EVALUATION OF TWO INSTRUMENT-LANDING DISPLAYS IN SIMULATED IFR APPROACHES WITH A HELICOPTER

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Abstract

Two instrument displays that differed principally in the manner in which course guidance was presented have been evaluated in landing approaches with a helicopter. In one display, course guidance information was presented as a flight-director command on a conventional cross-pointer indicator; in the other display, the information was presented on a moving-map indicator. The tests of the two displays were conducted under simulated IFR conditions along a 6° glide slope at approach airspeeds of about 30 knots. The approaches were carried to a 50-foot breakout and a visual slowdown to hover. The results of the tests are presented in terms of (1) flight performance (i.e., tracking along slope and course) and (2) pilot evaluation of the display concepts. The implications of the results to the design of improved displays are discussed.

Introduction

With present cockpit displays, the landing approaches of helicopters under IFR (Instrument Flight Rules) conditions are restricted to the low slopes (2.5° nominal) of the ILS (Instrument Landing System) and to breakout ceilings of 200 feet. If helicopters and other V/STOL aircraft are to be operated at steeper angles and to lower ceilings, improved instrument displays will be required - whether the aircraft are flown manually or controlled automatically. In the latter case, the improved display would still be required for monitoring the approach. In a program to determine the instrument display requirements for the landing of V/STOL aircraft, NASA is evaluating a variety of instrument displays using a helicopter as the test vehicle. This paper describes the results of tests of the first two displays that were evaluated in this program.[1,2]

Display Requirements

The term "instrument display requirement" refers not only to what information is required, but also how the information can best be presented. The basic information required for a V/STOL landing can be grouped according to attitude (roll, pitch, and heading), guidance (slope deviation, course deviation, range, and height), and speed (airspeed, vertical speed, and ground speed) (fig. 1).

Depending on the severity of the approach task (as determined by the glide slope, approach airspeed, and breakout ceiling), information in addition to the basic requirements may be needed. For example, for steep approaches to low breakout ceilings, the approach speed must be reduced to permit a safe transition to visual flight. If the required airspeed is below that for minimum power, the control technique for slope guidance requires that displacements from slope be corrected by power changes (collective control) and variations from the approach airspeed by changes in pitch attitude (longitudinal cyclic control). For slope guidance in this approach task, therefore, the instrument display must present two items of information - slope deviation for power control and pitch attitude from a selected reference for speed control.

In addition, the low airspeed of an approach can very well dictate the manner in which the information is presented. At very low speeds, for example, the effects of winds can be quite severe, causing continuous changes in attitude and position. For a constantly changing information situation, therefore, the items of information should be integrated in a meaningful display that permits easy interpretation and rapid assimilation.

Instrument Displays

The two test instrument displays were a cross-pointer type (fig. 2) and a moving-map type (fig. 3).

The instruments of the cross-pointer display included:

(1) A vertical situation indicator (VSI) for indications of roll and pitch attitude (on the artificial horizon), slope deviation (on the slope tab), reference pitch attitude (on the horizontal cross pointer), and flight director command for course control (on the vertical cross pointer).

(2) A horizontal situation indicator (HSI) for indications of heading (on the compass) and course deviation (on the double-line course bar).

(3) Vertical-scale indicators for the presentation of height and range (thermometer-type indications) and airspeed, vertical speed, and ground speed (moving pointers along fixed scales).

Note that reference pitch attitude was included as an information item since the tests of the two displays were conducted at speeds below the minimum power speed. Also note that this display includes two forms of course control information - course deviation and flight-director command.

In the moving-map display, the information presentations for vertical attitude (roll and pitch), slope control (slope deviation and reference pitch attitude), and airspeed, vertical speed, and height are the same as those on the

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cross-pointer display. The remaining items of information - those for course guidance - are presented on the map indicator. (Note that for the tests of this display, the vertical cross pointer on the VSI was deflected from view.)

The map indicator was an optical type that projects a map and an aircraft symbol (with axis extension line) on the rear face of a translucent screen. The map, a line drawing of the prescribed approach zone, moves laterally to indicate course deviation from the fixed aircraft symbol and moves vertically to indicate range to the landing pad. The aircraft symbol rotates to indicate heading with respect to the course center line.

The differences between the course guidance presentations on the two displays are illustrated in figure 4. The course-deviation indication of the HSI was not included in this figure since tests of the cross-pointer display showed the flight-director command to provide a more precise means of staying on course than the course-deviation indication. The flight-director command, incidentally, is a combined signal made up of course deviation, course-deviation rate, and roll angle; a deflection of the pointer indicates that a control action is required, and a centering of the pointer indicates that the proper control has been applied. The flight-director command, therefore, gives no explicit information on lateral position of the aircraft.

The most obvious difference between the two presentations in figure 4 is the fact that, with the cross-pointer display, the four items of information are presented on four indicators, whereas with the map display the information is combined as a single presentation. In the map display, the position information (course deviation and range) is combined in the form of a ground position plot. In the cross-pointer display, the range and lateral control information is not only presented separately, but also in a different form (i.e., a control command instead of a course-displacement indication). The heading indication on the cross-pointer display is true heading, whereas on the map display it is relative heading. The heading presentation on the map display also provides a pictorial representation of the angle, which the pilots found easier to use than the numbered-scale indication on the rotating compass of the HSI. The ground-speed indication on the cross-pointer display was also in numeric form and, although more precise, was more difficult to use effectively than the impressions of ground speed derived from the movement of the map.

