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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



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3285
(NASA-TM-X-68684) SPEED IN INFORMATION
PROCESSING WITH A COMPUTER DRIVEN VISUAL
DISPLAY IN A REAL-TIME DIGITAL SIMULATION
M.S. Thesis - Virginia Polytechnic Inst.
R.G. Kyle (NASA) Jun. 1972 79 P CSCL 09B G3/08
N72-28204
Unclas
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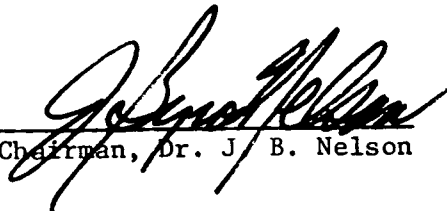
Submitted to the Graduate Faculty of the
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in partial fulfillment of the requirements for the degree of

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June 1972

Blacksburg, Virginia

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(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.

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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.

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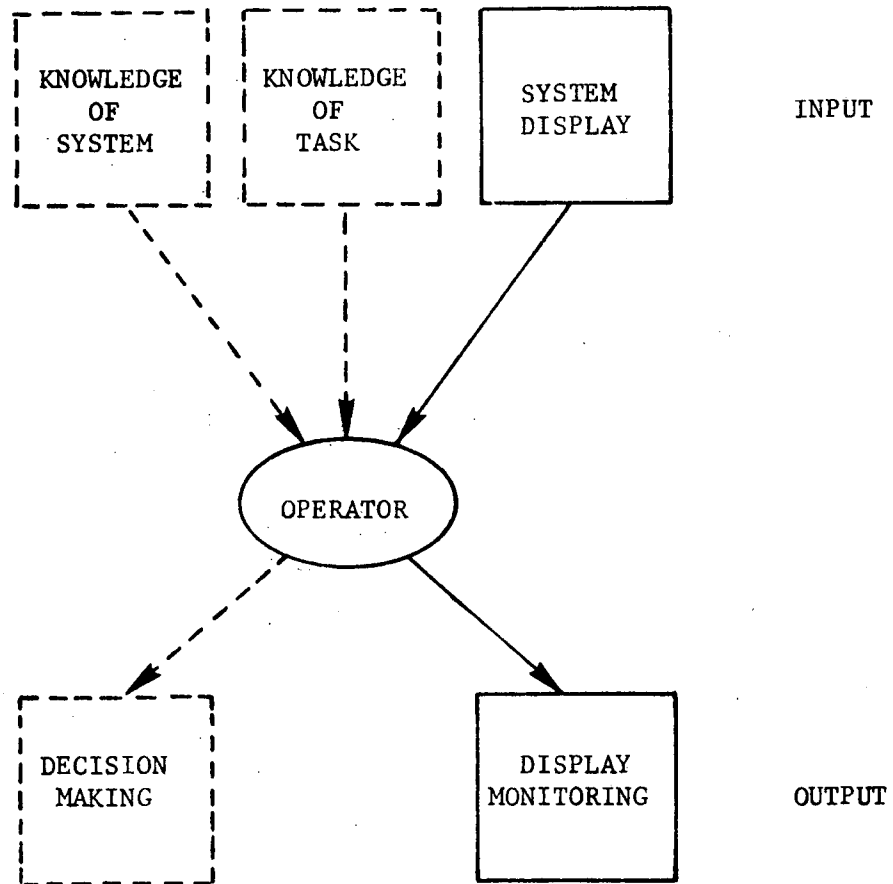
VI. INTRODUCTION

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.

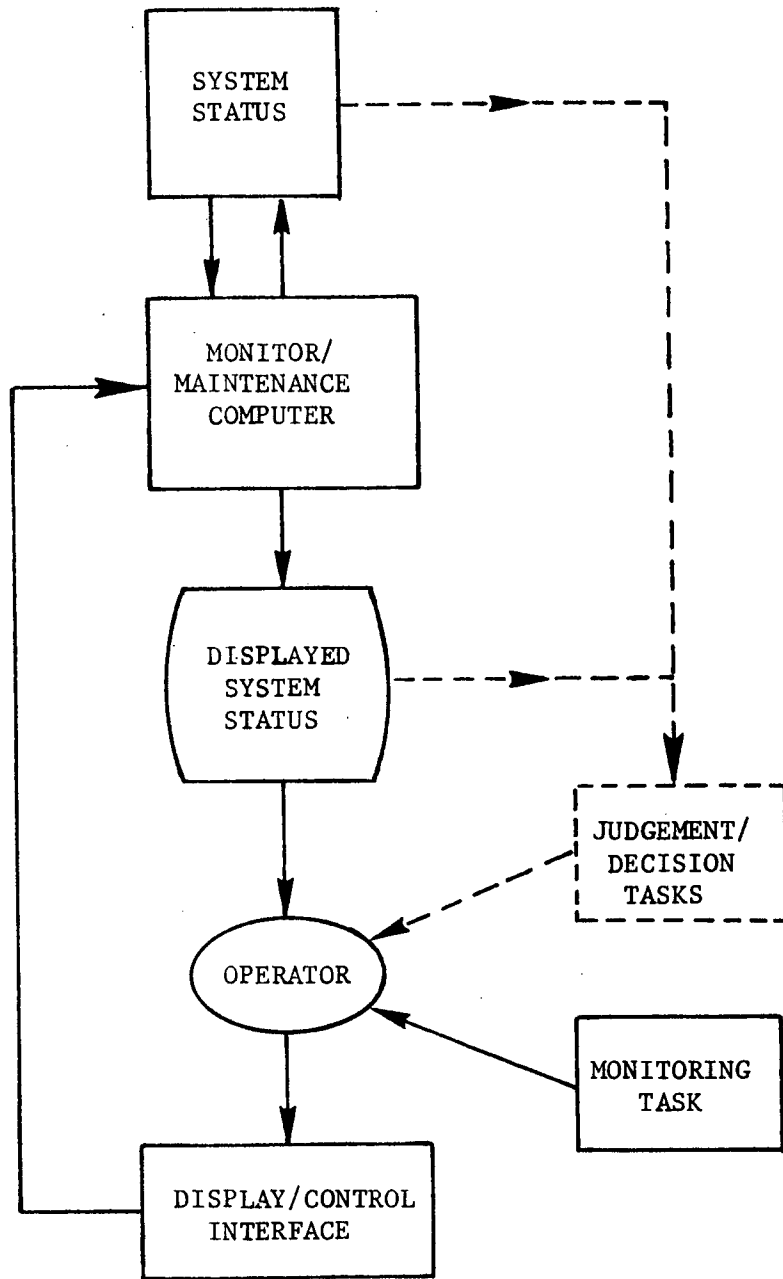
Figure 1a depicts the manual interface input/output situation where an operator is processing information from a visual display. His knowledge of the system operation and the tasks involved, together with a display system, form the input for his interface control with the system, by interacting with 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.



