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ABSTRACT

An experiment was conducted to determine the influence of three variables on the perception of the psychophysical phenomenon of flicker in wide angle cathode ray tube (CRT) displays. The three independent variables treated in the experiment were: 3, 6, and 9 foot-lambers (FL) illumination levels; four images, three static and one dynamic; and 26 fixation points positioned around a display from 0 to 120 in the horizontal axis and 60 to 90 up the vertical axis. Recorded measures in the factorial experiment consisted of: time to first observation of flicker, percentage of the total number of trials that flicker was observed, and the severity of flicker regarding its interference with a visual task. Conclusions drawn from the experiment were: 1) flicker will probably be encountered at all illumination levels between 3 and 9 FL; 2) the most prominent flicker effects will be encountered when fixating at a point 30 from the source of illumination with flicker being observed out to 120 horizontally and to +90 /-60 vertically; 3) each individual is fairly consistent in his sensitivity to flicker. (Author/MC)

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FOREWORD

This report describes research conducted in the facilities of the Air Force Human Resources Laboratory, Advanced Systems Division, at Wright-Patterson AFB, Ohio. This research was documented under Project 1710 (Task 07) entitled "Training for Advanced Air Force Systems," with Dr. Ross L. Morgan (AFHRL/AST) serving as Project Scientist.

The valuable assistance of members of the Simulation Techniques Branch is gratefully acknowledged.

This report has been reviewed and is approved.

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ABSTRACT

An experiment was conducted to determine the influence of three variables on the perception of the psychophysical phenomenon of flicker in wide angle CRT displays. The three independent variables treated in the experiment were: 3, 6, and 9 FL illumination levels; four images, three static and one dynamic; and 26 fixation points positioned around a display from 0 to 120° in the horizontal axis and 60° down to 90° up in the vertical axis. Recorded measures in the factorial experiment consisted of time to the first observation of flicker, percentage of the total number of trials that flicker was observed, and the severity of flicker regarding its interference with a visual task. ~~Analysis~~ of variance tests were applied to the experimental data. Conclusions drawn from the experiment are: (1) flicker will probably be encountered at all illumination levels between 3 and 9 FL; (2) the most prominent flicker effects will be encountered when fixating at a point 30° from the source of illumination with flicker being observed out to 120° horizontally and to +90°/-60° vertically; (3) the severity with which flicker interferes with a primary visual task is not expected to exceed a noticeable to moderate level of distraction; (4) subject differences are considerable in the perception of flicker, but each individual is fairly consistent in his sensitivity to flicker; (5) some individuals are prone to experiencing spatial disorientation when the display system presents a moving image, and further research is recommended on this phenomenon.

SUMMARY AND CONCLUSIONS

PROBLEM

The psychophysical phenomenon of flicker may be observed when viewing a CRT display. This phenomenon could affect the utility for this type of display in a wide-angle visual system for a flight simulator. A review of the literature revealed that there is insufficient definitive information regarding the flicker phenomena for wide-angle applications.

APPROACH

An experiment was conducted to determine the influence of three variables on the perception of flicker in wide angle CRT displays. The three independent variables treated in the experiment were: 3, 6, and 9 FL illumination levels; four images of which three were static and one was dynamic; and 26 fixation points positioned around a display from 0° to 120° in the horizontal axis and 60° down to 90° up in the vertical axis. Recorded measures in the factorial experiment consisted of time to the first observation of flicker, percentage of the total number of trials that flicker was observed, and the severity of flicker regarding its interference with a visual task. Twelve subjects were seated before a CRT display in an experimental booth and recited letters located at the various fixation points while being presented specific sets of invariable illumination levels and images.

RESULTS

Analysis of variance tests indicated the fixation point variable to be significant at the .05 level of confidence for all three measures of time, percentage, and rating. The interaction of fixation point and illumination level was also significant at .05 for time and rating. A triple order interaction of the three experimental variables was found to be significant (.05) for the percentage measure. The plotted data revealed an increase in flicker effect as illumination level was increased. No definitive trend was found regarding image format. The results indicated the fixation points surrounding the display, particularly those level or located above the display, produced the greatest flicker observation and effect with a general reduction in flicker as the fixation point deviated from the display. A spatial disorientation phenomenon was experienced by several subjects when fixating 30° off the display with a dynamic image format.

CONCLUSIONS

Conclusions drawn from the experiment are: (1) flicker will probably be encountered at all illumination levels between 3 and 9 FL; (2) the most prominent flicker effects will be encountered when fixating at a point 30° from the source of illumination with flicker being observed out to 120° horizontally and to +90°/-60° vertically; (3) the severity with which flicker interferes with a primary visual task is not expected to exceed a noticeable to moderate level of distraction; (4) subject differences are considerable in the perception of flicker, but each individual is fairly consistent in his sensitivity to flicker; (5) some individuals are prone to experiencing spatial disorientation when the display system presents a moving image, and further research is recommended on this phenomenon.

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INTRODUCTION

Under certain conditions, the psychophysical phenomenon termed "flicker" may be observed when viewing a cathode ray tube (CRT) display. Flicker is a rapid periodic change in a visual perception conditioned by a corresponding change in the intensity or other characteristic of the stimulus (English and English, 1958). The literature contains experimental data regarding the perception of flicker when the field of view is relatively narrow and the visual presentation is oriented to central or foveal vision. However, there is a lack of reported research on the flicker phenomenon as it relates to a wide-angle CRT display; i.e., with an eccentricity in excess of 30°. It is not known, for example, what conditions will preclude the apparent flickering in the periphery, or the effect that flicker has upon an individual's performance when he is operating in a wide-angle visual environment.

This problem has immediate applicability to the development of Air Force aircraft flight simulators with visual systems. A wide-angle or wrap-around visual system is composed of a number of CRT displays installed adjacently in a mosaic pattern and electronically integrated to provide a contiguous field of view. Such a system offers a feasible means of realistically representing the external visual scene in the aircraft flight simulator.

The purpose of the present investigation was to provide experimental data on the phenomenon of flicker in a wide-angle visual system. Specifically, the study was directed at empirically determining if flicker would be encountered from a CRT display as a function of several illumination levels, various types of images, and at numerous fixation points in a wide-angle field of view. A secondary requirement of the study was to assess the effect of any perceived flicker upon a visual task employing primarily foveal vision. The information derived from this investigation will provide guidance for the future development of wide-angle visual systems.

LITERATURE REVIEW

This section provides a literature review of pertinent research on the flicker phenomenon in the form of (a) presenting several of the more prominent theories postulated to explain the perception of flicker, and (b) discussing the variables influencing CFF and their interaction. CFF is the Critical Flicker (Fusion) Frequency or that rate of alternation (cycles per second-cps) of a fluctuating photic stimulus at which flicker disappears and a steady or fused sensation is produced (Hirsch and Wick, 1960). An excellent summary of information on flicker can be found in Brown, J. L., Chapter 10, entitled "Flicker and Intermittent Stimulation," in Graham (1965), upon which this review has drawn considerably.

The literature on CFF unfortunately contains a large number of contradictory research findings, which can be attributed principally to three reasons. First, the variation in results undoubtedly is a function of diverse methodological approaches used by various investigators, thus creating difficulties in comparing data from different studies. Secondly, it appears to partly originate in the interactions associated with the many variables studied. A third source of discrepancy surrounding experimental results may arise from the practice, conventional among researchers in this area, of utilizing a small number of subjects in an experiment. Often only one or two subjects are employed, and yet the

CFF is a measure on which there is considerable inter-subject variability manifested.

Theory of Flicker

Several theories have [illegible] suggested, and accordingly, experimentally treated, to explain the functions of the visual system and associated central processes involved that result in the fusion of a flickering light.

An early effort to definitively explain CFF was made by Ives (1922). His Diffusion Theory of intermittent vision assumed three steps in the perception process, the first of which is a reversible photochemical reaction. The second involves the conduction, by diffusion, in accordance with the Fourier diffusion law, of substance formed by the photochemical reaction. In the third step, the perception of intermittence depends on the time rate of change of a transmitted reaction which must exceed a constant critical value. The theory is in accord with the influence of light-dark ratio on the relation of CFF and luminance, the effects of dark adaptation, and the Talbot-Plateau Law. (See Glossary for definition of Talbot-Plateau Law.)

One of the most prominent theoretical interpretations of flicker fusion is the photochemical theory developed by Hecht (1937). This theory states that prolonged stimulation by an intermittent light results in a condition such that the decrease in concentration of photosensitive material during the illumination phase of the cycle will just be compensated by the increase during the dark phase. Thus, at fusion, a steady-state condition will exist which is the same as that existing with continuous illumination at a luminance that is a fraction of the light pulses. This situation adheres to the reaction defined in the Talbot-Plateau Law (Graham, 1965).

The photochemical formulation derived by Hecht has been criticized (LeGrand, 1957) on the grounds that it ignores the dual nature of regeneration of visual purple and that experimental data does not always appropriately fit Hecht's photochemical theory.

However, Jahn (1946) has derived an equation based on photochemical theory, which is of the same general form as Hecht's equation, and hence, will satisfy equally well all the data fitted by Hecht's equation. It is assumed that the fusion frequency is proportional to the reciprocal of the flash duration which causes a threshold change in the concentration of photoproducts, which, in turn, catalyzes the secondary reaction.

Another modification of photochemical theory has been proposed to account for flicker fusion phenomena. Hyman (1960) has added a statistical conception of transfer of excitation within receptors to Hecht's photochemical concept. Accordingly, fusion frequency is conceived as a resultant response which represents a number of individual mechanisms differing in wavelength sensitivity, luminance sensitivity, and amplitude of response to stimulation.

Another theory developed to provide a description of the interaction between CFF and log luminance (see Glossary) is the statistical concept by Crozier (Crozier, 1936; Crozier and Wolf, 1942; Landis, 1954a). On the assumption that the thresholds of receptor units, which participate in the visual response vary both in terms of time and units activated, it is reasoned that the probability of detection of fluctuations in the stimulus will increase with the luminance of the stimulus in accordance with the integral of the normal probability function. The maximum fusion frequency in Crozier's formulation is independent of temperature and chemical reactions and depends on a neural limitation. Differences between rods and cones are considered simply statistical consequences of variations in excitation threshold, and, according to Crozier, they do not justify the inference that there is a difference in the photochemistry of rods and cones (Crozier and Wolf, 1944).

In a subsequent theoretical paper, Svaetichin (1956) suggested that the relation of CFF to stimulus luminance can be explained in terms of the time constants of retinal units, the potential level of which varies with stimulus luminance. Therefore, when luminance is increased, the potential of these units increases at a decreasing rate to a final level determined by the luminance. If an increment of luminance is not sustained, the final potential level may not be reached before luminance is reduced. The shorter the duration of flashes at a given luminance, the smaller will be the changes in potential. Thus, the amplitude of potential changes will vary inversely with the frequency of a flickering stimulus. Svaetichin assumed that there is a threshold change in the amplitude of these retinal potentials for CFF. From a knowledge of the relation of potential to luminance and the time constants of the retinal units, he was then able to predict the relation of CFF to luminance fairly accurately as compared to the experimental evidence.

Lindsley (1958) demonstrated that neural, and particularly cortical, patterns of activity are crucial to the perception of flicker. Electrical activity was recorded at several places in the visual system, from retina to visual cortex. With the eye stimulated by a flickering light, the electrical activity at each of the loci tended to reproduce the frequency of the flickering light; i.e., the frequency of electrical discharges corresponded to the frequency of the light flashes. The first part of the system to stop following in this manner was the cortex. Thus, even while the retina was responding appropriately to high-frequency flickering light, the cortex had stopped following the stimulus. These results suggest that any differences in CFF between fovea and periphery are probably not simply a function of photochemical differences, as suggested by Hecht, but are more likely to be a function of differences in neural structure (Dember, 1963).

