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DETERMINATION OF THE OPTIMUM RESOLUTION ELEMENT FOR A PILOT WARNING INDICATOR

by

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June, 1970

S.M. Thesis

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(1969)

SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 1970

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Department of Aeronautics
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Certified by Renwick E. Curry

Thesis Supervisor

Accepted by ______________________

Chairman, Departmental
Graduate Committee

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Submitted to the Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, on June 4, 1970, in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

There is a need for a low cost pilot warning indicator for general aviation aircraft. This device, as currently proposed, would involve a xenon strobe mounted on all planes and a sensor element mounted on planes desiring the PWI capabilities. The PWI device would, on detection of a nearby aircraft, warn the pilot of the danger and assist him in locating the threatening aircraft.

Experiments were performed in order to determine how accurately the PWI device need establish the direction of an incoming threatening aircraft. It is important that pilot response be as rapid as possible but, at the same time, the cost of the warning device must be kept low. Because of this, a PWI resolution was sought such that near optimum pilot performance could be expected and such that no excessive resolution need be purchased.

Examination of the data revealed that a resolution element of about 11° X 11° is optimal for a low cost device. Resolution of about 6° X 6° gives somewhat better pilot performance, but the increased cost of instrumenting this reduced sector size was not justified by the slight increases in pilot performance.

Thesis Supervisor: Renwick E. Curry

Title: Assistant Professor of Aeronautics and Astronautics

ACKNOWLEDGEMENTS

The author wishes to thank Professors Renwick E. Curry and Laurence R. Young, and Mr. George Economou for their guidance and suggestions in preparation of this experiment.

Special thanks are offered to Dr. Ann Story for her interest and advice on pyschological aspects of this project and to Chuck Oman for his instruction on the hybrid computer.

Mr. Roger Marian also assisted in the construction of the test equipment.

This research was sponsored under NASA-ERC grant NGR-22-009-444.

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CHAPTER 1

INTRODUCTION

Most general aviation aircraft operate in the relatively crowded airspace of less than 10,000 feet. Many of these aircraft fly out of uncontrolled airfields and maintain minimum contact with air traffic control. Unlike commercial aviation or military aircraft, general aviation relies almost exclusively on the "see and be seen" principle to avoid mid-air collisions. That is, collisions are prevented merely by constant vigilence on the part of the pilot. One need only look at the alarming statistics on the number of mid-air collisions and the even greater number of near misses to recognize that this system is not satisfactory. The era in which such a simplistic approach was accepted is coming to a close. The higher speeds and the ever increasing density of aviation today call for a more reliable system.

Commercial and military aircraft planners have long recognized this problem. Elaborate collision avoidance aids have and are being developed for these craft. Unfortunately, these devices cost many thousands of dollars. In fact, the cost of current electronic collision avoidance devices is several times the purchase price of many small aircraft. It is hard to imagine installing these expensive aids on the typical small plane.

The pilot warning indicator is an attempt to find a compromise solution. Principally, this device would warn the pilot of possible collision threats and hopefully provide him with sufficient time and information to sight the threatening aircraft and take appropriate measures. It is hoped that, by sacrificing certain elaborate features of the existing collision avoidance devices, an acceptable, worthwhile and reasonably priced warning mechanism might be developed.

This economy represents several noteworthy reductions in performance. First, the PWI will not aid the pilot in selecting an effective evasive maneuver. The probability of a pilot error leading to a collision is therefore greater with the PWI than with the elaborate collision avoidance devices. Secondly, it will present the pilot with a significant number of false alarms, possibly as many as seven false alarms for every real one. Because of this, the pilot may develop a tendency to ignore warnings. The last and most serious flaw of the PWI device is that, in certain cases, it may in fact fail to give any warning of an approaching aircraft. The optical sensor is sensitive only in regions of likely threats. If an aircraft approaches from an unlikely angle, for example, from above, the PWI device may give no warning.

Despite these shortcomings, PWI offers an opportunity for increased safety since it supplements pilot senses so as to overcome basic weaknesses. A pilot of a general aviation aircraft seems to be poorly adapted to the task of maintaining constant and vigilent scanning of the sky for incoming planes. PWI will help him in this searching task and can reliably detect an approaching aircraft before it is even visible to the pilot. The sky is broken down into several sensitive regions or sectors. When the flashes from the strobe of a nearby plane are detected within a sector, an alarm is sounded and information indicating which sector originated the alarm is passed to the pilot. He can then scan the sky corresponding to the alarm sector. If this sector is sufficiently small, it is reasonable to expect that the pilot will more easily be able to locate the plane. Naturally, the design of the PWI should attempt to optimize the performance of the PWI/pilot system so as to achieve a maximum safety level.

PWI takes a task which was entirely in the domain of the pilot and breaks it into two parts. The first portion, initial detection of the plane, is assumed by the instrumentation and PWI hardware. Extensive hardware studies have been performed[1] or are currently in progress on various PWI systems. In general, they tend to confirm the soundness of the beacon-sensor concept for PWI. The second portion, final search, sighting and avoidance, remains with the pilot. Good pilot performance in his task requires a smooth interface between the instrument and the pilot. This interface is some kind of warning display. Work on various types of heads up and audio displays is being done in conjunction with this study at the Man-Vehicle Lab. In addition, some preliminary work on PWI displays was done at Dunlap and Associates[21] and by Charles Burr, again at the Man-Vehicle Lab. These studies have been primarily concerned with a comparison of the effectiveness of differing displays under similar PWI conditions.

Essentially, this instrument should not attempt to develop and relay uselessly detailed instructions as to target position in the sky. If the pilot can only effectively utilize a limited degree of resolution, an attempt to relay more detail is wasteful. First, it adds to the cost of the device without any benefit. Secondly, the added time spent by the pilot in analyzing the more detailed information may degrade his performance.

This study more closely analyzes the role of the pilot in a PWI system. The work done by John Volkmann[22] is suggestive of the problem which was investigated. Volkmann observed that, with relatively small search fields, the search time is reasonably short. Search performance is only slightly degraded as the field of search grows larger. This trend seems to break down sharply at some critical field size and further increases in size bring sharp drops in search effectiveness. This work suggests that the same factor may effect PWI implementation. If this is the case, PWI devices should strive to have a resolution segment of about the same size as this critical element. Increasing resolution could not be expected to substantially reduce search time. A decrease in resolution would result in heavy penalties because the pilot's search would become markedly less efficient. Naturally, if such an optimum size existed in the PWI situation, the critical sized sector might be expected to be a vague function of the varied out the window fields of view available from a cockpit.

The purpose of this study is to investigate the relationship between instrument resolution and the pilot's efficiency in locating the target. It was hypothesized that an optimum sized resolution element or sector might be found so as to guide the development of the actual PWI device. It was, of course, hoped that under most conditions the optimum sector size or area to be searched would not be the trivial solution, the smaller the better. The following factors were investigated:

(1) Time to locate a threatening target against a cluttered background. The variables were:

(a) Contrast between target and background

(b) Sector size to be searched

(2) Time to locate a threatening target against a relatively less cluttered background. The variables were:

(a) Contrast between background and target

(b) Sector size to be searched

All tests were conducted using a screen which covered $\pm$ 80° in azimuth (0° straight ahead) and $\pm$ 25° in elevation. No attempt was made to reproduce aircraft out the window scenes with any visual fidelity. Instead, a controlled background was created which was uniform in brightness and visual clutter over the entire screen. This allowed the establishment of reproducibly baseline data which might then be extrapolated to influence the design of an actual flight instrument.

CHAPTER 2

EQUIPMENT

The test equipment consisted of the following major items.

(1) Wide angle screen

(2) Three Kodak 600 slide projectors

(3) One Kodak 750 slide projector

(4) Turntable with associated drive equipment

(5) Hybrid computer; PDP-8/GPS 290T digital analog computer

Figure 2.1 shows the basic experimental arrangement of this equipment.

2.1 Wide Angle Screen

A wide angle circular screen was constructed from two 4'X8' masonite panels. The radius of curvature was roughly 4.75 feet. The center of the screen was about 4 feet from the floor. From the subject's point of view, the screen covered about 160^{0} horizontally and about 40^{0} vertically. The screen was painted white with a rough matte finish. Figures 2.2 and 2.3 show the screen and the subjects location relative to it.

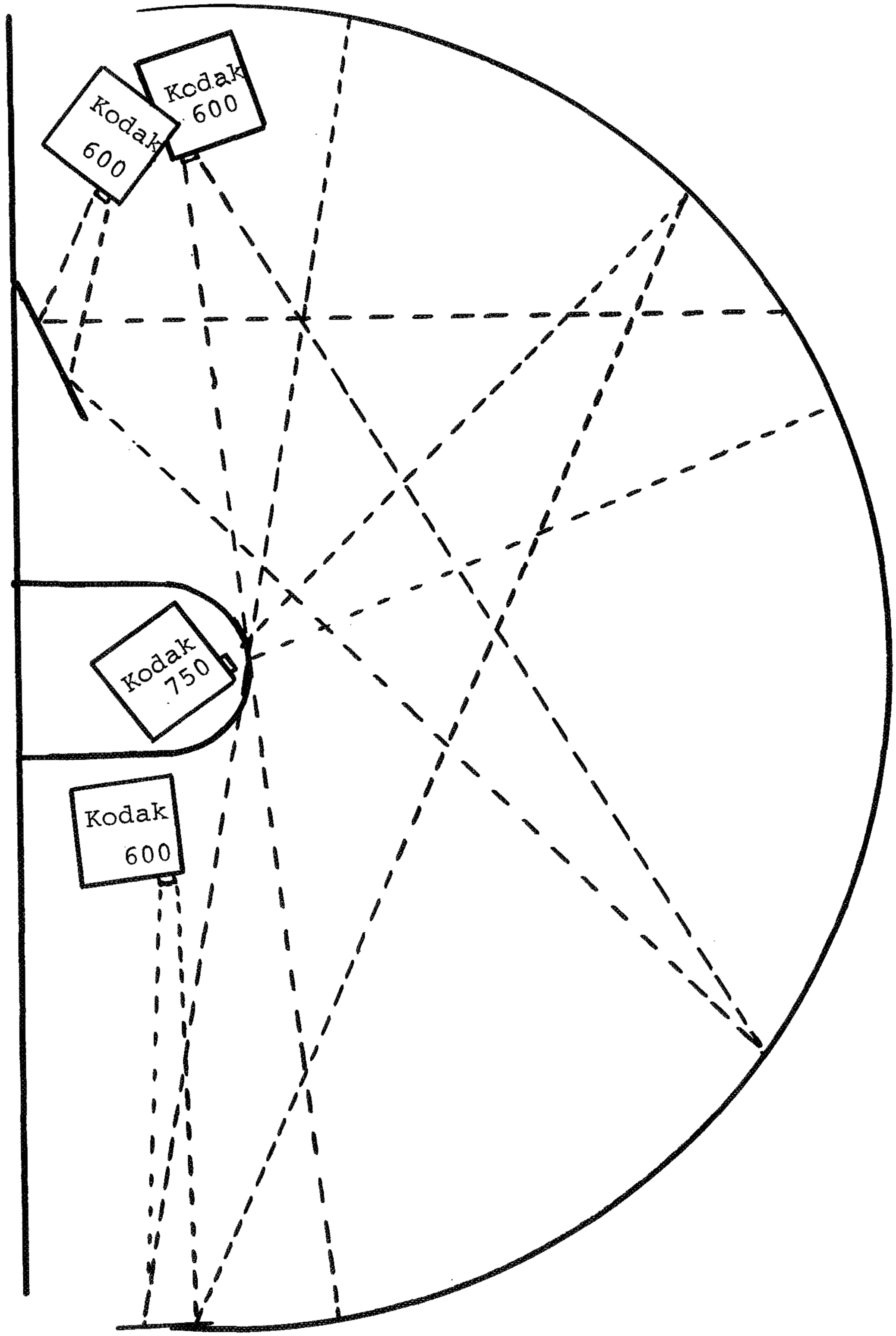


Figure 2.1: Basic Layout of Projectors and Screen.

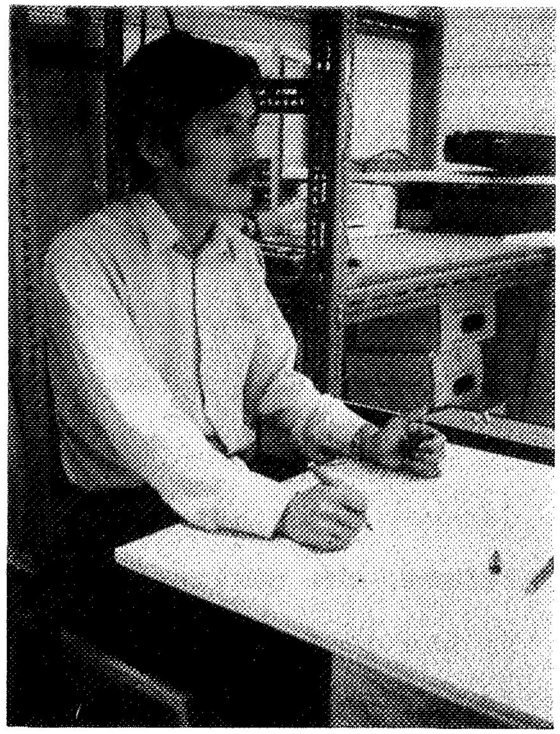


Figure 2.2 Subject in Position

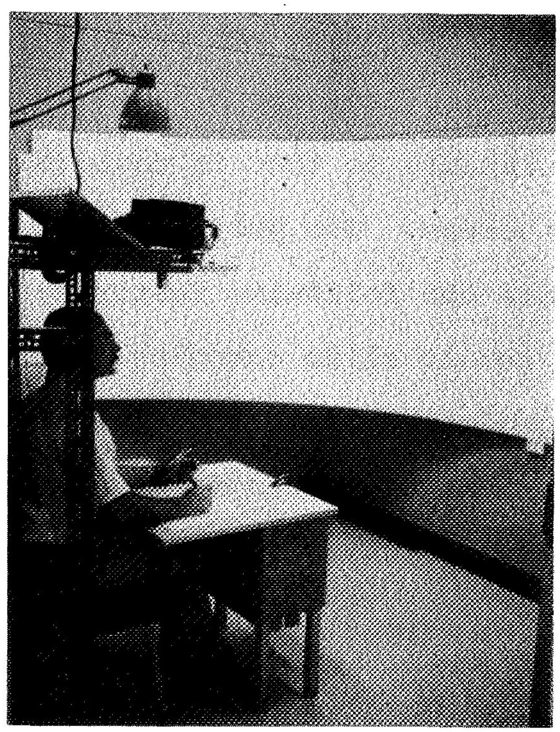


Figure 2.3 Subject Relative to Screen

2.2 Background Projectors

The three Kodak model 600 slide projectors were used to project a wide angle background scene onto the screen. Without slides, the three projectors provided an even 60 foot candles of light across the surface of the screen. This represented about the brightest white which could occur in the background scene. Ambient light in the room varied from 5 foot candles to 15 foot candles. This was essentially the darkest black which could occur in the background. Therefore, the maximum contrast ratios that could occur in the background were between 15 to 1 and 4 to 1. Two of the three projectors and shown in figure 2.4.

2.3 Target Projector

A Kodak model 750 slide projector was used to project the target and sector indication. The projector was mounted on a turntable so that it could be pointed at any portion of the screen. The projector was modified so as to incorporate the following features:

(1) Remote slide changing. Slides could be changed on command from the computer. Slide selection was either forward or backward through a circular tray.

(2) The projector lamp could be turned on or off via the computer.

Together, these modifications allowed the automated computer selection of any of the slides in the tray. In addition,

Figure 2.4: Two Background Projectors.

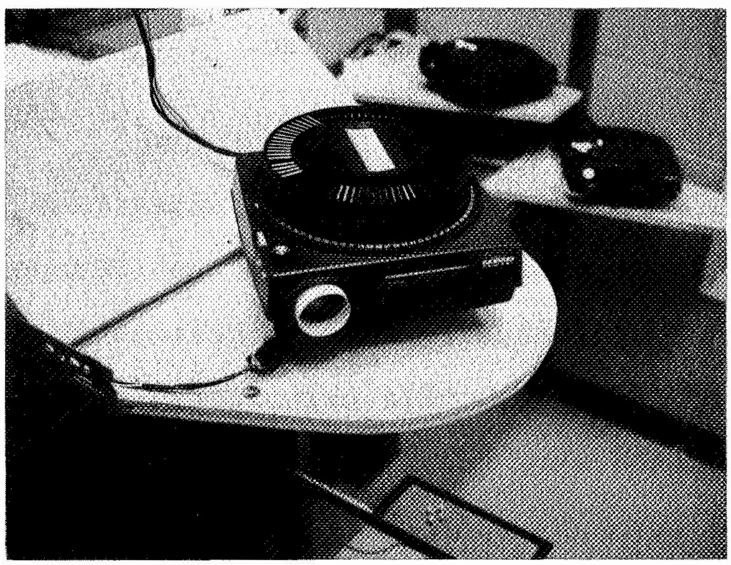


Figure 2.5: Target Projector on Turntable

the lens of the projector was fitted with two polarized filters which could be manually rotated against each other so as to vary the intensity. This allowed an easy adjustment of the contrast ratio between background and target. This projector is shown in Figure 2.5.

2.4 Turntable

The target projector was mounted on a low rpm turntable which could direct it toward any portion of the screen. The turntable turned at a constant speed of roughly one revolution per minute. The power supply needed to drive the motor was a 27 volt D.C. power supply. A feedback pot measured turntable position allowing closed loop control. Turntable movements and therefore target positionings were directed by the hybrid computer.

2.5 Hybrid Computer (Figures 2.6 and 2.7)

A hybrid computer controlled the experiment. It consisted of a PDP-8 with 4K of core, two DECtape drives, a teletype, and digital to analog interfaces to the GPS 290T analog computer. In this experiment, all logic and feedback functions were controlled via the digital portion of the system with the analog computer serving as an interface to relay open loop instructions to the equipment and conduct "sensory" measurements back to the digital logic. The computer selected the slides, controlled the turntable and provided timing of all events. In addition, the computer compiled relevant data during the execution of the experiment.

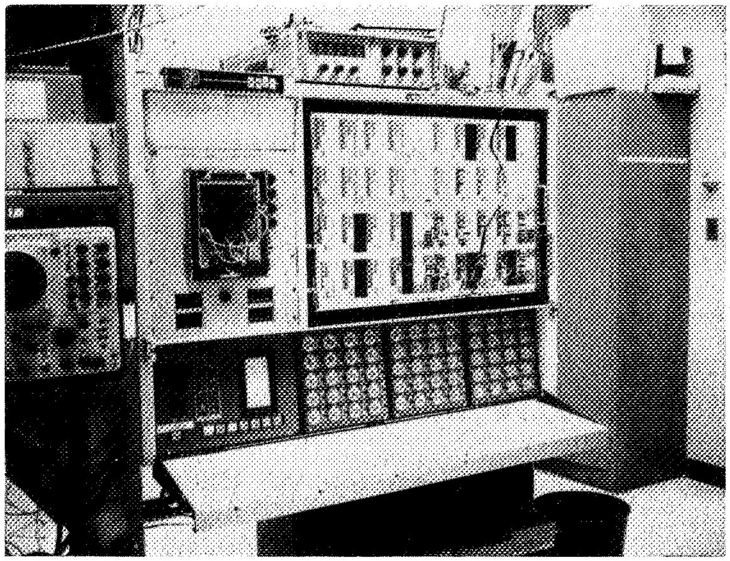


Figure 2.6: GPS 290T Analog Computer.

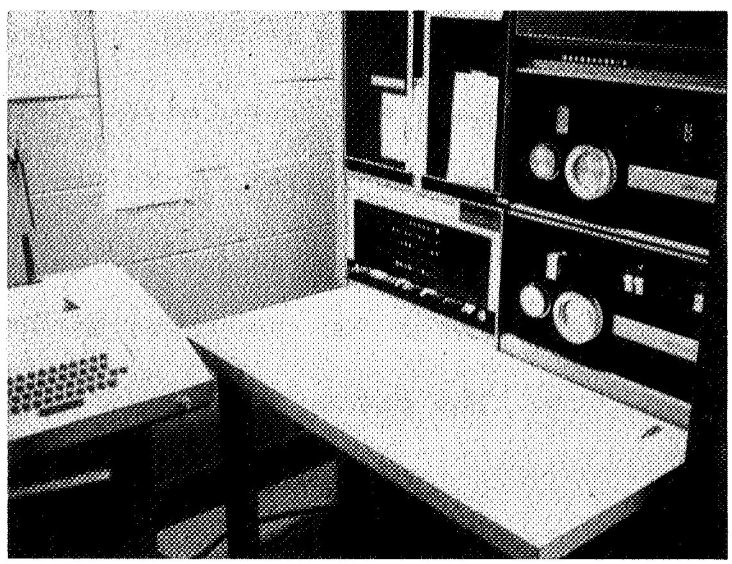


Figure 2.7: PDP-8 Digital Computer

CHAPTER 3

EXPERIMENTAL DESIGN AND PROCEDURES

The basic objective in the design of this experiment was to provide an efficient means of obtaining data on subject response to a number of idealized simulations of PWI warnings. In order for this basic objective to be met, it was necessary to conduct a large number of experimental trials varying several parameters. A highly automated means of performing this task was devised. With this technique, rapid data collection and repeated and varied trials were placed under computer control and combined with data reduction and analysis.

Computer control allowed for the rapid manipulations of several parameters. The parameters so controlled were as follows:

(1) Horizontal position of the search sector on the screen. This simulated warnings from different azimuths.

(2) Sector size. The area to be searched could

be varied in size simulating differing resolution PWI instrumentation.

(3) Background quality. The amount of visual clutter or noise in the background could be varied.

(4) Target contrast against the background. The conspicuousness of the target against the background could be varied by adjustment of 3 and 4.

(5) Position of the target within a given sector.

A single trial of the experiment followed a specific series of events.

