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# The Use of Displacement, Flash, and Depth-of-Flash Coded Displays for Providing Control System Information

P. N. ZIEGLER, R. E. REILLY, AND R. CHERNIKOFF

*Engineering Psychology Branch*
*Applications Research Division*

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U.S. NAVAL RESEARCH LABORATORY
Washington, D.C.

## ABSTRACT

Two experiments were performed to investigate the use of brightness-coding and flash-coding techniques for presenting information usually provided by displacement displays. The first experiment compared a conventional displacement display with this same display incorporating flash coding, using one of two frequencies to indicate high or low error direction. The results of this study showed that at longer viewing ranges, at which the displacement cannot be discriminated, tracking performance was enhanced by the addition of flash coding to the displacement display.

The second experiment, using a point source of light, compared flash coding (of error direction) with combined flash and brightness coding (of error direction plus magnitude). This latter display, termed "depth of flash," was found to be superior after a relatively short learning period. The findings indicate that the depth-of-flash technique may be a fruitful approach in the development of an effective landing aid.


## PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing on this and other phases.


## AUTHORIZATION

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# THE USE OF DISPLACEMENT, FLASH, AND DEPTH-OF-FLASH CODED DISPLAYS FOR PROVIDING CONTROL SYSTEM INFORMATION

## INTRODUCTION

Current optical landing systems such as the Fresnel Lens Optical Landing System (FLOLS) present glide path information in terms of displacement coding. That is, during a landing approach a target marker will appear to the pilot to be displaced from a fixed reference marker through a distance proportional to the instantaneous angular error of the aircraft from a prescribed glide path. To achieve and maintain this glide path, a pilot attempts to null the displacement between the two markers by making appropriate correction in the flight path of his aircraft.

A recent analysis (1) of the FLOLS has shown that effective display sensitivity, defined as the ratio of indicated error to the actual error, varies inversely as the square of viewing distance. The indicated error is defined as the angle subtended at the pilot's eye by the error indication. With displays such as the FLOLS, difficulty arises in attempting to use displacement information at ranges beyond a mile, due to the limitations of the human eye in discriminating visual angles of less than 2 min. Thus, doubling or even quadrupling the present size of the FLOLS would yield small returns in extending effective viewing distance.

It is evident that if viewing distance is sufficiently increased, all displacement-coded information on a luminous display is lost, and the observer sees only a point of light. However, it may be possible to utilize other dimensions of the display in order to increase its effectiveness; specifically, information may be presented through changes in intensity (brightness coding), and through interrupting the light (flash coding). These two methods of encoding may be utilized to present information currently provided by displacement coding. If the recoding is adequately carried out, the result may lead to a signaling method with an effective range substantially greater than that of present displacement-coded systems. The ability of the human to track while viewing a brightness-coded display has been demonstrated by Moss (2). His subjects were able to null out error presented as brightness changes above and below a fixed reference brightness.

Table 1
Coding Methods for Each Experiment

| Experiment | Coding Methods |
|---|---|
| I | (a) Displacement<br>(b) Displacement plus Flash |
| II | (a) Flash<br>(b) Flash plus Brightness (Depth of Flash) |

This report describes two experiments (Table 1). The first was to determine the effect of the addition of flash-coded directional information to a conventional displacement display. The second compared a display system which indicates error direction by means of flash coding with one where flash coding of error direction is combined with brightness coding of error magnitude. This latter combination is termed a "depth-of-flash" display.

## EXPERIMENT I

The purpose of Experiment I was to compare tracking performance at various viewing distances using (a) a traditional displacement display and (b) a displacement plus flash display which incorporates the use of two different flash rates to indicate either high or low error direction.

### Method

Apparatus – Figure 1 shows a block diagram of the equipment. The display was a 5-in. cathode-ray tube (crt) on which a 1/2-in.-long horizontal reference line was centered. A 1/32-in.-diameter dot moved along the Y axis normal to the center of the reference line. The switch (SW) in position A provided a displacement-coded display with the distance between the movable dot and the reference line proportional to system error. The upper and lower portions of the crt were masked to limit the visible range of marker dot excursions to 1/4 in. above and below the reference line.