There is ample evidence of photic driving of the alpha rhythm of the brain (Alp [illegible], 1961; White, Cheatham, and Armington, 1953), thus establishing the fact that a flickering light does affect the central process. However, the implications of the Talbot-Plateau Law and the evidence that flicker can be perceived, in response to electrical stimulation, at frequencies higher than those at which photic stimuli are seen to fuse (Brindley, 1962), indicate a retinal and possibly a photochemical limitation on flicker (Pieron, 1961). On the other hand, area and spatial interaction effects are not in accord with a purely photochemical determination of fusion. Evidence can also be found which does not support the retinal determination of fusion (Graham, 1965). For example, drugs which act on the cortex and probably not on the retina may elevate CFF, and it is possible to increase CFF by presentation of a facilitating signal. These findings suggest a more central limitation of the fusion frequency (Graham, 1965).

In summary, at the present time it can only be stated that CFF probably depends both on retinal and on cortical functions, and the relative importance of these functions will vary with conditions.

Variables Affecting Flicker Perception

The critical flicker frequency is a rather sharply defined threshold value, above which fusion occurs and below which there is a perceptible flicker. A high value of CFF implies high sensitivity to change (Dember, 1963). Flicker is encountered through the special combination of variables that may be generally classified as stimulus and as receptor variables. A great deal of research has been conducted on the variables influencing CFF, and each of these is discussed here separately.

1. RATE OF FLUCTUATION. The primary stimulus variable determining whether a light that is physically flickering is perceived as flickering is the rate of fluctuation. The most serious and unpleasant effects of flicker, such as nausea, trances, and even epileptic seizures, occur at rather low frequencies, in the range of 5-10 cps, due to the photic driving phenomenon. On the opposite end of the continuum, flicker can be observed at frequencies of 60 cps and above if the intensity is sufficiently high, as well as when there is a condition of the right combination of other relevant variables (Hecht and Smith, 1936; Hecht and Shlaer, 1936).

2. LUMINANCE. Probably the second most important stimulus variable affecting the flicker threshold is the luminance, also known as target intensity, of the intermittent stimulus. With respect to the luminance level of the target during the "on" phase, the general relationship is that as intensity increases, CFF increases (Dember, 1963). Alternatively, it can be stated that the higher the level of foot-lamberts, the higher the frequency where fusion occurs. (See Glossary for definition of foot-lambert.)

The critical frequency is low (5 cps) at low luminances and increases fairly rapidly in approximately a linear fashion up to 55-58 cps in the vicinity of 10,000 Trolands (Hecht and Smith, 1936). (See Glossary for definition of Troland). A point is ultimately reached where the curve becomes flat and increased intensity does not result in an increase in CFF. There is even some experimental evidence that at very high intensities, CFF begins to decline (Hecht and Smith, 1936).

The nearly linear relation between log luminance of the stimulus and CFF over a broad range of luminance, with the exception of the low luminances, represents the Ferry-Porter Law (Graham, 1965). The formulation for the Ferry-Porter Law is as follows:

$$F = a \log L + b$$

where F is CFF, L is luminance, and a and b are constants.

3. RETINAL LOCUS. The receptor variable of retinal location that is stimulated and the effect upon CFF has often produced conflicting experimental data. Whenever these data are analyzed, the complex interaction of several other pertinent variables must also be considered. For example, the interactions of luminance and stimulus size with retinal location probably afford an explanation of most of the apparently contradictory results of investigations of retinal location and CFF. Other contradictions may be attributed to experimental artifacts, such as the failure of the investigator to control the pupil size.

It is generally accepted that a higher CFF occurs in the periphery than in the fovea for low luminances. This is substantiated in data from Hecht (1938). As the intensity of the target increases, however, the difference between the periphery and fovea disappears, and, in fact, the value of CFF may be relatively independent of the retinal region stimulated at some intermediate luminance. At high intensities, the opposite relationship exists, i.e., the central fovea yields a higher CFF than does the periphery with a decrease in CFF when moving from the fovea toward the periphery (Ross, 1936).

The superiority of the fovea at high intensities may have several bases. For example, the fovea may benefit more from a brief dark phase than does the periphery. This would be true if dark adaptation proceeded more quickly in the cone-dominated fovea than in the rod-dominated periphery. In addition, the neural structures serving the fovea may simply be better able to "follow" a flickering light than those of the periphery.

The basic superiority of the fovea is not revealed at low intensities, for it is masked by the greater spatial summation and hence lower detection thresholds of the periphery (Graham, 1965).

Hylkema (1942) investigated the relation of CFF to retinal location with test field diameters of 0.5 to 10° visual angle. Maximum CFF occurred farther out in the periphery as test field size was increased. In the temporal field, CFF was depressed in the regions around the blind spot and reached a maximum at an eccentricity of approximately 40°. In the nasal field, CFF was maximum at an eccentricity of 25 to 30°.

Unfortunately, as Hylkema's experiment suggests, this interaction between the effects of retinal locus and luminance in relation to CFF cannot be assumed to be the same for any test field area. Summation effects occur over greater areas in the periphery than in the central retina (Granit, 1930), and thus, alter the relation of CFF to retinal locus for different test field sizes. For example, if a very small test field (12-minute diameter) is used, CFF is found to decrease with any displacement of the stimulus away from the fovea over a wide range of luminance (Creed and Ruch, 1932). On the other hand, for larger areas CFF may be higher in the periphery than in the fovea, even at relatively high luminances. Hylkema never found higher CFF in the fovea than in the periphery for test field diameters of greater than 1°. Granit and Harper (1930) suggested that a 2° test field diameter represented the critical size, below which CFF with central fixation would be higher than CFF with peripheral fixation.

Weale (1958) has suggested that changes in CFF with change in stimulus area might best be explained in terms of the associated changes in the number of receptors stimulated. Subsequent experiments (Angel, Herms, Rouse, Woledge, and Weale, 1959) have confirmed this view for centrally fixated test areas of up to 7.5° diameter. Therefore, it can possibly be concluded that any differences between fovea and periphery are probably due to a function of different neural structure rather than photochemical differences.

The following function provides a good description for the relation between intensity and critical fusion frequency for different retinal locations.

$$F = k \log LN^p + k'$$

where N is the number of receptors stimulated (estimated from retinal area and receptor density), p is index of retinal summation, k and k' are constants (Graham, 1965).

4. STIMULUS SIZE. The relationship between stimulus size, or alternatively known as target area, and CFF is rather straightforward; i.e., as stimulus size increases CFF increases (Dember, 1963) if all other variables are constant. It is interesting to note that stimulus size and intensity are, within certain limits, interchangeable regarding their direct effect upon CFF.

From studies of stimulus area (Graham, 1965), it is evident that summation occurs which results in an enhancement of flicker as the area of the stimulus is increased. This follows logically since the larger the target area, the greater the total amount of energy that reaches the visual system in the "on" phase, and hence, the greater the discrepancy in amount of energy between the "on" and the "off" phases of the cycle.

Granit and Harper (1930), using circular areas of from 0.98 to 5.0° diameter, found a nearly linear relation between CFF and the logarithm of area over a luminance range of about 1000 to 1 and for retinal locations as far as 10° from the fovea. CFF and log luminance were also linearly related over much of the range. The linear relation between CFF and log area is referred to as the Granit-Harper Law (Graham, 1965). This association has been confirmed by other investigators (Kugelmass and Landis, 1955; Berger, 1953) and has been extended up to a test field diameter of 49.6° over a wide range of luminances for central fixation (Roehrig, 1959a).

However, there is experimental evidence to indicate that the bases for the relation between CFF and stimulus size is not solely a matter of summation. For example, Roehrig (1959b) has shown that with central fixation, as area is increased, the resultant higher CFF may not depend on the area of the entire field but on the region added around the edge. Roehrig was able to darken large areas in the center of the stimuli (66% of the total area of a 49.6° diameter field) with no reduction of CFF.

Furthermore, Hecht and Smith (1936) clearly illustrated in the results of an experiment that with an increase in the area of a centrally fixated field, there is a change in the character of the receptor population which determines threshold. A plot of their data reveals that as area of the test field is increased from 0.3 to 19°, the relation between CFF and log luminance shifts to higher levels of CFF and also develops a distinct low luminance branch for test fields 6 and 19° in diameter. This low luminance branch is associated with the function of rods. The effect of increased area with central fixation is similar to the effect of a shift in location of a test field of fixed size from the fovea toward the periphery, that is, from a rod-free region to a region containing both rods and cones. Thus, the events in the eye per se or receptor are crucial in determining the perceptual outcome (Bartley, 1958).

The following formula represents the previously discussed Granit-Harper Law:

$$F = c \log A + d$$

where A is stimulus area, and c and d are constants.

5. LIGHT-DARK RATIO (LDR). A regularly intermittent light can be

regarded as consisting of cycles, each cycle composed of a dark phase and a light phase. LDR, also known as light-time fraction, designates the relative amount of the light phase in the total cycle of a repetitive stimulus pattern (Graham, 1965). The rate of repetition, duration of the light pulse, and the light-dark ratio (LDR) are interdependent variables in the study of flicker fusion to the extent that one cannot be varied without variation in one of the other two.

At low light intensities an LDR of unity, that is 0.50 sec "on" and 0.50 sec "off", yields the highest CFF. Under conditions of high illumination, however, the highest CFF is produced by the smallest LDR as the one in which the cycle is predominantly dark (Dember, 1963). When average luminance has been held constant, CFF has shown a continuous increase with decreased LDR (Graham, 1965). At high retinal illuminances (39,200 Trolands), a linear CFF-LDR relation of increasing CFF with decreasing LDR has been found (Ross, 1943), with no maximum illumination level evident (Bartlett, 1947). However, at low and intermediate luminances (20 to 500 ML), CFF rises in a nearly linear fashion with increase in the dark interval up to a maximum which corresponds to a log value of 1.7 to 1.85 (50 to 70%), following which it decreases.

Landis (1954b) demonstrated that area of the test field is significant in determining the relation of CFF to light-dark ratio. With luminance of individual flashes constant, CFF reached a maximum when flash duration represented 40 to 50% of the total cycle for a 10.4° test field diameter. For a 1.6° test field diameter, maximum was reached with a flash duration of 25%.

A precise formulation of the relationship of LDR, CFF, and luminance is provided in the Talbot-Plateau Law. This principle states that once the fusion frequency is reached, the perception is the same as would be produced by the amount of light spread uniformly throughout the cycle. For example, a steady light must be 1/2 the intensity of the flickering light to be equal. The Talbot-Plateau Law holds only for a light above the CFF, but is good over a wide range of light-dark ratios and intensities. In contrast, at subfusion frequencies the flickering target appears brighter than its non-flickering equivalent. This phenomenon, called brightness enhancement, seems to be maximal at a flicker frequency of approximately 10 cps, the frequency of the cortical alpha rhythm (Bartley, 1951).

The formula for the Talbot-Plateau Law is:

$$I_s = \frac{T_1}{T} I_f$$

where I_s is intensity of steady light, T_1 is the time the flickering light is on, T is the duration of the total light-dark cycle, and I_f is intensity of flickering light in the on phase.

6. TEMPORAL PATTERN OF STIMULATION. The temporal limen or threshold is the interval at which successive impressions fuse into a single experience. Probably the most common temporal pattern of stimulation employed in CFF research is one in which rectangular pulses of light are alternated with dark intervals of equal duration.

In general, it has been found that the longer the flickering stimulus duration, the higher the CFF (Granit and Hammond, 1931). Basler (1911) determined that the two identical flashes could be discriminated at a duration of 0.042 sec, but when the flash duration was reduced to 0.035 sec, they appeared fused. (A flash duration of 0.035 sec corresponds to a frequency of approximately 14 cps.) This finding agrees with Wundt's (1903) mean value of 0.043 sec whereby stimuli following each other at longer intervals are perceived as separate, and at shorter intervals they fused into one (Stevens, 1951). Lindsley and Lansing (1956) also found that under conditions where CFF was 40 cps, in order for two flashes to be seen as separate, it was necessary to increase the temporal interval between them until they compared with a frequency of 14 cps. Interestingly when Basler replicated his earlier study, with the exception that a series of flashes rather than just two flashes was investigated, he found CFF to be approximately 30 cps. The eye thus proved considerably more sensitive to a temporal pattern consisting of a series of flashes than for two flashes.

