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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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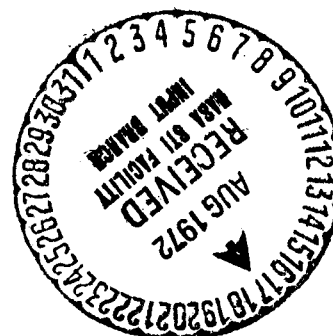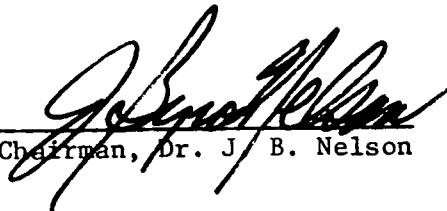Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

MASTER OF ENGINEERING

in

Industrial Engineering and Operations Research

APPROVED:

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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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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.
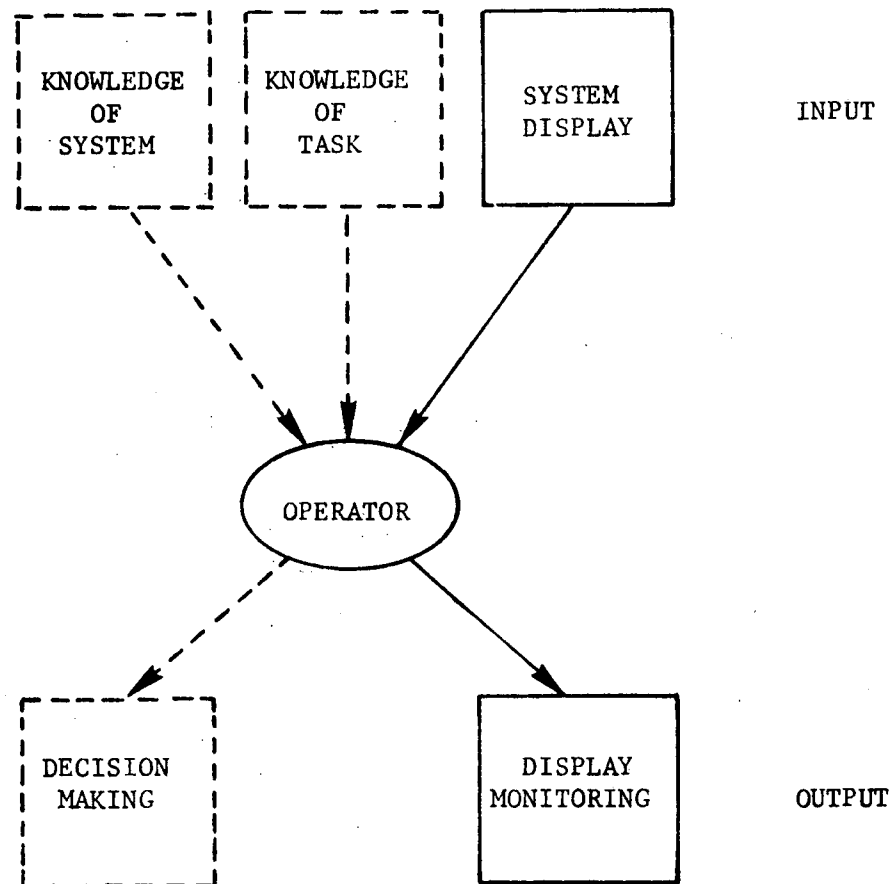
(a) Operator Input/Output

Figure 1.- Information Transfer for Manual Interface
with System Maintenance
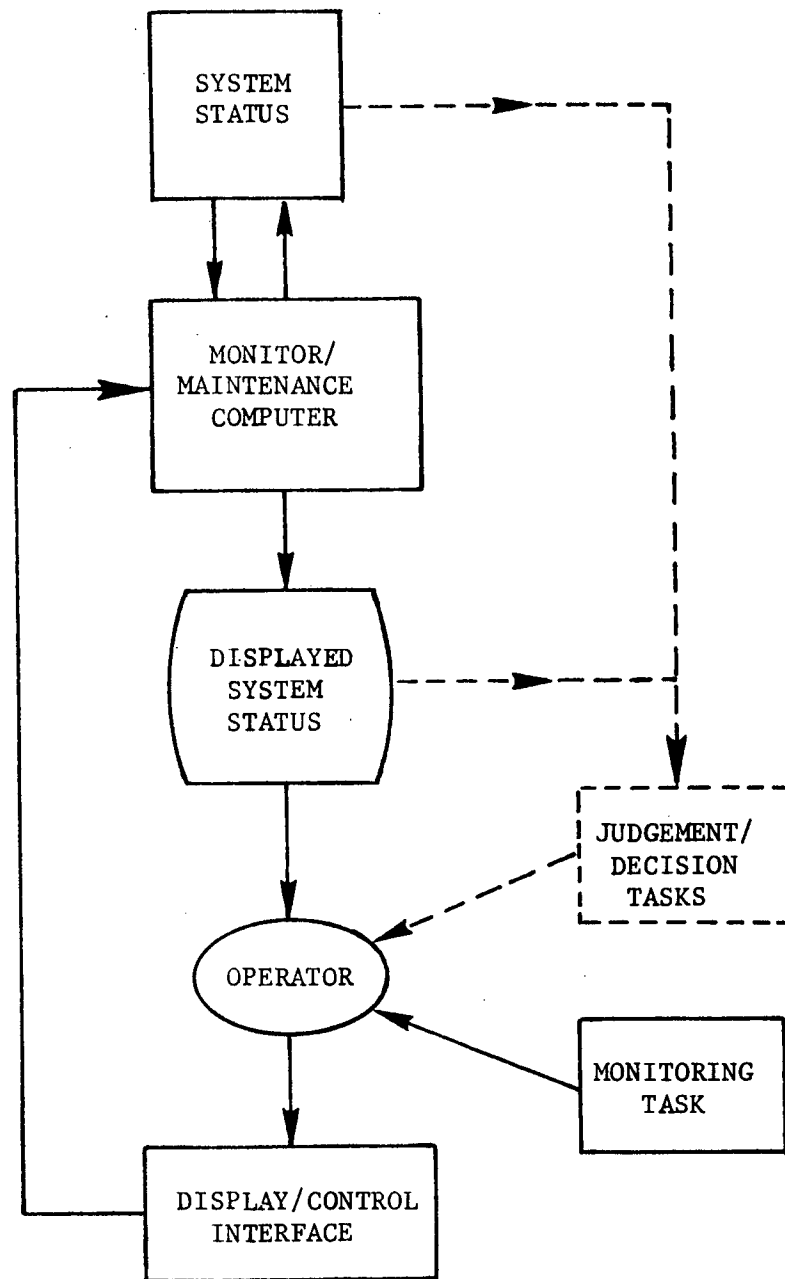
(b) Operator/System Interface