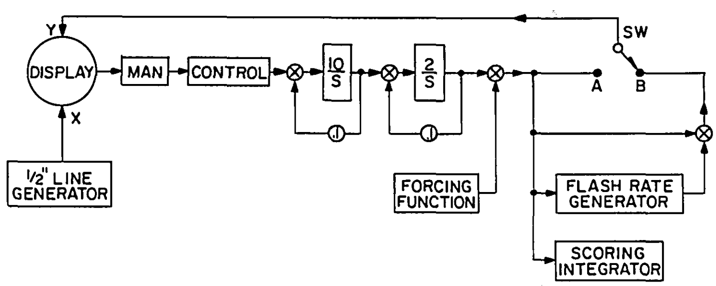


Fig. 1 - The apparatus used in Experiment I to produce a displacement-coded display (SW in position A) and a displacement-plus-flash-coded display (SW in position B)

Placing SW in position B enabled the marker dot to flash on and off with a 50-50 duty cycle. When the marker dot was 1/8 in. or more above the reference line, it flashed at a rate of 60 cpm to indicate "high" error direction. When the dot was more than 1/8 in. below the reference line, the flash rate was 120 cpm, providing "low" error direction information. No flashing occurred if the dot was within ±1/8 in. of the reference line.

Two cascaded analog computer integrators with a feedback loop around each integrator provided second-order tracking dynamics. The transfer function in Laplacian form for this system was $20/(s^2 + 1.2s + 0.2)$. The control was a spring-centered rod mounted vertically and free to move forward and backward only. Moving the control forward produced a downward movement of the display marker dot, while a backward control movement caused the dot to move upward. Maximum angular displacement of the control was ±30° from the vertical position. A 6-cpm sine wave with a display amplitude of ±1/4 in. served as the forcing function.

The tracking system output and the forcing function signal were summed algebraically. The resultant was fed to the crt as system error. System error was integrated without regard to sign over the final 50 sec of each 1-min tracking trial and recorded as the measure of system performance.

The experiment was conducted within a light-shielded room 20 ft long by 5 ft wide by 7 ft high. No extraneous light was visible, even after 30 min of dark adaptation.

Procedure – Each display was tracked at viewing distances such that the maximum visible dot displacement, from the reference line, subtended visual angles of 1, 2, 4, 8, and 16 min at the eye of the observer. These visual angles were obtained by varying the distance between the display and the subject and using a divergent lens (focal length of 2.75 in.) for the two smallest angles. Display conditions were given in order of decreasing visual angle starting with 16 min and finishing with 1 min. This order of viewing conditions was used in an attempt to minimize lost targets during the initial stages of practice.

The experiment consisted of three consecutive sessions on each of the five visual angles. During each session twelve 1-min trials were given with the displacement and displacement-plus-flash displays alternated in blocks of three trials each. Thus, the total number of trials given for each visual angle on each display mode was 18.

Seven naval enlisted men assigned to NRL to participate in research projects served as subjects. They had been trained in tracking higher order systems before being used in this study. The subjects were dark adapted for 15 min prior to the beginning of each experimental session.

## Results

Median error scores for the last six trials on each display-visual angle condition were determined for each subject. Subject means of these medians were then computed and plotted as shown in Fig. 2. This figure presents mean tracking error as a function of visual angle with the displacement and displacement-plus-flash displays shown separately. The dashed line (at 22 units) indicates the amount of error which would be accumulated if no control inputs were made by a subject.

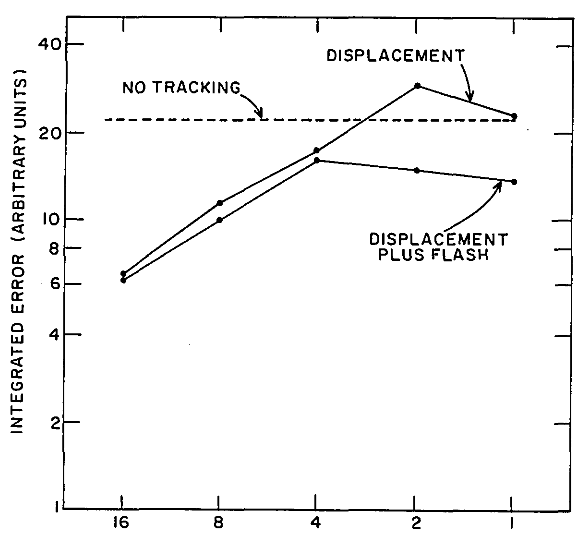


Fig. 2 - Tracking error as a function of visual angle for the Experiment II coding methods