As the separation between two flashes increases so that they do not fall within the critical duration, the amount of energy required for threshold rises. Zoethout (1947) found that the critical interval decreases with the intensity of the light to the extent that the critical interval between light stimuli may vary from more than 0.200 sec to less than 0.025 sec. Actually, the critical duration may vary from approximately 0.1 sec in the completely dark-adapted eye to 0.01 sec in the light-adapted eye. This would suggest that at very low levels of illumination, fusion of a flickering light may occur at a frequency as low as 10 cps, but at high levels of illumination it may reach frequencies as high as 100 cps. These extremes do, in fact, represent the approximate limiting frequencies for the perception of flicker in the human eye.

Attempts have been made to measure the apparent flicker rate of an intermittent stimulus and to investigate its relation to such parameters as stimulus luminance, retinal locus, and stimulus size (Graham, 1965). As the luminance of a stimulus of constant frequency is increased, the flicker rate appears to decrease. Reduction of luminance is accompanied by an apparent increase in rate. Thus a stimulus of very low luminance, which is changing at a rate of 3 or 4 cps, may appear to flicker at a higher rate than a stimulus of higher luminance with a rate of 30 or 40 cps (LeGrand, 1937). Bartley (1938) reported that with a continuous change in luminance the apparent change in frequency is discontinuous. Also, the apparent frequency of a flickering stimulus varies with the region of the retina stimulated. For stimulus frequencies greater than 10 cps, apparent frequency decreases with increased eccentricity of the stimulus from the fovea. This effect, however, undoubtedly depends on luminance. As the rate of variation of a large, centrally fixated stimulus field is reduced from a value above fusion frequency, flicker will appear first at the center if the luminance is high and first near the edges if the luminance is low (LeGrand, 1957).

7. AGE. The higher the frequency at which an individual can see flicker, the greater the fidelity and efficiency of his sensory visual mechanism. This efficiency declines with age, as shown by the decrease in CFF (Misiak, 1947; Misiak, 1951; Weekers, 1955; Coppinger, 1955). The reduction in CFF has been attributed to decrease in the flexibility of the ciliary muscles controlling pupil size, increased opacity of the lens, yellowing of the lens, and decrease in responsiveness of the nervous system with respect to regulation of pupil size. (Graham, 1965).

Misiak (1951) tested the foveal rate of 319 persons over a wide range of age, obtaining a linear decline amounting to 0.13 cps per year. Coppinger (1955) tested the central rate of 120 persons aged 20 to 80 years at three levels of illuminance. The most rapid rate of decline was found at the highest illuminance; this amounted to 0.18 cps per year. The average rate of decline, based on data from these two studies, is 0.15 cps per year for the fovea. These data clearly indicate that a decline in the critical fusion frequency commences soon after the twentieth year and continues at a rather uniform rate. This indicates that higher intensities of light are required to give the same brightness for older persons, which in effect is a decline in sensitivity.

Misiak and Loranger (1959, 1961) have reported a significant correlation between CFF and an index of intelligence between the ages of 68 and 80. They suggest that this correlation may illustrate increasing probability that CFF will be limited by the efficiency of cerebral function as this declines with age.

8. SURROUND ILLUMINATION. CFF is significantly affected by changes in the illumination of the retinal areas adjacent to the retinal image of the intermittent stimulus. CFF has been found to be elevated with the addition of an illuminated surround (Creed and Ruch, 1932; Berger, 1953). The effect of background area on CFF was investigated by Foley (1961) for small test fields restricted to the fovea, consisting of diameters of 0.5, 1, 2, and 4°. Background luminance was adjusted to match the brightness of the test field at a frequency above fusion. Under these conditions, CFF was found to increase linearly with an increase in the logarithm of background area. There was no interaction between background area and test field area or test field luminance under these conditions. Lythgoe and Tansley (1929) reported that for maximum CFF in the fovea, the brightness of the surround must match that of the test area. Also, for maximum CFF in the periphery, the brightness of the surround must be lower than that of the test field.

9. ADAPTATION. Flicker can be observed in exposures of very short duration. The CFF threshold varies as a function of the receptor variable known as adaptation and the interaction of adaptation with stimulus duration, retinal area, and luminance level.

Granit and Hammond (1931) studied the CFF threshold during very brief exposures (less than 100 msec) and found that CFF could not be measured. As duration of exposure is increased, CFF increases and a maximum is reached around 1 second of exposure. The higher the luminance level, the steeper is the rate of increase, but the later is maximum CFF reached.

A number of experiments have been performed on the effects of light and dark adaptation on CFF (Granit and Riddell, 1934; Granit and Therman, 1935; Granit, 1935). In general, an increase was found in CFF based both on retinal action potential and verbal report with an increase in light adaptation. Lythgoe and Tansley (1929) found a rise in CFF during light adaptation with a maximum reached after a duration of light adaptation of slightly more than 5 minutes. Hylkema (1942a) noted that with an increase in light adaptation, CFF may reach a maximum and then decrease with further increase in adaptation luminance at high luminances. A decrease in CFF, as well as inter-individual variability, occurs with an increase in dark adaptation. However, it is noteworthy that several investigators have found a lower CFF in the light-adapted eye than in the dark-adapted eye (Allen, 1900; Peckham and Arner, 1952).

The resolution of the divergent findings regarding the effects of adaptation require analysis of the influence of retinal area and luminance. For example, Monje (1952) determined clearly that the relation of CFF to retinal region stimulated changes with changes in adaptation. In the dark-adapted eye, a maximum CFF may be found 10 to 15° from the fovea but can be altered by variations in luminances of the stimulus. Lythgoe and Tansley (1929) performed an excellent study of the effects of dark adaptation on CFF for retinal areas from the fovea to 90° in the periphery and for luminances from 0.0003 to 7.3 ML. With the highest luminance, CFF was found to decrease with increased dark adaptation at all locations investigated. The reverse was true with the lowest luminance. With a luminance of 0.27 ML, there is a strong influence of retinal location. In the fovea, CFF fell, while 90° in the periphery CFF rose during dark adaptation. At 10 and 50° in the periphery, CFF first dropped and then increased during dark adaptation. Similar results have been found by Enroth and Werner (1936).

10. SPECTRAL DISTRIBUTION. Differences in the wavelength distribution of the stimulus light result in differences in the maximum value of CFF (Crozier and Wolf, 1941; Crozier and Wolf, 1943). Hecht and Shlaer (1936) determined the relation between CFF and log luminance for each of seven test field wavelengths with a 19° test field. The results illustrated good correspondence between brightness matching and CFF for various wavelengths. The study by Hecht and Shlaer suggests that although results for different wavelength regions are all very similar at high luminances, the curves for various wavelengths reach different maxima. When the two phases of the intermittent stimulus differ only in wavelength and not in intensity, flicker is much less in evidence (Woodworth and Schlosberg, 1938). For example, the rotation of a color wheel with red and green sectors of approximately the same brightness produces some flicker at low speeds, but any flicker remaining at higher frequencies is due entirely to brightness differences.

11. STIMULUS SHAPES. Hartmann (1923) experimentally found that the fusion point is a function of the shape of the stimulus, and various subjective factors. Configurations which possessed the simplest and

firmest structures tended to fuse most easily; circles tended to fuse more readily than triangles even when of the same area and surface intensity. Moreover, the same figure might fuse sooner, when it appeared phenomenally simple (e.g., a square with a diagonal), than when it appeared phenomenally complex (e.g., two separate triangles). Different figures exposed successively were, of course, more difficult to fuse than were similar figures (Vernon, 1952). Hartmann also found that flicker disappeared at a lower frequency in a field that was perceived as "ground" than in one that was perceived as "figure."

12. OTHER VARIABLES. A number of other variables have been investigated with regard to their effect upon CFF. For example, body position, practice and attention, concentration and relaxation, and diurnal rhythms all have been found to influence CFF. Body temperature, drugs, neurological disturbances, physical and mental work, and brain injuries also affect CFF. However, it is interesting to note that variation of optical accommodation and the correction or the lack of it for anomalous refraction have not been found to influence CFF (Graham, 1965).

EXPERIMENTAL VARIABLES

The present investigation is concerned with three of the more important variables related to a wide-angle visual system designed for utilization in a flight simulator.

The ambient illumination was experimentally adjusted to the values of 3, 6, and 9 FL. These illumination levels represented a realistic range that would be required in a wide-angle system that simulates the visual world. Based on the information acquired in the literature review, it is hypothesized that as the ambient illumination level is increased, the frequency and severity of flicker that is observed from the CRT display will increase.

In the investigation, four different images were projected on the display in order to determine individually the effect on the frequency and severity of observed flicker. These images, three static and one dynamic, consisted of realistic scenes that would be encountered by a pilot performing in a flight simulator with a wide-angle visual system. The static images were: homogeneous, which was a uniformly white field for the entire display; structured, a runway scene from ground level which projected vertical lines on the display in a symmetrical fashion; and, complex, which was a plan view of rugged terrain. The dynamic image consisted of terrain moving from top to bottom on the display in order to simulate altitude flight. Assuming that the images represent a continuum from simple to complex (homogeneous, structured, complex, dynamic), the hypothesis is that flicker will be observed progressively more frequently as the format of the image increases in complexity.

The third independent variable investigated dealt with the retinal location that is stimulated. Experimental data was collected on twenty-six fixation points around the CRT display that ranged from 60° down to 90° up in the vertical axis, and 0° (fixating directly at the display) to 120° in the lateral axis to the left side of the display only. Again, these values were selected due to the visual requirements, as well as the practical equipment limitations, of such a proposed wide-angle visual system. The hypothesis states that as the stimulus (CRT display) is displaced away from foveal toward peripheral vision, flicker is more frequently observed. Stated more precisely, the further the observer fixates vertically and laterally from the display, the more pronounced that flicker can be expected to be seen. However, this relationship is expected to be altered somewhat as a function of illumination level.

In summary, three independent variables were manipulated in the study with data collected on three dependent variables. The measures recorded on selected treatments of the independent variables, as well as any resulting interaction, consisted of the time to the first observation of flicker, percentage of the total number of trials that flicker was observed, and the severity of flicker regarding its interference with a visual task. The hypotheses derived from a review of the literature state that flicker will be more frequently observed as the illumination level is increased, the image becomes more complex, and the fixation point deviates from the display.

METHOD

APPARATUS

An experimental booth of approximately 3x4x6 feet was constructed of tubular framework over which a flexible translucent screen material was mounted (Figure 4, Appendix A). The booth was located in a laboratory darkroom that was secure from external light and noise that may have been emitted by equipment or personnel.

Since the screen permitted the transmission of light, the illumination level in the booth was produced by five floodlamps strategically positioned around the sides and over the booth. To provide uniform ambient illumination, the floodlamps were turned away from the booth so that the light reflected off large white cardboard surfaces toward the experimental booth. The illumination levels of 3, 6, and 9 FL were precisely controlled by a Variac and checked after each adjustment with a Gossen light meter.

A 27-inch cathode ray tube (CRT) television monitor with a 23-inch collimating lens was placed on a table in the experimental booth. The alignment of the monitor and lens effectively resulted in a 20-inch display. The CRT was a 1000-line system that had a sweep rate of 30 frames per second with a two-to-one interlace, which produced a rate of fluctuation of 60 hertz (cps). This method of interlace is similar to the standard general purpose television system. A No. 4 phosphor was used in the CRT. The display brightness was matched to the specific illumination level selected so that the ambient illumination was uniform.

