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EVALUATION OF A MOVING-GRAPH INSTRUMENT DISPLAY FOR LANDING APPROACHES WITH A HELICOPTER

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SUMMARY

A flight-test evaluation has been conducted of an instrument display for VTOL all-weather landing which included a moving-graph pictorial presentation for slope guidance. The instrument display included a moving-map presentation for course guidance, a large (4.5-inch-diameter (11.43-cm)) attitude indicator, and moving-pointer airspeed and vertical-speed indicators. The tests were conducted under simulated instrument flight rules conditions in landing approaches with a helicopter along a 6° glide slope at an airspeed of 30 knots.

Down to the 50-foot (15.24-m) breakout altitude, the pilots reported a high level of confidence in understanding the situation and in ability to control the flight path. Below this altitude, the pilots were unable to scan the separate indications of the vertical and horizontal situation, together with other information required, quickly enough to perform the deceleration to a hover and vertical-descent maneuver required for landing. The pilots indicated that the moving-graph vertical-situation indicator was a definite improvement over conventional abstract-symbolism indicators and provided an easily interpreted picture of the aircraft position relative to both the glide path and the ground. However, the improvements indicated by the pilots were not seen in the performance data.

INTRODUCTION

In an effort to determine the instrument display requirements for approaches and landing of V/STOL aircraft under zero-zero visibility conditions, the National Aeronautics and Space Administration is evaluating a variety of instrument displays with a helicopter as the test vehicle. Display concepts tested have included separate and combined displays of vertical- and horizontal-situation information in both abstract and combined abstract and realistic forms (refs. 1 and 2), a perspective display (ref. 3), and a closed-circuit television system (ref. 4). Guidance information was given as flight-director commands in some displays and as pictorial representations in others. The results of these tests showed that, in general, the glide-slope and localizer-tracking performance was improved by provisions of pictorial information compared with flight-director commands with an attendant reduction in mental workload. In the previous concepts tested, however, no separate pictorial representation of the vertical situation was studied.

For the present tests, the vertical situation was displayed on a moving graph giving a pictorial representation of aircraft deviation from the glide slope. The moving-map instrument used in the tests of reference 2 provided the horizontal-situation information. The concept of pictorial glide-slope guidance for V/STOL aircraft was first proposed by the U.S. Air Force; however, their display was to supplement primary flight-director information. For the present tests, a graphic-slope presentation was the only form of guidance information for the vertical task.

The present display was tested in the same helicopter as the displays of references 1 and 2 and by the same test pilots. The flight task was the same: a 30-knot simulated instrument flight rules (IFR) approach along a 6^{o} glide slope to a simulated 50-foot (15.24-m) breakout. The results of the evaluation are presented in terms of glide-slope and localizer-tracking performance and pilot opinion. The results are also compared with those obtained with the flight-instrument display of reference 2.

SYMBOLS

d_s	proportionate slope deviation, $\Delta z/w_s$
r	slant range, distance between radar antenna and aircraft, feet (meters)
w_s	displacement from glide slope for full-scale deflection of ILS slope-deviation indicator, feet (meters)
x	range, distance of aircraft from slope origin as measured in ground plane, along or parallel to course, feet (meters)
$\dot{x}$	rate of change of aircraft range, knots
y	course deviation, lateral displacement of aircraft from selected course, feet (meters)
z	height of aircraft above ground plane, feet (meters)
Δz	vertical displacement of aircraft from glide slope, feet (meters)
$\dot{z}$	vertical velocity of aircraft, feet per minute (meters per second)

β elevation angle of radar antenna, degrees

γ flight-path angle, degrees

θ pitch attitude of aircraft, degrees

ϕ roll attitude of aircraft, degrees

ψ relative heading, degrees

Ω azimuth angle of radar antenna, degrees

Abbreviations:

HSI horizontal-situation indicator

IFR instrument flight rules

ILS instrument landing system

VSI vertical-situation indicator

SAS stability-augmentation system

INSTRUMENT DISPLAY

The test instrument display (fig. 1) included a moving-map horizontal-situation indicator, a moving-graph vertical-situation indicator, a 4.5-inch-diameter (11.43-cm) attitude indicator, moving-pointer-type airspeed and vertical-speed indicators, and a dial-type torquemeter for power indication.

Moving-Map Horizontal-Situation Indicator

The moving-map horizontal-situation indicator (HSI) is an optical-type instrument in which a map and aircraft symbol are projected on the face of an acrylic plastic screen 7.5 inches (19.05 cm) wide by 5.5 inches (13.97 cm) high. The aircraft symbol fixed in the center of the screen has an extended center line and rotates to indicate relative heading ψ with respect to course, while the map beneath moves laterally to indicate course deviation y and vertically to indicate range x. A more detailed description of the operation of the map display may be found in reference 2.

The map used in the HSI for the present tests is shown in figure 2. Also shown at the same scale is the relative screen size of the display in order to define the part of the map visible at any one time. The numbers 5, 10, 15 and 20 along the center of the map represent the distance to the touchdown target in increments of 100 feet. The x- and y-scale factors are shown in the figure. Both the x- and y-scale factors change at a range of 2500 feet (762 m) by a factor of ten.

Moving-Graph Vertical-Situation Indicator

The moving-graph vertical-situation indicator (VSI) (fig. 1) is an instrument in which the slope-guidance information is presented in moving realistic formats. Slope deviation and range were presented in combined form on a mechanically actuated, altitude-range indicator. The aircraft symbol moved vertically from inputs of altitude z; and the chart on which the glide slope and slope boundaries were inscribed moved laterally from right to left with decreasing range x. The viewing area for the chart was 4 inches (10.16 cm) high by 2.5 inches (6.35 cm) wide.

Diagrams illustrating views and detail of the slope-guidance chart used in the moving-graph VSI are shown in figure 3. Figure 3(a) defines the two modes of operation and the relative part of the slope chart viewed for each operation. As indicated (fig. 3(a)), the moving presentation of altitude as a function of range occurred only during the final 2500 feet (762 m) of the approach; prior to that time, the chart remained fixed in range while the aircraft symbol moved along the left edge of the chart to indicate slope deviation relative to the fixed cross-pointer-type vertical scale. As indicated in figure 3(b), the various regions of the chart (that is, slope boundaries, ground plane) are color coded to aid in interpretation.

Attitude Indicator

The attitude indicator (fig. 1) presents roll ϕ and pitch θ on a roller screen. The roll-attitude sensitivity is in one-to-one relationship with the actual horizon, whereas the pitch attitude sensitivity is 10°/inch (3.94°/cm) – approximately three times that of conventional indicators. The viewing area of the attitude indicator is 4.5 inches (11.43 cm) high by 6 inches (15.24 cm) wide. The 3-inch (7.62-cm) vertical tape on the left-hand side of the attitude indicator is a sensitive thermometer-type altitude indicator in the range of 0 to 200 feet (0 to 61 m), whereas the vertical tape on the right-hand side of the attitude indicator is a pilot-selectable reference pitch-attitude indicator having a sensitive scale of 5°/inch (1.97°/cm).

