KNOWLEDGE ACQUISITION TECHNIQUES FOR EXPERT SYSTEMS: CONCEPTUAL AND EMPIRICAL COMPARISONS

Contract No. DAAB07-87-C-A045

Final Report

May 1988

Prepared for:

U.S. Army Communications Electronics Command
Fort Monmouth, NJ 07703

Prepared by:

James Geiwitz
Roberta L. Klatzky
Brian P. McCloskey

ANACAPA SCIENCES, INC.
P. O. DRAWER Q.
SANTA BARBARA, CA 93102
TELEPHONE (805) 966-6157

KNOWLEDGE ACQUISITION TECHNIQUES FOR EXPERT SYSTEMS: CONCEPTUAL AND EMPIRICAL COMPARISONS

Contract No. DAAB07-87-C-A045

Final Report

May 1988

Prepared for:

U.S. Army Communications Electronics Command
Fort Monmouth, NJ 07703

Prepared by:

James Geiwitz
Roberta L. Klatzky
Brian P. McCloskey

ANACAPA SCIENCES, INC.
P.O. Drawer Q
Santa Barbara, CA 93102
(805) 966-6157

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Knowledge acquisition techniques for expert systems: Conceptual and empirical comparisons.		5. TYPE OF REPORT & PERIOD COVERED Final Report 10/87 - 4/88
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. Geiwitz, R.L. Klatzky, & B.P. McCloskey		8. CONTRACT OR GRANT NUMBER(s) DAAB07-87-C-A045
9. PERFORMING ORGANIZATION NAME AND ADDRESS Anacapa Sciences, Inc. P.O. Drawer Q, 901 Olive St. Santa Barbara, CA 93102		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US Army CECOM Attn: AMSEL-RD-C3-IR-1 Fort Monmouth, NJ 07703-5202		12. REPORT DATE May 20, 1988
		13. NUMBER OF PAGES 126
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Artificial intelligence
Cognitive psychology
Expert systems
Knowledge acquisition
Route planning

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See over.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract

The knowledge-acquisition phase in the development of expert systems is hampered by inadequate techniques for the elicitation and representation of knowledge from human experts. The objective of this research is, ultimately, to develop guidelines for effective knowledge acquisition. The objective of this Phase I (SBIR) research is to establish the feasibility of designing and executing experiments comparing knowledge-acquisition techniques. These empirical comparisons should provide the data that permit us to categorize the kinds and amount of different kinds of knowledge that each technique elicits, so that the technique can be matched with the domain of expertise and the purpose of the resulting expert system to provide the knowledge engineer with the most effective means of building the knowledge base.

In a conceptual analysis of expert systems and knowledge-acquisition techniques (KATs), three related dimensions of knowledge were identified as critical to the effectiveness of KATs. First, knowledge has often been classified as declarative or procedural (knowing *that* vs. knowing *how*). Declarative knowledge is most useful for designing convergent expert systems, in which information is used to establish which node in a diagnostic network applies to the environmental situation. Determining which disease is active, given a list of symptoms, is a common example of a convergent problem. Procedural knowledge is most useful for designing divergent systems, in which a plan or sequence of actions is the output. The third related dimension of knowledge is data vs. algorithms, which focuses on the specific kinds of information provided by knowledge-acquisition techniques.

An experiment was designed utilizing Subject Matter Experts in the domain of military route planning (helicopter pilots). The two KATs used were the Repertory Grid Method, a similarity-based technique that promised effective elicitation of the basic dimensions of route evaluation, i.e., of expert knowledge suitable for the design of convergent expert systems; and the ARK Method, a structured interview technique which focuses on goals and goal sequences in the planning process (procedural knowledge).

The information elicited by the two KATs was clearly different. The Rep Grid Method produces dimensions of evaluation (e.g., Amount of Cover), along with data relevant to the determination of the importance of those dimensions for the task of route evaluations, and also data relevant to the determination of interrelationships among dimensions, suitable for cluster or factor analyses. The ARK Method produces primarily goals and goal sequences, declarative nets of factual material supporting the search for information relevant to goal achievement, constraints on the activation of procedures (e.g., weather), and dimensions of evaluation similar to those produced by the Rep Grid Method. The data on dimensions produced by the Rep Grid Method are quantitative, allowing precise estimates of interrelationships among dimensions and other variables, whereas the data on dimensions produced by the ARK Method are qualitative, which aids in the definition and understanding of the dimensions.

The conclusion afforded by these conceptual and empirical comparisons of KATs is that it is indeed feasible to design experiments to answer questions about the effective use of these techniques. In this limited domain of expertise, an expert system for route planning, a divergent task, would best be served by a KAT like the ARK Method, which produces procedural knowledge, and information on algorithms. An expert system for route evaluation, a convergent task, would best be served by a KAT like the Rep Grid Method, which produces dimensions for evaluation along with the quantitative data required to assess the relationships between the dimensions and the product of evaluation, i.e., the routes themselves.

ACKNOWLEDGMENTS

The experimental comparison of knowledge-acquisition techniques reported herein was arranged with the invaluable help of Dr. Charles Gainer of the Army Research Institute at Fort Rucker, Alabama; his research liaison, Major Lynn Hansen; and Dr. Theodore Aldrich and his staff at the Anacapa Sciences field office at Fort Rucker. Assistance during the formulation of the conceptual model and the design and analysis of experiments was provided by Drs. Steve Rogers, David Schwartz, Ken Cross, and Alan Spiker. The SMEs, who asked not to be acknowledged by name, were members of the 226th Attack Helicopter Battalion; their cooperation, indeed their generosity, was much appreciated.

Thanks are due also to Barbara Gates and Peggy Liborio for their skillful assistance in the preparation and publication of this report.

The contract monitor, Dr. Gerald Powell of CECOM, was an active and knowledgeable participant in this research, providing valuable advice and support during its various stages.

Any errors or misinterpretations are ours alone, and the conclusions we have drawn do not necessarily reflect the views of the SMEs, the Army, or CECOM.

JG
RLK
BPM

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

Section 1

INTRODUCTION

This document reports the results of an experiment designed to evaluate different techniques of knowledge acquisition for expert systems. Section 2 describes a conceptual model of the knowledge-acquisition process, a model that conceptually evaluates different knowledge-acquisition techniques (KATs) and thus provides the basis for the design of the empirical comparisons. Section 3 describes the experiment and the analysis of results. Section 4 relates the empirical data to the conceptual model and suggests the kinds of guidelines for choice of KAT, in a very limited domain. The basic purpose of this study is to provide proof of concept, that it is feasible to compare KATs in such a way that designers of expert systems can use the data to make intelligent and efficient selections of KATs for their particular needs.

STATEMENT OF THE PROBLEM

The burgeoning area of artificial intelligence, particularly in its representation in **expert systems**, promises significant force multiplication through mission planning aids, military intelligence integration and interpretation, robot supervision, and diagnostics in complex technical domains such as radar and mechanics. For this promise to be fulfilled, a number of critical research issues about expert systems must be resolved. One of the most critical of these issues is that of **knowledge acquisition**, in which the knowledge base of the expert system is acquired from the human expert the system hopes to model. Commonly referred to as the "bottleneck" in the development of expert systems (Feigenbaum & McCorduck, 1984), knowledge acquisition presents a number of related problems, roughly categorized as 1) the nature of knowledge representation in human experts; 2) the nature of knowledge representation in computers; 3) methods of knowledge elicitation, which should tap knowledge structures in the expert to produce knowledge structures for the computer; 4) the information requirements of the ultimate user of the expert system; and 5) methods of interface design, which should tap knowledge structures in the computer to produce appropriate and timely information for the user (see Figure 1). What is required is an integrated program of research on these five components of the knowledge-acquisition process. The product of this research would be specifications and guidelines for the best knowledge-acquisition techniques for the domain of interest and the intended purpose of the expert system.

The significance of the problem is best described in terms of the history of the field of artificial intelligence. From the first, the field has had difficulty with definitions. For example, one reviewer defines artificial intelligence as "... a branch of computer science that employs symbolic processing and heuristic techniques to develop computer programs that function intelligently" (Hillman, 1985, p.21). This definition suffers from a lack of definition in its key component--intelligence. What exactly is intelligent about artificial intelligence?

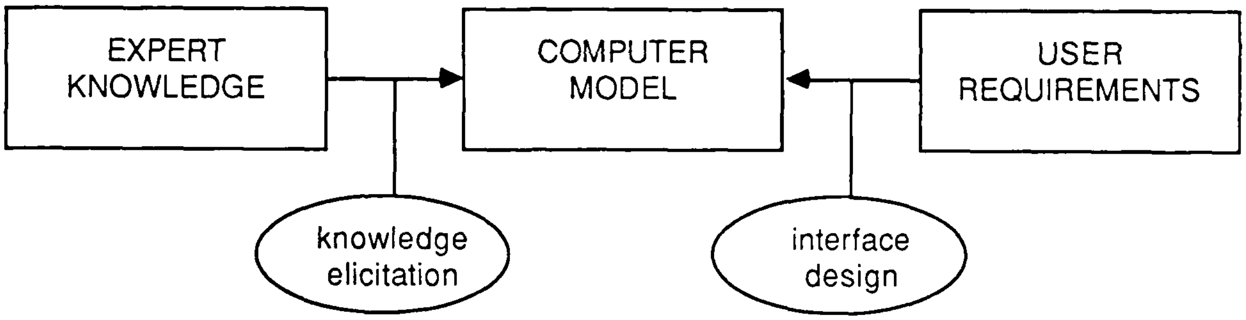


Figure 1. Components of the knowledge-acquisition process.

Reasoning is involved, especially those forms of reasoning other than the deductive, syllogistic reasoning that can be programmed in the framework of formal logic. Other forms include inductive reasoning, the development of general rules, ideas, or concepts from sets of specific instances or examples (Pellegrino, 1985). Inductive reasoning leads to conclusions that are probably correct, whereas deductive reasoning leads to conclusions that are necessarily correct. Human intelligence is often most directly observed in cases of inductive reasoning, where the problems are ill-defined and relevant information is incomplete, where reasoning by analogy is common, and where often there are several adequate solutions, with no one solution being optimal. Machine intelligence is also most clearly defined in such cases; most of what is called artificial intelligence is computerized induction. Intelligent computers, like intelligent humans, deal largely with probabilities, not the certainties of formal deductive logic and formal mathematical algorithms.

The first attempts to use artificial intelligence to solve problems were based on the belief that the reasoning process itself was the key to high performance levels. If one could program the basic techniques of inductive and deductive reasoning, then the speed and memory capacity of computers would produce superhuman performance. Since reasoning is a general skill, applicable to any content domain, one should be able to build a General Problem Solver (Newell, Shaw, & Simon, 1960). But these programs were not successful. The general-purpose problem-solving strategies were too weak to solve most complex problems (Newell, 1969). Interest shifted to problems in specific and limited domains. The idea persisted, however, that the key to success was in the formalisms of the AI programs, especially in the "inference engines" that generated the solutions to the problems from the knowledge base.

Research, however, soon documented the fallacy of this belief. It became apparent that performance of AI programs was not highly related to their inference schemes, but performance was highly related to the quality and size of the knowledge base itself (Feigenbaum, 1977). A major change of focus occurred. Simple programs, with simple inference engines, were packed full of expert knowledge. These programs were highly successful, and the era of **knowledge-based expert systems** began.

With the new interest in the knowledge base of expert systems, the knowledge acquisition phase became the "bottleneck." The major problem in the development of expert systems lay in the attempts to interview human experts, to gain their knowledge in a usable form (e.g., production rules), and program it into the computer. Literally years of work were required. The "knowledge engineers" had to read volumes of technical documents, simply to ask intelligent questions. Interrogations were lengthy and repeated several times a year, to fill in gaps (many) and to correct bugs (innumerable). Computer scientists sought desperately to automate knowledge acquisition; the better computerized acquisition programs had a general structure of the knowledge they were trying to obtain and systematically sampled from "unfilled" areas (Davis, 1983). But both the hand-crafted and automated knowledge acquisition techniques encountered difficulties.

One of the primary difficulties in knowledge acquisition is how to determine what another person knows. The naive approach to this problem was simply to ask the experts what they knew. Although the answers to this question were essential to the new, powerful expert systems, the answers were inadequate by several criteria: they were incomplete, they were insufficient, and in a surprising number of cases, they were incorrect. Experts found it exceptionally difficult to articulate their expertise, especially in forms (such as if:then rules) that their interrogators seemed to prefer. Many rounds of interaction were common, as the expert and the knowledge engineer struggled to understand one another.

Looking back, with the advantages of hindsight, the difficulties perhaps could have been anticipated. The issues involved are ones that, within psychology, are complex and controversial. How is knowledge represented in the human mind? There is no consensus. How do knowledge representations in the minds of experts differ from those in the minds of novices? Psychological research on this question has produced some unexpected answers. For example, studies of chess masters have shown that they do not think several moves ahead or even more moves ahead than less accomplished chess players (Chase & Simon, 1973; de Groot, 1966). In fact, it was the poorer players who traced the consequences of moves through several future possibilities, doing this for ill-advised moves as well as for inspired moves. Chess masters do not waste time in this manner; instead, they have mental frameworks, or schemata, for 10,000 to 100,000 chessboard configurations, and an appropriate response for each configuration. They found it extremely difficult to explain their knowledge in general if:then rules.

The articulation of expertise in a usable form is a continuing and critical research issue. One promising approach is based on cognitive (and computer-oriented) theories of human learning and human knowledge. In Anderson's ACT theory, for example, declarative knowledge is distinguished from procedural knowledge (Anderson, 1983). Declarative knowledge is represented as propositions--e.g., "Birds have wings"--and in general involves knowing that something is the case. Procedural knowledge is represented as productions--e.g., "If the light is green, then go"--and in general involves knowing how to do something. Knowledge acquisition in educational settings is quite different for declarative knowledge than for procedural knowledge (Gagne, 1985), and the same is true when acquiring knowledge for expert systems.

Another aspect of the knowledge-representation issue has to do with the way valid knowledge extracted from a human expert is represented for the ultimate user. How do we make an expert system "user-friendly"? Since the use made of an expert system determines its true value, this is clearly a critical issue, and yet it has received very little research attention. Studies of man-machine interfaces in general are relevant (e.g., Norman & Draper, 1986), but there is a peculiar issue of knowledge representation in expert systems that rarely gets addressed. That issue is knowledge representation in the ultimate user. Unlike representations in experts and computers, knowledge representation in the user focuses on usability--ease of retrieval, effective menus and dialogues. To design a usable interface, the designer needs to determine the user's "basic-level" concepts (Rosch, 1978) in a script-based, hierarchical "partonomy" of an event of interest (Rifkin, 1985). For example, in a tank-combat mission, the basic-level concepts of the users appear to be the major planning tasks which the mission comprises, such as route planning and selecting a battle position (Geiwitz, et al., 1986).

TECHNICAL OBJECTIVES

The general objective of this project was to determine the feasibility of systematic research on the relationships among knowledge representations in experts, computers, and users and on the effectiveness of various methods for extracting that knowledge for various purposes. The general objective was pursued in terms of three specific objectives:

1. **To develop a conceptual model of the knowledge-acquisition process.** In very broad terms, the conceptual model was designed to depict the relationships described in Figure 1. The purpose of this conceptual model was to guide the design of experiments comparing knowledge-acquisition techniques. The basic premise of this research is that different techniques are useful for different purposes and also within different domains of expertise. The conceptual model is intended to outline the reasons why techniques have differential utility, depending on domain and purpose. The conceptual model is described in Section 2.

2. **To compare experimentally different methods of knowledge elicitation.** Two knowledge-acquisition techniques were compared in a knowledge elicitation from experts in route planning for helicopter attack missions. The subject matter experts were experienced pilots at Fort Rucker, Alabama. The knowledge elicited by the two techniques was compared statistically and conceptually. In addition, the potential use of the elicited knowledge for two different purposes--route generation and route evaluation--was examined and compared. The experiment and its results are described in Section 3.

3. **To develop guidelines for knowledge-acquisition strategies.** Experiments on the knowledge-acquisition process provide data for validation and/or revision of the conceptual model. The conceptual model, which becomes an empirically-based structure, can then be used to develop "cookbook" guidelines for knowledge acquisition. Considerable research must be accomplished before the cookbook has any significant breadth of application; the goal of this small study is to provide a preliminary indication of its feasibility and to discuss such guidelines within the limited domain of investigation. The conclusions and suggested guidelines are described in Section 4.

Section 2

A CONCEPTUAL MODEL OF THE KNOWLEDGE-ACQUISITION PROCESS

The purpose of this conceptual model is to guide the design of experiments comparing knowledge-acquisition techniques. As stated in the introduction, the basic premise of this research is that different techniques are useful for different purposes. The conceptual model is intended to outline the reasons why techniques have differential utility, depending on domain and purpose.

In very broad terms, the conceptual model will deal with the relationships described in Figure 1 in the introductory section. The basic elements of the conceptual model, as shown in Figure 1, are five in number: 1) the human expert, who has the knowledge we want to elicit and program into our expert system; 2) the expert system itself; 3) the user, the person who will use the expert system to help solve the kinds of problems the system is expert in; 4) techniques for knowledge elicitation, which acquire knowledge from the human expert in forms suitable for the expert system; and 5) techniques for interface design, which allow information retrieval from the expert system in forms suitable for the user.

This section will deal with each of these elements in turn. We will focus in particular on the first four components of the model. The fifth category is the least critically related to knowledge acquisition and, thus, will be discussed only briefly, and only when factors in interface design have direct relevance to knowledge acquisition techniques. Our goal is to trace relationships among these components that will guide the development of knowledge elicitation for expert systems.

To understand the relations among these five elements of the conceptual model, we must have a lingua franca, a common language, with concepts and relationships that describe knowledge representations in human experts and computerized expert systems, and that are also relevant to the needs of expert-system users. This language must also permit descriptions of knowledge transfer, as accomplished by knowledge-elicitation techniques and the methods of interface design. In short, we must have a taxonomy of "knowledge units." The taxonomy to be developed is based on current models of human cognition in general, and of human expertise in particular. Thus our taxonomy is developed in connection with the component of the conceptual model denoted "expert knowledge."

KNOWLEDGE UNITS IN HUMAN COGNITION AND EXPERTISE

We describe knowledge units (KUs) at three levels. At the heart of our distinctions is a very basic one from cognitive psychology, between declarative and procedural knowledge, or between "knowing that" and "knowing how." Declarative knowledge is knowledge about facts, the "what is it" kind of knowledge. Procedural knowledge is knowledge "how to" do something; it is action-oriented. Often, knowledge is "proceduralized" (Anderson, 1982) to the extent that it cannot be articulated in verbal terms, e.g., how to type, or how to run down a flight of stairs.

This distinction will be expanded as we develop our conceptual model. However, we should note that we use the term "procedural" here to designate any knowledge about cognitive (or even perceptual/motoric) acts. Procedures effect activity of a system; they change states, manipulate data, and give executory commands to peripheral structures. In particular, we wish to distinguish between "implicit," or unconscious, knowledge, and "procedural" knowledge. Because the term procedural is often contrasted with "declarative," it is often assumed that procedural knowledge cannot be verbalized. However, we will include, in procedural knowledge, actions at a conscious as well as at an unconscious level. According to contemporary theories of skill (Anderson, 1982; Klatzky, 1984), procedural knowledge is articulable at early stages of learning and becomes largely implicit at later stages. We assume, however, with others such as Ericsson and Simon (1980), that at least some knowledge related to skilled activity can be articulated, and from this, information about implicit procedures can be inferred.

Our taxonomy of knowledge units is as follows:

Level 1: Atomic Knowledge Units

A. Nodes. Nodes represent integral units of knowledge, such as perceptual objects or events or concepts. We make no underlying assumptions about the fundamental nature of nodes. They could be realized as single nodes in network models, as a pattern of activation in a parallel distributed processing model, or in a number of other ways. But we recognize two types of nodes, which are commonly distinguished in psychological theories and computer simulations:

1. **Nominal nodes.** These are entities expressed linguistically by nouns.

2. **Predicate nodes.** These include attribute nodes, expressed linguistically by adjectives and adverbs. They also include **relational nodes** that describe interactions between nodes and are expressed linguistically by verbs and prepositions, together with their objects.

B. Links. These units connect nodes, constituting associations. Types of links can be distinguished within a particular approach, such as case grammars, which distinguish agent-action links, agent-object links, etc. Causality can be expressed by a special causal link. Directionality can also be an issue, that is, links can be unidirectional or bidirectional.

C. Weights. A weight is a quantity that can be attached to either a node or a link. When applied to nodes, weights express features such as availability or baseline activation level; when applied to links, weights express features such as associative strength or the potential for activation.

Level 2: Basic Knowledge Units

A. Propositions. Propositions are basic units of factual knowledge. They can be expressed in English as declarative sentences, e.g., "The canary is a bird." In programs such as ACT, all declarative knowledge is expressed in propositions.

B. Production rules. Production rules are if/then relationships or condition/action pairings, e.g., "If the light turns green, release the brake and step on the accelerator." In ACT, productions are the units of procedural knowledge.

Level 3: Macro Knowledge Units

A. Hierarchies. Propositions and simple knowledge units can often be organized into laddered grids, or hierarchies. For example, the levels in a hierarchy may represent class inclusion relations or component features. Propositions too may be organized into levels. The resulting structures can be represented as frames, schemas, or scripts. There may be "privileged" levels in a hierarchy, such as the "basic level" conceptualizations of Rosch.

B. Production systems. Sets of production rules that effect a complex behavior can be organized into a production system. Productions actually constitute a programming language, so that a system expresses some "algorithm." Flow of control in a production system is commonly expressed by including explicit goals in the condition of a production, and changing those goals as part of its action, thus invoking a new production.

We use the term **algorithm** here to mean any process that operates to effect intelligent, adaptive behavior. (See Anderson, 1987, for a similar use of this term.) Frequently, "algorithm" has been used to denote well-defined, deterministic, performance that is known in advance to effect some solution to a problem. It is in this sense that "algorithm" is contrasted with "heuristic." This sense is too strong for the present purposes, because we include behaviors that are false starts, subject to change on-line, and error prone. The term "heuristic," however, is too weak for our purposes, as it often denotes vague guidelines that do not directly instruct behavior (e.g., when in doubt, consult an authority). Thus our sense of "algorithm" is more process-descriptive than "heuristic" but does not necessarily mean a well established routine that is known to result in a solution state. It might be read as "heuristic search **or** established algorithm."

Our description of knowledge units applies to knowledge units in general. What constitutes the fundamental difference between the units of cognition in general, and units of expertise? Research on expertise points to several possibilities: (l) Experts have highly developed representations for concepts in their domain of expertise. This would include the formation of domain-related nominal nodes and macro units to support them. Work on chess experts, for example (Chase & Simon, l973), indicates that a vocabulary of strategic patterns is developed with experience in the game. (2) Experts have different productions. Anderson (1982) has described the development of cognitive skill as one in which discrete productions become combined, productions with variables that must be matched with declarative knowledge convert to productions with specific values (constants), and productions become generalized or narrowed in their domain of application. Note, however, that it is not generally claimed that the architecture of the basic cognitive system, nor the types of knowledge units, become different as expertise develops.

COMPUTER MODELS

Computer models related to expertise are of two general types: simulations of human psychological processes, and expert systems. Although the line between these may not always be clear, the goal of a simulation is to emulate, at a specified level, the cognitive operations of a human in some problem domain, whereas the goal of an expert system is to produce an output like that of an expert. Thus simulation of cognitive processes is incidental, if present at all, in the expert system.

Computer Simulations

We will discuss computer simulations of human cognition only briefly here, because, increasingly, cognitive theories are embodied in computer simulations. Thus the variety of knowledge units and processes that were discussed above are present in a number of contemporary simulation approaches.

We will briefly review here two simulation models that are meant to be very general architectures for cognition. One is the ACT system devised by Anderson; the other is the SOAR model of Alan Newell and associates.

The ACT model (Anderson, l983) incorporates three architectural structures. They are (i) a data base of declarative knowledge; (ii) a base of procedural knowledge; (iii) a working memory, storing active data encoded from external or system sources.

The data base of declarative knowledge takes the form of an associative network, in which weighted links connect nodes of various types. Anderson has used various labels for these links, the simplest of which define subject-predicate associations and relation-argument associations. Nodes connected by the subject-predicate association form propositions. Such a declarative network has virtually unlimited representational power, acting as a predicate calculus. The network also imposes a natural hierarchical organization on knowledge by virtue of subset-superset, part-whole, or other hierarchical relations. Activation of nodes in this network is a primary processing mechanism in ACT. Nodes are activated when they are brought into working memory, and activation spreads via links to associated nodes, in direct relationship to the link weights.

The procedural knowledge in ACT takes the form of organized sets of production rules, forming production systems. A rule is "fired," that is, its condition portion is satisfied, when the concepts specified in the condition are active in the working memory structure. If several productions are simultaneously satisfied, tie-breaking devices are used, such as selecting productions on the basis of associated weights. (A refractory mechanism is also used.) Adjustment of weights is a primary mechanism for learning in ACT. When a production is fired, it typically includes in its action some change in working memory that precludes its re-firing and triggers another production, thus constituting a flow-of-control mechanism for the production system. ACT uses explicit goals and subgoals to provide such a control mechanism.

The working memory in ACT is simply a buffer store of limited capacity, which holds currently active knowledge from perceptual sources, activation in the declarative net, or production outputs. Its main function is to control the firing of productions.

Laird, Newell, and Rosenbloom (1987) have called their program, SOAR, "an architecture for general intelligence." SOAR is the latest development in a line that begins even earlier than the General Problem Solver of Newell and Simon and continues through the development of production system languages and work on cognitive skill.

SOAR's architecture uses symbolic representations (i.e., nodes) and formulates every task as finding a desired state (goal) in a "problem space." The problem space is a well-known formalism that describes problem solving as search through a graph of states, with state transitions performed by "operators." "Procedural" representations , by which Laird et al. mean those not realized as problem spaces but rather as direct code or simple rules, are used for well-known paths through the problem space that routinely are used to effect solutions.

All knowledge in SOAR is represented by production systems; there is no propositional network as in ACT. Productions control search paths, provide operators that make state transitions, provide procedures for routine searches, and so on. SOAR, like ACT, has a working memory, whose data trigger the productions. A novel feature of SOAR is that it creates its own goals on-line, rather than having them necessarily written into the if-clause of productions. A goal is created when the system reaches a point of conflict, for example, when the conditions of several productions are satisfied and some choice must be made.

In essence, SOAR has processing mechanisms at two distinct levels -- (i) task-specific productions that provide mechanisms for state changes (e.g., in chess, a production for moving a pawn forward one space), enter data into working memory, and so on, and (ii) metaprocesses that are task-independent and constitute general knowledge about system operation and goal attainment. These latter include search control mechanisms (e.g., if the current state is unacceptable, back up to the previous one) and general mechanisms for resolving conflicts, such as ties between operators, to apply.

SOAR is viewed as a very general formalism for simulating intelligent behavior. It has learning as well as problem-solving capabilities. Although its generality has yet to be demonstrated, it is a promising development. It currently has been shown to perform standard AI problems such as Tower of Hanoi, routine algorithms such as syllogistic reasoning, and more heuristic, knowledge-intensive tasks as well. The SOAR architecture has been shown to perform like expert systems such as Mycin and the R1 system that configures computer hardware.

Expert Systems

An expert system can be generally defined as a computer program that produces an output comparable to that of a human expert in some problem domain. An expert system must represent knowledge about the application domain, including relevant concepts, their relations, and goals, and it must have available some processing mechanism to effect an output. Frequently, that mechanism is an ad hoc "inference engine" that can be used for a variety of expert systems. Thus the data in the system may be domain specific when the process is not. As put by Gallanti et al. (l985, p. 345), "Responsibility about *how* to use knowledge in order to solve the problem is left to the system, and the programmer only has to represent *what* is known about the problem."

We will briefly describe three systems of particular interest for our purposes. General reviews of several expert systems can be found in Hayes-Roth, Waterman, and Lenat, l983.

Mycin (Shortliffe, l976) is perhaps the best known of expert systems; its use is for medical diagnosis of bacterial infections and recommended therapy. Its primary source of data is a set of production rules. Some productions predict a diagnostic category on the basis of a set of properties (e.g., If the morphology of the organism is rod..., there is suggestive evidence that the organism is bacteroides). Mycin works backward from hypotheses about the identity of an organism, invoking a search for the appropriate antecedent conditions. If an initial hypothesis cannot be confirmed, subgoals are set to gather appropriate information by a similar series of tests. The inference engine of Mycin has been generalized for broader use in the form of Emycin. The system has also been the progenitor of a class of similar systems such as Prospector, which diagnoses problems in mineral exploration.

MDX (Chandrasekaran, l983) is a medical diagnostic system similar to Mycin in certain respects. It diagnoses a broader category of illnesses, but again uses rules and search through a hierarchy of goals. For example, confirmation of liver disease will lead to tests for more specific instances such as jaundice. MDX is of particular interest to us because it makes use of ancillary programs with different processing mechanisms. One, PATREC, makes medical inferences about the conditions of production rules. For example, if the required condition is recent exposure to anesthesia, and the system knows there was recently major surgery, it may infer that the condition was met, even though the knowledge base does not specify it exactly.

Hayes-Roth & Hayes-Roth (l979) have developed a model of **planning** *that is not,* strictly speaking, an expert system, in that it simulates the behavior of individuals making everyday plans. However, it is an expert systam in that this is a task in which ordinary individuals have considerable expertise. It uses a "blackboard" architecture first developed for the speech understanding program, Hearsay-II, and subsequently used by others as an expert-system architecture (e.g., Nii & Aiello, 1979). In the Hayes-Roth model, various "specialists" generate decisions during the planning process. Each specialist is a production rule; for example, one specialist looks for clusters of errands in a common location and identifies them as a set. Higher-level planning operations deal with allocation of resources, general rules about order of activities, and so on. An executive chooses which specialist to invoke, generates a new planning decision, leading to new specialists, and so on until a coherent plan is developed that meets specified criteria.

Various distinctions have been applied to expert systems. Initially, we make a distinction between convergent systems, divergent systems, and transformational systems. This distinction echoes one made in theories of human intelligence (Guilford, 1967).

Convergent systems. In general, a convergent expert system attempts to converge on some categorical output. (Clancey, 1985, has termed these "heuristic classification" systems.) The category might be "prospective mineral site" (Prospector), "diagnosis of meningitis" (Mycin), or the phrase "Bishop moves to king knight five" (Hearsay). Systems that deliver binary categorizations of the yes/no type are often called decision aids; these generally provide a more quantitative output as well. Categorization systems may generate potential data to be tested before arriving at a solution, but the desired output is of a categorical nature. Such systems frequently make use of two types of search processes:

- top-down, goal driven, with backward chaining, sometimes called successive-refinement processing

- bottom-up, data driven, with forward chaining, sometimes called signal-to-symbol processing (Smith, 1984)

Frequently, convergent systems make use of hierarchical data structures. For example, MDX uses a structure of nested categories for medical diagnosis. The features of these categories are expressed by production rules, in which the antecedent conditions are features and the consequent is the designated category. Hence these are often called rule-based systems. A top-down system such as Mycin or MDX starts with establishment of a high level node and refines by working down, and is top down in that sense. A system is bottom up when the features drive categorization.

Note that the production rules in such a system are considered to be declarative knowledge (by those who make a declarative/procedural distinction). In other words, the use of a production syntax, unlike its use in the ACT model, does not imply procedural knowledge.

