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Instrument Scanning and Controlling: Using Eye Movement Data To Understand Pilot Behavior and Strategies

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SUMMARY

Eye movement data were recorded while pilots flew ILS simulations of a B-737. In addition, other parameters were recorded including instrument readings, aircraft state and position variables, and control manuevers.

The flight path was broken into five segments, straight-and-level, start of descent, etc. The eye movement data were analized according to instrument position providing counts (time) spent looking at each instrument. These data were used to develop mean dwell (fixation) times, standard deviations and transitions from one instrument to another. These summaries were done for each segment of each landing and used in subsequent analysis.

The experiment itself employed seven airline pilots, each of whom flew approximately 40 approach/landing sequences. The flight conditions were manipulated in a random order and employed two levels of turbulence and two modes of control manual and autopilot. The simulator was equipped with a night visual scene but the scene was fogged out down to approximately 60 meters (200 ft).

The summarized data were entered into multivariate statistical procedures. Factor analysis was run on the entire set of data ignoring the flight condition manipulation. The results suggested 10 components which could be related to categories (packets) of information. In other words, the instrument scanning appeared to follow aircraft parameters not physical position of instruments.

The usefulness of the components were validated using discriminant analysis on the components in conjunction with the flight conditions, segments and pilots. The discriminant analysis was sucessful with 44% to 70% of the cases, depending on the condition.

These results provide a solid foundation for eye scan analysis. One important implication of the results is: Pilots look for categories or packets of information.

Control inputs were tabulated according to throttle, wheel position, column, and pitch trim changes. Three seconds of eye movements before and after the control input were then obtained. Analysis of the eye movement

data for the controlling periods showed clear patterns. For example, throttle changes were associated with looks at the command bars (in the flight director) and the air speed indicator.

The scan patterns found during controlling could be related to the factor components and to the success of discriminant analysis. For example, an "airspeed" component was a major component distinguishing manual versus autopilot approaches. Many more throttle changes were made in the auto pilot approaches.

Taken with the factor analysis, these results suggest a set of mini-scan patterns which are used according to the specific details of the situation. A model is developed which integrates scanning and controlling. Differentiations are made between monitoring and controlling scans. In addition, provisions are incorporated in the overall scan model to provide the flexibility in scanning the pilot seems to require.

INTRODUCTION

Instrument design and instrument layout are important problems in aviation. Accidents have occurred because critical information was not available to the pilot or because the pilot misinterpreted what he saw. While it may be impossible to eliminate all pilot error, the possibility remains that some accidents might have been avoided with different or better instrumentation. Clearly, improved instrument panels will lead not only to fewer accidents but also to increased safety margins, especially in increasingly busy terminal areas.

Despite considerable research effort we still do not know for sure how an instrument should be designed. To be sure, instrument designers and pilots have done very well: Aviation has a much better per mile safety record than any other means of transportation. To achieve additional gains will require a more complete understanding of every aspect of the cockpit. A topic which has not received full attention is how the pilot interacts with the instruments. Oddly enough, there is little research available on the way in which a pilot uses the instruments available to him. Before we can evaluate the advantages of new display technology it is appropriate to understand what the pilot does when using an existing instrument panel. A better understanding of this aspect will not only make instrument design easier and more efficient but ultimately will lead to increased safety.

The main theme of this report deals with the issue of how an aircraft pilot uses instruments. This report represents work which is part of a research program being carried out by the National Aeronautics and Space Administration. The purpose of these studies is multifold: (1) To build a data base to be used for evaluation of advanced displays, (2) To provide improved training procedures which would result in greater safety, and(3) To develop human performance theory to serve as a guideline in the design of advanced displays. The experimental approach is through the measurement of eye movements in conjunction with the measurement of control maneuvers and aircraft parameters. Researchers have worked on the study of eye movements since the time of Dodge (1907), and during these seven decades of research, somewhat more progress has been made in technology than in understanding the meaning of the eye movements themselves. The present report includes analyses of eye movement data in conjunction with, for the first time, control inputs. By means of analytic techniques developed for this research program, it is possible to demonstrate the existence of a number of instrument scan patterns which can be related to the purpose and controlling strategies (piloting techniques) of the pilot.

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THE PRESENT APPROACH

The approach in this report is different from previous work which has emphasized the eye movement measurements and the instruments. While these are of obvious importance, the emphasis here is on the cognitive and information processing characteristics of the pilot. We have attempted to dissect the task, to discover analytically the purpose or purposes of the pilot, and then to use these ideas in guiding the analysis.

The report also contains some re-evaluation of assumptions. One example of this concerns various opinions about the meaning of the eye movements themselves and what they tell us about how the instruments are used. An extreme version is the view that eye movement measurement tells us no more than the direction in which the eyes are pointing. While we don't accept this view, the data will show that simply measuring eye movements is not sufficient to understand fully how the pilot is using the instruments. Some additional considerations include information about what the pilot does about an instrument reading, what his purpose is in looking at the instrument, and the way this newly acquired information fits into his plan or strategy for landing the aircraft. A second assumption concerns individual differences. Eye scanning differences among pilots have not been studied in detail; knowledge about individual differences is important for understanding the generality of the results and may have future implications for training.

Analytic techniques may also contain implied assumptions. For instance, some investigators have applied Fourier analysis to the sequence of eye movements (Senders, Elkind, Grinnetti, & Smallwood, 1966; Clement, Allen, & Graham, 1971). One such implied assumption is that flying is a continuous task; this is probably not a legitimate assumption. The Fourier technique emphasizes physical characteristics of eye movements (what the eye is doing) but pays little attention to the form of the information or the redundancy in the display. Like most analysis techniques previously used, all fixations and eye movements are assumed to occur for the same reason -- the purpose of the operator is ignored. Some of the evidence presented in this report calls this assumption into question and the evidence leads to interpretations which will focus heavily on the purpose of the pilot.

Background

We turn now to lay some groundwork for the approach taken in this report. In the next sections we review briefly some of the characteristics of eye movements, provide a discussion of the task itself, and consider the instrument package. The assumptions on which the analyses are based are interwoven in the discussion. Following this introductory material, we will turn to the analyses themselves.

Eye Movements - The Saccade

There are a number of types of eye movements; the only type of critical importance, however, in the controlling situation is the voluntary movement - the saccade. The other types of eye movement including smooth pursuit do not appear to be under voluntary control and are not of major importance in instrument viewing. (See Bailey and Dick [1978] for a review.) While the visual scientist might accept this position without any question, there are people who do not hold this position and it is for them that this section is presented. The interpretations represent widely held views. It is possible, of course, that the experiments have missed one or more important features of performance in an applied situation.

Saccades, which are used in the majority of everyday viewing, can be characterized as periods of relative stationarity interspersed with periods of rapid movement. Saccadic eye movements are not smooth, continuous movements. That is, in instrument viewing, reading, and most everyday tasks, the eye is stationary on a point (A) for a minimum period of about 200 msec followed by a rapid movement (lasting for 20-40 msec) to point B. The eye again will be stationary on point B for 200 msec or more, followed by another rapid movement. Thus, the saccadic movement is composed of periods of stationarity (fixations) interspersed with rapid jumps.

Several other aspects about saccadic eye movements are of interest. (1) Four to five fixations (or movements) per second appear to be about the maximum number of fixation/movement cycles per second. (2) The fixation duration may last longer than 200 msec but there is little evidence for anything less than 200 msec in a non-laboratory task. (3) The velocity of the movement itself is partially a function of distance - the greater the distance, the higher the velocity. (4) Acuity is reduced for a brief period surrounding the movement with the consequence that little functional viewing occurs during the movement itself. (5) Finally, and of considerable importance, is the fact that the "decision" to move the eyes is made during the fixation and once that decision is made, nothing can alter the path or distance of the movement. That is, the length or direction of a saccade cannot be altered, either during the movement itself or for some period before the physical movement starts (Wheeless, Boynton, & Cohen, 1966). This latter point has an important implication for instrument displays: A change in the reading of an instrument during this immutable period will require two eye movements, the original movement from point A to B and a second movement to come to the new position.

Since there is no evidence to indicate that the rate at which the eye travels is influenced by cognitive or environmental factors, we can focus our interest on the fixations: In particular, the duration and sequence. It is during the pause or fixation that information is collected; thus, information acquisition is a discrete process. (See Note 1.) So too, can we consider the perceptual/cognitive analysis on the newly acquired information. Each fixation could have one or more decisions associated with it. One example would be the decision where to move the eyes next; another would be to take action to alter the path of the aircraft.

The primary reason a pilot looks at the instruments is to update his knowledge about the state of the aircraft. Setting aside issues such as visual threshold and other differences among pilots, we can define two conceptual categories of eye fixations. One leads directly to changes in controls. The other category consists of monitoring fixations which do not lead to control changes. Because information processing requirements differ depending on the purpose of the operator, the instructions, and the behavioral consequences (e.g., Posner, 1978), one would expect the eye movements associated with these two categories of fixations to differ in important ways, especially in the sequence and duration of fixation. However, because control changes occur at frequencies much lower than eye movements, there should be an imperfect relation between control use and eye movements. The analyses described in this report examine these issues.

The Instruments

A schematic of the primary instruments used in landing is shown in Figure 1. The schematic is derived from the instruments used by a United States airline in their Boeing 737 jet aircraft. The parameters of interest to the pilot include altitude, forward speed (airspeed), rate of descent (vertical speed), lateral position, and pitch angle of the aircraft. The parameters are co-related, that is, a change in one will have an effect on one or more of the others. For example, a change in direction may also produce a change in vertical descent rate. This aspect is covered early in pilot training and is well integrated into every pilot's controlling procedures.

Some Analytic/Interpretation Issues

First, the instruments themselves contribute a portion of the analysis problem - that of informational redundancy in the display. Altitude, for example, is obtained directly from the barometric altimeter before glide slope capture. However, after glide slope capture, relative and secondary information about altitude can be obtained or derived from the command bars (CB), the glide slope indicator (GS) and/or the instantaneous vertical speed indicator (IVSI). In addition, other aspects of the cockpit environment provide many cues. For example, co-pilot altitude call-outs and altitude alerting devices may preclude the necessity of looking at the altimeter at certain points in the flight path. There are, then, numerous and separate ways a pilot can get information about altitude. Because of these different sources of information, it is not sufficient to theorize based solely on information about where the eyes are pointing or even necessarily the duration of the fixation. To understand the situation fully, one must identify the factors which drive and determine the pattern of eye movements across the instruments, taking into account situational variables such as aircraft position and control mode. At a later time, the researcher will want to incorporate the other sources of information. For now, we restrict the discussion to vision as the primary source of information.

Second, we do not know for sure what kind of information the pilot gets from an instrument, whether it be rates or static values or a combination of the two. Almost all of the instruments provide numerical values yielding information about the aircraft parameters at a given point in time. Rates, however, are also important: many of the instruments contain indirect information about rate through needle movement. This indirect rate information would require a longer fixation time (dwell time) to integrate perceptually than would the numerical value; the perception of rate information requires a time sample. Mean dwell times (and their standard deviations) are, therefore, potentially important as a clue to the type of information the pilot is getting from the instrument.

A third problem has to do with what we learn about instruments and their use through the measurement of eye movements. Thus we face squarely the issue of instrument design vs. instrument layout. In practice, these two aspects cannot be divorced as easily as they can be analytically, but the point should be kept in mind. Hypothetically, a 'good' instrument is one which is easy to read and provides the pilot with the information he wants and needs. The airspeed indicator is probably a good instrument. It is possible to read it with one fixation and it provides rate information when needed. The barometric altimeter used in this instrument panel (drum and pointer) is probably not as good because there are times when it will require two fixations - one to read the pointer and one to read the drum. (There are times when both can be read at the same time and times when the pilot will read only one. There are also times when the pointer will block reading of the drum [Note 2]). All things being equal, which is to say theoretically, the amount of time required to read an instrument should be directly related to and measurable by fixation (mean dwell) times. In practice it is not possible to do this because it does not take into account the relative importance of the information. In human information processing terms the quality of the instrument would be a factor in determining the perceptual/cognitive processing time which would be a part of the cognitive workload.

One piece of information, however, is not enough; this is where instrument layout becomes important. The layout obviously should be convenient for scanning. In this context a number of factors may be relevant: The degree to which the pilot uses peripheral information; the kind of information he uses, rate (needle motion) vs. numerical readings; the amount of head movement required; and the required direction of eye movement - horizontal, vertical, or oblique. Scanning will also be a function of what the pilot has to do about the information he gets, i.e., task requirements.

Eye movement measurements are probably not going to yield direct, precise information about the quality of the individual instruments. There are alternative sources for almost every piece of information the pilot gets from a given instrument. What the eye movement data will provide is information about how the pilot uses the instruments to put together and update his knowledge (or mental picture) of where he is and what the airplane is doing. Whereas, the traditional approach has been to design an instrument and then find out how good it is for the pilot, the present approach is to find out where the pilot gets the information and what he does with it. Then these results can be used in instrument design and layout.

The Experiment

In the experiment, each airline pilot was asked to fly a series of instrument approaches in which data were recorded from eight miles out to touchdown. The specific task used was an ILS, precision approach (straight-in). Wind conditions were zero and no emergency conditions were imposed. The approach speed and altitude at the beginning of data collection were 150 knots and 457 meters (1500 ft.) respectively, and target landing speed was 128 knots. Turbulence was at one of two settings for a given run on the simulator; zero or full. In addition, the control mode was either manual or coupled (autopilot with manual throttle). Full details of the experimental conditions may be found in a report by Spady (1978).

Seven airline pilots flew a series of instrument approaches in an FAA rated Boeing 737 simulator. This simulator was equipped with a night landing visual scene; this scene was "fogged" out by the simulation computer down to a ceiling of about 30.5 meters (100 ft.) at which point the visual scene faded in. The conditions of flight are listed in Table 1. A modified

Honeywell oculometer was used to record eye movements (Merchant, Morrissette, & Porterfield, 1974). The electro-optical head containing an infrared light source, collection optics and a TV camera was mounted in the instrument panel. The signals were transmitted to a laboratory computer which calculated and recorded the X-Y coordinates and simultaneously controlled a mirror which permitted tracking within a cubic foot of head movement. In addition, a second TV camera took an over- the-shoulder view of the instrument panel; this permitted real time viewing of the eye movements by combining a signal from the lab computer with the instrument panel scene. This scene was also recorded on video tape. The X-Y coordinates of eye position were recorded on FM tape for later analysis, as well as other variables which included the readings on the instruments, motion characteristics of the aircraft, and state variables such as airspeed, glide slope position, pitch angle, as well as rates of acceleration. In addition, electronic sensors attached to the controls permitted continuous, on-line recording of all movements of the controls. In effect, everything the pilot saw, felt, and did, was recorded. More detail on the eye tracking equipment may be found in Appendix A prepared by M. Wise and J. Holt in the report by Spady (1978).

For purposes of analysis the instrument panel was partitioned into areas somewhat wider than the instrument. Further, the flight director was partitioned into nine areas, four of which contain instruments, four of which are empty of instruments and one which contained an inactive instrument. This latter area, FD-4, encompasses what is normally an active speed bug. The areas used in analysis are shown schematically in Figure 2.

Data Reduction

During the experiment, 28 channels of data were recorded, including X and Y coordinates of eye position, instrument readings, aircraft control inputs, aircraft parameters, and motion characteristics. All of the channels were digitized (at 32 frames per second) and then the X-Y coordinates of eye position were converted to "look points" referencing points on the instrument panel and these look points in turn were used to develop a series of measures which included mean dwell (average fixation time) for each instrument, standard deviations of the dwell times, and first order transitions from one instrument to another. Additionally, the program provided summary statistics on blink rate, oculometer tracking time and out of track time. The out of track time refers to the amount of time the pilot's eye was not in the oculometer range, this is called No Track time, etc. The characteristics of the flight path, speed, and deviation from glide slope were maintained as was the frequency of the use of each control.

Description of the Analyses

In Part I of this report, we attack the redundancy issue with multivariate statistical techniques: factor analysis and discriminate analysis. A number of measures of scanning have been used in this and previous studies including mean dwell (fixation) time, standard deviations of the mean dwell, and transition counts from one instrument to another. These measures may, of course, show interdependencies (correlation); these are addressed in the analytic procedure. The analysis is used to identify "what goes with what" in the way of instrument use; in practice it also combines correlated variables into a much smaller number of components making the results much easier to deal with. This analytic approach has not been used previously in the instrument scan context and we feel produces some interesting and potentially important results. It provides information about the scan patterns (note the plural) and some indications about the information acquisition strategies of the pilot. Tentatively, the interpretation involves the suggestion that the pilot is after categories or bundles of information. These bundles are related to aircraft parameters and not directly to specific instruments.

In Part II, we isolate the scan patterns used during controlling by means of examining controlling events. We are able to generate scan patterns associated with the various controls available. There appear to be several variations on some basic controlling scan patterns; our tentative interpretation is that these result from different purposes relating to different control maneuvers. These results are necessary for the interpretation of the information bundles and will be integrated with Part I in the general discussion.

In Part III we examine the control input frequencies and compare these to each other with regard to pilots, degree of automation, and turbulence. These data highlight pilot differences in amount of controlling and at the same time show both the tradeoffs and the consistencies in controlling technique. They also provide some useful clues for the integration of the results into theory.

ANALYSIS - PART I

Redundancy is by definition a correlation. Accordingly, it is appropriate to use multivariate (correlational) techniques to examine scanning across redundant instruments. If a pilot does, in fact, have a systematic mode of viewing the instruments, the pattern should be observed in a correlation matrix of the dependent variables. By using results from individual landings, there are enough repeated observations to assess any relation which may exist. Further, manipulation of the independent variables may also result in systematic changes in the dependent variables which in turn will result in systematic changes in the correlations. If there is no pattern, the correlation should be near 0.0 and relatively uniform. If, on the other hand, there is a pattern, the correlations will vary and differ from each other. The first step is an empirical one: to determine if there is a pattern within the confines of this analysis.

Given a viable result from the first step, a second step will be to evaluate theoretical concepts. There are many possible theories of which we will discuss three. The first is without any empirical foundation. The second is a distillation of the current state of the art, and focuses on the instruments. The third is a cognitive approach; it focuses on the pilot's information processing procedures and capabilities.