First, the sector size and target position within the sector are selected. This is done by the selection of a single slide from the slide tray. Both the target and the selector indication are projected from the same slide. As mentioned previously, the sector indication is a white box which encloses the area to be searched. The target is a triangle within that box. It is elongated and points either up, down, left or right. Because the target position within a sector on a given slide is fixed, it is necessary to have several slides with identical size sectors in order to vary target positioning within a sector. Once the slide has been chosen, it is loaded via the projector slide changing mechanism into a postion ready for projection.

Slide selection is done automatically on command from the hybrid computer. Although the computer may easily select slides at random, this was not in fact done. The slides were stepped through sequentially in the forward direction until they were exhauseted. The direction was then reversed and the same slides were backed through to the start slide by slide. On reaching the start, the process was repeated. A simple table stored in core memory provided the computer with the relevant information it needed to control this task. The slides were arranged in a psuedo random fashion within the tray so as to give the appearance of random slide selection.

After slide selection and loading, the projector is moved to point toward a particular portion of the screen. The projector is mounted on a turntable to facilitate this and a feedback pot measures projector position allowing closed loop control. Projector positioning is done by the computer under program control. In order to prevent the subject from attempting to track projector position as a function of the time required for positioning the projector, a random walk to several intervening positions is employed. Projector movements are executed in accordance with the entries in another data table stored in core memory. Positioning is done with an accuracy of 1 part in 64 over a range of roughly 160 degrees or to about 2 or 3 degrees.

When the slide is ready and the projector correctly positioned, an alarm is sounded and the projector lamp is lit projecting the target and sector indications onto the screen. This projector has two polarized lenses which can be rotated against each other in order to vary target and sector indicator intensities. This allows differing contrast ratios between the target and the background. The adjustment of this ratio is done manually before each series of trials. The alarm is a square wave tone of roughly 800 cycles per second.

When the subject locates the target within the sector, he presses a hand held button. Both the alarm and projector lamp are shut off on this signal. The computer records the total elapsed time from the onset of the alarm until the button is pressed. Timing is done utilizing the variable clock in the GPS 290T computer. Resolution in time is to better than one thousandth of a second.

The subject is then required to identify which direction the target was pointing. He indicates this response by pressing one of four buttons. Data from the trial is compiled into running statistical sums if he correctly identified the target. If he cannot, an error is recorded. If the subject is unable to locate the target within 32 seconds, the alarm and lamp are shut off and an error is recorded. While the computer is waiting to receive the target identification from the subject, the next slide is selected and the projector positioning initiated.

The subject is required to work on a secondary task during slack moments between trials. This task involves the marking of a table of random numbers identifying specific number patterns. Specifically, the subject was asked to mark chains of three increasing or decreasing digits. The exact nature of the task is described in great detail in the instructions to the subject, a copy of which is enclosed in the appendix.

Data from each trial is collected by the computer. At the end of each trial, this data is analyzed and combined with data from previous trials. In this fashion, data analysis and reduction takes place as the experiment is running.

Data from a single trial is combined with data from similar trials. The experimentor is free to define what characteristics the computer should use in defining or setting up these trial groupings. Sector size, target positioning within the sector, sector heading or any combination of the above may be used to define trial groupings. The computer has a capacity to accumulate statistics on up to 24 such groupings. For this thesis, the sector's size was used as the grouping parameter. Different series of runs were made for different target contrast and background conditions with the computer providing an instant analysis of the data broken down by sector size for each run.

Briefly, each statistical abstraction of data for one particular grouping or sector size includes the following data:

(1) Number of trials making up this group

(2) Number of valid trials included within this group. A valid trial is one in which the subject located the target within 32 seconds and was able to correctly identify it.

(3) Mean response time. This is the mean or average time required to locate the target. This

is the mean of the valid trials.

(4) Variance. This is the square of the standard deviation among the response times of the valid trials.

(5) Histogram of data. This is a simple compilation of a number of trials with reaction time lying in certain time intervals. The time intervals were broken down into half second segments from 0 to 27 seconds. The last segment 27.0 - 27.5 seconds also includes 27.5 - 32.0 seconds.

Subjects were run under various background and contrast conditions. Basically, contrast between background and target was adjusted by means of the double polarized lens on the target projector. Contrast within the background, that is, difference between maximum bright spots and maximum dark spots, was adjusted by changing the ambient light level in the room. This was done by changing the wattage of a single light source mounted just above the target projector.

A series of about 20 subjects was used and an attempt was made to limit the number of repeated subjects so as to eliminate any learning which might take place during repeated exposure to the mechanization of this experiment. Each series of runs was about 30 minutes long and included about 80 trial events.

CHAPTER 4

SUMMARY OF DATA

4.1 General Form Used in Data Presentation

Over 800 separate trials were conducted in order to compile the statistics presented in this thesis. Naturally, with such a large amount of raw data available, it was necessary to develop a means of summarizing the data in order to properly evaluate it.

Basically, two distinct series of trial runs were made. The first series of trials was conducted with a highly cluttered background. The search for the target against such a background might be compared in difficulty to the problem of locating another aircraft against the cluttered background of the ground below. A second series of runs was conducted against a much brighter and less cluttered background. This represented the task of locating a plan against the sky.

The background used in the first portion of the study was a speckled scene with each bright speckle being slightly smaller than the target. The region between speckles was relatively dark. Speckles were about 15 times as bright as the dark regions between them. The light projected on the surface of the white screen formed a speckled pattern which was 60 foot candles bright at the center of a speckle and 4 foot candles bright between speckles. A photograph of the highly speckled background is shown in Figure 4.1. Beneath the high contrast background is the brighter, more uniform background used in the second series of runs. This background is similar to the first except that the blobs are not as clearly defined. The maximum contrast between the lightest and darkest region has been reduced to about 4 to 1. The lightest regions are about 80 foot candles bright and the darkest regions are about 20 foot candles bright.

Within a single series, several sets of trials were run with targets of different brightness. Each of these smaller sets of trials included about 100 trial events. For each set, the brightness of the target was adjusted manually by means of the polarized lenses. This allowed an examination of the subject's reaction time as a function of target contrast and conspicuousness. At each of these fixed brightness levels, the subject was presented with a random mix of trial situations using differing sector sizes located at randomly selected headings.

Data is grouped such that all trials with the same sector size, target intensity and background are combined into one statistical picture. For a single group, these

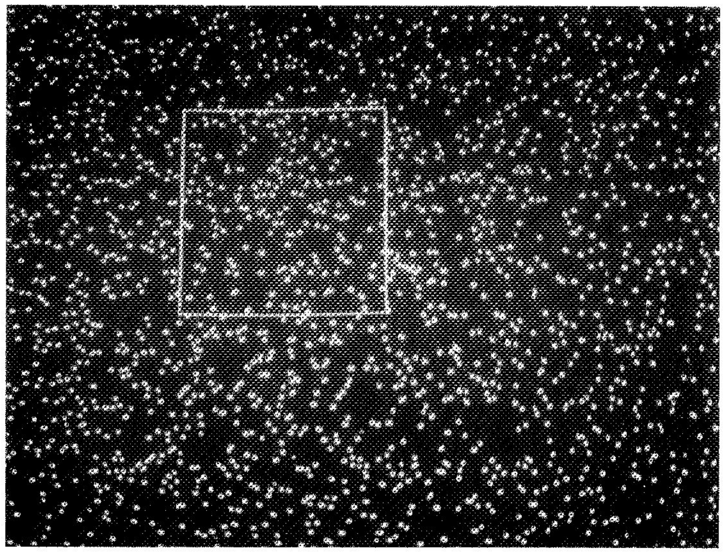


Figure 4.1: High Contrast Background

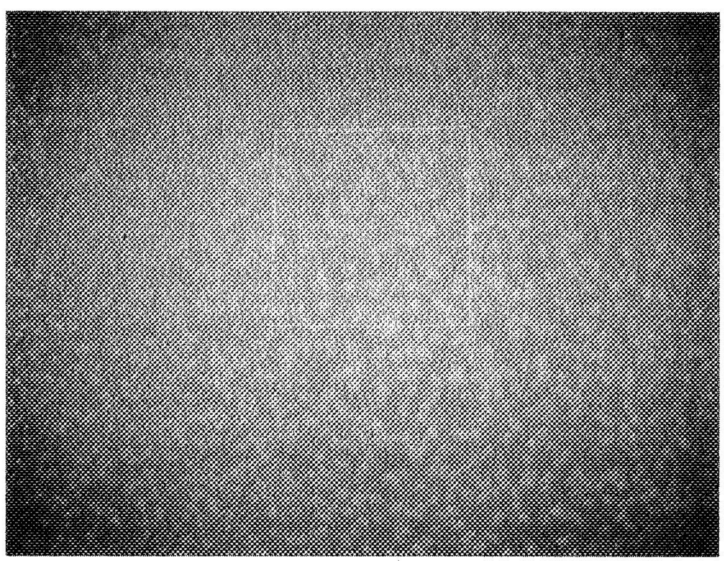


Figure 4.2: Uniform Background

statistics are reported on single pages in Section 4.2. The data items concerning a single data group are as follows:

(1) Background used; either high or low contrast.

(2) Target brightness; target projector light intensity at the surface of the screen.

(3) Sector size; field of view covered by the search sector.

(4) Mean time; the mean time required for the subject to locate the target.

(5) Standard deviation; the standard deviation of the time required to locate the target.

(6) Error rate; the percentage of trials in which the subject fails to correctly identify the target.

(7) Histogram of results; this is a graphical abstract of the data. The time axis is broken down into half second intervals and the percentage of trials with response times falling in the various half second intervals is shown. The bar labelled "e" on the graph represents the error rate.

It should be noted that, in some of the graphs, the data seems somewhat coarse. This coarseness is a function of the number of trials used in generating the data. If larger numbers of trials were made, it would be expected that the data might fit under a smoother envelope. The difficulty in performing greater numbers of trials for a single set of parameters more than outweighs the refinement in data possible with this increased effort. The decision was made to cover a larger number of basic parameter combinations rather than concentrate too heavily on a limited set of parameter combinations.

4.2 Tables of Results

Figures 4.3 through 4.27 summarize the data collected for this thesis.

