



Target acquisition performance and inflight collision avoidance  
by Michael John Kelly

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of  
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Abstract:

As the number of aircraft increases, the problem of inflight collisions will become more pronounced. Research is continuing in an effort to develop electronic anti-collision hardware, but the pilot remains as the primary sensor of conflicting air traffic. The avoidance of inflight collisions is his task and responsibility. This paper reviews some of the literature relating to the visual system, human performance in visual search tasks and factors affecting human vigilance as they may influence the ability of the pilot to acquire visual contact with a conflicting aircraft in time to take any evasive action deemed necessary.

In several recent inflight collisions, the target presented by the conflicting aircraft have appeared near the edge of the respective pilots' windows. Most previous studies would predict that this position near an artificial boundary of the visual field would not degrade the pilots' ability to acquire visual contact with these targets. These previous visual search studies, however, did not require the observer to search through any type of window having distinct boundaries. The conceptual hypothesis of the present study was that visual search through a window with distinct boundaries is a different task than "free" visual search and that the position of the target in such a task is a factor in acquisition performance.

In order to test the effect of target position on target acquisition performance, the observers searched through an experimental booth containing an aperture 25 x 38 in size. The target was a dark disk of near threshold size appearing on a white background, and could appear at any one of 45 possible positions. The results showed that the position of the target exerted effects on acquisition performance that were of statistical as well as practical significance. Difficulty in acquiring the targets appearing near the boundary of the window was manifested both by increased acquisition times and by a greater number of missed targets. The conclusion of the research was that target position can, indeed, contribute to the occurrence of inflight collisions.

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Date MAY 26, 1972

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COLLISION AVOIDANCE

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A thesis submitted to the Graduate Faculty in partial  
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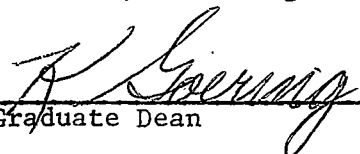
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Psychology

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Abstract

As the number of aircraft increases, the problem of inflight collisions will become more pronounced. Research is continuing in an effort to develop electronic anti-collision hardware, but the pilot remains as the primary sensor of conflicting air traffic. The avoidance of inflight collisions is his task and responsibility. This paper reviews some of the literature relating to the visual system, human performance in visual search tasks and factors affecting human vigilance as they may influence the ability of the pilot to acquire visual contact with a conflicting aircraft in time to take any evasive action deemed necessary.

In several recent inflight collisions, the target presented by the conflicting aircraft have appeared near the edge of the respective pilots' windows. Most previous studies would predict that this position near an artificial boundary of the visual field would not degrade the pilots' ability to acquire visual contact with these targets. These previous visual search studies, however, did not require the observer to search through any type of window having distinct boundaries. The conceptual hypothesis of the present study was that visual search through a window with distinct boundaries is a different task than "free" visual search and that the position of the target in such a task is a factor in acquisition performance.

In order to test the effect of target position on target acquisition performance, the observers searched through an experimental booth containing an aperture  $25^{\circ} \times 38^{\circ}$  in size. The target was a dark disk of near threshold size appearing on a white background, and could appear at any one of 45 possible positions. The results showed that the position of the target exerted effects on acquisition performance that were of statistical as well as practical significance. Difficulty in acquiring the targets appearing near the boundary of the window was manifested both by increased acquisition times and by a greater number of missed targets. The conclusion of the research was that target position can, indeed, contribute to the occurrence of inflight collisions.

## TARGET ACQUISITION PERFORMANCE AND INFLIGHT

### COLLISION AVOIDANCE

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On October second, 1910 -- roughly seven years after the Wright brothers made their historic first flight -- two aircraft from France and Great Britain collided and crashed near Milan, Italy. This, history's first recorded inflight collision, occurred at a time when there were only about 200 aircraft in existence.

Since that time, the number of aircraft has increased by more than a thousandfold. In 1967 there were registered, in the United States alone, some 155,132 aircraft. Of these, 2379 were listed as air transport or airline equipment. The remaining 152,753 aircraft make up the general aviation fleet, the so-called private airplanes which are flown for pleasure, business and instruction as well as such specialized tasks as aerial spraying and patrols. The Department of Transportation has estimated that by 1980 there will be nearly 295,000 aircraft registered in this country. These figures do not include aircraft which are owned and operated by the military services.

As the numbers of aircraft have increased, so have their speeds. While in 1910 the speeds of aircraft were under 100 miles per hour, there are now many in the air transport and general aviation fleets which cruise in excess of 500 m.p.h.

It is only logical that the increased numbers as well as the



increased speeds of today's aircraft would bring about an increase in the frequency of inflight collisions. The statistics indicate that this is, indeed, the case. In 1967 there were 26 collisions with 115 fatalities in the United States. In 1968 there were 38 collisions with 71 fatalities and in 1969 there were 28 collisions with 120 fatalities. A detailed study of these accidents indicates that a majority of the collisions occurred in the vicinity of an airport and could not be attributed to any type of visual obstruction caused by meteorological conditions.

On September 11, 1956, the Deputy Director of the Bureau of Safety Regulations of the Civil Aeronautics Board testified before the House Committee on Interstate and Foreign Commerce. A portion of his text stated:

For many years it has become increasingly apparent that conditions other than weather conditions are being encountered which directly affect aircraft separation and of which account must be taken in the continued development of air traffic rules. For instance, it appears that under certain circumstances the rate of closure of very high speed aircraft is such that the total time in which an aircraft may be visible to the pilot of another aircraft is so short that the pilots cannot be expected to insure separation between aircraft irrespective to the weather conditions in which they are flying. It is also apparent that the density of air traffic, particularly in the vicinity of certain major terminals, has approached or is

approaching serious proportions. Obviously, the greater number of aircraft movements within a given space the more difficult it is for a pilot to separate himself adequately from other traffic regardless of the vigilance exercised.

#### The See and Be Seen Concept

As can be seen from the above testimony, the primary method of reducing collision hazards has been through the imposition of regulations. This complex of regulations is known as Visual Flight Rules (VFR) and governs more than 90 percent of all flying done in this country. These regulations, in principle, require the pilot to have adequate visibility and separation from clouds to be able to detect conflicting air traffic in time to make any necessary evasive maneuvers. In addition, the regulations specify the altitude that the aircraft will maintain during the enroute phase of operation. If an aircraft is more than 3000 feet above the terrain and headed in an easterly direction, the regulations require that an odd numbered thousand plus 500 feet be maintained (e.g. 3500, 5500 or 7500 feet above sea level.) When flying in a westerly direction, a cruising altitude of even thousands plus 500 feet is required (e.g. 4500 or 6500 feet above sea level.) This regulation, however, applies only to aircraft being operated in level flight at altitudes in excess of 3000 feet above the ground and does not include those below this altitude or those which are climbing or descending. As a result, a substantial proportion of collisions

involve operations below 3000 feet or at least one aircraft which is climbing or descending (NTSB, 1969 ; NTSB, 1970b.)

Separation of aircraft operating under VFR is, then, primarily the responsibility of the pilot. The ability of the pilot to maintain this separation is directly related to his ability to detect the presence of conflicting traffic in sufficient time to alter the path of his aircraft. For this reason, any factor which affects the pilot's ability to acquire visual contact with this traffic or the amount of time required for visual acquisition will ultimately affect his ability to avoid a collision.

A large segment of the aviation industry has indicated a belief, perhaps with some justification, that with the great speeds of modern aircraft the pilot has been outmoded as the primary sensor of airborne traffic. An intensive effort is being undertaken to develop some type of anti-collision hardware which can be installed in the cockpit to aid the pilot in his watchkeeping task.