Vertical-Speed and Airspeed Indicators

The vertical-scale instruments (fig. 1) used for presentation of airspeed and vertical speed had fixed scales with moving triangular pointers. The airspeed and vertical-speed indicators were driven by signals derived from an electrical output of a pressure transducer connected to the aircraft pitot-static system. The vertical-speed instrument included an acceleration-lead network to compensate for the inherent lag of the pressure-measuring system.

Because of limitations of the airspeed transducer and the pitot-static system, the airspeed readings were unusable below 20 knots. The unusable part is indicated by the cross-hatched area at the bottom of the instrument scale. The scale lengths were 4.5 inches (11.43 cm), and the scale measured airspeed from 0 to 100 knots, and vertical speed from -800 to 200 ft/min (-4.06 to 1.02 m/sec).

GUIDANCE SYSTEM

The guidance system consisted of a ground-based radar with computers and telemetry for generating and transmitting aircraft position and slope-deviation information. The airborne equipment consisted of telemetry receivers and a computing system to process the information for the display. A description of the radar and telemetry systems is given in reference 1.

Figure 4 is a block diagram of the guidance and display system used in the present investigation.

RECORDING INSTRUMENTS

In the radar ground station, the horizontal (xy) and vertical (xz) tracks of the aircraft were recorded by two coordinate plotters on 10-inch by 15-inch (25.4-cm by 38.1-cm) charts. Time histories of x, $\dot{x}$, y, z, Δz, $\dot{z}$, and d_s were also recorded.

In the helicopter, time histories of airspeed, altitude, throttle, cyclic stick, collective control, and rudder pedals were recorded on two NASA flight recorders. A common timing signal was used for both the airborne and ground-based recorders by means of a radio link.

The accuracy of the position indications of the horizontal and vertical indicators was checked by hovering the helicopter over surveyed points along and to each side of the course. The lateral error of the moving-map HSI was found to increase from near zero at the landing pad to 10 feet (3.05 m) at a range of 2500 feet (762 m) whereas the longitudinal error was about 10 feet (3.05 m) at the landing pad and increased to 60 feet

(18.29 m) at a range of 2500 feet (762 m). The error in the height indication of the moving-graph VSI was near zero at the landing pad and increased to 5 feet (1.52 m) at a range of 2500 feet (762 m) whereas the longitudinal error was about 10 feet (3.05 m) at the landing pad and increased to 50 feet (15.24 m) at a range of 2500 feet (762 m). The accuracies of the coordinate plotters were found to be within the specified accuracies of the radar which, for the angular scanning ranges of the present tests, were as follows:

	1-sigma values
Range	10 feet (3.05 m) or 1 percent (whichever is greater)
Course deviation	3 feet (0.91 m) at zero range 8 feet (2.44 m) at 7000-foot (2133.60-m) range
Height	1 foot (0.30 m) at zero range 11 feet (3.35 m) at 7000-foot (2133.60-m) range

TEST AIRCRAFT

The test helicopter (fig. 5) for the present investigation was the same as that used for the tests of references 1 to 4. For the present tests, a rate-damped stability-augmentation system (SAS) was installed. It was found that the SAS did not significantly alter the pilot's ability to follow the desired approach pattern. As shown in figure 5, a test instrument housing was installed through the left windshield; this installation placed the test instrument panel at eye level and about 29 inches (73.66 cm) from the pilot's eyes. For improved radar tracking, a corner reflector was installed on the nose of the aircraft.

Two methods of simulating IFR flight conditions were used. For the first method, the windshield was covered with amber plastic and the pilot wore a removable blue visor. For the second technique, a translucent white curtain was installed in the cockpit to obscure the evaluation pilot's outside view and yet permit enough light for illuminating the instrument panel.

TEST PROGRAM

Approach-Path Patterns

The boundaries of the slope and course patterns (fig. 6) were similar to those used in the tests of references 1 and 2 with the exception that the course boundaries were widened between 5000 feet (1524 m) and 10 000 feet (3048 m) whereas the slope boundaries were narrowed between a range of 0 and 2500 feet (762 m). The boundaries of figure 6 correspond to the approach-path pattern drawn on the moving-map HSI and moving-graph VSI.

Approach Tests

The approach task for the present tests was the same as that used in the tests of references 1 to 4; namely, a simulated IFR approach along a 6° glide slope to a height of 50 feet (15.24 m) at a constant airspeed of about 30 knots. All approaches were started at a range of about 8000 feet (2438.4 m) in level flight roughly on course.

During the familiarization flights, attempts were made to continue the instrument approaches to a hover at the landing pad; but these attempts were unsuccessful. Therefore, for comparative performance evaluations with the results of the tests with the display of references 1, 2, and 3, the approaches were terminated at an altitude of 50 feet (15.24 m).

As previously noted, the tests were conducted with two different methods of simulating IFR conditions. The translucent curtain provided the pilot with an unobstructed view of the instrument panel; however, this method did not allow the evaluation pilot to make the transition from instrument to visual flight at breakout. The amber-windshield—blue-visor method, in which the pilot could raise the visor for visual flight at breakout, provided the pilot with a monochromatic view of the display, and thereby eliminated the effects of color coding provided on the attitude- and vertical-situation indicators.

Because of improved overall visibility and comfort, the translucent curtain was considered the primary and more desirable arrangement for IFR condition simulation and was used for the initial evaluations. The project pilot flew about 30 approaches using the translucent curtain method. After the project pilot's evaluation, two other NASA research pilots flew a series of 10 performance approaches. For comparison with previous tests, however, the project pilot also flew a series of 10 approaches with the amber and blue plastic method. For all simulated IFR landing approaches, the right seat was occupied by a safety pilot.

RESULTS AND DISCUSSION

Familiarization Flights

During the initial test when the translucent white curtain was used to simulate IFR flight conditions, the optical projection moving-map HSI display was found to be difficult to read because of the relatively high ambient light level compared with the brightness of the display. The other instruments, however, were well illuminated and easily read. In contrast, when the amber-windshield—blue-visor method was used, the moving-map HSI display appeared as the predominant feature of the instrument display. The monochromatic view combined with the lower light level made the other instruments more difficult to read. These differences in the predominant features of the display with the two methods of IFR simulation resulted in better performance by the pilots in horizontal tracking with use of the amber-windshield—blue-visor method and better performance in vertical tracking with use of the translucent white curtain.

The effects on tracking performance caused by the two different methods of IFR simulation were apparently subconscious; that is, the pilot felt that his performances with the two methods were comparable. However, because differences were found in the results, comparison of this display with previous displays was made only with results from the tests conducted with the amber-windshield—blue-visor method – the IFR simulation technique of references 1, 2, 3, and 4. All data presented were taken with the use of the amber-windshield—blue-visor method of IFR simulation.

