MASSACHUSETTS INSTITUTE OF TECHNOLOGY

DISPLAY RESEARCH
COLLISION WARNING SYSTEMS

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Supervisor: L. R. Young

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MAN-VEHICLE LABORATORY
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FINAL REPORT

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CHAPTER 1. INTRODUCTION

Background

The frequency of mid-air collisions is increasing at an alarming rate. There were 38 mid-air collisions in 1968 [1], all but four of which were between general aviation aircraft. The most costly accidents by any criterion are those involving air carrier aircraft. Two approaches have been mapped out in an effort to alleviate the current number of mid-air collisions and the greater number that are predicted to occur in the future as a result of increased traffic. The report of the so-called Alexander Committee [2] presents some suggestions on how to alleviate the traffic congestion in the terminal areas. These are directed toward the improvement of the air traffic control system as a whole. Another approach involves onboard instrumentation to allow aircraft to maintain proper separation.

There are two classes of onboard systems which are used to prevent mid-air collisions. These are the collision avoidance system (CAS) and the PWI system (Pilot Warning Indicator, or Proximity Warning Indicator). As described in [3], these systems are defined as follows.

Collision Avoidance Systems (CAS) - An airborne system that performs all the necessary functions such that its output is a signal indicating or intitiating an appropriate avoidance maneuver at a suitable time.

Pilot Warning Instrument (PWI) - An airborne instrument whose function it is to warn a pilot and provide suitable information to assist him in evaluating a collision threat.

As can be seen from these definitions the major difference between the two systems is that the CAS system performs the functions of detecting the target, evaluating the threat posed by the target, and deciding on the appropriate evasive maneuver. In the PWI system only the first of these functions is performed by the system itself. The evaluation of the threat and the appropriate maneuver are accomplished by the pilot himself.

The CAS system currently receiving the most attention is the time-frequency system being developed by the ATA [4]. These installations are very costly (approximately $30,000) and are designed primarily for use aboard air carriers. The cost for a less sophisticated version to be used by general aviation aircraft has been estimated as being no lower than $4,000 [4].

PWI systems, because of the greater reliance on the participation of the pilot, are considerably less expensive. The cost for the system proposed by RCA, which uses radio frequencies, ranges from approximately $500 to $20,000, depending on system capability. Other systems are under development which use xenon strobe lights as the transmitting source, and the cost for these is approximately $1,500. Another system that is currently on the market [5] at $395 indicates when an aircraft with an operating transponder is within a certain range of one's own aircraft.

The Infrared PWI System

The type of PWI system currently under evaluation by NASA, and the system on which the display studies were based, is an infrared PWI system. This system uses the currently available xenon strobe lights as a transmitting source. The receivers are built around silicon detectors. The good match between the detector responsivity and xenon lamp energy distribution is shown in Figure 1.1 taken from [6]. As an aside, it is interesting to note the peaks of energy which match the silicon detector characteristics are in the infrared region, and do not contribute to the visibility characteristics of the xenon lamp for which the lamps were initially intended.

The two prototype systems which are being evaluated use an array of silicon detectors at the receiver. Incident light is focused on the mosaic by a lens. For the Fecker system, each individual silicon detector covers a field of view of approximately 20° by 20°. The arrangement of these detectors is shown in Figure 1.2 [7]. It can be seen that the maximum coverage in azimuth is approximately 160° and maximum coverage in elevation is ±60°. The Loral system

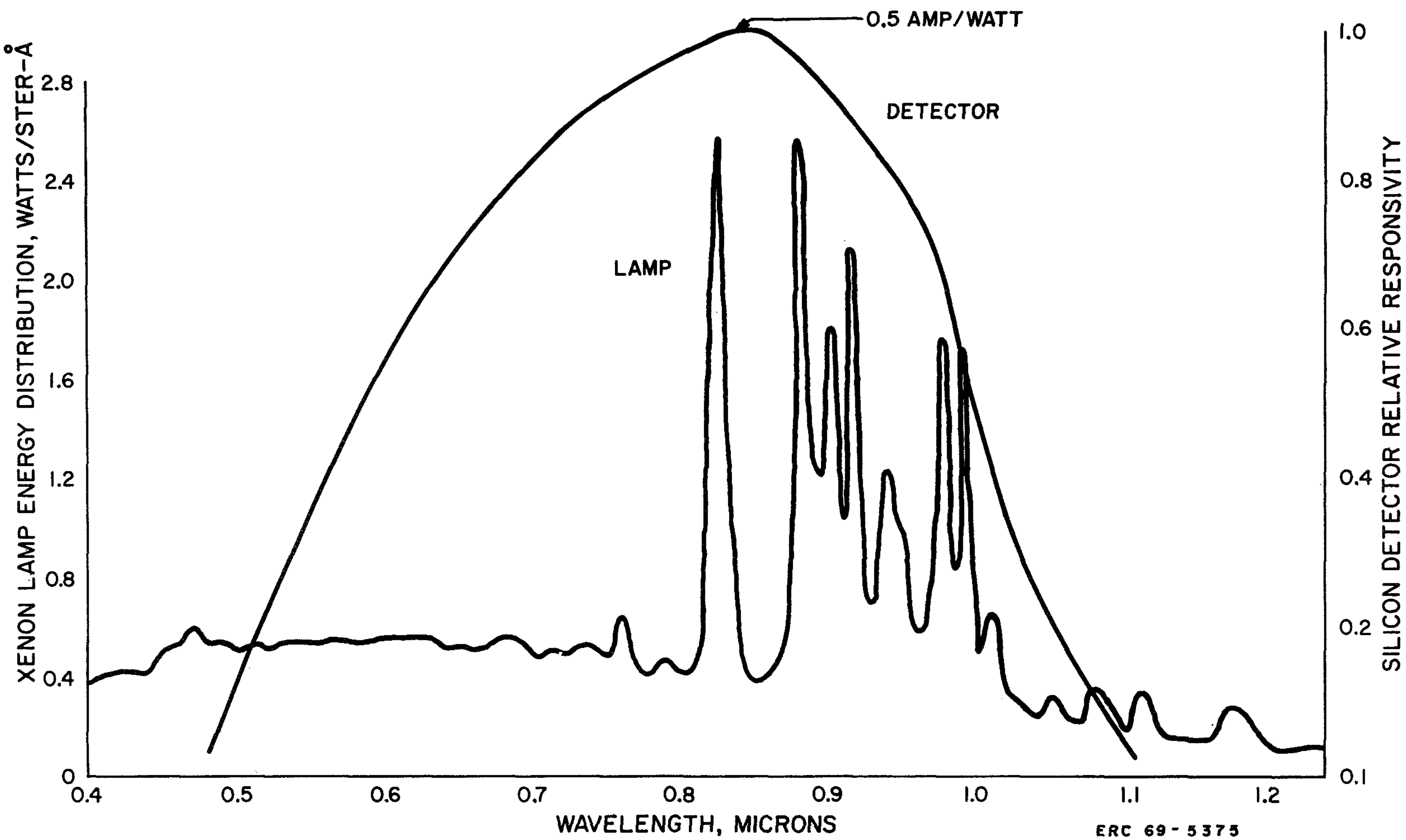


Figure 1.1 Spectral Intensity of a Xenon Lamp and Spectral Response of a Silicon Detector.

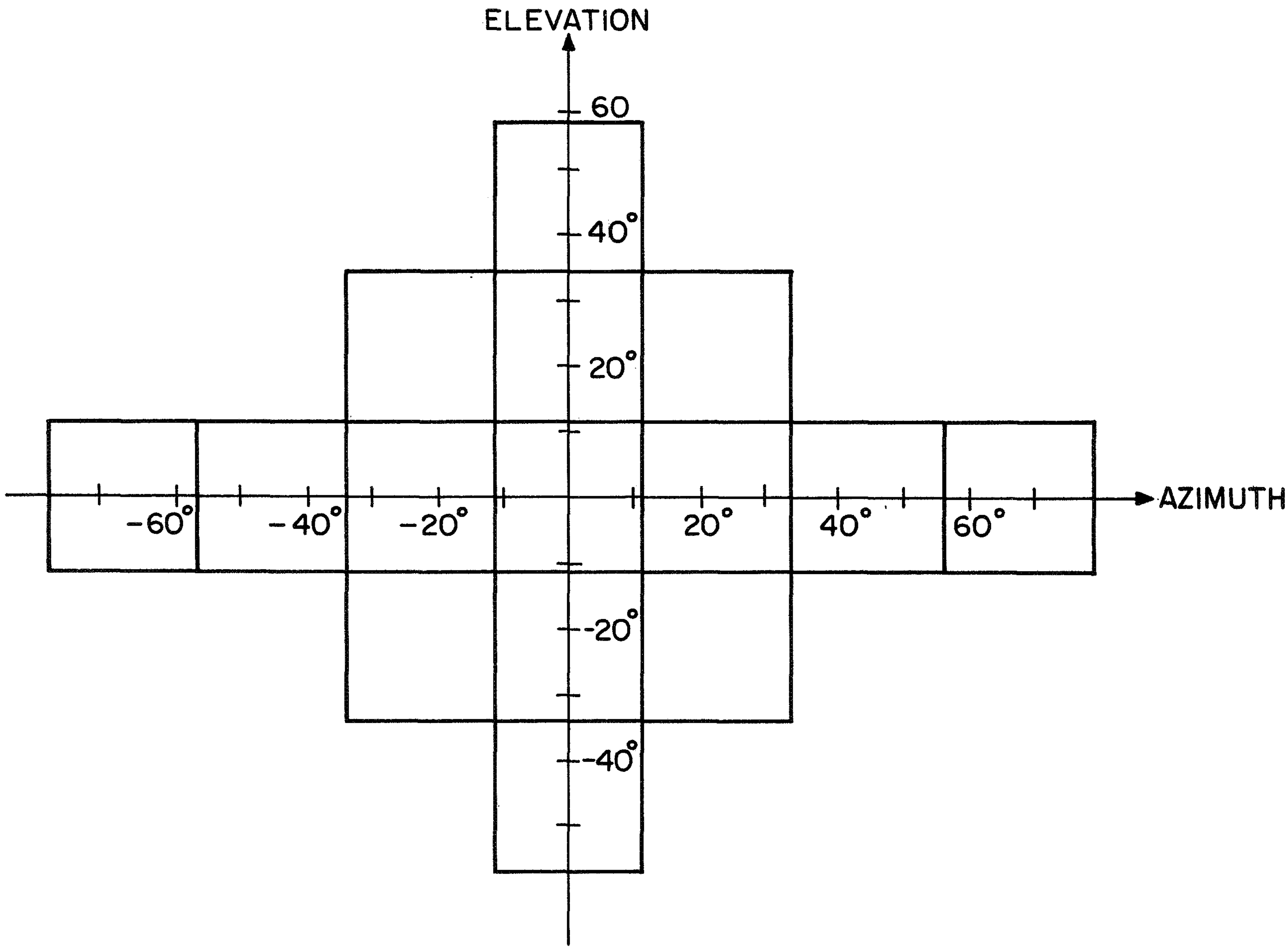


Figure 1.2 Azimuth and Elevation Coverage of Fecker Systems Display.

uses a single row of 8 detectors and each segment covers a field of view of ±10° in elevation and 30° in azimuth for a total of 240° coverage in azimuth.

The primary limitation in the infrared PWI system is the lack of range and range-rate data. The atmospheric conditions can cause the detection range of the system to vary from 2 to 5 miles. Thus one cannot infer the range of a xenon source when it is first detected. In addition, the pulse-to-pulse variation in received amplitude can be on the order of 2 or 3 to 1 [6]. This precludes the effectiveness of taking differences of successive received pulses to obtain range-rate information. In spite of these limitations, however, the optical PWI system does provide bearing and elevation information about the target's position. In the case of the Fecker system, this is done with a resolution of ±11 1/4°. In the Loral system this is done with a resolution of ±15° in azimuth and ±10° in elevation.

Displays

The workload of the pilot in today's traffic environment is increasing regardless of the pilot's rating or the aircraft he is flying. This is especially true in high density traffic areas where the two tasks of maintaining vigilance for other aircraft and following instructions from air traffic controllers create a heavy load on the pilot's ability to fly his aircraft in a safe manner. A

PWI system should not add to this workload, but should alleviate a portion of it. Therefore, one of the major factors is the PWI display, the interface between the system and the pilot. The display is important not only from the point of view of the workload, but primarily because the pilot must quickly detect the target and evaluate the situation for the PWI system to work effectively.

Ideally, any modality (sensory input) can be used in a display to transmit information, although audio, visual, and tactile are the primary methods that are used. Only audio and visual displays are considered in this report, even though a tactile display described in [3] seems effective in conjunction with a command for a CAS type of system.

One experiment was conducted in the area of audio displays by Charles Burr, and he investigated the feasibility of creating a stereophonic alarm to be used in the cockpit. The purpose of this display would be to create a sound which emanated from the direction of the target. The use of such a display would allow the pilot to turn his head immediately toward the target and start searching without having to refer to any visual instruments. The details are described in Chapter 2.

Visual displays fall into two broad categories: head-up and panel mounted. The head-up display is of interest in connection with PWI systems because of the critical nature of detecting a target as quickly as possible. Assuming that the pilot is accommodated at infinity, a panel mounted display would require that the pilot accommodate to the panel upon hearing an audio alarm and then re-accommodate at infinity to search for the target. Some experimental work in this regard is described in [6], and the time to accomplish this task is on the order of 2 seconds. On the other hand, a head-up display would allow the pilot to detect the target without accommodation and would save most of this time.