Forward and backward chaining represent a general-purpose and relatively simple control structure. For this reason, they are quite limited in their utility

(Hayes-Roth, et al., 1983, p. 176). Chandrasekaran (1983, p. 15) refers to these as "surface models," i.e., "a data base of patterns with a more or less simple control structure to navigate through...". He argues that, instead, there should be specialized processes embodied in the data base itself.

Divergent systems. The term "divergent problem" describes one in which the output is an analysis or breakdown derived from an input. Thus the system is divergent rather than convergent in terms of the input/output relation. Divergent systems may generate features, feature tests, sequences of actions, and the like. The label "generative" was used by Hayes-Roth and Hayes-Roth (1979) to describe such a system in a discussion of their model of planning. This constitutes a situation where the output is far more complex than the input. For example, the input may be some planning goal such as "plan a trip to the market." This would generate a more complex sequence of events, involving the creation of a marketing list, planning the travel route, and so on. Chandrasekaran (1983) provides a somewhat different example in a component of his diagnostic system that is to deal with consequence finding. This component answers questions of the "what would happen if" form, "exploding" the question into a set of consequences. For example, "what would happen if the fan belt broke on a car?" would generate such events as temperature gauge rising, steam from engine, and so on. Systems that diverge in this manner are far less frequent than convergent systems.

Transformational systems. Transformational systems do not converge or diverge (explode) as do the systems described above, but rather represent a *relatively constant* level of complexity that is transformed by rules. An example from Chandrasekaran (1983) is the inference program PATREC, which can infer that "anesthetic is possible" from "major surgery was performed." Again, expert systems dedicated to transformation are relatively rare, although there are inference programs within AI more generally.

The foregoing taxonomy is based on the complexity of input relative to output. Other distinctions can also be made. In particular, one that was alluded to previously concerns the flow of processing control. Hayes-Roth and Hayes-Roth (1979) characterize their planning model as hierarchical, opportunistic, and multidirectional. Its processing structure is one in which individual specialists or detectors act independently and autonomously, writing their decisions on a group blackboard. This is contrasted with the clear top-down flow of the establish/refine approach.

Another distinction concerns the separation of the processing and data roles in expert systems. Chandrasekaran (1983) has explicitly addressed this issue, making the following points:

- One need not develop a data base operated on by simple, ad hoc procedures. It is possible to construct the data base in such a way as to allow specialized processes.

- Whatever the advantage of specialized, domain-specific procedures, they lack the economy of general inference engines. Specialized procedures, embedded in the data base, require redundant data bases if there are different types of processes. Chandrasekaran's diagnostic system in fact includes several components that interact, each with its own data base and its own processing rules.

- The appropriate level for an expert system is between the surface and the deep level. While "levels" in this sense are not well defined, we can characterize a surface-level program as one in which there is a superficial representation of static data, operated on by simple search processes. A deep level is a conceptually organized structure like that of the human expert. The expert system level, ideally, is a formalized realization of those aspects of the deep level that are relevant to a particular problem.

Chandrasekaran makes the point that different components of a complex expert system require unique types of processing mechanisms. The separation between data and process is therefore clear in his work. Diagnosis uses categorization processes, including confirmation and exclusion rules. Inference uses a process of searching through a frame representation for specific features, which can be perpetuated to successor nodes by inheritance. Consequence finding focuses on cause/effect relationships in its search process. It would be possible to model each of these process components as a set of production rules that are external to a data base, although Chandrasekaran chooses to incorporate them redundantly within the data bases.

Hayes-Roth and Hayes-Roth (1979) also make a distinction between data structures and processes in the planning model, although the distinction is not necessarily explicit in the program's architecture. They distinguish among features of the plan, and executive decisions about the planning process. We can note that in addition, the simulation includes a very different type of data structure -- a spatial layout. This fits with Anderson's (1983) distinction among data structures, three in number, one being "spatial images."

Knowledge Units in Computer Models

It should be obvious that computer simulations of psychological processes make use of the variety of knowledge units described in the previous section on components of cognition. Indeed, the focus on the nature of cognitive representations that has pervaded cognitive science over the last decade has largely been motivated by computer models of psychological processes.

A less straightforward issue is how units of cognitive knowledge are represented in expert systems. Levels 1 and 2, which describe atomic and basic knowledge units, are very evident in expert systems. For example, MDX uses a node-link structure to represent the hierarchy of diagnostic categories, and that hierarchy embodies propositional knowledge of the form "category X is a subset of category Y." Mycin uses a production-rule syntax to describe the features of categories. Weights are inherent in the system as well, in that features are weighted by their diagnosticity.

Level 3, macro knowledge units, can also be found in expert systems. The hierarchical structure of categories in establish-refine systems is one macrostructure. Others are found as well. For example, Chandrasekaran has used a frame representation for his inference program. Production systems can also be found. In particular, Georgeff and Bonollo (l983) have incorporated sets of if/then rules that are invoked only in certain contexts, and that have explicit orderings.

A difference emerges, however, when one considers how declarative and procedural knowledge are distinguished in cognitive models (both psychological theories and computer simulations), as compared to expert systems. This distinction has clearly achieved more prominence in cognitive theories than in artificial intelligence.

The distinction between procedural and declarative knowledge is clearly related to distinctions between processes and data structures within an expert system. Procedural knowledge has recently become of some interest to expert system designers (Georgeff and Bonollo, 1983), who note the need for rules that are context dependent and/or must be applied in a specific sequence. Their procedural rules (or "knowledge areas") can be invoked not only by data, but by goals, as is typical of production systems.

Gallanti, et al., (1985) have described a similar system which separates declarative and procedural knowledge. They view procedures as being evoked in "deterministic" situations, where concepts are precise. An example of such a situation is interpreting data by looking for specific signals of an alarm condition. In contrast, In cases where knowledge is imprecise, fragmentary, and nondeterministic, they view the more typical declarative knowledge structures (i.e., production rules, which is typical for representing declarative knowledge in expert systems if not cognitive models) as appropriate.

The view of "procedural" knowledge among the developers of expert systems does not seem to be identical to that among cognitive psychologists. "Procedures," in the sense of processing mechanisms of the system, appear at two very different levels of specificity in expert systems. On the one hand, the inference engine of the system constitutes a "procedure," although generally it is one quite external to the domain of expertise. On the other hand, the work cited above brings in procedures at a very specific level within the domain of expertise. For example, a procedure described by Georgeff and Bonollo is one for isolating an electrical-system fault in an automobile engine.

What is missing from expert systems, and present in cognitive models, is procedural knowledge that represents fairly general algorithms within the domain of expertise. One reason that production systems have arisen to program algorithms in cognitive science is because the human processor is extremely flexible, being used for a variety of purposes. The algorithms for these purposes may be modeled (e.g., in ACT) as production systems, which use as "data" the knowledge stored in a separate base. For example, separate algorithms operating on a "mental map" would be used to plan a route and to generate a crow-flies distance.

In fact, it may be useful to establish general "algorithms" in an expert system, representing procedural knowledge of the expert. To the extent that algorithms are domain-specific, they should also be considered part of the knowledge of the expert. Consider, for example, the current efforts to model expertise in military planning (Loberg & Powell, in press). In this complex field, experts have knowledge of basic data structures regarding terrain, battlefield situations, military structure and equipment, and so on. With this knowledge base, they must perform an extremely complex and varied set of procedures. Those include, for example, defining the initial mission assignment in terms of present situation variables, converting terrain data to mission-relevant characteristics, projecting prospective changes in enemy action, and so on. All of these constitute "algorithms" that are part of the experts' knowledge.

Hayes-Roth, et al. (1983, p. 255) have made a similar point by asking whether the reasoning process in an expert system should simulate that of the expert. They suggest that "it is with regard to this issue that the interface between knowledge engineering and psychology is the greatest." Yet expert-system development has been largely inattentive to simulating expertise in procedures of this sort.

Another potential use for procedural representations in an expert system is to describe meta-rules (e.g., Genesereth, 1983; Georgeff, 1982). Hayes-Roth, et al., (1983) describe "metaknowledge" as knowledge about the knowledge in an expert system. For example, a rule of the form "Productions with two constants in their if clause will be used less frequently than those with one constant" is a metarule. So is "Use less costly methods before more costly methods."

In short, we see the procedural/declarative distinction as a potentially important area to develop further in expert systems. This will pose new and exciting problems for the knowledge acquisition process. Indeed, knowledge elicitation for declarative and procedural purposes is likely to be quite different. Separate methods of knowledge elicitation for declarative data and procedural algorithms does not mean, of course, that expert systems will have to carry through the distinction. Although some of the systems cited above currently use different formats for declarative and procedural knowledge, it is quite conceivable that the distinction would stop at the point of knowledge elicitation, and the two types of content would be expressed in the same format within an expert system. The important point here is the potential importance of extracting procedural and declarative knowledge explicitly, through distinct methods of knowledge elicitation. It is necessary to determine not only the fundamental concepts on which experts operate, but what operations they perform and how they perform them. Thus a single elicitation approach is almost certainly not feasible.

It is important, too, to note that not all problem domains are likely to require the procedural/algorithmic approach. This approach seems more suited to divergent and transformational systems than to convergent systems, in which the primary process of interest is convergence on some diagnostic category.

USER REQUIREMENTS

The developer of an expert system has (a) some problem currently subjected to the scrutiny of experts, and (b) a reason to believe that the problem can be represented within an expert system. What is the domain of such problems?

One approach to this question is to consider the types of problems that have been addressed with existing expert systems. Hayes-Roth, Waterman, and Lenat (1983, p. 14) have provided a set of "generic categories" of applications that is useful in this regard. Their categories are shown in Table 1.

TABLE 1
CATEGORIES OF USER APPLICATIONS

Category	**Problem Addressed**
Interpretation	Inferring situation descriptions from sensor data
Prediction	Inferring likely consequences of given situations
Diagnosis	Inferring system malfunctions from observables
Design	Configuring objects under constraints
Planning	Designing actions
Monitoring	Comparing observations to plan vulnerabilities
Debugging	Prescribing remedies for malfunctions
Repair	Executing a plan to administer a prescribed remedy
Instruction	Diagnosing, debugging, and repairing student behavior
Control	Interpreting, predicting, repairing and monitoring system behaviors

In a previous section, we categorized expert systems as of three types: convergent, divergent, and transformational. It is important to note that this same taxonomy can be applied to Table 1. Of the entries in the table, interpretation, diagnosis, monitoring, debugging, and initial components of instruction and control can all be subsumed under "convergent systems," in the present terminology. In all these cases, the system takes in a set of data and produces some output category, be it one of a set of situations, a system malfunction, one of a set of predefined vulnerabilities, or a solution for some "bug." Prediction, design, planning, and repair are "divergent systems." These generate consequences, configurations, and plans.

Thus, we can see that the user requirements for expert systems (as inferred from existing systems) take a variety of forms, but can nevertheless be described largely within the "convergent" or "divergent" categories. Transformation, the third category described above, is not well represented in Table 1, although R1 (the VAX configuration program) and DENDRAL (interpreter of mass spectographs that outputs molecular structure and atomic constituents) are programs with inputs and outputs at an equally complex level, and hence might be designated as transformational systems. Within the general categories of convergence and divergence, a substantial variety of problems have been explored, however.

It seems clear that user requirements for expert systems will lag behind the development of the system technology. Were very different approaches to expert systems to be developed, the set of tractable problems would be enlarged. The current set of problems clearly does not begin to exhaust the set of domains in which humans are said to develop expertise.

It is a mistake, however, to treat the category of user requirements as open ended. Some constraints on the set of problems tractable to the expert-system approach are evident. These include a domain with a reasonably confined set of knowledge, availability of experts, reasonable stability of domain knowledge over time, and well defined inputs and outputs. The availability of declarative data should not be considered such a constraint, however. With appropriate knowledge elicitation methods, it should be possible to represent knowledge that is not intrinsically declarative to the expert.

It is true, nevertheless, that almost all existing expert systems use declarative knowledge exclusively. It is in part for this reason that they are almost exclusively of the convergent-system variety, because convergent systems are able to capitalize on a hierarchical semantic structure that can be elicited declaratively. Diagnostic systems are the primary exemplars of this approach. The reason for the reliance on declarative data is that nobody has a good technique for eliciting and representing knowledge that is fully procedural, and thus implicit, from a human expert.

To this point, we have discussed user requirements as determined by the set of problems addressed in current expert systems. However, users have requirements in another sense: The product delivered by the system must be in a form that it can be utilized in the applied context. For the convergent systems, this problem is minimal, in that the program delivers a description in terms of prespecified categories. Within divergent systems, the output format may be more variable. In this case, consultation with the ultimate user is necessary, in order to design the output to user specifications.

This problem leads to focus on an appropriate user interface. Smith (l984) estimated that the interface constitutes by far the most costly component of an expert system, in terms of amount of code and developmental resources. For maximum flexibility of use, the interface should provide the user with options to format output in different ways.

KNOWLEDGE ACQUISITION TECHNIQUES (KATS)

There have been many classifications of Knowledge Acquisition Techniques (KATs). Representative among these have been those by Olson and Rueter (in press) and Burton and Shadbolt (in press). We present these to give the flavor of the kind of categorization of KATs based on factors of concern to researchers in the field. However, these categorizations are inappropriate for our purposes; we would make different divisions and categorizations, a point we shall develop throughout this section.

In the Olson-Rueter classification scheme, KATs are divided into **direct methods** and **indirect methods:**

A. Direct Methods
   1. Interviews
   2. Critical Incident Technique: interview with a focus on a particular case, in detail; examine rules for generality later
   3. Questionnaires (especially good for eliciting uncertainties)
   4. Observation of task performance
   5. Protocol Analysis: task performance while thinking out loud
   6. Interruption analysis: interrupt problem solving (no thinking out loud) when observer cannot follow actor's reasoning
   7. Drawing closed curves: for indicating relationships among objects, draw closed curves around those that go together
   8. Inferential flow analysis: interview that focuses on causal relationships

B. Indirect Methods
   1. Multidimensional scaling (MDS): requires similarity measure
   2. Johnson Hierarchical Clustering: similarity measure
   3. General weighted networks (e.g., Schvaneveldt's Pathfinder): similarities
   4. Ordered trees from recall: cluster analysis from recall data
   5. Repertory Grid Analysis: objects presented in groups of 3: SME is asked how 2 are the same, and how different from the third? then cluster objects and dimensions

The very active European groups working on expert system development are well represented by Burton and Shadbolt:

1. Interview, sometimes called Forward Scenario Simulation: SME to solve hypothetical problems, verbalize process; focus on important variables to be considered, the outcomes (problem solutions), and rules to connect variables to outcomes
2. Protocol Analysis: observe expert on the job, thinking out loud

3. Goal decomposition techniques:
    a. 20 questions: analyzes information requests from expert to develop rules
    b. Laddered grid: problem is represented as a hierarchy of goals; elicitor makes random entry into hierarchy, probes up, down, and across hierarchy (e.g., what are examples of X? [down])
4. Multi-dimension techniques
    a. Repertory Grid
    b. Card sort: objects on cards, sort repeatedly on different dimensions
    c. Multidimensional scaling
    d. Factor analysis
5. Automatic elicitation
    a. Dumb, e.g., carry out a Rep Grid
    b. Smart; elicitation programs that learn, go from examples to rules, use rule induction algorithms
6. Multi-phase elicitation
    a. Rapid prototyping
    b. Second phase only: build expert system from books, show prototype to expert (experts find it easier to tell you what is wrong than to specify the system in the first place)
7. Combinations of techniques (what's the best combination?) and sequencing of techniques (what's the best sequence?)

Proposed Distinctions among KATS

In terms of the distinctions we have made between human experts and human novices, between computer programs, and between user requirements, we would suggest the following potential distinctions among KATs:

Type of Knowledge Unit elicited: Nodes, hierarchical nets, weighted links, etc.
Elicitation of Top-Down vs. Bottom-Up Processing
Elicitation of Convergent vs. Divergent vs. Transformational Processing
Elicitation of Procedural Knowledge vs. Declarative Knowledge
Elicitation of Data vs. Domain-Specific Algorithms

These dimensions have not been entirely overlooked in the literature on KATs. In fact, one can reasonably say that some have been among the major concerns of researchers in the area of expert systems. Others, however, have been overlooked. And even where these distinctions have been made, concern has produced more heat than illumination. We will next consider how (and whether) these distinctions have been handled.

Knowledge units. It is clear that different KATs work with different types of knowledge units. Some KATs require that there be a starting set of units, particularly some set of concepts (nodes). For example, clustering and multidimensional scaling are techniques that require sorting or similarity judgments of a set of concepts provided by the knowledge elicitor. In protocol analysis, in contrast, the nodes emerge from the expert's discourse.

Similarly, KATs vary considerably in the nature of the knowledge units they elicit. Multidimensional scaling elicits dimensions along which the given set of concepts vary; this is essentially eliciting a set of properties of the concepts, along with weights. Protocol analysis (Ericsson & Simon, 1980) elicits a richer set of data, which can be considered to be the outputs of procedures, at least those outputs that enter working memory. These outputs may include full propositions. The goal of the laddered grid technique is explicitly to construct a hierarchy of domain-specific elements; it elicits nodes and their subset/superset relations (but not, typically, weighted links).

Top-down vs. bottom-up processing. This is a distinction that has been recognized in the knowledge elicitation area. Some KATs, such as laddered grid, attempt to elicit category structure in both a top-down and bottom-up direction, for example. KATs might generally be labeled top-down or bottom-up, depending on whether they start with a structured script-based interview or a set of minimal data, as does twenty questions (Leddo & Cohen, l987).

This dimension has also been of considerable interest to the AI community. It makes sense to distinguish systems that are goal-directed (top-down), for example, from those that are data-driven (bottom-up). However, it should be noted that almost all systems have both top-down and bottom-up activation components; there are probably no pure systems on this dimension. Almost every problem domain for which an expert system is appropriate is interactive, with both top-down and bottom-up requirements.

There seems at best limited correspondence between the way in which the top-down/bottom-up distinction is used in the knowledge-elicitation and expert-system communities. Both groups are using these terms to describe their own techniques. What is required is a means of diagnosing KATs as top-down or bottom-up, not because of the formalities of the elicitation technique, but because of their suitability to expert system components of the top-down or bottom-up variety. That is, the goal should be to determine which components of an expert system are better acquired by a given KAT. Any real-life knowledge acquisition activities will require combinations of KATs to be relevant to either a top-down or bottom-up component, we suspect. And, it is extremely unlikely that there will be a direct match between those expert-system components called top-down (or bottom-up) and those KATs given the same label.

Convergent/divergent/transformational. The distinction between convergent, divergent, and transformational systems is not independent of the foregoing distinctions. Convergent systems, which almost always are diagnostic systems of one sort or another, consist almost entirely of declarative knowledge networks (which may explain why they have been the most successful of the expert systems). In addition, convergent systems may require initial bottom-up processing (e.g., the symptoms of a medical patient) to establish a very high level node (Chandrasekaran,1983), which is then refined, top-down style, into more specific instances (e.g., liver disease into, specifically, hepatitis). The expert system may indeed call for more data (bottom-up) as it tries to establish the lower level nodes (top-down). Divergent systems, on the other hand, would be considered top-down by most theorists, because they try to explode the higher-level nodes into meaningful parts. But, like the convergent systems, they often require data input (bottom-up) to determine the appropriately active lower-level node (e.g., subtask) and the appropriate data for these subtask procedures.

For our purposes, the most important difference between convergent and divergent expert systems is not in the type of knowledge or in a simple top-down/bottom-up distinction, but rather, in the complexity of the algorithms required to simulate human expertise. Convergent systems have tended to make use of a simple inference engine. Divergent systems like the Hayes-Roths' planning program have departed considerably from this mode, acknowledging the complexity of processes that analyze inputs rather than converge on a diagnostic category.

Transformational systems -- for example, language understanding programs or inductive reasoners that go beyond simple categorization -- are potentially even more dependent on sophisticated reasoning procedures to operate on data bases for their output. The reasoning algorithms can be considered to be procedural knowledge, although they also require a large declarative knowledge base on which to operate. There are very few transformation systems instantiated as functioning expert systems, and one reason for this is the inability of knowledge engineers to elicit the expert-specific, domain-specific reasoning processes from their Subject Matter Experts.

Declarative vs. procedural knowledge. Reasoning processes may be associated with procedural knowledge. The declarative/procedural distinction is not well handled by existing KATs, which understandably focus on declarative knowledge. Multidimensional scaling, however, is an exception, in that the inferred dimensions may not be overtly apparent to the expert. Just how to elicit procedural knowledge is unclear. The twenty-questions and structured-interview techniques directly attempt to elicit rules, of the sort found in an establish/refine expert system. However, as was noted above, this is still declarative knowledge. Although expert systems typically represent such knowledge by production rules, models in cognitive psychology such as ACT use productions to represent procedural knowledge. The most common representation of procedures in AI, in contrast, is by means of event graphs or Petri nets. This confusion about the appropriate representation for procedural knowledge is no accident; it reflects corresponding confusion about the nature of procedures, particularly in skilled performers where procedural knowledge is largely unavailable to introspection and declaration.

Data vs. algorithms. Our last distinction is between KATs that elicit a static representation of data, and those that elicit the algorithms or reasoning processes an expert applies to data in the domain of expertise. This distinction is clearly related to those made previously: (i) We have noted that divergent and transformational expert systems are most likely to make use of such algorithms; (ii) We have noted that the reasoning processes of the expert are procedures, rather than intrinsically declarative data.

A useful distinction among reasoning processes has been made by Kornell (1987). There are formal reasoning processes, of the sort found in logic (the syllogism, for example), and represented in the inference engines of most expert systems. But in heuristic reasoning, or "narrative reasoning" as Kornell terms it, one can distinguish (i) "patterns of reasoning," which are meta-level rules, from (ii) "kinds of reasoning," which are specific ways of ordering and relating information such as "reasoning by analogy." For example, a military planner may have a metarule (pattern of reasoning) such as: Focus on enemy capabilities; resort to inferring enemy intentions only when capability analyses are insufficient (Loberg & Powell, in press). This same planner may use a "kind of reasoning" in which actions in unknown terrain, such as a jungle, are related to known positions in regions with similar terrain. The distinction is not so important as the recognition that domain-specific reasoning procedures, including algorithms that operate on data in the domain, must be one of the goals of knowledge acquisition. We cannot hope to obtain merely the data base and, thus, reproduce the output (decisions) of the human expert.

It is likely that in complex domains, we need to elicit the procedures of experts as well as their static knowledge base. Specifically, we need to elicit the domain-specific procedures, or algorithms, not the general, logical procedures to be found in an inference engine. Even defining such domain-specific procedures is a problem, but it is clear they are needed, if expert systems are to progress well beyond simple diagnostic convergent systems.

The foregoing analysis raises many questions about KATs. A new approach to taxonomy is clearly called for, one which concentrates less on the formal properties of KATs and more on their relationships to the fundamental nature of expert systems. Particularly important is to elucidate which KATs might be used to elicit algorithmic knowledge.

Features of KATS

In this section, we consider ten exemplar KATs and evaluate each with respect to 3 of the distinctions raised above: types of knowledge units elicited, elicitation of static data structures vs. algorithms, and elicitation of top-level data (e.g. goals) vs. bottom-level (e.g., stimulus primitives). We do not consider the declarative/procedural distinction because of its redundancy with data vs. algorithms. Similarly, we have not included relevance to convergent vs. divergent vs. transformational systems, because those KATs that provide information about algorithms are generally relevant to divergent and transformational systems, whereas those providing only static data are more probably relevant to convergent systems. We also consider an additional dimension of interest -- how much knowledge about the domain of expertise must be held by the knowledge elicitor, in order to successfully implement the KAT.

The ten exemplars we are considering are as follows:

1. Structured Interviews
   We assume the task itself is not observed, but experts are questioned about the nature of the task environment and their efforts to perform it.

2. Protocol Analysis
   We assume a think-aloud instruction with interruption by the elicitor. Hence both products that become conscious to the expert, and answers to "why" questions, are elicited.

3. Laddered Grid
   This technique elicits a hierarchical network by asking the expert to generate nodes that are subsets (exemplars) of the current node, or, alternatively, supersets. Movement up and down the hierarchy and laterally, through generation of additional nodes, is performed.

4. Minimal Scenario Techniques
   As in the Twenty Questions Technique, the expert is presented with a task and, initially, minimal data. The expert's request for additional data indicates relevant variables and values. The result is a set of data needed to perform the task, but not necessarily how it is used.

5. Similarity Judgments
   The expert is asked to rate pairs of elicitor-provided items for similarity, or to sort them into similar groups. These patterns are used with a number of additional data-analysis techniques, such as multidimensional scaling, Pathfinder, cluster analysis, factor analysis, etc. We take, as a representative analysis, cluster analysis, which provides a dendrogram indicating when pairs of judged items are linked into a graph structure, and a transformed similarity measure at the point of linkage.

6. Repertory Grid
   The expert is given a set of concepts in groups of three and asked to indicate how two of them are similar and different from the third. The selection of triads is random. The technique generates a dimensional structure for the concepts, somewhat like multidimensional scaling.

7. Reaction/Criticism Techniques
   These are of three types:
   a) rapid prototyping (elicitor builds expert system based on previous elicitation by any technique; expert critiques system; system is revised)
   b) self-informed prototyping (elicitor builds expert system based on own study of area; critique and revision follow)
   c) Likert scale technique (elicitor provides strongly worded statements on task; expert rates from strong-disagree to strong-agree and explains why).

We will use type "b," the self-informed prototyping variant, as an example of reaction/criticism techniques for purposes of relating to the dimensions of interest.

8. Flow Analyses with Petri nets, event graphs, etc.
   The expert and elicitor cooperatively build a flow chart of task activity.

9. Classical Task Analysis
   The elicitor interviews the expert as to nature of the component tasks in the area of expertise. The elicitor constructs a task list, not necessarily of a temporal/sequential nature. Characteristics of task such as initiating cues and standards of successful performance are also elicited.

10. ARK
   The ARK technique was devised by Geiwitz and Klatzky, based on the ACT model of cognitive performance. It is a structured interview intended to elicit both a network of static knowledge about the expertise domain, and procedures performed on that knowledge by the expert.

Table 2 presents a summary of our evaluation of these ten representative methods, with respect to the distinctions named above. It should be noted that in determining the knowledge units provided by a KAT, we have listed the most complex level when appropriate. We have reserved the term proposition for factual entities beyond simple noun-property links, annotating the list where appropriate to point out simpler structures. Similarly, "production" means something more complex than the Mycin type rule (antecedent features–consequent category), unless otherwise noted.

It can be seen that the table strongly differentiates the various KATs on these dimensions. The open-ended nature of the structured interview makes it least well defined. However, different techniques clearly have their own strengths and are potentially relevant to particular aspects of expert-system development.

TABLE 2
CHARACTERISTICS OF SELECTED
KNOWLEDGE ACQUISITION TECHNIQUES

KAT	**Expertise Needed by Elicitor**	**Knowledge Unit Types Extracted**	**Data vs. Algorithm Elicited**	**Top vs. Bottom Elicited**
Structured Int.	Could be high	Any	Both poss.	Both poss.
Protocol Anal.	Low	Nodes, Propositions, Productions, Macrostructures possible	Both poss.	Both poss.

TABLE 2 (Continued)
CHARACTERISTICS OF SELECTED
KNOWLEDGE ACQUISITION TECHNIQUES

KAT	Expertise Needed by Elicitor	Knowledge Unit Types Extracted	Data vs. Algorithm Elicited	Top vs. Bottom Elicited
Laddered Grid	Low	Nominal nodes, Links, Hierarchical structure	Data	Both
Minimal Scenario	Low	Predicate nodes, Links	Data	Mostly bottom
Similarity + Cluster	High (elicitor provides nodes)	Links, Weights, Hierarchical structure	Data	Both
Repertory Grid	High (elicitor provides nodes)	Property links, Weights	Data	Top (underlying dim'ns)
Reaction/Criticism	High (elicitor provides expert system)	Revised nodes, Links, Weights, Rules	Both poss.	Both
Flow Analysis	Low	Temporal links, Propositions	Algorithm	Both
Task Analysis	Low	Nominal nodes, Predicate nodes, Propositions	Data	Bottom
ARK	Low	Productions Propositional network	Both	Both

The Promise of the Conceptual Model

In this document, we have described components of a conceptual model for knowledge acquisition, in relation to the development of expert systems. We have related the components of the model in terms of "knowledge units" involved, as well as other information-processing distinctions. We have pointed out where current theories of cognition, expert systems, and knowledge acquisition techniques share common ground. We have also pointed out areas where expert systems fail to capitalize on theories of human cognition, and areas where knowledge acquisition techniques fail to meet the demands (current or potential) of expert systems. Further theoretical and empirical work is needed to support and expand on our proposals. However, in its current initial form, the conceptual model described here appears to hold substantial promise for facilitating developments in these areas of human technology.

Section 3

CONVERGENT AND DIVERGENT TECHNIQUES FOR KNOWLEDGE ACQUISITION: AN EXPERIMENTAL COMPARISON

Our conceptual model of the knowledge-acquisition process identified the convergent-divergent distinction as critical in the functional description of expert systems and the techniques used for the elicitation of expert knowledge. Convergent systems attempt to identify (or converge upon) a single node in a network representation of knowledge that fits with the available data; a common example is an expert system for medical diagnosis, in which the goal is to identify the disease represented by the symptoms of the patient. Divergent systems attempt to "explode" a node into its constituent parts, usually to prescribe the proper sequence of steps (subtasks, subgoals) to reach the goal represented by the superordinate node; planning tasks are of this sort, and thus examples are provided by expert systems that function as decision aids for mission planning.

Knowledge acquisition techniques (KATs) similarly differ, in the degree to which they elicit information relevant to convergent or divergent systems. Some KATs are well designed to elicit declarative networks, but do not elicit procedural knowledge well; these KATs are suitable for convergent expert systems, but not for divergent expert systems. Other techniques are better at eliciting procedural knowledge and thus should be more efficient for building divergent expert systems. The experiment to be described compares two KATs in their ability to elicit the two different kinds of knowledge.

The domain of expertise to be explored is route planning in Army helicopter missions. Knowledge from Army experts will be elicited by one or the other technique, and the resulting information will be evaluated for its relevance for one of two purposes: (1) route evaluation, a convergent task in which a selected route is "diagnosed" as impossible, inefficient, efficient, or optimal; or (2) route planning, in which the (divergent) steps of a heuristic procedure are sought.

The hypotheses to be tested are:

H1: The kinds of information elicited by the two techniques will be significantly different.

H2: The convergent technique will elicit primarily dimensions of evaluation, suitable for the development of a convergent expert system. The divergent technique will elicit more procedural information such as goals, planning sequences, informal algorithms, rules, and procedures--suitable for the development of a divergent expert system.

Obviously, these hypotheses are related. The first contradicts the null hypothesis, that there will be no difference in the information elicited. The second specifies the nature of the expected difference and relates it to differences in purpose.

KNOWLEDGE ACQUISITION TECHNIQUES

The two KATs compared in this experiment were 1) the ARK method, a goal-decomposition technique designed to obtain both the declarative net and the procedural rules of a decision-making activity, and 2) the repertory grid method (RGM), a similarity-based technique with apparent strengths for the description of the declarative net and the development of convergent, categorization systems.

The ARK Method of Knowledge Extraction

The ARK methodology for knowledge acquisition is a structured-interview technique based on models of knowledge representation such as John Anderson's ACT system (Anderson, 1983). The ACT model incorporates three architectural structures. They are (1) a data base of declarative knowledge; (2) a production-based procedural knowledge; (3) a working memory for active data encoded from external sources or activated in the declarative system. We will describe each in turn.

