NASA Technical Memorandum 80069

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MAY 1979

NASA

1 Report No NASA TM-80069	2 Government Accession No	3 Recipient's Catalog No
4 Title and Subtitle COMPARISON OF ELECTROMECHANICAL AND CATHODE-RAY-TUBE DISPLAY MEDIUMS FOR AN INSTRUMENT APPROACH DISPLAY		5 Report Date May 1979 6 Performing Organization Code
7 Author(s) Terence S. Abbott		8 Performing Organization Report No L-12805
9 Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		10 Work Unit No 513-54-13-02 11 Contract or Grant No
12 Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13 Type of Report and Period Covered Technical Memorandum 14 Sponsoring Agency Code

15 Supplementary Notes

16 Abstract

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17 Key Words (Suggested by Author(s)) Display systems Helicopter instrument flight reference	18 Distribution Statement Unclassified - Unlimited Subject Category 06

19 Security Classif (of this report) Unclassified	20 Security Classif (of this page) Unclassified	21 No of Pages 13	22 Price* $4.00

* For sale by the National Technical Information Service, Springfield Virginia 22161

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Comparison of Electromechanical and Cathode-Ray-Tube Display Mediums for an Instrument Approach Display

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National Aeronautics
and Space Administration

Scientific and Technical
Information Office

1979

SUMMARY

The increased use of electronic displays, particularly cathode-ray-tube displays, has become apparent in the modern flight-deck environment. For this reason, a piloted, ground-based simulation study was undertaken to compare a single electromechanical display format with similar cathode-ray-tube display formats. The effects of color, shading, and dimensionality were evaluated with respect to the pilot's ability to interpret and respond to displayed information.

INTRODUCTION

Future commercial aircraft operations will require the capability to perform curved, decelerating, steep instrument approaches into high-traffic-density terminal areas. Although increased control sophistication and automation themselves may lessen pilot workload, the increased complexity of the piloting task necessitates higher integration and interpretability of the multitude of visual data presented to the pilot (refs. 1 and 2). Electronic displays, in particular cathode-ray-tube (CRT) displays, have shown great potential in reducing the pilot's visual workload, and their ever increasing use in the aircraft environment is apparent.

With this increasing use of CRT displays in the cockpit, a basic study was undertaken to determine the effect on pilot performance of replacing a single electromechanical (EM) display with similar CRT displays. Although the advantages of using CRT displays in terms of flexible, integrated formats have been established, some of the desirable features of the EM instruments may be lost when displayed on a CRT. The attitude flight director indicator (ADI), for example, may employ a multicolored, three-dimensional attitude ball. This study was conducted to evaluate this "loss/gain" relationship between an EM display and similar CRT display formats, with emphasis on the effect on pilot performance of color, three dimensionality, and shading.

Use of trade names or names of manufacturers in this report does not constitute an official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

DESCRIPTION OF EQUIPMENT

General Description

This study employed a fixed-base simulator with the cockpit configured as a helicopter. The control response and flight dynamics that were modeled were those of a highly augmented helicopter. The simulator's cockpit instrument panel was configured to accept either an EM instrument or a CRT as the primary display. No other displays or instruments were used during this study in order to focus the pilot's visual attention to the one display. Therefore, this was not a handling-qualities study, and it was not assumed that actual instrument flight would be conducted under this restriction. A configuration block diagram of the simulation/display system is shown in figure 1. The host computer for the simulation, which contained the aircraft dynamics and the flight director command algorithms, was a Control Data 6600 computer system. Signals were sent from the Control Data 6600 to an Adage graphics computer and, by means of an interface, to a conventional ADI. Either a closed-circuit television (CCTV) picture or a computer graphics system was utilized to produce the alternate CRT displays tested.

A test matrix (fig. 2) was developed to allow, by process of elimination, the determination of the effects of three dimensionality, color, and monochromatic shading on pilot performance. The ordering of the test was such that the EM display was presented to the pilots first so that it could be used to evaluate the other test cases. The CRT displays were then presented to the pilots in a random order.

Baseline Display

The display chosen as a baseline for this study, Case I, was a Sperry HZ-6B Attitude Director Indicator, as shown in figure 3. This is an electromechanical instrument that provides pitch and roll attitude, three flight director commands (pitch, roll, and power), glide-slope deviation, cross-range deviation, sideslip, rate of turn, and altitude (rising runway below some fixed altitude). The instrument is a multicolored instrument and is inherently three dimensional. It was mounted in the simulator cockpit for the baseline portion of the study.