(a) Operator Input/Output

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 multi-channel 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

		<u>BACKUP MODE</u>			
		STATIC	STANDBY	ACTIVE	OPERATIONAL
<u>PRIMARY</u> <u>MODE</u>	ACCEPTABLE	1	3	4	1
	CAUTION	4	1	4	2
	CRITICAL	3	3	3	4
	FAILED	4	3	4	1

CODE 003 PRIMARY CAUTION BACKUP STATIC

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

BACKUP MODE

		STATIC	STANDBY	ACTIVE	OPERATIONAL
<u>PRIMARY</u> <u>MODE</u>	ACCEPTABLE	1	1	2	2
	CAUTION	2	4	2	1
	CRITICAL	1	3	3	3
	FAILED	3	2	4	2

CODE PRIMARY ACCEPTABLE BACKUP STATIC


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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.

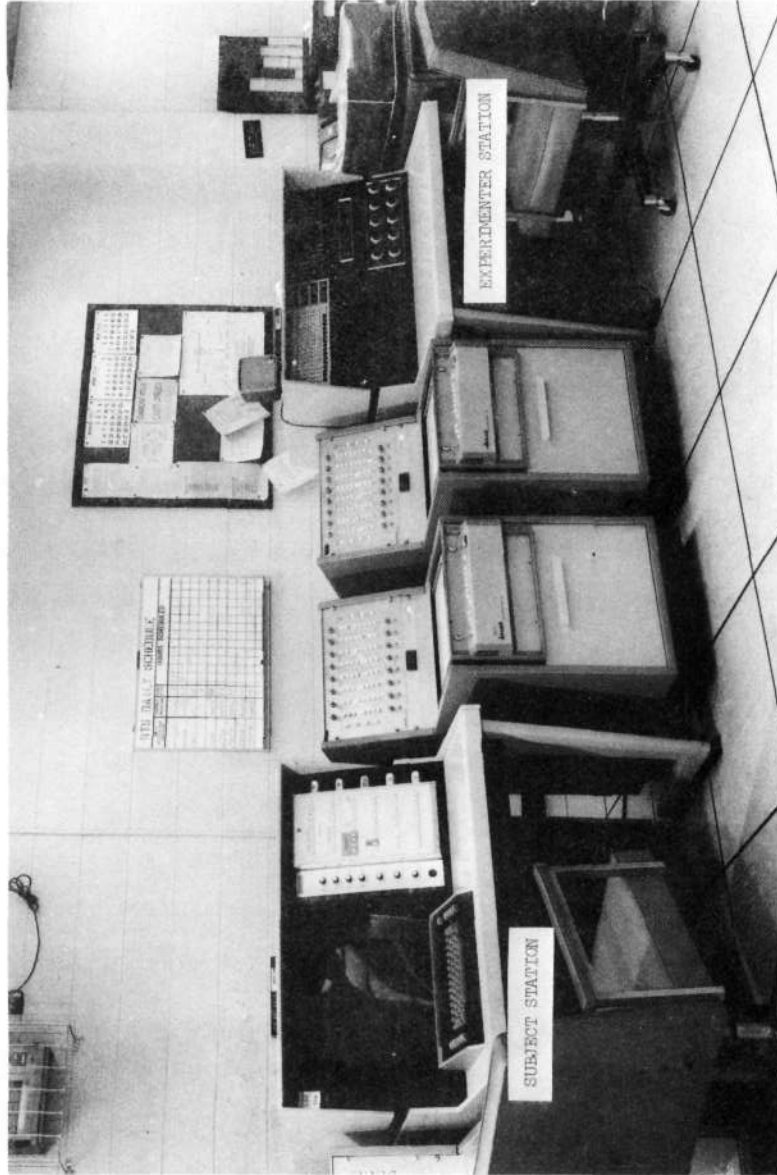
Reaction time reflects the subject's uncertainty about which of a set of response movements are to be made, while movement time reflects

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

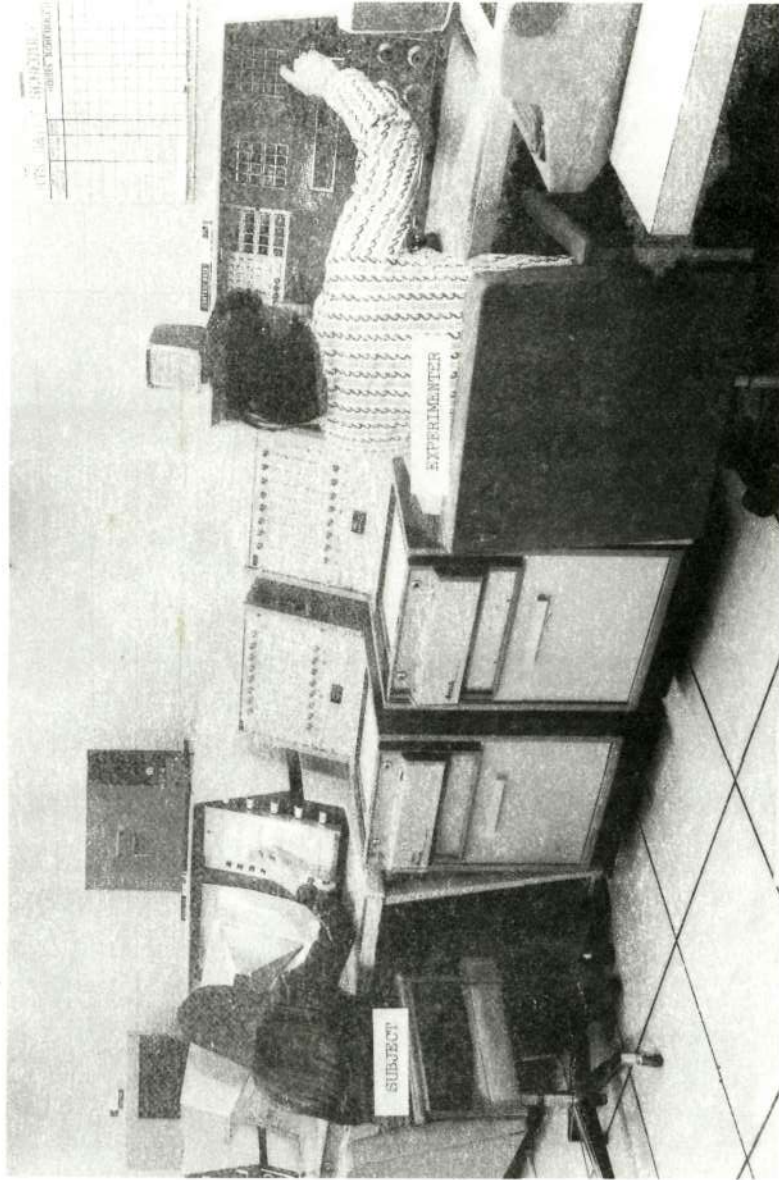
The thirty-one test subjects were between the ages of 22 and 53 years of age, and had a minimum education of a B.S. in the sciences or engineering. None of the subjects had prior lab experience in tests with CRT displays, but knew of the system operation and its potential in advanced cockpit design. 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



(a) Hardware Setup

Figure 4.- Subject's and Experimenter's Test Stations



(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 subjects 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