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 re-
search 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 combina-
tions. 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 by-passes 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

BACKUP MODE

	STATIC	STANDBY	ACTIVE	OPERATIONAL
ACCEPTABLE	1	3	4	1
CAUTION	4	1	4	2
CRITICAL	3	3	3	4
FAILED	4	3	4	1

PRIMARY

MODE

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 kayboard. 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

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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 ex-
pected 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
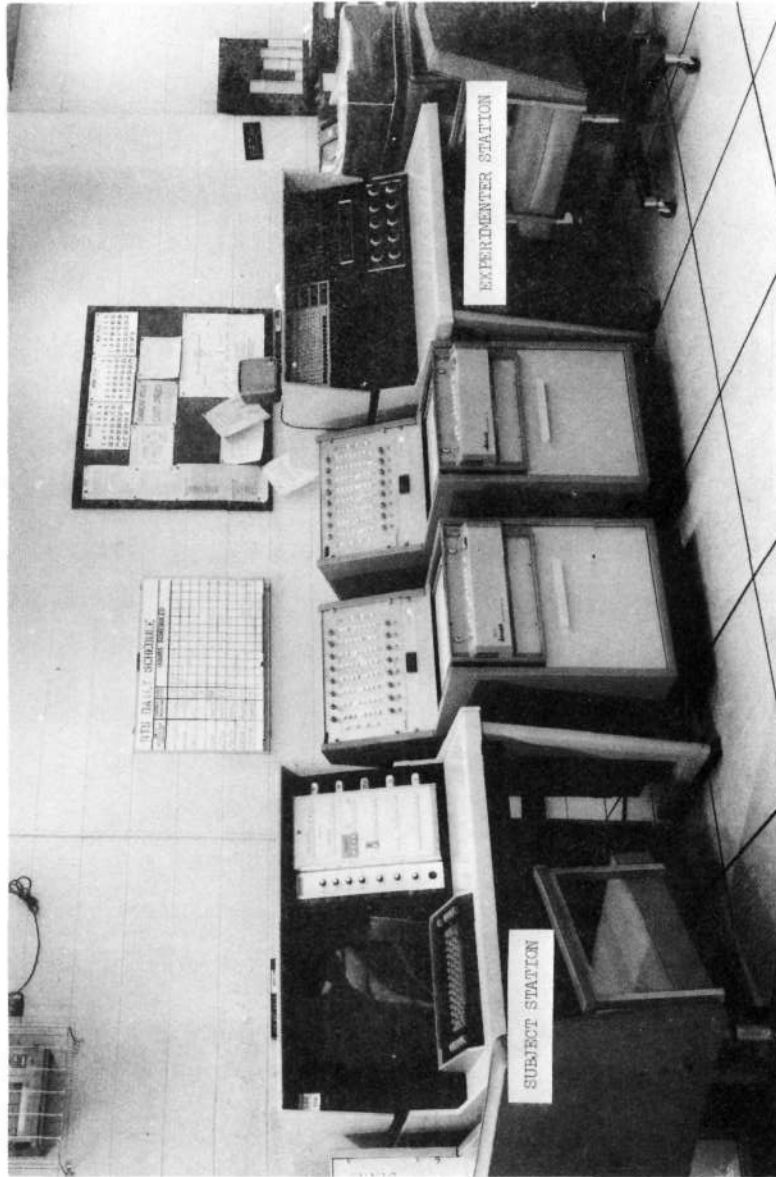
(a) Hardware Setup