The indications on the instruments of the two diagrams in figure 4 were arranged to show how the same information might appear on the two displays. This illustrative example is intended to indicate the comparative ease with which the information on the map display can be interpreted.

Approach Tests

The two displays were evaluated by the same test pilots, in the same helicopter and by the same approach task (a simulated IFR approach along a 6° glide slope to a 50-foot breakout). The approaches to the breakout were made at a constant airspeed of about 30 knots, or about 25 knots below the minimum power speed for the test helicopter. The IFR conditions were simulated by covering the windshield with amber plastic and having the pilot wear a visor of blue plastic. At the breakout height (as indicated on the height indicator), the pilot lifted his visor and brought the helicopter to a hover over the course line in as short a distance as possible.

The approach path patterns for the tests of the two displays were essentially the same. The slope path was $\pm 2^{\circ}$ with a terminal path ±50 feet wide for the final 1500 feet. The course path was $\pm 3^{\circ}$ with a terminal path ±75 feet wide for the cross-pointer display and ±100 feet for the map display. The boundaries of these paths corresponded to the maximum deflections of the slope tab and course bar, and to the maximum course-deviation input of the flight-director command. With the map display, the course boundaries were drawn on the landing approach charts.

Figure 5 shows the best of four approach charts that were tested in the map indicator. The chart is a two-part map with a 10-to-1 scale difference (1000 ft/in. for the initial part of the approach, 100 ft/in. for the final). The chart is a line drawing representing the course path shown on the left of the figure. The initial 7.5-inch portion of the map covers the first 7500 feet of the approach, and the final 25-inch portion covers the last 2500 feet. The intent of this arrangement was, of course, to give the pilot more precise position information in the terminal zone. The overall length of the approach chart as displayed on the screen was 33.5 inches. The relative size of the screen and map is indicated by the diagram of the screen on the terminal map.

For the tests of both displays, the position of the aircraft (in terms of range, height, course deviation, and slope deviation) was determined by a ground-based, precision-tracking radar (ref. 1). This position information, together with ground-speed and vertical-speed signals (which were also determined by the radar), was transmitted to the aircraft by radio link.

Results

The results of the tests of the two displays are presented in terms of (1) tracking performance along course and slope and (2) longitudinal and lateral deviations from the specified point for the 50-foot breakout. Performance data are given for one of the three pilots who evaluated the displays.

Figures 6 and 7 present the course and slope tracks of seven approaches with each of the displays. The course deviations and heights on these figures are plotted to scales five times the range scale, so that the plotted tracks present a distorted picture of the actual tracks. The winds for both series of tests were about the same - 8 to 9 knots with an appreciable cross-wind component.

With the flight-director command on the cross-pointer display (fig. 6), the course tracking was very precise; for the final mile of the approach, the maximum deviation was no greater than 50 feet. The slope tracking, however, was less precise than the course tracking, and the rapid deviations from path in some of the approaches were a matter of serious concern because they indicate a loss of either speed or attitude control.

With the map display (fig. 7), the deviations from course in the range beyond 1000 feet were much greater than with the flight-director command. The tracks, however, were all well within the course boundaries, and the tracking improved as the breakout point was approached. The slope tracking with this display was generally better than with the cross-pointer display, thus indicating a more precise control of speed and attitude. An examination of the time histories of the airspeeds for the two series of approaches showed that the airspeed variations from the approach speed were about ±3 knots with the map display and about ±5 knots with the cross-pointer display.

The deviations from the specified 50-foot breakout point are shown in figure 8. The lateral deviations for the two displays are about the same (within ±30 feet), but the longitudinal deviations (which are an indication of the slope deviations at breakout) are smaller with the map display.

From a consideration of both tracking performance and precision of position at breakout, the results of the tests showed that the pilots' overall performance (control of course, slope, airspeed, and attitude) was generally better with the map display than with the flight-director command of the cross-pointer display.

Discussion

The pilots' evaluations of the two course-guidance presentations were in agreement with their tracking performance with the two displays. Using the flight-director command, which gave no information on lateral position, the pilots tended to concentrate on keeping the cross pointer centered in order to insure that they would not stray too far from course. The flight-director command, therefore, essentially constrained the pilots to follow the center line of the course. With the continual movement of the cross pointer at low speeds under adverse wind conditions, the lateral control task demanded so much of the pilots' attention that insufficient time was left for satisfactory control of speed, attitude, and slope.

With the map display, the pilots were able to see at a glance their position with respect to the course boundaries and thus had the option of deciding whether they should correct for course or attend to the other control tasks. This positive knowledge of position in the approach zone gave the pilots a feeling of confidence that had the effect of reducing their workload. The fact that the presentation of position and heading was so easily interpreted was felt to allow better distribution of the pilots' attention to all of the control tasks.