Some aviation experts feel a good scan pattern is a circular one, sampling all instruments in turn. Each instrument would be of roughly equal importance in the sampling or transition sequence. The time spent on individual instruments could vary but the frequency each instrument is looked at should be the same for all instruments. This would result empirically in a clear pattern in the transition data from instrument to instrument. Under such an hypothesis the transitions expected would be unidirectional: high from instrument A to instrument B and low from B to A.

A second alternative consists of treating the instrument panel as spokes of a wheel with the flight director at the hub. Under this hypothesis, the transition data would show large correlations (transition values) between the flight director and other instruments, other possible transitions would show small values, e.g., the altimeter and the IVSI would seldom be linked. The transition links will be based entirely in terms of physical instruments. The 'basic T' configuration of instrument layout is in accord with this hypothetical scan pattern.

A third hypothesis has an information processing and cognitive basis which takes into account the redundancy available. That is, the pilot will try to obtain a particular category of information, e.g., about altitude, and will use (or look at) those instruments which provide both direct and indirect information about altitude. Rates on aircraft parameters would be important here; altitude information without knowledge of the rate of descent may not be valid information for very long. On the other hand, altitude information at an early point plus knowledge about a stable rate of descent may not require updating very often. The theory further predicts the instruments themselves will be less important than the categories of information.

Previous work reporting transition values (Barnes, 1972; Spady, 1978; Weir & Klein, 1970) provides no support for the circular scan hypothesis. These data, however, do not help to distinguish between the spoke hypothesis and the information category hypothesis. The importance in differentiating between these two hypotheses lies in the determining factors of the scan pattern itself and its implication for instrument design and layout. The spoke hypothesis implies a physical and spatial determinant of the scan path in which the eye movement pattern would be driven by the instruments; the prediction seems to be that as an instrument changes more frequently, the dwell times should become shorter and the number of transitions should increase to reflect a higher sampling rate. The interpretation, however, does not take into account the redundancies present. (See Note 3.)

The theory behind the information processing approach implies a cognitively and experimentally determined basis for scanning. It consists of preprogrammed motor sequences each of which, when initiated, is run off more or less completely and independently of specific instrument readings. While there is no clear precedent for this motor program suggestion in the literature at least with specific reference to eye movements in the instrument scanning context, there is ample evidence that motor sequences can be and are preprogrammed and will 'run off' without interruption (Lashley, 1951; Luria, 1966). The selection of a particular sequence is a complicated issue which will be discussed in the interpretation.

Thus, the cognitively determined pattern would show little change as a result of frequency changes due to turbulence but marked changes resulting from task demand changes (workload) such as autopilot or manual control. This latter change would be expressed in reduced dwell times resulting from reduced information processing requirements (reduced workload). Further, the information processing approach demands that the scan pattern be in terms of coherent information categories or packages. An information package can be defined as one which includes transitions among instruments which provide structurally and statistically redundant information (Garner, 1962). With the emphasis on categories of information, the cognitive approach does not require that the scan-connected instruments need be physically adjacent. By the same token a failure to find coherent correlation combinations (information packages) would be evidence against the view.

Data Analysis and Results

Data reduction was done for each approach (run) for each pilot (Note 4). Because the task demands vary across time and the distance from the runway, the run was segmented into the five parts illustrated in Figure 3. The data used in the factor analysis consisted of the summaries for each segment e.g., mean dwell, standard deviations, and transitions within each segment. Each segment from an individual run is defined as a case. The results of these data reduction procedures were then prepared for the subsequent analysis.

Because variables not containing any data would produce a singular matrix and therefore would not permit the analysis to be completed, the data were checked to determine which variables, if any, did not contain useful data. Those variables which had 0.0 means and 0.0 standard deviations were set aside. After the data were checked for variables containing only zeros, they were entered into factor analysis with VARIMAX rotation (Dixon, 1975). (See Note 5.) VARIMAX retains the orthogonality of the dimension and is the most conservative approach (Harmon, 1967).

In an earlier analysis (Dick, Brown, & Bailey, 1976) the standard criterion of an eigenvalue equal to 1.0 was used as a cut-off (Harmon, 1967). The factor analysis results from this earlier study were subjected to several validation techniques (Dick, 1977). (1) Pilots were asked to rate the components as to what the components meant to a pilot. This is a fairly subjective procedure but it indicated that a number of the factors were reasonable while a few did not make sense. (2) The cases were then randomly split into halves for each pilot/condition and subjected to statistical double cross-validation. The cross-validation procedure indicated that those variables which the pilots did not understand were the ones which did not appear consistently in the two split halves. (3) As the final step, coefficients of congruity (Harmon, 1967) were calculated between the two halves. This procedure indicated that several of the components did not correlate highly between the two halves, and therefore these components should be discarded (Dick, 1977).

The guiding principles for the present analysis were based on this earlier work. In the present experiment, up to 22 components could be generated (eigenvalue = 1.0), accounting for 78% of the variance in the measurements. However, as with the earlier experiment (Dick, et al., 1976), the higher order components were not used by the discriminant analysis. While one could argue as to how many factors should be retained, the contribution of high order components appears to be questionable. Ten factors appeared to be a good compromise and fit reasonably well with previous work. (See Note 6.)

The main factor analysis provided the 10 components described in Table 2. It is based on 81 variables (Appendix A) and accounts for 57% of the total variance (sum of eigenvalue/81). This component table represents a combination of the conditions, pilots, and segments. The table may be considered to represent the most important characteristics of eye scan behavior during ILS landing. This is not to say each pilot uses each component; it only implies that these are the major components in the data set. In addition, in the table some indications are provided about what each of the components contributes in terms of classifying the variables when discriminant analysis is applied.

There are several ways of validating the meaning of the factor components; these have been described above. We did not ask pilots to rate the components again from the present results, for the simple reason that the components show good consistency with the previous work. A fourth procedure was used: discriminant analysis was done on the factor scores to see how well cases could be categorized (classified) on the basis of one or more case variables. (Note 7).

Discriminant analysis is a statistical procedure in which the data are used to generate an equation for each group or condition entered into the analysis. The analyses reported were all done using the following general rules: The control input frequencies and the components were entered as separate entities in the analysis. Using factor analytic procedures, the original data were transformed into factor scores for each case: pilot, segment, and condition combination. The scores for each case in the discriminant analysis were (a) the ten factor scores derived from the ten components, (b) the frequencies of control inputs or (c) both. Further, to be conservative in the analysis, an F = 10.0 or more was required to allow the program to bring the variable into the analysis. A series of analyses were done examining each of the variables (pilots, segments and conditions) individually and in combination, the latter to look for interactions among the variables.

Pilots

The analysis by pilots will provide evidence about the uniformity among the pilots of collection of information bundles. In the analysis of pilots, nine of the ten factors entered into the discriminant analysis, but none of the control input frequency variables entered. Component 8 (Glide Slope Tracking) was the strongest in the discriminant analysis, with Component 1 (Airspeed monitoring), Component 2 (Horizontal and vertical situation), and Component 9 (Lateral tracking) also showing considerable strength. The equations can be used to identify correctly 72% of the cases into six pilot categories. The discriminant results suggest six different combinations of the components are used by the seven pilots. These different combinations are not, according to the analysis, related to control input frequencies.

Individual differences among pilots exist in the way in which they collect the information. The success of the discriminant analysis in distinguishing pilots is the result of differential weightings of the components. Some pilots apparently check one parameter at a time (e.g., components 3 and 4) while others may combine vertical and horizontal position into one (e.g., component 2). The similarity in mean dwell times (Spady, 1978) shows the pilots are using the instruments for the same amount of time while the components show that the integration of the instrument in the scan may be different for different pilots. Thus while individual scan patterns may differ, the emphasis on categories of information remains fairly stable and it is this emphasis on information which apparently gets translated through to control inputs. However, this does not necessarily imply that the basis for decision making about an individual control is the same for all pilots.

Conditions

The analysis by conditions showed that just the components 7 (monitoring technique), 1 (Monitoring airspeed), and 5 (Altitude) entered the analysis to yield 44% correct classification overall. The strength of the analysis lies in being able to discriminate the manual from the autopilot modes of flying. Monitoring technique reflects the increased rate of scanning in the autopilot case and component 1 is seen because of the differences in the task for the two modes. Conditions 1 and 3 differ only in the amount of the turbulence, as do conditions 2 and 4. The analysis shows considerable confusion within these pairs of conditions. Apparently scanning is not strongly influenced by turbulence.

The frequency of control variables was omitted from the factor analysis but was maintained in the data set. As a result the control input measures can be compared with the components. Turbulence can be detected when control inputs are permitted to enter the discriminant analysis and the percentage of correct classification jumps to 71%. Associated with this increased classification accuracy is the ability to discriminate within manual and within autopilot modes of flying. Supplementary analyses show that if just control inputs are used, ignoring all of the eye scan statistics, classification is better than 70% accurate.

To analyze the manual conditions in more detail, a discriminant analysis was run omitting the autopilot conditions. This leaves two manual conditions, differing only in turbulence. Using just the control inputs the analysis correctly classifies about 80% of the cases. This result is important because it differentiates between control maneuvers and scanning and implies a differentiation between turbulence and control mode. This result has also been reported by Dick, Brown, & Bailey (1976) using a similar analytic technique on data from another experiment using a slightly different instrument panel and a wider turbulence variation. They found that eye scan patterns were relatively immune to changes in turbulence but were sensitive to small changes in the instrument panel.

Interpretation. It appears that once eye scanning patterns are formed, they appear to be stable and modifiable only by changing the local availability of information. In the autopilot mode the task demands change considerably with the pilot controlling only the throttle and monitoring the instruments to check on the autopilot. A mode change seems to cause the pilot to use a somewhat different eye scan "program" but one which is also relatively immune to turbulence.

Implication. Component 7 which was the strongest component in the mode differentiation is composed primarily of mean dwell times and standard deviations on those mean dwells. Obviously, the reason for the statistical differentiation is due to the longer dwell times in the manual condition (Spady, 1978). As a tentative interpretation it is suggested that this component is one which reflects a need for different information. As suggested above, to derive rate information would require longer fixations because of the necessity to sample across time. One interpretation of Component 7 is that it reflects the differential use of rate information. There are other reasons why the dwell times would be longer which will be discussed later.

Theoretical implication. These results have some important implications for theoretical development. Frequency theories have been developed to evaluate instrument displays. In the simplest form it is assumed that the frequency of change on the instrument dials will be associated with a change in frequency in eye movements (e.g., Senders, et al. 1966). The present data indicate this not to be the case. Within the range of manipulation applied, we do not find any appreciable changes in the frequency of eye movements as a function of turbulence and therefore of frequency of instrument change. It may be noted that this argument also applies to an information theory formulation of instrument display evaluation. Increased turbulence will lead to a mathematical increase in uncertainty; however, we find little evidence to support the view that the pilot increases or changes his scanning to compensate for this increase. This result is in agreeement with Garner (1962) who suggested physical uncertainty is not nearly as important for performance as psychological uncertainty.

Segments

The reason to analyze segments is to determine if the components are used differentially across the flight path. The general answer to the question is that they are. However, when analyzing segments we must remember that the analytic differentiation among segments is more or less arbitrary. While it is clear that the task changes across segments/position on the glide path, the pilot attempts to make a smooth transition from one segment to another. Accordingly he may be a little ahead or a little behind his projected time course which would lead to the confusion among adjacent segments. The results of the analysis are also contingent upon whether segment 5, the final portion of the glide slope, is included or not. In this last segment from 30.5 m (100 ft) of altitude on down to the runway, there is little room to maneuver the aircraft (Note 8). If properly lined up and stable, the pilot monitors the flight of the aircraft to insure a proper touchdown is attained. When segment 5 is included we can identify correctly about 60 percent of the cases. Removal of segment 5 from the analysis causes the percent of correct classification to drop to about 50%. Many of the classification errors arise because of incorrect placement of the case into an adjacent segment (Note 9). The analysis has difficulty discriminating between segments 2 and 3 and between segments 3 and 4. The one control input that enters the equation is wheel position which facilitates discrimination on segment 1. This point is consistent with pilot instruction and verbal comments; pilots like to get lined up with the runway as early as possible.

Implication. The analysis is moderately successful in differentiating segments based solely on eye movement measures. This suggests the eye movement patterns change systematically across the flight path. The need for and the use of different information is consistent with the changing task. A sizable portion of the misclassifications is into adjacent segments. In part, this illustrates a difficulty with the analysis, and in part the need for flexibility on the part of the pilot.

CONCLUSIONS AND IMPLICATIONS - PART I

Summary. Eye scan statistics were analyzed with factor analysis and the factor components were analyzed with discriminant analysis. The results of the factor analysis provided components which are consistent with pilot comments and with a previous experiment. These components (information bundles) could be used with reasonable success to discriminate among pilots, automation conditions and position on the glide slope (segments). An analysis by pilots showed large individual differences in scan patterns.

Implication. The rotated factor components (Table 2) can easily be identified with aircraft state variables. This suggests the pilot's coordinated eye movement pattern is such that it yields information for him about a parameter. Several points are consistent with this interpretation: (1) Pilots can identify with and name the components, (2) Similar patterns were obtained from a different experiment (Dick, et al., 1976) with different pilots, and (3) Finally, the components could be used to distinguish among several of the experimental variables.

Speculation. It is possible that principal components analysis provides a general technique to analyze eye movement data from instrument displays. If this be the case, one would expect similar factor components from various different displays. That is, whether one examined a futuristic display which contained totally different symbology or a display less sophisticated, the components should be highly similar. Indeed, this is precisely the first step in testing the generality of the present results.

Implication. If the present results are found to be robust through additional research they could have an important impact on both theory and instrument design. The information bundle hypothesis focuses on the pilot's behavior. The pilot appears to go after a category of information and will look at instruments in overlapping combinations to obtain information about that category. In other words, the results suggest the pilot decides on the bundle and then assembles the information by checking and cross-checking the appropriate instruments. This interpretation places the locus of control of scanning squarely on the pilot.

As noted above, other approaches in display design put the emphasis on the instruments themselves implying that the pilot presumably is led by the instruments. However, if this were true, the components would be tied to instruments and not cut across instruments as the factor analysis results seem to show.

Speculation. The components provide an alternative view to instrument layout. If the instruments relevant to an information bundle were somehow positioned in a cluster, the number of eye movements required to assimilate the bundle would be reduced. This could lead to faster assimilation of the bundle and to reduced workload. This is, of course, the goal behind integrated display work. The integrated design tends to involve pictorial representations but it is not clear that any consideration has been given to categories of information. It is possible the information bundles would be more dispersed in an integrated display and therefore make it more difficult to collect the information. This would be especially true if one or more portions of the display are not fixed in position. If the pieces of information move, the pilot would have to search a little before finding it.

Some Theory

One of the reasons for examining eye movements is to determine the guidance for scan patterns. Many investigators have apparently assumed that a fixation generates the information for the next movement. Research, however, has shown that if a series of saccades are to be made in a regular sequence, the observer will begin to anticipate the target after a rather short interval. Complete reliance on a physical determination of eye movements would preclude the possibility of any learning of integrated eye movement patterns. While no one has proposed such a rigid view, there is the matter of degree. The present analysis with its finding of information bundles places a heavy emphasis on the cognitive determination of scan patterns. At present there is no detailed information available about sequences within a category; nevertheless, it is clear from the marked pilot differences that pilots have different techniques for establishing the sequence in which they get information. The existence of the pilot differences is not only evidence for the cognitive basis of scan patterns, but also for the flexibility of the patterns and that several scan techniques are functional.

Previous analyses show two major empirical changes in the scan characteristics for the autopilot mode over the manual mode which are: (a) the shorter fixations on individual instruments and (b) a large increase in total time on airspeed and somewhat smaller increases on raw data instruments (Spady, 1978). There are several explanations for these results.

In one, the decision about where to move the eyes next is based primarily on the previous fixation. This approach is fairly traditional and does not incorporate the concepts of motor pre- programming or information bundles. Bailey (1977) has shown changes in fixation duration to occur as a function of whether or not the scan path should be changed as a result of the information collected during the fixation. In the autopilot case especially, most of the instruments reflect states which require no action on the part of the pilot. Thus, the next fixation position can be predetermined independently of the reading of the instrument in this mode (cf. Littman & Becklen, 1976). Fixations in the manual case are much more likely to require control decisions and therefore the results of a fixation may alter the direction of the scan contingent upon integration of information from various sources. The integration itself would slow down the scan rate and would leave the pilot with less time to examine the lesser used instruments. That is, the cognitive effort is higher and this increased workload is associated with longer fixations.

A second interpretation involves the type of information the pilot obtains from the instruments. He may be extracting rate information in the manual mode but not (as much) in the autopilot mode. Like the previous interpretation, this would have the effect of slowing the scan rate. We favor the latter interpretation; the information bundle idea implies the decision about where to move the eyes next is not part of an individual fixation. The integrated results of an information bundle are used to determine, in part, the next mini-scan. We have no evidence from this experiment which would permit a differentiation of these two alternatives.

ANALYSIS - PART II

The factor analysis in Part I identified some components which we have labeled information bundles. It is suggested these bundles represent categories of information and indirectly, mini-scan sequences. However, because the data were summarized across segments, potentially important information about timing is lost. A more detailed analysis maintaining timing and sequence information may provide further insight into the strategies and purposes of the pilot. Specifically, the analysis will be helpful in interpreting the information bundles.

Another reason for developing the second analysis is to determine which instruments the pilot looks at immediately before and after making a control input. Whereas Part I utilized summarized eye movement data from the entire landing sequence, Part II uses data only from those occasions in which the pilot has changed a control; the rest are discarded in this analysis. The differences between the way the pilot looks at the instruments over entire segments (Part I) vs. the way he looks at them while controlling (Part II) will also provide some important clues as to how he uses the instruments for different purposes.

The Logic of the Analysis

The logic is actually fairly simple and is illustrated in Figure 4. For each landing, we proceed through the sequence until we find a control input (for example, turning the wheel), and when a control input is identified, we stop and take the three seconds of eye movement data prior to the control input and the three seconds immediately following the control input. By using six seconds we are assured of capturing the changes related to the controls and obtaining base line data before and after the event. These six seconds of time are then saved and we then proceed on to the next control input. When the process is complete for that landing, there might, for instance, be ten blocks of data representing ten control changes which are then summed and averaged. This summary represents the controlling activity, both in terms of the control maneuvers and of the eye movements for that particular landing. All landings by a pilot under the same condition are pooled to increase the sample size. The turbulence conditions were pooled since the previous analysis did not show major effects of turbulence on scanning.

