DTIC FILE COPY

(4)

AD-A210 827

AAMRL-TR-88-057

THE EFFECTS OF STRESS ON PILOT JUDGMENT IN A MIDIS SIMULATOR (U)

CHRISTOPHER D. WICKENS
ALAN STOKES
BARBARA BARNETT
FRED HYMAN

UNIVERSITY OF ILLINOIS

DTIC
S ELECTE AUG 01 1989 D
D

FEBRUARY 1989

FINAL REPORT FOR PERIOD DECEMBER 1987 - AUGUST 1988

Approved for public release; distribution is unlimited.

ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
HUMAN SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

89 8 01 044

NOTICES

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from the Armstrong Aerospace Medical Research Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Federal Government agencies and their contractors registered with the Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Center
Cameron Station
Alexandria, Virginia 22314

TECHNICAL REVIEW AND APPROVAL

AAMRL-TR-88-057

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AAMRL-TR-88-057
6a. NAME OF PERFORMING ORGANIZATION University of Illinois* Institute of Aviation 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION AAMRL/HEG
6c. ADDRESS (City, State, and ZIP Code) Aviation Research Laboratory #1 Airport Road Savoy, IL 61874	7b. ADDRESS (City, State, and ZIP Code) Wright-Patterson AFB, OH 45433-6573
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DOE EGG C87-101376-2 AMR 7-013
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.
62202F	7184	14	23

11. TITLE (Include Security Classification)

THE EFFECTS OF STRESS ON PILOT JUDGMENT IN A MIDIS SIMULATOR (U)

12. PERSONAL AUTHOR(S)

Wickens, Christopher D., Stokes, Alan, Barnett, Barbara, and Hyman, Fred

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Dec 87 TO Aug 88	1989 February	44

16. SUPPLEMENTARY NOTATION

*Subcontract to Idaho National Engineering Laboratory, 4580 Sawtelle Road, Idaho Falls, ID 83401

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Decision making, stress, pilot judgment, divided attention, cognitive task analysis

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

This report presents an information processing framework for predicting the effects of stress manipulations on pilot decision making. The framework predicts that stressors related to anxiety, time pressure, and high risk situations will restrict the range of cue sampling and reduce the capacity of working memory, but will not affect decisions that are based upon direct retrieval of knowledge from long term memory. These predictions were tested on MIDIS, a microcomputer-based pilot decision simulator. Performance on a series of 38 decision problems was compared between ten subjects in a control group and ten subjects who had performed under conditions of noise, concurrent task loading, time pressure, and financial risk. The results indicated that the stress manipulation significantly reduced the optimality and confidence of decisions. The manipulations imposed their greatest effect on problems that were coded high on spatial demand and on problems requiring integration of information from the dynamic instrument panel. The effects of stress were relatively independent of problem demands for working memory and knowledge.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Gary B. Reid	22b. TELEPHONE (Include Area Code) (513) 255-8749 22c. OFFICE SYMBOL AAMRL/HEG

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

PREFACE

The author's acknowledge the invaluable assistance of Rob Rosenblum and Tak Ming Lo in carrying out the computer programming necessary to implement MIDIS and perform the data analysis.

Accesion For
NTIS CRA&I
DTIC TAB
Unannounced
Justification
By
Distribution /
Availability Codes
Dist | Avail and / or Special
A-1

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Faulty pilot judgment has been identified as a contributing cause in a majority of aircraft accidents attributed to pilot error (Jensen, 1981). Furthermore, given that such errors often occur in bad weather, or at times of instrument or system failure, it is reasonable to assume that the resulting stress from these anxiety provoking situations may exert an important degrading influence on the quality of decision making. Indeed there is an ample abundance of anecdotal reports and post hoc accident and failure analyses that attributes the degrading influence of stress as one source of faulty decision making (e.g., Connolly, Blackwell, & Lester, 1987; Lubner & Lester, 1987; Simmel, Cerkovnik, & McCarthy, 1987; Simmel & Shelton, 1987).

Post-hoc analysis has an important role to play (for example in Air Force and NTSB accident reports), and, because its data stem from the operational environment rather than from the laboratory, it is an important source of hypotheses. As a research method, however, this approach is less than fully satisfactory for two reasons. In the first place, post hoc analyses are always subject to the 20-20 vision of hindsight. It is always easy to say after the fact that "the pilot should have done x, rather than y." But such an analysis does not fully consider the probabilistic nature of the environment in which any pilot operates (i.e., the "right" decision may occasionally produce the "wrong" outcome and vice versa). Post-hoc analysis always risks loading the dice toward interpretations of events that reinforce, or at least are consistent with, preconceptions, assumptions and expectations. It is more sensitive to these, perhaps, than to the exact nature of the information available to the pilot at the time, and to the precise characteristics of the cues that influenced the decision making process.

Secondly, it is well established that most accidents are determined by a cascading or confluence of multiple factors, only one of which may be stress.

As such, it is not at all easy to establish the role of stress in a complex event. It is always difficult to determine which, if any, of the known factors in a mishap is a primary cause and which may be relatively less important. Post-hoc analysis can plausibly posit that stress had an impact upon pilot decision-making in any particular case or cases, but in the end such analysis can only allow speculation of what or how. This provides a weak basis for generalization and prediction.

A complementary approach to post-hoc analysis in establishing the role of stress as a contributing cause of poor decision-making is one that is based on a clear and coherent model of stress. Such a model allows for a number of experimental manipulations to be formulated to impose "stressors" (i.e., potentially stressful stimuli), in a controlled environment. The effect of those stressors on decision task performance can then be measured.

Indeed there is a relatively rich experimental data base which examines the effects of stress on performance, much of it carried out in the 1950's and 1960's (see Broadbent, 1971; Hamilton & Warburton, 1979; Hockey, 1984, 1986; for good reviews). Much of this literature, however, is equally limited in its applicability to the current issue because most studies were designed to examine performance on relatively simple perceptual-motor and cognitive tasks, rather than on decision making tasks per se. Nevertheless, a considerable amount of useful predictive information may be derived from such studies. For example, stress effects can be identified as selectively influencing different information processing components, and analysis of decision making tasks can reveal a corresponding set of component processes. Using this approach, one should be able to predict the influence of selective stressors on decision making performance as a joint function of the components that are influenced by the stressors and the components that are required for specific decision problems.

A recent integration of the literature on expected stress effects carried out by Hockey (1984, 1986) and an information processing model of decision making developed by Wickens and Flach (1988) and evaluated by Wickens, Stokes, Barnett, and Davis (1987) appear to provide the two components of such a predictive analysis.

Hockey's analysis identified different patterns or "signatures" of effects which different stressors (i.e., noise, anxiety, sleep loss) exerted on different fundamental components of information processing (Table 1). The most important of these signatures from the standpoint of the current report was that produced by "anxiety"--a state that maps closely to the conditions of danger and uncertainty that are characteristic of an accident-causing flight environment. Table 1 reveals changes in three important features of the information processing system: (a) an increased selectivity or "tunneling" of attention, (b) a decreased capacity of working memory, and (c) a shift in the speed-accuracy tradeoff toward more rapid, but error-prone responding. An equally important aspect of Table 1 is that the signature of stress imposed by anxiety is identical to that imposed by noise. This aspect means that it should be possible to mimic the effects of anxiety on the information processing system by imposing noise stress, an assumption that makes the experimental investigation of stress effects on decision making considerably more tractable.

