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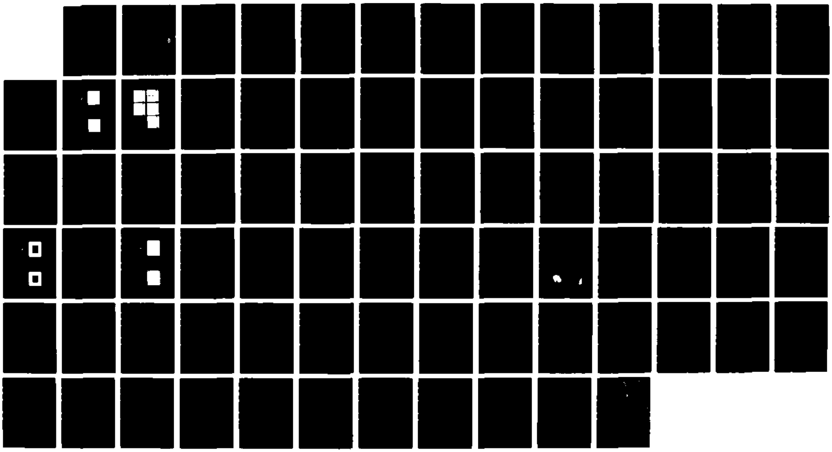

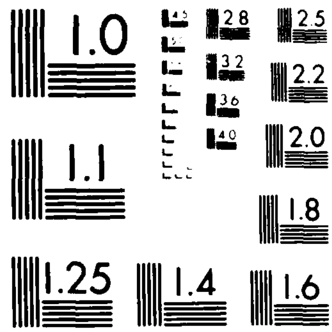
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QUANTIFYING SOME INFORMATION PROCESSING ASPECTS OF THE PILOT'S INSTRUMENT CROSSCHECK

A Dissertation Presented

by

Joseph L. Bunecke

Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
of the requirements for the degree of

Master of Science

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Industrial Engineering and Operations Research

QUANTIFYING SOME INFORMATION PROCESSING ASPECTS

OF THE PILOT'S INSTRUMENT CROSSCHECK

A Thesis Presented

by

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Chapter 1

INTRODUCTION

An aircraft instrument panel contains a multitude of data sources from which a pilot gathers the information needed to safely and efficiently control and navigate the aircraft during flight. In order to insure that instrument indications remain within specified tolerances, pilots switch their attention among/between the various displays by employing a visual scanning technique called crosscheck. While most studies of the pilot's eye movements attempt to model the crosscheck under ideal conditions in an effort to describe an optimal scan, this study approaches the issues from a training perspective to identify a potential cause of and to propose a possible solution to non-optimal scanning.

I've divided this analysis into eight chapters. To provide the context for this research, the first describes the task environment in which the pilot uses the crosscheck. In the second and third sections, I review pertinent literature to establish the crosscheck as a skill and use the Multiple Resource theory of attention (Wickens, 1984) as a base to present my rationale for teaching this visual scanning behavior in a part-task scenario. I speculate as to the potential benefits of teaching and developing crosscheck skills using a graphics-capable computer training-aid in the fourth section. In the final four chapters, I analyze the experimental data gathered by one such training-aid and describe the implications of the results in terms of the present methods of crosscheck instruction.

Chapter 2

TASK ANALYSIS AND DEFINITIONS

To put the instrument crosscheck into the proper perspective, one must realize that it is a small yet vital part of the more complex skills required to fly. Drowatsky (1975) identifies the "facility in making rapid comparisons of visual forms with accurate descriptions of similarities and differences" (page 269) as one of nine factors which contribute to a pilot's psychomotor skills. When there isn't a cloud in the sky, this rapid visual scan is not extremely important since ground references and the horizon provide ample visual cues (which are even peripherally sufficient) for the pilot to remain oriented to the earth.

One of the most challenging situations for both students and experienced pilots alike is flight in instrument meteorological conditions (IMC; the acronym is synonymous with the word "clouds" and defined as any situation in which the horizon is obscured and unusable for navigation). When flying in IMC conditions, the only way pilots can acquire information necessary to confirm and maintain their orientation to the ground is through a disciplined instrument crosscheck. When one considers the added demands of navigation, instrument approach procedures, threatening weather, and/or a system malfunction, it's obvious that maintaining aircraft control (and hence gathering the information pertinent to the situation) must be somewhat automatic.

To fit this description into a more formal context, consider the model of a generic pilot/aircraft system shown in Figure 1. Aircraft sensors detect and display environmental state information in the cock-

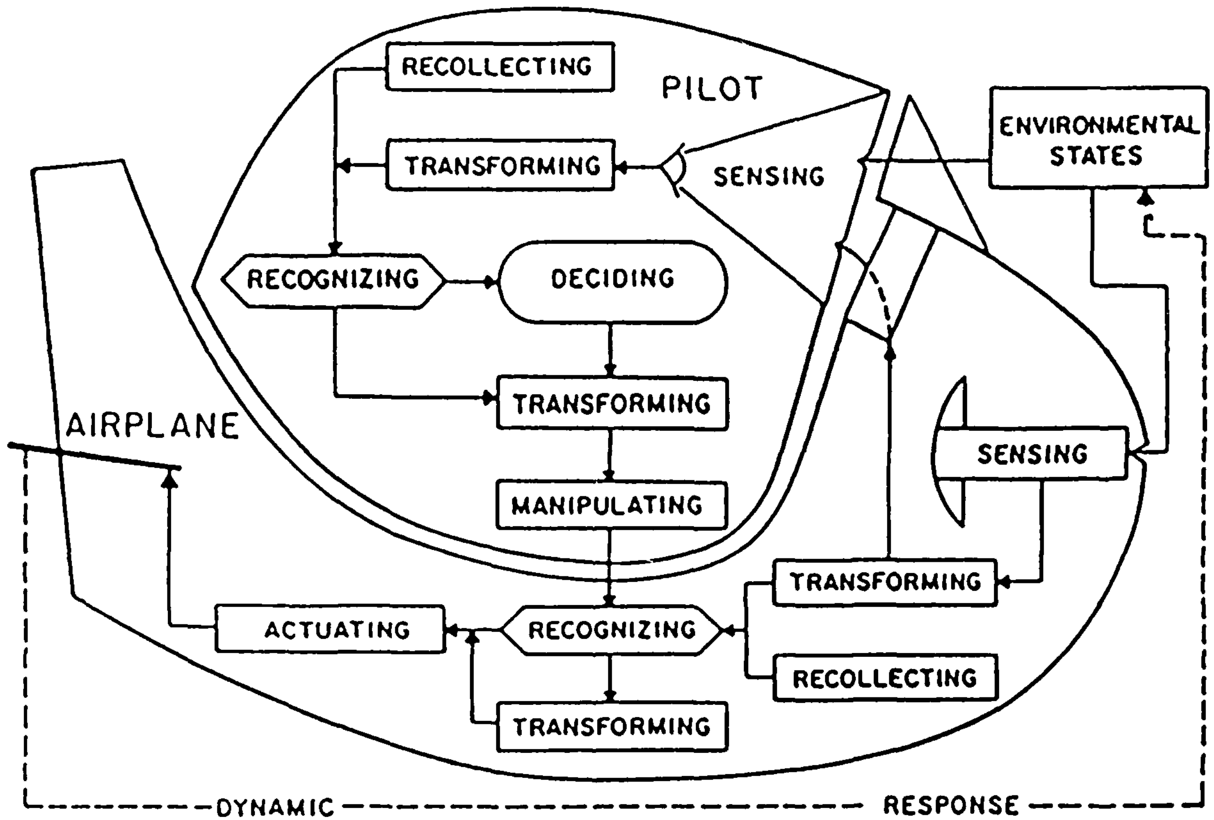

Figure 1. Pilot/aircraft system (Roscoe, 1980, pg 4).

pit, and during IMC flight, the pilot relies primarily on visual cues to transform displayed information into appropriate control inputs. In Roscoe's words:

> "the analysis of the transformations that pilot's must make in performing a given mission defines not only the information they must receive from the displays or the outside world but also the things they must do with that information to control the aircraft successfully" (1980, page 36).

Figure 2 defines the nature of the required processing in more specific terms. To complete any mission, the pilot must specify an overall goal, its related subgoals, and formulate indicies of desired performance with respect to the constraining factors of flight. Thus, at any point during the mission, a standard exists to evaluate progress. Although the hierarchical levels of the flight task are, for the most part, functional, they may also be delineated in temporal terms. Feedback at the lowest level is immediate, while the affects of these control inputs take incrementally longer amounts of time to become apparant at the outer levels. The pilot's task is to interpret the cockpit instruments (i.e., the indicies of actual performance), compare them to the indicies of desired performance, and act to null the differences between the two. Isolating the information processing involved in these transformations is the primary focus of this research, and in order to do so, defining some of the specific displays in terms of the flight task hierarchy is the next step.

Individual instruments may be categorized according to the type of actual performance they communicate. Control instruments (attitude indicator and tachometer) portray the aircraft's pitch, bank, and thrust. Performance instruments (altimeter and heading, airspeed, vertical

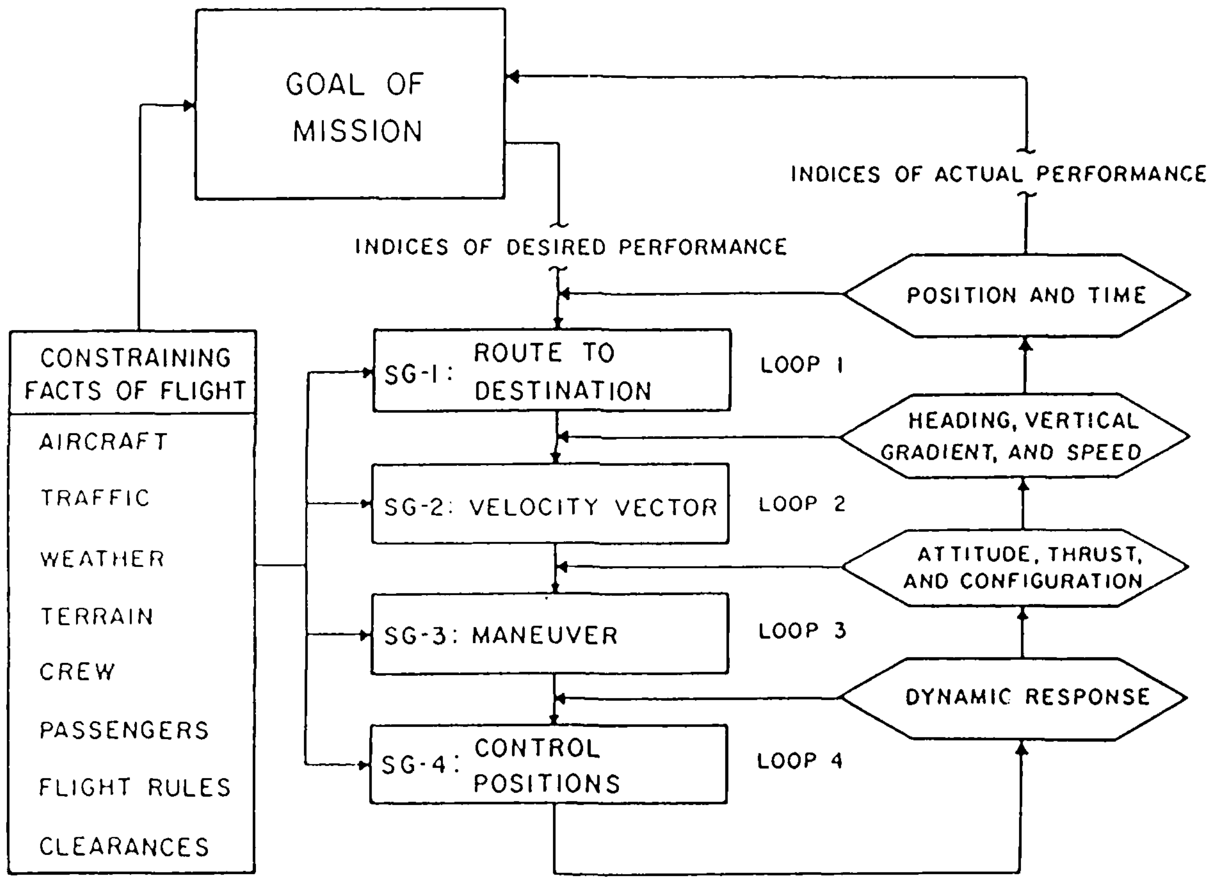

Figure 2. Hierarchical flight task (Roscoe, 1980, pg 36).

velocity, and turn and slip indicators) display the aircraft's vectors in three dimensional space, and the navigation instruments (horizontal situation indicator and distance measuring equipment) indicate the aircraft's position relative to selected topographical references (Air Force Manual 51-37). The control and performance instruments pertinent to this study are displayed in Figure 3, and for the purpose of comparison, Figure 4 depicts one type of navigation instrument. In a general sense, the processing required to maintain basic aircraft control (i.e., the moment-to-moment control of the heading, airspeed, and altitude vectors) is delineated by the lower three levels of the flight task hierarchy (Figure 2), while processing at the outermost level describes navigation. The design of each instrument display, to a large extent, determines the quality of the pilot-aircraft interface, but for the purposes of this study, individual display design is considered fixed. As aircraft evolved, however, other important design aspects accommodated human limitations in visual scanning.