From Fig. 2 it can be seen that as visual angle decreased (viewing range increased) tracking error was found to increase for both the displacement-coded and displacement-plus-flash-coded displays. There appears to be no essential difference in performance between displays for the 16-min through the 4-min visual angle conditions. However, the curves diverge for the 2-min and 1-min conditions. An analysis of variance (Table 2) was performed on the data summarized in Fig. 2. Of primary interest is the significant VA × D interaction, which indicates that for certain visual angles performance is improved by the addition of flash-coded error information. Using *t* tests, visual angles of 2 min and 1 min were found to be significantly superior for the displacement-plus-flash display; no other differences were significant.

Table 2
Analysis of Variance of Tracking Error With Displacement and Displacement-Plus-Flash Displays

| Source | df | MS | F |
|---|---|---|---|
| Visual Angle (VA) | 4 | 540.0 | 39.42* |
| Display (D) | 1 | 470.9 | 34.37* |
| Subjects (S) | 6 | 105.2 | 7.68* |
| VA × D | 4 | 130.62 | 9.53* |
| S × VA | 24 | 19.36 | 1.41 |
| S × D | 6 | 13.72 | 1.00 |
| S × VA × D | 24 | 13.7 | |

* $P < .01$

It would appear that at 4 min of visual angle the displacement display approached the limit of effectiveness while the displacement-plus-flash display still provided usable information. Differences in performance between the two displays were most pronounced under viewing conditions where displacement-type information approached the threshold of discrimination (1 and 2 min of visual angle). Under these viewing distances, however, the displacement-plus-flash display still indicated clearly the direction of error, even though it appeared as a point source of light indiscriminable from the reference line. The performance curve for the displacement-plus-flash display appeared to level off for the 1-min and 2-min conditions. This would be expected, since subjects were tracking using only error direction information contained in the display. As long as the two flash rates were discernible, performance would not be dependent upon viewing distance.

## EXPERIMENT II

Experiment II compared tracking performance using a point source display which presented either (a) error direction alone, by means of flash coding, or (b) error direction plus error magnitude, with magnitude encoded by changes in flash brightness. The combination described in (b) comprises the depth-of-flash display.

### Method

Apparatus – The light-shielded room described in Experiment I was used, with subjects seated 16 ft from the display. Figure 3 presents a block diagram of the apparatus. The display consisted of a 1/16-in.-diameter spot of white light obtained by masking a 6-watt fluorescent lamp. By use of appropriate analog computer circuitry, the spot of light was made to flash at either 60 cpm or 120 cpm to provide information as to whether the error direction was "high" or "low" (SW in position B). The light flashes were on a 50-50 duty cycle, with the intensity alternating between approximately 50 foot-lamberts (ft-L) and 1200 ft-L, measured at the surface of the lamp by a Macbeth Illuminometer.