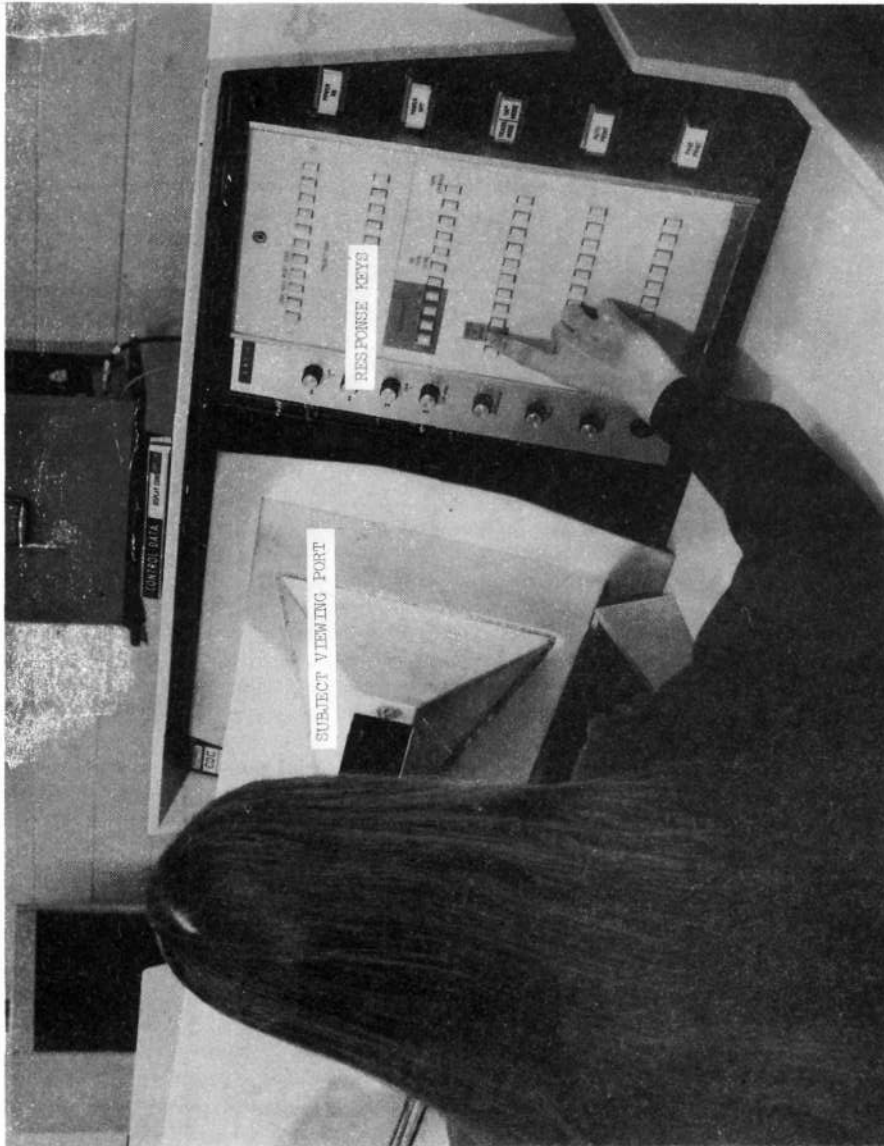


Figure 5.- Test Apparatus for the Keying Response

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

$i = 1, 2, \dots, t$ subject blocks

$j = 1, 2, \dots, r$ cell location treatments

$k = 1, 2, \dots, s$ samples/treatment/block (replicates per cell)

and

- Y_{ijk} : Subject's speed in seconds per treatment
 μ : 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:

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

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

$$B_i \text{ are NID } (0, \sigma_B)$$

$$R_k \text{ are NID } (0, \sigma_R)$$

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 I
ANALYSIS OF VARIANCE EQUATIONS, TWO WAY - MIXED MODEL

<u>Source</u>	<u>D.O.F.</u>	<u>SS</u>	<u>EMS</u>
Subject Blocks, B	(t - 1)	$rs \sum_{i=1}^t (\bar{Y}_{i..} - \bar{Y}....)^2$	$\sigma^2 + rs\sigma_B^2$
Cell Treatments, T	(r - 1)	$ts \sum_{j=1}^r (\bar{Y}..j. - \bar{Y}....)^2$	$\sigma^2 + s\sigma_{BT}^2 + ts\sigma_T^2$
Replicates, R	(s - 1)	$rt \sum_{k=1}^s (\bar{Y}..k. - \bar{Y}....)^2$	$\sigma^2 + tr\sigma_R^2$
B x T	(t - 1)(r - 1)	$s \sum_{t=1}^t \sum_{j=1}^r (\bar{X}_{ij.} - \bar{Y}_{i..} - \bar{Y}..j. + \bar{Y}....)^2$ $t = 1, j = 1$	$\sigma^2 + s\sigma_{BT}^2$
Error	(rt - 1)(s - 1)	$t \sum_{i=1}^t \sum_{j=1}^r \sum_{k=1}^s (\bar{Y}_{ijk} - \bar{Y}_{ij.} - \bar{Y}..k. + \bar{Y}....)^2$ $i = 1, j = 1, k = 1$	σ^2
TOTAL	trs - 1	$\sum \sum \sum (Y_{ijk} - \bar{Y}....)^2$	

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 studied, 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

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

Test Parameters: t = 31 subjects

r = 16 cell location treatments

s = 8 sample/treatment/subject

TABLE III

Subject Data

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

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:

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

$$H_1: \sigma_{TB}^2 \neq 0$$

$$2. \text{ Test Statistic: } F_{(450, 3465)} = \frac{S_I^2}{S_E^2} = 1.50$$

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: $F_{(30, 3465)} = \frac{S_B^2}{S_E^2}$

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:

$$1. H_0: T_1 = T_2 = \dots T_j = \dots T_r = 0$$

H_1 : Not all zero

$$2. \text{ Test Statistic: } F_{(15, 450)} = \frac{S_T^2}{S_I^2}$$

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 pth 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 pth comparison where:

$$\sum a_p = 0$$

The test of significance is given by:

$$t = \frac{d_p}{S_p}$$

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

$$t = \sqrt{F'} = \underline{+ 5.06}$$

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:

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}

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.

2.5	2.5	(2.6)	(2.2)
(2.7)	(2.7)	(2.7)	(2.6)
(2.8)	(2.8)	(2.8)	2.5
2.5	2.5	(2.7)	2.3

(a) Individual Comparisons with $C_{14} = 2.2$ sec.

2.5	2.5	2.6	2.2
(2.7)	(2.7)	(2.7)	2.6
(2.8)	(2.8)	(2.8)	2.5
2.5	2.5	(2.7)	(2.3)

(b) Individual Comparisons with $C_{44} = 2.3$ sec.