Soon after the technological explosion of military hardware during World War II, early aviation psychologists realized that crosscheck efficiency was a direct function of ease of instrument interpretation and panel arrangement. Instrument design began to take stereotypical human conceptions and perceptions into account (Grether, 1949). The pioneer work of Fitts, Jones & Milton (1950) in measuring pilot eye movements, forms the basis for the design principles employed in constructing instrument panels in today's general aviation aircraft. Their analysis of link values of eye movements between instruments revealed a specific scan pattern. Fitts, Jones & Milton (1950), concluded that the most

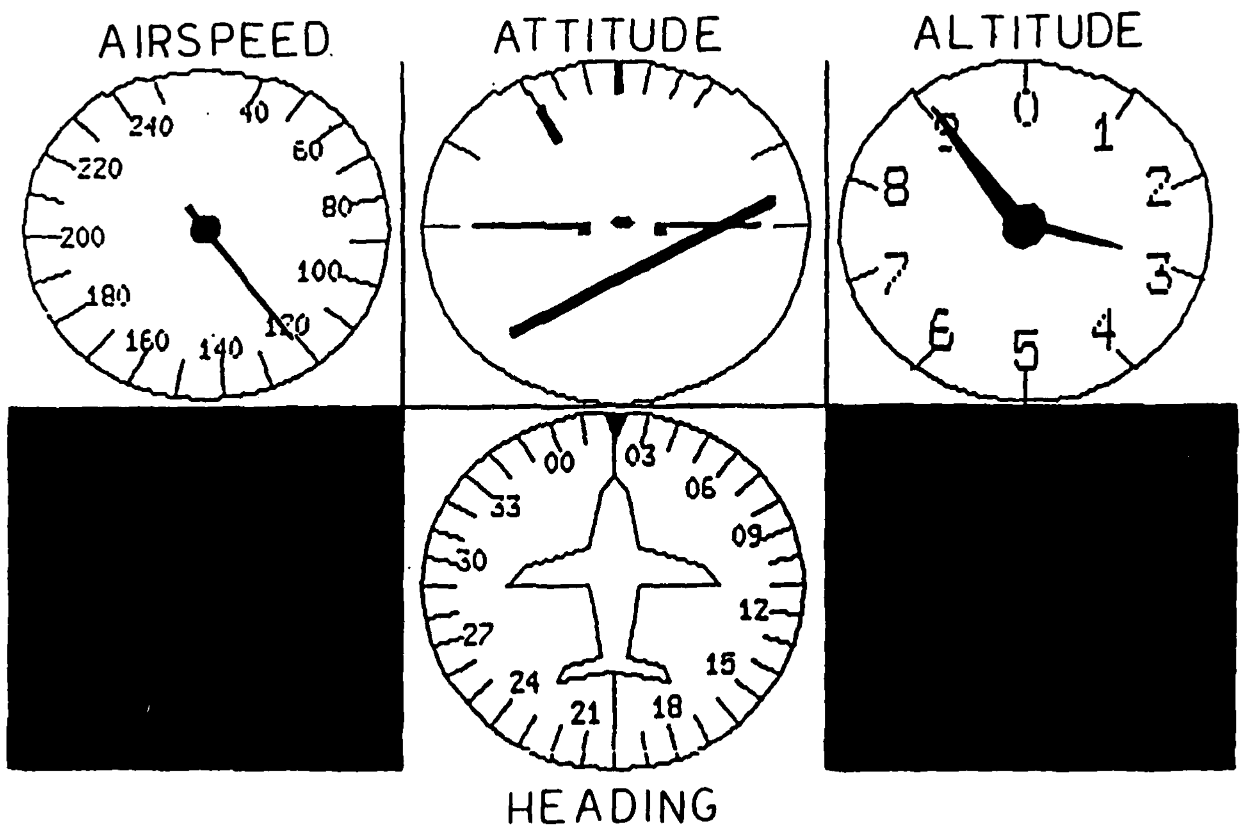

Figure 3. Control and performance instruments.

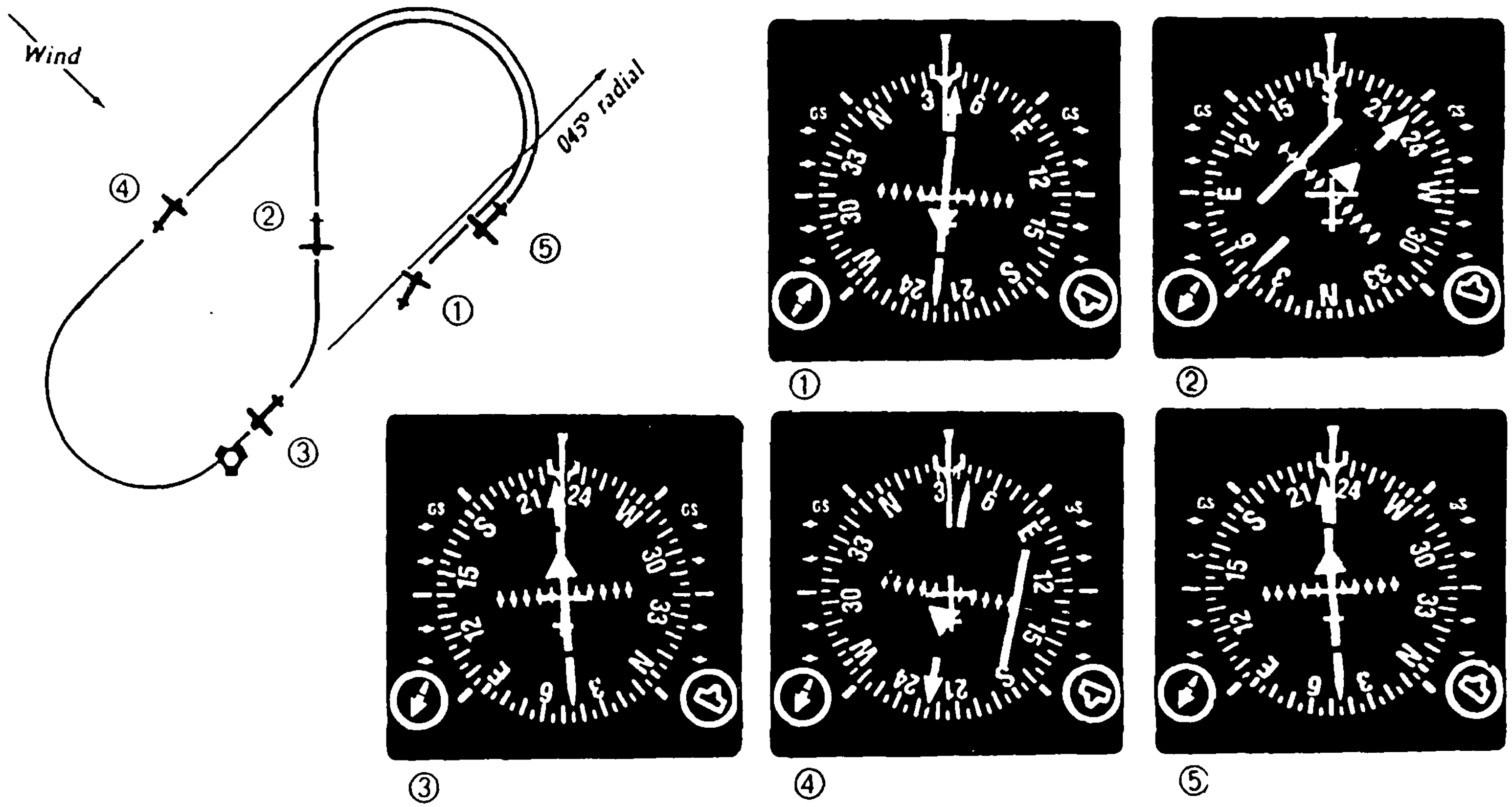

Figure 4. Navigation instrument (Horizontal Situation Indicator).

important instruments (as judged by the number of fixations) should be centrally located, and as a result, panel arrangement took on a distinct structure.

In an effort to standardize the crosscheck, the Federal Aviation Administration presently requires the relative positioning of the instruments displaying attitude, airspeed, altitude and heading to be consistent in all aircraft (FAR-AIM, 1986). Since the attitude indicator displays the aircraft's orientation to the horizon, the most critical parameter when flying in IMC, it is located in the top center position of the instrument panel. Research has confirmed that the attitude indicator is the instrument most fixated upon (Gainer & Obermayer, 1964; Senders, 1973), and crosscheck training emphasizes its importance. Air Force Manual 51-37 (AFM 51-37), Instrument Flying Manual, states that "devoting more attention to the attitude indicator is desirable to minimize the effects of the fluctuations and lag indications of the performance instruments" (1979, pages 2-4). "Attention to the attitude indicator is inserted between glances at the performance instruments. ... This crosscheck technique can be compared to a wagon wheel. The hub represents the attitude indicator and the spokes represent" (eye movements to) "the performance instruments" (pages 2-4). This sequential order corresponds to the lower three levels of the flight task hierarchy diagrammed in Figure 2, and is referred to as the "control-performance concept of visual scanning" (AFM 51-37, pages 2-1).

Chapter 3

THE CROSSCHECK AS A SKILL

The description of the crosscheck thus far has hinted that it entails more than just moving the eyes. How well a pilot flys depends, in part, on his/her ability to perceive, integrate and act upon the information displayed in the cockpit. More precisely, an effective crosscheck consists of: interpreting the instruments at a glance (average fixation duration is approximately 400 msec; Fitts, Jones & Milton, 1950; Gainer & Obermayer, 1964; Weir & Klein, 1970; Senders, 1973; Robinson, 1979); moving the eyes in an ordered sequence; and using perceptions to both formulate control movements and guide further scanning. Moray (1984) summarizes the pilot's visual sampling decisions as:

"1. Which instrument needs examination.

2. At what moment to examine it.

3. How long to examine it.

4. How to combine the information with other information the operator possesses.

5. Whether the new observation is reliable, or whether the operator would do better to rely on his or her partly forgotten knowledge.

6. What action to take, if any.

7. How the new information that he or she acquires is to be used to make further decisions as described in this list" (page 487).

This description fits neatly into Welford's (1976) skill classification scheme. Welford views human performance in terms of a model whose central processing mechanism translates some sensory input into a specific output, and he postulates that the central mechanism is capable of three kinds of skill development.

> "Perceptual skills consist of the coding of and giving coherence to sensory data ... and in the linking of this data to material stored in memory to give them context in space and time. ...
>
> "Motor skills are well practiced motor coordinations seemingly automatic and capable of being carried out without detailed conscious attention. ...
>
> "Intellectual skills, commonly thought of as sensory-motor skills, involve linking perception to the action implied in deciding what should be done" (1976, pages 12-13).

He classifies these skills in relative, rather than absolute terms, as a specific skill likely contains components of each. The crosscheck may be thought of as a perceptual skill since it primarily involves instrument interpretation, but it also has intellectual and motor components. The pilot must know which instrument to look at next (an intellectual skill) and be able to move his eyes quickly and repeatedly between instruments (a motor skill). Welford (1976) goes on to say that a common feature in the development of each skill is "the deployment of capacity in a manner which becomes more efficient with experience" (page 13). It follows that enhancing student pilot's perceptual, motor, or intellectual skills should speed crosscheck development.

Given that the crosscheck may be conceptualized as a skill in and of itself, one might raise the question of the validity of teaching it apart from overall instrument flight. Fitts & Posner (1967) would argue that task simplification is an aid to learning since complex skills are composed of simpler skills. Drowatsky (1975) summarizes several studies of whole verses part-task instruction and concludes that, in general, the whole method is appropriate in teaching simple skills, while a more fine tuned and error-free performance results from teaching complex skills using part-task instruction. However, skill acquisition by teaching component parts, really confronts two separate issues. First, is the crosscheck a candidate for separation? Is it necessary to teach it as a separate skill? Secondly, if separated, what should be taught to insure a positive transfer of training?

Chapter 4

THE VALIDITY OF PART-TASK INSTRUCTION

Using Wickens' Multiple Resource theory as a basis, I argue that the crosscheck should be taught as a separate part of instrument flight. To explain the consequences of dual task performance, Wickens (1984) states that humans possess several different capacities with resource properties. In reality, instrument flight does not consist of two mutually exclusive tasks, yet basic aircraft control (i.e., heading, altitude and airspeed control) might be considered as the primary task and the incremental application of navigation procedures in applied situations (i.e., instrument approaches) qualify as secondary tasks. Basic aircraft control, a task in which a student must demonstrate proficiency prior to even attempting instrument flight, should, at some level of experience, become a perceive and react task, and therefore utilize minimal resources. In other words, the information processing required to maintain basic aircraft control should eventually become automatic in the sense that it will not consume attentional resources. Navigating via the instruments alone requires compliance with specific procedures and a conceptualization of aircraft position relative to earth reference points. Recalling the functional and temporal distinctions along the flight task hierarchy (Figure 2) and comparing the performance instruments in Figure 3 with the navigation instrument in Figure 4, implies that navigation imposes more of a cognitive load than does maintaining basic aircraft control. As Figure 2 implies, however, basic aircraft control is a part of navigating, and as such, the two tasks are not entirely separable; yet Multiple Resource theory accurately characterizes their combination. In the context of time-sharing in dual task studies, Wickens proposes that

> "resources may be defined by three relatively simple dichotomous dimensions. There are two stage-defined resources (early versus late processes), two modality-defined resources (auditory versus visual encoding), and two resources defined by processing codes (spatial versus verbal)" (1984, page 302).

Thus a task can be described in terms of the structure of it's demand for attentional resources, and Figure 5 portrays the relationship between these limited capacity resource dimensions. If two tasks demand common resources, Wickens predicts poor timesharing between them and hence, a performance decrement. Since navigation and basic aircraft control both compete for the same stage (early), modality (visual), and code (spatial) resources, simultaneous performance of both should not equal the sum of each performed alone. Until basic aircraft control information processing becomes automatic, this is indeed the case.