The favorable acceptance by the pilots of the graphic presentation of course guidance information on the map display suggests that pictorial representations might well be applied to the other control tasks. From this consideration, it might appear that the answer to the V/STOL landing-display problem might be the contact analog, in which the information for all of the control tasks can be presented as a single display. However, the work that has been done with the contact analog thus far (see, for example, ref. 3) has demonstrated that the position information of this type display is not sufficiently precise for the landing to a preselected point on the ground, and that the display must, therefore, be augmented by separate indications of position - particularly height, and possibly range.

Another approach to the problem of creating realistic presentations, in terms of control tasks, has, therefore, been considered. In this approach, the information for slope guidance would be presented on a moving height-range chart on which the glide slope and slope boundaries would be depicted. This indicator would be incorporated in a display that includes the map indicator, a new attitude indicator (that presents vertical attitude and reference pitch in an uncluttered format), and vertical-scale indicators for airspeed and vertical speed. The instruments for such a display have been designed and will be evaluated as a display concept in the NASA instrument display program.

Summary

In 30-knot, 6° approaches to a 50-foot breakout, the pilots' performance of the overall control task was better with the map display than with the cross-pointer display. At the 50-foot breakout, the lateral deviations were about the same with the two displays, but the longitudinal deviations were smaller with the map display. Although course tracking prior to breakout was more precise with the flight-director command of the cross-pointer display, the pilots' concentration on the command signal resulted in a tendency to neglect the control of slope, speed, and attitude. In contrast, the ground-position plot of the map display was so easily and quickly interpreted that it allowed a better distribution of the pilots' attention to the overall control task. The ready acceptance by the pilots of the realistic presentation of course-guidance information on the map indicator has suggested that this moving-graph concept might well be applied to the presentation of slope guidance information.

References

1. Gracey, William; Sommer, Robert W.; and Tibbs, Don F.: Evaluation of a Cross-Pointer-Type Instrument Display in Landing Approaches With a Helicopter. NASA TN D-3677, 1966.

2. Gracey, William; Sommer, Robert W.; and Tibbs, Don F.: Evaluation of a Moving-Map Instrument Display in Landing Approaches With a Helicopter. Proposed NASA TN, 1967.

3. Joint Army Navy Aircraft Instrumentation Research (JANAIR) Project Tech. Report No. D228-420-009, Flight Evaluation of the Contact Analog Pictorial Display System. Bell Helicopter Company, February 1966.

ATTITUDE	GUIDANCE	SPEED
ROLL	SLOPE DEVIATION	AIRSPEED
PITCH	COURSE DEVIATION	VERTICAL SPEED
HEADING	RANGE	GROUND SPEED
	HEIGHT	

Figure 1.- Basic information required for V/STOL landing approach.

