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OPERATIONAL ASPECTS OF STEEP VTOL APPROACHES AS DETERMINED FROM HELICOPTER TESTS UNDER SIMULATED IFR CONDITIONS

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ABSTRACT

The operational factors pertaining to steep VTOL approaches under IFR conditions are discussed. The factors that determine the structure of the landing-approach corridor include glide slope angle, path widths, approach length, breakout height and location of landing pad with respect to slope origin. With a selected approach structure, operational data determined in tests of two experimental instrument displays under simulated IFR conditions are presented. The data include tracking performance, breakout precision, stopping distance and overall time for the approach.

INTRODUCTION

In the planning of approach corridors for VTOL landings under instrument conditions, questions arise regarding such operational factors as (1) steepness of glide slope and path widths for slope and course, (2) ceiling and visibility minimums, and (3) approach speeds and length of approach. Information on these factors are needed for considerations of obstacle clearance, weather forecasting and traffic handling. The answers to these operational questions depend for the most part on the flight characteristics of the aircraft (particularly its controllability at the approach airspeed) and on the capabilities and limitations of the cockpit display.

In early studies at the Langley Research Center (ref. 1), an investigation was made of the steep approach capabilities of a helicopter under simulated IFR conditions. In a more recent evaluation of instrument-landing displays in another helicopter (refs. 2-4), tests were conducted to determine usable values, not necessarily optimum, for the operational factors relating to VTOL approach corridors.

Although the operational information obtained in the display tests applies specifically to the displays tested, it is believed it will apply generally for other displays designed for steep VTOL approaches. Furthermore, although the information was determined for constant-speed approaches to a specified breakout height, it is believed the structure of the approach will also be applicable for future displays that permit zero-zero landings.

TEST INSTRUMENT DISPLAYS

The first of the two displays of the recent investigation is shown in figure 1. In this display, conventional flight indicators were used for the presentation of attitude and guidance information. Vertical scale instruments were used for the indication of airspeed, vertical speed, ground speed, range and height.

Slope guidance information was presented as slope deviation on a moving index; for approach speeds below the speed for minimum power, the slope-deviation information was used in conjunction with a reference pitch-attitude indication on the horizontal needle of the cross-pointer. Course guidance information was presented as a flight director command on the vertical needle of the cross-pointer.

The second display is shown on figure 2. This display differs from the first in presenting course guidance information on a moving map indicator. The information for slope guidance, speed and attitude control is in the same form as on the first display.

The map indicator is an optical type that projects a map on the rear face of a transluscent screen. The maps used in the display evaluation were simple line drawings of the type shown on the photograph. The map moves laterally and vertically to indicate course deviation and range to the landing pad. The aircraft symbol at the center of the screen rotates to indicate heading with respect to the course line.

The tests of the first display showed that the pilot concentrated on the flight director command for course guidance to the extent that he tended to neglect the control of speed, attitude and slope guidance. At approach speeds of 30 knots (a speed well below the minimum power speed), the pilot found the task to be quite difficult and the work load very high. At speeds of 60 knots (above the minimum power speed), the task was less demanding and the work load somewhat reduced.

The tests of the second display showed that, because the pilot could see immediately his position with respect to the course boundaries, he was able to spend more time on the other control tasks; thus, his overall performance of the approach task was better than with the first display. The work load for 30-knot approaches was also noticeably lower than for the 30-knot approaches with the first display.

OPERATIONAL FACTORS

The operational factors that have to be considered in setting up a landing-approach corridor for steep VTOL approaches are illustrated in figure 3.

The maximum glide slope angle γ that can be used depends primarily on the minimum speed at which the pilot can adequately control the aircraft and on the maximum rate-of-descent at which he can stay on the glide slope. In the helicopter approach tests of reference 1, it was concluded that, for an approach system designed to handle traffic at approach speeds of from 25 to 65 knots, the maximum practical angle for day-to-day operations with a reasonable level of pilot effort is about 6 degrees. The displays of the recent investigation, therefore, were both evaluated along a 6-degree glide slope.

The angular widths θ and Ψ of the slope and course paths required for satisfactory tracking are dependent on the characteristics of both the aircraft and the display. For the test helicopter and the two displays of the recent program, it was determined that satisfactory tracking could be achieved within a slope path of ±2 degrees and a course path of ±3 degrees. This course path is about the same width as that of the ILS (Instrument Landing System), but the slope path is about three times the width of the ILS slope path. As shown on figures 4 through 6, the path patterns for the display tests differed from the angular paths of the ILS in providing constant-width paths for the final 1500 feet of the approach. For the slope path, the terminal path was ±50 feet wide; for the course path, it was ±75 feet for the first display and ±100 feet for the second. These combined angular and constant-width paths were generated by the computing equipment of a tracking radar used to determine the position of the helicopter during the approach.

The required length L of the approach corridor is determined by the time needed, for a given approach speed under zero wind conditions, to intercept the course, acquire the glide slope and stabilize on the approach speed for a sufficient time prior to the breakout. The tests of the two displays showed that a distance of two miles is ample for an approach speed of 60 knots. For 30-knot approaches, a length of about 1-1/2 miles is sufficient. Thus, a two-mile corridor would be sufficient to accommodate both approach speeds. For the two-mile approach, the intercept altitude H on a 6-degree slope would be about 1000 feet; for a 1-1/2-mile approach, it would be about 750 feet. With the conventional 5-mile, 2-1/2-degree approach of the ILS, the intercept altitude is about 1200 feet.

