SPEED IN INFORMATION PROCESSING WITH A COMPUTER-DRIVEN VISUAL DISPLAY
IN A REAL-TIME DIGITAL SIMULATION

By
Robert Gordon Kyle

Submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University
in candidacy for the degree of
MASTER OF ENGINEERING
in
Industrial Engineering and Operations Research

June 1972
SPEED IN INFORMATION PROCESSING WITH A COMPUTER-DRIVEN VISUAL DISPLAY
IN A REAL-TIME DIGITAL SIMULATION

by

Robert Gordon Kyle

Submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF ENGINEERING

in

Industrial Engineering and Operations Research

APPROVED:

Chairman, Dr. J. B. Nelson

Dr. K. E. Case

Dr. Walter W. Wierwille

June 1972

Blacksburg, Virginia
SPEED IN INFORMATION PROCESSING WITH A COMPUTER-DRIVEN VISUAL DISPLAY IN A REAL-TIME DIGITAL SIMULATION

By
Robert Gordon Kyle

(ABSTRACT)

Information transfer between the operator and computer-generated display systems is an area where the human factors engineer discovers little useful design data relating human performance to system effectiveness. This study utilized a computer-driven, cathode-ray-tube graphic display to quantify human response speed in a sequential information processing task. The performance criteria was response time to sixteen cell elements of a square matrix display. A stimulus signal instruction specified selected cell locations by both row and column identification. An equal probable number code, from one to four, was assigned at random to the sixteen cells of the matrix and correspondingly required one of four, matched keyed-response alternatives. The display format corresponded to a sequence of diagnostic system maintenance events, that enable the operator to verify prime system status, engage backup redundancy for failed subsystem components, and exercise alternate decision-making judgments. The experimental task bypassed the skilled decision-making element and computer processing time, in order to determine a lower bound on the basic response speed for a given stimulus/response hardware arrangement. Response speed
differences, as a function of cell location within the matrix, were 
significant, and comparisons among the cell treatment means identified 
cell patterns of minimum response time.
## II. TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Title</td>
<td>1</td>
</tr>
<tr>
<td>II. Table of Contents</td>
<td>ii</td>
</tr>
<tr>
<td>III. Acknowledgements</td>
<td>iii</td>
</tr>
<tr>
<td>IV. List of Figures</td>
<td>iv</td>
</tr>
<tr>
<td>V. List of Tables</td>
<td>vi</td>
</tr>
<tr>
<td>VI. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Load and Speed</td>
<td>5</td>
</tr>
<tr>
<td>Graphic Displays</td>
<td>7</td>
</tr>
<tr>
<td>Design Application</td>
<td>9</td>
</tr>
<tr>
<td>VII. Experimental Task Design</td>
<td>12</td>
</tr>
<tr>
<td>VIII. Experimental Method</td>
<td>21</td>
</tr>
<tr>
<td>IX. Analysis of Data</td>
<td>27</td>
</tr>
<tr>
<td>Analysis of Variance</td>
<td>27</td>
</tr>
<tr>
<td>Comparison on Cell Treatment Means</td>
<td>38</td>
</tr>
<tr>
<td>X. Concluding Remarks</td>
<td>47</td>
</tr>
<tr>
<td>XI. Bibliography</td>
<td>48</td>
</tr>
<tr>
<td>XII. Appendices</td>
<td>51</td>
</tr>
<tr>
<td>A. Subject Instructions</td>
<td>51</td>
</tr>
<tr>
<td>B. Computer Program for Analysis of Data</td>
<td>54</td>
</tr>
<tr>
<td>C. Computer Program for Real-Time Simulation</td>
<td>58</td>
</tr>
<tr>
<td>XIII. VITA</td>
<td>71</td>
</tr>
</tbody>
</table>
III. ACKNOWLEDGEMENTS

The author expresses thanks to the National Aeronautics and Space Administration for the use of computer research facilities at the Langley Research Center in acquiring the data presented in this project. Appreciation is expressed to Mr. Ralph W. Will of the Langley Research Center for software development of the computer-generated display. Appreciation is also expressed to my advisor, Dr. J. Byron Nelson, Dr. Kenneth E. Case, Dr. Walter W. Wierwille, and to Dr. Randall M. Chambers of the Langley Research Center. A special thanks to Mrs. Myrtle Wells and Miss Linda Branch for initial typing of the text.
IV. LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Information Transfer for Manual Interface with System Maintenance</td>
<td>3</td>
</tr>
<tr>
<td>(a) Operator Input/Output.</td>
<td>3</td>
</tr>
<tr>
<td>(b) Operator/System Interface.</td>
<td>4</td>
</tr>
<tr>
<td>2. Schematic Form of Visual Display Stimulus.</td>
<td>15</td>
</tr>
<tr>
<td>3. Visual Display Stimulus for the Experimental Task.</td>
<td>17</td>
</tr>
<tr>
<td>4. Subject's and Experimenter's Test Stations</td>
<td>22</td>
</tr>
<tr>
<td>(a) Hardware Setup</td>
<td>22</td>
</tr>
<tr>
<td>(b) Test Setup</td>
<td>23</td>
</tr>
<tr>
<td>5. Test Apparatus for the Keying Response</td>
<td>25</td>
</tr>
<tr>
<td>6. Significant Single Cell Comparisons with the Minimum Response Time Cells, $C_{14}$ and $C_{44}$</td>
<td>43</td>
</tr>
<tr>
<td>(a) Individual Comparisons with $C_{14} = 2.2$ sec.</td>
<td>43</td>
</tr>
<tr>
<td>(b) Individual Comparisons with $C_{44} = 2.3$ sec.</td>
<td>43</td>
</tr>
<tr>
<td>7. Significant Comparison of Cells $C_{14}$ and $C_{44}$ to Grouped Remaining Cells</td>
<td>44</td>
</tr>
<tr>
<td>8. Significant Comparison of Cell $C_{14}$ to Other Grouped Cells of Top Row</td>
<td>44</td>
</tr>
<tr>
<td>9. Significant Comparisons of Top Row to Row 2 and Row 3</td>
<td>45</td>
</tr>
<tr>
<td>(a) Top Row versus 2nd Row</td>
<td>45</td>
</tr>
<tr>
<td>(b) Top Row versus 3rd Row</td>
<td>45</td>
</tr>
<tr>
<td>10. Significant Comparisons of Column 4 to Column 3, Column 2, and Column 1</td>
<td>46</td>
</tr>
<tr>
<td>(a) Column 4 versus Column 3</td>
<td>46</td>
</tr>
<tr>
<td>(b) Column 4 versus Column 2 or Column 1</td>
<td>46</td>
</tr>
</tbody>
</table>
V. LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Analysis of Variance Equations, Two-Way-Mixed Model</td>
<td>29</td>
</tr>
<tr>
<td>II. Analysis of Variance Results.</td>
<td>32</td>
</tr>
<tr>
<td>III. Subject Data.</td>
<td>33</td>
</tr>
</tbody>
</table>
VI. INTRODUCTION

Human operators in computer-driven display environments are taxed to process the volume of information that confronts them. Communication between man and the computer in real-time operations is becoming more important as the complexity and capabilities of computing systems increase, and as the requirements for automation continue to grow. In future manned spacecraft, the checkout systems will shift from ground to onboard monitor and checkout operations. It is therefore essential that the spacecraft crew be able to process all the data required for interfacing at the monitoring and checkout level. Hence, the information receiving task must be made efficient in order to improve the operator's probability of acting properly on the signals available.

To maximize information transfer rates in the monitoring and checkout tasks, efforts will focus on systems in which man and computer can cooperatively make up for each other's deficiencies in analyzing and processing information, and at the same time maximize the particular advantage of each. Automatic deterministic logic schemes which require extensive memory and that are concerned with repetitious events to easily detectable conditions, can be made automatic with reliable performance. Manual override capability is still extremely desirable and essential where a choice between many different plans of action depend upon a complex set of circumstances, of which not all may be anticipated.
Figure 1a depicts the manual interface input/output situation where an operator is processing information from a visual display. His knowledge of the system operation and the tasks involved, together with a display system, form the input for his interface control with the system, by interacting with a display in the monitoring and decision making functions. This study utilized a computer-driven visual display to examine the speed of response for a display format designed for system maintenance applications. The display format presented the stimulus data in a matrix arrangement, which could be applied to several information processing tasks such as flow-network operations, information retrieval techniques, and the class of procedures requiring operator interface control with computer stored logic.

System maintenance technology considers system status monitoring, system fault classification, failure diagnosis, and component replacement (Anderson, 1970). Before information processing tasks can be made more efficient, display techniques must be developed to quantify and measure basic human performance in performing these maintenance operations. Figure 1b is a typical flow chart of the information transfer process for manual interface with system maintenance. The operator's monitoring and skilled judgement, together with the displayed deterministic computer logic form the basis of decision making which the human operator then implements via a display/entry system which subsequently feedbacks to the computer to complete the information loop.
Figure 1.- Information Transfer for Manual Interface with System Maintenance
(b) Operator/System Interface

Figure 1.— Concluded
The cognitive processes involving human judgement and decision making must be experimentally determined for specific tasks by appropriate skilled operators. However, the system implementation loop (solid lines - Figures 1a and 1b), via the display/entry and feedback through the computer analysis, bypasses the decision-making factor (dashed lines), and may be identified as a basic human performance task and more readily quantified. The present study used a computer-driven visual display and associated keyboard to measure the speed of basic human information processing in this type of sequential information processing task. A problem of this research is to first design an adequate display stimulus having a small memory requirement to minimize operator load stresses, enough stimulus realism for practical design applications, and yet a readily identifiable stimulus format to maximize the information content. These three problem areas of stimulus design must be considered from load and speed variables, application of computer-generated displays, and integration of these concepts to formulate a realistic task to measure basic information processing rates that may be used as baseline processing speed for design applications.

**Load and Speed**

The presentation format of visual displays for information processing influences the speed and accuracy of the checkout or monitoring task. Two variables, load and speed, are usually considered with overall operator performance in visual information
processing (McCormick, 1964). Load refers to the variety of stimuli or number of signals to which unique responses must be made. Speed relates to the number of stimuli per unit of time.

The load and speed variables frequently appear as important factors in conventional cockpit layouts. The following studies serve to indicate related human performance problems with multichannel display arrangements. Initial studies by Conrad (1951, 1955), in an experiment with an arrangement of dials having revolving pointers, determined that experimental errors occurred when signals requiring response action were bunched together, and when the subject failed to determine the correct signal order for processing. In the situation where responses are required for each of two successive stimulus signals, the second of the two signals shows a longer than normal reaction time and has been called the psychological refractory period. The extent of the delay in the response to the second signal decreases with the increased interval between the signals. An interval of 0.5 sec is necessary to avoid delay overlaps (Vince, 1949). Mackworth and Mackworth (1956) confirmed the disadvantage for skilled achievement under signal overlap during which the given signal is overlapped by any other signal, even when there is not a change in average speed of presentation. The greatest drawback of multichannel displays was believed to be the tendency to give rise to momentary, but damaging, peaks of speed stress which increases signals missed, rather than wrong decisions. This preponderance of errors of omission over errors of commission have been also supported by Hammer and Ringel (1965) in
studies with symbolic information. Another dial study (Olson, 1963) recognized that arrangement and location, as well as load and speed, are potentially important factors in the ability of individuals to deal with incoming information. It was also concluded that displays should be centrally located and at eye level for best performance. A study of effects of divided attention on visual monitoring of multichannel displays (Gould and Schaffer, 1967) determined that the rate of display change and the number of channels monitored were the most important determinants of accuracy.