Figure 4.- Subject's and Experimenter's Test Stations
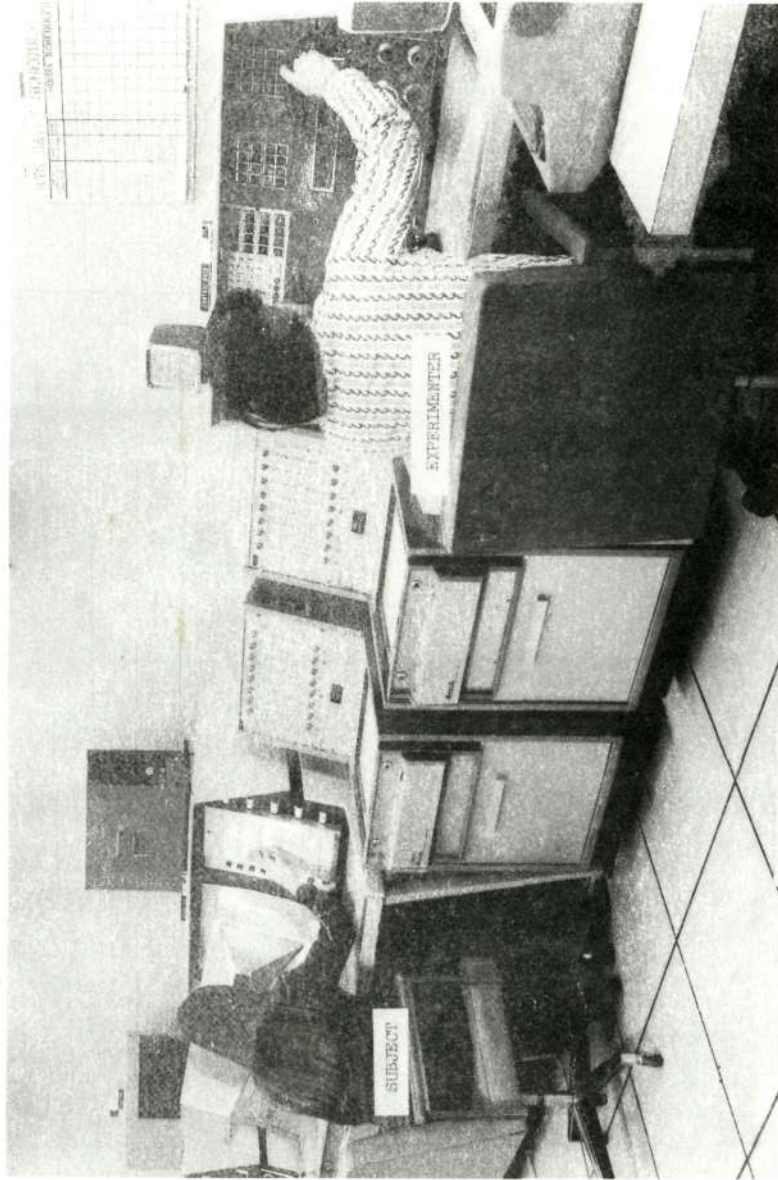
(b) Test Setup

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
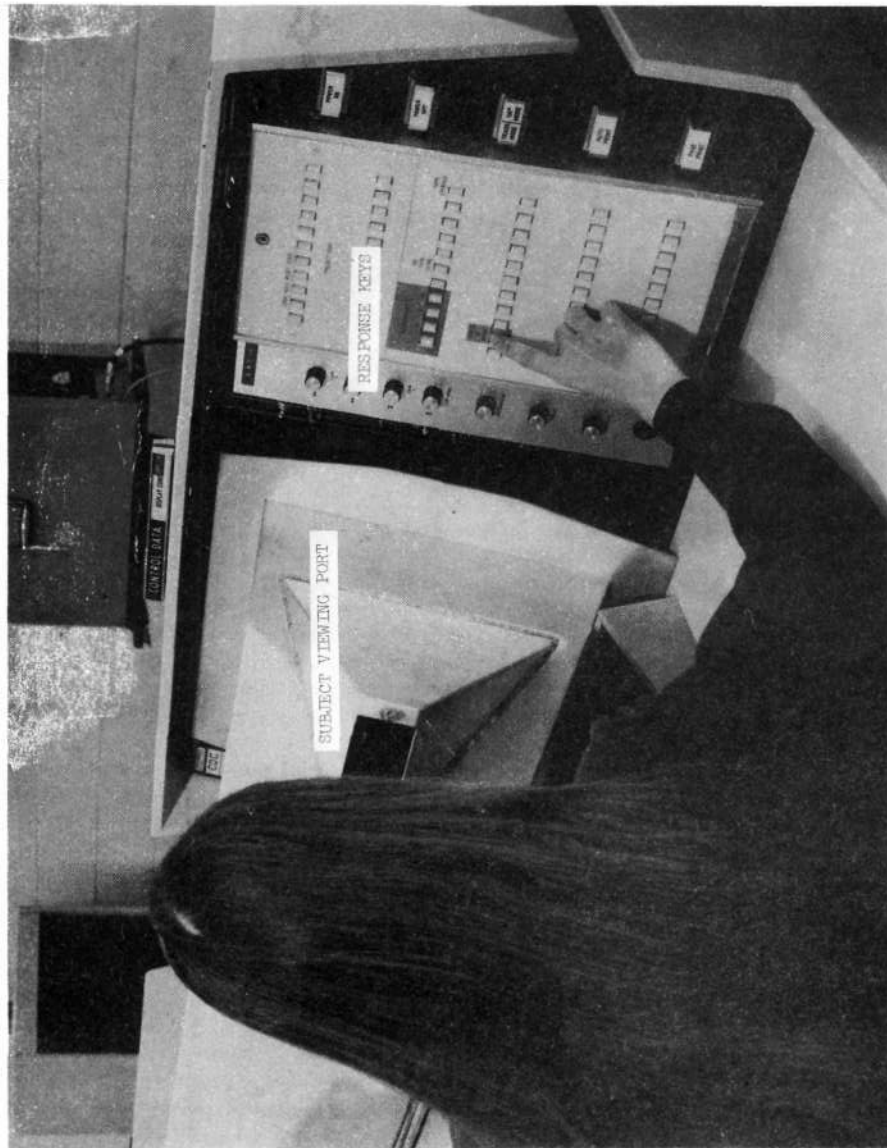
Figure 5.- Test Apparatus for the Keying Response