The minimum permissible breakout height for a given glide slope and approach speed depends on the deceleration capabilities of the aircraft and on the time required for the pilot to effect a safe transition to visual flight. In 60-knot approaches with the first display, it was found that 100 feet was a practical lower limit for a safe breakout. In 30-knot approaches with both displays, a 50-foot breakout was found to be the minimum feasible. If a 6-degree slope is considered the maximum presently feasible for VTOL operations and 30 knots the minimum safe flying speed for this slope, then a 50-foot breakout would appear to represent the lower limit for constant-speed VTOL approaches.

The distance l between the slope origin and the center of the landing pad is dependent on the allowable longitudinal dispersion at breakout (determined by the width of the slope path at the breakout height) and on the distance required to bring the aircraft to a stop following the breakout. In the tests of the two displays, it was found that, for all head and cross wind conditions encountered in the tests, the combined longitudinal dispersions and stopping distances were such that the helicopter was brought to a stop at or short of the slope origin. From this result, it might appear that, for an operational approach corridor, the landing pad could be located at the slope origin. However, if the slope width at the breakout height is ±50 feet, the pilot could break out as much as 500 feet "long" from a 6-degree slope. To provide for this possibility, therefore, it would appear advisable to locate the landing pad about 500 feet down course from the origin of a 6-degree slope.

OPERATIONAL DATA

The operational data obtained from the tests of the two displays include tracking performance, breakout precision, stopping distance and overall time for the approach.

For the tests of the two displays, IFR conditions were simulated by covering the windshield with amber plastic and having the pilot wear a visor of blue plastic. The approaches were started at a position about 500 feet to one side of the course and a height of about 1000 feet for the 60-knot approaches and 600 to 800 feet for the 30-knot approaches. On reaching the breakout height, as indicated on the altimeter, the pilot lifted his visor and brought the helicopter to a stop along the course line.

The tracks along slope and course for the 60-knot and 30-knot approaches with the first display and the 30-knot approaches with the second display are presented in figures 4, 5, and 6. Note that the excursions from slope and course are exaggerations of the actual excursions because the course deviations and heights were plotted to a scale five times the range scale. The average values of the winds for these approaches were from 8 to 11 knots, with cross-course components.

The plots in figures 4, 5, and 6 show that the width of the slope path is generally compatible with the tracking performance obtained with the slope guidance presentation on the two displays. Although the course path appears wider than necessary for the cross-pointer display, the width is obviously needed for satisfactory tracking with the map display. Since a display incorporating the essential features of the map display would probably be needed for 30-knot approaches to a 50-foot breakout (because of the great difficulty of flying the cross-pointer display at 30 knots), an approach system intended for both 50-foot and 100-foot breakouts would probably require the ±2-degree slope path and ±3-degree course path of the display tests. From a consideration of the slope deviations at breakout, it would appear that the constant width paths are advisable for the final 1500 feet of the approach.

The tracks on figures 4, 5, and 6 also illustrate two statements made previously, namely: (1) that in the 30-knot approaches (particularly with the map display), the slope and course were acquired at ranges of about 1-1/2 miles and (2) for all approaches, the helicopter was brought to a stop at or short of the slope origin, even for those cases where the breakout occurred on the "long" side of the prescribed breakout point.

The longitudinal and lateral deviations at breakout for the runs shown on figures 4, 5, and 6 are plotted in figure 7. For both the

60-knot and 30-knot approaches, the lateral deviations were within 30 feet. The longitudinal deviations were generally on the "short" side, and those on the "long" side (the ones of concern from the standpoint of staying within an allowable stopping distance) were all less than 100 feet. With the exception of one run with the first display at 30 knots, the dispersions on the "short" side were all within about 200 feet.

The minimum, maximum, and average stopping distances from breakout for the breakouts shown on figure 7 are presented on figure 8. For the 100-foot breakout, the distance from the prescribed breakout point to the slope origin is about 1000 feet; for the 50-foot breakout, it is about 500 feet. As shown on figure 8, the stopping distances for the 60-knot approaches were all less than 1000 feet and those for the 30-knot approaches were all less than 500 feet. From these results, it might be concluded that the visibility minimums sufficient for 100-foot and 50-foot breakouts could be about 1000 feet and 500 feet, respectively. However, in view of the fact that the slope pattern used in the present tests would allow a breakout about 500 feet short of the prescribed breakout point, visibility minimums of 2000 feet RVR would be required for a 100-foot breakout and 1500 feet RVR for a 50-foot breakout (assuming, as indicated earlier, that the landing pad is located 500 feet down course from the slope origin). These values of visibility requirements are appreciably greater than the estimated values derived from the analysis of reference 5.

For the 60-knot approaches of the display tests, the average time to fly the approach was a little over 3 minutes; for the 30-knot approaches, the average time was just under 3 minutes.

SUMMARY

For a VTOL landing corridor designed to accommodate approaches through a speed range of from 25 to 65 knots, a glide slope angle of about 6 degrees appears to represent the maximum for routine operations. For constant-speed approaches within this speed range, an approach distance of about two miles is sufficient for 60-knot approaches to a 100-foot breakout and 1-1/2 miles for 30-knot approaches to a 50-foot breakout. Path widths found practical for a 6-degree slope are ±2 degrees for slope and ±3 degrees for course; for approaches to 100-foot and 50-foot breakouts, the angular paths should advisedly terminate in constant-width paths (for about the final 1500 feet) of ±50 feet for slope and ±75 to ±100 feet for course.