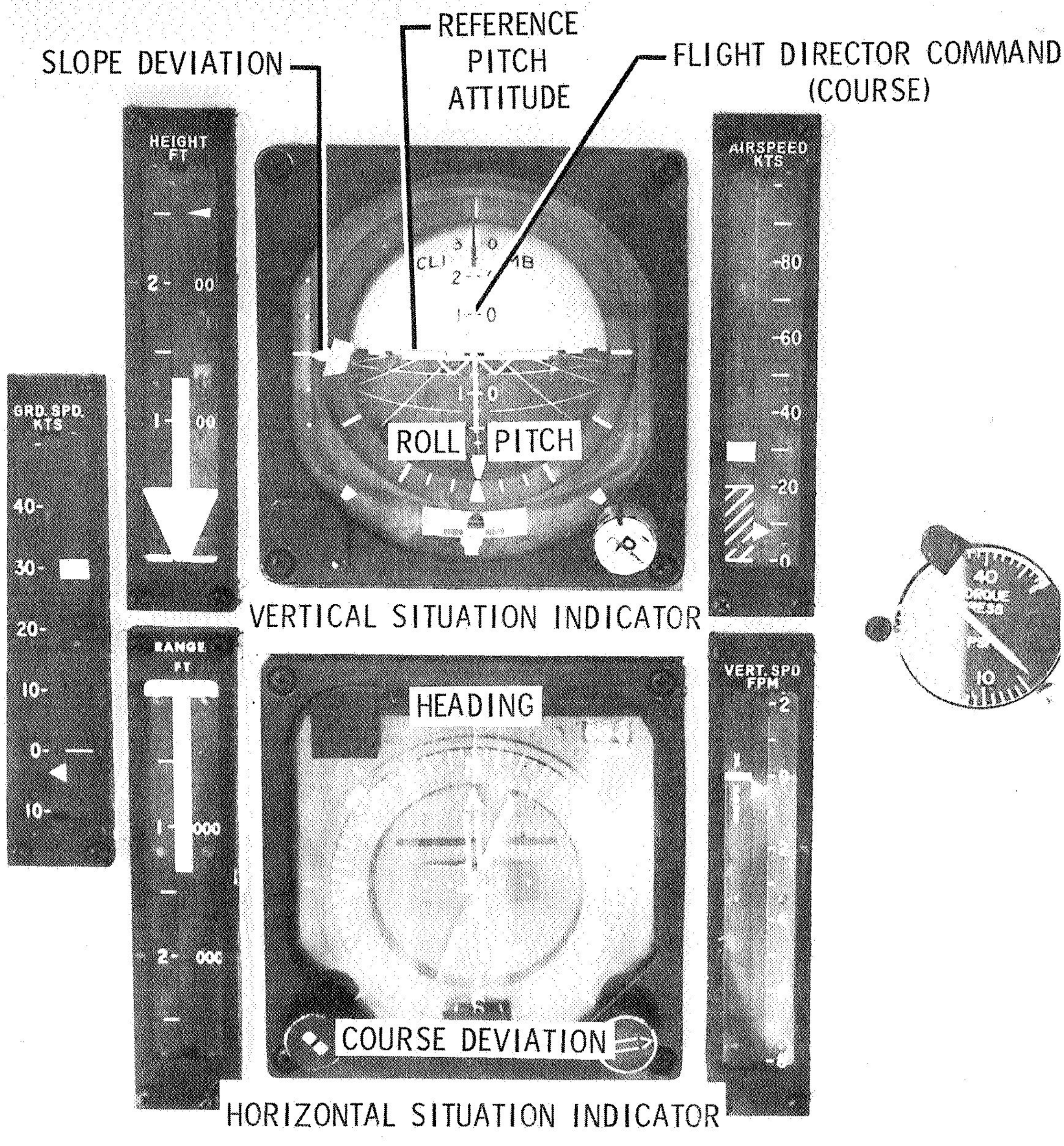

Figure 2.- Cross-pointer display installed in helicopter.

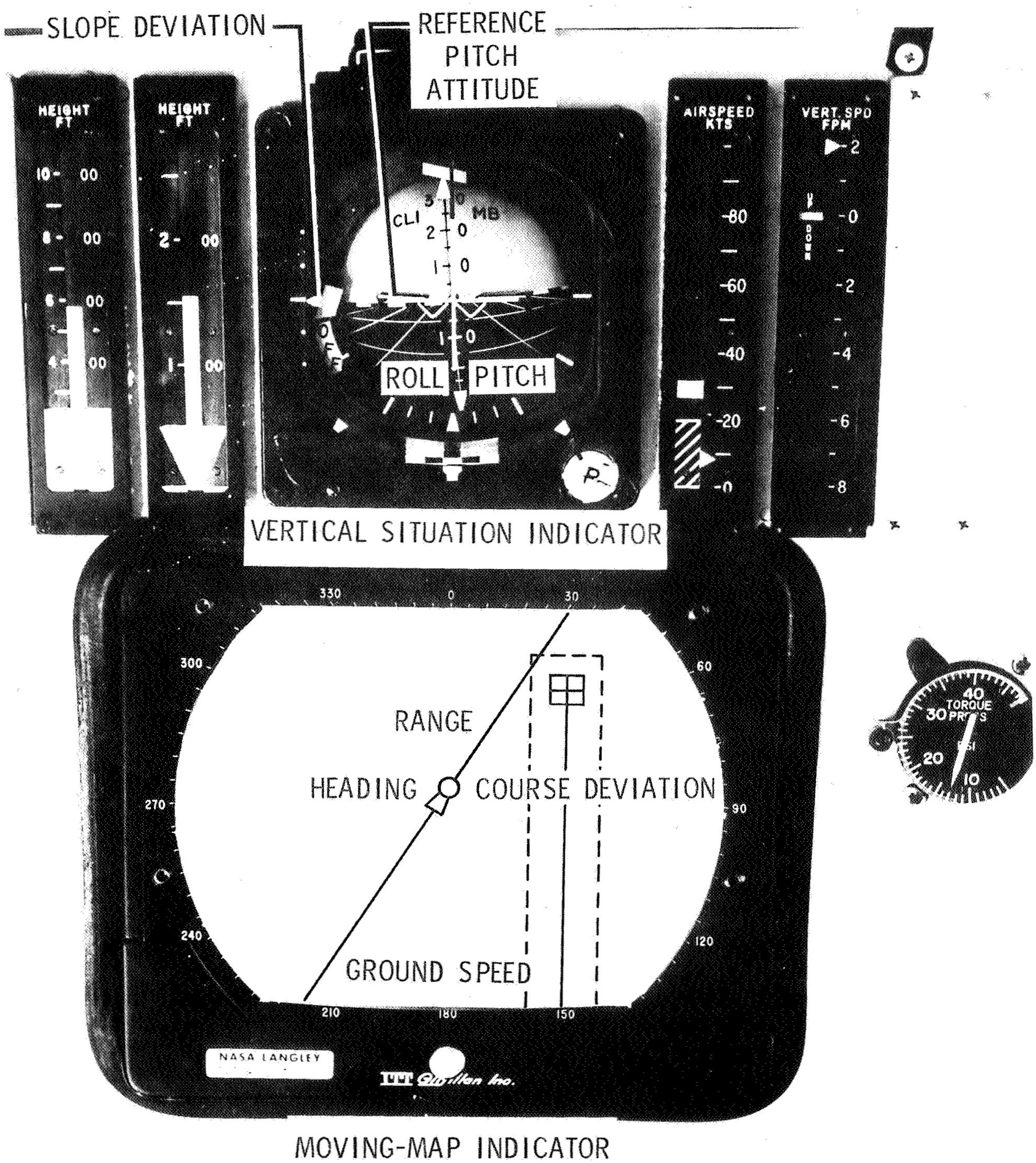

Figure 3.- Moving-map display installed in helicopter.