Without going into further discussion of these studies, it may be noted that they all report deterioration on the performance of the particular tasks investigated as the load and speed increase. Despite these findings, designers are still bound to the notion that operators can process more information via multichannel arrangements than sequential presentation in single channels. Graphic display investigations employing minimum channel media seem warranted to get the required information to the operator in a timely and logical manner.

**Graphic Displays**

Some justification is required for the application of computer generated visual displays to the information transfer task. The recognized trend toward increasingly more complex pilot tasks, along with studies of the great amount of scanning activity using conventional instrument arrays, have led to proposals for an integrated, time-shared display using a computer-driven device such as the cathode-ray-tubes. It is generally noted that the time to interpret and respond
to a graphic display system, will be less than that needed to scan and utilize a cluster of dials and switches. Acceptance to the presence of a graphic visual display as a panel instrument has been attributed (Stein, 1970) to principally three factors: (1) graphic displays provide an effective method of presentation for a great amount of data in a small physical space, (2) a new breed of pilot is moving into the command seat with greater familiarity, understanding, and acceptance of avionics hardware, and (3) the capabilities and reliability demonstrated by new avionics equipment in the manned space program has had a profound selling effect. Thus, this general-purpose display concept seems to offer the potential for more effective information transfer as well as for less equipment and panel space, which results in lower total weight and volume. In addition, a single display device is more easily integrated with a computer than are a host of individual panel instruments. Graphic displays are also practical in advanced avionics systems, since microminiaturization technology permits the development of standardized monitoring circuits to take the critical subsystem maintenance measurements and to compare these with standard limits for presentation on the graphic display.

The information required for navigation and control is reasonably well established (Roscoe, 1968), but two areas for improvement are methods of grouping information in integrated displays and the means of presenting encoded information. One current aerospace concept is a command panel that contains three cathode-ray-tubes and a single digital input-output circuit (Mueller, 1970). The three primary modes
are attitude control, navigation status, and system monitoring.

For system monitoring and checkout, the astronaut would use the digital
input-output circuit via the keyboard to select specific display
parameters, move switches, acknowledge signal instructions, and call
for details of subsystem status when needed. The status tube would
be used before launch for checkout and during flight to keep the crew
informed of system condition. Here, the expanded capacity of the
computer-driven graphic display would display to the operator "what
he needs to know" and "when he needs to know it." For instance, in
an emergency, the display would flash an alarm and the appropriate
action to take. Less serious malfunctions would be noted in a less
urgent manner. In all cases, the nature of the problem would not
only be indicated on the cathode-ray-tube, but also the recommended
action pertinent to that portion of the mission rules. The crew
would also use the keyboard to summon up further details of the
problem and call options, such as predictive modes, stored in the
computer memory and programmed software. In attempting to combine
the best of both man and computer, the premise has been to take
advantage of man's unique ability to interpret information and at the
same time to present the same data to a computer in a digital form
that the computer can digest.

Design Application

The primary goal of this study will be to generate applicable
information about human speed performance in sequential information
processing from visual CRT displays. Mission-oriented simulation research differs from this basic human performance statistical research primarily in the kind of information generated and the use to which it is put. Most mission-oriented simulations are conducted to evaluate and demonstrate the application of specific procedures and equipment to specific operations. Most basic human performance research seeks to describe and measure relationships between operator performance measures and system variables. Much of the present dissatisfaction with both simulation studies and human performance research (Alluisi, 1967, Auerback Corp., 1968, DeGreene, 1970, Knowles, 1967) lies in the fact that neither of these efforts has paid off very well in terms of information which is usable in formal system design and trade-off analysis. The most elegant model for a display monitoring task is useless if it cannot predict performance in an actual monitoring task. This study is aimed at the middle ground where system evaluation and human performance are dealt with in terms of empirical functions systematically determined and where the systems engineer finds useful design data.

The dependent variable, response time, for this manual keying task is only one response from an ensemble of S-R matching combinations. As such, this S-R compatibility is the single parameter in this experiment that will primarily determine the speed of information transmitted. Hence, as Moss (1966) points out, this design eliminates consideration of other aspects of the entire response set which could significantly alter the reaction times. Therefore, the validity of
application to useful design data requires correct interpretation of the components of response time for this specific S-R task. It would then be possible for an equipment designer to predict operator information processing speeds on similar graphic displays. In this study, the basic human performance element of an applied task is isolated from the decision making element. In this manner, a lower bound on the response time may be quantified, and in effect give the systems designer a starting point on whether a desired number of display sequences, will fit within the mission/hardware time bound constraints. For instance, if a time-critical maintenance task required a certain number of display sequences for proper identification and corrective action, then knowledge of the minimum processing time, exclusive of decision making, would indicate whether the desired maintenance task could fit within the operator's integrated response times for that task.
VII. EXPERIMENTAL TASK DESIGN

Very few systematic or formal quantitative studies have been made of man-computer interactions in a time sharing environment, or of the factors that affect the quality or productibility of those interactions (Nickerson, Elkind, and Carbonell, 1968). In performing a system checkout or failure diagnosis, the operator addresses the computer to display a serial sequences of statements or instructions that enable him to verify system status, localize the failed sub-system component or take repair actions. In application cases the operator is performing a decision function, since there would be no need to display information that the computer can make pre-programmed decisions upon. For instance, the cathode-ray-tube displays status information for a particular component and give primary mode status, backup system status, and required action for pilot approval. The subject will be required to take a specified form of action for each discrete display stimulus, whereas the real world operator would be required to determine if the displayed action is necessary based upon his knowledge of the immediate situation.

The task of the experimental display stimulus is to focus the operator's attention on a specific cell of a matrix form of coding (figure 2). In realistic applications, this orientation is directed by deterministic computer logic, and skilled operator judgement would involve consideration of information in adjacent cells. Also, in realistic applications, the matrix cells would contain maintenance information relevant to the decision making function, whereas in this
synthetic task the cells are number coded. This is analogous to having the primary and backup systems in a given related status, but allowing the operator to override the automatic sequence by making the final judgment as to the next appropriate step based upon the current and un-programmed situation. In an applications task, each cell gives specific information on fault classification, failure diagnosis, and component replacement. When he selects other cell alternatives, in reviewing the cell displayed deterministic data, then the decision making factor is being fully utilized. This experimental task bypasses the decision-making element (dotted lines, Figures 1a and 1b) to determine the basic speed of response for a given stimulus/response hardware arrangement. This study then examines the speed of response including choice reaction time and movement time, for a constant size matrix stimulus where the cells are number coded rather than giving pertinent maintenance status information for system operation. This determination of baseline speed data, for the realistic stimulus/response interaction, is a prerequisite to task design requirements where skilled operators must make real-time action decisions. For instance, this baseline speed data will determine the time required for cell by cell processing, and indicate if the proposed maintenance data will fit within the total lower bound constraints of the required checkout task. Furthermore, for this experiment design, the cell locations for quickest recognition are identified, and may be used to improve the speed of information transfer.
As preliminary to higher order decision processes, the present information transfer task must be rapidly and accurately assimilated from the graphic display. In operational situations where speed and accuracy are critical, the use of display instruction coding can result in a substantial reduction in viewing time per quantity of information while accuracy is actually increased (Hammer and Ringel, 1965). Therefore, each signal instruction format presented to the subject will be structurally similar, and have constant coding for the processing of those stimulus signals presented, such that no short-term memory is required. A short symbolic form of display signal instruction will be used, consisting of component identification for stimulus ordering, primary mode status, and backup system status. A horizontal format was selected (Williams, 1966) for the signal instruction and has the form:

CODE: ___ PRIME: ___ BACKUP: ___

where CODE identifies each numbered signal instruction (identify a component in an applications task); PRIME mode status has four possible states - acceptable, caution, critical, and failed; and BACKUP system status also has four possible states - static, standby, active, and operational. A typical signal instruction and the response matrix is shown in figure 2. This simple signal instruction format is selected since subjects draw information in rough proportion to the difficulty of the task (only two inputs require his attention) and prefer to operate with less risk on easy instructions and, consequently, make fewer errors (Schrenk, 1964). Information taking decreases with
Figure 2.- Schematic Form of Visual Display Stimulus
increasing input history (Yntenna, 1963). Hence, the four variable stimulus states for each row and column of the display matrix are fixed and only the selection elements of the signal instruction vary.

The subject's initial task is to examine the signal instruction for the current combined status of the primary and backup modes of a particular integrated subsystem operation. He then refers to the response matrix, and for that simultaneous combination of primary and backup status, selects one of four numbers coded as 1, 2, 3 or 4 to response via a matched keyboard. Both the four numbers and the cell locations are assigned at random. To illustrate, a signal instruction combination giving "caution" primary and "static" backup modes requires a key 4 response for that specific signal instruction (figure 2). The response matrix is coded with numbers for a matched keyed response, since speed of correct cell recognition by test subjects and not skilled operators, is the dependent variable. Figure 3 shows the computer-generated display stimulus as viewed by the subject.

If an operator must keep track of a display that provides more information than he is capable of processing completely, and if the information includes elements having different payoff values, then some form of selectivity or filtering is likely to occur (Kanarick and Petersen, 1969). Also, it has been frequently found in display research that the presence of unneeded data impedes human data processing, thus making it harder for an operator to retrieve required information (Baker, 1966). In this study, then, the subject's task will be only to process information into subcategories for further
Figure 3.- Visual Display Stimulus for the Experimental Task
action by the automatic systems which, in turn, will be presented in additional detail in the next signal instruction of a predetermined sequence.

The experimental task will not examine the effect of speed on long-term memory. Instead, by action on the signal instructions via the response matrix, the subject communicates with the computer and automatic systems through the response keys, and the computer will perform the function of keeping track of memory sequences selected by the subject.

The background survey on variables that relate to the rate of visual information processing have identified S-R compatibility and learning as the primary parameters. Other influencing factors on reaction time, but not generally affecting transmission rate, were methods of manipulating uncertainty, the mode of stimulus presentation, boundary conditions, and speed and accuracy trade-offs. The following topics discuss how these above considerations affect the experimental task and the research model.

Response Time.—Perceptual failures under given load conditions have, in part, been found to be related to the speed of signal instructions, where the stimuli occur close together (psychological refractory period). Considering the information processing task in responding to the signal instructions, this means that if the stimuli are close together or if the instructions come in bunches, the operator's response to them frequently are missed, delayed, or otherwise affected. Capacity for random information is low, and operators
make mistakes when keeping track even for only a few things at once (Yntema, 1963). In general, operators should not be under severe time constraints in processing information from displays in order to have sufficient time to extract the required data (Taub, Monty, and Laughery, 1967).