Performance Tests

In the performance tests with the display, the project pilot flew 10 consecutive approaches in quartering headwinds of from 8 to 14 knots. The course and slope tracks for these approaches are shown in figure 7. Note that the course deviation and height are plotted to a scale five times the range scale. Also plotted are the 50-foot (15.24-m) breakout height and the slope and course boundaries corresponding to those that were drawn on the horizontal- and vertical-situation indicators.

The slope and course tracks down to the 50-foot (15.24-m) breakout point were generally within the prescribed boundaries. The performance with the instrument display of the present tests can be compared in a general way with the performance with the display of reference 2. Shown in figure 8 are the course and slope tracks from reference 2. In the display of the present test (fig. 1) and the display of reference 2 (fig. 9) the same moving-map instrument for the horizontal situation was used, whereas, in the present display a pictorial moving-graph presentation for the vertical-situation indicator was used instead of the conventional cross-pointer vertical-situation indicator of reference 2. In comparison, the slope and course tracks for the present display appear to be worse than those for the test with the display of reference 2.

In determining the overall performance of an approach task, one must consider the control of attitude and speed along with course control and slope control. Figure 10 shows time histories of the magnitude of the airspeed variations for the 10 approaches of figure 7. These approaches were flown at a speed slightly higher than the selected reference speed. In general, the pilot's ability to hold a constant airspeed was not significantly different from that experienced in the tests of reference 2.

The large attitude indicator (4.5-inch (11.43-cm) diameter) of the present tests did not significantly improve the pilot's ability to control pitch and roll attitude as compared with the conventional 3.5-inch-diameter (8.89-cm) indicator of the moving-map display arrangement of reference 2. In the present tests, the pilot experienced some difficulty in precisely determining roll attitude and found it necessary to check roll attitude by frequent reference to the position indicator at the top of the instrument. The pilot found that he was unable to use the vernier-scale pitch tape because of the workload involved in controlling the other parameters.

Although the pilots felt that the moving-graph VSI display was an improvement over previously tested displays, an overall analysis of the data indicates poorer performance than in the previous tests. There are two factors which could possibly contribute to the poorer performance in the present tests. First, the present tests with the moving-graph VSI display were flown under larger headwinds and crosswinds than the previous tests of reference 2. In fact, the lowest winds experienced in the present tests are higher than the maximum winds experienced during the tests of reference 2. Although high winds increase the difficulty of the control task, the actual degree of degradation in performance is not known.

Second, the present display required a relatively longtime scan pattern. This condition is partly attributed to the fact that the present display occupies an area about 15 percent larger than the display arrangement of reference 2. Also, the use of this type of pictorial display tended to increase the pilot's scan time because of the need to spend more time deriving rate information.

From flight tests of the present display and the displays of references 1 and 2, it has been found that with guidance information separated into horizontal and vertical situations, the pilot could not quickly integrate the information in order to make the necessary control corrections for a slowdown to hover and land. Although, when horizontal- and vertical-situation guidance information was combined in a completely realistic presentation of a closed-circuit television (ref. 3), landings in fact were accomplished under zero-zero conditions.

Pilot Opinion

The three pilots were of the opinion that the moving-graph vertical-situation display was a definite improvement over a cross-pointer-type display, in that it provided the pilot with an easily interpreted picture of the aircraft position. Although it was still difficult to make small precise changes with this display, the pilots noted a marked increase in the ability to evaluate the situation and make corrections. The pilots felt that improved ability to control flight path by use of the graphic vertical-situation indicator, combined with similar benefits of the moving-map horizontal-situation indicator, resulted in a higher level of confidence throughout the approach. (No improvements were measured in flight-path control as shown by figure 7.) However, during the final part of the approach, the pilots indicated difficulty in making corrections because, even though the pilot knew his aircraft position, he was unable to scan the display fast enough to assess the results of corrections made.

CONCLUDING REMARKS

An evaluation of an instrument display incorporating separate pictorial indications for both the horizontal and vertical situations has been conducted during landing approaches with a helicopter. The tests were conducted under simulated IFR conditions along a 6° glide slope at an approach speed of 30 knots.

Down to the breakout altitude, the pilots reported a high level of confidence in understanding the situation and in their ability to control the flight path. Below this altitude, the pilots were unable to scan the separate indications of the vertical and horizontal situations, together with other information required, quickly enough to perform the deceleration to a hover and vertical-descent maneuver required for landing. The pilots indicated that the moving-graph vertical-situation indicator was a definite improvement over conventional abstract-symbolism indicators and provided an easily interpreted picture of the aircraft position relative to both the glide path and the ground. However, the improvements indicated by the pilots were not seen in the performance data.

From previous tests of conventional-type instruments, pictorial presentations, and integrated pictorial real-world displays, it appears that the optimum display for manual landing of VTOL aircraft should provide guidance information in a single, easy-to-interpret, integrated presentation. The information provided should allow the pilot to assess his flight condition during the initial part of the approach, to slow down to hover and to land with cues matching as closely as possible realistic visual cues.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., September 2, 1970.

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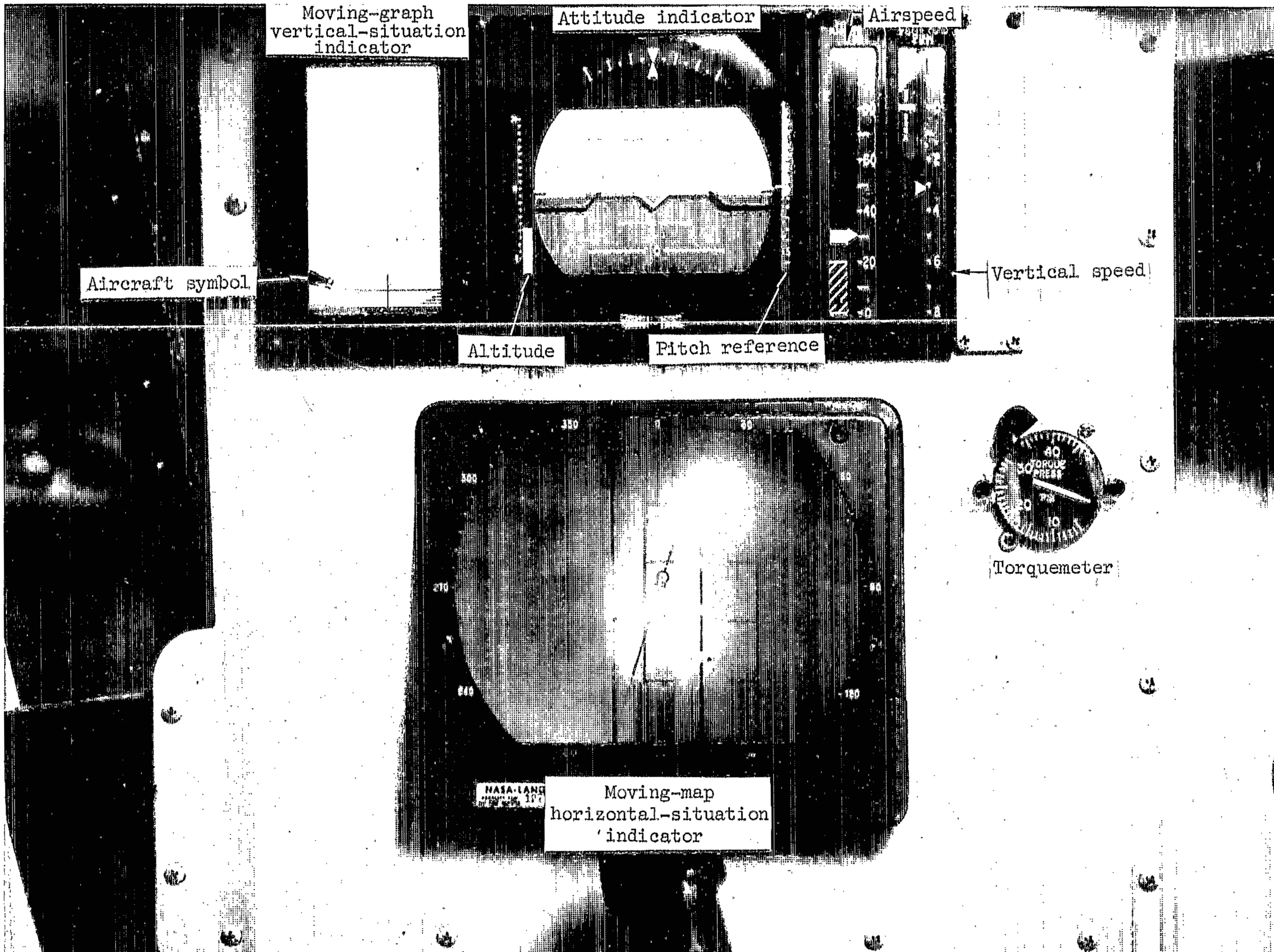