In tests of two experimental instrument displays in the approach structure noted above, 30-knot approaches were flown to a 50-foot breakout and visual slowdown to hover; with one of the displays, 60-knot approaches were flown to a 100-foot breakout. In both the 30-knot and 60-knot approaches, the helicopter was brought to a stop at or short of the slope origin. However, because of the possibility of a breakout 500 feet "long" (assuming a ±50-foot slope width and a 6-degree slope), the landing pad should be located about 500 feet

down course from the slope origin. With this location of the pad and the possibility of a breakout 500 feet "short," the visibility requirements would be 1500 feet for a 50-foot breakout and 2000 feet for a 100-foot breakout.

The time to fly a 2-mile approach at 60 knots and a 1-1/2-mile approach at 30 knots was about 3 minutes.

REFERENCES

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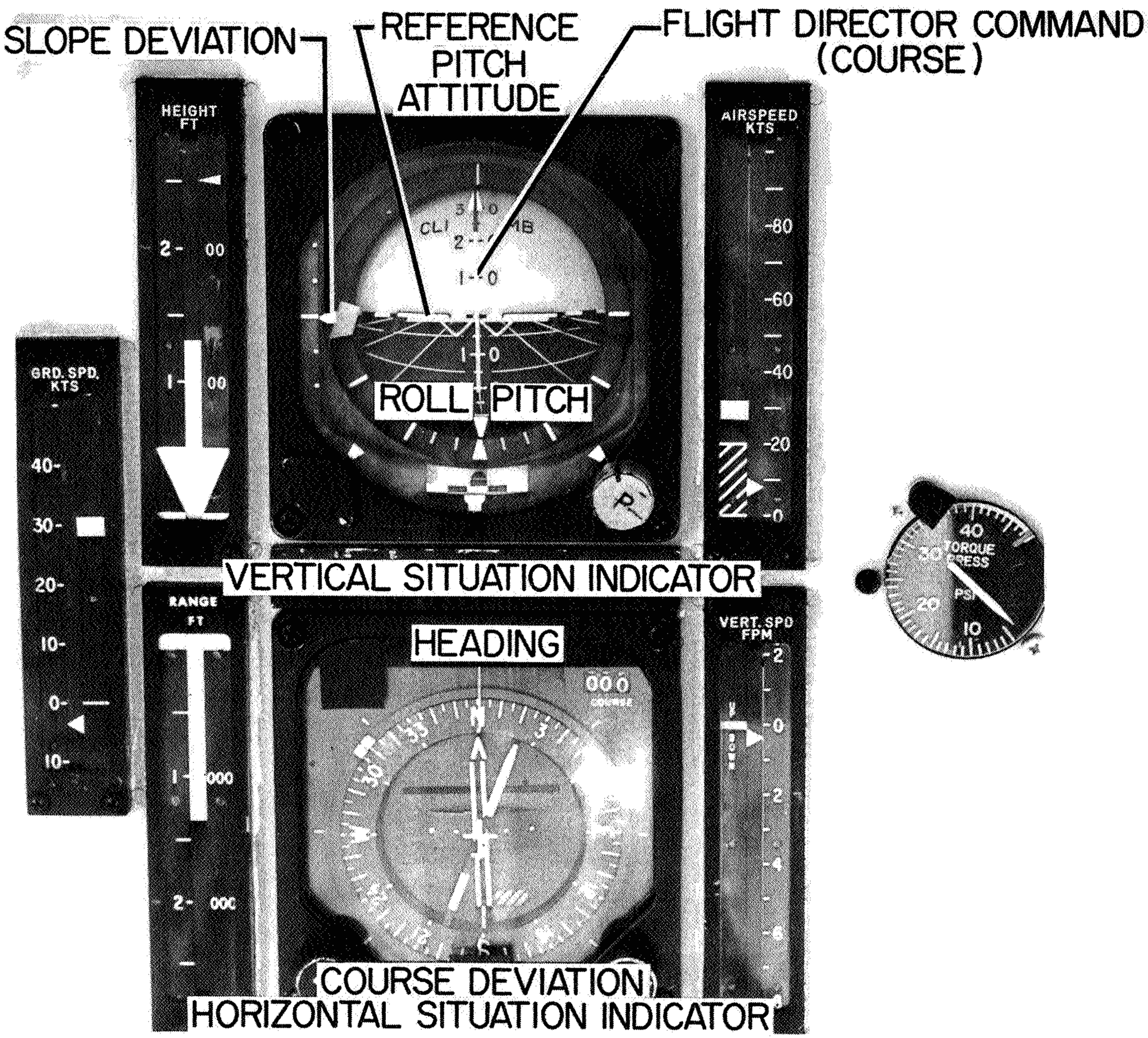

Figure 1.- Cross-pointer display installed in the test helicopter.