This hardware can be classified into two general types, the Collision Avoidance System (CAS) and the Pilot Warning Indicator (PWI). The CAS establishes radio contact between aircraft and provides the respective pilots with an indication that another aircraft is intruding into their airspace. It also indicates a specific course of action to be taken to avoid an imminent collision. The PWI merely provides a warning of nearby aircraft but does not advise the pilot

what action to take.

In a report to the National Transportation Safety Board (NTSB, 1970c) researchers from McDonnell-Douglas described a CAS system presently undergoing testing. This system provides contact between aircraft operating in a 3-minute time bracket and has been operational in test aircraft for several years. The present cost of this system is \$30,000 per installation. It was estimated that a less complex system of this type could be developed to sell for around \$10,000 and if mass produced, it could market for about \$8,500.

At the same hearing, NASA representatives reported on two PWI systems currently under development. These are both "cooperative" systems in that they require operational equipment of the same type in each aircraft. One system involves detection of radiation from an infrared generator mounted in other aircraft while the other uses radio signals. No cost estimate was given for the PWI systems but it was emphasized that for this system to be workable, regulations would have to demand that the equipment be installed in all registered aircraft. Little progress has been made in the development of a "non-cooperative" PWI system.

It can be seen that there are several problems in any anti-collision program which depends on this hardware. At the present time, the systems which have been developed are priced well outside the financial capability of the average general aviation aircraft owner and

pilot. While the NTSB is considering regulations which would require all air transport and all large general aviation aircraft to use a CAS or PWI system, this would still leave the vast majority of aircraft unprotected. These systems are also, unfortunately, far from being foolproof and therefore present a danger of creating a state of overconfidence and overdependence in the pilot which could result in a lowered vigilance level and a situation more hazardous than the present one.

It is therefore impractical to assume that in the near future the watchkeeping task of the pilot will be taken over by electronic detectors. The visual system of the pilot will continue to be the primary warning system for conflicting traffic and an effort should be made to improve the effectiveness of this system.

The first step in an effort to improve the effectiveness of any system is to discover and study the factors which limit the efficiency of the present system. Such a study should reveal which, if any, of the limiting factors present an absolute limit which cannot be overcome by the application of existing antidotes and which factors can be overcome to improve the efficiency of the system.

This paper will attempt to identify and isolate some of the factors which may affect the ability of the pilot to quickly acquire visual contact with other aircraft in flight.

### Acquisition of Conflicting Traffic

In a discussion of acquisition of visual targets during spacecraft rendezvous, Vanderplas (1963) defines five visual subtasks which are important. First is the determination of the presence or absence of an object in the visual field. The detection probability is a function of the apparent size of the target, the brightness contrast and shape of the target as well as the adaptive state of the observer's visual system.

The second subtask is the discrimination of the detected object from other objects in the visual field. In the orbital environment this visual noise may consist of stars or of objects on the planetary surface.

The third and fourth subtasks are recognition of the object and its assignment to a classification. The observer must decide whether the object under consideration is actually the target spacecraft or merely a star.

The final and perhaps most difficult subtask is the judgement of the location and behavior of the target. In order to effect a successful rendezvous, the observer must accurately judge the course, speed and distance of the target spacecraft.

It can be seen that the problem of target acquisition in the orbital environment is quite analogous to the problem being considered by this paper. Only the ultimate goals -- separation versus rendezvous -- are fundamentally different. In order to avoid an imminent collision

the pilot must perform all of these tasks, either simultaneously or in the given order. From the information determined during the judgement subtask he must then decide upon and undertake a course of action to avoid the collision.

#### The Detection Subtask

Inflight traffic detection is an extremely complex task combining elements of both vigilance and visual search tasks. Vigilance generally involves the detection of a signal in a known position with a condition of temporal uncertainty (Frankmann and Adams, 1962.) The usual visual search problem is the reverse situation involving acquisition of a target which is present during a known period of time but in an unknown position within the visual field. The inflight traffic acquisition problem, of course, combines both temporal and spatial uncertainty into one task. Any investigation of the human factors involved in inflight must, then, study factors which affect performance in both these types of tasks.

#### The Discrimination Subtask

This task involves differentiating the target from other visual stimuli within the field. This is accomplished primarily through shape discrimination with brightness and hue discrimination being contributing factors. The shape discrimination capability of the observer depends on visual acuity with both static and dynamic visual acuity playing some roles in the process.

Visual acuity is largely a function of the brightness of the target and the background (Baker and Grether, 1954). Acuity thresholds were shown to vary from 1' of arc for conditions of high background brightness and contrast to over 10' of arc at low background brightness and contrast. According to these findings, shape discrimination performance would be maximized with the target seen in silhouette against a bright sky. Discrimination would be degraded as the sky darkened and the contrast decreased.

Dynamic visual acuity is defined as the manner in which one's visual acuity deteriorates as a function of increasing target speeds (Goodson and Miller, 1959). Targets which exhibit a high angular velocity are relatively unimportant, however, in inflight collision avoidance for reasons to be discussed later. It should, then, be sufficient to note here that as the angular speed of a target increases to about  $100^{\circ}$  per second, the acuity threshold has been shown to increase by about a factor of six (Ludvigh and Miller, 1953).

Several studies (e.g. Cowart, 1959; Baker, 1960) have explored the use of hue and brightness discrimination to improve the discriminability of aircraft. These involved the use of special types of visibility enhancing paint upon aircraft surfaces. The results of such tests have been somewhat contradictory, agreeing only that the paint improved the discriminability of relatively close aircraft. Several factors, including the resistance of potential buyers to solid orange



or striped orange aircraft, caused abandonment of the program.

A factor which has been shown to have a tremendous effect in degrading both detection and discrimination performance is "empty field myopia" (Whiteside, 1953). When the eye is presented with a visual field which does not offer sufficient information to implement proper focusing, the ciliary muscles in the eye tend to slowly contract, bringing about a focus on a relatively near point in space. A bright, cloudless sky presents a sufficiently unstructured field for this to occur. This may also take place when the pilot momentarily turns his attention to objects within the aircraft and then returns his gaze to the comparatively empty field outside. Unless the visual system is then consciously focused upon some distant point, it may remain focused at the nearer distance. Having the eyes focused at a point within a few feet of the observer will, of course, greatly increase both detection and acuity thresholds if the target is several miles distant.

To compensate for this potential problem, pilots should be trained to consciously focus their eyes on a distant mountain peak or cloud formation every few seconds. This will keep the visual system focused near infinity and more ready to detect intruding traffic.

#### The Recognition and Classification Subtasks

Recognition and identification of the target depends greatly on the first two subtasks -- detection and discrimination -- and the factors which influence them, particularly visual acuity. They are

also influenced by the observers past experience with acquisition of air traffic and the related problems of transfer and stimulus generalization (Vanderplas, 1958). Miller (1969), however, has shown that pilots with large amounts of flight time have a greater collision incidence than the low time pilot. This would seem to indicate that the effect of increased experience in recognition and identification exerts only a minor influence upon the total acquisition performance.

#### The Judgement Subtask

When a target has been detected and recognized as an aircraft, the next step is to determine the behavior of the intruder -- its course, distance and speed -- in order to decide what, if any, evasive maneuver is necessary. The primary method of determining whether two aircraft are on a collision course is based on the "bearing fixity principle" (see Figure 1.) When two aircraft are on intersecting courses, the angular velocity of each is zero when viewed by the pilot of the other aircraft. Both pilots will, then, see the other aircraft as motionless targets which are either growing or shrinking depending on the direction of motion.