<u>Mean Difference</u>	<u>Σa_p^2</u>	<u>S_p</u>	<u>d_p</u>	<u>t</u>
0.6	2.0	0.0735	0.6	8.18
0.5	2.0	0.0735	0.5	6.82
0.4	2.0	0.0735	0.4	5.45

Figure 6.- Significant Single Cell Comparisons with the Minimum Response Time Cells, C_{14} and C_{44}

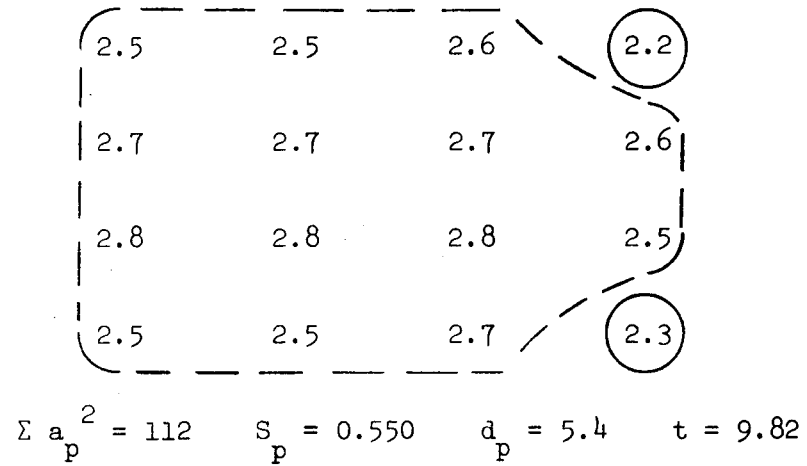


Figure 7.- Significant Comparison of Cells, C_{14} and C_{44} , to Grouped Remaining Cells.

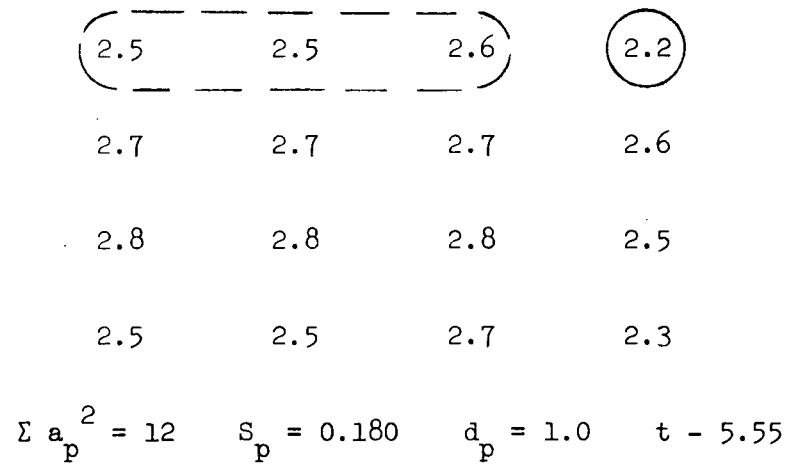


Figure 8.- Significant Comparison of Cell C_{14} to Other Grouped Cells of Top Row

2.5	2.5	2.6	2.2
2.7	2.7	2.7	2.6
2.8	2.8	2.8	2.5
2.5	2.5	2.7	2.3

$$\Sigma a_p^2 = 8 \quad S_p = 0.147 \quad d_p = 0.9 \quad t = 6.12$$

(a) Top Row versus 2nd Row

2.5	2.5	2.6	2.2
2.7	2.7	2.7	2.6
2.8	2.8	2.8	2.5
2.5	2.5	2.7	2.3

$$\Sigma a_p^2 = 8 \quad S_p = 0.147 \quad d_p = 1.1 \quad t = 7.48$$

(b) Top Row versus 3rd Row

Figure 9.- Significant Comparisons of Top Row to Row 2 and Row 3

2.5	2.5	(2.6)	(2.2)
2.7	2.7	2.7	2.6
2.8	2.8	2.8	2.5
2.5	2.5	(2.7)	(2.3)
$\Sigma a_p^2 = 8$ $S_p = 0.147$ $d_p = 1.2$ $t = 8.17$			

(a) Column 4 versus Column 3

2.5	(2.5)	2.6	(2.2)
2.7	2.7	2.7	2.6
2.8	2.8	2.8	2.5
2.5	(2.5)	2.7	(2.3)
(2.5)	2.5	2.6	(2.2)
2.7	2.7	2.7	2.6
2.8	2.8	2.8	2.5
(2.5)	2.5	2.7	(2.3)
$\Sigma a_p^2 = 8$ $S_p = 0.147$ $d_p = 0.9$ $t = 6.12$			

(b) Column 4 versus Column 2 or Column 1

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.

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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	<u>048</u>	PRIMARY	<u>CAUTION</u>	BACKUP	<u>STANDBY</u>
------	------------	---------	----------------	--------	----------------

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.

C2

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), YEARS(LB(50), YBARCEL(16), NCLM(50),
YERMEAN
      1(50,16),NRUNN(50),YBARREP(8)
      REAL KLRT
C
C *** READ TOTAL NUMBER OF SUBJECTS
      READ(5,1) NSUB
      JLIM=16
      KLIM=8
      1 FORMAT(I2)
      IF(NSUB .GT. 50) GO TO 99
C
C *** READ IN DATA
      DO 2 I=1,NSUB
      READ(5,3) NUMSUB,NRUN
C
      3 FORMAT(2I2)
C *** ASSIGN DUMMY NUMBERS TO SUBJECTS
      NDUM(I)=NUMSUB
      NRUNN(I)=NRUN
      READ(5,4) ((Y(I,J,K),J=1,16),K=1,8)
      4 FORMAT(16F5.1)
      2 CONTINUE
C
C *** COMPUTE MEAN OVER ALL SUBJECTS
      YBARTOT=0.
      DO 5 I=1,NSUB
      DO 5 J=1,JLIM
      DO 5 K=1,KLIM
      5 YBARTCT=YBARTCT+Y(I,J,K)
      YBARTOT=YBARTCT/(NSUB*JLIM*KLIM)
C
C *** COMPUTE MEAN FOR EACH SUBJECT
      DO 6 I=1,NSUB
      YBARSUE(I)=0.
      DO 6 J=1,JLIM
      DO 6 K=1,KLIM
      6 YBARSUB(I)=YBARSUB(I)+Y(I,J,K)
      DO 7 I=1,NSUB
      7 YBARSLB(I)=YBARSUB(I)/(JLIM*KLIM)
C
C *** COMPUTE CELL TREATMENT MEANS OVER ALL SUBJECTS
      DO 8 J=1,JLIM
      YBARCEL(J)=0.
      DO 8 I=1,NSUB

```