High Contrast Background

Sector Size = 2.7° X 2.7°

Target Intensity = 20 foot candles

Mean = 2.3 Median = 2.3

Standard Deviation = .37

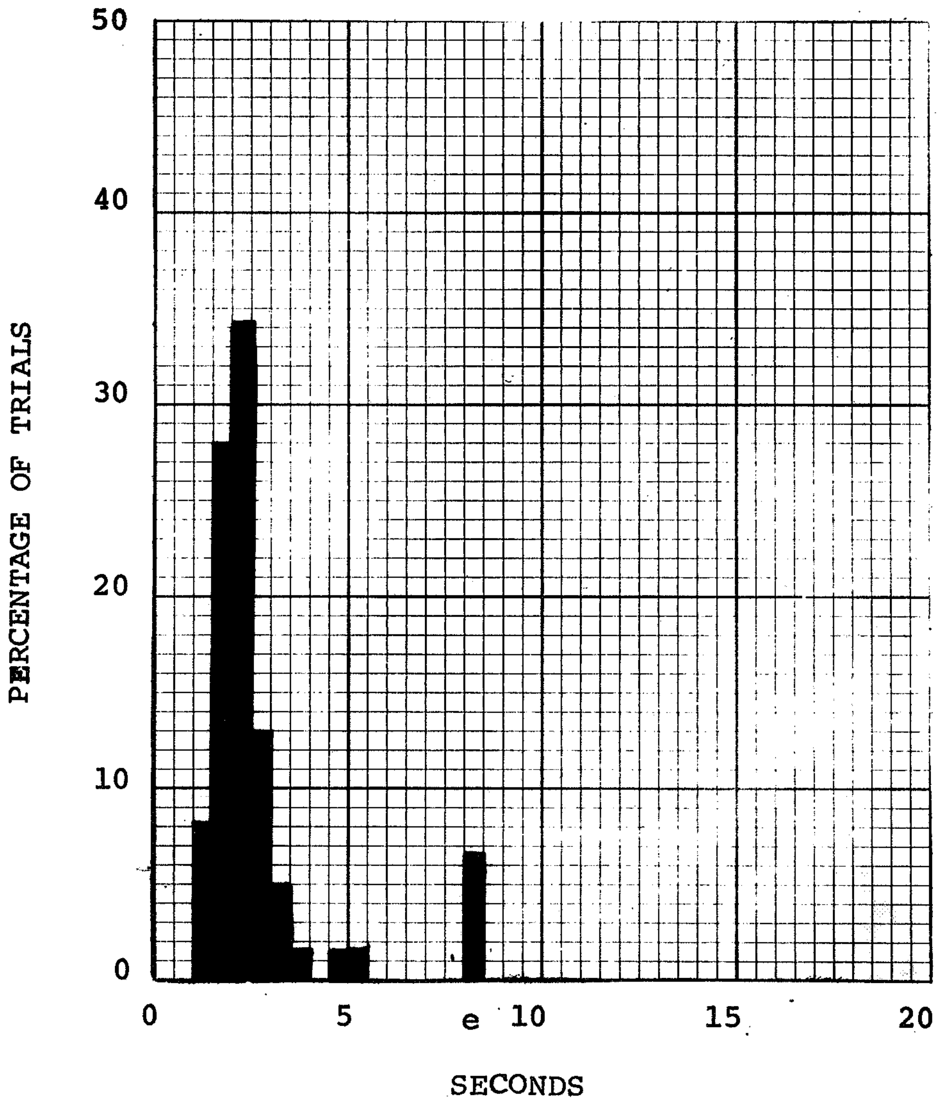


Figure 4.3

High Contrast Background

Sector Size = 5.5° X 5.5°

Target Intensity = 20 foot candles

Mean = 2.4   Median = 2.4

Standard Deviation = .65

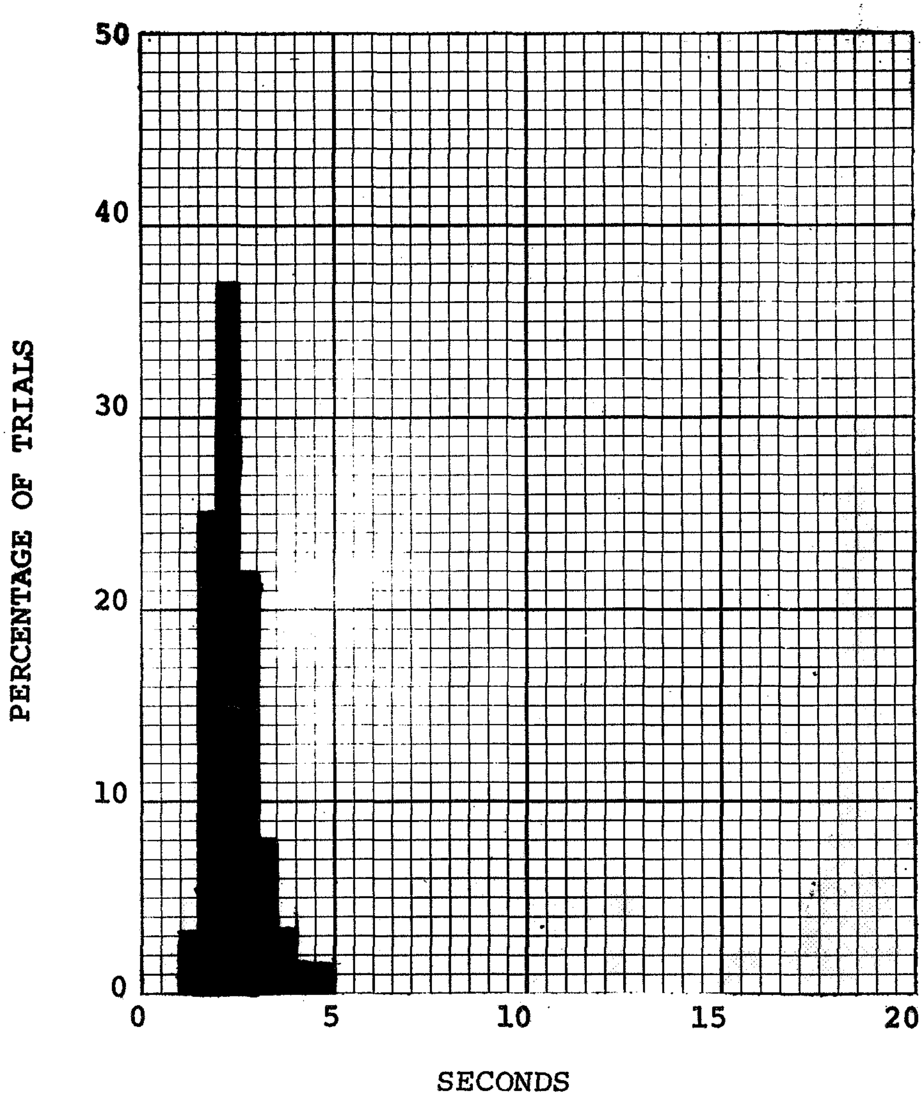


Figure 4.4

High Contrast Background

Sector Size = 11° X 11°

Target Intensity = 20 foot candles

Mean = 3.3 Median = 2.6

Standard Deviation = 2.9

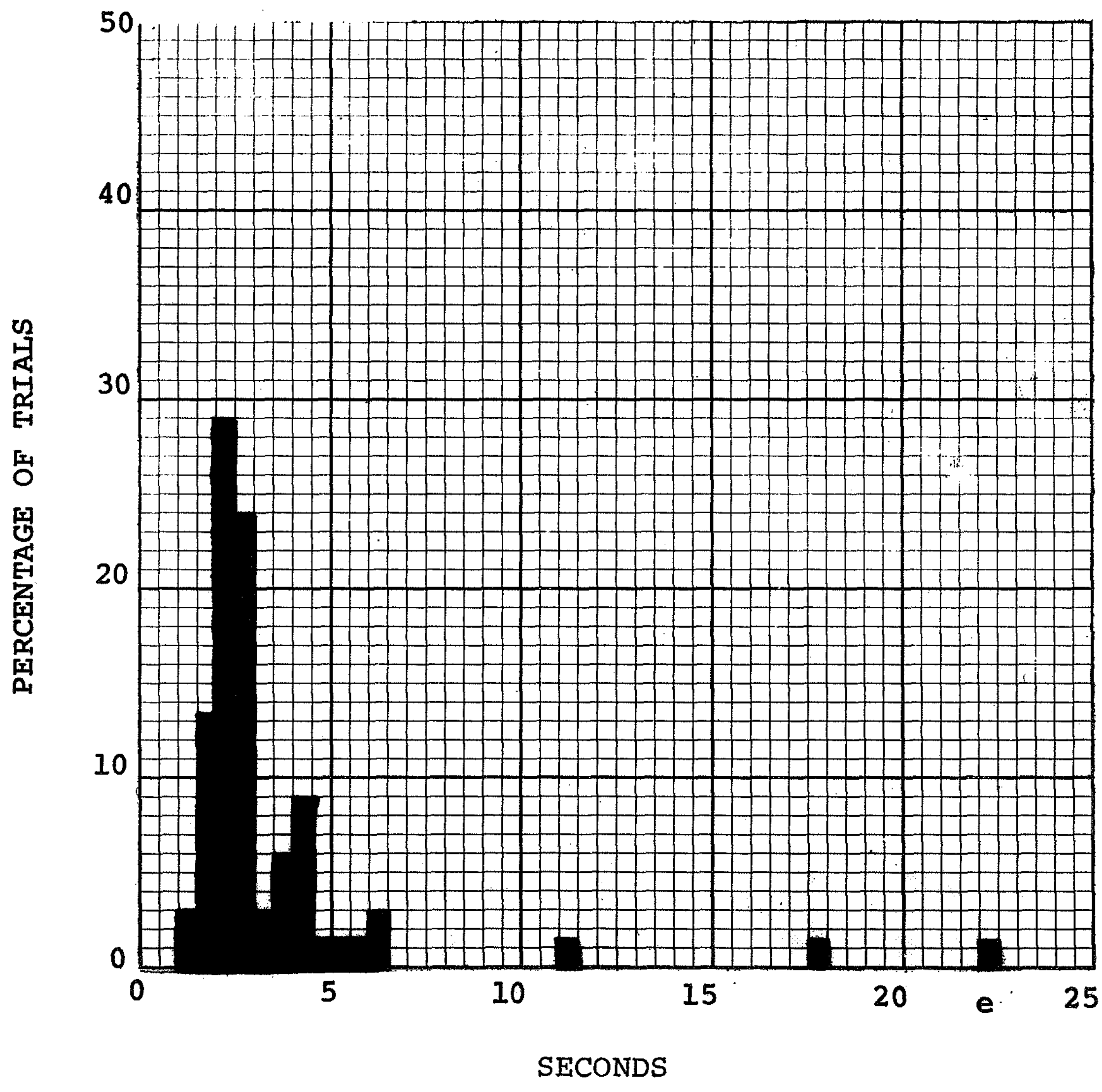


Figure 4.5

High Contrast Background

Sector Size = 22° X 22°

Target Intensity = 20 foot candles

Mean = 7.9 Median = 8.0

Standard Deviation = 5.6

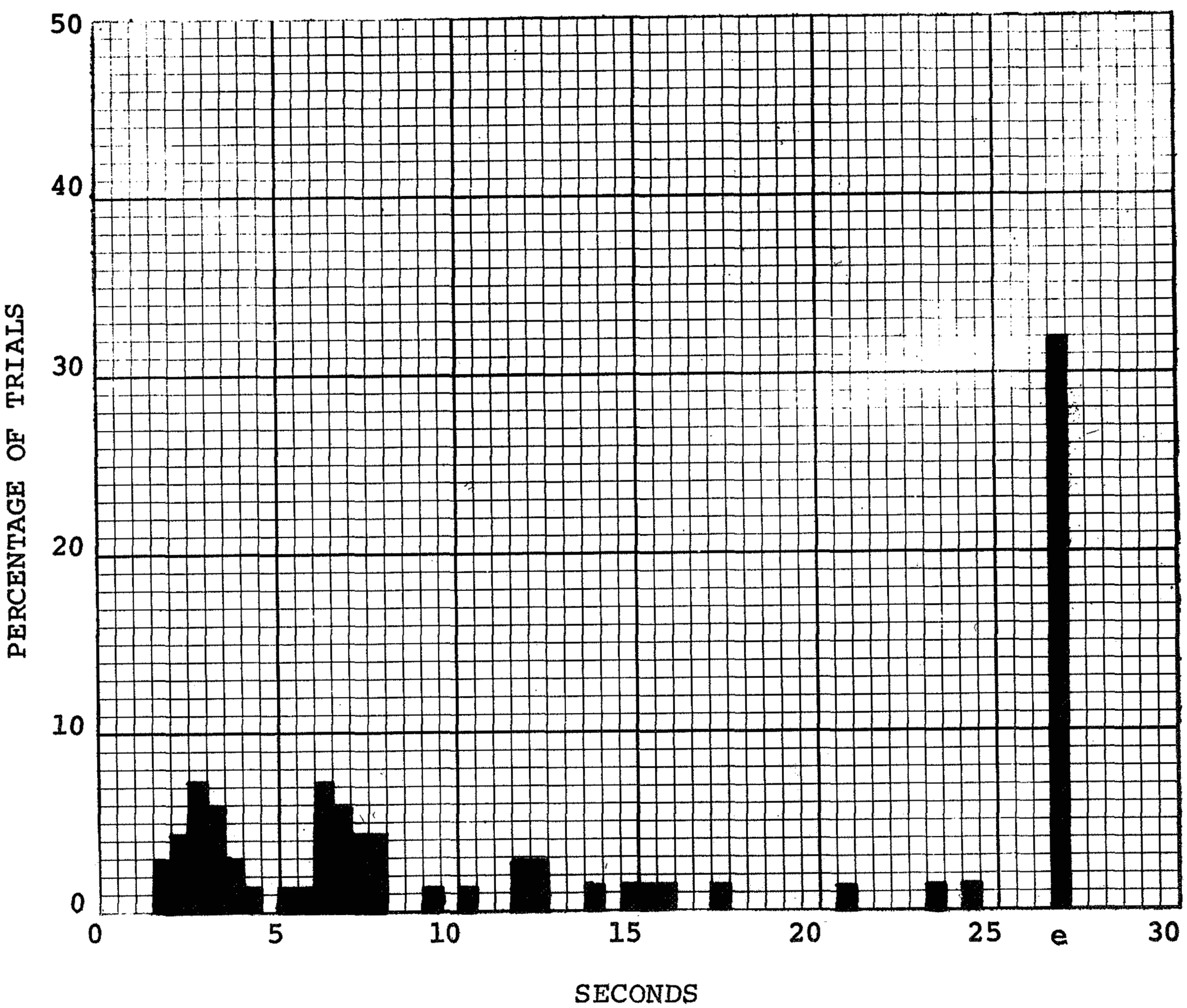


Figure 4.6

High Contrast Background

Sector Size = 2.7° X 2.7°

Target Intensity = 35 foot candles

Mean = 1.7 Median = 1.7

Standard Deviation = .40

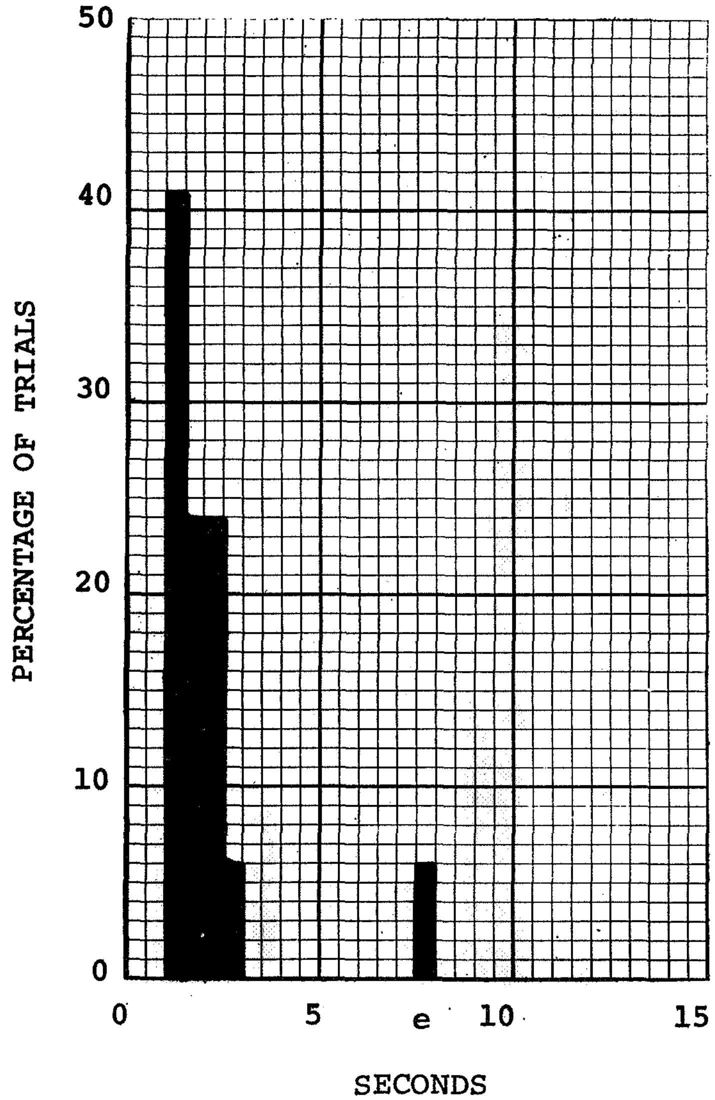


Figure 4.7

High Contrast Background

Sector Size = 5.5° X 5.5°

Target Intensity = 35 foot candles

Mean = 1.6 Median = 1.6

Standard Deviation = .33

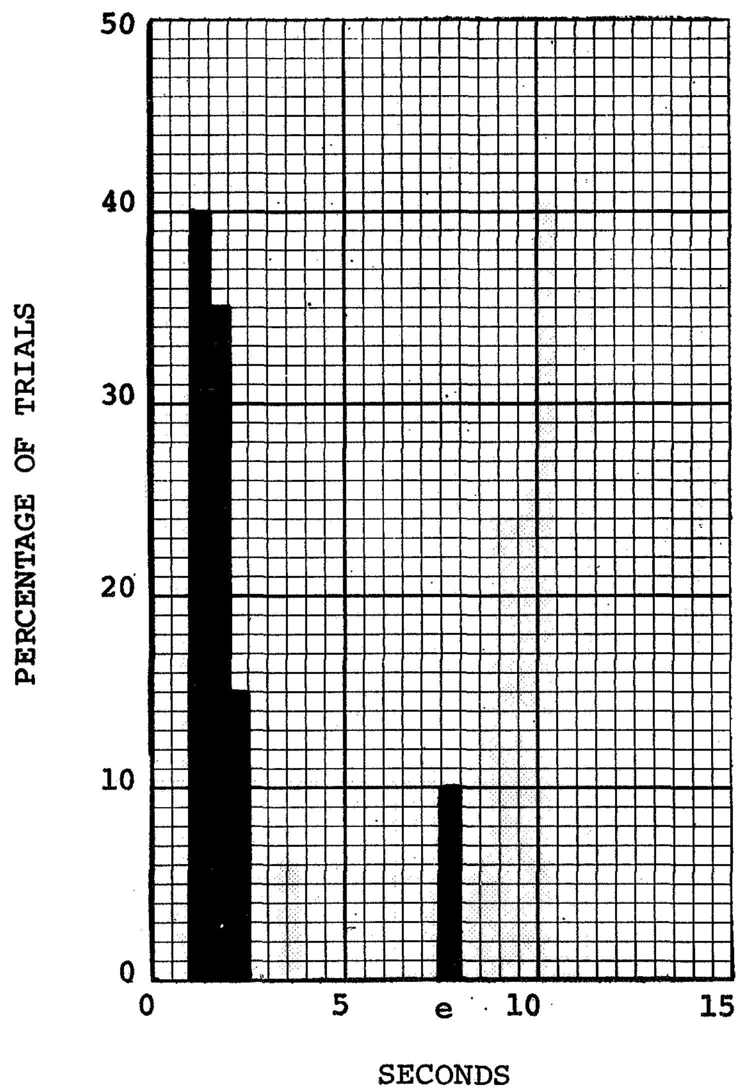


Figure 4.7

High Contrast Background

Sector Size = 11° X 11°

Target Intensity = 35 foot candles

Mean = 2.1   Median = 1.9

Standard Deviation = .75

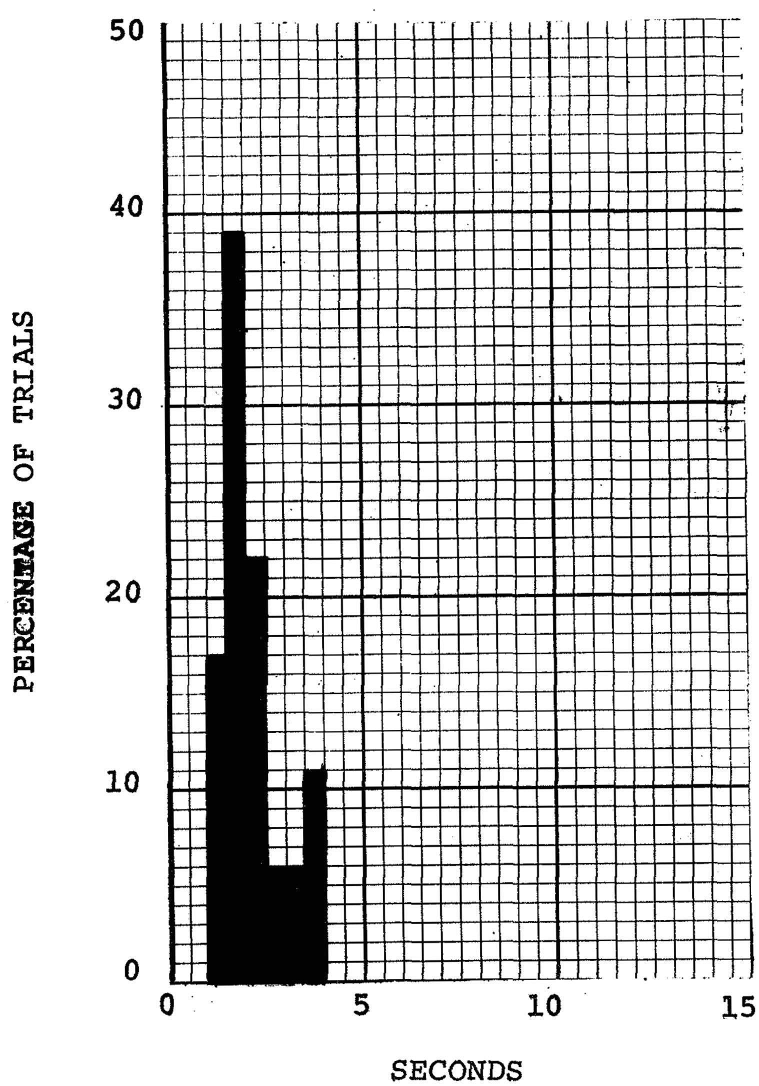


Figure 4.8

High Contrast Background

Sector Size = 22° X 22°

Target Intensity = 35 foot candles

Mean = 7.1 Median = 8.4

Standard Deviation = 6.0

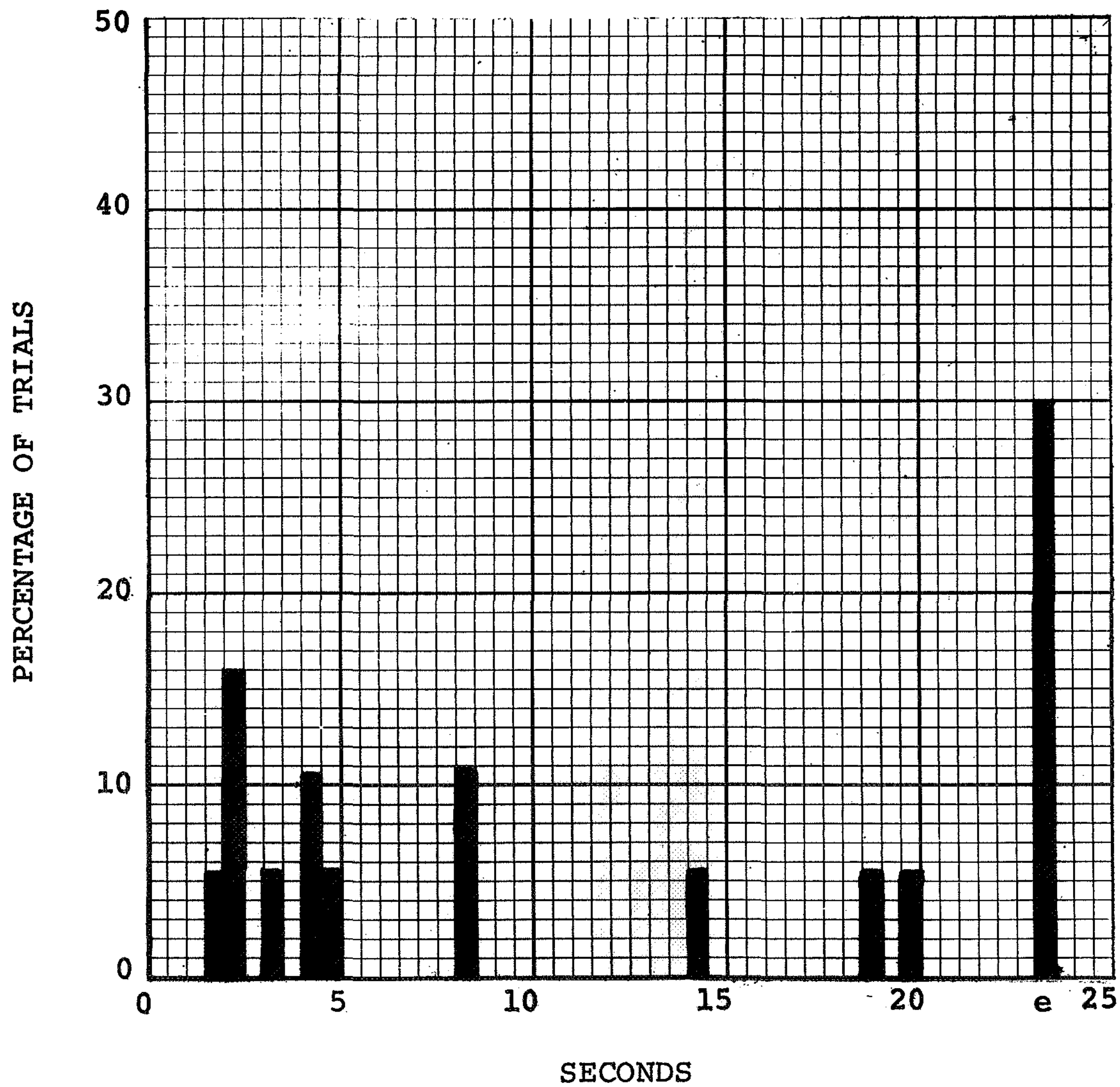


Figure 4.9

High Contrast Background

Sector Size = 2.7° X 2.7°

Target Intensity = 45 foot candles

Mean = 2.9 Median = 3.0

Standard Deviation = 1.2

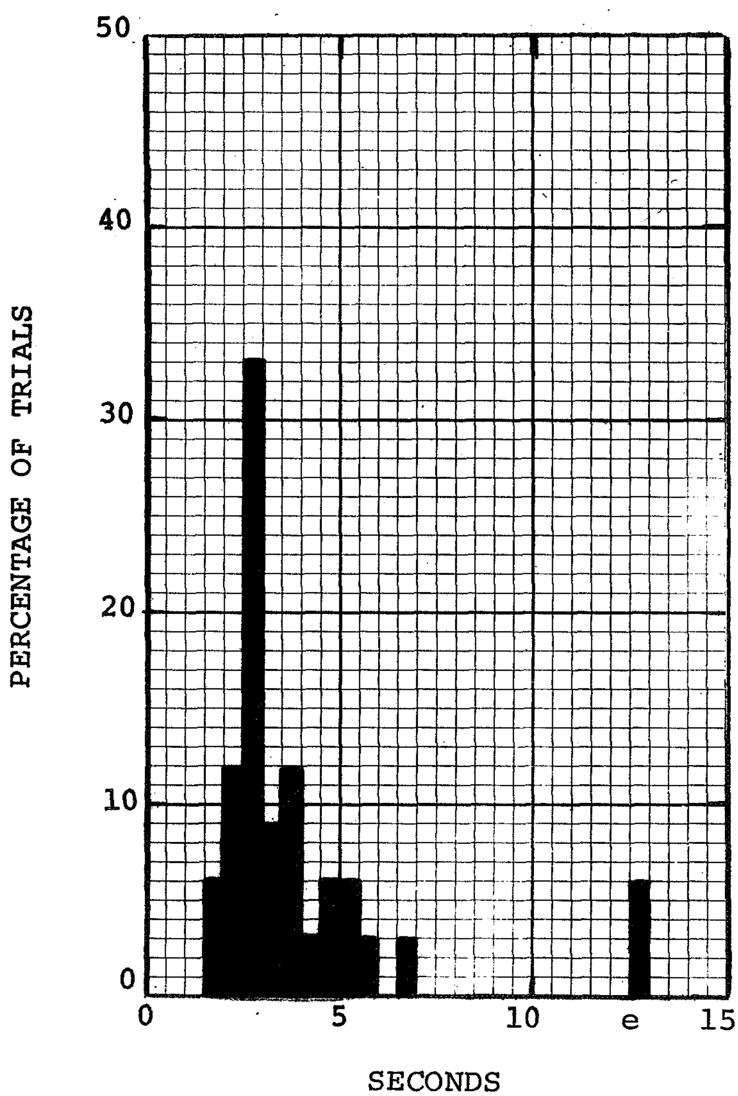


Figure 4.10

High Contrast Background

Sector Size = 5.5° X 5.5°

Target Intensity = 45 foot candles

Mean = 2.8   Median = 2.7