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

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

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

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

and

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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 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 I

ANALYSIS OF VARIANCE EQUATIONS, TWO WAY - MIXED MODEL

Source	D.O.F.	SS	EMS
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	$(t-1)(r-1)$	$s \sum_{t=1}^{t}\sum_{j=1}^{r} (\bar{X}_{ij.} - \bar{Y}_{i..} - \bar{Y}_{.j.} + \bar{Y}_{...})^2$	$\sigma^2 + s\sigma_{BT}^2$
Error	$(rt-1)(s-1)$	$\sum_{i=1}^{t}\sum_{j=1}^{r}\sum_{k=1}^{s} (\bar{Y}_{ijk}-\bar{Y}_{ij.}-\bar{Y}_{..k}+\bar{Y}_{...})^2$	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_o, 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_o is relevant evidence in this case. To properly interpret H_o, 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 informa-

tion 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_o."

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

Source	D.O.F.	SS	MS	F-Ratio
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	3465	2312.18	.67	
Total	3967	4171.97		

Test Parameters: t = 31 subjects

r = 16 cell location treatments

s = 8 sample/treatment/subject

TABLE III

Subject Data

Subject Number	Sex	Age	Response Errors	Mean Speed
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 responsed 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 view-point 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_o: $\sigma^2_{TB} = 0$

   H_1: $\sigma^2_{TB} \neq 0$

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

3. Reject H_o 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_o: $\sigma^2_B = 0$

   H_1: $\sigma^2_B \neq 0$

2. Test Statistic: $F_{(30, 3465)} = \dfrac{S_B{}^2}{S_E{}^2}$

3. Reject H_o 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_o: $\sigma_R^2 = 0$

   H_1: $\sigma_R^2 \neq 0$

2. Test Statistic: $F_{(7, 3465)} = \dfrac{S_R{}^2}{S_E{}^2}$

3. Reject H_o 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_o: $T_1 = T_2 = \ldots T_j = \ldots T_r = 0$

   H_1: Not all zero

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

3. Reject H_o 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:

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

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:

$$\Sigma a_p = 0$$

The test of significance is given by:

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

where d_p is the weighted comparison factor for the pth comparison and is computed from:

$$d_p = \Sigma \ C_{ij} \ a_p$$

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:

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

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 signi-

ficant 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.

Mean Difference	$\Sigma\, a_p^2$	S_p	d_p	t
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}

$$\Sigma\, a_p^{\,2} = 112 \qquad S_p = 0.550 \qquad d_p = 5.4 \qquad t = 9.82$$
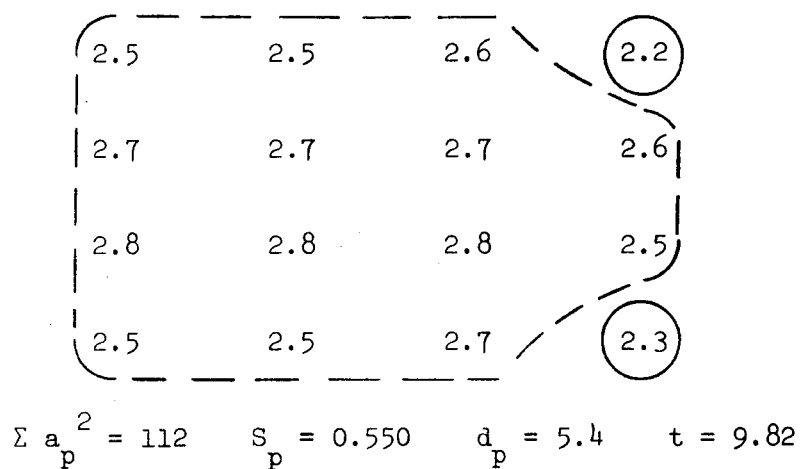
Figure 7.- Significant Comparison of Cells, C_{14} and C_{44}, to Grouped Remaining Cells