```

      DO 8 K=1, KLIM
      8 YBARCEL (J)=YBARCEL(J)+Y(I,J,K)
      DO 9 J=1, JLIM
      9 YBARCEL (J)=YBARCEL(J)/(NSUB*KLIM)
C   ** COMPUTE REPLICATION MEAN
      DO 20 K=1, KLIM
      YBARREP(K)=0.
      DO 20 I=1, NSUB
      DO 20 J=1, JLIM
      20 YBARREP(K)=YBARREP(K)+Y(I,J,K)
      DO 21 K=1, KLIM
      21 YBARREP(K)=YBARREP(K)/(NSUB*JLIM)
C
C
C   *** COMPUTE ERROR MEAN
      DO 11 I=1, NSUB
      DO 11 J=1, JLIM
      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
      DO 10 J=1, JLIM
      DO 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
      YNOW=YBARCEL (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
      YNOW=YBARSUB(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*YNCW
SSR=SSR*JLIM*KLIM
C
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*YNCW
C *** COMPUTE INTERACTION SUM OF SQUARES
SSI=TSS-SSC-SSS-SSE-SSR
C
C COMPUTE STANDARD DEVIATION
DECM=NSUB*JLIM*KLIM
SDNCW=TSS/DECM
STDDEV=SQRT(SCNOW)
C
C COMPUTE SKEWNESS
SKEW=(TSS3/DECM)/(SDNOW*STDDEV)
C
C COMPUTE KURTOSIS
KURT=((TSS4/DECM)/(SDNOW*SCNOW))-3.
C
C *** COMPUTE MEAN SQUARES
TMINUS 1=NSUB-1
RMINUS 1=JLIM-1
SMINUS 1=KLIM-1
SSUBS2=SSS/TMINUS 1
SSUBC2=SSC/RMINUS 1
SSUBR2=SSR/SMINUS 1
RTMIN1=TMINUS 1*RMINUS 1
SSUBI2=SSI/RTMIN 1
RTSTOT=(NSUB*JLIM-1)*(KLIM-1)
SSUBE2=SSE/RTSTOT
RTSMIN1=(NSUB*JLIM*KLIM)-1
C
C *** COMPUTE SCHEFFE COMPARISONS
SUMASQ=2.
SDI=SQRT((SSUBE2*SUMASQ)/(NSUB*KLIM))
DI1=.6
DI2=.5
DI3=.4
TI1=DI1/SDI
TI2=DI2/SDI
TI3=DI3/SDI

```



```

C
C *** COMPUTE F-RATIOS
  FRSUB=SSUBS2/SSUBE2
  FRCEL=SSUBC2/SSUBI2
  FRREP=SSUBR2/SSUBE2
  FRINT=SSUBI2/SSUBE2
C
  WRITE(6,200)
200 FORMAT(1H1,6X*SCURCE*11X*C.C.F.*6X*SS*1CX*MS*6X*
  F-TWO WAY*//)
  WRITE(6,201) TMINUS 1,SSS,SSUBS2,FRSUB
201 FORMAT(1X*SUBJECT BLOCKS*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*REPLICATION*4X,F12.0,3F12.2/)
  WRITE(6,203) RMINI,SSI,SSUBI2,FRINT
203 FORMAT(1X*SUBJECTS X CELL*,F12.0,3F12.2/)
  WRITE(6,204) RTSTOT,SSE,SSUBE2
204 FORMAT(1X*ERRCR*10X,F12.0,2F12.2/)
  WRITE(6,210) RTSMINI,TSS
210 FORMAT(1X*TOTAL*10X,F12.0,F12.2//)
  WRITE(6,205) YEARTOT,STDDEV,SKEW,KURT
205 FORMAT(1X*TOTALMEAN=*F5.1,5X*SIGMA=*F6.2,5X*SKEW=
  *F6.3,5X*KURT=*F6 1.3//)
  WRITE(6,214) T11,T12,T13
214 FORMAT(1X*T.FCR .6=*F5.2,5X*T FOR .5=*F5.2,5X*T FOR
  .4=*F5.2//)

  WRITE(6,211)
211 FORMAT(1X*OVERALL CELL MEANS*/)
  WRITE(6,212) YBARCEL
212 FORMAT(10X,4F8.1/)
  WRITE(6,206)
206 FORMAT(1X*OVERALL SUBJECT MEANS*/)
  DO 209 I=1,NSUB
  WRITE(6,207) NCLM(I),NFUNN(I),YBARSUB(I)
207 FORMAT(5X,I3*-*I2,F6.1)
209 CONTINUE
  GO TO 100
  99 WRITE(6,208)
208 FORMAT(1X*TOO MANY SUBJECTS SUBMITTED*/)
100 CONTINUE
  END

```

APPENDIX C

COMPUTER PROGRAM FOR REAL-TIME SIMULATION

PROGRAM EXECUTIVE

```

OVERLAY(OLFILE,0,0)
PROGRAM INFO(INPUT=201,OUTPUT=201,PUNCH)
COMMON/REALTIM/ANALGIN(32),DIGOUT(64),LDISI(108),LDISO(196),
1 NOPER,NHOLD,NRESET,NTERM,NPRINT,NREAD
COMMON/VARBLK/VAR(20),INTEG(5),LOGIC(5),IVARBUF(5),VARCHNG
COMMON/DSPL/NVAR,NINTEG,NLOGIC,NALGIN,NDIGOUT,NLDISI,NLDISO
COMMON/INTBUFF/TOGSW(15),MCM5W(11),EXECFLA
COMMON/EXTRA/MF,IPL,ISL
COMMON/STIM/ISTIM(128),IMIS(128),IREAD
COMMON/PTOUT/LEM(128),IAN(123),NITER,NRUN
COMMON/DISP/MINI,ISMAIL,MED,LAR,IBLINK,IONCE
COMMON/ALPHA/ALPH(45),XRRC(4),YRRC(4)
LOGICAL EXECFLA,TOGSW,MCM5W,VARCHNG,LDISI,LDISO,LOGIC
EQUIVALENCE (INTEG(1),ISCAN) , (INTEG(2),ITYPE)
EQUIVALENCE (LDISI(48),INTABLS)
90034 FORMAT(6X* INFC-R.G.KYLE *5X*JOB,43,77777,75000. A3112,
113544.1, R.W.WILL R2142*)
OLFILE=6LOLFILE
CALL NAMECRT(6LCRTTPE,FRR)
CALL PRIMARY(OLFILE,MF,90034S,LDISI,IPL,ISL,TOGSW,MCM5W,EXECFLA)
END

```

SIMULATION INITIALIZATION

```

OVERLAY(OLFILE,1,0)
PROGRAM AINIT
COMMON/REALTIM/ANALGIN(32),DIGOUT(64),LDISI(108),LDISO(196),
1 NOPER,NHOLD,NRESET,NTERM,NPRINT,NREAD
COMMON/VARBLK/VAR(20),INTEG(5),LOGIC(5),IVARBUF(5),VARCHNG
COMMON/DSPL/NVAR,NINTEG,NLOGIC,NALGIN,NDIGOUT,NLDISI,NLDISO
COMMON/INTBUFF/TOGSW(15),MCM5W(11),EXECFLA
COMMON/EXTRA/MF,IPL,ISL
COMMON/STIM/ISTIM(128),IMIS(128),IREAD
COMMON/PTOUT/LEM(128),IAN(128),NITER,NRUN
COMMON/DISP/MINI,ISMAIL,MED,LAR,IBLINK,IONCE
COMMON/ALPHA/ALPH(45),XRRC(4),YRRC(4)
LOGICAL EXECFLA,TOGSW,MCM5W,VARCHNG,LDISI,LDISO,LOGIC
EQUIVALENCE (INTEG(1),ISCAN) , (INTEG(2),ITYPE)
EQUIVALENCE (LDISI(48),INTABLS)
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,180)
ISCAN=32
NVAR=20
NINTEG=5
NLOGIC=5
NALGIN=32
NDIGOUT=64
NLDISI=108
NLDISC=196

```

