

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

CP 86143

HUMAN FACTORS PROGRAM FOR THE COOPERATIVE PILOT WARNING INDICATOR SYSTEM

FINAL REPORT

FACILITY FORM 602

N69-23893	
(ACCESSION NUMBER)	(THRU)
32	1
(PAGES)	(CODE)
CN-86143	02
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

PREPARED FOR:
SPACE OPTICS LABORATORY
NASA-ERC
CAMBRIDGE, MASSACHUSETTS
CONTRACT NAS 12-2013

Final Report

HUMAN FACTORS PROGRAM FOR
THE COOPERATIVE PILOT WARNING
INDICATOR SYSTEM

Prepared for:

Space Optics Laboratory
NASA-ERC
Cambridge, Massachusetts 02139
Contract No. NAS 12-2013

31 December 1968

Prepared by:

Leroy L. Vallerie
Roland C. Casperson, Responsible Officer

Dunlap and Associates, Inc.
One Parkland Drive
Darien, Connecticut 06820

ABSTRACT

A study was conducted under controlled laboratory conditions using an aircraft simulator to assess the effectiveness of four types of displays for presenting pilot warning information. Displays investigated were a simple auditory alarm, the Matrix Display, the Hedge Display, and the Dunlap Auditory Display (DAD). Based on the results of the study, it appears appropriate to conclude that visual surveillance of outside airspace has a detrimental effect on control performance and that PWI displays can be successfully employed to aid pilots in detecting and locating aircraft. Simulator pilots were able to detect and locate both single and multiple targets with the greatest speed using the Matrix Display. Visually searching for targets with this display also produced an insignificant reduction in control performance. There appears to be little, if any, difference in detection speed between the Matrix and Hedge Displays when used to find single targets. The Matrix Display, however, is significantly superior to the Hedge Display when multiple targets (two or three) appear simultaneously.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the following individuals for their assistance in carrying out the study:

- . Mr. James Link for his help in conducting the experiment and the statistical analyses.
- . Mr. Allan Matthews for programming the aircraft simulator and building the display circuits.
- . Mr. Joseph Hull and Dr. Anne Story for their interest and guidance.

TABLE OF CONTENTS

	<u>Page</u>
I. Introduction	1
II. PWI Displays	4
A. The Matrix Display	5
B. Hedge Display (Heads-up, Edge-Lighted)	6
C. Dunlap Auditory Display (DAD)	6
III. Method	9
A. Control Task	9
B. Detection Task	12
C. Subjects	13
D. Procedure	13
IV. Results and Discussion	14
V. Summary and Conclusions	18
VI. Recommendations for Future Research	19
Appendix	

LIST OF TABLES AND FIGURES

<u>Tables</u>		<u>Page</u>
Table I.	Average Time (Sec.) for Target Detection and Percent Decrease in Control Performance	14
Table II.	Analysis of Differences Between Individual Pairs of Means	16
 <u>Figures</u>		
Figure 1.	Block Diagram of the Aircraft Simulator	10
Figure 2.	Relationship Between Display Resolution and Detection Time (hypothetical)	19
Figure 3.	Sweep Time Circuit (DAD)	A-1
Figure 4.	Amplifier and Inverter Circuit (DAD)	A-2
Figure 5.	Frequency-Sweep and Square Wave Converter	A-3
Figure 6.	Hedge Control Interface	A-4
Figure 7.	UJT Oscillator and Driver	A-5
Figure 8.	Matrix Driving Circuit	A-6

HUMAN FACTORS PROGRAM FOR THE COOPERATIVE PILOT WARNING INDICATOR SYSTEM

by Leroy L. Vallerie

Dunlap and Associates, Inc.
One Parkland Drive
Darien, Connecticut 06820

I. INTRODUCTION

The increase in air traffic and the consequent increase in the number of mid-air collisions have created serious safety problems which demand an immediate solution. Aircraft accident reports indicate that the highest percentage of mid-air collisions occur in the vicinity of airports under conditions of good visibility and involve private light aircraft. Many of these accidents could have been prevented if pilots were able to maintain adequate visual surveillance outside their aircraft, especially in terminal areas around airports. Adequate visual surveillance, however, is extremely difficult if not impossible since pilots must simultaneously attend to other tasks involving the primary control of their aircraft. Military operations, in particular, make surveillance of the outside airspace even more difficult since they usually require pilots to give the most attention to their cockpit instruments and little to the outside airspace. Collision avoidance, therefore, appears to be beyond the natural ability of pilots, especially in view of their visual limitations and high workload requirements.

One solution to the problem of mid-air collisions has been to improve the visibility of aircraft through various means. These involve the use of fluorescent paint, rotating beacons, and smoke/contrail generation. Several commercial airlines, for example, presently employ the Aircraft Recognition Light System (ARLS), which consists of a high intensity xenon light with high output in the visible range. Such devices do, in fact, increase the visibility of aircraft; however, they do not warn the inattentive pilot or aid him in directing his gaze to the location of the hazard in his immediate environment. Merely improving the visibility of aircraft still does not ensure that they will be detected in sufficient time for the pilot to take collision avoidance action. Visibility improvement, therefore, does not mean that detection will take place at a great enough range for sufficient warning; i. e., visibility is not synonymous with detectability.

Visibility refers to the ability to see or discriminate--knowing when and where some object will appear in the visual field. In contrast, detectability

refers to the "ability" of the stimulus to draw the pilot's attention to itself without the pilot knowing when or where the object will appear. Detecting an aircraft, therefore, is quite different from seeing it. The essential difference between these two visual functions involves the concept of attention. The span of visual attention does not include the entire visual field at any one instance of time. Hence, a pilot normally sees and attends to only that which he is looking at with his central vision while he scans his cockpit instruments and the outside airspace. Since there is a low probability that a threatening aircraft will fall directly in his line of sight, especially in view of his high visual workload, he must rely on his ability to detect aircraft with his peripheral vision. The threatening aircraft, therefore, must produce a sufficient change--either in brightness, color, size, etc., to draw the pilot's attention to itself; i. e., the initial alert is induced involuntarily in the periphery in most cases.

No doubt, techniques for improving the visibility of aircraft will assist in making them more detectable in the periphery. However, such techniques do not ensure that detection will occur since the pilot may be attending to other aspects of his environment and the threatening aircraft is not conspicuous enough either to draw his attention or to warn him in sufficient time for evasive maneuvering. Consequently, initial detection should not rely primarily on the pilot's visual mechanism, but rather on an automatic detection and warning system which would augment his visual capability and always be attentive. Such a system would not be subject to human limitations involving the physiology of the eye, latencies in visual scanning, fatigue, limited information processing capacity, and other factors involving atmospheric conditions which interfere with normal visual detection.

In designing a Pilot Warning Indicator (PWI) system, the question arises concerning such factors as the amount of time constituting a safe margin for detection and collision avoidance. Unfortunately, no simple measure is available. At a FAA symposium on pilot warning instruments, a warning time of "3 miles plus 30 seconds" was recommended (Proceedings, 1967). Taking aircraft speeds into account, minimum warning ranges recommended were 2 to 3 nm for aircraft speeds of 150 kts. and 5 to 6 nm for aircraft speeds of 300 kts. Other factors to be considered involve cost, since it is unlikely that civilian light aircraft pilots could be expected to purchase and install an expensive system. If the system were effective and yet inexpensive it could be made mandatory. To be effective, the system would also have to be capable of multi-target detection.