$$\Sigma\, a_p^{\,2} = 12 \qquad S_p = 0.180 \qquad d_p = 1.0 \qquad t - 5.55$$
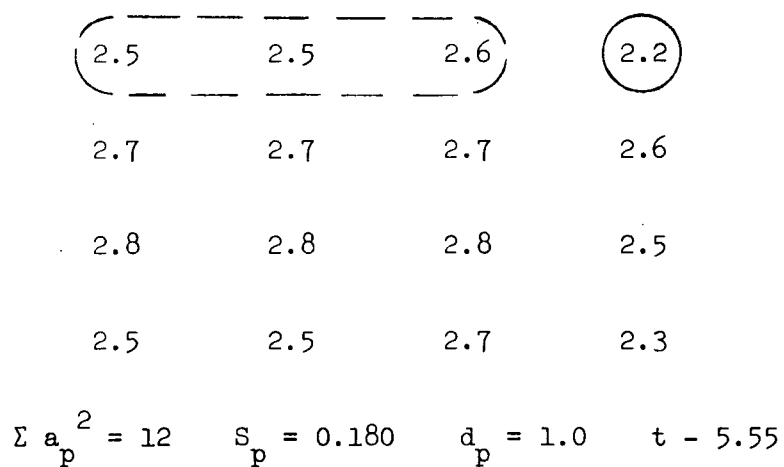
Figure 8.- Significant Comparison of Cell C_{14} to Other Grouped Cells of Top Row

$$
\begin{array}{cccc}
\boxed{2.5 \qquad 2.5 \qquad 2.6 \qquad 2.2} \\
(2.7 \qquad 2.7 \qquad 2.7 \qquad 2.6) \\
2.8 \qquad 2.8 \qquad 2.8 \qquad 2.5 \\
2.5 \qquad 2.5 \qquad 2.7 \qquad 2.3
\end{array}
$$

$$\Sigma \, a_p^{\,2} = 8 \qquad S_p = 0.147 \qquad d_p = 0.9 \qquad t = 6.12$$

(a) Top Row versus 2nd Row

$$
\begin{array}{cccc}
\boxed{2.5 \qquad 2.5 \qquad 2.6 \qquad 2.2} \\
2.7 \qquad 2.7 \qquad 2.7 \qquad 2.6 \\
(2.8 \qquad 2.8 \qquad 2.8 \qquad 2.5) \\
2.5 \qquad 2.5 \qquad 2.7 \qquad 2.3
\end{array}
$$

$$\Sigma \, a_p^{\,2} = 8 \qquad S_p = 0.147 \qquad d_p = 1.1 \qquad t = 7.48$$

(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. Com-
parisons 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 (exluding 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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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.

•

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

```
PRCGRAM BARF (INPUT,OUTPUT,TAPE 5=INPUT,TAPE 6=OUTPUT)
DIMENSION Y(50,16,8), YEARSLB(50), YBARCEL(16), NCLM(50),
YERMEAN
     1(50,16),NRUNN(50),YBARREP(8)
       REAL KLRT
C
C *** READ TCTAL NUMBER OF SUEJECTS
       READ(5,1) NSUB
       JLIM=16
       KLIM=8
     1 FORMAT(I2)
       IF(NSUB .GT. 5C)  GO TC 99
C
C *** READ IN DATA
       DO 2 I=1,NSUB
       READ(5,3) NUMSUB,NRUN
C
     3 FORMAT(2I2)
C *** ASSIGN DUMMY NLMBERS TC SUEJECTS
       NDUM(I)=NLMSUB
       NRUNN(I)=NRUN
       READ(5,4) ((Y(I,J,K),J=1,16),K=1,8)
     4 FORMAT(16F5.1)
     2 CONTINLE
C
C *** COMPUTE  MEAN CVER 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 FCR EACH SLBJECT
       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 GVER 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
      CO 15 J=1,JLIM
      DO 15 K=1,KLIM
      YNOW=Y(I,J,K)-YERMEAN(I,J)-YBARREP(K)+YBARTCT
   15 SSE=SSE+YNOW*YNOW
C *** COMPUTE INTERACTICN SUM OF SQUARES
      SSI=TSS-SSC-SSS-SSE-SSR
C
C     COMPUTE STANDARC CEVIATICN
      DEOM=NSUB*JLIM*KLIM
      SDNCW=TSS/DEOM
      STDDEV=SQRT(SCNOW)
C
C     CCMPUTE SKEWNESS
      SKEW=(TSS3/DECM)/(SDNOW*STCCEV)
C
C     COMPUTE KURTOSIS
      KURT=((TSS4/DECM)/(SCNCW*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/RTSTCT
      RTSMIN1=(NSUB*JLIM*KLIM)-1
C
C *** COMPUTE SCHEFFE CCMPARISCNS
      SUMASC=2.
      SDI=SQRT((SSUBE2*SUMASC)/(NSUB*KLIM))
      DI1=.6
      DI2=.5
      DI3=.4
      TI1=DI1/SDI
      TI2=DI2/SDI
      TI3=DI3/SDI
```

```
C
C *** COMPUTE F-RATICS
      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 BLCCKS*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*REPLICATICN*4X,F12.0,3F12.2/)
      WRITE(6,203) RTMIN1,SSI,SSUBI2,FRINT
  203 FCRMAT(1X*SUBJECTS X CELL*,F12.0,3F12.2/)
      WRITE(6,204) RTSTCT,SSE,SSUBE2
  204 FORMAT(1X*ERRCR*10X,F12.0,2F12.2/)
      WRITE(6,210) RTSMIN1,TSS
  210 FORMAT(1X*TOTAL*10X,F12.0,F12.2//)
      WRITE(6,205) YEARTOT,STCDEV,SKEW,KURT
  205 FORMAT(1X*TOTALMEAN=*F5.1,5X*SIGMA=*F6.2,5X*SKEW=
     *F6.3,5X*KURT=*F6 1.3//)
      WRITE(6,214) TI1,TI2,TI3
  214 FORMAT(1X*T .FCR .6=*F5.2,5X*T FOR .5=*F5.2,5X*T FCR
     .4=*F5.2//)




      WRITE(6,211)
  211 FORMAT(1X*OVERALL CELL MEANS*/)
      WRITE(6,212) YEARCEL
  212 FORMAT(10X,4F8.1/)
      WRITE(6,206)
  206 FORMAT(1X*OVERALL SUBJECT MEANS*/)
      DO 209 I=1,NSUB
      WRITE(6,207) ACLM(I), NFUNN(I), YBARSUB(I)
  207 FORMAT(5X,I3*-*I2,F6.1)
  209 CONTINUE
      GO TO 100
   99 WRITE (6,208)
  2C8 FORMAT (1X*TOC MANY SUBJECTS SUBMITTED*/)
  100 CCNTINUE
      END
```