Two experiments were performed with visual displays. Basil Smith investigated the effects of the fields of view covered by the individual silicon detectors on a person's ability to locate targets. This is briefly described in Chapter 3, and the details are contained in his Master's thesis [8]. John Hatfield constructed a moving-base simulator and compared the time to detect targets using a head-up display, a panel mounted display, and a warning-only (buzzer) display.

CHAPTER 2. FEASIBILITY STUDIES FOR A STEREOPHONIC AUDIO ALARM

Introduction

The purpose of this series of experiments is to examine the feasibility of a stereophonic audio alarm. Such an alarm could provide bearing information and, perhaps elevation information, by synthesizing a point source of sound in the direction of the intruding aircraft using two or more speakers.

Synthesis of an Apparent Sound Source

When a person hears a sound from a single source his ability to locate the source of the sound is based on several cues. The interaural differences in the intensity of the sound and in the time at which the sound reaches the ear are very important. Echoes from the pinnae also provide important cues such that people who are deaf in one ear are able to determine the direction of a sound source, although not with as great accuracy as people who can use both ears.

One mathematical model of the ears is simply a pair of holes separated by a sphere. For a given sound source, which for simplicity's sake is a pure tone of frequency ω, the instantaneous sound pressure at the left and right ears, respectively, may be written

$$P_L = A_L \sin \omega t$$

and

$$P_R = A_R \sin \omega(t + \Delta t)$$

where Δt is the interaural time difference. The spherical model allows a simple calculation of Δt which agrees closely with experimental values. The sound wave must travel an extra distance, Δd, to reach the far ear. Figure 2.1 shows the geometrical justification of the formula [9]

$$d = r(\theta + \sin\theta).$$

Thus the interaural time difference is simply

$$t = \Delta d/c.$$

With a radius of 8.75 cm and a speed of sound of 34,300 cm/sec.,

$$\Delta t_{\mu\ sec} = 254(\theta + \sin\theta).$$

The interaural intensity difference is more difficult to predict. Essentially the human head acts as a low pass filter. Thus, the interaural intensity difference varies not only with the direction of the source but also with the frequency of the sound. Values of the intensity difference have been determined experimentally by W. E. Fedderson et al. [10] and these values are used in this study. Basically the intensity levels are equal when the source is directly in front of or behind the head ($\theta = 0°$ or $180°$) but the intensity difference grows as the source moves to either side of the head. The difference is greatest at $\theta = \pm 90°$, about 20 db at 6,000 cps, 11 db at 2,500 cps, and not more

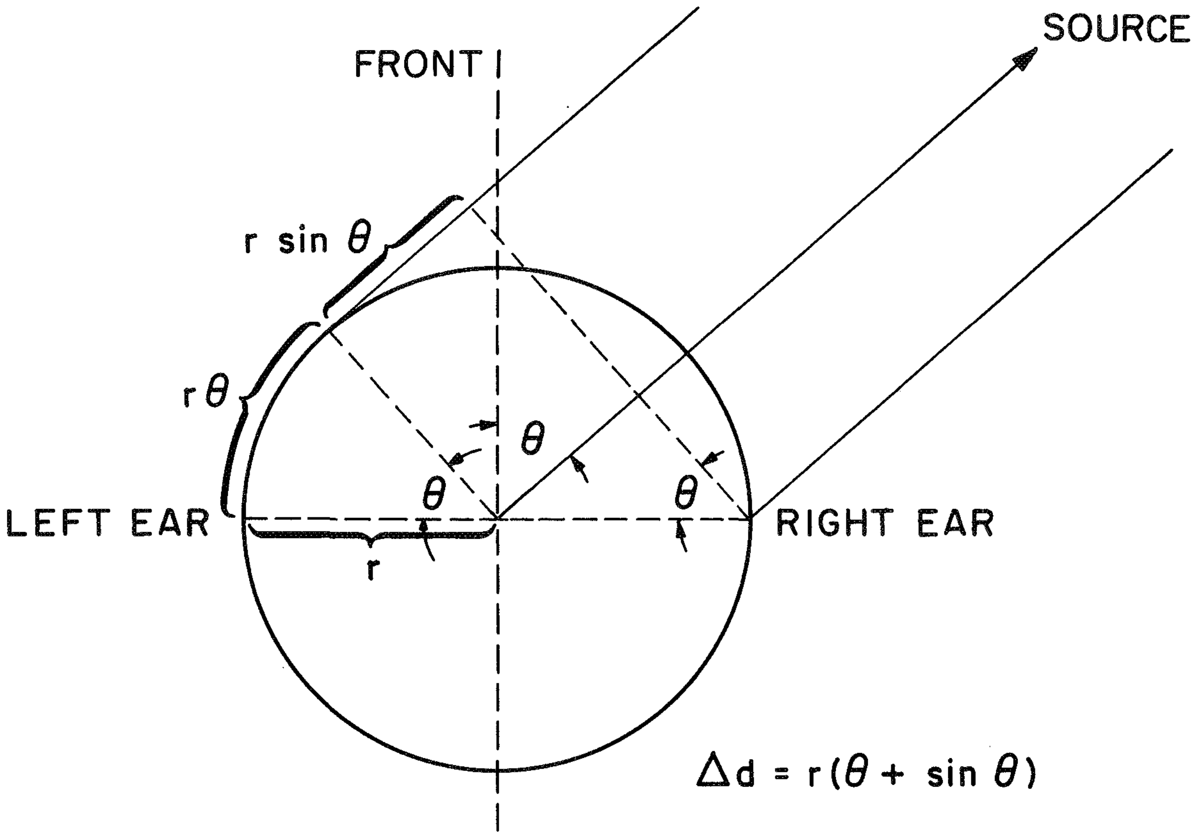


Figure 2.1 Model for Determining Interaural Time Difference.

than 1 db at 200 cps.

Man's mechanism for localizing sound sources depends mainly on the interaural time difference for frequencies less than about 1500 cps. Above 1500 cps, the intensity difference is the primary cue. It has been found in other studies [11] that the interaural time difference becomes an almost negligible factor in the localization of higher frequency tones. Results from parts of this experiment bear this out.

To synthesize an apparent sound source by varying the output of two speakers, sound waves should be created at the two ears which are nearly the same as would be created by a real source in the intended direction. For example, consider Figure 2.2, showing two speakers, 1 and 2, and their relative position to the listener's head. The instantaneous sound pressure at each ear is the sum of the components from the two speakers, that is

$$P_R = P_{1R} + P_{2R}$$

and

$$P_L = P_{1L} + P_{2L}$$

where P_{1R} is the component from speaker 1 at the right ear, P_{2R} is the component from speaker 2 at the right ear, etc. If we consider

$$P_{1R} = A_{1R} \sin \omega t$$

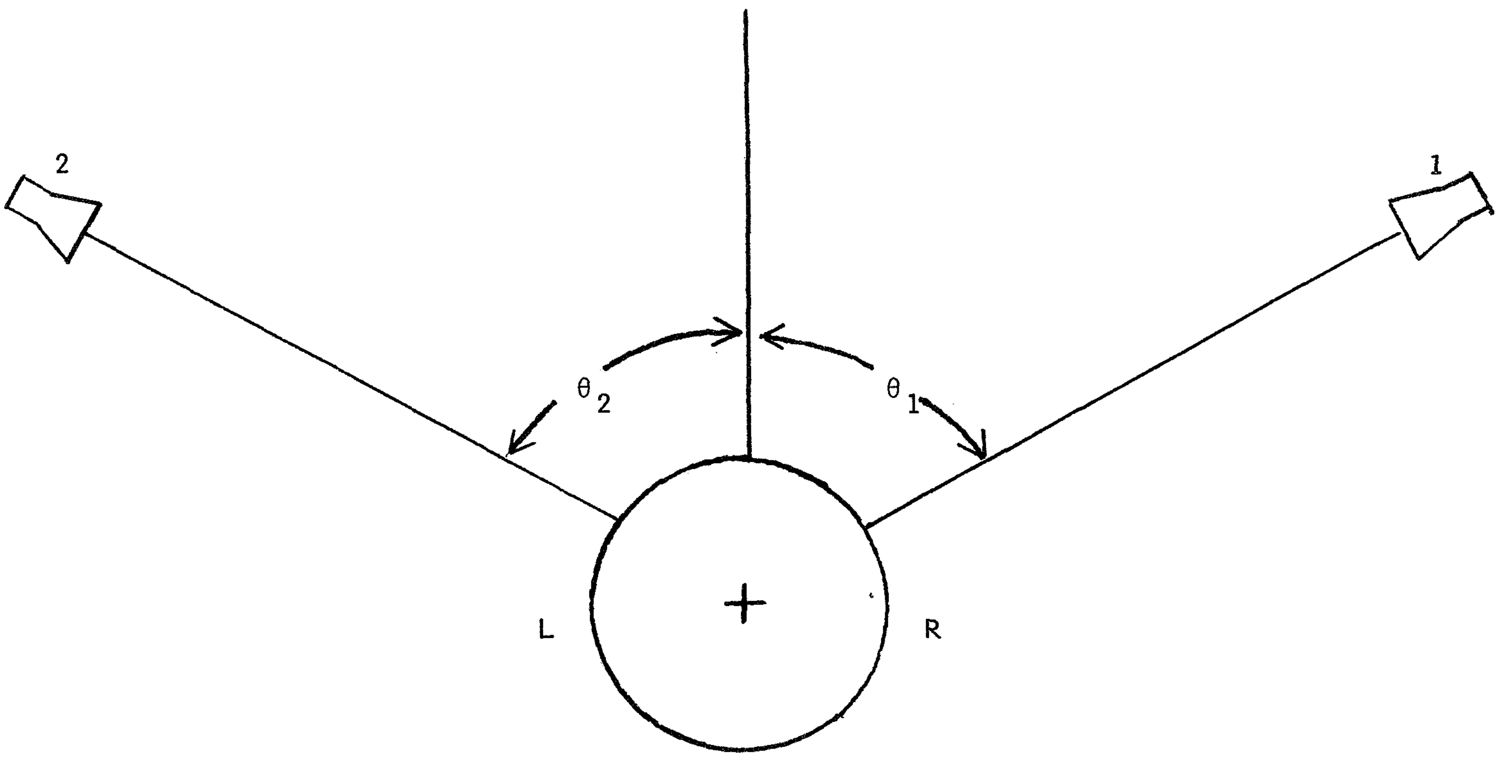


Figure 2.2 Speaker Layout

then

$$P_{1L} = A_{1L} \sin \omega(t - \Delta t_{1L})$$

where

$$\Delta t_{1L} = \Delta t(\theta_1) \qquad \Delta t(\theta)_{\mu sec} = 254(\theta + \sin\theta).$$

If we know the interaural intensity difference $\Delta I_{db}(\theta)$ for the frequency ω, the amplitude A_{1L} can be written

$$A_{1L} = A_{1R}\, k(\theta_1)$$

where

$$k(\theta) = \exp(-\Delta I_{db}(\theta)/20).$$

Thus P_{1L} is a function of P_{1R} and θ_1,

$$P_{1L} = A_{1R}\, k(\theta_1) \sin \omega(t - \Delta t(\theta_1)).$$

Similarly the sound pressure components from speaker 2 can be written

$$P_{2L} = A_{2L} \sin \omega(t - \Delta t_d)$$

and

$$P_{2R} = A_{2L} k(\theta_2) \sin \omega(t - \Delta t_d - \Delta t(\theta_2))$$

where Δt_d is any time delay which might occur between P_{1R} and P_{2L}. Such a time delay might be caused by unequal distances between speaker 1 and the right ear and between speaker 2 and the left ear or by an artificially induced delay at the speakers themselves. Finally, adding the various components, we obtain

$$P_R = A_{1R} \sin \omega t + A_{2L} k(\theta_2) \sin \omega (t - \Delta t_d - \Delta t(\theta_2))$$

and

$$P_L = A_{1R} k(\theta_1) \sin \omega (t - \Delta t(\theta_1) + A_{2L} \sin \omega (t - \Delta t_d).$$

Vector addition provides a simple graphical technique for this addition. The resultants of the two additions can be expressed as

$$P_R = A_R \sin \omega (t + \Delta t_R)$$

and

$$P_L = A_L \sin \omega (t + \Delta t_L).$$

We are interested in the interaural intensity difference, ΔI_{db}, and the interaural time difference, Δt, which are specified for the desired direction. These two parameters are defined

$$\Delta I_{db} = 20 \log_{10} (A_R/A_L)$$

and

$$\Delta t = \Delta t_R - \Delta t_L.$$

It is tedious but possible to determine the appropriate components given a desired direction by iterative methods. Values used in the tests were determined by an iterative graphical method.

Problems Caused by the Cockpit Environment

Several basic problems exist in the operating cockpit conditions which might limit the audio system's capability to create the appropriate sound pressures at each of the pilot's ears or which might diminish the pilot's ability to localize a sound source.

The pilot's workload produces a strain on his abilities which must not be neglected. In the tests discussed in this report no workload was placed on the subject; the distraction caused by the pilot's need to control the aircraft will very likely reduce his ability to localize the audio alarm. This possibility must be seriously considered since the most probable time that the alarm will be used is when the pilot's workload is the heaviest, just after takeoff and just before landing.