Tests carried out by the FAA indicate that a PWI can significantly improve a pilot's ability to locate other aircraft. These tests also indicated that alerting the pilot to the "mere presence" of another aircraft is of some value; however,

the big improvements come when accurate information is given to the pilot in both azimuth and elevation planes. In summary, the basic requirements for an effective PWI system include the provision of an initial alert as well as an early indication of the visual locations of threatening aircraft. The system must also be relatively inexpensive, and adaptable to any one of a variety of light planes.

In response to these requirements and in the interest of public safety, NASA-ERC has developed a cooperative PWI system based on the detection of infrared energy emitted by a xenon light source. The sensor employs a diffused silicon detector. Tests conducted by ERC indicate that the system is capable of multi-target detection in excess of 3 to 5 miles. Under conditions where haze limited visibility to 3 miles, the source was still detectable, so that the system was effective from clear weather conditions down to VFR minimums. The system is envisioned as ultimately being capable of presenting the pilot with a warning alert as well as position information on aircraft in the proximal airspace. This information would be presented to the pilot through a display system which is now under development and is the primary concern of the present research endeavor.

II. PWI DISPLAYS

The sensors of the NASA PWI are expected to pick up aircraft some seconds before the pilot would normally see them visually, even if he knows their location. Visual detection time and range, of course, depend on such factors as aircraft size, cross section and time of day. However, it is estimated that, on the average, aircraft will be visible within two seconds or less after the sensors have detected the signal. In order to be effective and to take full advantage of system capabilities, the display must demand the pilot's immediate attention and aid him in directing his gaze to the location of the threatening aircraft without wasting precious time in visual search. Lag times by the pilot in utilizing such a display must, therefore, be held to an absolute minimum. Lag times which should be given primary consideration in the design of a PWI display are those due to attention switching between and within sensory input channels and those due to visual switching between information sources. For example, visually switching the point of fixation between near and far locations successively, in a task that includes visual acuity, recognition, and response, has been shown to be 1.06 sec. (Travis 1948). In the same vein, the time required to shift fixation from the environment outside a cockpit to an inside instrument and then back again has been shown to exceed two seconds (Wulfeck, 1958). Hence, a saving of seconds at the point of display input to the pilot would be worthwhile. This saving could also be cumulative since there is interaction from input to output.

The traditional approach to the design of a PWI display would probably be to provide a simple auditory alarm for alerting the pilot, and to indicate aircraft location by means of a conventional visual display mounted on the cockpit instrument panel. The visual display might take many forms and would most likely indicate azimuth and elevation of the threatening aircraft. It would be the pilot's task to translate this information to the outside environment once alerted by the auditory alarm. Without detailing the time lags and inaccuracies involved in the detection process, it is quite evident that such a display system would require the pilot to shift his visual fixation back and forth between his instrument panel and the outside environment, a time consuming and inaccurate process. Such shifting of visual fixation or scanning instruments and the outside airspace become increasingly difficult as the workload on the pilot increases. The pilot workload is at its highest point in the vicinity of airports--precisely where collision avoidance information is required. A display system which requires visual switching, therefore, would waste time, interfere with the pilot's ability to perform tasks associated with the control of his aircraft, and would place the task of transferring displayed position information to the outside environment on his shoulders.

An alternate approach might be to install a head-up projection display to reduce or eliminate the amount of visual switching involved in the detection process. Such a system might be justified in the case of commercial jet aircraft; however, the high cost eliminates such sophistication in small planes and should not be given serious consideration if other less expensive configurations can be developed.

In addition to cost, there are other factors which must be considered in the design of a PWI display. For example, the display must fit into all aircraft currently being built and capable of retrofit to all kinds of aircraft built in the past. The display also must not interfere with existing cockpit instrument panels and must be compatible with projected cockpit configurations.

In view of the above considerations, three design concepts have been developed for the display of PWI information. These concepts appear to hold promise but require careful examination and testing under controlled conditions in order to assess their effectiveness.

A. The Matrix Display

The Matrix Display consists of a matrix of almost invisible wires embedded in the aircraft windshield. A grain of wheat lamp is installed at every intersection of the wires. An illuminated lamp alerts the pilot and indicates the location of threatening aircraft in the surrounding airspace. The pilot merely locates the illuminated lamp and searches "through" it in the projected cone area of his line of sight. Flashing is used to improve the attention-getting quality of this lamp. Range information could be encoded by varying the flash rate of intensities of the lamp. An auditory warning device would normally be employed with the Matrix Display to provide the pilot with an initial warning alert and to enhance the visual signal.

In a test model, #36 wire was used for ease of installation in the simulated windshield. A wire size as small as #50 could be used in the operational display. Once in production, the smaller size could be handled without difficulty. When the test model wires and lights were installed in a Piper Cherokee, the pilot experienced no interference in his surveillance of environment. Pinlite Co. Model 15-15 or 15-45 lamps with a diameter no more than 0.030 inches were used; thus, the ratio of windshield area covered by wires and lights was roughly 1/7000, small enough not to interfere with the pilot's field of view.

B. Hedge Display (Heads-up, Edge Lighted)

The Hedge Display consists of strings of lights in the periphery of the pilot's visual field, a horizontal string below the normal line of sight of the pilot along the bottom frame of the windshield, and the vertical string or strings, to his side, along the vertical frame(s) of the windshield. A plane is indicated by the synchro. as flashing of two sets of lights, one on the horizontal x-axis and one of the vertical y-axis. The location of the plane is in the area of a line of sight through the implicit intersection of the coordinates of the two sets of lights.

The Hedge Display was installed in a Piper Cherokee to determine the feasibility of such a display configuration. It was found that a pilot could indicate a "non-displayed" target with considerable accuracy and with no training. Only single pairs of lights were tested during this flight. Two pairs of three lights would be employed in the operational model. To accommodate multiple aircraft, the synchrony of pairs of flashes differs for each aircraft. Increased directedness toward the point of intersection is effected by using three lights flashed in quick succession, as in some car turn-signals. An auditory signal would be employed with the display to alert the pilot whenever the number of planes within range of his sensors increased. The number of beeps sounded could be made to correspond to the number of planes on potential collision courses.

C. Dunlap Auditory Display (DAD)

The Dunlap Auditory Display (DAD) is designed to utilize auditory signals to provide an initial warning alert as well as location indices on the position of threatening aircraft. Auditory warning signals are considered best for alerting the pilot of imminent danger, since they are omnidirectional and attention demanding. For this reason, an auditory signal is used in conjunction with both the Matrix and Hedge Displays, discussed above.