A swivel chair, which permitted free rotation, was fixed in place in front of the display system, resulting in a viewing distance of 27 inches from the lens to the subject's eye and a visual angle subtended of 40°39'. Based on anthropometric data for the mean seat to eye level height, the eye of the seated subject was approximately 48.5 inches from the floor to an elevation that represented the middle of the display.

Total trial time and the time to the first observation of flicker were recorded by two Hunter timers that were wired with a switching logic and common reset capability. Upon activation, one timer continuously indicated the elapsed time on each trial, and the other timer was stopped whenever the subject in the experimental booth depressed a button on a remotely operated handheld control.

Since the experimenter's station was located in an adjacent room, an interphone system was fabricated to provide instant "hot mike" communication between the subject in the experimental booth and the experimenter.

Fixation points were established in the interior of the experimental booth at specific angles representing horizontal and vertical increments of 30 degrees. The mean eye level height (48.5 inches) and viewing distance (27 inches) was the basic reference point from which the fixation points were measured. The horizontal fixation points were plotted on the left side of the display only. Because the normal human visual system perceives equally well in either horizontal field, the number of experimental treatments required was thus reduced by one-half. The 26 fixation points are depicted in Table I.

TABLE I

ANGULAR LOCATION OF THE 26 FIXATION POINTS

		Horizontal Angle (Left)				
		0°	30°	60°	90°	120°
Vertical Angle	+ 90°	X				
	+ 60°	X	X	X	X	X
	+ 30°	X	X	X	X	X
	0°	X	X	X	X	X
	- 30°	X	X	X	X	X
	- 60°	X	X	X	X	X

A 1-inch-square white paper chip was attached to the translucent screen at the plotted fixation points, with the exception of the 0/0° point directly on the CRT display. The chip contained 24-28 randomly generated alphabet characters typed in upper case in four rows. The letters were of sufficient size to be discernible under low illumination levels.

A dual-channel television system with two GPL 1000-line portable cameras, TV monitor, and control console (Figure 5) projected the images on the subject's display. The three static images were projected by one camera that was mounted on a table (Figure 6). The homogeneous image,that appeared as a blank white screen to the subject, was produced by placing the cap cover over the TV camera lens. The structured image of the runway scene (Figure 7) and the complex image consisting of a rugged terrain scene (Figure 8) were photographs that were placed before the camera and floodlighted. The second camera was mounted perpendicular to a vertically moving Link SMK-23 terrain model belt (Figure 9) that projected a dynamic image on the CRT display and approximated flight over the terrain at 264 knots at an altitude of 1500 feet. Figure 7 is a representative view of the terrain on the moving belt.

PROCEDURE

The psychophysical method of constant stimuli was employed in the investigation (Underwood, 1949). With this procedure, each trial consisted of the presentation of a specific set of invariable stimuli (illumination level, fixation point, and image), and the subject was asked to report the presence or absence of flicker and the severity of the flicker observed.

Upon reporting for the experiment, the subject was asked to read a prepared sheet of instructions (Appendix B) that briefly described the nature of the study and the details of the experimental procedure.

It was explained to the subject that any flicker observed from the TV monitor was not being introduced by the experimenter at any time by manipulating equipment. Rather, flicker is a subjective phenomenon and the data is unique to the individual. An example of the flicker phenomenon was demonstrated by directing his attention to a fluorescent light on the ceiling that characteristically flickered. Additionally, several artifacts of the display were pointed out to the subject so that they would not be construed as related to the flicker phenomenon observed in an experimental treatment.

The subject was briefed on the use of the "hot mike" interphone system and hand-operated timer control. The interphone system proved invaluable as a means for the subject to verbally rate the effects of flicker,as well as to ask questions and receive instructions regarding experimental procedure and equipment observations.

The subject was requested to sit erect during the experimental trials and rotate the chair so that he was facing directly at each specific fixation point. Prior to the commencement of each trial, the experimenter provided directions via the interphone system regarding the location of the fixation point. The first number transmitted to the subject was the horizontal angle of the fixation point from 0°, looking forward at the TV display, around to the left through 30, 60, 90, to 120° from the display. The second number relayed was the vertical angle from level or 0°, down through -30 to -60° on or near the floor, up to +30, +60, and +90° over the subject's head. These two numbers provided the coordinates for the precise fixation point for the trial, and when the subject had located the point, he reported "ready."

At the verbal command from the experimenter to start the trial, the subject recited the letters at that fixation point once through in a normal sequence and then in a reversed order (right to left and bottom to top). Accuracy was stressed as being more important than speed when reciting the letters. As the subject verbally reported the letters, the experimenter monitored the tasks by checking against a master sheet containing the letters of all the fixation points (Appendix C). In this manner, the experimenter could be assured that the subject was fixating at the properly assigned point, and that his attention continued to be concentrated at that specific point throughout the entire trial. This was an important factor to collecting valid data on the perception of flicker under the various experimental treatments.

Usually, the subject consumed the entire 30-sec trial time to recite the letters at a rate of approximately two letters per second in the forward and reverse sequence. The first time the subject observed flicker during the trial, he signified his perception by depressing the button on the handheld timer control, but continued to recite the letters until advised to "stop" by the experimenter.

At the conclusion of the 30-sec trial, the subject rated the effect of the flicker that was observed. Because of the subjective nature of the flicker phenomenon and lack of convenient psycholophysical units, the subject's ratings were made on an ordinal scale. Thus the magnitude of the differences were not quantitatively defined, but the rating was performed on the degree to which the flicker phenomenon distracted the subject from the primary task within the following general guidelines:

None - no flicker was observed during the trial.

Noticeable - flicker was observed but created no difficulty.

Moderate - flicker was somewhat distracting while reading the letters.

Severe - flicker was so prominent that it was very distracting and uncomfortable to view.

The subject's flicker rating was recorded as 0 through 3 according to the categories of none through severe, respectively. Occasionally, the subject wished to rate the flicker between two of the categories, which was permitted. In this event, the rating was recorded in increments of 0.5 scale units. Thus, a moderate to severe rating was recorded as a 2.5 value.

Each subject participated in only one experimental session that ranged in time from 1:30 to 2:00 hours with a mean of 1:39 hours. The experimental session was divided into four periods of approximately 20 minutes' duration with five minutes' rest between periods. Each period represented a different image with the 26 fixation points being presented within each period. A personal data questionnaire was completed by the subject during one of the rest periods (Appendix D).

EXPERIMENTAL DESIGN

A Winer (1962) three-factor mixed experimental design with repeated measures was employed in the study. Twelve subjects were divided at random into three groups of four subjects with each group being administered one of the three illumination levels in conjunction with all possible combinations of 26 fixation points and four images. The 26 fixation points were presented in a random sequence within each of the image treatments. The order of administration for the images was counterbalanced across subjects within each of the three illumination groups as shown in Table II.

TABLE II

PRESENTATION ORDER FOR THE IMAGES BY SUBJECT

	Illumination Level Group			Image Order			
	6FL	3FL	9FL				
Subject Number	1	5	9	H	S	C	D
	2	6	10	D	C	S	H
	3	7	11	S	D	H	C
	4	8	12	C	H	D	S

NOTE - Image Symbols

H - Homogeneous

S - Structured

C - Complex

D - Dynamic

SUBJECTS

Twelve males, with a mean age of 27.1 years, voluntarily participated as subjects in the experiment. There was essentially no difference in the mean age between the three illumination groups. All subjects met the requirement of possessing 20/20 uncorrected vision in both eyes. The vision requirement was ascertained prior to the individual's being accepted as a subject by either of two methods: the successful completion of an Air Force physical within the previous six months, or the administration of a vision test by the experimenter. A stereoscope manufactured by Bausch and Lomb, which is the standard Armed Forces Vision Tester, was used to test for normal vision.

RESULTS

Analysis of variance statistical tests were applied to the experimental subjects' mean data for three response measures including: (1) time to the first observation of flicker, (2) percentage of the total number of trials that flicker was observed, and (3) rating of flicker severity. In this factorial experiment in which there were repeated observations, the ANOVA test assumed that illumination level, image, and fixation point were fixed factors, and subjects a random factor (Winer, 1962). The summaries are presented in Tables III, IV, and V.

The results of the tests indicate the fixation point variable to be significant at the 0.05 level of confidence for all three measures of time, percentage, and rating. The interaction of fixation point and illumination level was also significant at the 0.05 level for time to the first observation of flicker and the rating of flicker severity. Additionally, the triple order interaction of illumination level, image, and fixation point was significant at the 0.05 level of confidence for the percentage of the total number of trials that flicker was observed. Illumination level was not found to be significant for any of the three dependent variables. Furthermore, statistical significance was not indicated for the image variable, the interaction of illumination level and image, nor for the interaction of image and fixation point.

TABLE III

SUMMARY OF ANALYSIS OF VARIANCE FOR MEAN PERCENTAGES OF THE TOTAL NUMBER OF TRIALS THAT FLICKER WAS OBSERVED

Source of Variation	SS	df	MS	F
Between subjects				
A (illumination level)	14,781.3	2	7,390.6	3.79
Subj w. groups	17,543.3	9	1,949.3	
Within subjects				
B (image)	677.4	3	222.5	1.32
A X B	1,774.7	6	295.8	1.76
B X subj w. groups	4,549.9	27	168.5	
C (fixation point)	48,495.1	25	1,939.8	20.66*
A X C	8,473.9	50	169.5	1.81*
C X subj w. groups	21,125.9	225	93.9	
B X C	5,510.9	75	73.5	1.29
A X B X C	9,278.4	150	61.9	1.09
B X C X subj w. groups	38,336.7	675	56.8	
Total	170,547.5	1247		

TABLE IV

SUMMARY OF ANALYSIS OF VARIANCE FOR MEAN PERCENTAGES OF THE TOTAL NUMBER OF TRIALS THAT FLICKER WAS OBSERVED

Source of Variation	SS	df	MS	F
Between subjects				
A (illumination level)	26.9	2	13.45	2.85
Subj w. groups	42.4	9	4.71	
Within subjects				
B (image)	1.2	3	.40	1.25
A X B	2.8	6	.47	1.47
B X subj w. groups	8.6	27	.32	
C (fixation point)	66.9	25	2.68	12.76*
A X C	12.7	50	.25	1.19
C X subj w. groups	46.5	225	.21	
B X C	9.6	75	.13	1.18
A X B X C	20.3	150	.14	1.27*
B X C X subj w. groups	72.5	675	.11	
Total	310.4	1247		

* $p < .05$

TABLE V

SUMMARY OF ANALYSIS OF VARIANCE FOR MEAN RATINGS OF FLICKER SEVERITY

Source of Variation	SS	df	MS	F
Between subjects				
A (illumination level)	69.4	2	34.70	2.18
Subj w. groups	143.3	9	15.92	
Within subjects				
B (image)	2.2	3	.73	.78
A X B	5.7	6	.95	1.01
B X subj w. groups	25.3	27	.94	
C (fixation point)	167.4	25	6.70	20.94*
A X C	36.0	50	.72	2.25*
C X subj w. groups	72.6	225	.32	
B X C	21.5	75	.29	1.21
A X B X C	43.1	150	.29	1.21
B X C X subj w. groups	164.3	675	.24	
Total	750.8	1247		

* $p < .05$

The mean percentages, times, and severity ratings for observed flicker are plotted against an abscissa scale of illumination level in Figure 1 and a scale of image type in Figure 2. The ordinate represents all three measures of response such that an increase in the percentage of the total number of trials that flicker was observed (0-100%), and the rating of the flicker severity (0-3) is correspondingly reflected in a decrease in the time to the first observation of flicker (30-0 sec).

The plotted experimental data reveals a consistency across all three measures. For example, the illumination level function portrayed in Figure 1 shows a rapid increase for percentage, time, and rating for the 3 FL to the 6 FL level of illumination. However, a well defined break occurs at 6 FL where the flicker effect continues to increase to 9 FL but at a diminished rate for the percentage and time dependent variables and a slight decrease in rating.