To apply such analysis for predicting the degrading effects of anxiety/noise on decision making, a set of information processing components analogous to those shown in Table 1, must be obtainable through decision analysis. Figure 1 presents the results of this analysis (Stokes, Barnett,

Table 1. The Patterning of Stress Effects across Different Performance Indicators (From Hockey, 1986)

	Performance Indicators Speeded Responding					
	GA	SEL	S	A	STM	Sources/Reviews
Noise	+	+	0	–	–	2, 3, 4, 5, 7, 8
Anxiety	+	+	0	–	–	4, 12
Incentive	+	+	+	+	+	2, 4, 5
Stimulant drugs	+	+	+	0	–	2, 4, 13
Later time of day	+	?	+	–	–	1, 2, 4, 5, 6, 8
Heat	+	+	0	–	0	2, 4, 11
Alcohol	–	+	–	–	–	2, 4, 7, 8, 13
Depressant drugs	–	–	–	–	–	2, 4, 10, 13
Fatigue	–	+	–	–	0	2, 4, 9
Sleep loss	–	–	–	–	0	2, 4, 5, 7, 8
Earlier time of day	–	?	–	+	+	1, 2, 4, 5, 6, 8

The table summarizes the typical outcome in various studies using these stress variables in terms of their effect on the five behavioral indicators shown: GA = general alertness/activation (subjective or physiological arousal); SEL = selectivity of attention; S and A refer to overall speed and accuracy measures in speeded responding tasks; STM = short-term memory. A plus (+) indicates a general increase in this measure, a zero either no change or no consistent trend across studies, and a minus (–) a general tendency for a reduction in the level of the indicator. A question mark is used to indicate cells where there is insufficient data. Sources of data: (1) Blake (1967a, 1971); (2) Broadbent (1971); (3) Broadbent (1978); (4) Davies & Parasuraman (1982); (5) M. W. Eysenck (1982); (6) Folkard (1983); (7) Hamilton, Hockey, & Rejman (1977); (8) Hockey (1979); (9) Holding (1983); (10) Johnson and Chernik (1982); (11) Ramsey (1983); (12) Wachtel (1967, 1968); (13) Wesnes and Warburton (1983).

Figure 1.

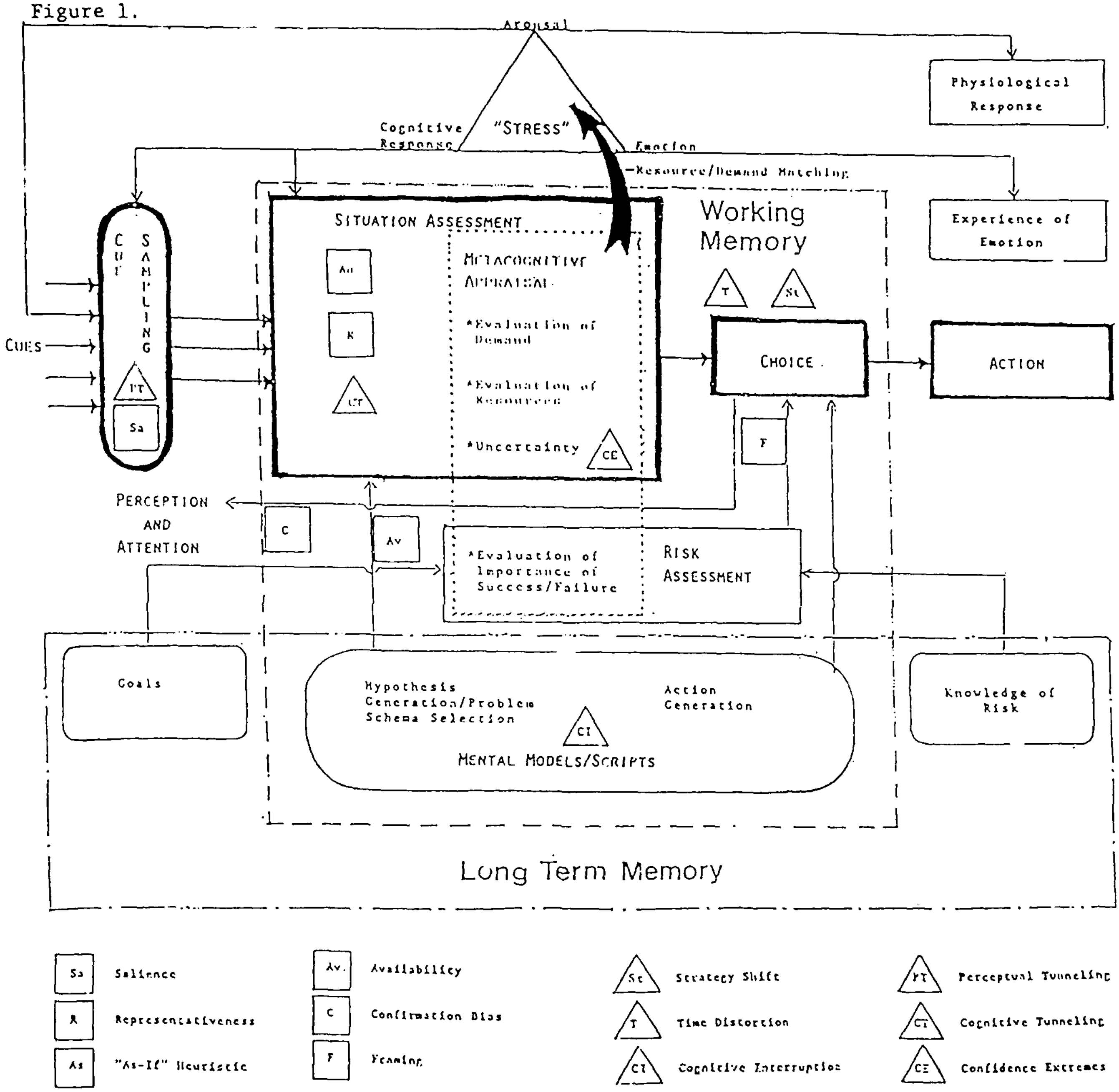

Figure 1. A Model of Stress and Decision Making.

and Wickens, 1987). The figure represents the information processing model of pilot judgment developed by Wickens and Flach (1988), elaborated to incorporate the effects of stress. While the details of the model and its representation of deci`_on making heuristics and biases are described in Wickens et al. (1987), the important characteristics of the model from the standpoint of the current analysis are the specific effects attributable to stress that are also highlighted by Hockey's analysis. Three effects are identified:

(1) Cue sampling. Many decision problems require the integration of information from a number of sources. To the extent that the number of these sources is restricted by stress, and the more informative, rather than the irrelevant cues are filtered, decision performance will be expected to suffer.

(2) Working memory capacity. The dashed box in Figure 1 contains a series of processing activities in decision making that depend upon the fragile, resource-limited characteristics of working memory. These include such processes as considering hypotheses, or evaluating and comparing the expected utilities of difficult choices of action. Also included are the spatial transformations and representations necessary to bring spatial awareness to bear on a decision problem (Baddeley, 1986). Stressors that decrease the capacity of the working memory system will be expected to have degrading effects on decision making performance.

(3) The two stages in the model related to situation assessment and choice are both subject to a speed-accuracy tradeoff. For both processes, the quality of the output (i.e., the extent to which all information is considered and all alternatives are carefully weighed) will vary with the time available for the decision process.

The previous analysis suggests that the quality of decision making will inevitably degrade under the influence of a stressor that affects cue sampling or working memory. However, such a conclusion fails to consider that many aspects of decision making depend less on these "fragile" attention and memory components than upon direct retrieval of information from long term memory (represented in the box at the bottom of Figure 1). For example, the skilled physician need not systematically compare each symptom with its likelihood of arising from a particular disease, but may instead perform a "pattern match" between the set of observed symptoms and the "syndrome" that is characteristic of a particular disease (Wickens, 1984). This syndrome is represented by a stored representation of the disease in long term memory. Similarly, a skilled pilot may immediately recognize a pattern of instrument readings as attributable to an underlying failure mode and not have to go through the time-consuming logical reasoning process (Stone, Babcock, & Edmunds, 1985). Because the direct retrieval of familiar information from long term memory is relatively immune to the effects of stress, it is conceivable that many aspects of decision making may not suffer stress effects.

While the model of stress effects presented in Figure 1 appears to be intuitively plausible, and can be justified on logical grounds, it remains to be validated, and as noted, studies that have systematically examined stress effects on decision making are few in number. Those decision studies that have operationally manipulated stress in a way that corresponds directly to risk/anxiety appear to be non-existent. However, using time stress and task loading, four investigations have supported the validity of the model. Wright (1974) examined the effects of time stress and the distracting effect of irrelevant noise (a radio program) on the integration of attributes in a car purchasing decision. He found that both stressors reduced the optimality of information integration--cue sampling--in such a way that subjects gave more weighting to negative cues (what was wrong with a car) than on positive ones.

Bronner (1982) manipulated time stress for subjects engaged in a business decision making simulation, and observed a general loss in the quality of performance.