Recent studies of background noise in private light aircraft show that noise in the cockpit runs as high as 105 db at low frequencies of about 60 cps. The intensity drops off as the frequency increases, but is still as high as 65 db at 2500 cps [12].

By concentrating the audio alarm in the higher audio frequencies, such as 2000 to 5000 cps, this problem should not be significant since the background noise is not so predominant in these regions.

A problem which was neglected in this report until now but which is evident in the results of the tests is the question of the extent of the disruption of the intended sound waves from a multitude of directions can literally destroy the intended effect of the two speaker system. Very early in the testing it was found that a continuous alarm created a sound that seemed to come from all directions even when just one of the two speakers was used. However, pulsing the alarm at about two pulses per second seems to have limited this problem.

The freedom of head movement might seem to create a problem for the synthesis of an apparent sound source. Since the time differences to be created correspond to a distance travelled of only a few centimeters, only a small change in the pilot's head position will seriously affect the timing. However, with the use of higher frequency tones (above 1500 cps), which are desirable because of the lower background noise, the effect of the interaural time difference seems to be negligible. As long as the pilot is not relatively close to either speaker, a moderate head movement should not seriously affect the interaural intensity difference of an alarm with a large number of frequencies. In the tests of this system, subjects were left free to move their heads at will. The only position constraint was that the pilot's seat belt be fastened in order to keep the subjects in approximately the same position through various tests.

Tests and Results

The tests of the two speaker alarm system were held in the Link GAT-1 to evaluate the stereophonic alarm under realistic conditions. The measurement of angles was made difficult by the cramped area inside the cockpit and measure of the speaker output was complicated by the presence of echoes in the cockpit. As a result the angle measurements are only accurate to about ±3°, adequate for this experiment. Because of the echoes the speaker input was measure in these tests. Testing the speakers individually outside the cockpit, it was determined that with the sound levels used the response of the two speakers was virtually identical and the output level increased proportionally to increases in the input level.

In the cockpit, the speakers were mounted on both sides of the pilot. Since the pilot warning indicator system roughly scans ±60° in azimuth, it was originally intended to mount the speakers at ±60° from the front of the pilot's head. However, because of difficulties in measurement and installation, speakers 1 and 2, respectively, were mounted at 45° and -51° for test I and at 50° and -55° for test II.

These test were designed to determine how well a subject could localize an audio signal from the two speakers. The subject was seated in the cockpit with the seatbelt fastened as an approximate position constraint. When the subject heard an alarm he gave the direction he thought the sound came from by selecting the appropriate number from a numbered tape which ran horizontally across the middle of the windscreen. Using a one way voice communication link, the subject reported this number to the tester who then turned off the alarm.

A 2500 cps square wave was chosen as the waveform of the audio alarm. Its simplicity made the measurement of intensity differences and time delays convenient. The signal was also sufficiently above the 1500 cps region where a person's ability to localize a sound is poor.

It was immediately found that a continuous alarm was impossible to localize since echoes gave the impression that the sound came from all directions. It was found that one could not even tell when just one of the two speakers was operating. The effect of the echoes was greatly reduced by pulsing the alarm, that is, turning it on and off, at the rate of about 2 times per second. In tests I and II, the waveform was generated by a square wave generator triggered by a sine wave generator running at 2 cps to pulse the alarm. The signal was divided between the two speakers by a center tapped potentiometer. This allowed the relative intensity difference to be adjusted. No time delay was used.

The results of test I (two subjects) and II (five subjects) show that the sense of direction responds well to changes in the intensity levels. A definite bias is indicated by the pull to the left in test I and to the right in test II as shown in Figures 2.3 and 2.4. The only difference in the two tests was the position of the two speakers. The results, however, indicate that there is no correlation between the bias and the closer speaker (speaker 2). Evidence in other tests leads one to suspect echoes within the cockpit as the major cause of this bias. The standard deviation from the average localization value is 18.9°. In general, the subjects found the alarm somewhat confusing to localize exactly. The general direction was fairly easy to determine but the direction seemed to shift slightly as the subject moved his head. Response time was not measured but seemed to average about 5 seconds.

Other tests were performed using the interaural time difference cue to create an apparent source. As expected, this was not effective because the fundamental frequency was 2500 Hz, above the level where the time difference is an effective cue. Similar results are shown in [14]. These tests were useful, however, since conditions of one speaker only were intermingled with the time-difference cases. They showed biases of 12° and 6°, and standard deviations of 22° and 17° for speakers 1 and 2, respectively. These are much larger than similar tests in anechoic chambers [13, 14], and point to the fact that echoes are probably a prime source of the difficulty in obtaining consistency in perceived hearing of the apparent source of sound.

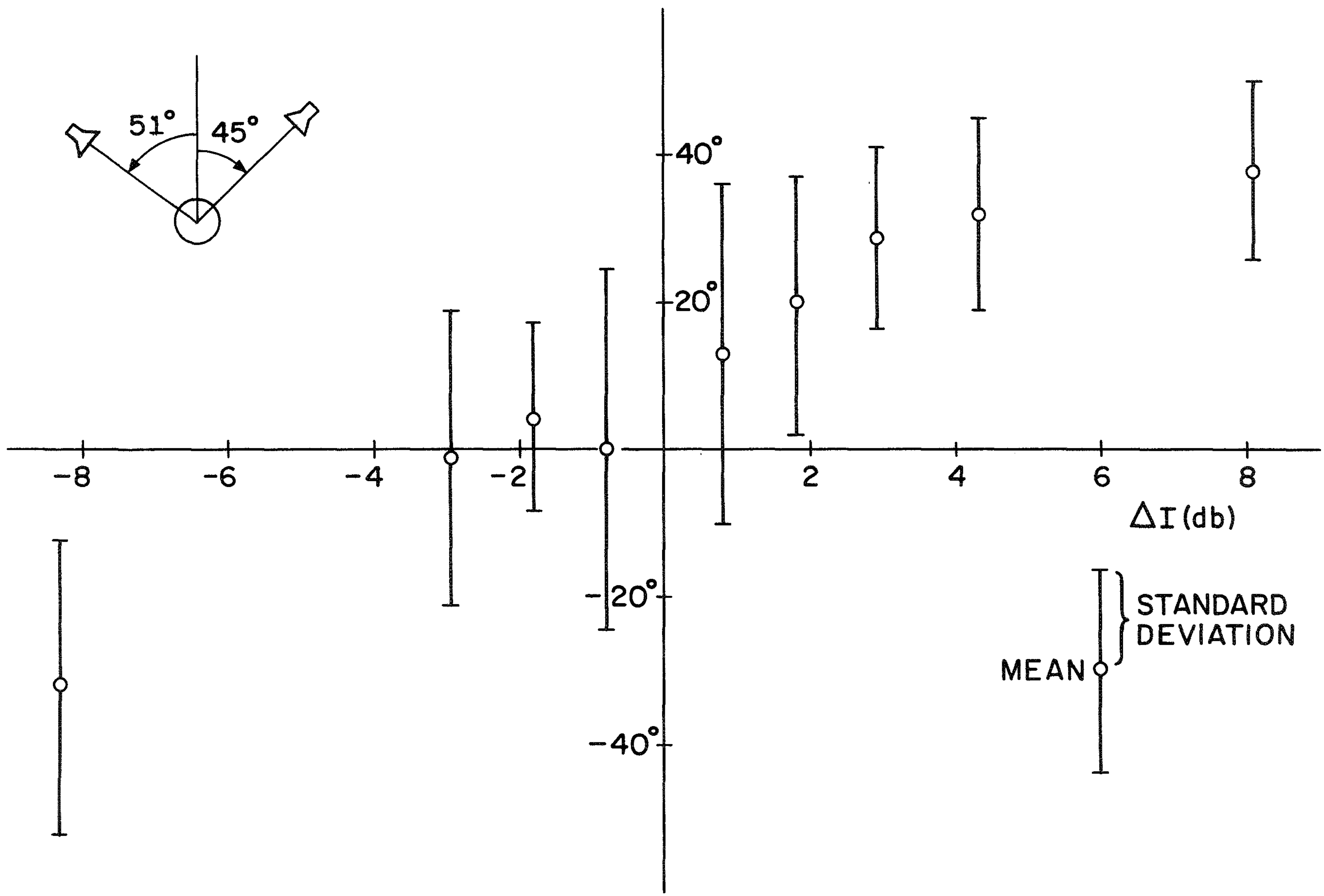


Figure 2.3 Perceived Azimuth of Source vs. Interaural Intensity Difference. (Test I)

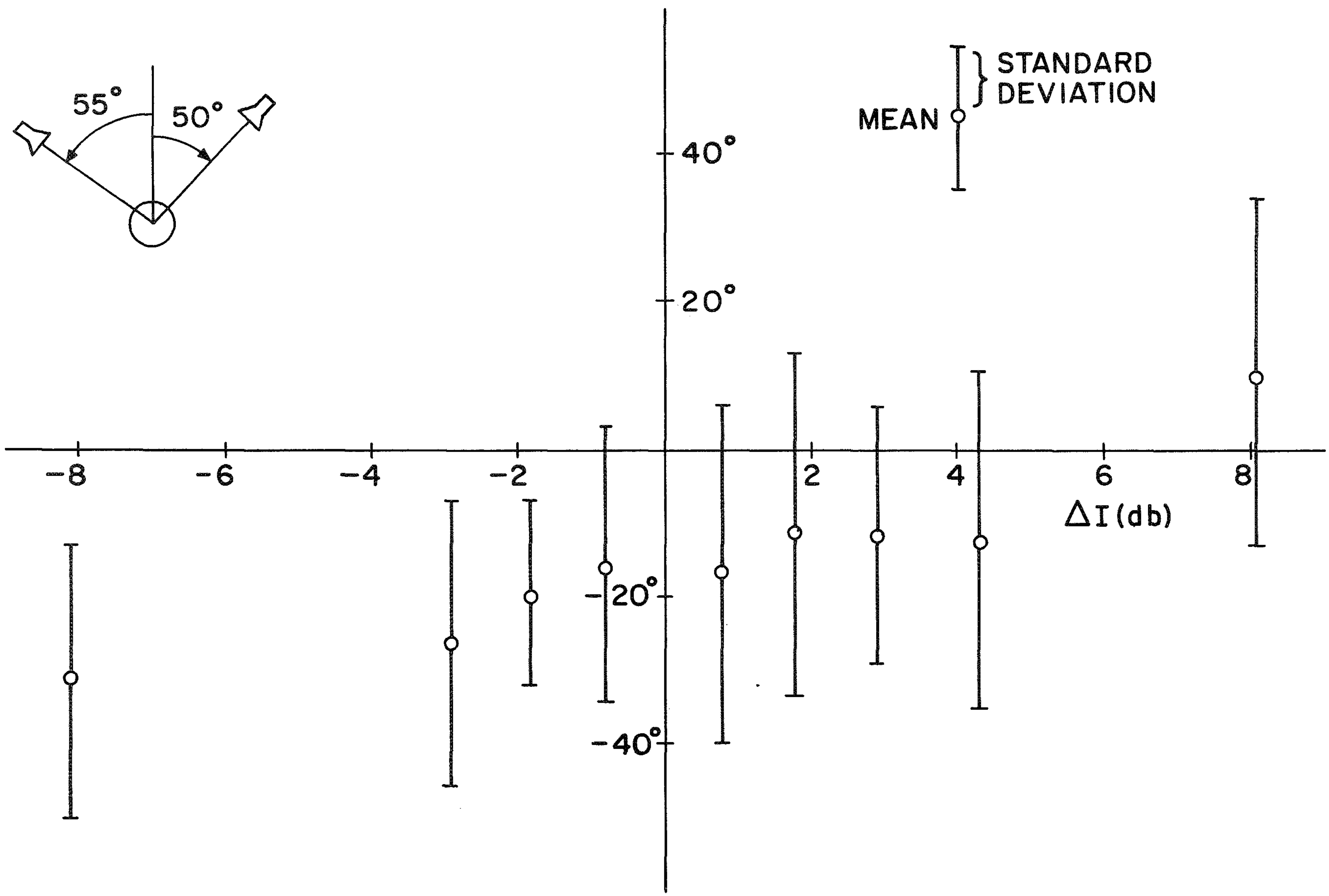


Figure 2.4 Perceived Azimuth of Source vs. Interaural Intensity Difference. (Test II)

Conclusions

The two speaker system has been shown to be subject to one of the basic weaknesses of the cockpit environment: echoes. In the case of the GAT-1 the echoes appeared to bias the results to either side depending on the placement of the speakers. Each cockpit will have its own particular echoes which will make the audio system subject to readjustment in each of the cockpits.

In the current form, the system displayed at best an accuracy which can only be considered borderline in conjunction with IR detectors whose field of view is about 20°. The standard deviation of the system is of this order without the problem of background noise and pilot workload. The results are more centered than one would expect, but this can be alleviated simply by moving the speakers further apart. In general, the system will probably have at best no better than borderline accuracy under operating conditions.

The dependence of the apparent sound source on only the relative intensity levels of the two speakers makes the two speaker stereo system relatively easier to realize in inexpensive physical equipment, an important criterion of the total cooperative Pilot Warning Indicator System.

CHAPTER 3. EFFECT OF DISPLAY RESOLUTION

Introduction

The purpose of this study is to investigate the relationship between PWI 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. A detailed description of this study is contained in [8]. 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 ±80° in azimuth (0° straight ahead) and ±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 reproducible baseline data which might then be extrapolated to influence the design of an actual flight instrument.

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.