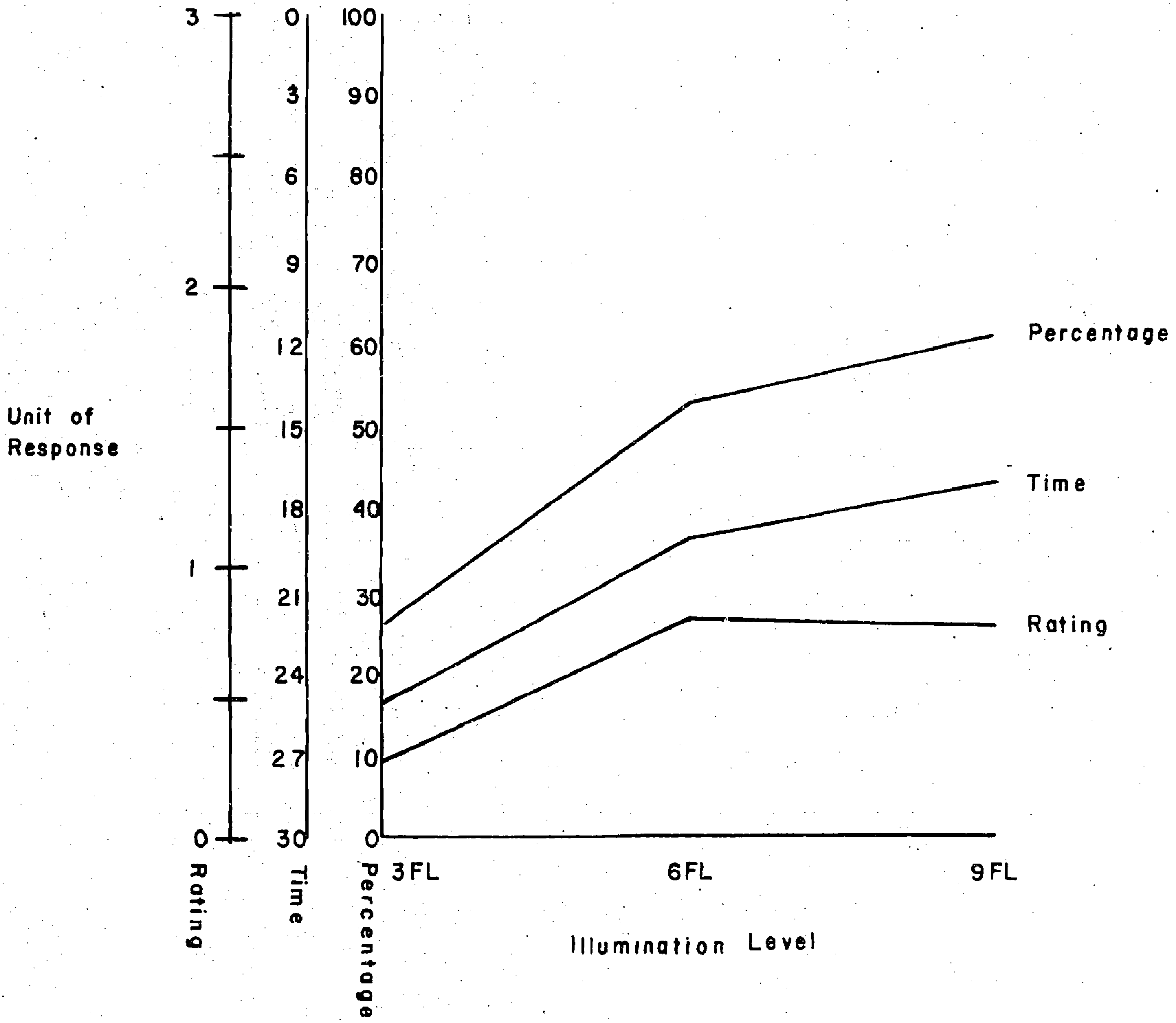


Figure 1. Plot of the Mean Percentages, Times, and Severity Ratings for the Observation of Flicker as a Function of Illumination Level.

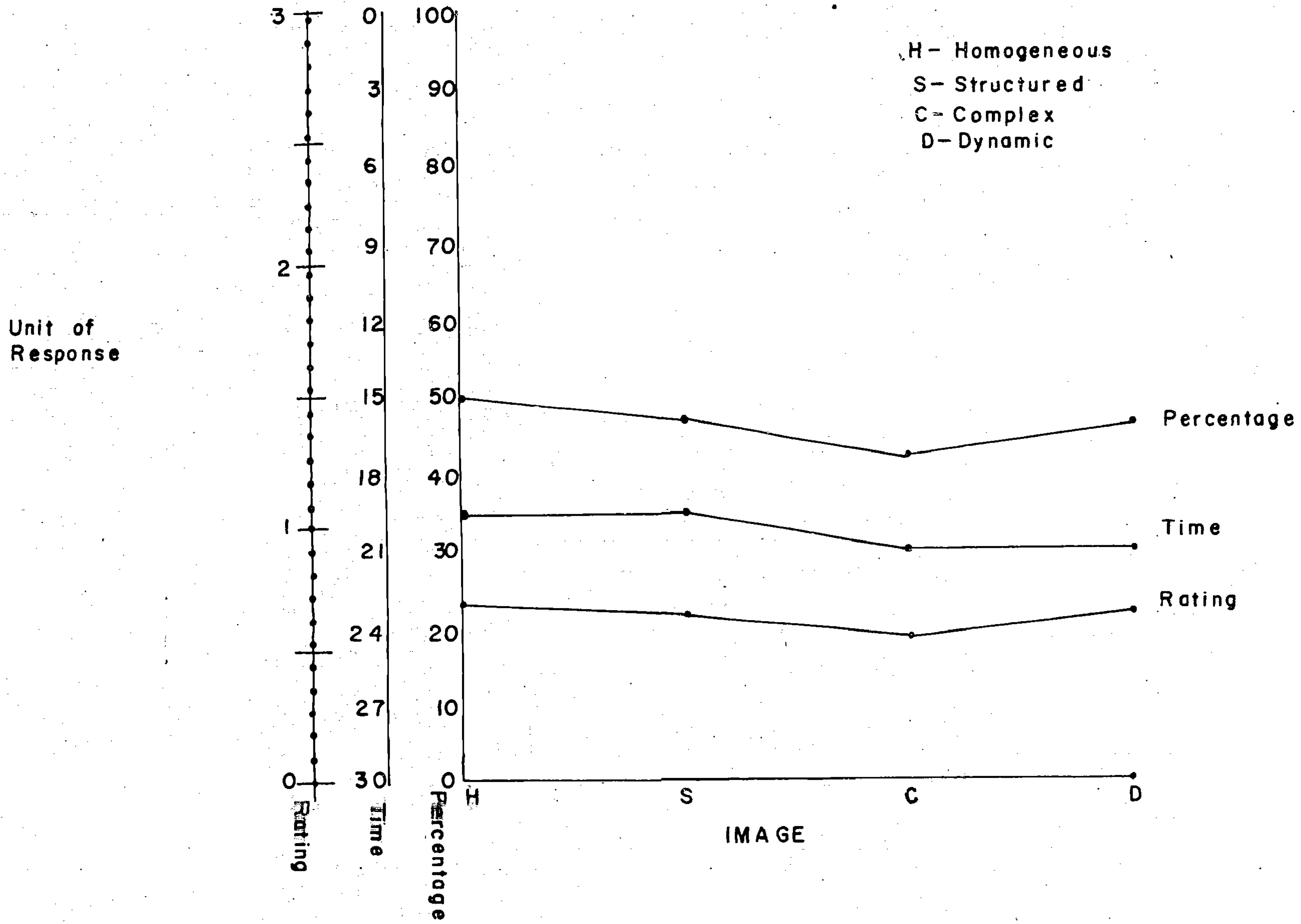


Figure 2. Plot of the Mean Percentages, Times, and Severity Ratings for the Observation of Flicker as a Function of Image Presentation

Similarly, the image data depicted graphically in Figure 2 possess identical characteristics for the percentage, time, and rating measures. The curves are in accord with respect to the slightly decreasing observation and effect of flicker as a function of image complexity on a continuum extending from homogeneous to structured to complex. The reversal of this trend for the dynamic image is again reflected by both the percentage and rating measures but the time plot indicates no change from the static complex image.

Figure 3 is a geographically oriented plot of the mean percentages of flicker observation for the 26 experimental fixation points. By applying the theoretical standard of a 50% threshold level to the data, the plot exhibits the symmetry of a square around the CRT display. This means that flicker was observed for 50% or greater of the total number of trials presented in a region that ranged from -30 to $+60^{\circ}$ in the vertical axis and from 0 to 60° in the horizontal axis for those illumination levels and images treated in the experiment.

The mean values of time, percentage, and rating that were computed for the three illumination levels and four images are presented in Tables VI, VII, and VIII, respectively. In analyzing the illumination level the time, percentage, and rating data indicate that as illumination level is increased the effect of flicker becomes greater regardless of images. Specifically, the time to the first observation of flicker becomes shorter, the percentage of the total number of trials in which flicker is observed increases, and the higher the rating of flicker severity as illumination level is raised. The only exception to this general result is the cell for 9 FL and the structured image, which produced either a reversal (time and rating) or a leveling off (percentage) of this illumination effect.

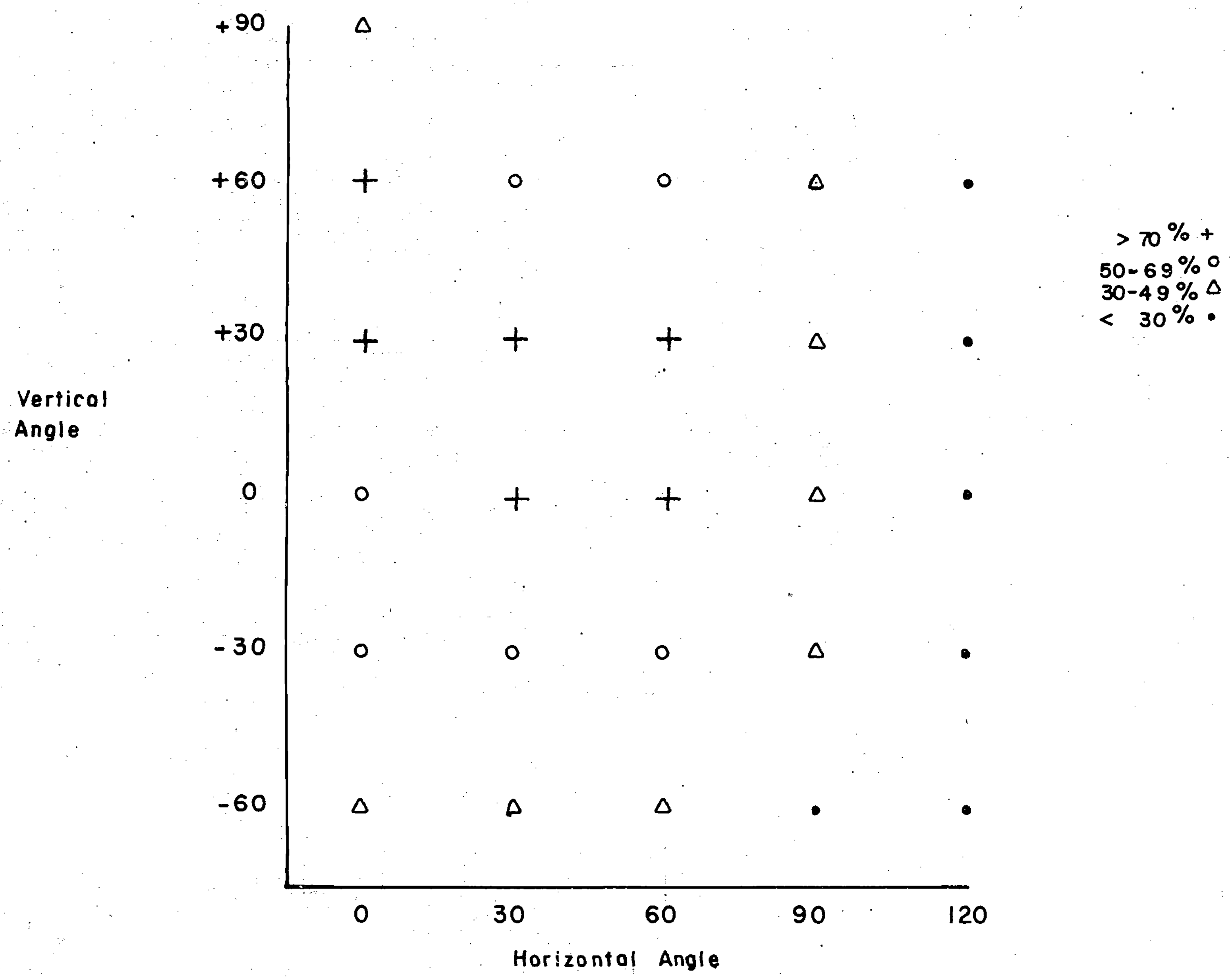


Figure 3. Plot of the Mean Percentages of Flicker Observation for Fixation Points