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Figure 1.- Test instrument display.

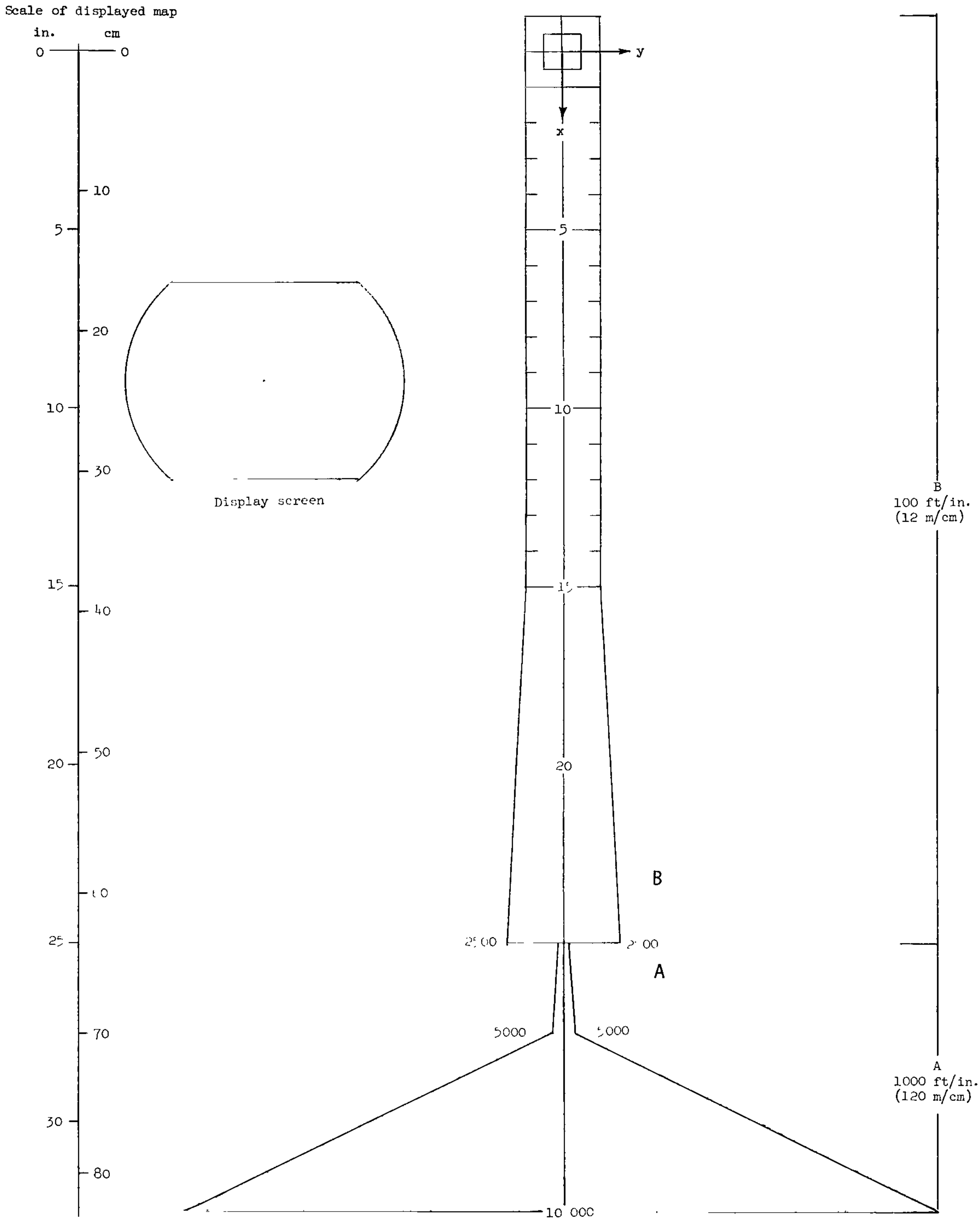
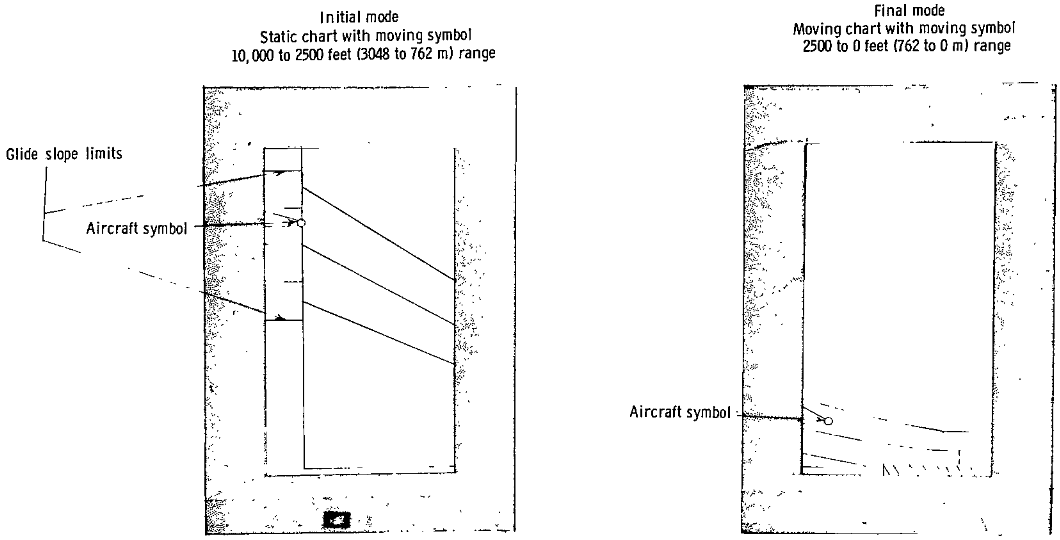
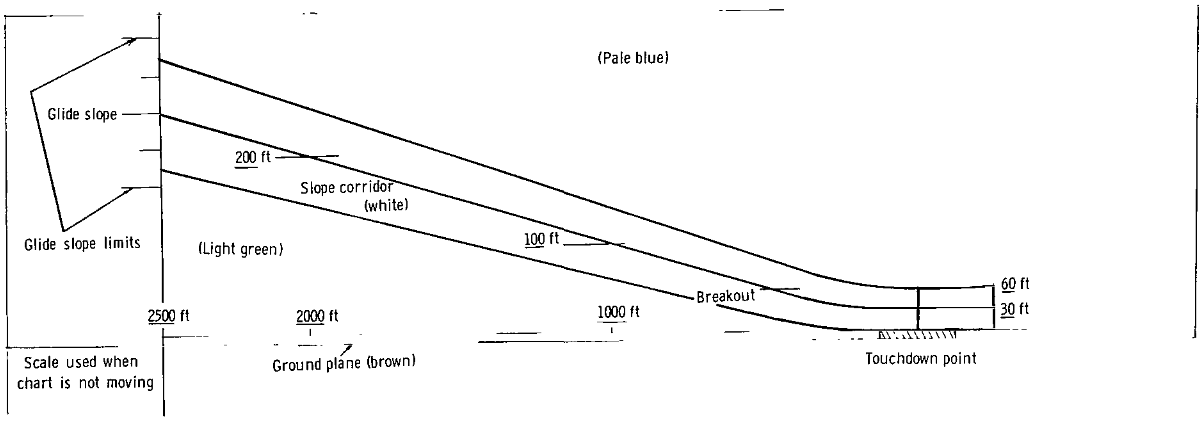