Basic aircraft control suffers considerably during a student's initial attempts to perform simple navigational procedures and continues to be affected as he/she tries to apply the navigation instrument indications in the context of the different types of procedurally oriented instrument approaches. The task now becomes one of deciding which resource is most likely depleted. Since all of the instruments can not be simultaneously fixated in foveal vision, the modality resource is a candidate. The processing resource might also be implicated since the displays are, for the most part, analog. But the issue is a practical one since re-design of the instruments or instrument panel is not an option. Therefore, the focus rests entirely

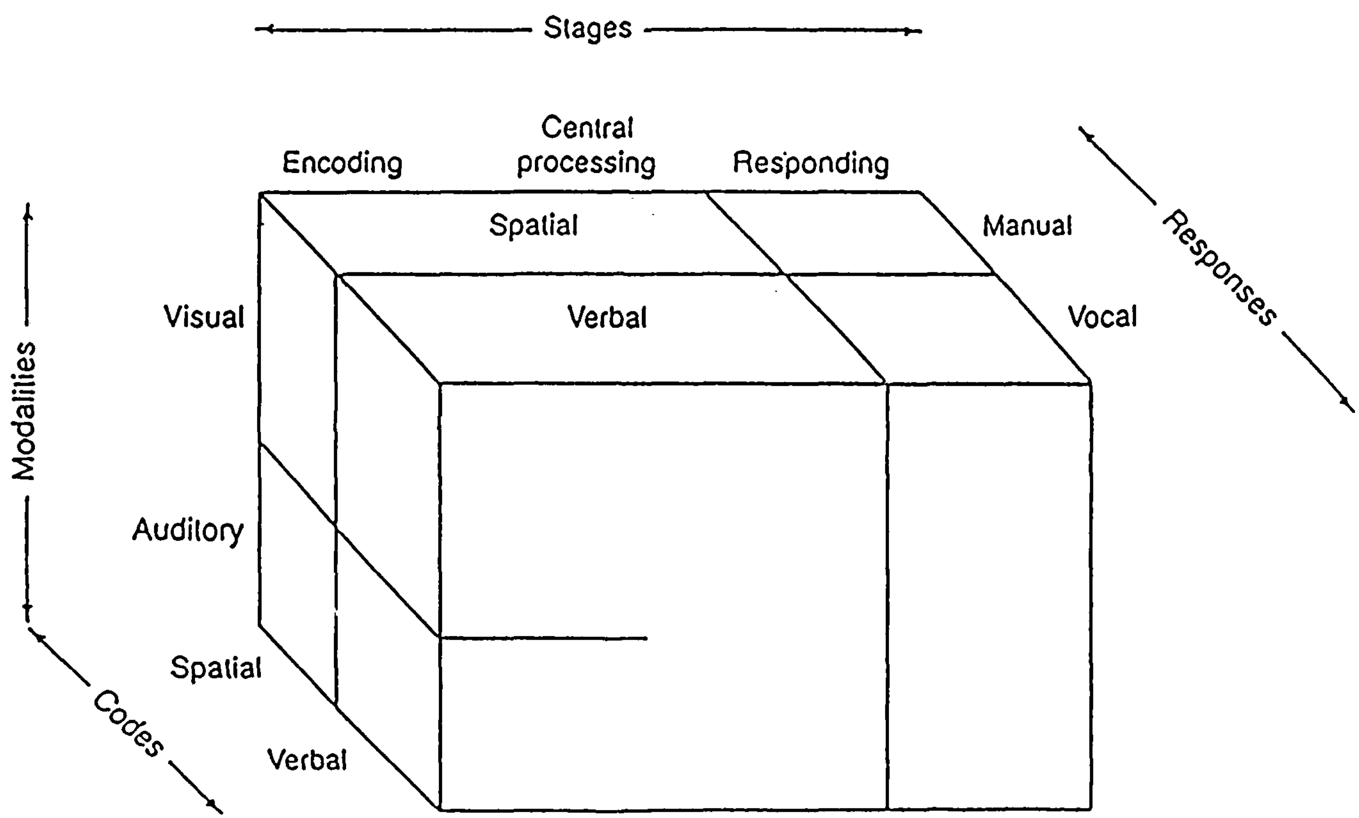

Figure 5. Theoretical structure of multiple processing resources (Wickens, 1984, pg 302).

upon the stage resource. The performance decrement in aircraft control (the primary task) might be caused by an inability to either gather sufficient information or to process the information which is available. The distinction, however, is a moot point because Wickens (1984) contends that encoding and central processing both demand resources in the early stage of processing.

Reading research also indicates that eye movements are tied to cognitive processing (Carr & Polletsek, 1985). Rayner (1978) found that fixation duration increased, as did the number of regressive eye movements (i.e., movements backwards through the text), as he systematically varied grammar and syntax to manipulate cognitive load. More direct observation (my own) confirms that the duration of fixations on all instruments increases dramatically with the addition of the navigation tasks. Additionally, where a student focuses his/her eyes is susceptible to instructor prompting, e.g., just the word "altitude" spoken by the instructor is sometimes sufficient to direct the student's eyes to the altimeter alone at the expense of the other instruments. It follows that decreasing the encoding and central processing demands of aircraft control early in training by improving the perceptual and intellectual skills of the crosscheck (as they pertain to aircraft control) would ease the burden imposed by the addition of navigation tasks. In other words, if moving the eyes (a motor skill) to gather information (encoding: a perceptual skill) from the performance instruments (specified so as not to require intellectual skill) requires minimal resources, less interference would result in the dual task scenario.

The previous rationale seems to indicate the validity of teaching some aspects of the crosscheck separately. But is it necessary? Pilots eventually become able to aviate and navigate simultaneously without any specialized crosscheck instruction. Senders (1986, personal conversation) believes that such training is "trivial." From the standpoint of the eye having a "mind of its own", he argues that the statistical properties of the instruments would serve to guide and pace eye movements without conscious control. In essence, the mind's eye would recognize and provide the context of a maneuver, and the mind of the eye would take over based on this schema. In aviation tasks, where the instruments are correlated and vary predictably, the specific maneuvers determine fixation rate and structure (Senders, 1973; Gainer & Obermayer, 1964; Allen, Clement & Jex, 1970; Weir & Klein, 1970; Fitts, Jones & Milton, 1950). In a paradigm where the instrument information varied both randomly and independently, Haga & Moray (1986) found that there were "marked individual differences in frequency, mean duration, and patterns of visual sampling" (page 794). Therefore, the research data proves Senders' ascertion true, and indeed, the information characteristics of the instruments seem to structure the eye movements. Since maneuvers are defined in terms of specific parameters, it's not surprising that scanning behavior is maneuver dependent. While this has implications concerning the content of crosscheck instruction (a point I will address later), it is erroneous to equate these conclusions to teaching the crosscheck to instrument-naive student pilots. The comparison is invalid because Senders based his judgement of crosscheck training on data gathered from expert subjects. All of the experiments cited used experienced pilots as subjects, and for the most part, charted eye movements under ideal conditions. An experienced pilot, by definition, has a working knowledge of the statistical properties of the flight instruments in the context of his/her ability to perform a particular maneuver. The novice pilot, on the other hand, has to shift his/her attention from one display to another in a more conscious fashion (Ellis & Stark, 1986). Even though a novice may not utilize the same cues as an expert, Senders' rationale implies that the ends justify the means. That is, the training method is irrelevant, and once a pilot proves he can operate his aircraft in IMC, his performance is assumed to be indicative of an effective crosscheck. Current theories assert that this is an erroneous assumption.

Theoretical attempts to link performance, training, workload, practice, and differences in individual abilities hypothesize that performance is not a sufficient criteria to determine the effectiveness of training (Hart, 1986; Ackerman, 1986; Kramer, 1986). Mane and Wickens (1986) postulate that since investing resources in a task involves costs, "learners avoid performance strategies that require large amounts of resources" (page 1124). In order to cope with high workload demands, they adopt strategies to simplify the task and improve performance early in training. These strategies later prove to be "less than optimal" because they act to "prevent developing expertise to its full potential" (Mane & Wickens, 1986, page 1125). In addition, task-saturated students "will be unable to assimilate the deluge of information into a viable internal model of the system or learn how to integrate and organize competing demands for their attention" (Hart, 1986, page 1117). Schneider & Detweiler (1986) observe that training programs have a tendency to graduate jacks-of-all-trades and depend on inconsistent "on-the-job training to develop the fast automatic component skills for acceptable job performance" (page 1129). Hart (1986) phrases the issue in terms of the acquisition of flight skills.

> "In military flight training, instruction for many critical tasks is given under conditions of very high workload and stress to emulate the conditions that might be encountered in battle. The assumption is that skills learned in a more benign environment might not transfer to a high-stress, life-threatening situation. While it is true that some experience approximating operational conditions should be provided during training, to allow the trainee to make 'safe' mistakes, this practice is not one that promotes learning, at least in the initial stages. The result may be that critical skills are inadequately acquired, and may be forgotten under subsequent high-workload, stressful circumstances" (page 1119).

Weirwille's (1979) comprehensive review of research concerning physiological measures of aircrew mental workload prompted him to draw some interesting conclusions which localize the training issue to crosscheck skills. He states that scan patterns are sensitive to increases in attentional demands; an inference which is consistent with Wickens' (1984) multiple resource model and the reading research previously cited. The finding which indicates a need for standardized crosscheck instruction, however, was that eye movement patterns "did not change systematically with operator loading" (Weirwille, 1979, page 585). Using Senders' own logic, since scanning behavior under normal conditions mirrored the information transmission probabilities of the instruments and was, therefore, optimal, the fact that the eye movements do not display similar patterns in the presence of increased workload implies non-optimality. A recent incident provides evidence that the crosscheck "breaks down" in non-optimal fashion and serves to illustrate my point.

> "On the morning of February 19, 1985, ... China Airlines Flight 006, a 747, was enroute from Taipei, Taiwan, to Los Angeles, California cruising at 41,000 feet. The five man crew ... were experienced airmen, and according to the National Transportation Safety Board qualified for their flight duties. ... Due to turbulence-induced wind shear, airspeed began to fluctuate, and the autopilot began adjusting the throttles to restore the selected airspeed. ... The airspeed decreased to about Mach 0.84, and the autopilot moved the throttles forward. Three of the engines accelerated normally; Number Four, the right outboard engine did not. ... The National Transportation Safety Board determined that although its throttle had been advanced, the engine was unable to accelerate. ... The safety board said the Captain should have devoted his attention to controlling the aircraft while monitoring his crew's efforts to handle the abnormal situation. ... Instead, the Captain initially became preoccupied with the engine problem ... and then became distracted by the aircraft's decreasing airspeed. His instrument scan became fixated on the airspeed indicator. As a result, the Captain did not notice that the aircraft was rolling to the right. ... The 747 rolled over ... and plunged 31,500 feet before the flight crew regained control" (Lacagninia, 1986, pages 73-74).

Although this incident did not involve loss of life, it demonstrates the seriousness of the potential consequences of a non-optimal instrument scan in a stressful situation.

The optimal/non-optimal distinction raises another aspect of attention. Given that each instrument must be processed individually, attention must be switched between them in a manner which reflects a situationally-dependent strategy. The optimality of this strategy may be defined terms of an event's utility (i.e., value or cost) and the probability of its occurrence. Senders' (1973) queueing model describes optimal sampling behavior using the probability distribution of a particular instrument's information content. After the pilot fixates on an instrument, "as time since the last observation increases, the probability of a new demand increases to a maximum and then diminishes monotonically to zero" (Senders, 1973, page 115) at the next fixation. The pilot's "internal model" of these probabilities guides his eye movements (Wickens, 1984). Kahneman's (1973) research of attention under conditions of stress concludes that under high arousal, fewer instruments are sampled and these instruments tend to be those perceived as most important. However, as Wickens (1984) points out, the salience of a particular cue is also a determinant of importance. For the task-saturated student pilot, the instructor's prompts are salient, and for the crew of China Airlines Flight 006, the engine malfunction and airspeed were more salient than they should have been. Since the most salient cue is not always the most important cue, crosscheck instruction would be useful in that it might increase the probability that all of the performance instruments (always important, but not always salient) would be sampled in times of high workload/stress.

The arguments thus far have established two reasons to teach the crosscheck as a separate skill. First, it would ease a student's cognitive load as he learns to apply the navigation and instrument approach procedures. Drowatsky (1975) predicts that the result would be an instrument pilot whose skills are more fine-tuned and error-free; a definite plus when one considers that precise aircraft control might be the difference between life and death. The second reason to teach this skill in a part-task scenario, is that crosscheck instruction might induce ingrained perceptual-motor responses in times of stress. These motor responses would increase the likelihood that the most important information would be available for the decision-making process, and that aircraft control would be less susceptable to fluctuations in resource demand.

Chapter 5

WHAT TO TEACH

In building my case for separate crosscheck instruction, I've partially revealed some of the aspects of what is learned in the process of acquiring the skills used during instrument flight. Presently, student pilots learn crosscheck skills by reading instructional texts and by actually practicing in some type of simulator or in the aircraft itself. By allowing presentation of the instruments individually, at variable rates, and in different sequences, computer graphics and animation technologies offer considerable possibilities to expand, diversify, control, and standardize the instruction of the skills involved in the crosscheck. This section delineates the specific component skills of the crosscheck that a computer training-aid might help a student develop. As I've already alluded, in determining what to teach, a central concern is to insure a positive transfer of training to the more complex skill of instrument flight of which the crosscheck is a part. With transfer of training effects as a guide, I now address the mechanics of skill acquisition.

Schneider & Fisk (1982) tie together some aspects of attention theory and skill acquistion to account for the overall improvement in performance predicted in flying skill as students learn the fundamentals of the instrument crosscheck. Assuming attention as a finite resource, they manipulated mental processing in a visual search task through the use of consistently mapped (automatic processing) or variably mapped (controlled processing) targets and distractors. They found that controlled processing was always sensitive to reductions in processing demands, and that automatic processing became less resource demanding with practice. These findings imply the need for consistency within the part-task instruction and between (transfer effects) the part-task and the whole-task. In an experiment to further quantify Schneider & Fisk's findings, Ackermann (1986) concludes that consistent tasks reduce attentional load and decrease the influence of intellectual abilities as well. He goes on to say that "the abilities required for successful performance have changed from the broader, more general abilities, to those associated with the development and use of the perceptual/motor program (i.e., non-cognitive/non-attentional demands)" (page 271). In other words, consistency is the key to automatizing any skill. While this research qualifies what to teach, it doesn't provide the specific guidance.