In the DAD system, the fact that man possesses two ears and is able to distinguish changes in pitch, is taken advantage of as a means of providing aircraft position information. Three speakers are mounted in the cockpit around the pilot--one on his left, one in front, and one on his right side; each speaker corresponding to a sector of airspace surrounding his aircraft. When a plane enters a sector, a signal is sounded for approximately 1/2 second through the appropriate speaker giving relative azimuth. Relative elevation is indicated by varying the pitch of the signal. Hence, the pilot simultaneously receives both a warning alert and an indication of aircraft position. When the threatening aircraft is at the same altitude, pitch remains constant; when it is higher or lower, pitch is swept either 500 Hz above or below a 2500 Hz signal which is

employed as the base frequency. The 2500 Hz base frequency is generated by a simple square wave generator which produces an impure and annoying tone. Since the ear acts as a frequency analyzer, periodic signals can be detected in noise even when they are considerably weaker than their background. This is true for both pure and complex tones.

To ensure that signals employed in the DAD system could be easily heard against aircraft noise, sound recordings and sound pressure readings were obtained during flight in a single engine light aircraft. Levels were found to range from 90 to 102 db with the highest levels in the lower frequency bands. During a pilot study in the laboratory, the recorded noise was reproduced at the measured levels and auditory signals tested for their distinguishability under realistic conditions. The results of this study indicate that a 2500 hz signal could be easily heard even when it was 20 db below the average noise level of 95 db. For this reason the DAD system is considered feasible for operational use even under conditions of high ambient noise.

The multiple target situation is not easily handled by an auditory display system since hearing is a temporal sense rather than spatial, as is the case with vision. In the DAD system, the situation is handled by activating the three speakers in sequence for an interval of two seconds each. Multiple aircraft in one sector, therefore, are indicated by a series of auditory signals sounded in quick succession. The appropriate number of signals would be repeated again six seconds later provided both aircraft remained in the same sector. The pilot is not expected to count the number of signals but merely to pay more attention to the sector with the largest number of signals. By employing this technique (i. e., speaker sequencing at periodic intervals), it appears feasible to use an auditory system to display multiple targets.

As is the case with any simple visual display for the PWI system, DAD only aids the pilot in bringing his attention to that portion of the airspace containing the intruding aircraft. The pilot still must locate the aircraft visually. An auditory system, however, is not limited by extreme variations in ambient illumination; e. g., flying into the sun, glare, and reflections. In addition, an auditory system would probably be less expensive, adaptable to a greater number of aircraft cockpits, and require less maintenance than a visual display system.

Any of the above-mentioned display systems will provide the pilot with a warning alert and aid him in visually locating aircraft within his proximal airspace. Based on past research and theoretical considerations, it is difficult to determine which system would be the most effective one in the operational environment and holds the greatest promise for further development.

An effective system is one which demands the pilot's immediate attention and accurately directs his gaze to the threat without wasting precious time in visual search. These activities must take place even under conditions of high workload where the pilot's visual mechanism and his capacity for information processing are being taxed to their maximum extent by those tasks involving the basic control of his aircraft. For these reasons, display concepts for the PWI system must be assessed and evaluated based primarily on actual performance data collected during ongoing aircraft type control tasks. As an initial step, this can best be accomplished under controlled conditions in the laboratory using aircraft simulation equipment. A laboratory study was undertaken by Dunlap and Associates, Inc., to obtain performance data on the above-mentioned displays and to evaluate them with particular emphasis on the human factor aspects of their design. The primary purpose of this report is to describe the results of this study.

III. METHOD

Displays for the PWI System were compared and evaluated on the basis of performance data collected under controlled conditions during a laboratory study. Performance data consisted of the speed with which simulator pilots detected and located targets while performing a two-dimensional control task. The control task was employed as a means of loading the pilot as he would be in the actual operational environment, and involved the correction of errors in pitch (x) and roll (y) by means of compensating tracking using a hand control and an oscilloscope display. While performing this task, the pilot was also required to detect and locate targets with and without the aid of the three PWI displays discussed above.

A. Control Task

Error information for the control task was presented to the pilot on an oscilloscope by means of displacing a dot from the center of the screen. The pilot's task was to null the errors in pitch and roll by centering the dot using a pressure stick hand control. The stick was situated directly in front of the pilot and oriented vertically for use with the right hand. The control-display relationship was arranged in an "outside in" configuration; the pilot moved the stick in opposition to the direction of movement in order to null the errors in pitch and roll.

The screen was 34.6 cm on the diagonal and was located in front of the pilot, slightly below his line of sight at a distance of 2.42 meters. The screen was located at this relatively great distance to ensure that the pilot's eyes were accommodated and converged for distance as would be the case in the operational environment. A greater distance could not be used because of the physical limitations of the laboratory area provided for the study.

The difficulty level and scoring of the control task was accomplished by using a technique developed by Kelley (1962). This technique involved the use of self-adjusting loops in the control circuits of the simulator. Conventionally, a variable score is employed to represent the pilot's performance in a task of fixed difficulty. In this case, a score representing the desired performance (error tolerance) was fixed and the difficulty of the task varied automatically as a function of the pilot's performance to produce the fixed performance score. The difficulty level achieved and maintained was the performance index for the control task.

A block diagram of the simulator is shown in Figure 1. Detailed circuit diagrams are presented in Figures A-1 through A-6 of the Appendix. Equations of