A study (Fitts, 1963) of a speed versus accuracy trade-off function indicated that the rate of response which subjects adopted, resulted in nearly optimal information transmission. The control group was given ambiguous instructions (be as fast and accurate as possible) and performed at nearly the established 10 percent error rate for maximum information transmission. Hick (1952) found that the same linear function fitted the data when errorless performance was required and also when the subject speeded up his responses to the point where a substantial number of errors occurred. These studies demonstrate the delicacy with which human processing capacities adjust to the environment. It, therefore, appears that in performing system checkout or failure diagnosis it could be advantageous for the pilot to control the speed at which the signal instructions are presented on the graphic display. Furthermore, self-pacing may be faster in the case where the controlled pace is slowed down or otherwise changed for variable task requirements. Performance accuracy to a high degree is required in this study, and for this reason self-pacing of signal instructions will be used to determine the rate of information processing.

Reaction time reflects the subject's uncertainty about which of a set of response movements are to be made, while movement time reflects
the relative accuracy of termination required by the movement. In a neuroanatomical analysis of human operator response speed (Wargo, 1967) for several states of the same stimulus, each of which is associated with a particular correct response, choice reaction time can be expected to range from 0.133 to 0.528 second. This estimate is based upon reception delays, afferent transmission delays, central process delays, efferent transmission delays, muscle latency, and activation time. By definition, reaction time estimates do not include any significant movement time. In the manual control context, however, movement time is a significant component of total response time. On the basis of data reported by Brown and Slater-Hammel, 1948, a minimum movement time on the order of 0.3 second can be expected for most control activities. With the subject making a keyed response, the accuracy of terminating the movement is unimportant and, hence, the hand movement amplitude will not affect movement time. Therefore, the predictive neuro and movement response time for this task would be from 0.433 to 0.828 seconds.
VIII. EXPERIMENTAL METHOD

The thirty-one test subjects were between the ages of 22 and 53 years of age, and had a minimum education of a B.S. in the sciences or engineering. None of the subjects had prior lab experience in tests with CRT displays, but knew of the system operation and its potential in advanced cockpit design. Subjects were selected at random from several scientific disciplines and included three female participants. Subject motivation was enhanced by the realistic test apparatus, and by the logical context and format of the stimulus instructions. The resulting high performance motivation of engineer subjects was also utilized in the within-subjects experimental design. To reduce bias due to experimenter-subject interaction, each subject received a sheet of typed instructions (Appendix A) and verbal communication with the experimenter was limited to clarification of these instructions. The subjects were not instructed as to scan and search patterns, in order to get a better inference for a general class of display operators. In all cases except one, a single 16-unit run was sufficient for the subject to understand and perform the S-R task. The 128-unit measured run followed immediately. Each run had 8 observations in each cell for replication effects. All subjects were interested in their relative performance as compared to overall subject means. No sample size estimation was determined because no prior data was available to estimate the population variance and mean difference error.

The computer interface equipment, consisting of subject and experimenter stations is shown in figure 4a. Both consoles are linked
Figure 4. - Subject's and Experimenter's Test Stations

Hardware Setup
(b) Test Setup

Figure 4. Concluded
to a Control Data 6600 series digital computer complex. A hood was placed over the CRT screen to prevent reflected glare from the overhead lights. The subject then monitored the display through a viewing port as shown in figure 4b. The subject's test apparatus consisted of a CDC Model 250 CRT console, and used four of the momentary switch keys for the keying response (figure 5). The graphic output system consists of a plot language in the form of Fortran subroutine calls, and a set of processors which conditions the output of the plot language routines to the CRT graphic device. A real time plot language was used to build the graphic picture by calling routines that will scale the picture, draw and annotate axes, plot an array of data points, and present printed messages. Figure 3 shows the display stimulus as generated by programmed software. The manipulation and sequencing of the display picture is accomplished by pre-programmed software, and through the experimenter's program control console. The software equations for the real-time display experiment are in Appendix C.

Subject response times for each matrix presentation were recorded together with the selection errors. This is important, because if the task fails to convince the subject of its importance and validity, the subject's performance on the task may reflect fluctuations in his interest and motivation independently of the parameters under study. The information transfer task reflects the genuine speed performance changes that occur under the conditions of study. On the other hand, the task was not so sensitive as to suggest serious
Figure 5. - Test Apparatus for the Keying Response
impairments when none actually exist. The timing between the occurrence of each stimulus signal instruction and the subject's keyed response is recorded by the computer to $1/32$ second and then rounded to the nearest $0.1$ second. Raw data for statistical analysis was stored on punch cards for off-line computations. A computer program was generated to analyze this data and is listed in Appendix B.
IX. ANALYSIS OF DATA

The test data were analyzed by a two-way, mixed model analysis of variance (Wicks, 1964 and Ostle, 1963), and Scheffe's test for comparisons among the treatment means (Edwards, 1968).

Analysis-of-Variance

Assumptions.- The two-way classification model is appropriate when both block and treatment sources of variation are anticipated. The block or subject effect was random while the cell treatments were fixed, resulting in a mixed model. The known subject variance was measured and blocked from the experimental error so that the difference among the treatments means would contain no contribution attributable to subject sources. The basic assumption for this design is that the observations be represented by a linear statistical model of the form:

$$Y_{ijk} = \mu + B_i + T_j + R_k + (BT)_{ij} + e_{ijk}$$

where

$$i = 1, 2, \ldots, t \text{ subject blocks}$$
$$j = 1, 2, \ldots, r \text{ cell location treatments}$$
$$k = 1, 2, \ldots, s \text{ samples/treatment/block (replicates per cell)}$$
\( Y_{ijk} \): Subject's speed in seconds per treatment

\( \mu \): Overall mean effect

\( T_i \): Cell treatment effect (Fixed Level)

\( B_j \): Subject block effect (Random Level)

\( R_k \): Replication effect (Random Level)

\( (TB)_{ij} \): Interaction between treatments and blocks

\( e_{ijk} \): Experimental error

The experimental error, \( e_{ijk} \), is the value of an independent, normally distributed random variable having a zero mean and a common variance.

The parameters of the mixed model are restricted by the conditions:

\[
\sum_{j=1}^{r} T_j = \sum_{j=1}^{r} (TB)_{ij} = 0
\]

\[
\sum_{i=1}^{t} (TB)_{ij} \neq 0
\]

\( B_i \) are NID \( (0, \sigma_B) \)

\( R_k \) are NID \( (0, \sigma_R) \)

The analysis of variance equations are presented in Table I, where the dot subscripts denote a summation over the replaced \( i \), \( j \) or \( k \).
<table>
<thead>
<tr>
<th><strong>Source</strong></th>
<th><strong>D.O.F.</strong></th>
<th><strong>SS</strong></th>
<th><strong>EMS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject Blocks, B</td>
<td>(t - 1)</td>
<td>rs ( \sum \frac{t}{i=1} (\overline{Y}<em>{i...} - \overline{Y}</em>{...})^2 )</td>
<td>( \sigma^2 + rs \sigma_B^2 )</td>
</tr>
<tr>
<td>Cell Treatments, T</td>
<td>(r - 1)</td>
<td>ts ( \sum \frac{t}{j=1} (\overline{Y}.j - \overline{Y}_{...})^2 )</td>
<td>( \sigma^2 + s \sigma_{BT}^2 + ts \sigma_T^2 )</td>
</tr>
<tr>
<td>Replicates, R</td>
<td>(s - 1)</td>
<td>rt ( \sum \frac{t}{k=1} (\overline{Y}..k - \overline{Y}_{...})^2 )</td>
<td>( \sigma^2 + tr \sigma_R^2 )</td>
</tr>
<tr>
<td>B x T</td>
<td>(t - 1)(r - 1)</td>
<td>s ( \sum \frac{t}{t=1} \sum \frac{r}{j=1} (\overline{X}<em>{ij} - \overline{Y}</em>{i...} - \overline{Y}.j + \overline{Y}_{...})^2 )</td>
<td>( \sigma^2 + \sigma_{BT}^2 )</td>
</tr>
<tr>
<td>Error</td>
<td>(rt - 1)(s - 1)</td>
<td>( \sum \frac{t}{i=1} \sum \frac{r}{j=1} \sum \frac{s}{k=1} (Y_{ijk} - \overline{Y}<em>{i...} - \overline{Y}.j + \overline{Y}</em>{...})^2 )</td>
<td>( \sigma^2 )</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>trs - 1</td>
<td>( \sum \sum \sum (Y_{ijk} - \overline{Y}_{...})^2 )</td>
<td></td>
</tr>
</tbody>
</table>
In addition, it is assumed we are sampling independent, normally distributed populations with the same but unknown variance. With the possible exception of the assumption of homoscedasticity, these conditions are ordinarily not tested in the course of performance of a statistical analysis. Rather, they are presumptions which are accepted with some control, and their validity determines the meaning of the probability statement. However, these parametric methods are relatively insensitive to violations of the assumption of normality as well as the assumption of equal variances.

Null Hypothesis. The null hypothesis, $H_0$, represents a special case of statistical testing and its proper use depends primarily upon meeting two logical criteria (Ellis, 1967). For this design, these are that: (1) the speed performance measure must be an observable and recordable representation of the task relationship underlying the man-machine interplay being studies, and (2) the apparatus used for measuring task performance during experimentation must be sensitive to small but meaningful changes in the speed variable. Thus, if determining whether or not differences do exist between cell location treatments, then accepting or rejecting the $H_0$ is relevant evidence in this case. To properly interpret $H_0$, based on the data it will be necessary to develop and maintain a high correlation between statistical and practical significance. Ellis's recommendations for accomplishing this objective from a statistical standpoint include using an alpha level of 0.05. From the standpoint of practical
significance of data, the overriding recommendation is to depend upon the knowledge of other technical disciplines. This particular aspect has already been emphasized as one of the guidelines of this experimental task in order to generate useful design data for information transfer in graphic display systems. Accordingly, it was decided that measurement of response time to 0.1 second would be representative for the maintenance task. Since the criteria as stated by Ellis for the null hypothesis are satisfied in this test, the measures for interaction, treatment, replication, and block effects will be based upon the null hypothesis $H_0$.

**Experimental Results.** The analysis of variance results for thirty-one subjects and 128 responses per subject, are given in Table II.

The overall mean response was 2.6 sec, which was measured from the occurrence of stimulus on the CRT screen to the subject depressing the momentary switch keys. This response time did not include computer processing time, which would added to overall elapsed time in an applications experiment. Subjects made on average of 4.5 errors for the 128 signal instructions, and the response time for wrong selections was added to the total time for that correct cell identification. Individual mean scores and other subject data are given in Table III.