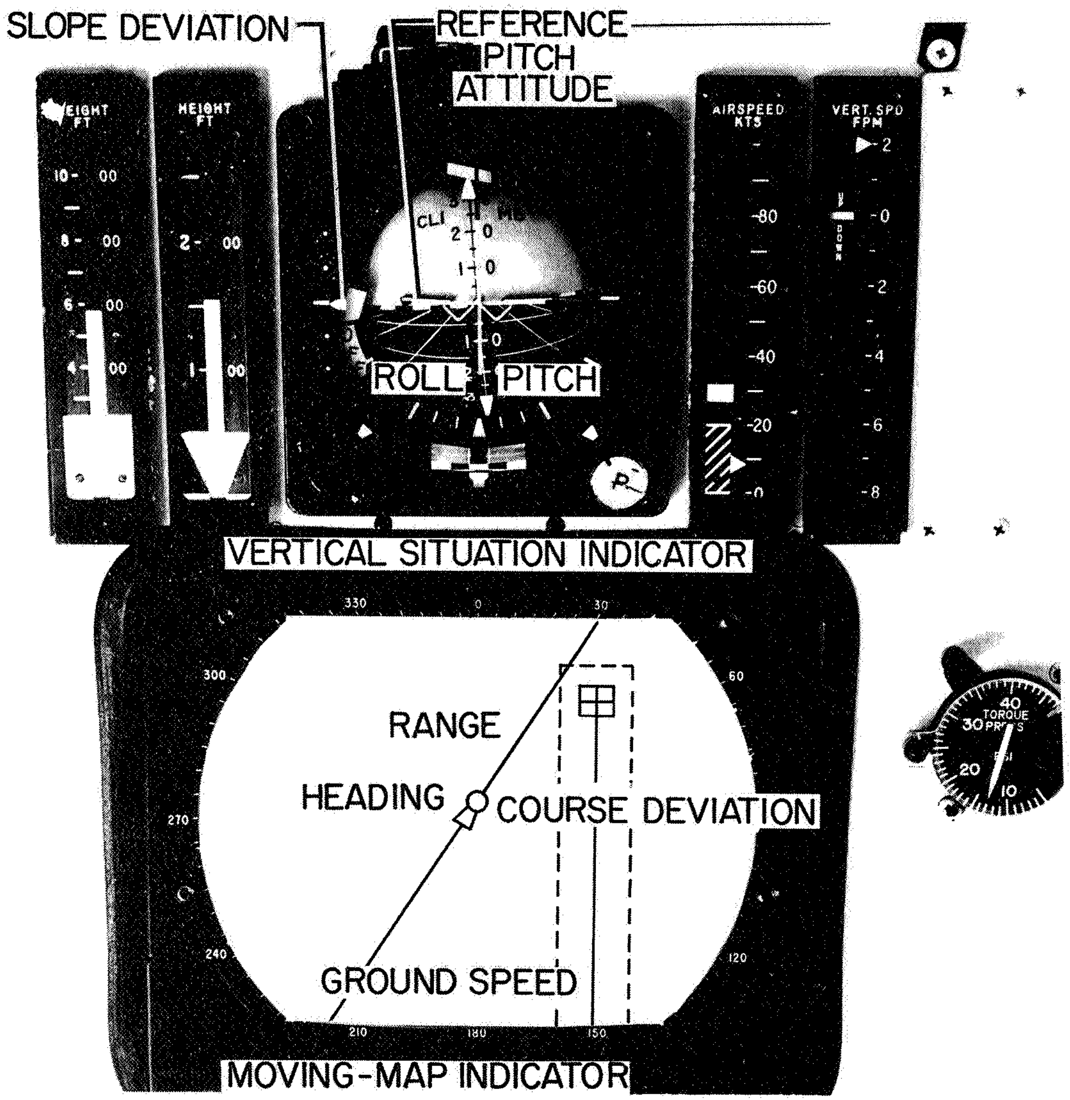

Figure 2.- Moving-map display installed in the test helicopter.

