is called "CRM Integration" and is represented by a new paradigm.

3. The realization that attention needed to be given to the development of training which integrated the CRM and the Flight Comtrol/Technical skills and these skills *must* be not only taught but assessed **together.**

4. The beginnings of work to assess a flightcrew's CRM and technical skills at the same time--an integrated evaluation of integrated skills. These efforts encompass the continuing work by major airlines in the design/development of flight simulator scenarios to be used in all Line Operational Simulations (LOS), including Line Oriented Flight Training (LOFT) and Line Oriented Evaluation (LOE).

These four break-throughs have taken CRM to the brink of CRM III.

A Cutting Edge: (CRM) Integration

The integration, and assessment, of Crew Resource Management and flight control skills has received considerable attention---and, a fair share of concern and skepticism---over the past few years. As one response, in 1990 the ATA formed an air carrier/FAA/academe working group to deal with this, and other CRM issues.

The main issues in doing a simultaneous and integrated assessment of CRM and flight control performance revolve around:

a. Identifying, developing and validating the observable/ rateable performance behaviors that define CRM.

b. Developing a behaviorally-anchored scale, or set of scales by which to assess these CRM performance behaviors. There was also the problem of developing a set of crew performance behaviors for the technical flight control skills similar in format to the CRM performance markers; this set would then be used in any attempt at the integration with the CRM behaviors.

c. Developing an analytic paradigm which could both identify and demonstrate (*what* are) the CRM performance behaviors embedded in, and intrinsic to, the flight control skills necessary for safe, efficient missions. Such a paradigm must be able to analytically show *where* the integration of CRM and flight control skills occurred, i.e. where during the accomplishment of *which* maneuvers/tasks/sub-tasks. And, any model should be capable of dealing, on a specific level, with not only different aircraft types but with different environmental conditions and with the different SOP's in use by the different air carriers.

Finally, any CRM Integration model or paradigm needed to be both operationally-oriented and very accurate. This is because any CRM Integration paradigm would immediately confront a mind-set that has evolved in the development and "selling" of CRM and from the idea of the existence of "soft" (as opposed to "hard") piloting skills.

EXPANDED OVERVIEW

Historically, much of the original impetus for the formalized CRM research and development came from analyses of a series of commercial aviation accidents . In these well-publicized, fatal mishaps, neither aircraft malfunction nor maintenance were the causal factor(s). Rather, communication, command, leadership and other psycho-social factors were called out as the real problems.

There were several persons who had recognized these issues prior to the string of accidents and who had begun the research and development (or, in some cases, continued their existing work) which brought forth much of initial CRM. However, almost from its inception, CRM was seen as somewhat of a stand-alone and/or a "fix" for a certain type of accident, usually called a "pilot-error" or, later a "human factors/performance error" accident. Since many of the people who next came into the field were from the discipline of organizational development, a perception also grew that CRM was involved only with soft, squishy "crow like a rooster" activities and skills. Lastly, in an effort to encourage the air carriers to give CRM training and to encourage line pilots to take this training in a non-jeopardy context, the FAA began to grant a recurrency waiver if CRM training was taken. This action by the FAA may have had the additional effect of reinforcing a view that CRM training was a separate, stand-alone activity.

In fact, CRM often *was* a stand-alone piece of training with either insufficient or ineffective input from the pilot community in development and delivery----and, with little, or no effort to relate CRM to traditional flying skills. A mind-set came into place which incorporated these data.

Many pilots and researchers with flying experience knew, almost intuitively, that CRM-type skills were part and parcel of what good aviators *did*, and had always done and taught. As CRM grew and evolved, a view also began to grow that CRM skills had mistakenly and artificially been separated from the flight control skills. By the early 1990's, with on-going research and development in CRM, along with the FAA's SFAR on Advanced Qualification Programs (AQP) for aircrew providing a push, CRM Integration efforts have begun.

Issues a. and b. above have been extensively worked by Helmreich, in conjunction with several major air carriers. At this time, a complete set of flightcrew CRM performance markers ("CRM behavioral markers") with behaviorally-anchored rating scales have been developed and initial research on them has begun. Several air carriers are investigating the use of these markers in LOFT and on actual flights.