Figure 2.- Horizontal-situation map of the HSI used in present investigation.



(a) Views of chart in initial and final modes of operation.



(b) Chart showing glide-slope scale in initial mode and glide-slope altitude-range plot used in final mode. Digital information and color coding displayed as shown.

Figure 3.- Diagrams illustrating views and detail of slope-guidance chart used in moving-graph VSI indicators.

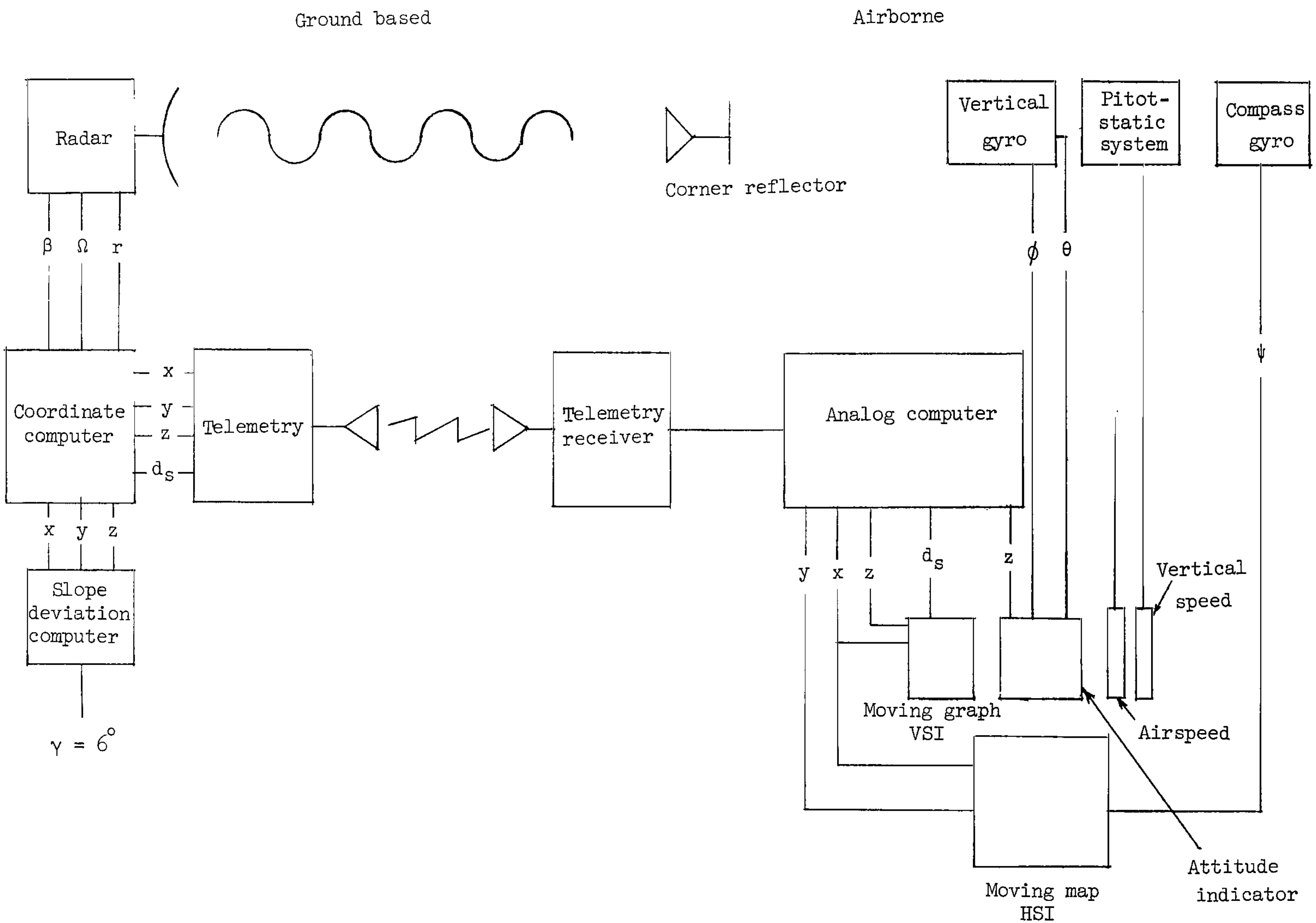


Figure 4.- Diagram of guidance and display system.