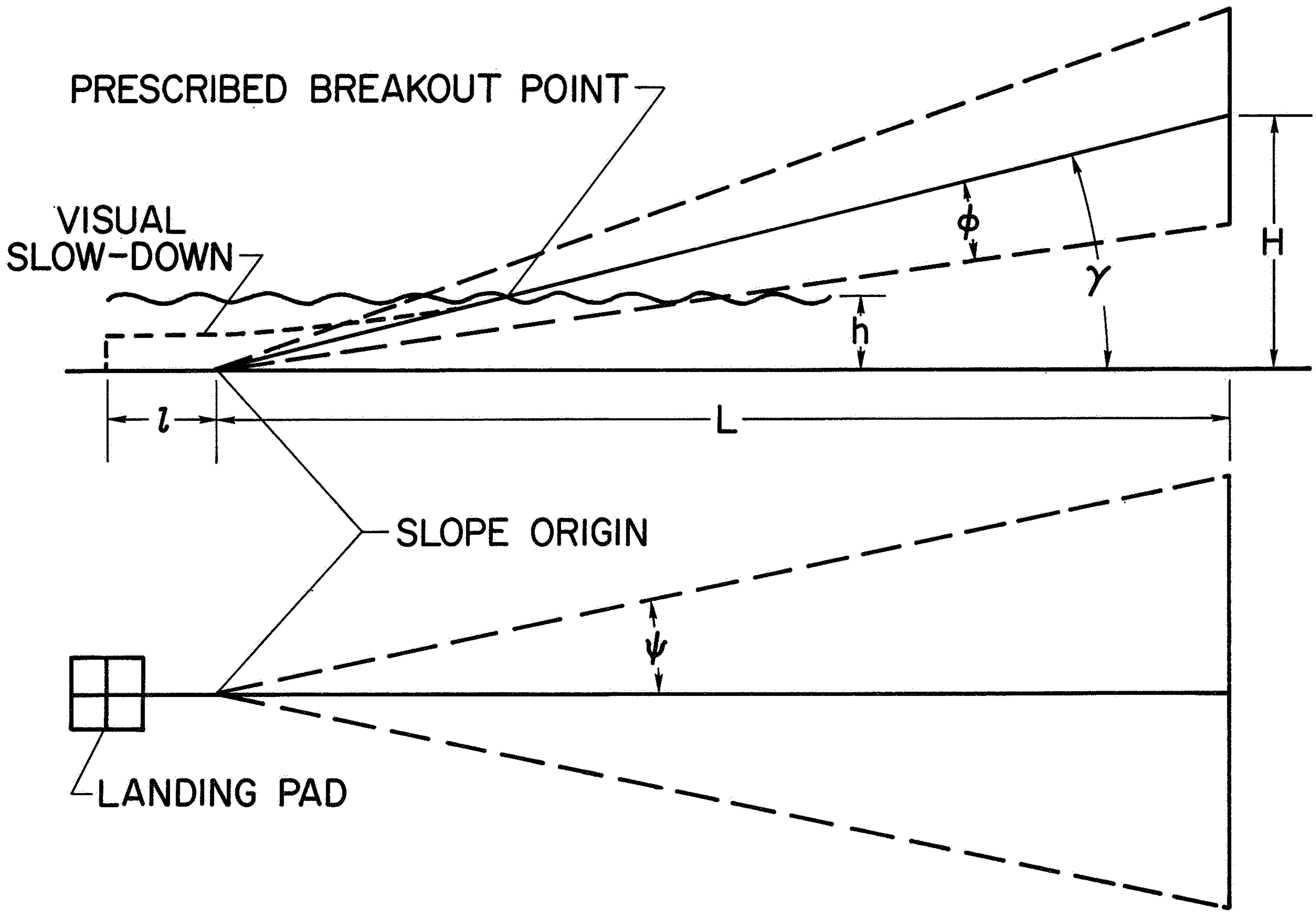

Figure 3.- Operational factors relating to the structure of a landing-approach corridor.

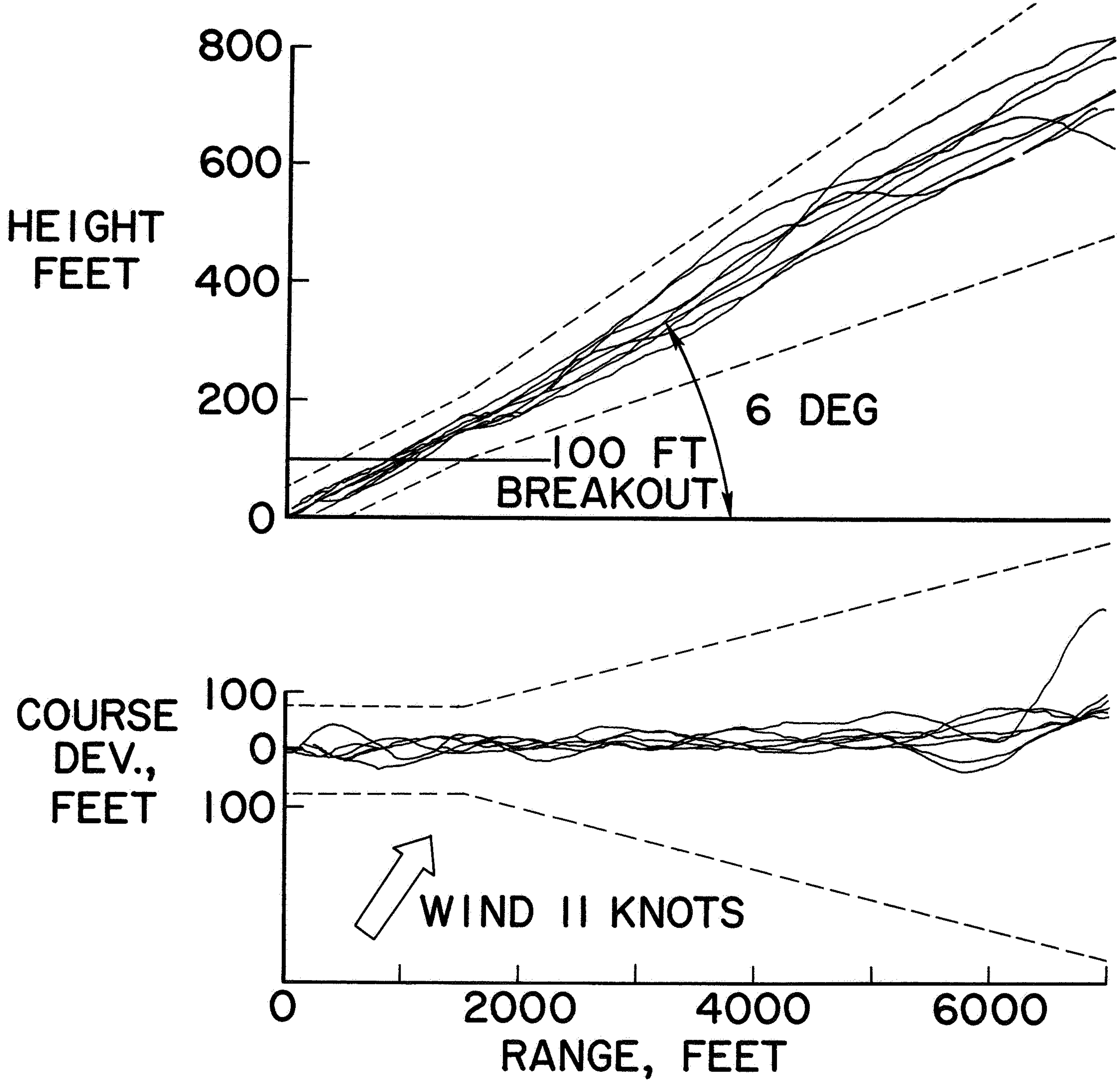

Figure 4.- Slope and course tracks of 60-knot approaches with the cross-pointer display using a flight director command for course guidance.