Most theorists agree that learning a skill progresses through some general phases. Gentile (1975) identifies two stages of learning a motor skill: getting the idea of the movement and fixation/diversification. Describing learning as a simplification process, Drowatsky (1975) delineates cognitive, associative, and autonomous stages of skill development. He also states that visual-perceptual cues are most important early in the learning process. Welford's (1976) model of skill acquistion is similar, but he subdivides the process further in the cognitive dimension to include short and long term memory. He stresses that short term memory is easily overloaded and points out that storage in long term memory is organized by associations called schema. Drowatsky (1975) summarizes Fleishman's important contributions to skill acquisition research. Fleishman found that different abilities account for variations in performance during the chronological stages of practice. Environmental cues (especially spatial-visual) are important early, and as the skill becomes more refined, psychomotor coordination plays a larger role. Although the focus of this research was predominantly simple motor skills, the theory readily generalizes to the continuum of skill.

Another skill which has undergone extensive investigation is reading. While reading and the crosscheck are certainly dissimilar skills, a general comparison is useful and valid (Rayner, 1986, personal conversation). The knowledge of top-to-bottom (page) and left-to-right (line) spatial conventions in reading logically preceeds letter and word recognition, which at some point in learning, parafoveally determines (Rayner, 1986) the locus of subsequent fixations. It seems that visual cues/conventions convey the idea of the movement and drive movement practice until perception develops to a degree which enables the faster, higher-level, word recognition processes to assume control. Rayner (in press) lists several skills which preceed word recognition and appear to be "crucial to the development of efficient reading." I quote these skills and opposite each, propose an analogous crosscheck component.

READING	CROSSCHECK
Letter recognition	Instrument interpretation
Learn to discriminate left from right	Learn each instrument's relative position on the instrument panel
Gain cognitive control of eye movements	Know that the attitude indicator is the hub from which eye movements eminate (the AFM 51-37 analogy)
Become word conscious	Become aware of the parameters which determine specific maneuvers
Develop orthographic and phonological awareness	Develop an understanding of the inter-relationships between instruments

Rayner (in press) elaborates further on the eye movement control pre-requisite by pointing out that "children have never had to focus their attention so precisely upon a specified region of the stimulus array. ... And prior to reading, a series of saccades in any particular direction is not called for." Similarly, a student pilot has only made repetitive saccades for any duration during reading, and these movements are different both physically and deterministically from those involved in the crosscheck. Although the relationship may be abstract, this comparison with some pre-requisites of reading helps to formulate some component skills of the crosscheck that might be important to crosscheck development.

An instruction method which is a specialized type of part-task instruction is adaptive training (AT). AT would be an ideal method to teach the crosscheck because it varies task difficulty based on individualized learning curves. Lintern and Roscoe (1980) review some AT experiments which have direct aviation applications. They found that the majority of them failed because they assumed "that any convenient manipulation of task difficulty would be satisfactory" (page 244), and didn't consider transfer effects. They conclude that when tasks are control oriented, variations in the control-display dynamics (order or lag) are counter-productive. Lintern & Gopher's (1978) extensive review of AT research identifies perceptual manipulations as the most promising variable to evoke positive transfer. Since these variables "progressively extend the repertoire of the stimulus-response relationships rather than change them" (page 540), the task becomes a specialized extension of the more traditional part-whole training scheme. However, Lintern & Gopher's (1978) analysis of skill acquisition theory failed to identify appropriate perceptual variables that might be used in practical applications. Schneider & Detweiler (1986) are equally vague as they only recommend distinguishing between totally consistent, context consistent, and inconsistent task components. Theory has provided some general guidelines and researchers must empirically determine what the practical applications might be.

Few attempts have been made to teach eye movements or scan patterns. Again I refer to reading research for an example. Rayner's (1978) assessment of speed reading courses is that they are relatively ineffective when judged in terms of comprehension. Recordings of eye movements show different movement patterns after training, but normal reading strategies returned when the subjects knew that they would be tested for comprehension. The training effects are susceptible to task demands. Therefore, the only applicable conclusion that might be drawn from attempts to teach speed reading is that training can possibly alter scan patterns.

Most aviation research investigating the eyes has attempted to construct a descriptive/predictive model of the pilot's visual scan. Recently, however, issues concerning eye training have surfaced due to accidents/incidents involving fighter aircraft which use heads up displays (HUDs). Designers assumed that the collimated imagry of the HUD would allow the pilot to simultaneously view the outside world and the information on the visual display mounted on the wind-screen directly in his line of sight. Since each demanded that the eye focus at optical infinity, there would be no need to shift attention in the depth dimension. Using data gathered from the early 1950's to the present time, Roscoe and his collegues (Roscoe, Hasler & Dougherty, 1966; Hull, Gill & Roscoe, 1982; Roscoe, 1985; Iavecchia, 1985), have proved this assumption false. The initial studies demonstrated that objects viewed through a forward-looking, aircraft-mounted periscope appeared smaller than they actually were (Roscoe, Hasler & Dougherty, 1966). Iavecchia's (1985) empirical studies linked this misaccommodation to the eye's dark focus (i.e., empty field or resting focus). She reports that "where the eye focuses for any stimulus is greatly dependent on an individual's dark focus" (Iavecchia, 1985, page 15). It seems that in an environment devoid of sufficient references, the actual distance at which the eye focuses might be thought of as a weighted average of the dark focus and the optical distance of the object of intrest. In Roscoe's words, "other things being equal, the more distant the eyes accommodate, the larger an object of fixed angular size appears" (1980, page 617). This finding explains why a pilot using a HUD perceives smaller outside images when attending to the HUD's visual information. His eyes are viewing at his dark focal distance and the horizon is at optical infinity. Since equipment re-design would be extremely expensive and time consuming, Roscoe & Couchman (1986) have experimentally determined that training can develop volitional focus control. They found that by exercising the ciliary muscles of the eye, they were able to decrease the overall effect of the dark focus. The applicability of this research to crosscheck training is straightforward. While Roscoe trained the eye to adapt to the depth dimension of the fighter pilot's crossheck, I propose training for the lateral demands of the crosscheck in more conventional aircraft.

From a synthesis of the information presented thus far, I conclude that a computer training-aid, which presents cockpit instruments individually, might modestly be expected to teach/reinforce the following aspects of the crosscheck:

1). Instrument interpretation - By controlling the amount of time each instrument is visible, the computer could gradually decrease interpretation time to the durations observed in pertinent studies (i.e., approximately 400 msec).

2). Relative instrument position - The student would learn that certain information is always associatied with a specific location (i.e., altitude is always to the right of the attitude indicator).

3). An idea of the eye movements - By prompting the eye to move from instrument to instrument, the computer can convey a conceptualization of the motor control needed (direction and rate) to perform the crosscheck.

4). Information processing - Extended practice combining relevant information sources and comparing actual to desired parameters to formulate control inputs might reduce, and eventually eliminate, the resource demands of maintaining basic aircraft control.

The notable characteristic which is absent from this list is the concept that maneuvers dictate the order of the visual scan. The fact that a training-aid can convey the idea of the movement, implies that it is also capable of teaching the order of fixations. Although Senders (1973) might argue that there is an optimal scanning order, by his own admission, real systems are markedly different from sanitary laboratory conditions. His queueing model predicts the distribution of attention of only three pilots as they fly three different maneuvers in a Link simulator. For simple maneuvers (i.e., transition from level flight to a descent and a turn) and given the conditional probabilities of the fixations, the model accurately predicts the pilot's sampling strategy. However, for an instrument final approach, his estimates are rather "dubious at best", and Senders admits that the model is only applicable "when the pilot is not engaged in effectively continuous control of the signals he is presented with" (page 127). Even if an optimal order were determined and taught, there would still be no guarantee that the pilot would adhere to this scan pattern in high workload situations. Senders' work does make a case for instruction programs which teach the underlying aerodynamic principles and the statistical properties of the instruments which determine the order of the visual scan. I feel that this material would be beyond the capabilities of a computer training-aid and best taught in a classroom.

From an instructor pilot's viewpoint (my own), the overall objective of a training-aid is to convey basic instrument relationships (i.e., their relative physical positioning) and provide a general idea of the motor skills and information processing involved in an instrument crosscheck. To imply that a rigid structure exists, would inhibit the development of the cognitive skills, and therefore the ability to generalize to unfamiliar situations. As I've already implied, a student has flown for some period of time before he/she attempts flight using the instruments alone. He/she has already formed the foundations of an internal model of control-display relationships. Since eye movement stagnation usually occurs during periods of transition within and between maneuvers (a critical time when the statistical properties of/between instruments are changing), it is imperative that the student observe the physical changes of the instruments during this time to maintain consistent mapping of information during practice. An ingrained motor program of saccadic eye movements should help to maintain the information flow and aid in the development of the student's model of system dynamics. Teaching an order of scan which is not consistent with his/her understanding of system operation would assuredly induce negative transfer of training effects. In the fast-paced, dynamic environment of flight, the most valuable asset is the adaptability of manual control. To cultivate the development of this important resource, the order of presentation should demonstrate only the general movement pattern and reinforce instrument interpretation and position.

Summary

The crosscheck is an integral part of instrument flight. It is the medium through which the pilot gathers the information to assess the differences between desired and actual aircraft performance at each level of the flight task hierarchy. Since Multiple Resource theory predicts that tasks which compete for common attentional resources will interfere with each other when performed simultaneously, a student's attempts to maintain basic aircraft control and navigate concurrently inhibits learning either task. Teaching visual scanning, using part-task instruction, could eventually automate the information processes required to transform the indicies of actual performance into control inputs which achieve desired performance. This training would allow the student to formulate an internal model of the system which should be more resistant to stress-inducing high workload situations. Computer technology provides an ideal method to teach the crosscheck because it is capable of producing faithful instrument representations and of moving the eyes by presenting instruments individually. All of these assertions rest on my assumption that maintaining basic aircraft control via the control performance concept of visual scanning requires attentional resources. The following experimental paradigm tests this hypothesis.

Chapter 6

METHODS

The purpose of this research was to isolate and quantify resource-demanding aspects of an instrument crosscheck which employs the control-performance concept of visual scanning to maintain basic aircraft control. To accomplish this with any degree of fidelity, entails a task which replicates the transformations required in the dynamic control context, and a criterion to judge effective processing.

Equipment and Task

A DEC Pro 380 graphics-capable computer, its keyboard, and two monitors (a 13" and a 12") were used to gather the data in this experiment. An airspeed indicator, attitude indicator, altimeter, and heading indicator were displayed on the 13" screen as shown in Figure 6. Each instrument was actually circular, 2.6" in diameter, and outlined by a 2.8" square. The solid line representing the horizon on the attitude indicator was blue, otherwise all instruments were outlined in white on the black background. The dividing lines and solid boxes were a light green in color, and framed the instruments to provide a stationary reference when the space was empty. The instruments themselves and their arrangement on the display terminal are reasonably faithful reproduction of a portion of a Singer-Link GAT-1 simulator's instrument panel.

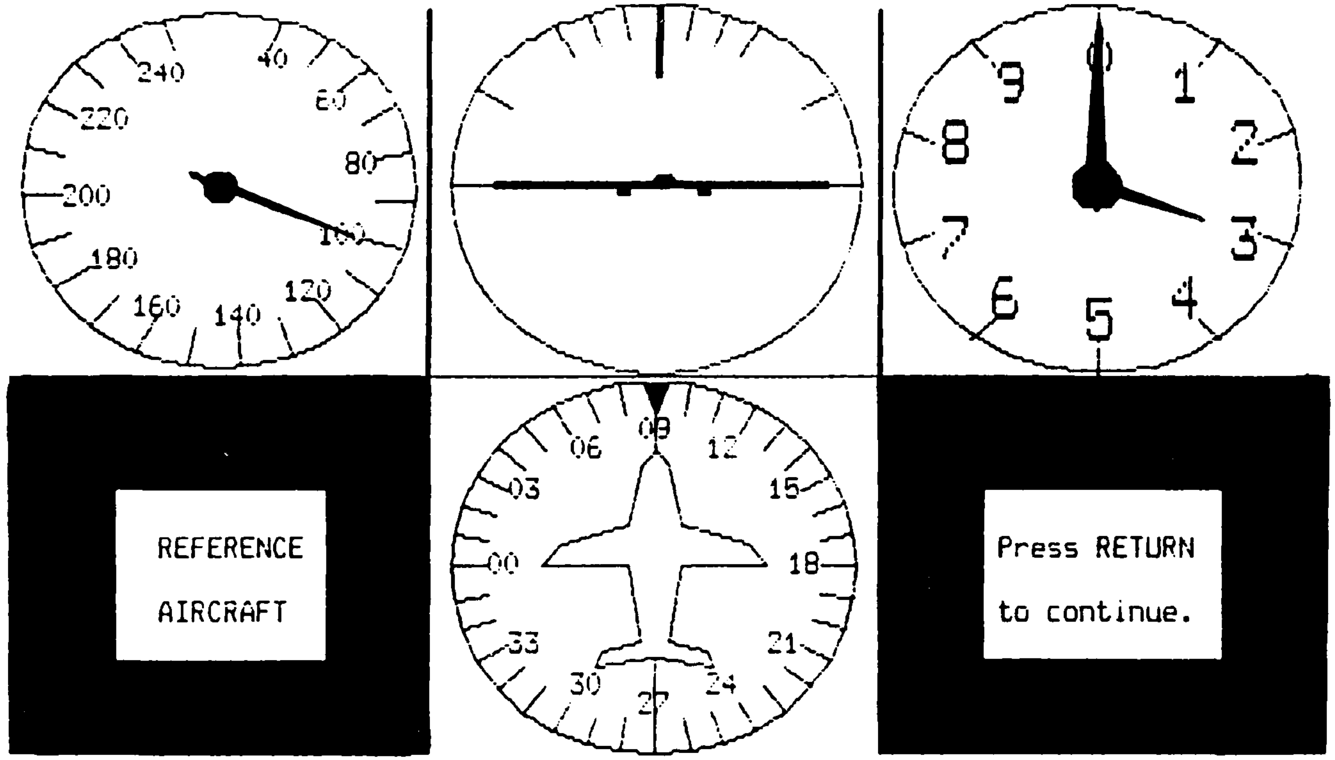

Figure 6. Reference aircraft indications.

