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SUMMARY

An evaluation of an instrument display consisting of a contact analog, a torquemeter, a ball skid indicator, and vertical-scale instruments for the indication of airspeed, vertical speed, and height has been conducted in landing approaches with a helicopter under simulated IFR (Instrument Flight Rules) conditions. In addition to a horizon line and a ground grid, the contact-analog presentation included an inclined pathway, fixed in a ground-coordinate system, that provided information for slope and course guidance. The tests were conducted along a 6° glide slope at approach speeds of about 30 knots to a breakout that was followed by a visual slowdown to hover.

The tests of the display showed that because of the limited horizontal view of the contact analog (24°) and an incorrect generation of the lateral movement of the pathway, the pilots were constrained to fly within ±100 feet (±30.48 m) laterally of the path center line. Furthermore, the use of the pathway for slope control was found to be difficult because of the limited vertical view of the contact analog (18°) and the necessity of flying an appreciable distance above the pathway to prevent inversion of the pathway. For the slope offset of the present tests (50 feet (15.24 m)), the nearest visible part of the pathway was a considerable distance ahead of the helicopter; thus slope deviations were difficult to detect. The display also presented an unrealistic quality because of the relative motions of the ground grid and the pathway tip.

Despite the limitations and deficiencies in the contact-analog presentation, four research test pilots were able to fly the approaches to breakout heights of less than 100 feet (30.48 m). In tests by one of the pilots, the approaches were carried to a 50-foot (15.24-m) breakout height.

INTRODUCTION

As a part of the program at the Langley Research Center to investigate the instrument-display requirements for the landing of V/STOL aircraft (refs. 1, 2, and 3), an evaluation has been made of a contact-analog display in landing approaches with a helicopter. The contact analog used was an electronic display in which a stylized representation of a ground plane was generated in a ground-coordinate system and displayed on a television monitor. The contact analog included representation of an inclined pathway, fixed in the ground-coordinate system, that provided information for slope and course guidance. Like any "real-world" cockpit instrument display, this contact analog had a limited angular view, which was 24° horizontal and 18° vertical.

Tests of a contact analog similar to that used in the present investigation have previously been conducted in an aircraft simulator (ref. 4) and in a helicopter (ref. 5). For the flight tests of reference 5, the helicopter was flown along an 8° glide slope at an approach speed of 65 knots. The approaches were terminated when the safety pilot assumed control at heights ranging from 1 foot (0.31 m) to 1100 feet (335.28 m) above the ground.

In the present investigation, the helicopter was flown along a 6° glide slope at an approach speed of about 30 knots. The approaches were flown under simulated IFR (Instrument Flight Rules) conditions to a breakout (change from instrument to visual flight) that was followed by a visual slowdown to hover over the landing pad. The results of the present tests are presented in terms of pilot evaluation and performance. The results of the correctness with which the contact-analog presentation was generated are also included.

SYMBOLS

The units used for the physical quantities defined in this paper are given both in the U.S. Customary Units and in the International System of Units (SI). Factors relating the two systems are given in reference 6.

r	slant range, distance between radar antenna and aircraft, feet (meters)
x	range, distance of aircraft from slope origin as measured in ground plane along or parallel to course, feet (meters)
$\dot{x}$	longitudinal velocity of aircraft, knots
y	course deviation, lateral displacement of aircraft from selected course, feet (meters)
$\dot{y}$	lateral velocity of aircraft, knots
z	height of aircraft above ground plane, feet (meters)
Δz	slope deviation, 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	glide-slope angle, degrees
θ	pitch angle of aircraft, degrees
ϕ	bank angle of aircraft, degrees
Ψ	heading angle of aircraft, degrees
ψ	azimuth angle of radar antenna, degrees

INSTRUMENT DISPLAY

The instrument display (fig. 1) consisted of a contact analog, a torquemeter, a ball skid indicator, and vertical-scale instruments for the indication of airspeed, vertical speed, and height.

Contact-Analog Monitor

The contact-analog monitor was a 1000-line limiting resolution, black-and-white cathode-ray tube with 525 scan lines, 60 fields and 2-to-1 interlace. The screen was 7 inches (17.8 cm) wide and 5.25 inches (13.3 cm) high. The symbols displayed on the monitor were formed in a symbol generator (fig. 2). The positions and movements of the symbols were controlled by inputs to the symbol generator of aircraft positions x, y, z, and Δz, position rates $\dot{x}$ and $\dot{y}$, and attitudes ϕ, θ, and Ψ.