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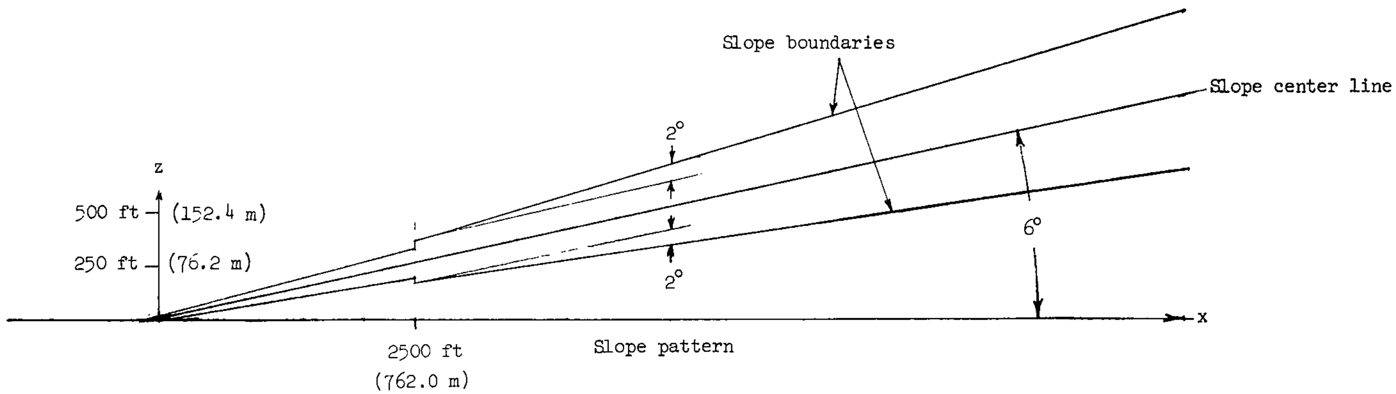
Figure 5.- Test helicopter.



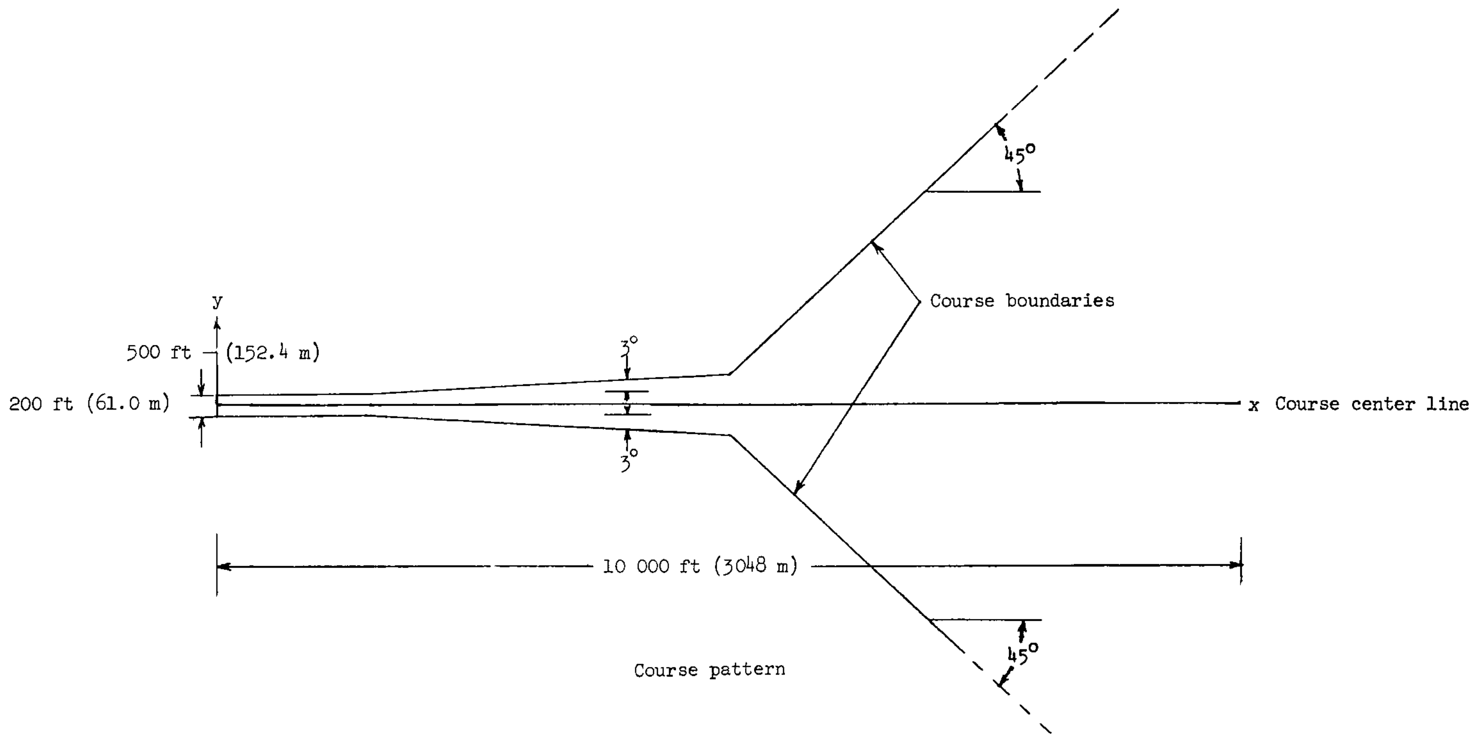


Figure 6.- Approach-path patterns.