The instrument indications of Figure 6 were referred to as the Reference aircraft (REFa/c), and signaled the beginning of each trial. Pitch and bank are displayed on the attitude indicator and the REFa/c's nose is on the horizon (i.e., 0 degrees pitch) and its wings are level (i.e., 0 degrees bank). The remaining parameters of the REFa/c are: airspeed - 100 mph, altitude - 3000 feet, and heading - 090 degrees (i.e., east). These indications remained constant throughout each experiment, and represented the indicies of desired performance. As indicated in the bottom right box of Figure 6, the subject pressed the RETURN key to initiate presentation of the altimeter, and heading, attitude, and airspeed indicators of Own aircraft (OWNa/c); the indicies of actual performance. The sample OWNa/c indications shown in Figure 7 are: pitch - nose high, bank - 30 deg. right, airspeed - 120 mph, altitude - 2900 feet, an heading - 020 deg.

Upon completion of OWNa/c's presentation, the 13" monitor was blanked and the three questions shown in Figure 8 were presented sequentially on the 12" screen. In other words, the next question was not displayed until the computer's input buffer contained an answer to the question presently on the screen. The stem of each question is the same, but the questions differ in subject matter. The first concerns pitch, the second, bank, and the third, power. The subject's task was to determine if OWNa/c's controls needed to be repositioned (and if so, how) in order to attain the desired indications of the REFa/c. For example, the correct answers for the OWNa/c indications of Figure 7 are: B, B, and C respectively. The left, down, and right arrow keys are adjacent on the keyboard, and were re-labled A, B, and C, from left to

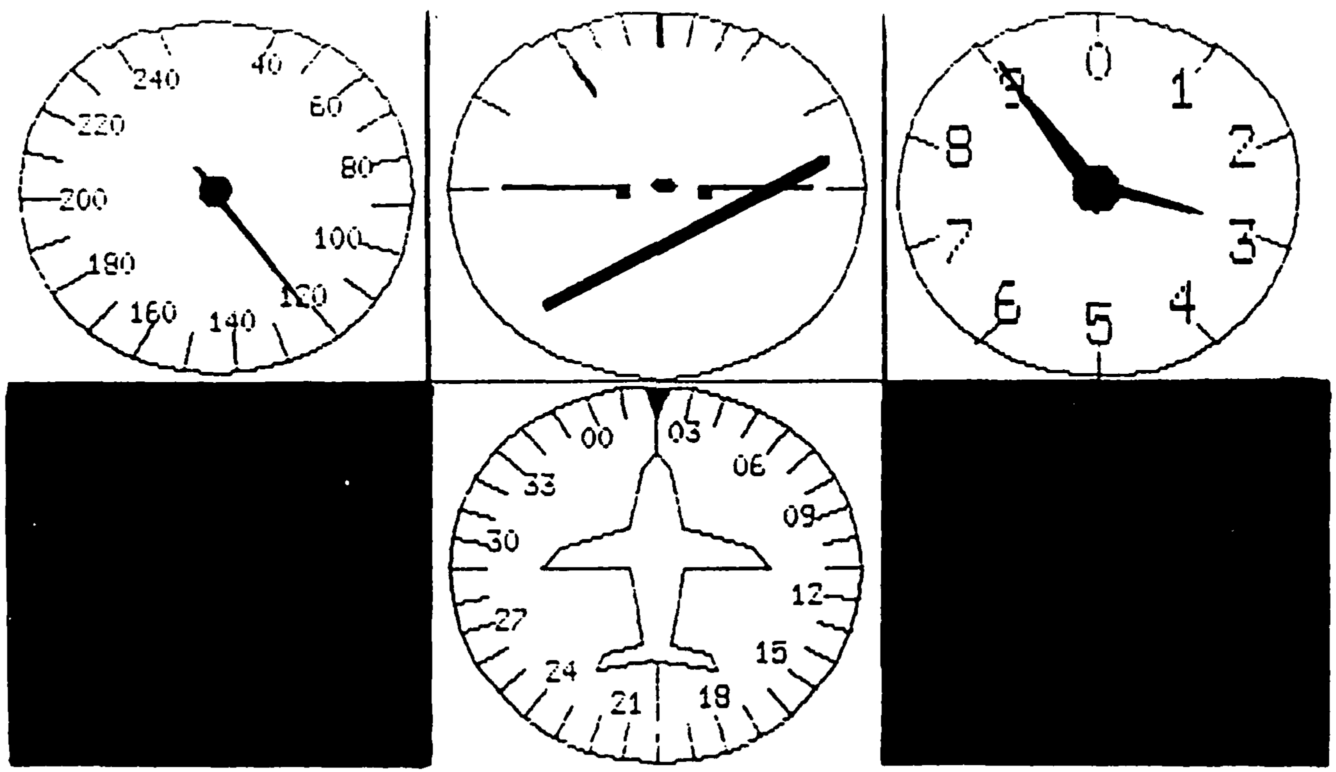

Figure 7. Sample Own aircraft indications.

Answer these questions by just pressing either the a, b, or c key. The reference aircraft's nose is on the horizon and it's wings are level. Altitude is 3000 feet. Heading is 090 (east). Airspeed is 100 miles per hour.

In order to maneuver this aircraft to the same position as the reference aircraft, you must ___

a. move the yolk forward to lower the nose.
b. not move the yolk to adjust pitch.
c. move the yolk rearward to raise the nose.

In order to maneuver this aircraft to the same position as the reference aircraft, you must ___

a. turn the yolk clockwise (right turn).
b. not move the yolk to adjust bank.
c. turn the yolk counter-clockwise (left turn).

In order to maneuver this aircraft to the same position as the reference aircraft, you must ___

a. push the throttle forward (increase power).
b. not adjust the throttle.
c. pull the throttle rearward (decrease power).

Figure 8. Control input question format for each set of OWNa/c instrument indications.

right, for the subject to enter responses. All other keys were disabled. Significantly, the computer's input buffer would accept responses to all three questions, in order, immediately after the OWNa/c indications disappeared (i.e., the subject did not have to wait until the question was displayed to respond). Responses were recorded and scored on the 12" screen as shown in Figure 9, and OWNa/c's instruments were displayed again on the 13" monitor to provide feedback. The subject pressed the RETURN key to initiate the next trial.

To eliminate confusion, the possible set of OWNa/c indications was restricted in size. Obviously, pitch changes (without corresponding power adjustments) affect airspeed. For example, suppose OWNa/c's pitch, altitude, and airspeed are nose high, 3300 feet, and 90 mph respectively. To correct to the reference altitude of 3000 feet requires lowering the nose, and the resultant descent will cause a concomitant increase in airspeed. Whether the airspeed reaches or exceeds 100 mph now becomes a function of the magnitude of the required altitude correction and whether or not the power is adjusted. Modeling this aerodynamic characteristic may have been confusing, therefore, those combinations of pitch, altitude, and airspeed with ambiguous answers to the power question were eliminated. Appendix A lists the subset of combinations used. The resultant set of OWNa/c indications simplified the task somewhat, in that the airspeed indicator was essentially isolated from the other instruments. In other words, the only information necessary to answer the power question was OWNa/c's airspeed, whereas pitch/altitude and bank/heading combinations were required to correctly answer the pitch and bank questions. The actual

Answer these questions by just pressing either the a, b, or c key. The reference aircraft's nose is on the horizon and it's wings are level. Altitude is 3000 feet. Heading is 090 (east). Airspeed is 100 miles per hour.

In order to maneuver this aircraft to the same position as the reference aircraft, you must _b_ CORRECT

a. move the yolk forward to lower the nose.
b. not move the yolk to adjust pitch.
c. move the yolk rearward to raise the nose.

In order to maneuver this aircraft to the same position as the reference aircraft, you must _a_ INCORRECT

a. turn the yolk clockwise (right turn).
Correct answer ---> b. not move the yolk to adjust bank.
c. turn the yolk counter-clockwise (left turn).

In order to maneuver this aircraft to the same position as the reference aircraft, you must _c_ CORRECT

a. push the throttle forward (increase power).
b. not adjust the throttle.
c. pull the throttle rearward (decrease power).

Figure 9. Corrected control input questions for one set of OWNa/c instrument indications.

OWNa/c indications and their correct answers are displayed in Appendix B.

Subjects were divided into two groups (Paced or Static) to assess differences in OWNa/c instrument encoding, combining relevant OWNa/c displays, comparing OWNa/c to REFa/c, and deciding if, and how, to re-position OWNa/c's controls. Subjects in the Paced group viewed each instrument individually. Approximately 50 msec elapsed between the extinguishing of one instrument and the onset of the next. Each instrument appeared and disappeared as a whole (i.e., not erased directionally). The attitude indicator was presented (duration: 1 sec) first, last, and subsequent to each performance instrument. Each performance instrument was randomly presented twice, subject to the constraint that all three were shown once (duration: 500 msec) before any was presented a second time (total time: 10.6 sec). The order and pace of instrument presentation reflect the control-performance concept and experienced pilot fixation durations. Because the performance instruments were presented randomly, fixation duration was increased from 400 msec (as previously quoted) to 500 msec to accommodate a 150 - 175 msec reaction time of the eye. This range represents the mean latency when spatial or temporal uncertainty is eliminated (Rayner, 1986). The Static group viewed all four instruments simultaneously.

Chapter 7

EXPERIMENT 1

Subjects

Participants were recruited from local airports, flying clubs, and the Air Force ROTC detatchment on campus. The ten student pilots/pilots in this study had logged a minimum of 10 hours total flight time (median total flight time: 16.5 hrs., range: 10 - 250 hrs.) and had not received formal training in IFR procedures. Each subject possessed at least an FAA Third Class medical certificate or had passed an Air Force flight physical. All subjects were aware of the experimenter's experience as an Air Force instructor pilot and participated with the expectation that they would be exposed to crosscheck concepts and have the opportunity to practice instrument interpretation.

Procedure

Each subject participated in three sessions within a five day period. One session consisted of 70 different OWNa/c and lasted approximately 45 minutes. Subjects evaluated the same set of OWNa/c indications for each session, but the order of presentation was randomized across sessions. Data was collected in a lighted, sound-attenuated booth. The monitors and keyboard were arranged on a 25" x 40" desktop. The subject was seated approximately 18" from and directly in front of the 13" screen, and the 12" monitor was displaced approximately 15 degrees to the right (see Figure 10). Subjects were free to adjust keyboard position to their own level of comfort.

Prior to the first session, the experimenter read a prepared set of instructions (Appendix C) to each subject. Participants were instructed to respond as quickly as possible in order to discourage guessing in the event that pertinent information had decayed or was not encoded. Additionally, all subjects were informed of the restrictions placed on the set of possible OWNa/c indications as well as the characteristics of the input buffer. The experimenter observed one trial and explained the answers to each question. After all aspects of the task were explained to the subject's satisfaction, the experimenter left the booth and the session began.

Subjects were informed of their accuracy scores after each session, and prior to Sessions 2 and 3, subjects were again shown the previous session's score. At this time, they were reminded that the overall objective was to show improvement with each session.