The data base of **declarative knowledge** takes the form of a conventional semantic-memory network. Concepts are represented as "nodes" in the network. Interconcept relations are represented by labeled links. ACT interrelates nodes in the network to form **propositions**, the conceptual representations of facts. Such a declarative network has virtually unlimited representational power, acting as a predicate calculus. For present purposes one important point is that the network imposes a natural hierarchical organization on knowledge by virtue of subset-superset, part-whole, or other hierarchical link types.

The procedural knowledge in ACT takes the form of organized sets of **productions**, or rules. Collectively, a set of rules forms a production system. Each rule is a condition-action pairing. A rule can be implemented, or "fired," when its condition is satisfied; it fires by execution of the paired action. To say that a condition is "satisfied" means that the concepts specified in the condition are active in the working memory structure. In later versions of ACT, Anderson has used explicit goals and subgoals as the data in working memory that control the flow of execution. This device forms a critical element of our own knowledge-acquisition system. One important point to note about goal-based flow of control is that it imposes a weak hierarchy on the productions within a system: A production P is subordinate to a production Q if the action in Q changes working memory so as to satisfy a goal specified in the condition of P.

The **working memory** in ACT is simply a buffer store of limited capacity, which holds currently active knowledge. Its main function is to control the firing of productions by activating knowledge requisite to their conditions. We make little explicit use of this in our methodology, but it is an essential element in simulation of a working model.

The methodology of knowledge extraction proposed here is called ARK, for ACT-based Representation of Knowledge. At the heart of this method are two key elements of ACT: (1) the distinction between procedural and declarative knowledge; (2) the use of goal structures to hierarchically organize and control the flow of rules. The method is designed to (a) extract declarative knowledge in the form of a network, and distinct from procedural knowledge; (b) extract procedural knowledge in the form of explicit rules; (c) extract the goal/subgoal structure of a specific scenario and impose that on the rules. In order to do so, the process uses the following procedure:

Step I. Establish with the Subject Matter Expert (SME) the definition of goals and actions. To do so, explain that the process begins with a scenario top-level goal. It then proceeds in a series of steps. At each step, there is an existing subgoal, and a decision must be made as to whether to next describe a goal or an action. The decision is made as follows:

A new subgoal will be designated if there is some **action, information, or tool** that must be acquired in order to proceed.

An action will be designated if there is some step that can be taken immediately, with available **tools, information, or action capabilities**.

Step II. Proceed iteratively through task domain, in a series of steps. For each step:

There exists a current subgoal.
There exists a current set of tools, information, and action capabilities.
A decision is made as to whether to establish a new subgoal or perform an action.

IF there is to be a new subgoal, then:

1. Enter the subgoal into the goal/subgoal structure of the scenario. Add a production rule representing the goal/subgoal relationship.
2. Enter into declarative net a representation of any new objects (i.e., noun concepts), properties, and relations indicated by SME. (This is established by limited interview.)

IF there is to be an action, then:

1. Construct a rule in which the condition is: current goal, and available tools, information, and action capabilities that enter into the action; and the action is the action taken at this step. The action must be either a primitive (i.e., not further decomposed in this particular system) or must call some other

production system by satisfying conditions of its productions.
Enter rule into procedural knowledge base.

Proceed through scenario until final goal is reached.

Possible results of such a methodology for mission planning are shown in Figure 2. It roughly orders the acquisition of knowledge over time from top to bottom.

The Repertory Grid Method of Knowledge Elicitation

The Rep Grid Method (RGM) of knowledge acquisition uses SME judgments of similarity/distance to generate a declarative network of factual information. Production rules can be developed to use relevant data to diagnose or categorize a situation, object, or event, in a convergent manner. The Rep Grid Method was first designed to investigate the idiosyncratic constructs or dimensions people use to view their personal life (Kelly, 1955)--do they see their friends as arranging themselves on a "good-bad" dimension, or do they more frequently view others as "clean-dirty" or "hostile-friendly"? As a knowledge-acquisition tool (Boose, 1986), the Rep Grid Method determines the variables that are important to the expert when classifying something--a suitable route, for example.

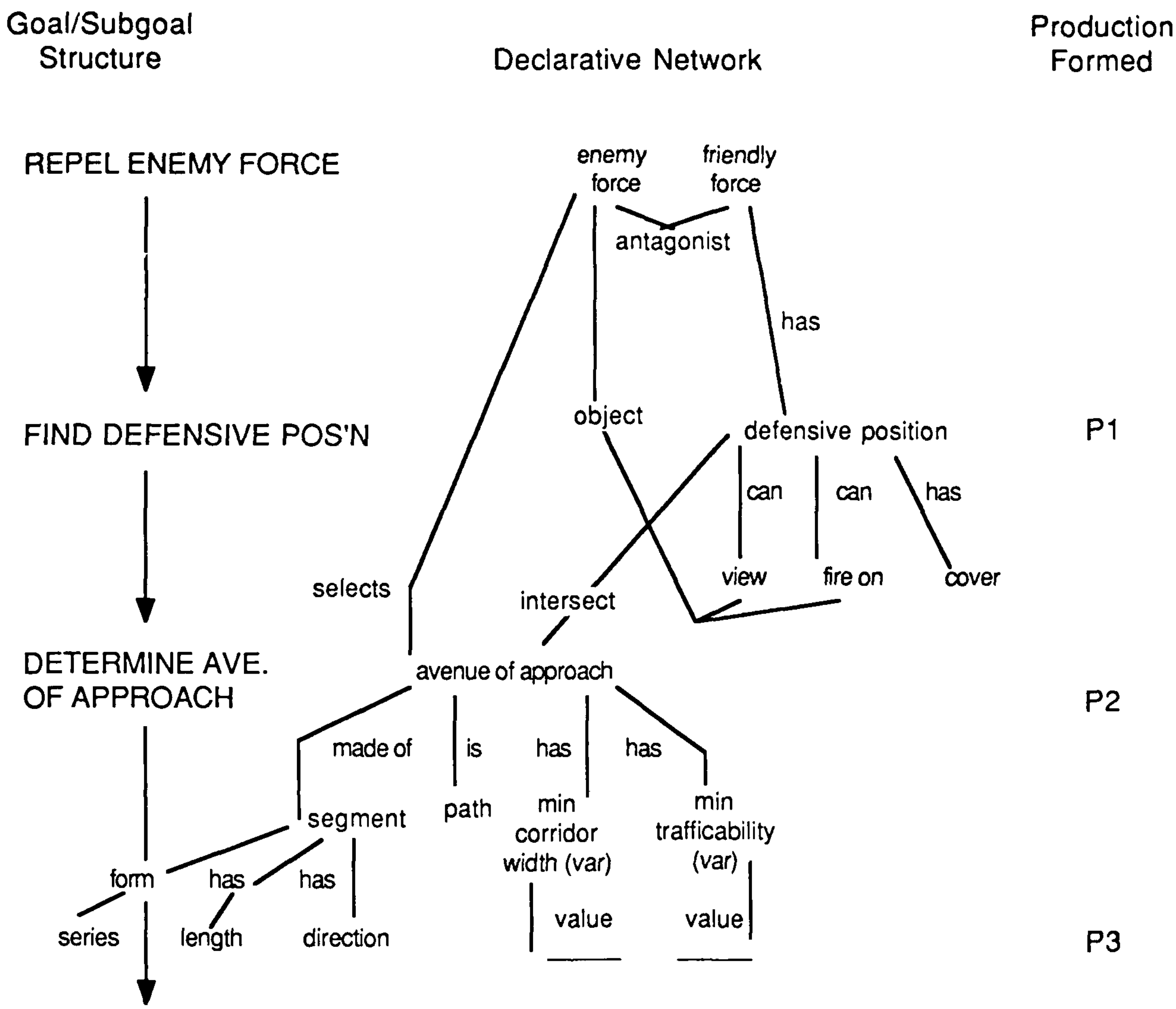
The Rep Grid Method proceeds by a series of steps:

Step I: Develop a list of the elements for which the relevant constructs are to be elicited. The elements of an expert system are the outputs of the system, that is, the recommendations of the system after input and scrutiny of data. For a route-planning system, the outputs would be routes. Thus we begin with a list of routes, which can be depicted on maps.

Step II: Form groups of three (triads) of the elements to be judged. Present these triads to the SME with the instruction, "Tell me some important way in which two of these elements are alike, and different from the third." For routes, the SME might begin to describe the important dimensions for the consideration of a route: "A and B are long, while C is short." "A and B have cover at the end point, C does not." "A and B are likely to be defended, C is not." These responses describe bipolar dimensions on which all the routes can be rated: long-short, cover-no_cover, defended-undefended.

Step III: As the dimensions are uncovered, all the elements are rated (usually on a 5-point scale) on each dimension. This is called the grid. It determines a value for each element on each dimension.

Step IV: Rules are generated from the information in the grid. For example, a rule might have the form, "If you require a route with cover and concealment enroute, then Route A is recommended." By combining several rules of this sort, defining preferences on several relevant dimensions, the expert system will recommend the route which satisfies a combinatorial algorithm for such variables as the number of rules satisfied, the degree of satisfaction, and the importance of rules satisfied.



PRODUCTIONS

P1: IF the goal is to repel an enemy force,
and there is no defensive position known,
THEN the subgoal is to find a defensive position.

P2: IF the goal is to find a defensive position,
and there is no known enemy avenue of approach,
THEN the subgoal is to find an enemy avenue of approach.

P3: IF the goal is to determine an enemy avenue of approach,
and there exists intelligence on size, type, and weather,
and there exists a map of terrain,
THEN determine enemy avenue of approach (by known algorithm) and POP the goal.

Figure 2. Possible results of ARK methodology for mission planning.

This, in overview, describes the Rep Grid Method. In addition, there are many details of the Method, for specific problems one might encounter. If the SME is unwilling or unable to provide a list of elements, for example, there is an incremental mode of interviewing that can build this list while the dimensions are being discovered. Another supplemental technique, called laddering, can be used to fill out the declarative network by determining relationships among dimensions--which are superordinate, which are subordinate, for example.

DOMAIN OF EXPERTISE

Our requirements for a domain of expertise in which to compare the two KATs were that 1) it be such that a knowledge-elicitation session of three to four hours will be sufficient to gather much of the critical information relevant to making decisions in the domain, at least for a constrained problem, and 2) it be such that both convergent and divergent activities are performed. These requirements are met by an important component of planning in helicopter missions, **route planning.** For a commander of a helicopter unit, route planning is that area of mission planning that must be left to the on-site personnel. Mission planning, which usually occurs at the corps or division level, will stipulate that the helicopter unit perform such and such a mission, with start point (staging area) A and end point (battle position) B. The actual route from A to B is selected by the unit commander, according to certain criteria, algorithms, and heuristics (rules of thumb), and even the end point, or battle position, must be determined specifically from its functional description. For example, the mission might be phrased in terms of an attack upon an enemy tank unit, and the battle position described functionally as one that affords good cover and concealment prior to attack. Route planning is a difficult task, one in which expertise born of experience is highly valued.

SYSTEM PURPOSE

It has been one of our main contentions in this research that the purpose to which an expert system is to be directed should be one of the primary determinants of the KAT to be used. In the research to be described, system purpose will be one of the primary independent variables, along with the two different KATs. Specifically, we define the two purposes as follows:

1) route evaluation: Given a route, it can be assigned to one of several evaluative categories, e.g., unacceptable / inefficient / efficient / optimal. For an expert system to accomplish this goal, it must obtain values on variables related to route quality and then must "diagnose" or converge on the appropriate category.

2) route planning: Given a spatial layout (or spatial representation) with a start point and goal, along with other relevant data (a scenario), a route can be generated (or described). For an expert system to accomplish this goal, it must use knowledge of relevant variables to generate a route plan.

EXPERIMENTAL METHOD

Subjects

The subjects, the subject-matter experts, were eight (8) attack helicopter pilots (AH-1 Cobras) stationed at Fort Rucker, Alabama. The rank and estimated experience in route planning of the subjects was:

	rank	exp[1]		rank	exp[1]
SME#1	WO1	1	SME#5	CW3	3
SME#2	WO1	1	SME#6	CW2	2
SME#3	CW2	1	SME#7	CW2	2
SME#4	CW2	2	SME#8	CW2	3

[1] Experience in route planning, estimated by interrogation of the subject, is rated on a 3-point scale, where 1=little; 2=moderate; and 3=considerable.

Materials

The primary materials used were four maps of areas in West Germany. These maps are 1:50,000 in scale, covering 22 km by 24 km areas:

1. Series M745, L5724: Bad Bruckenau.
2. Series M745, L6530: Furth.
3. Series M745, L6332: Forchheim.
4. Series M745, L6330: Hochstadt.

These maps were chosen to exhibit a variety of terrain features relevant to route planning. The maps were always covered with an acetate overlay, with markings described in the procedures, below. The SMEs were provided with marking pens, in those instances where a route was to be generated by them; they drew the routes directly on the covering acetate.

The subjects were interviewed, one by one, in a small room in the offices of the Army Research Institute at Fort Rucker. A large desk was used to display and to work with the maps. A Sony tape recorder was used to record the ARK sessions for later transcription.

Procedures

The subjects were scheduled for three hours each. First they were given a brief description of the purpose of the experiment and assured of full confidentiality of their responses; they were then asked to read the Privacy Act Statement, which repeated the above information.

Each S's session was broken into two parts, each part consuming approximately 1-1/2 hours, with a short break between the two. The first part was devoted to the ARK method of knowledge acquisition, and the second was devoted to the RGM. Thus, the design is **repeated-measures**. This design allows us to compare KATs within individuals. The techniques are different enough that very little influence of one technique on the other can be observed; if there is any bias, it should favor RGM, the second technique.

The same experimenter (Geiwitz) tested all Ss.

ARK method. The Ss were presented with Map #1 (Bad Bruckenau), with an overlay on which had been drawn the following:

- an assembly area, approximately 20 km behind a FEBA
- a line depicting the Forward Edge of Battle Area (FEBA)
- an engagement area, along an avenue of approach by an enemy unit
- the designation of the enemy unit as a motorized rifle regiment

The Ss were then told that the overall goal was to attack and destroy the enemy unit, and that, for this interview, their primary goal was to plan a route from the assembly area to the engagement area for this purpose. They were then led, by a series of informal questions, to the subgoals that they believed had to be achieved in order to achieve the primary goal of route planning. They were asked to "think out loud," as they developed these subgoals and tried to achieve them--as they were planning the route, in other words. Their descriptions were tape-recorded (with their permission) for later analysis.

RGM. The Rep Grid Method, as described above, consists of a series of steps in which Ss consider a set of preplanned routes. First they are to say in what way two of the routes are similar and different from a third. The Ss in this study steadfastly refused to make this kind of judgment. Therefore, an on-the-spot adjustment of procedure was required, and the experimenter attempted to retain the essential features of RGM while presenting a task that the Ss were willing to perform. It was clear that the Ss were having difficulty with the triads, and a two-part judgment, one of similarity and the other of difference. After some experimentation with the first SME, it was decided to modify the RGM in the following way:

On each of the four maps, the first SME and the experimenter designed two routes, from different assembly areas to the same engagement area on that map. Each route was given a name: Matt, Mary, etc. The following seven SMEs were then presented with the maps, one at a time, and asked: "Which of these two routes would you prefer to fly, and why?" and "Which of these two routes is better, and why?" This task elicited considerable response from the Ss; they described in great detail the ways in which the two routes differed, and thus provided the same kind of information that the traditional RGM elicits. When they had completed this task, they were asked to compare all eight routes at the same time, rank ordering them from best to worst.

The second part of the RGM is to rate each route on all of the dimensions generated in the first part of the RGM, and this could be done directly. That is to say, an S might say that Route Matt is preferable to Route Mary because it is easier to navigate. Later this S would rate all eight routes on "ease of navigation," even if this dimension had not been mentioned for other routes. Thus the typical Repertory Grid was generated. On each dimension (self-generated), each of the eight routes was rated on a 5-point scale, where 1 = worst, 3 = average, and 5 = best.

For the Ss tested early, only their own, self-generated dimensions could be used for rating the routes. For the Ss tested later, some of the dimensions from other Ss were added to their own, so that we had some basis for assessing the interrelationships among dimensions. For example, "ease of navigation" was added to the Repertory Grid rating procedure for several of the later Ss; they had no trouble with these additional dimensions.

Dimensions that appeared to the experimenter to be strikingly similar, perhaps even identical--for example, "exposure" and "exposure to observation"--were nevertheless kept separate during the Grid ratings. The almost identical ratings used for these dimensions thus provided empirical reasons for collapsing the two.

Finally, the entire list of dimensions was rated on "importance," on a 5-point scale running from 1 = not very important, to 3 = of average importance, to 5 = extremely important.

RESULTS

The data obtained from the ARK method are words on a tape recording, which can be transcribed, with the results shown in Appendix A. These raw data must be reduced and analyzed in a variety of ways, in order to understand the nature of the information obtained. The data from the RGM are more direct, consisting of a list of dimensions generated by each S, a Repertory Grid in which each of eight routes is rated on each of the generated dimensions, a rank ordering of the eight routes from best to worst, and a rank ordering of the dimensions from most important to least important. The raw data from the RGM are presented in Appendix B. Numerous analyses will be described, but the essential results are immediately clear and "eyeball" comparisons are most appropriate:

Both hypotheses are clearly confirmed: The information obtained by the different techniques is clearly different. The ARK method produces primarily goals, goal sequences, declarative nets of factual material supporting the search for information relevant to goal achievement, and dimensions of evaluation similar to those produced by the RGM. The RGM produces dimensions of evaluation, along with data relevant to the determination of the importance of those dimensions for the task of route evaluation, and also data relevant to the determination of interrelationships among dimensions, suitable for cluster or factor analyses. The ARK method thus provides the

information required for the development of divergent expert systems; it happens also to be effective in providing information for the development of convergent systems. The RGM provides information that is suitable only for the development of convergent expert systems.

Dimensions of Route Evaluation

Dimensions are given directly in the RGM and must be determined by content analysis in the ARK method, but ARK, after analysis, provides essentially the same number of evaluative dimensions as the RGM. The content analysis is relatively straightforward: Any evaluative statement about routes, e.g., "I'd come down here instead of here, because this would be a lot easier to navigate," was coded as defining a dimension, in this case, "ease of navigation." Table 3 describes the overall number of dimensions generated by the two techniques; SME #1, who generated the routes evaluated by the later subjects, has no score for RGM. The mean number of dimensions generated is almost identical for the two techniques, 8.25 to 8.29. A statistical test is surely inappropriate here, but for the record, the paired t-test value is 0.11, not significant. The correlation between the number of dimensions generated by ARK and the number generated by RGM is, perhaps interestingly, .03, not significantly different from zero. The number of dimensions an individual subject generates by one technique is not correlated at all with the number of dimensions the same subject generates by the other technique. If nothing else, this finding supports the decision to use a repeated-measure design, since it suggests little influence of one technique on the later use of the other.

Table 4 shows the exact dimensions generated and the number of Ss using that dimension for each KAT. Cover and Concealment is, not surprisingly, the most often mentioned. Exposure to Observation, a negative characteristic of a route, is also common, as are features that result in potential exposure: Travel near Populated Areas, Built-Up Areas, Highways, Flat Open Land, and Silhouetting. Pilots were also concerned with Ease of Navigation, which they sometimes expressed as Good Checkpoints or Simplicity, and Maneuverability, a characteristic of a route that allowed them to respond quickly and effectively if unexpectedly engaged along the route. Exposure to Enemy Fire was a dimension that was rarely mentioned explicitly, but all of the dimensions listed as related to Exposure to Observation had the possibility of being shot down as a secondary concern; Time at Risk, Travel near Likely Locations of Enemy Air Defense, Travel Time near FEBA, and Travel near Dangerous Areas near FEBA were some of the ways the pilots expressed their goal of avoiding potential enemy fire.

The SMEs were very concerned about maintaining the element of surprise in their attack, which is one of the reasons they want to avoid exposure to observation; they also felt that if they were exposed and lost the element of surprise, they faced increased dangers from enemy fire in the engagement area. A number of the dimensions reflect this concern. One is an appreciation of routes that Permit Speed; speed was seen as a tradeoff with Cover and Concealment obtained through

Table 3
NUMBER OF DIMENSIONS GENERATED

	ARK	RGM
SME 1	7	—
SME 2	11	8
SME 3	7	8
SME 4	7	6
SME 5	6	12
SME 6	13	9
SME 7	10	8
SME 8	5	7
Mean	8.25	8.29
Std. Dev.	2.76	1.89

nap-of-the-earth (NOE) flight. NOE flight is safer than flight at higher altitudes, but it is quite slow, especially if combined with bounding overwatch. The slower one flies, the greater the probability that surprise will be compromised. The desire for short routes, with less Travel Time, also reflects the concern about compromising one's surprise.

Short Travel Times also mean that the pilots can use their resources in other ways: increased time on station and/or increased weapon loads. The quite complicated calculations of fuel and ammunition requirements for the mission were described in detail in the ARK sessions, to be reported later. Essentially, a long travel time meant that they could spend less time attacking the enemy, with less ammunition, unless complicated and risky arrangements of Forward Area Rearming and Refueling Point (FARP) locations were planned.

Although the average number of dimensions elicited by the two techniques does not differ significantly, there are some differences between techniques in the particular dimensions elicited, and clear differences in the supplementary data useful for the interpretation and understanding of the dimensions. In ARK, the SMEs planned their

Table 4

DIMENSIONS OF ROUTE EVALUATION

	ARK (N=8)	RGM (N=7)
1. Populated areas (-)	8	2
2. Cover and concealment (+)	7	7
3. Ease of navigation (+)	6	2
4. Exposure to observation (-)	5	5
5. Good checkpoints (+)	5	2
6. Highways (-)	5	1
7. Flat, open land (-)	5	0
8. Silhouetting (-)	4	2
9. Low ground (+)	4	0
10. Travel time (-)	3	6
11. Likely enemy air defense (-)	3	0
12. Built-up areas (-)	2	3
13. Maneuverability (+)	2	3
14. Transmission lines (-)	1	2
15. NBC areas (-)	1	0
16. Simple (+)	1	0
17. Permits speed (+)	1	0
18. Military crest (+)	1	0
19. Friendly positions (-)	1	0
20. Better alternative available (-)	0	4
21. Good approach angle (+)	0	2
22. Best possible terrain use (+)	0	2
23. Flat land early (+)	0	1
24. Permits surprise (+)	0	1
25. Possible enemy surprise (-)	0	1
26. Good relative terrain (+)	0	1
27. Crosses enemy avenue of approach (-)	0	1
28. Exposure to fire (-)	0	1
29. Linear obstacle (-)	0	1
30. Good river crossing (+)	0	1
31. Time at risk (-)	0	1
32. Dangerous areas near FEBA (-)	0	1
33. Good down-pilot points (?)	0	1
34. Threat to assembly area (-)	0	1
35. Travel time near FEBA (-)	0	1

own routes, whereas in RGM, they critiqued routes drawn by others. Thus, a dimension such as Better Alternative Available is one that could be elicited only in RGM, because ARK, by definition, produces what the SMEs consider to be the best alternative. A number of dimensions are more commonly mentioned in ARK than in RGM, and these dimensions all could reasonably be called "planning dimensions": They are like subgoals in the route-planning process, motivators of information searches and planning procedures. Avoidance of Populated Areas, Highways, and Flat Open Land can be so construed, as can avoidance of likely Enemy Air Defense Locations. Other planning dimensions are Ease of Navigation, Good Checkpoints, and the search for Low Ground. RGM, on the other hand, produces "evaluative dimensions": They provide the basis for rating an existing route as good or bad. An existing route, unless it has been designed randomly, typically has confronted the planning issues posed by the planning dimensions, and thus they are not as often a basis for evaluation. Instead, the critic is faced with the results of decisions about tradeoffs, and evaluates the route on this basis. An example is Travel Time, which is a dimension of evaluation of existing routes which have already traded increased travel time for the avoidance of populated areas. Other evaluative dimensions tend to be quite specific, noting again the results of tradeoff decisions in the planning process. Crosses Enemy Avenue of Approach is an example; Linear Obstacle is another, a dimension used to criticize a route that found and used the Low Ground well but that ran for a long distance along a power line that restricted maneuverability along the route. The specificity of the evaluative dimensions is supported by the observation that 14 of the RGM dimensions were defined by a single SME, compared to 6 of the ARK dimensions.

The rich verbal descriptions obtained from ARK provide considerably more information than RGM on the meaning and interrelationships of the dimensions. Why do you want the route to Avoid Populated Areas? SMEs in ARK sessions often spontaneously answer this question, as part of their externalized reasoning process. They want to avoid possible exposure to observation in areas known to have living human beings, some of whom almost certainly are spies, if not active enemy scouts; they want to avoid possible engagement with enemy units in an area that is difficult to attack and in which it is easy to hide; they want to avoid the transmission lines, towers, and tall structures that one finds in and around cities. It is possible to obtain this information in RGM, with additional interrogations or supplementary techniques such as laddering, but the costs in additional time and effort required are considerable.

RGM produces a large amount of quantitative data on the dimensions and is, in this respect, superior to ARK. From these data, we can estimate a number of interesting relationships among SMEs, among dimensions, and between dimensions and other variables such as rank order of the eight routes. **It is this quantitative aspect that leads one to favor RGM over ARK for the development of convergent expert systems.**

Relationships among SMEs. For the seven SMEs who performed the RGM (the first SME designed the routes used by the others for their judgments and ratings), we can ask the question, Did they all evaluate the eight routes in the same way? This question can be answered by the correlations among SMEs on the rank orders they gave to the routes, as shown in Table 5. These correlations document surprisingly different judgments of the routes by different SMEs, with coefficients ranging from a high of .95 between SME #6 and SME #7 to a low of -.50 between SME #5 and SME #8. The latter statistic is incredibly low, reflecting opposite judgments of the sort that when SME #5 ranked a route as good, SME #8 ranked the same route as poor. There are three negative correlations in Table 5, all involving SME #8. The least one can say is that SME #8 was evaluating the routes on different criteria than SMEs #5, 6, and 7.

Table 5

CORRELATIONS AMONG SMEs ON ROUTE RANK

	SME #2	3	4	5	6	7	8
SME 2	1.00	.68	.81	.24	.19	.09	.55
3		1.00	.55	.29	.26	.19	.50
4			1.00	.50	.64	.50	.33
5				1.00	.83	.76	-.50
6					1.00	.95	-.28
7						1.00	-.35
8							1.00

These quantitative measures of difference among SMEs would be very useful in resolving the general problem of how to combine the information provided by several experts into a single expert system. Numerous analyses, most beyond the scope of this project, could be done, to determine the nature of these relatively large differences in relationships among SMEs. An examination of other correlations suggests, for example, that SME #8 valued the dimension Ease of Navigation much more highly than other SMEs, and this unique value produced evaluations of routes quite different from those of other SMEs. Also, SMEs #2, 3, and 4 were similar in their judgments, and SMEs #5, 6, and 7 were similar, but the two groups were different. This comparison is of interest because SMEs # 2, 3, and 4 have quite a bit less experience in route planning than the group of SMEs # 5, 6, and 7.

Criteria for ratings. The RGM provides ratings on various dimensions for each of the eight routes, and these ratings can be compared to route rankings, to determine the dimensions that are the primary criteria for the overall judgment of rank order. These correlations can be generated within SME, where they reflect the use of the criteria by individual SMEs, or from the mean ratings on the dimensions by all SMEs who used the dimension, to be correlated with the mean rank of the routes, across all SMEs. Table 6 shows the results. The major criteria--that is, the dimensions given the greatest weight in evaluating routes--are identified, in most cases, by both statistics. Cover and Concealment is clearly a major criterion of evaluation, as is the Avoidance of Populated Areas. This analysis also clearly identifies characteristics of the route near the battle position (across the FEBA) as critical in SME evaluations: Exposure to Fire, Time at Risk, and Amount of Travel near FEBA are illustrative dimensions.

A collection of dimensions used by a single SME also signify the importance of characteristics of the route near the battle position. These are Permits Surprise, Possible Enemy Surprise, Good Relative Terrain, and Good Approach Angle, all of which have to do with the use of terrain near the battle position to provide protection from observation and fire. The SME who used these dimensions used them all in the same way, as we will note in the following section on the interrelationships among dimensions; it is doubtful that the SME made any real distinctions among these dimensions.

Relationships among dimensions. A correlation matrix for the dimensions of evaluation in RGM can be generated in two ways, within SME or between average ratings, across SMEs. The latter matrix is presented in Appendix C, along with a cluster analysis of the intercorrelations. Within SME data is presented in text, as appropriate; for example, the high intercorrelations among Permits Surprise, Possible Enemy Surprise, Good Relative Terrain, and Good Approach Angle, described above, are the basis for the conclusion that the SME who used these dimensions was using them all in the same way. A reasonable conclusion is that the SME had a single dimension in mind, a single dimension called by four different names. That single dimension has to do with routes that permit the pilot to sneak in unobserved, surprise the enemy unit, and attack from a good angle (flank or rear). The correlations within this grouping of dimensions for SME #6 are .98, 1.00, .96, .95, .98, and .96; clearly he is not using the dimensions differently for the evaluation of the routes.

Similarly, intercorrelations can be used to combine other dimensions, prior to the development of an expert system utilizing these dimensions. We kept the dimensions Amount of Exposure and Potential Exposure to Enemy Observation separate during the ratings, because it is possible that Amount of Exposure would be used as a multifaceted dimension including not only exposure to observation but also exposure to fire. But the observed correlation between these two dimensions, between SMEs, is .77, quite high, and thus we believe these two dimensions are essentially the same. The dimensions Maneuverability and Flexibility correlate .84, and probably should be combined. The dimensions Avoid Built-Up Areas and Avoid Man-Made Features correlate .83, and probably should be combined.

Table 6
CORRELATIONS OF DIMENSIONS WITH ROUTE RANK

	Within S[1]	Average S[2]
Populated areas (-)	-.77	-.85
Cover and concealment (+)	-.72	.97
Ease of navigation (+)	-.29	.36
Exposure to observation (-)	-.67	-.69
Good checkpoints (+)	-.30	-.87
Highways (-)	-.42	.00
Silhouetting (-)	-.22	-.18
Travel time (-)	-.33	.18
Built-up areas (-)	-.62	-.61
Maneuverability (+)	-.55	-.09
Transmission lines (-)	-.40	-.39
Better alternative available (-)	-.52	-.49
Good approach angle (+)	-.57	-.78
Best possible terrain use (+)	-.81	-.60
Flat land early (+)	.24	.16
Permits surprise (+)	-.92	-.77
Possible enemy surprise (-)	-.96	-.85
Good relative terrain (+)	-.92	-.77
Crosses enemy avenue of approach (-)	-.52	-.56
Exposure to fire (-)	-.79	-.89
Linear obstacle (-)	.41	.28
Good river crossing (+)	.42	.03
Time at risk (-)	-.80	-.47
Dangerous areas near FEBA (-)	-.32	-.50
Good down-pilot points (?)	-.21	-.41
Threat to assembly area (-)	-.62	-.63
Travel time near FEBA (-)	-.43	-.77

[1] This figure is the mean of the correlations, within SME, of the dimension with route rank.

[2] This figure is the correlation of the mean route rating on the dimension, across the SMEs who used the dimension, with the mean route, across SMEs.

The dimension Good Down-Pilot Points deserves special mention. It refers to a characteristic of a route that it has along it areas that would be good spots for downed pilots to go to, to be rescued. SMEs did not agree among themselves that this was a desirable characteristic. In fact, most of them asserted that they did not want the Down-Pilot Points along the route at all, because the route was likely to be defended, and they preferred a pickup point that was safely away from the primary route.