CRT Displays

Three CRT displays were selected for evaluation against the baseline display. The first CRT display, Case II, was a high-resolution, color CCTV picture of the electromechanical baseline display. This display was chosen to determine the effect of the loss of three dimensionality on pilot performance since the CRT display is, for all practical purposes, a two-dimensional (planar) display. The second CRT display, Case III, was again a CCTV picture of the baseline display, except that a monochromatic image was presented to determine the effect of the loss of color on performance. Both Case II and Case III displays employed a CRT mounted in place of the ADI in the simulator cockpit and a video camera aimed at an externally mounted ADI. The third CRT display, Case IV, was that of a computer-generated, graphic representation of the baseline display (fig. 4). This display was used to evaluate the effect of the loss of monochromatic shading on pilot performance. The cockpit-mounted CRT was again employed with its input from the Adage computer by means of a stroke-to-raster video converter. The CRT displays were of unity magnification, and all displayed symbology was sized and scaled to give a one-to-one correlation with the EM instrument.

TASK DESCRIPTION

The pilot's primary task for this study was flight director command-bar tracking which produced a steep, decelerating, manual instrument approach that terminated in a hover over a predetermined point (fig. 5). The initial conditions for the tests were level flight at 60 knots airspeed, zero vertical speed, 244 m (800 ft) altitude, 4572 m (15 000 ft) range from the landing pad, and 914 m (3000 ft) to the right of the extended runway center line. These conditions were chosen so that the extended center-line capture occurred before glide-slope capture. Upon initialization of the task, a roll-attitude command was displayed to the pilot which would produce a 45° intercept angle to the extended center line of the runway. At 2175 m (7136 ft) in range, a 6° glide slope was intercepted that terminated in a 15-m (50-ft) hover. At approximately 854 m (2800 ft), a deceleration command was initiated that would result in a zero-speed stabilized hover. The flight director logic was taken from work done in reference 3. The pilot's use of the simulator aircraft pedal controls was not required since sideslip was nulled by an automatic-turn coordination pedal input from the Control Data computer. The task was terminated after approximately 10 sec in a hover condition. A calm air assumption was used.

TESTS SUBJECTS

A total of five pilots was used for the qualitative data portion of the study. Three of the subjects were NASA test pilots with both helicopter and flight director experience. The other two test subjects were aerospace engineers related to the study and were former military helicopter pilots. Quantitative data were taken on one of the engineers and two of the research pilots.

RESULTS AND DISCUSSION

Both qualitative and quantitative data were taken during this study. The qualitative data were in the form of pilot comments, and the quantitative data were in the form of position and command tracking errors and control positions.

Quantitative Analysis

Using an analysis of variance technique, no significant difference could be found between the four display formats with regard to position tracking errors. A cross-correlation analysis was then made on each of the command tracking errors (flight director commands) and the applicable pilot control input by using the following equation:

$$\text{Correlation coefficient} = \pm \frac{\left(\sum x\right)\left(\sum y_\tau\right)}{\sqrt{\left(\sum x^2\right)\left(\sum y_\tau^2\right)}}$$

For this equation, x was equal to the ADI command for a particular axis, minus the mean of that command. The y_{τ} variable was equal to the pilot's control input in the same axis as the command, minus the mean of the inputs. The y_{τ} samples were correlated from a lag of 5 sec to a lead of 5 sec relative to the x samples in the time domain. Nine data runs were made with each display case, with approximately 4000 sampling intervals per run. This analysis was used to ascertain the pilot's response time to a given visual cue as an indication of the pilot's interpretability of a given display. Figure 6 presents the cross-correlations of the pilot's lateral control input and ADI roll command. Similar trends were shown for all of the display formats except the monochromatic CCTV display. The same correlation trends were shown for the longitudinal axis (fig. 7). The pilot's response to the vertical axis (power) command was inherently of much lower frequency than either the pitch or roll axis, and the analysis using this technique was inconclusive.

Qualitative Analysis

The basis for the qualitative analysis, in the form of pilots' comments, was with regard to the electromechanical display task.

In general, it was found that the loss of three dimensionality had no apparent effect on command bar tracking ability. Conversely, the lack of a parallax problem with the CRT displays could be an advantage since the command bars directly overlayed the command centering symbology; thus, an apparent zero command was a zero command regardless of the viewer's look angle. A disadvantage to this lack of parallax arose in several instances when multiple symbols overlayed (i.e., the pitch command bar, the fixed aircraft symbol, and the pitch and roll attitude line), and a shifted look angle could not differentiate the symbology. It should also be noted that a general complaint of eye strain was voiced when simulation sessions with the CRT displays ran continuously for more than 1 hr.