An event recognition program was developed which permits control input analysis for any control maneuver including pitch trim, column movement (stick), wheel, and throttle. The term 'event' is defined generically to refer to any control input. After careful study of the data, it was decided to use the following values for control input determination; each control had to be changed by this amount (or more) to be counted as an event (a control change).

Pitch trim: 0.2 units
Stick position: 1.5 degrees
Wheel position: 7 degrees
Throttle: 0.8 degrees

Further, because preliminary results had indicated differences for the direction of control movement, the sign of the control input was maintained separately. That is, the data on throttle increases and decreases, nose up and nose down for stick position, positive and negative pitch trim, and left and right turns for wheel position were maintained separately. These data were then subjected to a variety of statistical analyses including a technique which analyzed the look-point data for increases and decreases across time.

Wheel Position: Validation

The use of the wheel control constitutes an important internal check on the validity and consistency of the analysis. Since the wind conditions were zero and the initial starting point was essentially in line with the runway, there is no reason to expect any differences between left and right turns due to external influences, provided the airplane is trimmed. Thus, the only reasons differences would be found in the analysis should be attributed either to a failure of the analytic technique or to pilot differences.

In general, the pattern of viewing the instruments is quite similar for both left and right turns and is similar across pilots. Typically, the percent of looking reaches a peak on the command bars and at the event with the trade off coming from airspeed. Between 1/2 and 1 second before the event, airspeed look-time reaches a peak and then declines, reaching a low at the event. There are some exceptions, all of which occur with regard to the timing of the tradeoff. The variation in timing between the two directions is 1/2 second or less for any pilot.

Only one pilot (of the seven) showed a complete reversal; he was looking at the command bars while turning one direction and off the command bars in the other direction. We don't want to put a lot of emphasis on this result; it is presented primarily to show the validation was not perfect and secondarily as an interesting scientific result, one which reminds us that we do not understand human performance fully. Similar differences have been found in automobile drivers; Mourant and Rockwell (1971) reported that experienced drivers move their eye to the right when approaching a right turn, but did not show a significant change when approaching a left turn (cited in McDowell & Rockwell, 1978). These authors offer no explanation for this result; however, one possible explanation involves brain laterality. It has been well established that the dominance of a brain hemisphere varies directly with behavioral function, e.g., language vs. spatial tasks, which could lead to this result. (See Dick (1976), Gazzaniga (1970), and Luria (1966) for general reviews relevant to laterality.)

The scan pattern used while making a turn consists of:
(a) Looking at airspeed about a second before and
(b) Looking at the command bars during the actual wheel turn.

Approximately half of the pilots show a second peak in the command bars 1 to 1-1/2 seconds prior to the event. The consistency of looking at airspeed prior to the event suggests that the decision to turn has already been made and they are cross-checking airspeed prior to the turn. On a speculative note, the magnitude of the turn could be decided from the command bars just prior to the event. Since the pilots do not look at other instruments consistently, it is likely the information for the turn decision was derived earlier from looking at the command bars or from a pattern of movements like Component 9. There are no consistent effects across pilots in the amount of time spent on the localizer, the HSI, the IVSI, or the ADF. An individual pilot may show a consistent pattern for one of these instruments, but the lack of consistency across pilots suggests this is due to use of different information bundles and individual controlling strategies or techniques. A summary of turn frequency and percent look times is provided in Table 3.

In summary, there are two points to be derived from the wheel across pilots for left vs. right turns. This is an important index to assess the importance of differences in other types of controls and adds credibility to the other control analyses. Second, there is a clear scan pattern associated with turns which shows generality across pilots.

Throttle

All pilots show trade-offs in frequency of looking at the airspeed indicator and the command bars. The most common pattern is

a. Look at the the command bars about one second before
   (off airspeed)

b. Look at the airspeed indicator at the time the throttle is changed.
c. Look at engine instruments sometime during this period. (This is an inference based on the measure of no track time which is a measure of the amount of time the oculometer did not track the eyes.)

The change in the no track time is probably related to engine gauges. No track time goes as high as 35% during the control period. While every pilot shows a change in no track there is little temporal consistency among pilots. Because of this the engine instruments look like a third priority item which gets sandwiched in and around the airspeed indicator and the command bar look time.

The oculometer track time is 92% and 88% for the manual and coupled modes, respectively (Spady, 1978). In examining the time the oculometer was not tracking, Spady has reported 5 and 10% of the pilot's time is devoted to fuel flow and engine pressure (based on video tape analysis). The present control input analysis indicates the no track time around the control change is much higher than either of these figures. Because the present analysis sets aside a portion of the total data, our interpretation is that most of the no track time is related to control maneuvers.

Column Movement: Raising and Lowering the Nose

As a general statement about where the pilot looks before and during a column movement, again like turns, the airspeed and command bars show trade-offs. However, this trade-off has less than perfect temporal regularity either within or across pilots. Further, with the exception of the barometric altimeter none of the other instruments appear to be used with a high degree of consistency across pilots.

As mentioned earlier, the control events were categorized according to sign - this corresponds to a relative change of raising or lowering the nose of the aircraft. Whereas we expected and found almost identical patterns in the use of instruments between and within pilots for left vs. right turns, we did not find the same kind of consistency for column movements. Generally speaking, whatever the pilot did with the airspeed and command bars when raising the nose, he showed the opposite tradeoff when lowering the nose. It is as though the pilot treats the forward and backward movement of the column as two separate and different tasks. Clearly, the data show two different scan patterns associated with these two control movements and it would appear these are related to different cognitive sequences.

A segregation of controlling with respect to whether the aircraft is climbing or descending shows still further complication. Many of the control inputs during climb are from the straight and level portion of the flight before glide slope capture. The command bars are not yet available. (The command bar position also contains an artificial horizon.) While the airspeed/command bars tradeoff still exists, the timing is different. If the data were analyzed in terms of straight-and-level versus on-the-glide-slope, we might see some interesting differences with respect to the use of the instruments. This should be done to examine additional differences in cognitive sequencing.

The control input analysis shows a number of mini-scan patterns during controlling. Because of the consistency shown in the wheel turn analysis we may infer the differences in the nose-up vs. nose-down results are important. Further, these scan patterns straddle the event for about one second before and after. Accordingly, we conclude the pilot has already decided not only about the control but also about the direction of the control one second before making the maneuver.

There are strong temporal variations in the way pilots look at the instruments during a controlling period. With column changes, for example, the pilots show reversed patterns with regard to raising or lowering the nose. Our interpretation of these reversals is in terms of pilot strategy, individual differences. This points up the problem associated with detailed analysis, namely: If averages were taken across an entire flight path, many of these effects would be lost and there would certainly be a distortion in the results. (Note 10). An even more serious distortion would occur if the results of all of the pilots were averaged. As we have indicated, there are some marked differences among pilots. We will illustrate these points in detail while discussing the results from several pilots.

Pilot 1

Figures 5a and 5b provide illustrations of the relative changes in look-time for various instruments during a column movement. The no track time is assumed to be time spent primarily on engine instruments (Spady, 1978), although it may include look-time for other areas in the cockpit. The column labeled "Percent time at the event" provides a reference to assess the changes.

The correlation in the figure is a simple correlation coefficient between the eye movement patterns for each instrument associated with the control maneuvers differing in sign. It is calculated on the percent time for each frame covering the period from one second prior to one second after the event. A high correlation indicates that the patterns are similar

(+1.00 would mean they are identical; -1.00 would indicate complete opposites); and a correlation near 0.0 indicates there is no relation between the patterns. The value of the correlation will depend on the amount of time (number of frames) included; including more would reduce the coefficient while using fewer frames would generally appear to make it larger. Accordingly, it should only be taken as a crude index of the degree of similarity.

While changing the column during descent, it appears Pilot 1 is doing the following:

a. Airspeed has been observed a second or so before the event.
b. Vertical situation is checked at the event.
c. The command bars are monitored during the event.
d. Engine instruments (inferred from no track) have been checked one second or so prior to the event and again after the event.

From these scan patterns, we can see that the pilot has collected information about most of the critical parameters of the aircraft at the time he makes a course adjustment. That is, he has checked engine gauges, airspeed, horizontal position, and vertical descent rate. He has not checked his absolute altitude, but that information can be inferred from the reading on a prior check combined with airspeed information, vertical rates, and glide slope deviation obtained from the command bars.

An interesting difference between raising and lowering the nose is that when he lowers it, he appears to go back to the airspeed indicator afterwards, perhaps to check to be sure that the aircraft airspeed hasn't increased too much.

The look-pattern is considerably different when the aircraft is climbing. (Many of these events will be from straight-and-level flight prior to descent along the glide slope.) We note the peak look-time for the airspeed indicator and the vertical situation indicator are different for two directions of column movement. He checks the airspeed before lowering the nose, and vertical descent rate after the event. The latter check may be due to the fact that he remembers he was climbing prior to the change and therefore, the vertical descent rate presents no immediate problem and also that it takes a little time for the IVSI to give a correct reading. (Despite the fact that it is called the Instantaneous Vertical Situation Indicator, it is not instantaneous, and will on occasion give erroneous readings immediately after a control maneuver. Pilots are taught and understand the functioning of this instrument.)

The nose-up maneuver may well represent an attempt to slow the aircraft down. This presumption is based on the fact that he is not descending (by definition of the analysis) and the admittedly weak evidence that he is apparently unconcerned about airspeed prior to the event but is concerned about it after the event.

Pilot 6

Pilot 6 is discussed because of his remarkably simple scan pattern (as compared to other pilots) and what amounts to a marked reversal of the scan pattern as a function of the sign of the control maneuver.

Almost all of this pilot's time related to column movements is divided between the command bars and the airspeed indicator. We may note also that an unusual amount of time is recorded in the FD-4 position (Figure 1) which is located between the command bars and the airspeed indicator. Clearly, he is dividing his attention solely between the command bars and airspeed.

We see rather clear-cut trade-offs between the command bars and the airspeed indicator. This is shown in the graphic display of his look-times as well as the correlations between look-pattern for the differing signs of the event (Figure 6a). This pilot performs relatively few control maneuvers (4) prior to starting his descent; accordingly there were not enough observations to yield any meaningful results in the analysis.

While Pilot 6 obviously uses the other instruments, he does not use them in any consistent manner while controlling. Further, because of his rather large amount of time in FD-4, it may be that he is monitoring rates of movement of the needles rather than obtaining the numerical value per se. He could use this type of information to decide when to make the change.

ANALYSIS - PART III

The results from the factor and discriminant analysis in Part I imply the turbulence and control mode manipulations fall on different dimensions: controlling frequency is related to turbulence while scanning is related to control mode. Several additional factor analyses were done to study this idea.

Control Input Frequency and Information Bundles

When the frequency of control inputs was included in the factor analysis, the resulting components were essentially unchanged from those shown in Table 2. (Any differences which did arise consisted of minor changes in the loadings for the eye movement data in the second or third decimal place.) The throttle frequencies load on Component 1 (Airspeed) while wheel and column frequencies load positively on Component 9 (Lateral) and negatively on Component 2 (Horizontal and vertical situation). Table 4 shows the loadings. The negative loading means high values of a component (e.g., Component 2) are associated with relatively low control change frequencies. This suggests Components 1 and 9 are related to controlling while Component 2 is related to monitoring and not controlling.

It is of interest to note, in the analyses, the frequency of control inputs was not as highly correlated with the components as the scanning measures were. This result might be expected for several reasons. One is that, only in the manual condition will scanning be related to the control inputs. Because the autopilot mode has few control inputs, the correlations could be spuriously low. This possibility was evaluated with a separate factor analysis in which the autopilot cases were set aside, using only manual cases. The factor loadings did not change appreciably for the control input frequencies (the largest loading was in the .40 range - representing about 20% of the variance in a factor).

Another possibility argued throughout this report is that scanning is controlled by cognitive factors, specifically, task demands. We may recall that the components did not distinguish between turbulence levels. Although it would appear that scanning is strongly influenced by control mode, it will be necessary to examine other control modes to evaluate this suggestion fully.

Control Inputs Alone

Comparisons among the control input frequencies can be used to provide some hints about workload. For example, we assume control frequency is related predominantly to physical workload. The use of the autopilot also provides some evidence about cognitive workload. Another point of information in the control inputs is the relative importance of the various scan patterns and their interrelation. The correlation between control input frequencies is shown in Table 5.

Pitch Trim

Pitch trim constitutes a kind of "reverse" control; it is used to maintain the current configuration in contrast to the other controls which are used to change the current trend/state. This implies that use of the pitch trim will be inversely related to use of other controls. Table 6 gives the average use of the control as a function of turbulence; in 11 out of 14 comparisons (seven pilots by two directions of control), trim is used more frequently in the no turbulence condition than in the turbulence condition. Another point of interest is the relatively low use of this control as compared with the others.

Just as use of pitch trim should differ from the other controls, so would one expect the scan patterns to differ. There are difficulties with control input analysis because of the infrequent use of trim. However, the data from pilot 4 indicate a pattern quite different from his use of the instruments associated with other controls. His pattern is to look at the command bars steadily at an increased percentage for the period one second before to one second after pushing the button. Unlike his scan patterns with other controls, look times at airspeed and no track are below average. One also sees evidence of checking the airspeed and IVSI about 2 seconds before or after the control input.

The frequency of use of pitch trim is associated with component 8 (Tables 2 and 3). The emphasis in component 8 is on the glide slope indicator. The control input analysis indicates an increased amount of time on this instrument for one pilot, however, the frequency of use of this control is too low to analyze in most pilots. Hence, the generalizability across pilots is not known.

Wheel

We have already said a great deal about the wheel control. The frequencies shown in Table 7 indicate the pilots change the wheel position frequently even in non-turbulent conditions.

Column

The frequency of moving the column is shown in Tables 8 and 9. The average number of times the column is moved is 14.2 times in smooth air and 65.4 times in turbulent air. Each condition contains 23 runs. This indicates the turbulence manipulation had an effect. It is also of interest that the pilots show considerable variation with some pilots using more than double the number of control inputs as other pilots. One could speculate that this difference would be related to their perceived workload; about which we will have more to say later.

Throttle

The throttle remains under manual control even when the autopilot is used. This gives us an opportunity to compare use of the throttle under different workload conditions. The use of throttle is shown in Tables 10, 11, 12, and 13. The reader may wish to note, the frequency of throttle usage increases in the coupled mode; this corresponds to an increased amount of time spent on fuel and engine gauges in the coupled mode (Spady, 1978).

Overall, the throttle is used more often with the autopilot than in the manual mode. Individually, the pilots show wide variation within conditions and between conditions; nevertheless, 13 out of 14 comparisons show increased use of the throttle under the autopilot conditions. These differences may arise for a number of reasons. One possible reason has to do with workload, and for the most part, the increased use of the throttle can be explained by reduced workload in the coupled condition. While each pilot, on the average, increases his use of throttle, most of the ranges for manual and autopilot in the tables show considerable overlap in frequency. If the increase is due simply to reduced workload, we might find bugspeed to be controlled more precisely. Further analysis will be necessary to examine this point.

RESULTS AND DISCUSSION

Intergration of the Analyses

The results of Parts I and II indicate the existence of a number of identifiable mini-scan patterns. At a preliminary level, these patterns represent "information bundles" showing integrated patterns of eye movement related to aircraft parameters. The bundles represent a dissociation of the overall scan pattern into component parts; these parts can be subdivided further into monitoring and controlling scans. The mini-scans (components) can be used to distinguish between control modes, among segments, and among pilots. The mini-scans (components) are not successful at distinguishing between turbulence levels. The analysis from Part I indicates that different pilots use these mini-scans with different frequencies.

The three analyses taken together provide some important hints about a number of issues. In addition to the mini-scan idea which has been documented in Parts I and II there are some other important points. First, the extent that frequency of control inputs loads on these information bundles provides an index of the degree to which the information bundles are related to control inputs. The factor loadings of frequency of input on any given component did not reach 0.50 and therefore would account for less than 25% of the variance contained in any component. One could interpret these results to mean either that the pilot does not get his information from the instruments very often or that the correlation is unidirectional. The use of a mini-scan does not necessarily lead to a control input. The fact that we find fairly consistent scan patterns within each pilot for control maneuvers, indicates the latter alternative is the more acceptable. Second, because the scan patterns and frequency of control are subject to different influences, this provides the basis for some comments about dissociation of workload into two major categories. We will deal with the workload issue first and then turn to discuss a model which outlines the scanning-controlling interrelation.

Task Demands, Workload and Scanning

The opinion is often expressed that scanning behavior will reflect workload conditions. Several investigators have failed to find differences among eye movements as a function of turbulence (Krebs & Wingert, 1976; Dick, et al., 1976). Using a different anaylsis technique, Waller (1976) has found some differences due to turbulence but the results do not account for a very large percentage of the variance. The model being developed here would predict turbulence to produce very modest differences, if differences are even found. Cognitive workload does appear to be reflected in eye movments as assessed here with the control mode manipulation.

The analysis in Part I adds considerable detail and changes the emphasis of the interpretation as compared with the eye movement work reported previously (Barnes, 1972; Spady, 1978). The difference between the present work and previous work rests primarily with the determining factors guiding the eye movements. Some previous work seems to imply a physical determination of eye movements. From this point of view, it would be predicted that external conditions affecting the readings of the instrument (such as turbulence) would have an influence on the scan pattern.

The fact of the matter is that turbulence does not have a major effect on scanning either overall (e.g., Spady, 1978) or in an analysis of the present type. (See also, Dick et al. 1976.) This relative immunity from turbulence is an important clue to understanding the mechanisms of scanning and workload. The basis of the theorizing is as follows: Turbulence influences physical workload while control mode influences cognitive workload. To discuss the cognitive workload it is necessary to digress to clarify and explicate a concept which has been alluded to above but not fully developed.

Task demands. A generic label for the concept might be "perceived task demands." There are a number of parts to it; we will consider only one (Note 11). Performance is the result of not only what the individual has to do but also a result of what he might have to do. This is, of course, one of the fundamental reasons training is provided: To acquaint and practice an individual so as to be able to handle the extraordinary as well as the ordinary. In commercial aviation, a great deal of emphasis is placed on emergency procedures during both training and recurrent training. The training is provided because it is expected to carry over into practice to help the pilot diagnose and handle the unexpected. Through training, certain expectations and procedures are 'built into' the pilot.