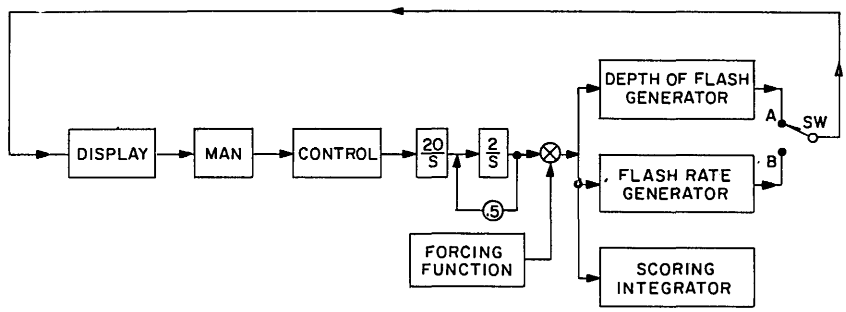


Fig. 3 - The apparatus used in Experiment II

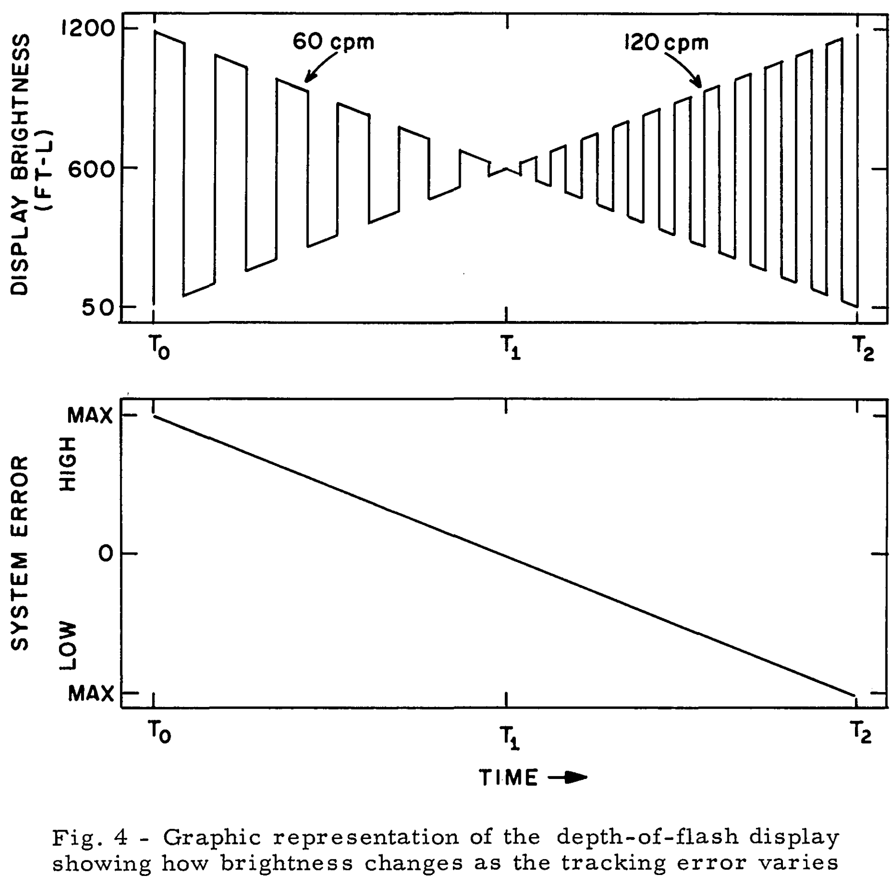


Fig. 4 - Graphic representation of the depth-of-flash display showing how brightness changes as the tracking error varies

For the depth-of-flash condition (SW in position A), the same flash rates as above (60 or 120 cpm) were used to indicate high or low error direction, but in addition the brightness of the light varied as a function of the amount of error. This brightness variation with changes in system error is presented graphically in Fig. 4, using a constant rate of change in the error as an example.

The lower protion of Fig. 4 shows a time plot of the constant-rate error, which starts at a maximally high value ($T_0$), decreases to zero ($T_1$), and increases to a maximally low value ($T_2$). The upper portion of the figure depicts the changes in display brightness for this constant-rate error. At time $T_0$, the error is maximum in the high error direction, and the light is alternating at 60 cpm between 50 and 1200 ft-L. As the error decreases, the brightness difference both above and below the reference brightness becomes less until at $T_1$ (zero error) the subject momentarily sees a steady light of 600 ft-L. Beyond $T_1$, the error begins to increase in the low error direction, resulting in a flash rate of 120 cpm. The brightness difference, both above and below the reference, increases until at maximum, time $T_2$, the light alternates between 50 and 1200 ft-L again. Note that the average brightness of the display remains constant.

The control was the same as that used in Experiment I. Tracking dynamics consisted of a second-order system having a Laplacian transfer function $40/(s^2 + s)$. The forcing function was the sum of two sine waves, 1.7 cpm and 6 cpm, with equal amplitudes. Voltages from the system output and course generator input were summed algebraically, with the resultant voltage integrated by the scoring integrator without regard to sign over the final 50 sec of each 1-min trial. A score of 60 arbitrary units of error was accumulated for an untracked trial.

Procedure – A different group of eight naval enlisted men, experienced in tracking higher order systems, were used as subjects. They were given 10 experimental sessions, each consisting of five 1-minute trials on each of the two display conditions. Before being tested, subjects were dark adapted for 15 min. The order in which the flash-coded and depth-of-flash conditions were given was varied so that each display mode was given first an equal number of times to each subject.