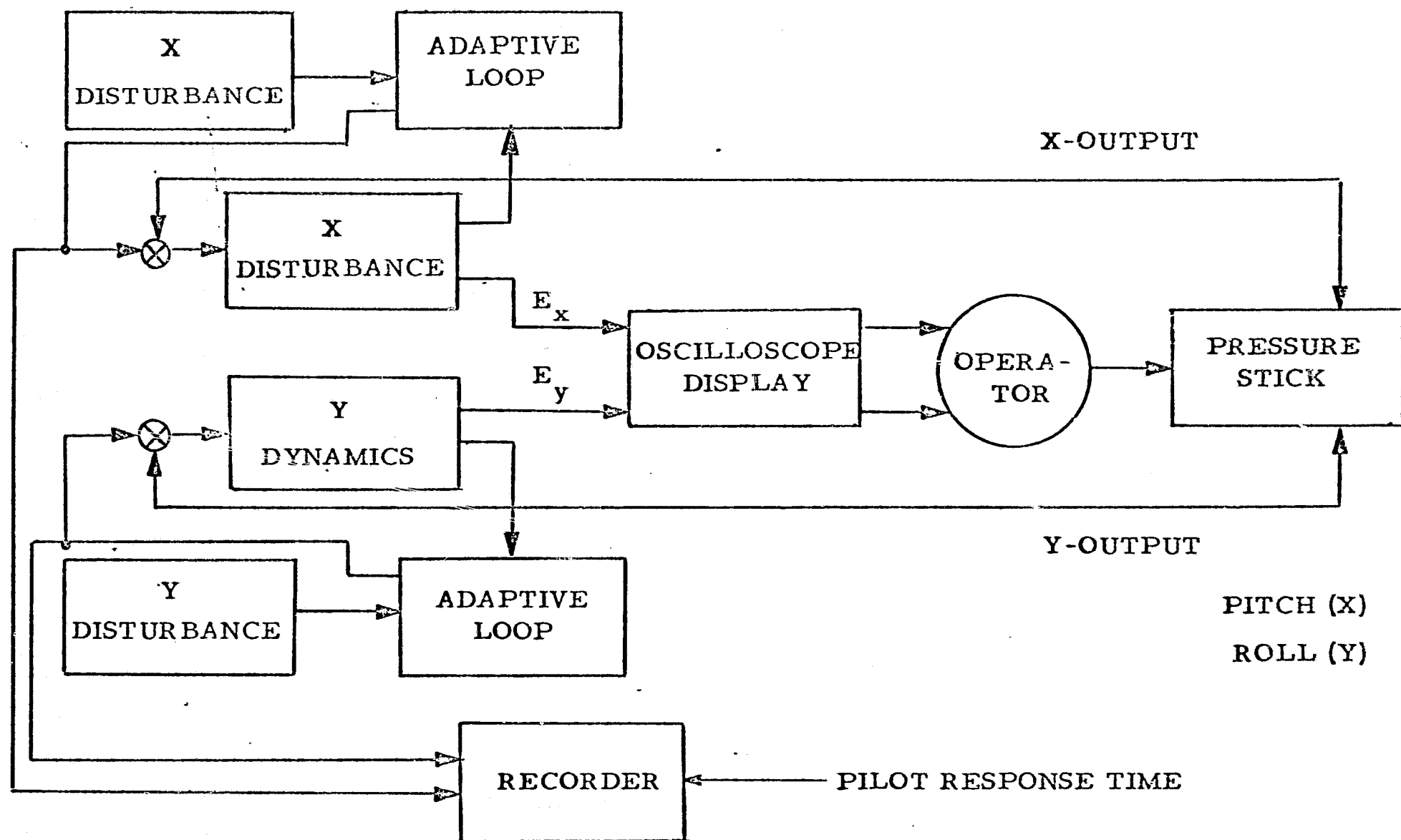


Figure 1. Block Diagram of the Aircraft Simulator

motion were programmed on an analog computer to provide second-order dynamics for the control task. The second derivative of the simulator output was obtained by summing the outputs of the hand control and a disturbance function generator for the pitch and roll channels of the control task.

The disturbance function generators were programmed to produce acceleration errors via an adaptive loop in each control channel. Each generator consisted of three independent sinewave oscillators. The frequencies of oscillation (see Appendix) were selected to generate a random waveform whose period was long enough to prevent the pilot from memorizing or anticipating the control task inputs. The amplitude of the summed frequencies from the oscillators was controlled by the adaptive loop.

The pilot's task was to null the input errors using a pressure stick control. As the error in either pitch or roll was decreased and approached zero, the adaptive loop caused an increase in the output of the disturbance function generator and a greater error to be displayed to the operator. The adaptive loop equation for both control channels was of the form:

$$C = K \int_0^T (e_L - |E|) dt + C_{\text{initial}}$$

C = the percent of disturbance, a higher value denoting better performance

e_L = the "error threshold" or error criterion the task is to meet

$|E|$ = the absolute error

K = a coefficient governing the rate of increase or decrease of C

Whenever the error was less than criterion, task difficulty increased. When error was greater than criterion, however, difficulty decreased and the task became easier. Thus, the task was adjusted to the difficulty level that produced e_L units of error, and oscillated around that value. C_{initial} was set at zero at the beginning of each trial; i. e., the pilot achieved a difficulty level which he could control at the error threshold (e_L) which was preset at .33 of E_{max} .

A relatively high value of K was employed so the system would quickly respond to errors $|E|$ exceeding e_L but without oscillating in an uncontrolled fashion.

A multi-channel recorder was used to record the output from each of the adaptive loops. This output is an index of the task difficulty level achieved by the pilot while he controlled the simulator. A high score, therefore, indicates that a large amount of disturbance could be maintained within the fixed performance tolerances. Control performance, of course, was not of primary interest in this study since the control task was used primarily to load the pilot as he would be while flying and using the PWI System. However, these records were analyzed to identify any serious effects on control performance during those time periods in which a collision alert was given to the pilot.

B. Detection Task

Of primary interest in the study was the relative speed with which pilots detect and locate targets with the aid of the PWI displays. Four display conditions were presented to each pilot in a different order as a means of attenuating any adverse effects or biases which might have influenced their performance due to fatigue or learning. The displays investigated were the Matrix, the Hedge, the DAD, and a control condition. The control condition was employed to obtain baseline data. During this condition, no display was used except for an auditory warning alarm of 2,500 Hz, which announced the presence of a target but did not aid the pilot in directing his gaze to the target location. The alarm was also used with the Matrix and Hedge Displays, but not with DAD since it already makes use of auditory signals for indicating target position. Sound pressure level for both DAD and the auditory alarm was set and maintained at 75 db, which was 20 db below the average aircraft noise level (95 db) employed throughout the study.

Targets for the detection task consisted of the letter "X" embedded in a confusion matrix of capital letters. Targets were presented randomly in twenty-seven different locations in the matrix. The matrix was made up in the form of 35mm slides and displayed by means of three projectors on a large panoramic screen. The screen was situated at a distance of 3.75 m from the pilot. Projectors were fitted with remote controls and special, wide-angle lenses to fill the screen completely. The screen subtended 190° of visual arc in width and 38° in height. The average density of the confusion matrix was 145 letters per square degree.

A chin rest was used to hold the pilot's head in a relatively stationary position. In this way, it was possible to stabilize the Matrix and PWI displays in his visual field as he viewed the oscilloscope display. He was allowed to turn his head in any direction as long as his chin remained on the rest.

Each pilot was given a total of twenty-four trials under each of the four display conditions. During eight of these trials, multiple targets were presented simultaneously. Multiple targets were not presented with the Dunlap Auditory Display due to equipment cost and time restrictions involved in developing the necessary circuits for sequencing the speakers at periodic intervals.

The pilot was required to detect and locate targets (X) as quickly as possible and to depress a pushbutton with his left hand. An electronic timer was used to measure the speed with which targets were located in the confusion matrix. The timer was started at the instant of target presentation and stopped by the pilot with his pushbutton. The experimenter recorded the elapsed time for target detection, reset the timer, and presented the next target(s).

C. Subjects

Six staff members of Dunlap and Associates, Inc., participated as simulator pilots during the study. Eyesight was tested and determined to be within normal limits without corrective lenses using standard tests of central and peripheral vision. These tests were carried out with a Ferree-Rand Perimeter and a Keystone Telebinocular.

D. Procedure

Standard instructions were given to the simulator pilots. They contained an explanation of the overall purpose of the study, the control and detection tasks, and the operation of the PWI displays. Care was taken not to bias the pilots in any way. They were allowed to fixate any display in their visual field and to move their heads provided they kept their chin on the rest. Each pilot received a total of one hour's training on the simulator and the various display configurations to ensure that he would be familiar with the display/control relationship and the operation of the displays for the study.