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Insert Figure 1 About Here  
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Little research has been done to determine the thresholds for a change in angular size of a stationary target which, in this case is

the primary visual cue for the behavior of the target. Baker and Steedman (1961) evaluated the effects of luminance level and target velocity on the line-of-sight motion threshold of a light target in a dark field. They found that at relatively high closing speeds, motion was correctly identified 95% of the time when the distance travelled in a one second glimpse was about 5% of the initial distance. If these results are extrapolated to the present problem, it can be estimated that line-of-sight motion should be readily recognizable approximately 20-25 seconds before a collision.

#### Expectancy and Target Acquisition

Considerable research and discussion have centered around the performance of observers as a function of their ability to predict the future behavior of the search area. Adams and Boulter (1964) investigated the effects of uncertainty -- both spatial and temporal -- on the detection time for a visual signal. They found that while both spatial and temporal uncertainty caused a significant decrement in performance, spatial uncertainty was the more dominant factor. Their study utilized only three possible target positions while in the inflight acquisition task, a target may appear in any one of an infinite number of possible positions. It would be expected that this would tend to degrade performance even further.

Deese (1955) proposed an "expectancy hypothesis" of vigilance behavior to explain the relationship between temporal patterns of

signal appearance and detection performance. Under this hypothesis, the observer continually averages the intervals of time between previous signals which he has detected and extrapolates from this to form an expectancy about the future performance of the search field. This expectancy or readiness to respond to a signal is greatest at the instant that the interval since the previous signal is equal to the mean of all previous intersignal intervals.

This has been demonstrated by Mowrer (1940) using reaction time as a measure of expectancy. Subjects responded to a tone occurring at 12 second intervals. When an occasional "test trial" with an interval ranging from 3 to 24 seconds was introduced, the reaction time was considerably longer than for the normal trials.

Baker (1959) introduced an "expectancy function" which indicated that immediately after detection of a signal, expectancy drops to a low level and then rises rapidly as the time for the next signal approaches. If the expected signal time passes without a signal being detected, the level of expectancy slowly drops. This phenomenon was demonstrated for inter-trial intervals ranging from 10 seconds to 2 minutes.

In an application of the methodology of signal detection theory to the expectancy problem, M. Treisman (1964) demonstrated a lowering of the detection threshold at the time that the next signal is expected. He found, however, that this threshold change was due to

changes in the observer's response criterion as a result of decision processes rather than being due to any change in the sensory systems.

It is difficult to predict from these experiments how the temporal expectancy function would affect signal detection in a complex task such as aerial target acquisition. Neither study by Mowrer or Baker investigated the effect of unequal intertrial intervals. Deese and Ormond (1953), who did vary the intervals, did not attempt to produce the type of function presented by Baker.

A vigilance model based on the Deese hypothesis as modified by Baker would have to consider such problems as the perception of time. Cohen (1964) demonstrated that the perceived length of a time interval is a logarithmic rather than linear function of its actual length. This would cause some difficulty in a model involving averaged interval length, especially if they were of widely disparate length. Another difficulty could appear if the signals occurred in a definite temporal pattern instead of the assumed random distribution. Would the observer learn to extrapolate from the observed pattern or would he continue to base his expectancy level on interval means?

The expectancy hypothesis, thus, seems to provide a promising framework on which to build a model describing vigilance behavior and its influence on target acquisition performance. In order to make such a model reasonably valid, however, more research must be done to determine the role of a number of other variables which may be

encountered in any real world watchkeeping task.

#### Target Position and Acquisition Performance

A factor which has received little attention in relation to acquisition is the position of the target within the visual field. In a study investigating the time necessary to detect a faint visual object in a "broad, unstructured" visual field, Krendel and Wodinsky (1960) found that position had no effect on acquisition time.

Howell (1959) reports, however, that during a visual search task using an artificially restricted visual field -- windows in an aircraft cockpit -- the observers' eye fixations tended to concentrate on the central portion of the visual field. Areas near the edges of the window received little attention as the number of fixations tended to form a gradient moving from the center, outward. This could be expected to degrade acquisition performance when the target appeared near the perimeter of the field.

Reports of several recent inflight collisions (e.g. NTSB, 1970a) indicate that the target position of the conflicting aircraft were near the perimeter of the respective pilots visual fields, appearing near the edge of a window. If the data reported by Howell are confirmed and the expected degradation of acquisition performance actually occurs, this characteristic of search behavior may be shown to be a factor in the occurrence of such inflight collisions.

The present study was undertaken, then, to test the effect

of the position of a target in an artificially restricted visual field on the target acquisition performance of an observer. While nearly all of the published evidence would predict no position effect, my hypothesis was that a strong position effect would be found.

### Method

Nine university students, 5 males and 4 females served as experimental observers. All were volunteers from an introductory psychology class and received extra course credit for their participation. All observers had at least 20/20 vision with or without correction.

The experimental booth was a plywood box 36 inches in width, 30 inches in height and 36 inches in horizontal depth. This was positioned on a table 30 inches in height. The interior was painted a solid flat black. One end of the box was left open to accommodate the observer's station. At this station was mounted a head constraint consisting of a chin rest and a cheek bar. The constraint was adjustable to comfortably accommodate different size and shape faces but was designed to ensure that all observers' eyes were in the same position. At the observers' right hand was a control box with a lever connected to a clutch driven electrical timer with readout in hundredths of seconds.

The end of the booth opposite the observers' station contained a rectangular aperture through which a field  $25^{\circ}$  high and  $38^{\circ}$  wide.

in visual angle could be seen by each eye. The plane of this window panel was 32 inches forward of the observers' eye position. A diagram of the experimental booth appears in Figure 2.

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Insert Figure 2 About Here  
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Because of the distance between the observer's eyes, a slightly different field was seen by the right and left eyes. Therefore, an area of monocular vision with a width of approximately  $4^{\circ}$  appeared at the right and left sides of the field. These areas of monocular vision are represented by the areas surrounded by dashed lines on Figure 3.

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Insert Figure 3 About Here  
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The target was a dark disk with a diameter of  $4'$  visual angle and a brightness of 1.6 Ft-Lamberts appearing on a white background screen with a uniform brightness of 7.9 Ft-L. The brightness contrast of the target was, therefore, 79.7%. The background screen was positioned 120 inches forward of the observers' eye position. There were 45 possible target positions as can be seen from figure 3. These were  $0^{\circ}$ ,  $5^{\circ}$  and  $10^{\circ}$  above and below the center of the field and  $0^{\circ}$ ,  $5^{\circ}$ ,  $10^{\circ}$ ,  $15^{\circ}$  and  $18^{\circ}$  left and right of center. The targets in the positions  $18^{\circ}$  left and right of center fell within the areas of



monocular vision as is shown on the figure.

At the start of his experimental session, the observer was seated in the proper position and the head constraint was adjusted to a comfortable configuration. He was read the prepared instructions which appear in Appendix 1 and which state, in effect, that the target may appear in any position in the field which can be seen through the window and during some trials might not be present at all. He was then given two practice trials with the target placed in positions chosen randomly.

Each observer was then given 50 timed acquisition trials in two groups of 25 trials each with a 5 minute rest period between the groups of trials. These 50 trials included one trial with each of the 45 possible positions and 5 blank trials with no target presented. The blank trials were introduced in an effort to reduce the problem of false reports. The order of target presentation was randomly determined and differed for each observer.

Between experimental trials, the target was manually repositioned with the background screen unlighted and the window aperture closed. When the target was in position the aperture was uncovered and as the lamp was lighted, illuminating the field, the timer was started. When the observer found the target, he pressed the lever at his right hand which stopped the timer.

The experimenter was seated behind the observer and during

acquisition trials maintained a watch to insure that the observer did not move his head from the proper position.

### Results

Target acquisition performance was measured through two dependent variables, the acquisition time and the proportion of targets visually acquired during the allotted time. A third variable, the frequency of false reports on blank trials was used as an indication of the dependability of the observer's reports on the other trials.