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

The hybrid computer and the experimental setup is shown in Figures 3.1 through 3.3.

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 sector indication are projected from the same slide. 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 position ready for projection. Slide selection is done automatically on command from the hybrid computer.

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

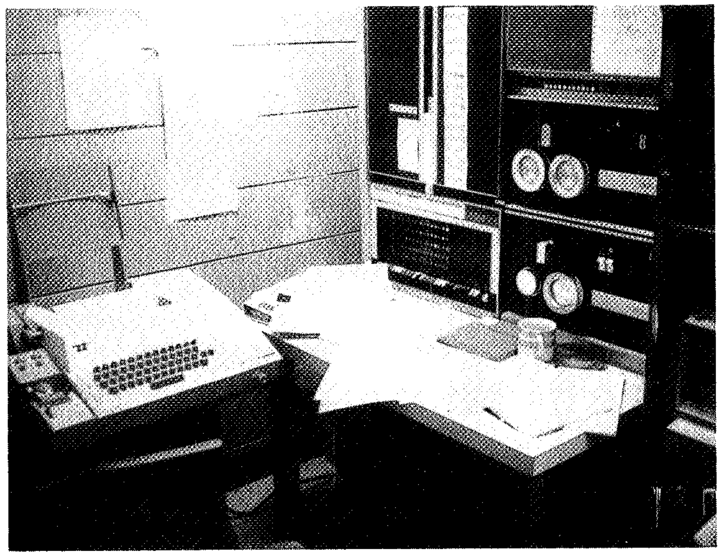


Figure 3.1 PDP-8 Digital Computer.

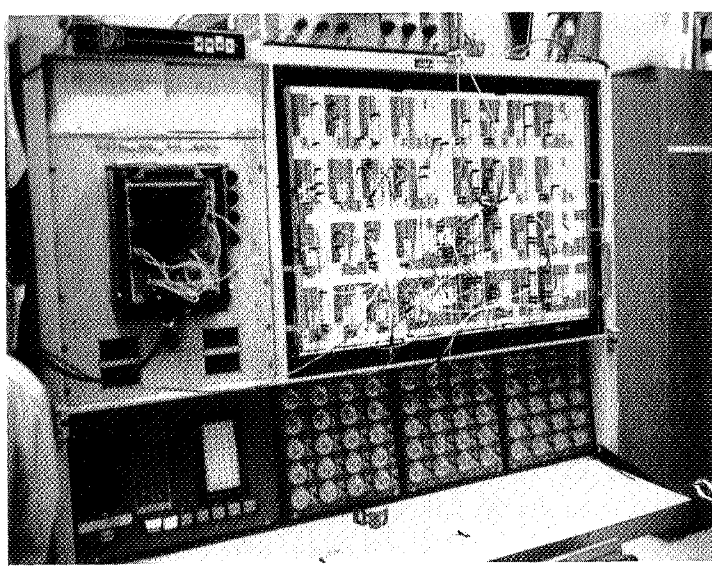


Figure 3.2 GPS 290T Analog Computer.

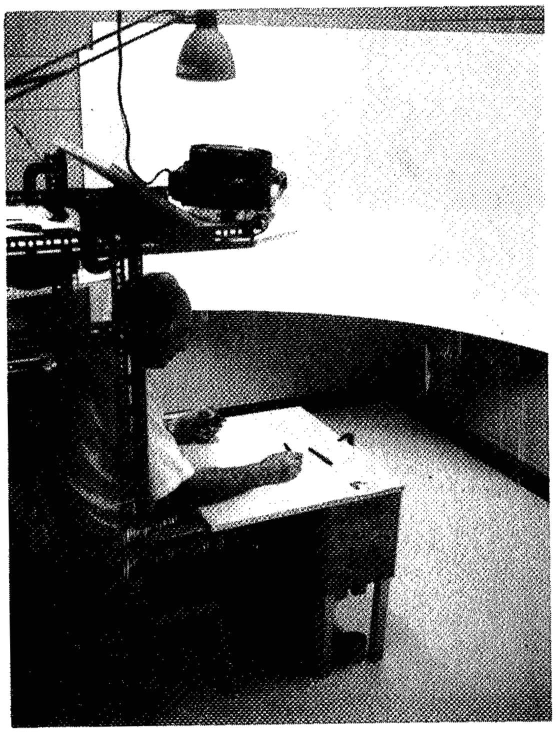


Figure 3.3 Subject Relative to Screen and Target Projector.

closed loop control. Projector positioning is done by the computer under program control.

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. Then 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.

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 also 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.

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.

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 includes the data for all reaction times in excess of 27 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 leval 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 events.

Conclusions

This study provided baseline data (see [8] for numerical results) concerning several important factors which will affect 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, although this should be verified in a cockpit environment. 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° nearly corresponds 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° and 15° on a side (subject to further verification).

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.

CHAPTER 4. MOVING-BASE SIMULATOR AND DISPLAY EVALUATION

Introduction

One of the requirements necessary for a PWI system to be effective is that the information output of the system be transmitted to the pilot in a way that enables him to locate the intruder as soon as possible, without appreciably impairing his performance in controlling his aircraft. A PWI system is intended primarily for use under VFR conditions, i.e., under conditions in which the pilot's attention will be directed mostly outside the cockpit. A head-up PWI display has obvious advantages under these conditions.

It was important to evaluate the displays in a realistic cockpit environment, so a GAT-1, a single seat trainer, was used for the experiment. No attempt was made to simulate realistic views of intruding aircraft against realistic backgrounds, as this requires a complicated expensive simulation. However, an attempt was made to make the degree of difficulty in locating the simulated target about the same as that that might be encountered in a real situation. The construction of this moving-base simulator constituted a major portion of the effort. In the short remaining time a simulation program was undertaken to evaluate a head-up display, a panel mounted display, and a "warning only" display that consisted merely of an audio alarm without any azimuth or elevation information.

Displays Evaluated

It was assumed that the displays being evaluated were for use with a detection system similar to the Fecker system. The detection system contained thirteen sectors, each sector being 22 1/2° by 22 1/2° arranged as shown in Figure 4.1.

The head-up display consisted of strips of 1 inch wide Sylvania green Panelescent Tape-Lite, mounted just above the windshield and the side windows, each strip corresponding to one of the seven central sectors. Also, three 1/2 inch wide strips of Tape-Lite were mounted on the top of the dash, each strip corresponding to one of the three front sectors. Some of these strips can be seen in Figure 4.2. If an intruder was detected in one of the side sectors, the strip above the relevant sector would light. If an intruder was detected in one of the three front central sectors, the panels above and below the appropriate sector would light. Only the upper panels would light if the intruder was in a front upper sector, and only the lower panel would light if the intruder was in a front lower sector.

In Figure 4.3, the electroluminescent strips are lettered A through K. The letter in each sector indicates the strip that was energized when an intruder was indicated in that sector.

Sylvania Panelescent Tape-Lite is flexible, and thus easy to mount on the curved surfaces inside a cockpit, and

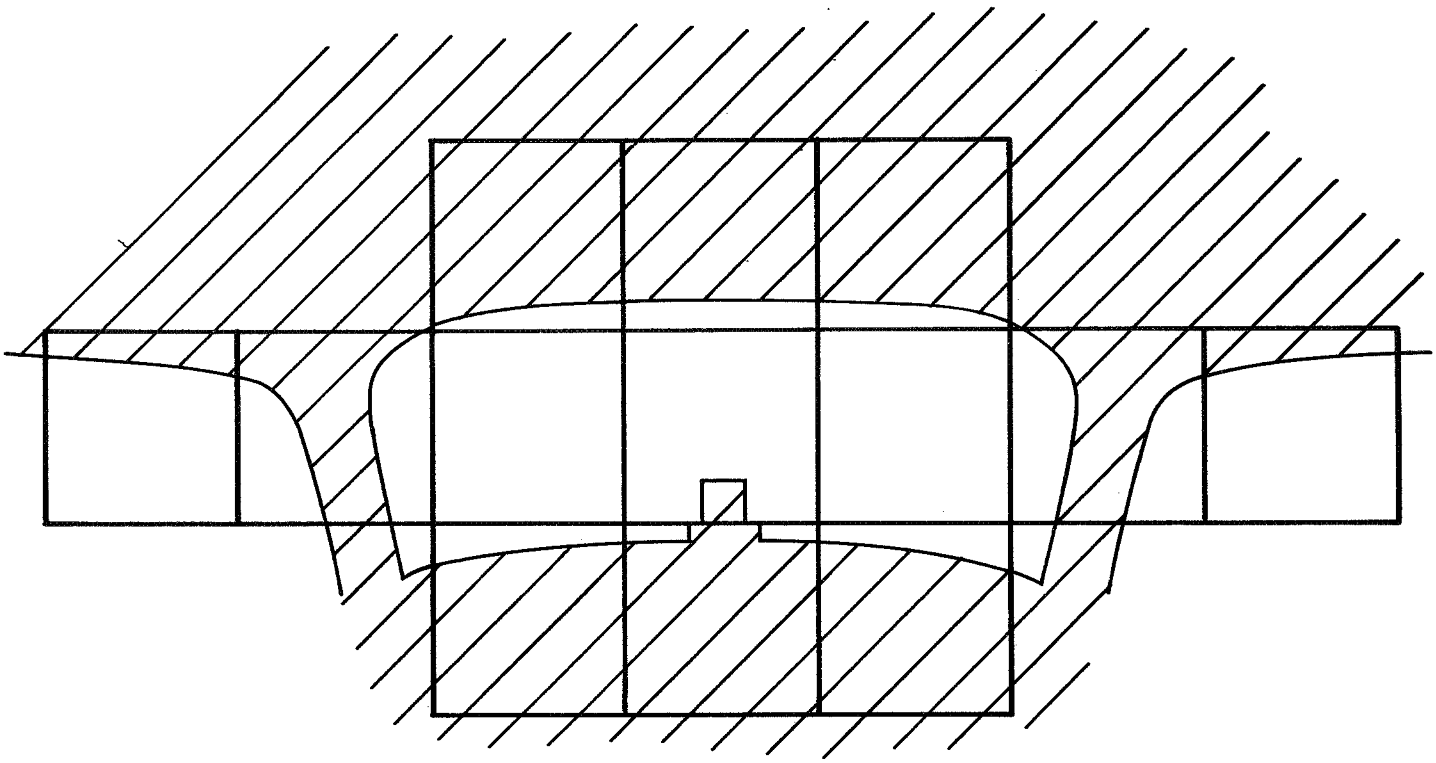


Figure 4.1 Projection of Windshield and Side Windows on Detection Sectors.

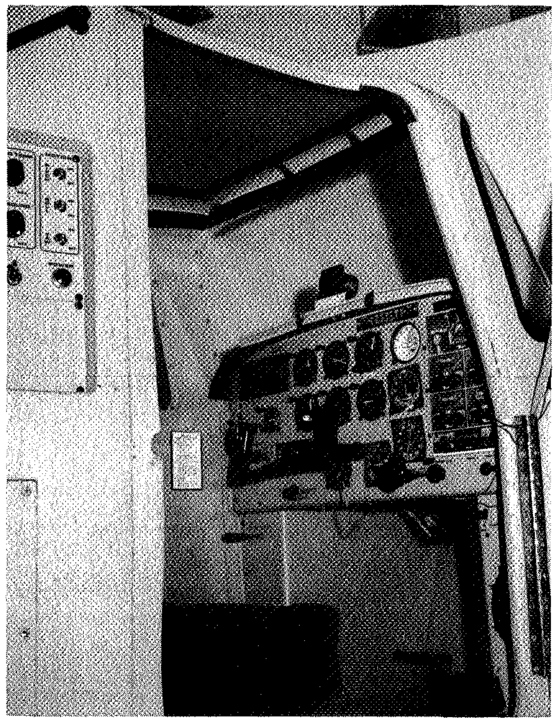


Figure 4.2 View of Panelescent Tape-Lite Strips

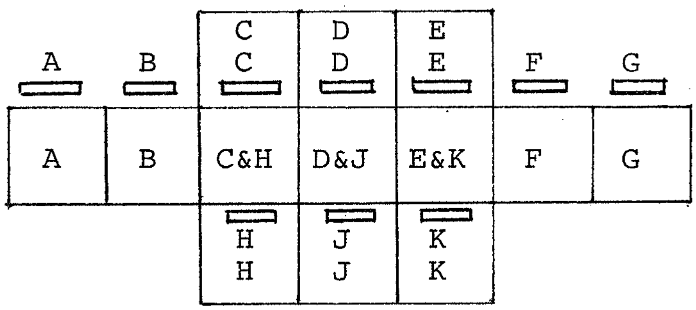


Figure 4.3 Layout of Sectors and Panelescent Tape-Lite Strips

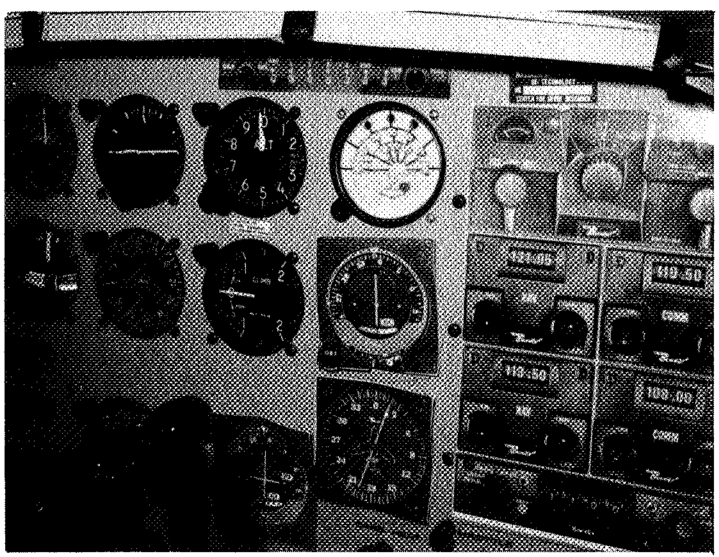


Figure 4.4 Panel Mounted Display

uses very little power (approximately 0.3 watts/ft at 120v, 60Hz). Tape-Lite has to be energized by an AC source. The brightness of the panel is a function of both the applied voltage and the frequency. (It is thought that a simple device could be constructed to vary the applied frequency, so that the brightness of the panels could be made a function of the light intensity inside the cockpit. At 120 volts, the brightness of the green Tape-Lite is 5 foot-lamberts at 60Hz, and 30 foot-lamberts at 400Hz.)