Barnett and Wickens (1986) examined the influence of time stress and dual task loading on an information integration task involving a highly abstract aviation decision making task. Subjects integrated probabilistic information from a number of cues regarding the advisability of continuing or aborting a flight mission (e.g., weather information, engine temperature). Cues varied in their diagnosticity and in their physical location on the display. Barnett and Wickens found that time-stress produced a slight tendency to focus processing on more salient (top left) display locations, replicating an effect reported in a more abstract paradigm by Wallsten and Barton (1982). Barnett and Wickens also found that the "stress" caused by diverting cognitive resources to a concurrent task produced an overall loss in decision quality. The latter effect did not appear to be a perceptual one related to the restriction of cue sampling, but rather was related to the accuracy with which the mental integration of the cues was carried out. That is, diverting cognitive resources appeared to reveal a working memory limitation.

It should be noted that both tasks used by Wright, and by Barnett and Wickens, were "computationally intensive," and neither one required decision making in which an extensive knowledge base had to be exploited to yield direct retrieval of solutions from long term memory (i.e., the stress-resistant component at the bottom of Figure 1). Some indirect evidence for the potential role of direct retrieval in context-specific decision making is provided by the extensive study of individual differences in pilot judgment carried out by Wickens et al. (1987). This study also provides the foundation for the current investigation and will be discussed in some detail.

The study by Wickens et al. used a microcomputer-based simulation of pilot decision tasks known as MIDIS. Subjects viewed a computer display that contained an instrument panel and a text window. The text window was used to display a description of various decision "problems" as they unfolded in the course of a realistic flight scenario. Each problem was characterized by a set of cognitive attributes (e.g., its demand for cue integration, working memory capacity, or the accurate utilization of risk information). Correspondingly, each of the 38 instrument rated pilots (20 novices, 18 experts) who participated in the experiment were also characterized by a set of 11 cognitive attributes, assessed on a battery of standardized tests. These attributes are defined in Table 2.

The analysis of decision performance in this study resulted in a number of interesting conclusions. First, expert pilots were not better decision makers than novices, although subjects in the former group were significantly more confident in their choices. Secondly, the cognitive variables that predicted performance for dynamic problems that required real-time integration of information off of the instrument panel were different from those that predicted performance for static problems--those that required the interpretation of text. Thirdly, the variables that predicted performance for experts were different from those that predicted performance for novices. In particular, while performance on dynamic problems was predicced for both groups by tests of the working memory of capacity, substantial differences between the groups were found on static problems. Variance in the performance of novices was related to declarative knowledge. But most variance in the performance of the experts was simply unrelated to any of the cognitive tests employed in the battery. This included both tests of memory, attention and cognitive ability, as well as tests of declarative knowledge stored in long

Table 2. Scenario Demands of Cognitive Attributes

1. Flexibility of Closure - the ability to find a given configuration in a distracting perceptual field.

2. Simultaneous Mental Integrative Processes - the ability to keep in mind simultaneously or to combine several premises or rules in order to produce a correct response.

3. Simultaneous Visual Integrative Processes - the ability to sample a select number of items from a complex visual display, and to combine this information in order to produce a correct response.

4. Sequential Memory Span - the ability to recall a number of distinct, sequential items from working memory.

5. Arithmetic Load - the ability to perform basic arithmetic operations with speed and accuracy.

6. Logical Reasoning - the ability to reason from premise to conclusion, or to evaluate the correctness of a conclusion.

7. Visualization of Position - the ability to perceive or maintain orientation with respect to objects in space, and to manipulate this image into other arrangements.

8. Risk Assessment and Risk Utilization - the ability to accurately assess the probability or riskiness of a situation, and to utilize this assessment in effectively carrying out decisions.

9. Confirmation Bias - the tendency to seek confirmatory, rather than the more appropriate disconfirmatory evidence, when testing a given hypothesis.

10. Impulsivity-Reflectivity - a measure of cognitive style differentiating those who tend to be fast and inaccurate (impulsive) or slow and accurate (reflective).

11. Declarative Knowledge - the ability to answer correctly a number of "textbook" questions covering a broad range of general aviation issues. This measure specifically excludes procedural or experience-based issues, focusing only on declarative facts and guidelines.

term memory (i.e., facts about aviation assessed through FAA questions). We concluded that expertise in pilot judgment may be more heavily related to procedural knowledge or to the pattern-recognition, from direct memory retrieval processes than to the computationally intensive algorithms that would be predicted by tests of logical reasoning, memory and attention capacity. If in fact this is the case, then in accordance with the decision model in Figure 1, it may well be that certain aspects of pilot judgment are indeed relatively immune to stress effects, particularly for the expert pilot.

The objective of the current experiment then was to validate the use of the model in predicting stress effects on pilot decision performance. A MIDIS flight, similar to the one employed in the previous study by Wickens et al. (1987) was used for this second study. However, certain characteristics of the flight were modified to provide a greater degree of structure to the experiment. Two groups of ten instrument rated pilots flew the same flight, one under manipulations imposed to induce stress and the other under no stress conditions. All subjects had participated in the previous MIDIS experiment. In order to increase the power of our design, subjects were assigned in pairs, matched on total flight hours, age, and on their scores in the earlier MIDIS experiment. One subject in each pair was assigned to each group.

Stress was manipulated by imposing four variables simultaneously: (1) time-stress imposed by providing guidance to complete the flight in one hour, (2) financial risk imposed by imposing a steep loss in monetary reward if flight time exceeded the one hour deadline and penalties suboptimal responding, (3) concurrent task loading imposed by requiring performance of a secondary Sternberg memory search task, and (4) noise stress imposed by providing a mixture of both predictable noise and unpredictable noise. A predictable noise condition was created by presenting the noise any time a subject exceeded a deadline for responding to a secondary task. Unpredictable noise was created by random presentation of the noise. The noise in both conditions was an annoying sequence of tones and bleeps at an intensity of 74 dB spl.

Our decision to impose all four stressors concurrently, rather than imposing each independently was taken for two reasons. First, as this is viewed as the initial experiment in a larger program of research, we were most interested in providing a sufficiently powerful combination of stressors to assure performance effects. Application of cognitive appraisal theory of stress (Stokes et al., 1987) indicated that this combination of stressors should induce a subjective perception of failing to meet the task demands, and hence, an experience of stress. Secondly, because only each subject was available for only one flight, we were required to use a between-subjects design for our stress manipulation (there is a lot of flight-specific learning to MIDIS, so the same subject could not be run through the same flight under two different stress conditions without substantial performance improvement from the first to the second). Because only a limited number of subjects from the previous MIDIS experiment were available for this experiment, we were restricted to only two groups in the between-subjects design.

The cost of our decision to examine the four stressors in consort was some lack of resolution of stress effects within the framework of the information processing model. Yet all four stressors are predicted to impose specific loads on the "fragile" components of the model. The competition between pilots, enhanced by the financial rewards and penalties was believed to induce some level of anxiety, and noise is found to mimic those same effects (although it is important to note that the 74 dB intensity of noise stress used here is considerably less than the 100 dB levels typically employed in noise stress studies). Hence, both of these stressors are predicted by Hockey's stress signature analysis to shift the speed-accuracy tradeoff, and to reduce the breadth of cue sampling. Furthermore, these two should also combine with concurrent task loading to deplete working memory capacity, and combine with time-stress to exaggerate the restriction of cue sampling. Hence, our prediction is for the four stressors to operate in consort on those decision problems that heavily demand these fragile computation-intensive processes, but to leave relatively unaffected those problems that depend more on pattern matching through long term memory retrieval.

METHODS

Subjects

The subjects were 20 instrument rated pilots with a mean level of 306 hours of total flight time and a range of 155 to 520. All subjects were recruited from the sample that had served in the previous MIDIS experiment (Wickens et al., 1987). Subjects were selected to fall in the mid-range of flight experience of the original sample, and were chosen with the constraint that each subject could be "paired" with another who had roughly equivalent flight hours and optimality score on the previous MIDIS flight. A subsequent examination also revealed that the two groups did not differ significantly from each other on the cognitive abilities, assessed prior to the previous experiment. In this way, a set of matched pairs was constructed, allowing greater comparability between the stress and non-stress group.