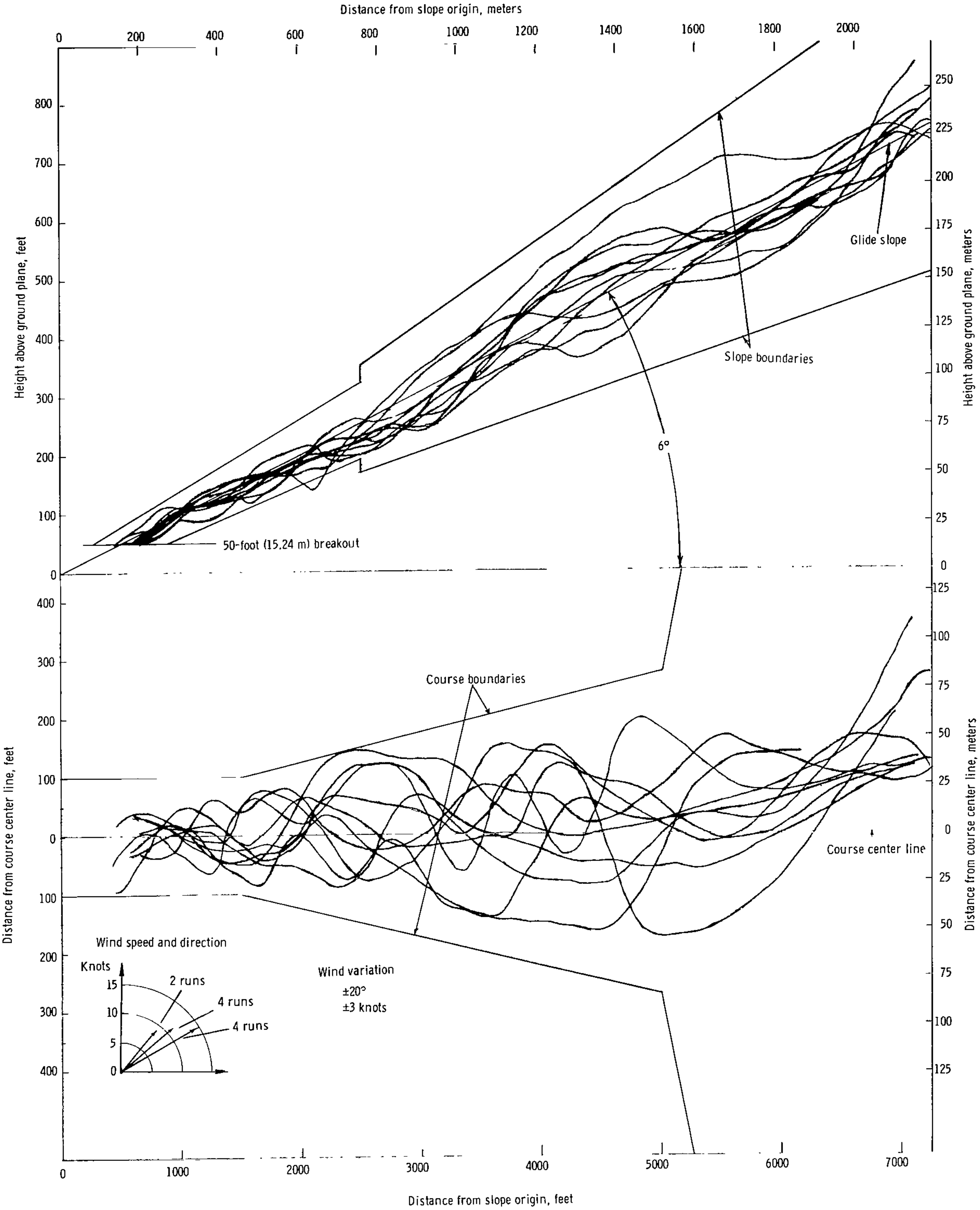


Figure 7.- Course and slope tracks for ten 30-knot approaches to 50-foot (15.24-m) breakout with the moving-graph VSI and moving-map HSI.

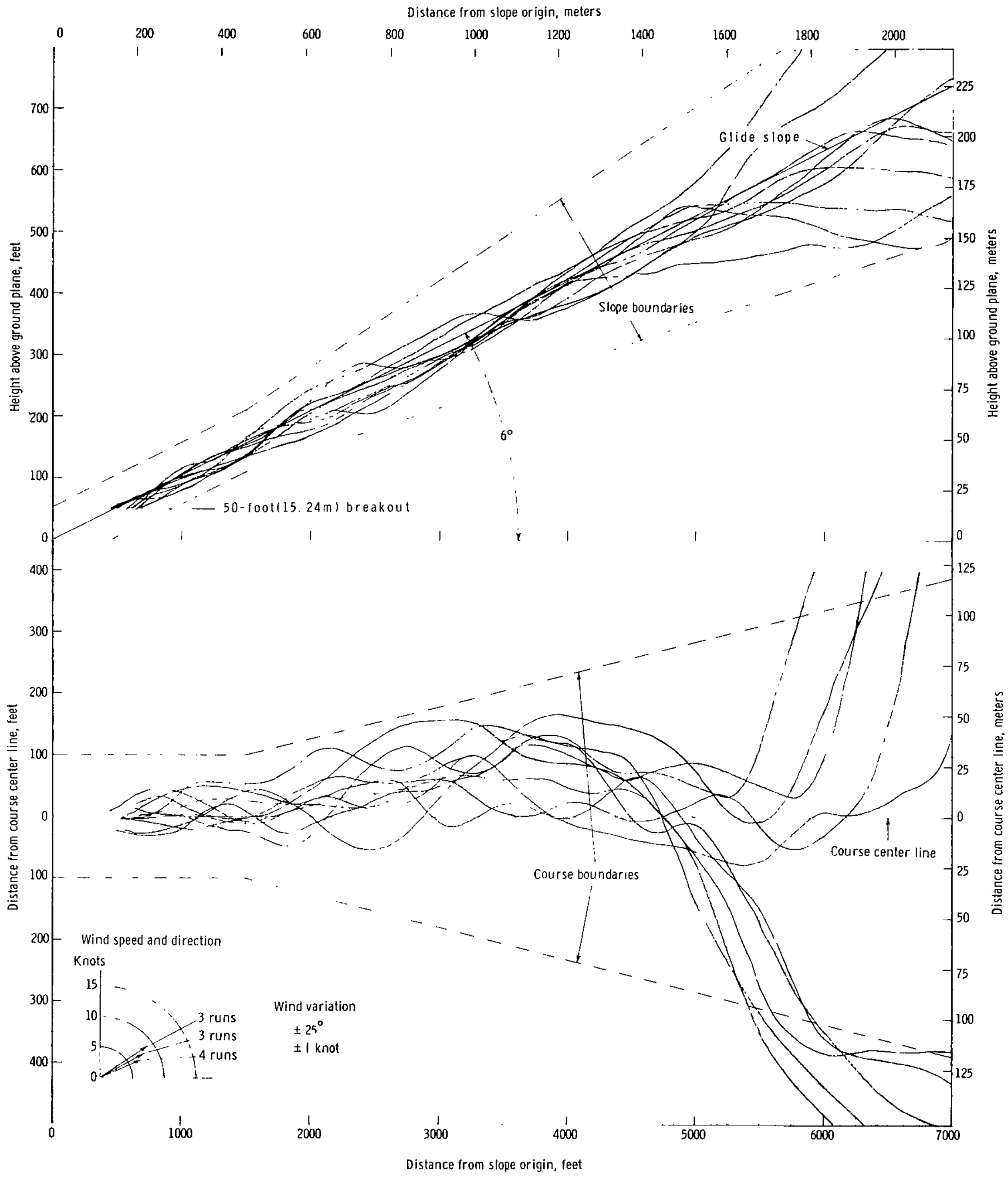


Figure 8.- Course and slope tracks for ten 30-knot approaches to 50-foot (15.24-m) breakout with the display of reference 2 (map IV).