Each session consisted of twenty-four trials under one of the four display conditions, and lasted an average of one hour except for those sessions in which the DAD was employed. The pilot spent the initial five minutes of each session in establishing and achieving a difficulty level for the control task which he attempted to maintain during the remainder of the session. No targets were presented during the initial warm-up period. Throughout the entire study, aircraft noise, which had been recorded and measured during flight, was played back in the simulator cockpit at an average level of 95 db. The laboratory room was dimly illuminated to allow the use of projectors. Pilots were given knowledge of their results at the completion of each session.

IV. RESULTS AND DISCUSSION

The primary results of the study are indicated in Table I. The table contains the average time required by the simulator pilots to detect and locate the targets as well as the average degradation in control performance (percent decrease in C) associated with the use of each display system. The detection times, in general, may appear excessive when viewed in light of the operational requirements discussed above. Time scores of this magnitude, however, were not unexpected due to the nature of the confusion matrix and the targets employed in the study. Targets were deliberately chosen to be difficult, and in some instances, almost impossible to locate without following a careful visual search procedure. For this reason, detection times should not be considered representative of those expected in real flight, but rather as indices of performance for the purpose of design evaluation in the laboratory.

TABLE I
Average Time (Sec.) For Target Detection and Percent
Decrease in Control Performance

		TARGETS		
		Single Targets	Multiple Targets	All Targets
DISPLAY CONDITIONS	Control	57' 39%*	48' 42%*	55' 40%*
	Matrix	10' 12%	11' 10%	10' 16%
	Hedge	14' 13%	25' 28%*	17' 17%
	DAD	26' 20%	N/A	N/A

*Decrease in control performance is significant at the 5% level and cannot be reasonably attributed to chance fluctuation of scores.

As shown in the table, the largest amount of time (55 seconds) was spent in locating targets under the control condition in which a simple auditory alarm was employed to alert the pilot of the target's presence. No directional assistance was given, i. e., the pilot knew a target was situated in his simulated airspace but did not know where to search for it. As was expected, control of the simulator, in both pitch and roll, was adversely affected to the highest degree under this condition. Statistical tests revealed that this reduction in control performance can be considered real and not attributable to chance fluctuation of the performance scores. This conclusion is also supported by statements made by the simulator pilots. They reported, for example, that they could not give sufficient attention to the control of the aircraft simulator since it required a great deal of time to search for targets when no directional aid was provided by a PWI display. In contrast, little time (10 seconds) was required to locate targets with the Matrix Display. As a consequence, there was relatively small and insignificant reduction in control performance with this display system.

Average detection time with the Hedge Display was 17 seconds, a significant reduction when compared to the time of 55 seconds for the control condition, but a significant increase over 10 seconds obtained with the Matrix Display. In addition, the reduction in control performance with the Hedge was not as great as that under the control condition. The average reduction was 17% which was not found to be significantly different from zero and can be attributed to chance fluctuation of the performance scores. Some confusion in using the Hedge Display was reported by the simulator pilots. Difficulty was experienced in identifying the correct pairs of lamps corresponding to a target search area when multiple targets were presented simultaneously. Evidently, this difficulty explains the rather high detection time of 25 seconds for multiple targets with the Hedge, as can be seen in the table.

Of particular interest during the study was performance with DAD, a simple system employing three speakers, situated around the pilot, to provide gross directional information. This system might be considered the next step up the ladder of complexity and cost from a simple auditory warning alarm which was utilized during the control condition. Target azimuth information was presented by simply activating the appropriate speaker or pairs of speakers. Elevation information was provided by sweeping a base signal of 2500 Hz either up or down 500 Hz. With this system, average search time was reduced to less than half of that obtained with the simple auditory warning alarm. There was also a reduction in the adverse effects on control performance. Based on these results, it would appear appropriate to continue the development of DAD as a cost-effective system for private light aircraft. Unfortunately, time and cost restrictions only allowed the development of a

simple feasibility model of DAD for this study. For this reason, it was not possible to test the display with multiple targets using the sequencing technique described above.

The performance data obtained during the study were subjected to a series of analyses of variance to determine whether the differences between the mean time and error scores could be accepted as real or attributed to chance. A summary of the results of these analyses are contained in Table II.

TABLE II
Analysis of Differences Between Mean Times to Find Single
Targets and Percent Decrease in Control Performance

		DISPLAY CONDITIONS		
		Control	Matrix	Hedge
DISPLAY CONDITIONS	Matrix	47'*		
	Hedge	43'*	4'	
	DAD	31'*	16'*	12'*
		27%*	1%	7%
		26%*	8%	
		19%*		

Critical Difference = 12' and 9% @ .05 level.

*P < .05

Based on the results of the analyses, it appears reasonable to conclude that there was a real improvement in target detection speed with any one of the three PWI displays investigated as compared with that obtained with a simple auditory warning alarm. In addition, adverse effects on control performance were reduced by utilizing PWI displays to assist the pilot in searching for targets. Even though the Matrix Display produced the best overall performance, it was not significantly better than the Hedge Display when employed to present information on single targets, i. e., the apparent differences in the performance scores can be accounted for on the basis of chance. With

multiple targets, the difference in mean performance was higher, favoring the Matrix Display, and statistically significant. As seen in the table, differences between mean scores for the Matrix Display and DAD, as well as for the Hedge Display and DAD can be accepted as real at the 95% confidence level. Speed of detection and adverse effects on control performance were also significantly higher with DAD as compared with the other two displays.

V. SUMMARY AND CONCLUSIONS

A study was conducted under controlled laboratory conditions using an aircraft simulator to assess the effectiveness of four types of displays for presenting pilot warning information. Displays investigated were a simple auditory alarm, the Matrix Display, the Hedge Display, and DAD. Based on the results of the study, it appears appropriate to conclude that visual surveillance of outside airspace has a detrimental effect on control performance and that PWI displays can be successfully employed to aid pilots in detecting and locating aircraft. Simulator pilots were able to detect and locate both single and multiple targets with the greatest speed using the Matrix Display. Visually searching for targets with this display also produced an insignificant reduction in control performance. There appears to be little, if any, difference in detection speed between the Matrix and Hedge Displays when used to find single targets. The Matrix Display, however, is significantly superior to the Hedge Display when multiple targets appear (two or three) simultaneously.

By modifying a simple auditory warning alert to provide directional cues (DAD), both speed of detection and adverse effects on control performance can be reduced to a significant degree. The operational utility of an auditory display does, therefore, appear feasible but further research is required to assess its capabilities for presenting information on multiple targets. Auditory displays are not expected to be as effective as visual displays due to the fact that hearing is temporal and not a spatial sense as is the case with vision. Man's ability to localize sound is also relatively poor as compared with his ability to localize visual stimuli. Despite these limitations, an auditory display does possess many advantages that should be considered in developing a cost effective system. Among these are relatively low cost, high reliability, and simple maintenance requirements.

VI. RECOMMENDATIONS FOR FUTURE RESEARCH

Even though this research effort has accomplished its stated objectives, there remains one question critical to the design of an operational PWI system. This question concerns how accurately or with what degree of resolution must a PWI display direct the eye or indicate the actual location of an aircraft to ensure that the pilot will find it in sufficient time to take evasive action. The answer to this question will influence the design of the display which, in turn, will also affect the design of the IR sensor and its related system components.