Task

MIDIS has a full, high-fidelity instrument panel based on a Beech Sport 180, the type of aircraft used for training at the University of Illinois Institute of Aviation. This display, implemented via the HALO graphics package and 16 color Enhanced Graphics Adapter, represents a full IFR "blind flying" panel with operating attitude, navigational and engine instruments. The MIDIS software allows the readings on the instrument panel to change throughout the course of the "flight" in synchrony with the prevailing scenario. These changes may occur either discretely or continuously. MIDIS does not attempt to simulate the flight dynamics of an aircraft from control inputs. Rather it imposes judgment requirements by presenting a series of time slices or "scenarios" in the course of a coherent unfolding flight, schematically represented in Figure 2. Note that at some points the subject's choice of action can affect the nature of the flight, and therefore the

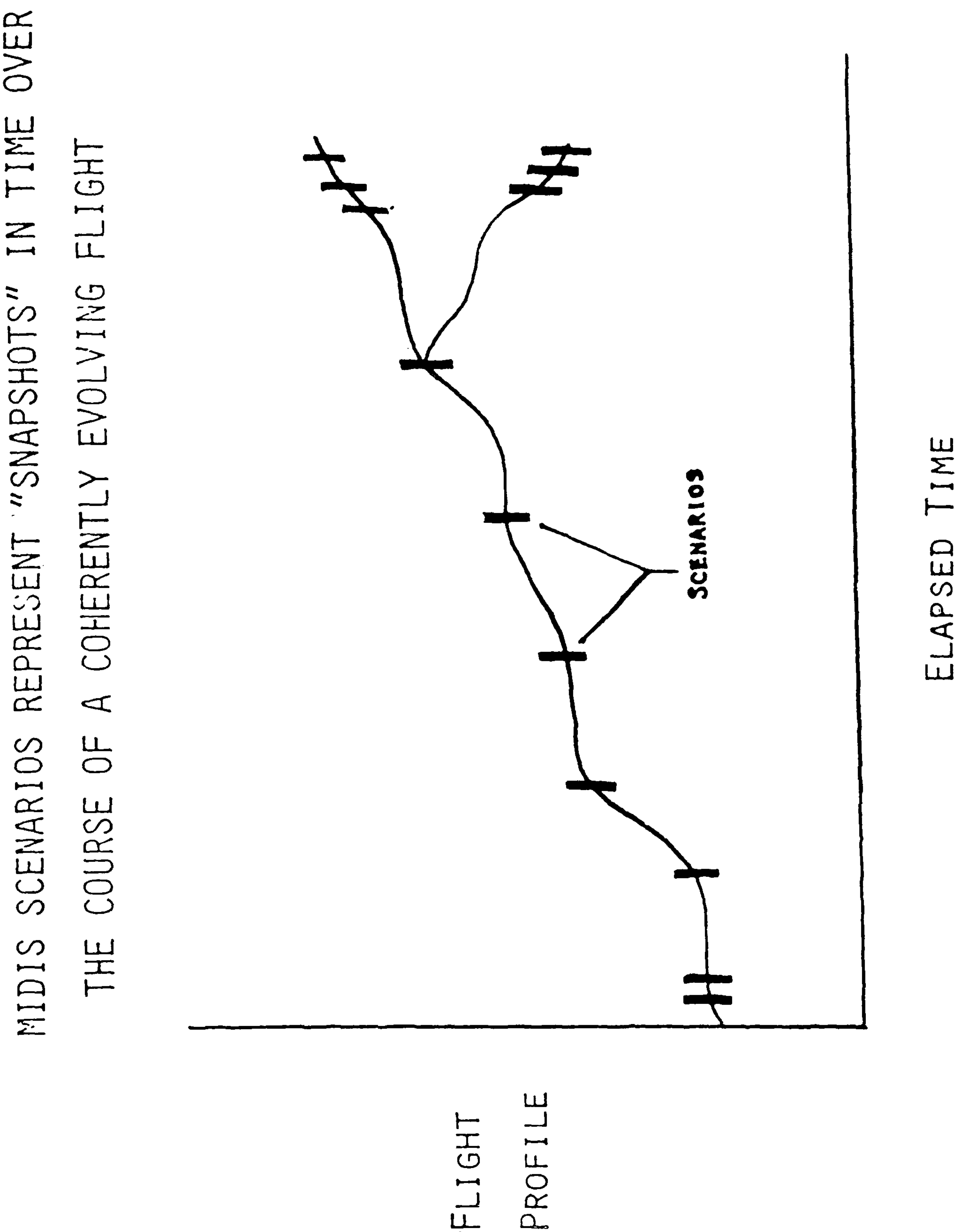

Figure 2. Schematic Representation of a MIDIS Flight.

content of future scenarios. Figure 3 presents a screen print of the MIDIS display.

A scenario can be defined by either the instrument panel together with a text description of particular circumstances, or by the particular normal or abnormal configuration of the instrument panel alone. These two representations are known as static and dynamic scenarios, respectively. Where text accompanies the panel, the instruments are stable - showing no rate of change. In the dynamic scenarios, when there is no text, the instruments can show a rate of change. This allows us to study an important class of decisions, those involving the detection of changes and the integration of decision cues in real time. The dynamic scenario may represent a problem or it may not. A problem scenario is one in which the circumstances have clear and present implications for the efficiency or safety of the flight, requiring diagnostic and corrective action to be taken. For example, it may involve a loss of oil pressure, or a rate of climb that is too slow for the given power setting.

After viewing the static display describing the scenario, subjects press the return key to request the options. After viewing these, the number of the selected option is indicated by a keypress, and this is to be followed by a second numerical keypress to indicate confidence on a scale ranging from 1 to 5. This response automatically steps the program forward to the next flight scenario (which may or may not be contingent upon the nature of the response). When a dynamic scenario is viewed (e.g., portraying steady state flight through turbulence, or recovery from an evasive maneuver), subjects are allowed to press a special key to indicate whether they believe that an abnormality has occurred. After the dynamic scenario is played out (usually 1-3 minutes), assuming that a failure actually has occurred, the list of