Any target which was not reported as found within a 12 second search time was recorded as a missed target. A diagram of the pattern of missed targets appears in Figure 4. This figure represents the visual field of the observer and the numbers in each cell are the number of targets in that position which were recorded as missed. The cells without numbers represent areas in which no targets were missed.

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Insert Figure 4 About Here  
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As can be seen from Figure 4, a large proportion of the missed targets were those which appeared near the bottom of the visual field. In fact, in the area of binocular vision, this was the only place in which any targets were missed. Targets in this row were those which were positioned  $10^{\circ}$  below the center and  $2\frac{1}{2}^{\circ}$  above the bottom. In order to determine whether this relationship between vertical position

and miss frequency was significant, a chi-square test was performed. The resulting value of the test statistic was 66.39 which, with 4 degrees of freedom, was significant beyond the .005 level of alpha.

There were a total of 28 missed targets out of 405 targets presented for a "hit" percentage of 93.1%. Of a total of 45 blank trials, there were a total of 2 false reports which indicates "correct rejections" on 95.5% of the blank trials.

In order to test the assumption of homoscedasticity necessary for the use of an additive analysis of variance model, a Cochran test was made on the acquisition time data. The value of C was found to be significant at the .01 level indicating that the group variances were, indeed, heterogenous. As a result, the data were stabilized using the transformation  $Y' = \sqrt{Y+0.5}$ . A second Cochran test was then performed on the transformed data and this time the value of C failed to reach significance. This indicated that the variances were now sufficiently homogenous to proceed with the analysis of variance.

Because of the number of missed targets, the model selected for the analysis was the model for nearly proportional cell frequencies used as an approximation to a complete least squares analysis, described by Snedecor and Cochran (1971 p. 482). This analysis involves the calculation of unbiased estimates of all row and column totals based upon an assumed proportional cell frequencies model. The analysis then proceeds as for the proportional frequencies model. This is

considered an adequate approximation to a complete least squares analysis if the ratios of proportional to observed cell frequencies all lie between .75 and 1.30. With the present data, all 45 ratios fell between .81 and 1.21 -- well within these criterion limits.

The summary table for the analysis of variance on the transformed acquisition time data appears in Table 1. The F-ratio for the effect of horizontal displacement from center, 8.88, was significant beyond the .001 level. The vertical displacement F-ratio, 4.78, was significant beyond the .005 level. The interaction effect was not statistically significant, indicating that the magnitude of the horizontal position effect does not change with a change in vertical position.

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Insert Table 1 About Here  
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The untransformed data were then subjected to a least squared differences (LSD) test on both significant main effects. In these tests, the row means and the column means were rank ordered and the differences between means are calculated. These differences between experimental means are then compared with a computed LSD confidence interval which is based on the t-distribution and the differences which fall outside of the interval indicate which means are statistically different. The LSD test does not, however test the simultaneous

level of significance and with the 46 differences between means which were tested, there is about a .65 probability that at least one difference is falsely indicated. The LSD test results should therefore be considered indicative of trends in the data but not necessarily conclusive.

The ranked differences were then tested using the Newman-Keuls procedure. This procedure, based on the Q-distribution, does give simultaneous significance levels and with the .05 significance level placed on these confidence intervals, there is a .95 probability that no false differences were found by this test. The conservative nature of this procedure results in some true differences being hidden due to the loss of power and both the LSD and Newman-Keuls results should be examined to obtain an accurate picture of differences in the data. The tables of differences between the experimental means as well as a summary of the results of the LSD and Newman-Keuls analyses are presented in Table 2 and Table 3. In the analysis summaries, as is customary, any two means which are not underscored by a common line are taken to be statistically different.

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Insert Table 2 and Table 3 About Here  
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The mean acquisition times as a function of the horizontal displacement from the center of the field are presented in Figure 5.

It can be seen that the shortest acquisition times were for targets which appeared near the center of the field. The mean times become progressively longer as the target position approaches the perimeter of the artificially restricted field, generating a U shaped curve.

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Insert Figure 5 About Here  
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The plot of the acquisition times for the 5 values of vertical position (Figure 6) reveals a somewhat more complex relationship. Some indication of a U shaped function can be seen from this plot and is also indicated by the LSD test results (Table 3). It is evident, however, that most of the variation is a result of the difference between the  $-10^{\circ}$  group and the others.

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Insert Figure 6 About Here  
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### Discussion

These data indicate that there is indeed a decrement in acquisition performance when the target position is near an artificial boundary of the visual field. This decrement is manifested both in the acquisition time and in the "hit-miss" probabilities. This would tend to substantiate the data of Howell (1959) concerning the manner in which the eye fixation pattern is structured.

The Krendel and Wodinsky (1960) study found that there was no pattern to the eye movements in their study of search in a "broad, unstructured" visual field and concluded that visual search can be described as a process of random and independent eye fixations. It would seem, then, that an acquisition task which involves search through an optical aperture such as a window must be described by a different model than a task involving "free" visual search.

Evidence was found that a second factor may also act to degrade acquisition performance in this type of artificially defined field. A serendipitous observation was made that the female observers had a considerably higher proportion of missed targets than the males. The mean number of misses by females was 6.25 with a range of from 4 to 9, while the mean number for males was 0.4 with a range of from 0 to 2. A chi-square test of this difference was significant beyond the .001 level. While this may reflect an actual sex difference or may be merely some artifact of the experimental procedure, a statistical difference of this magnitude is a strong indication that an actual difference of some type was present during testing.

Bieri, Bradburn and Galinsky (1958) discuss sex differences in perceptual abilities and indicate a belief that these may be the result of developmental factors. Broverman, Klaiber, Kobayashi and Vogel (1968), however, argue that these differences are innate and are physiologically centered. They demonstrate that females excel in tasks

involving rapid, repetitious and overlearned responses and that they possess lower absolute and differential thresholds. Males, on the other hand, excel in tasks involving separation of figure from ground, perceptual inhibition and restructuring. This is, they reasoned, the effect of the excitatory effect of female hormones and the inhibitory effect of male hormones.

This theory could provide an explanation for the type of sex difference which was suggested in the present study. All missed targets were either in an area of monocular vision or within  $2\frac{1}{2}^{\circ}$  of the artificial boundary of the field. In these areas it may be that the dominant element of the field is its abrupt terminus rather than any object which may be present within the field. This domination could take the form of an inward shift in eye focus -- especially if the field seen through the aperture has little structure -- or could result from a more central inhibitory process akin to the lateral inhibition in contour enhancement (e.g. Osgood, 1953 pp.230-232). If the argument of Broverman, et.al. is accepted, a male observer should be more able to inhibit this type of sensory interference and would have less difficulty in the detection of a near threshold target near the boundary of the field. This hypothesis, while highly speculative, would provide an interesting basis for further research.

Some external validation for the acquisition time data can be found in the data from the Krendel and Wodinsky (1960) study. Figure 7



compares the cumulative percentage of targets visually acquired across time in the present study with that reported by Krendel et.al. for a search area of similar size. It can be seen that the curves are remarkably similar with the only major difference being the performance during the first two seconds. It is possible that this difference is

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Insert Figure 7 About Here  
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an artifact of the experimental method of starting each trial by illuminating the previously darkened screen. This is unlikely, however, as is shown by the data of Figure 8. This shows that the cumulative curve for areas near the center of the field shows the same shape as the Krendel et.al. curve. It is only when the data for targets near the perimeter are plotted that the cumulative curve shows the pronounced initial lag in acquisition performance in the restricted search task.