In 1991, Captain Kevin Smith (United AirLines) and Jan Demuth (FAA Flight Standards) developed an initial set of performance markers for Technical/Flight Control skills. Both the CRM and the Technical sets of markers are being used in the next step of CRM Integration; the attempt at developing an analytic paradigm (i.e. issue c). Smith created the framework for a model which *does* demonstrate that the CRM human factors skills and the Technical flight control skills are interrelated, interdependent and are

often simultaneous in execution----that, for safe and efficient flight, CRM is integral to flight control, and vice-versa. This model is called the Mission Performance Model (MPM). (See Figure II)

[INSERT FIGURE II ABOUT HERE]

Members of an Air Transport Association (ATA) working group on CRM proceeded to extend, articulate and apply the MPM to actual flight maneuvers, such as an engine out at V_1, with a turn procedure required by the terrain. The MPM seems readily adaptable to use in crew performance analyses; training evaluation and development; crew evaluator training. (Lofaro, 1991; Lofaro, 1992). However, a *caveat* is in order: The MPM is still in its developmental stage; there is much work that remains to be done before it is a fully articulated and operational paradigm. Additionally, as Kuhn has pointed out is the case with all new paradigms, there are elements of controversy attached to the use and "value" of the MPM.

CRM III

THE FAA's REVISED CRM ADVISORY CIRCULAR

Much of the work in the 1990's should be somewhat shaped by the revised FAA Crew Resource Management Advisory Circular (AC 120-51A). This gives CRM a new name, "Crew Resource Management" and incorporates new developments in CRM.

The revised CRM Advisory Circular will offer a new definition of CRM; expansion of the concept of CRM; guidelines for building, implementing and evaluating CRM programs. Much of the CRM Advisory Circular revision comes from an ATA subcommittee on CRM/LOS Integration . This working group is composed of airline, FAA and research community representatives. The revised Advisory Circular is now in the process of review by the Industry and approval by the FAA, with an expected publication date of mid to late 1992.

There is one other point to consider. There have been, and still are, attempts to define a single method for aeronautical decision making (ADM). Additionally, there are questions as to whether CRM encompasses ADM, or vice versa--and whether ADM is the desired outcome of CRM or whether good CRM results in good ADM.

ADM meets its "crunch time" in those unique situations which are highly stressful due to time compression and a lack of established procedures which cover (sometimes, even analogously) the situation. It would seem as if the search for a single

methodology or model to use for making decisions in the cockpit may not prove feasible. In fact, in the dynamic cockpit environment, a single method or model of ADM may be counter-productive. However, as research and development on ADM goes foward, emphasis must be placed on identifying and training those conditions and environments which stimulate and challenge the crew decisional *processes*.]

FAA's SFAR 58: ADVANCED QUALIFICATION PROGRAM (AQP)

The FAA's SFAR 58, signed in October 1990, gives reinforcement to some of what is happening in CRM. Under AQP, air carriers can design and develop innovative aircrew training (initial qualification; transition; recurrent) programs--with FAA . approval. CRM and its evaluation is called for as a component of Line Oriented Flight Training/Line Operational Simulation (LOFT/LOS) scenarios used in some flight simulator components of aircrew training. Due to the length required even to introduce vitally related work on the use of CRM in LOFT/LOS scenario development and evaluation, this article will not attempt to go any further in this area.

CRM IN THE FUTURE

CRM stands out as the most significant new concept for aircrew training and certification of the past ten-or-so years. The unanticipated effects of such revolutions of going from "steam gauge" to "glass" cockpits make one somewhat hesitant about confidently projecting the impact of CRM III. Nevertheless, some things about CRM III seem clear: It gives aviation safety and aviation human factors personnel new insights and new challenges, as well as the potential for effective solutions to very difficult problems. It gives commercial (and military) aviation a more comprehensive and better way to do business--on the flight deck, as well as in training.

CRM holds the promise of making air travel even safer in an age of increases in automation; airspace system and traffic complexity; demands on airspace capacity. It does this by a new focus on, and understanding of, the man/man interface and the human side of the man/machine interface and interaction.