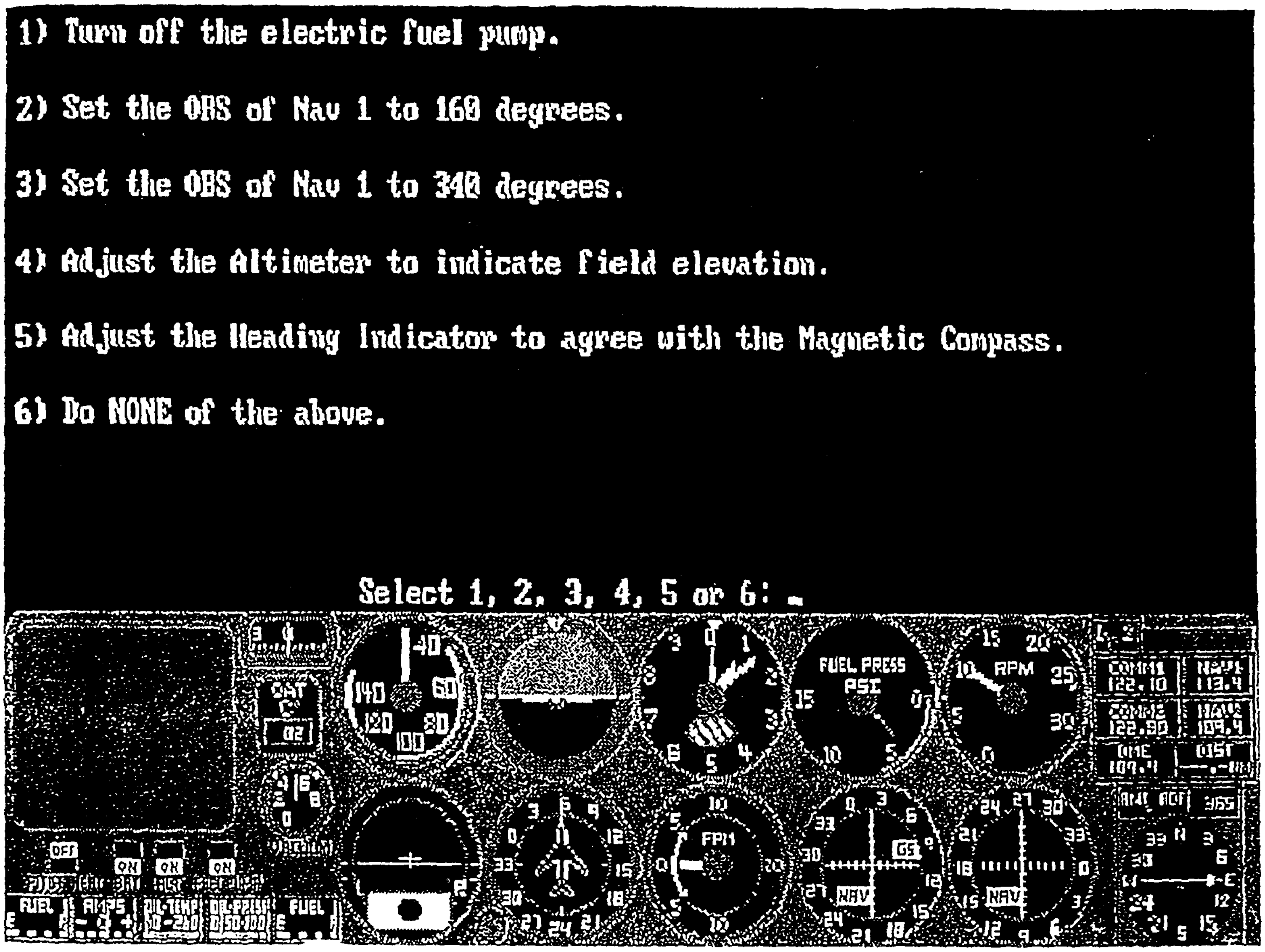

Figure 3. A representative MIDIS display panel.

possible options is presented and the subject proceeds as in the static scenarios.

Altogether 38 scenarios were presented in the flight, 17 of which were dynamic. In addition to those dynamic scenarios which involved a problem, the flight consisted of a number of episodes of non-problem flight, preserving some of the natural dynamic characteristics of normal flight.

Seven performance variables were monitored, most of them unobtrusively. Four of these relate to response selection: decision choice, optimality, decision time (latency), and decision confidence. Each subject's mean reading speed was unobtrusively calculated in syllables per second during the reading of the program run instructions. Since scenarios and options were analyzed for word and syllable counts, as described above, individual differences in reading speed could then be factored out of the data.

Attribute and Option Coding

After creating each MIDIS scenario, the flight instructor on the design team proceeded to generate two kinds of codes, which were applied to, and characterized, the scenario in question. First, each option in a decision scenario was assigned an optimality rating, on a scale from 5-1, in which the correct (best) option was assigned a value of 5. The less optimal options were assigned values ranging from 1-3, depending upon how close they were to being plausible alternatives. Second, the correct option in each scenario was assigned an attribute value code for each of the 11 critical cognitive attributes listed in Table 2. These attributes were selected based upon our content analysis of the flight scenarios in MIDIS, guided by our expert analysis of pilot judgment. A value of zero indicated that the attribute was not relevant to the decision. Values from 1-3 indicated how critical it was for the subject to possess strength in the attribute in question, in order to choose the optimum option. In this way each scenario can be characterized by a profile of demand levels which allow prediction of how it should be affected by stress.

Secondary Task/Stress Manipulations

The secondary task consisted of a Sternberg memory search task (Sternberg, 1975). Prior to the beginning of the MIDIS flight, subjects were presented with a 4 letter memory set which they were to memorize. Subsequently during the flight, probe stimuli (single letters) would appear in the blank panel on the left side of the instrument panel as shown in Figure 3. These stimuli would occur at semi-random intervals from 2 to 7 seconds following a response, and subjects were instructed to indicate with a keypress response whether the letter was or was not a member of the memory set. Target members were presented on 50% of the trials. Letters were displayed in relatively large format (1.5 cm square). When subjects were seated a standard distance of 2/3 meter from the display, the letters could be perceived in peripheral vision even when fixation was on the far corner of the display. Presentation of the noise, an annoying computer-generated squawking sound of 74 dB spl, was governed by two independent procedures: (1) there was contingent noise, which would only be presented if the subject failed to respond correctly to the Sternberg task within 4 seconds after stimulus presentation. This noise remained on for a duration of 12 seconds, unless the subject subsequently made a correct response. When a correct response was made, the noise terminated after a fixed duration of 2 seconds, and the next stimulus letter was presented. (2) Bursts of noise at random times of 15 seconds' duration which would appear independent of the subjects' action. Thus, by appropriately dealing with the secondary task, subjects could eliminate half of the distracting noise.

Procedure

Subjects participated for one session of approximately 1 1/2 hours' duration. Subjects were first instructed on the details of the MIDIS system. They were then introduced to the specifics of the flight from Saranak, New York to Boston's Logan Airport and were allowed up to half an hour for pre-flight planning, during which time they were given maps of the relevant airspace and meteorological information. Subjects in the stress conditions were then given instructions regarding payoffs and secondary task requirements. They were instructed that the consequences of ignoring the secondary task would be twofold: (1) to initiate the annoying noises, (2) to deplete a pool of financial resources--$8.00 that was reserved for them contingent upon completing the flight, while meeting the various performance criteria. The pool was depleted at a rate of 10 cents for every secondary task stimulus that was missed, or responded to correctly after the deadline. In addition, this pool was depleted by $1.00 for every five minutes that the flight extended beyond 1 hour (not to deplete total earnings below $5.00). This contingency was included in order to impose an overall level of time stress on the flight task. The 1 hour baseline estimate was derived on the basis of the mean performance of the non-stressed group, all of whose data had been collected prior to running subjects in the stressed condition.

All subjects in both groups were paid a base rate of $7.50 for the session. In addition, subjects in both groups were in competition for a first prize of $10.00 for the top scorer in the flight, and two second prizes of $5.00. Scores were based upon a combination of optimality and latency, and the competition was implemented in order to insure a high motivation to meet the criteria of safety and efficiency.

RESULTS

The data were analyzed from two perspectives with increasing levels of specificity regarding the effects of the stress manipulations. The first analysis was intended to determine if the manipulations had any overall effect on performance; the second analysis assessed the specific pattern of those effects on problems of differing types of demand.

At the first level of analysis, there was a clear reduction in performance for the stressed group. This reduction was evident in decision optimality ($F_{1,9} = 6.41$; $p = 0.032$) and in the lower level of confidence ($F_{1,9} = 5.18$; $p = 0.05$), but not in terms of an increase in decision latency ($F < 1$). The absence of an effect on latency was anticipated because a major component of the stress manipulation was indeed the imposition of time pressure; the incentive to respond more rapidly. It is important to reiterate here the group matching procedure employed in our design, which assured that the two groups did not differ from each other in terms of flight experience or aviation decision making abilities (as assessed from the first MIDIS flight). Hence differences that we observed here can be reasonably attributed to the experimental manipulations that were imposed.

To accomplish the second level of analysis detailing the more specific effects of our manipulations, it was necessary first to define subsets of problems that were rated high, medium, or low on different cognitive attributes. The factor analysis of cognitive abilities from the earlier MIDIS study (Wickens et al., 1987) had revealed three important attribute clusters related to spatial demands, working memory demands, and knowledge demands. Our objective in the current research was to identify problems that were rated high, medium, and low on each of these attribute clusters. To assess spatial demands, the coded value of attributes related to flexibility of closure and visualization of position (see Table 2) were summed for each scenario, and the scenarios were then assigned to one of three categories of spatial demand. The categories' values depended upon whether the sum was 0 or 1 (low), 2 or 3 (medium), or 4 to 6 (high). This categorization scheme assigned roughly thirteen scenarios each to the low, medium, and high spatial demand category.

A similar procedure was employed to categorize problems into three levels of working memory demand, and three levels of dependency on stored knowledge. In the former case, coded values were summed across the attributes of simultaneous mental integrative processes, sequential memory span and logical reasoning (Table 2), all of which impose intense demands on working memory. The resulting scheme assigned approximately equal numbers of scenarios to the low, medium, and high memory demand conditions. To categorize problems on the basis of stored knowledge, the coded values were summed across the two attributes of declarative knowledge and risk utilization. Here 3, 18, and 17 problems belonged to the low, medium, and high categories respectively. (The small number of problems in the "low" category reflects the fact that most decision scenarios that were created required a substantial degree of declarative knowledge in this context-specific domain.) Table 3 provides examples of the static decision problems that were coded low and high respectively on each of the three "macro attributes."