With respect to specific displays, the following comments were noted. First, the color CCTV display seemed no different to the pilots than the EM instrument except for parallax. However, when color was removed for the monochromatic display study, two major points were noted: (1) a higher level of concentration on the display was required; the pilots felt they had to "dig out" the information, and (2) it was found that during some portions of the task, the pitch command bar, the fixed aircraft symbol, and the artificial horizon would all overlay, making the display very difficult to interpret. The Case IV display (the computer-generated display) was easier to interpret than the monochromatic CCTV display. This may not hold true, however, if all of the symbology lines of the Case IV display are of the same width and could then overlay, as happened with the monochromatic display. Also, since there was no difference in shading between the upper and lower half of the attitude ball, the pilots were not consciously aware of their pitch attitude.

It should be noted that all displays were determined to be acceptable for the given task.

A summary of pilots' comments is given in table I.

CONCLUSIONS

Simulated flight tests were conducted to determine the effect on pilot performance of replacing an electromechanical display with similar CRT displays. Based on the qualitative results, the following conclusions are drawn:

1. The greatest detrimental effect on pilot perception was the loss of color. This was attributed to the ability of color to visually declutter the display. This visual clutter also led to the degraded command tracking ability of the monochromatic, multiple-shaded display relative to the single shade, computer-generated display.

2. The loss of three dimensionality had no apparent effect on pilot perception.

3. Interpretation problems can arise with a monochromatic, multiple-shaded display.

4. The lack of parallax may be an advantage with color displays, but parallax could be used to differentiate overlaying symbology in a monochromatic display.

5. All display formats were acceptable for the given task.

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April 9, 1979

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TABLE I.- SUMMARY OF PILOTS' COMMENTS

Electromechanical display	Cathode-ray-tube display		
Case I - three-dimensional, color	Case II - two-dimensional, color CCTV	Case III - two-dimensional, monochromatic CCTV	Case IV - two-dimensional, single shade of color, computer generated
Baseline	Three-dimensional loss has no effect Eye strain No apparent difference	Three-dimensional loss has no effect Eye strain Greatest detrimental effect - lack of color Have to dig out information Lose pitch command bar at transition to hover	Three-dimensional loss has no effect Eye strain Greatest detrimental effect - lack of color Easier than Case III Seems unreal Not aware of pitch attitude