Standard Deviation = .94

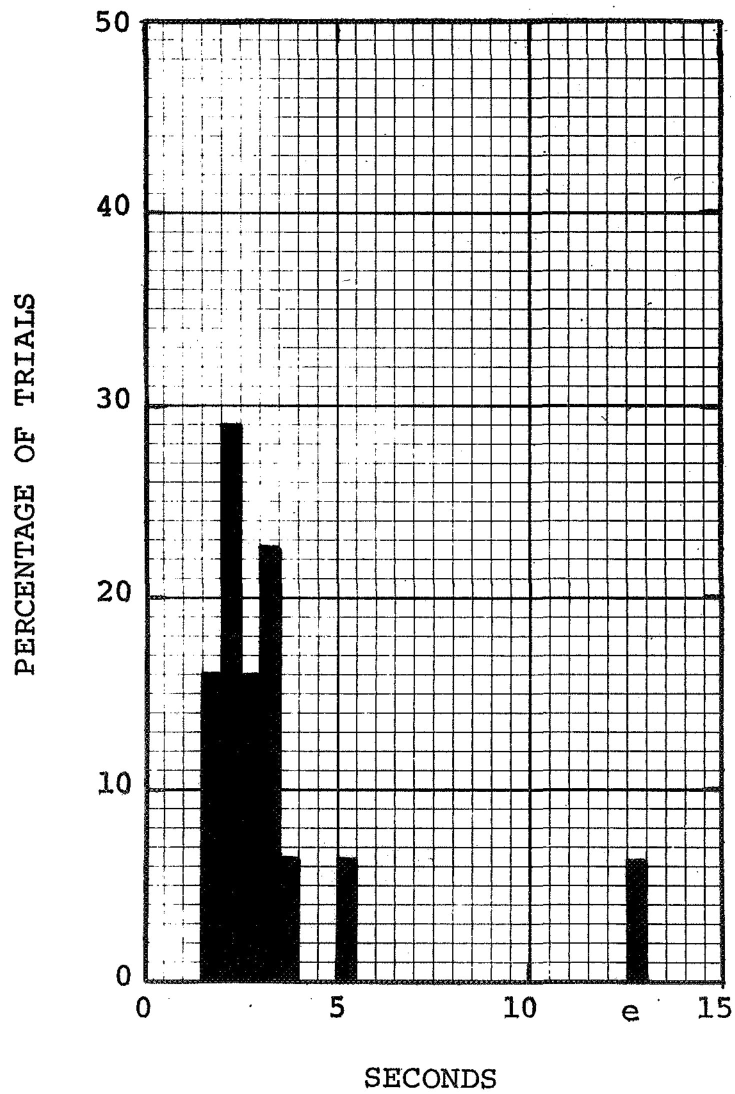


Figure 4.11

High Contrast Background

Sector Size = 11° X 11°

Target Intensity = 45 foot candles

Mean = 3.4   Median = 2.8

Standard Deviation = 1.2

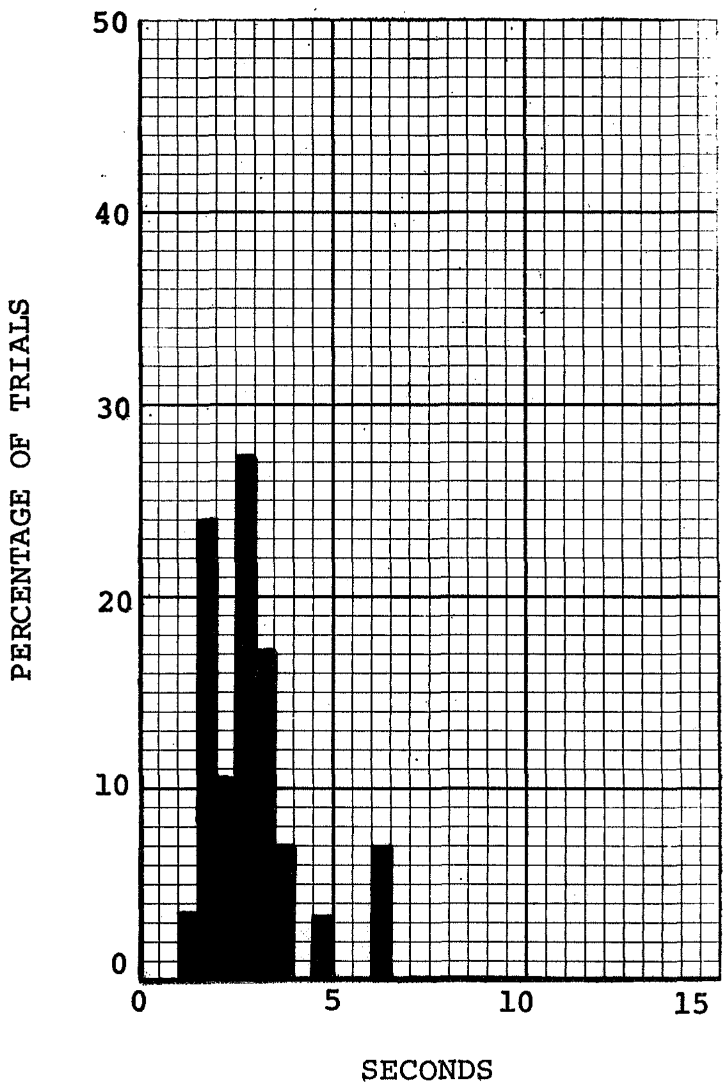


Figure 4.12

High Contrast Background

Sector Size = 22° X 22°

Target Intensity = 45 foot candles

Mean = 9.1   Median = 6.0

Standard Deviation = 8.4

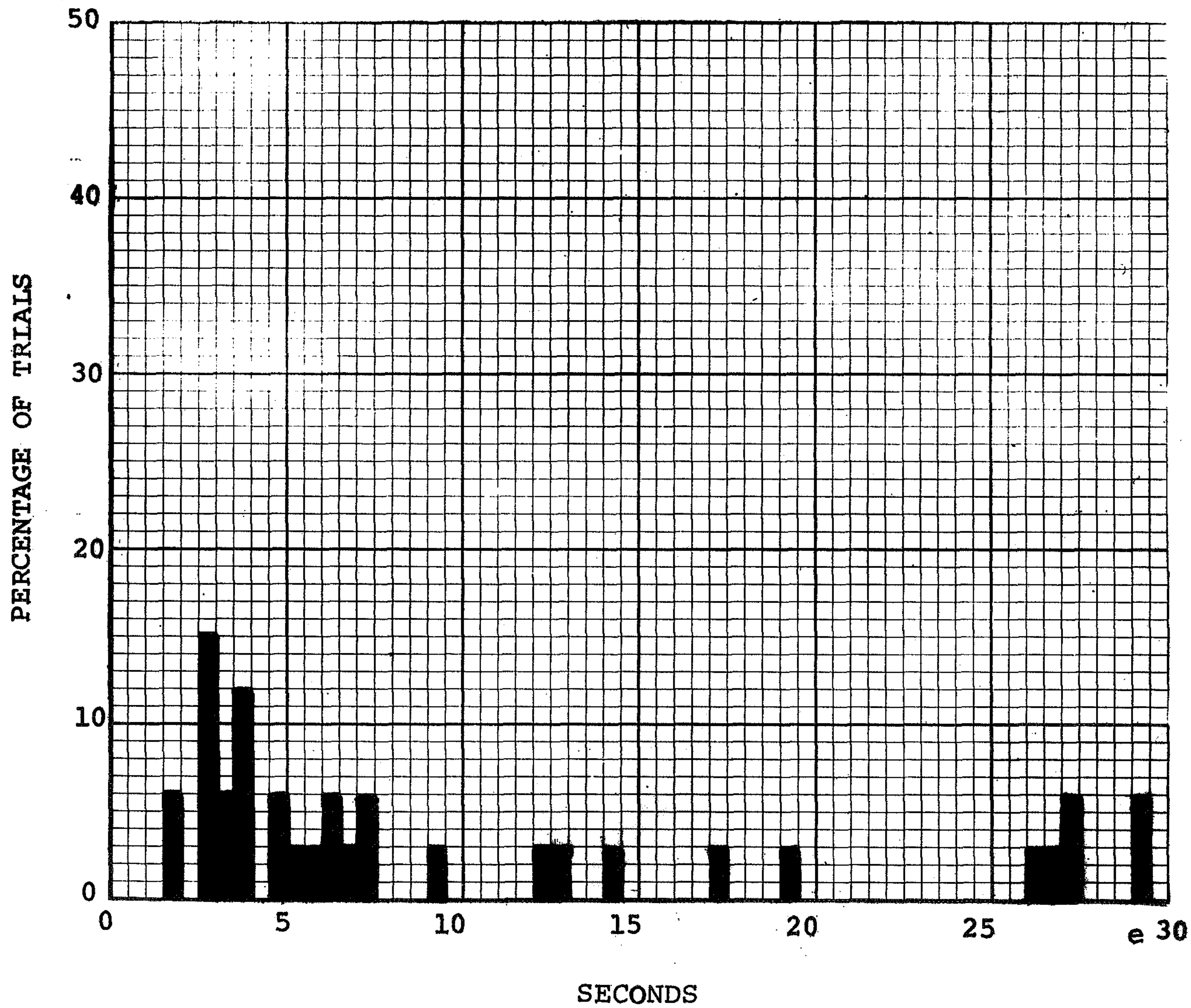


Figure 4.13

High Contrast Background

Sector Size = 2.7° X 2.7°

Target Intensity = 55 foot candles

Mean = 1.5 Median = 1.3

Standard Deviation = .56

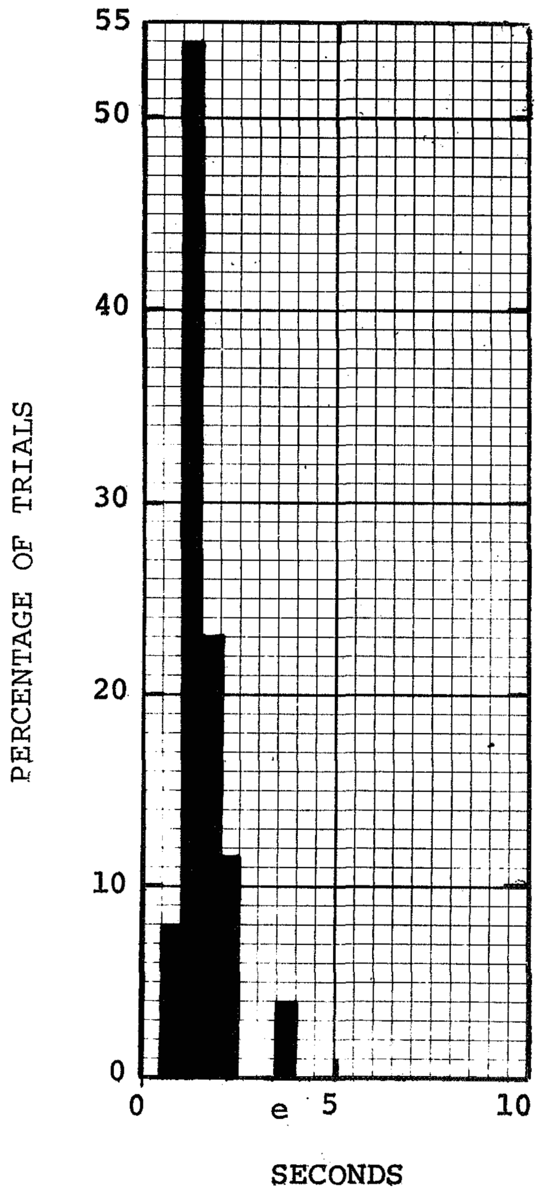


Figure 4.14

High Contrast Background

Sector Size = 5.5° X 5.5° Mean = 1.4 Median = 1.3

Target Intensity = 55 foot candles Standard Deviation = .32

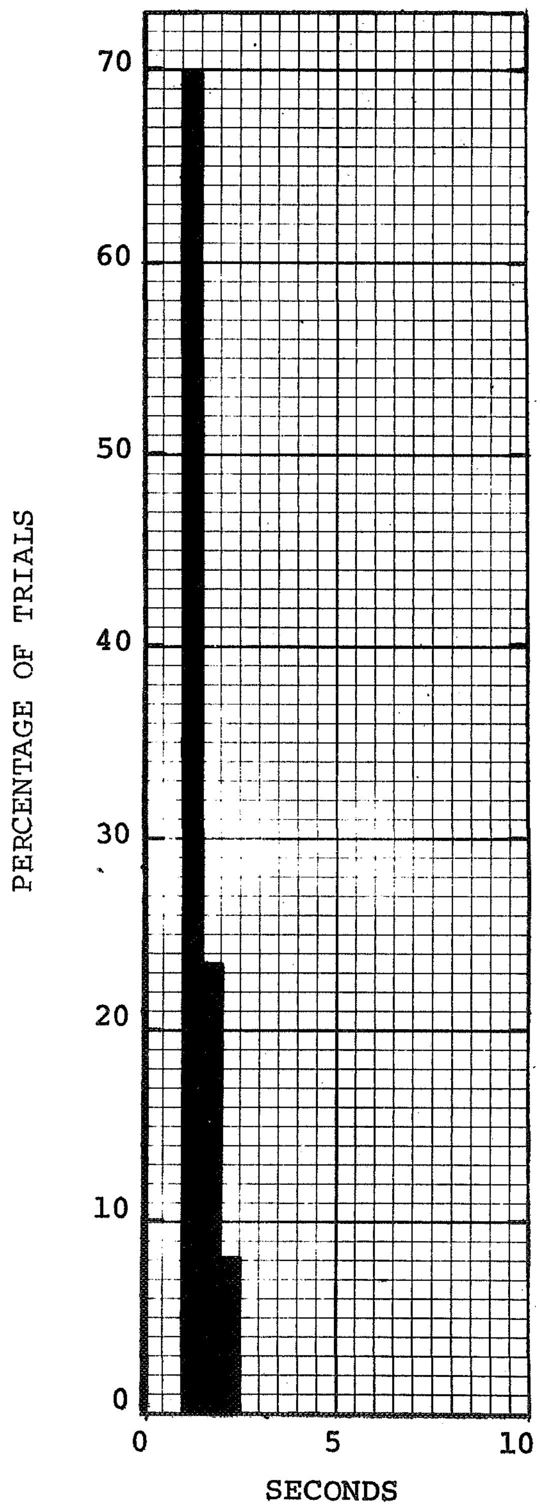


Figure 4.15

High Contrast Background

Sector Size = 11° X 11°

Target Intensity = 55 foot candles

Mean = 1.45 Median = 1.4

Standard Deviation = .31

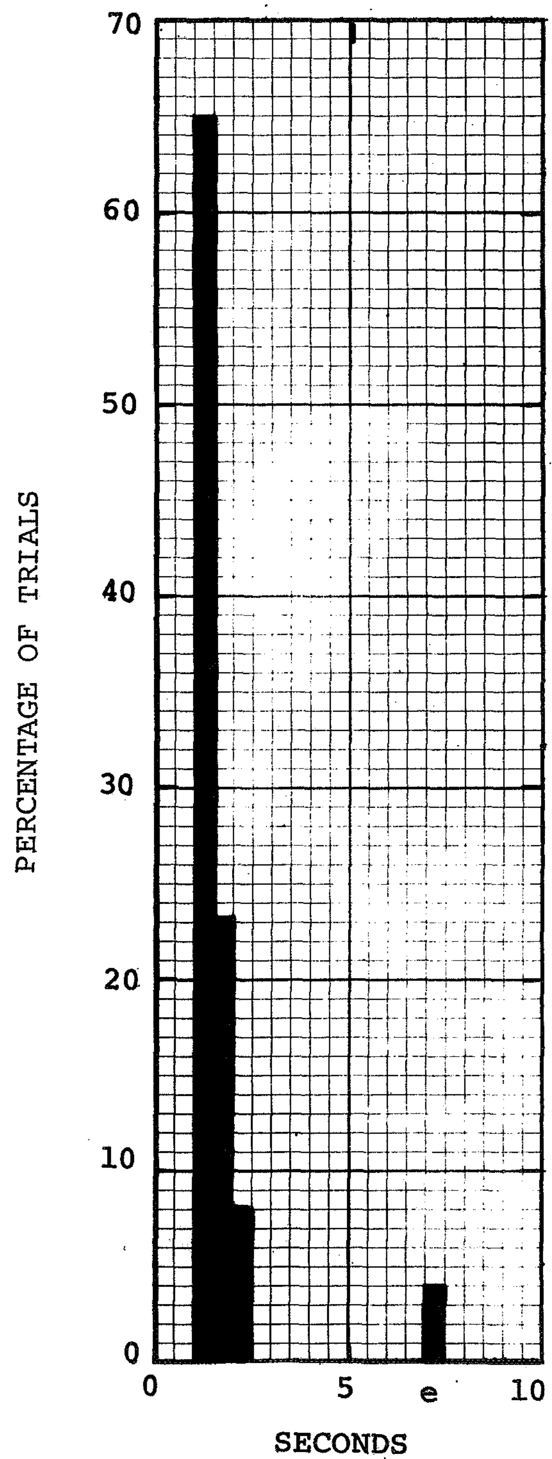


Figure 4.16

High Contrast Background

Sector Size = 22° X 22°

Target Intensity = 55 foot candles

Mean = 2.9 Median = 2.1

Standard Deviation = 1.8

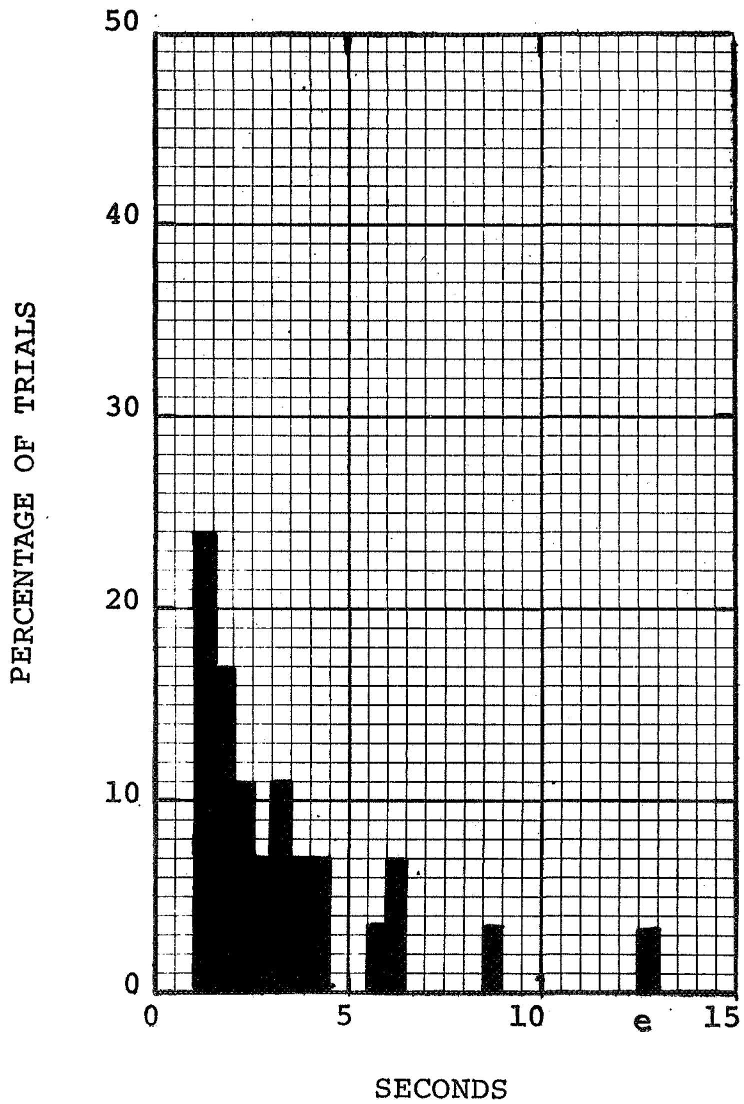


Figure 4.17

Uniform Background

Sector Size = 2.7° X 2.7°

Target Intensity = 25 foot candles

Mean = 3.9   Median = 4.0

Standard Deviation = 1.1

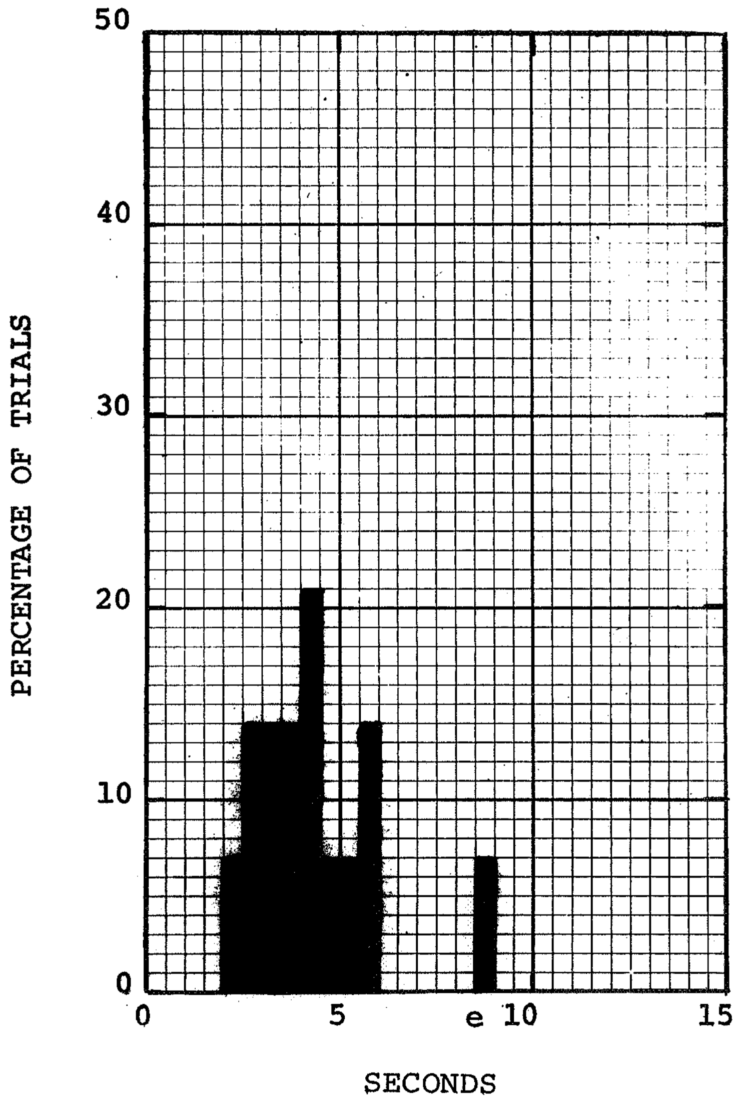


Figure 4.18

Uniform Background

Sector Size = 5.5° X 5.5°

Target Intensity = 25 foot candles

Mean = 5.9   Median = 5.3

Standard Deviation = 3.1

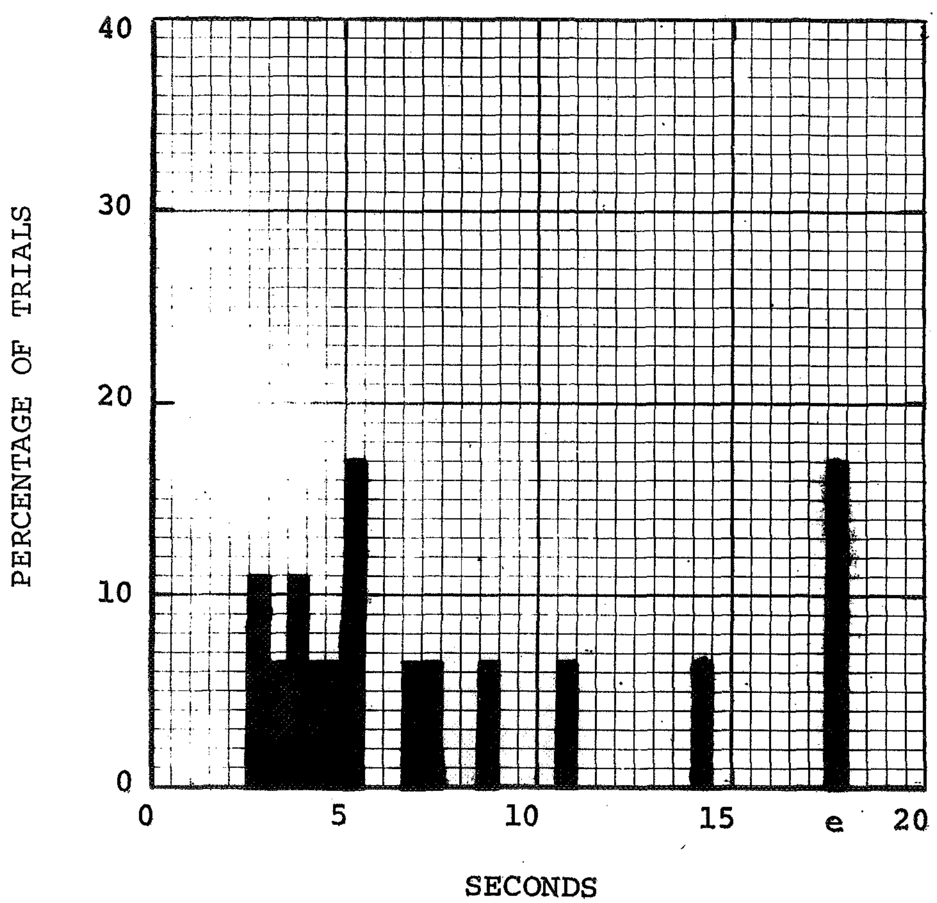


Figure 4.19

Uniform Background

Sector Size = 11° X 11°

Target Intensity = 25 foot candles

Mean = 7.3 Median = 7.4

Standard Deviation = 4.5

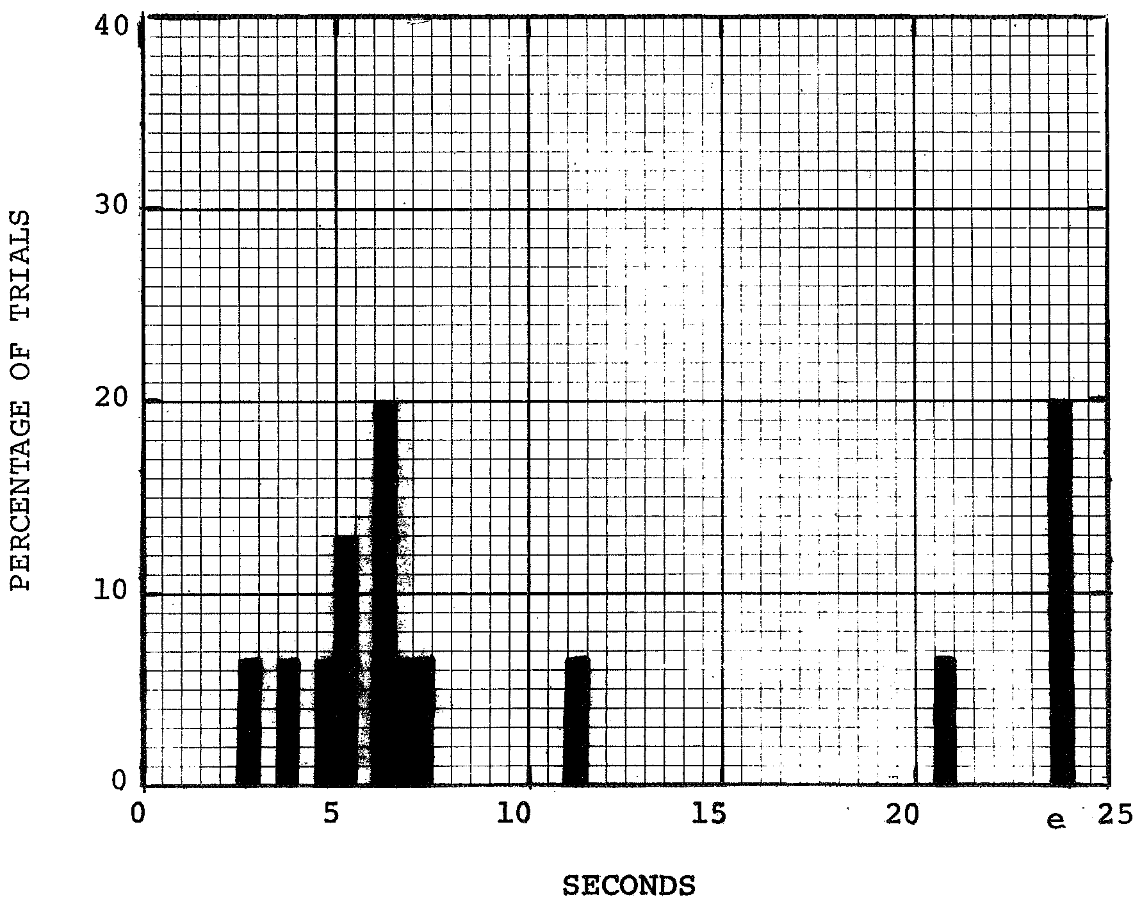


Figure 4.20

Uniform Background

Sector Size = 2.7° X 2.7°