Figures 4 a, b, and c present the mean optimality scores across the three demand levels, when these levels were coded by spatial demand, knowledge demand and memory demand respectively. The two curves in each figure represent ratings of the control (solid line) and stressed (dashed line) groups. Examining first the spatial demand analysis, three features are evident. First, the stressed group shows a reduced level of optimality. This finding of course represents a restatement of the result presented in the

Table 3. Examples of Low and High Attribute-Coded Problems

1. Low Spatial

After performing a preflight, including your weather briefing, and avionics checks you check the weight and balance. Using the weights provided during your preflight, you determine that the aircraft is 28 lbs over maximum allowable gross takeoff weight and within CG limits. You proceed as follows:

a) You are not concerned about the 28 lbs, as you will burn this off before takeoff.

b) You are not concerned, as the weights of passengers and baggage are not that accurate to begin with.

c) You know the density altitude is high today and you will drain an additional 5 gallons of fuel.

2. High Spatial

You are climbing and are in and out of altocumulus clouds, you are looking for the traffic, but have negative contact with the advised traffic. You are aware that you will need to level off while entering the hold and maintain hold air speed. ATC advises VFR traffic 11 o'clock 2 miles westbound intersecting course, altitude fluctuating, indicating 9000 at present unverified.

a) You acknowledge the advisory with "negative contact" and continue climbing and looking for traffic. You recognize that with your wind correction the traffic is more like your 10 o'clock position.

b) You acknowledge the advisory with "negative contact" and request vectors around the traffic.

c) You commence an immediate right turn using a bank of about 45 degrees and advise ATC of your turn and that you would like to continue in a "360" until traffic is no longer a factor.

d) You commence an immediate left turn using a bank of about 45 degrees and advise ATC of your turn and that you would like to continue in a "360" until traffic is no longer a factor.

3. Low Memory

While climbing to 7000 feet, initial contact is made with Boston Center. They advise "radar contact, advise reaching 7000." As you climb through a broken layer you experience light turbulence. Once on top you see widely scattered cumulus with tops you estimate to be between 10000 and 15000.

a) Your mode C is probably not working, you will confirm this with Boston Center.

b) Convective activity is unlikely to present a problem as you should be able to circumnavigate this activity.

c) Mode C is probably "ok," ATC simply needs to verify their readout.

d) Convective activity is probably going to present a major problem on this flight.

4. High Memory

As you approach GRISY intersection you wish to retune your navigation radios to identify GRISY. You make the following changes.

a) You set the #1 nav to 115.1(CTR) with the OBS set to 016 and the DME to 110.6(GDM).

b) Tune the #1 nav to 110.6(GDM) with OBS set to 118, the DME to 110.6(GDM), and leave the #2 nav on 117.8(ALB).

c) Tune the #1 nav to 110.6(GDM) with the OBS set to 118, #2 nav to 115.1(CTR) with the OBS set to 016, and the DME set to 110.6(GDM).

5. Low Knowledge

You are just about to your clearance limit and are about to call Boston Center when they call you. "Sundowner 9365S hold northwest of Keene on the 339 radial maintain 7000, expect further clearance, as requested, at 1815Z, time now is 1754Z.

a) You need to slow the airplane up and you should have called ATC sooner.

b) ATC expects that you will intercept the 339 radial prior to the fix, and have reduced your air speed to 80 knots.

c) You are required to read back the clearance and report when you are established in the hold. ATC should have given you the hold on the 350 radial.

d) You will slow the aircraft up and make a direct entry to the holding pattern. You should have contacted ATC sooner.

6. High Knowledge

Boston Center informs you to maintain your original course and that they will have a turn for you in approximately 5 minutes. The turbulence has not abated. You ask if there is conflicting traffic at your altitude and are informed that ATC needs the time to process a new route for you.

a) You inform ATC that you are proceeding from your present position direct to Cambridge VOR and request clearance from Cambridge via 169 radial to GRAVE, V2 GDM, V431 BOS as you understand that course is south of the convective activity.

b) You request of ATC to remain out of the area of cumulus build-ups informing them that you either need to proceed south or west to insure this. You also request clearance to Cambridge, Cambridge 169 radial to GRAVE, V2 GDM, V431 BOS.

c) You WILCO ATC's instructions and request a clearance from your present position direct to Cambridge VOR and request clearance from Cambridge via 169 radial to GRAVE, V2 GDM, V431 BOS as you understand that course is south of the convective activity.

---

overall analysis presented above. Second, there is a main effect for spatial demand on optimality (F - 9.73; p - 0.002). Problems coded higher on the spatial demand attributes generally yielded less optimal decision choices. Third, this effect seems to be primarily confined to the stress group, and the interaction between these two variables approached statistical significance (F2,18 - 2.99; p - 0.075). (When the analysis is repeated with only the two extreme levels, this interaction is significant; F1,9 - 5.64; p - 0.042--in spite of the reduced number of degrees of freedom.) Therefore, the data in Figure 4a suggest that problems with high spatial demand are particularly sensitive to the degrading influence of our experimental stress manipulations.

The data in Figure 4b also show a clear dependence of problem optimality on problem demand. Those scenarios that call for greater utilization of declarative knowledge and risk assessment yield significantly less optimal choices (F2,18 - 24.4; p < 0.001). However, this effect is identical for the two groups, thereby suggesting that the effect of knowledge demand is immune to the effects of stress (F interaction < 1). Here again one of the proposed hypotheses is supported: Problems dependent upon direct retrieval of stored knowledge information are relatively unaffected by stress influence.