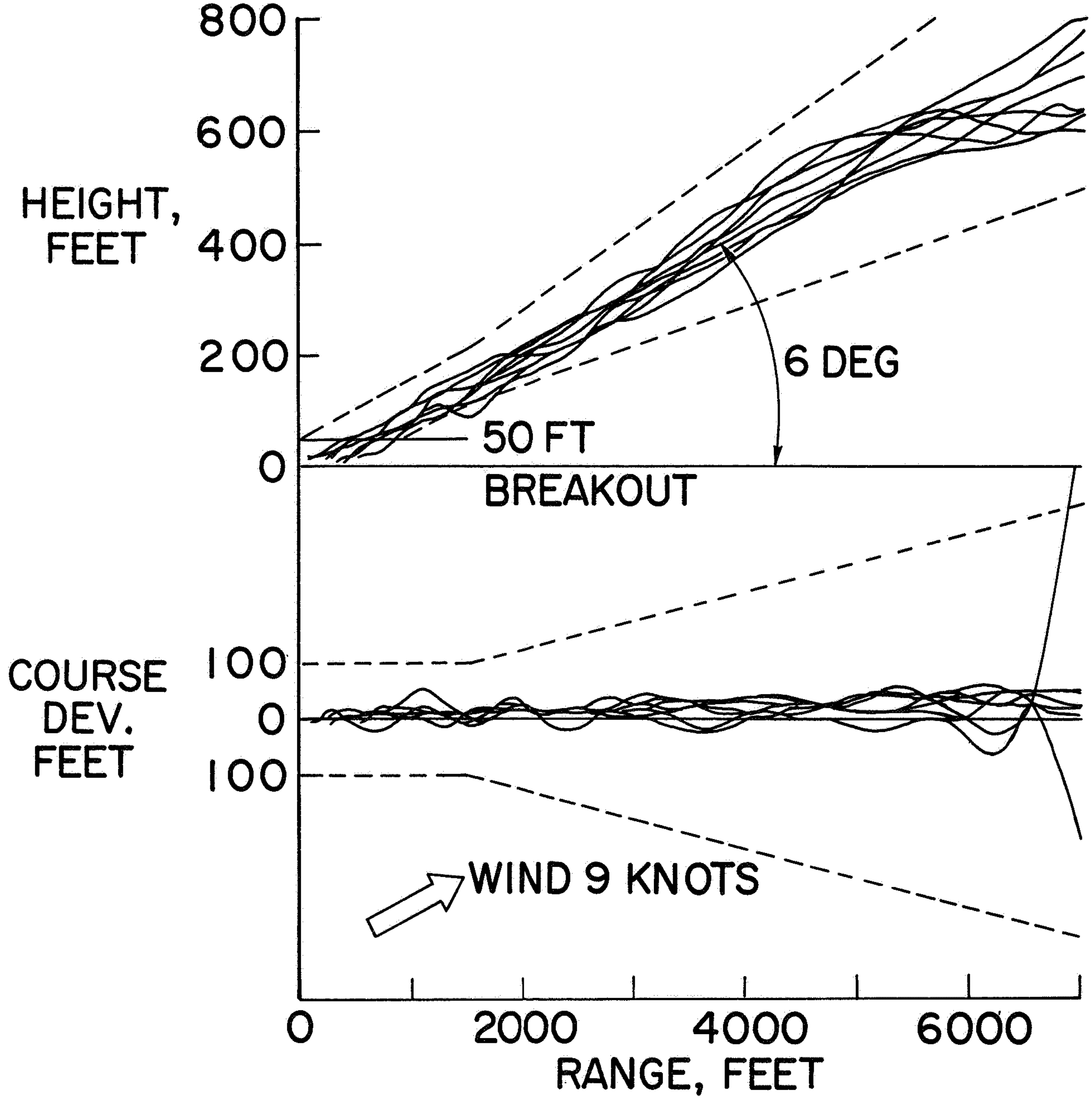

Figure 5.- Slope and course tracks of 30-knot approaches with the cross-pointer display using a flight director command for course guidance.