REFERENCES

Cooper, G.E., White, M.D. & Lauber, J.K. (Eds.). (1979). "Resource Management on the Flight Deck", *NASA Conference Publication 2120*, Moffett Field, CA: NASA-Ames Research Center.

Foushee, H.C. (1984). "Dyads and Triads at 35,000 feet: Factors affecting group process and aircrew performance", *American Psychologist, 39*, 886-893.

Foushee, H.C., and Manos, K.L. (1981). "Information Transfer Within the Cockpit: Problems in Intracockpit Communication". In Billings, C.E. and Cheaney, E. (Eds.), *Information Transfer Problems in the Aviation System. (NASA TP 1875)*, Moffett Field, CA: NASA-Ames Research Center.

Gregorich, S., Helmreich, R.L. & Wilhelm, J.A. (1990). "The Structure of Cockpit Management Attitudes". *Journal of Applied Psychology, 75(6), 682-690.*

Gregorich, S., Helmreich, R.L., Wilhelm, J.A., & Chidester, T.R. (1989). "Personality Based Clusters as Predictors of Aviator Attitudes and Performance". In R. Jensen (Ed.), *Proceedings of the Vth International Symposium on Aviation Psychology.* Columbus, Ohio: Ohio State University.

Helmreich, R.L. & Wilhelm, J.A. *Reinforcing and Measurin Flightcrew Resource Management: Training Captain/Check Airman/Instructor Reference Manual.* NASA/The University of Texas at Austin Technical Manual 87-1. Revised 4/15/88.

Helmreich, R.L., Foushee, H.C., Benson, R., & Russini, R. (1986). "Cockpit Management Attitudes: Exploring the Attitude-Performance Linkage". *Aviation Space and Environmental Medicine, 57, 1198-1200.*

Helmreich, R.L. (1984). "Cockpit Management Attitudes". *Human Factors, 26*, 583-589.

Lauber, J.K., and Foushee, H.C. (1981). *Guidelines for Line-Oriented Flight Training. Vol. I and II.* NASA Conference Publication 2184. Moffett Field, CA: NASA-Ames Research Center.

Lauber, J.K., (1984). "Resource Management in the Cockpit". *Airline Pilot, 53,* 20-23 and 38.

Lofaro, R.J., (1991). "Crew Resource Management and The FAA's Advanced Qualification Program". *The Airworthy Aviator: A Forum for Human Factors in Aviation, Vol II, No. 12.*

Lofaro, R.J., (1992). "Crew Resource Management(CRM): 1991 and Beyond". *Proceedings* of the Jan. 1992 SAE G-10 Committee: Warrendale, PA.

Orlady, H.W., & Foushee, H.C., (Eds.). *Cockpit Resource Management Training: Proceedings of the NASA/MAC Workshop. NASA Conference Publication CP-2455*, Moffett Field, CA: NASA-AMES Research Center.