According to this view, one would expect the pilot to scan the instruments in a way which is strongly influenced by what he expects might happen. His experience tells him that he might encounter wind changes as he gets closer to the ground and should be prepared for such an event. This means in smooth manual flight the pilot should often invoke a control scan mode but without a control change. If the pilot is viewing the instruments in a similar way for both smooth and turbulent conditions, all statistics should be fairly similar which is precisely what the discriminant analysis is telling us. The only difference in the statistics resulting from a turbulence manipulation would be due to the amount of time spent in actually controlling. This interpretation also explains why there is a less than perfect relation between scanning and frequency of controlling.

A change in control mode affects the strategy used in scanning. The autopilot vs. manual mode differentiation would affect and change the number of times the pilot shifted into the control scan mode vs. the number of monitoring scans. We have already discussed data showing fixation time differences which occur depending on what the observer has to do about the information acquired during the fixation. An unexpected change in eye movement direction takes more time. This raises an intriguing possibility: A preprogrammed sequence of eye movements may not require each fixation to be of 200 + msec duration. Based on a review of the existing literature, this possibility does not seem to have been explored in the context of monitoring. However, work on other motor patterns (e.g., Lashley, 1951) suggests that shorter fixations might be possible.

The monitoring patterns can also be discussed in terms of changes in the perceptual/cognitive processing required to deal with the information acquired. In some ways the workload reduction is analogous to a 'priming effect' (Beller, 1971; Posner, 1978). The priming effect occurs when advance information is given to a subject in a choice reaction time experiment, resulting in shorter reaction times. Clearly, the experimental subject somehow uses the advance information to eliminate or avoid some of the information processing steps normally required. The exact mechanism for this effect is not known; however, it may be mediated through mental imagery. If this be true, the analogy may be very close to aviation. Some pilots claim they develop a mental picture of the aircraft as they come down the glide slope. In the manual mode, the pilot would have to determine the instrument reading and then collate that information with his mental picture. In the coupled mode, the pilot can predict what the instrument reading should be and then look at the instrument to verify his prediction. The use of the autopilot should reduce the information processing requirements for the pilot and therefore, with more time available, he can scan faster. An implication of a fast scan strategy, however, may be that autopilot errors will not be detected quickly.

Individual Differences. We have presented evidence concerning individual differences in scan patterns among pilots. This shows up in Part I by being able to discriminate among pilots using the factor components. It appears in Part II in the use of the instruments while controlling and it shows up in Part III in frequency of controlling. Because all of the pilots in the present experiment have had extensive experience in the B-737, the results mean that piloting strategies have a considerable influence in the detailed way pilots use the instruments.

Some other pieces of evidence add to this picture. In previous work (Dick, et al., 1976), it was found workload ratings could be predicted fairly well based on control input frequency for two pilots. The equations for the two pilots, however, were grossly different. For one, the predicting equation contained aileron frequency and simultaneous aileron and elevator frequency. For the other, the equation contained elevator frequency and thrust change frequency. These differences imply different control scan procedures.

A difference in workload is one possible reason for changes in throttle control frequency. Another reason is different piloting techniques. Some pilots simply control more often than others. This again points up the importance of individual pilot differences, and on a more speculative note, possibly a wide variation in susceptibility to workload changes. A pilot who has a high, self-generated workload has little "room" (spare capacity) to accommodate further increases. As an aside, a significant workload reduction might be possible by appropriate training (e.g., Nideffer, 1976; Nideffer & Sharpe, 1978).

A Model and a Little More Theorizing

The decisions made during a landing are numerous and varied. For purposes of the discussion, we will restrict the comments to instrument scanning and controlling, and ignore the other activity in the cockpit during landing. Figure 7 lays out in schematic form the types of decisions and the possible branch points at each decision. At any point in time, the process can be broken into several conceptual parts. Beginning at some arbitrary point, the operator engages in information collection, getting bundles of information. Each bundle contains a decision about the possibility of changing the controls. Some bundles are clearly monitoring only; others may lead to control inputs. If a monitoring bundle is selected the pilot gets the information and immediately selects the next bundle.

If a control bundle is selected, scanning typically emphasizes the command bars and airspeed. This second mode of information collection focuses on aspects of the possibility of a change and, if necessary, timing of the control change and the magnitude of the change, i.e., the additional decisions. Because these additional decisions will take additional time, one would expect longer dwell times to be associated with controlling than with monitoring. This seems to be the case in small aircraft, single pilot situations but this aspect needs to be evaluated further. It is during the control scan (at choice 2), that the "when" decision is made. The decision "now" will lead to an estimate of magnitude (choice 3) and a control input. The input may be verified, followed by a return to the monitoring mode. If the decision is not to control, the next decision is about a pitch trim adjustment vs. return to monitoring.

The justification of the choice point elements of the model is as follows:

Choice point (1): The differentiation between monitoring and controlling can be justified on theoretical grounds but there are empirical grounds as well.

a. The finding that some components show correlations with frequency of control inputs while others do not.
b. The typical control scan pattern shows marked differences from the summary statistics.
c. The summary statistics themselves show considerable differences between manual and coupled modes.

Choice point (2): The branching at the timing decision is based on two factors.

a. Logically, a model must permit the pilot to change his mind. Turbulence could move the airplane down, but by the time the controlling mode was implemented the airplane might be back on track.
b. The magnitude of the factor loadings of control input frequency with the scan components shows an imperfect relation; the "later" path reflects that result.
c. This point can also be expressed in terms of the pilot's threshold for "out-of-bounds" states of the aircraft. If the observed values are out of bounds, a correction would occur immediately. If the values are within bounds, the correction may be deferred.

Choice point (3): represents the decision about the magnitude of the control input. The magnitude is typically determined by factors such as current configuration coupled with experience in translating the instrument reading to a motor control action.

Choice point (4): reflects the fact that a given control input may be the only information needed to make the control/monitor decision. For example, a change in pitch may be associated with and followed by a change in throttle (Bailey & Dick, 1978). Another example would be lowering the landing gear which may lead to increased throttle.

Choice point (5): represents an infrequently used decision path that of pitch trim. The use of trim is different from the others in that it is the only control which is used more frequently in the less turbulent conditions. Again this can be referenced to "out-of-bounds" states. If the state(s) is out of bounds, the pilot would have control. To get to this choice point the aircraft is within the pilot's tolerance threshold. Choice point 5 reflects further refinement of the "within bounds" condition. If he likes what he sees and wants to hold it he may use the pitch trim control.

As an aside, an uncontrollable or difficult to control aircraft can be represented in the model. This would involve getting locked into the 2-3-4 back to 2 loop with no time available for monitoring or verifying control inputs.

One further complication may be needed in the model to handle coordinated maneuvers. We have not seen any cases in which a control input follows a like control input by less than a second. That is, two column changes are separated by at least one second. By the same token, however, it is possible to see two different controls being used within one second of each other. While coordinated maneuvers exist, our analysis to date has not separated out such combined maneuvers like wheel and column or column and throttle, however, as shown in Table 6, the latter combination does not appear likely. It would be of interest to determine if the second maneuver decision is based on instruments or is derived from knowledge about the other maneuvers.

Discussion of the Model

There are a number of other models extant (Waller, 1979). Each of these differs from the others in one or more respects. We will not attempt to hit each of these differences but rather highlight a few of the important differences and implications of the present model as compared with others. Two of the most important considerations involve (a) the information bundle idea and (b) the notion of preprogrammed motor sequences. These ideas may have important potential implications.

Essentially, what we are claiming with the information bundle idea is that each pilot has not a single scan pattern, but rather a series of information collection procedures (mini patterns) which are used flexibly in combination with controlling strategies. Flexibility is of the essence in mini-scan selection. Each landing will differ from the previous one in a variety of ways, both in terms of the conditions and what the pilot does.

While flexibility is needed in choosing among bundles, there may be little flexibility within a bundle. This is the preprogrammed motor sequence notion. Such motor sequences are quite inflexible and resistant to interruption (Luria, 1966). Because the integration of information takes a little time, this means that the information acquired during a monitoring scan may be unlikely to influence the decision about the next mini-scan. How then is the next mini-scan selected? We turn now to consider this point.

Mini-scan selection. To this point we have avoided specifics about the way a mini-scan might be selected; we will attempt to correct this situation and discuss some hypotheses here. There are several important general considerations. Based on the data, the single most important one is the task demand, the type of control mode. Autopilot control mode seems to set a bias toward monitoring patterns which are faster (i.e., shorter fixation duration). But in human performance, increased speed generally has a trade-off with accuracy. This includes two possibilities: (a) the pilot's mental picture of the aircraft position is less accurate in the automatic mode and/or (b) he will be less likely to detect a significant deviation of the aircraft in the autopilot mode than he would be in the manual mode.

A second consideration is psychological uncertainty. The pilot's actions are predicated on what he knows or thinks he knows about the position of the aircraft. The pilot's uncertainty about a parameter will grow from the time of last examination and will be weighted by the relative (subjective) importance attached to the parameter. As indicated earlier, knowledge about a starting altitude and a constant, known rate of descent would yield a slow growth of uncertainty. Because of instrument redundancy, the rate of growth of uncertainty will not necessarily be dependent on the time which has elapsed since his last look at a particular instrument. For instance, the eye movement data suggest the altimeter is an instrument of low (objective) priority despite the fact that trainers and some pilots claim it to be high (Dick & Bailey, 1976; Spady, 1978). The pilot's report about his concern for altitude is not inconsistent with his looking behavior if we include the secondary information he has available from other instruments. The category 'altitude' may have a high priority but uncertainty will grow rather slowly, keeping the altitude information bundle (Component 5) in a lower priority position than some other bundles. The uncertainty level for a parameter will be a function of the pilot's memory (from previous looks), his integration of that information into the overall picture which will depend on more recent information from other correlated instruments, and his prediction based on the integration.

Indicated airspeed is one of the least redundant parameters on the instrument panel. As an information bundle it is always at the top or near the top of the pile of statistical results. Not only is it a relatively non-redundant parameter it is also the parameter which is most predictive of the ultimate safety of the operation. Accordingly, one would expect the pilot to have a narrow personal margin on airspeed and as a result he will try to maintain a low uncertainty.

Uncertainty is the key to selection of the mini-scan pattern. Some readers may argue that all we have done is to put a label on something about which we know very little. In a sense this is true; in another sense it is not. In order to discover the driving mechanism of the mini-scan selection, we need to have some idea of what to look for. The uncertainty idea can be tested by studying what the pilot knows about the aircraft at any given time. Some parts of the experiment would be tedious, but determining what he knows about airspeed would be fairly simple. Altitude would be another simple one to determine. The arguments presented here imply the pilot would know what the altitude was fairly accurately without having looked at it in a while. Measuring the accuracy of a verbal response in relation to the time since the pilot looked at the instrument should give a reasonable indication of his uncertainty.

CONCLUDING REMARKS

The model is first and foremost of pilot behavior and secondarily how he interacts with the information available. By reducing the dependency on specific instruments and focusing on information bundles, the model begins to show long-sought-after signs of generalizability. Most other models focus on the individual instruments; a different instrument panel would require a number of changes in the model to handle altered look patterns and changes in the use of the instruments. Because of the information bundle idea, there is no such requirement in this model. A thorough test of the model would require the examination of different types of displays to be sure it shows generalizability.

A different instrument layout would, of course, produce different summary statistics (e.g., mean dwell times, transitions, etc.) across the flight. However, according to the cognitive theory being developed here, the information bundles will be consistent across a wide variety of displays. One might see a change in the statistics as a function of the difficulty of extracting the information relevant to an information bundle. That is, the quality of the instruments will influence the specific measurement variable. Thus, the variable loadings could change within a component and perhaps cause a reordering of the components. The major components, however, should be identifiable with one of those reported here, i.e., the information bundles will be comparable. There are clear similarities between the factor components described in this report as compared with those in an earlier report (Dick et al., 1976). This in and of itself constitutes an important step toward validation, but as pointed out in several places, more needs to be done.

Table 1

Flight Conditions Used in the Analysis.
All conditions employed an approximate 30.5 meters (100 ft.) visibility ceiling.

Condition Number	Mode	Description
1	Manual	No turbulence
2	Coupled	No turbulence
3	Manual	Max turbulence
4	Coupled	Max turbulence

Table 2

Description of Rotated Factor Analytic Components

The variables with primary loadings on the component are given together with the correlation of that variable with the component. (Loadings less than 0.5 were arbitrarily eliminated.) The analysis was based on the variables listed in Appendix A. Control input frequency omitted. The full structure table is provided in Appendix B.

Component 1: Monitoring Airspeed. Includes both airspeed indicator and speed bug region. Command bars negatively related. (Used in Conditions, Pilots, and Segments.) FD-4 is the inactive speed bug.

Variable #	Label	Loading (Correlation)
77	FD-4 - FD-4	.851
78	CB - FD-4	.843
82	FD-4 - CB	.831
9	Airspeed - FD	.792
15	FD - Airspeed	.731
8	Airspeed - Airspeed	.627
108	Standard Dev FD-4	.601
102	Mean Dwell FD-4	.572
83	CB - CB	-.545

Sum of Eigenvalue for all variables 6.09

Component 2: Horizontal and vertical situation. The horizontal situation indicator can be used in place of command bars and for de-crabbing in segment 5. Evidence for both is available. (Used to discriminate pilots and Segment 5.)

Variable #	Label	Loading (Correlation)
18	FD - HSI	.791
32	HSI - HSI	.750
30	HSI - FD	.744
33	HSI - VSI	.653
16	FD - FD	-.617
39	VSI - HSI	.557
35	HSI - ADF	.551
103	Mean Dwell CB	-.514

Sum of Eigenvalue for all variables 5.50

Component 3: Lateral information. Includes both ADF and localizer. (Relevant to Segs 1,4, & 5; Pilot differences.)

56	ADF - ADF	.801
70	Standard Dev. ADF	.714
51	ADF - FD	.672
21	FD - ADF	.671
63	Mean Dwell ADF	.624
95	LOC - LOC	.618
85	LOC - CB	.524
14	Airspeed - ADF	.519
111	Standard Dev. LOC	.519
50	ADF - Airspeed	.512

Sum of Eigenvalue for all variables 5.12

Component 4: Glide slope tracking/Vertical situation. Primarily, use of Vertical Situation Indicator and/or coupling VSI with other instruments. (Reflected in pilot differences.)

40	VSI - VSI	.695
64	Standard Dev Airspeed	.721
57	Mean Dwell Airspeed	.681
67	Standard Dev HSI	.583
68	Standard Dev VSI	.570
66	Standard Dev BA	.549
59	Mean Dwell FD	.548
60	Mean Dwell HSI	.528

Sum of Eigenvalue for all variables 4.42

Component 5: Altitude - "Where he is and when." Break over from straight and level flight to glide slope and also at decision height. (Differentiates Segments, especially 2 / Conditions 1 & 2 / Pilots.)

14	BA - BA	.821
23	BA - FD	.815
17	FD - BA	.784
88	CB - GS	.656
84	GS - CB	.586
45	RA - BA	.509

Sum of Eigenvalue for all variables 4.71

Component 6: Monitoring position: Integrating vertical and horizontal position. Straight and level flight / prepare for glide slope capture. (Strength on Segment 1.)

46	RA - HSI	.892
94	GS - LOC	.851
90	LOC - GS	.798
27	BA - RA	.755
47	RA - VSI	.734
48	RA - RA	.732

Sum of Eigenvalue for all variables 4.64

Component 7: Monitoring technique: Changing scan patterns reflecting position of glide slope and manual vs. autopilot. (Used in discriminating manual vs. autopilot conditions and segments, especially 5 but also 1 & 3. Also used for pilots.)

64	Standard Dev - Airspeed	.721
57	Mean Dwell - Airspeed	.681
67	Standard Dev - HSI	.583
68	Standard Dev - VSI	.570
66	Standard Dev - BA	.549
59	Mean Dwell - FD	.548
100	Mean Dwell - HSI	.528

Sum of Eigenvalue for all variables 4.42

Component 8: Glide slope tracking. Heavy emphasis on glide slope indicator. (Strongest discrimination among pilots.)

88	CB - GS	.505
104	Mean Dwell GS	.769
89	GS - GS	.736
110	Standard Dev GS	.732
129	Blink rate	.503

Sum of Eigenvalue for all variables 4.19

Component 9: Lateral tracking. Negatively related to other parameters. (Differentiates segments and pilots.) (Seg. 9 is the lower right hand corner of the flight director. It probably represents oculometer measuring and/or drift from the localizer. The negative values in the latter part of the list indicate these variables are inversely related to the information bundle.)

112	Standard Dev Seg 9	.680
106	Mean Dwell Seg 9	.680
	Secondary components	
16	FD - FD	.374
95	LOC - LOC	.330
105	Mean Dwell LOC	.489
111	Standard Dev. LOC	.404
50	ADF - Airspeed	-.342
45	RA - BA	-.316
62	Mean Dwell RA	-.322
69	Standard Dev. RA	-.300
	Sum of Eigenvalue for all variables	3.54

Component 10: Roll. Roll information is normally used in turning. (Shows up as a pilot difference.)

107	Standard Dev. Roll	.793
101	Mean Dwell Roll	.763
71	Roll - Roll	.751
	Sum of Eigenvalue for all variables	3.12

Total of Eigenvalues	45.75
Variance accounted for	56.5 %

Table 3

Wheel Position

Number of turns and percent time on Airspeed (AS) and command bars (CB) at the time the turn was being executed.

Pilot	Number of runs	LEFT TURN Number of turns	LEFT TURN Percent time at event AS	LEFT TURN Percent time at event CB	RIGHT TURN Number of turns	RIGHT TURN Percent time at event AS	RIGHT TURN Percent time at event CB
1	8	87	9	58	86	12	45
2	7	152	4	59	154	3	63
3	5	69	1	72	72	2	68
4	8	189	10	66	188	2	71
5	5	150	5	73	140	0	71
6	5	104	8	56	112	8	60
7	8	114	6	59	118	3	52

Table 4

Factor Loadings (Correlations) of Control Input Frequency on the Ten Components.
The analysis was identical to that of Table 2 except for the addition of the control input frequency.
(The variance accounted for may be obtained by squaring the factor loading.)
(A factor loading of 0.316 accounts for 10% of the variance.)