Further analysis of the RGM data might include factor or cluster analyses. A cluster analysis was performed on our RGM data, with the results shown in Appendix C and summarized in Table 7. The first cluster to fall out was the one discussed above: Permits Surprise, Possible Enemy Surprise, and Good Relative Terrain. Considering the analysis as a whole, three large clusters appear. One appears to be comprised of dimensions that have to do with protection from enemy fire, that is, Cover. Exemplars of this cluster are Amount of Travel at Risk, Exposure to Fire, Amount of Travel near FEBA, and Crosses Enemy Avenue of Approach. The second major cluster includes dimensions that have to do with Concealment, that is, the avoidance of exposure to enemy observation. Exemplars of this cluster are Permits Surprise, Avoids Populated Areas, and Exposure to Observation. The third cluster is less easily named. It appears to collect those dimensions that have to do with flight, such as Ease of Navigation and Maneuverability.

Table 7

RESULTS OF CLUSTER ANALYSIS PERFORMED ON RGM DATA

	Cluster 1: Cover (Protection)		Cluster 2: Concealment (Avoid Observation)		Cluster 3: Flight Characteristics
26	Time at risk	22	Man-made objects	8	Good down-pilot points
24	Potential silhouette	18	Good terrain relative to threat terrain	30	Travel time
28	Threat FAA			3	Available flat land early
15	Flexibility	6	Does not compromise surprise	21	Maneuverability
17	Good checkpoints	13	Less impact on surprise	20	Linear obstacles
7	Cover	1	Avoid built-up areas	23	Crosses power lines
10	Exposure to fire	5	Close to population	11	Ease of navigation
29	Amount of travel near front	31	Best possible terrain use	19	# highways crossed
4	Better alternative available	14	Amount of exposure		
2	Best possible avoidance of populated areas	16	Good approach angle		
		12	Exposure to observation		
27	Travel next to cities, woodline near front	25	Best possible river crossing		
9	On probable enemy avenue of approach				

Goals and Goal Sequences

The primary output of the ARK method of knowledge acquisition was goals and goal sequences. RGM, of course, produced none of this, and thus no comparison is appropriate. The following section describes and analyzes the kinds of information that the ARK method elicits.

It is useful to begin this discussion with a thorough analysis of one of the SMEs, to show both the kinds of information obtained and how the kinds of information are classified and identified.

SME #1:

Goal: Determine a suitable route from the assembly area to the battle position.

Goal Determine a suitable battle position (the end point of the route).

Goal: Determine enemy situation.

Facts: Intelligence usually provides enemy situation. Greatest need to know size and type (e.g., motorized rifle regiment) and avenue of approach. If tanks are the target, then primary ammo should be TOWs. Range from battle position to target should be at least 2500 meters, because this puts the aircraft out of range of tank guns and also of the ZSU 23-4, the primary enemy anti-aircraft capability.

Goal: Determine weather constraints on battle position.

Facts: Time of day is a major consideration. Want the sun in back of you. Want the sun to cast a shadow on you, if possible. (This means that you want a hill and the sun in back of you.) If there is significant wind, wind should be coming from the front or side, not the back.

Goal: Determine a suitable holding area for the battle position selected.

Facts: Normally the holding area is about 5 km from the battle position.

Goal: Plan a route from assembly area to the holding area.

Dimensions: The route should be covered and concealed and away from populated areas, using the low ground as much as possible.

Goal: Plan a route from the holding area to the battle position.

Goal: Plan a route for egress from the battle position.

Goal: Plan a route from the battle position to the Forward Area Rearming and Refueling Point (FARP).

Facts: Depending on the nature of the mission, the kinds and amounts of ammunition required, and the length of the routes in and out, the pilots determine when they will stop at the FARP. Usually they stop on their way out, but may have to stop on their way in. Sometimes the helicopters cycle back and forth from the FARP to the engagement area, rotating three companies so that one is on station, one is at the FARP, and the third is enroute.

Goal: Determine likely locations of enemy air defense.

Facts: The greatest threats are the individual soldiers with surface-to-air missiles (SA7s, SA14s). Soviet doctrine places these individuals along rivers and treelines. It may be impossible to avoid this threat, but at least the pilot can be wary when approaching likely locations.

Goal: Plan a route from the FARP to the battle position.

Facts: As described above, if the mission is to keep up constant attack, then the 3 companies of the battalion cycle back and forth from the FARP to the battle position. The battle positions will be different, however, because reusing a battle position eliminates any element of surprise and also presents a threat to the pilots, if the enemy is poised to attack the used battle position. Battle positions should be used in order of quality: best, second best, etc.

Goal: Determine a suitable battle position.

Goal: Determine enemy avenue of approach.

Facts: The avenue of approach is usually estimated (by intelligence) from an estimate of the enemy's objective. What are they trying to accomplish?

Goal: Determine best area of attack (engagement area).

Dimensions: Avoid towns, because it is easy for them to hide in towns.

Goal: Determine suitable battle positions.

Goal: Plan a route from the assembly area to the battle position.

Dimensions: Covered and concealed.

Facts: A covered and concealed route becomes more important, the closer you get to the FEBA and across. You should assume scattered enemy on both sides of the

FEBA. This determines the following rule we use: Start Nap-of-the-Earth flight (NOE) when you get within 5 km of the FEBA, and also bounding overwatch, if you have time.

Goal: Plan a route from the assembly area to the holding area.

Dimensions: Ease of navigation; good checkpoints. Low ground close to FEBA. Avoid towns.

Facts: Roads (in this case) are examples of good routes for ease of navigation, especially back of FEBA, in relatively secure areas where cover is less important and navigation is more important. Good checkpoints are things like road intersections, road crossings, river crossings, etc. Closer to FEBA, stick to low ground and any major terrain features that might provide ease of navigation. Closer to FEBA, stay away from towns, especially after you start NOE, because lots of enemy observers in towns there.

Goal: Plan route from holding area to battle position.

Dimensions: Simplicity, flexibility.

Facts: You can't be too detailed in this area, you have to adjust quickly. You have to have a general idea, the rest is sneak and peak.

Goal: Plan an alternative route.

Dimensions: Good checkpoints, avoid towns, stay low, covered and concealed.

Facts: In general, you want to hug terrain like treelines. Follow stream beds, roads, rivers, draws.

[SME #1 repeats process on second map]

Goal: Plan the early portion of the route.

Dimensions: Ease of navigation, low ground.

Goal: Determine holding area.

Dimensions: Area that aircraft can land, nice open place.

Goal: Determine battle position.

Facts: Want a battle position with slopes up behind you, with hopefully trees on that slope. Sun at your back. With a treeline in front, to pop up behind.

Goal: Determine alternative route.

Goal: Determine early route.

Facts: Follow these fields, don't worry about much until 5 km from from FEBA. Then use NOE flight and hug the terrain.

Goal: Determine later route.

Dimensions: Avoid open field, if not too much out of the way.

Facts: In later route, have to be more flexible, have to see what the situation is, and adjust when you get there.

Dimensions: Ease of navigation.

Facts: Use major river into holding area.

Goal: Plan egress route.

Dimensions: Ease of navigation. Cover from the back (FEBA).

Facts: Want to get out fast. Want to know where you are. Want cover from enemy fire, so if you can put a hill between you and FEBA, great.

[SME #1 repeats process on third map]

Goal: Determine enemy objective.

Facts: You look for big population centers as most likely objectives. Intelligence usually makes this determination, but everyone knows this basic process.

Goal: Determine enemy avenue of approach.

Goal: Determine best area of engagement.

Facts: You do not want to engage near a populated area, because they can hide too easily, plus engages innocent citizens.

Goal: Determine battle positions.

Facts: Route-relevant considerations include that battle positions have to have low ground, with something to hide behind, to pop up behind, with a good background.

[SME #1 repeats process on fourth map]

Goal: Determine enemy objective.

Facts: You assume that they're after the larger cities.

Goal: Determine battle positions.

Facts: This area has a nice river bed, with treelines toward the enemy and low ground behind, and hills behind that.

Goal: Determine route.

Facts: (Narrative) Follow this low ground, this has a hill on both sides, avoid this open ground.

Dimensions: Low ground, cover and concealment, avoid open ground.

Goal Sequences: 1. Ascertain mission plan. 2. Plan route. 3. Determine battle position. 4. Determine enemy situation for battle position. 5. Determine holding area. 6. Plan route from assembly area to holding area. 7. Plan route from holding area to battle position. 8. Determine FARP location. 9. Plan route from battle position to FARP (egress).

Supplemental Sequences: 1. Locate likely enemy ADA sites. 2. Plan route from FEBA to battle position. 3. Avoid (if possible) enemy ADA sites.

1. Determine enemy situation for battle position. 2. Determine enemy objective. 3. Determine probable enemy avenue of approach. 4. Determine best area of attack (engagement area). 5. Determine battle position.

It is clear that the goals and goal sequences are the primary motivators in the planning activities of these SMEs. Thus their stated goal sequences are of primary importance in describing their expertise. Disregarding the additional information obtained, the major goal sequences of the seven other SMEs is as follows:

SMEs 2-8: Major Goal Sequences

SME #2:

1. Plan a route from the assembly area to the battle position. 2. Understand mission plan. 3. Determine enemy situation (especially enemy objective). 4. Determine battle position. 5. Determine holding area. 6. Plan route from assembly area to holding area. 7. Plan route from holding area to battle position. 8. Plan route from battle position to FARP (egress).

SME #3:

1. Plan route from assembly area to target. 2. Understand mission plan. 3. Coordinate with friendly ADA and artillery (establish air passage corridors). 4. Determine ingress and egress routes from FEBA to battle position and out. 5. Determine ammunition/fuel tradeoffs (to determine travel time). 6. Determine likely enemy air defense capabilities and locations. 7. Determine location of FARP. 8. Assess influence of weather factors. 9. Plan route from assembly area to FEBA. 10. Plan NOE route (from about 5 km from FEBA to battle position). 11. Determine holding areas. 12. Plan route from holding area to battle position. 13. Plan egress route from battle position to FARP.

SME #4:

1. Determine location of major targets. 2. Determine nature of major targets. 3. Determine mission and location of friendly forces. 4. Determine air passage corridor across FEBA. 5. Determine fuel/ammo tradeoff, and thus the location of the FARP, and whether it will be used on the way in or the way out. 6. Plan route from assembly area to battle position. 7. Adjust route on the basis of weather considerations. 8. Adjust route on the basis of day/night considerations. 9. Plan route from FEBA to battle position. 10. Plan route from battle position to FARP.

SME #5:

1. Plan a route from the assembly area to the battle position. 2. Select good battle position. 3. Plan a flank approach to battle position. 4. Adjust route for time of year, time of day, weather, general environment (desert, Europe, etc.). 5. Plan backwards from battle position (time on station required, ammo required). 6. Determine likely enemy ADA locations and avoid them if possible. 7. Determine most effective location for FARP. 8. Plan route from battle position to FARP or other egress point. 9. Determine tradeoffs for attack vs. risk, speed vs. possible lack of surprise. 10. Determine tradeoff between fuel and ammo and location of FARP.

SME #6:

1. Plan a route from the assembly area to the battle position. 2. Select a suitable battle position. 3. Determine the air corridor. 4. Plan a route from the FEBA to the battle position. 5. Attempt to avoid enemy air defense, especially individuals with SA7s and SA14s. 6. Determine the probable location of the primary target (usually tanks). 7. Plan the route backwards from the battle position to the assembly area. 8. Plan the route from the FEBA to the battle position. 9. Plan the route from the assembly area to the FEBA. 10. Determine possible travel time from fuel/ammo tradeoff. 11. Determine suitable FARP (location). 12. Plan the route from battle position to the FARP (egress). 13. Plan the route from the assembly area to the FEBA. 14. Plan the navigation checkpoints. 15. Adjust route for unusual circumstances, e.g., night operations.

SME #7:

1. Plan a route from the assembly area to the battle position. 2. Determine the battle position. 3. Plan the route from the FEBA to the battle position (ingress) and out (egress). 4. Coordinate with other units, especially for air passage corridors across the FEBA. 5. Plan egress route. 6. Planning sequence: start point, end point, route planning, adjust for friendly ADA. Also: first plan FEBA to BP, then egress, then AA back and forth to FEBA. 7. Estimate locations of enemy ADA, especially SA7s, and try to avoid them. 8. Work backwards from objective, start with routes from FEBA to battle position, egress routes, then others, as stated in 6. 9. Adjust routes for different environments, day/night, seasons. 10. Plan route in general. 11. Plan the egress route. 12. Plan the route from the assembly area to the FEBA. 13. Plan the route from the battle position to the FARP.

SME #8:

1. Plan the route from the assembly area to the battle position. 2. Adjust the assembly area for the mission planned. 3. Determine the values of the dimensions relevant to route planning: enemy situation, weather, ADA threat, night/day, time of year, etc. 4. Plan the beginning of NOE flight. 5. Estimate map reliability. 6. Plan the route from the assembly area to the battle position (same as 1). 7. Determine battle position. 8. Plan route from the (forward) assembly area to the battle position. 9. Determine the air corridor across the FEBA. 10. Determine the holding areas for the mission planned. 11. Plan the egress route. 12. Integrate FARP location into planning. 13. Plan cyclical routes from FARP to BP, if required by "rotating companies" mission. 14. Compute fuel/ammo tradeoffs, to determine primarily location and use of FARP.

Dimension Hierarchies

Another kind of information obtained from ARK is a verbal description of dimension hierarchies, which define and explain relationships among dimensions used for planning and evaluation of routes. For example, SME #1 described the following relationships:

SME #1: Dimension Hierarchies

Explanations: 1. Avoid populated areas. --> 1a. To avoid possible exposure to observation. 1b. To avoid man-made obstacles such as power lines and towers, large buildings, etc.

2. Approach with sun at back. --> 2a. To keep sun out of your eyes, in their eyes. 2b. To avoid reflection from canopy. 2c. To avoid silhouetting yourself. 2d. To cast shadow on your aircraft (with hill also behind you).

Expansions: 1. Cover and concealment. --> 1a. Exposure to potential observation. 1b. Exposure to potential fire.
2. Ease of navigation. --> 2a. Good checkpoints (major terrain features).

Thus, there are four reasons why SME #1 wanted a route that entered the battle position with the sun at his back. Similarly, Cover and Concealment was a multifaceted dimension comprising at least the protection from enemy fire (cover) and avoidance of exposure to enemy observation (concealment).

We have distinguished between the dimensional relationships we call "explanations" and those termed "expansions." An explanation tells us why a given dimension is considered important. Why do you want to avoid populated areas? Because it exposes you to potential observation by enemy spies or scouts, etc. An expansion adds detail or breaks a dimension into lower-level components, as Cover and Concealment is broken into its two major parts.

The dimensional relationships obtained from ARK are qualitative, compared to the quantitative relationships that we elicit with RGM. These two kinds of information about dimensional relationships are complementary, supporting one another. RGM provides the detailed statistical data that permits systematic exploration of relationships in cluster analyses and similar considerations, whereas ARK, in essence, tells you what these analyses mean.

Constraints

Another kind of information elicited by ARK but not by RGM we call constraints on route planning, because they describe conditions under which the usual planning process must be modified for some reason. The three most prominent constraints were time of day, time of year, and weather. Time of day includes the modifications of the planning process required by night flight; one needs better navigational aids at night, and the night vision goggles are shut down by bright lights, making the avoidance of cities more important at night than during the day. Also, on a sunny day, whether the attack occurs in the morning or afternoon is important, since the SMEs indicated that they want a route that brings them into the engagement area with the sun at their back. As for time of year, winter flights pose certain problems not faced in the summer. For example, if the snow is dry and powdery, one cannot fly under power lines because the rotor wash can easily blind the pilot and cause a crash. Weather such as rain and low visibility create the need to modify one's route for a number of reasons, including the fact that rain affects the trafficability of the terrain on the ground and alters estimates of the likely enemy avenue of approach.

Facts

Last but not least, the ARK method elicits a considerable amount of factual material related to the planning process. Among the small networks of declarative knowledge that could be developed from our material are mission planning considerations; analysis of the enemy situation; facts about enemy air defense capabilities; selection of a suitable battle position; coordination for air passage corridors; and considerations for ingress and egress around the engagement area. A particularly intricate network was developed for the balancing of amount of fuel, the ammunition required for the mission, the time on station required, and the location of the FARPs.

Section 4

SUMMARY, CONCLUSIONS, AND GUIDELINES

SUMMARY

We summarize the results of this study as follows.

It is feasible to evaluate methods for knowledge elicitation in the context of different task domains. The two methods used here -- ARK and RGM -- elicited different types of data. Specifically, RGM produced the names of dimensions along which routes could be evaluated. It also produced quantitative data, including the value of each route along each dimension, correlations between dimensions and route rankings, and correlations between the dimensions themselves. ARK produced the names of dimensions as well, and tended to match the dimensions produced by RGM. In addition, ARK produced a goal/subgoal structure describing the nature of the planning process, a set of facts about routes (a declarative knowledge network), and constraints on the use of dimensions (e.g., that a dimension was relevant only during winter). Clearly, the value of each method will depend on the goals of the designer of the expert system which is to use its output.

CONCLUSIONS

These data therefore support the general hypothesis of the present study, namely, that the RGM would be suitable for a "convergent" problem such as route evaluation, whereas the ARK method would be more suitable for the development of an expert system in a "divergent" domain, such as route planning. In this case, goals are more open-ended, and imposing a structure on those goals can be of considerable value.

To further evaluate the use of the KATs, a simple expert system was devised from the RGM data. The system was developed in a commercially available shell (VP-Expert), which uses a backward chaining search algorithm. The goal of the system was to evaluate routes, given input data on various dimensions. The constraint was adopted that it be able to evaluate all eight routes in agreement with the summary evaluation of the SMEs.

The development even of such a simple system raises some revealing issues. The first is how to determine the rating of new routes, given the existing ratings. The existing routes can be viewed as establishing 8 points in a multidimensional space, the axes of which are the dimensions of the SMEs. Eight points in such a space are very sparse data, and it is unlikely than any new route will match one exactly (hence being given the same rating). An obvious solution is to establish a distance metric, determine the proximity of each route to those rated previously, and assign the rating of the nearest route. This is beyond the scope of the present shell, besides raising further issues such as adjustment of ratings as a function of distance. The scope of the search through the space can be reduced, however, by reducing the number of dimensions considered. That is, certain dimensions can be considered most important, and ratings assigned immediately if the new route's values on those are particularly high or low.

Other issues have to do with treatment of the data. The present output consisted of numerical values on the dimensions, and a numerical average rank. Search on the dimensions is made easier if those are converted to ordinal data (good/fair/poor, for example). Still other issues arise because of differences among the SMEs. Some rules are idiosyncratic and might not be useful. There is also the problem of pooling discrepant data from different individuals. Further, some rules may be given different names but be equivalent; here they were judged to be so if the dimensional intercorrelations were very high and the dimensions were conceptually similar.

Ultimately, the expert system used eight dimensions. In order of decreasing importance, they are: degree of cover, better alternative available, maneuverability, potential exposure to observation, good approach angle, potential silhouette, avoids built-up areas, and good checkpoints. Importance ratings were used to weight the dimensions in assigning probabilities to the conclusion. Values on the dimensions were converted from numerical ratings to three-point ordinal scales (good/fair/poor) or yes/no binary scales. Average route rankings were similarly converted to a four-point ordinal scale (excellent/good/fair/poor).

The eight dimensions were used in 90 rules. Some reflected the importance of particular dimensions, such as, "If cover is poor, the route is poor." The general form of a rule was a conjunction of antecedent conditions and a resultant rating, such as, "If cover is good and maneuverability is poor and exposure is good and approach is good, then the route is fair." These rules accurately predicted the evaluation based on mean SME ranking.

This exemplar system is useful both to demonstrate the ease with which RGM data can be converted to rules and the data augmentation or amendment that is necessary. It is particularly important here to note that the system programmer induced the rules from the route rankings and dimensional values, given the constraint that the average ranking be predicted for the given routes. With increasing numbers of routes and/or dimensions, this approach would become computationally very complex. At some point, a KAT that explicitly generated rules would become highly preferable, even if it did not yield quantitative values initially. In fact, system designers might profit from data produced by both KATs, each with its own advantages.

FURTHER IMPLICATIONS

The present results suggest a number of further implications for the users of KAT methodology.

1. The designer of an expert system would do well to describe to the knowledge engineer the content of the system. Note that this should go beyond the syntax, such as "if/then rules." For example, in a convergent situation, goals and subgoals are not of primary importance. However, if the system is to describe a more complex, open-ended problem, goals and subgoals could be of great value.

2. Conversely, the knowledge engineer could facilitate system development by describing to the designer a set of potentially available tools and their outputs. The system designer could then select the tool must useful for the content. In short, we are suggesting that system development be a fully collaborative process between these two elements.

3. KATs may be useful for evaluating degrees of expertise as well as for producing data for expert systems. In the present RGM data, SMEs were observed to produce different total numbers of dimensions and different numbers of idiosyncratic dimensions. Experienced SMEs evaluated routes differently from those less experienced. Similarly, the ARK method produced different numbers of dimensions from individuals, and the goal/subgoal structure of the outputs also differed considerably. This suggests that the individuals conceptualized the planning process in different ways.

4. KATs may also have a pedagogical value. The conceptual structure elicited from methods like ARK might be useful in developing training tools, so that a match could be made between experts' view of the problem and its presentation to the novice. Ultimately, intelligent tutors based on expert evaluation are a desirable goal.

GUIDELINES

The preceding sections describe general conclusions and implications from the present study. In this section, we propose a set of more specific guidelines related to the two methods studied here.

1. If the goal is to determine a set of dimensions that can be applied to a set of existing products (e.g., potential routes), in order to classify or evaluate them, RGM is clearly the preferred method. It is more available to the inexperienced knowledge engineer and simpler to administer. It directly makes such dimensions available, and produces no surrounding "noise."

-- Correlational analysis should be used in conjunction with RGM to combine dimensions that are given different names by different individuals. Such diversity of naming appears to be the rule more than the exception.

-- If the number of dimensions to be considered is limited, for example, due to computer capacity or restricted time of individuals, then two procedures are advocated: Idiosyncratic dimensions -- which can be determined by correlations -- should be eliminated, and importance ratings for each dimension should be obtained so that the most important are preserved.

2. If the goal is to provide a product, rather than to evaluate an existing one, the ARK method is preferred. It produces not only dimensions on which potential products vary, but also a sequence of goals and subgoals that culminate in the creation of an effective product. These goals and subgoals motivate the sequence in which dimensions are considered. Factual material directs the information search, and constraints modify the scope of dimension-based rules.

-- If ordinal values on dimensions are desirable, the interviewer can interject a request for expanded description of each dimension as it is mentioned.

-- Use of multiple contexts (in the present case, terrain environments in which routes are to be planned) should further be useful to expand the set of dimensions obtained. Variability in context is also a potential means of determining the generality of goals and subgoals -- if these apply to the planning process in general, they will emerge despite variations in the eliciting conditions.

3. In general form, the two preceding rules translate to "convergent KATs for convergent systems; divergent for divergent systems." Further research is needed both to expand on the classification of KATs and to provide means of evaluating applications, so that an optimal fit between the products of the expert-system designer and the knowledge engineer can be achieved.

REFERENCES

Anderson, J.R. (1982). Acquisition of cognitive skill. *Psychological Review, 89,* 369-406.

Anderson, J.R. (1983). *The architecture of cognition.* Cambridge, MA: Harvard.

Anderson, J.R. (1987). Methodologies for studying human knowledge. *Behavioral and Brain Sciences, 10,* 467-505.

Burton, M., & Shadbolt, N. (in press). Knowledge engineering. In N. Williams & P. Holt (Eds.), *Expert systems for users.* New York: McGraw-Hill.

Boose, J.H. (1986). *Expertise transfer for expert system design.* New York: Elsevier.

Chandrasekaran, B. (1983). Towards a taxonomy of problem solving types. *The AI Magazine, 4(1),* 9-17.

Chase, W.G., & Simon, H.A. (1973). Perception in chess. *Cognitive Psychology, 4,* 55-81.

Clancey, W.J. (1985). Heuristic classification. *Artificial Intelligence, 27,* 289-350.

Davis, R. (1983). TEIRESIAS: Experiments in communicating with a knowledge-based system. In M.E. Sime & M.J. Coombs (Eds.), *Designing for human-computer communication.* New York: Academic Press.

de Groot, A. (1966). Perception and memory versus thought: Some old ideas and recent findings. In B. Kleinmuntz (Ed.), *Problem solving.* New York: Wiley.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review, 87,* 215-251.

Feigenbaum, E.A. (1977). The art of artificial intelligence: Themes and case studies of knowledge engineering. *Proceedings of the Fifth International Joint Conference on Artificial Intelligence,* 1014-1029.

Feigenbaum, E.A., & McCorduck, P. (1984). *The fifth generation: Artificial intelligence and Japan's computer challenge to the world.* New York: New American Library.

Gagne, E.D. (1985). *The cognitive psychology of school learning.* Boston: Little, Brown.

Gallanti, M., Guida, G., Spampinato, L., & Stefanini, A. (1985). Representing procedural knowledge in expert systems: An application to process control. In *IJCAI 1985, Vol. 1,* 345-352.

Geiwitz, J., Thomas, I.M., Fuller, R.G., & Harris, D.H. (1986). *Functional analysis of the tool requirements for the Vehicle Integrated Intelligence Soldier-Machine Interface* (Tech. Rep. No. 575-7). Santa Barbara, CA: Anacapa Sciences.

Genesereth, M. (1983). An overview of meta-level architecture. In *NCAI 1983,* 119-124.

Georgeff, M.P. (1982). Procedural control in production systems. *Artificial Intelligence, 18,* 175-201.

Georgeff, M., & Bonollo, U. (1983). Procedural expert systems. In *IJCAI 1983, Vol. 1,* 151-157.

Guilford, J. P. (1967). *The nature of human intelligence.* New York: McGraw-Hill.

Hayes-Roth, B., & Hayes-Roth, F. (1979). A cognitive model of planning. *Cognitive Science, 3,* 275-310.

Hayes-Roth, F., Waterman, D. A., & Lenat, D.B. (Eds.). (1983). *Building expert systems.* Reading, MA: Addison-Wesley.

Hillman, D.J. (1985). Artificial intelligence. *Human Factors, 27,* 21-31.

Kelly, G.A. (1955). *The psychology of personal constructs.* New York: Norton.

Klatzky, R.L. (1984). *Memory and awareness: An information-processing perspective.* New York: Freeman.

Kornell, J. (1987). Formal thought and narrative thought in knowledge acquisition. *International Journal of Man-Machine Studies, 26,* 203-212.

Laird, J. E., Newell, A., & Rosenbloom, P.S. (1987). SOAR: An architecture for general intelligence. *Artificial Intelligence, 33,* 1-64.

Leddo, J.M., & Cohen, M.S. (1987). *A cognitive science approach to elicitation of expert knowledge* (Working Paper #87-13). Alexandria, VA: Army Research Institute.

Loberg, G., & Powell, G.M. (in press). A knowledge-based model of operational military planning. In *Defense applications of artificial intelligence: Progress and prospects.* Boston: Lexington.

Newell, A. (1969). Heuristic programming: Ill-structured problems. In A. Aronofsky (Ed.), *Progress in operations research* (Vol. 3). New York: Wiley.

Newell, A., Shaw, J.C., and Simon, H.A. (1960). A variety of intelligent learning in a general problem-solver. In M.C. Yovits and S. Cameron (Eds.), *Self-organizing systems.* New York: Pergamon.

Nii, H.P., & Aiello, N. (1979). AGE (Attempt to Generalize): A knowledge-based program for building knowledge-based programs. In *IJCAI 1979,* 645-655.

Norman, D.A., and Draper, S.W. (Eds.) (1986). *User centered system design.* Hillsdale, NJ: Erlbaum.

Olson, J.R., & Rueter, H.H. (in press). Extracting expertise from experts: Methods for knowledge acquisition. *Journal of Expert Systems.*

Pelligrino, J.W. (1985). Inductive reasoning ability. In R.J. Sternberg (Ed.), *Human abilities: An information-processing approach.* San Francisco, CA: Freeman.

Rifkin, A. (1985). Evidence for a basic level in event taxonomies. *Memory and Cognition, 13,* 538-556.

Rosch, E. (1978). Principles of categorization. In E. Rosch & B.B. Lloyd (Eds.), *Cognition and categorization.* Hillsdale, NJ: Erlbaum.

Shortliffe, E.H. (1976). *Computer-based medical consultation: MYCIN.* New York: Elsevier.

Smith, R.G. (1984). On the development of commercial expert systems. *The AI Magazine, 5(3),* 61-73.

APPENDIX A:

TRANSCRIPTS OF ARK SESSIONS

Transcripts of ARK Sessions

SME-1, Ft. Rucker, 3/7/88
rank: WO1
experience in route planning: little (1 on 3-pt scale)

holding areas are the last point where youll be waiting, before you engage, in AHB, take off from AA, fly to HA, Cobras do, scouts go to BPs, already depicted on map. whats the en unit, mech inf company? will know this from intell, what kind of vehicles we expecting, determines distance of HA to BPs, here prob within 5 kms.

from AA to HA, want route that is covered and concealed (CC), up this river, up this low ground, try to avoid major cities, where you expect enemy to be. between HA and BP, fly NOE. dont want to pick set route for NOE, because youre sneaking and peaking in the trees, do whatever you can to get up to those positions. from AA to HA, want CC, try to have two or three diff routes, primary route, alternate route in case the primary has contact with enemy, and a separate route coming out, bec if en sees you go in, will set up to ambush you on the way out. routes will be named, like Route Red is the primary, Route Julie is the alternate, follow Route Tango to leave the area. S3 names the routes. low level flight when youre not expecting en contact and speed is essential, 25 km behind the FEBA or so, but in this situation would be contour and NOE.

HA to BP. wont necessarily have routes designated, bec scouts drop off AHs at HA, scout up to BP, radio back that its OK to come up there or tell them to deviate up N to BP 13, scout is checking it out right on the spot. BPs are on the map at our briefing, and hopefully theyll be scouted out before the en arrives, but that doesnt always happen. HAs on the map too, usually. Usually pretty much of a direct line between HA and BP, depends on terrain and probability of en contact. At NTC, we ended up fighting the en from the holding area. they arrived earlier than expected. we had HA at the base of this hill, and scouts went up, and the en came around the corner, and we called back and got permission to engage, so fought them right there, the scouts got caught behind, got cut off.