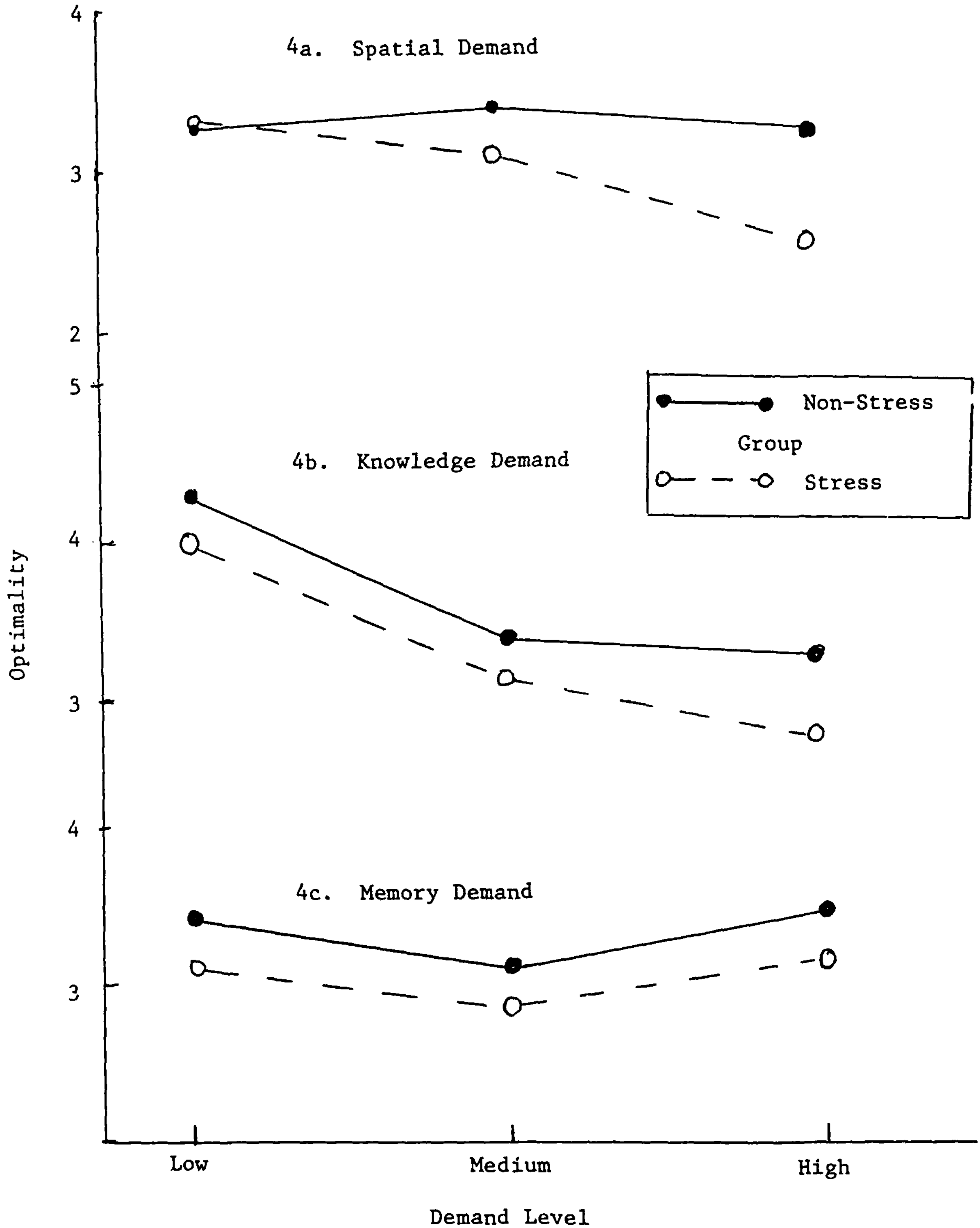

Figure 4. Effect of 3 kinds of demand level on decision optimality for subjects in stressed (dashed line) and control (solid line) group. Top: Spatial demand. Middle: Knowledge demand. Bottom: Working memory demand.

The data in Figure 4c, presenting optimality as a function of working memory demand, present a less interpretable pattern. There is once again a main effect of stress (this is the same as that viewed in Figure 4a since the total set of problems is identical). However, beyond this, there are no significant effects. Working memory demand as coded in our problems does not affect optimality, nor are problems coded high on this demand more sensitive to the degrading effects of stress than the problems that are rated low.

The effect of problem difficulty on the confidence ratings and response latencies was also not informative. As noted above, confidence was lower for the stressed group than for the non-stressed group. However, across the problems coded by working memory demand and spatial demand, the effect of problem demand on confidence, while significant, was non-monotonic.[1] Only for problems categorized by knowledge demand was the effect of demand significant and monotonically related to demand level. Ironically the effect of knowledge demand was reversed from the effect on optimality. Problems that required higher knowledge (which had received less optimal responses) were responded to with <u>greater</u> confidence than the problems that required less knowledge demand.

As noted above, latency was not affected by stress manipulation, nor did this manipulation interact with problem demand for any of the three coding schemes. Latency was affected in a non-monotonic fashion by spatial demand ($F2,18 = 16.8$; $p < 0.001$), and was <u>reduced</u> for problems with increasing knowledge demand ($F2,18 = 7.60$; $p < 0.01$).

The previous analyses have considered both static and dynamic scenarios together. The differential effect of the stress manipulations was also examined for static and dynamic scenarios separately, as shown in Table 4 which presents the mean optimality, confidence, and latency measures for the two groups of subjects and the two types of decision problems. Inspection of

Table 4. Effect of Stress Manipulation on Performance of Static and Dynamic Scenarios

	Static Scenarios		
	Control Group	Stress Group	t - Value
Optimality	3.37	3.27	t = 0.86 p = 0.412
Confidence	3.97	3.66	t = 1.93 p = 0.085
Latency	12.33	15.45	t = -0.88 p = 0.400
	Dynamic Scenarios		
	Control Group	Stress Group	t - Value
Optimality	3.33	2.71	t = 4.15 p = 0.002
Confidence	3.75	3.27	t = 2.11 p = 0.064
Latency	7.47s	10.44s	t = -1.00 p = 0.342

this table reveals that the effects of the stress manipulations on optimality were primarily confined to the dynamic scenarios. During the static (text-based) scenarios, stress did produce a loss in decision confidence, but brought about no significant reduction in decision optimality.

Secondary task performance was also analyzed, and revealed a mean response latency of 2.9 seconds, well above the value that would be expected from single task performance of the Sternberg task (around 500 msec). Subjects were also generally quite accurate in performing the secondary task, with a mean error rate of 6.6%. Two of the eight subjects appeared to have neglected the secondary task substantially more than others, producing a skewed distribution of latency and accuracy. The median values for these two measures are therefore considerably lower (2.6 sec and 3% respectively).

DISCUSSION

In our experimental examination of the influence of stressors on pilot judgment, it was first important to demonstrate that the manipulations had indeed imposed a cost on decision making quality. The performance data in Figure 4 suggest that such an effect was in fact obtained. This result in itself is significant and important, for in spite of the many anecdotal reports of stress effects on pilot judgment, only one experiment located in the literature has actually manipulated stress and systematically induced a performance decrement on domain-specific decision behavior (Bronner, 1982). Even in Bronner's study, the problems were far more structured and homogeneous, dealing with utility-based business marketing decisions, than were the heterogeneous set of problems used in the current study. Hence, the demonstration in the current study that stress manipulations can degrade performance, while in hindsight perhaps not surprising, remains an important initial finding.

The effects that we did obtain are both interpretable and predictable under either of two stress models that may be adopted. According to the cognitive appraisal model (Stokes et al., 1987), the highly salient demands of the secondary task, and the repeated occurrences of the annoying noises were constant reminders to the subjects that they were unable to cope with the demands of the decision environment. Although subjects were not explicitly asked to rate the perceived demands of the environment, nor their inability to cope, comments made by subjects in the stress group after the sessions revealed that the experience of the side task and the noise was highly salient. According to a cognitive appraisal model, therefore, our manipulations were successful in creating the conditions for a selective degradation of decision performance.

The qualitative nature of this degradation may be partially predicted by Hockey's stress signature analysis. In the first place the observed effect corresponds roughly to the predicted speed-accuracy tradeoff. Accuracy was clearly lost under stress, but there was no corresponding loss of speed. Secondly, we chose a sufficient number of manipulations (noise, resource demand, time pressure, and financial risks) so that problems depending heavily upon both working memory and the distribution of attentional resources were predicted to suffer. In the current analysis we selected three broad "macro attributes," which could be used as dimensions for categorizing the set of 38 problems in terms of different demand levels: spatial demand, working memory demand, and knowledge demand. Each of these will be discussed in turn.

Two cognitive attributes, rated by our flight instructor, were employed in conjunction to define problems of high spatial demand. These were flexibility of closure, and visualization of position. Flexibility of closure defines the ability to locate visual information in a complex perceptual field. Visualization of position defines the spatial awareness necessary to locate one's aircraft in space, relative to ground landmarks, weather patterns, and other traffic, and to mentally translate and rotate the aircraft representation as needed. Both of these abilities clearly demand some degree of spatial working memory (Baddeley, 1986; Wickens & Weingartner, 1985), and the working memory system is predicted to be susceptible to stress manipulations like those used in the present study. The results in Figure 4 showed that decision performance did degrade to the extent that problems were coded high on this attribute of spatial demand.

Which or how many of the four manipulations were responsible for the degrading effect cannot of course be determined from the current data since we purposely manipulated all four together. One possibility is that the total effect was due simply to the visual scan time imposed by the secondary task stimulus. In this case the effect could not really be labeled one of stress at all, but simply one resulting from the delay in attaining the necessary information. We have some reason however to doubt that this was the sole source (or even the primary source) of the effect. Our argument is based on the fact that the time required to encode the single letter stimuli, whether processed in foveal or peripheral vision can be estimated to be in the order of 1/4 second. With secondary task stimuli arriving at a frequency of roughly one every seven seconds, this would indicate that only 1/28th of the total time was required for visual attention to be directed away from the MIDIS display; not really enough to produce the magnitude of performance decrement observed here. Hence, it is presumed more likely that the effects were the result of degraded perceptual/cognitive processes, and not simply receptor-level effects. Nevertheless, our future work in this area will be devoted to more specifically establishing the independent effects of the separate variables.