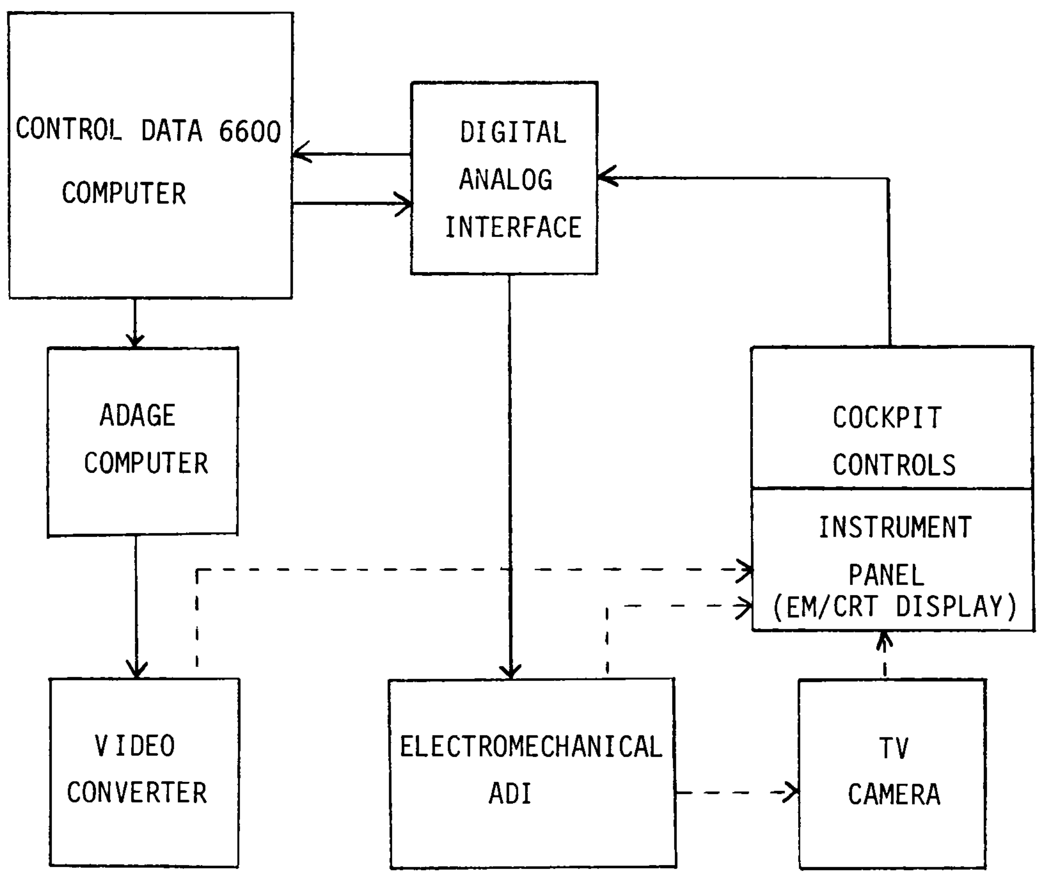

Figure 1.- Configuration block diagram.

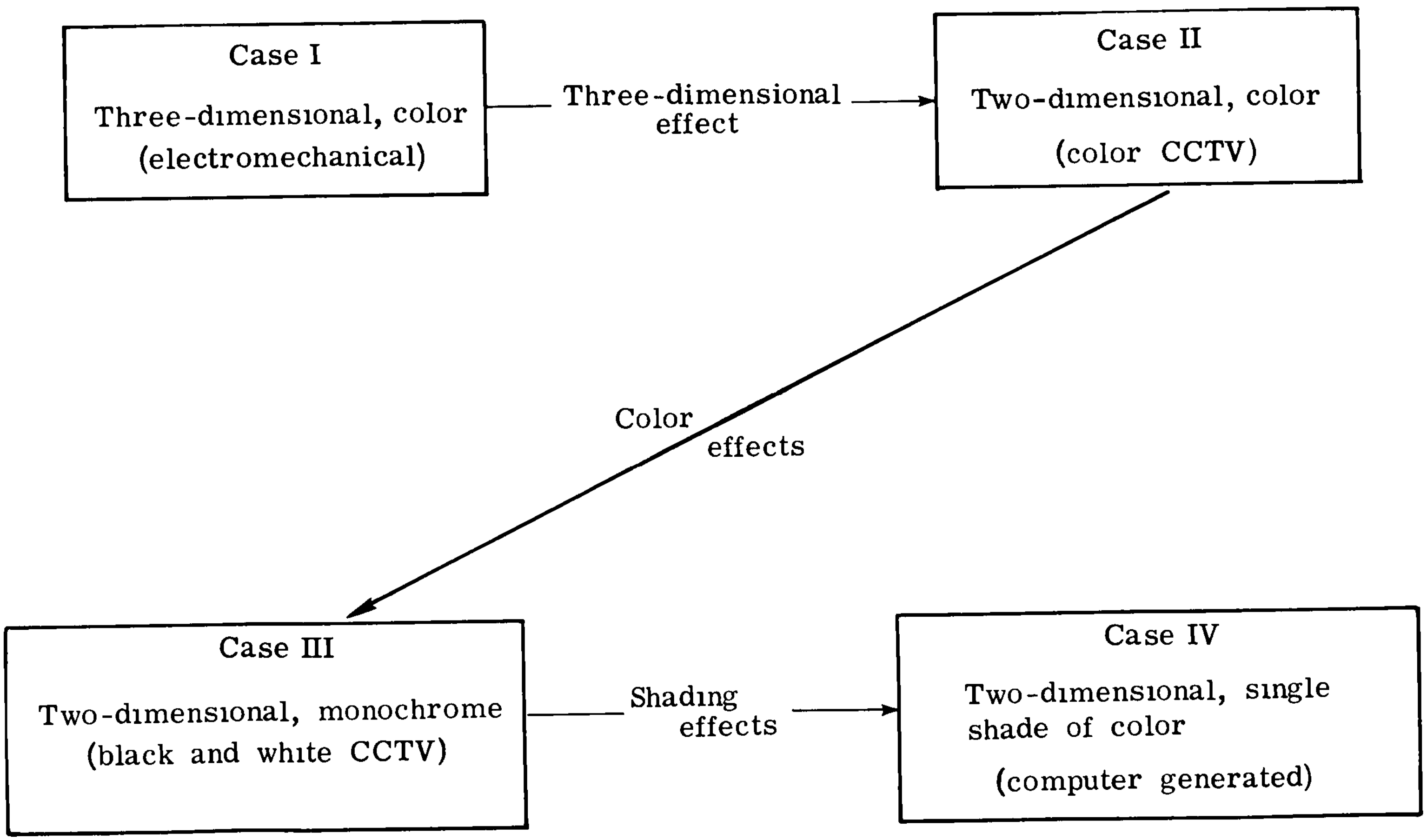

Figure 2.- Test matrix.