Target Intensity = 50 foot candles

Mean = 2.2 Median = 2.2

Standard Deviation = .46

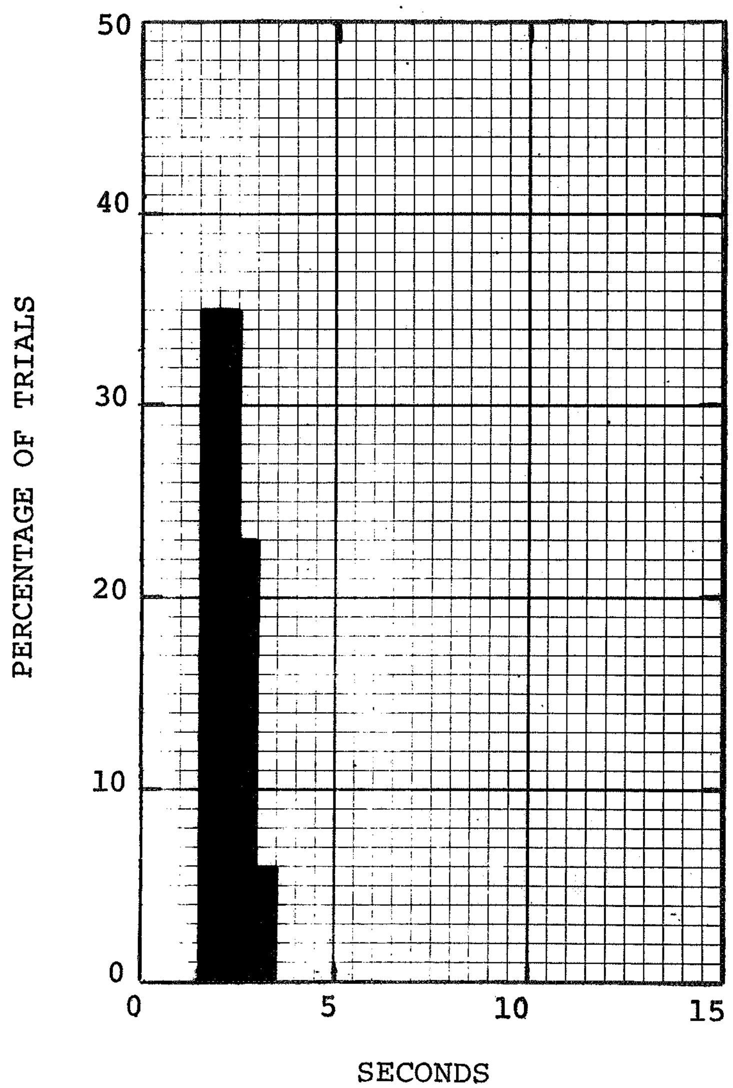


Figure 4.21

Uniform Background

Sector Size = 5.5° X 5.5°

Target Intensity = 50 foot candles

Mean = 3.5 Median = 3.1

Standard Deviation = 1.5

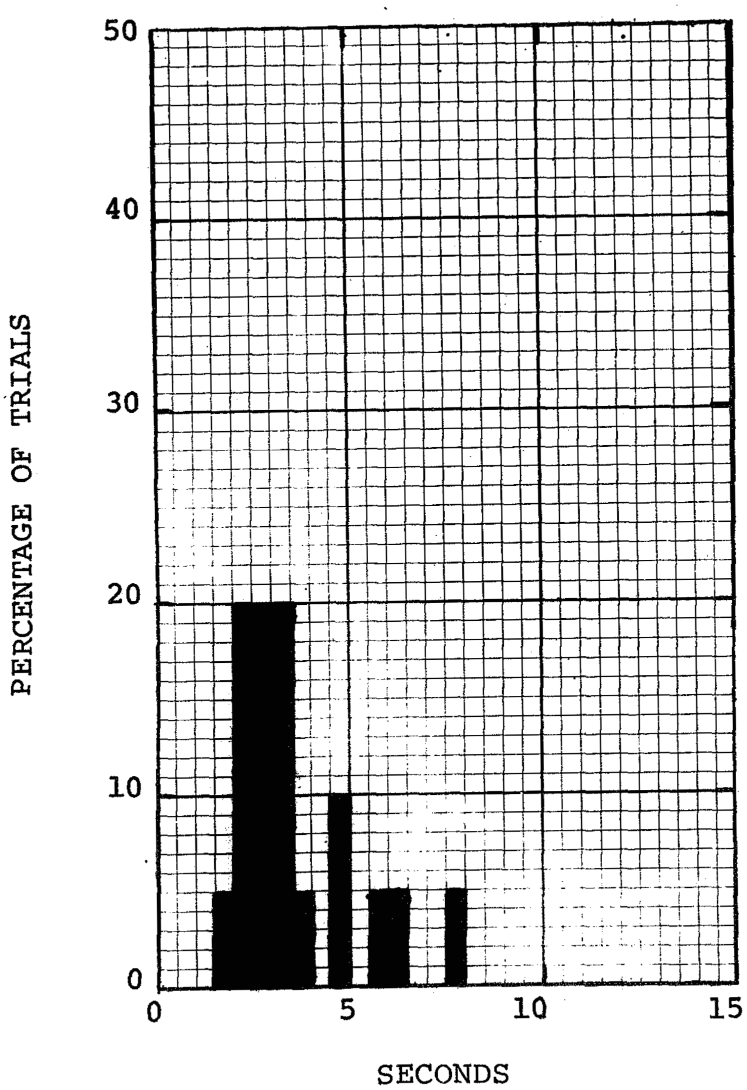


Figure 4.22

Uniform Background

Sector Size = 11° X 11°

Target Intensity = 50 foot candles

Mean = 6.9   Median = 4.5

Standard Deviation = 6.1

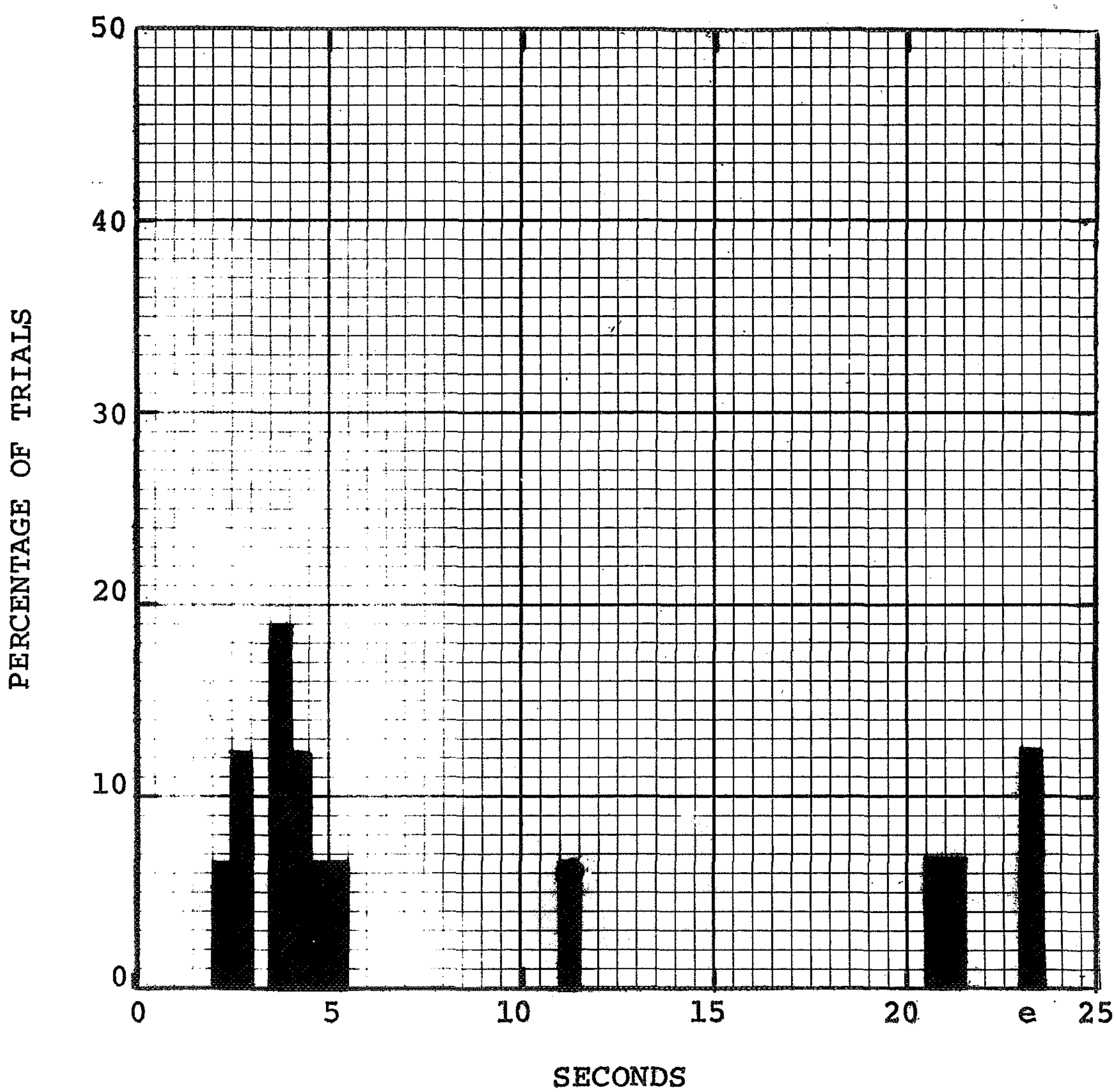


Figure 4.23

Uniform Background

Sector Size = 2.7° X 2.7°

Target Intensity = 75 foot candles

Mean = 1.7 Median = 1.7

Standard Deviation = .49

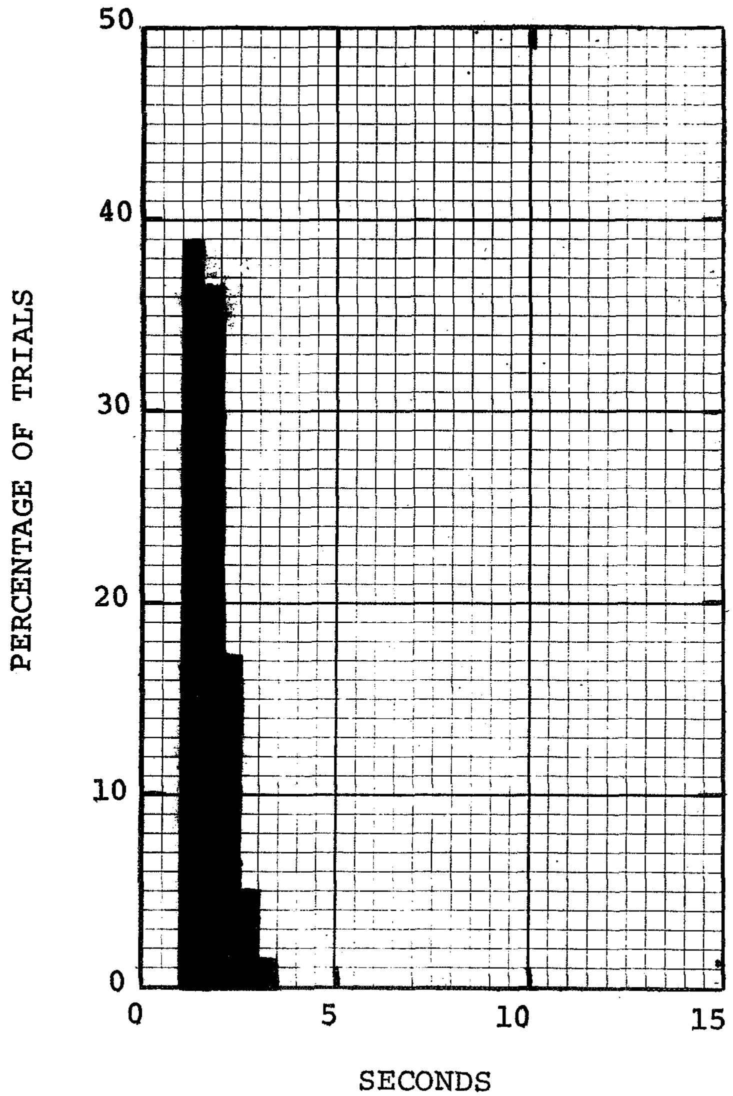


Figure 4.24

Uniform Background

Sector Size = 5.5° X 5.5°

Target Intensity = 75 foot candles

Mean = 1.7 Median = 1.7

Standard Deviation = .36

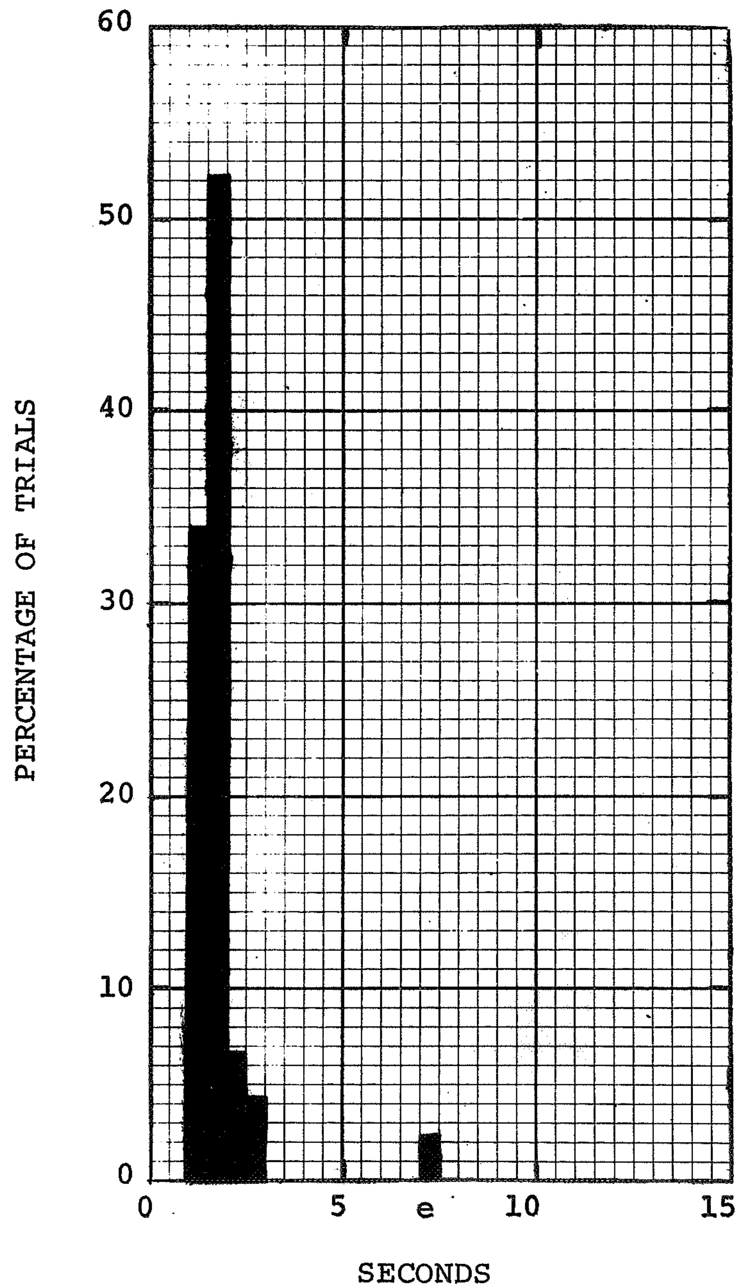


Figure 4.25

Uniform Background

Sector Size = 11° X 11°

Target Intensity = 75 foot candles

Mean = 2.1   Median 1.9

Standard Deviation = .68

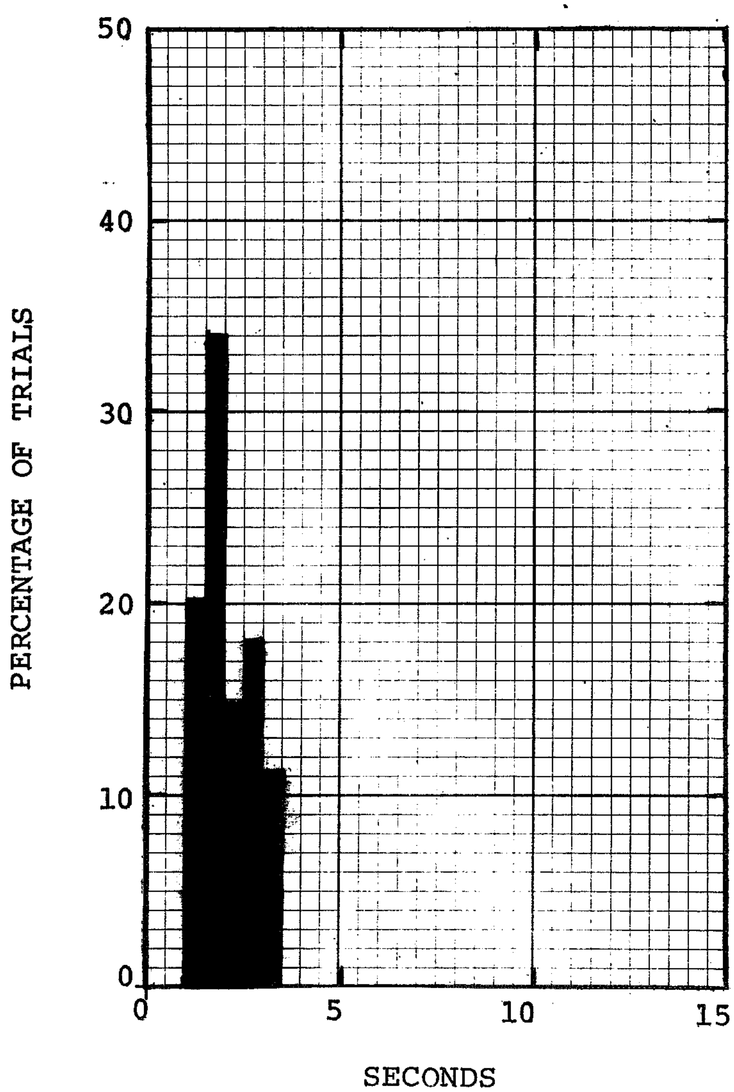


Figure 4.26

Uniform Background

Sector Size = 22° X 22°

Target Intensity = 75 foot candles

Mean = 6.5   Median = 7.2

Standard Deviation = 4.6

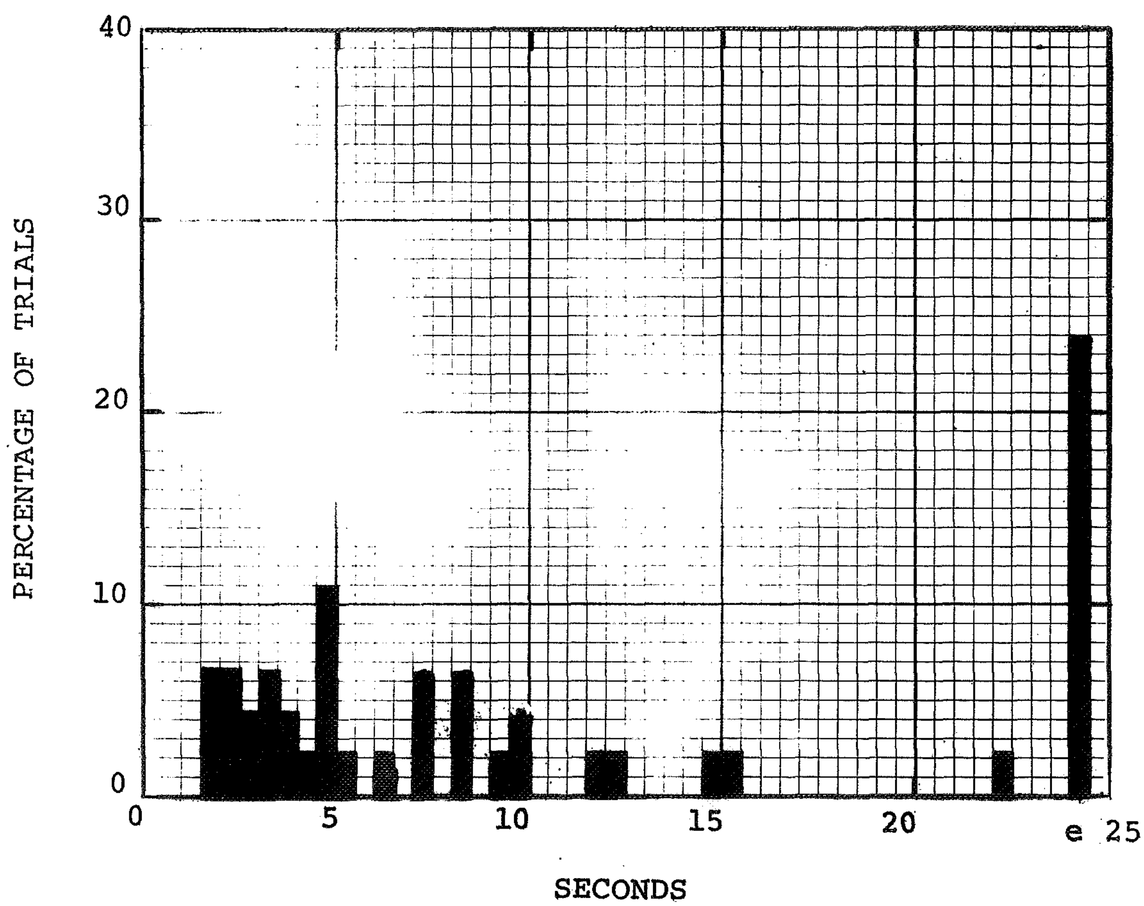


Figure 4.27

4.3 Evaluation of the Secondary Task

Subjects were broken down into roughly two categories by their performance on the secondary task. The first group of subjects tended to progress rather slowly through the task making very few errors. The second group processed the random numbers about three times as fast, but had a very high error rate. The accurate group worked through about 10 lines of 50 digits each, while the inaccurate group went through about 27 lines with an average error rate of about one missed or incorrectly marked chain for every two correctly marked chains.