The variance for this experiment was 1.06 sec$^2$, which is small enough as to suggest that the subjects exhibited uniform matrix search
TABLE II

ANALYSIS OF VARIANCE RESULTS

<table>
<thead>
<tr>
<th>Source</th>
<th>D.O.F.</th>
<th>SS</th>
<th>MS</th>
<th>F-Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject Blocks</td>
<td>30</td>
<td>1266.88</td>
<td>42.23</td>
<td>63.28</td>
</tr>
<tr>
<td>Cell Treatments</td>
<td>15</td>
<td>128.39</td>
<td>8.56</td>
<td>8.56</td>
</tr>
<tr>
<td>Replication</td>
<td>7</td>
<td>14.71</td>
<td>2.10</td>
<td>3.15</td>
</tr>
<tr>
<td>Blocks x Treatments</td>
<td>450</td>
<td>449.82</td>
<td>1.00</td>
<td>1.50</td>
</tr>
<tr>
<td>Error</td>
<td>3465</td>
<td>2312.18</td>
<td>.67</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3967</td>
<td>4171.97</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test Parameters:  \( t = 31 \) subjects

\( r = 16 \) cell location treatments

\( s = 8 \) sample/treatment/subject
# TABLE III

**Subject Data**

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Sex</th>
<th>Age</th>
<th>Errors</th>
<th>Mean Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>28</td>
<td>1</td>
<td>2.3</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>34</td>
<td>2</td>
<td>2.4</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>33</td>
<td>3</td>
<td>3.8</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>29</td>
<td>9</td>
<td>1.9</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>27</td>
<td>13</td>
<td>2.5</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>47</td>
<td>5</td>
<td>2.0</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>35</td>
<td>2</td>
<td>3.4</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>26</td>
<td>2</td>
<td>2.4</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>51</td>
<td>6</td>
<td>2.7</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>27</td>
<td>5</td>
<td>1.9</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>36</td>
<td>9</td>
<td>2.3</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>22</td>
<td>3</td>
<td>2.0</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>30</td>
<td>10</td>
<td>3.0</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
<td>26</td>
<td>1</td>
<td>4.3</td>
</tr>
<tr>
<td>15</td>
<td>M</td>
<td>30</td>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>16</td>
<td>M</td>
<td>32</td>
<td>5</td>
<td>2.0</td>
</tr>
<tr>
<td>17</td>
<td>M</td>
<td>25</td>
<td>4</td>
<td>2.0</td>
</tr>
<tr>
<td>18</td>
<td>M</td>
<td>24</td>
<td>4</td>
<td>2.0</td>
</tr>
<tr>
<td>19</td>
<td>M</td>
<td>29</td>
<td>-</td>
<td>2.2</td>
</tr>
<tr>
<td>20</td>
<td>F</td>
<td>30</td>
<td>11</td>
<td>2.7</td>
</tr>
<tr>
<td>21</td>
<td>M</td>
<td>51</td>
<td>7</td>
<td>2.7</td>
</tr>
<tr>
<td>22</td>
<td>M</td>
<td>45</td>
<td>0</td>
<td>2.1</td>
</tr>
<tr>
<td>23</td>
<td>M</td>
<td>32</td>
<td>3</td>
<td>2.8</td>
</tr>
<tr>
<td>24</td>
<td>M</td>
<td>47</td>
<td>3</td>
<td>3.0</td>
</tr>
<tr>
<td>25</td>
<td>M</td>
<td>30</td>
<td>7</td>
<td>3.0</td>
</tr>
<tr>
<td>26</td>
<td>M</td>
<td>41</td>
<td>1</td>
<td>3.5</td>
</tr>
<tr>
<td>27</td>
<td>M</td>
<td>33</td>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>28</td>
<td>M</td>
<td>35</td>
<td>13</td>
<td>2.3</td>
</tr>
<tr>
<td>29</td>
<td>F</td>
<td>30</td>
<td>4</td>
<td>2.6</td>
</tr>
<tr>
<td>30</td>
<td>M</td>
<td>52</td>
<td>0</td>
<td>2.5</td>
</tr>
<tr>
<td>31</td>
<td>M</td>
<td>53</td>
<td>1</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Overall Mean Speed = 2.6 sec  
Standard Deviation = 1.03 sec

Average Age = 34.5 years  
Median Age = 32 years

Average Number of Errors = 4.5

Mean Speeds:  
Key 1 = 2.4 sec  
Key 2 = 2.7 sec  
Key 3 = 2.7 sec  
Key 4 = 2.8 sec
results, which also accounts for a high kurtosis factor. This observation is explained by considering the four discrete steps the subjects perform for each response. First, he must read the signal instruction line, which instructs him to the second step of searching the display matrix, for the correct cell location. The third step requires an identification of the number in that chosen cell location, followed by the fourth step which is the action of making the appropriate key response. Now, reading and remembering the column/row signal instruction, recognizing a number, and matching that number to a matched keyed response were designed to be relatively simple and straightforward tasks. However, the second step of searching the matrix for the correct cell location, was far more difficult, which of course was the intent of the experiment. With the fact that the variance was small compared to the mean response time of 2.6 sec, then indicates that the subjects responded nearly the same on their search effectiveness. This was supported by a high positive kurtosis factor of 4.672. The distribution of time frames versus number of occurrences was skewed positive with a value of 1.293, and was due to the zero time origin.

As discussed previously, the predictive neuro and moment response time would be on the order of magnitude of one second or less. This implies that the 4 x 4 matrix search time on the order of two seconds, is a significant time requirement, and should be optimized for given applications. This data is now analyzed from the statistical viewpoint of significant cell location treatments, followed by significant comparisons of response speed as a function of cell location.
**Interaction Effect.**—The test for interaction between blocks and treatments is a measure of the failure of the cell location speeds to behave in the same manner from subject to subject. The test for interaction is:

1. \( H_0: \sigma_{TB}^2 = 0 \)

\( H_1: \sigma_{TB}^2 \neq 0 \)

2. Test Statistic: \( F(450, 3465) = \frac{S_1^2}{S_E^2} = 1.50 \)

3. Reject \( H_0 \) if:

\( F(450, 3465) > F(.05, 450, 3465) \)

4. Since:

\( F(450, 3465) = 1.50 > F(.05, 450, 3465) = 1.19 \)

we conclude that there is a slight interaction effect between the subject and cell treatment effects. Reducing the alpha level to 0.01 near tabled values of 1.0, does not alter the interaction effect.

**Subject Block Effect.**—Although there is a slight interaction effect, the anticipated subject effect was two orders of magnitude greater. The test for subject effects is:

1. \( H_0: \sigma_B^2 = 0 \)

\( H_1: \sigma_B^2 \neq 0 \)
2. Test Statistic: \[ F(30, 3465) = \frac{S_R^2}{S_E^2} \]

3. Reject \( H_0 \) if:

\[ F(30, 3465) > F(.05, 30, 3465) \]

4. Since:

\[ F(30, 3465) = 63.28 > F(.05, 30, 3465) = 1.51 \]

we conclude that there is a highly significant subject effect, as was expected. As in the test for interaction, reduction of the alpha level does not increase the tabled value of \( F \) by more than a few tenths.

**Replication Effect.** - The replication effect was included to further reduce the error variance and indicate any differences among the eight independent replicates for each sequence of cell treatments. The test for replication is:

1. \( H_0: \sigma_R^2 = 0 \)

\( H_1: \sigma_R^2 \neq 0 \)

2. Test Statistic: \[ F(7, 3465) = \frac{S_R^2}{S_E^2} \]

3. Reject \( H_0 \) if:

\[ F(7, 3465) > F(.05, 7, 3465) \]
4. Since:

\[ F(7, 3465) = 3.15 > F(.05, 7, 3465) = 2.05 \]

we conclude that a slight replication effect exists. This effect is believed to be due to learning and fatigue factors, where the test run required ten to fifteen minutes of concentration. Reducing the alpha level to 0.01 for \( F = 2.70 \), results in the same conclusion.

**Cell Treatment Effect.**—The most interesting effect was the speed differences among different cell locations. The significant test for cell treatments is:

1. \( H_0: T_1 = T_2 = \ldots T_j = \ldots T_r = 0 \)

   \( H_1: \) Not all zero

2. Test Statistic: \( F(15, 450) = \frac{S_T^2}{S_T^2} \)

3. Reject \( H_0 \) if:

   \[ F(15, 450) > F(.05, 15, 450) \]

4. Since:

   \[ F(15, 450) = 8.56 > F(.05, 15, 450) = 1.71 \]

we conclude that there are strong differences among at least two of the cell treatment means. Again, reducing alpha
to the 0.01 level does not alter the results since the tabled value of $F$ increases only to 2.11. This result was analyzed by a comparison test among the treatment means.

Comparisons on Cell-Treatment Means

The determination of quickest subject speeds, as a function of cell location within the matrix, was of an exploratory nature and trends of those comparisons which might be of interest were not available prior to the collection and analysis of the data. Accordingly, Scheffe's test for comparisons was used in order to avoid the statistical restriction that relevant comparisons should be selected in advance of any data analysis. Scheffe's test for comparisons on the treatment means (Edwards, 1968) computes a standard error for the $p$th comparison as:

$$S_p = \sqrt{\frac{S_E^2}{n} \sum a_p^2}$$

where $S_E^2$ is the error mean square of the analysis of variance; $n$ is the number of observations for each mean and $a_p$ is a coefficient factor for the $p$th comparison where:

$$\sum a_p = 0$$

The test of significance is given by:
where \( d_p \) is the weighted comparison factor for the \( p \)th comparison and is computed from:

\[
d_p = \sum C_{ij} a_p
\]

for given \( C_{ij} \) cell location means. The computed value of \( t \) can then be evaluated by comparing it with the square root of \( F' \) computed from:

\[
F' = (j - 1)F
\]

where \( F' \) is \((j - 1)\) times the tabled value of \( F \) for the cell treatment degrees of freedom and the error degrees of freedom. In this experiment we have \( S_E^2 = 0.67 \) with 3465 D.O.F., and \( j = 16 \) cell means. The tabled value of \( F \) is:

\[
F_{0.05, 15, 3465} = 1.71
\]

and \( F' \) becomes:

\[
F' = (15)(1.71) = 25.65
\]
Hence, to be judged significant, the computed $t$ must be equal or greater than

$$ t = \sqrt{F'} = \pm 5.06 $$

The analysis of the treatment mean comparisons resulted in several significant comparison trends, which are presented in the following sections. Reducing the alpha level to 0.01 gives a $t$ value of 5.72, which does not alter the significant comparisons to any large degree. The figures accompanying these discussion sections show the mean time response matrix and illustrate the faster response cells by solid link construction and the significantly slower comparisons by dotted lines. Cell location designations are given by the matrix notation:

$$
\begin{array}{cccc}
  C_{11} & C_{12} & C_{13} & C_{14} \\
  C_{21} & C_{22} & C_{23} & C_{24} \\
  C_{31} & C_{32} & C_{33} & C_{34} \\
  C_{41} & C_{42} & C_{43} & C_{44} \\
\end{array}
$$

consisting of four horizontal rows and four vertical columns.
Single Comparisons.—Figure 6 shows the significant single cell comparisons for the two cells having the minimum response times. Cell location $C_{14}$ in the upper right corner of the matrix had the fastest response time at 2.2 sec. The next fastest response time was for cell location $C_{44}$ in the lower right hand corner at 2.3 sec. These two dominant faster speeds are believed due, in part, to the large word "operational", which appeared over the right most column, as compared to smaller words over the other columns, and served in effect as a focus to readily identify these two cell locations with the top and bottom row headings. Cell by cell comparisons with $C_{14} = 2.2$ sec are shown in figure 6a, where significant individual comparisons to $C_{14}$ are enclosed by the dashed circles. Likewise, figure 6b shows significant individual comparisons with cell location $C_{44} = 2.3$ sec.