Control Type	Component 1	2	3	4	5	6	7	8	9	10
P. Trim	0.253	-0.007	0.248	0.023	0.179	0.027	-0.023	0.301	-0.056	-0.076
Stick	-0.077	-0.303	-0.073	-0.026	0.006	-0.178	-0.017	-0.150	0.525	0.126
Wheel	0.082	-0.332	0.248	0.097	0.211	-0.168	-0.012	-0.019	0.414	0.162
Throttle	0.335	-0.001	-0.001	0.081	0.073	-0.129	0.020	0.094	0.071	-0.123

Table 5

Correlations Among Frequency of Control Input Types (by Segment)

	Pitch trim	Column Pos.	Wheel Pos.
Col. pos.	-.236		
Wheel pos.	.009	.642	
Throttle	.317	.062	.100

Table 6
Frequency of Use of Control by Pilot

CONTROL TYPE:
TRIM

		No Turbulence					Turbulence					
		-		+				-		+		
Pilot	No. of runs	Mean	Range	Mean	Range	Aver/ run	No. of runs	Mean	Range	Mean	Range	Aver/ run
1	4	0.0	-	4.2	4-5	4.2	4	0.2	0-1	2.0	1-3	2.2
2	3	1.3	0-3	5.0	4-6	6.3	4	2.0	1-3	4.5	4-9	6.5
3	3	1.0	0-2	6.0	4-7	7.0	2	0.5	0-1	3.5	3-4	4.0
4	4	1.2	0-3	7.0	5-9	8.2	4	0.7	0-2	4.2	4-6	5.0
5	2	1.0	1-1	3.0	3-3	4.0	3	1.0	0-2	4.3	2-6	5.3
6	3	0.0	-	4.0	4-6	4.0	2	0.0	-	2.0	2-6	2.0
7	4	0.0	-	4.2	4-6	4.2	4	0.0	-	3.2	1-6	3.2
Overall Mean		0.6		4.8		5.4		0.6		3.4		4.0

Table 7
Frequency of Use of Control by Pilot

CONTROL TYPE:
WHEEL

		No Turbulence					Turbulence					
		-		+				-		+		
Pilot	No. of runs	Mean	Range	Mean	Range	Aver/ run	No. of runs	Mean	Range	Mean	Range	Aver/ run
1	4	5.2	3-9	5.5	4-7	10.7	4	16.5	13-22	15.5	14-17	32.0
2	3	18.0	16-20	18.0	18-18	36.0	4	24.5	22-27	22.5	21-32	47.0
3	3	11.0	10-12	12.7	9-14	23.7	2	17.5	13-22	17.0	14-20	34.5
4	4	18.2	15-24	16.5	10-20	34.7	4	29.0	21-37	30.5	22-37	59.5
5	2	17.0	17-17	16.5	12-21	33.5	3	38.7	33-47	35.7	30-40	74.4
6	3	17.7	13-21	30.7	17-26	48.4	2	25.5	24-27	25.0	23-27	50.5
7	4	4.8	4-7	5.2	5-7	10.0	4	22.8	10-30	23.2	12-30	46.0
Overall Mean		13.1		15.0		18.1		24.9		24.2		49.1

Table 8
Frequency of Use of Control by Pilot

CONTROL TYPE:
ELEVATOR

No Turbulence

		Climbing				Descending				
		-		+		-		+		
Pilot	No. of runs	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Aver/ run
1	4	0.0	-	0.0	-	7.8	4-12	8.2	4-11	16.0
2	3	0.3	0-1	1.3	0-2	5.0	1-8	3.8	0-11	10.4
3	3	1.3	1-2	1.0	0-3	3.7	3-5	5.0	4-7	11.0
4	4	1.0	0-2	0.2	0-1	4.8	7-10.0	10.2	9-13	16.2
5	2	0.5	0-1	1.5	1-2	5.5	4-7	9.0	8-10.0	16.5
6	3	0.0	-	0.0	-	12.7	9-15	12.7	9-17	25.4
7	4	0.0	-	0.0	-	1.8	1-3	2.0	1-3	3.8
Overall Mean		0.4		0.6		5.9		7.3		14.2

Table 9
Frequency of Use of Control by Pilot

CONTROL TYPE:
ELEVATOR

Turbulence

		Climbing				Descending				
		-		+		-		+		
Pilot	No. of runs	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Aver/ run
1	4	8.2	5-14	5.0	3-7	24.5	21-27	24.5	24-25	62.2
2	4	7.0	4-10.0	2.8	2-3	23.0	18-28	23.8	26-29	56.6
3	2	8.5	6-11	5.0	3-7	10.0	16-24	26.5	24-29	50.0
4	4	13.8	8-19	11.0	8-16	28.0	25-34	32.0	26-40	84.8
5	3	14.0	11-21	12.7	9-19	32.7	26-44	37.3	29-46	96.7
6	2	4.5	4-5	2.0	1-3	22.5	20-25	28.0	26-30	57.0
7	4	4.0	1-7	1.0	0-2	22.5	19-27	23.2	22-29	50.7
Overall Mean		8.6		5.6		23.3		27.9		65.4

Table 10
Frequency of Use of Control by Pilot

CONTROL TYPE:
THROTTLE

Manual - No Turbulence

		Climbing				Descending				
		-		+		-		+		
Pilot	No. of runs	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Aver/ run
1	4	0.8	0-1	1.0	0-3	6.0	4-10	4.8	3-6	12.6
2	3	2.0	0-3	1.7	0-3	1.3	1-2	4.3	2-7	9.3
3	3	2.3	2-3	0.3	0-1	4.3	2-6	4.0	3-5	10.9
4	4	0.8	0-1	0.2	0-1	4.2	3-5	4.0	2-6	9.2
5	2	0.5	0-1	0.0	-	2.0	2-2	4.5	4-5	7.0
6	3	0.0	-	0.0	-	9.7	5-14	9.3	9-10	19.0
7	4	0.8	0-3	1.8	0-7	8.8	0-25	5.0	3-9	16.4
Overall Mean		1.0		0.7		5.2		5.1		12.6

Table 11
Frequency of Use of Control by Pilot

CONTROL TYPE:
THROTTLE

Manual – Turbulence

		Climbing				Descending				
		–		+		–		+		
Pilot	No. of runs	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Aver/run
1	4	4.1	1-8	0.0	-	7.8	4-12	7.0	4-9	18.9
2	4	0.5	0-1	1.8	0-4	2.2	1-3	2.2	1-3	6.7
3	2	0.5	0-1	1.0	1-1	5.5	5-6	4.5	4-5	11.5
4	4	2.8	1-5	3.0	2-6	4.5	4-6	6.5	4-9	16.8
5	3	2.7	1-4	1.7	1-3	6.7	4-10	10.0	5-14	21.1
6	2	2.0	1-3	1.0	1-1	13.5	10-17	16.0	14-18	32.5
7	4	2.8	1-7	0.0	-	9.2	8-11	10.8	6-15	22.8
Overall Mean		2.2		1.2		7.1		8.1		18.6

Table 12
Frequency of Use of Control by Pilot

CONTROL TYPE:
THROTTLE

Auto - No turbulence

		Climbing				Descending				
		-		+		-		+		
Pilot	No. of runs	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Aver/ run
1	4	1.8	0-3	1.2	0-3	5.0	4-6	5.8	5-7	13.8
2	3	1.0	0-3	0.7	0-2	2.3	1-4	2.7	1-4	6.7
3	5	2.2	1-4	1.7	0-3	4.8	2-7	4.0	2-7	12.7
4	3	1.7	1-2	1.0	0-3	3.3	1-7	4.0	2-7	10.0
5	3	2.0	1-3	2.0	0-5	5.3	1-8	6.0	2-9	15.3
6	4	0.0	-	0.0	-	12.8	11-16	13.0	12-14	25.8
7	4	0.0	-	0.0	-	8.0	4-9	8.8	5-11	16.8
		1.2		0.9		5.9		6.3		14.4

Table 13
Frequency of Use of Control by Pilot

CONTROL TYPE:
THROTTLE

Auto - Turbulence

		Climbing				Descending				
		-		+		-		+		
Pilot	No. of runs	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Aver/ run
1	4	2.5	0-7	3.1	2-4	9.2	7-11	8.2	4-12	23.0
2	3	1.0	1-1	2.3	1-3	5.0	1-9	5.0	4-7	13.3
3	3	1.0	1-1	1.3	1.2	6.0	5-7	8.0	6-10	16.3
4	3	1.7	1-2	3.0	2-4	6.7	3-9	7.0	5-10	18.4
5	3	7.0	4-12	5.7	3-10	16.7	12-26	16.0	8-26	45.4
6	2	0.0	-	2.5	1-4	21.5	19-24	15.0	14-16	39.0
7	4	0.5	0-1	1.8	0-4	13.8	11-20	12.8	8-18	28.9
Overall Mean		2.0		2.8		11.3		10.3		26.3

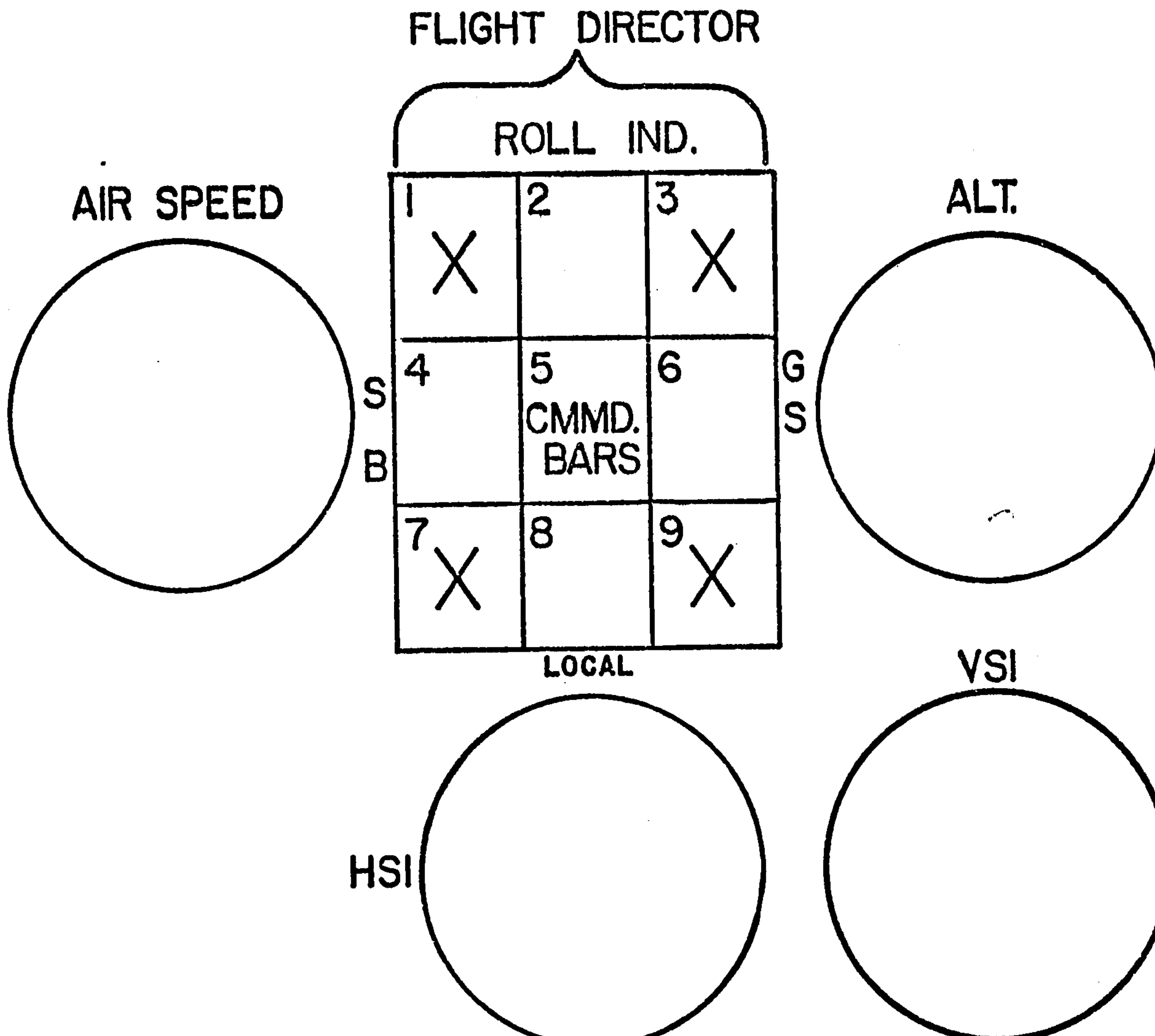

Figure 1. Schematic of instrument layout. See Spady (1978) for a photograph of the original.

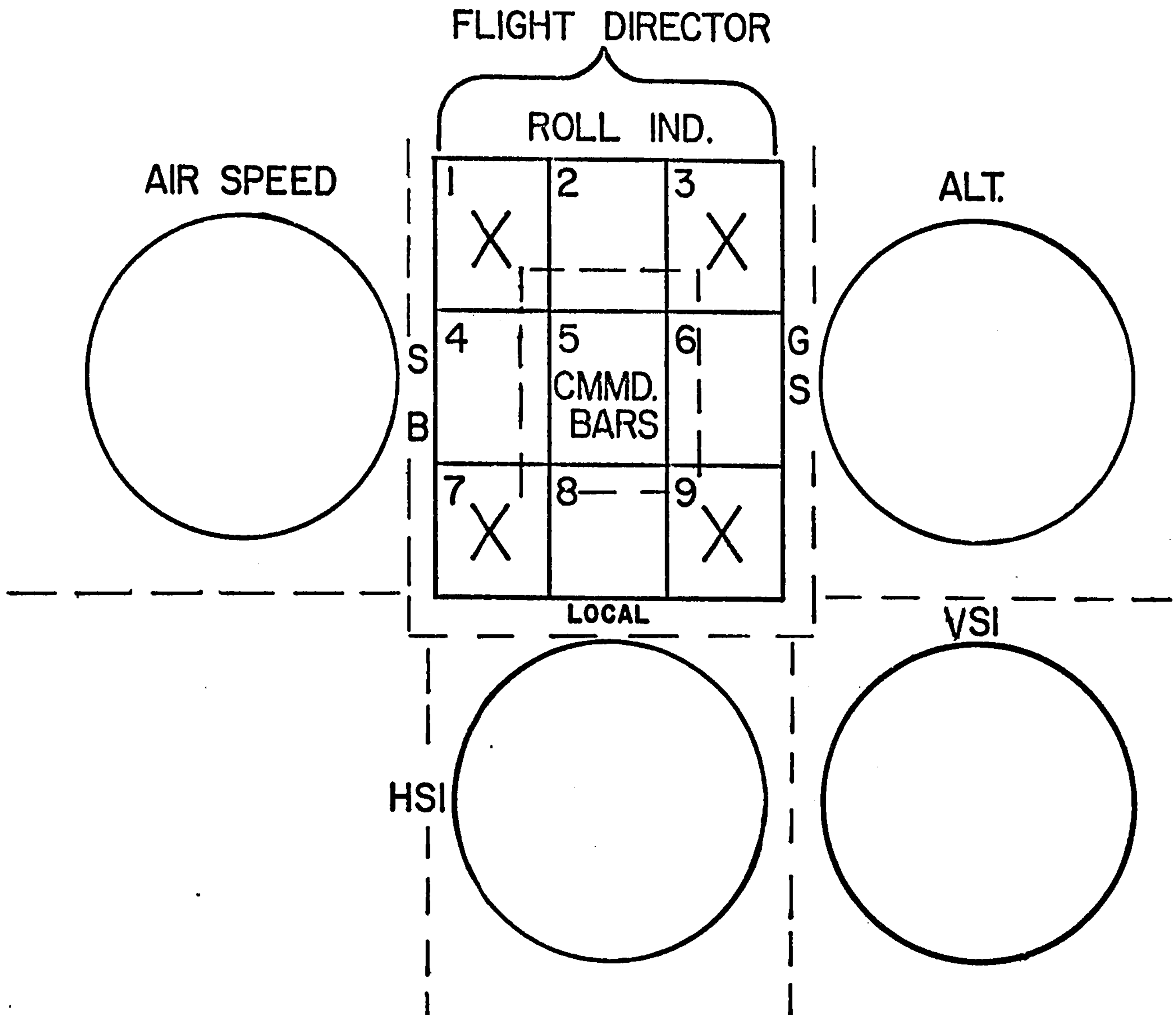

Figure 2. Illustration of the expanded instrument boundaries used in analysis.

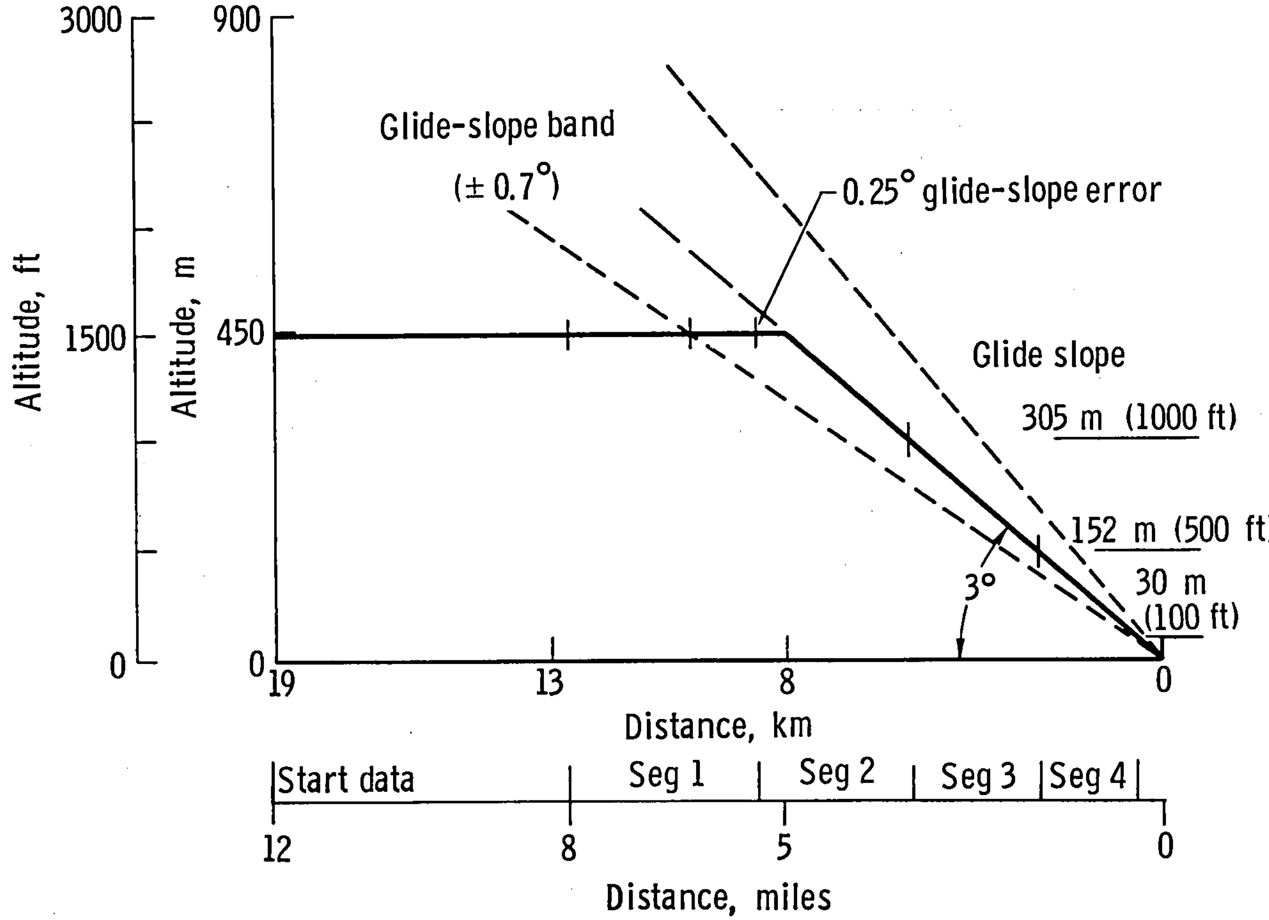

Figure 3. Flight profile showing segments used in analysis. From Spady (1978).