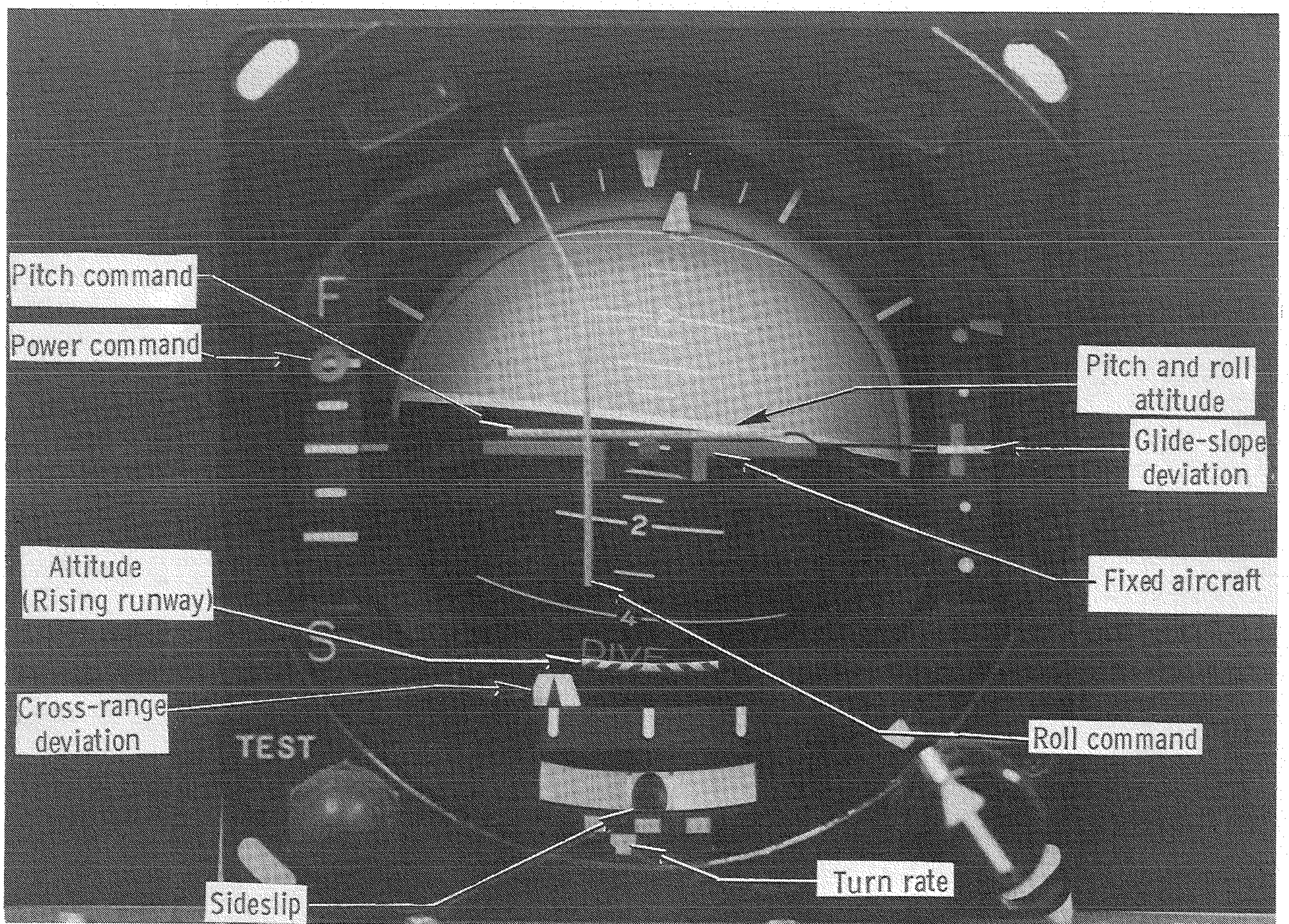

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Figure 3.- Electromechanical attitude flight director indicator.