(set overall goal: offensive mission, attack and destroy enemy force. subgoal: determine battle position) need ave of approach, METT-T, like to attack when the en is moving or in battle engagement, not when theyre dug in, dont have the weapons to dig them out. to select BP, and firing positions (FPs) within the BPs, so like this whole side could be a BP, with 3-4 FPs within there. laundry list of good-to-haves for BPs and FPs. scouts may guide AHs into best FPs on the spot, all depends on how fast en is moving. (how does scout identify FPs, especially ones created on the spot?) map coordinates, or "big rock by the trees, go hide over there", which is a lot easier. dont want to be reading map coords during engagement or right before battle, trying to get your TOWs ready, want to put your map away. six digit coords.

en ave of approach comes from intell. usually have good info on size and type of en force. usually fairly accurate. so to determine BPs, need to know the nature of the target. in this case, mechanized forces, so will be using TOWs, so BPs can be up to 2500 m from ave of app. max effective range of TOW is 3750 m, try to engage in last one third of effective range, 2500-3750 range. two factors: 1)close enough to have good hit %, and 2) far enuf away to have protection from their weapons. Most small arms and tank weapons dont go beyond 2000 m. ("nature of target" means en weapons capabilities?) well, your weapons, too, bec if this was foot soldiers, wouldnt use TOW, would use rockets and 20 mm. Rockets could be 3000 m away or 1500 m (max effective range) for the 20 mm. Tanks and mech vehicles, use TOWs, again thats 3750 max range on that, 2500 you want. How close you need to be, how close you can be. for 20 mm, want to be 1000 m, 1250, away. 20 mm is a Gatling-type cannon. 2.75in folding-fin aerial rocket (FFAR). solid rocket motor and no real guidance, on the modernized Cobra you got little HUDs that has little cross hairs that float around and we got the M73 on our Cobras, fixed reticle, you dial in the mil setting depending on how fast youre going, how far the target is, put the cross hairs on the target and punch a couple of rockets off, and adjust off it. basically indirect fire, but you can fire rockets direct fire, within 6600 m, but for a direct shot, its more like 3000 m or less, anything after that, youre pretty much indirect firing, or at least looping them in. they say you can shoot them up to 9000 m indirect, i dont know about that. HMD, on the Cobra weve got this little eye piece that comes down on the helmet. used for sighting, little reticle in there, little light in there, put it on it and fire, not super accurate, use it for when youre flying along and someone starts shooting, you can just look over there, hit the action bar, and the reticle will flash until the guns aligned and then shoot, just to get something on there quick, and also the little TSU, where you track the TOW missile, you can also acquire targets with the eye sight, theres a little switch that the gunners got, you can tell the gunner that youve got a target, he'll go ahead and push the acquire-pilot switch, and the TSU will slew to where the pilot was looking, and then the gunner can look in there, then a little cockpit communication, like, "You looking at a tank? Yeah. OK, I got it."

only want to use FPs once, so you might need, depending on how much fighting youre going to be doing there, like 10 FPs in one BP. (how many AHs are we talking about?) not just one. Like a heavy team is usually 2 58s and 3 Cobras, 4 TOW per gunship, or 12 FPs, really more like 10 FPs, can use a FP more than once, but dont want to if you can avoid it. if you think they didn't see you, or if you got the guys who did see you, it all depends.

when we go out, therell be what they call the air battle captain. hell be the co commander or one of the platoon leaders, in a 58, basically be running the show. once the bullets start flying, usually the Cobra guys just pick their own targets. sometimes pick their own FP too, it depends. the scout guy makes sure the BP is secure, etc., and the en comes, well he's essentially done. calls back his battle damage assessment and stuff like that. but pretty much done. may call in artillery at that time, or talking to A10s, the jets, once they give us the final handoff on a situation like this, its pretty much were on our own. were firing, and we tell the scout, were going back to the FARP. we dont need the scout to tell us we can go back now.

the FARP we also have to consider in route planning. not going to be at one point for too long, not in a hi-intensity conflict. moves around. to points depicted on your overlay, initial and subsequent positions, with the times. (planned routes to FARP? each FARP?) really arent expecting en contact back here, back of FEBA, so usually dont have routes, may have route to first FARP, then follow route FARP people took to new location, thats what we did out at NTC.

back to BP considerations: type of en units, what weapons youre going to use against them: tanks, TOWs, basically a point weapon; trucks and personnel, rockets. 20 mm. primarily a suppression weapon, get them to button up, but can destroy trucks and equipment, at least at close range. use the rockets first, infantry scatters, tank commanders button up, maybe even 20 mm. then pop up and hit them with the TOW. bec now theyre looking for you in this little square, 4" x 2" (vision blocks), and trying to scan the sky. when tanks stop, theyre very hard to see. use artillery the same way as 20 mm, for suppression, scatter the infantry, get them to button up, so we can pop up and shoot them.

en air defense (ada): big one is the SA7 or the new one the SA14, same thing, longer range, infantry-carried missile. these guys are hard to spot. (do you avoid likely spots for these guys, in your route planning?) to some extent, and you can read Soviet doctrine, like they like to set up ada along rivers like this, or where trees have been cleared, good line of sight bec of the terrain. want good intell, updates where all the ZSU 23-4s (4-barrelled ...) are at, all the sa8 and sa9s are at. zsus eff range is only about 1000 m, maybe 2000. (main manuals for route planning?) FC 1-112, Attack Helicopter Battalion Operations, 1-114, Air Cavalry Operations.

battalion is smallest maneuver unit, when we go out, well have two teams per company, a heavy team (3 Cobras, 2 scouts [one with co comm]) and a light team (2 Cobras, 1 scout, with a Cobra pltn ldr, in charge of light team). not sure of this. doctrine keeps changing. can alternate companies, 1 at BP, 1at FARP, 1 enroute, to keep up constant attack, or mass destruction, all three companies fighting. AHC (company) has an attack platoon (7 Cobras) and a scout platoon (4 scouts), mix them up for real fighting, into teams. plan to use in battle 5 Cobras, 2 down for maintenance, 3 58s, 1 down for main.

BPs and FPs: use factors described by NORMA (BP): nature of target, orient on the target objective, range of your weapon, multiple firing positions, adequate area for dispersal. for FP, use BRASSCRAF: background (want a hill in back of you, forested hill, do not silhouette yourself), range (your own weapon, last 1/3 of your effective range; 80 % hit rate with TOWs from this range), altitude (above or equal alt to target), shadows (hide in them; best case is hill behind you and sun behind you, so hill casts a shadow on you in FP; good place for a digital map with slope shading), sun (want the sun to your back, out of your eyes, in their eyes), cover & concealment (cover in front of you, to pop up and duck down behind), rotor wash (gives you away; stay away from dust, leaves, powdery snow), adequate maneuver area (can turn around from behind cover), fields of fire (for TOWs, need about 20 sec en exposure to reach the target, plus time for aim, fire, etc.). of the BRASSCRAF factors, the two most important are range and field of fire. next two most important, background and cover. those are the four big ones. others are just nice to have.

(drawing actual routes on the Forchheim map) first thing I look at is the objective. if the en continues on same ave of app, will go thru this area, so in this broad strip, where's the best place for me to attack. thats the first question. route is from A to B, so have to select a pt B to go to. set up two engagement areas, OBJECTIVE PIG and OBJECTIVE COW. dont want to engage too close to a town, bec once they get into town, its hard, lots of places to hide stuff, all you can do is call in arty. same holding area for both objectives, call it HA BLUE. look for covered and concealed routes. really gets critical around the FEBA, we can assume scattered en on both sides of FEBA, right here where we cross the 60 grid line, we start flying NOE, within 5 km of FEBA, thats doctrine.

traveling techniques: traveling (low level), traveling overwatch (contour), bounding overwatch (NOE). use traveling overwatch up to 60 grid, bounding afterward.

looking at it might not be too great of a HA. well, maybe OK. let's find out. let me do my route to the HA first. again, back here were not too worried, our territory, so I'm going to follow this road first, cause I want something to navigate on, and a road is real easy. after that, low ground or any major terrain features. if these fields, green fields, good checkpt is the V in the road, go ahead just follow in these fields, and right when we cross this road, thatd be a checkpt, its time to start flying NOE, right near 60 grid line (leans forward to check out terrain more closely on the map), follow these fields, have to pop up against the vegetation a little bit bec its almost like a barrier there, go down this way, try to stay away from these towns, bec youre near the en and people like to congregate around towns anyway, split these in half, have to fly over veg anyway, this is kinda small, come up, follow this low ground until youve got these two hi mts, follow this little draw up into the HA BLUE. this would be my primary route. bad part would be right here, prob be the worst part of it, but good hi ground all around you almost, thats about the only place that you could sneak up in there.

(do you need a route from HA to BP?) not really, not per se a route, bec it all could change right then and there, and its pretty much ... from here on, this is bounding overwatch and stuff like that, and youre going to do what you can do to get there, basically.

(alternative route?) (above route is Bill, alternative is Jill) along this rt, too, youll have checkpts where youll call other people at, but that will be worked out with S3 and stuff. stay away from towns, seek the low ground, cover and concealed, is what Im looking for. trying to look backwards a little here, to help out here. down this draw, hug these mts, try to stay away from towns, kinda hard bec theres a lot of them. dash across this low ground here and again trying to stay away from that larger one there (town?) and hug this terrain, this forested terrain on this hill, after you pass this city and go ahead and pick up this stream, stream bed, follow that out, after that, follow the roads out maybe even follow this river out, pick it up that way. that might be a little better. (erases) thats better, just follow that river out of the holding area, and pick up that draw, follow that into this river, try to stay away from the towns and stuff.

air routes are depicted this way, a thick line (like ave of app) that crosses over in the middle.

(goto map of ?)on this map have to use more of the terrain features, like the fields and the trees and stuff, like from this HA, it wouldnt be too bad just to follow this river, this low ground right here, til you got to the pt of Ridenburg, after that get up on this higher terrain here and start following these fields around, go around this town, come around this way, valley right here, go between the two valleys, got hi ground on both sides, get into this area right here, follow this little river into this general area, and where you had your BPs set up, and again bypass the towns, esp after the FLOT, just have to use the edge of the fields to hide behind, really not too much, except between the two valleys, hi grd on both sides.

right in here would be a good HA, want an area where the aircraft can land, possibly roll the throttles down to idle, be ready to go, nice open place, maybe here, if its not compromised yet, but its kinda hard here, bec theres not too much here, you have to catch right as they come onto this map, possibly even have your obj right on the edge, so you could use this grassy terrain right here, actually this would be good, bec youve got lowgrd, its sloping up behind you onto this hi grd and you got trees right here, which is nice, bec youve got the background of the hill and if its late in the evening, the suns going to be over here, so youd want to set up your FPs over here and try to hit them while theyre coming into these fields in here, and actually this whole line right here, youve got this whole tree line, thats right before this little stream right here, with the grd slopin up behind you, itd be pretty good, so id set up my BPs here and here, with separate FPs right along this tree lines with that river, actually a nice place, nice and close, could engage them before they even got onto the map. (grid coordinates of the "real nice area"): both of them, bec this continues down on the other side, just south of Hassenbach, so this one is right on the edge: 6569. and this lower one is 634687-ish.

actually in this route right here, if that was my HA, id prob change this a little, bec the terrain still slopes up around here. hug this higher terrain right around here, bec youve got this, it still goes up a little bit but this is the highest point right in here.

(another route?) way back here, id come down here, follow these fields, up here, dont have to worry too much until you get 5 km up here, about Mondlow, start going NOE, using this terrain, hug it, only bad part about this route is right here, crossing this open field, but its kinda out of the way to come all the way down here, but it depends, on what the situation is when you get there, and from here, id use the same route, just jump in there. this would be a good base right here, this major river, get routes into that. good, bec good terrain navigation, except for this guy, but hes friendly, so dont have to worry about him too much.

egress out of these BPs here, nice river here with real nice hi grd all over the place, and pick up back that route, take this lo grd back into that HA, take that route out, this is nice! i like it. or you could come down here, ha, ha, ha. the guys in Germany, say, **Germany was built for the attack helicopter.** terrain is beautiful; the weather conditions, real good power margins, can carry heavier loads; the trees, the hills, all that stuff.

(map of Furth, L6530) this one is a little more difficult. they like to have roads right by the rivers in Germany. this might work, but wed have to move quick tho. their objective is most likely this city, or the big one, if it was the big one, theyd prob be coming in from the east, if it was for real. try to engage them on this road right here, youve got, kinda hard, the city and stuff there, unless you waited a little bit. BP has this lo grd, and the trees are on the other side, you can hide behind there, sloping-up terrain, for background, this nice treeline in here, and thats within range easily. (erases part of BP) erase that, got the town over there. in this HA, can go straight north here, wont be much around until you get about 5 klicks, when you get here, start hugging the terrain a little bit, cut these dudes in half and jump down in this little draw here, and then this major stream bed from there. a little bad right there. switch to NOE 5 klicks from FEBA, so id say just passing this road, until the HA, put the HA here, have the route going into the HA.

(second route?) diff HA from this direction, more like right here, pretty straight shot except again follow the side of this terrain here, go NOE right here, this road or maybe even this road right here. (is NOE indicated on your routes?) very possibly, at a checkpt. the checkpt would be on my overlay, and id be told to start NOE there. cut across here. no other real possibility. this is hard, bec not any good terrain, and all occupied. open and occupied.

(routes on map of Hochstadt L6330) come up from the north here. en symbols should be in red. or a double line around units. im assuming the larger cities, Hochstadt, is what theyre after. might get some nice, farther down here, HA right here. got some nice BPs right in here. another river with tree lines toward the en, and hills towards behind it, so thats real nice. maybe even have successive BPs back toward this way. might be better if i move that back a little bit. real nice trees and lo grd, some more ponds at, not too much on the S side of the road there. actually this will work out quite nice, come up straight N here, and then just follow the edge of this terrain, on up N, kinda lo grd right in between there, and then in the entrance, youve got a hill just to the N and to the S into the HA. again, when cross this major road, start going NOE right about there. maybe even after you turn this corner. come up N on this lo grd, hug this terrain, cross this major road here, start NOE right about there. the only bad part right there is youre crossing this nice open land right there. that northern route is better, i think. thats about it.

SME-2, Ft. Rucker, 3/8/88
rank: WO1
experience in route planning: little (1 on 3-pt scale)

alpha, bravo, charlie are the three companies in an attack helicopter battalion (AHB), in each company, have two attack teams, the heavy and the light, and the bat commander will determine who will be the first attack, the second, and the third, in phases, suppose we keep it alpha, bravo, charlie in that order. then alpha co will have the first phase of the attack, they have only so much time on station, just before their time on station is over, the second attack would come in, youd rotate it, and that way youll always have pressure on the en, the engagement would be going on continually. what do you want to do to en? destroy him, stop him, aggravate him. teams work different areas of engagement, heavy team at strongest pt, light team to aggravate or maybe draw their attn away from hvy tm, more of a recon. in diff BPs, usually. very seldom line up together. light tm is basically a rcon team, or cover the hvy tms rear, keep an eye on the battlefield, are there if you need them. heavy team has 4-5 AHs, 2-3 scouts; lght tm has 2-3 AHs, 1-2 scouts. one of the scouts has the air mission commander, controls the battle, with the hvy tm, usually co commander. bat commander there quite a bit, too, he may not be in a scout, may be in a Blackhawk or Huey, he's generally there most of the time, back and forth to the FARP, as needs exist, but when he's there, he's running the show. when gone, he turns it over.

symbols on map: anything to do with en is red, and we're blue or black. FEBA would be blue or black, labeled as FEBA or FLOT.

(route planning: whats the first thing you need to know?) the mission, my mission. just exactly what the mission is. attack and destroy; recon (wouldnt use heavy team); aggravate them or cause havoc on their side.

(assume "attack and destroy"; this defines the overall goal) ive got the mission, and in that mission, the rest of METT-T: equipment, time, terrain, troops (just ours, the AHC, and maybe some ground troops we are supporting). terrain shows me a lot of towns between here and there, and we want to avoid them as much as possible. my interest in their troops is where they are located and where they are going, also how strong their forces are, and their ada.

(their ada) ZSU 23-4, were worried about him, but with all these mts here, were worried about the little guy with the SA7, because if hes hiding in the mts, he can zap us as we go by, a lot easier for him than the ZSU, hes the hard guy to defend against, more of a threat, easier to hide, plus hes more mobile. (do you route plan around likely spots for these individual soldiers with SA7s?) yes. likely spots would be tops of mts. we dont get above the mts, bec we want to stay concealed, but hes got the shot down the mt, and a broader area for a shot, overlooking valleys and waddies. hes easily deployable, he can be dropped off by a troop-transport helicopter on the top of a mt, or a jeep-type vehicle. in the valleys, its really something, if theres a place for him to hide, hes got the valleys, so you might fly up higher on the military crest, to avoid giving him a good shot. he might be up in a little draw that we might use for hiding during a fight. (factors in considering SA7s?) how long en has been in this area, bec it takes time to place him, also whether en is moving, or in def posture; at NTC, it was pushed more than anything else, was look out for the little guy. youre going to use as much lo grd as poss, stay away from open fields, use as much cover, veg, lo grd, valleys, the draws, whatever it takes to get from our area to his area, were going to use it, and he knows that, but he knows we know he knows, so hes going to be hidden. but we want to outguess him, bec we know hes going to be waiting on us, and we know what kind of spots hes going to be looking for, he knows were going to use lo grd, veg. were not going to become paranoid, if hes there, hes there, thats why we have the scouts, theyre looking, searching, he wont hit the scout, hell wait and hit us, so hopefully the scout can pick him up. hard to find them, tho, at least until the missile is fired, thats the problem. hes vulnerable after the first missile, the gunships turn on that spot immediately. if he can get one gunship, hes doing good damage. more than one individual out there, anyway. at NTC, we saw three, the scouts picked them all up and we zapped him. not necessarily on the very top of the mt. this one, he was on the hi grd, but there was a little draw, he was right on the edge of the draw, for example, on the Bad Bruck map at 6071, another example at , we wouldnt fly over a town, too much open area here, but just as an example of the kind of place they were hiding, at 648668, put him in this draw, right in here, and say we were using the river, and there was no town here, the river or the lo grd here between the hi grd, were coming up the river, hes hiding in the draw here, up on the higher grd of it, has a fan of fire in both directions, thats just the way we saw them out at NTC.

if youre in a valley between two mts, going down a river, theres not a lot of maneuvering you can do. most you could do would be to nose it up and try to turn it around and get out of there, and then you put your rear end to him, and you dont know what hes doing, so theres really not a lot you can do in an area like that.

another factor in the expectation of a SA7 is the distance from his main force or from the FEBA, not normally found on our side of the FEBA, but does happen, so you have to be wary. for a certain distance from AA, we dont have anything to worry about, free cruise. then we get into a combat cruise as we get closer to FEBA, and then we slow it down, leapfrogging it, or whatever it takes to get in there. were tighter, well, maybe not tighter, but more capable of covering each other, the closer we get. we get slower, the more watch weve got, never let the scout out of our sight.

(whats the first thing to do in route planning?) know where youre going. have to pick your BPs. if we know where the en is, we try to pick some possible looking BPs. try to find them on the map, and adjust on the basis of the real terrain, etc. FPs are selected the same way, projected and then adjust when you get there. so you have one big BP, say this whole side here, and within that BP, were going to have to find FPs, our angle of fire, our field of view, the range, dont want to give ourselves away with out rotor wash or our shadows or reflections off the windscreen. field of view and range most important factors. (how many FPs within a BP?) depends on how big it is, maybe 2 or 3. personally, id want to surround them as much as possible, fire from every area, but i wouldnt use more than 2, it becomes too cluttered. id split my team, i wouldnt put all 4 cobras in the same battle pos, id use more than one BP, cause they can use MLRS to wipe out a whole grid square, then im gone. Multiple Launch Rocket System, mobile rocket launcher. ZSUs and tanks not a problem. we try to hit them in the last third of our max eff range, thats out of their range, were still accurate, but the MLRS can get to us.

once you fire, you dont fire again from the same spot. you move. alternate spots are also projected in advance, plus when youre going in, you can find them too, we did that a lot at NTC. lot of waddies, once we were there, we said, hey, weve got a better shot over here. adjusted. have a first choice, have to have a plan, tho.

(how does scout indicate firing position?) grid coords or "over by that big rock", whatever it takes. textbook says follow me, then mark, we stop right there. try to communicate on secure radio. TEIRS, may give us the TEIRS #, say drop 500 add 6. better than grid coords. most of the time the scout just says follow me.

(back to route planning; assume we have a feasible BP) have to decide whether or not to use a HA, with the distance here, yes Id say wed use one. (what would be your first consideration, after selecting BP?) ive got the distance, most of the terrain is mts, lot of valleys, a lot of hi country, but between us and them there are a lot of cities too. we dont want to fly in the city, we want to stay away as much as we can. we dont want open grd. (why avoid cities?) information. we dont want to be seen, we assume that some en agents are in the cities, radioing info to the en. we may use the same route, esp back here in the secure areas, but when we get close, we wont use the same route coming out that we used going in. wont use it twice unless necessary. but back here if were using this route a lot, their intell will say, hey, theyre going right by Bad Bruckenau, so just for visibility, we avoid cities. if at night, the lights of the city are going to render our night vision goggles less effective. dont like to fly in the mts, NOE, without your goggles. want to stay as low as we can. even in day, want to avoid the cities. (looking at distance, and looking at whats between pt a and pt b?) yes. want the shortest route, but sometimes the shortest way is not feasible. have to consider time on station. we only have so much time, with the Cobra in particular, we tradeoff between ammo and fuel, which is time on station. so we sacrifice fuel for a heavy load of armament. if we need a lot of time on station or do want a lot of bullets, so thats a key factor in the route we select.

the best course of action on this map, i would stay away from over here, bec of all the cities. over here, you have some open area, but theres a lot of lo grd. now, using rivers, if theyve been reconned, our intell says no worry about wire obstacles strung across hillsides, theyre a good place to use, and theyre not a good place to use. it depends. its a shot youre going to have to call. if they know were coming up the rivers, then were sitting ducks. say they dont know were coming: then staying to this lo grd, its natural. easy navigation, just follow the river, and you know where you are on the map. (look for good landmarks for navigation?) yes. important feature of a good route is the ease of navigation. use the low grd, not nec the river, but the lo grd. hilly in here, so you have quite a bit of cover. head up the draw here, its still lo, stay to the bottom here, avoiding this open area, swing around the bottom here, to avoid Overbach, starts downsloping here. got these waddies here. hit this little stream here, little village here, youre going to hit some. down the waddi, staying to the low grd here, but avoid the autobahn. (why avoid autobahn?) traffic. dont want to be seen. stay north here, Rodenburg, stay in here in the veg, stay out to the side, stay in lo, fly around here, using this hi grd to my advantage. (how flying here?) NOE. contour from AA to here. traveling overwatch with contour, bounding overwatch with NOE. fixing to fight here, so thats not too good, theyre up on a hill shooting down, thats what we dont want. dont want to put us at the bottom of the hill.

(tell me about the tradeoff between station time and ammo) with a full bag of fuel we cant carry a full load of ammo. we do "performance planning" which tells us at what weight our aircraft will hover out of ground effect, and naturally during the flight you burn fuel and you lose weight, so you have more power at the destination, you have to figure that in. depends on the conditions of the day. if its hot, that makes it even worse. bec the aircraft doesnt perform, dont have the power to do your hovering fire, or wont have the power to stay up high. lot comes into play. (full load of ammo?) 8 TOWs, 500 rds of 20 mm, and 2x19=38 rockets. very little room for gas, so no station time. typical configuration is 4 TOW, 500 rds of 20 mm, 20 rockets. about half of the full load. (full load of fuel would allow how much ammo?) something, but not much. also the conditions of the day, if its hot, forget it, might as well not even go. at NTC, we didnt really carry any ammo, but to make it realistic, we assumed 4 tow, etc, and we put on 1200 lb of fuel, which is realistic for that load, and still, until we burned off some of our fuel, we had engine bleedoff, we had to fight from the lo waddi. we couldnt get up. after we burned some of the fuel, we could get up, but by then it was time to go home. thats whats so good about the 64, it has two engines, so it has the power to carry a full load. (what do you use 20 mm for?) suppression, to get their heads down, scatter, and also effective against light-skinned vehicles.

they wont be fighting on the hilltop, as shown here. more likely down in here someplace, on the road going around the bottom of the hill, a motorized rifle regiment. if theyre here, we could come up from this side, if theyre traveling this road here (assume that they are) ok, then we can still come through here, use this lo grd, and come up here, their destination is ... Ohrburg, if thats their destination, then we could come as we were awhile ago, and heres a hill, its open, up in here, its a draw, and theres roads in here, theyd have to reconned, in this draw, but you have the whole city, you have your field of fire here, on the side of this mt, you have this whole side of this mt, if theyre coming up the road, then these guys have them, and these guys have them. if i could, id use this draw, bec its pretty easy to get over a mt in a draw, bec when youre going up the draw, the only people youre vulnerable to are the people out in front of you, out here, but in the draw, even then, its not that bad, draw gives you cover, dont have to get up hi to go over the mt.

now we have them stopped, if theyre coming up this road, we have them cold. (holding area?) use a ha big enough to get the whole attack team in, so big enuf is first consideration, suitability on the grd, dont want them to sit down on a marsh or a plowed field, look for cover, not near town, secure from battle area, maybe halfway between FEBA and BP, along the route chosen for other reasons. on the way in. heres another draw here, this open grd is not good. but for example, suppose this was veg here, we find a route home, on their way back to the FARP, rotating back and forth. (FARP?) suppose we know that Overbach is ours, ok? still we need some flat grd for the farp. say we use this here, easily accessed by our trucks, they can use this road here. one good thing about this farp is that its close enuf so we could have two companies fighting and only one at the farp, rotate that way. so really the farp and the ha become the same thing. (if the ha is separate?) here then. got the hi grd here, youre pretty well concealed, theres some roads there, but its pretty far from the BP, not quite halfway (farp to BP), but close enuf, scatter them around the veg here, hi grd all around.

so, got the route in and the route out, and the route out may, just may pass by the ha, we avoid all these cities and still use this hi grd to our advantage.

(whats the difference in considerations for ingress and egress?) want different egress route, bec you might have been seen going in, and they might be waiting for you. once you get this rotation set up, then you know whats happening along the route, bec you always have scouts out, always watching. a good scout is hard to find. you can find a good OH-58 driver, but to find a good scout... bec a scout has to be familiar with us, and we have to know what hes doing, so he doesnt put us in some place thats going to get us killed, but the scout has to know us, our station time, how well we can manuever, where we can go, the range of our weapons, speed, and everything. a scout pilot has a lot to know. (how are the scouts chosen?) some personal choice, same rank pretty much, scout or gunship. they use an algorithm score from flight school, you had to make a certain score to even qualify as a potential scout pilot. I am scout qualified, and most of your gun pilots are scout qualified. we go thru the scout track and then thru the gun track, so we basically know when the scout has done something stupid. scout pilot is not always a gun pilot, tho.

SME-3, Ft. Rucker, 3/8/88
rank: CW2
experience in route planning: little (1 on 3-pt scale)

(overall goal is to attack and destroy the en unit; major subgoal is to plan a route to achieve this purpose; what is the first thing you want to know, or do, to achieve this goal of an acceptable route from the assembly area to the enemy position?) first id get the latest intell update, for intell on METT-T. any info that affects the area of operations. phase lines, sectors of responsibility, doesnt restrict you to planning route in this area, but you want to know where people are, where the friendlies are, usually the AHB will be opconned to a brigade, brg will have a sector of responsibility, you become responsible for helicopter ops in that area or for en activity that might impact on that area. also from intell, the latest satellite, and also map recon. (weather?) minuscule, one of the things we look at later on down.

map recon is affected by satellite photos, something may have changed from the map, what the map has. usually the maps are pretty old, so you need a sat update. even stuff the S2 hasnt accomplished yet. fairly new capability. digitized map, or aerial photos. also when i go in for the intell update at bat, we get overlay, which may have NBC stuff, areas to avoid in route planning.

on the map overlays, you have units, and holding areas, FLOT, and sometimes air passage corridors thru friendly ADA, need to look at that, its a preprogrammed line we have to fly, we need to know where our friendly ADA is, where the FLOT was, where the troops are exactly along the FLOT, dont want to fly over the gun sight line of our own artillery. (tell me more about air passage corridors) usually a narrow corridor, with a time window, have to cross a phase line plus or minus a minute, very tight time constraints. sometimes you give a time when you want to cross the FLOT, then theyll put down an arty barrage, then a 5-minute window, then more arty to keep their heads down until we get clear.

one route in another route back. never use the same route both ways. corridor varies in width, too. usually about a km on each side of expected line of flight. (is it more common to have a corridor specified, or not) depends on the unit youre working with, and how big a scale it is. like a route recon or a movement to contact, you wouldnt have any of this corridor stuff. on a delib attack, usually have a corridor preprogrammed up to a certain pt., established at higher, or at the unit, depending on what time frame youre working. if we plan this the night before, usually the S3 will preprogram our route for us. but if its a hasty attack or movement to contact, wed do our own route in. so it depends on the kind of mission.

(continue route planning) have to look at en troops, known size of en ADA, want to know all the friendly troops, too. want to know the status of the air, who has supremacy, or parity, what we can expect. what kind of target are we going up against. are we going against heavy armor with tanks, or mech rifle reg, so we know what kind of weapon system were going to carry. with Cobras, youre limited in the amt of time you can stay on station, you have to compute how long its going to take to fly here, how long on station, how long to fly back, in minutes, in amt of fuel required. so we have x amt of gas, leaves us with x amt of weight left over that we can use to load on weapons. need heavy TOW for armor, or lighter TOW mix, with more rockets and more 20 mm if were going up against a mech infantry unit. have to remember that even a mech rifle regiment has tanks. complex calculation, fuel and weapons mix. in the Cobra, max out at 9300, 9400 lb, with full, 2 hr 30 min gas on board, 600-700 lbs for ammo, each TOW is 55 lb, adds up fast. what target were going after, subtract the amt of time to get there, and back, that determines the gas youre going to put on, and this much armament were going to have. (how do you do these calculations?) use planning sequence and you have your weight and balance off your aircraft, op manual has weights for say 100 rds of 20 mm, per TOW, and TOW tube, add it all up on the form (distance critical) true. in the 64, whole different sequence of events, because the 64 still about 1000 lbs under its max gross, with everything on it. full fuel, full armament, everything.

(their ADA capabilities?) ZSU 23-4, 23 mm self propelled radar-guided, 4 barrel. travels with the battle units, always work in pairs. like rattlesnakes. beg of column, middle, or end. right behind the forces that are moving forward. also worry about SA9s, mounted on a BRDM-2 chassis, with missiles mounted on top, in their recon units. SA7 or SA-14, 14 is the newer model of the SA7, handheld, mech infantry dismounts, then you have to worry. SA8, will be farther back. larger missile than the SA7, or the SA9, radar-guided, heat sensing, but with its own radar, looks like 6 wheels, big boat kind of thing, missiles in front, with radar right in back of it, theyll be farther back behind the leading element. recon is 15-25 km ahead of the main body. main battle tanks, need to keep them in mind, bec they can reach out and touch you with a sabot round at 2000 m easily, if hes turning his turret toward you, you need to do something about it. he can fire in 10-15 sec, whereas TOW takes 18 sec, dont duel one on one with a tank, youre going to lose. but if i know where he is, i can stay far enuf away to stay out of his range. maneuver around him, flanks and in back. TOW range is 3750 m at max, and problem is at max range, missile starts flying like this, nose up, might bounce off tank, esp in front. keep your nose pointed at them, presents much less of a target for them.

what we want to know about our own troops is what arty units are direct support to us, and what units are general support. usually in aviation you get a battery that is direct support to you, and then you have the general support, theyll support the general operation, say in case something happens to your direct support. troubleshooters. then we look at the time and the weather. time is time is takes to get there, how long were going to stay there, how long to get back. get back to the FARP, which is closer to FLOT than AA. FARP stays in one place no longer than an hr or 1 1/2 hr, has to move around a lot. all the locations of the FARPs are preprogrammed.

(assume best guess BPs have been chosen; route planning from there) you establish FPs inside of BPs, you meaning the Cobra pilot. 4-8 TOWs, so 4-8 shots, move from one BP to the next, 1-2 TOWs per BP.