Display resolution should be no higher than that required by the pilot for effective localization of aircraft in his immediate airspace. High resolution systems are costly and, therefore, should be avoided if they offer no significant improvement in pilot performance. In the development of the present system, cost has been a major factor which cannot be ignored by human engineers in their pursuit of an effective display.

Display resolution would be expected to affect pilot performance time in a non-linear fashion. It is hypothesized that detection time decreases as display resolution increases until an asymptote is reached as depicted in the following graph.

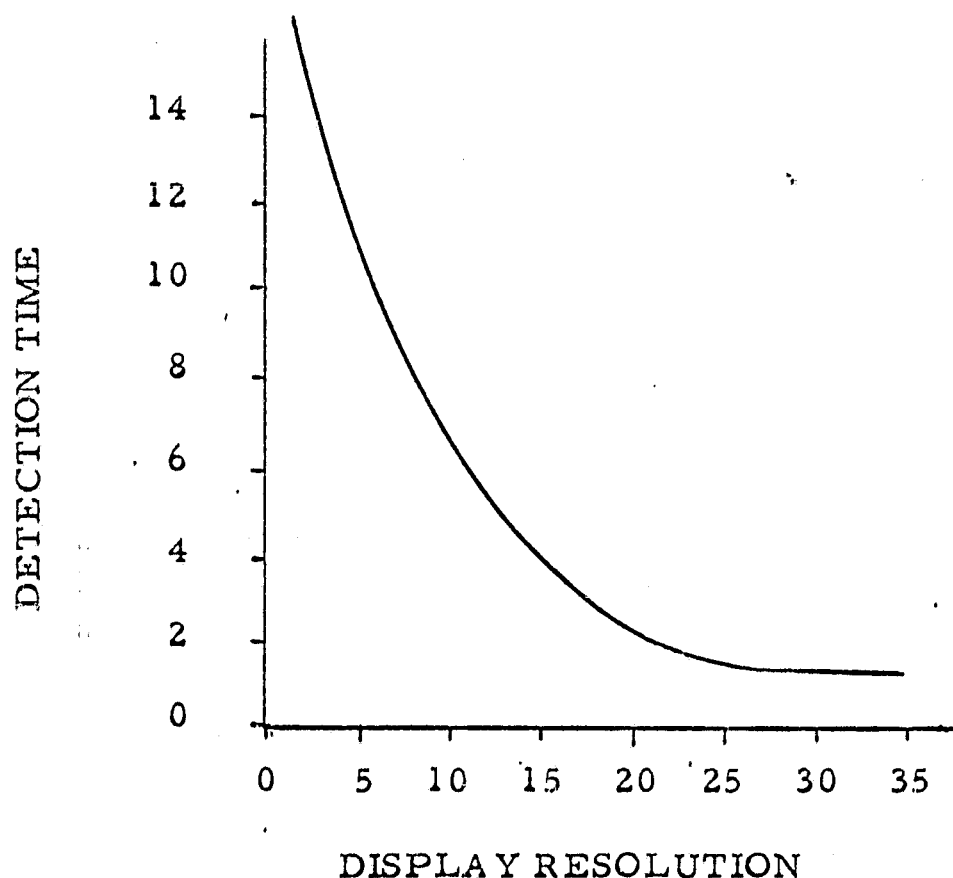


Figure 2. Relationship Between Display Resolution and Detection Time (hypothetical)

At the present time, it is impossible to specify the exact shape of this curve with any degree of certitude, i. e. , how detection time relates to display resolution expressed in some form of information content. Of particular interest in this design effort is knowing where detection time begins to level off and is no longer significantly reduced by increasing display resolution. With this knowledge, system resolution for both the display interface and the sensor can be specified based on more than mere guesswork. For this reason, it is strongly recommended that further research be carried out under controlled laboratory conditions to investigate display resolution and its effect on detection time. The matrix display is ideally suited for research of this sort since the number of elements comprising the display can easily be increased or decreased in order to provide various degrees of display resolution. An auditory display such as DAD, of course, may be employed during the study but its resolution in the auditory dimension would be restricted by the ability of the pilots to localize sound. The pilot's ability to localize sound, however, may exceed or compare favorably with the resolution requirements found to be optimum for a cost effective PWI System.

In the actual aircraft environment, the pilot must use the PWI display while he is performing the tasks involving the control of his aircraft. In many instances his workload will be sufficiently high to approach the limits of his capacity for information processing. This is the primary reason why pilots cannot maintain adequate surveillance of their outside airspace unless given some type of assistance. It would be expected that actual detection time would be influenced significantly by the demands of his control task. Performance data on display resolution should, therefore, include the effects of the total workload placed on the pilot. For this reason, the laboratory study should include an aircraft-type control task to load the pilot in a manner comparable to what he would experience in the operational environment.