```

CALL DATBLX(VAR,NVAR,INTEG,NINTEG,LOGIC,NLOGIC,ANALGIN,NALGIN,
1 DIGOUT,NDIGOUT,LDISI,NLDISI,LDISO,NLDISO)
NT=1
CALL NM218(5LOSCAR)
CALL XDSPLAY(LDISI,LCISC,VARCHNG,ITYPE,IVARBUF,INTABLS)
DG 85 IND=1,196
85 LDISO(IND)=.F.
DG 86 IND=1,108
86 LDISI(IND)=.F.
DG 87 IND=1,15
87 TGGSW(IND)=.F.
DG 89 IND=1,11
88 MOWSW(IND)=.F.
EXECFLA=.F.
CALL CRTNAM(4HINFO,0,0,5FAINIT,1,0)
CALL CRTNAM(7HAOUTPUT,2,0,6FAINPUT,3,0)
CALL CRTNAM(6HRTMAIN,4,C,0)
ALIM=128.
ALPH( 1)=4RXBAC
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)=4RXOPE
ALPH(13)=4KXRAT
ALPH(14)=4RXICN
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)=4RXERR
ALPH(29)=4RXOR
ALPH(30)=4RXAKN
ALPH(31)=4RXSBY
ALPH(32)=4RXOPR
ALPH(33)=4RXCRI
ALPH(34)=4RXTIC
ALPH(35)=4RXAL
ALPH(36)=4RX
ALPH(37)=4RXEXE
ALPH(38)=4RXRCI

```

```

-----
ALPH(39)=4RXSE
ALPH(40)=4RXCOM
ALPH(41)=4RXPLE
ALPH(42)=4RXTE
-----
ALPH(43)=4RXTHA
ALPH(44)=4RXNK
ALPH(45)=4RXYOU
XRR(1)=350.
XRR(2)=475.
XRR(2)=600.
-----
XRR(4)=725.
YRR(1)=715.
YRR(2)=590.
YRR(3)=465.
YRR(4)=340.
DG 69 J=1.128
-----
ISTIM(J)=11
IMIS(J)=0
IAN(J)=0
69 LEM(J)=0
IREAD=0
NITER=32
-----
SCT=8.
SUBJECT=1.
RUNNO=1.
MINI=ISETSYM(0,0,0)
ISMAIL=ISETSYM(1,0,0)
MED=ISETSYM(2,0,0)
-----
LAR=ISETSYM(3,0,0)
IBLINK=ISETSYM(2,0,1)
IGNCE=10
DELAY=0.
NRUN=0
-----
IPL=4
ISL=0
RETURN
END

```

OUTPUT PRINTOUT

```

OVERLAY(CLFIL,2,0)
PROGRAM AOUTPUT

```

```

C
C
C
C

```

```

***** TOGSW (6) - RELEASE
***** TOGSW(11) - STORE DATA ON TAPE

```

```

COMMON/REALTIM/ANALGIN(32),DIGCUT(64),LDISI(108),LDISO(196),
1 NOPER,NHOLD,NRESET,NTERM,NPRINT,NREAD
COMMON/VARBLK/VAR(20),INTEG(5),LOGIC(5),IVARBUF(5),VARCHNG
COMMON/INTBUFF/TOGSW(15),MUMSW(11),EXECFLA
COMMON/EXTRA/MF,IPL,ISL
COMMON/STIM/ISTIM(128),IMIS(128),IREAD
COMMON/PTCLT/LEM(128),IAN(128),NITER,NRUN
COMMON/DISP/MINI,ISMAIL,MED,LAR,IBLINK,IGNCE

```

```

LOGICAL EXECFLA, TOGSH, MCMSH, VARCHNG, LDISI, LDISO, LOGIC
EQUIVALENCE (INTEG(1), ISCAN) , (INTEG(2), ITYPE)
EQUIVALENCE (VAR(2), SCT)
EQUIVALENCE (VAR(3), ALIM)
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(10)
DIMENSION AMEN(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(NRUN .GT. 99) NRUN=99
CALL DAYTIM(RESULT)
WRITE(MF, 7)
WRITE(MF, 8) RESULT, NRUN, ISUB
IF(SCT .GT. 9.9) SCT=9.9
XX=3H E
DC 23 I=1, 10
23 AMN(I)=VA(I)=0.
DC 540 I=1, 16
DC 540 J=1, 8
540 AERR(I, J)=3H
DC 541 I=1, 16
541 IEK(I)=1
DC 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
ANITER=NITER
ID=C
AMAX=SIGMAX=0.
LISP=C

```

```

      DG 2010 J=1,LIM
2010 LISP=LISP+LEM(J)
      DISPL=LISP/ANITER
      WRITE(MF,2011) DISPL
      IRCT=0
      DG 2000 I=1,16
      DG 2000 J=1,8
2000 AMEN(I,J)=0.
      DG 1999 J=1,LIM
      AL=10.*LEM(J)/ANITER
      ILL=AL
      AL=AL-ILL
      IF(AL .GT. .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(IFK,INK)=AL
      IF(IMIS(J) .LT. 1) GC TO 1999
      ISS=IEK(IRK)
      IEK(IRK)=IEK(IRK)+1
      AERR(IRK,ISS)=B(INK)
1999 CONTINUE
      WRITE(MF,2003)
      WRITE(MF,2004)(J,(AMEN(I,J),I=1,16),J=1,8)
      DG 2005 I=1,16
      ATOT(I)=0.
      DG 2017 J=1,8
2017 ATOT(I)=ATOT(I)+AMEN(I,J)
2005 ATOT(I)=ATOT(I)*.125
      WRITE(MF,2005) ATOT
      WRITE(MF,2018)
      WRITE(MF,2019) AERR
      55 IRCT=IRCT+1
C
C ***** STATISTICAL ANALYSIS
      DG 16 J=1,32
16 CGUNT(J)=0.0
      ISAMP=0
      DDEL=SCT/32.
      ERCT=C
      DG 3 J=1,LIM
      IF(IRCT .GT. 1 .AND. IAN(J) .NE. ID) GO TO 3
      IF(LEM(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 - 8.*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 CGUNT(ICTDT)=COUNT(ICTDT) + 1.
ISAMP=ISAMP+1
3 CONTINUE
IF(ISAMP .EQ. 0) GO TO 2122
BASE=.5*DDEL
XTRA=C.0
DO 4 I=1,32
XTRA=XTRA + CCUNT(I)*BASE
4 BASE=BASE + DDEL
AMEAN=XTRA/ISAMP
BASE=.5*DDEL
XTRA=C.0
ZTRA=C. $ UTRA=0.
DO 5 I=1,32
YTRA=BASE - AMEAN
XTRA=XTRA + CCUNT(I)*YTRA*YTRA
ZTRA=ZTRA+COUNT(I)*YTRA*YTRA*YTRA
UTRA=LTRA+COUNT(I)*YTRA*YTRA*YTRA*YTRA
5 BASE=BASE + DDEL
SIG=XTRA/ISAMP
IF(IRCT .LT.2) GO TO 212
IF(AMEAN .GT. AMAX)AMAX=AMEAN
IF(SIG .GT. SIGMAX) SIGMAX=SIG
AMN(IRCT-1)=AMEAN
VA(IRCT-1)=SIG
212 CONTINUE
ZIG=SQRT(SIG)
PIG=ZIG*ZIG*ZIG
RIG=SIG*SIG
SKW=ZTRA/(ISAMP*PIG)
AKUR=LTRA/(ISAMP*RIG) -3.
WRITE(MF,66) AMEAN,SIG,ZIG,SKW,AKUR,ERCT,ISAMP
2122 CONTINUE
BASE=-.5*DDEL
AMXCT=0.

```