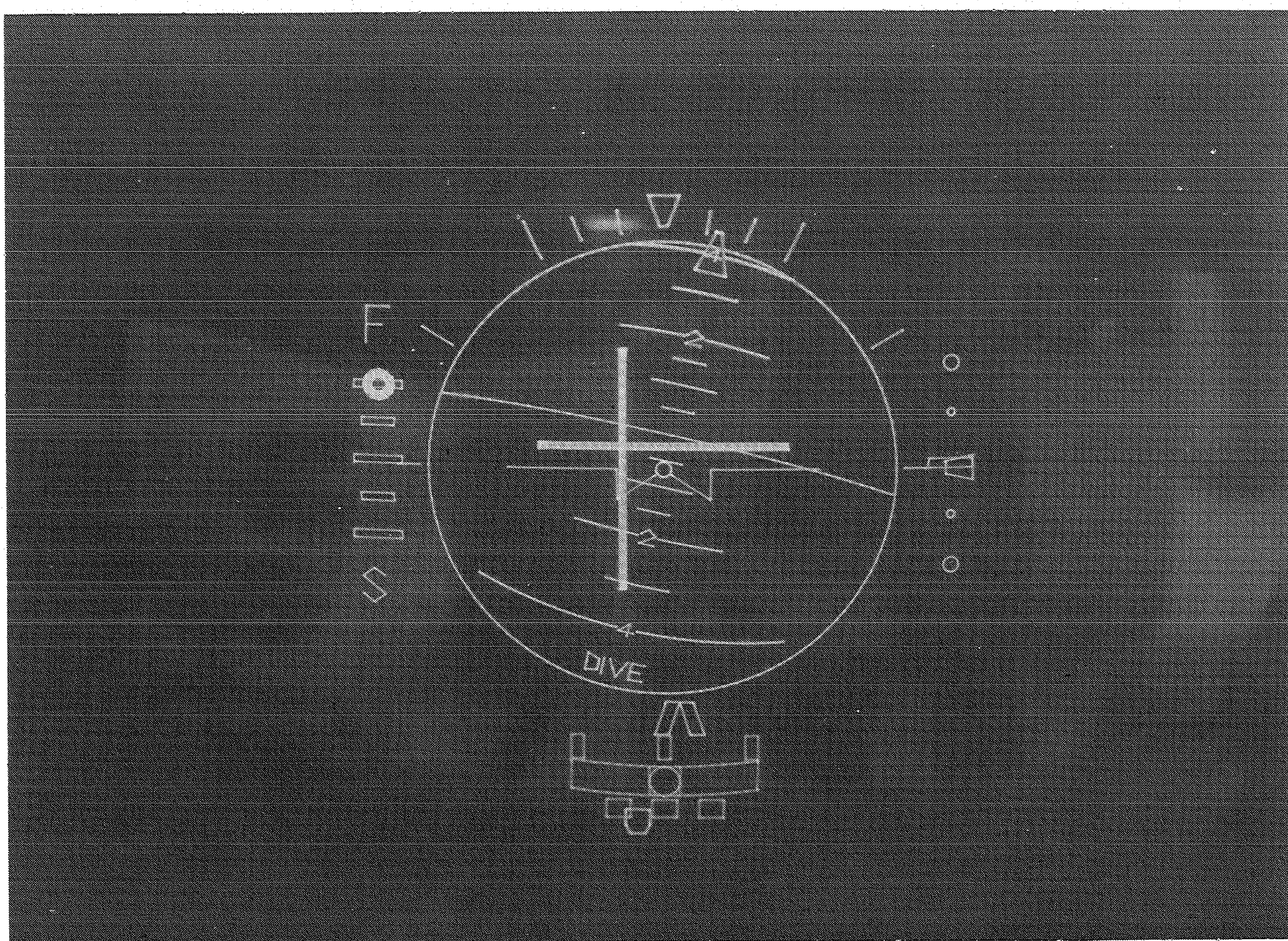

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Figure 4.- Computer-generated attitude flight director indicator.