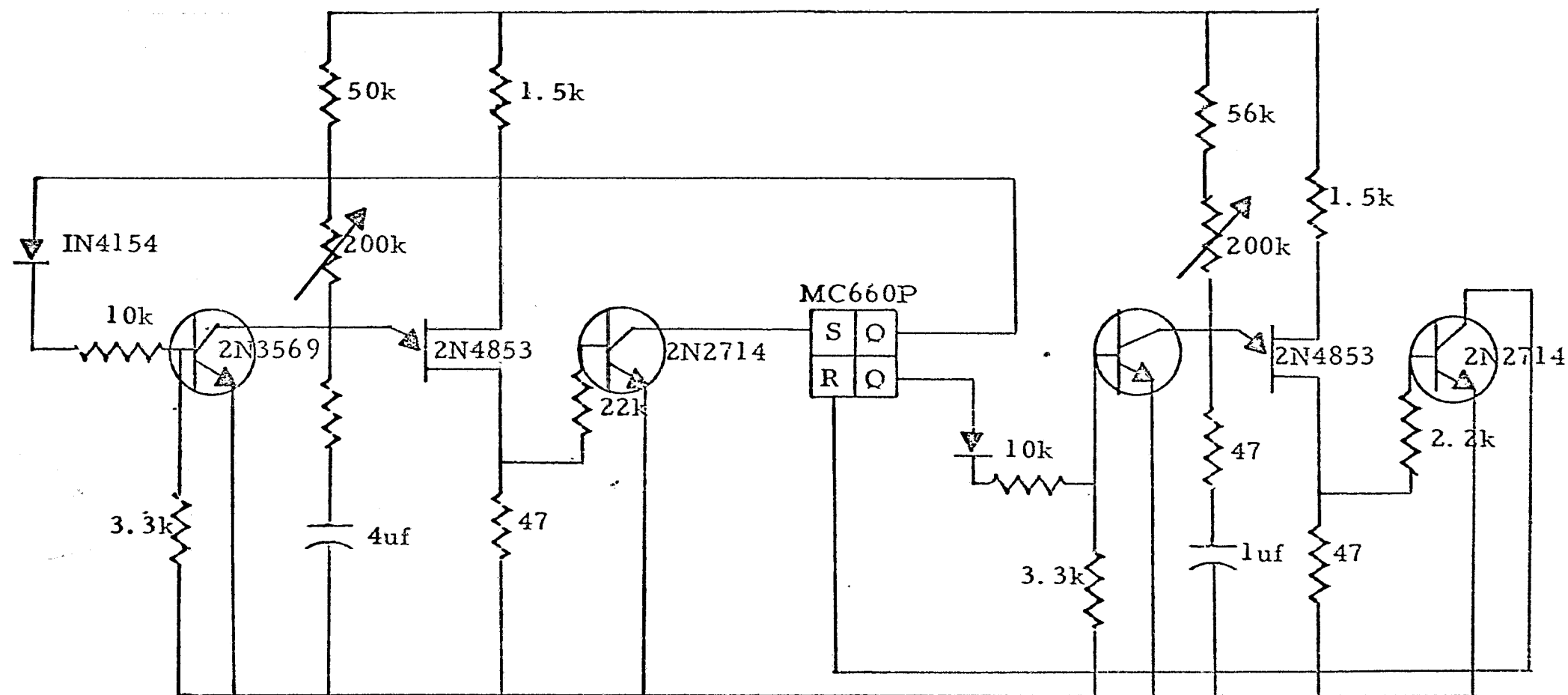


Figure 3.. Sweep Time Circuit (DAD)