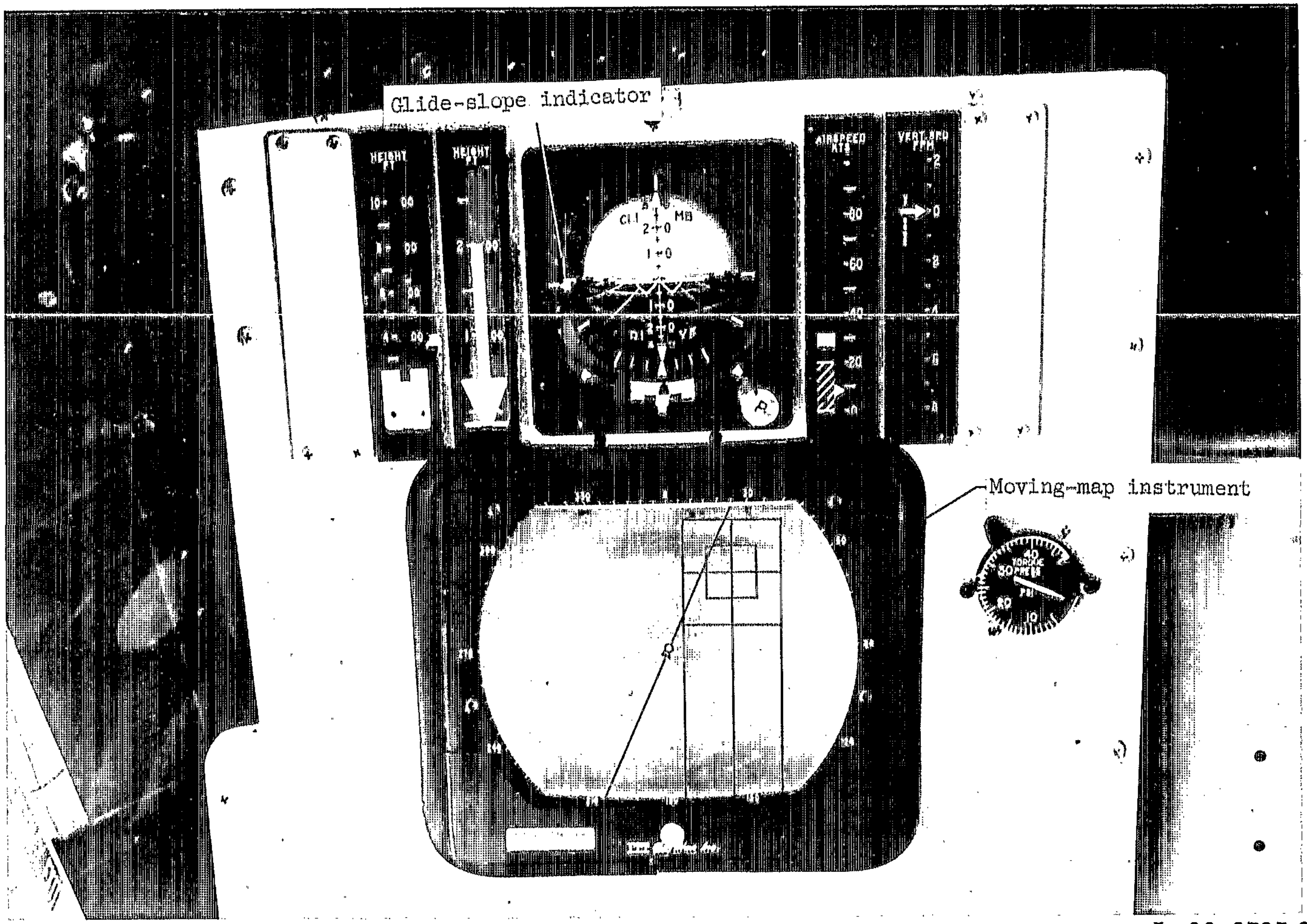


Figure 9.- Instrument display of reference 2.

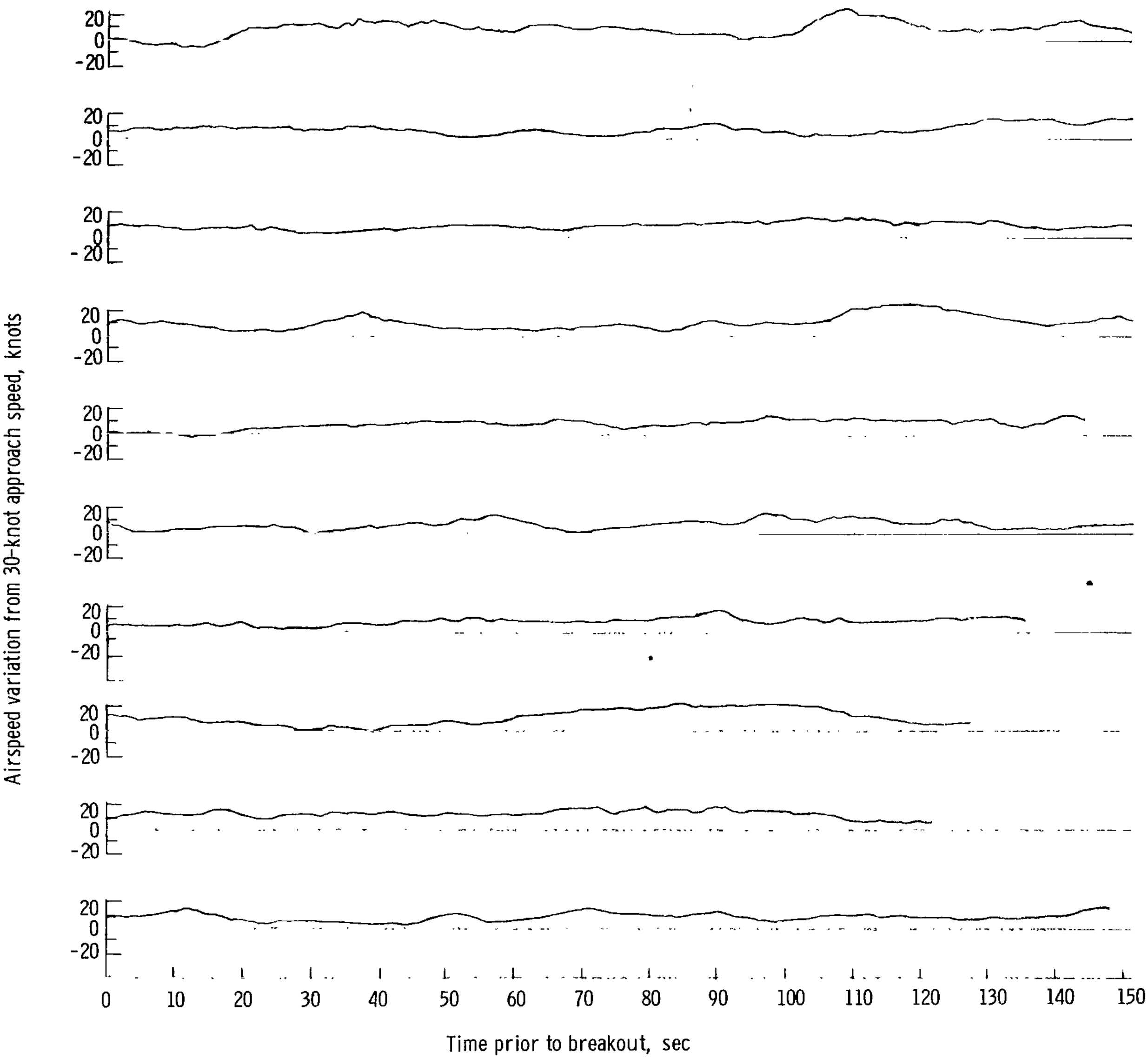


Figure 10.- Time histories of airspeed variations from approach speed of 30 knots.

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