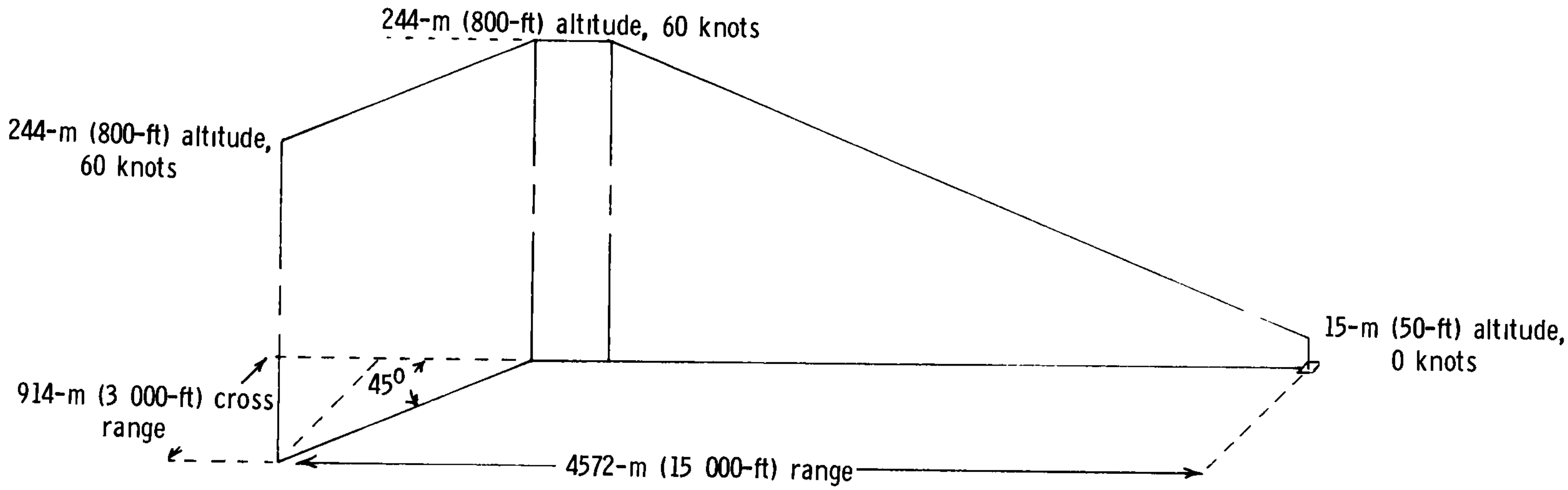

Figure 5.- Simulated flight profile.

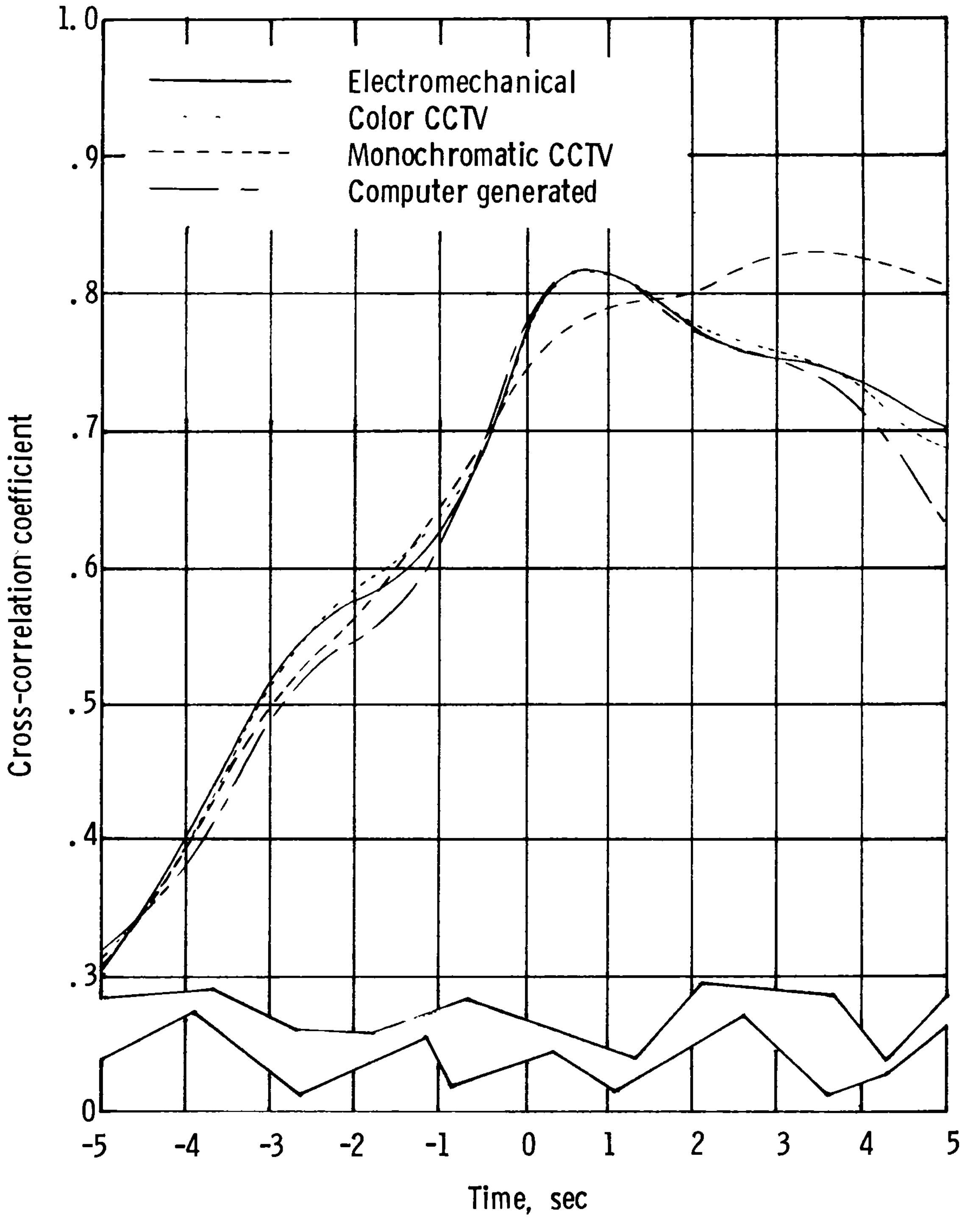

Figure 6.- Cross-correlation of pilot lateral control input and ADI roll command.