•

Figure 5. Frequency-Sweep and Square Wave Converter

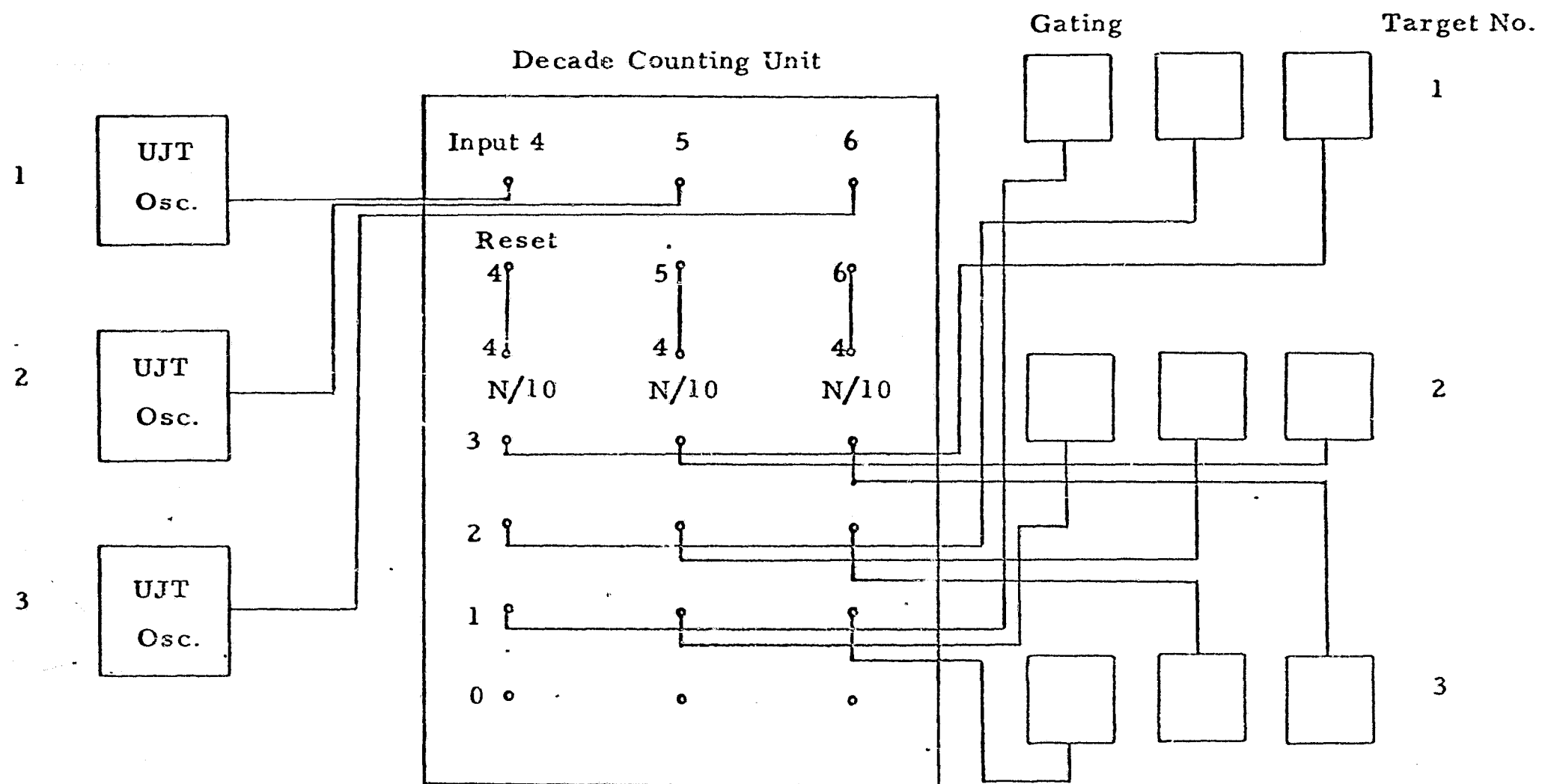


Figure 6. Hedge Control Interface

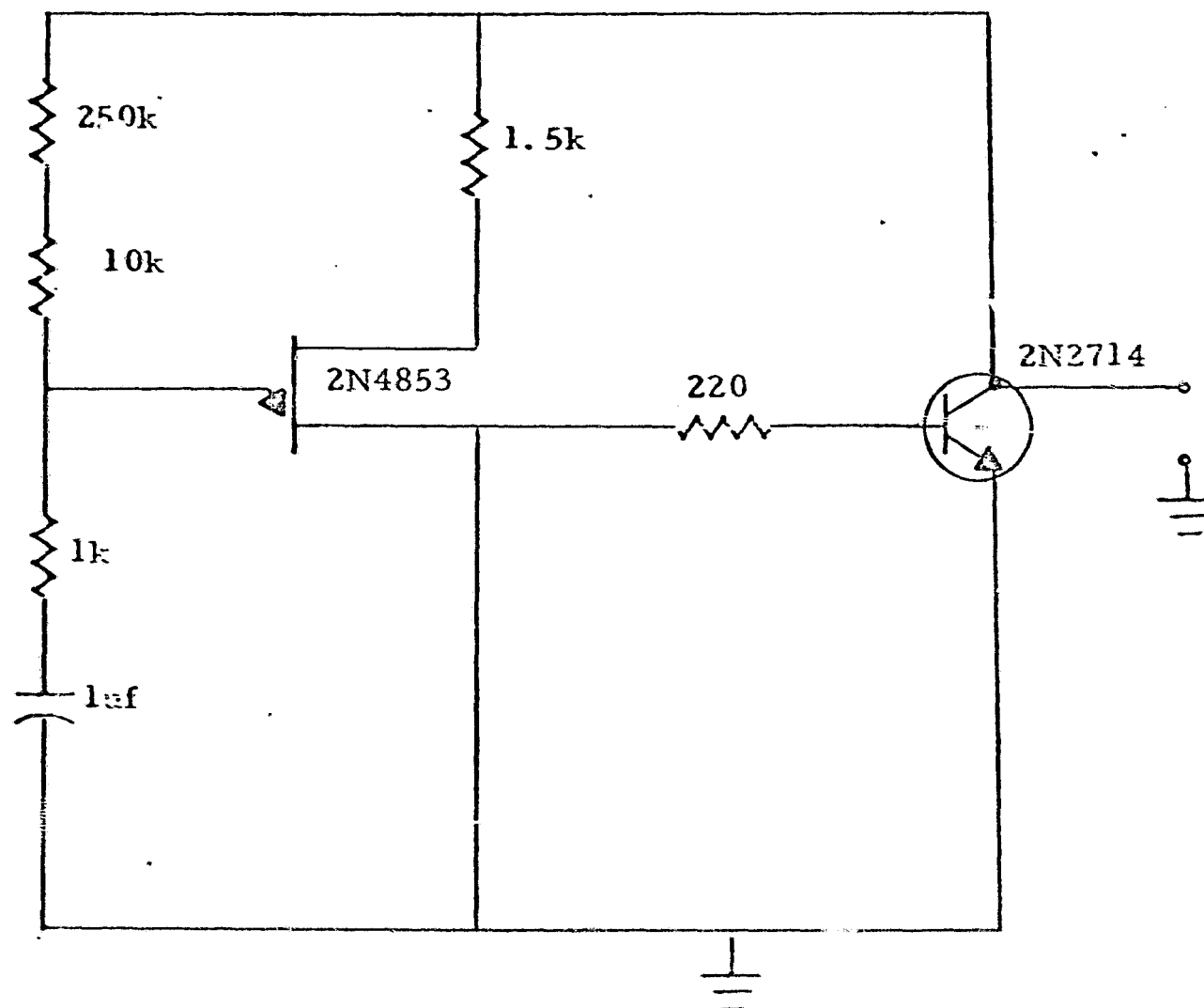


Figure 7. UJT Oscillator and Driver

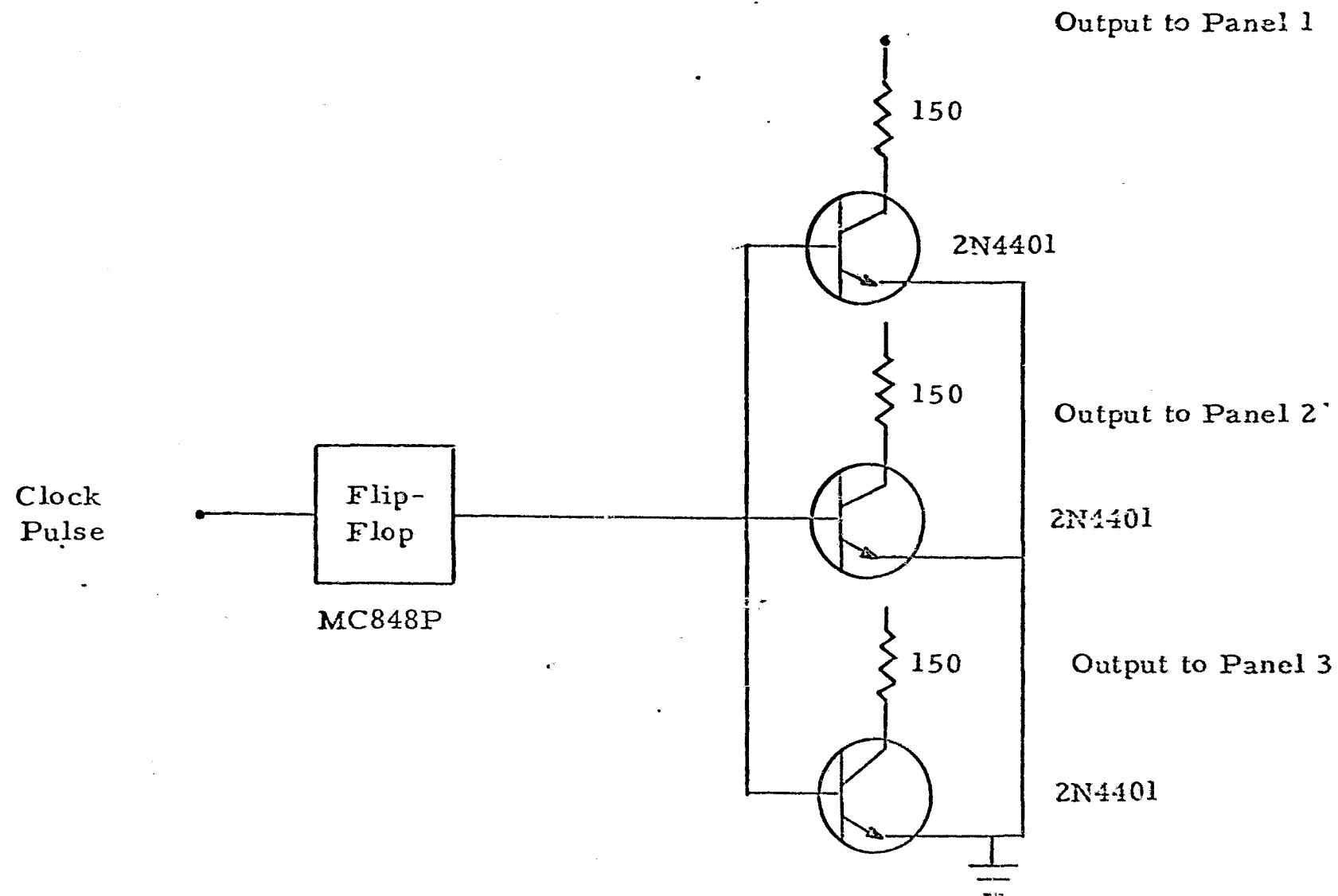


Figure 8. Matrix Driving Circuit

BIBLIOGRAPHY

1. Kelley, C. R. , Dunlap and Associates, Inc. , Self-Adjusting Vehicle Simulators. Paper presented to the IRE International Congress on Human Factors in Electronics, Long Beach, California, 3-4, May 1962.
2. Lindquist, E. F. , Design and Analysis of Experiments in Psychology and Education. Houghton Mifflin Company, Boston, Massachusetts, 1953.
3. McNemar, Q. , Psychological Statistics, John Wiley and Sons, Inc. , New York, New York, 1962.
4. Proceedings of a Symposium on Pilot Warning Instruments, Federal Aviation Administration, Washington, D. C. , December 1967.
5. Travis, R. C. , "Measurement of Accommodation and Convergence Time as Part of a Complex Visual Adjustment," J. exp. Psychol. , 1948, 38, 395-403.
6. Vallerie, L. L. , Peripheral Vision Displays, NASA: CR-808, 1967.
7. Wulfeck, J. W. , Weisz, A. , & Raben, M. W. , Vision in Military Aviation, WADC Tech. Rept. 58-399, Wright-Patterson Air Force Base, Ohio, 1958.