APPENDIX C

COMPUTER PROGRAM FOR REAL-TIME SIMULATION

PROGRAM EXECUTIVE

```
      OVERLAY(OLFILE,0,0)
      PROGRAM INFO(INPUT=2C1,CUTPUT=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),MOMSW(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,ISMALL,MEC,LAR,IBLINK,IONCE
      COMMON/ALPHA/ALPH(45),XRRC(4),YRRC(4)
      LOGICAL EXECFLA,TOGSW,MOMSW,VARCHNG,LDISI,LDISO,LUGIC
      EQUIVALENCE (INTEG(1),ISCAN) , (INTEG(2),ITYPE)
      EQUIVALENCE (LDISI(48),INTABLS)
90034 FORMAT(6X* INFC-R.G.KYLE *5X*JOB,43,77777,75000. A3112,
     1 113544,1, R.W.WILL  R2142*)
      OLFILE=6LOLFILE
      CALL NAMECRT(6LCRTTPE,ERR)
      CALL PRIMARY(CLFILE,MF,9C034S,LDISI,IPL,ISL,TOGSW,MOMSW,EXECFLA)
      FND
```

SIMULATION INITIALIZATION

```
      OVERLAY(OLFILE,1,0)
      PROGRAM AINIT
      COMMCN/REALTIM/ANALGIN(32),DIGOUT(64),LDISI(1C8),LDISO(196),
     1 NOPER,NHOLD,NRESET,NTERM,NPRINT,NREAD
      CCMMON/VARBLK/VAR(20),INTEG(5),LOGIC(5),IVARBLF(5),VARCHNG
      CCMMON/DSPL/NVAR,NINTEG,NLOGIC,NALGIN,NDIGOUT,NLDISI,NLDISO
      CCMMCN/INTBUFF/TOGSW(15),MCMSW(11),EXECFLA
      CCMMON/EXTRA/MF,IPL,ISL
      CJMMON/STIM/ISTIM(128),IMIS(128),IREAD
      CCMM'JN/PTOUT/LEM(128),IAN(128),NITER,NRUN
      CCMMON/DISP/MINI,ISMALL,MED,LAR,IBLINK,IONCE
      CO4MON/ALPHA/ALPH(45),XRRC(4),YRRC(4)
      LOGICAL EXECFLA,TCGSW,MCMSW,VARCHNG,LDISI,LDISO,LCGIC
      EQUIVALENCE (INTEG(1),ISCAN) , (INTEG(2),ITYPE)
      EQUIVALENCE (LDISI(48),INTABLS)
      EQUIVALENCE (VAR(1),CELAY)
      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
      NVAR=20
      NINTEG=5
      NLOGIC=5
      NALGIN=32
      NDIGOUT=64
      NLDISI=108
      NLDISC=196
```

```
      CALL DATABLX(VAR,NVAR,INTEG,NINTEG,LOGIC,NLOGIC,ANALGIN,NALGIN,
     1 DIGOUT,NDIGOUT,LDISI,NLDISI,LDISO,NLDISO)
      NT=1
      CALL NM218(5LDSCAR)
      CALL XDSPLAY(LDISI,LDISC,VARCHNG,ITYPE,IVARBUF,INTABLS)
      DO 85 IND=1,196
   85 LDISO(IND)=.F.
      DO 86 IND=1,108
   86 LDISI(IND)=.F.
      DO 87 IND=1,15
   87 TOGSW(IND)=.F.
      DO 88 IND=1,11
   88 MOMSW(IND)=.F.
      EXECFLA=.F.
      CALL CRTNAM(4HINFO,0,0,5HAINIT,1,0)
      CALL CRTNAM(7HAOUTPUT,2,0,6HAINPUT,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)=4RXNOB
      ALPH( 9)=4RXY
      ALPH(1C)=4RXACT
      ALPH(11)=4RXIVE
      ALPH(12)=4RXOPE
      ALPH(13)=4RXRAT
      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
      XRRC(1)=350.
      XRRC(2)=475.
      XRRC(3)=600.
      XRRC(4)=725.
      YRRC(1)=715.
      YRRC(2)=590.
      YRRC(3)=465.
      YRRC(4)=340.
      DO 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)
      ISMALL=ISETSYM(1,0,0)
      MED=ISETSYM(2,0,0)
      LAR=ISETSYM(3,0,0)
      IBLINK=ISETSYM(2,0,1)
      IONCE=10
      DELAY=0.
      NRUN=0
      IPL=4
      ISL=0
      RETURN
      END
```