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Insert Figure 8 About Here  
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It appears from these data that adding an artificial boundary to a visual field has a tendency to add a certain structure to the observers' search technique which is not present when the field is not so restricted. The observer in this type of task concentrates his search in the central part of the field and only when he finds no

target there does he begin to search elsewhere. Thus, the probability of acquisition of a target near the perimeter is low at the onset of search. Then as the search progresses, the acquisition probability of these targets increases.

Since the lag in acquisition of targets near the periphery appears only in the first few seconds of search, it seems logical to ask whether this initial concentration on the central areas would be a problem in a continuous search task such as aerial target acquisition. The data presented in the Howell report indicate that, indeed, it is. His data suggest that during a continuous restricted search task the pattern of eye fixations is similar to that found in about the first second of the present study and that the largest proportion of glimpses are directed toward the center of the field throughout the task.

What are the implications of these results for the aviation industry? First, as has been suspected, the target position can be regarded as a factor in collisions where the conflicting aircraft have appeared within a few degrees of the edge of a window. Aircraft cockpits should be designed so that as little as possible restriction is placed on the pilots' visual field and large aircraft employing two pilots should be designed so that whenever possible areas near the edge of one pilot's window will be near the center of the other's. Since acquisition performance is greatly degraded near the bottom of the field, the windows should either extend lower than they presently

do or the pilot should be seated somewhat higher to extend the visual field lower than in present aircraft. Until such equipment changes can come about, the pilot should be taught that it is not enough to "keep your head on a swivel" as is presently taught. The should be taught to actively search by moving his entire upper body, thus changing the areas of the outside field covered by each window.

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**APPENDIX**

## Appendix 1.

### Instructions to Observers

Do you see the small black spot in the center of the screen? This is the target for which you will be searching during the experiment. It may appear at any position within the area which you can see through the window. When the light comes on begin searching for the target and when you find it, quickly press down on the lever by your right hand. While you are looking for the target, keep your chin on the chin rest and do not move your head.

There will be several trials during the experiment during which there will be no target on the screen so if you don't see a target, don't press the lever. In this case I will stop the trial myself after a few seconds.

The first two trials will be practice trials to be sure that you understand the procedure. Do you have any questions?



TABLE 1  
 Analysis of Variance Table for Transformed  
 Acquisition Time Data

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES	F RATIOS
HORIZONTAL DISPLACEMENT	8	12.3099	1.5387	8.88 **
VERTICAL DISPLACEMENT	4	3.3153	0.8288	4.78 *
INTERACTION	32	5.3008	0.1657	0.96
WITHIN SUBCLASSES	332	57.5402	0.1733	
TOTAL	376	78.4662		

\*  $p < .005$

\*\*  $p < .001$



Table 3  
Differences Between Experimental Means  
Vertical Displacement Groups

		Groups				
	X <sub>5</sub>	X <sub>1</sub>	X <sub>2</sub>	X <sub>4</sub>	X <sub>3</sub>	
X <sub>3</sub>	1.37	0.37	0.27	0.05	0.00	
X <sub>4</sub>	1.32	0.32	0.22	0.00		
X <sub>2</sub>	1.10	0.10	0.00			
X <sub>1</sub>	1.00	0.00				
X <sub>5</sub>	0.00					