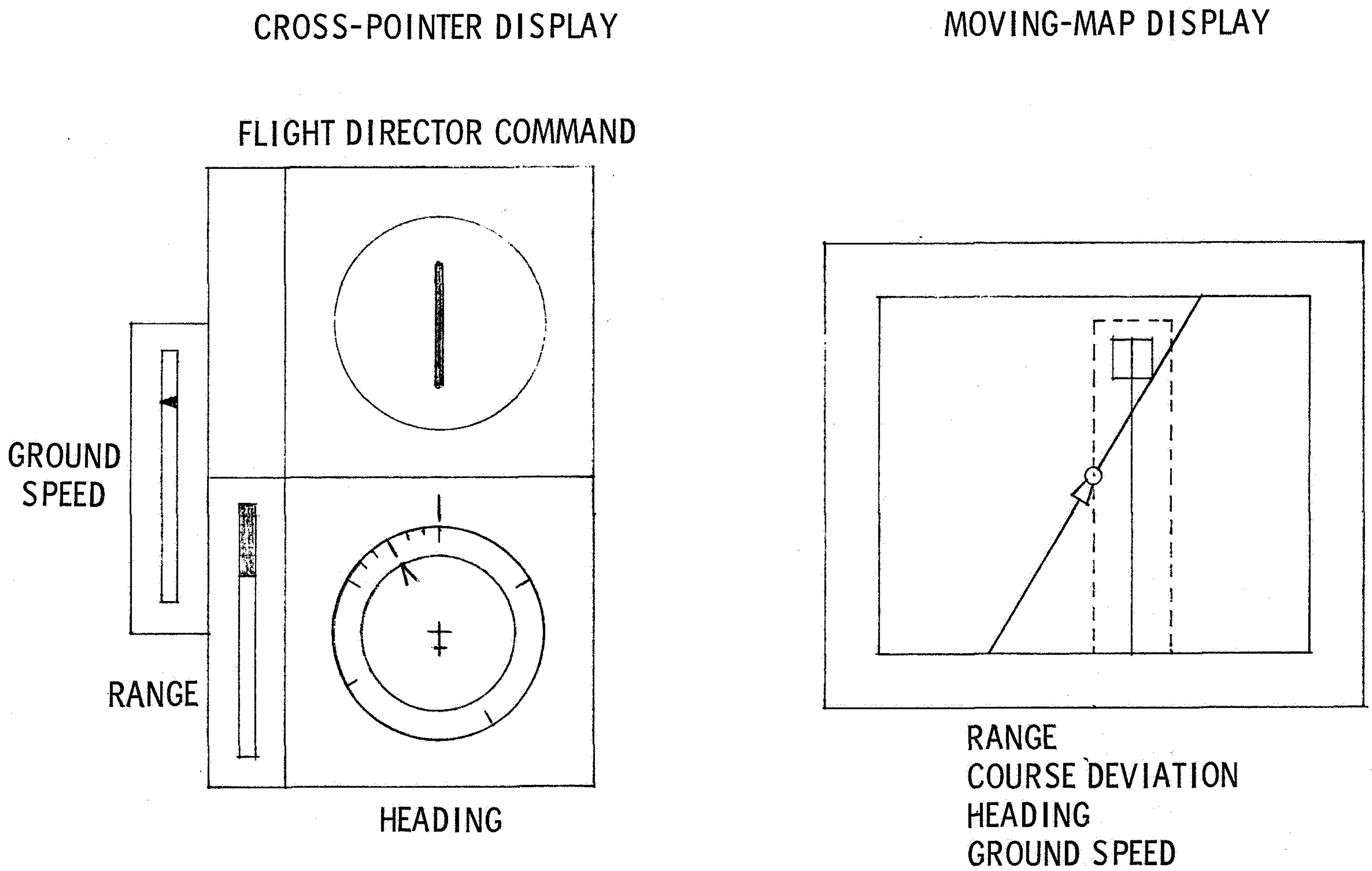

Figure 4.- Comparison of course guidance presentations on cross-pointer display and on moving-map display.