TABLE VI

MEAN TIMES (SECONDS) TO THE FIRST OBSERVATION OF FLICKER FOR ILLUMINATION LEVELS AND IMAGES COLLAPSED ACROSS FIXATION POINTS

		Illumination Level			
		3 FL	6 FL	9 FL	Mean
Image	H	24.8	19.3	15.0	19.7
	S	22.9	17.8	17.9	19.6
	C	27.7	19.8	15.9	21.1
	D	25.0	19.3	18.9	21.1
	Mean	25.1	19.1	17.0	20.4

Note – Image code: H – Homogeneous
S – Structured
C – Complex
D – Dynamic

TABLE VII

MEAN PERCENTAGES OF THE TOTAL NUMBER OF TRIALS THAT FLICKER WAS OBSERVED FOR ILLUMINATION LEVELS AND IMAGES COLLAPSED ACROSS FIXATION POINTS

		Illumination Level			
		3 FL	6 FL	9 FL	Mean
Image	H	30	55	66	50
	S	35	54	54	47
	C	12	49	63	42
	D	28	53	59	46
	Mean	26	53	61	46

Note – Image code: H – Homogeneous
S – Structured
C – Complex
D – Dynamic

TABLE VIII

MEAN RATINGS OF FLICKER SEVERITY FOR ILLUMINATION LEVELS AND IMAGES COLLAPSED ACROSS FIXATION POINTS

		Illumination Level			
		3 FL	6 FL	9 FL	Mean
Image	H	.34	.80	.88	.67
	S	.38	.87	.64	.63
	C	.13	.74	.80	.56
	D	.31	.78	.81	.63
	Mean	.29	.80	.78	.62

Note - Image code H - Homogeneous
S - Structured
C - Complex
D - Dynamic

Rating scale for flicker severity:

0 - None
1 - Noticeable
2 - Moderate
3 - Severe

The data in Tables VI, VII, and VIII do not reflect as orderly a function regarding the observation and effect of flicker for the image variable as was found for illumination levels. Generally, flicker was the most pronounced for the homogeneous image and the least evident for the dynamic image. However, there are notable exceptions to this fact, one of which is the complex image and 3 FL cell which produced the lowest observation percentage, lowest flicker rating, and correspondingly, the highest time to the first observation of flicker of any of the 12 cells composed of image and illumination combinations. In contrast, the structured image resulted in some of the more salient effects of observed flicker as demonstrated by the 6 FL cell for the time and rating measures, and the 3 FL cell for all three response measures.

The means for the fixation points for the three response measures are presented in Tables IX, X, and XI. The data indicate the +30°/0° fixation point immediately above the CRT display had the shortest time and, accordingly, the highest observation percentage and the highest severity rating. Those fixation points surrounding the display for both the vertical and horizontal axes produced the greatest flicker observation and effect. Conversely, the least effect of flicker was encountered at the 120° horizontal angles. A universal trend existed for the vertical axis fixation points that are level or located above the display to result in more pronounced problems with the flicker phenomenon, rather than the depressed fixation points, irrespective of the horizontal angle. This result is supported by all three measures of time, percentage, and rating. Furthermore, Tables IX, X, and XI, reveal that the observation and effect of flicker is reduced as a function of excursion from the 0 to the 120° horizontal angle with two exceptions, 0°/0°, and -60°/0°.

In summarizing the data collected on all experimental trials for the three independent variables of illumination level, image, and fixation point, the mean time to the first observation of flicker was 20.4 seconds, the mean percentage of the total number of trials that flicker was observed was 46%, and the mean rating of flicker severity was 0.62.

TABLE IX

MEAN TIME (SECONDS) TO THE FIRST OBSERVATION OF FLICKER FOR 26 FIXATION POINTS COLLAPSED ACROSS ALL TREATMENTS OF ILLUMINATION LEVEL AND IMAGE PRESENTATION

		Horizontal Angle					
		0	30	60	90	120	Mean
	+90	22.4	–	–	–	–	22.4
	+60	11.9	15.2	18.5	24.4	25.8	19.2
	+30	7.8	11.4	11.7	23.7	28.1	16.5
Vertical Angle	0	17.6	10.4	13.0	21.5	28.4	18.2
	−30	16.9	19.7	20.2	24.6	28.5	22.0
	−60	25.3	23.8	23.9	26.6	28.2	25.6
	Mean	17.0	16.1	17.5	24.2	27.8	20.4

TABLE X

MEAN PERCENTAGES OF THE TOTAL NUMBER OF TRIALS THAT FLICKER WAS OBSERVED FOR 26 FIXATION POINTS COLLAPSED ACROSS ALL TREATMENTS OF ILLUMINATION LEVEL AND IMAGE PRESENTATION

		Horizontal Angle					
		0	30	60	90	120	Mean
	+90	44	–	–	–	–	44
	+60	77	65	60	40	23	53
	+30	85	77	77	38	10	58
Vertical Angle	0	54	81	73	46	12	53
	−30	60	50	50	33	8	40
	−60	33	44	33	19	15	29
	Mean	59	63	59	35	16	46

TABLE XI

MEAN RATINGS OF FLICKER SEVERITY FOR 26 FIXATION POINTS COLLAPSED ACROSS ALL TREATMENTS OF ILLUMINATION LEVEL AND IMAGE PRESENTATION

		Horizontal Angle					
		0	30	60	90	120	Mean
Vertical Angle	+90	.51	–	–	–	–	.51
	+60	1.03	.84	.83	.46	.33	.70
	+30	1.50	1.27	.97	.41	.10	.85
	0	.71	1.25	1.01	.53	.15	.73
	-30	.72	.59	.66	.41	.17	.51
	-60	.40	.50	.45	.25	.19	.36
	Mean	.81	.89	.78	.41	.19	.62

Note – Rating scale for flicker severity:

0 – None
1 – Noticeable
2 – Moderate
3 – Severe

DISCUSSION

Based on information acquired in the literature review on the phenomenon of flicker, three hypotheses were derived regarding the expected frequency and severity of flicker to be observed from the CRT display in the present investigation: (1) flicker would increase as the illumination level is increased, (2) flicker would increase progressively as the image complexity increased, and (3) flicker would be more pronounced the further the observer fixates from the display.

The hypothesis for the variable of illumination level was not supported by the empirical data at the 0.05 level of significance that was established a priori. Thus, the perception of flicker as a function of the three illumination levels was not sufficiently demonstrated to be statistically significant. However, there is a trend in the data plots that somewhat supports the prediction that flicker observation and severity rating tend to increase, rather than decrease or remain unchanged, as a function of increasing illumination level. Figure 1 indicates that the percentage and time for flicker observation and the severity rating all increased as illumination level was increased. The single exception to this general trend is the slight decrease in severity rating from the 6 FL to 9 FL level. Verification to the basic increasing function is supplied by Tables VI, VII, and VIII. For the three illumination levels of 3 FL, 6 FL, and 9 FL, Table VI shows that the mean time to the first observation of flicker (collapsed across images) decreased correspondingly: 25.1, 19.1, and 17.0 seconds. Table VII reflects a 26, 53, and 61 step increase in the mean percentage of the total number of trials that flicker was observed as illumination level was increased. Table VIII supports the trend for the 3 FL and 6 FL points with a 0.29 to 0.80 increase in the mean rating of flicker severity. Again, the drop to a 0.78 rating at 9 FL is the sole data point that refutes the predicted function. Thus, within the experimental conditions defined herein, the data reflected that the subjects had a propensity for observing flicker more quickly and for considering the flicker phenomenon as more pronounced as the intensity of illumination was increased. Perhaps if this factor of the study were replicated with a larger subject sample, statistical significance might result that was not demonstrated in this experiment.

The experimental data collected on the illumination level is directly related to the mixed experimental design employed in the investigation. In designs of this mixed type, the inter-subject treatment comparisons are usually much less precise than the intra-subject comparisons. For example, inspection of the individual subject data disclosed good stability, or, conversely, the lack of variability, in the responses within each subject in the perception of flicker, but established the fact that large differences can and did exist between subjects. Since sensitivity to flicker apparently is unique with each individual and, of course, difficult to quantify, there is no definite method of determining how well the three experimental illumination level groups were equated.

Perhaps the three illumination levels selected for treatment in the present investigation represent intensities where the effect upon flicker is considerably lessened. This aspect may be particularly valid for those intensities above the 6 FL point since the plotted data graphically illus-

trates that this area resulte
crease of the flicker effect.
with the earlier findings of
mately reached where the crit
creased intensity does not pr

The flicker effect data
the image variable was not st
confidence. Consequently, th
progressively as the image co
fact, an examination of the p
Figure 2 indicates the flick
the homogeneous to structured
this trend evident for the dy

Inasmuch as the results
analysis of the image data su
the assumption that the image
tion represented a continuum
(homogeneous, structured, com
erroneous. Each image format
completely unrelated from any
common characteristic other t
alternative explanation or hy

Previous findings by Har
is less in a field that is pe
is perceived as "figure." Po
scene of rugged terrain, was
explain the fact the complex

ted in a considerably diminished rate of in-
t. Furthermore, this premise is in agreement
f Hecht and Smith (1936) that a point is ulti-
itical frequency curve becomes flat and in-
produce an increase in CFF.
ta produced from the experimental treatment of
statistically significant at the 0.05 level of
the hypothesis that flicker would increase
complexity increased must be rejected. In
plots for percentage, time, and rating in
cker effect actually decreased slightly from
ed to the complex image, with a reversal of
dynamic image.
s were not consonant with the hypothesis,
suggests several possible explanations. First,
ges selected for presentation in the investiga-
m of image complexity from simple to complex
omplex, dynamic) could conceivably have been
at may be unique, and thus result in a response
ny other image. Or the images could possess a
than complexity. This leads to the second
hypothesis.
artman (1923) indicated that flicker effect
perceived as "ground" than in one that
Possibly the complex image consisting of a
s viewed as a ground phenomenon. This could
x image produced the lowest mean flicker effect

for all three response measures of time, percentage, and rating. Also, the structured image of the runway, that resulted in markedly greater flicker effects, could easily be considered as consisting primarily of a figure property. The experimental data on the homogeneous image, however, does not support the figure-ground concept. The white homogeneous image resulted in the most pronounced flicker effects of the four images presented. It should be noted at this point that a significant interaction of illumination level, image, and fixation point occurred on the percentage measure, which may provide an explanation for the contradiction in the results of the image variable.