Between these two groups, there was little difference in the performance of the primary task. The single exception to this rule was one subject who performed with utter zeal on the secondary task, progressing through about 40 lines, achieving an all time high in the number of errors made and setting some sort of record as to the lack of attention paid to the primary task. Data from this run appears in the third set of tables, Figures 4.10 through 4.13 of Section 4.2. This factor accounts for the unusually poor performance shown by that group of subjects and may illustrate the effect of heavy pilot workload on PWI effectiveness. Judging from general performance on the primary task, it would seem that both the accurate and inaccurate groups devoted equal effort to the secondary task. Because of this, the data can be viewed as representing equal subject loading.

CHAPTER 5

DISCUSSION OF RESULTS

5.1 Comparison of Subject Performance Under Differing Backgrounds

The most surprising result of this experiment was the fact that, with equivalent contrast ratios between target and screen brightness, most subjects performed markedly better with the highly cluttered background than with the more uniform one. Initially, a reasonable guess would have been to suspect that the uniform background would ease the task of locating the target since it was the only sharply defined object in the sector. This would also have seemed true because the cluttered background contained many items which were similar in size and shape to the target. With the cluttered background, the subject had to essentially locate the triangle by rejecting all other possible candidates in the sector. Despite this, he was able to quickly locate the target even when it was almost completely hidden under a bright speckle.

A possible explanation of this phenomenon is that the uniform background gave the subject nothing to focus on, possibly forcing him to scan the sector without his vision being focused at the surface of the screen. Because of this, the triangle would not have appeared sharp and would therefore have been more difficult to locate. This would imply that, for a PWI instrument, search sectors above the ground cannot be made extra large because the pilot can be expected to have difficulty locating a plane in the uncluttered sky. Blank sky is, like the screen used in this test, devoid of any keys or aids which might help to maintain pilot focus at infinity. This situation, which is known as space myopia, has been observed to occur in other aviation situations[18]. It is likely therefore that the pilot may find it difficult to locate a plane against the sky or a uniform overcast due to this factor.

5.2 Effect of Target Conspicuousness on Optimum Sector Selection

Target contrast was varied in the runs with both types of backgrounds. As might be expected, the more visible a target, the less effect sector size had on the time required to locate it. Increased target brightness tended to reduce the performance differential between the largest and smallest sectors. Unfortunately, target visibility is a factor over which PWI designers have little control. At reasonably low values of target visibility which might be comparable to real life situations, such as a plane against the ground below, the subject performs rather poorly with oversized sectors. Therefore, there would seem to be a requirement for incorporation of small sectors in a PWI device.

5.3 Analysis of Effect of Sector Size on Search Time

Reducing the size of the sector to be searched tends to reduce the time required to locate a target within the sector. Figure 5.1 shows a plot of the time below which ninety percent of the observations fall versus sector size. However, it should be noted that the benefit of decreasing sector size below a critical size is marginal or non-existent. Increasing sector sizes above this minimum critical size markedly reduces the subject's ability to locate the target within it.

This critical sector size is roughly 11° X 11° under the conditions of this experiment. The consistency of this conclusion, across all trials under all backgrounds and contrast ratios used, suggests that this size might be optimum under an even wider range of situations. Examinations centered around this sector size in a more realistic PWI situation, possibly a flight test or careful simulation, would certainly be justified.

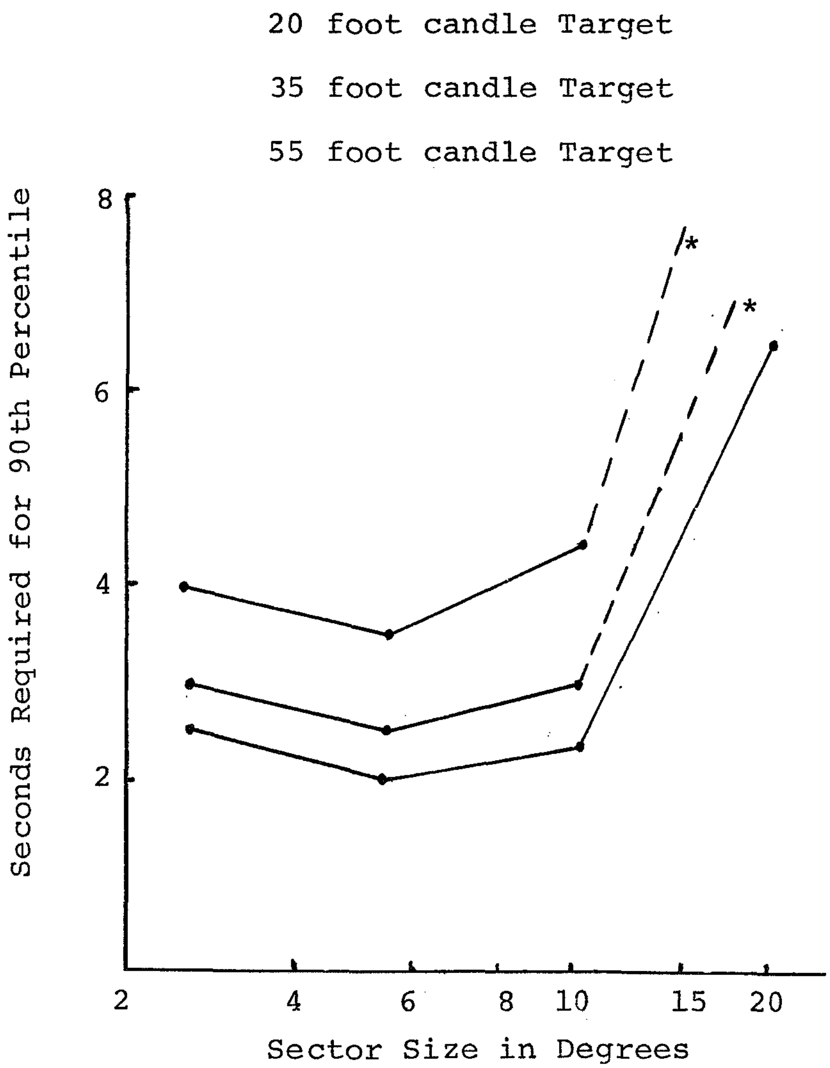


Figure 5.1: High Contrast Background Statistics

* Dashed line indicates that error rate had become so high that 90th percentile was never reached.

5.4 Central Vision Versus Peripheral Vision in a Search Situation

A possible explanation of the uniform performance across a whole range of smaller sector sizes may involve the use of central vision versus peripheral vision during the search. With the larger sectors, the subjects complained of an inability to search such a large area. Generally, they commented that they found themselves searching the same areas of the sector repeatedly. Judging from their performance, many areas also went completely unsearched. In contrast, no one found it at all difficult to locate the actual sector indication on a screen many times the area of the largest sector.

The logical conclusion is that the process by which the target was located differed considerably from the process in which the sector was located. The sector could be easily spotted with peripheral vision while the target generally required the use of the central vision to locate it. Since the area which can be viewed by the central vision is relatively small, it is possible that an effective, rapid search can only be carried out when the area to be searched is no larger than the area covered by the central vision with a single fixation of the eyes or when only a small group of tightly related fixations are required to cover the search region. With the larger sector sizes, the search pattern required numerous fixations across relatively unmarked landscape and allowed inefficiencies to occur. The search moved at random around the sector missing areas and covering certain areas more than once. In addition, the subject might have attempted to fall back on his peripheral vision as an aid to locating the target. If such an attempt was made, it clearly would be non-productive as the target under most conditions was too small and too dim to locate with this less acute vision.

The implication of this theory is that the sectors should be adjusted to a size which might easily be scanned using the central vision. The results of this experimentation suggest that an $11^{\circ}X11^{\circ}$ field of view might very nearly be such an ideal sized area. The dangers of attempting to make do with a larger sector are twofold. First, the pilot will not perform as satisfactorily with such a device. Secondly, since he will no doubt notice the considerable number of alarms for which he can not spot a plane, his trust in the device may be reduced to the point where he will not use it. The later case of an alarm for which the pilot never spots a plane is a sort of false false alarm. An alarm from a plane which is not on a collision course is a false alarm. Device failure may, however, generate an even worst case false alarm where a warning is given when no plane at all is present. If the pilot cannot spot the plane, he may tend to believe that it is the second type of false alarm. Pilot patience with what appears to be device failure will, no doubt, be considerably less than his patience with a device which issues warnings for all nearby aircraft, some of which may not represent a real threat. It is important to keep sector size small so as to prevent the appearence of device failure, thereby maintaining pilot confidence in the instrument.

5.5 Realistic PWI Devices

A realistic PWI display will be considerably less ideal than was the warning presentation used in this experiment. Sectors will almost certainly not be completely surrounded by a white box. The performance of the pilot will naturally tend to be degraded by a less than perfect display.

The following factors will probably weigh most heavily on the pilots performance:

(1) Indefinite edges to the sector will probably cause the pilot to view the sector as somewhat larger than it actually is.

(2) Instrumentation of this device may be subject to flaws or weaknesses. This may cause some uncertainty as to which sector the warning originated from when it is near a sector edge.

(3) Lack of visually marked edges may cause the pilot's search to wander out of the correct sector.

These factors may modify the optimum sector size. It might be possible to reduce the sector size in order to compensate for them. However, these effects may be so large as to completely mask any benefits from small sectors.

CHAPTER 6

CONCLUSIONS

This study provides baseline data concerning several important factors which will effect the performance of a PWI device. Because this experiment is an abstraction of a real life situation, some of the conclusions tend to be somewhat more qualitative than quantitative. The data does point to some primary design considerations and provides a basis for a preliminary PWI design. Further, more refined work should be done on a prototype instrument with more realistic simulation or actual flight tests.

The most unexpected conclusion which can be drawn from this study concerns the difficulty subjects encountered in locating targets against the uniform background. An initial guess on a possible cost saving trick for PWI might have been to tie several sectors together so that only a few large sectors covered the sky. Smaller, more refined sectors might then have been employed to cover the ground cluttered field of view. This study indicates that a pilot may have a great deal of difficulty locating a plane in the blank sky. Reasonable PWI resolution would therefore be required both above and below the horizon.

Since the same sector size was optimum under a wide range of conditions, design of the PWI with identical above and below the horizon resolution is indicated. This optimum sector size was around 10° to 15° on a side. Pilot performance was generally higher at somewhat smaller values of sector size. However, it is likely that the extra cost incurred to reduce the sector to below the 10° to 15° size would not be justified by the marginal increases in performance. Pilot performance with a larger sector size is markedly worse than with the optimum. The 11° sector would therefore appear to be the most cost effective size. Without a cost constraint, a 6° sector is the more ideal size, but this would represent a doubling of sectors for only slight performance increases.

The absolute optimum of 6° corresponds almost exactly to the central vision size. Therefore, the size judged most cost effective can be covered in about four fixations of the eye. The subject would seem to be capable of conducting such a small term scan efficiently. When the sector is as large as 22°, requiring on the order of twenty well placed fixations, his efficiency drops dramatically. A closer study of the exact relationship between scan procedures and search effectiveness might develop a means of enlarging the optimum search area to a more economical size. Such techniques might include differently shaped sectors, pilot training or scan guides with a single sector. If such a technique could be employed effectively, a considerable savings in PWI cost might be realized.

In summary, this study concludes that a PWI instrument should probably have the following features:

(1) Equal area sectors throughout the field of view.

(2) Sectors of between 10° to 15° on a side.

It also recommends that further work be devoted to a more careful study of the exact role of the central vision in a detailed search task. It also recognizes that deviation from conclusions (1) and (2) may be desirable in certain cases due to further considerations. A typical such consideration might be a concentration of PWI resolution into areas of most probable threat.

APPENDIX I

The following instructions were read by each of the subjects before the experiment. A sample table of random numbers is also included.

Instructions

This experiment is designed to test various factors involved in visual search procedures. You will be given two tasks, a primary search task and a secondary background loading task.

Primary task

You will be presented with a series of search situations to be solved. Each of these trials will be similar in nature with certain parameters varied between trials. A single trial will consist of the following:

1) An alarm will sound indicating the beginning of the trial.
2) An area to be searched will be marked out on the screen by enclosing it with a white square.
3) A target to be searched for will be displayed somewhere within the search sector. This target is an enlongated triangle which will be pointing either up,down,left, or right.

You are to search the indicated region for the triangle and when you have located it,you should press the hand held button. This portion of the task should be performed with as much speed as possible.

After pressing the hand held button,the target and sector indication will disappear. At this time,you should press the panel button which corresponds to the direction in which the triangle was pointing. Time is not important in this phase of the trial so take your time and press the correct button. Press these buttons firmly so as to assure switch closure. If the projector motor stops without presenting a new trial,the computer is waiting for your response. Repeat your response if you have already pushed the button. If you have not yet responded,respond normally.

Return to the secondary task at this time and await the next alarm.

Note: Failure to respond within 32 sec. after the onset of the alarm is interpreted as a failure to locate the target and the computer will automatically record such and proceed to the next trial. At the end of the 32 seconds,the alarm will be turned off and you should return immediately to the secondary task.

Secondary Task

You are provided with a sheet of numbers. Work from left to right, line by line, performing the following task:

1) Mark through chains of 3 increasing digits with a red pen.

2) Mark through chains of 3 decreasing digits with a green pen.

Note: a) Once a chain of digits has been marked through, they may not be used or incorporated into other chains.
b) In the case of a conflict where a single digit could be part of either of two different chains, mark the first occurring chain. For example, 25743 contains the chain 257 and 743 but only one of these chains may be marked since they share a digit. Mark the 257 chain.
c) A 3 digit chain must not be part of a larger chain of four or more digits. For example, 234567.
d) Ignore the spaces between groups of five digits as these are merely to assist you in keeping track of your place.
e) Start over at the beginning of each line; do not try to run a chain off the end of one line and onto the beginning of another.

92630	78240	19267	95457	53497	23894	37708	79862	76471	66418
79445	78735	71549	44843	26104	67318	00701	34986	66751	99723
59654	71966	27386	50004	05358	94031	29281	18544	52429	06080
31524	49587	76612	39789	13537	48086	59483	60680	84675	53014
06348	76938	90379	51392	55887	71015	09209	79157	24440	30244
28703	51709	94456	48396	73780	06436	86641	69239	57662	80181
68108	89266	94730	95761	75023	48464	65544	96583	18911	16391
99938	90704	93621	66330	33393	95261	95349	51769	91616	33238
91543	73196	34449	63513	83834	99411	58826	40456	69268	48562
42103	02781	73920	56297	72678	12249	25270	36678	21313	75767
17138	27584	25296	28387	51350	61664	37893	05363	44143	42677
28297	14280	54524	21618	95320	38174	60579	08089	94999	78460
09331	56712	51333	06289	75345	08811	82711	57392	25252	30333
31295	04204	93712	51287	05754	79396	87399	51773	33075	97061
36146	15560	27592	42089	99281	59640	15221	96079	09961	05371
29553	18432	13630	05529	02791	81017	49027	79031	50912	09399
23501	22642	63081	08191	89420	67800	55137	54707	32945	64522
57888	85846	67967	07835	11314	01545	48535	17142	08552	67457
55336	71264	88472	04334	63919	36394	11196	92470	70543	29776
10087	10072	55980	64688	68239	20461	89381	93809	00796	95945
34101	81277	66090	88872	37818	72142	67140	50785	21380	16703
53362	44940	60430	22834	14130	96593	23298	56203	92671	15925
82975	66158	84731	19436	55790	69229	28661	13675	99318	76873
54827	84673	22898	08094	14326	87038	42892	21127	30712	48489
25464	59098	27436	89421	80754	89924	19097	67737	80368	08795
67609	60214	41475	84950	40133	02546	09570	45682	50165	15609
44921	70924	61295	51137	47596	86735	35561	76649	18217	63446
33170	30972	98130	95828	49786	13301	36081	80761	33985	68621
84687	85445	06208	17654	51333	02878	35010	67578	61574	20749
71886	56450	36567	09395	96951	35507	17555	35212	69106	01679
00475	02224	74722	14721	40215	21351	08596	45625	83981	63748
25993	38881	68361	59560	41274	69742	40703	37993	03435	18873
92882	53178	99195	93803	56985	53089	15305	50522	55900	43026
25138	26810	07093	15677	60688	04410	24505	37890	67186	62829
84631	71882	12991	83028	82484	90339	91950	74579	03539	90122
34003	92326	12793	61453	48121	74271	28363	66561	75220	35908
53775	45749	05734	86169	42762	70175	97310	73894	88606	19994
59316	97885	72807	54966	60859	11932	35265	71601	55577	67715
20479	66557	50705	26999	09854	52591	14063	30214	19890	19292
86180	84931	25455	26044	02227	52015	21820	50599	51671	65411
21451	68001	72710	40261	61281	13172	63819	48970	51732	54113
98062	68375	80089	24135	72355	95428	11808	29740	81644	86610
01788	64429	14430	94575	75153	94576	61393	96192	03227	32258
62465	04841	43272	68702	01274	05437	22953	18946	99053	41690
94324	31089	84159	92933	99989	89500	91586	02802	69471	68274
05797	43984	21575	09908	70221	19791	51578	36432	33494	79888
10395	14289	52185	09721	25789	38562	54794	04897	59012	89251
35177	56986	25549	59730	64718	52630	31100	62384	49483	11409
25633	89619	75882	98256	02126	72099	57183	55887	09320	73463
16464	48280	94254	45777	45150	68865	11382	11782	22695	41988