The panel mounted display was a modified Fecker display. It is clearly shown in Figure 4.4.

Figure 4.5 shows the arrangement of the lamps. The original display had three more lamps mounted outside the three central ones, and thus there was a one-to-one correspondence between lamps and sectors. However, to use the same relay logic that was used for the head-up display, the three outer lamps were not used. Thus, if an intruder was in an upper front sector, the outside light would be energized, if the intruder was in a central front sector both lamps on the same radius would light, and if an intruder was in a lower front sector only the inner lamp would light. The display as used was not as "natural" as the original display and the performance obtained with the modified display may not have been quite as good as would have been obtained with the original display. However, it is felt that if there was any degradation in performance, it was very small. The lamps used in this display were energized

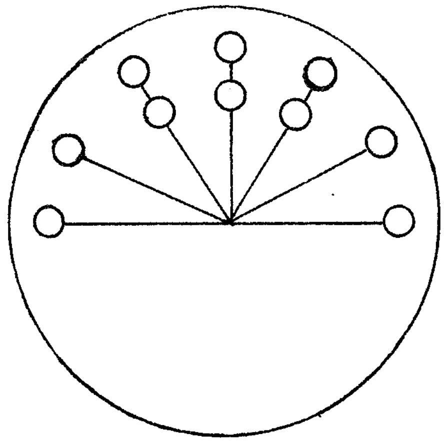


Figure 4.5 Lamp Arrangement in Panel Mounted Display

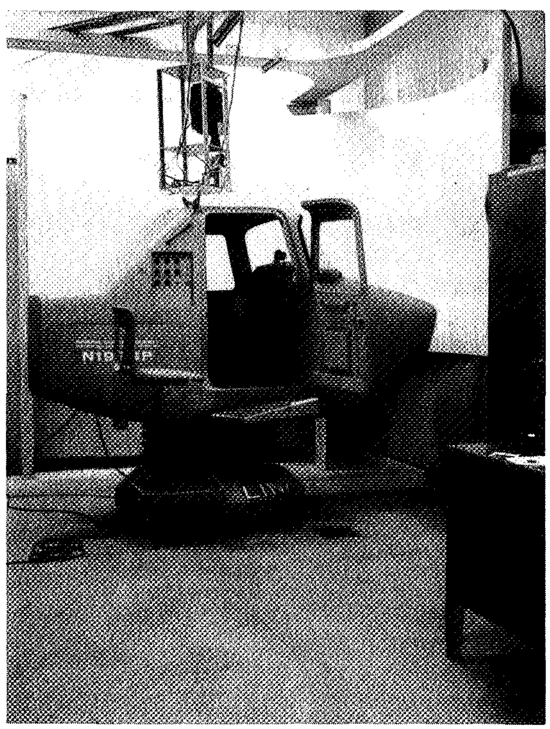


Figure 4.6 The GAT-1, Projection Apparatus, and Screen

by a 6v DC supply.

An audio signal was used with both displays whenever an intruder was detected. This signal was 1500 Hz square wave, and was loud enough to be easily heard above the engine noise. The speaker was mounted under the dash. To obtain baseline data to evaluate both the head-up and the panel mounted displays, tests were also conducted with just the audio signal enabled.

Experimental Setup

Figure 4.6 shows a view of the GAT-1, the target projection system mounted above the trainer, and the screen on which the targets were projected.

The screen was constructed of Masonite. It formed a 180° arc, at a radius of approximately 6 feet from the pilot's normal head position. The screen was 6 feet in height, enabling targets to be projected that were between elevations of approximately +30° and -25°. The screen had a matte white painted surface.

The projection system, which was suspended above the trainer, consisted of a vertically mounted projector, equipped with a 6 inch focal length lens, and a mirror that was gimballed about the yaw and elevation axes. Figure 4.7 is a view of the projection system. D.C. motors were used to drive the mirror about the two axes. Potentiometers measured the rotation about each axis, enabling complete control of target location. The target consisted of a spot

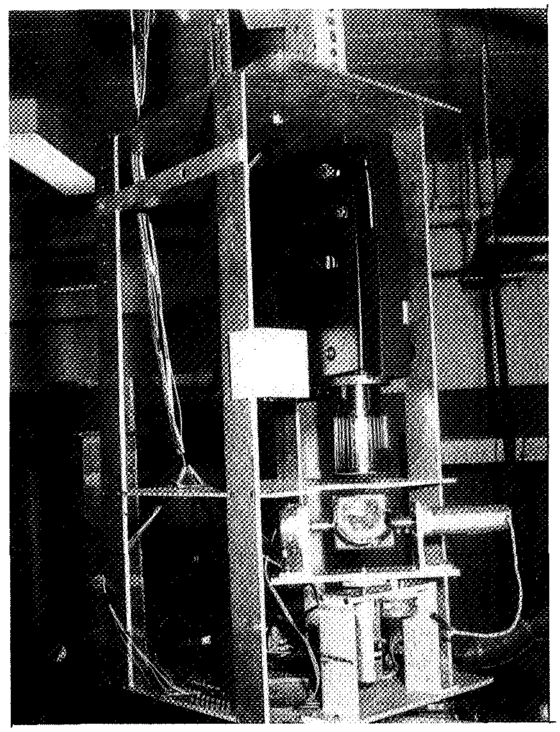


Figure 4.7 Projection System

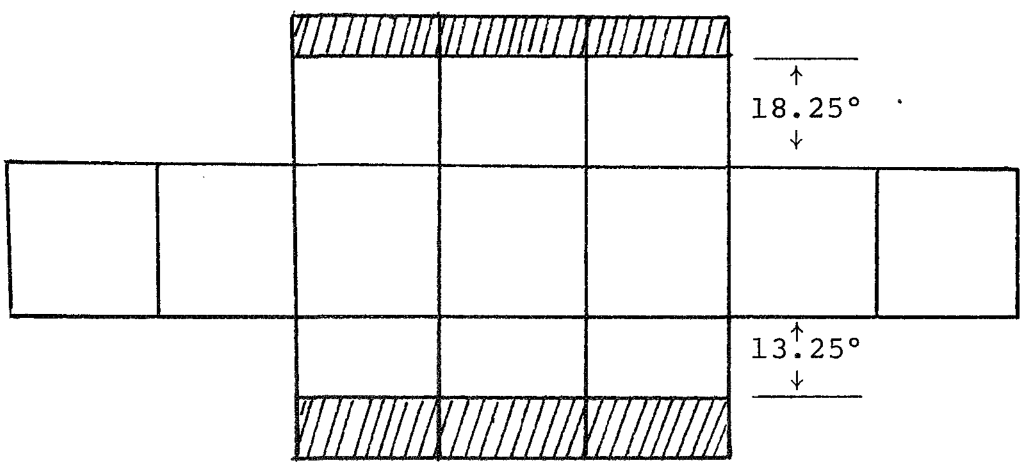


Figure 4.8 Areas in Which Targets Were Presented

of light, approximately 0.25 inches in diameter, subtending an arc of approximately 10 arc minutes at the pilot's eye. The experiment was conducted with normal laboratory lighting, giving a screen background brightness of 23 foot-lamberts. Two target brightnesses were used during the experiment, one of 46 foot-lamberts, and the other of 34.5 foot-lamberts, giving contrast ratios of 1.0 and 0.5 respectively. Spot brightness was controlled by using poloarized filters in front of the projector. The experiment was controlled by a hybrid GPS 290T/PDP-8 computer. Relay logic was implemented to control the motors driving the mirror, the switching on and off of the projector lamp, the audio alarm, and the switching of the display lights.

The GAT-1 was instrumented to enable the measurement of its attitude and the measurement of indicated altitude. These data were used to compute target position in body-fixed coordinates, and the appropriate portion of the display could be activated regardless of trainer attitude or target position.

Method of Conducting Experiment

Eight subjects were used during the experiment. All of them were familiar with flying the trainer. Five had experience flying general aviation airplanes. The following procedure was adopted for the testing of each display with each target brightness.

The pilot was asked to climb to an altitude of 1000 feet, and to maintain that altitude at an indicated airspeed of approximately 95 knots. The engine noise was adjusted to the level of that of a typical light plane. The rough air control on the trainer was adjusted to its mid-position. (No attempt was made to make a quantitative measurement of the simulated gusts.) The pilot was asked to fly a heading corresponding to the center of the screen. When the trainer had been trimmed for level flight at 1000 feet, the experiment began. Each experiment consisted of displaying a sequence of 40 targets. As soon as a target was projected onto the screen, the audio alarm would sound and the appropriate display would light up. When the pilot had located the target, he depressed a switch mounted on the left side of the control yoke. The time interval between the target appearing on the screen and the pilot finding its location was thus measured. The audio alarm and the projector lamp were turned off when the pilot depressed the switch.

The computer used a random number generator to position each target. Thus, there was no correlation between the positions of sequential targets. Each target was as likely to be in any position in any sector as in any other position, except that no targets were projected on the areas shown shaded in Figure 4.8. The time interval between a target and the projection of the next target was a random period, equally likely to be anywhere from 0 to 20 seconds in length, plus the time to rotate the mirror to the next location.

Figure 4.1 shows that the only complete sectors that could be seen by the pilot without moving his head were the three front central ones. The complete side sectors could be scanned by the pilot by moving his head, as could the portions of the upper front sectors onto which targets were projected. However, if a target was projected onto the lower front part of the screen, then the pilot could not see the target by moving his head. (It is difficult to raise the head much when in a sitting position, and even if one could, the nose of the trainer prevented one from seeing targets projected onto the lower front part of the screen.) In the event of a target being below the nose of the trainer, the pilots were instructed to make a turn, either left or right, until the target was located, and then return to the nominal heading.

The difference between the maximum and minimum altitudes flown during each run was also measured.

The order in which the displays were tested was changed for each subject.

Results

The results obtained from all the runs are recorded in Tables 1 through 7. In Tables 1 through 6 are recorded the means, the medians, and the standard deviations of the times to locate targets in each sector for each subject. The 9th column in each of these tables gives the results for each sector for all subjects. The expected number of events in each central, lower and upper sector for each subject with each display is 3.57, 2.10 and 2.90 respectively. These values became 28.56, 16.80 and 23.20 respectively when all subjects are considered. (The random variable $(\overline{x} - \mu)\sqrt{n}/s$, where $\overline{x}$ is the estimated mean, s is the estimated standard deviation, μ is the true mean, and n is the number of samples, has a t-distribution. Thus if s = 0.5 sec, -- a typical value for the center sectors with the head-up display or the panel mounted display -- and n = 28, there is a 90% probability that the estimated mean is within ±0.17 seconds of the true mean. The above assumes that the individual samples are independent and normally distributed.)

There do not appear to be any outstanding differences in the performances of the eight subjects, so all further remarks will be confined to discussion of the results obtained by combining those of all subjects. The mean target location times for target contrast ratios of 1.0 and 0.5 have been plotted in Figures 4.9 through 4.14. Inspection of these figures brings out the following points.