```

DG 76 J=1,32
76 IF(COUNT(J) .GT. AMXCT) AMXCT=COUNT(J)
DG 77 J=1,32
IDIS=COUNT(J)+1
DG 766 I=1, IDIS
766 A(I)=CISTR
BASE=BASE+CDEL
IF(IRCT .EQ. 1) WRITE(MF,22) BASE,COUNT(J),(A(K),K=1,39)
DG 767 I=1, IDIS
767 A(I)=3H
77 CONTINUE
GG TO(201,202,203,204,211),IRCT
201 ID=1
WRITE(MF,2007) ID
GG TO 55
202 ID=2
WRITE(MF,2007) ID
GG TO 55
203 ID=3
WRITE(MF,2007) ID
GG TO 55
204 ID=4
WRITE(MF,2007) ID
GG TO 55
211 CONTINUE
ILT=0
79 ILT=ILT+1
C
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
C ***** STORE DATA ON TAPE
PUNCH 777 , ISUB,NRUN
777 FORMAT(2I2)
PUNCH 78 , AMEN
78 FORMAT(16F5.1)
12 CONTINUE
RUNNO=RUNNO+1.
13 CONTINUE
DG 69 J=1,LIM
IMIS(J)=0
IAN(J)=0
69 LEN(J)=0
2 FORMAT(I4,44A3)
DG 70 I=1,16
DG 70 J=1,8
70 AMEN(I,J)=0.
65 FORMAT(5X*MEAN=*F5.2,5X*VAR=*F5.2,5X*SIGMA=*F5.2,5X*SKEW=*F5.2,5X*
1KURT=*F5.2,5X*ERRORS=*F5.0,5X*OCCURENCES=*I4//)
7 FORMAT(1H1)
8 FORMAT(10X*DATE=*24IC,10X*RUN=* I5,5X*SUBJECT NO.*12/)
9 FORMAT(4I5)
22 FORMAT(E10.2,F5.0,39A3)

```



```

2003 FORMAT(5X*C11*2X*C12*2X*C13*2X*C14*2X*C21*2X*C22*2X*C23*2X*C24*2X*
1C31*2X*C32*2X*C33*2X*C34*2X*C41*2X*C42*2X*C43*2X*C44*///)
2004 FORMAT(1X,11,1X,16F5.1//)
2006 FORMAT(3X,16F5.1//)
2007 FORMAT(1X*KEY*I2)
2011 FORMAT(10X*CUMUL RESP TIME=*F9.1//)
2013 FORMAT(1X*ERROR SUMMARY*)
2019 FORMAT(5X,A3,2X,A3,2X,A3,2X,A3,2X,A3,2X,A3,2X,A3,2X,A3,2X,A3,
12X,A3,2X,A3,2X,A3,2X,A3,2X,A3,2X,A3)
2021 FORMAT(1X*TOTAL ERRORS =*I3)
RETURN
END

```

READ INPUT

```

OVERLAY(OLFILE,3,0)
PROGRAM AINPUT
COMMON/REALTIM/ANALGIN(32),DIGOUT(64),LDISI(108),LDISO(196),
1 NOPER,NHOLD,NRESET,NTERM,NPRINT,NREAD
COMMON/VARBLK/VAR(20),INTEG(5),LOGIC(5),IVARBUF(5),VARCHNG
COMMON/INTBUFF/TOGSw(15),MCMsw(11),EXECFLA
COMMON/EXTRA/MF,IPL,ISL
COMMON/DISP/MINI,ISMAIL,MED,LAR,IBLINK,IONCE
COMMON/ALPHA/ALPH(45),XRRRC(4),YRRRC(4)
COMMON/STIM/ISTIM(128),IMIS(128),IREAD
COMMON/PTOUT/LEM(128),IAN(128),NITER,NRUN
LOGICAL EXECFLA,TOGSw,MCMsw,VARCHNG,LDISI,LDISO,LOGIC
EQUIVALENCE (INTEG(1),ISCAN) , (INTEG(2),ITYPE)
IF(IREAD .GT. 0) GO TO 7777
IREAD=5
READ 1 , ISTIM
1 FORMAT(16I4)
7777 CONTINUE
IGNCE=0
RETURN
END

```

REAL TIME LOGIC

```

OVERLAY(OLFILE,4,0)
PROGRAM RTMAIN
COMMON/REALTIM/ANALGIN(32),DIGOUT(64),LDISI(108),LDISO(196),
1 NOPER,NHOLD,NRESET,NTERM,NPRINT,NREAD
COMMON/VARBLK/VAR(20),INTEG(5),LOGIC(5),IVARBUF(5),VARCHNG
COMMON/INTBUFF/TOGSw(15),MCMsw(11),EXECFLA
COMMON/EXTRA/MF,IPL,ISL
COMMON/STIM/ISTIM(128),IMIS(128),IREAD
COMMON/PTOUT/LEM(128),IAN(128),NITER,NRUN
COMMON/DISP/MINI,ISMAIL,MED,LAR,IBLINK,IONCE
COMMON/ALPHA/ALPH(45),XRRRC(4),YRRRC(4)

```