APPENDIX II

The PDP-8 computer program which conducted the experiment is listed with the appropriate data tables and their explanations.

```
                *20
0020  0000  START,    0000         / CLEAR ALL D/A LINES
0021  7300            CLA CLL
0022  6552            DAL1
0023  6554            DAL2
0024  6562            DAL3
0025  6564            DAL4
0026  6572            DAL5
0027  6574            DAL6
0030  6472            DAL7
0031  6474            DAL8
0032  6422            DACG
0033  7402            HLT
0034  6046            TLS          / SET PRINTER FLAG
0035  7300            CLA CLL
0036  1102            TAD   BLANK / CLEAR BLANK STAORAGE TABLES
0037  3010            DCA   10
0040  1103            TAD   LENGTH
0041  7041            CIA
0042  3000            DCA   0
0043  3410            DCA I 10
0044  2000            ISZ   0
0045  5043            JMP   .-2
0046  7240            CLA CMA
0047  3104            DCA   ANSWER
0050  1110            TAD   C1
0051  3100            DCA   VECTOR  / SET UP INITIAL VALUES
0052  1111            TAD   C2
0053  3101            DCA   SP
0054  4471            JMS I SSTEPS
0055  4466            JMS I SNEXT
0056  7300            CLA CLL
0057  3104            DCA   ANSWER

                /MAIN CONTROL ROUTINE FOR CONDUCTING TEST

0060  4467  CONTRL,   JMS I STEST
0061  4466            JMS I SNEXT
0062  4472            JMS I SSTAT
0063  4471            JMS I SSTEPS
0064  4473            JMS I PRINT
0065  5060            JMP   CONTRL
0066  0600  SNEXT,    NEXT
0067  0705  STEST,    TEST
0070  0400  SSTEPP,   STEPP
0071  0411  SSTEPS,   STEPS
0072  1000  SSTAT,    STAT
0073  0434  PRINT,    PRNT
```

```
                / PRIMARY CONSTANTS SECTION

                *100
0100  3000  VECTOR,   3000    / POINTER TO TABLE OF PROJECTOR POIN
0101  3200  SP,       3200    / POINTER TO SLIDE INFORMATION
0102  3377  BLANK,    3377    / START FOR BLANK STORAGE FOR DATA
0103  3400  LENGTH,   3400    / LENGTH OF BLANK STORAGE AREA
0104  0000  ANSWER,   0000    / EVALUATION OF ACCURACY CODE
0105  0000  TIME1,    0000    / LEAST SIGNIFICANT BITS OF TIME OF
0106  0000  TIME2,    0000    / MOST SIGNIFICANT BITS
0107  3777  SSW,      3777    / DIRECTION OF SLIDE MOTION CODE
0110  3000  C1,       3000    / INITAL VECTOR VALUE
0111  3200  C2,        3200   / INITIAL SP VALUE
0112  2000  TP,       2000    / POINTERS TO TEST REPORT GEN INFO
0113  0000  DISP,     0       / PROJECTOR DISP FROM CENTER
```

```
                 *200
0200  0000  TYPE,   0000         / TYPE CHARACTER
0201  6041          TSF          / IN THE ACCUMULATOR
0202  5201          JMP   .-1
0203  6046          TLS
0204  7200          CLA
0205  2200          ISZ   TYPE
0206  5600          JMP I TYPE
0207  0000  CRLF,   0000         / TYPE CARRIAGE RETURN
0210  7300          CLA CLL      / LINE FEED
0211  1213          TAD   .+2
0212  4200          JMS   TYPE
0213  0215          215
0214  1216          TAD   .+2
0215  4200          JMS   TYPE
0216  0212          212
0217  2207          ISZ   CRLF
0220  5607          JMP I CRLF
0221  0000  DIGIT,  0000         / TYPE A SINGLE DIGIT
0222  2221          ISZ   DIGIT
0223  7440          SZA
0224  5227          JMP   .+3
0225  7420          SNL
0226  5621          JMP I DIGIT
0227  1231          TAD .+2
0230  4200          JMS TYPE
0231  0260          260
0232  7120          CLL CML

0233  5621          JMP I DIGIT

0234  0000  SPACE,  0000          / TYPE A SPACE
0235  2234          ISZ   SPACE
0236  7200          CLA
0237  1241          TAD   .+2
0240  4200          JMS TYPE
0241  0240          240
0242  5634          JMP I SPACE
0243  0000  POINT,  0000          / TYPE DECIMAL
0244  2243          ISZ   POINT
0245  7200          CLA           / POINT
0246  1250          TAD   .+2
0247  4200          JMS   TYPE
0250  0256          256
0251  5643          JMP I POINT
0252  0000  TRIDIG, 0000         / TYPE THREE DIGIT SEQUENCE OF DIG
0253  2252          ISZ    .-1
0254  7421          MQL
0255  7010          RAR
0256  3266          DCA   TRI1
0257  7407          DVI
0260  0144          144
0261  3303          DCA TRI2
```

```
0262  1266              TAD TRI1
0263  7004              RAL
0264  7501              MQA
0265  4221              JMS DIGIT
0266  0000   TRI1,      0
0267  7200              CLA
0270  1303              TAD TRI2
0271  7421               MQL
0272  7010              RAR
0273  3266              DCA TRI1
0274  7407              DVI
0275  0012              12
0276  3303              DCA TRI2
0277  1266              TAD TRI1
0300  7004              RAL
0301  7501              MQA
0302  4221              JMS DIGIT
0303  0000   TRI2,      0
0304  7200              CLA
0305  1303              TAD TRI2
0306  4221              JMS DIGIT
0307  0000              0
0310  5652              JMP I TRIDIG

0311  0000   STRING,      0000                      / TYPE STRING OF CHAR
0312  2311                ISZ        .-1
0313  3010                DCA        10             / STARTING ADDRESS IN
0314  1410                TAD I      10             / STRING TERMINATED B
0315  7450                SNA
0316  5711                JMP I      STRING
0317  4720                JMS I      .+1
0320  0200                TYPE
0321  5314                JMP        .-5
```

```
                *400
0400  0000  STEPP,   0000                      / SELECT NEXT POINTER
0401  2100           ISZ       VECTOR
0402  7300           CLL CLA
0403  1500           TAD I     VECTOR
0404  7440           SZA
0405  5600           JMP I     STEPP
0406  1110           TAD       C1
0407  3100           DCA       VECTOR
0410  5600           JMP I     STEPP

0411  0000  STEPS,   0000                      / SET UP POINTERS
0412  7300           CLA CLL                   / TO NEXT SLIDE
0413  1101           TAD       SP
0414  1233           TAD       DIR
0415  3101           DCA       SP
0416  1101           TAD       SP
0417  1233           TAD       DIR
0420  3000           DCA       0
0421  1400           TAD I     0
0422  7440           SZA                       / MAKE SURE NEXT STEP
0423  5611           JMP I     STEPS           / WILL NOT BE OFF END
0424  1107           TAD       SSW             / OF LIST
0425  7041           CIA
0426  3107           DCA       SSW
0427  1233           TAD       DIR
0430  7041           CIA
0431  3233           DCA       DIR             / IF SO TURN ARROUND
0432  5611           JMP I     STEPS           / DIRECTION
0433  0002  DIR,     2
0434  0000  PRNT,    0000
0435  7300           CLA CLL                   / PRINT REPORT IF LEF
0436  7404           OSR                       / SWITCH SET
0437  7004           RAL
0440  7430           SZL
0441  4643           JMS I     REPORT
0442  5634           JMP I     PRNT
0443  1200  REPORT,  1200
```

```
                *600
0600   0000   NEXT,    0000                / POSITION PROJECTOR ROUTINE
0601   6454            CLAF                / CLEAR ANALOG FLAG
0602   6461            SNAF                / WAIT TILL FLAG SET AGAIN
0603   7410            SKP
0604   5202            JMP    .-2
0605   4263            JMS    ASK          / CHECK 4 BUTTONS FOR RESPONCE
0606   6541            ADCC                / READ PROJECTOR POSITION
0607   6544            ADIC
0610   6532            ADCV
0611   6531            ADSF
0612   5211            JMP    .-1
0613   7300            CLA CLL
0614   6534            ADRB
0615   7041            CIA                 / MAKE NUMBER MINUS
0616   1500            TAD I  VECTOR       / AC NOW EQUAL DESIRED POS. MI
0617   0221            AND    .+2          / DISCARD LEAST SIGNIFICANT BIS
0620   7410            SKP
0621   7740            7740
0622   7440            SZA                 / SKIP IF IN CORRECT POSITION
0623   5253            JMP    MOVE
0624   7200            CLA                 / STOP MVEMENT
0625   6552            DAL1
0626   6551            DACX
0627   1104            TAD    ANSWER
0630   7450            SNA
0631   5201            JMP    NEXT+1
0632   7300            CLA CLL             / DEPOSIT DISPLACEMENT
0633   1500            TAD I  VECTOR
0634   7413            SHL
0635   0005              5
0636   0247            AND    NX1
0637   3113            DCA    DISP
0640   4650            JMS I  NX2          / INCREMENT TO NEXT POSIITION
0641   2252            ISZ    NXB
0642   5201            JMP    NEXT+1
0643   7300            CLA CLL
0644   1251            TAD    NXC
0645   3252            DCA    NXB
0646   5600            JMP I  NEXT
0647   0700   NX1,     0700                / MASK FOR DISP GENERATION
0650   0400   NX2,     STEPP               / ADD OF STEP ROUTINE
0651   7774   NXC,     -4                  / MINUS COUNT OF STEPS TO BE T
0652   7774   NXB,     -4                  / MINUS NO. OF STEPS LEFT
0653   7510   MOVE,    SPA                 / PUT OUT +10 VOLTS
0654   5257            JMP    .+3          / IF AC POSITIVE
0655   7350            CLA CMA CLL RAR        / PUT 3777 IN AC
0656   7410            SKP
0657   7330            CLA CLL CML RAR        / IF NEG AC PUT 4000 IN AC
0660   6552            DAL1              / LOAD ANALOG
0661   6551            DACX              / CONVERT TO ANALOG
0662   5201            JMP    NEXT+1
0663   0000   ASK,       0000                       / THIS ROUTINE
```

```
0664  7300    CLA CLL                / CHECKS SENSE LINES
0665  1104    TAD       ANSWER       / IF ANSWER TO QUESTIO
0666  7440    SZA                    / IS REQUIRED IF NOT
0667  5663    JMP I     ASK          / REQUIRED (ALREADY A
0670  6435    LASL                   / RETURN DOING NOTHING
0671  7440    SZA
0672  7410    SKP
0673  5663    JMP I     ASK
0674  0501    AND I     SP
0675  7440    SZA
0676  5302    JMP       .+4
0677  7340    CLA CLL CMA
0700  3104    DCA       ANSWER
0701  5663    JMP I     ASK
0702  7324    CLA CLL CML RAL
0703  3104    DCA       ANSWER
0704  5663    JMP I     ASK
```

```
0705  0000  TEST,   0000              / RUN A NEW TRIAL
0706  7350          STA CLL RAR
0707  6564          DAL4
0710  6561          DACY
0711  7200          CLA               / SET CLOCK TO ZERO
0712  3105          DCA   TIME1
0713  3106          DCA   TIME2
0714  6454  COUNT,  CLAF              / WAIT FOR NEXT CYCLE
0715  6461          SNAF
0716  7410          SKP
0717  5315          JMP   .-2
0720  2105          ISZ    TIME1      / COUNT TIME UNITS
0721  7410          SKP
0722  2106          ISZ    TIME2
0723  6545          ADCC ADIC         / GET TO A-D 2
0724  6544          ADIC
0725  6532          ADCV              / CONVERT
0726  6531          ADSF              / IF IT HAS GONE POSITIVE
0727  5326          JMP    .-1        / HE HAS PUSHED BUTTON
0730  7300          CLA CLL
0731  6534          ADRB              / RUN OVER
0732  7510          SPA               / IF NEGATIVE LOOP ANOTHE
0733  5314          JMP    COUNT
0734  4360          JMS    TIME
0735  7200          CLA               / IF OVER TURN OFF EVERYT
0736  6564          DAL4              / SHUT ALARM OFF
0737  1107          TAD     SSW
0740  6562          DAL3              / CHANGE TO BLANK SLIDE
0741  6561          DACY
0742  7300          CLA CLL
0743  1357          TAD     TAU       / WAIT FOR SLIDE TO CHANGE
0744  6454          CLAF
0745  6461          SNAF
0746  7410          SKP
0747  5345          JMP     .-2
0750  7001          IAC
0751  7420          SNL
0752  5344          JMP     .-6       / NOW OPEN SWITCH
0753  7200          CLA               / WHEN SLIDE HAS CHANGED
0754  6562          DAL3
0755  6561          DACY
0756  5705          JMP I   TEST
0757  6260  TAU,    6260              / MINUS NUMBER OF TICKS A
                                      / ALLOWED FOR SLIDE CHANGE
0760  0000  TIME,   0000                 / DESPLAY TIME ON DVM
0761  7200          CLA                  / CLEAR AC
0762  1105          TAD     TIME1
0763  7421          MQL                  / LOAD 24 BIT TIME REG
0764  1106          TAD     TIME2        / INTO AC-MQ
0765  7415          ASR
0766  0001           1
0767  7300          CLA CLL
0770  7405          MUY
```

```
0771  6431         6431                  / CONVERT TO PROPER RA■
0772  6554         DAL2                  / AND PUT NUMBER OUT T■
0773  6551         DACX
0774  5760         JMP I    TIME
```

```
                *800
1000  0000  STAT,     0000           / ROUTINE TO COMPILE STATISTICS
1001  7300            CLA CLL

1002  1101            TAD       SP / SET UP INDEX TO DATA AREA
1003  7001            IAC
1004  3374            DCA       INDEX
1005  1774            TAD I     INDEX
1006  1113            TAD       DISP
1007  3374            DCA       INDEX
1010  2774            ISZ I     INDEX

1011  1104            TAD       ANSWER   / THEN FILL OUT WHETHER GOOD
1012  7510            SPA                / OR BAD TRIAL
1013  5222            JMP       .+7
1014  2374            ISZ       INDEX    / IF GOOD COUNT AS GOOD
1015  2774            ISZ I     INDEX
1016  2374            ISZ       INDEX
1017  7300            CLA CLL
1020  3104            DCA ANSWER
1021  5230            JMP       .+7
1022  2374            ISZ       INDEX    / IF BAD COUNT AS BAD AND
1023  2374            ISZ       INDEX    / RETURN
1024  2774            ISZ I     INDEX
1025  7300            CLA CLL
1026  3104            DCA       ANSWER
1027  5600            JMP I     STAT

1030  2374            ISZ       INDEX    / NOW COMPUTE
1031  7300            CLA CLL            / SUM OF TIME
1032  1774            TAD I     INDEX
1033  1105            TAD       TIME1
1034  3774            DCA I     INDEX
1035  2374            ISZ       INDEX
1036  7430            SZL
1037  7101            CLL IAC
1040  1106            TAD       TIME2
1041  1774            TAD I     INDEX
1042  3774            DCA I     INDEX

1043  2374            ISZ       INDEX    / NOW COMPUTE SQUARE
1044  1105            TAD       TIME1    / AND ADD TO SUMM OF
1045  7421            MQL                / SQUARES
1046  1105            TAD       TIME1
1047  3251            DCA        .+2
1050  7405            MUY
1051  0000            000
1052  3371            DCA       Q2
1053  7501            MQA
1054  3370            DCA       Q1
1055  1105            TAD       TIME1
1056  7421            MQL
1057  1106            TAD       TIME2
```

```
1060  7104        CLL RAL
1061  3263        DCA      .+2
1062  7405        MUY
1063  0000        000
1064  3372        DCA      Q3
1065  7501        MQA
1066  1371        TAD      Q2
1067  3371        DCA      Q2
1070  7430        SZL
1071  7101        CLL IAC
1072  1372        TAD      Q3
1073  3372        DCA      Q3
1074  1106        TAD      TIME2
1075  7421        MQL
1076  1106        TAD      TIME2
1077  3301        DCA      .+2
1100  7405        MUY
1101  0000        000
1102  7430        SZL
1103  7101        IAC CLL
1104  3373        DCA      Q4
1105  7100        CLL
1106  7501        MQA
1107  1372        TAD      Q3
1110  3372        DCA      Q3
1111  7430        SZL
1112  2373        ISZ      Q4
1113  7300        CLL CLA


1114  1370        TAD      Q1          / NOW THAT SQUARE IS CALCU
1115  1774        TAD I    INDEX       / ADD TO SUMM
1116  3774        DCA I    INDEX
1117  7430        SZL
1120  7101        CLL IAC
1121  1371        TAD      Q2
1122  2374        ISZ      INDEX
1123  1774        TAD I    INDEX
1124  3774        DCA I    INDEX
1125  2374        ISZ      INDEX
1126  7430        SZL
1127  7101        CLL IAC
1130  1372        TAD      Q3
1131  1774        TAD I    INDEX
1132  3774        DCA I    INDEX
1133  2374        ISZ      INDEX
1134  7430        SZL
1135  7101        CLL IAC
1136  1373        TAD      Q4
1137  1774        TAD I    INDEX
1140  3774        DCA I    INDEX

1141  7300        CLA CLL              / NOW DETERMINE WHICH BLOC
```

```
1142  1105            TAD      TIME1       / TRIAL SHOULD BE ADDED TO
1143  7421            MQL
1144  1106            TAD      TIME2
1145  7413            SHL
1146  0002            002
1147  7001            IAC
1150  3370            DCA      Q1
1151  1370            TAD      Q1
1152  7041            CIA
1153  1367            TAD      MAXSIZ
1154  7500            SMA
1155  5361            JMP      .+4
1156  7300            CLL CLA
1157  1367            TAD      MAXSIZ
1160  5363            JMP      .+3
1161  7300            CLL CLA
1162  1370            TAD      Q1
1163  1374            TAD      INDEX
1164  3374            DCA      INDEX
1165  2774            ISZ I    INDEX
1166  5600            JMP I    STAT        / FINISHED RETURN
1167  0067  MAXSIZ,   67
1170  0000  Q1,        0
1171  0000  Q2,        0
1172  0000  Q3,        0
1173  0000  Q4,        0
1174  1174  INDEX ,    0
```