Vertical-Scale Instruments

The vertical-scale instruments were of the fixed-scale type with moving pointers (triangles on the tapes) for the airspeed and vertical-speed indicators and thermometer-type presentations for the height indicators.

The scale length of the indicators was 4.5 inches (11.4 cm) and the scale ranges were as follows:

Airspeed	0 to 100 knots
Vertical speed	-800 to 200 ft/min (-4.06 to 1.02 m/sec)
Height (fine)	0 to 110 ft (33.53 m)
Height (coarse)	0 to 1100 ft (335.28 m)

The airspeed and vertical-speed indicators were actuated by electrical pressure transducers that were connected to the service pitot-static system; the vertical-speed transducer included an accelerator element to compensate for the inherent lag of the pressure-measuring system. The two height indicators were actuated by a height signal z from a ground-based radar and, thus, indicated the geometric height of the aircraft above the ground landing pad.

The hatched area at the bottom of the airspeed scale (fig. 1) indicates that the readings are unreliable in the range below 20 knots because of limitations in the pressure transducer. The two white rectangles at the bottom of the 1100-foot (335.28-m) height scale indicate the height at which the pilot should transfer his attention to the sensitive height indicator.

CONTACT ANALOG

Symbols

The symbol configuration of the contact analog of the present investigation was made up of a horizon line, a ground grid, and an inclined pathway (fig. 3). The angular view of the displayed scene was 24° horizontal and 18° vertical.

The ground grid and pathway were generated in a system of ground coordinates and were sized in terms of real-world dimensions. Dimensions of these symbols were selected from considerations of limitations of the display system, that is, restricted view angle and symbol definition. Accordingly, the symbols were sized so that they would be small enough to fill only a part of the screen at short distances and large enough so that they could be distinguished at long distances. The sizes of the symbols, although scaled to real-world dimensions, would have real-world significance to the pilot only if he had experience with corresponding sized objects in the real world and if his visual angle (the angle formed by his viewing distance and the size of the screen) was the same as the view angle of the display. (For a detailed discussion of the effects of pilot's visual angle and display view angle on the sizes of images on a monitor screen, see ref. 3.)

Horizon line.- The horizon line was a white band at the top of the ground grid that was intended to provide a distinguishing reference between the ground grid and the light-gray sky area. The horizon line was generated to rotate and move vertically with the ground grid to indicate aircraft roll and pitch attitude in 1:1 correspondence with the real horizon.

Ground grid.- The ground-grid pattern of squares changes size by a factor of 10 at a height of 200 feet (60.96 m); at this same height, the black-and-white pattern of the grid reverses. At heights above 200 feet (60.96 m), the grid was sized to represent 400-foot

(121.9-m) squares and the pattern consisted of white squares with black dividing lines (fig. 3(a)). At heights below 200 feet (60.96 m), the squares were sized to 40 feet (12.19 m) and the pattern reversed to black squares with white dividing lines (fig. 3(b)). Within each of the height ranges, the size of the squares varied inversely with inputs of aircraft height. The grid translated laterally and longitudinally with inputs of aircraft position rates. Note that the upper part of the grid disappears in a haze area that extends about 3° below the horizon line.

Pathway.- The pathway was sized to represent a path 20 feet (6.10 m) wide which was inclined at an angle of 6°. With the symbol generation system of the present tests, the pathway was of infinite length, that is, terminated at a point, for heights greater than 200 feet (60.96 m) (fig. 3(a)); for heights below 200 feet (60.96 m), the pathway was of finite length with the end of the pathway at the ground plane (fig. 3(b)).

The pathway moved laterally with inputs of aircraft lateral position y and changed width with inputs of slope deviation Δz. When the path was of finite length, it decreased in length with decreasing range x. Figure 4(a) shows the width of the pathway for an aircraft height of 100 feet (30.48 m) above the pathway and figure 4(b) shows the width at a height of 50 feet (15.24 m) above the pathway. For aircraft positions below the pathway, the pathway flips to the top of the screen and inverts, as shown in figure 4(c) for an aircraft 10 feet (3.05 m) below the pathway.