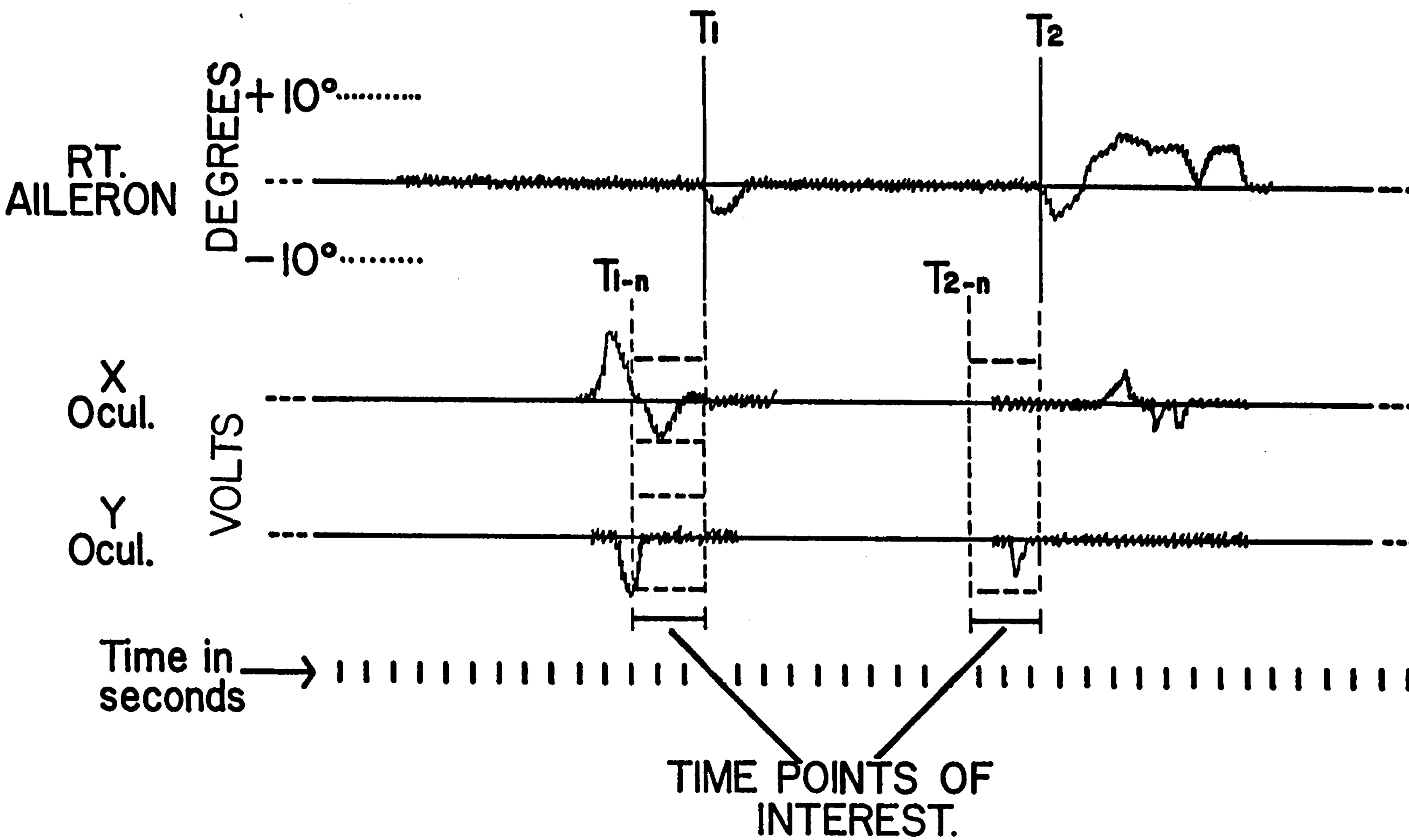

Figure 4. Schematic of the control input analysis. T1 and T2 represent wheel turns.

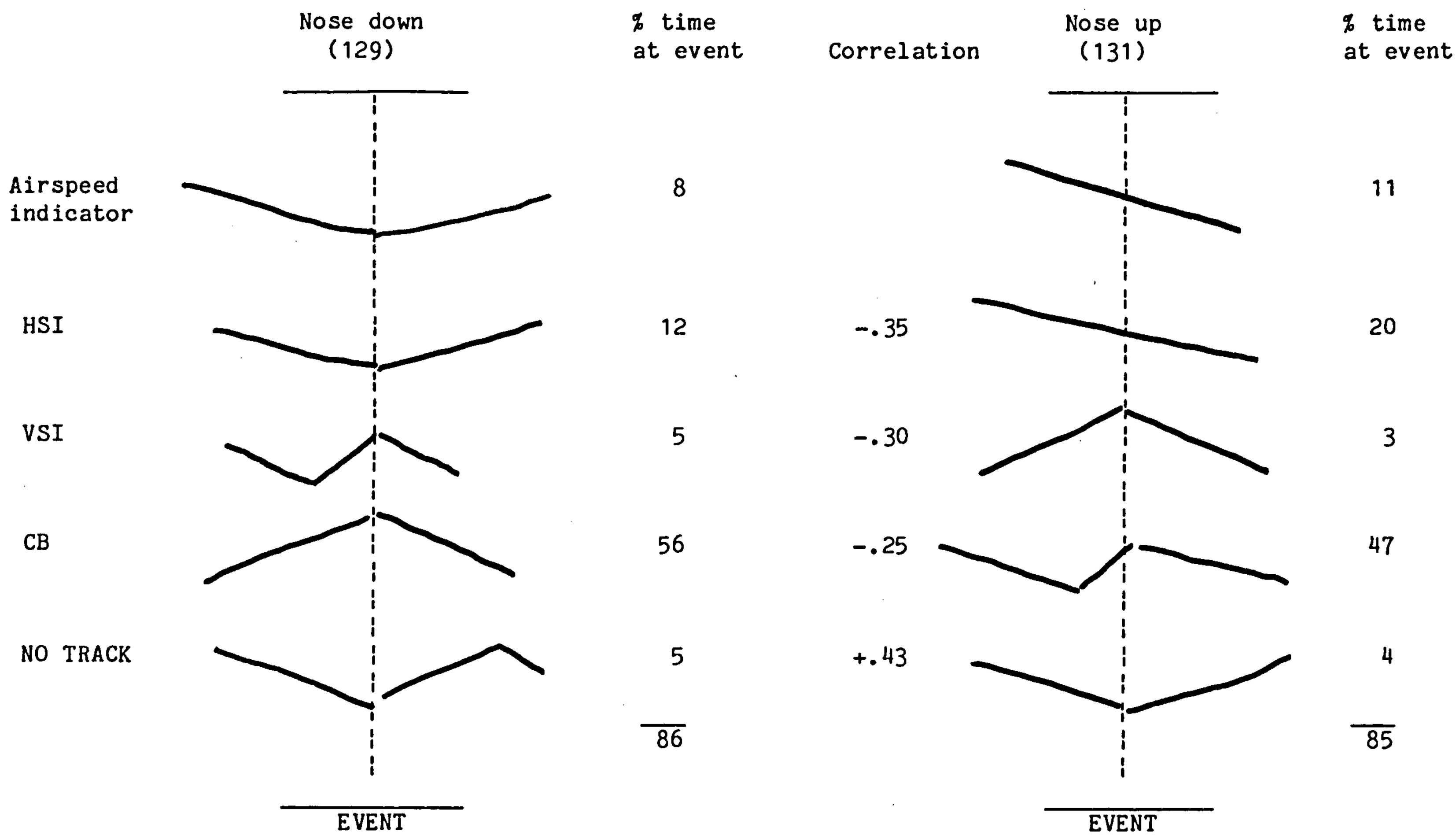

Figure 5a. Pilot 1. Eight Landings, Descending - Column Movement.

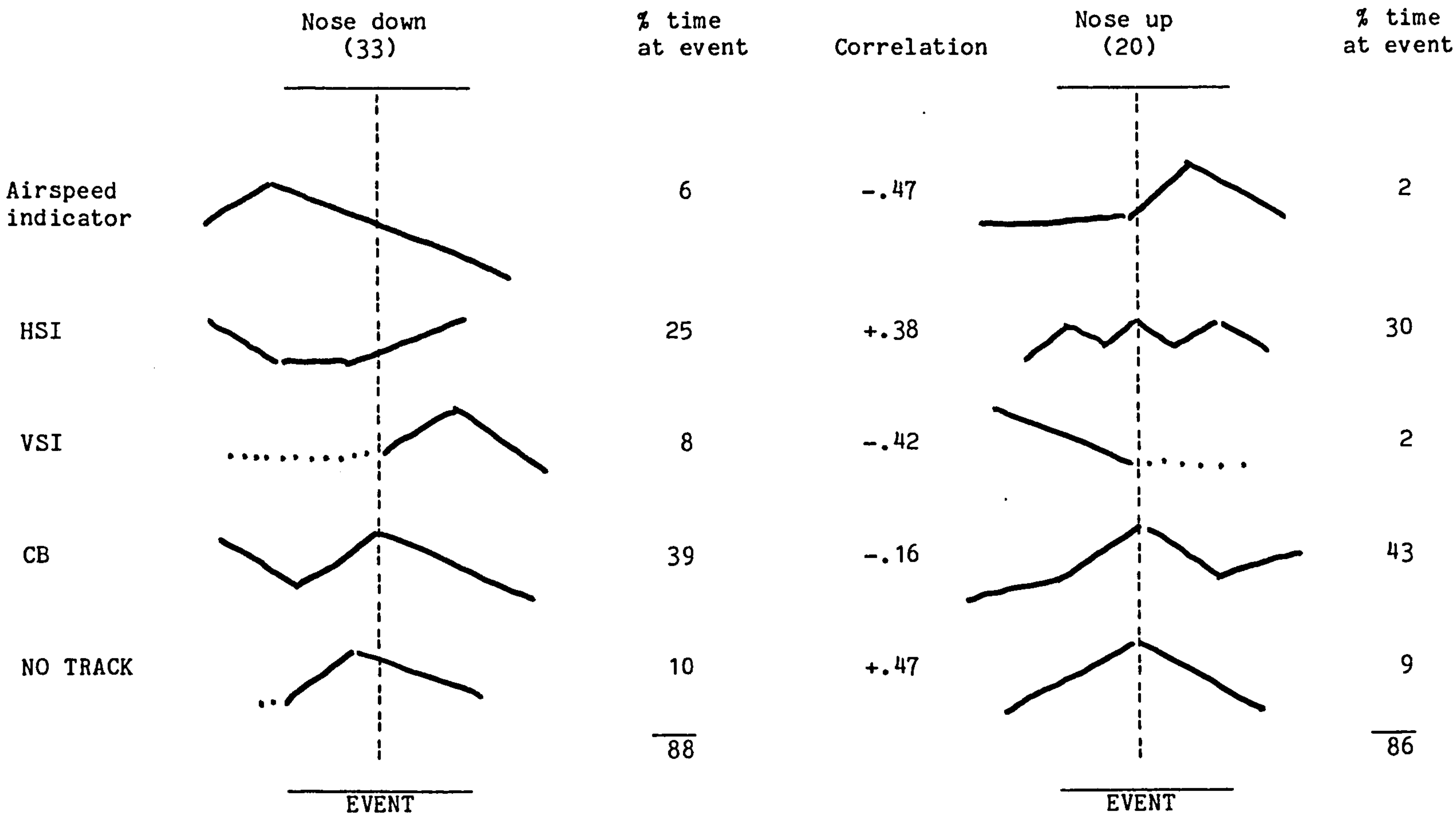

Figure 5b. Pilot 1. Eight Landings, Climbing - Column Movement.

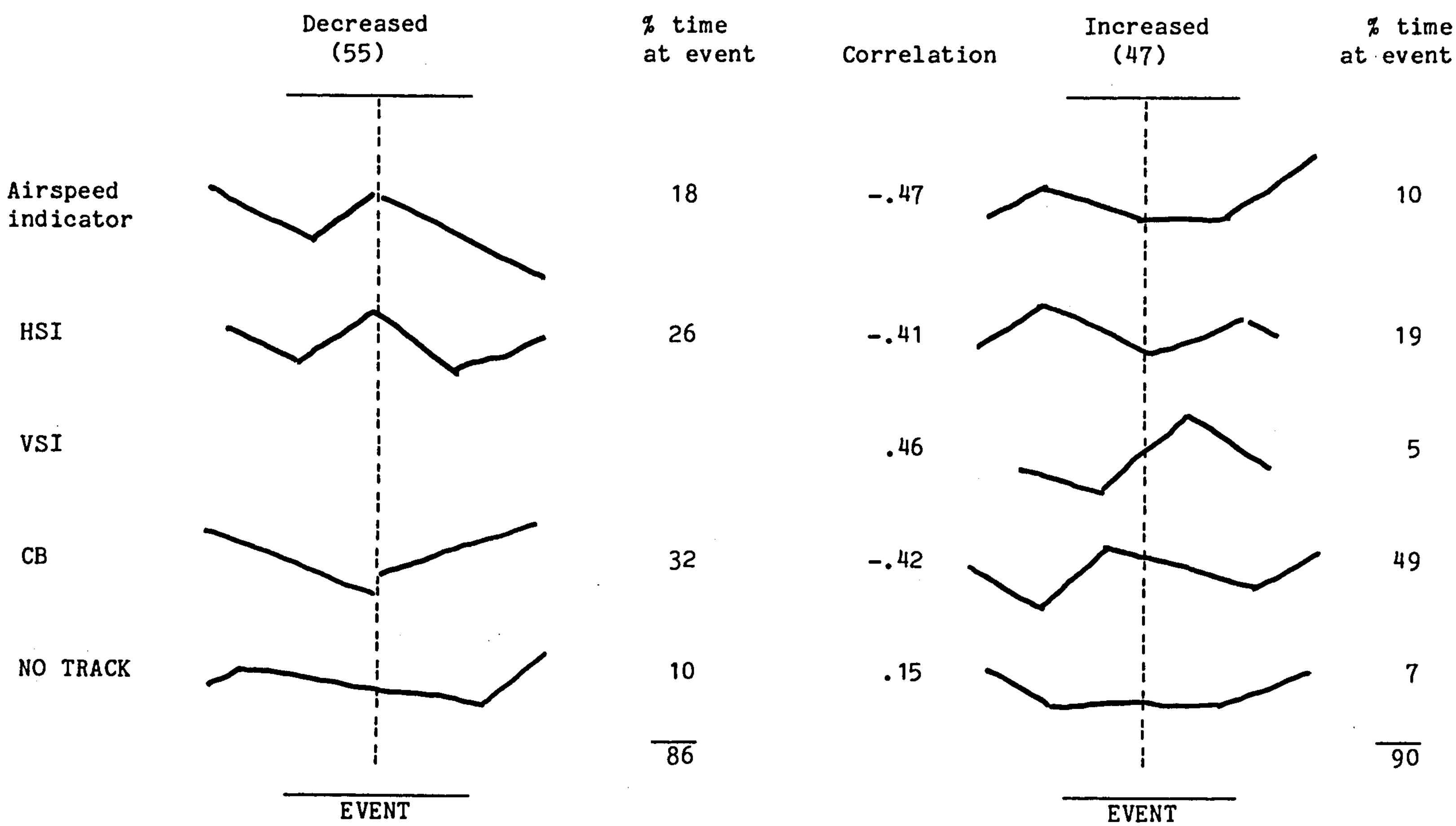

Figure 5c. Pilot 1. Eight Landings, Manual, Descending - Throttle Movement.