Design

Subjects were assigned to either the Paced or Static group in an effort to obtain an approximate group match according to average total flight time. Individual flight times are listed in Table 1, and each subject participated in three sessions. The resulting design was 2 (Paced or Static group) x 3 (sessions) with subjects nested under

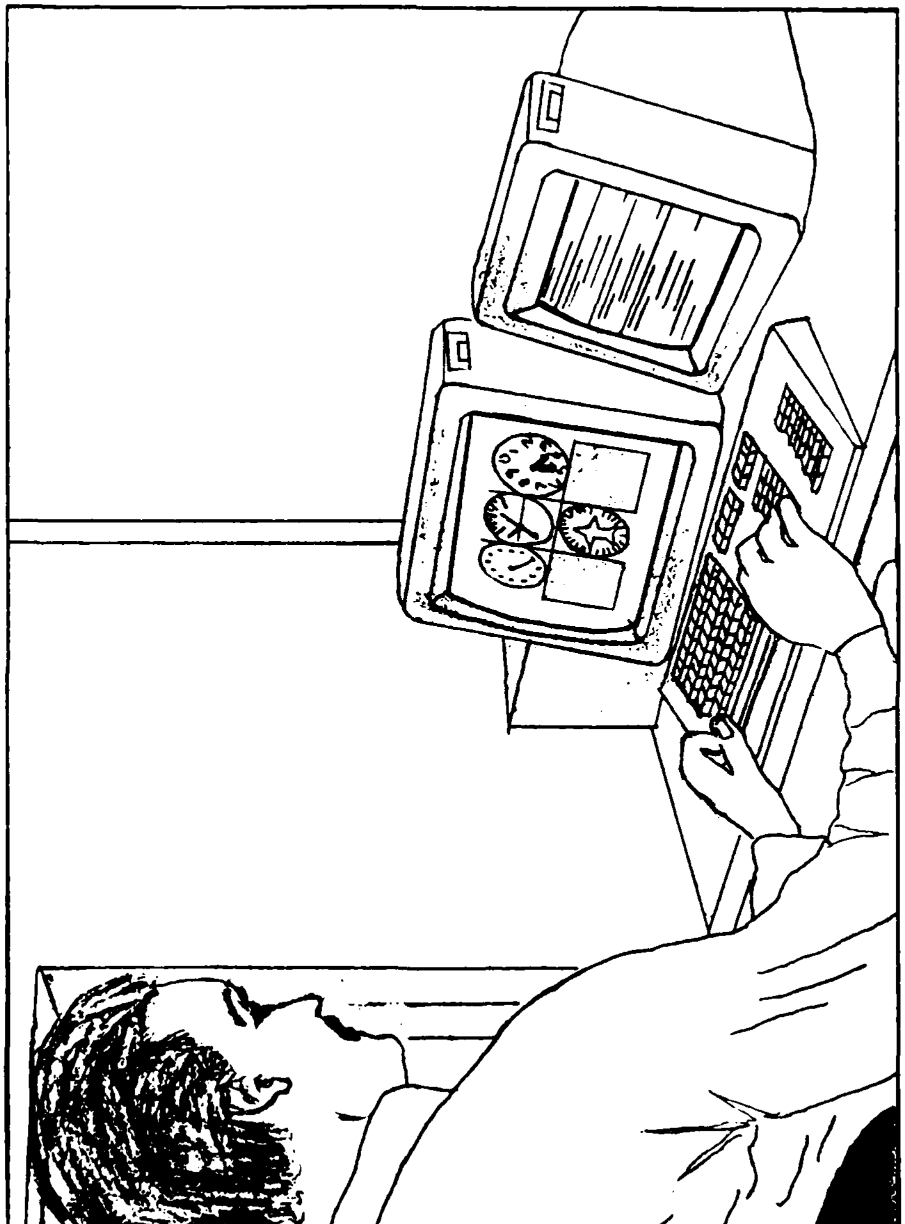

Figure 10. Sketch of experimental setup.

Table 1. Individual flight times and accuracy scores by session for Experiment 1.

Subject	Flight Time	Session 1 Num Wrong	Session 2 Num Wrong	Session 3 Num Wrong
STATIC				
S01	10	25	7	1
S02	18	8	4	2
S03	97	16	2	0
S04	15	19	4	0
S05	70	10	3	0
Mean	40	15.6	4.0	0.6
PACED				
P01	11	97	79	57
P02	120	79	42	25
P03	12	16	8	3
P04	15	40	10	9
P05	250	75	45	21
Mean	82	61.4	36.8	23.0

groups. The computer recorded accuracy scores for the 210 total questions per session.

Results

Individual accuracy scores are given in Table 1. The graph of accuracy over sessions (Figure 11) clearly depicts that the Static group scored higher (i.e., less wrong responses) than the Paced group. An ANOVA of percent incorrect yielded a significant group effect ($F(1, 8) = 15.08$, $P = .0242$), session effect ($F(2, 16) = 35.73$, $P < .0001$), and group x session interaction ($F(2, 16) = 6.61$, $P = .0081$).

Discussion

Although an attempt was made to equate the groups on the basis of total flight time, the Paced group's average flight time (81.6 hrs) was double that of the Static group (40.0 hrs). Upon closer inspection of the individual flight times in Table 1, it's obvious that the groups are fairly well matched except for subject P05. However, this subject's accuracy scores did not make as significant a contribution to the group average as did his flight time. In fact, the two pilots with the highest flight totals were in the Paced group and they both recorded lower accuracy scores than any member of the Static group. The correlation between total flight time and session accuracy scores is .23, .12, and .03 respectively. Therefore, it seems clear that the rate and order of processing dictated by pacing affects processes which are independent

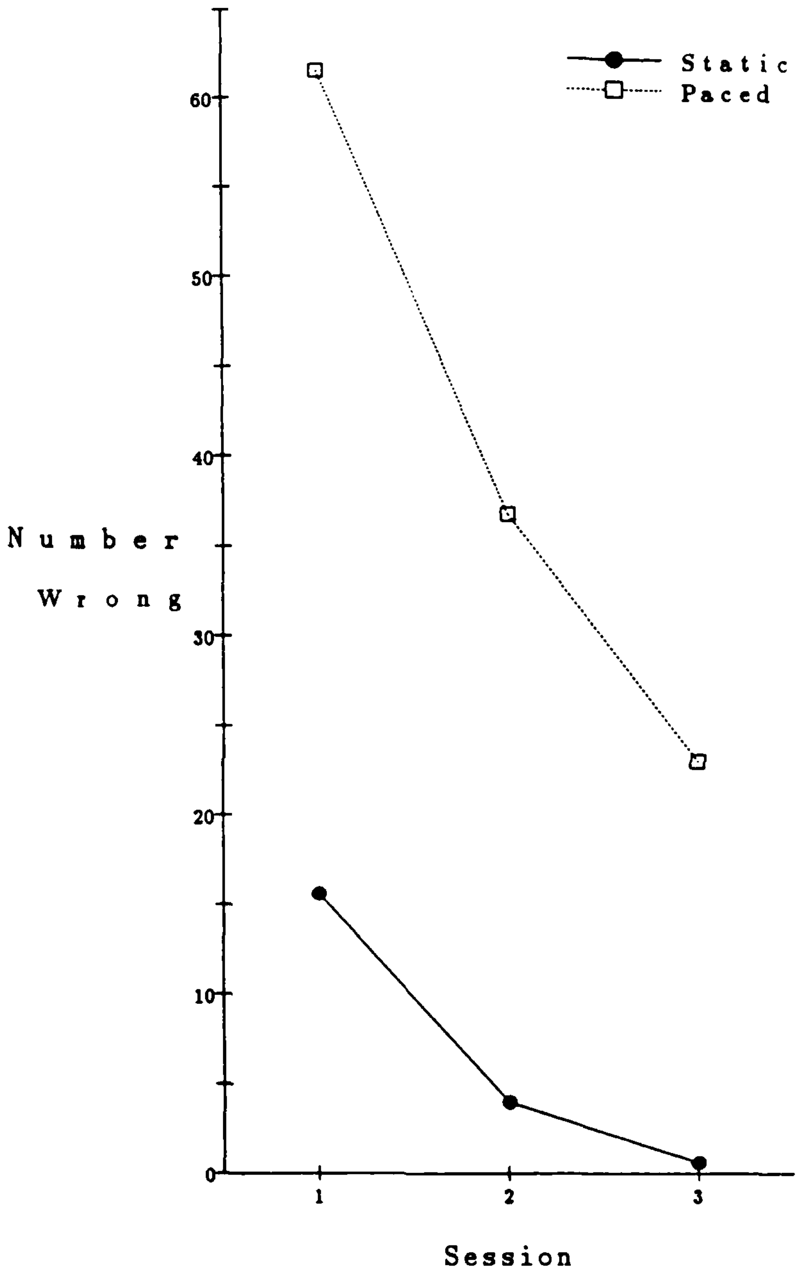

Figure 11. Experiment 1 accuracy scores by session.

of total flight time. A corollary assertion is that the skills dictated by the control-performance concept do not develop automatically with experience. Extended practice, which is standardized and relatively specific in nature, may be necessary to develop the information processing skills of the crosscheck to a level at which they will be insensitive to fluctuations in resource demand.

Subjects with at least 10 hours of flight time were used to minimize the variability in scores due to instrument interpretation and control input decisions. Certainly after 120 hours the ability to read the basic flight instruments is asymtotic. Therefore, in light of the significant group and group x session interaction effects, it seems reasonable to conclude that forced, random-paced viewing primarily affected processing subsequent to encoding. In other words, the subjects were able to identify the displayed parameters of the relatively direct-reading performance instruments, but could not formulate pitch/altitude and bank/heading combinations, assess actual versus desired deviations, or decide how to re-position the controls. The rationale here is that the necessary information is available, but further processing is interrupted by the presentation of the next instrument, or that on-going processing continues, and any new information is encoded but not retained. The Paced group's low accuracy scores are not a function of the ability to encode instrument indications in the allotted time, but rather an indication that central processing capacity limits have been exceeded (ref. Figure 5; the Stage dimension).

In addition to revealing the effects of a forced, random-paced presentation, the accuracy scores also provide a measure of task fidelity. While it seems that the allotted time (i.e., 10.6 sec) was more than sufficient for the Static group to achieve realistic accuracy scores, the Paced group never exhibited processing which would be acceptable in the aircraft. Experiment 2 modifies pacing slightly to permit a group comparison under conditions of qualitatively equivalent processing.

Chapter 8

EXPERIMENT 2

Subjects

The sixteen participants in this experiment were volunteers from the same sources and had the same minimum flight time and medical qualifications as those in the first study. Their median total flight time was 19.5 hours and individual flight time ranged from 10 to 130 hours. As in Experiment 1, the subjects were not paid, yet agreed to participate to gain an appreciation for the concepts of the instrument crosscheck and to practice their instrument interpretation skills.

Procedure

In order to allow the Paced group to achieve more realistic accuracy scores, the task was modified slightly. The order and duration of instrument presentation for the Paced group were the same as in Experiment 1, except that after each performance instrument had been presented once, pacing was discontinued, and all four instruments were displayed. The Static group again viewed all instruments simultaneously. The subject's task was to extract the information necessary to answer the control questions as quickly as possible, terminate viewing (blanking the 13" monitor) by pressing the SPACEBAR, and answer the questions as fast and as accurately as possible.

The instructions were changed as shown in Appendix C. Prior to the second and third sessions, the subjects were informed of their average viewing time per trial, average answer time per trial (i.e., three questions), and accuracy on the preceeding session. They were also reminded that the objective was to try to improve all three elements of the total performance "package".

Design

The design remained 2 (Paced or Static group) x 3 (sessions) and subjects were assigned to and nested under groups as in Experiment 1. The Static group averaged 54.8 hours while the Paced group logged an average of 44.9 total hours. Individual flight times are listed in Table 3. The computer recorded view time (measured from the onset of OWNa/c to the pressing of the SPACEBAR), answer time for each question (measured from the time the entire question and answer choices were displayed to the time the input buffer contained a response), and accuracy for each of the 70 trials.

Results

The accuracy scores do not reflect a group effect ($F(1, 14) = .65$, $P = .4344$), and, when compared to the scores of Experiment 1, the actual values (Figure 12) are quite a bit more representative of what actually occurs in the aircraft. However, both groups' low Session 1 accuracy

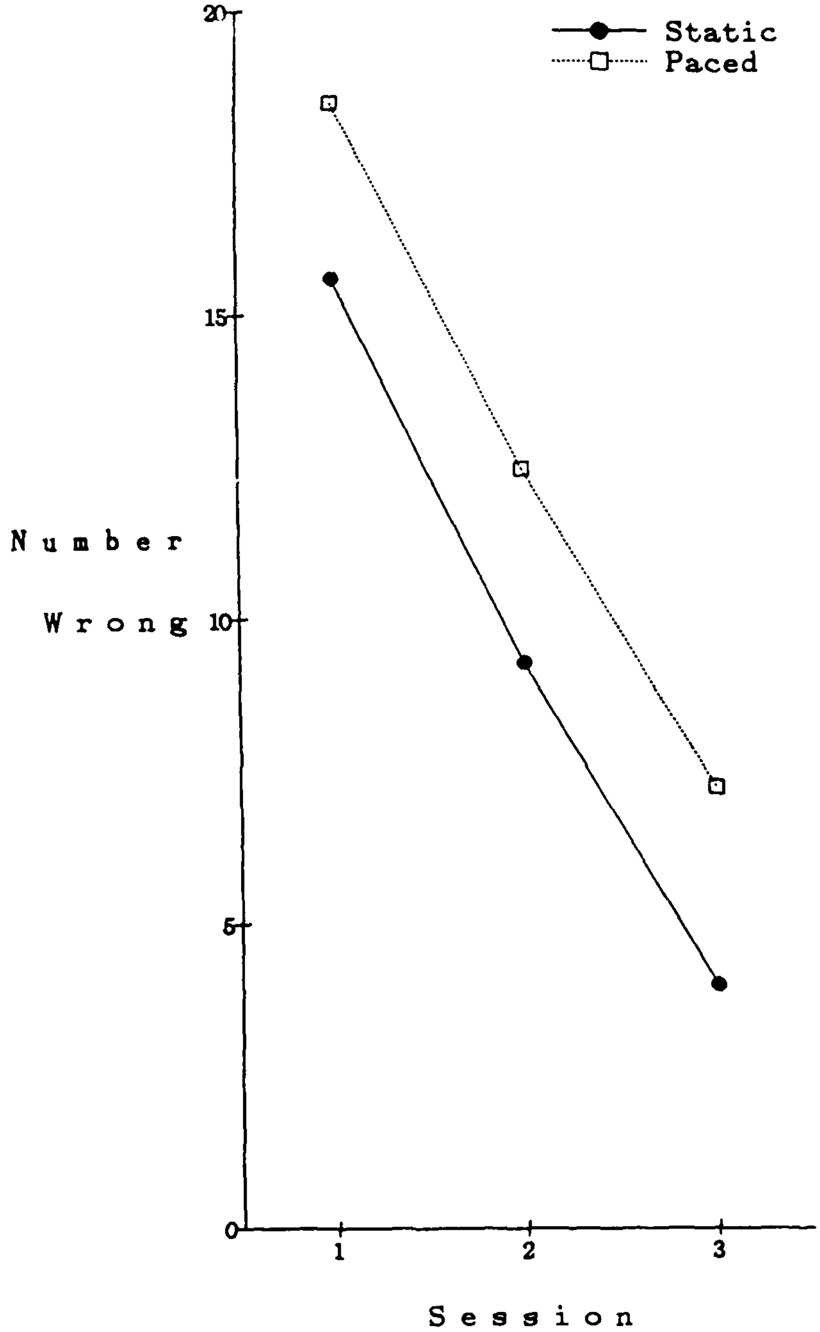

Figure 12. Experiment 2 accuracy scores by session.

scores (high number wrong in Figure 12) are an artifact of the experimental paradigm since fewer erroneous control inputs tend to occur under normal circumstances in the aircraft. Indeed, some subjects attributed a portion of their inaccurate bank responses to the pairing of a right (clockwise) control input with the left (A) key and visa versa. To account for this tendency to "fly the keyboard", a 95% correct session accuracy criterion (i.e., ten or less wrong), would seem to be reasonably indicative of effective processing. This cutoff also accommodates the control reversals which are characteristic of novice (and sometimes experienced) instrument pilots.