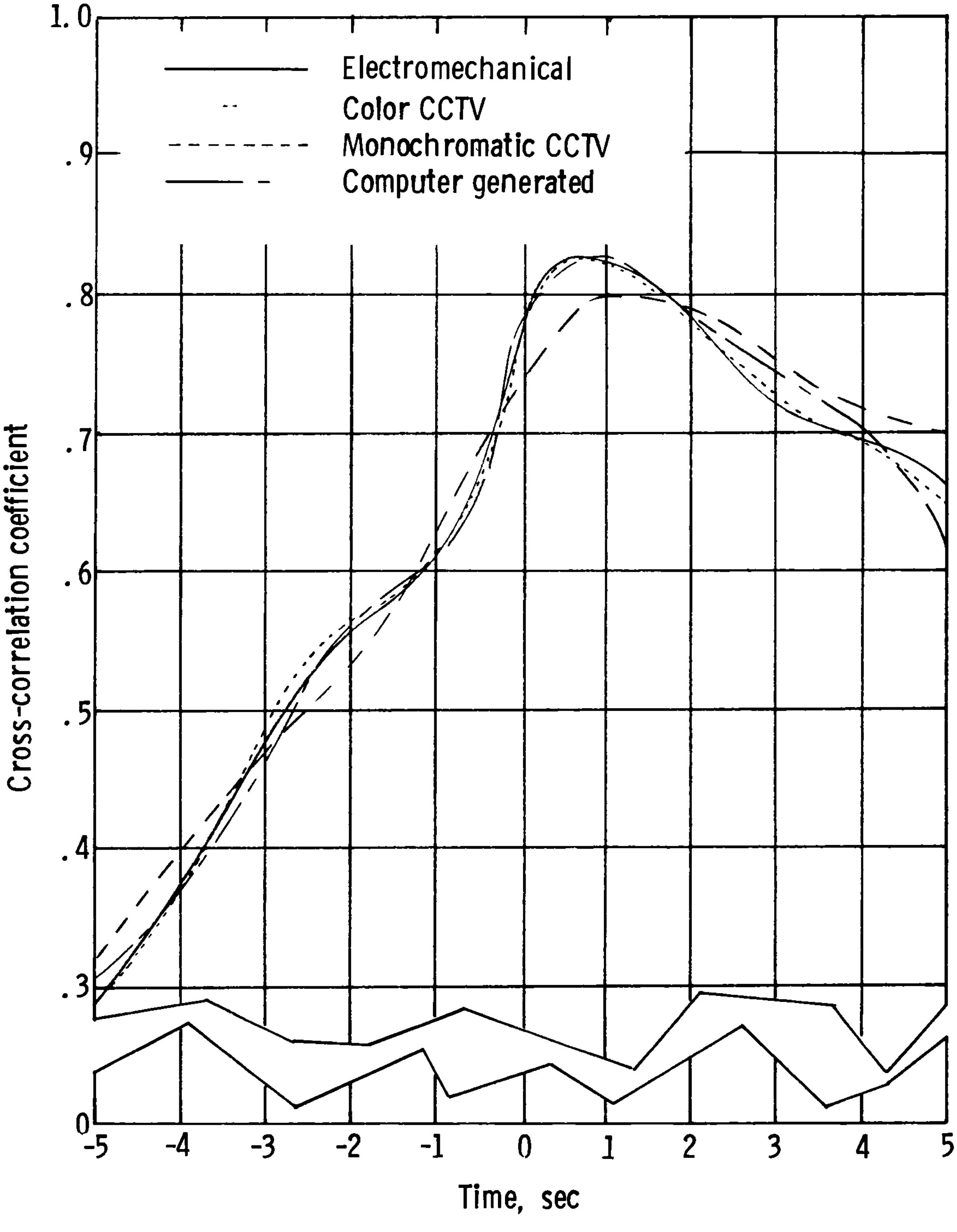

Figure 7.- Cross-correlation of pilot longitudinal control input and ADI pitch command.

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