Summary of LSD Analysis

X <sub>5</sub>	X <sub>1</sub>	X <sub>2</sub>	X <sub>4</sub>	X <sub>3</sub>

Summary of Newman-Keuls Analysis

X <sub>5</sub>	X <sub>1</sub>	X <sub>2</sub>	X <sub>4</sub>	X <sub>3</sub>

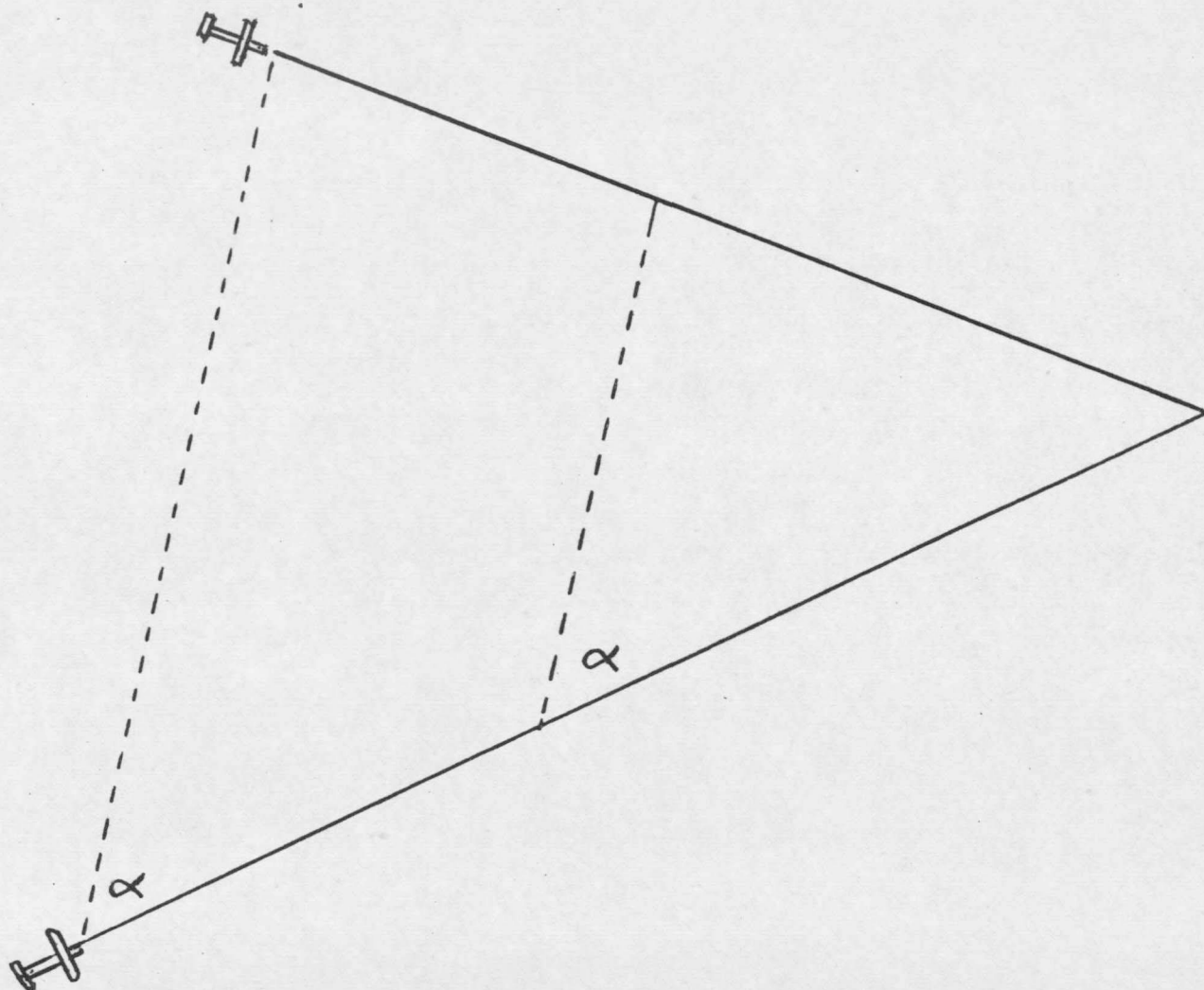


Figure 1. The Bearing Fixity Principle

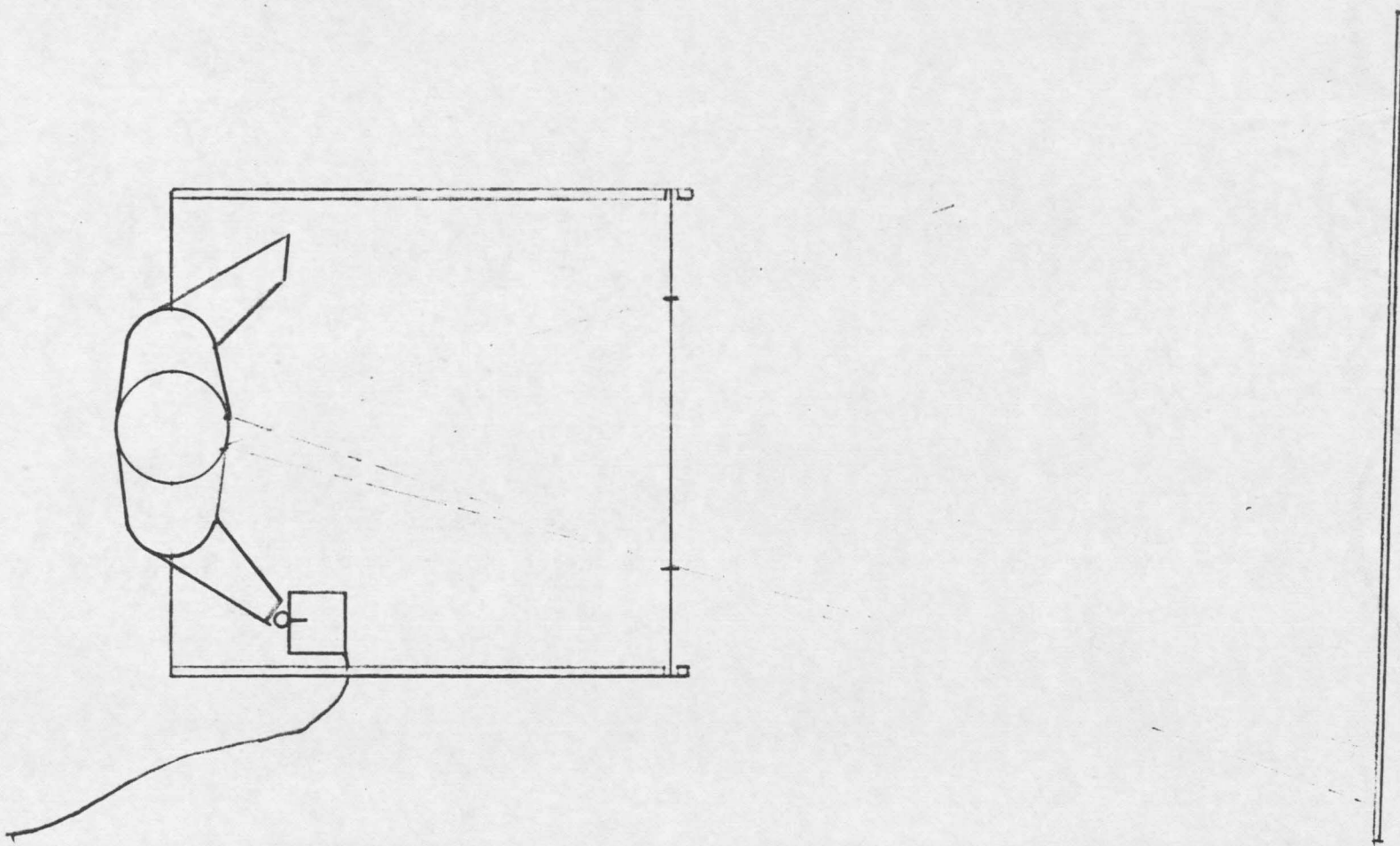