The increase in the flicker effect for the dynamic image, which was essentially the same image format as the static complex image except the dynamic image was moving, can possibly be attributed to an experimental artifact. Subjects reported the observation of bright spots on the moving scene that attracted their attention. According to comments solicited from the subjects, they were prone to react to these bright spots as flicker when in reality they were not flicker.

The main effect for the factor of fixation point was found to be statistically significant at the 0.05 level for all three responses of time, percentage, and rating. The hypothesis that flicker would be more pronounced the further the observer fixates from the display was confirmed only for those angles ranging from $0^{\circ}/0^{\circ}$, or looking directly at the display, to the 30° angles up and down in the vertical axis and out to 30° in the horizontal axis. Beyond this 30° deviation from the CRT display, the flicker effect very definitely decreased in all directions, as manifested by the experimental data collected on all three response measures.

These data are in full accord with the results from previous studies regarding the interaction of luminance, retinal locus, and stimulus size variables. Hecht (1938) found the higher CFF occurring in the periphery only for the low luminances. At some intermediate luminance level, Hecht observed that CFF may be relatively independent of the retinal region stimulated. Ross (1936) noted that for high intensities there was a decrease in CFF when moving from the fovea toward the periphery. With stimulus sizes up to 10° visual angle, Hylkema (1942) reported an increasing CFF up to a maximum value at 25 to 30° for the nasal field and approximately 40° for the temporal field.

The significant interaction at the 0.05 confidence level for fixation point and illumination level on the time and rating measures supports the principle that the higher intensitites create more pronounced flicker effect toward the periphery. The luminance levels in the present investigation, particularly 6 FL and 9 FL, were sufficiently high for the subjects to encounter the region of a reversed relationship which had been hypothesized.

The possibility exists that the flicker effect encountered by the subjects when fixating directly at the CRT display (0°/0°) may have been depressed to a certain degree due to an experimental artifact. The CRT display was positioned behind a cutout in a large plywood board that was painted black. In an earlier study, Lythgoe and Tansley (1929) reported that maximum CFF in the foveal region is achieved when the brightness of the surround is matched to that of the stimulus area. Since the surround consisted of a darkened area, the resultant flicker effect may be less than if the surround had been a grey or white surface. This artifact does not apply for the peripheral fixation points since maximum CFF in the periphery is achieved by adjusting the brightness of the surround to a lower value than that of the test field (Lythgoe and Tansley, 1929), which was the case in the present investigation.

Theoretically the human eye perceives equally well up and down - to approximately 60° visual angle (Stevens, 1951). In variance to this conception, the present results on fixation point indicate the 50% threshold level of flicker was displaced upward 30°. The 50% flicker threshold ranged from -30° to +60° for all horizontal angles up to and including 60° (Figure 3). Furthermore, the response measures of time, percentage, and rating reflected nearly a 2:1 ratio of flicker effect for the upper vertical angle than its lower counterpart. For example, a comparison of +60° with -60° vertical angles at the 0° horizontal position in Tables IX, X, and XI shows that flicker was perceived in half the time (11.9 - 25.3 sec), observed on better than twice as many trials (77 - 33%), and rated considerably more severe (1.03 - 0.40) for the elevated fixation point. This ratio for the upward displaced flicker effect applied universally regardless of the illumination level established or the image presented. These incongruous results suggest that further research on this aspect is certainly warranted in an endeavor to determine possible subtle relationships that may be operating that were not evident in the present investigation.

As mentioned earlier, there was a wide range in responses between subjects regarding the observation and effect of flicker. It was noted when some subjects observed flicker and accordingly depressed the response button, their rate of recitation of the letters slowed down noticeably and, upon occasion, even stopped momentarily. This would signify the observed flicker was quite distracting from the primary visual task and that the subjects generally reflected that impairment by rating the flicker in the higher or more severe categories.

Differences in peripheral vision capabilities of subjects were readily apparent by their flicker responses and post-experimental verbal comments. Some subjects reported seeing little or none of the CRT display when turned toward a 120° horizontal fixation point. Other subjects responded fairly consistently to flicker at the 120° point under certain experimental treatments. A specific peripheral vision test for the experimental subjects would have been useful in correlating their peripheral vision capabilities with the flicker effect data.

All experimental subjects concurred with the fact that the flicker phenomenon was encountered intermittently rather than continuously throughout the 30-sec trial. However, the severity of flicker did not change within the same experimental trial.

The locus of the flicker was reported to vary as a function of the fixation point viewed for the same image. For example, one subject stated that with the structured image the flicker he encountered fluctuated between the horizon line and the white portion of the runway (Figure 7) depending upon which of the vertical fixation points at the 30° horizontal position he was viewing.

One unusual result obtained in the study, that is not manifested in the data per se, is a spatial disorientation phenomenon reported by several experimental subjects. This phenomenon, alternatively known as vertigo, is a condition of dizziness or the inability of an individual to properly relate to space, time, and surrounding objects (English and English, 1958). Vertigo is normally created by conflicting sensory inputs from the various balancing mechanisms or proprioceptive receptors, such as the visual system, inner ear canal, muscles, etc.

The vertigo phenomenon was experienced by four subjects, although others may have encountered the condition and not reported it. Vertigo was restricted to those trials when the subject was reciting the letters with the dynamic image moving from top to bottom on the CRT display and at the following horizontal/vertical fixation points: 0°/+30°, 30°/0°, 30°/+30°. Interestingly, these same three points, representing a 30° deviation around the display and an upward displacement, produced the greatest flicker effects as measured by time, percentage, and rating.

It is difficult to specify the actual source of vertigo in this experimental environment. Perhaps the concentration required to accurately read the letters with foveal vision and the concurrent perception of movement in the periphery created the condition. Or possibly, vertigo was encountered simultaneously with the observation of flicker causing conflicting stimulation of the visual system. It is quite conceivable that the vertigo phenomenon interacted to some extent with the flicker effect. However, more importantly, the vertigo phenomenon itself could have far reaching implications to the employment of dynamic scenes in a wide-angle visual system.

CONCLUSIONS AND RECOMMENDATIONS

This experiment was conducted to investigate the extent and effect of observed flicker as a function of the variables of illumination level, image, and fixation point. The following conclusions may be drawn regarding the implications of the study results to wide-angle visual systems:

a. Flicker will probably be encountered at all illumination levels between 3 and 9 FL.

b. The most prominent flicker effects will be encountered when fixating at a point 30° from the source of illumination. However, flicker will be experienced up to 120° horizontally and +90°/-60° vertically when performing a visual task in a wide-angle CRT system.

c. The severity with which flicker interferes with a primary visual task is not expected to exceed a noticeable to moderate level of distraction.

d. Subject differences are considerable in the perception of flicker, but each individual is fairly consistent in his sensitivity to flicker.

e. Some individuals are prone to experiencing vertigo when the display system presents a moving image.

Further research is recommended on the problem of vertigo encountered with the dynamic image; variables such as rate of movement, direction of movement, image format, illumination level, and off-axis fixation point should be considered as pertinent experimental variables. Subjects should have the capability of responding to both flicker and vertigo in order to determine the possible interaction of the two phenomenon.

APPENDIX A

APPARATUS FIGURES

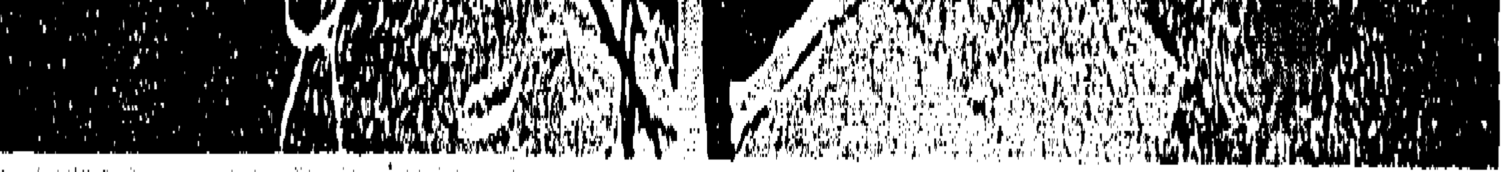
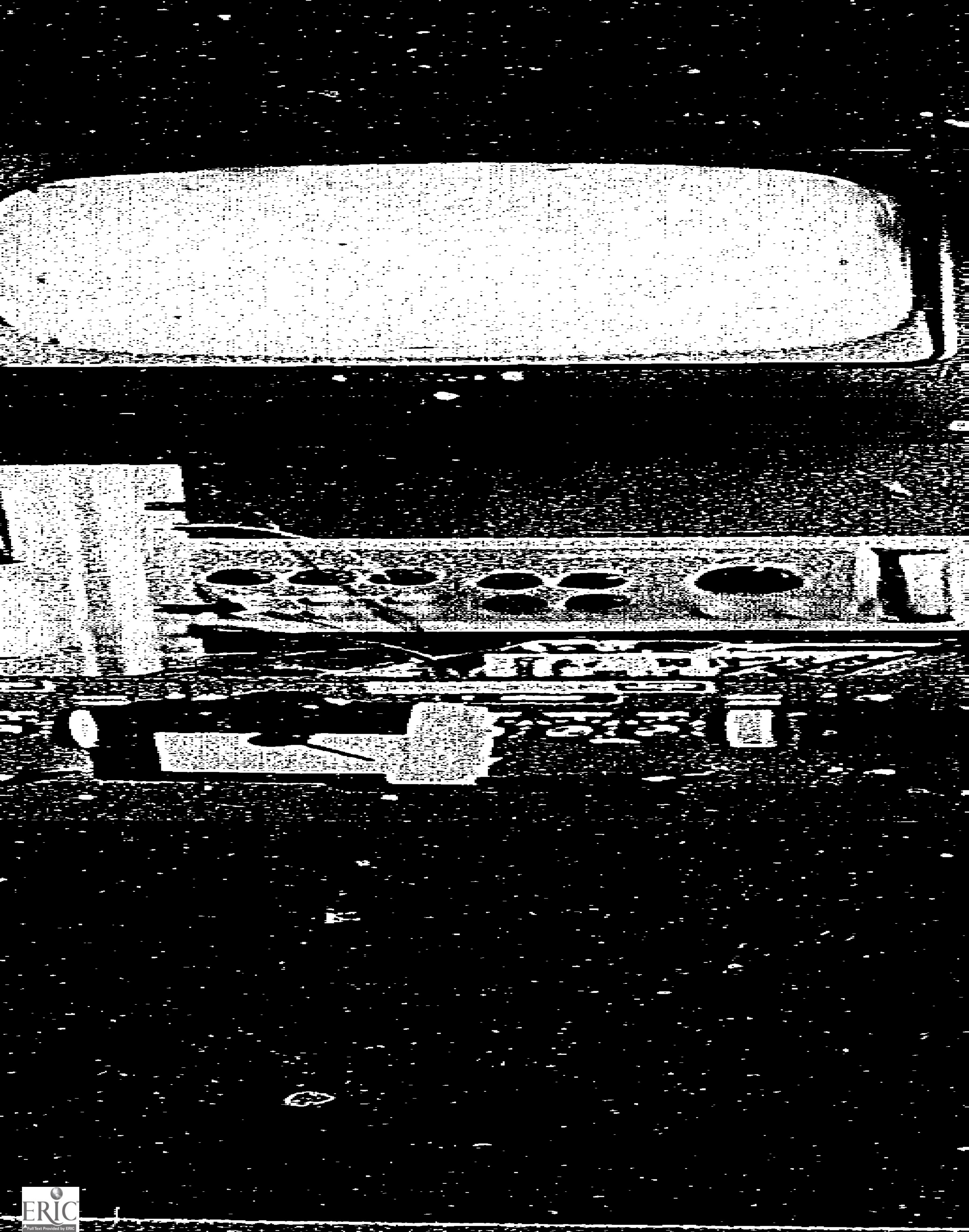