(back to route planning) one more thing to consider is weather. low ceilings are gonna keep you slower, lower, poor vis. clear weather, have to know where the sun is shining at, want the sun at your back or at least at your side, dont want to look into the sun. sun can reflect off your canopy too, have to watch that too. also the wind, how strong the wind is, if you plan to hover in ridge lines, have to watch your wind, esp with a loaded Cobra. with lo ceilings, wont be able to go thru some of these hi mtn passes. have to stay lower, and with bad weather, will keep threat air down, keep the fast movers down, but the helos will still be able to operate. night bad weather, not fun, but good opportunity bec nobody else is out there. also, in bad weather, the trafficability of the roads is affected, so the movement of the en is restricted. and the maneuverability of the en. if visibility is poor, say a mile or less, can we see the target? can the target see us? we have to consider poor nav in bad weather, might get lost. so, if vis is poor, need route with better checkpts, for nav. on the other hand, might take routes you wouldnt otherwise, in good weather, say across flat land. also lo clouds keep you down.

avoid all man-made areas. avoid roads, populated areas, bec you dont know how far advanced their recon or their special operations have gotten. try to follow the contour of the land, to make nav easy for you. never silhouette yourself by flying on top of a ridge line. sometimes you may have to fly over a pop area, but you just do the best you can do. fly down this valley, across this path, back down to this valley, up thru that pass, down to the level, flat land. start going NOE here, close to the FLOT. may want to do bounding overwatch also. usually NOE and bounding overwatch are highly correlated. never leap beyond your scouts. can lose your scout, if they go too fast. if you have inexperienced scout.

(how do you parcel out BPs to the companies?) if were the first to arrive, we take the BP that is best from the pt of view of where the en is, what hes doing, wheres the best place to shoot him up from. the scout goes up, determines situation, comes back and says to us, lets go to BP # 1. we have our route that weve established getting in there, usually the checkpts are phase lines, when you cross the phase line, youll say, i crossed, what the brevity code says a phase line means, PL Ford. pls are terrain-based, ridge lines, rivers, try to avoid manmade objects as much as possible, such be a predominant terrain feature. (holding areas?) yeah, depends on, hit the release point, the scout might tell you to establish a ha, anywhere in here, or somewhere along the route, or sometimes predetermined has. sometimes have no has, depends on how complex you want to get this thing. usually its better if the scouts make the decision on the spot of whether to hold, and where. so has are usually establ by the team itself. sometimes the scout will look for good possibilities beforehand, on the map. scout determines ha. sometimes theres a need to move quickly to BP, en moving, so just skip the ha stuff.

fly as comp to RP then split off into light and heavy teams. usually 3-5 mix in co, 3 scouts and 5 gunships. heavy team is 3 guns, 2 scouts, light team is 2 guns and 1 scout. air battle captain is usually the co comm, pltn leader is the gun lead, also is the IP (instructor pilot) usually too. air bat capt usually sticks with heavy team, scout pltn leader will be in charge of the light team. sometimes air bat capt will move back and forth between the two teams, depending on how close you are, terrain between you. (what are the criteria of a good ha?) distance to the BP, has to be fairly close. (why do you take a different route coming out than going in?) bec there is usually someone else coming up that route. traffic reasons. and also dont want to fly the same route a lot, bec someone might be waiting for you to come out. might wait for next co to come in, too, but they are armed, and when you come out you dont have any bullets left, you shot your wad at the en. (considerations for the egress route?) same process as going in, in reverse. NOE and bounding, then contour and traveling. NOE until well past the FLOT.

in a normal cross-FLOT operation, usually go much deeper, hit them in the rear, usually dont fight this close to the FLOT. most of the other operations are right on the flot or feba.

SME-4, Ft. Rucker, 3/9/88
rank: CW2
experience in route planning: moderate (2 on 3-pt scale)

FEBA is more common than FLOT lately. battle is more fluid than it used to be, have to update it every 3-4 hours. (overall goal is attack and destroy the en unit) may give you specific targets, e.g., mech infantry unit, go in and knock out the tanks. usually know where the tanks are, bec soviets have an arrangement according to doctrine, and they stick to it pretty closely. but if this scenario was in Honduras or Iran, may not follow doctrine as closely, even if trained and supplied by soviets, but here in Germany, should know within 3-4 klicks where the tanks are.

have to have a lot more info about the objective, etc., before you actually go down there and start shooting tanks. intell info. info relevant to mission planning, to where you set up your BPs and FPs. FPs are going to depend more on terrain, what you find when you get there, bec youre talking about an educated guess at this point. sometimes when you get to the spot, it looks different from what you expected from the map. so you may want to go to your alternate, or deviate from your planned position. so Ill do plan a, BPs if everything goes right, and plan b, as backup. just alternate BPs.

would be nice to know where all our friendlies are at. maybe here at this hill behind Middenfield, do we have friendlies in there? where are our troops, and where is our air defense? our ADA? that gives me some options. if we have friendlies in specific areas, then i can be confident that those areas are reasonably secure. if we have friendlies across this front line somewhere, these people over here may be in contact with another element. different picture. is it just one isolated area of contact were talking about, nothing else going on? may have massive amt of activity. or maybe its sporadic. want to know where the friendly units are and what theyre doing. thats basically it.

(what kinds of problems do you have with friendly ADA?) they do shoot us down sometimes, by accident (i hope). its a big deal to have corridors coordinated, so that the friendlies know... now, im reasonably confident that Joe Snuffy, the Spec4 who's out here with a rocket launcher, doesnt want to shoot down friendlies, but hes real excited, and anything he sees... and if the helos are doing their thing properly, you arent going to see much of the helos. you might know that hes there, may get a glimpse, or youll hear him. but Joe Snuffy is going to be real excited, could shoot first and ask questions later, that sort of thing. what are they operating under? if theyre operating under weapons tight, or weapons free, thats going to determine what kind of info he has to get in order to shoot. if they give him free rein, hes prob going to shoot at you, bec hes excited, and its a helo. air defense corridors are going to be very important. but then again it depends. if these guys are up here and the bad guys are down here, 12-15 klicks away, probably Joe wont shoot so quickly without a positive id, not compared to them being 5-6 klicks away. if hes getting reports that theyre on their way, chargin up this direction, were being probed, vs. theyre in an assembly area 15 klicks, but theyre not coming yet.

typically we tell them what we want. we will request a corridor, from ADA, a window (time) and a corridor. time window is very important. lets say were going to come up this valley and cross over here and hit them from their left flank. we may actually use this draw, this stream right here. we tell them that we want a km either side of this river, for 5 minutes, or 7 minutes, were going to send a bunch of friendly helos thru here, so you tell your guys to not shoot us down. probably have a bunch of individuals sitting on hillsides with Stingers, too. very hard to spot. the individuals are supposed to be in communication with command. of course were assuming that these 40-yr old radios theyve got work, were assuming they got fresh batts, were assuming the guy hasnt been out there for 14 days with no resupply. they may drop off 6 or 8 or 10 2-man teams out there, with stingers, radio, and some rations, and tell them to report in twice a day, three times a day, unless you see something, and its possible that everything wont work according to plan. im frankly more concerned about the guy with the rocket launcher, with 21 rockets to throw at you. stinger has to pick up your heat signature, hes got to be visually looking at you. if Joe Snuffy, the pfc or the spec 4 or e5 doesnt know what a cobra looks like, he should go back to school. threat id should be second nature to him by the time he gets out into the field. im not so concerned with the optically guided missiles as i am the radar launched, where they can say, just saw a helo, lets shoot the radar at him, we can pick something up, we have obscuration and cant really see that good, we can pick him up on the radar, we dont know who he is, lets just fire him up.

(friendly arty?) need to know what theyre doing, so you dont get in their umbrella. the window were talking about here would also include arty. say our mission is to go in there and destroy tanks, theyre going to prep that area with arty, to start with. in the big sequence, theyre going to throw arty on them; when the arty stops, were supposed to be there. coordination obviously involved, so that we get there right when the arty stops. not before it stops, not 15 min after it stops, that gives them time to regroup.

(route planning continued) if were coming from clear up here, im assuming its a little ways in the rear, were going to need bullets and gas somewhere up here before continuing across the FEBA. need to plan a FARP for on the way in. 4 or 5 klicks back of the FEBA. say were coming in on their left flank again, as before, the same scenario, and were going to be using this for our window. are we going to fly from the AA fully armed, which is going to consume more fuel and slow us down a bit. do we want to come in fast, bust them up and get out fast, what kind of distance do we need to travel. in a cobra its diff from the 64 in that you cant fly with full armament and full gas. two scenarios ill give you: come a long distance from the AA, not coming armed, coming to a FAA, a forward assemby area. 10-12 klicks from your likely contact you have your FAA, with a jump TOC, and likely your rearm and refuel point is going to be there too. doesnt have to be there, and tactically it might not be smart to have it there, bec with all the aircraft coming and going out of there, if the en has any observers around, theyd get keyed that something is going on. FARP should be separate but a lot of times its not, theyre co-located, or very close together. (jump TOC?) a tactical operations center that is designed to be up here 10-12 klicks from the bad guys, and it can move in an hour or less, a couple small tents some radios a couple of CUTVVs, and if the situation changes, they pack up and in 10 minutes theyre gone someplace else. sometimes theyll run a jump TOC out of a Huey, as a command or control bird. anyway, two scenarios: your rear assembly area, an airfield back in friendly territory, youre going to have to come a distance thats impractical to come loaded bec of fuel considerations. headed for the FAA, which could have a FARP co-located there, in this scenario, prob would have the FARP there. if they werent co-located, could skip the FAA and go directly to the FARP. stay in radio contact with them, the FAA, basic things like where were at, checkpoint Lima, checkpt November. that way the FAA people, the C2 people, would know where we were at, and at each station, they would know what was going on, to see if its all according to plan. if things didnot work we would have a code word saying the mission was scrubbed, or the shits hit the fan, or whatever.

ok, so weve come from the rear ass area to the FAA, picked up bullets and fuel, probably be nice if we had an intell update at the FAA, just to see if the situation has changed. interested in anything covered in METT-T, if it had changed. is the en still doing what we thought he would do, have any friendly elements changed their activities, have some of our outposts or recon units made some significant observation. then come on up thru your window, hit your target, go out thru a different area, have to have another window. thats one method. the other method would be where youd be loaded when youre coming, come thru your window, hit your target, and then egress. in this second scenario, youre going to have to get fuel on the way out.

not only do you need a diff route coming out as going in, but also, on a given route, say going in, you might have an individual down there with a missile, and hes probably going to be surprised by the first helo, maybe wont have time to get the second, but the third is dead meat. hes looking for the other helos to fly over in the same exact spot he saw the first. so you have to vary the route a little even on the same route, dont fly over exactly the same ground, S turns and zigzags and whatever. that happened a lot in Vietnam. the first guy was ok, and maybe the second and third, but numbers 6,7,8 all got shot down. like ducks in a pond. (how much can you vary a route when youre flying NOE?) the tactics i was taught, the schools teach you one thing, and the IPs in your unit teach a variation on that. the way i was talking makes the most sense, when youre flying to or from somewhere, the aircraft ahead of you, youre respons to cover him, so you need to be within weapon range of him, do not need to right up on him in a nice tight formation. so youre looking at, where can he be engaged from, what would engage him, most likely (the range of small arms fire, e.g., if thats the only likely poss). range is one klick, lets say, and our weapon range is accurately 2-3 klicks, were talking 1-1 1/2 klicks away from him, so if he gets engaged, we can immed suppress. other people think you should fly very close to each other. i dont like that, it doesnt make sense to me. but if were flying in a narrow valley, usually the lead guy flies down in the bottom of the valley, the other guys fly on either side, up a bit, off of the valley floor. it may be giving you a little more exposure than to be down in the lowest part of the valley, but if the en has an outpost halfway up the side of one of the [illegible]s, when he engages your guy on the other side of the valley, youve got a wing man thats coming right up on top of him. so he gives himself away, hes dead meat. taking some risk, but covering some other risks. danger there is you dont want to silhouette yourself, get too hi up on the ridge line. part way up the ridge line is really pretty effective.

the problem i see in our battle drills and rehearsals, using a fixed FARP, is that its unrealistic in the sense that the battlefield is going to be fluid, its going to be moving. #2 is, if theyve got any kind of observation people out here, if they see a helo go in, and land, you dont want to go in there and land again, bec theyre going to be expecting that.

if we have 3 companies circulating from FARP to BP, theyd probably all use the same corridor. if we want to keep up the attack for a long time, the corridor may be open for, say, an hour. may have two corridors, both open for an hour. 1/3 rule is ok for cav missions, but not for all-out attack. cav missions are more recon, screening type missions, or flanking action. if our mission is to destroy all these tanks, the 1/3 rule means well have only 1/3 of our guns on line at any one time. real difficult to coordinate 3 companies in sequence. usually a gap between one team pulls away and the next one comes in, gives en time to regroup, put up better defense. plus, after the first company attacks, youve lost your element of surprise anyway. i like all 3 companies, all we got, on line at once, in a destroy mission.

in a grd support mission, suppressing, then the 1/3 rule works real fine. bec youve got something on station that offers the grd comm suppression. experience dictates, its a judgment call.

(criteria for route planning?) terrain, terrain is the first thing you look at, to make sure that you have something between you and your opposition. looking for cover. i would also avoid as many built-up areas as i could. cities, towns, major roads. (why avoid highways?) same as avoiding built-up area of a city, bec the less people who know youre there, the less the chance the en will get forewarning, the better the chance of surprise. if we go by a metropolitan area, the odds are pretty decent that somebody's going to recognize a whole bunch of cobras, and the en is going to be represented in that group. its just asking for trouble. if the en gets the info, their intell can piece it together and get a pretty good idea of whats going on. the soviets have most of the actual numbers of our aircraft, so they know the unit, everything thats operating in their area. twice since ive been here, soviet spies have been arrested, taking pictures of the numbers on our helicopter.

like to stay lo bec lo generally means good cover. if youre in terrain that is rolling and wooded, the people on the grd are going to have a tough time detecting you, bec their visibility, their field of view is limited. lo altitude may make you undetectable. (weather?) if our route were to take us over a ridge line thats gonna be obscured bec of a low ceiling, thats gonna be a big factor. but in general, dont consider weather very much, hard to plan ahead on. if were gonna do this mission tomorrow morning, we can guess about the weather, but we really dont know. the kinds of things a pilot needs to know, like fog, etc., is diff from a grd person, in a tank, for example, our stuff is much more variable, much less predictable. low visibility... well, maybe we could fly closer to a city, bec they cant see us so good. but the weather can change really fast, and all of a sudden youre out there in plain view. so in the planning stages, weather generally wont make that much diff. for us. it might have more impact on en, like rain is going to affect where tanks go, stuff like that. so it might effect our probable BPs. (night?) im not real experienced with goggles, bec your checkpts are gonna have to be different, bec some things are gonna be hard to identify at night. but not a big factor. air speed might be a little slower, bec you cant see as well. more danger of running into something. still avoid built-up areas. corridors, FARPs, all that stuff pretty much the same. more prominent checkpts is the major thing you would do different at night. (rivers?) i like rivers, bec they usually have river valleys, which give you good cover. in a hi threat area, i would not be caught flying down the middle of a river. rivers are used for travel, esp in 3rd world countries like Vietnam, and therefore are like highways. want to avoid them. also en will guard rivers, bec they expect you to come up there. so rivers are dangerous in hi threat conditions. but i like river valleys, if the danger isnt there. same as other kinds of valleys, maybe the lead is down along the river, the wings are out along the side, up higher along the trees. in a jungled area, the river gives you a place to set down, if you have mechanical problems. id rather swim than eat leaves.

(experience?) flying cobras since 84, maybe 500 cobra hrs.

(route considerations across the FEBA?) i like to hit them from the flank or the back. avoid all this built-up area. not nearly as important to avoid built-up areas during egress. so maybe come in this side, with less built-up area, and go out that side, which has more. if the best terrain for cover was near a built-up area, id choose to avoid the built-up area more than go for the cover. avoid built-up area by 3-4 klicks. cross here, drop down to the lo grd, stay with the lo grd, jump over this road here, stay on the edge of this marsh, skirting the high grd for cover, and then dash direct across this open area to this little draw, come around on the back side of this hi grd here. dont avoid going over this road, just dont parallel it. come thru this draw around to the hi grd. we might locate our FARP in this area, a good road to access it in there, set up off the road here. it would be nice for the FARP location to have someone recon the area, bec might be a perfect little field on the map, with a little road, wooded area, but open for aircraft. (FARP requires access by trucks?) in my unit, all FARPs are handled by trucks. doesnt have to be i suppose, could use helicopters, drop blivets of gas. but that requires coord with another unit, and i prefer doing as much in house as i can, have more control over things. its really easy for things to get confused, the times, locations, directions, etc. in house people give a little better service too, bec theyre part of whats going on. another unit is not going to take any risks on our behalf. they dont know us, dont have any loyalty to us.

i would avoid this town by coming around and staying on the back side of the hi grd. if that is a ridge line there, it may not be, it may be just a slope. come into our FARP.

then avoid all this area in here, bec it looks relatively flat. looks like swamp. gotta little bit of terrain here and here, but if this is their ave of app, theyre going to have observation out here ahead of their main body, so big risk of being detected there, more than if we came around and used this hi grd, come around into this lo grd, using this hi grd here for cover, skirt around the edge and then come in from this direction.

from the FLOT to the objective: it gets a little trickier. the book says NOE here, with bounding overwatch. (what do you say?) low and fast. speed is a real concern of mine. i want to get in and out as quickly as poss. #1, you gotta have the element of surprise. the more time they have to react to your threat, the less your chances for you to accomplish your mission. the more your chances of getting shot down. theyre like us, people have specific tasks to perform in a defensive situation, so if you give them time to get to their positions to do what theyre supposed to do, the more dangerous they are to you. the tradeoff is skill of flying. you can fly low and fast, you just have to be a damn good pilot. regular NOE, its pretty slow. too slow, in my opinion. im gonna come in, almost NOE, but full speed ahead. 15 feet above the deck, ok, i can go full out. its dangerous flying, but if you are trained well enuf, you can do it. have to know your helicopter like the back of your hand. right now its unacceptable, in battle drills, bec you cost too much, too many blade strikes, so you practice in a way that in fact you would never fight. they punish aggressiveness. tactics they teach today is good for the schoolhouse, but in a real war youre going to nick some trees. NOE, slow and in the cover, is useful for recon missions, movement to contact. but in an attack mission, just to bust up as many tanks as i can, i want to get in there without getting shot down, dont give them any reaction time. the second thing is that i want to put as much of my ordnance on the target that i can, so my primary concern is to get there in one piece and fire the target up. if im recon, want to go slow anyway, bec by definition you know less about whats there, dont want to come in full blast to something unexpected anyway.

i was taught to keep your aircraft spread out. your lead element is going a lot slower, doing a lot of sneakin and peakin, bec hes clearing the route for the rest of the element, who is covering him. the rear element need to be moving fast, esp toward the end, bec you have to tighten up again, but coming into this area, they need to be spread out. (a tradeoff between cover by NOE and speed?) not really. i think you can use almost all available cover without sacrificing speed, but there is risk. most pilots fly too high and too slow. in a war, theyre going to change quickly. in some areas, you have to expose yourself, you have no choice, and then you really want to move fast.

were doing economically acceptable tactics now, not survival tactics.

SME-5, Ft. Rucker, 3/9/88
rank: CW3
experience in route planning: considerable (3 on 3-pt scale)

the gunship pilots dont do a lot of route planning, the scouts do most of it. send three scouts up ahead, one is the air battle captain, and he would send one back to get the guns, and he would bring the guns up on line, shoot and leave, or reposition then shoot again. so the guns are really led around, may or may not know exactly where they are going to be taking you. briefings in the morning about where the en is, etc., can drastically change thru the day, and you may be out all day. misconception about the cobras, too, about when it can fight. e.g., it cant fight in the dark, not really.

(if youre given a route, how closely do you follow it?) within a km or two. try to stay in the vicinity. but the people who drew the route, they dont know whats really out there, and you may take a valley over. scout may be shot at, and so we stop and consider our options, may take a different route. but attack pilots have opinions, theyll argue about routes with the co comm and the scout, whoever. depends on the S3 how much input he allows from the pilots on route planning. these guys vary a lot, some like a lot of opinions, some dont think the pilots know shit.

(route planning?) METT-T pretty well sums up the major considerations. what's your mission, is it to attack people? first off, its a bad location to attack people. i would not want to conduct an attack in that valley, bec #1, youre in a forest, and the German forests have 70-100 ft trees in there, youre talking about down in the valley, around the bend, one little small clearing, small road, 2-lane hardtop. id like to be up on the ridge here and get them just south of Kaltzenbach, before they left this main road here, or wait until they get to the bottom. very diff to attack with cobras any type of target in here with our weapons. our TOWs wouldnt work in there. (move the EA back to a more suitable place) up here, at the intersection by Kalzerbach, theyd be coming out of the town here, theyre in the open, open fields all around. what time of day is it? need to know where the sun is, when you attack. is the sun behind you, in front of you. looking for backdrop, for good firing positions. standoff range for the TOWs is about 3750 m, you want about 3000 m, so i can come around here from Poppenreich, chances are that you are not going to be able to shoot over this altho, maybe, its about the same height as the town. or you can come up the valleys and shoot up, either this valley or from here, get up here and shoot this way. coming down that same valley, theres no roads there, you can get down in here and shoot from here, youve got some trees to shoot over, which would give you an edge. Or come around that area. you have to worry about that town down there but you can standoff from that town a little bit. that would leave you a lot more options. here, in the valley, you have no options. (how many BPs would be set up?) 2 or 3, i would want to choose from. bec as youre going in you can look at the map, one may not be any good, and then you can move on to the next. you plan BPs but when you get there it may not be like you expect, or maybe the en is not where you expect, have to adjust.

(route from AA to BP) problem is, probably have to come off this map, come around here a little, to get up into this area below Katzenbach. id prob come down here, theres a major gorge here. this one here might be covered somewhat, bec youre across the FEBA. this valley here would prob be covered, but then again, youve got very, very tall trees, so if theyre up on this ridge here, they cant see you down in the valley. they can hear you, but they cant see you. but they have missiles available, so just come 3 klicks over here up this valley. this is a very steep valley here, come around this way. that leaves you plenty of room, so theyre not going to get you. i would try to work my way down. if youre starting from here, you come out and move across into the wooded areas and valleys for protection, so you can stay down below radar. youre trying to sneak in, surprise them. plus if you come down thru this gorge here, youre far enuf away, even if they saw you coming with radar or something, theyre not exactly sure youre going to come around here and come into them. so basically you want to fly around and flank them. id come down over here, cross over the river, theres nowhere along the river, esp in germany, that youre going to be totally away from folks, so come down like this, across this area. trying to avoid some of the built-up area. (highways?) dont want to follow the highways, unless its your mission to check them, keep the highways open. the en might have broken thru, and if they did, they would be on the roads. if its winter, youre going to have to stick to the roads a little more closely, unless the snow is packed enuf, the grd is frozen, then you can go anywhere. if snow is not frozen, you sink out of sight if you try to land. need a good 6-8 inches froze to land your helo. so, time of year makes a difference in route planning. (weather?) visibility, i can get closer to things. the commanders are going to be very interested in the main roads, like the autobahns and the bridges along the autobahns, so the en is going to have people up there watching them. they will be much less interested in this valley over here.

avoid populations, bec likely place for en observers. altho there could be a guy on one of the hilltops, counting helos as they go by. we do the same.

(snow?) stay closer to road. obscures a lot of things, obscures checkpts and stuff like that, esp if you dont know the area very well. the more familiar you are with an area, the better youre going to operate. that goes double when theres snow on the grd. you can get lost really easy in limited visibility, fog, low ceilings, haze, snowing. the person in the lead aircraft has to be knowledgeable and competent in map reading. bec you can make a mistake in peacetime and overfly something. like using the autobahn, in bad weather, i know thats here, to my north, well, if i bump into it, i can find myself. major checkpts, like rivers, ok, i hit the river, i can confirm where im at. in bad weather, you may not see the hill here, in the center of the valley. ordinarily they would be good navigation pts, they stand out. the roads in the fields out there, they all look the same, the villages all look the same. unless youre very familiar with the area.

(if you know youre going to use a certain route, do you get one of the scouts to go out to recon the route, become familiar with it?) if you can send someone out one or two days ahead, to scout the area, its great. most of the time you dont have it. (then experience counts, right? you know better than most pilots what the map terrain is going to look like in snow, right?) yes. map reading is a real skill, takes a long time to learn. a seasoning effect, cant hurry it, do it over and over, in all different conditions.

back to weather effects: pressure, temperature, altitude; winds, where are the winds at, how strong. hover power, hover capabilities are determined by pressure, temp, alt. higher the altitude, the less able we are to hover. temperature, correlated with time of day. its a consideration, to take just enuf fuel so that given what you burn off going down there, youre able to hover when you get there. when you shoot, you lessen weight even more. depends on terrain at BP, too. in hills, want to hover-fire. but in deserts, never hover, bec throws up a big dust signature. use running fire. in Europe, you can hover fire. hover fire is stationary fire. running fire, always move fast enuf so theres no dust raised on the grd, so no one can see across the desert floor. can run in a circle, and as you come out of the circle, or its more like an oblong, do your firing, then move out of the way, and the guy in back of you comes in and fires. (running fire, is it accurate?) some of your weapons are more accurate that way. TOW, you fly at the target, control that way. its been controversial. the problem with the TOW is that it drops a very fine wire, its guidance wire. it kicks out all its wire almost immediately, its very rapid. two schools of thot on this: from the aircraft out, youve got 3750 m max. problem is that when the TOW comes out of the aircraft, it drops a little, then comes back up, and as it flies along, the propellent is used up very rapidly. so later its flying on aerodynamics totally, theres nothing to push it. after a very short time. and the tail begins to drop, and the nose comes up, the further out it is. by 3750 m, nose is up, and esp on tank fronts, slanted up, target at an angle, will bounce off. when you fire it, the wire is one of the limiting factors. if youre moving say at 80 knots when you fire, can you shoot more than 3750 m? will the wire drop down, or fly out toward the target like the missile? when you fire from hover, the missile starts at zero airspeed. should be able to shoot much farther than 3750 m, maybe 5000 m. nobody has ever tested this bec they dont consider the TOW to be a running fire weapon. doctrine is you shoot it from a hover. the 2.75 rockets are much better when youre running, but then again, you have factors that enter into the acc of the weapons that we dont teach our young pilots. we dont teach them running fire. the emphasis is on stationary fire. we did all our firing in Vietnam while running, but theyve declared that mentality as obsolete. that was a lo intensity battlefield, everything we did there wont work in a hi intensity battlefield, as when the soviets attack in Europe. dont allow for another lo intensity war again, which strikes me as very likely, look at S. America.

(route planning: youre thinking a lot about the BP and whats going to be happening there; youre thinking about whats going to happen at the end of the route, and using that to guide some of your decisions about route planning up in the beginning) you have to look at the overall situation. whats the mission? my mission is to come here and shoot, so you have to do backwards planning. if ive gotta get here and i wanna shoot when i get there, what do i have to do to get there? what are the capabilities i have to have to perform the mission. i gotta have the fuel to do this, i gotta have the bullets. i have to be able to get there without getting shot down. tradeoffs galore: fuel and bullets. time of day has a lot to do with it. weather. important at the BP but also for route planning. e.g., weather may be quite different at BP and at pts along the route. to shoot a TOW, i need good visibility. so it can be poor vis along the route, but when i get there, i gotta have good vis.

(tell me about station time) i gotta figure out how much fuel do i need to get to BP, where im at now, where i need to go to shoot effectively. i need to shoot from here, or here, or here, give myself some choices. need then to find a route from pt A to pt B, and back, from pt B to pt A. that will tell me how much fuel i need to get there and back. then, how much time do i need on station? i may have to tell the commander that, well, i can get there and i can be on target for 10-15 min to shoot, chances are that you wont want much more than that, bec theyre going to figure out where you are real quick, but youre going to have to set up a refueling pt about halfway back to pt A, bec i cant make it all the way back. or refuel me in Weisenbach, here, set up a forward pt here, then how much fuel will i need to complete that mission. (do you typically have one time on target, or do you cycle around for several times on target?) problem is that when you shoot, you have to move to shoot again, else youre dead, theyll just wait for you to pop up in the same place. (arent you out of range of their weapons?) they can lob in high explosives, or call in arty.

in our exercises at Ft Hood, the most effective weapon against us was the individual soldier on a motorcycle. very mobile, good speed, could just sit there and wait and not be seen. put a soldier under a tree with a RPG. if you hover next to him, youre gone, he can knock you right out of the air. also hard to spot even after he shoots, bec he usually kills the only guy who is in a good position to see him. (is this a consideration in route planning?) you do consider it, worry about it, but you cant change your route much on this basis. (are you an expert in figuring out likely spots for these guys, from your 22 years experience?) better areas for ambush include confined spaces, like narrow canyons, function like chokepts; down next to the river, its also hard to manuever there; sudden clearings; places that have good access, trails or roads that lead there. may want to stop and hover and look for a second before you go on, in likely areas. hope that your scouts will pick them up, hopefully without them getting hurt. its kinda a feeling you have about areas, like this place doesnt look good to me; dont always know why.

(is setting up the FARP part of the route-planning process?) it may be. in this particular mission, i would say yes. how deep am i going? am i going to use 3/4 of my fuel getting there and shooting them up, with only 1/4 for the return? *if so, got to refuel* on the way back. this is what we talk to the S3 about. where we put the FARP depends on the route we select. European thinking is to set it up in or near a town, cant be detected with IR from a sattelite or whatever, altho Americans tend not to like to set up near towns. Europeans think this is dumb, and so do i.

(why do you have a diff egress route?) bec theyre gonna be set up waiting for your return, if you use the same route out. (with 3 companies rotating, all use the same ingress route; isnt that the same problem?) you have to come back to whats the target? what kind of security do you have on the grd? may indeed have to use 3 diff routes in, for the 3 companies. but then, the target may not allow that. and the comm says, its a risk, but its worth the risk. its a tradeoff.

going in, not moving very fast, but have your arms. going out you can move a lot faster. (tradeoff between speed and security, coming in?) mainly, you want to sneak up on the target. the more time, the more the chance that theyll be ready, youll lose your surprise, so speed is not unimportant, but more important to stay out of sight. also you have to remember that, if the target is shut down, just sitting there, they can hear the helos coming. dont know the direction theyre coming from, but you know theyre coming. if the tanks are running, tho, you cant even hear the helos. their tanks are noisier than ours. another factor to consider. theyre going to have scouts out tho, so complete surprise is hard to achieve. even if their scouts do spot you, tho, you have to ask how close you are, they might not have time to react very much.

one important factor is you want to attack them while they are moving. when they stop, theyre very hard to see. in forested areas, they can scoot into the treeline, and then forget it, theyre invisible. on the desert, if they stop, theyre damn near invis.

in conventional war, theyre going to have their scouts out. thats one reason you dont want to come straight in at them, bec its too easy for them to figure out what youre after. also flank is better for vulnerability, its the only way to kill a tank. front of the tank is very small target, heavy armor, and slanted up. TOW comes in nose up and just glances off.

in Europe, 1/3 of the TOWs would not shoot, would not function. so you have to figure one dud out of every three shots.