ANSWER	0104
ASK	0663
BLANK	0102
CONTRL	0060
COUNT	0714
CRLF	0207
C1	0110
C2	0111
DIGIT	0221
DIR	0433
DISP	0113
INDEX	1174
LENGTH	0103
MAXSIZ	1167
MOVE	0653
NEXT	0600
NXB	0652
NXC	0651
NX1	0647
NX2	0650
POINT	0243
PRINT	0073
PRNT	0434
Q1	1170
Q2	1171
Q3	1172
Q4	1173
REPORT	0443
SNEXT	0066
SP	0101
SPACE	0234
SSTAT	0072
SSTEPP	0070
SSTEPS	0071
SSW	0107
START	0020
STAT	1000
STEPP	0400
STEPS	0411
STEST	0067
STRING	0311
TAU	0757
TEST	0705
TIME	0760
TIME1	0105
TIME2	0106
TP	0112
TRIDIG	0252
TRI1	0266
TRI2	0303
TYPE	0200
VECTOR	0100

```
                *1200         / ROUTINE TO REPORT RESULTS
1200   0000   REPORT, 0000        / PRINT REPORT
1201   7300     CLA CLL       / SET UP INDEX
1202   1112     TAD    TP / TO RPORT TABLE
1203   7041     CIA
1204   7040     CMA
1205   3016     DCA    INDEX1

1206   1416   LOOP,    TAD I INDEX1
1207   7450     SNA
1210   5600     JMP I REPORT
1211   4612     JMS I .+1
1212   0311     STRING        / TYPE HEADING

1213   1416     TAD I INDEX1    / SET UP INDEX
1214   7041     CIA
1215   7040     CMA
1216   3017     DCA    INDEX

1217   4620   S1,  JMS I .+1    / PRINT FIRST STATISTIC
1220   0207     CRLF
1221   7200     CLA
1222   1234     TAD    T1
1223   4624     JMS I .+1
1224   0311     STRING
1225   7200     CLA
1226   1417     TAD I     INDEX
1227   4630     JMS I .+1
1230   0252     TRIDIG
1231   4632     JMS I .+1
1232   0207     CRLF
1233   5256     JMP    S2

1234   1234   T1,     .
1235   0316     316
1236   0317     317        / "NO. OF TRIALS = "
1237   0256     256
1240   0240     240
1241   0317     317
1242   0306     306
1243   0240     240
1244   0324     324
1245   0322     322
1246   0311     311
1247   0301     301
1250   0314     314
1251   0323     323
1252   0240     240
1253   0275     275
1254   0240     240
1255   0000     000
              INDEX=17
              INDEX1=16
```

```
1256  7300  S2,  CLA CLL      / TYPE NO. OF VALID TRIALS
1257  1417    TAD I INDEX
1260  3331    DCA   NUMBER
1261  1331    TAD   NUMBER
1262  4663    JMS I .+1
1263  0252    TRIDIG
1264  2017    ISZ   INDEX
1265  7300    CLA CLL
1266  1276    TAD   T2
1267  4670    JMS I .+1
1270  0311    STRING
1271  7300    CLA CLL
1272  1331    TAD   NUMBER   / IF NO VALID TRIALS REPORT FINISHED
1273  7440    SZA
1274  5317    JMP   S4
1275  5206    JMP   LOOP
1276  1276  T2,  .
1277  0240    240
1300  0326    326       / " VALID TRIALS  "
1301  0301    301
1302  0314    314
1303  0311    311
1304  0304    304
1305  0240    240
1306  0324    324
1307  0322    322
1310  0311    311
1311  0301    301
1312  0314    314
1313  0323    323
1314  0215    215
1315  0212    212
1316  0000    000

1317  7300  S4,  CLL CLA      / PRINT MEAN =
1320  1357    TAD   T4
1321  4722    JMS I .+1
1322  0311    STRING
1323  1417    TAD I    INDEX / CALCULATE MEAN
1324  7421    MQL
1325  1417    TAD I    INDEX
1326  7415    ASR
1327  0003    3
1330  7407    DVI
1331  0000  NUMBER, 0      / FORM OF MEAN
1332  7701    CLA MQA  / FIRST 6 BITS WHOLE SEC.
1333  3356    DCA   MEAN  / SECOND 6 BITS FRACTION
1334  1356    TAD   MEAN  / OF SECOND
1335  7100    CLL       / PRINT INTERGER
1336  7417    LSR       / PART
1337  0005    5
1340  4741    JMS I .+1
1341  0252    TRIDIG
```

```
1342  4743     JMS I  .+1
1343  0243     POINT      / PRINT DECIMAL POINT
1344  7300     CLA CLL
1345  1356     TAD   MEAN
1346  7417     LSR
1347  0005     5
1350  7405     MUY        / PRNT FRACTIN
1351  1750     1750
1352  7120     CLL CML
1353  4754     JMS I  .+1
1354  0252     TRIDIG
1355  4377     JMS   S6
1356  0000  MEAN,    0000

1357  1357  T4,   .
1360  0215     215
1361  0212     212        / MEAN =
1362  0315     315
1363  0305     305
1364  0301     301
1365  0316     316
1366  0240     240
1367  0275     275
1370  0240     240
1371  0000     000
```

```
              *1377
1377  73ØØ  S6,  CLA CLL  /TYPE VARIANCE
14ØØ  1367    TAD   T6
14Ø1  46Ø2    JMS I .+1
14Ø2  Ø311    STRING
14Ø3  73ØØ    CLA CLL      / CALCULATE VARIANCE
14Ø4  1366    TAD   D1ADD
14Ø5  3Ø1Ø    DCA   1Ø
14Ø6  1365    TAD   NM4
14Ø7  3ØØ7    DCA   7  / MOVE SUM OF SQUARES
141Ø  1417    TAD I INDEX
1411  341Ø    DCA I 1Ø / TO D1 THRU D4
1412  2ØØ7    ISZ   7
1413  521Ø    JMP   .-3
1414  1364    TAD   D4 / NOW DIVIDE BY NUMBER
1415  7421    MQL
1416  1757    TAD I NUMB
1417  3221    DCA   .+2
142Ø  74Ø7    DVI
1421  ØØØØ  TMP, Ø
1422  3221    DCA   TMP
1423  75Ø1    MQA
1424  3364    DCA   D4
1425  1363    TAD   D3
1426  7421    MQL
1427  1757    TAD I NUMB
143Ø  3233    DCA   .+3
1431  1221    TAD   TMP
1432  74Ø7    DVI
1433  ØØØØ    Ø
1434  3221    DCA   TMP
1435  75Ø1    MQA
1436  3363    DCA   D3
1437  1362    TAD   D2
144Ø  7421    MQL
1441  1757    TAD I NUMB
1442  3245    DCA   .+3
1443  1221    TAD   TMP
1444  74Ø7    DVI
1445  ØØØØ    Ø
1446  3221    DCA   TMP
1447  75Ø1    MQA
145Ø  3362    DCA   D2
1451  1361    TAD   D1
1452  7421    MQL
1453  1757    TAD I NUMB
1454  3257    DCA   .+3
1455  1221    TAD   TMP
1456  74Ø7    DVI
1457  ØØØØ    Ø
146Ø  77Ø1    CLA MQA
1461  3361    DCA   D1
1462  73ØØ    CLA   CLL
```

```
1463  1362    TAD   D2 / NOW THAT DIVISION IS
1464  7421    MQL      / DONE REDUCE TO CORRECT
1465  1363    TAD   D3
1466  7413    SHL      / FORM
1467  0003    3
1470  3364    DCA   D4
1471  1361    TAD   D1
1472  7421    MQL
1473  1362    TAD   D2
1474  7413    SHL
1475  0003    3
1476  3363    DCA   D3 / D4 CONTAINS INTERGER SEC.
1477  1760    TAD I AVE   / D3 CONTAINS FRACTION
1500  7421    MQL
1501  1760    TAD I AVE   / GET MEAN SQUARED
1502  3304    DCA   .+2
1503  7405    MUY
1504  0000    0
1505  7140    CMA CLL
1506  3362    DCA   D2
1507  7501    MQA
1510  7041    CIA
1511  7430    SZL      / PUT IN D2 AND D1
1512  2362    ISZ   D2 / (X**2/N)-M**2
1513  7100    CLL
1514  1363    TAD   D3
1515  3361    DCA   D1
1516  1362    TAD   D2
1517  7430    SZL
1520  7101    CLL IAC
1521  1364    TAD   D4
1522  3362    DCA   D2
1523  7300    CLL CLA     / PRIN T VARIANCE
1524  1362    TAD   D2
1525  7421    MQL
1526  7407    DVI      / DIGITS IN EXCESS OF 999
1527  1750    1750
1530  3362    DCA   D2
1531  7501    MQA
1532  7100    CLL
1533  7450    SNA
1534  5340    JMP   .+4
1535  4736    JMS I .+1
1536  0252    TRIDIG
1537  7200    CLA
1540  1362    TAD   D2
1541  4742    JMS I .+1
1542  0252    TRIDIG
1543  4744    JMS I .+1
1544  0243    POINT    / FINISH INTERGER PART
                    / THEN PUT OUT POINT
1545  7200    CLA
1546  1361    TAD   D1
1547  7421    MQL
```

```
1550  7405     MUY
1551  1750     1750
1552  7120     CLL CML
1553  4754     JMS I .+1
1554  0252     TRIDIG
1555  5756     JMP I .+1
1556  1620     S10
1557  1331  NUMB,   NUMBER
1560  1356  AVE, MEAN
1561  0000  D1,  0
1562  0000  D2,  0
1563  0000  D3,  0
1564  0000  D4,  0
1565  7774  NM4, -4
1566  1560  D1ADD,  D1-1
1567  1567  T6,  .
1570  0215     215
1571  0212     212
1572  0326     326
1573  0301     301
1574  0322     322
1575  0256     256
1576  0240     240
1577  0275     275
1600  0240     240
1601  0000     000

            *1620
1620  7300  S10, CLA CLL       / PRINT DISTRIBUTION
1621  1275     TAD   T10
1622  4623     JMS I .+1
1623  0311     STRING
1624  7300     CLA CLL
1625  1273     TAD   N54
1626  3000     DCA   0
1627  3001     DCA   1
1630  7300  S11, CLL CLA
1631  1417     TAD I INDEX
1632  7450     SNA
1633  5264     JMP   SKIP
1634  3003     DCA   3
1635  1001     TAD   1
1636  7417     LSR
1637  0000     0
1640  4641     JMS I .+1
1641  0252     TRIDIG
1642  4643     JMS I .+1
1643  0243     POINT
1644  1001     TAD   1
1645  7010     RAR
1646  7200     CLA
1647  7430     SZL
1650  1274     TAD   N5
1651  7120     CLL CML
```

```
1652  4653     JMS I  .+1
1653  0221     DIGIT
1654  4655     JMS I  .+1
1655  0234     SPACE
1656  7300     CLA CLL
1657  1003     TAD    3
1660  4661     JMS I  .+1
1661  0252     TRIDIG
1662  4663     JMS I  .+1
1663  0207     CRLF
1664  2000  SKIP,     ISZ    0
1665  7410     SKP
1666  5271     JMP    .+3
1667  2001     ISZ    1
1670  5230     JMP    S11
1671  5672     JMP I  .+1
1672  1206     LOOP
1673  7711  N54,  -67
1674  0005  N5,   5
```

```
1675  1675  T1Ø, •
1676  Ø212    212
1677  Ø212    212
17ØØ  Ø215    215
17Ø1  Ø212    212
17Ø2  Ø323    323
17Ø3  Ø3Ø5    3Ø5
17Ø4  Ø3Ø3    3Ø3
17Ø5  Ø256    256
17Ø6  Ø24Ø    24Ø
17Ø7  Ø326    326
171Ø  Ø323    323
1711  Ø256    256
1712  Ø24Ø    24Ø
1713  Ø3Ø6    3Ø6
1714  Ø322    322
1715  Ø3Ø5    3Ø5
1716  Ø321    321
1717  Ø256    256
172Ø  Ø215    215
1721  Ø212    212
1722  Ø212    212
1723  ØØØØ  ØØØ
            CRLF=2Ø7
            POINT=243
            SPACE=234
            STRING=311
            TP=112
            TRIDIG=252
            DIGIT=221
```

AVE	156Ø
CRLF	Ø2Ø7
DIGIT	Ø221
D1	1561
D1ADD	1566
D2	1562
D3	1563
D4	1564
INDEX	ØØ17
INDEX1	ØØ16
LOOP	12Ø6
MEAN	1356
NM4	1565
NUMB	1557
NUMBER	1331
N5	1674
N54	1673
POINT	Ø243
REPORT	12ØØ
SKIP	1664
SPACE	Ø234
STRING	Ø311
S1	1217
S1Ø	162Ø
S11	163Ø
S2	1256
S4	1317
S6	1377
TMP	1421
TP	Ø112
TRIDIG	Ø252
T1	1234
T1Ø	1675
T2	1276
T4	1357
T6	1567

```
            / PATCH TO WORKING PORTION OF PROGRAM ALLOWS SYSTEM
            / TO SCORE A FAILURE AFTER 32 SEC. WITH NO RESPONCE.
            *714
0714  4716    JMS I .+2   / REPLACE CLOCK WAIT
0715  7410    SKP
0716  0500    ALARM     / WITH  TIME LIMIT PLUS
0717  7000    NOP       / CLOCK TICKER
            *500
0500  0000  ALARM,  0000      / CHECK TOO SEE THAT 32
0501  7300    CLA CLL     / NOT EXCEEDED
0502  1106    TAD   TIME2
0503  1322    TAD   NM32
0504  7420    SNL
0505  5315    JMP   CONT
0506  7340    CLA CLL CMA
0507  3104    DCA   ANSWER
0510  7300    CLA CLL
0511  6564    DAL4
0512  6561    DACY
0513  5714    JMP I .+1
0514  0734    ENDIT
0515  6454  CONT,   CLAF
0516  6461    SNAF
0517  7410    SKP
0520  5316    JMP   .-2
0521  5700    JMP I ALARM
0522  7770  NM32,   -10
            TIME2=106
            ANSWER=104
            ENDIT=734
```

ALARM	Ø5ØØ
ANSWER	Ø1Ø4
CONT	Ø515
ENDIT	Ø734
NM32	Ø522
TIME2	Ø1Ø6

Report Control Table

This table governs the order in which data blocks are to be printed by the report generator. Each entry is a double word. The first word contains the address of the starting location of a string of 7 bit ASCII characters. The second word contains the location of the first word of the data block. The string of ASCII will be printed then the report will be typed allowing a descriptor to precede the report. The last entry of the table must be zero. The program will generate a series of reports starting with the first entry and progressing until the zero entry is reached. Origin of the table is location 2000_8. The character strings must consist of 7 bits full ASCII, right justified, one character per word and terminated by a zero word. Both table and string storage must fit entirely within the 2000_8 to 2777_8 block of storage.

```
                / REPORT CONTROL FOR CONSOLIDATED TABLES
                *2000
2000    0000    0000
2001    0000    0000
2002    2200    XS
2003    5300    5300
2004    2205    S
2005    3400    3400
2006    2211    M
2007    4100    4100
2010    2215    L
2011    4600    4600
2012    0000    0000
2013    0000    0000
                *2200
2200    0215    XS,  215
2201    0212      212
2202    0330      330
2203    0323      323
2204    0000      000
2205    0215    S,   215
2206    0212      212
2207    0323      323
2210    0000      000
2211    0215    M,   215
2212    0212      212
2213    0315      315
2214    0000      000
2215    0215    L,   215
2216    0212      212
2217    0314      314
2220    0000      000
```

L	2215
M	2211
S	2205
XS	2200

Slide Tray Table

This table contains all the information concerning the slides required by the program. In addition, the appropriate data area for each slide is given.

Entries in this table are each two words long. The first word contains the code corresponding to a proper switch response by the subject. For this experiment, possible codes were either 1, 2, 4 or 8 corresponding to right, up, left and down. The second word contains the starting address of the data block set aside for this slide or type of slide. This address will be modified by the amount specified in the vectoring table to arrive at a specific 64 word block of core. The statistics for this trial will then be added to accumulated statistics already resident there.

The first double word entry in this table is zero and the last double word entry is zero. The remaining entries correspond to the slides in the tray with early slides in the tray coming first in the table. Origin of the table is 3200_8 and the length is no more than 200_8.

```
            / SLIDE TABLE GIVES PROPER SWITCH RESPONCE & DATA AREA

            *3200
3200  0000  0
3201  0000  0
3202  0001  1
3203  4100  4100
3204  0002  2
3205  4600  4600
3206  0010  10
3207  5300  5300
3210  0001  1
3211  4100  4100
3212  0010  10
3213  4100  4100
3214  0004  4
3215  4600  4600
3216  0010  10
3217  3400  3400
3220  0004  4
3221  4600  4600
3222  0001  1
3223  5300  5300
3224  0004  4
3225  4100  4100
3226  0010  10
3227  5300  5300
3230  0004  4
3231  3400  3400
3232  0001  1
3233  4100  4100
3234  0002  2
3235  3400  3400
3236  0004  4
3237  4600  4600
3240  0002  2
3241  5300  5300
3242  0002  2
3243  3400  3400
3244  0010  10
3245  4600  4600
3246  0001  1
3247  3400  3400
3250  0002  2
3251  5300  5300
3252  0000  0
3253  0000  0000
```

<u>Vectoring Table</u>

This table describes each point on the screen to which the projector will be directed. The program will start at the top of the table and point the projector at each point listed in the table until the table is exhausted. When this happens, the program will start again at the top. Four vectoring commands are used for each trial, 3 to provide the intermediate positions of the random walk and 1 to provide the final position. If the table is not an even multiple of 4 but is divisible by 4 with a remainder of 1, the table will precess such that all the table entries will be used to point the project for a trial once every four times through the table.

The point on the screen to which the projector is to be directed is given by the bits 1-6 of the entry. 000001 points to the extreme right and 111111 points to the extreme left.

Bits 9-11 of the entry designate the azimuth grouping of this vectoring command. This number is used to modify the data address given in the slide table. In a sense, the data area can be viewed as a two dimensional array with each item in the array being the data for a single type of trial. The slide table then gives the first index and the vectoring table the second. Storage requirements for the data are 64 words of core for every cross point used.

Azimuth groupings should be assigned numbers between 0 and 7 with 0 being used first and 7 last.

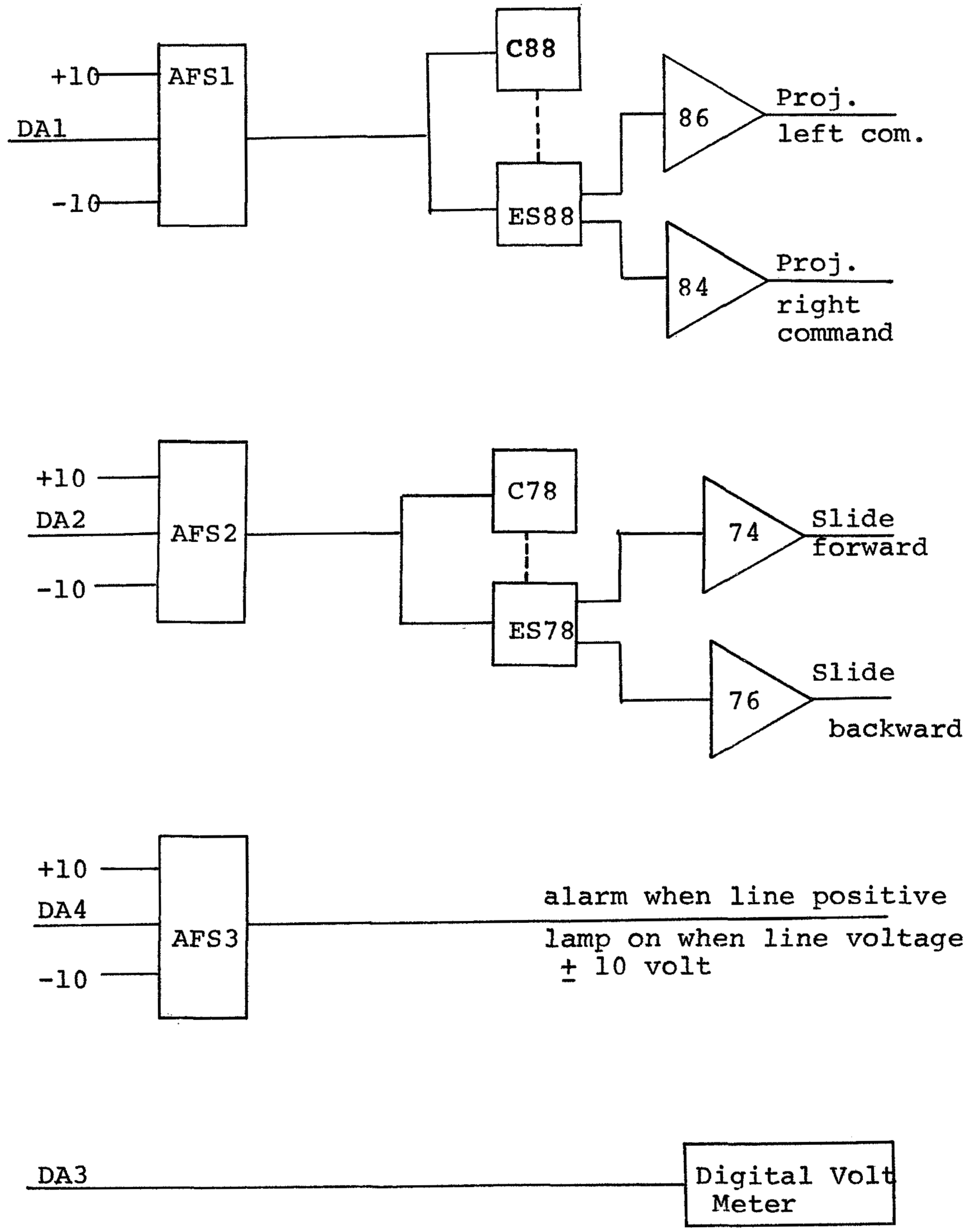
Bits 0, 7, and 8 of the word must be zero. The last entry in the table must be all zero.

```
                / VECTORING TABLE WITH SCREEN DIVISION
                *3000
3000   2000   2000
3001   2100   2100
3002   0600   0600
3003   2500   2500
3004   2200   2200
3005   0600   0600
3006   2200   2200
3007   1400   1400
3010   1100   1100
3011   0400   0400
3012   1200   1200
3013   0400   0400
3014   1200   1200
3015   0600   0600
3016   1000   1000
3017   0400   0400
3020   0200   0200
3021   0600   0600
3022   1200   1200
3023   1100   1100
3024   1500   1500
3025   2100   2100
3026   2500   2500
3027   2600   2600
3030   3200   3200
3031   3600   3600
3032   3100   3100
3033   3400   3400
3034   3000   3000
3035   3300   3300
3036   3300   3300
3037   2700   2700
3040   3000   3000
3041   2300   2300
3042   3100   3100
3043   3500   3500
3044   3300   3300
3045   3700   3700
3046   3400   3400
3047   2700   2700
3050   2200   2200
3051   3400   3400
3052   1600   1600
3053   1200   1200
3054   1300   1300
3055   0400   0400
3056   2600   2600
3057   3200   3200
3060   1500   1500
3061   0600   0600
3062   1400   1400
```

3063	0600	0600
3064	1200	1200
3065	1500	1500
3066	3200	3200
3067	3600	3600
3070	2700	2700
3071	0000	0000

APPENDIX III

Figures A.III.1 and A.III.2 show the wiring logic for the GPS 290T computer and the attached equipment.



Digital to Experiment Links

Figure A.III.1

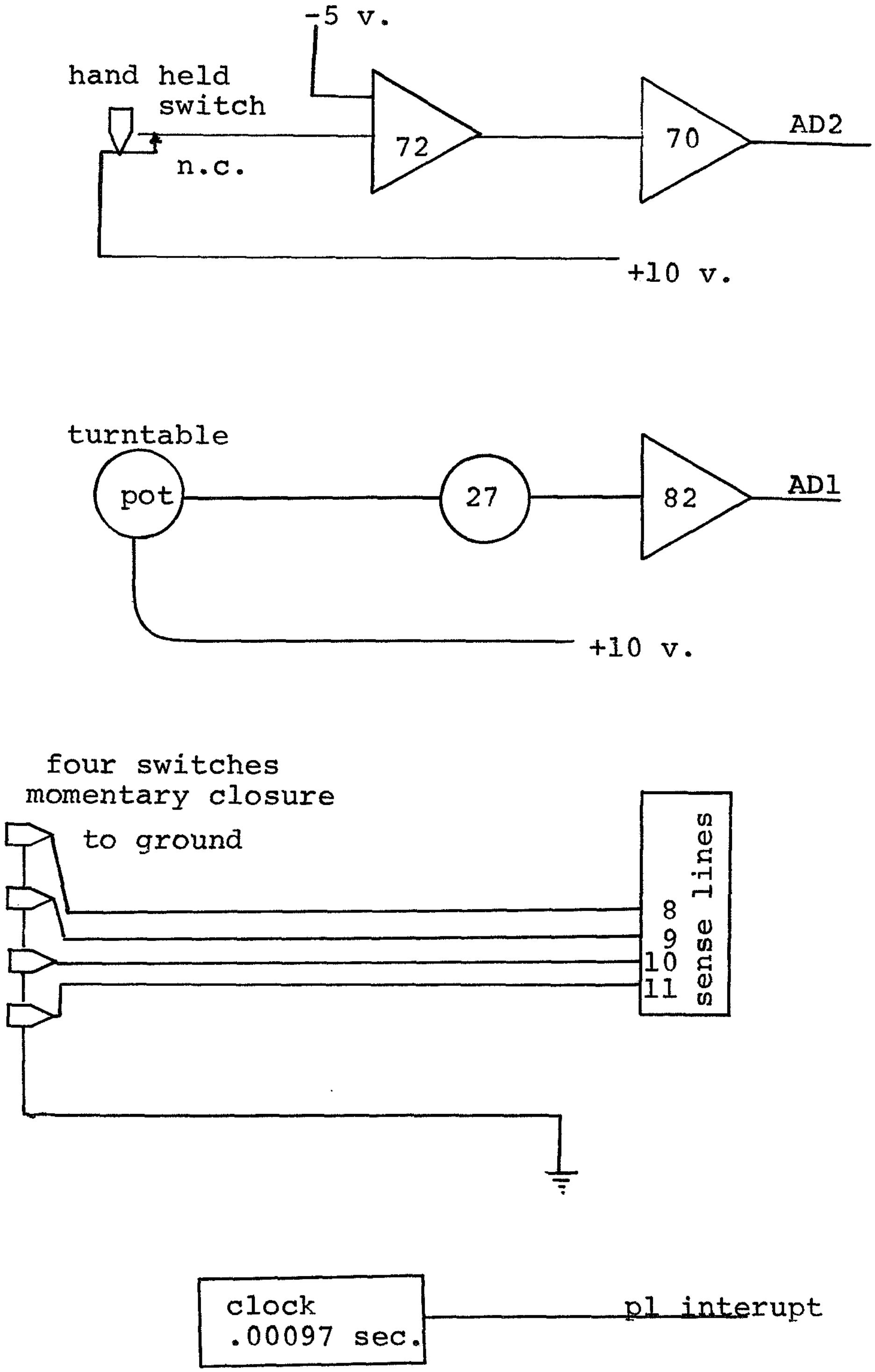


Figure A.III.2. Experiment to Digital Links

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