Symbol Calibrations

To determine the correctness with which aircraft attitude, position, and speed were presented by the symbol configuration of the contact analog, calibrations were conducted by applying fixed signals corresponding to selected aircraft attitudes and positions to the symbol generator. The resulting symbol configurations on the monitor screen were photographed, and the correctness of the configurations was then determined from measurements of the photographs or from a comparison of the photographs with configuration diagrams developed on the basis of the actual positional information and the angular view of the display. Examples of photographs of some of the symbol configurations examined and diagrams of the corresponding computed configurations are presented in figure 5.

Roll, pitch, and heading.- Figure 5(a) shows the symbol configuration for a roll attitude of 0°, a pitch-down attitude of 2°, and a heading of 0°. Variations from this configuration in roll and pitch showed that both roll and pitch attitude were correctly presented in 1:1 angular correspondence with the real horizon.

The presentation of heading (with the aircraft on course is shown to be correctly indicated by the pathway, as exemplified by the 8° heading change in figure 5(b). Heading changes as indicated by the ground grid, however, are difficult to interpret because the grid is not generated in true perspective; that is, the longitudinal lines do not converge to a common point on the horizon. Additional tests of the pathway movement with heading showed that the pathway moved off the screen with a heading change of 12°, the limit of the horizontal view of the display.

Slope deviation.- The photograph in figure 5(a) shows the size of the pathway for an aircraft height of 50 feet (15.24 m) above the pathway. Comparison of the photograph with the computed diagram shows that the slope deviation indicated by the position of the pathway is correct. Additional tests above and below the 50-foot (15.24-m) height showed the pathway to correctly indicate slope deviation at heights ranging from about 5 feet (1.524 m) to 100 feet (30.48 m) above the pathway.

Course deviation.- Figure 5(c) shows a situation of 0° heading and a lateral position of 75 feet (22.86 m) to the right of the prescribed course. A comparison of the photograph and the computed diagram shows the course deviation to be incorrectly presented by the displacement of the pathway tip and also by the incorrect position of the rear edge of the pathway. The principal reason for the incorrect course-deviation presentation is that the pathway tip is generated to move laterally with course deviation and independently of range, whereas in actuality the lateral movement of the pathway tip on the screen should be a function of range. Because of this feature of the display, the lateral path within which the pathway provides course-deviation information is of constant width rather than converging. Additional tests of the lateral movement of the pathway showed this lateral pathway width to vary ±100 feet (±30.48 m) from the center line. As a matter of incidental interest, the incorrectness in the display of course deviation was even greater for aircraft positions below the pathway (fig. 5(d)).

Height.- The accuracy with which height information was displayed by the change in size of the squares of the ground grid was difficult to determine because the squares along any lateral row in the grid were of different sizes. Measurements of selected squares, however, indicated that, in general, the squares of the grid had been generated to increase properly with decreasing height. Even so, the change in grid size provided only a qualitative indication of changes in height. For this reason the quantitative height indicators were included in the display.

Range.- Since the ground grid moved longitudinally with inputs of range rate, the only range information on the display was that provided by the change in length of the pathway when the pathway was of finite length (that is, at heights below 200 feet (60.96 m)). Calibrations of the variation in pathway length with range showed this range presentation to be essentially correct.

Ground speed.- Ground speed was not indicated correctly by the motion of the ground grid throughout the altitude range of the approaches of the present investigation. Although the rate of grid movement was generated in terms of both ground speed and altitude, the altitude dependence was approximated as a straight line instead of the proper nonlinear function. Because of this incorrect rate generation, the ground grid appeared to move underneath the pathway, both laterally and longitudinally. With the pathway of infinite length, however, the ground grid would still have moved longitudinally with respect to the pathway even if the rate generation had been correct, since in this mode no longitudinal position input to the pathway generation exists.

GUIDANCE SYSTEM

The guidance system consisted of a ground-based radar with computers and telemetry for generating and transmitting aircraft position and position-rate information and airborne receiving and computing equipment for processing the information for the symbol generator. A description of the radar and the telemetry systems is given in reference 1.

A diagram of the guidance and display system used in the present tests is given in figure 6. As indicated by this figure, the position and position-rate inputs to the display were in the form of rectangular coordinates (x,y,z and $\dot{x},\dot{y},\Delta z$). The aircraft attitude inputs (ϕ, θ, and Ψ) to the symbol generator and computer were derived from aircraft gyros.