(how many TOWs can you carry?) i think 4. they carry racks for 8, but can you carry 8? no. not unless you have no rockets, no 20 mm, and very little fuel. can you go out to a BP and shoot 8 TOWs? by doctrine, no, you cant. you have to change FP each time, to shoot. impossible to have 5 x 8 = 40 distinct FPs in an area. not so much the fuel or the weight, you just cant shoot 8 TOWs from one BP. consider how long you have to be up to shoot a single TOW. TOW in flight at max distance is 27 seconds, have to find the target, lock it in your sights, get the missile off, then guide it enroute. cant maneuver around much while up bec too close to other helos in their neighboring FPs. 200 ft apart, in a row. also after first few rounds, en takes cover, and theres smoke all over, vis is not very good, just not a good target environment. so even not thinking about the other things, chances are that you couldnt fire more than 4 TOWs effectively anyway. just unnecessary weight, in my opinion to take more than 4.

rockets are an area suppression weapon, its not accurate at all. will not hurt a tank, just makes them button up. 20 mm also works for suppression, but can shoot a rocket from way out there, 20 mm you have to be a lot closer. rockets have a big bang. two sizes of rocket pods, 9 shots and 18 shots, x2, or 18 or 36, if you carry a full load. im looking at how far i have to go, how much fuel i need to get there, which leaves x lbs for bullets. id say 1300 lbs of fuel to do this mission, for example, that will give me 10-15 minutes station time. thats without holding, without sitting down somewhere, just straight mission. gotta get there, gotta get back, need 10-15 station time. ok, how many lbs of bullets? im going out to shoot tanks, i need 4 TOWS. anything left over, ill put on rockets and turret ammo. i may not have any surplus to work with. so another decision, should i go there overweight? if i do, can i shoot down here at a hover? you can figure that out fairly accurately from your charts.

rockets can be shot 1 at a time, 2 at a time, multiples up to the total. not very effective that way. just point them and hope for the best. sight is a Korean war vintage air force reject. M73 sights. in the fully modernized cobras, they have a computerized sight called a HUD, integrated rocket management system. M73 sights were so inaccurate that alot of units took them off, bec they didnt help. werent any more acc than a bug spot on the window. in Vietnam, wed use a grease pencil and make an X on the windshield, and it worked quite well. bec you were firing rockets all the time. and theres techniques you have to use to shoot rockets accurately. practice, experience.

SME-6, Ft. Rucker, 3/10/88
rank: CW2
experience in route planning: moderate (2 on 3-pt scale)

first, you need to know your BPs, which should be around here. bec to come down from the north, youre going to be too exposed. too much built-up area to cross. one of the considerations of a good BP is that you have a good entry, and a good way out, and those are basically route-type considerations. once you put a signature up, everybody and their brother is going to be firing up that way. the BP will be from the 67 grid line to 63, and 64 to 67, taking in about a 6x2 klick area. within the BP, there will be FPs. (predetermined?) usually the scout will recon the site down to the BP, and on the map you look for good FPs, im going to have the sun to my back, in the evening. if were up here looking down, its going to be by my side either way, a bigger glint on the canopy of the cobra. (sun?) engagement is easier in the morning with the sun coming up over your head, to the rear of you, or in the evening when its setting behind you. its better to be perpendicular to it. less shadow, less glint. and the skinniest profile of the cobra is its frontal view. you want the sun right behind you. if its to your side, or youre gonna be facing it, you get more canopy, the glints a lot easier to pick up. also its a lot harder to navigate, esp in a desert environment, if youve got to go into the sun, or if its flanking you. its harder to pick out the terrain, bec of the shadows on the rocks, etc. is it rock or shadow? these BPs would be best in the evening, bec the sun would be setting in the west. the best morning BPs would be on the other side, off this map. also want en to be looking into the sun, definitely obstructs their vision. they cant pick you up on the horizon. so 3 factors with sun: want it on your back to avoid reflections, to make it hard for them to see, and so its easier for you to navigate.

(if the weather is bad?) clearly sun, time of day, etc, has much less weight. in a desert scenario, overcast skies are very rare. in a European scenario, overcast skies occur a lot more.

(would the availability of a good holding area be a factor in the choice of BP?) you can almost always find something suitable, so its rarely an important consideration. if you cant sit directly on the grd, to conserve fuel, you could just go to an area and hover, if you had to. often you could even go in without a holding area at all.

(you have a BP; what do you think about next?) where the air corridor is. where theyve established it might not be where you need to cross. if they havent already established it, you can have your liason officer link up with the arty, and its possible you can set your own corridor. tell them what you need open. usually its briefed down to us what is open. do your plan from that. the purpose of the air corridor is to keep friendly air defense arty (ADA) from shooting you down, esp crossing the FEBA, obviously theres gonna be ADA on the FEBA. they just open the corridor for a few minutes, and they give you a particular time you have to meet, its a major element in planning, bec if you go into the corridor at the wrong time, well, if it flies it dies. if they have weapons free, which they would have. normally. they have a real problem with Stinger gunners, they cant distinguish friend and foe aircraft. were supposed to be up on our transponder, squawking the proper code. but if someones jamming, youd be jammed right out of that. he interrogates your code, and if its not right, even though youre in the corridor, hes going to interrogate with the weapon. at NTC, most of the time we got shot down by our own Stinger gunners. about 50 %. maybe boredom out there. but friendly ada is the major concern of most pilots. (width?) 1-2 klicks wide, usually theyll draw you a line and you have to stay within a klick, 500 m either way. and time window is usually an entry time, plus or minus 5 minutes.

one problem is that en likes to wait for these corridors to be set up, and then use them themselves, coming over to our side. try to set them up on secure radio, of course, but its pretty clear that if 6-12 cobras come thru and nobody shoots at them, you know whats going on. usually they pick you up coming back, just pick up and trail you thru the corridor.

i know what doctrine is about return corridors, that they should be different from the crossing corridors, but in my experience, they are almost always the same. dangerous.

they also give you a direction and azimuth to cross the feba. eg 90° and 270°, pretty much narrowed down to what you can do. so you can use a slightly different route, even tho its in the same corridor.

(what are your route planning goals once you cross the FEBA?) avoid the little guy with the SA7 or the newer SA14. want a terrain feature on both sides of me, i esp look for hi pts that are likely spots for these guys, on the map, and then i try to put a terrain feature between me and the spot. once you cross the feba, im going to look for the highest pt on the map, or i might have already been briefed abt where en ada is, so im going to put a terrain between that location and myself. the 23-4s and the 57, they like to pull up on the highest spot. and look around. like this spot here, theyd have a 360° shot, 3000 m. 23-4s are usually deployed forward (of, with?) the main battle group. in a regiment, will have 8 of these, running in pairs. spread across 7-10 klick area, pretty wide sector, they could be anywhere in a 10-15 klick area, so bad if you have no intell on them. dont know where they will pop up.

(other threats?) well, have to stay out of the range of tanks, of course. get to your standoff range. in europe, they cant get thru forests, too tight, so theyll be along tree lines and the roads. in desert, always, avoid any built-up towns, bec too easy for them to hide, back up against the buildings and stuff. in desert, stick with rougher terrain, get the most vertical route i can find, wont be tanks up there, no 23-4s, etc. even the 7s and 14s cant crawl around on the rocks much. also in desert, theyll run in the waddies, down in the washouts, cant see them at all. they can hear you coming, but they cant tell where you are. fly right over them, but we can turn around faster, put 20 mm on them, make them button up. can get down to within 2-3 ft of the ground, get away before they can shoot me. what helps us in desert scenarios is the speed we can move away from them. higher speed closer to ground. at hi speeds, dont leave much of a dust trail. if you stay in the shadow of the side of a hill, theyre not going to be able to see you.

(length of corridor?) they could say that the feba's 4-5 klicks thick, average 2-4 klicks in length.

(steps: pick BP, determine air corridor across feba...what next?) id just look at the overall terrain, start at the BP and work my way back to the assem area. easier to change stuff on our side than across the feba. terrain, i want to stick to the hi terrain, just off the crest, the military crest. military crest is down from the geographical top of the mtn or ridge, so if i need to engage on the side im on, i can see down to the low grd, if someone shoots at me, i can hop over to the other side. military crest is where you are no longer skylighted. travel thru the corridor, dont have much choice of terrain. past the feba, go back to my method. (NOE?) yes, id be flying NOE. NOE flying at the military crest. in an attack aircraft, people say, NOE, 40 knots or slower, down in the trees, but in fact, we fly NOE and we fly as fast as we possibly can. we want to get there as quick as possible, drop whatever we have, get back, bec the fuel consumption is so much higher with your weapons on board. in combat, youre going to have to be right on the trees, 100-120 knots. you have to be on the ball. there isnt going to be any other way to get there. (why up on the crest?) if anyone has infiltrated thru the feba, they see a line of copters moving at 40 knots across the trees, easy to spot. and predict. thats about as good as it can get for a SA7 gunner sitting up there on the hillside.

NOE, if you dont come back with branches hanging off your skids, then you were too high. if someone can see you -- given the weapon systems they have now -- youre gonna die.

a lot of people dont like what im saying, bec of the safety aspect of it. but im worried bec they dont train this way, and if they fly slow and low in combact, theyre dead meat. there isnt going to be any time for mistakes, cant rely on instruments, its gonna be seat of the pants, or nothing. cant be looking at instruments to check my torque when im rolling around trying to avoid something. have to have a good sense of your machine. the SA14s they got now, theyve extended another 2 klicks out to 4-6K.

(across the feba) find the hi grd. not going to go that way, bec of the town. veg is going to thin out too. another town here, two more towns here. id try to find whatever hi grd there is and then fly in from that. if theres a tank unit here, theres gonna be people over here also. hi grd is possible ada or at least observation. hi grd means potential exposure to fire and/or observation. keep terrain between you and hi grd. this is a bad spot here, bec you have to cross this swamp, flat grd. two towns here. a town up here. your only option here is to come like this and around.

(avoid populated areas?) yes. soviets like to hang out there. got water and food there, etc. less hassle in logistics. easier for them to hole up there. exposure to observation at least, scouts or spies.

(friendly arty on prominent hi points?) yes. but they arent very accurate. and single soldier with missiles, arty not effective. even with preplotted arty, dont count on it. nice to have, and even me, i can fire indirect over there with my rockets, if i dont get preplotted arty. if its within 10 klicks, i can put rounds on it. so im not as concerned about it as the scout is.

(other concerns?) crossing roads, dont want to cross where they can see you. avoid straight stretches, 2-3 klicks, try to take the road at a curve. least amt of exposure.

(compare book learning with field experience) book learning ok, but have to have real experience. even the field exercises are so canned, dont get good training. they give me a map, i jump in my cobra, i follow the cobra in front of me until we get to where were going. thats the training. if you can regurgitate your METT-T and all that stuff, they love your ass. i think they should teach more infantry tactics. tactics on the grd and in the air, theyre pretty much the same. and infantry teaches better tactics. **if you dont have a basic understanding of the ground battle, youre not going to survive in the air.**

(crossing roads effectively) if the stretch is straight, you look for a spur or something, to give you some cover thru there. the reason again, is to avoid exposure. avoid detection. theyll have their recon elements deployed, 8-10 klicks ahead of them, so theyll be out here, looking for you. theyll have a tank company with them. another thing to avoid is open fields. also worry about wires in the area. away from built-up areas, not so much a problem, but close to towns, a problem. of course, 90% of the wires on a map are not there in reality. and wires turn up in real life where you least expect them. in Germany they run lines from hilltop to hilltop, and we can fly under them. in US, closer to grd, present problems, have to fly over them.

(combine the various factors?) have to take in everything, give up one thing to satisfy two or three other things. try to determine the best outcome overall. if i knew there was an open field right there, but there was a hill, i could get over there easier than coming up here, i would go up there, skirt the edge of the field, rather than flying over it.

id cross here, one way in, one way out. cross over at 660627 and cross back at 623662.

(on the friendly side of the feba) still going to look at the terrain there, see what i have. esp close to the feba. look at all the hi terrain there bec en is going to have people observing across the feba, and SA7 gunners. similar to across the feba. worry about the spudniks. soviet version of the special forces. cross the feba, not ada type stuff, threat only in terms of observation. if they see a HA or a FARP close to the feba, 5 minutes later, that grid square will not exist.

(FARP) if you want to go heavy, then the farp has to be closer. bec you cant take as much fuel. were talking, in the desert, 600-800 lbs of gas, which gives you 10-15 minutes station time, to get rid of everything you have. 4-8 TOWs, usually 4-6 TOWs, with the heavy team, the light team may have 1-2 TOWs, will be heavy on rockets. In the desert environment, youre going to have a big tradeoff, bec the PA is a lot higher, the heat and everything. PA is pressure-altitutude density, youve already cut the amt of power your aircraft can hover with by 20 % or so, so thats less weight you can put on the aircraft already. thats like saying that theres already an imaginary 2000 lbs. so youre looking at less gas. but a person with 4 TOWs and 20 mm, youre talking 800 lbs of gas, 5-10 min to move up to your area, another 10 min to shoot and get home. obviously gonna need a jump FARP right before you go across the feba.

jump FARP can be supplied by a cargo helo, which can drop a fuel blivet, but usually Hammocks, an 8-wheeled truck, pull that up there and supply you on the edge of a field somewhere. jump FARP means a mobile FARP, gas you once and then move on to another spot. be there maybe 30-40 minutes, so you can return to him on the way out.

maybe can rotate 3 companies, but usually only on the first sortie of the day. when the first company comes back with only one guy alive, the plan is going to change pretty quick. have to plan on worst case scenario.

(how do you set up the FARP?) usually theyll give us maybe 4 locations, 4 sets of grid coords. might be someone at all 4, or they might say that this hour its gonna be here, two hours later its gonna be here, but usually pilots dont have much say in the location. theres a lt in charge of the FARP section, and its his job to go out and set them up. he has to know the mission, where were going, etc. when we get the warning order, he knows the air corridor is here, and that were going over here. (does he need to know your route?) even if hes 5-6 klicks off my route, makes no difference, so he doesnt need to be on my route, in fact, i dont want him on my route.

(how far is the FARP from the FEBA?) in places like the desert, the feba moves so fast that the farp is gonna end up on the wrong side, so that farps out of business. thats another wrench that gets thrown in this business. farp might be there, attack air might see it and kill it, youre coming out here and youve got 10 min of fuel and theres no farp, so you have to straight line it to someplace you can get gas. when the battle starts rolling, thats usually what happens. the farps are out of business in about 10-20 min, just as soon as theyre set up. once the battle front starts moving. so you cant count on them. like to have more fuel, therefore. usually a gun that finds the farp gone, the scout stays on station, damage assessing. scout has 2-3 hrs of gas, bec has no weapons. with our ammo on board, we have only 30-40 min fuel, max. even the apache has problems, no helo in the world you can put a full tank of gas on, in the desert. soviets have problems, too. very heavy aircraft. hard to manuever.

(how do you route plan if your farp has been destroyed?) im gonna whip out the map and, this is off the top of your head, youve got the map and youre looking at it and flying at the same time. max protection for the straightest line. get there as fast as you can with the least amt of exposure.

(normally, how far back of the feba is the farp?) it varies. could be 10 klicks. feba can move pretty quickly. this part of feba can move, this part stays the same. usually try to get 10-15 klicks, 10 klicks back. that would be the furthest you would want it, bec otherwise you arent going to be able to make it back and forth in cross-feba operations. if you were just coming to engage on the feba, then the farp would be further back, maybe 20 klicks. stationary farp in the rear, a jump farp within 10 klicks of where youre actually fighting. if youre going out there to kill tanks, you have to have something close (like a farp within 10 klicks of BP). bec youre not going to able to keep the tempo of the battle.

if im trying to get out of there, to a new farp further back, then im concerned about putting terrain between me and the feba. thats my primary consideration. once im out of their range (feba), im gonna pick a straight line and go. out of range = 3-4 klicks. if you can put a hill between you and the feba, you can go straight immediately.

(route planning far from feba) still look at terrain. still going to avoid flying thru towns and stuff. fly pretty much the same as close to feba. obviously up here im gonna plot the friendly units, im not gonna overfly friendly units. if i can help it. NOE, but at a much higher speed. no bounding overwatch. takes too much fuel. one guy moves, the other guy covers. we get into a staggered formation. (do you do bounding overwatch across the feba?) not particularly, along as we, once we cross into the area, and the scout might hold us, the battle captain, he might tell you to come up to BP, at that time, the majority of guys are not going to poke back and forth, theyre going to get in a staggered formation, and get up there as fast as they can. bec usually in battle, the tanks are rolling, and if im over here, bounding overwatch is going to take us 20 min to get over there, and we dont have the fuel to do it. you just have to get on top of the trees or the sand or whatever youre in, and just go. (do you fly a little higher farther away from the feba?) not really. still got friendly guys back there that will shoot you down just as easily as the bad guys up here do. just a fact of life. the first time an infantry company gets shot by a helo, the next one that comes by is gonna get shot by them. esp in the modern battlefield, where you have an air assault unit in there, using helos to lift people, theres gonna be helos all over the place. easier to stay on top of the trees, in a scenario like this, the airspace we own is like a 100 feet and down. the air force has everything else, thats the way they brief us. dont want to mix it up with F4s and stuff. easier to stay on the trees and mind your own business.

(why avoid populations, cities, and friendly forces?) easier to stay away from this stuff. might get shot down, might run into lotsa traffic (helos), just easier to stay away and get going to where you want to go. other helos might be on another frequency, or theyre jabbering and dont hear you. time and distance is a consideration, of course. dont want to go way out of your way. avoid them if possible. like the villages and towns, youve got towers and wires, easier just to stay away from them, one less thing to worry about hitting. cities also have spies, etc.

(coordination in navigation; do you think abt the quality of checkpts?) you have to have checkpts, left and right limits, so when you draw your route, you should make it almost like a corridor. a route with good checkpts is a better route than one that just goes across the flat plain out there, just makes your job easier. not a major consideration tho.

(travel time?) fuel considerations. all in your reverse planning. thats where youre going to start saying, i can only take 4 TOWs, id really like to take 6, so start looking for a more direct route, and what do we have to do to get there. if ive got to cross this open field, im not gonna do it, im gonna carry two less tows, bec youre leading in to the feba with an open area, which is your worst case. (the more travel time, the less station time?) if you cant get a jump farp up there.

(night?) id rather fly goggles into a battle area than to attack at morning. thats your ideal situation, is to fly up to an assembly area in the middle of the night, jump up to the jump farp, refuel, right at daylight come cruising in on them. best case. night, dont have to worry so much about cover and sticking exactly to the hi grd, but then again, to navigate with goggles its a lot easier to navigate across the hills than it is out in the flat area. to me, thats why sticking to the hi grd, whether its night or day, im better off. might need somewhat better checkpts at night, for navigation. in this map area, i dont think it would be a problem, has a lot of terrain for nav. with goggles, i wouldnt worry much abt checkpts. unaided, need good checkpts.

SME-7, Ft. Rucker, 3/10/88
rank: CW2
experience in route planning: moderate (2 on 3-pt scale)

(first step in route planning?) define end pts. we have the begin pt, need the end pt. thats the BP. my concerns would be the acess in and out of, its all hardball rds, en will be sending patrols out there, lots of rds out here. all flat area, with some towns. of course, when youre sneaking around, you want to stay away from towns and built-up areas, bec if you have any en patrols or anything like that, they may pick up on you. now if youre hovering around up in here somewhere, theres a chance. this is the engagement area. this is the BP?

depending on the terrain here and how high it is, you could kinda come in front of the face of the hill and kinda mask yourself, toward the east you dont have much to hide behind, pretty much flat land. i suppose as it is, its as good as any. (BPs) (what are the route planning considerations from the BP?) need good ingress, egress, without being seen. when everything starts, theyre going to know that youre there, so the best egress is a route thats most direct, you can get out fast, still staying away from populated areas, or roads. (sun position?) thats a consideration. when do you plan on attacking? morning or evening. flying into the sun, or away from the sun. you want the sun behind you instead of in front of you. the BPs here, are ok for an afternoon attack, but for a morning attack, would be bad. if you had the sun to your back, and say you were a little down from the ridge of the hill, youd blend in pretty well with the foliage. but then if it was morning, the sun to your face, it would highlight you against the hillside. plus youre flying and firing into the sun. not good.

(you have start pt, and BP; whats the next step?) coordination with other units around, ADA units, free-fire zones, passage pts. friendly ada. making sure that your routes dont conflict with their fire zones, and if they do, you have to coord with them to open up those holes there so that you can get in and out at your designated times. if it doesnt conflict with their fire zones, you dont have to worry about corridors. if it does, then you have to coord, where and when. set up corridors. in this scenario, its likely that youll have to set up corridors. crossing the feba in the vicinity of the en movement. so our ada is going to have sectors that theyre watching. (what is the friendly ada?) individuals with Stingers. people with Vulcans, 20 mm cannons. you have to worry about the friendly ada, the guy with the Stinger, he sees a helo, he says well lets see how this thing works, and he shoots you down. hopefully everything works right, your transponder, and theyre interrogating you, and your transponder is sending them back a good signal, so theyre not going to fire at you. but lines get crossed sometimes. transponder is a device that gets interrogated, and it sends back a signal. youre not active in this process. before you leave you set it in the proper code. if it fails, they shoot you.

(describe typical corridors) depends on the coords you make with the grd units. usually it will be done thru the S2. the plan is going to come down to the pilot. corridor length depends on how much space theyre watching. width is typically 500 m on each side of a line, up to 1 klick. depends on the number of aircraft. time constraints are, say, from 0100 to 0110. time window is based on the time they want you to hit the objective and then it all backs up from there. theyll give you the coords of the corridor, and then theyll say, theyre expecting you there at such and such a time.

(do you need a corridor out as well as in?) depends on whether friendly ada or arty is covering the area youre coming out of.

S2 typically coords with both friendly ada and friendly arty.

(why do you take a different route out?) just on the chance that an en patrol spotted you on the way in, theyd be waiting for you to come back out the same way. (if you had 3 companies rotating, would they each need their own corridors in and out?) assuming that the area youre flying from is safe, from AA to the FLOT, can use the same route. after that each company may have their own route. once you passed your friendly ada, you have to start thinking about different routes.

(route planning, continue) you got your start pt, you got your finish pt. do your route planning first, then see if you need to coord with ada and arty. if you need to, then do it.

depends on time of day, flying into or away from the sun, type of terrain, is it flat or hilly, do you have cover going in and coming out. keep below ridge lines. (is this the route planning down by the BP?) yes, i would plan going into the area, then plan an exit, then last the safe part, behind the feba. assume were flying in the afternoon and the suns behind us. a whole laundry list of things to consider. time and terrain, the troops youre going to working against, and of course you get your intell, see what their setup is, do they have dismounted infantry along the ridge lines? are they moving? in Korea, that was the big thing, the ridges would be full of infantry. youd be looking where you think the en might be, are they sticking to the roads and the valleys, or any little valleys running off of the main valley where they may be moving, where they might have a platoon or something.

concerned about dismounted infantry bec of SA7s, or simply small arms. cant spot them. route planning consideration, bec if you know theyre in the ridge line, you have to avoid that ridge line. thats the purpose of the scouts and also NOE, so hopefully you spot them before they spot you. you cant really avoid their places. you would say that theres a place they might be, thats where i would sit. youre just more wary around such places, but it doesnt affect your route planning very much. if you have confirmed reports that theyre there, then you stay away from those places. might call in arty on those places. but of course arty lets them know that somethings coming, somethings happening, so may alert them more than disrupt them. esp if youre trying to sneak in there. (smoke? can you use it to your advantage?) it may be a detriment in some cases, inhibits your laser range finders and stuff, like with the 64s, were trying to designate targets with our lasers. laser may not work. and with wind shifts and stuff, you may end up in the smoke. i dont like smoke, not up close, i dont think it would do us much good. better just to get down there, sneaking around, taking it slow. smoke wont help much to mask a helo. no thermal viewers on the cobra, i dont know about the apache, i think it has FLIR. night vision stuff is thermal, i think.

so, get the routes in and out, work backwards from the objective. keep the route simple. less to remember, less chance for error. when things start going bad, they start going bad fast. easy, good nav points. something simple, like hill masses, valleys, distinctive land masses, stay away from built-up areas with people. choose these distinctive nav pts from map analysis, use them as checkpts. depending on the time of the mission, as we discussed before, keeping the sun behind, esp try not to fly into the sun. if youre in a flat sandy area, use different techniques than if youre in a hilly area. less cover in the first. like on this map, theres lots of stuff to sneak around, to hide behind, good cover and concealment. in a flat desert situation, not much cover to hide behind, may have to attack in a simple straight line, just pop straight up to attack and then go down low again to get out of there. fast and low, pop up to acquire target. the goal is to stay as low as you can without creating much of a signature, 15-20' off the grd. if the en is moving on the desert, they create a heck of a dust cloud, so you know where they are. pop up at 2500m - 3000m, get some rounds off, then back down and get out. hilly land, you can fire, go down, move a little, pop up again, shoot again. flat land, no, basically just run and fire tactics. shoot on the run. not diving fire, tho. too dangerous, with their ada and stuff.

(night mission; differences in route planning?) nvg mission, well, wouldnt have to worry about the sun, but might have to worry about the moon, dont want to fly into a full moon. stay away from built-up areas, stick to easy routes, good nav pts, its more important at night. need something simple. stay away from cities, bec goggles are sensitive to light. goggles kinda shut down, dim down, dont work as well. magnify starlight a thousand times, so car lights, x 1000, too bright, just shuts down. i dont like nvg flights much, but the goggles are better than unaided vision.

(winter?) work over snow? how does it affect the terrain, or the look of the terrain. also have to worry about your rotor wash, might give you away. kinda like being in the desert, where you hover and start kicking up sand.

keep it simple, bec its always gonna change, when you get there and see the real terrain.

stay away from populated areas, staying away from the ridge tops, to avoid silhouetting, stay right below the ridges, high along the military crest. depends on how high the ridge is, of course. may not want to be down in the valley, maybe halfway up between the valley and the ridge. that way i have a better view of the valley, whats coming up or down the valley, plus the fact that i can use the veg of the ridge area to kinda mask myself. (NOE?) yes. right on top of the trees, halfway up the ridge line. or just below the crest. it gives me a better out, if something happens. if im down in the valley, just above the river, and i have to look up for en, or i might meet the en, eye to eye. what do i have to do to get out of there? have to climb up over the ridge, turn around and go back, or just keep going forward. but if im halfway up the ridge, im looking down on them. if i had to get out, i could build up speed by descending. also i could pop over the ridge, and its better to go over half than to start all the way at the bottom of the valley.

(route out, any difference in criteria?) yes. more concerned about speed on the way out. going in, youre sneaking in, want to be quiet and not noticed. after your attack, of course, everyone knows youre there, so sneaking has no meaning. still might be NOE, for cover, but speed is more important than going in. more of a straight line, a more direct route out.

(route from AA to FEBA; what are the considerations there, are they diff from route in and route out?) youre in a more secure area, you could use this road for example. follow the road. start with traveling, then traveling overwatch. could start at a couple hundred feet or so, max speed, then drop down to contour, with traveling overwatch. dont need to get below the ridge lines yet. kinda at the tops. at the feba, go NOE with bounding overwatch. getting out, NOE for protection, but no reason for bounding overwatch. technically not NOE bec youd be going faster than the definition for NOE, which is maybe 20 knots or so.

another consideration is any kind of obstacles you might encounter on the route, esp when youre NOE. like transmission lines that might get in your way.

(how does the FARP enter into your route considerations?) someone else designates where it is. you may have to hit the FARP on the way down, gas up, maybe armed up, too. so you really have to plan the route in legs, AA to farp, farp to BP, and maybe (in a relief on station rotation) BP back to farp again. most of the time the whole thing is given to you, the route, the farp, the whole thing. cant plan routes around farps, bec they move so often. the farp is there to support the aircraft anyway, so the farp is planned around your mission, not the other way around; you dont plan your route around the farp, the farp is put conveniently for your route. its gonna be where you need it.

SME-8, Ft. Rucker, 3/11/88
rank: CW2
experience in route planning: considerable (3 on 3-pt scale)

(what are the steps in route planning? what do you do first, what do you do second, what do you do third? also interested in the factors you consider during each of these steps.) start by considering the engagement areas. normally you pick out several possible EAs, make a good map recon, see, en armor is not going to roll thru here, i.e., have to know what your target is going to do, where its going to go. tanks are not likely to go thru this area at all, would prob bypass it. if they did go thru here, theyll be on secondary roads. if they encounter resistance, then theyll go off the main roads. they wouldnt take a big one, bec theyre sitting ducks on a big one. they can make good time on roads, in here it would take them days. also its so steep in here, they couldnt make it.

(mission is to attack and destroy) AA is where you sleep, its entirely too close on this map, should be back another 10 Ks or so. you could have a FAA, a forward assembly area, in the morning you crank up and move out to the FAA, after you sleep at the AA. FAA provides for quick response, but has to be out of arty range. dont worry too much about security. (how far back from feba?) well, HA is supposed to be 5 Ks from the BP, AA out of arty range, that would be 20-25 Ks, FAA maybe 10-15 Ks from the BP. this info is mostly in the AHB manual, FM 1-112.

so we start out at the AA, wake up in the morning, and of course we have already, the night before, planned possible EAs. we have an overview of the en situation, so we have several ideas about where theyre going to go. we have 2-3 FAAs we can use, depending on where the battle is going to take place. weve picked out several engagement areas and several BPs. for each EA, weve picked out a HA. ideally, from map recon, youve picked out everywhere you could possibly do battle on that day. orders, then, are like execute holding area 3, dont need grid coords, saves time too. execute engagement area kilo.

route planning starts with analysis of en situation, bec that indicates where youre going to go. weather is always one of your first considerations, do we have the weather to get there. en situation: ada threat, cross the FLOT, we have to coord with our ada people, so we can get across without getting shot by our own troops. but the en situation drives the whole train, bec thats what gonna tell you where to go. (specific route planning aspects of en situation?) ada. also want to know where the lead elements are, bec thats the guy who can get us, small, we could go past without seeing them, and they could shoot us. or at least observe. also want to know where the main thrust is, where the tanks are. (lead elements?) BMPs, recon vehicles, well out in front, 30-40 km probably. probing, to find out whats going on. normally theyre no threat to us, but thats the indicator where everything else is. normally they dont see us, if we fly our routes properly, and even if they do, they dont know for sure where were going. they just know were in the area. what youre looking for in a route is of course cover and concealment. if you have that, you shouldnt have to worry about the advance guard seeing you.

(individual soldiers with SA7s) en just takes a bunch of these guys and drops them off, by helo or whatever, all over the place. hard to defend against, bec you cant see them. defense is good terrain flight, trust in God. (do you avoid likely spots for these guys?) arty wont help, theyre in holes, single guys. recon trying to find these guys early. but we probably would not go out of our way to avoid likely spots, lost only one helo, and the reason, i think they had trouble acquiring us in the mission that we fly. in my past experience working with ada and that kind of thing, esp radar-driven, it has a real difficult time acquiring a helo, and ive flown against the Baretta, which is the Army's threat/radar, supposed to equalize the ZSU 23-4, and its never got me. several times, and it never got anyone in my group. the individ with an SA7 is a much bigger threat to us. esp dangerous at like the BP where youre hovering, a very nice target for this guy. just cant see them. when youre traveling, its not so bad, bec we fly very lo, and were masked in the trees. and also you go by them, they dont have that much time to see you.