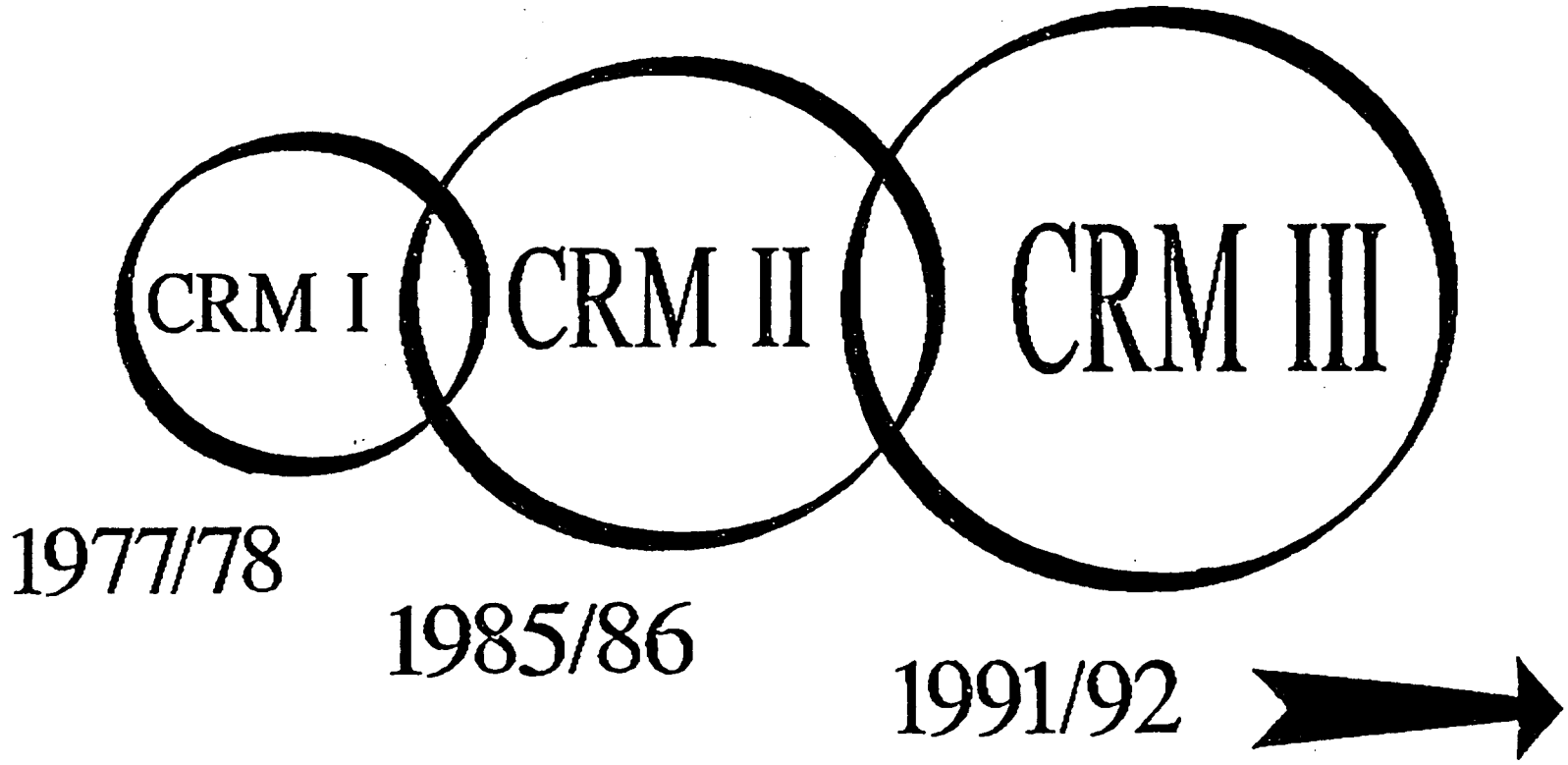
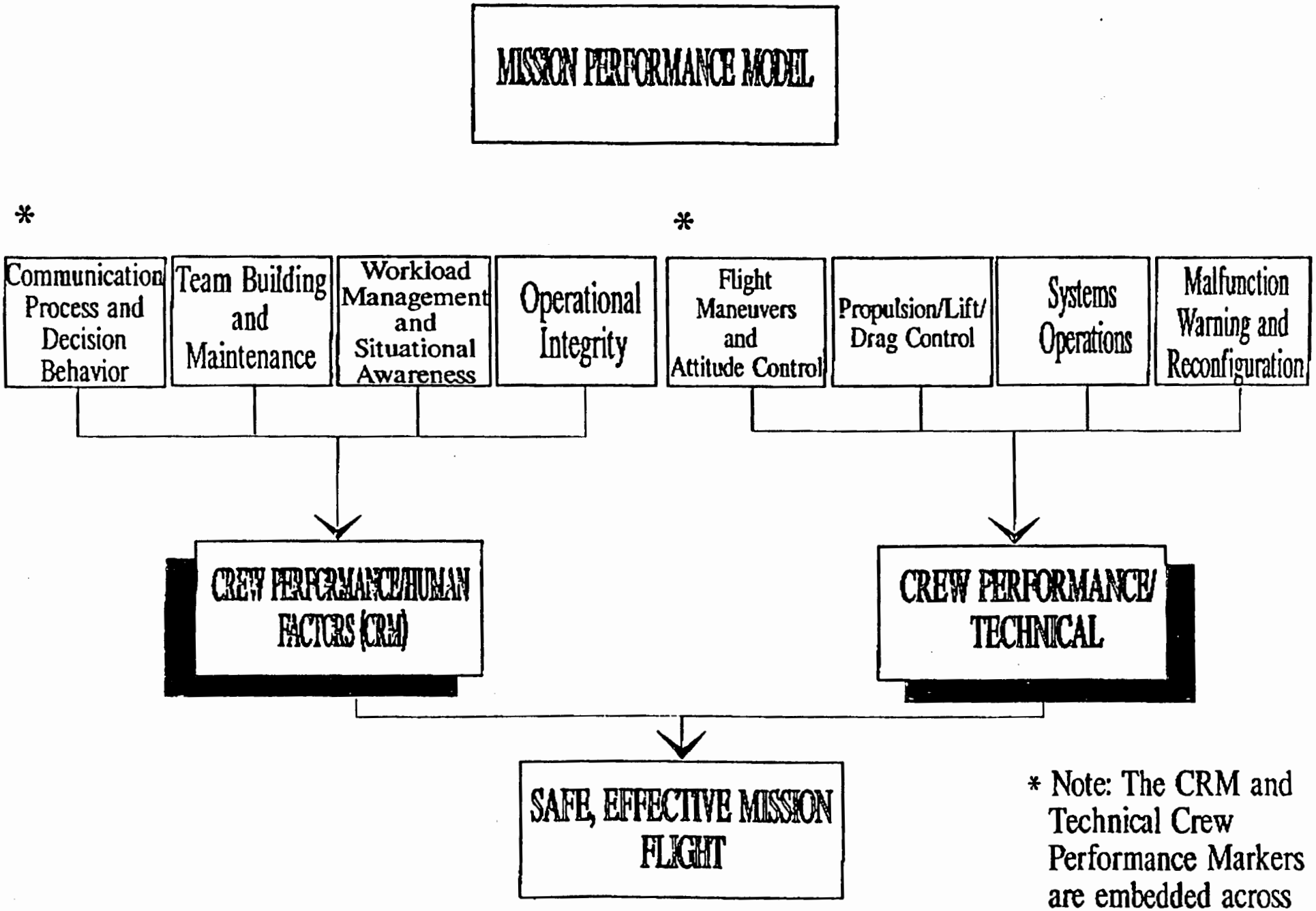