Analysis of the answer time data provides the means of confining the encoding, combining, comparing, and deciding processes to the view time for the purpose of evaluation. To this end, consider that an entirely plausible task-induced strategy might consist of encoding all instruments during the view time, terminating viewing, and synthesizing the information during the answer time. To capture the processing involved in the transformation of OWNa/c parameters to control inputs, the answer time analysis must account for this worst-case scenario. Figure 13 depicts the changes in answer time across sessions. Since the highly significant session effect ($F(2, 13) = 65.31$, $P < .0001$) implies between-session learning, it is not unreasonable to expect some change in the answer times within each session as well. Although the Static group had the luxury of formulating their responses in the same order in which the questions were asked (while the Paced group did not), answer times do not exhibit a group effect ($F(1, 14) = .79$, $P = .3891$) or a group x session interaction ($F(2, 13 = .09$, $P = .9162$). Therefore, answer times

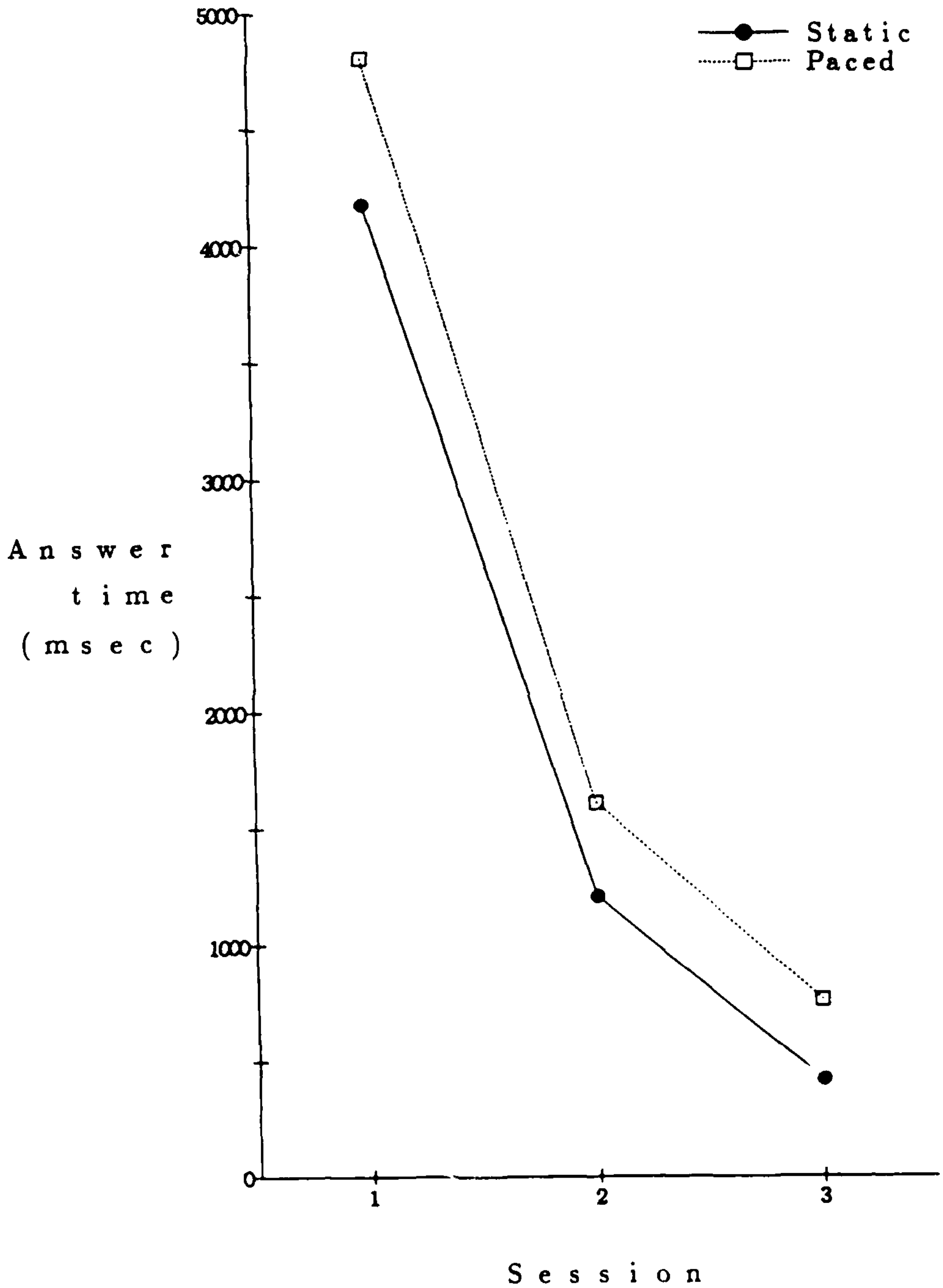

Figure 13. Experiment 2 answer time by session.

Table 2. Experiment 2 average answer times for Trials 1-35, Trials 36-70, and Trials 1-70.

Subject	Session 1 Mean Answer Times Trial 1-35	Trial 36-70	Trial 1-70	Session 2 Mean Answer Times Trial 1-35	Trial 36-70	Trial 1-70	Session 3 Mean Answer Times Trial 1-35	Trial 36-70	Trial 1-70
STATIC									
S11	3627	919	2273	1492	360	926	333	173	253
S12	1459	4083	2771	2987	1155	2071	862	908	885
S13	7749	2853	5301	1193	493	843	415	255	335
S14	6930	1622	4276	2070	784	1427	320	202	261
S15	8362	60	4211	377	61	219	103	53	78
S16	7658	360	4009	998	306	652	181	309	245
S17	6953	2587	4770	2532	914	1723	639	311	475
S18	8439	3181	5810	1925	1695	1810	963	663	813
PACED									
P11	11247	5629	8438	4938	2736	3837	2927	1725	2326
P12	7627	6267	6947	3746	2372	3059	1943	1057	1500
P13	4823	1835	3329	1515	597	1056	562	274	418
P14	4820	2508	3664	1995	1955	1975	338	178	258
P15	5429	581	3005	476	318	397	170	216	193
P16	3670	1160	2415	850	316	583	271	159	215
P17	9654	3656	6655	1819	959	1389	884	858	871
P18	6468	1584	4026	949	227	588	371	257	314
Mean	6557	2430		1866	953		705	475	
std dev	2486	1805		1217	818		746	452	
S. E.	622	451		304	205		186	113	
df = 15									
	99% Confidence Int. t(.005) = 2.947			90% Confidence Int. t(.025) = 2.131			50% Confidence Int. t(.25) = 0.691		
	Trials 1-35 4724 - 8390			Trials 1-35 1333 - 2399			Trials 1-35 577 - 833		
	Trials 36-70 1101 - 3759			Trials 36-70 594 - 1312			Trials 36-70 397 - 553		

were pooled to compare response latency over the course of a session. Table 2 demonstrates a significant difference between each half of Sessions 1 and 2. The response format was easily mastered during the first half of these sessions, and the average answer time for the second half is indicative of the responding strategy used during that session. Hereafter, the term, answer time, will refer to the average answer time during the last half of each session's trials. Individual view times, answer times, and accuracy scores are listed in Table 3. The following two methods of data analysis attempt to account for task effects, and to isolate the differences between groups due to the rate and order of presentation.

The first method makes some conservative assumptions concerning perceptual-motor abilities to confine all information processing to the view times. This analysis also accounts for individual rates of task acquisition. Suppose a subject encoded the information, combined relevant information sources, compared this information to the REFa/c indications, decided how to move the controls, and then terminated viewing, but had not memorized the key/letter assigned to each control input. In order to answer a question, the subject would have to wait until the responses to that question were displayed on the screen to transform a control input to a letter response. Assuming that this transformation and keypress took slightly longer than 300 msec per question (Fitts, 1951; Klemmer, 1956) an average answer time of less than 1 sec per trial over the last half of the trials would indicate that the information processes of interest were stationary, and measured in terms of the average viewing time for that session. Trials on which these two

Table 3. Individual flight times and data by session for Experiment 2. (Ans time averaged over last 35 trials)

	Flight Time	Session 1 View Time	Session 1 Ans Time	Session 1 Num Wrong	Session 2 View Time	Session 2 Ans Time	Session 2 Num Wrong	Session 3 View Time	Session 3 Ans Time	Session 3 Num Wrong
STATIC										
S11	15	5310	919	8	3673	360	3	3682	173	3
S12	57	5502	4083	8	4182	1155	7	4224	908	1
S13	24	9521	2853	17	4532	493	2	3452	255	2
S14	130	10299	1622	12	5814	784	20	4485	202	7
S15	12	15409	60	36	9249	61	22	6507	53	13
S16	100	9616	360	14	5204	306	6	3650	309	0
S17	90	8414	2587	19	4359	914	15	4040	311	5
S18	10	12393	3181	11	7702	1695	0	4952	663	1
Mean	55	9549	1958	16	5589	721	9	4374	359	4
PACED										
P11	10	13428	5629	26	8146	2736	9	6713	1725	4
P12	60	5677	6267	45	5288	2372	40	5105	1057	15
P13	40	8468	1835	11	5946	597	2	5729	274	8
P14	115	10275	2508	15	5935	1955	10	5913	178	4
P15	10	8877	581	10	5305	318	11	5069	216	15
P16	12	9827	1160	10	6915	316	10	5552	159	3
P17	97	9992	3656	15	6080	959	8	5707	858	5
P18	15	10290	1584	16	6925	227	10	6334	257	4
Mean	45	9604	2903	19	6318	1185	13	5765	591	7

Underlined data denotes first session where both answer time and accuracy criterion are met.

conditions are met are underlined in Table 3. Subjects S15, P11, and P12 did not meet both the accuracy and answer time criteria. The 95% confidence interval for the Static and Paced groups' view times are 4637 - 5129 msec and 5591 - 7961 msec, respectively. Since the intervals do not overlap, the rate and order of presentation had a significant effect on the Paced group's ability to perform the required transformations.

An alternative analysis employs the 95% accuracy criterion and capitalizes on the fact that the input buffer was able to accept responses to each question prior to its display on the screen. The answer time to each question was calculated by subtracting the time at which an entire question and its responses were displayed, from the time at which the input buffer contained an answer. Depending upon the number of manipulations necessary to subtract these terms, an answer time of between 16 and 96 msec (in increments of 16 msec) indicated that a response had been entered to that question before the entire question and it's response choices had been displayed. Based on the same reaction time estimates as the first method (Fitts, 1951; Klemmer, 1956) and the frequency at which each multiple of 16 msec occurred, an answer time of 400 msec or less on a trial is evidence that all of the relevant processing was accomplished during the view time. For those subjects who attained at least a 95% accuracy score on Session 3, Table 4 contains the average view time for all trials with an answer time of less than or equal to 400 msec. Note that subjects S15, P12, and P15 did not meet the accuracy criterion. Since the 95% confidence interval of the Static group (3475 - 4369 msec) does not overlap that of the Paced group

Table 4. Session 3 average view time for trials with answer times ≤ 400 msec.

STATIC			PACED		
Subject	Average View time	Num Trials Ans time ≤ 400 msec	Subject	Average View time	Num Trials Ans time ≤ 400 msec
S11	3619	58	P11	6787	5
S12	3915	21	P12	----	--
S13	3342	58	P13	5734	45
S14	4381	59	P14	5833	61
S15	----	--	P15	----	--
S16	3561	57	P16	5498	65
S17	3920	53	P17	5514	34
S18	4715	32	P18	6188	55
Mean	3922	48		5926	44
df	6			5	
t (.025)	2.45			2.57	
S.E.	447			515	
95% confidence interval	3475 - 4369			5411 - 6441	

(5410 - 6441 msec), the second method of analysis also indicates a significant effect of pace and order.

Separate repeated measures ANOVAs of view time ($F(2, 13) = 43.99$, $P < .0001$) and accuracy ($F(2, 13) = 13.02$, $P = .0008$) indicate significant changes across sessions. Subjects were apparently able to adapt their information processing skills to the demands of the experimental paradigm with relative ease. Neither group x session interaction was significant (accuracy: $F(2, 13) = .00$, $P = .9965$; view time: $F(2, 13) = 1.07$, $P = .3708$).

Discussion

Removing the information processing required to maintain aircraft control from the in-flight environment will induce some degree of transfer effects. In Roscoe's words, "the efficiency of transfer of old learning to new varies widely" (1980, pg. 182). Instead of translating instrument deviations into yolk and throttle inputs, the experimental paradigm required subjects to transform instrument indications into key presses. The visual and mental processing requirements were the same, but the context had changed. Subjects employed various strategies to adapt their processing skills to the demands of the task. A cursory review of Table 3 yields ample proof of the different task-induced strategies. Subject S15 spent a great deal of time studying the instruments and then answered all three questions in rapid succession. On the other hand, subject P12 minimized view time and attempted to synthesize the information as he answered each question. Interestingly, neither ever met the accuracy criterion. Between these extremes, lies the continuum of strategies which the analyses described in the previous section attempt to separate from the effects of pacing.