1. There were no significant differences in performance with the two different brightnesses of targets. Apparently, there was no more difficulty in locating the less bright target than the brighter one.
2. The azimuth and elevation information in the head-up and panel mounted displays was of considerable

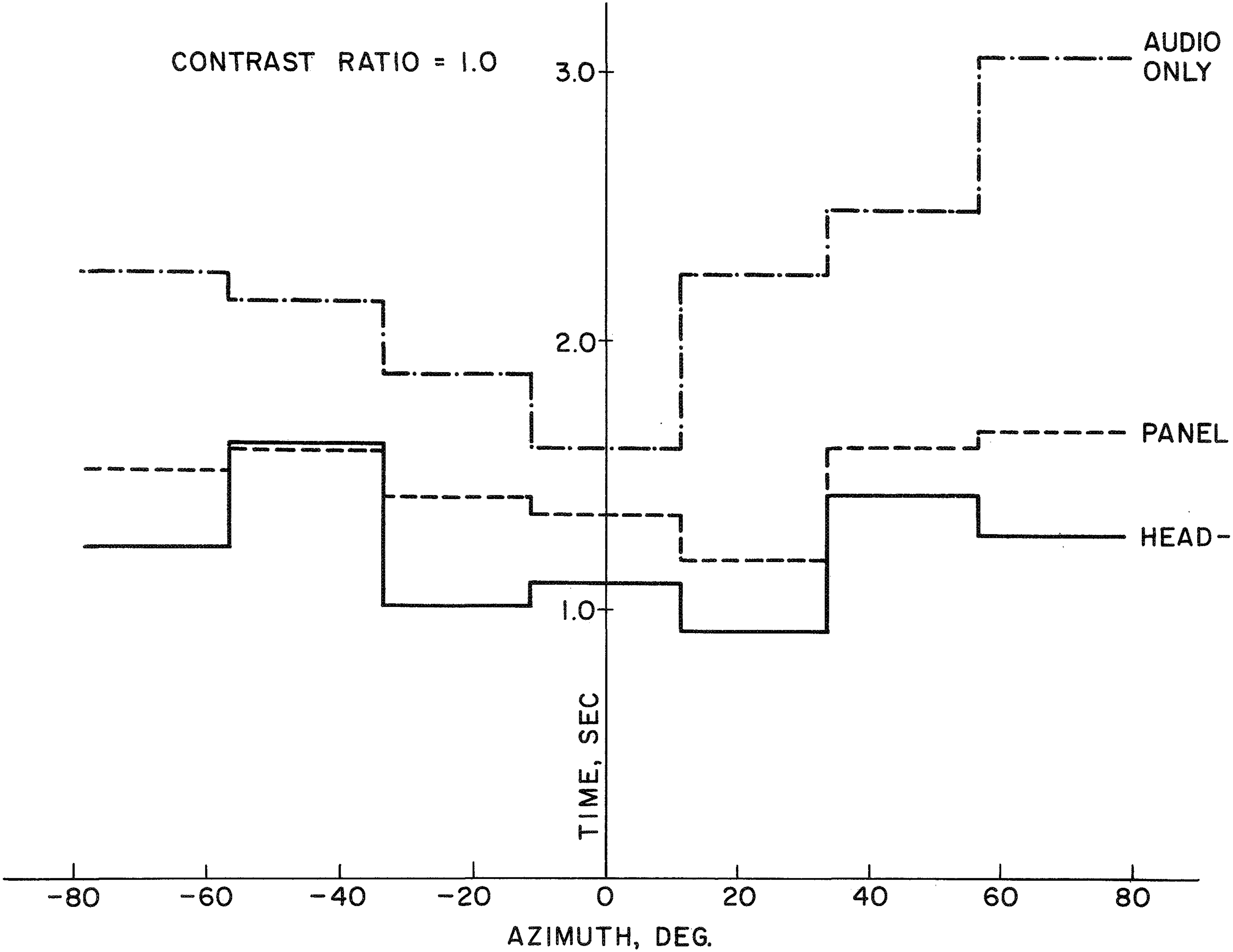
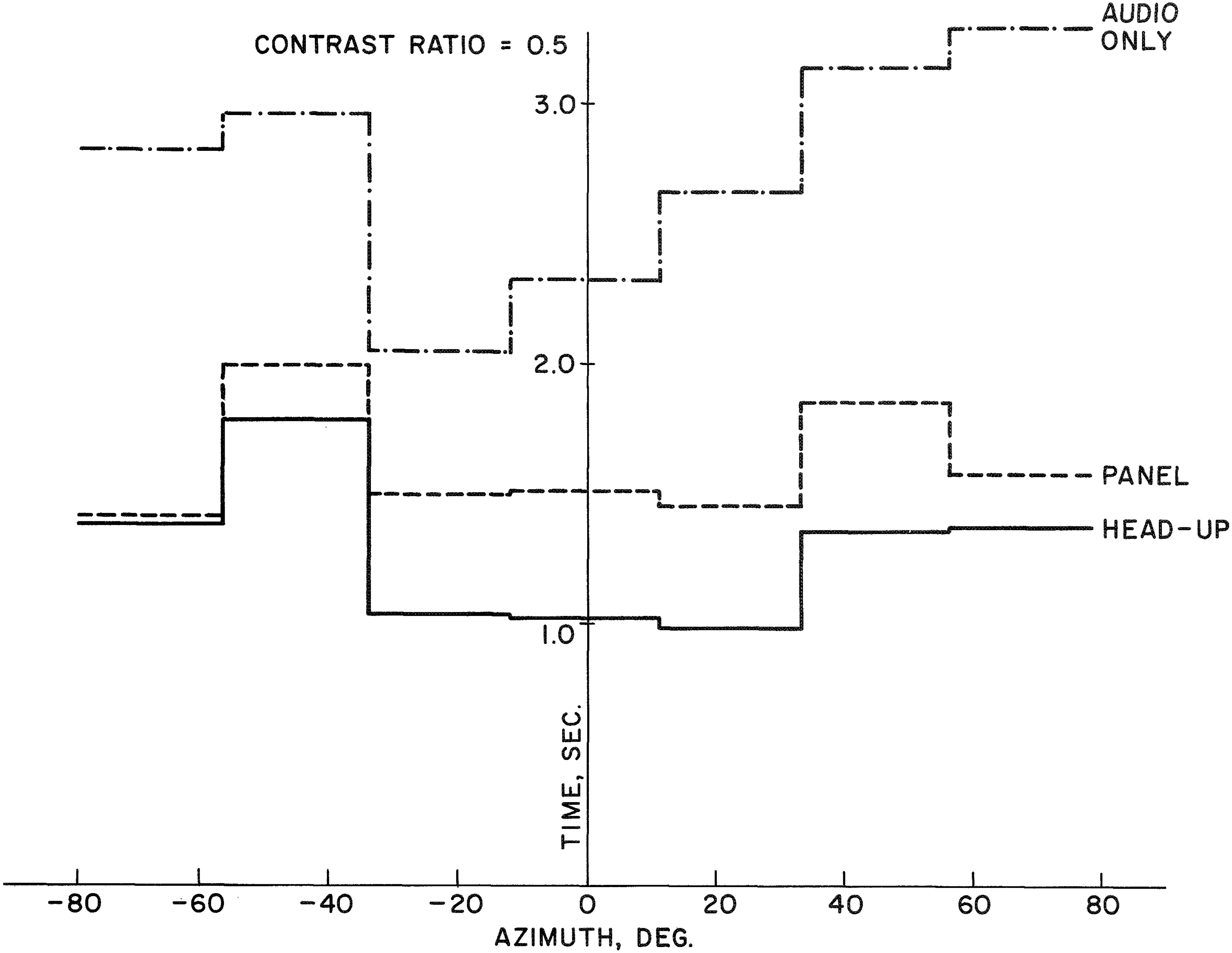


Figure 4.9 Mean Time to See Target Center Sectors.



-48-

Figure 4.10 Mean Time to See Target Center Sectors.

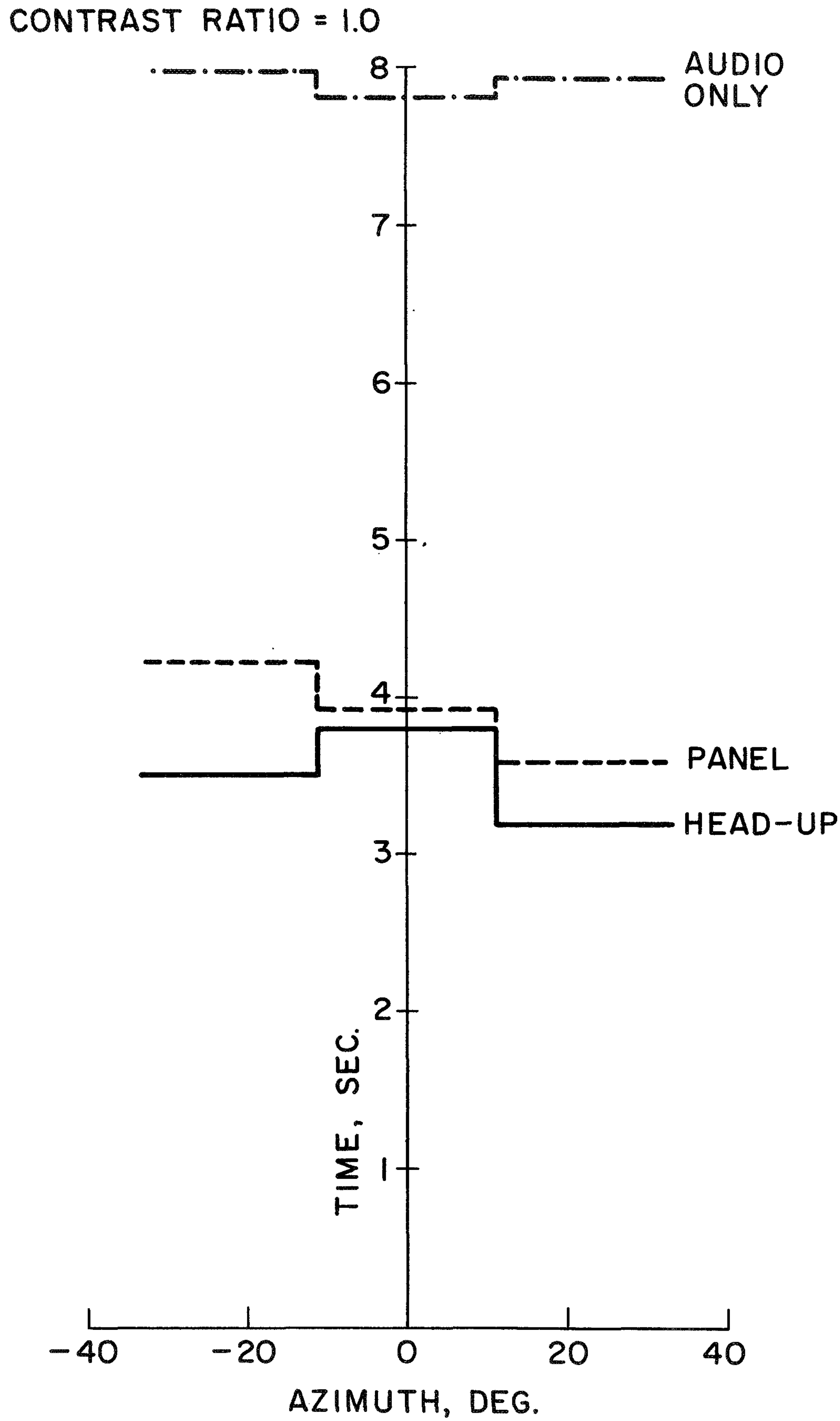


Figure 4.11 Mean Time to See Target Lower Sectors.

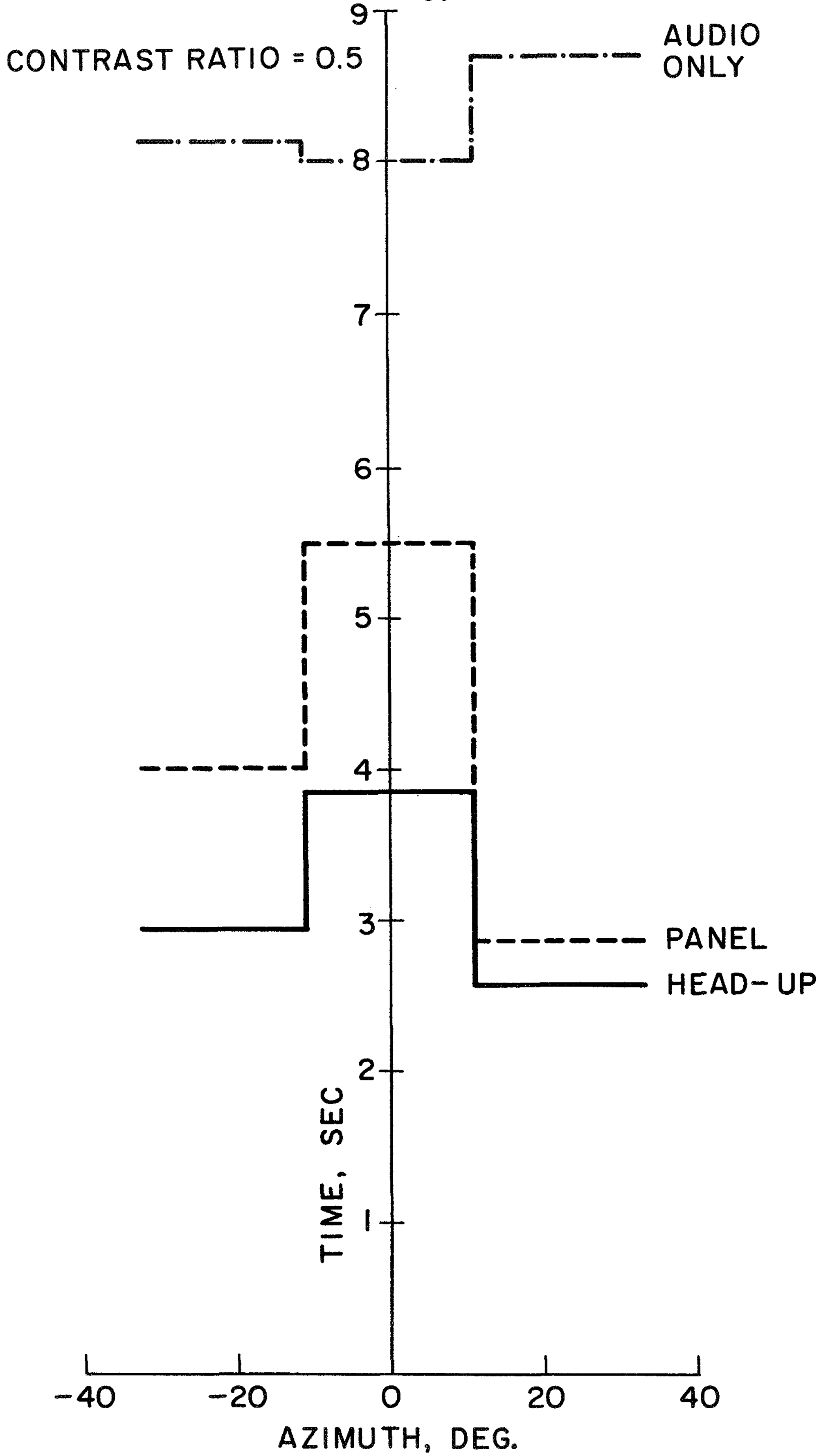


Figure 4.12 Mean Time to See Target Lower Sectors.