Multiple Comparisons.—For multiple comparisons, groups of cells are compared to other cell groupings. Figure 7 illustrates that the two, grouped, minimum response time cells, $C_{14}$ and $C_{44}$, are significantly faster than the remaining fourteen cells taken as a group. Figure 8 illustrates that response to cell $C_{14}$ is significantly faster than the three other grouped cells of the top row. Similar comparisons among the other rows were not significant.

Row Comparisons.—Significant row to row comparisons are shown in figure 9 where the response to the top row of the display matrix is faster than either row 2 or row 3. The faster response time mean of cell $C_{44}$ results in no significant speed differences between the top row and row 4.
Column Comparisons.—Figure 10 illustrates that column 4 response, at the far right of the matrix, is significantly faster than each of the other three columns, taken separately. Also, the grouped speed of column 4 was significantly faster than the remaining cells, grouped collectively.
Figure 6. Significant Single Cell Comparisons with the Minimum Response Time Cells, $C_{14}$ and $C_{44}$
Figure 7.- Significant Comparison of Cells, C\textsubscript{14} and C\textsubscript{44}, to Grouped Remaining Cells

\[ \sum a_p^2 = 112 \quad \mu_p = 0.550 \quad d_p = 5.4 \quad t = 9.82 \]

Figure 8.- Significant Comparison of Cell C\textsubscript{14} to Other Grouped Cells of Top Row

\[ \sum a_p^2 = 12 \quad \mu_p = 0.180 \quad d_p = 1.0 \quad t = 5.55 \]
### (a) Top Row versus 2nd Row

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>2.5</td>
<td>2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
<td>2.6</td>
</tr>
<tr>
<td>2.8</td>
<td>2.8</td>
<td>2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>2.5</td>
<td>2.5</td>
<td>2.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>

\[ \sum a_p^2 = 8 \quad S_p = 0.147 \quad d_p = 0.9 \quad t = 6.12 \]

### (b) Top Row versus 3rd Row

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>2.5</td>
<td>2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
<td>2.6</td>
</tr>
<tr>
<td>2.8</td>
<td>2.8</td>
<td>2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>2.5</td>
<td>2.5</td>
<td>2.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>

\[ \sum a_p^2 = 8 \quad S_p = 0.147 \quad d_p = 1.1 \quad t = 7.48 \]

---

**Figure 9.** Significant Comparisons of Top Row to Row 2 and Row 3
Figure 10.— Significant Comparisons of Column 4 to Column 3, Column 2 and Column 1.
X. CONCLUDING REMARKS

This study utilized a computer-driven, cathode-ray-tube graphic display in a real-time information processing task. For this stimulus/response hardware arrangement, response speed differences, as a function of cell locations within the display matrix, were significant. Comparisons among the treatment means identified several significant minimum response time cell patterns. Responses were fastest, on either a cell-by-cell or grouped comparison, to the uppermost right cell and the lowermost right cell. These speed differences, in part, supported the other dominant trend, that the top row and last column, taken as groups, were significantly faster than the other rows (excluding row 4) and columns. These results are most likely due to the combined effects of scanning/memory patterns and word stimulus recognition. However, the important fact is that an optimum arrangement of matrix stimulus design could be designed for specific applications, to benefit from these types of speed differences among the matrix cells. Also, for design methods, a combined reaction and movement time of 2.6 sec for this typical matrix display/keyed response task, serves as a lower bound on baseline timeline requirements, prior to application testing involving skilled decision making and computer processing times. These summary observations also may be considered to apply for a general class of display operators because of the diverse sampling populations.
XI. BIBLIOGRAPHY


34. Schrenk, L. P.: Objective difficulty and input history as factors in sequential decision making. *Human Factors*, 1964, 6(2), 49-55.


APPENDIX A

SUBJECT INSTRUCTIONS FOR INFORMATION PROCESSING TASK

1. These are the complete instructions that are required for you to perform a sequential information processing task.

2. Ask the experimenter to clarify any instructions not clear to you, but otherwise, do not communicate with anyone.

3. From the viewing port, note the 4 x 4 matrix on the display screen. There are a total of 16 cells in which one of four numbers, 1, 2, 3, or 4 appear in each cell.

4. A signal instruction also requires your attention and is displayed under the display matrix as:

   CODE____________ PRIMARY____________ BACKUP____________

   CODE will identify the sequence of signal instructions starting at 001 and finishing at 128, but will not require your attention.

   PRIMARY identifies one of four current status modes of the primary system, and these four modes are listed on the display as ACCEPTABLE, CAUTION, CRITICAL and FAILED.

   BACKUP identifies one of four current status modes of the redundant system, and these four modes are listed on the display as STATIC, STANDBY, ACTIVE and OPERATIONAL.
5. Your initial task is to scan the signal instruction for a specific combination of the PRIMARY and BACKUP modes, and then refer to the appropriate row and column of the display matrix to identify what number is in that cell location. The task is completed by pressing and releasing one of the four response keys on the red panel to your right. Note: Release the Key immediately after pressing!

For example: If a signal instruction appears as:

```
CODE 048 PRIMARY CAUTION BACKUP STANDBY
```

then you select the number appearing in the CAUTION row and STANDBY column, and then depress the response key corresponding to the number in that cell location. For instance if the number 3 was in that cell location then you would select key 3 as your response.

6. Pressing one of the four response keys sends your number selection to the computer, and serves to measure the elapsed time between the appearance of the display matrix and your response.

7. The task contains 128 signal instructions; and both the four response numbers and the matrix cell locations are assigned at random. The task will take about 10 minutes of concentration.
8. If you make an error in your response selection, then the signal instruction will be repeated and the word ERROR will appear, blinking just above the signal instruction. You must then make another selection and continue the run.

9. The speed of your response is the primary variable measured. Errors only slow down your overall speed. In brief, then, make the correct selection, but, make it quick.

10. The first run is for practice to familiarize you with the apparatus, and contains only 16 signal instructions. The second run will be used in the statistical analysis and will contain 128 signal instructions. When you complete the test run (approximately two minutes), the sequence will stop and the experimenter will set-up the second and measured run.

11. Your task instructions are complete. The experiment and clock starts when you depress the green PRESS TO START key (located on the panel below the four response keys).
APPENDIX B

COMPUTER PROGRAM FOR ANALYSIS OF DATA

PROGRAM BARF (INPUT, OUTPUT, TAPE 5=INPUT, TAPE 6=OUTPUT)
DIMENSION Y(50,16,8), YARSLB(50), YBARCEL(16), NCLM(50),
YMEAN(1(50,16),NRRUN(50),YBARREP(8)
REAL KLRT

C *** READ TOTAL NUMBER OF SUBJECTS
READ(5,1) NSUB
JLIW=16
KLIM=8
1 FORMAT(12)
IF(NSUB.GT.50) GO TO 99

C *** READ IN DATA
DO 2 I=1,NSUB
READ(5,3) NUMSUB,NRUN
2 CONTINUE

C *** ASSIGN DUMMY NUMBERS TO SUBJECTS
NDUM(I)=NLMSUB
NRUNN(I)=NRRUN
READ(5,4) ((Y(I,J,K),J=1,16),K=1,8)
4 FORMAT(16F5.1)
2 CONTINUE

C *** COMPUTE MEAN COVER ALL SUBJECTS
YBARTOT=0.
DO 5 I=1,NSUB
DO 5 J=1,JLIM
DO 5 K=1,KLIM
5 YBARTC1=YBARTC1+Y(I,J,K)
YBARTOT=YBARTOT/NSUBJLIMKLIM

C *** COMPUTE MEAN FOR EACH SUBJECT
YBARSU(1)=0.
DO 6 J=1,JLIM
DO 6 K=1,KLIM
6 YBARSU(1)=YBARSU(1)+Y(I,J,K)
7 YBARSUB(I)=YBARSUB(I)/JLIMKLIM

C *** COMPUTE CELL TREATMENT MEANS COVER ALL SUBJECTS
DO 8 J=1,JLIM
YBARCEL(J)=0.
8 DO 8 I=1,NSUB

54
DO 8 K=1,KLIM
  8 YBARCEL(J)=YBARCEL(J)+Y(I,J,K)
DO 9 J=1,JLIM
  9 YBARCEL(J)=YBARCEL(J)/(NSL*KLIM)
C   ** COMPUTE REPLICATION MEAN
DO 20 K=1,KLIM
  20 YBARREP(K)=0.
DO 20 I=1,NSUB
  20 J=1,JLIM
  20 YBARREP(K)=YBARREP(K)+Y(I,J,K)
DO 21 K=1,KLIM
  21 YBARREP(K)=YBARREP(K)/(NSL*JLIM)
C
C   *** COMPUTE ERROR MEAN
DO 11 I=1,NSUB
  11 J=1,JLIM
  11 YERMEAN(I,J)=0.
DO 12 K=1,KLIM
  12 YERMEAN(I,J)=YERMEAN(I,J)+Y(I,J,K)
  11 YERMEAN(I,J)=YERMEAN(I,J)/KLIM
C
C   *** COMPUTE TOTAL SUM OF SQUARES
TSS=0.
  TSS3=0.
  TSS4=0.
DO 10 I=1,NSUB
  10 J=1,JLIM
  10 K=1,KLIM
  YNOW=Y(I,J,K)-YBARTOT
  TSS=TSS+YNOW*YNOW
  TSS3=TSS3+YNOW**3
  10 TSS4=TSS4+YNOW**4
C
C   *** COMPUTE CELL TREATMENT SUM OF SQUARES
SSC=0.
DO 13 J=1,JLIM
  13 YNOW=YEARCEL(J)-YBARTOT
  13 SSC=SSC+YNOW*YNOW
SSC=SSC*NSUB*KLIM
C
C   *** COMPUTE SUM OF SQUARES FOR SUBJECT BLOCKS
SSS=0.
DO 14 I=1,NSUB
  14 YNOW=YEARSUB(I)-YBARTOT
  14 SSS=SSS+YNOW*YNOW
SSS=JLIM*KLIM*SSS
C
C   *** COMPUTE REPLICATION SUM OF SQUARES
SSR=0.
DO 22 K=1,KLIM
YNOW=YEARREP(K)-YBARTCT
22 SSR=SSR+YNOW*YNOW
SSR=SSR*JLIM*KLIM

C *** COMPUTE ERROR SUM OF SQUARES
SSF=0.
DO 15 I=1,NSUB
DO 15 J=1,JLIM
DO 15 K=1,KLIM
YNOW=Y(I,J,K)-YERMEAN(I,J)-YBARREP(K)+YBARTCT
15 SSF=SSF+YNOW*YNOW

C *** COMPUTE INTERACTION SUM OF SQUARES
SSI=SSS-SSC-SSS-SSE-SSR

C COMPUTE STANDARD DEVIATION
DENM=NSUB*JLIM*KLIM
SDNOW=TSS/DENM
STODEV=SORT(1,SDNOW)

C COMPUTE SKEWNESS
SKEW=(TSS3/DENM)/(SDNOW*STODEV)

C COMPUTE KURTOSIS
KUR=((TSS4/DENM)/(SDNOW*STODEV))**3.