The first method recognizes individual differences in task acquisition, and contrasts view times when accuracy and answer times first hint that the task has been mastered. Under these assumptions, view times represent the effects of pacing prior to substantial learning. As a result, the magnitude of the difference between group view times is apt to be the greatest at this point. However, evaluation at this point also allows for the possibility that some of the information processes of interest may occur during the answer time. On the other hand, the second analytical method compares groups only when answer times are of such a short duration that any processing subsequent to the view time is highly improbable. The price of this certainty is that differences in group view times may now be more a function of the fixation durations chosen for the Paced group than of the effects of pacing on the information processing involved. To assess this possibility, consider that sufficient information to answer the control input questions was available to the Paced group at 4900 msec (i.e., the approximate time to pace through the performance instruments once). Adding a constant reaction time to press the SPACEBAR (i.e., 500 msec, Klemmer, 1956; Fitts, 1951), yields a conservative estimate of the minimum view time that might be expected of the Paced group (i.e., 5400 msec). Since this value does not fall within the calculated confidence interval, the influence of fixation duration in this study is minimal. Subjects P12 and P15 anticipated the presentation of the third performance instrument in an effort to minimize view time, and demonstrated a speed-accuracy tradeoff. The effects of order and pace on the information processing requirements of maintaining basic aircraft control via the control-performance concept are indeed significant.

An encouraging aspect of the view times concerns the changes across sessions. The effect of session on accuracy and view times was highly significant, while the group x session interactions were not. Essentially, both groups improved at the same rate. Accuracy scores (Figure 12) prove that the transfer effects on the actual information processes were minimal, and view time (Figure 14) illustrates the changes in the amount of information assimilated by each group. For the Paced group, each session brought a decrease in the amount of time in excess of 4900 msec and therefore, an increase in the quantity of information processed during paced viewing. Since this improvement was primarily due to the Paced group's ability to adapt to the forced, random-order presentation, it seems that acquisition of these skills might be accomplished in a minimal amount of time.

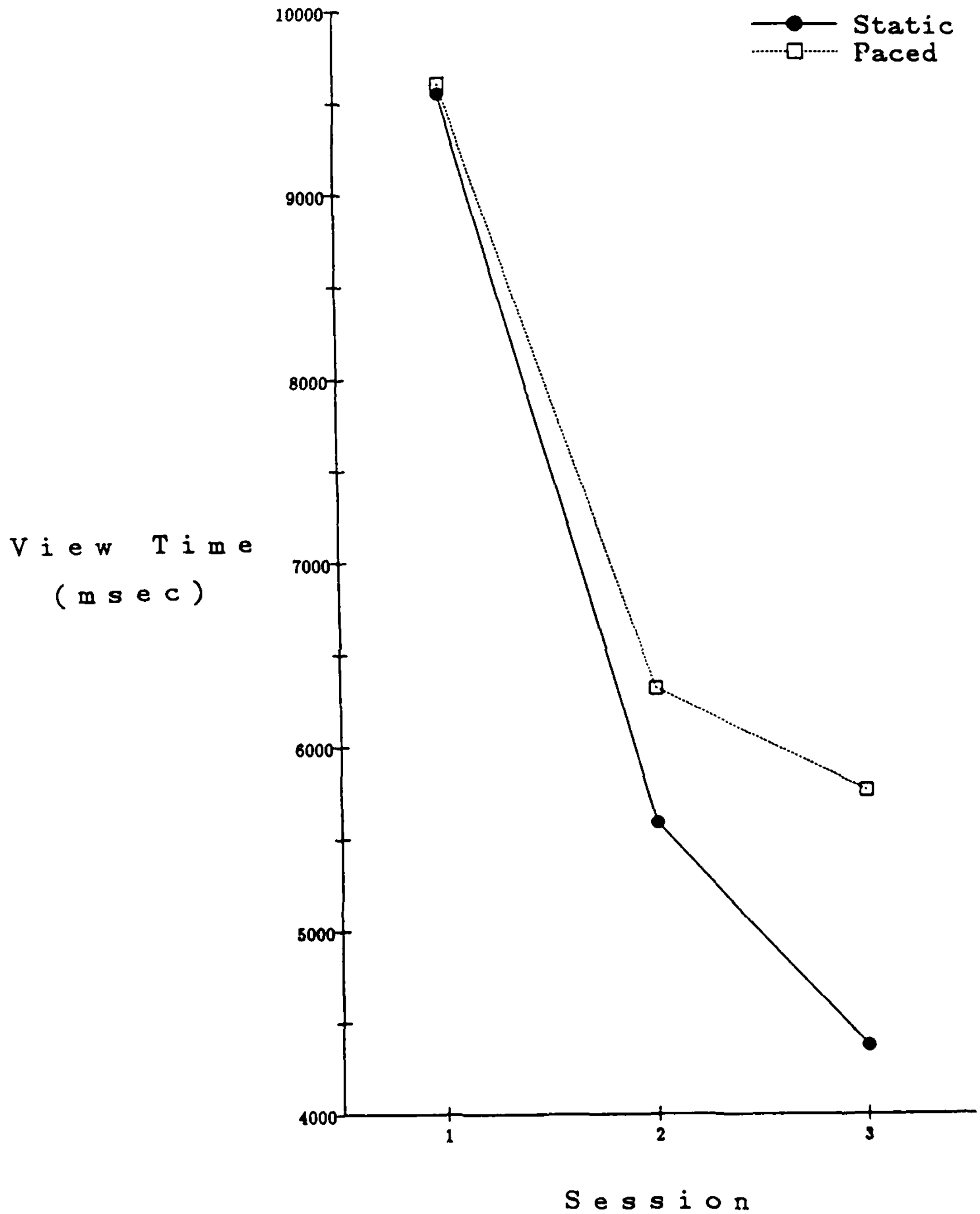

Figure 14. Experiment 2 view time by session.

Chapter 9

CONCLUSIONS

In and of itself, demonstrating the resource demands of the control-performance method of visual scanning is not extremely interesting. However, the experience level (i.e., average total flight time) of the subjects participating in this research is fairly representative of student pilots attempting IMC flight for the first time. Therefore, the implications of the experimental results come into much clearer focus when one considers the data in the context of a generic flight training program/syllabus.

In the normal sequence of IMC flight instruction, student pilots must first demonstrate the ability to maintain basic aircraft control in simulated IMC conditions. They achieve an adequate level of performance with a minimal amount of practice. Since this performance is considered to be indicative of the student's "mastery" of crosscheck skills, students advance to the navigation phase of training. At this point, the resource demands of a control-performance crosscheck become relevant. If one accepts the conservative assumption that navigation consumes all resources which might be invested in basic aircraft control, the research cited above (i.e., Mane & Wickens, 1986; Hart, 1986) predicts that the crosscheck will reflect the student's attempts to minimize his/her workload. Since progress is typically evaluated on the basis of the indicies of actual performance, it is not surprising that students adopt a scanning strategy which fixates on the performance instruments. Hypothetically, these maladaptive scan patterns might eventually become ingrained and be used in any high workload situation. To put it bluntly, I feel that the experimental results implicate the introduction of navigation principles, before the information processing involved in maintaining aircraft control becomes automatic, as a probable cause of non-optimal scanning patterns exhibited by experienced pilots in stressful situations.

Such an assertion certainly represents an inductive leap. While definite proof would require long-term study and an objective measure of workload, computer-aided crosscheck training need not await substantiation of this broad hypothesis. In the short-term, such training might induce novice pilot's eye movements to mirror the cause-effect relationship which actually exists between the control and performance instruments. Ellis & Stark (1986) refer to this eye movement pattern as "statistical dependency caused by closed-loop control" (pg 432). At the very least, crosscheck instruction would be standardized and students would be afforded the opportunity to practice instrument interpretation, eye movements, and information integration.

In the final analysis, this research represents the first step towards establishing computer-aided training as not only a viable, but a necessary alternative to current methods of crosscheck instruction. It also outlines the need for and the direction of further research. I believe the results reported here indicate the necessity to redirect the focus of the study of pilot's eye movements from a descriptive/predictive perspective to one which investigates how and why eye movement patterns develop in the first place.

APPENDIX A

Pitch, Power, Altitude, and Airspeed Experimental Combinations

Pitch Altitude	Airspeed A/S > 100	 A/S = 100	 A/S < 100
Nose high Alt > 3000′	Decrease PCH Decrease PWR	------------ ------------	------------ ------------
Nose high Alt = 3000′	Decrease PCH Decrease PWR	------------ ------------	------------ ------------
Nose high Alt < 3000′	Maintain PCH Decrease PWR	Maintain PCH Maintain PWR	Maintain PCH Increase PWR
Nose level Alt > 3000′	Decrease PCH Decrease PWR	------------ ------------	------------ ------------
Nose level Alt = 3000′	Maintain PCH Decrease PWR	Maintain PCH Maintain PWR	Maintain PCH Increase PWR
Nose level Alt < 3000′	------------ ------------	------------ ------------	Increase PCH Increase PWR
Nose low Alt > 3000′	Maintain PCH Decrease PWR	Maintain PCH Maintain PWR	Maintain PCH Increase PWR
Nose low Alt = 3000′	------------ ------------	------------ ------------	Increase PCH Increase PWR
Nose low Alt < 3000′	------------ ------------	------------ ------------	Increase PCH Increase PWR

Key
PCH = Pitch, PWR = Power, Alt = Altitude, A/S = Airspeed.

APPENDIX B

OWNa/c Indications and Correct Answers

BNK	PCH	HDG	A/S	ALT	ANS	BNK	PCH	HDG	A/S	ALT	ANS
30R	-20	020	120	2900	bbc	60R	30	210	100	3500	bcb
20L	30	150	110	3500	bbc	60R	-30	340	110	3000	abc
20L	-20	090	120	3000	aac	60L	-20	190	110	3000	abc
30L	-30	160	100	2500	bbb	20R	20	050	90	2900	cba
60L	-30	330	110	2400	bac	0	0	100	110	2900	ccc
30R	10	010	110	3000	cbc	30L	0	080	90	2600	caa
10R	0	090	90	3000	bca	30R	-30	170	80	2500	bca
30R	20	180	80	3300	bca	0	20	120	90	2600	cca
60R	0	010	80	3000	bba	0	10	090	80	3000	cba
10L	0	250	110	3000	bbc	30R	-10	030	110	3200	abc
30L	20	090	90	2700	caa	0	-30	120	100	1800	bcb
20R	30	070	100	3600	bbb	0	-20	110	110	3200	acc
10R	30	080	110	3400	bbc	10R	-20	290	110	3000	abc
10L	10	330	90	3000	caa	20R	30	130	80	3500	bca
30L	30	010	80	3500	baa	20R	-20	150	100	2700	bcb
0	30	050	100	3700	bab	20R	-30	040	90	2600	bba
0	0	360	90	3000	baa	10R	-20	080	90	3000	aba
20L	0	240	100	3000	bbb	30L	10	360	90	3000	caa
10R	-30	120	120	3100	acc	60R	-20	200	110	3200	acc
10L	-30	110	90	2800	bba	0	10	100	120	2900	ccc
10R	10	060	90	3000	cba	10R	20	110	100	3200	bcb
20L	-20	130	110	3000	abc	20L	-10	290	100	2900	bab
0	0	250	110	3300	acc	0	-10	090	110	3100	abc
30R	-10	160	90	3000	aca	30L	20	170	100	3200	bbb
60R	0	280	80	3100	aba	20L	20	040	100	3100	bab
60L	-10	350	80	3000	aaa	20L	-30	030	110	2700	bac
10L	20	120	90	2800	cba	10L	-10	100	110	3100	abc
30L	-10	180	120	3200	abc	20R	10	140	90	3000	cca
60L	20	340	90	2900	caa	10L	30	070	80	3400	baa
30L	-20	020	90	2600	baa	0	0	030	80	3100	aaa
30R	30	360	110	3600	bbc	10R	-10	100	90	3000	aca
0	0	280	90	2800	caa	20L	10	140	110	3000	cbc
60R	-10	330	100	2900	bbb	20R	-10	030	110	2800	bbc
60R	10	190	110	3000	ccc	60L	10	210	110	3000	cbc
60L	30	200	110	3600	bbc	60R	20	350	90	2800	cba

Key
BNK = Bank, PCH = Pitch, HDG = Heading,
A/S = Airspeed, ALT = Altitude, ANS = Answers.

APPENDIX C

Experiments 1 and 2 Instructions to Subjects

Your objective in this training session is to view an aircraft's attitude, heading, airspeed and altitude displays, and decide how you would move the controls of that aircraft to correct the displays. Each trial begins with the instruments as they should look. This is referred to as the REFERENCE AIRCRAFT. You may view these instruments as long as you wish. There is no need to memorize them as they will be available verbally when you answer the control questions. When you have finished viewing the REFERENCE AIRCRAFT, press the RETURN key. The aircraft's instruments (as they look now) will appear on the screen for a short time (approximately 10 seconds). Interpret the instruments as they appear, and after time has expired, this screen will go blank. Questions which ask you to determine how to move the controls of this aircraft to make its instruments look like the REFERENCE AIRCRAFT will appear on the smaller screen to the right.

{ At this point the subject was shown a copy of FIGURE 8. }

Try to answer the questions accurately and as fast as you are able. Speed and accuracy are equally important when answering the questions. Don't sacrifice one for the other. After you've answered the questions, they will be corrected. The aircraft instruments will again appear on this screen so that you can study any incorrect responses. Pressing the RETURN key repeats the cycle.

If you have any questions, feel free to ask them now. Press RETURN when you're ready to begin.

For Experiment 2 the underlined portion was changed to read:

The aircraft's instruments (as they look now) will appear on the screen. Interpret the instruments as they appear, and after you've acquired the information to decide how to move the controls, press the SPACEBAR, and this screen will go blank.

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