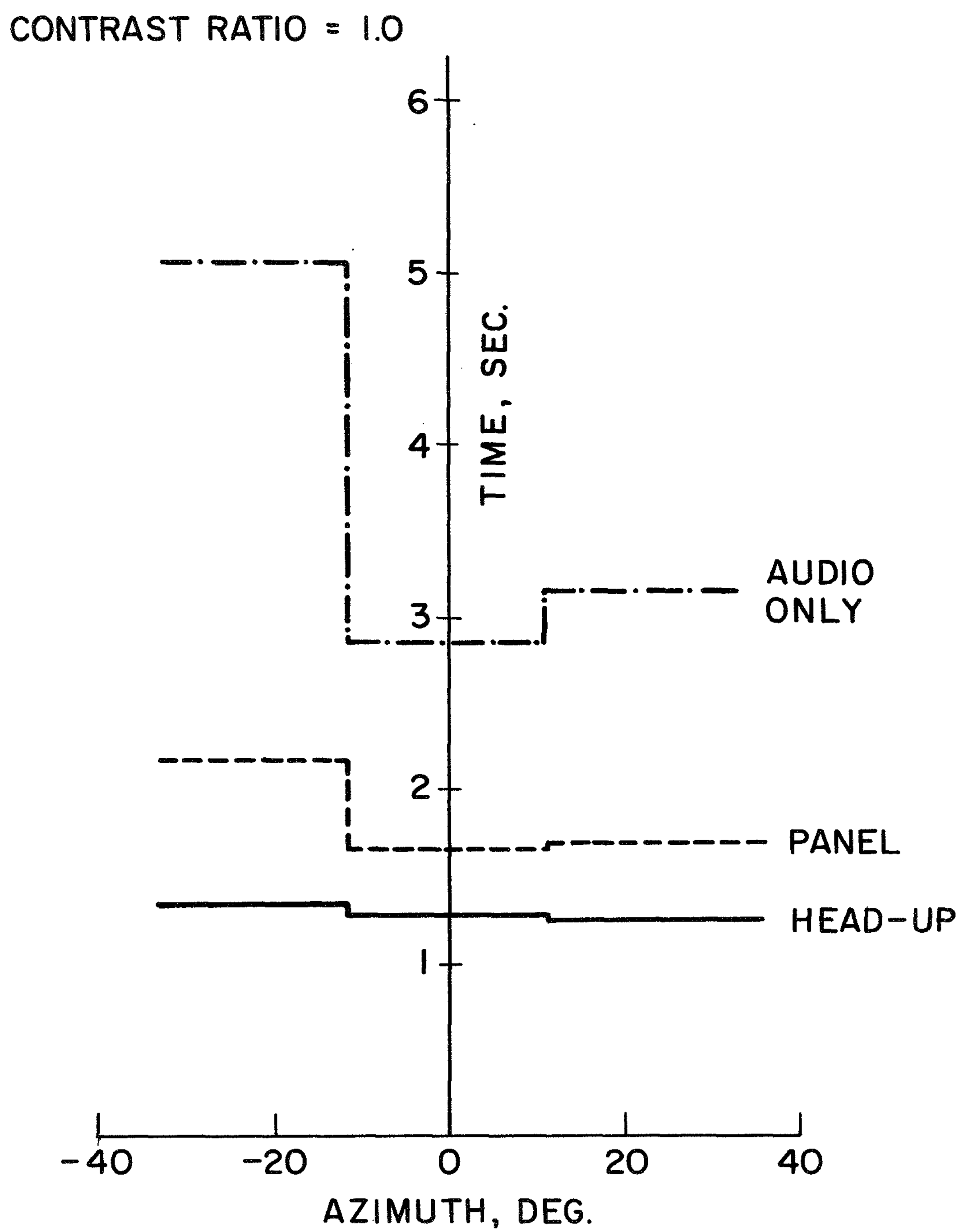


Figure 4.13 Mean Time to See Target Upper Sectors.

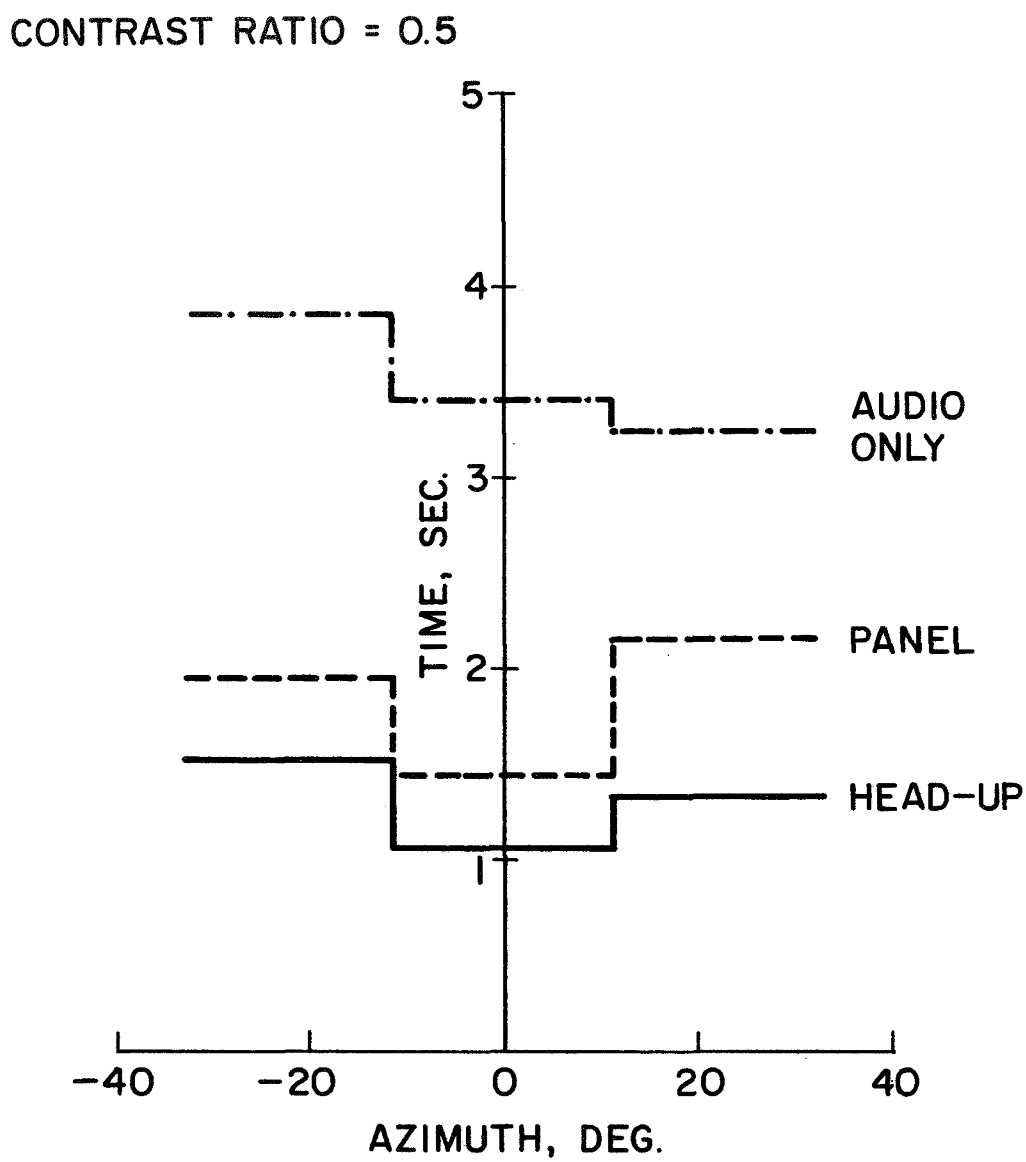


Figure 4.14 Mean Time to See Target Upper Sectors.

help to the pilot in locating the target. This was particularly so when the target was out of the normal field of view of the pilot and a maneuver was required to enable the target to be seen.

3. Performance with the head-up display was consistently better than with the panel mounted display. The average difference between the mean target location times over all sectors for these two displays was approximately 0.45 seconds.
4. The target location times for the two sectors containing the pillars on each side of the windshield tended to be higher than for the other central sectors.
5. There were no great variations in ability to maintain altitude with the different displays, although performance with the head-up display was slightly better.

Conclusions

Azimuth and elevation information in a PWI system appreciably reduces the time required to locate an intruding aircraft for the very limited range of viewing conditions used. One would expect the discrepancy between the warning-only display and the directional displays to be reduced as the target became larger and more visible. On the other hand, the advantage of the head-up display should become more pronounced as the target becomes more difficult to detect. Quantitative results can easily be obtained with the use of the moving-base simulator.

A	B	C	D	E	F	G	H	All	Subject / Sector
0099	0112	0119	0089	0144	0104		0189	0123	Center L to R
0207	0157	0106	0130	0145	0167	0121	0250	0163	
0084	0097	0108	0084	0095	0094	0080	0165	0102	
0082	0087	0106	0068	0086	0148	0118	0165	0110	
	0097	0134	0090	0087	0084	0073	0104	0092	
0133	0141	0162	0098	0111	0131	0228	0183	0143	
0131	0244	0103	0102	0137		0117	0191	0128	
0604	0100	0272	0364	0592	0132	0360		0352	Lower L to R
0616	0284	0401		0359	0404	0580	0268	0382	
0458	0218	0256	0334	0208	0242	0305	0436	0320	
0118	0193	0149	0094	0152	0128	0111	0266	0131	Upper L to R
0150	0140	0113	0110	0172	0134		0084	0128	
0132	0113	0147	0100	0155	0130	0109	0113	0126	

MEAN

A	B	C	D	E	F	G	H	All	Subject / Sector
0106	0112	0108	0086	0150	0122		0166	0112	Center L to R
0246	0182	0112	0124	0174	0176	0132	0272	0154	
0088	0100	0102	0084	0088	0092	0082	0162	0088	
0086	0088	0098	0070	0080	0234	0094	0194	0088	
	0098	0134	0090	0088	0082	0074	0090	0088	
0130	0144	0164	0102	0124	0134	0348	0186	0134	
0126	0244	0108	0104	0148		0094	0228	0114	
0660	0100	0272	0364	0592	0194	0392		0364	Lower L to R
0616	0146	0396		0362	0556	0580	0426	0396	
0456	0332	0256	0382	0192	0342	0352	0392	0342	
0100	0138	0136	0088	0152	0114	0136	0266	0116	Upper L to R
0134	0148	0112	0110	0172	0152		0090	0122	
0132	0122	0148	0100	0124	0130	0118	0130	0128	

MEDIAN

A	B	C	D	E	F	G	H	All	Subject / Sector
0012		0032	0014	0033	0025		0049	0042	Center L to R
0054	0055	0011	0048	0061	0068	0019	0055	0066	
0005	0016	0048		0035	0018	0012	0078	0039	
0005	0000	0022	0003	0012	0121	0075	0061	0056	
	0006			0020	0014	0003	0047	0025	
0050	0004	0003	0003	0017	0004	0169	0045	0059	
0052		0014	0016	0029		0055	0052	0047	
0078					0087	0059		0193	Lower L to R
	0260	0204		0004	0214		0223	0191	
0016	0161		0067	0102	0140	0065	0080	0124	
0051	0146	0022	0018		0033	0037		0068	Upper L to R
0030	0018	0006	0003		0037		0008	0030	
	0023	0021		0088	0021	0042	0029	0039	

STANDARD DEVIATION

All entries in hundredths of a second.

Table 1 Head-up Display, Contrast Ratio = 1.0.