OUTPUT PRINTOUT

```
      OVERLAY(CLFILE,2,0)
      PROGRAM AOUTPUT
C
C      ******      TOGSW (6)   -   RELEASE
C      ******      TOGSW(11)   -   STORE DATA ON TAPE
C
      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),MOMSW(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,ISMALL,MED,LAR,IBLINK,IONCE
```

```
      LOGICAL EXECFLA,TOGSW,MCMSW,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),RUNNO) , (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
      DO 23 I=1,10
   23 AMN(I)=VA(I)=0.
      DO 540 I=1,16
      DO 540 J=1,8
  540 AERR(I,J)=3H
      DO 541 I=1,16
  541 IEK(I)=1
      DO 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=0
      AMAX=SIGMAX=0.
      LISP=0
```

```
      DO 2010 J=1,LIM
 2010 LISP=LISP+LEM(J)
      DISPL=LISP/ANITER
      WRITE(MF,2011) DISPL
      IRCT=0
      DO 20C0 I=1,16
      DO 20C0 J=1,8
 2000 AMEN(I,J)=0.
      DO 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(IRK,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)
      DO 2005 I=1,16
      ATOT(I)=0.
      DO 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
      DO 16 J=1,32
   16 COUNT(J)=0.0
      ISAMP=0
      DDEL=SCT/32.
      ERCT=C
      DO 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
      ICTOT=1
      BASE=16.*DDEL
      IF(DEL .LT. BASE) GO TO 531
      ICTOT=ICTOT + 16
```

```
      BASE=16.*DDEL + BASE
 531  BASE=BASE - 8.*DDEL
      IF(DEL .LT. BASE) GO TO 532
      ICTDT=ICTDT+8
      BASE=BASE+8.*DDEL
 532  BASE=BASE-4.*DDEL
      IF(DEL .LT. BASE) GO TO 533
      ICTDT=ICTDT+4
      BASE=EASE + 4.*DDEL
 533  BASE=BASE - 2.*DDEL
      IF(DEL .LT. BASE) GO TO 534
      ICTDT=ICTDT+ 2
      BASE=EASE + 2.*DDEL
 534  BASE=BASE - DDEL
      IF(DEL .LT. BASE) GO TO 535
      ICTDT=ICTDT+1
 535  COUNT(ICTDT)=COUNT(ICTDT) + 1.
      ISAMP=ISAMP+1
   3  CONTINUE
      IF(ISAMP .EQ. 0) GO TC 2122
      BASE=.5*DDEL
      XTRA=C.0
      DO 4 I=1,32
      XTRA=XTRA + COUNT(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 + COUNT(I)*YTRA*YTRA
      ZTRA=ZTRA+COUNT(I)*YTRA*YTRA*YTRA
      UTRA=UTRA+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=UTRA/(ISAMP*RIG) -3.
      WRITE(MF,66) AMEAN,SIG,ZIG,SKW,AKUR,ERCT,ISAMP
 2122 CONTINUE
      BASE=-.5*DDEL
      AMXCT=0.
```

```
      DO 76 J=1,32
   76 IF(COUNT(J) .GT. AMXCT) AMXCT=COUNT(J)
      DO 77 J=1,32
      IDIS=COUNT(J)+1
      DO 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)
      DO 767 I=1,IDIS
  767 A(I)=3H
   77 CONTINUE
      GO TO(201,202,203,204,211),IRCT
  201 ID=1
      WRITE(MF,2007) ID
      GO TO 55
  202 ID=2
      WRITE(MF,2007) ID
      GO TO 55
  203 ID=3
      WRITE(MF,2007) ID
      GO TO 55
  204 ID=4
      WRITE(MF,2007) ID
      GO 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(.NOT. MOMSW(6) .AND. .NOT. 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
      DO 69 J=1,LIM
      IMIS(J)=0
      IAM(J)=0
   69 LEM(J)=0
    2 FORMAT(I4,44A3)
      DO 70 I=1,16
      DO 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.*I2/)
    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,I1,1X,16F5.1/)
 2006  FORMAT(3X,16F5.1//)
 2007  FORMAT(1X*KEY*I2)
 2011  FORMAT(1CX*CUMUL RESP TIME=*F9.1/)
 2018  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,A3,2X,A3)
 2021  FORMAT(1X*TOTAL ERRORS =*I3)
       RETURN
       END                          READ INPUT


       OVERLAY(OLFILE,3,0)
       PROGRAM AINPUT
       COMMON/REALTIM/ANALGIN(32),CIGOUT(64),LDISI(1C8),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,ISMALL,MED,LAR,IBLINK,IONCE
       COMMON/ALPHA/ALPH(45),XRRC(4),YRRC(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
       IONCE=0
       RETURN
       END
```