C *** COMPUTE MEAN SQUARES
TMINUS 1=NSUB-1
RMINUS 1=JLIM-1
SMINUS 1=KLIM-1
SSUBS2=SSS/TMINUS 1
SSUAC2=SSC/RMINUS 1
SSUBR2=SSR/SMinus 1
RTMIN1=TMINUS 1*RMINUS 1
SSUBL2=SSI/RTMIN1
RTSTOT=(NSUB*JLIM-1)*(KLIM-1)
SSUBF2=SSE/RTSTOT
RTSMIN1=(NSUB*JLIM*KLIM-1)

C *** COMPUTE SCHEFFE COMPARISONS
SUMASC=2.
SDI=SORT(1,SSUBF2*SUMASC)/(NSUB*KLIM))
DI1=.6
DI2=.5
DI3=.4
TI1=DI1/SDI
TI2=DI2/SDI
TI3=DI3/SDI
C
C *** COMPUTE F-RATIOS
FRSLB=SSUBS2/SSUBE2
FRCEL=SSUBC2/SSUIC2
FRREP=SSUBR2/SSUBE2
FRINT=SSUBI2/SSUBE2
C
WRITE(6,200)
200 FORMAT(1H1,6X*SCUPCE*11X*C.C.F.*6X*SS*1CX*MS*6X*
F-TWO-way*///)
WRITE(6,201) TMINUS 1,SSS,SSUBS2,FRSUB
201 FORMAT(1X*SUBJECT BLCKS*1X,F12.0,3F12.2/) WRITE(6,202) RMINUS 1,SSC,SSUBC2,FRCEL
202 FORMAT(1X*CELL TREATMENTS*F12.0,3F12.2/) WRITE(6,213) SMINUS 1,SSR,SSUBR2,FRREP
213 FORMAT(1X*REPLICATIONS*4X,F12.0,3F12.2/) WRITE(6,203) RIMIN1,SSI,SSLE12,FRINT
203 FORMAT(1X*SUBJECTS X CELL*F12.0,3F12.2/) WRITE(6,204) RISTOT,SSE,SSLBF2
204 FORMAT(1X*ERROR*10X,F12.0,2F12.2/) WRITE(6,210) RTSMIN1,TSS
210 FORMAT(1X*TOTAL*10X,F12.0,2F12.2/) WRITE(6,205) YEARTOT,STDEV,SKEW,KURT
205 FORMAT(1X*TOTAL-MEAN=*F5.1,5X*SIGMA=*F6.2,5X*SKEW=*F6.3,5X*KURT=*F6.1//)
WRITE(6,214) TI1,TI2,TI3
214 FORMAT(1X*FCR .6=*F5.2,5X*T FOR .5=*F5.2,5X*T FC
.4=*F5.2//)
WRITE(6,211)
211 FORMAT(1X*OVERALL CELL MEANS*/)
WRITE(6,212) YEARCEL
212 FORMAT(10X,4FE.1/) WRITE(6,206)
206 FORMAT(1X*OVERALL SUBJECT MEANS*/) DO 209 I=1,NSUB
WRITE(6,207) NCLM(I), NFUN(L), YBARSUB(I)
207 FORMAT(5X,I3-*I2,F6.1)
209 CONTINUE GO TO 100
99 WRITE (6,208)
208 FORMAT (1X*TOC MANY SUBJECTS SUBMITTED*/) 100 CONTINUE END
APPENDIX C

COMPUTER PROGRAM FOR REAL-TIME SIMULATION

PROGRAM EXECUTIVE

OVERLAY(OLFILE,0,0)
PROGRAM INFO(INPUT=201,CLTPUT=201,PUNCH)
COMMON/REALTIM/ANALGIN(32),DIGOUT(64),LDISI(108),LDISO(196),
1 NOPER,NHOLD,NRESET,ATERM,NPRINT,NREAD
COMMON/VARBLK/VAR(20),INTEG(5),LOGIC(5),IVALBUF(5),VARCHNG
COMMON/DSPL/NVAR,NINTEG,NLOGIC,NALGIN,NDIGOUT,NLDISI,NLDISO
COMMON/INTBUF/TGSSW(15),MCMSSW(11),EXECFLA
COMMON/EXTRA/VIPL,ISL
COMMON/STIM/ISTIM(128),IMIS(128),IREAD
COMMON/PTOUT/LEM(128),[AN(128),NITER,NRUN
COMMON/Disp/NMIN,SMALL,MED,LAR,IBLINK,IONCE
COMMON/ALPHA/ALPH(45),XRRC(4),YRRC(4)
LOGICAL EXECFLA,TGSSW,MCMSSW,VARCHNG,LDISI,LDISO,LOGIC
EQUIVALENCE (INTEG(1),ISCAN), (INTEG(2),ITYPE)
EQUIVALENCE (LDISI(48),INTABS)
96C34 FFORMAT(6x* INFC-R.G.KYLE *5x*JOB,43,77777,75000. A3112,
113544.1, R.W.WILL R2142*)
OLFILE=6LOFILE
CALL NAMECRT(6LCRTTP,FRR)
CALL PRIMARY(CLFILE,PF,9C34S,LOISI,ISLO,TGSSW,MCMSSW,EXECFLA)
RAND

SIMULATION INITIALIZATION

OVERLAY(OLFILE,1,0)
PROGRAM AINIT
COMMON/REALTIM/ANALGIN(32),DIGOUT(64),LDISI(108),LDISO(196),
1 NOPER,NHOLD,NRESET,ATERM,NPRINT,NREAD
COMMON/VARBLK/VAR(20),INTEG(5),LOGIC(5),IVALBUF(5),VARCHNG
COMMON/DSPL/NVAR,NINTEG,NLOGIC,NALGIN,NDIGOUT,NLDISI,NLDISO
COMMON/INTBUF/TGSSW(15),MCMSSW(11),EXECFLA
COMMON/EXTRA/VIPL,ISL
COMMON/STIM/ISTIM(128),IMIS(128),IREAD
COMMON/PTOUT/LEM(128),[AN(128),NITER,NRUN
COMMON/Disp/NMIN,SMALL,MED,LAR,IBLINK,IONCE
COMMON/ALPHA/ALPH(45),XRRC(4),YRRC(4)
LOGICAL EXECFLA,TGSSW,MCMSSW,VARCHNG,LDISI,LDISO,LOGIC
EQUIVALENCE (INTEG(1),ISCAN), (INTEG(2),ITYPE)
EQUIVALENCE (LDISI(48),INTABS)
EQUIVALENCE (VAR(1),DELAY)
EQUIVALENCE (VAR(2),SCT)
EQUIVALENCE (VAR(3),ALIM)
EQUIVALENCE (VAR(4),SUBJECT)
EQUIVALENCE (VAR(5),RUNNC),(VAR(6),RESTIME)
CALL INOUT(ANALGIN,32,DIGOUT,64,LDISI,60,LDISC,18C)
ISCAN=32
NVAP=20
NINTEG=5
NLOGIC=5
NALGIN=32
NDIGOUT=64
NLDISI=108
NLDISC=196
CALL DATABLX(VAR, NVAR, INTEG, NINTEG, LOGIC, NLOGIC, ANALGIN, NALGIN, DIGOUT, NOTDIGOUT, LDISI, NLDISI, LDISO, NLDISO)
NT=1
CALL NM218(5LOSCAR)
CALL XDSPLAY(LDISI, LDISC, VARCHNG, ITYPE, IVARBUF, INTABS)
DO 95 IND=1,196
85 LDISO(IND)=.F.
DO 86 IND=1,108
86 LDISI(IND)=.F.
DO 87 IND=1,11
87 TGSSW(IND)=.F.
DO 88 IND=1,11
88 MOV;SW(IND)=.F.
EXECFLA=.F.
CALL CRTNAM(4HINFO,0,0,5HINIT,1,0)
CALL CRTNAM(7HAOUTPUT,2,0,6HINPUT,3,0)
CALL CRTNAM(6HRTMAIN,4,C,0)
ALIM=128.
ALPH(1)=4RXHAC
ALPH(2)=4RXKUP
ALPH(3)=4RX M
ALPH(4)=4RXODE
ALPH(5)=4RXSTA
ALPH(6)=4RXTIC
ALPH(7)=4RXSTA
ALPH(8)=4RXNDB
ALPH(9)=4RXY
ALPH(10)=4RXACT
ALPH(11)=4RXIVE
ALPH(12)=4RXSPE
ALPH(13)=4RXMAT
ALPH(14)=4RXINC
ALPH(15)=4RXAL
ALPH(16)=4RXACC
ALPH(17)=4RXEPT
ALPH(18)=4RXABL
ALPH(19)=4RXE
ALPH(20)=4RXCAU
ALPH(21)=4RXTIO
ALPH(22)=4RXN
ALPH(23)=4RXFAI
ALPH(24)=4RXLED
ALPH(25)=4RXPRI
ALPH(26)=4RXMAR
ALPH(27)=4RX C
ALPH(28)=4RXERP
ALPH(29)=4RXOR
ALPH(30)=4RXAKN
ALPH(31)=4RXSBY
ALPH(32)=4RXOPR
ALPH(33)=4RXCR1
ALPH(34)=4RXTIC
ALPH(35)=4RXAL
ALPH(36)=4RX
ALPH(37)=4RXEXE
ALPH(38)=4RXKCI
60

\[
\begin{align*}
\text{ALPH}(39) &= 4RXSE \\
\text{ALPH}(40) &= 4RXCOM \\
\text{ALPH}(41) &= 4RXPLE \\
\text{ALPH}(42) &= 4RXTE \\
\text{ALPH}(43) &= 4RXTHA \\
\text{ALPH}(44) &= 4RXNK \\
\text{ALPH}(45) &= 4RXYOU \\
\text{XRRC}(1) &= 350. \\
\text{XRRC}(2) &= 475. \\
\text{XRRC}(3) &= 600. \\
\text{XRRC}(4) &= 725. \\
\text{YRRC}(1) &= 715. \\
\text{YRRC}(2) &= 590. \\
\text{YRRC}(3) &= 465. \\
\text{YRRC}(4) &= 340. \\
\text{DG} &= 69. \text{ J} = 1.129. \\
\text{ISTIM}(J) &= 11 \\
\text{IMIS}(J) &= 0 \\
\text{IAN}(J) &= 0 \\
\text{ILEV}(J) &= 0 \\
\text{IREAD} &= 0 \\
\text{NITER} &= 32 \\
\text{SCT} &= 8. \\
\text{SUBJECT} &= 1. \\
\text{RUNNO} &= 1. \\
\text{MINI} &= \text{ISETS}(0.0, 0.0) \\
\text{SMALL} &= \text{ISETS}(1.0, 0.0) \\
\text{MED} &= \text{ISETS}(2.0, 0.0) \\
\text{LAR} &= \text{ISETS}(3.0, 0.0) \\
\text{IBLINK} &= \text{ISETS}(2.0, 1) \\
\text{IGNCE} &= 10 \\
\text{DELAY} &= 0. \\
\text{NRUN} &= 0 \\
\text{IFL} &= 4 \\
\text{ISL} &= 0 \\
\text{RETURN} &
\end{align*}
\]