MEAN

Subject / Sector	A	B	C	D	E	F	G	H	All
Center L to R	0172	0118		0148	0121	0209	0135	0141	0152
	0139	0191	0128	0168	0196	0156	0116	0154	0159
	0114	0146	0153	0154	0148	0133	0127	0146	0141
	0120	0167	0165	0139	0099	0144	0124	0078	0135
	0110	0138	0123	0107		0122		0118	0119
	0119	0125	0232	0130	0126	0146	0241	0112	0161
	0118	0169		0168	0161	0151	0194	0172	0167
Lower L to R	0628	0612	0156	0464	0200		0462	0270	0422
	0624	0223	0240	0745		0337	0230	0445	0391
	0414	0263	0232	0661	0504	0170	0302	0192	0357
Upper L to R	0240	0551	0165	0121	0141	0236	0214	0142	0218
	0116	0162	0147	0144	0137	0232	0176		0168
	0201	0167	0144	0195	0220	0153		0126	0169

MEDIAN

Subject / Sector	A	B	C	D	E	F	G	H	All
Center L to R	0176	0118		0148	0122	0144	0140	0144	0134
	0146	0144	0128	0176	0206	0162	0116	0150	0150
	0108	0156	0154	0180	0162	0138	0144	0152	0144
	0110	0148	0164	0132	0104	0152	0126	0076	0126
	0100	0146	0130	0108		0130		0118	0122
	0120	0124	0300	0130	0128	0156	0176	0112	0136
	0154	0148		0160	0130	0152	0150	0178	0148
Lower L to R	0628	0578	0156	0448	0200		0462	0202	0448
	0650	0250	0258	0888		0342	0230	0450	0342
	0478	0284	0304	0388	0578	0170	0328	0248	0304
Upper L to R	0144	0240	0164	0108	0132	0180	0222	0106	0152
	0116	0192	0168	0150	0124	0152	0182		0150
	0198	0162	0150	0188	0220	0170		0128	0166

STANDARD DEVIATION

Subject / Sector	A	B	C	D	E	F	G	H	All
Center L to R	0050				0012	0156	0014	0014	0067
	0023	0088		0030	0030	0008		0036	0041
	0017	0014	0028	0036	0019	0006	0024	0027	0025
	0026	0064	0027	0027	0006	0021	0003	0007	0042
	0027	0021	0015	0017		0011		0003	0019
	0001	0018	0096		0034	0014	0160	0003	0094
	0050	0086		0068	0096	0027	0130	0056	0082
Lower L to R		0259		0052				0167	0212
	0036	0038	0031	0202		0199		0006	0213
	0090	0145	0101	0676	0104		0121	0078	0291
Upper L to R	0201	0599	0041	0022	0020	0157	0069	0071	0214
		0042	0027	0008	0026	0168	0024		0076
	0044	0030	0026	0078		0026		0006	0046

All entries in hundredths of a second.

Table 2 Panel Display, Contrast Ratio = 1.0.

A	B	C	D	E	F	G	H	All	Subject / Sector
0149	0175	0376	0290	0116		0284	0213	0226	Center L to R
0276	0153	0231	0186	0154	0222	0211	0322	0215	
0193	0242	0182	0338	0086	0098	0101	0343	0187	
0093	0182	0207	0148	0130	0149	0137	0238	0160	
0511	0135	0174	0280	0102	0204	0098	0306	0225	
0116	0240	0372	0195	0250	0394	0251	0248	0248	
0200	0471	0275	0225	0301	0478	0266	0235	0306	
1632	0822	0220	0595	0192	1015	0616	0408	0798	Lower L to R
0985	0783	0436	0864	0458	0606	1303	0840	0781	
0561	0342	1710	0743	0628	0991	1163	0700	0793	
0474	0626	0662	1704	0416	0258	0290	0491	0506	Upper L to R
	0168	0094	0248	0954			0132	0284	
0297	0269	0260	0165	0729	0367	0191	0222	0316	
				MEAN					
0136	0144	0402	0320	0094		0322	0214	0194	Center L to R
0204	0138	0216	0174	0130	0302	0250	0322	0186	
0230	0138	0178	0328	0086	0094	0112	0520	0114	
0088	0220	0288	0108	0106	0086	0104	0178	0106	
0630	0156	0214	0238	0094	0110	0104	0306	0140	
0140	0240	0372	0156	0260	0450	0274	0222	0240	
0132	0340	0266	0214	0308	0536	0272	0230	0272	
2440	0822	0220	0984	0192	1266	0736	0408	0736	Lower L to R
1332	0872	0512	0944	0582	0624	1796	0840	0784	
0540	0342	1710	0794	0732	1012	1608	0836	0792	
0474	0452	0196	1704	0394	0312	0234	0294	0312	Upper L to R
	0184	0094	0248	1802			0120	0134	
0312	0280	0230	0172	0462	0288	0214	0222	0236	
				MEDIAN					
0044	0059	0157	0129	0043		0108	0025	0121	Center L to R
0155	0028	0069	0113	0092	0096	0108		0107	
0123	0217	0022	0229	0002	0007	0014	0249	0150	
0016	0075	0118	0080	0098	0144	0091	0196	0109	
0245	0029	0063	0227	0023	0186	0012		0191	
0033			0089	0014	0078	0032	0072	0092	
0110	0303	0040	0092	0009	0264	0104	0087	0187	
1142			0549		0530	0169		0628	Lower L to R
0490	0204	0106	0113	0174	0025	0696		0351	
0060			0348	0147	0029	0629	0286	0386	
	0500	0875		0301	0096	0179	0410	0474	Upper L to R
	0067			1199			0030	0480	
0021	0022	0181	0046	0694	0303	0059		0292	
				STANDARD DEVIATION					

All entries in hundredths of a second.

Table 3 Audio Only, Contrast Ratio = 1.0.

A	B	C	D	E	F	G	H	All	Subject / Sector
0154	0144		0106		0114	0085	0192	0138	Center L to R
0247	0225	0145	0144	0127	0167	0120	0144	0179	
0106	0119	0113	0095	0096	0087	0123	0097	0104	
0115	0139	0123	0102	0085	0089	0077	0089	0103	
0088	0136	0128	0096	0073	0086	0079	0086	0098	
0171	0162	0158	0109	0133	0100	0112	0150	0136	
0210	0143	0174		0114	0112		0142	0137	
		0202	0392	0408	0180	0342		0294	Lower L to R
0828	0301	0274	0550	0299	0669	0483	0293	0387	
0364	0376	0218	0182	0350	0144	0160	0186	0258	
0136	0128	0177	0105	0255	0132	0107	0140	0152	Upper L to R
0118	0134	0106	0102			0103	0083	0106	
0150	0152	0108	0093	0168	0147	0105	0114	0132	
				MEAN					
0138	0132		0100		0108	0086	0230	0132	Center L to R
0314	0170	0170	0130	0136	0130	0120	0206	0140	
0100	0126	0110	0106	0096	0082	0086	0120	0100	
0118	0142	0140	0102	0090	0090	0086	0102	0098	
0084	0122	0134	0094	0072	0080	0078	0090	0090	
0178	0178	0158	0132	0146	0096	0142	0200	0142	
0210	0162	0130		0122	0108		0154	0124	
		0310	0392	0420	0162	0424		0262	Lower L to R
0828	0434	0300	0550	0404	0752	0558	0320	0342	
0382	0438	0202	0084	0374	0154	0246	0186	0246	
0124	0128	0154	0116	0162	0118	0118	0116	0124	Upper L to R
0130	0156	0086	0106			0102	0088	0102	
0158	0170	0108	0094	0140	0158	0118	0116	0126	
				MEDIAN					
0027	0048		0018		0031	0001	0048	0047	Center L to R
0127	0113	0034	0071	0025	0137		0087	0102	
0039	0009	0015	0019	0018	0027	0080	0032	0037	
0004	0023	0030		0010	0012	0012	0019	0027	
0007	0047	0044	0018	0002	0014	0014	0005	0033	
0009	0028		0032	0017	0014	0042	0070	0037	
	0026	0111		0023	0023		0028	0050	
		0152		0248	0074	0115		0166	Lower L to R
	0187	0035		0148	0116	0105	0103	0187	
0094	0162	0102	0176	0033	0014	0121		0136	
0023		0084	0014	0212	0034	0037	0069	0098	Upper L to R
0033	0031	0041	0015			0026	0009	0027	
0019	0025		0022	0066	0018	0020	0007	0038	
				STANDARD DEVIATION					

All entries in hundredths of a second.

Table 4 Head-up Display, Contrast Ratio = 0.5.

A	B	C	D	E	F	G	H	All	Subject / Sector
MEAN									
	0136	0132		0111	0148	0113	0261	0142	Center L to R
0166	0197	0214	0255	0106	0214	0159	0206	0199	
0140	0181	0136	0163	0140	0129	0137	0150	0150	
0155	0133	0175	0167	0128	0179	0109	0143	0151	
0156	0187	0106	0144	0127	0144	0172	0125	0145	
0182	0183	0233	0261	0159	0163	0132	0135	0185	
0196	0167	0177	0184	0107	0154	0127		0157	
0594	0367	0272	0377				0335	0400	Lower L to R
0972	0509	0206	0596	0428	0341	0454	0630	0550	
0676	0231	0271	0312	0256	0290	0252	0177	0287	
0177	0228	0147	0162	0231	0130	0289	0143	0195	Upper L to R
0140		0156	0168	0166	0175	0137	0122	0147	
0124	0307	0165	0150	0356	0183	0242	0120	0218	
MEDIAN									
	0136	0132		0110	0156	0118	0360	0132	Center L to R
0174	0192	0228	0360	0106	0170	0198	0206	0186	
0138	0194	0136	0204	0146	0132	0144	0130	0136	
0164	0136	0162	0164	0120	0124	0112	0146	0146	
0120	0180	0106	0144	0154	0132	0234	0116	0126	
0198	0196	0196	0302	0172	0178	0136	0152	0172	
0156	0154	0166	0192	0108	0176	0130		0142	
0504	0308	0330	0422				0360	0360	Lower L to R
0976	0514	0206	0648	0492	0482	0484	0846	0514	
0676	0266	0294	0330	0256	0280	0252	0234	0266	
0178	0180	0148	0134	0278	0130	0326	0148	0164	Upper L to R
0140		0152	0168	0176	0196	0152	0124	0150	
0124	0252	0170	0150	0210	0204	0212	0122	0170	
STANDARD DEVIATION									
	0015			0016	0025	0004	0139	0056	Center L to R
0025	0032	0043	0124	0000	0077	0054		0071	
0023	0020	0000	0055	0008	0004	0009	0036	0031	
0032	0011	0037	0025	0023	0101	0004	0004	0041	
0096	0027		0018	0038	0067	0087	0036	0057	
0022	0017	0134	0057	0017	0032	0005	0024	0073	
0088	0046	0084	0039	0015	0031	0014		0058	
0413	0232	0082	0095				0034	0223	Lower L to R
0114	0006		0095	0204	0199	0067	0304	0241	
	0049	0072	0025		0150		0080	0133	
0033	0107	0017	0068	0081		0186	0009	0094	Upper L to R
		0017		0041	0029	0025	0020	0030	
	0184	0011		0332	0038	0128	0011	0161	

All entries in hundredths of a second.

Table 5 Panel Display, Contrast Ratio = 0.5.

A	B	C	D	E	F	G	H	All	Subject / Sector
0182	0268	0224	0302	0149	0450			0282	Center L to R
0156	0220	0527	0540	0258	0274	0214	0266	0296	
0125	0456	0224	0413	0136	0117	0106	0217	0204	
0186	0316	0100	0166	0315	0191	0134	0367	0232	
	0387	0193		0231		0092	0554	0266	
0377	0147	0270	0447	0211	0370	0282	0215	0314	
0192	0438	0206	0377		0360	0332	0325	0329	
2100	0795	0616		0387	0498	0684	0574	0818	Lower L to R
0788	0916	0638	0626	0737	0398	1058	0815	0801	
0865		0368	0861	0750	0621	1734	0910	0871	
0906	0462	0438	0238	0210	0246	0136	0507	0387	Upper L to R
0428		0236	0241	0373	0439			0340	
0393	0345	0304	0232	0543	0198	0249	0221	0323	
MEAN									
0164	0186	0244	0266	0190	0432			0244	Center L to R
0192	0232	0544	0540	0160	0274	0246	0262	0232	
0152	0700	0230	0502	0128	0122	0104	0272	0152	
0098	0286	0100	0112	0518	0090	0070	0466	0112	
	0596	0208		0224		0092	0560	0202	
0416	0146	0348	0654	0232	0362	0388	0262	0262	
0244	0436	0216	0372		0352	0318	0346	0318	
2216	0864	0616		0676	0498	0580	0652	0676	Lower L to R
0788	0902	0638	0626	0816	0398	1104	0934	0816	
0694		0368	0460	1066	0946	1856	1108	0712	
0826	0596	0526	0310	0216	0140	0124	0218	0222	Upper L to R
0370		0232	0230	0228	0160			0230	
0374	0230	0356	0222	0826	0198	0196	0132	0222	
MEDIAN									
0066	0192	0087	0153	0057	0230			0172	Center L to R
0050	0082	0353		0203		0091	0119	0204	
0038	0344	0100	0125	0035	0006	0018	0069	0141	
0220	0145		0092	0286	0176	0150	0184	0177	
	0295	0052		0126		0006	0472	0235	
0286	0035	0110	0266	0029	0131	0149	0065	0187	
0073	0036	0014	0112		0182	0146	0093	0134	
0163	0097			0408		0270	0261	0589	Lower L to R
	0033			0111		0064	0167	0193	
0520			0701	0446	0462	0172	0279	0530	
0787	0271	0192	0156	0094	0224	0031	0730	0444	Upper L to R
0229		0084	0105	0363	0629			0341	
0050	0329	0130	0147	0454		0157	0209	0243	
STANDARD DEVIATION									

All entries in hundredths of a second.

Table 6 Audio Only, Contrast Ratio = 0.5.

Subject / Display	A	B	C	D	E	F	G	H	Mean
HU#1	143	65	234	104	182	208	143	130	151
P#1	182	104	-	-	325	156	273	65	184
A#1	182	104	117	260	299	156	130	104	169
HU#2	156	156	78	169	156	130	130	143	140
P#2	195	221	104	195	117	130	221	117	163
A#2	247	-	104	299	143	156	156	78	169

HU Head-up

P Panel

A Audio only

#1 Contrast Ratio = 1.0

#2 Contrast Ratio = 0.5

Table 7 Table of Differences Between Maximum and Minimum Altitudes, in Feet

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