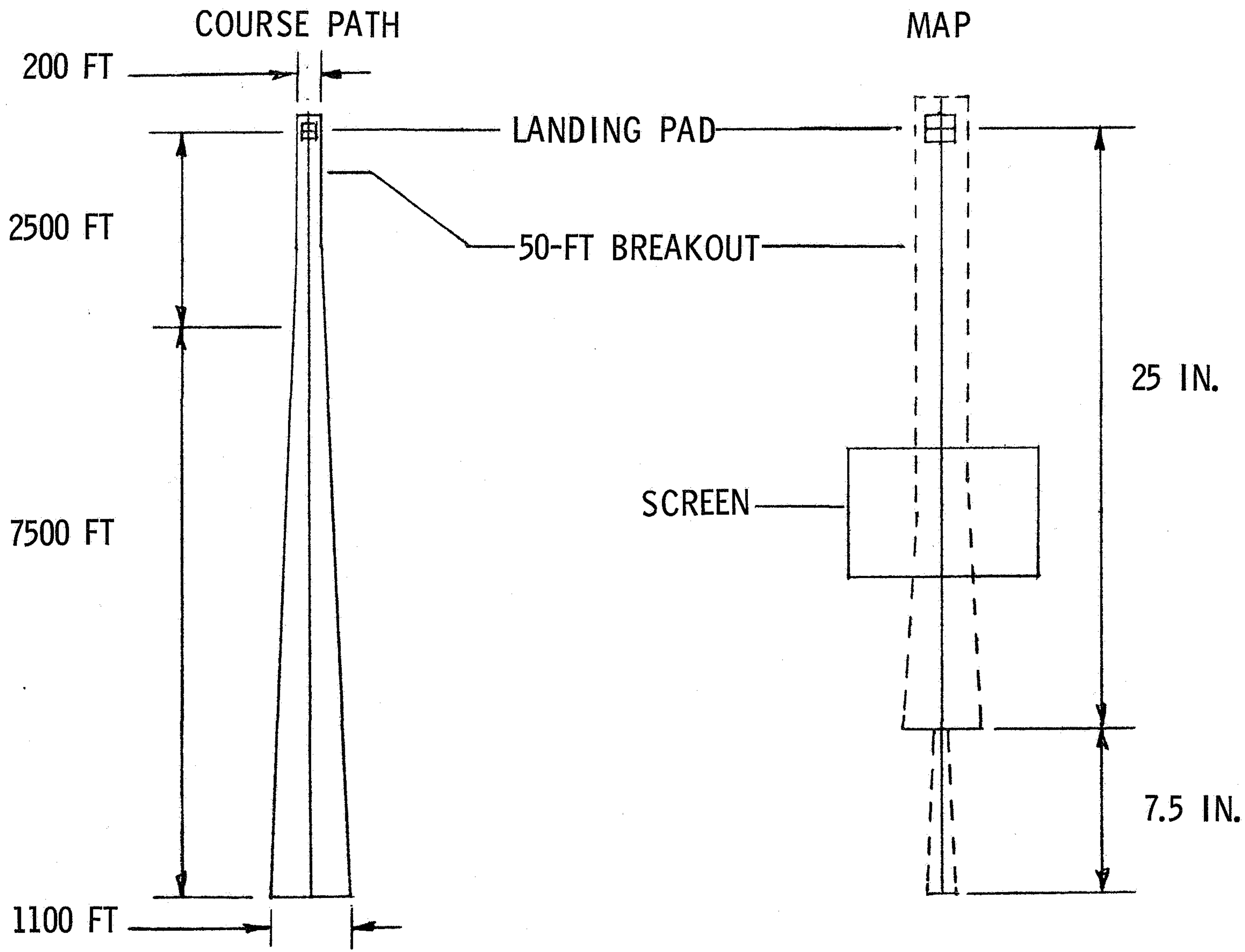

Figure 5.- Landing approach map and course path used in tests of moving-map display.