\text{END}

\text{OUTPUT PRINTEROUT}

\text{OVERLAY(CLFILE,2,0)}

\text{PROGRAM AOUTPUT}

\text{TOSW(6)} \quad \text{RELEASE}

\text{TOSW(11)} \quad \text{STORE DATA ON TAPE}

\text{COMMON/REALTIM/ANALGIM(32), DIGCUT(64), LDISI(108), LDISO(196),}

\text{1 NOPER, NHOLD, NRESET, NTERF, NPRINT, NREAD}

\text{COMMON/VARBLK/VAR(20), INTEG(5), LOGIC(5), IVARBUF(5), VARCHNG}

\text{COMMCM/INTBUF/TOGSw(15), MUMSw(11), EXECFLA}

\text{COMMCM/EXTRA/MF, IPL, SSL}

\text{COMMCM/STIM/STIM(128), IMIS(128), IREAD}

\text{COMMCM/PTCLT/LEM(128), IAN(128), NITER, NRUN}

\text{COMMON/DISP/MINI, ISMALL, MED, LAR, IBLINK, IGNCE}
L3GICAL EXECFLA, TOGSH, MCMSw, VARCHNG, LOISIL, LDISO, LOGIC
EQUIVALENCE (INTEG(1), ISCAN), (INTEG(2), IYPE)
EQUIVALENCE (VAR(2), S1CT)
EQUIVALENCE (VAR(3), AL1M)
EQUIVALENCE (VAR(4), SUBJECT)
EQUIVALENCE (VAR(5), RUNNC), (VAR(6), RESTIME)
DIMENSION A(44), B(10), C(10)
DIMENSION COUNT(32)
DIMENSION RESULT(2)
DIMENSION AMN(10), VA(1C)
DIMENSION AMN(16,8)
DIMENSION AERR(16,8), IEK(16)
DIMENSION ATOT(16)

C

LIM=ALIM
IF (LIM .LT. 100) GO TO 13
ISUB=SUBJECT
NRUN=RUNNO
IF (ISUB .GT. 99) ISUB=99
IF (NPUN .GT. 99) NRUN=99
CALL CAYTIM (RESULT)
WRITE (MF,7)
WRITE (MF,8) RESULT, NPUN, ISUB
IF (SCT .GT. 9.9) SCT=9.9
XX=3H E

DG 52 I=1,10
23 AMN(I)=VA(I)=0.
DG 540 I=1,16
DG 54C J=1,8
540 AERR(I,J)=3H
DG 541 I=1,16
541 IEK(I)=1
DG 10 I=1,44
10 A(I)=3H
B(1)=3H 1
B(2)=3H 2
B(3)=3H 3
B(4)=3H 4
B(5)=3H 5
B(6)=3H 6
B(7)=3H 7
B(8)=3H 8
B(9)=3H 9
B(10)=3H 0
C(1)=3H 1
C(2)=3H 2
C(3)=3H 3
C(4)=3H 4
C(5)=3H 5
C(6)=3H 6
C(7)=3H 7
C(8)=3H 8
C(9)=3H 9
C(10)=3H 0
DISTR=3H I
AN1TER=N1TER
ID=0
ANAX=SIGMAX=0.
LISP=C
DO 2010 J=1,LIM
LISP=LISP+LEM(J)
DISPL=LISP/ANITER
WRITE(MF,2011) DISPL
IRCT=0
DO 20CO I=1,16
DO 20CO J=1,8
2000 AMEN(I,J)=0.
2000 J=1,LIM
AL=10.*LEM(J)/ANITER
ILL=AL
AL=AL-ILL
IF(AL .GE. 5) ILL=ILL+1
AL=1.*ILL
IRK=ISTIM(J)-10
IF(IRK .GT. 10) IRK=IRK-6
IF(IRK .GE. 15) IRK=IRK-6
IF(IRK .GT. 15) IRK=IRK-6
INK=1
2002 IF(AMEN(IRK,INK) .EQ. 0) GC TO 2001
INK=INK+1
GO TO 2002
2001 AMEN(IRK,INK)=AL
IF(IMIS(J) .LT. 1) GC TO 1999
ISS=IEK(IRK)
IEK(IRK)=IEK(IRK)+1
AERR(IRK,ISS)=B(IINK)
1999 CONTINUE
WRITE(MF,2003)
WRITE(MF,2004) (J,(AMEN(I,J),I=1,16),J=1,8)
2005 ATOT(I)=0.
DG 20C5 I=1,16
ATOT(I)=ATOT(I)+AMEN(I,J)
2002 ATOT(I)=ATOT(I)*.125
WRITE(MF,2006) ATOT
WRITE(MF,2C18)
WRITE(MF,2019) AERR
55 IRCT=IRCT+1
C **** STATISTICAL ANALYSIS
DG 16 J=1,32
16 COUNT(J)=0.0
ISAMP=0
DDEL=SCT/32.
ERCT=G
DG 3 J=1,LIM
IF(IRCT .GT. 1 .AND. IAN(J) .NE. ID) GO TO 3
IF(ILEP(J) .EQ. 0) GO TO 3
ERCT=ERCT+IMIS(J)
DEL=LEM(J)/ANITER
ICTDT=1
BASE=16.*DDEL
IF(DEL .LT. BASE) GO TO 531
ICTDT=ICTDT + 16
BASE=16.*DDEL + BASE
531 BASE=BASE - 9.*DDEL
   IF (DEL .LT. BASE) GO TO 532
   ICTDT=ICTDT+8
   BASE=BASE+3.*DDEL
532 BASE=BASE-4.*DDEL
   IF (DEL .LT. BASE) GO TO 533
   ICTDT=ICTDT+4
   BASE=BASE + 4.*DDEL
533 BASE=BASE - 2.*DDEL
   IF (DEL .LT. BASE) GO TO 534
   ICTDT=ICTDT+2
   BASE=BASE + 2.*DDEL
534 BASE=BASE - DDEL
   IF (DEL .LT. BASE) GO TO 535
   ICTDT=ICTDT+1
535 CCOUNT (ICTDT) = COUNT (ICTDT) + 1.
   ISAMP = ISAMP + 1
   CONTINUE
   IF (ISAMP .EQ. 0) GO TO 2122
   BASE = .5*DDEL
   XTRA = 0.
   DO 4 I = 1, 32
   XTRA = XTRA + CCOUNT(I)*BASE
4 BASE = BASE + DEL
   AMEAN = XTRA/ISAMP
   BASE = .5*DDEL
   XTRA = 0.
   ZTRA = 0.
   LTRA = 0.
   DO 5 I = 1, 32
   YTRA = BASE - AMEAN
   XTRA = XTRA + CCOUNT(I)*YTRA*YTRA
   ZTRA = ZTRA + CCOUNT(I)*YTRA*YTRA*YTRA
   UTRA = UTRA + CCOUNT(I)*YTRA*YTRA*YTRA*YTRA
5 BASE = BASE + DEL
   SIG = XTRA/ISAMP
   IF (IRCT .LT. 2) GO TO 212
   IF (AMEAN .GT. AMAX) AMAX = AMEAN
   IF (SIG .GT. SIGMAX) SIGMAX = SIG
   AKN (IRCT-1) = AMEAN
   WAI (IRCT-1) = SIG
212 CONTINUE
   ZIG = SQRT (SIG)
   PIG = ZIG * ZIG
   RIG = SIG * SIG
   SKW = ZTRA/(ISAMP*PIG)
   AKUR = UTRA/(ISAMP*RIG) - 3.
   WRITE (MF,66) AMEAN, SIG, ZIG, SKW, AKUR, IRCT, ISAMP
2122 CONTINUE
   BASE = -.5*DDEL
   AMXCT = 0.
64

DO 76 J=1,32

76 IF(COUNT(J) .GT. AMXCT) AMXCT=COUNT(J)

DO 77 J=1,32

77 IDIS=COUNT(J)+1

DO 766 I=1,IDIS

766 A(I)=CISTR

BASE=BASE+CDEL

IFI (IRCT .EQ. 1) WRITE(MF,22) BASE,COUNT(J),(A(K),K=1,39)

DO 767 I=1,IDIS

767 A(I)=3H

201 ID=1

WRITE(MF,2307) ID

202 ID=2

WRITE(MF,2G07) ID

203 ID=3

WRITE(MF,2307) ID

204 ID=4

WRITE(MF,2G07) ID

211 CONTINUE

ILT=0

79 ILT=ILT+1

C

******** AUTOMATIC STOP — STORE DATA(11) OR RELEASE(6)

11 CALL OPERATE

LDISO(79) = .T.

IF(NCT. MOMSW(6) .AND. NCT. MOMSW(11)) GO TO 11

LDISO(79) = .F.

IF(MOMSW(6)) GO TO 12

******** STORE DATA ON TAPE

PUNCH 777 , ISUB.NRUN

777 FORMAT(212)

PUNCH 78 , AMEN

78 FORMAT(16F5.1)

12 CONTINUE

RUNNO=RUNNO+1.

13 CONTINUE

DO 69 J=1,LIM

69 INIS(J)=0

IANT(J)=0

FORMAT(14,44A3)

DG 70 I=1,16

70 AMEN(I,J)=0.

66 FORMAT(5X*MEAN=**F5.2,5X*VAR=**F5.2,5X*SIGMA=**F5.2,5X*SKW=**F5.2,5X*

.. KURT=**F5.2,5X*ERRORS=**F5.0,5X*OCCURENCES=**14////)