The present data also indicate that our manipulations did not simply produce equivalent effects across all decision problems, as revealed by the absence of stress effects when the spatial load was small (Figure 4a). Correspondingly a conclusion that any manipulation of problem demand might enhance the degrading influence of stress is countered by the analysis of problems categorized by the second macro attribute--knowledge demand. Here we had combined two cognitive attributes--declarative knowledge and risk utilization--that were suggested in our previous study (Wickens et al., 1987) to cluster together both in terms of cognitive abilities and in the prediction of decision performance. When problems were ordered according to the demands of this attribute, the information processing analysis was again nicely supported. Problems with high demand for the direct retrieval from long term memory, while performed less optimally, were no more disrupted by the stress manipulation than problems without such demand. Within the framework of the model, this direct retrieval process is not one that engages heavy reliance on the "fragile" information processing components of attention and working memory, and hence was not predicted to suffer a degrading effect of this sort.

These conclusions with regard to direct memory retrieval are certainly compatible with those drawn from our previous study. In that study we found that decision performance of skilled pilots depended less on the fragile information processing components, and we hypothesized a greater dependence on the direct retrieval schemes postulated above.

A second interesting characteristic that emerged from our analysis of the coding of problems by knowledge demand concerned the tradeoff between decision optimality on the one hand, and latency and confidence on the other. As problems required more dependence upon declarative knowledge, the decisions were less optimal, but were made more rapidly with greater confidence. This tradeoff illustrates a phenomenon that Fischoff (1977) and Fischoff and MacGregor (1981) have examined in other domains of decision making and forecasting, and labeled "cognitive conceit." It describes the tendency of people to become over confident in the extent of their own knowledge of the world. The current data indicate that this tendency is manifest in our pilot subjects as well.

While the ordering of problems by spatial demands and by knowledge demand both present a coherent set of data consistent with the information processing model, when problem difficulty was ordered in terms of working memory demand (i.e., logical reasoning and integrating information), a puzzling picture emerged. Problems of greater coded demand on working memory were not responded to less optimally, nor were those problems more influenced by the stress manipulation. There are three possible interpretations to these negative results. These may be offered if the premise is accepted that working memory capacity _is_ resource limited, and therefore should be sensitive both to the diversion of resources allocated to the concurrent task and to the anxiety-producing stress effects that were shown to have robust effects on other aspects of processing.

The first possibility is that the decision model, captured in Figure 1, is incorrect and that most decision problems do not involve the "workbench" of working memory. While this possibility is acknowledged, it does contradict an intuitive analysis of decision making, as well as previous work which has found effects of secondary task loading on computational-intensive decision performance (Barnett & Wickens, 1986). Thus, a second possibility is that our coding of working memory demands may be inaccurate. This would explain jointly the lack of effect of problem demand and absence of interaction of memory demand with stress level. The potential for such inaccuracy exists because, at this point, only one set of attribute codings have been used, those assigned by a single flight instructor. Prior to further analysis, attribute coding from a second analyst will be obtained. Yet a third possibility relates to the lack of independence of attribute levels across problems. Thus, it is possible that performance on those problems that were coded low on memory demands was dominated by particularly high problem demands on a different resource-sensitive attribute. This possibility too is the subject of future analysis.

In conclusion, the results of the current analysis have shown a relatively substantial degree of internal consistency between three sets of variables: model predictions, difficulty demand, and stress effects. Where the model predicts stress effects and performance indicates that a demand effect was obtained (spatial demand), a stress effect was found. Where the model predicts no stress effect (knowledge demand), none was found, in spite of the observed effect of demand. Finally, when no difficulty effect was observed (working memory demand), then no stress effect was found. The only surprise here is why no effect of working memory demand was found in the first place, a question that is currently being examined. In any case, the results are promising and suggest that the model, and the MIDIS task to which it has been applied, represent important elements for the experimental examination of the critical interface between stress and pilot judgment.

ibm>karen>chris>inelfin.rep/02-01-89

REFERENCES

Baddeley, A. (1986). Working memory. Oxford: Claredon Press.

Barnett, B., & Wickens, C.D. (1986). Non-optimality in the diagnosis of dynamic system states. University of Illinois Cognitive Psychophysiology Laboratory (Tech. Rep. CPL-86-8). Champaign, IL: Department of Psychology.

Broadbent, D. (1971). Decision and stress. New York: Academic Press.

Bronner, R. (1982). Decision making under time pressure. Lexington, MA: D.C. Heath.

Connolly, T.J., Blackwell, B.B., & Lester, L.F. (1987). A simulator-based approach to training in aeronautical decision making. Proceedings of the Fourth International Symposium on Aviation Psychology.

Fischoff, B. (1977). Perceived informativeness of facts. Journal of Experimental Psychology: Human Perception and Performance, 3, 349-358.

Fischoff, B., & MacGregor, D. (1981). Subjective confidence in forecasts (Technical Report PTR-1092-81-12). Woodland Hills, CA: Perceptronics.

Hamilton, P., & Warburton, D. (1979). (Eds). Human stress and cognition. Chichester: John Wiley and Sons.

Hockey, G.J.R. (1984). Varieties of attentional state: The effect of environment. In R.S. Parasuraman & D.R. Davies (Eds.), Varieties of attention. Orlando: Academic Press.

Hockey, G.J.R. (1986). Changes in operator efficiency. In K. Boff, L. Kaufman, & J. Thomas (Eds.), Handbook of perception and performance. Vol. II. New York: John Wiley and Sons.

Jensen, R.J. (1981). Prediction and quickening in prospective flight displays for curved landing and approaches. Human Factors, 23, 333-364.

Lubner, M.E., & Lester, L.F. (1987). A program to identify and treat 'pilot error,' particularly, poor pilot judgment. Proceedings of the Fourth International Symposium on Aviation Psychology.

Simmel, E.C., Cerkovnik, M., & McCarthy, J.E. (1987). Sources of stress affecting pilot judgment. Proceedings of the Fourth International Symposium on Aviation Psychology.

Simmel, E.C., & Shelton, R. (1987). The assessment of nonroutine situations by pilots: A two-part process. Aviation, Space, and Environmental Medicine, 1119-1121.

Sternberg, S. (1975). Memory scanning: New findings and current controversies. Quarterly Journal of Experimental Psychology, 27, 1-32.

Stokes, A.F., Barnett, B.J., & Wickens, C.D. (1987). Modeling stress and bias in pilot decision-making. Proceedings of the Annual Conference of the Human Factors Association of Canada. Montreal, Canada.

Stone, R.B., Babcock, G.L., & Edmunds, W.W. (1985). Pilot judgment: An operational viewpoint. Aviation, Space, and Environmental Medicine, 56, 149-152.

Wallsten, T.S., & Barton, C. (1982). Processing probabilistic multidimensional information for decisions. Journal of Experimental Psychology: Learning, Memory, and Cognition, 8(5), 361-383.

Wickens, C.D. (1984). Engineering psychology and human performance. Glenview, IL: Scott, Foresman Pub. Co.

Wickens, C.D., & Flach, J. (1988). Human information processing. In E. Wiener & D. Nagel (Eds.), Human factors in aviation (pp. 111-155). New York: Academic Press.

Wickens, C.D., Stokes, A., Barnett, B., & Davis, T., Jr. (1987). Componential analysis of pilot decision making. University of Illinois Aviation Research Laboratory (Final Tech. Rep. ARL-87-4/SCEEE-87-1). Savoy, IL: Institute of Aviation.

Wickens, C.D., & Weingartner, A. (1985). Process control monitoring: The effects of spatial and verbal ability and current task demand. In R. Eberts & C. Eberts (Eds.), Trends in ergonomics and human factors. North Holland Pub. Co.

Wright, P. (1974). The harassed decision maker: Time pressures, distractions and the use of evidence. Journal of Applied Psychology, 59, 555-561.

FOOTNOTES

[1]The finding of a non-monotonic relation of performance across the demand level of one attribute is not surprising. This is because our scenario development did not insure that equal levels of all other attributes were preserved across all three levels of a given attribute. There was, in short the potential for correlation between attribute coding across scenarios. Hence, it is always possible, for example, that the middle level of demand on attribute A may contain a substantial number of problems that were coded high on attribute B.

☆ U.S. GOVERNMENT PRINTING OFFICE 1989 - 648-002/80235