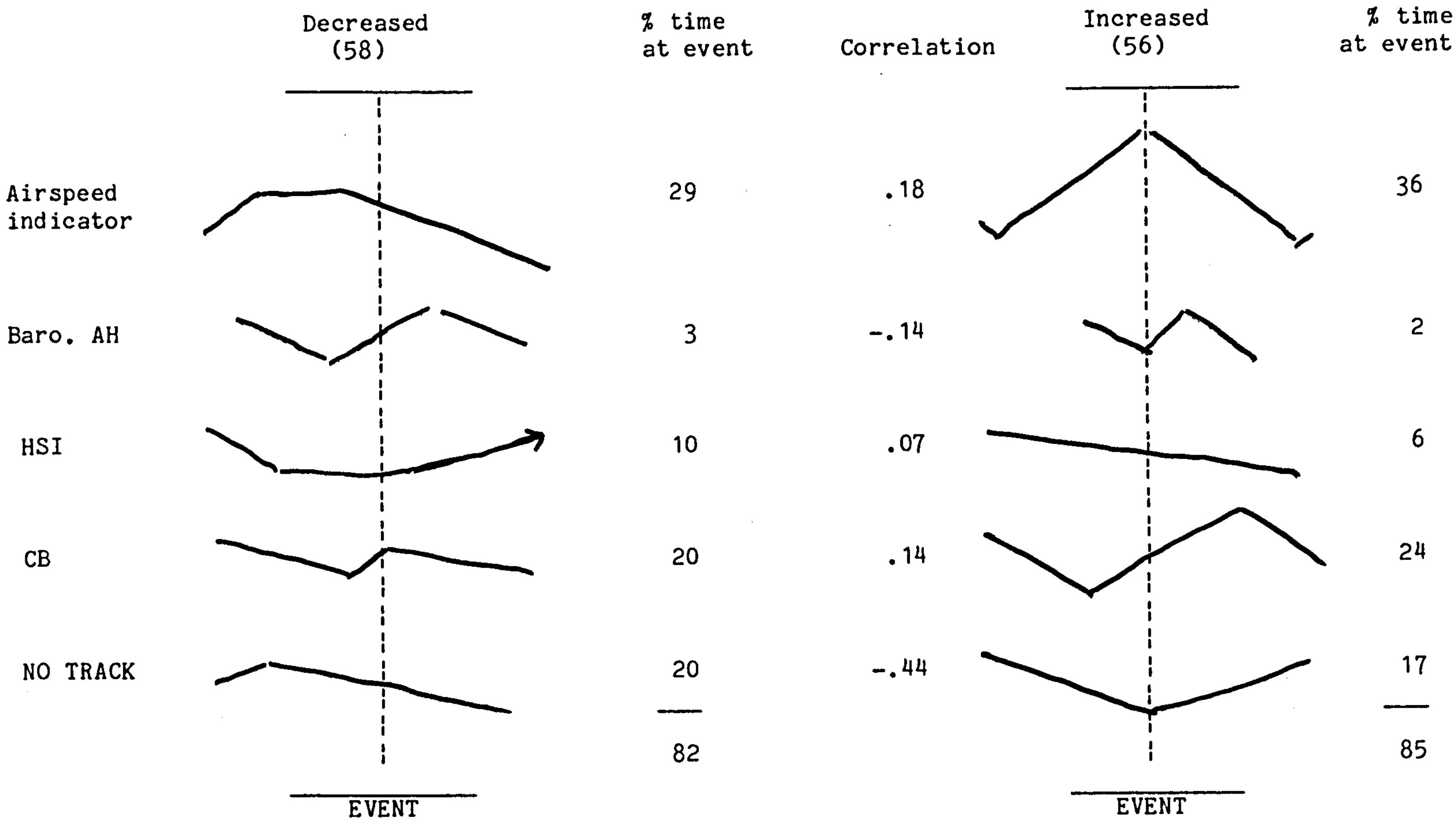

Figure 5d. Pilot 1. Coupled, Descending - Throttle Movement.

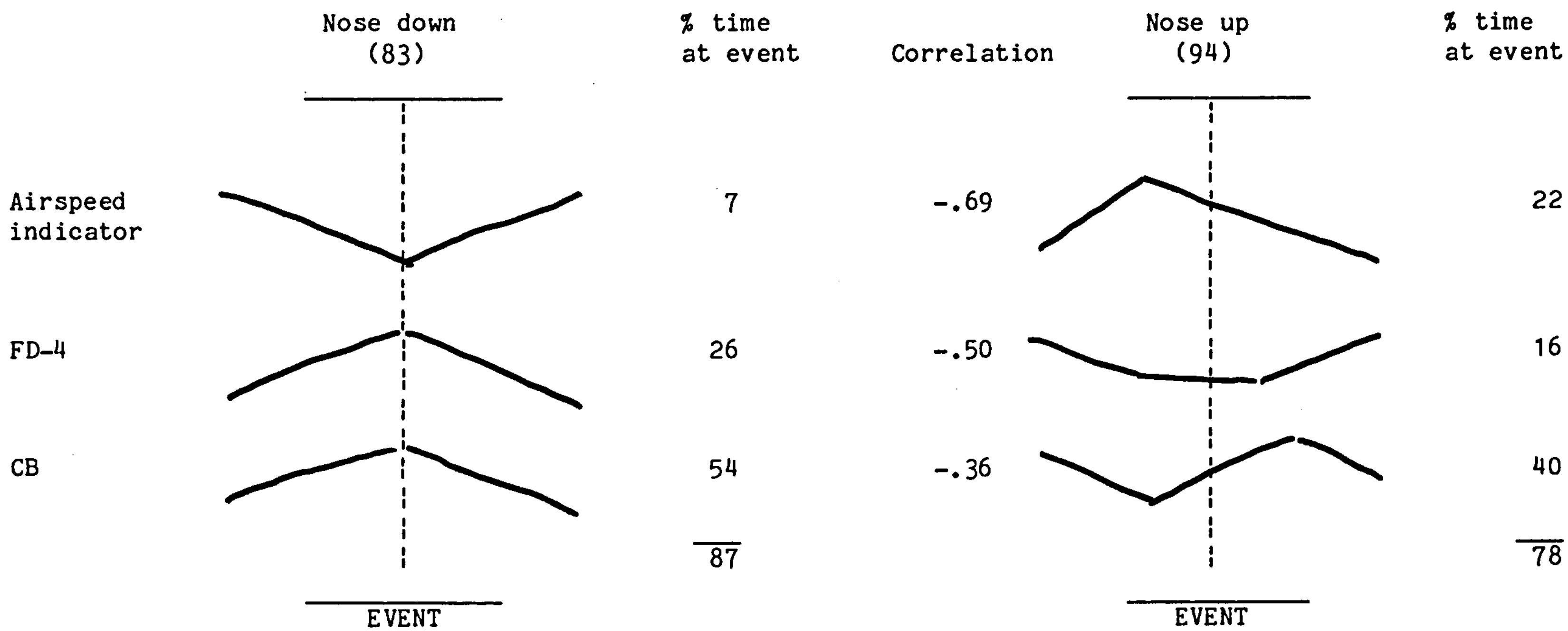

Figure 6a. Pilot 6. Five Landings, Descending - Column Movement.

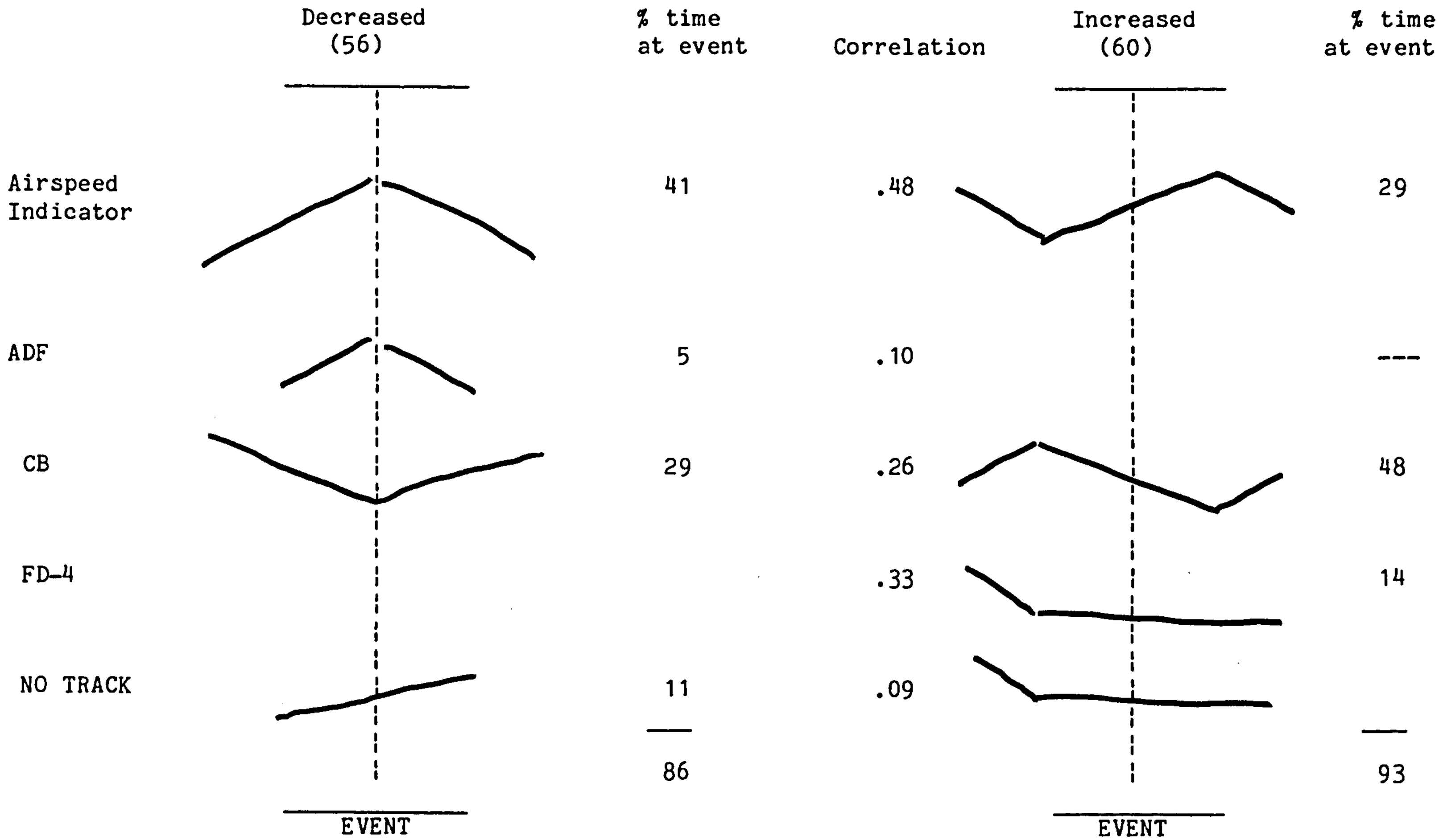

Figure 6b. Pilot 6. Five Landings, Manual, Descending - Throttle Movement.

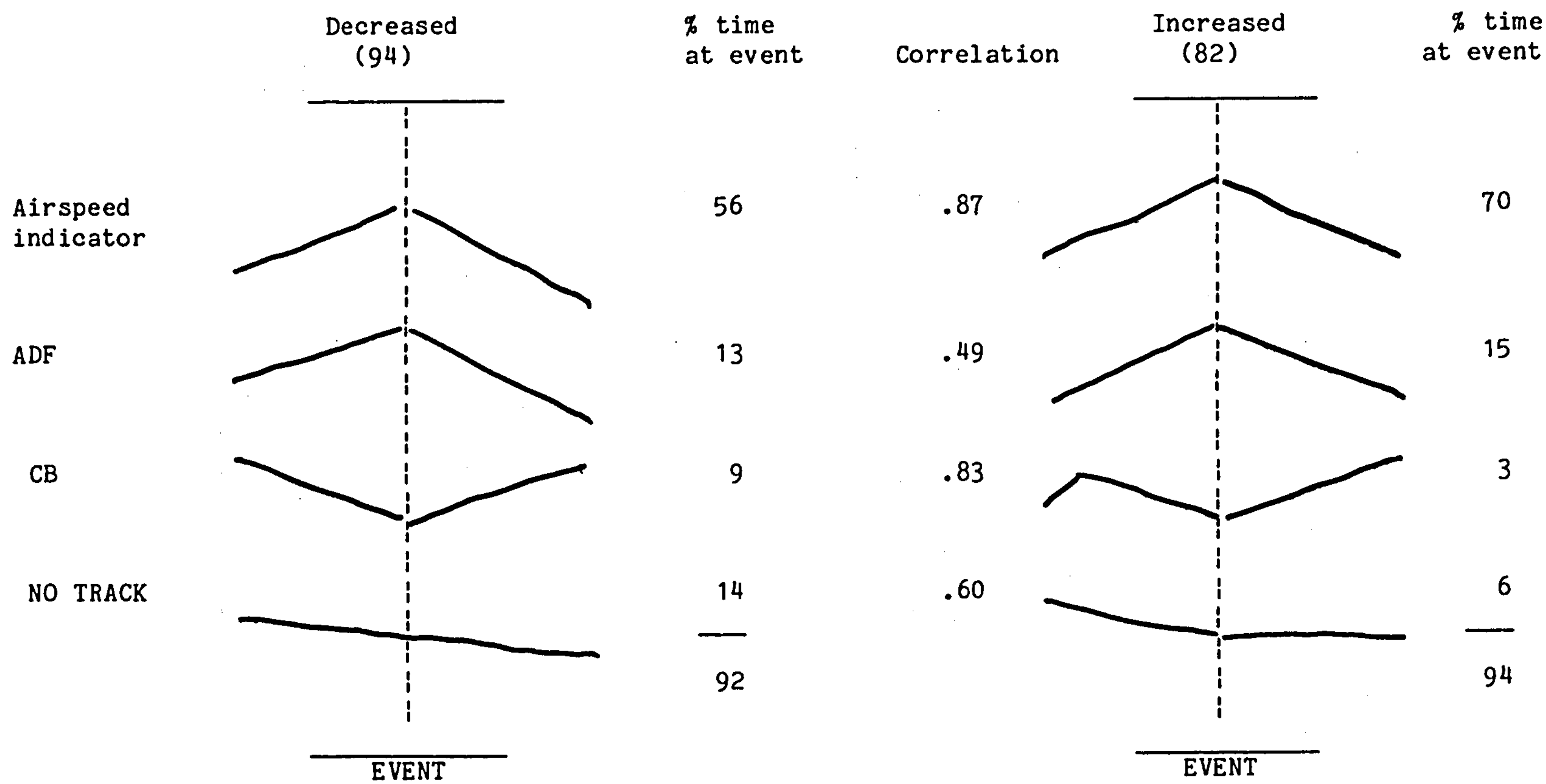

Figure 6c. Pilot 6. Coupled, Descending - Throttle Movement.

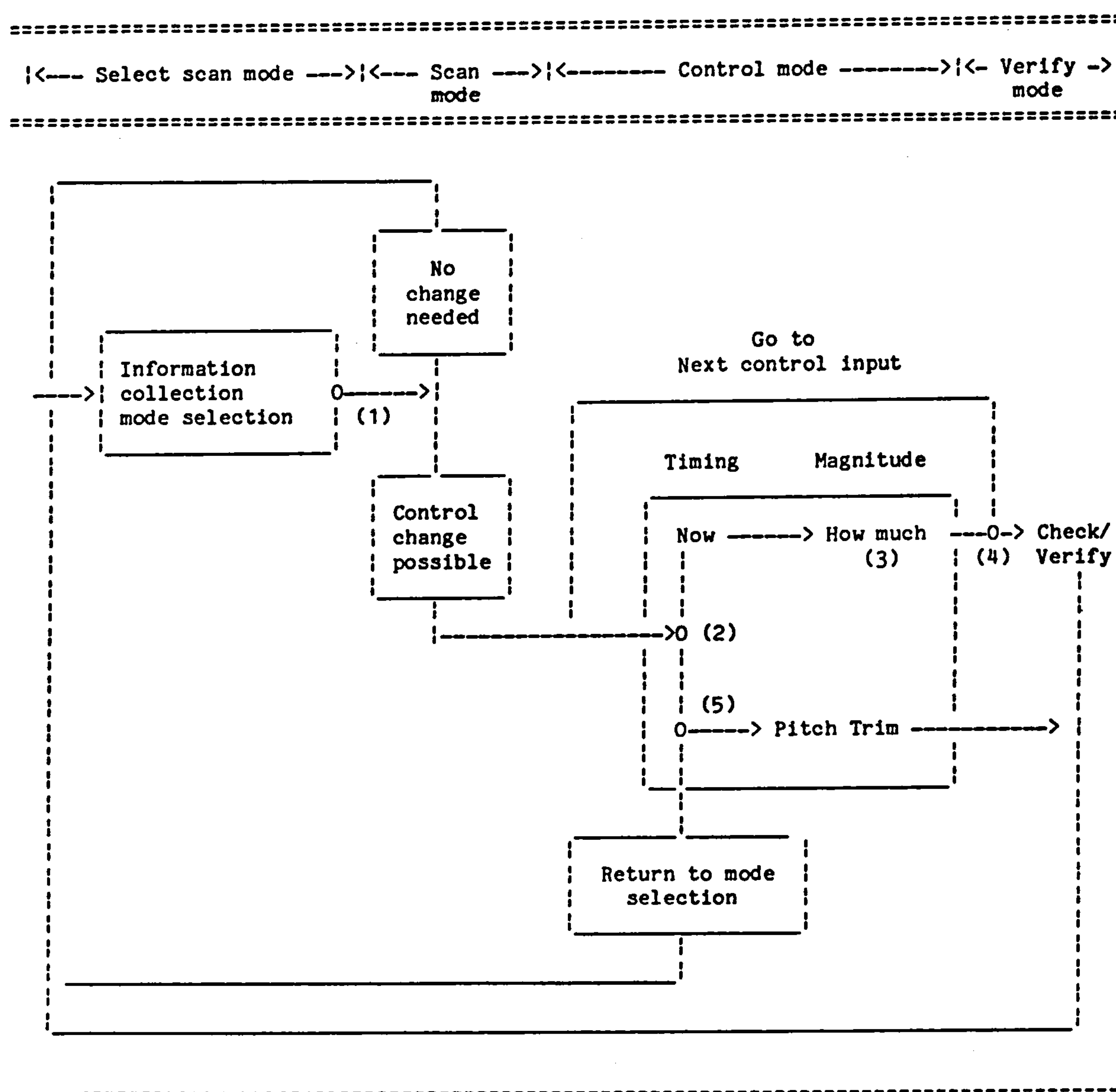

Figure 7. Stages, Choice Points, and Decision Paths Associated with Instrument Viewing. Decision points are indicated by O and a (#).

NOTES

Note 1. This raises the theoretical question of why perception seems to be continuous, but that discussion is beyond the scope of this report. Interested readers might pursue other sources, including Bouma (1978).

Note 2. An informal experiment was done using highly experienced pilots. Pictures of the altimeter were shown tachistoscopically for 1/4 sec. which is the average fixation time found in this study (Spady, 1978). The altitude settings were mostly in sequence from 518 meters (1700 ft.) down to 0 in approximately 30.5 meters (100 ft.) decrements. From this little study it is clear that the pilot operates from memory much of the time. He uses his memory of the last position combined with his reading of the pointer. Catch trials in which the drum was changed by 305 meters (1000 ft.) often resulted in mistakes.