Figure I



* Note: The CRM and Technical Crew Performance Markers are embedded across these categories.

FIGURE II

APPENDIX B

WORKSHOP PRESENTATION TOPICS AND AUTHORS

APPENDIX B

WORKSHOP PRESENTATION TOPICS AND AUTHORS

TOPICS	SPEAKER	AFFILIATION
Overview of ADM Effectiveness	Dr. Alan E. Diehl	USAF
Decision Making Training Methods at Delta	Steve Paul	Delta Airlines
Decision Making in Operational Systems	Kevin Smith	Opcon
Bootstrapping Experience: What makes the Expert Pilot Decision Maker Expert & Why	James E. Irving	United Airlines
The Effect of Trans-Cockpit Authority Gradient on Navy & Marine Aircraft Mishaps	Dr. Robert A. Alkov	U. S. Navy
How Expert Pilots Think	Rich Adams	AAC
Methodology for Studying & Training Expertise	Dr. Anders Ericsson	U. of CO.
Enhanced ADM Training Alternatives	Rich Adams	AAC
A Cognitive Model for Training Decision Making in Aircrews	Dr. Gary A. Klein	Klein Assoc.
Elements of a Theory of Natural Decision Making	Dr. John Bloomfield	Honeywell
Shared Mental Models in Crew Decision Making	Dr. Judith Orasanu	NASA
Heliprops, Embedded ADM to Reduce Human Error Accidents in Helicopters	Roy Fox	Bell Heli.