### Results

Median integrated error scores for each set of five trials were computed for each of the eight subjects. Subject means were then determined for both displays for each session. Figure 5 presents the mean error score as a function of sessions for both the flash-coded and depth-of-flash displays. The results of an analysis of variance performed on this data are shown in Table 3. Of particular interest was the significant Se $\times$ D interaction. Comparisons ($t$-tests) between displays showed the depth-of-flash display to be significantly superior to the flash-coded display for all but the first two sessions. From Fig. 5 it can be seen that after the initial sessions approximately 1-1/2 times as much error was made when display information was limited to error direction alone as compared to the performance level based upon error direction plus error magnitude information. The learning curves for the two displays indicate that although some practice is needed to establish a difference between displays, the superiority of depth of flash is evident after a relatively short learning period.

## DISCUSSION

The present experiments were concerned with the feasibility of translating error direction and magnitude information from displacement coding to other methods of coding available with a point source display. Experiment I demonstrated that a given displacement-coded display has a predictable maximum effective range beyond which no information may be derived but that flash coding of error direction in conjunction with displacement coding provides usable information which extends the functional range of the displacement display.

In Experiment II the displays encoded a point source of light which provides no displacement information. This study was concerned with determining whether the addition of brightness coding of error magnitude to flash-coded error direction results in improved overall system performance. The data indicated that system performance was improved considerably over that achieved with the flash-coded display alone.

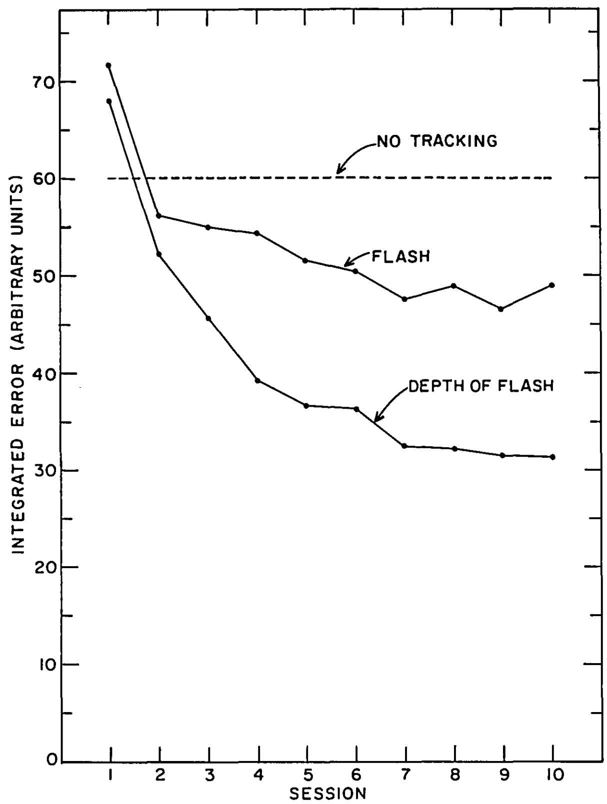


Fig. 5 - Tracking error as a function of training for the Experiment II coding methods

Table 3
Analysis of Variance of Tracking Error with Flash and Depth-of-Flash Displays

| Source | df | MS | F |
|---|---|---|---|
| Displays (D) | 1 | 6451.00 | 190.80* |
| Sessions (Se) | 9 | 1433.66 | 42.40* |
| Subjects (Su) | 7 | 180.57 | 5.34* |
| Se × D | 9 | 101.56 | 3.00* |
| Su × Se | 63 | 36.81 | 1.09 |
| Su × D | 7 | 97.14 | 2.87 |
| Su × Se × D | 63 | 33.81 | |

* $P < .01$

The finding that combining flash coding with a displacement display extended the display's viewing distance has implications for extending the range of the FLOLS. However, the flash-coding technique has limited usefulness since it provides only binary information (above or below glide path) at the extended ranges. A more fruitful approach may be to utilize a depth-of-flash display system, which was found to be superior to the binary flash-coded display. The development of a practical depth-of-flash display system for use as a landing aid has already been undertaken at NRL.

ACKNOWLEDGMENT

The authors wish to express their appreciation to Mrs. Cecelia E. Burke for performing the statistical analyses presented in this report.

## REFERENCES

1. Perry, B.L., "The Computation of Effective Display Sensitivity in Aircraft Landing," NRL Report 6055, Jan. 1964

2. Moss, S.M., "Tracking with a Differential Brightness Display: I. Acquisition and Transfer," J. Appl. Psychol. 48:115-122 (1964)

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13. ABSTRACT

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