Note 3. The crux of the issue is that of accuracy vs. utilization of the information. From an engineering standpoint, an instrument which displays high frequency changes might be considered to be more accurate and perhaps better. From the human information processing standpoint, an instrument which displays the information in convenient form is better even if it is somewhat less "accurate." The human operator is concerned with accuracy but he is also concerned with convenience. Thus it is likely that an instrument which produces a high cognitive workload will not be used if the information can be obtained elsewhere.

Note 4. A number of computer programs were used in the analysis. The program, SUPER, was developed by the Simulation and Human Factors Branch (now Flight Management), Langley Research Center, National Aeronautics and Space Administration. The factor analysis and discriminate analysis programs are in the biomedical package, BMDP (Dixon, 1975). Programs for the control input analysis were developed by BRAG.

Note 5. When the factor analysis was run, several other variables were discovered to have values so small so as to produce singular matrices - these variables were also set aside. (The entire list of variables is provided in the appendix; those variables not used are indicated.)

Note 6. The entire analysis (including discriminant) was also done with 9 and 11 factors. The analysis with nine factors did not fare as well as with ten and the one with 11 factors fared no better than the one with ten - another reason for settling on ten factors.

Note 7. Discriminant analysis is a generalized version of regression analysis and permits the entry of any number of classifications simultaneously. Regression analysis permits only two.

Note 8. There is a question as to whether the last few feet of altitude are realistic in the simulator. Capt. John Gallagher has suggested, in the simulator he gets the "aircraft" as far down as he can - to about 7.5 meters (25 ft.) - and then lets it "hit the runway," something he does not do in the real thing.

Note 9. There were a total of 177 misclassifications of segments. Of these, 91 (51%) were into adjacent segments. Under a null hypothesis argument, one would expect the overall distribution to be nearly a rectangular one with approximately 4% of the cases in each cell. In the 5 by 5 matrix, there are 5 correct cells, 8 adjacent cells and 12 non-adjacent cells; the expected value for the adjacent cells would be 32% as contrasted with the 51% obtained.

Note 10. The data show oscillating (sine wave) characteristics. Taking the arithmetic average of sine waves differing only in frequency and/or amplitude disguises the essential differences between and among the different functions. In the eye movement context, a difference between mean dwell times may reflect large internal differences in the data; however, a lack of difference does not mean the internal characteristics are identical.

Note 11. An important part of the task demand idea has to do with the way in which the individual executes or performs the task. There can be no assurance that the individual performs the task exactly as instructed. In laboratory tasks, for example, it is sometimes possible to observe changes in performance as the observer becomes familiar and practiced with the task. Thus, the initial performance on two similar tasks may be similar, but the later performance clearly indicates that the experimental subject is performing in two quite different manners, despite the 'fact' that only 'minor' variations exist between the two tasks. The subject has believed the experimenter for a little while (long enough to try the experimenter's method) but probably soon develops and uses a more efficient technique.

There are various parts to the task demand idea: (a) The way the experimenter thinks the task should be done. This corresponds with the experimenter's best guess as to how he thinks he does the task, (b) The translation of the experimenter's instructions by the subject into something the subject can follow, (c) The type of performance the subject thinks the experimenter wants coupled with the typical attempt by the subject to perform as well as he possibly can, (d) As the subject performs the task he learns more efficient ways which may diverge from the instructions, and finally, e) The subject tries to anticipate the unexpected and perform in a way so as to be prepared for extraordinary situations.

All of these factors, of course, are highly susceptible to differences in training, experience, and preferences of the pilot. For example, a pilot who does not have complete faith in the autopilot would be much more likely to use his manual pattern than a pilot who has total faith in the autopilot. The important general point is this: There are a number of 'unseen' factors which influence performance.

APPENDIX A

List of Variables Extracted from the Experiment.

APPENDIX A

List of Variables Extracted from the Experiment

Those variables which could not be used (see text) are so labeled. The control input frequencies were set aside for the main analysis.

TRANSITIONS

Variable No.	FROM		TO
1.	Clock		Airspeed
2.		Not used	F D
3.		Not used	Baro. Alt.
4.		Not used	H S I
5.			I V S I
6.			Radar Alt.
7.		Not used	Adf
8.	Airspeed		Airspeed
9.			F D
10.		Not used	Baro. Alt.
11.			H S I
12.		Not used	I V S I
13.		Not used	Radar Alt.
14.			Adf
15.	Flt. Div.		Airspeed
16.			F D
17.			Baro. Alt.
18.			H S I
19.			I V S I
20.		Not used	Radar Alt.
21.			Adf
22	Baro. Alt.	Not used	Airspeed
23.			F D
24.			Baro. Alt.
25.		Not used	H S I
26.			I V S I
27.			Radar Alt.
28.		Not used	Adf
29.	HSI	Not used	Airspeed
30.			F D

31.		Not used	Baro. Alt.
32.			H S I
33.			I V S I
34.		Not used	Radar Alt.
35.			Adf
36.	IVSI	Not used	Airspeed
37.			F D
38.			Baro. Alt.
39.			H S I
40.			I V S I
41.			Radar Alt.
42.	Radar Alt.	Not used	Adf
43.		Not used	Airspeed
44.		Not used	F D
45.			Baro. Alt.
46.			H S I
47.			I V S I
48.			Radar Alt.
49.		Not used	Adf
50.	Adf		Airspeed
51.			F D
52.		Not used	Baro. Alt.
53.		Not used	H S I
54.		Not used	I V S I
55.			Radar Alt.
56.			Adf

MEAN DWELL

57.			Airspeed
58.		Not used	F D
59.			Baro. Alt.
60.			H S I
61.			I V S I
62.			Radar Alt.
63.			Adf

STANDARD DEVIATIONS

64.			Airspeed
65.		Not used	F D
66.			Baro. Alt.
67.			H S I
68.			I V S I

69.			Radar Alt.
70.			Adf

FLIGHT DIRECTOR BREAKDOWN
TRANSITIONS

	FROM		TO
71.	Roll		Roll
72.	S B		
73.	C B		
74.	G S		
75.	LOC		
76.	Roll		S B
77.	S B		
78.	C B		
79.	GS	Not used	
80.	LOC	Not used	
81.	Roll		C B
82.	S B		
83.	C B		
84.	G S		
85.	LOC		
86.	Roll	Not used	G S
87.	SB	Not used	
88.	C B		
89.	G S		
90.	LOC		
91.	Roll	Not used	LOC
92.	SB	Not used	
93.	C B		
94.	G S		
95.	LOC		
96.	Roll	Not used	Seg 9
97.	SB	Not used	
98.	C B		
99.	G S		
100.	LOC		

MEAN DWELL - FLIGHT DIRECTOR

101.	Roll
102.	S B
103.	C B

104.		G S
105.		LOC
106.		Seg 9

STANDARD DEVIATIONS - FLIGHT DIRECTOR

107.		Roll
108.		S B
109.		C B
110.		G S
111.		LOC
112.		Seg 9
113.		Altitude
114.	Not used	Accuator 1
115.	Not used	Accuator 2
116.	Not used	Glide Slope Error
117.	Not used	Localizer Error
118.		Measured Air Speed

EVENT FREQUENCIES

119.	Set aside	Events - Stick Trim
120.	Set aside	Events - Stick Pos.
121.	Set aside	Events - Wheel Pos.
122.	Not used	Events - Rudder
123.	Set aside	Events - Throttle

MISC. OCULOMETER MEASUREMENTS

124.		ICOUNT
125.		NCNT
126.	Not used	ITIME
127.		MMCNT
128.		BLINKRT
129.		NBLNKRT

APPENDIX B

Rotated factor loadings (Pattern).

Appendix B

Rotated factor loadings (Pattern).

The loadings are from the main analysis described in the report. The VP for each factor is the sum of the squares of the elements of the column of the factor pattern matrix corresponding to that factor. The VP is the variance explained by the factor. The number of variables is 81; thus, the percent variance is obtained by VP / 81.

VARIABLE NUMBER	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8	FACTOR 9	FACTOR 10
5	-0.061	-0.142	-0.012	0.678	-0.023	0.072	0.083	-0.056	-0.072	-0.050
6	0.036	-0.030	0.022	0.360	0.137	0.037	-0.109	-0.090	-0.146	0.041
8	0.627	0.132	0.116	-0.040	-0.088	0.133	0.517	0.013	-0.241	-0.060
9	0.792	0.023	-0.044	0.014	0.004	-0.019	0.215	0.116	0.186	-0.177
11	0.002	0.367	0.003	-0.020	-0.082	-0.003	-0.023	-0.020	-0.211	-0.019
14	0.365	0.026	0.519	-0.132	-0.137	0.029	0.136	0.002	-0.273	-0.070
15	0.731	0.042	-0.073	-0.024	-0.017	-0.017	0.239	0.095	0.244	-0.163
16	-0.146	-0.617	-0.264	-0.132	-0.231	-0.165	-0.159	0.128	0.374	-0.116
17	0.072	-0.058	-0.094	0.065	0.784	0.122	-0.013	0.077	0.216	-0.090
18	0.034	0.791	0.007	-0.032	-0.038	-0.013	-0.015	-0.122	0.202	0.057
19	-0.131	0.113	-0.014	0.568	0.011	0.011	-0.098	0.419	0.197	-0.187
21	0.078	-0.015	0.671	0.093	-0.115	0.010	-0.050	0.196	0.011	-0.090
23	0.035	-0.010	-0.115	-0.052	0.815	-0.036	0.019	0.080	0.175	-0.078
24	-0.057	-0.072	-0.011	0.215	0.821	0.072	0.199	0.048	0.025	0.020
26	0.068	-0.032	0.044	0.634	0.297	-0.058	0.093	0.036	0.132	-0.066
27	-0.117	-0.025	-0.021	0.039	0.406	0.755	0.026	-0.003	-0.225	-0.103
30	-0.060	0.744	0.023	-0.051	-0.049	-0.007	-0.001	-0.111	0.255	0.000
32	-0.129	0.750	0.097	-0.049	-0.045	-0.034	0.102	-0.248	-0.009	0.181
33	0.011	0.653	-0.123	0.056	-0.018	-0.015	0.084	0.229	0.058	-0.150
35	-0.024	0.551	0.232	-0.050	-0.065	-0.010	0.050	-0.033	-0.130	-0.014
37	-0.116	0.099	-0.010	0.597	-0.019	0.175	-0.106	0.382	0.196	-0.062
38	0.028	0.032	0.081	0.630	0.285	-0.009	0.187	0.026	0.081	-0.037
39	0.020	0.557	-0.078	0.087	0.046	-0.070	0.071	0.239	0.171	-0.277
40	-0.091	0.189	-0.015	0.695	0.088	0.005	0.197	0.401	0.023	-0.177
41	-0.030	-0.032	-0.023	0.552	-0.038	0.020	0.128	-0.067	-0.192	0.093
45	-0.143	-0.035	-0.075	0.035	0.509	0.476	0.031	-0.006	-0.316	-0.110
46	0.024	-0.024	-0.000	-0.106	-0.049	0.892	-0.034	0.002	0.079	0.034
47	-0.029	-0.030	0.063	0.190	-0.025	0.734	0.014	0.014	-0.039	0.083
48	-0.136	-0.035	-0.027	0.150	0.391	0.732	0.076	-0.041	-0.281	-0.071
50	0.374	0.032	0.512	-0.087	-0.132	-0.038	0.134	0.070	-0.342	-0.109
51	0.029	0.084	0.672	-0.056	-0.090	0.253	-0.109	0.101	0.091	-0.040
55	0.062	-0.038	-0.027	-0.057	-0.086	0.030	0.048	0.194	0.011	0.250
56	0.015	0.064	0.801	-0.084	0.011	-0.047	-0.061	-0.041	-0.083	-0.017
57	0.323	-0.042	-0.126	-0.033	-0.068	-0.017	0.681	0.058	-0.060	0.029
59	-0.055	-0.089	0.120	0.058	0.456	-0.010	0.548	0.176	0.122	0.109
60	-0.060	0.282	0.173	0.023	0.005	-0.038	0.528	-0.265	0.024	0.138
61	-0.127	0.142	0.072	0.264	0.099	-0.033	0.488	0.441	0.050	-0.100

VARIABLE NUMBER	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8	FACTOR 9	FACTOR 10
62	-0.070	-0.034	-0.019	0.286	0.367	0.340	0.255	0.075	-0.322	-0.043
63	0.065	0.114	0.624	-0.005	0.068	-0.040	0.203	0.089	0.025	-0.055
64	0.311	0.056	0.113	-0.071	-0.041	0.195	0.721	0.059	-0.145	0.054
66	-0.031	-0.132	0.125	0.194	0.431	0.025	0.549	0.117	0.032	0.121
67	-0.021	0.382	0.220	-0.033	0.056	-0.033	0.583	-0.135	0.020	0.125
68	-0.062	0.038	0.105	0.354	0.162	-0.023	0.570	0.279	0.067	0.007
69	-0.075	-0.028	0.028	0.273	0.274	0.360	0.274	-0.069	-0.300	-0.037
70	0.055	0.069	0.714	-0.048	0.054	-0.069	0.209	0.001	-0.072	-0.013
71	-0.100	0.075	-0.050	-0.009	-0.008	0.007	0.019	-0.077	-0.125	0.751
72	0.042	0.006	-0.040	0.092	-0.039	0.021	0.073	-0.043	-0.253	0.084
73	-0.235	0.342	-0.079	-0.058	-0.079	0.145	-0.231	-0.137	-0.215	0.489
74	0.028	-0.032	-0.005	-0.045	-0.066	0.027	0.077	0.252	0.078	0.354
75	-0.041	-0.069	0.190	0.036	-0.036	0.023	-0.011	0.053	0.148	0.024
76	0.010	-0.073	-0.032	-0.004	-0.067	0.002	-0.061	0.012	-0.006	0.244
77	0.851	-0.085	0.028	-0.045	0.013	-0.070	-0.192	-0.128	-0.062	-0.006
78	0.843	0.060	0.055	-0.050	-0.077	0.018	0.052	-0.073	-0.204	-0.090
81	-0.233	0.194	-0.027	0.004	0.044	0.047	-0.216	-0.128	-0.222	0.442
82	0.831	0.082	0.025	-0.085	-0.087	-0.060	0.082	-0.091	-0.177	-0.050
83	-0.545	-0.329	-0.350	-0.291	-0.224	-0.050	0.239	-0.100	-0.040	-0.148
84	-0.024	0.072	-0.028	0.345	0.586	-0.053	-0.041	0.493	0.035	-0.125
85	-0.099	0.485	0.524	0.209	-0.101	-0.003	0.082	-0.159	0.166	-0.057
88	-0.074	0.010	-0.054	0.172	0.656	-0.017	-0.066	0.505	-0.007	-0.069
89	-0.111	-0.059	-0.014	0.194	0.277	-0.006	-0.105	0.736	0.013	0.025
90	-0.016	0.121	0.025	0.034	-0.100	0.798	-0.058	0.027	0.148	0.086
93	-0.163	0.492	0.496	0.255	-0.092	-0.007	0.073	-0.165	0.137	-0.064
94	0.037	0.032	0.064	-0.071	-0.039	0.851	0.019	-0.006	0.106	0.004
95	-0.116	0.213	0.618	0.401	-0.000	0.100	0.014	-0.123	0.330	-0.093
98	-0.015	0.265	-0.083	0.119	-0.053	0.138	-0.100	0.116	0.195	0.069
99	-0.015	0.081	-0.009	0.460	0.005	-0.004	-0.097	0.234	0.148	0.033
100	-0.037	0.162	0.125	0.633	0.012	0.055	-0.028	0.083	0.236	-0.102
101	-0.137	0.022	-0.103	-0.056	0.049	-0.026	0.270	-0.005	-0.071	0.763
102	0.572	-0.289	-0.064	-0.117	0.003	-0.132	-0.065	-0.139	0.218	-0.025
103	-0.452	-0.514	-0.281	-0.236	-0.261	-0.115	0.129	-0.117	0.094	-0.138
104	-0.107	-0.108	0.051	0.079	0.146	-0.005	0.110	0.769	0.179	0.051
105	-0.137	-0.160	0.386	0.260	0.080	0.040	0.219	0.009	0.489	-0.166
106	0.076	0.209	-0.007	0.187	0.109	-0.030	0.132	0.123	0.680	-0.074
107	-0.082	0.001	-0.058	-0.056	0.059	-0.052	0.220	0.031	0.013	0.793
108	0.601	-0.260	0.058	-0.065	0.018	-0.099	-0.081	-0.074	0.160	0.017
109	-0.434	-0.495	-0.241	-0.218	-0.234	-0.116	0.143	-0.113	0.110	-0.091
110	-0.080	-0.138	0.079	0.062	0.114	0.011	0.138	0.732	0.111	0.158
111	-0.138	-0.113	0.519	0.264	0.088	0.013	0.164	-0.030	0.404	-0.093
112	0.161	0.142	-0.011	0.144	0.147	-0.005	0.038	0.066	0.680	-0.060
128	0.118	0.181	0.046	-0.025	0.018	0.072	-0.444	0.360	-0.239	-0.027
129	0.163	-0.030	0.284	0.005	0.013	-0.019	-0.013	0.503	-0.055	-0.015
VP	6.093	5.496	5.124	4.999	4.711	4.645	4.421	4.194	3.544	3.116

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16. Abstract

Eye movement data were recorded while pilots flew ILS simulations in a B-737. In addition, other parameters were recorded including instrument readings, aircraft state and position variables, and control maneuvers. The experiment itself employed seven airline pilots, each of whom flew approximately 40 approach/landing sequences. The simulator was equipped with a night visual scene but the scene was fogged out down to approximately 60 meters (200 ft). The summarized data were entered into multivariate statistical and factor analysis procedures. The results suggested 10 components which could be related to categories (packets) of information. In other words, the instrument scanning appeared to follow aircraft parameters not physical position of instruments. These results provide a solid foundation for eye scan analysis. One important implication of the results is: Pilots look for categories or packets of information. Control inputs were tabulated according to throttle, wheet position, column, and pitch trim changes. Three seconds of eye movements before and after the control input were then obtained. Analysis of the eye movement data for the controlling periods showed clear patterns. The scan patterns found during controlling could be related to the factor components and to the success of discriminant analysis. The results suggest a set of mini-scan patterns which are used according to the specific details of the situation. A model is developed which integrates scanning and controlling. Differentiations are made between monitoring and controlling scans. In addition, provisions are incorporated in the overall scan model to provide the flexibility in scanning the pilot seems to require.

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