Fig. 2. The Experimental Booth

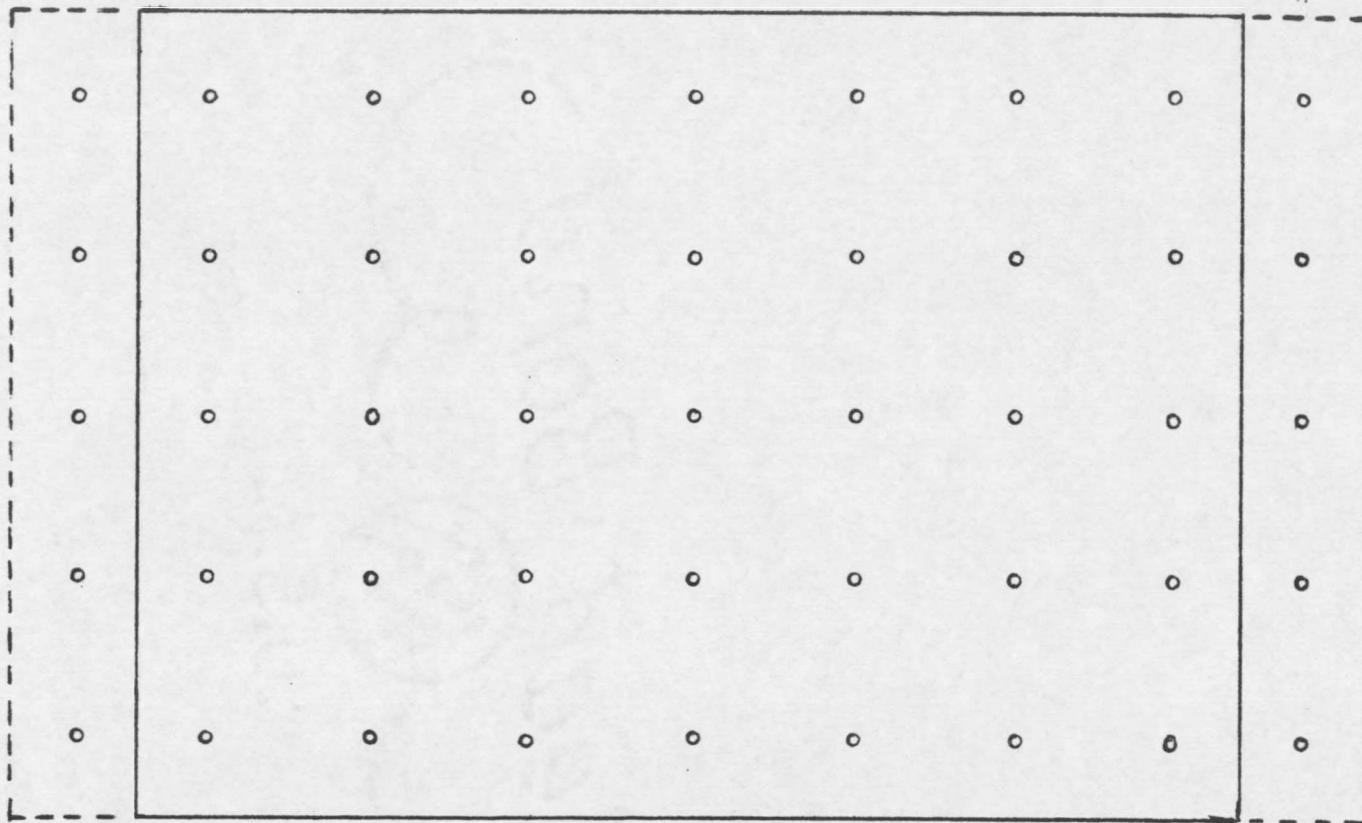


Fig. 3. Positions of Targets

1								
								1
1								2
1	2	2	3	3	2	2	4	4

Fig. 4. Pattern of Missed Targets

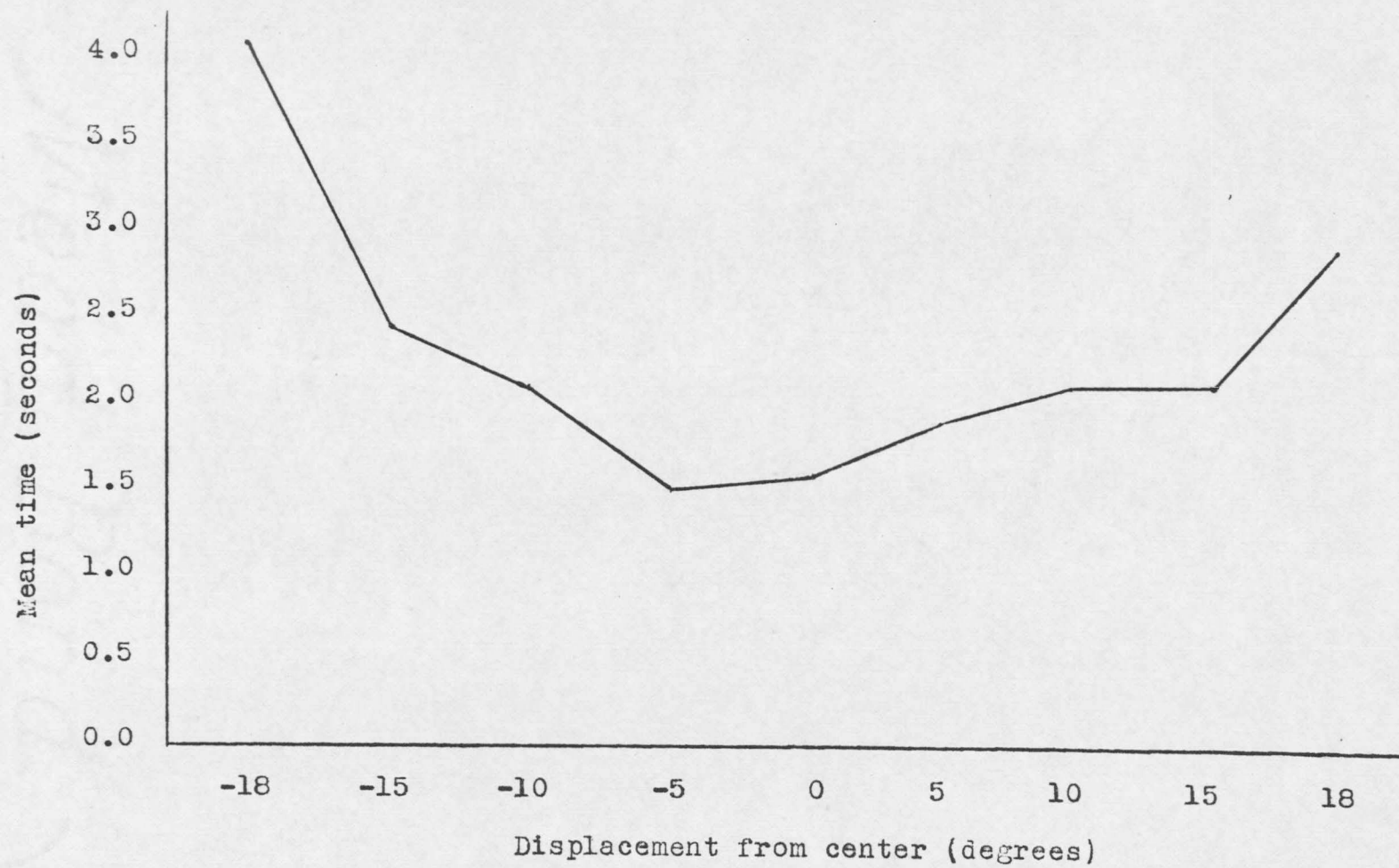


Fig. 5. Acquisition Time vs. Horizontal Position



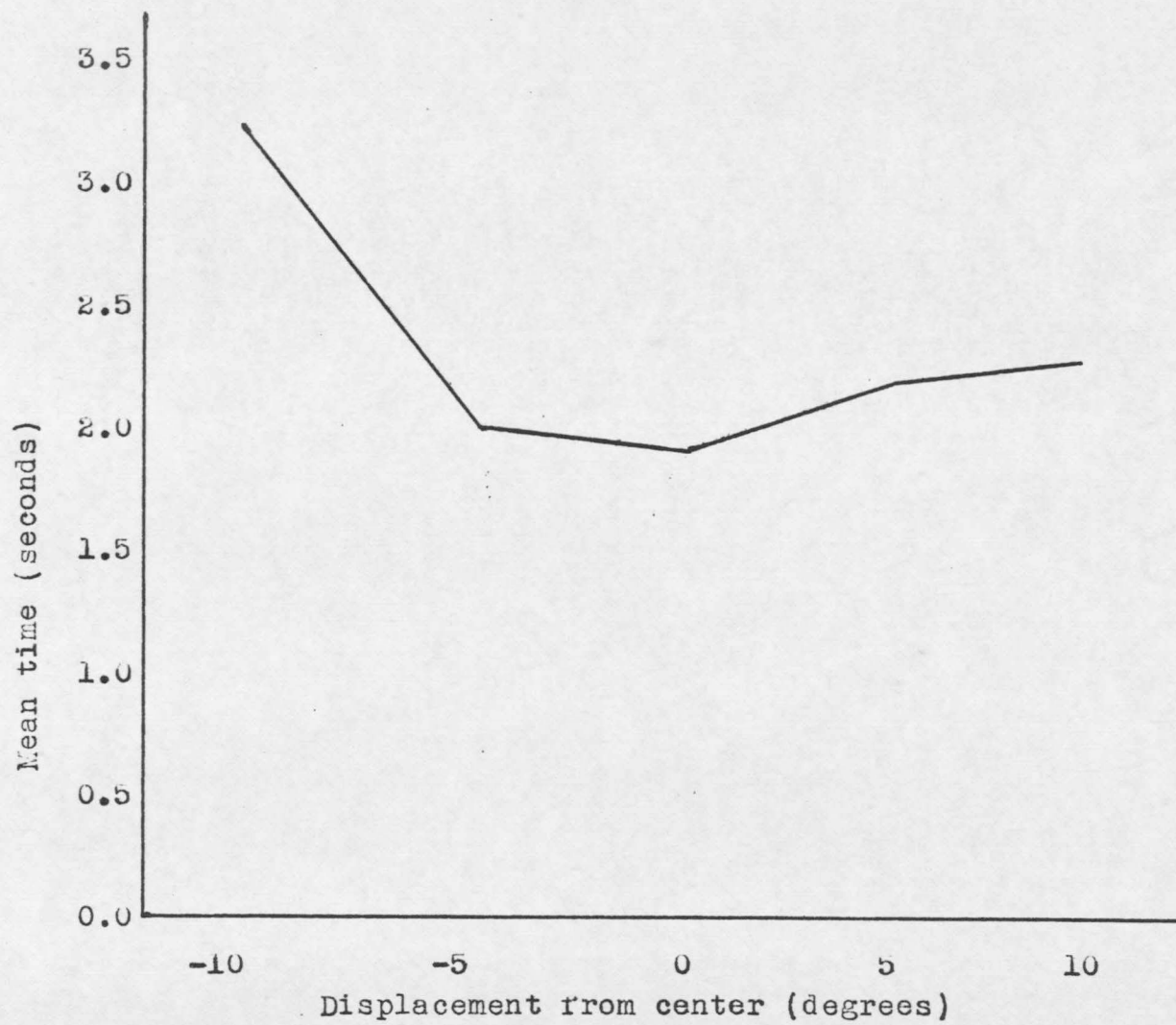