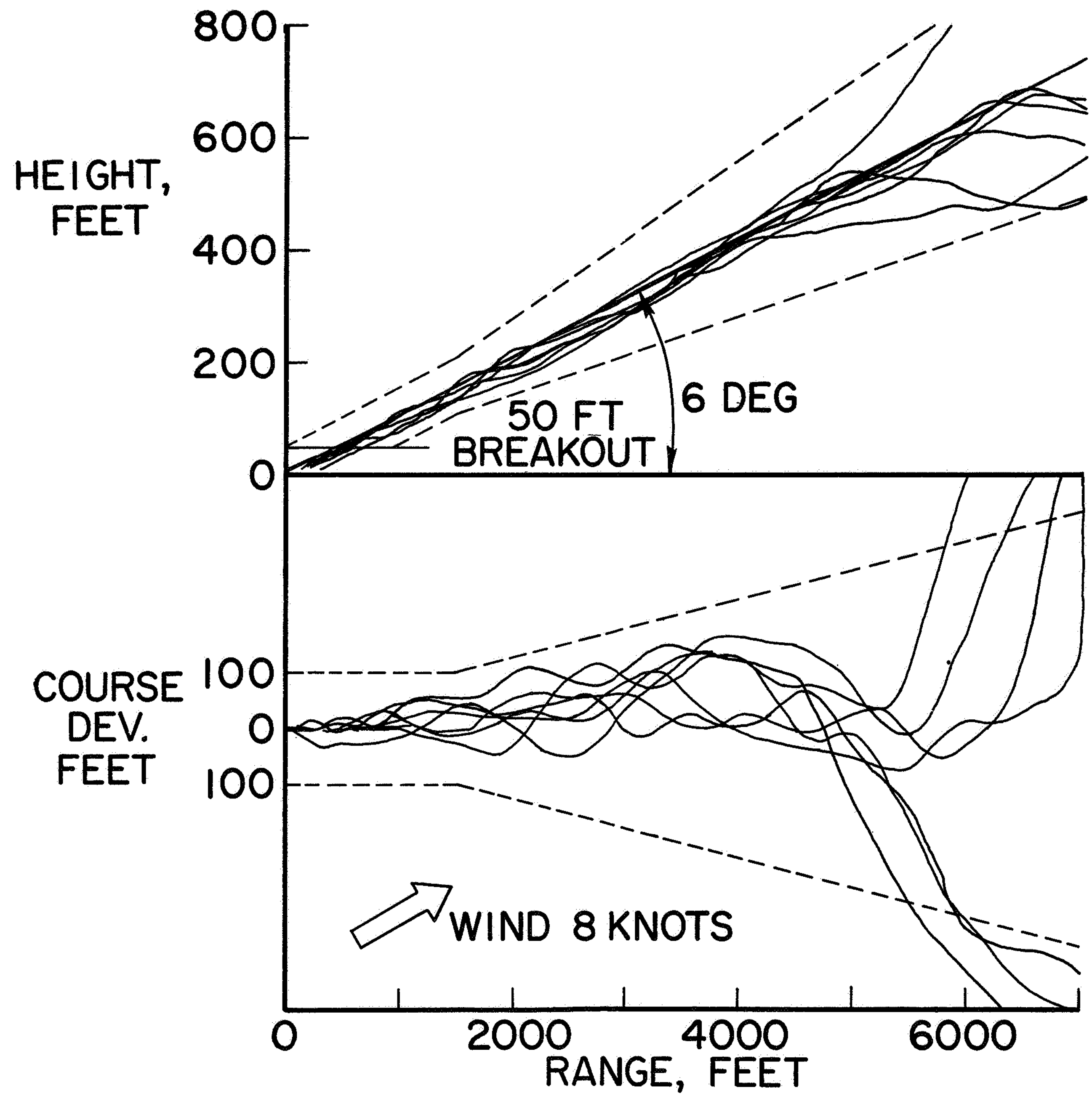

Figure 6.- Slope and course tracks of 30-knot approaches with the moving-map display.