Figure 4. Experimental Booth



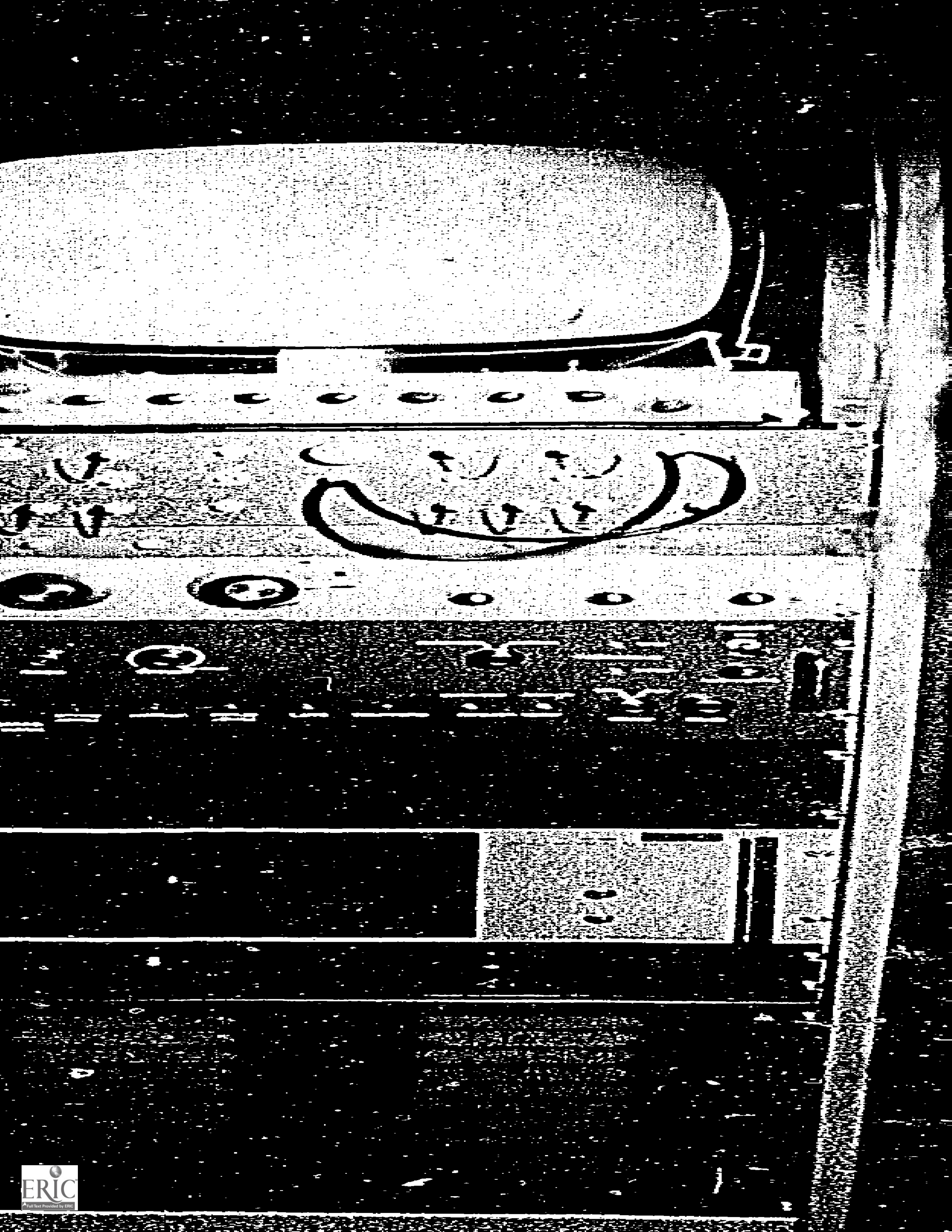


Figure 6. Projection Method for Static Images

Figure 7. Structured Image

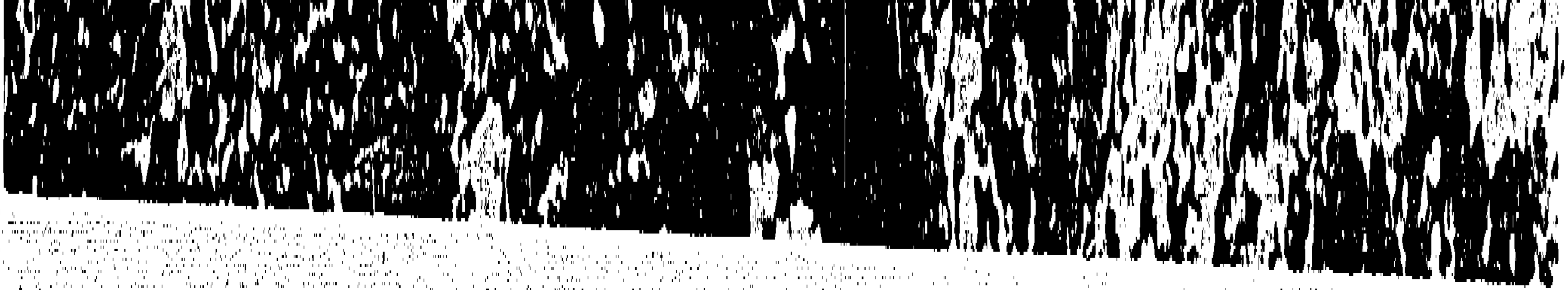


Figure 8. Complex Image

Figure 9. Projection Method for Dynamic Image

Figure 10. Dynamic Image

APPENDIX B

EXPERIMENTAL INSTRUCTION

This study is designed to investigate the possible appearance of a visual phenomenon known as "flicker" that can sometimes be observed when viewing a TV display. The interest in this research is the application of video displays to produce a large wrap-around visual scene of the external world for Air Force flight simulators.

Your task in the experiment will be as follows:

1. Sit erect in the chair with your back against the chair back.

2. Upon directions from the experimenters, via the "hot mike" interphone system, you will be asked to turn the chair so you are directly facing a specific fixation point.

3. The <u>first</u> number you hear will be a <u>horizontal</u> angle from 0°, looking forward at the TV display, around to the left, through 30, 60,90, to 120° from the screen.

4. The <u>second</u> number you hear will be a <u>vertical</u> angle from level or 0°, down through -30 to -60° on or near the floor, up to +30, +60, +90° over your head.

5. These two numbers provide the coordinates for the precise fixation point for that trial. When you have located the proper fixation point, report "ready."

6. When the experimenter advises you to start the trial, recite the letters at that fixation point once through normally and then in a reversed order (right to left and bottom to top). Accuracy is important, whereas speed is not.

7. The first time you observe flicker during the trial, depress the button <u>fully</u> and release, but continue to recite the letters until requested to "stop."

8. At the conclusion of the 30-second trial, the experimenter will ask for your rating, regarding the effect of the flicker that you observed, according to the following scale:

NONE - no flicker was observed during the trial

NOTICEABLE - flicker was observed but created no difficulty for you

MODERATE - flicker was somewhat distracting to you while reading the letters

SEVERE - flicker was so prominent that it was very distracting and uncomfortable to view

9. Rest periods will be provided periodically during the experiment, but you may ask for an additional "break" anytime you desire.

10. After you have read and understood the instructions and have had all your questions satisfactorily answered, we will demonstrate an example of the "flicker" phenomenon.

APPENDIX C

FIXATION POINT LETTERS

	120°	90°	60°	30°	0°
+ 90°					MJNHBG QAWSED WSEDRF CFVGBH
+ 60°	ZAQSWD UJIKOLP IKOLPMN OKIJUHY	HNJMKL UYTREW TREWSD JUNHBY	VFCDXS RFTGYH TGYHUJ NJMKLP	ZSXCDF HNTGBY NJKLMU JMIKOL	MLPKOJ PQOWIE QAWSED PLOKMN
+ 30°	POKIJUH QASDFG FGHJKIU GTFRDCE	GTFRDES SAQWED ZSXDCF AQWSED	GTFRDES ERFGTYH GMZNXB FGZMXN	JUUJMIP LPRFDEW EIRUTYL OEIRUTY	UYHGTRF ZRFVEDC DRFCDXS ZEDCRFV
0°	WAQAZ RFTGYH VGBHNJ RFTGYH	GBYHNU WAQAZ HNUJMI LMIJNE	IHUYHGT URYTLAK CFTXDRZ HBGVFCD	OKIMUJ IJNUHB JNUHBQ AQWSXC	(Display)
- 30°	UJHYTG MIKUJY UJYGDS WSAQZA	PLOKMI MNBVCX MNMKOI ZSEXDR	JMIKLPO SXDCFVG KLKJHGF DCRFVTG	GTYHNM HUJIKO ZAQPWO HFGQPW	LKIJUHY SAQWSD AKSJDHF LAKSJDH
- 60°	KIJUHY GCFXDZ GYFTDR FCDXSR	DEWSAQ TGBRFV ZAVFGB TGBYHN	WSQAZS JMKLPO DFGHYU JMIKML	WQAZXC JUIKOLP CVPQOW CBVLAKS	KMIJNU BHNJMK DSAOWE BYHNUH

APPENDIX D

PERSONAL DATA QUESTIONNAIRE

No____________

1. Date________________
2. Name (Last, First, MI)________________________________
3. Rank____________________
4. Occupation_______________________________________
5. Organization and Symbol______________________________
6. Duty Station______________________________________
7. Duty Phone______________
8. Name of CO_______________________________________
9. Age___________
10. Height_______________
11. Weight_______________
12. Vision (Circle) Corrected Uncorrected
13. Comments

GLOSSARY

Foot-Lambert (FL) - a unit of luminance or photometric brightness equal to the luminance of a perfectly diffusing, perfectly reflecting surface whose illuminance is one foot candle everywhere (English and English, 1958).

Lambert - a unit of uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of one lumen per square centimeter (English and English, 1958).

Log Luminance - the amount of luminance, or light energy emitted, measured in logarithmic units.

Millilambert (ML) - the most commonly used unit of luminance, equal to one thousandth of a lambert (English and English, 1958).

Talbot-Plateau Law - if a surface is illuminated by a light that is interrupted so rapidly that no flicker is perceived, its brightness will be reduced from that of steady illumination by the ratio between the period during which the light actually reaches it and the whole period (English and English, 1958).

Troland - a unit of visual stimulation defined as that illuminance of the retina equal to that produced by viewing a surface whose luminance is one candle per square meter through an artificial pupil of one square millimeter area centered on the natural pupil. Formerly called photon (English and English, 1958).

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VARIABLES INFLUENCING THE PERCEPTION OF FLICKER IN WIDE ANGLE CRT DISPLAYS

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13. ABSTRACT

An experiment was conducted to determine the influence of three variables on the perception of the psychophysical phenomenon of flicker in wide angle CRT displays. The three independent variables treated in the experiment were: 3, 6, and 9 FL illumination levels, of which there were four images, three static and one dynamic; and 26 fixation points positioned around a display from 0 to 120° in the horizontal axis and 60° down to 90° up in the vertical axis. Recorded measures in the factorial experiment consisted of time to the first observation of flicker, percentage of the total number of trials that flicker was observed, and the severity of flicker regarding its interference with a visual task. Analysis of variance tests were applied to the experimental data. Conclusions drawn from the experiment are: (1) flicker will probably be encountered at all illumination levels between 3 and 9 FL; (2) the most prominent flicker effects will be encountered when fixating at a point 30° from the source of illumination with flicker being observed out to 120° horizontally and to +90°/-60° vertically; (3) the severity with which flicker interferes with a primary visual task is not expected to exceed a noticeable to moderate level of distraction; (4) subject differences are considerable in the perception of flicker, but each individual is fairly consistent in his sensitivity to flicker; (5) some individuals are prone to experiencing spatial disorientation when the display system presents a moving image, and further research is recommended on this phenomenon.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Flicker						
Video Flicker						
Flicker Fusion						
Perceptual Flicker						
Display Flicker						
Wide Angle Displays						
Perception						
Vision						
CRT Displays						

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