```

LOGICAL EXECFLA,TOGSw,MCMSW,VARCHNG,LDISI,LDISO,LOGIC
LOGICAL IERR
EQUIVALENCE (INTEG(1),ISCAN) , (INTEG(2),ITYPE)
EQUIVALENCE (LDISI(48),INTABLS)
EQUIVALENCE (VAR(1),DELAY)
EQUIVALENCE (VAR(2),SCT)
EQUIVALENCE (VAR(3),ALIM)
EQUIVALENCE (VAR(5),RUNNG) , (VAR(6),RESTIME)
EQUIVALENCE (VAR(7),STIMNO)
DIMENSION XV(7),YV(7)
DIMENSION NAA(4,4)
CALL SECOVL
CALL CYCLE(90006S)
ASSIGN 90001 TO NOPER
ASSIGN 90002 TO NHCLC
ASSIGN 90003 TO NRESET
ASSIGN 90004 TO NTERM
ASSIGN 90014 TO NPRINT
ASSIGN 90015 TO NREAD
AC=RANF(.5)
PROB1=PROB2=PROB3=.25
CALL READY
CALL RTMCDE
90003 CONTINUE
C ***** RESET LOOP
   TOGSw(1)=.F.
   IF(IGNCE .EQ. 0) GO TO 110
1  CALL SEND
   CALL ENABLE(1S)
   CALL HALT
   IGNCE=0
   CALL UNLODE
   CALL READY
110 CONTINUE
   LIM=ALIM
   IF(LIM .GT. 128) LIM=128
   IGO=0
   IEV=0
   IDEL=DELAY*NITER
   ICT=-1
   ITIM=C
   ISTART=0
   IEND=C
   ITWO=1
   SAVE=C.
90002 CONTINUE
C ***** HCLD LOOP
90006 CONTINUE
C ***** OPERATE LOOP
   AC=RANF(.5)
C *** SCANNER FUNCTION*****
90047 LDISO(124)=LDISI(22)
   IF(LDISI(22)) CALL SCANNER(ISCAN)
C**** COMMUNICATION WITH REAL TIME DISPLAY
   CALL DDISPLAY
C**** RETURN TO MODE CONTRCL SUBROUTINE
90050 CONTINUE

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IF( .NOT. LDISI(17)) GO TO 29
IGNCE=10
IF(ICT .GT. 0) GO TO 29
GO TO(41,34,26,30),ITWO
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(MOMSw(1)) GO TO 24
IF(MOMSw(2)) GO TO 24
IF(MOMSw(3)) GO TO 24
IF(MOMSw(4)) GO TO 24
GO TO 28
24 CONTINUE
IF(MOMSw(1) .AND. IANS .EQ. 1) GO TO 25
IF(MOMSw(2) .AND. IANS .EQ. 2) GO TO 25
IF(MOMSw(3) .AND. IANS .EQ. 3) GO TO 25
IF(MOMSw(4) .AND. IANS .EQ. 4) GO TO 25
IERR=.T.
IMIS(IEV)=IMIS(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=RAMF(0.)
NAA(I,J)=1
IF(AC .GT. PROB1) NAA(I,J)=2
IF(AC .GT. (PRCB1+PRCB2)) NAA(I,J)=3
IF(AC .GT. (PROB1+PRCB2+PRCB3)) NAA(I,J)=4
101 CONTINUE
IPRIM=.1*ISTIM(IEV)
ISEC=ISTIM(IEV)-10.*IPRIM
GO TO (2,3,4,5),IPRIM
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

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JAT=2
GO TO 11
8 JALPH=7
JAT=3
GO TO 11
9 JALPH=10
JAT=2
GO TO 11
10 JALPH=12
JAT=4
11 IANS=NAA(ISEC,IPRIM)
IERR=.F.
34 CONTINUE
CALL ENABLE(34S)
IF(ITWO.NE.2) ITWO=12
LDISO(58)=.F. $ LDISC(59)=.T.
CALL CRTCODE(1,ISMAIL,O,C)
CALL CRTCODE(1,ALPH(36),460.,150.)
CALL CRTCODE(1,ALPH(36),740.,150.)
CALL CRTCODE(1,ALPH(36),232.,150.)
ICT=IDEL+3
GO TO 27
25 CONTINUE
CALL ENABLE(26S)
IF(ITWO.NE.3) ITWO=13
LDISO(58)=.T. $ LDISC(69)=.F.
CALL CRTCODE(1,ISMAIL,J,C)
CALL CRTCODE(NAT,ALPH(NALPH),460.,150.)
CALL CRTCODE(JAT,ALPH(JALPH),740.,150.)
CALL ENCODEI(IEV,3,232.,150.)
CALL CRTCODE(1,MEC,O,O)
CALL CRTCODE(2,ALPH(1),470.,895.)
CALL CRTCODE(2,ALPH(3),570.,895.)
XV(1)=465. $ XV(2)=650.
YV(1)=YV(2)=875.
CALL VECTORS(1,XV,YV)
XV(1)=330. $ XV(2)=580. $ XV(3)=830.
YV(1)=YV(2)=YV(3)=300.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=425.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=550.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=675.
CALL VECTORS(2,XV,YV)
YV(1)=YV(2)=YV(3)=800.
CALL VECTORS(2,XV,YV)
YV(2)=550. $ YV(3)=300.
XV(2)=XV(3)=330.
CALL VECTORS(2,XV,YV)
XV(1)=XV(2)=XV(3)=455.
CALL VECTORS(2,XV,YV)
XV(1)=XV(2)=XV(3)=580.
CALL VECTORS(2,XV,YV)
XV(1)=XV(2)=XV(3)=705.
CALL VECTORS(2,XV,YV)
XV(1)=XV(2)=XV(3)=830.

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CALL VECTORS(2,XV,YV)
CALL CRTCODE(2,ALPH(25),20.,560.)
CALL CRTCODE(1,ALPH(9),140.,560.)
CALL CRTCODE(2,ALPH(3),10.,500.)
XV(1)=15. $ XV(2)=160. $ 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(27),100.,150.)
CALL CRTCODE(1,ALPH(4),160.,150.)
CALL CRTCODE(2,ALPH(25),300.,150.)
CALL CRTCODE(1,ALPH(9),420.,150.)
CALL CRTCODE(2,ALPH(1),600.,150.)
XV(1)=230. $ XV(2)=290. $ YV(1)=YV(2)=130.
CALL VECTORS(1,XV,YV)
XV(1)=450. $ XV(2)=575.
CALL VECTORS(1,XV,YV)
XV(1)=730. $ XV(2)=872.
CALL VECTORS(1,XV,YV)
CALL CRTCODE(1,ISMAIL,0,C)
CALL CRTCODE(2,ALPH(5),356.,830.)
CALL CRTCODE(3,ALPH(7),475.,830.)
CALL CRTCODE(2,ALPH(10),606.,830.)
CALL CRTCODE(4,ALPH(12),702.,830.)
CALL CRTCODE(4,ALPH(16),190.,725.)
CALL CRTCODE(3,ALPH(20),208.,600.)
CALL CRTCODE(3,ALPH(23),202.,475.)
CALL CRTCODE(2,ALPH(23),214.,350.)
CALL CRTCODE(1,LAR,0,0)
DG 102 I=1,4
DG 102 J=1,4
102 CALL ENCODEI(NAA(I,J),1,XRRC(I),YRRC(J))
IF(.NOT. IERR) GO TO 27
CALL CRTCODE(1,IBLINK,0,C)
CALL CRTCODE(2,ALPH(28),500.,210.)
GO TO 27
36 IGO=0
37 CONTINUE
CALL ENABLE(37S)
CALL FALT
CALL UNLDE
CALL READY
IEND=1
GO TO 29
30 CONTINUE
CALL ENABLE(30S)
IF(ITWO .NE. 4) ITWO=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 FALT
CALL CLRBUSY
CALL READY

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ITWO=ITWG-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. TOGSW(1)) ISTART=0
RESTIME=SAVE/NITER
STIMNC=IEV
CALL RTMODE
90001 CALL RECYCLE
90004 CALL ATERM
90014 CONTINUE
90015 CONTINUE
RETURN
END
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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.