Fig. 6. Acquisition Time vs. Vertical Position

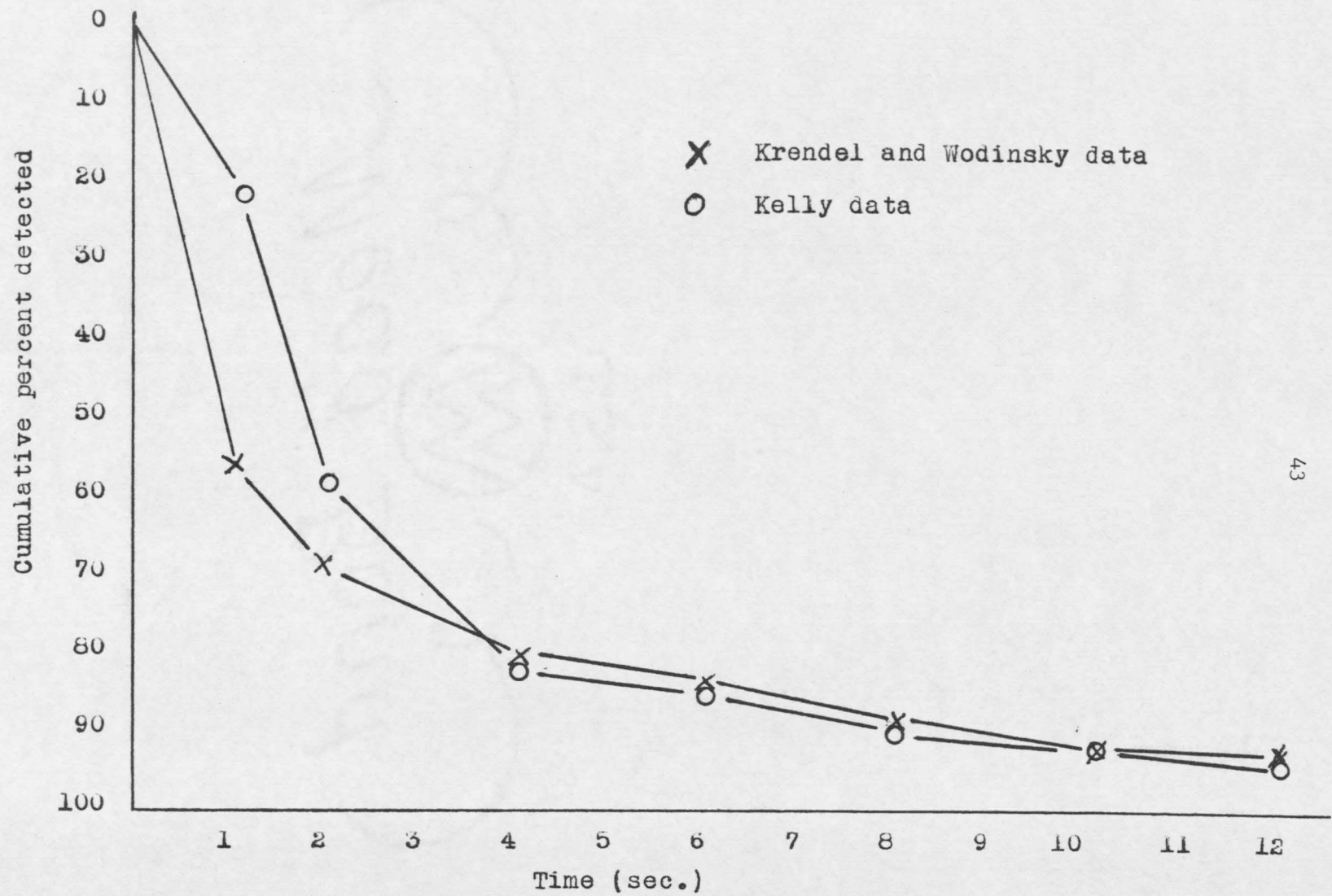


Fig. 7. Cumulative Percentage of Targets Detected vs. Search Time

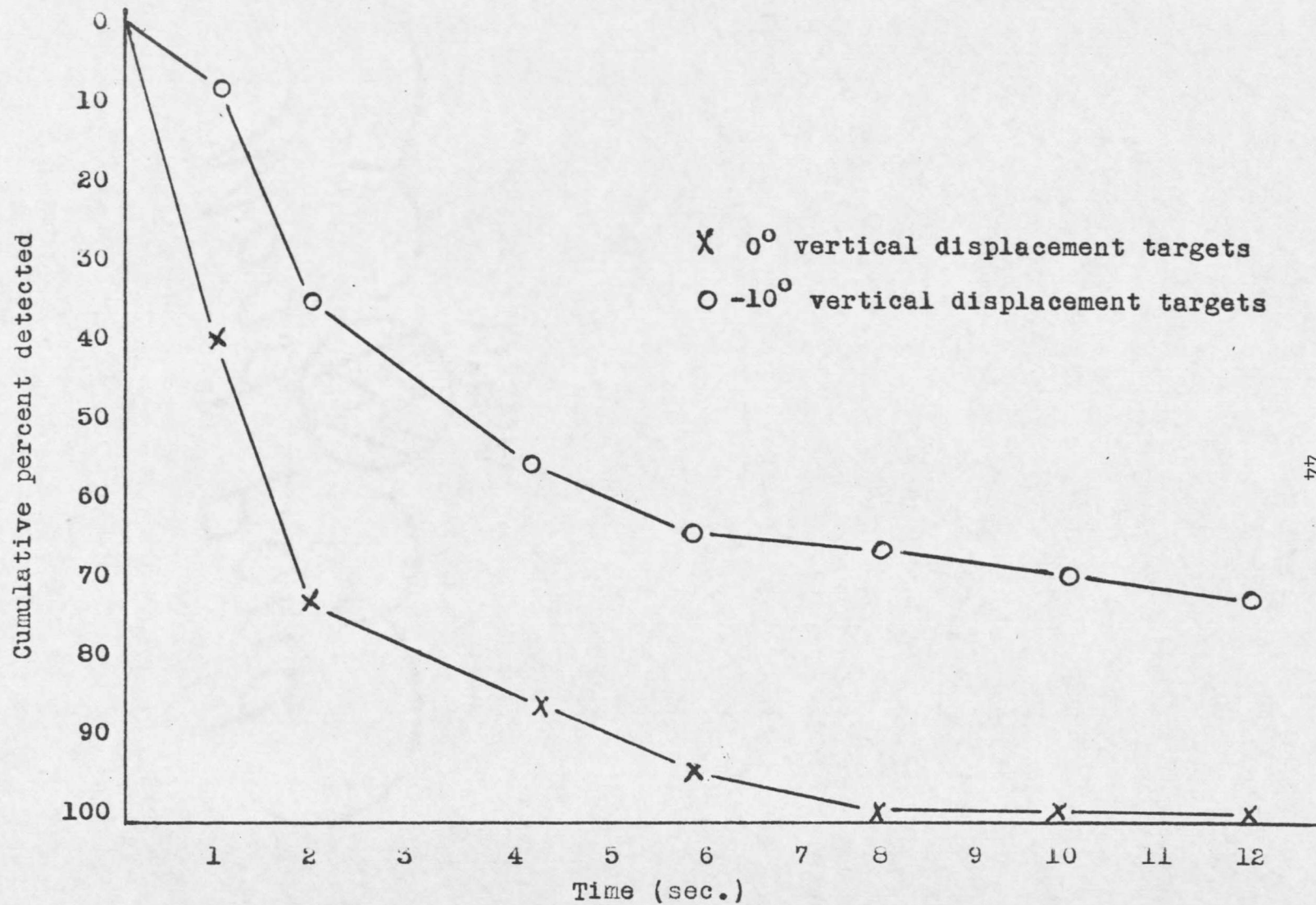


Fig. 8. Cumulative Percentage of Targets Detected Across Time

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