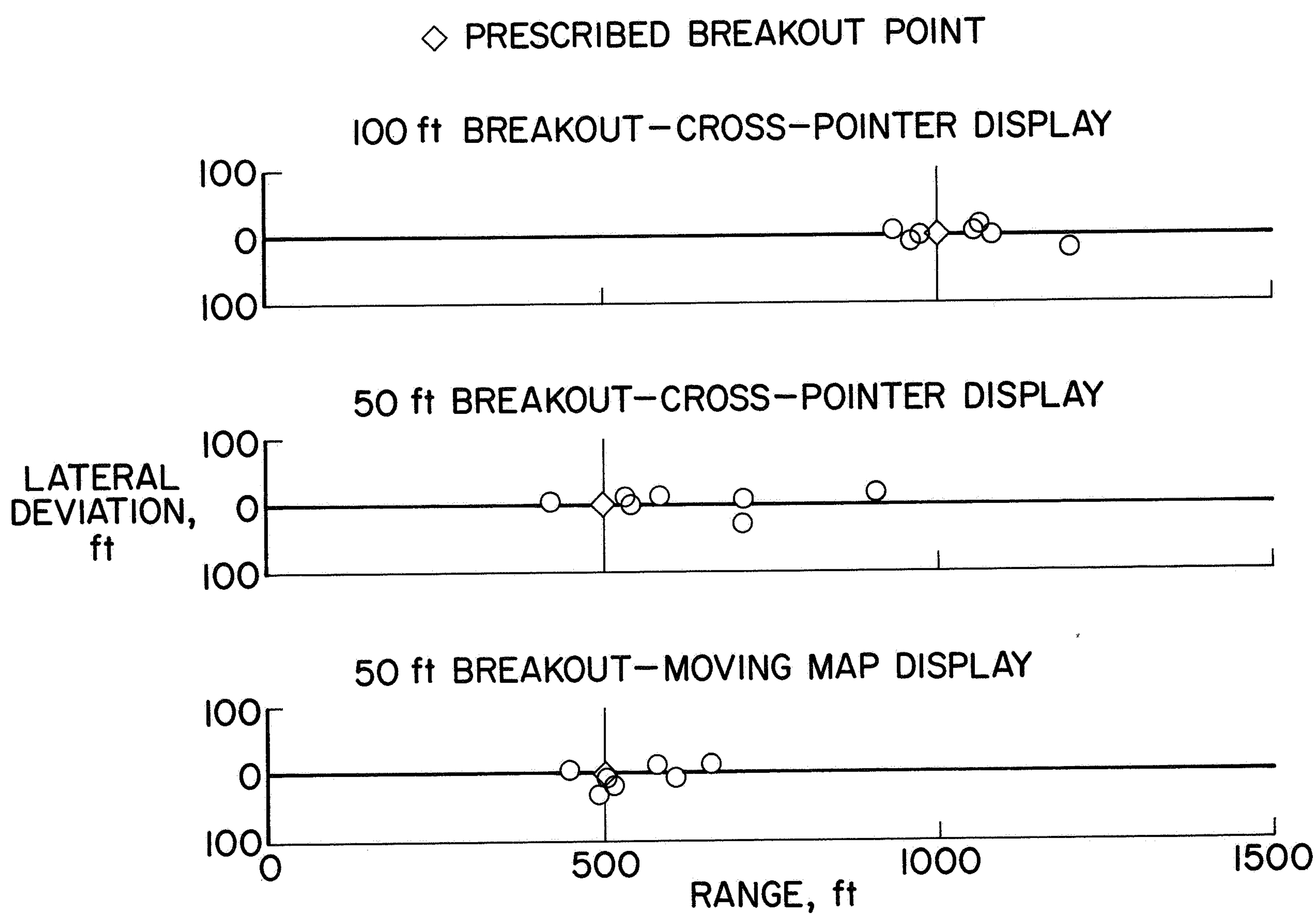

Figure 7.- Breakout deviations for the approaches presented in figures 4, 5, and 6.

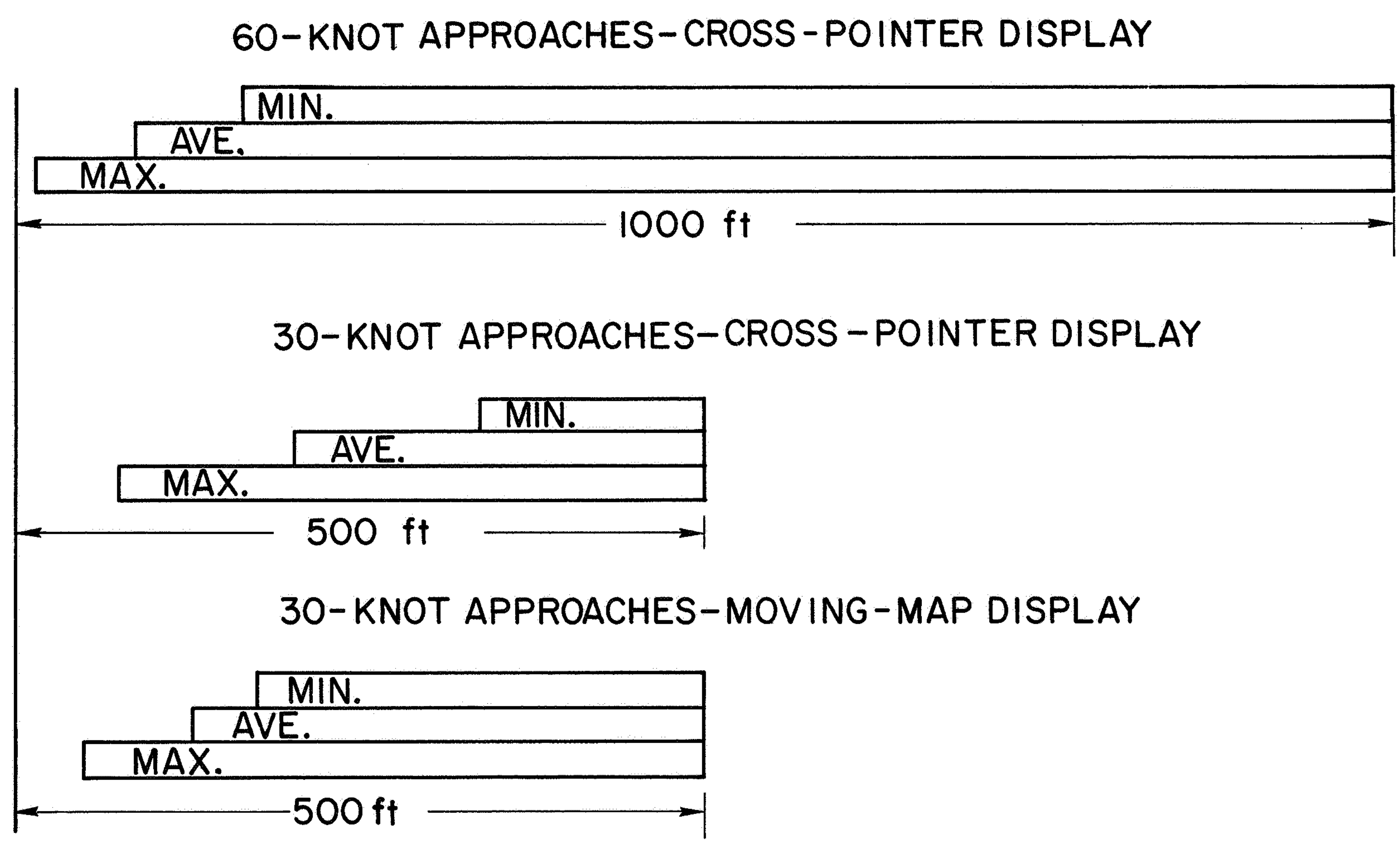

Figure 8.- Stopping distances from breakout to hover for the breakout deviations shown in figure 7.

NASA Langley. 1967