REAL TIME LOGIC

```
       OVERLAY(OLFILE,4,0)
       PROGRAM RTMAIN
       COMMON/REALTIM/ANALGIN(32),CIGOUT(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,ISMALL,MED,LAR,IBLINK,IONCE
       COMMON/ALPHA/ALPH(45),XRRC(4),YRRC(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),CELAY)
      EQUIVALENCE (VAR(2),SCT)
      EQUIVALENCE (VAR(3),ALIM)
      EQUIVALENCE (VAR(5),RUNNG) , (VAR(6),RESTIME)
      EQUIVALENCE (VAR(7),STIMNO)
      DIMENSICN XV(7),YV(7)
      DIMENSICN NAA(4,4)
      CALL SECOVL
      CALL CYCLE(90CC6S)
      ASSIGN 90001 TC NOPER
      ASSIGN 90002 TO NHCLC
      ASSIGN 90003 TO NRESET
      ASSIGN 90004 TO NTERM
      ASSIGN 9C014 TO NPRINT
      ASSIGN 90015 TO NREAC
      AC=RANF(.5)
      PROB1=PROB2=PRCB3=.25
      CALL READY
      CALL RTMCDE
90003 CGNTINUE
C     *****                    RESET LOOP
      TCGSW(1)=.F.
      IF(IGNCE .EQ. 0) GO TC 110
    1 CALL SEND
      CALL ENABLE(1S)
      CALL HALT
      IGNCE=0
      CALL LNLODE
      CALL READY
  110 CGNTINUE
      LIM=ALIM
      IF(LIM .GT. 128) LIM=128
      IGO=0
      IEV=0
      ICEL=DELAY*NITER
      ICT=-1
      ITIM=C
      ISTART=0
      IENO=C
      ITWO=1
      SAVE=C.
90002 CGNTINUE
C     *****                    HCLD LCOP
90006 CGNTINUE
C     *****                    CPERATE LOOP
      AC=RANF(0.)
C  ***       SCANNER FUNCTION**********
90047 LDISO(124)=LDISI(22)
      IF(LDISI(22)) CALL SCANNER(ISCAN)
C**** CCMMUNICATION WITH REAL TIME DISPLAY
      CALL CSPLAY
C**** RETURN TO MODE CCNTRCL SLBRCUTINE
90050 CGNTINUE
```

```
        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(MCMSW(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(MCMSW(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=RANF(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 6
    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
     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(68)=.F. $ LDISC(59)=.T.
          CALL CRTCODE(1,ISMALL,0,C)
          CALL CRTCODE(1,ALPH(36),460.,150.)
          CALL CRTCODE(1,ALPH(36),740.,150.)
          CALL CRTCODE(1,ALPH(36),232.,150.)
          ICT=ICEL+3
          GO TO 27
    26 CONTINUE
          CALL ENABLE(26S)
          IF(ITWO .NE. 3) ITWO=13
          LDISO(68)=.T. $ LDISC(69)=.F.
          CALL CRTCODE(1,ISMALL,0,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,0,0)
          CALL CRTCODE(2,ALPH(1),470.,895.)
          CALL CRTCODE(2,ALPH(3),570.,895.)
          XV(1)=465. $ XV(2)=690.
          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.
```

```
      CALL VECTORS(2,XV,YV)
      CALL CRTCODE(2,ALPH(25),20.,560.)
      CALL CRTCODE(1,ALPH(5),140.,560.)
      CALL CRTCODE(2,ALPH(3),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(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)=29C. $ 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,C)
      CALL CRTCODE(2,ALPH( 5),356.,830.)
      CALL CRTCODE(3,ALPH( 7),475.,830.)
      CALL CRTCODE(2,ALPH(1C),606.,830.)
      CALL CRTCODE(4,ALPH(12),702.,830.)
      CALL CRTCODE(4,ALPH(16),190.,725.)
      CALL CRTCODE(3,ALPH(20),208.,6CC.)
      CALL CRTCODE(3,ALPH(33),202.,475.)
      CALL CRTCODE(2,ALPH(23),214.,350.)
      CALL CRTCODE(1,LAR,0,0)
      DO 102 I=1,4
      DO 102 J=1,4
  102 CALL ENCODEI(NAA(I,J),1,XRRC(I),YRRC(J))
      IF(.NCT. IERR) GO TC 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 HALT
      CALL UNLODE
      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(4C),372.,468.)
      CALL CRTCODE(3,ALPH(43),356.,304.)
   27 CONTINUE
      CALL RITE250
      CALL HALT
      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. TOGSW(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 ███████████ and received his primary and
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