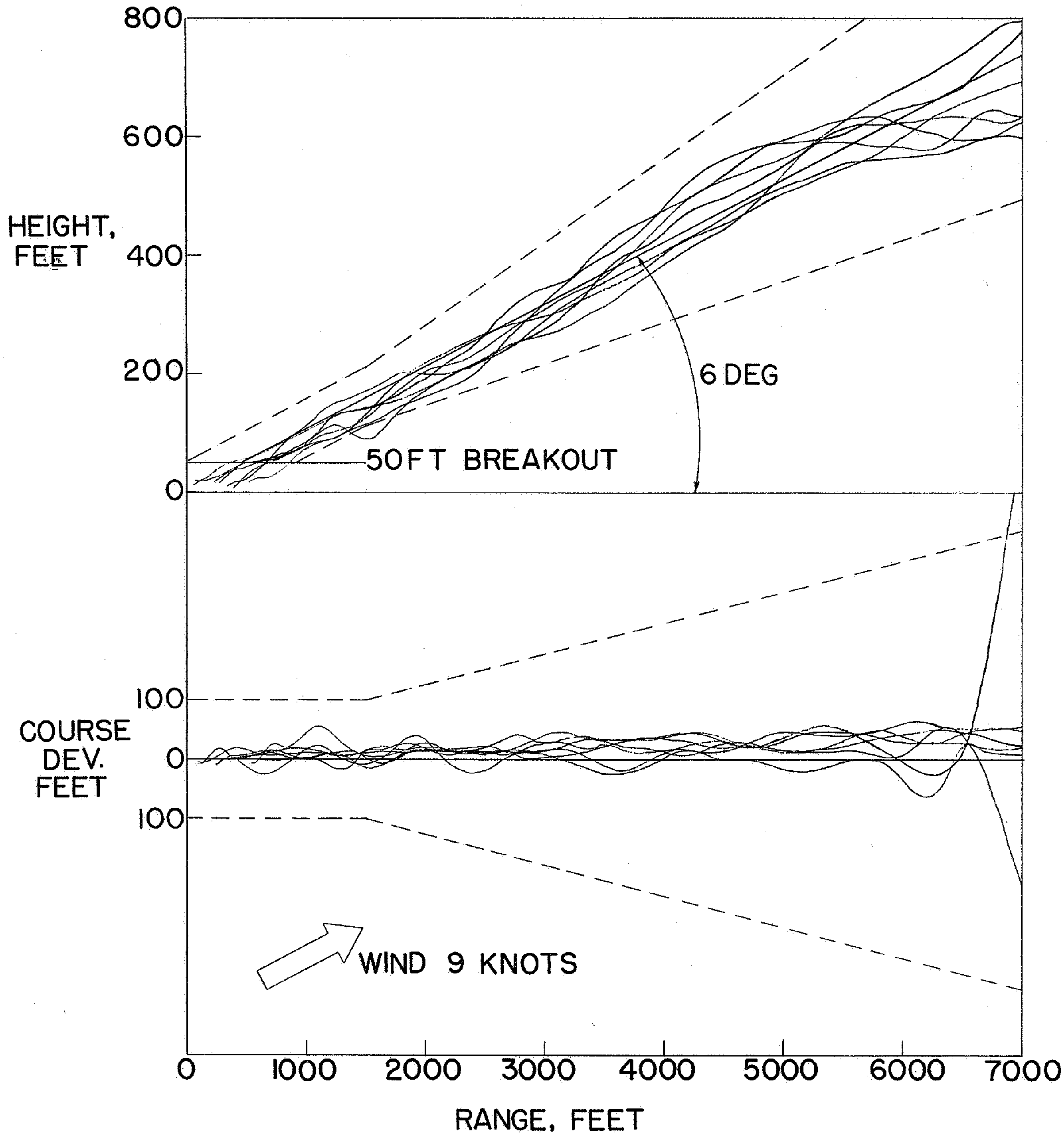

Figure 6.- Slope and course tracks of seven approaches with cross-pointer display using flight director command for course guidance.