(weather?) if the ceilings are low, you have to consider esp the hills, you have to go around, youre not going to be able to go over them. if visibility is way down, you have to consider whether you should even be out there, bec we want to shoot from a long range, last 1/3 of max eff range, 3000 m or more, (2 mi or so), and so visibility is more important to us than to them, they have less range anyway. so wed have to fly closer, put ourselves in jeapardy. 1/2 mi visibility is 800 m, and the shortest TOW range is 500 m, due to the way it swerves at the beginning. the degree of capture for a TOW is real large at the beginning of its flight, 6°, then it goes 1.25, finally at 500 m, it goes to .25°. very narrow scope and it goes that way all the way to the target.

lo vis can be good, if youre just trying to move someplace undetected. cause if you cant see them, they cant see you either. but have to fly slower too, might fly right over them. esp if theyre dug in, for some reason. you cant see a tank in the woodline. ive been caught hovering right over them before, look down, and theyve shot me. if theyre out there attacking, thats the best time to attack them.

(night flights?) need better weather at night. also affects nav, gonna need some good features to nav by. nvg is even easier. most of the time we use nvg. with nvg, youd use almost the same route that you would use in the daytime. would need good light, tho. good moon. theres quite a difference in the amt of light available at night. in general, dont fly quite as low, a little slower, but more importantly your ability to nav is diminished at night. look for a route with very prominent land forms for nav. good checkpts. even on a good night, you want a route that would be easy to nav, like here, coming up this stream bed. its a little stressful flying nvg in a narrow valley, bec you have a very narrow field of view, you might slide into one side or the other. roads are not the greatest. avoid populated areas, bec of the lights, knocks the goggles back, a city will shut them down. quality of vision goes way down. also avoid cities bec thats where the en is, a lot of times. but you can use a city as a nav feature (from a distance), bec with goggles, you can see a big city for a 100 miles. use it, but avoid it.

(time of year?) in Germany, in winter with snow on the grd, have to consider the fact that your rotor is going to kick up the snow, and the en can see you coming. so dont fly quite as low, and fly a little faster. then you dont kick up the snow. if youre flying contour, doesnt make much difference. but when you get to the ha and moving forward from there, normally use NOE, you have to consider the fact that youll have to hover maybe 50-60 ft off the grd, like at the BP. sometimes 70 ft. but nav in general, didnt really use any different techniques in winter as i did in summer.

the beauty of Germ is that the maps are so accurate, also predominantly evergreen forests, stay green all the time. NOE, the best way to nav is just by following the tree lines. like here, just follow this tree line right around, itd have that little bump in it. just like a road, showing you where to go. itll be there, just like it is on the map. in the US, the maps are no good, out of date, etc. you can never count on something being there in real life. cant count on following tree line, may go someplace other than it shows on the map. in germ, maps better, terrains better, and the power lines are higher. 300-400 ft off the grd. most of the wire hits, tho, are in low level or contour flight, bec youre moving a lot faster. highlight the wires in yellow on your map before you take off, usually. now they have wire overlays for our maps.

(what do you think about these BPs?) we have to figure out how were going to get there, thats quite a ridge line, this one here is acceptable, we can come up this stream bed right here. work our way in, and theyd never see us. but you have to consider, this alt is 392, and this is 381, so youre trying to look over a ridge line thats higher than you are. so youre not going to have any backdrop, skylight yourself, they can see you quite easily. so youre going to have to, maybe you could work into this ridgeline, ease above it slightly to see what you can see. i dont think youre going to see anything. just from experience. if you want a better BP, i can tell you right now that to engage them were going to have to be within 1000 m, which is not optimal. you want to be at least 2000 m, which is the range of the tank guns. you want 2500 m or more. but here with this rolling terrain, your shots gonna be 1000-1500 m. take your chances. id be willing to try this one right here, bec i got a good way to get in there and get my shot. like to set up more than one BP, tho. you could come in here and spread your aircraft along here, but i dont like it bec youre going to have to go so high to come up over this ridge. normally what you want is the hi grd looking down into the lo grd. if you could move around the ridge line and come in on this side of it, this is the hi part here and its sloping down toward here, but if you can move into here, where you have the hi hill behind you, and then engage them. its a short shot, 1000 m, but youve got cover and you could move up in there, just come around the town and come up in here, youre concealed the whole time. you have to be able to see them, so its a tradeoff between you seeing them and their seeing you.

you can take an aircraft with the sun behind you so you dont have the glint off the canopy, put it on a green ridge line, hover right out in the open, you think they can see me for miles, but the truth is, they cant see you at all. the green aircraft no sun glint off rotors or canopy, youre in the shadow of the hill (with the sun behind the hill). gotta have a hill behind you, and it would be nice if it were green. come over the hill, tho, youre skylighted. the real secret to cover and concealment is to keep the glint off the canopy and rotors. thats what they spot, 9 times out of 10.

(assume this BP, and tell me about the rest of the route planning) ok, this is acceptable. if we move up in here slowly, with this hill which is 392, were coming down here, its already 30 feet below us in this green, its an open field here, we can hover quite low, move right on up in here, and even tho were 1000 m away, well be able to see them. if youre back here, you have to look across all this stuff, and this hill here is higher than you are. youd have to be at a 100 ft hover back here, just to have a shot at them. and youd be skylighted. the closer BP, youd have to watch your rotor wash, make sure you didnt kick anything up, but they cant see you. the farther one, you cant see well, but they can. youd be skylighted. this closer way, you wouldnt even unmask yourself.

(route to BP from FAA?) turn the map the way we nav. in the cockpit, the way you nav is you turn the map so youre heading forward on the map. that way, when you see terrain features, you see them the same way youre going to see them for real. so im going to start from the FAA. first thing to consider is the weather. you tell me the weather is good, then i think about en positions, their ada, if i knew there was an ada site right here, then i would avoid it by at least 5 ks. feba is not a reliable concept in todays war, when you got tanks moving at 40k per hr. it moves fast. friendly ada, make sure theyre on weapons hold, then i dont have to worry about them. want to know what their status is, but i dont want to worry about my own guys. IFF system we have, they can identify friend or foe. our transponder puts out a signal, and these Stinger guys can tell if youre friend or foe. plus the soviet helos are ugly huge things, with 15 blades on it, anyone can tell the diff. theyre getting more that look like ours, tho. like the apache in particular. that might be a problem.

(corridor across the feba?) if you cross the feba, youre going to have a corridor. you have to coord with the grd guy, to cross his ground, and also the ada to give us weapons hold for a certain time period, so we can cross at a given pt. arty would normally be lifted, but you have to consider that too. (who decides where the corridor will be?) normally the S3 does the route. certain instances due to time that the line co comm will, with his pltn leaders, plan out the route. across the FLOT, 99% will be S3. the guy who does the route planning does the corridor. dimensions are pretty standard, about 3 Ks or so. in width.

(coord pts for corridor passage?) youd have a checkpt for entry, and a time, plus or minus 3 minutes, and youd have air control points along the way that enable you to maintain your time. air control points are checkpts that are used for control purposes. you can speed up or slow down, once you know where you are and when. you report each checkpt, also used by the lead navigator to slow down or speed up. ACPs are used for control, so that the head commander can know where his troops are along the route. theyre also used for nav, bec theyre a terrain feature that is easily found. theyre also used to time out your route as youre going, since youve planned it out, and you know that at this time you should be at this checkpt. (spacing of ACPs?) depends on mode of flight, NOE theyre closer together, see.

normally on a mission, we dont draw a lot of routes. the reason is, you dont know where exactly youre going to go. youd go to your FAA, get your route to the FAA, bec you know where youre going there, but beyond there, its very spontaneous, and the guy that navigates, the best senior guy youve got, all he does, he gets the coords of where hes gonna go, or the holding area, or whatever, and looks at his map, he doesnt draw a line, just picks out his route and goes, its not drawn out or anything. the battle is just too fluid, you dont have time, he takes 3 minutes to look at the map and were gone.

(normally you wouldnt have a well planned route?) depends on the mission. 9 times out of 10, there are so many uncertainties that it doesnt make sense to plan a route in advance. the en might be here instead of there. so that route is worthless, theres nothing at the end of it. also, you have all these possible EAs on your map, and if you planned routes to all of them, your map would be so cluttered you couldnt read it. its already cluttered too much the way it is now. cross the FLOT, tho, probably a route would be planned. thats a risky mission. reg attack mission, which would be move out of the AA at first light to the FAA, youd have a route there and an alternate route, but after that, youd do route planning for maybe 3 min in your head, how youre going to get there.

(so you head in this direction until the scout tells you to do something else?) no, no, what you do is you get a mission brief, were going to use EA whatever, sometimes they dont move you into a ha, might say just go to BP1, they say, 06 Golf, go to BP1, and i say roger, and i look at my map, and i say, how do i want to get there? consider the en situation. well, i know the en is over here, so i dont have to worry about that too much, now im looking at nav. whats the easiest way for me to nav there and still be concealed. from here to there, there aint nothing the greatest, so we can come right out of here, once we get past this pt, we do this first part contour, we come right up here, come right thru there, and right on here. start NOE right here. (bounding overwatch, too?) that depends. we actually dont use bounding overwatch that much, and the reason is, its so time consuming. the benefit is lost. they dont realize how long it takes to do NOE, with bounding overwatch. they say, well, youre moving 20 knots, yes, but not in a straight line. normally the scout would have already been up in this area here, done the recon, and concluded it was secure. so we could move a little faster. skip the bounding overwatch, at least.

in my experience, the feba is meaningless in todays battle, bec you cant draw it fast enuf. so i dont think about it very much. im not concerned about the feba so much as the en and where theyre at. i worry abt the little picture, where are the people im supposed to go shoot.

(right abt here you get more concerned abt terrain? start NOE?) even along here, youre flying contour, so youre flying 60-100 knots (in Europe), at 50 feet, wouldnt go over this hill, dart down this wood line, follow it around, youre down there and they cant see you. (so you have a route in mind, and adjust when you see the actual terrain?) yes, you cant make up your mind until you see it. not really following a line. what you tell your guys is, initially youre here, take off on a heading of 060, once you see the hill, you say, ok, i want you to cross just to the left of that hill. when you get across the hill, look down to your left, youll see a wood line, go for it, then head left, keep the wood line out your right door, when you come across here, youll see an opening to your right, want you to dodge down there, therell be a town, go just to the right of it. ok, just follow this wood line up to your left front, hill to your left front, just abt now crossing 4 lane hwy, be a town toward 12 oclock, pass to the right of it, then head down to your right, we have a ridge line to our front, come down and well hit a stream bed into our area. thats how youd talk, tell them how to fly in here.

(role of holding areas?) HAs, not in all cases, but when the scout wants you up close, but he wants to go up and take a closer look, but if he needs you, it only takes him a couple of minutes to get you. in this case, you could use a HA right in here somewhere. of course, want cover and concelmt. has to be in range of the route to the BP. normally planned before we go out. what they can do, since the battle is so fluid, is put reference pts on the map, maybe four on a map, and if there was no HA, theyd say, not grid coords, bec thats slow, takes a while to figure out, he can say, reference pt 1, down 9, give the shifts.

(egress?) lot of time, dont take the same way out. many times dont have a choice. have to take the same way out. here, id come out the same way. but normally use a different FAA, and so the route out has to be different to that extent. theyd move you to wherever they thought theyd need you next. you never know where youre going to go. so when they told you go to FAA2, look at your map and find your way out. takes about 3 minutes. sometimes do HAs this way too. (do you draw a straight line, then look at the terrain when you get out there?) no. cant nav a straight line, cant see the terrain features the way you want to, only the way the straight line wants you to. need cover and concealment. here, id follow this stream bed right on up, right around here, right on in. i have something to follow all the way. straight line, id have to count things, wires, ridge line, town, can be done, but not covered and concealed.

(FARP?) normally the FARP is back further than the FAA, but with the UHs, theyre getting bolder, theyll get them up closer. you have to remember that this is only 10 min flying time, at most, at 3 ks per minute at 100 knots, not even 5 minutes here. normally would like to see FARP out of artillery range, bec en can pick up aircraft activity at a certain location. but normally not able to get out of arty range, so normally would NOE into FARP, lots of routes in, etc. and move the FARPS around a lot.

(why do you want a different egress route?) if i saw no en coming in, i wouldnt worry much about it. doctrine, however, say take a diff route. but usually you pick the ingress bec its the best route, so usually best route out, too. lot a time the only way out. (worry abt SA7s coming back out the same way?) it is a consideration. have to make your decision when youre there. if there exists a better route out, ill take it. but if not, i dont worry abt it.

(3 companies rotating, use same ingress?) the same co wouldnt be using the same BP as another, so normally use diff ingress. one thing to remember is that once youve used a BP, engaged tanks out of it, then its no good no more. takes 3-4 ks to spread our aircraft out for a single engagement. multiple shootings, very hard.

(station time: route relevant considerations? tradeoffs with travel time? and ammo that can be carried?) in peacetime, we always get concerned about station time, but in war, wed be shooting bullets and wed have to go back to farp anyway. bullets dont last long when theres en out there to be shot at. 1hr 10 min total flying time, really, once were loaded with ammo. 4 TOWs, 20 rockets, 300-400 rds of 20 mm. normally we figure around 1100 lb of gas for a combat load, roughly. use about 700 lb per hr. puts you at 1hr, 40 min about, but you have to remember you need some gas to get home on.

our load is standard. if you pile on all the bullets you can hold, its down around 900 lbs max.

we can figure this out. one TOW weighs 54 lb. so with 8 TOWs (the max load) = 432 lb (uses calculator). one rocket weighs 21 lb., so 38 rockets = 798 lb. 750 rds of 20 mm, where 100 weigh 67 lb = 509 lb. total = 1739 lbs, max ammo load. max weight of the aircraft is 10,000 lb. with no ammo but with a full tank of gas (1700 lb), weigh 9600 lb. that gives us 400 lb of gas we can put on. (figures replacing the 1700 lb of gas with 1739 lb of ammo) aircraft at 10,000 lb will hover at 85% of torque. 100 lb = 1 % torque, so if you were at 11,000, hover at 95% torque. its a power problem.

normal ammo load is 4 TOW, 15 rockets, 250 20mm. with that you can take around 1100 lbs of gas. 1hr 40min. cruise flight at 100 knots, 680 lb per hr, NOE maybe 850 lbs per hr.

no reason for 8 TOWs anyway, cant shoot that many from one BP.

wind is another factor in route planning, or at least in BP. dont want a heavy tailwind (say 40 knots). much prefer a crosswind. or a headwind. takes less power in a headwind.

(discusses in-ground effect, hovering close to ground, where air, beaten down, piles up and slows the induced flow of air past the rotors, which makes the rotors relatively more efficient; and out-of-ground effect, at 1 1/4 rotor lengths, about 50 ft., where the air, beaten down, increases the induced flow, making rotors less efficient, requiring more power)

key to route planning is really en situation. i dont mind highways unless theres some reason to believe the en might be on them. i dont mind cities, either, cant avoid them in Europe, make great nav aids. worst problem about cities is lack of cover and concealment.

APPENDIX B:

SME DATA FROM
REPERTORY GRID METHOD

SME 2

IMP	Dimension	JIM	TIM	MARY	MATT	BILL	JILL	JACK	JANE
5	Degree of cover	4	3	3	3	5	4	1	2
4	Closeness to populated areas	2	2	1	2.5	4	2	1	2
4	# of highways crossed	2	3	3	1	3	2	2	2
3	Available flat land early	1	1	2	2	2	2	2	2
4	Good down-pilot points	2	2	3	4	5	3	3	3
4	Travel time (directness)	3	3	5	2	5	3	4	3
3	Best possible river crossing	1	NA	3	NA	3	1	3	3
4	Good checkpoints	4	3	3	4	3	3	4	5

SME 3

IMP	Dimension	JIM	TIM	MARY	MATT	BILL	JILL	JACK	JANE
5	Degree of cover	3	5	3	3	3	5	3	3
5	Better alternative available	3	1	1	3	3	3	1	3
3	Time near man-made objects	3	1	1	5	5	3	3	3
1	Threat to FAA	5	5	1	3	3	3	1	3
1	Travel time	1	1	5	3	3	3	5	3
3	Good checkpoints	3	3	3	3	5	5	3	5
5	Flexibility	3	3	1	3	1	5	1	3
3	Potential silhouette	3	3	1	1	1	5	1	5
5	Risk time	3	3	1	1	3	5	1	5

SME 4

IMP	Dimension	JIM	TIM	MARY	MATT	BILL	JILL	JACK	JANE
5	Degree of cover	4	4	1	4	4	5	2	2
5	Closeness to populated areas	2	3	1.5	3	5	3	1	2
3	Travel time	2	4	4	3	5	4	4	3
4	Best possible terrain use	3	3	3	5	4	5	2	3
4	Best possible avoid. pop.	4	3	1	4	4	4	1	3
5	Avoids exposure to observation	1	1	1	5	4	4	1	4
3	Checkpoints	5	4	3	3	4	5	3	3

SME 5

IMP	Dimension	JIM	TIM	MARY	MATT	BILL	JILL	JACK	JANE
5	Degree of cover	5	3	3	4	5	3	2	4
3	Exposure to observation	4	2	1	3	5	2	2	4
5	Better alternatives available	5	3	2	3	5	4	3	5
3	Linear obstacle	5	2	5	4	5	4	5	5
2	Travel time	5	5	5	5	5	5	5	5
4	Exposure to fire	3	3	1	3	4	3	2	3
4	Travel next to cities, highway, woodlines near front	4	2	2	2	4	2	1	4
5	Amount of travel near front line	4	2	1	3	5	5	2	4
5	Flexibility	4	4	2	4	5	4	3	4
2	Crosses power lines	5	5	5	5	5	5	3	2
5	Good checkpoints	5	5	4	4	5	5	3	3
4	Crosses probable enemy avenue of approach	4	2	1	2	5	2	1	5
3	Silhouetting	4	4	3	3	5	5	3	3

SME 6

IMP	Dimension	JIM	TIM	MARY	MATT	BILL	JILL	JACK	JANE
3	Degree of cover	2	4	2	4	4	3	2	3
3	Amount of exposure	2	3	2	5	4	3	2	3
3	Avoids man-made features	2	3	1	4	4	1	2	3
4	Avoids built-up areas	3	4	2	4	4	1	1	4
4	Best possible use of terrain	1	2	1	5	4	1	2	4
4	Good terrain relative to threat's terrain	3	4	1	5	5	3	1	5
5	Doesn't compromise surprise	3	4	1	5	5	3	1	5
5	Less impact of enemy surprise	3	4	1	5	5	3	1	4
4	Good approach angle	4	4	1	5	5	4	1	5
4	Travel time	4	3	2	4	4	3	3	4
2	Good checkpoints	3	4	3	4	4	3	2	4
4	Flexibility	4	4	2	4	4	4	3	5

SME 7

IMP	Dimension	JIM	TIM	MARY	MATT	BILL	JILL	JACK	JANE
5	Degree of cover	4	3	2	3	4	3	2	3
4.5	Possibility of exposure	3	4	2	3	3	3	2	3
3	Travel time	3	3	3	4	5	2	3	4
4	Ease of navigation	3	3	4	5	3	4	4	3
3	Best alternative	4	2	1	3	3	2	2	3
4	Angle of approach	3	3	2	5	4	4	2	4
5	Silhouetting	3	2	5	5	3	4	5	5
4	Near built-up areas	3	3	3	4	4	3	3	3
5	Flexibility	3	4	3	3	3	3	3	3

SME 8

IMP	Dimension	JIM	TIM	MARY	MATT	BILL	JILL	JACK	JANE
4	Degree of cover	4	2	4	3	3	4	2	3
5	Ease of navigation	4	2	5	3	1	5	3	2
1	Maneuverability	3	2	5	3	3	2	3	3
4	Exposure	3	2	4	4	3	4	3	3
5	Better alternative available	4	2	5	5	2	4	4	2
3	Travel time	4	2	5	3	3	4	3	3
3	Wire crossing problem	5	2	5	3	5	5	3	2
3	Good approach angle	5	3	2	5	5	5	5	5

APPENDIX C:

INTERCORRELATIONS AMONG DIMENSIONS AND CLUSTER ANALYSIS

LIST OF DIMENSIONS

1. Avoid built-up areas
2. Best possible avoidance of populated areas
3. Available flat land early
4. Better alternative available
5. Close to population
6. Does not compromise surprise
7. Cover
8. Good down pilot points
9. On probable enemy avenue of approach
10. Exposure to fire
11. Ease of navigation
12. Exposure to observation
13. Less impact of enemy surprise
14. Amount of exposure
15. Flexibility
16. Good approach angle
17. Good checkpoints
18. Good terrain relative to threat terrain
19. # highways crossed
20. Linear obstacles
21. Maneuverability
22. Time near man-made objects
23. Crosses power lines
24. Potential silhouette
25. Best possible river crossing
26. Time at risk
27. Travel next to cities, woodlines near front
28. Threat to FAA
29. Amount of travel near front
30. Travel time
31. Best possible terrain use

PEARSON CORRELATION MATRIX

	AVGRANK	D(1)	D(2)	D(3)	D(4)
AVGRANK	1.000				
D(1)	-0.579	1.000			
D(2)	-0.755	0.365	1.000		
D(3)	0.155	-0.141	0.104	1.000	
D(4)	-0.489	0.255	0.916	-0.000	1.000
D(5)	-0.891	0.666	0.588	0.063	0.310
D(6)	-0.769	0.858	0.612	-0.046	0.435
D(7)	-0.973	0.434	0.785	-0.246	0.554
D(8)	-0.407	0.428	0.412	0.701	0.212
D(9)	-0.561	0.586	0.604	-0.092	0.597
D(10)	-0.888	0.613	0.704	-0.174	0.532
D(11)	0.364	-0.627	-0.025	0.243	0.027
D(12)	-0.706	0.635	0.826	0.346	0.686
D(13)	-0.848	0.867	0.638	-0.098	0.431
D(14)	-0.660	0.543	0.718	0.385	0.490
D(15)	-0.717	0.344	0.603	-0.309	0.458
D(16)	-0.777	0.594	0.853	0.067	0.727
D(17)	-0.869	0.396	0.746	-0.206	0.559
D(18)	-0.769	0.858	0.612	-0.046	0.435
D(19)	0.004	-0.031	-0.475	-0.218	-0.593
D(20)	0.280	-0.195	0.249	0.509	0.445
D(21)	0.551	-0.094	-0.311	0.333	-0.170
D(22)	-0.641	0.833	0.345	-0.123	0.188
D(23)	-0.387	-0.118	0.345	-0.101	0.228
D(24)	-0.180	-0.307	0.397	0.226	0.332
D(25)	0.033	0.575	-0.381	-0.000	-0.485
D(26)	-0.472	0.013	0.431	-0.092	0.314
D(27)	-0.502	0.540	0.586	-0.195	0.618
D(28)	-0.626	0.460	0.381	-0.816	0.347
D(29)	-0.767	0.219	0.871	0.104	0.740
D(30)	0.180	-0.061	-0.105	0.724	-0.164
D(31)	-0.604	0.711	0.610	0.420	0.404

	D(5)	D(6)	D(7)	D(8)	D(9)
D(5)	1.000				
D(6)	0.718	1.000			
D(7)	0.797	0.659	1.000		
D(8)	0.691	0.396	0.259	1.000	
D(9)	0.594	0.698	0.546	0.281	1.000
D(10)	0.822	0.837	0.836	0.366	0.724
D(11)	-0.550	-0.589	-0.254	-0.208	-0.695
D(12)	0.720	0.841	0.618	0.674	0.737
D(13)	0.793	0.979	0.739	0.433	0.623
D(14)	0.582	0.687	0.569	0.629	0.213
D(15)	0.408	0.729	0.736	-0.111	0.475
D(16)	0.636	0.879	0.724	0.401	0.662
D(17)	0.686	0.706	0.911	0.144	0.741
D(18)	0.718	1.000	0.659	0.396	0.698
D(19)	0.206	-0.210	0.000	-0.051	0.061

D(20)	-0.096	-0.250	-0.242	0.357	0.303
D(21)	-0.315	-0.458	-0.554	0.156	-0.185
D(22)	0.709	0.812	0.477	0.460	0.410
D(23)	0.337	-0.199	0.484	0.181	-0.103
D(24)	-0.071	0.175	0.277	-0.158	0.271
D(25)	0.116	0.336	-0.226	0.191	-0.226
D(26)	0.262	0.444	0.546	-0.151	0.590
D(27)	0.503	0.580	0.528	0.167	0.955
D(28)	0.347	0.561	0.678	-0.381	0.453
D(29)	0.647	0.584	0.804	0.363	0.719
D(30)	0.219	-0.232	-0.258	0.711	0.040
D(31)	0.635	0.808	0.453	0.719	0.350

	D(10)	D(11)	D(12)	D(13)	D(14)
D(10)	1.000				
D(11)	-0.633	1.000			
D(12)	0.784	-0.392	1.000		
D(13)	0.866	-0.544	0.811	1.000	
D(14)	0.502	0.093	0.767	0.733	1.000
D(15)	0.777	-0.293	0.554	0.715	0.454
D(16)	0.873	-0.351	0.919	0.868	0.746
D(17)	0.823	-0.382	0.665	0.702	0.435
D(18)	0.837	-0.589	0.841	0.979	0.687
D(19)	-0.114	-0.370	-0.378	-0.192	-0.504
D(20)	-0.190	0.123	0.227	-0.319	-0.084
D(21)	-0.696	0.323	-0.289	-0.488	-0.192
D(22)	0.771	-0.657	0.618	0.865	0.533
D(23)	0.018	0.399	-0.058	-0.049	0.194
D(24)	0.196	0.164	0.312	0.066	0.174
D(25)	0.000	-0.297	0.000	0.359	0.236
D(26)	0.531	-0.291	0.416	0.352	0.107
D(27)	0.577	-0.551	0.608	0.513	0.150
D(28)	0.640	-0.396	0.212	0.598	0.118
D(29)	0.812	-0.277	0.790	0.577	0.479
D(30)	-0.227	-0.035	0.117	-0.240	0.000
D(31)	0.585	-0.204	0.849	0.820	0.930

	D(15)	D(16)	D(17)	D(18)	D(19)
D(15)	1.000				
D(16)	0.805	1.000			
D(17)	0.814	0.747	1.000		
D(18)	0.729	0.879	0.706	1.000	
D(19)	-0.312	-0.511	0.045	-0.210	1.000
D(20)	-0.459	-0.044	-0.135	-0.250	-0.143
D(21)	-0.842	-0.579	-0.548	-0.458	0.218
D(22)	0.477	0.675	0.354	0.812	-0.161
D(23)	-0.139	-0.097	0.228	-0.199	0.242
D(24)	0.576	0.387	0.541	0.175	-0.246
D(25)	-0.069	0.000	-0.336	0.336	0.000
D(26)	0.755	0.513	0.817	0.444	0.061
D(27)	0.367	0.526	0.708	0.580	0.128

D(28)	0.756	0.491	0.671	0.561	0.000
D(29)	0.690	0.811	0.874	0.584	-0.204
D(30)	-0.671	-0.268	-0.268	-0.232	0.348
D(31)	0.425	0.787	0.374	0.808	-0.458

	D(20)	D(21)	D(22)	D(23)	D(24)
D(20)	1.000				
D(21)	0.582	1.000			
D(22)	-0.376	-0.492	1.000		
D(23)	0.095	0.202	-0.199	1.000	
D(24)	0.082	-0.376	-0.305	-0.159	1.000
D(25)	-0.535	0.000	0.603	-0.412	-0.552
D(26)	-0.101	-0.555	-0.000	-0.140	0.855
D(27)	0.354	-0.000	0.240	0.072	0.220
D(28)	-0.535	-0.612	0.452	0.082	0.092
D(29)	0.204	-0.518	0.306	0.199	0.585
D(30)	0.643	0.628	-0.160	0.190	-0.229
D(31)	-0.061	-0.210	0.724	-0.085	0.063

	D(25)	D(26)	D(27)	D(28)	D(29)
D(25)	1.000				
D(26)	-0.453	1.000			
D(27)	-0.318	0.522	1.000		
D(28)	0.000	0.453	0.477	1.000	
D(29)	-0.508	0.719	0.626	0.381	1.000
D(30)	-0.059	-0.308	0.028	-0.769	-0.045
D(31)	0.429	0.078	0.218	0.086	0.436

	D(30)	D(31)
D(30)	1.000	
D(31)	0.081	1.000

NUMBER OF OBSERVATIONS: 8

COMPLETE LINKAGE METHOD (FARTHEST NEIGHBOR)
TREE DIAGRAM

```
                                         DISSIMILARITIES
-2.000                                                                 2.000
 D(26)DDDDDDDDDDDDDDDDDDD?
                        CDDDDDDDDDDDD?
 D(24)DDDDDDDDDDDDDDDDDDDY            3
                                     CDDDDDDDDDD?
 D(28)DDDDDDDDDDDDDDDDDDDDD?          3          3
                          CDDDDDD?    3          3
 D(15)DDDDDDDDDDDDDDDDDDDDDY      3   3          3
                                 CDDDY           3
 D(17)DDDDDDDDDDDDDDDDDD?         3              3
                       CD?        3              3
 D(7) DDDDDDDDDDDDDDDDDDY 3       3              3
                         3        3              3
 D(10)DDDDDDDDDDDDDDDDDDDD4       3              3
                         CDDDD?   3              3
 D(29)DDDDDDDDDDDDDDDDDDDDY    3  3              3
                              CDDY               3
 D(4) DDDDDDDDDDDDDDDDDD?      3                 3
                       CDDDDD?3                  3
 D(2) DDDDDDDDDDDDDDDDDDY     33                 3
                             CY                  3
 D(27)DDDDDDDDDDDDDDDDDD?     3                  3
                       CDDDDDY                   3
 D(9) DDDDDDDDDDDDDDDDDDY                        3
                                                CDDD?
 D(22)DDDDDDDDDDDDDDDDDDDD?                      3   3
                         CDD?                    3   3
 D(18)DDDDDDDDDDDDDDDDD?  3  3                   3   3
                      3  3  3                    3   3
 D(6) DDDDDDDDDDDDDDDDD4  3  3                   3   3
                      CD?3  3                    3   3
 D(13)DDDDDDDDDDDDDDDDDY 33  3                   3   3
                        CY  3                    3   3
 D(1) DDDDDDDDDDDDDDDDDDDY   3                   3   3
                            CD?                  3   3
 D(5) DDDDDDDDDDDDDDDDDDDDDDDY 3                 3   3
                              CDDDDDDDD?         3   3
 D(31)DDDDDDDDDDDDDDDDDD?      3        3        3   3
                       CDD?    3        3        3   3
 D(14)DDDDDDDDDDDDDDDDDDY  3   3        3        3   3
                          CDDDY         3        3   3
 D(16)DDDDDDDDDDDDDDDDDD?  3            3        3   3
                       CDDY             3        3   3
 D(12)DDDDDDDDDDDDDDDDDDY               3        3   3
                                       CDDDDDDDDDY   3
 D(25)DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDY            3
                                                    CDDDDDDDDDDDDDDDDDDD
 D(8) DDDDDDDDDDDDDDDDDDDDDD?                        3
                           CDDDDDDDD?                3
 D(30)DDDDDDDDDDDDDDDDDDDDDD4        3               3
                           3         3               3
 D(3) DDDDDDDDDDDDDDDDDDDDDDY        3               3
```

```
                                   CDDDDD?         3
D(21)DDDDDDDDDDDDDDDDDDDDDDD?      3     3         3
                            CDDDDDDY     3         3
D(20)DDDDDDDDDDDDDDDDDDDDDDDY            3         3
                                         CDD?      3
D(23)DDDDDDDDDDDDDDDDDDDDDDDDDD?         3  3      3
                               CDDDDDDDDDY  3      3
D(11)DDDDDDDDDDDDDDDDDDDDDDDDDDY            3      3
                                            CDDDDDDY
D(19)DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDY
```