7 FORMAT(111)

8 FORMAT(10X*DATE=**2A1C,10X*RUN=**15,5X*SUBJECT NO.*12//)

9 FORMAT(415)

22 FORMAT(E10.2,F5.C,39A3)
REAL TIME LOGIC

OVERLAY(OLFILe,4,0)
PROGRAM RTMAIN
COMMON/REALTIM/ANALGIN(32),CIGOUT(64),LDISI(108),LDISO(196),
       NOPER,NHOLD,NRESET,NERP,APRINT,NREAD
COMMON/VARBLK/VAR(20),INTEG(5),LOGIC(5),IVARBUF(5),VARCHNG
COMMON/INTBUFF/TGSMW(15),MGMSW(11),EXECFLA
COMMON/EXTRA/MINI,ISmall,ECAL,IBLINK,IONCE
COMMON/ALPHA/ALPH(45),XRRC(4),YRRC(4)
COMMON/STIM/ISTIM(128),ISMIS(128),IREAD
COMMON/PTOUT/LEM(128),IAN(128),NITER,NRUN
LOGICAL EXECFLA,TGSMW,MGMIS,VARCHNG,LDISI,LDISO,LOGIC
EQUIVALENCE (INTEG(1),ISCAN), (INTEG(2),ITYPE)
IF(IREAD .GT. 0) GO TO 7777
IREAD=5
READ 1 , ISTIM
IF(IREAD .GT. 0) GO TO 7777
CONTINUE
IGNCE=0
RETURN
END

```
NOPER,NHOLD,NRESET,ATERP,APRINT,NREAD
COMMON/VARBLK/VAR(20),INTEG(5),LOGIC(5),IVARBUF(5),VARCHNG
COMMON/INTBUFF/TGSMW(15),MGMSW(11),EXECFLA
COMMON/EXTRA/MINI,ISmall,ECAL,IBLINK,IONCE
COMMON/ALPHA/ALPH(45),XRRC(4),YRRC(4)
COMMON/STIM/ISTIM(128),ISMIS(128),IREAD
COMMON/PTOUT/LEM(128),IAN(128),NITER,NRUN
LOGICAL EXECFLA,TGSMW,MGMIS,VARCHNG,LDISI,LDISO,LOGIC
EQUIVALENCE (INTEG(1),ISCAN), (INTEG(2),ITYPE)
IF(IREAD .GT. 0) GO TO 7777
IREAD=5
READ 1 , ISTIM
IF(IREAD .GT. 0) GO TO 7777
CONTINUE
IGNCE=0
RETURN
END
```
LOGICAL EXECFLA, TOGSH, MCMUSW, VARCHNG, LDISH, LDISO, LOGIC
LOGICAL IERR
EQUIVALENCE (INTG(1), ISCAN), (INTG(2), ITYPE)
EQUIVALENCE (LDISH(4), INTABLS)
EQUIVALENCE (VAR(1), CELAY)
EQUIVALENCE (VAR(2), SCT)
EQUIVALENCE (VAR(3), ALIM)
EQUIVALENCE (VAR(5), RUNNC), (VAR(6), RESTIME)
EQUIVALENCE (VAR(7), STIMNO)
DIMENSION XV(7), YV(7)
DIMENSION NA(4, 4)
CALL SECOVL
CALL CYCLE(9006S)
ASSIGN 90001 TO NOPER
ASSIGN 90002 TO NMCNC
ASSIGN 90003 TO NRESET
ASSIGN 90004 TO NTERP
ASSIGN 90014 TO NPRINT
ASSIGN 90015 TO NREAD
AC=RANS(1.5)
PROB1=PROB2=PROB3=.25
CALL READY
CALL RMCDE
90003 CONTINUE
C ***** RESET LOOP
TGSWM(1)=.F.
1 IF(IONCE .EQ. 0) GO TO 110
CALL SEND
CALL HALT
IGNCE=0
CALL LNLOAD
CALL READY
110 CONTINUE
LIM=ALIM
1 IF(LIM .GT. 128) LIM=128
IGO=0
IEV=0
IDEL=DELAY*NITER
ICT=-1
ITIM=C
ISTART=0
IEND=0
ITWO=1
SAVE=C.
90002 CONTINUE
C ***** HCLD LCOP
90006 CONTINUE
C ***** OPERATE LOOP
AC=RANS(J)
C *** SCANNER FUNCTION***********
90047 LDISO(124)=LDISO(22)
1 IF(LDISH(22)) CALL SCANNER(ISCAN)
C**** COMMUNICATION WITH REAL TIME DISPLAY
CALL CSPLAY
C**** RETURN TO MODE CCNTRL SUBRCUTINE
90053 CONTINUE
```
IF (.NOT. LDIST(17)) GO TO 29
    IGNCE=10
    IF (ICT .GT. 0) GO TO 29
    GO TO (41,34,26,30), ITH0
41 CONTINUE
    IF (ICT .EQ. 0) GO TO 26
    IF (IEND .EQ. 2) GO TO 29
    IF (IEND .EQ. 1) GO TO 30
    IF (.NOT. TOGSW(1)) CR, ISTART .EQ. 1) GO TO 112
    ISTART=1
    GO TO 25
112 CONTINUE
    IF (IGC .LT. 1) GO TO 29
    IF (MOPSW(1)) GO TO 24
    IF (MOPSW(2)) GO TO 24
    IF (MOPSW(3)) GO TO 24
    IF (MOPSW(4)) GO TO 24
    GO TO 28
24 CONTINUE
    IF (MOPSW(1) .AND. IANS .EQ. 1) GO TO 25
    IF (MOPSW(2) .AND. IANS .EQ. 2) GO TO 25
    IF (MOPSW(3) .AND. IANS .EQ. 3) GO TO 25
    IF (MOPSW(4) .AND. IANS .EQ. 4) GO TO 25
    IERR=.T.
    IINS(IEV)=IINS(IEV)+1
    GO TO 34
25 CONTINUE
    IF (IGC .NE. 1) GO TO 225
    IAN(IEV)=IANS
    LEM(IEV)=ITIM
    SAVE=ITIM
225 CONTINUE
    IGO=1
    IEV=IEV+1
    IF (IEV .GT. LIM) GO TO 36
    DO 101 I=1,4
    DO 101 J=1,4
        AC=RAHF(0)
        NAA(I,J)=1
        IF (AC .GT. PROB1) NAA(I,J)=2
        IF (AC .GT. (PROB1+PRCB2)) NAA(I,J)=3
        IF (AC .GT. (PROB1+PRCB2+PRCB3)) NAA(I,J)=4
101 CONTINUE
    IFIM=.T.*ISTIM(IEV)
    ISEC=ISTIM(IEV)-1G.*IPRIP
    GO TO (2,3,4,5), IPRIP
2 NALPH=16
    NAT=4
    GO TO 5
3 NALPH=20
    NAT=3
    GO TO 6
4 NALPH=33
    NAT=3
    GO TO 6
5 NALPH=23
    NAT=2
6 GO TO (7,8,9,10), ISEC
7 JALPH=5
```
JAT=2
GO TO 11
9 JALPH=7
JAT=3
GO TO 11
9 JALPH=10
JAT=2
GO TO 11
10 JALPH=12
JAT=4

11 IANS=NAA(ISSEC,IPRIM)
IERR= .F.
CONTINUE

34 CALL ENABLE(345)
IF(ITWO .NE. 2) ITWO=12
LDISO(68)=.F. & LDISC(59)=.T.
CALL CRTCODE(1,ISMAI,0.,C)
CALL CRTCODE(1,ALPH(36),460.,150.)
CALL CRTCODE(1,ALPH(36),740.,150.)
CALL CRTCODE(1,ALPH(36),232.,150.)
IGT=ICEL+3
GO TO 27

26 CALL ENABLE(265)
IF(ITWO .NE. 3) ITWO=13
LDISO(68)=.T. & LDISC(69)=.F.
CALL CRTCODE(1,ISMAI,0.,C)
CALL CRTCODE(IAT,ALPH(36),460.,150.)
CALL CRTCODE(1,ALPH(36),740.,150.)
CALL CRTCODE(1,ALPH(36),232.,150.)
CALL CRTCODE(1,ISSEC,IPRIM)
IERR= .F.
CONTINUE

CALL VECTORS(1,XV,YV)
XV(1)=330. & XV(2)=560. & XV(3)=830.
YV(1)=YV(2)=YV(3)=305.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=425.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=555.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=675.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=705.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=830.

CALL VECTORS(1,XV,YV)
XV(1)=330. & XV(2)=560. & XV(3)=830.
YV(1)=YV(2)=YV(3)=305.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=425.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=555.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=675.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=705.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=830.
CALL VECTORS(2, XV, YV)

CALL CRTCODE(2, ALPH(25), 20, 560)

CALL CRTCODE(1, ALPH(6), 140, 560)

CALL CRTCODE(2, ALPH(2), 1C, 500)

XV(1) = 15, $ XV(2) = 16C, $ YV(1) = YV(2) = 540

CALL VECTORS(1, XV, YV)

XV(1) = 15, $ XV(2) = 130, $ YV(1) = YV(2) = 480

CALL VECTORS(1, XV, YV)

CALL CRTCODE(1, ALPH(17), 100, 150)

CALL CRTCODE(1, ALPH(4), 160, 150)

CALL CRTCODE(2, ALPH(25), 300, 150)

CALL CRTCODE(1, ALPH(5), 420, 150)

CALL CRTCODE(2, ALPH(1), 60C, 150)

XV(1) = 230, $ XV(2) = 2EC, $ YV(1) = YV(2) = 130

CALL VECTORS(1, XV, YV)

XV(1) = 45C, $ XV(2) = 575

CALL VECTORS(1, XV, YV)

XV(1) = 730, $ XV(2) = 872

CALL VECTORS(1, XV, YV)

CALL CRTCODE(1, ISMALL, 0, 0)

CALL CRTCODE(2, ALPH(5), 356, 830)

CALL CRTCODE(3, ALPH(7), 475, 830)

CALL CRTCODE(2, ALPH(1C), 60C, 830)

CALL CRTCODE(4, ALPH(12), 702, 830)

CALL CRTCODE(4, ALPH(16), 190, 725)

CALL CRTCODE(3, ALPH(20), 298, 6C0)

CALL CRTCODE(3, ALPH(23), 302, 475)

CALL CRTCODE(2, ALPH(23), 214, 350)

CALL CRTCODE(1, LAR, 0, 0)

GO TO 102

102 CALL ENCODEI(NAA(I,J), XRC(I), YRC(J))

IF(NCT, IERR) GO TO 27

CALL CRTCODE(1, IBLINK, 0, C)

CALL CRTCODE(2, ALPH(28), 500, 21C)

GO TO 27

36 IGO = 0

37 CONTINUE

CALL ENABLE(37)

CALL FAI

CALL LNLDO

CALL READY

IEND = 1

GO TO 29

30 CONTINUE

CALL ENABLE(30)

IF(IWO .NE. 4) IWO = 14

IEND = 2

CALL CRTCODE(1, LAR, 0, 0)

CALL CRTCODE(3, ALPH(37), 372, 632)

CALL CRTCODE(3, ALPH(40), 372, 468)

CALL CRTCODE(3, ALPH(43), 356, 304)

27 CONTINUE

CALL RITE250

CALL FAI

CALL CLRBUSY

CALL READY
ITWO=ITWO-10
IF(ITWO.LT.0) ITWO=1
ITIM=-1
28 ITIM=ITIM+1
29 CONTINUE
ICT=ICT-1
IF(ICT.LT.-1) ICT=-1
IF(.NOT. T0GSH(1)) ISTART=0
RESTIME=SAVE/NITER
STIMNC=IEV
CALL RTMODE
90001 CALL RECYCLE
90004 CALL ATERM
90014 CONTINUE
90015 CONTINUE
RETURN
END
XIII. VITA

The author was born on [redacted] and received his primary and secondary education in public schools in [redacted]. He attended Concord College in West Virginia for one year, before entering Virginia Polytechnic Institute where he was graduated with the degree of Bachelor of Aerospace Engineering in June 1964. He was then employed as a research engineer at NASA's Langley Research Center and through the Virginia Associated Research Center in Hampton, Virginia, received the degree of Master of Science in Aerospace Engineering from the University of Virginia in June 1969. He has remained with the National Aeronautics and Space Administration, employed in research, operational and management positions.