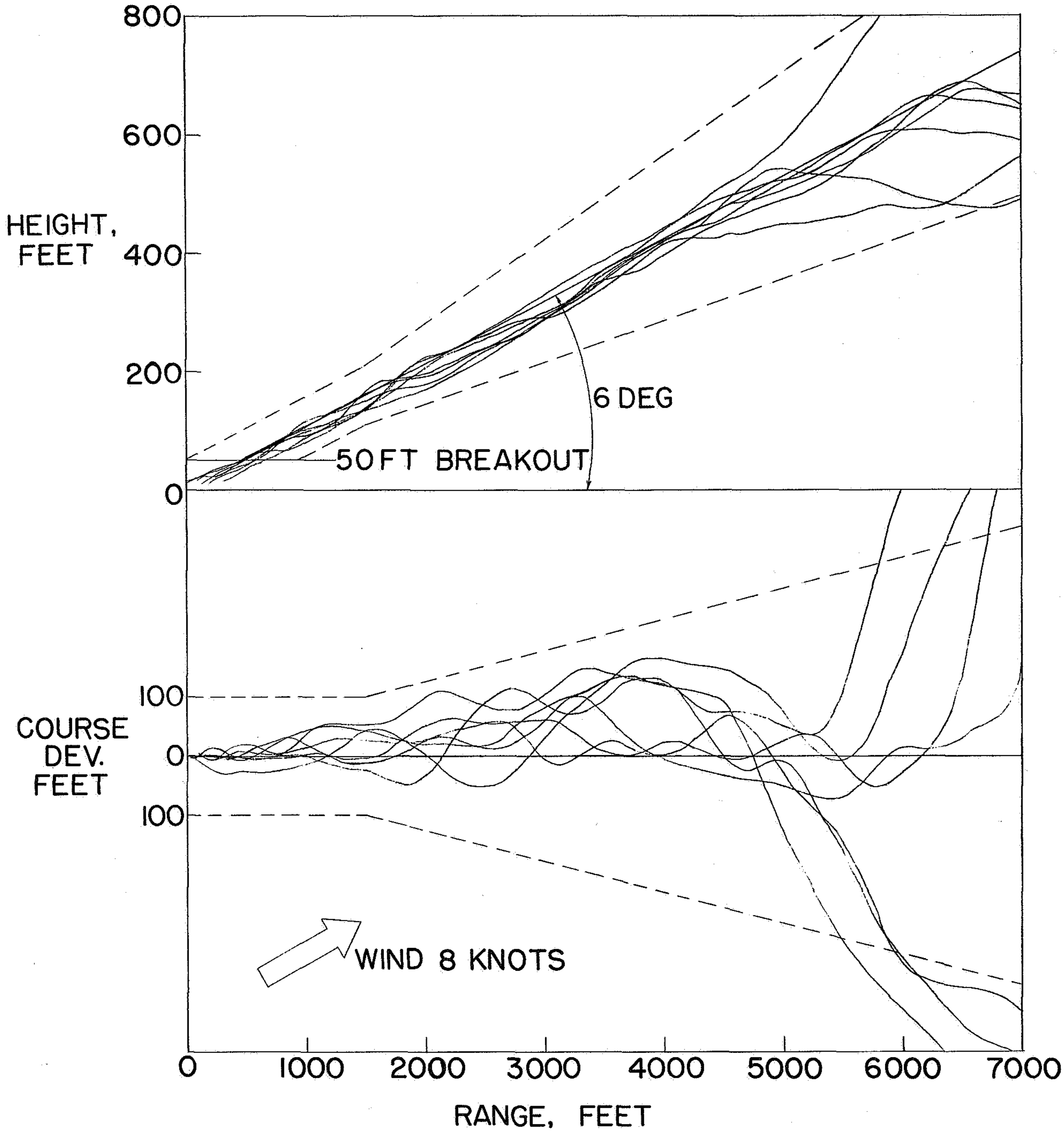

Figure 7.- Slope and course tracks of seven approaches with moving-map display using map shown on figure 5.

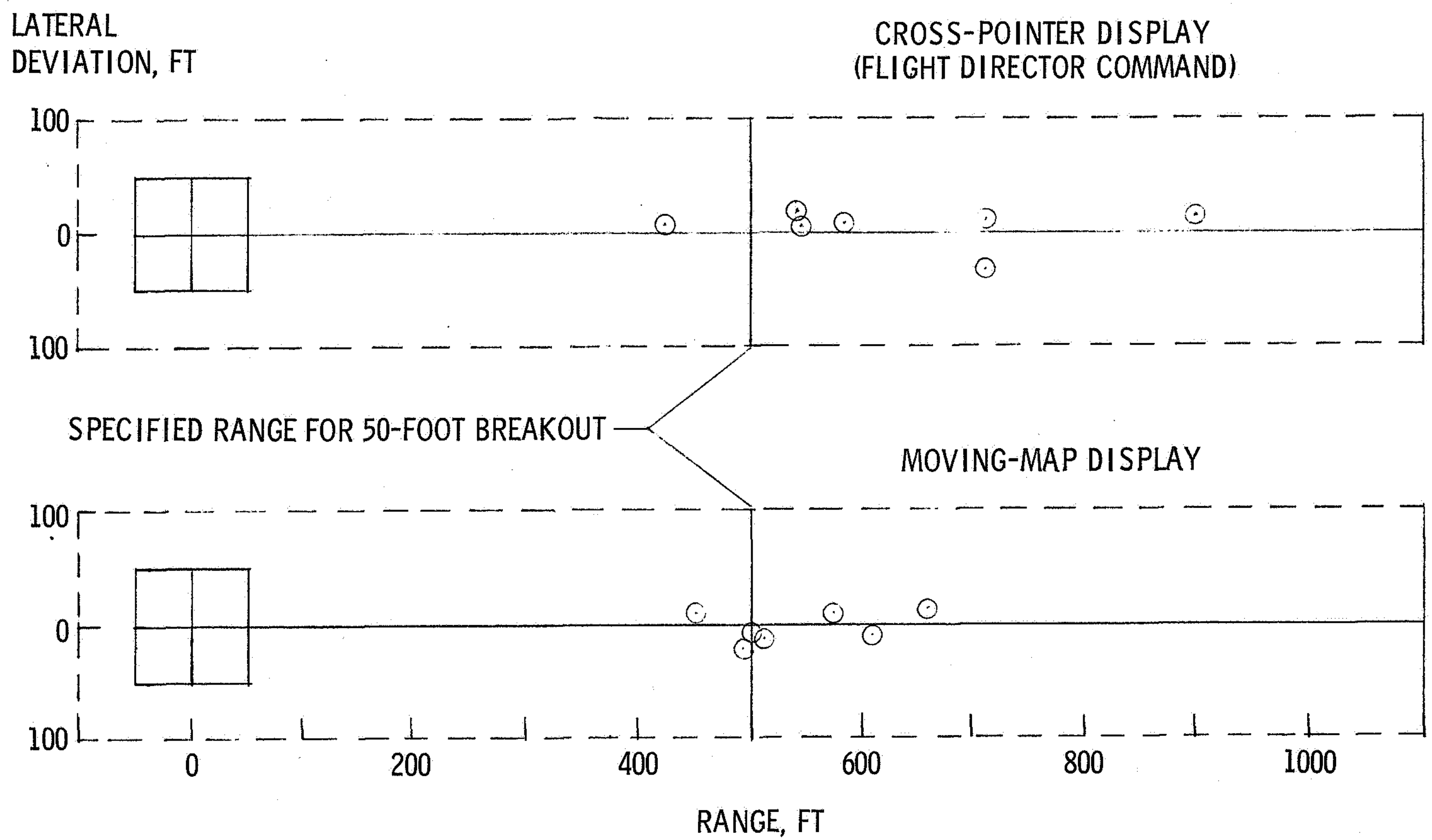

Figure 8.- Deviations at 50-foot breakout for the approaches shown on figures 6 and 7.

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