RECORDING INSTRUMENTS

In the radar ground station, the horizontal (x-y) and vertical (x-z) tracks of the aircraft were recorded on two coordinate plotters. The quantities x, $\dot{x}$, y, z, Δz, and $\dot{z}$ were recorded as time histories on a recorder.

In the helicopter, time histories of airspeed and the movements of the four cockpit controls were recorded on two NASA flight recorders. The records of these instruments were synchronized with those of the ground-station recorders by a radio link.

INSTRUMENT ACCURACIES

The accuracies of the airspeed, vertical-speed, and height indicators were determined by calibration tests to be within the reading accuracies of the instruments (ref. 1).

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 (2134-m) range
Height	1 foot (0.31 m) at zero range 11 feet (3.35 m) at 7000-foot (2134-m) range

TEST AIRCRAFT

The helicopter (fig. 7) used in the present tests was the same as that used for the tests reported in references 1, 2, and 3. This helicopter was not equipped with artificial stabilization. As shown in figure 7, a test instrument housing was installed through the left windshield and a radar-beam corner reflector was installed on the nose of the aircraft. The instrument display was located about 29 inches (73.7 cm) directly in front of the pilot's eyes.

For the simulation of IFR conditions, the windshield was covered with amber plastic and the pilot wore a removable blue visor.

TEST PROGRAM

The contact-analog display was evaluated in landing approaches with a helicopter under simulated IFR conditions along a 6° glide slope at indicated airspeeds of about 30 knots. The approaches were started at a height of about 700 feet (213.4 m), about 50 feet (15.24 m) above the pathway, within 100 feet (30.48 m) of the course line, and with a heading deviation less than 12°.

In order to prevent frequent flipping of the pathway from bottom to top of the screen and because of an inaccurate presentation of course deviation when the pathway was inverted at the top of the display, the pathway was set 50 feet (15.24 m) below the glide slope. This distance was selected after consideration of the slope deviations that were experienced with the test helicopter in the tests of the displays of references 1 and 2.

A diagram showing the pathway set 50 feet (15.24 m) below the glide slope and the vertical view angle of the contact analog is shown in figure 8. In this figure, the aircraft has been positioned on the glide slope at a height at which the tip of the pathway is lost from view on the contact analog with the aircraft in a 3° pitch-down attitude (the usual attitude for the approaches along a 6° slope). This diagram shows that the pathway disappears at a height of about 100 feet (30.48 m).

The tests were conducted by four NASA research test pilots. The project pilot was the same pilot who evaluated the displays of references 1, 2, and 3. The pilots performed a number of approaches to familiarize themselves with the contact analog and to form opinions of its information presentation. Following these flights, each of the four pilots flew 10 more approaches for performance measurements. In the performance tests with three of the pilots, the approaches were carried to a breakout height that was determined by the pilot when the end of the pathway was lost from view. This height was generally less than 100 feet (30.48 m) and varied from one approach to another depending on the slope deviation and pitch attitude at the time the pathway disappeared. In the performance tests by the project pilot, however, the approaches were carried to a breakout height of 50 feet (15.24 m) as indicated by the height indicator; this lower breakout was achieved by flying closer to the pathway toward the end of the approach. All approaches were terminated with a transition to visual flight and a slowdown to hover.

RESULTS AND DISCUSSION

Familiarization Flights

During the familiarization flights, the pilots experienced difficulties in flying the approaches because of (1) the limited view angles of the display, (2) certain deficiencies in the generation of the symbols and their movements, and (3) the fact that slope and course guidance information was derived from a single element, the inclined pathway.

With the limited horizontal view angle (24°), difficulties were experienced in course guidance because the pathway could be lost from view with relatively small changes in heading (12°) or with deviations from course of only 100 feet (30.48 m). Whenever the pathway was lost from view, the display was reduced to a view of the uniform ground pattern which sometimes made returning to the course path difficult. For this reason, the pilots were effectively constrained to follow a comparatively narrow course path, and therefore constant attention to the control of course guidance was required.

Difficulties in course guidance were also experienced because of the similarity in appearance of some heading and course-deviation presentations (compare, for example, figs. 5(b) and 5(c)). As a result, course deviations could be misinterpreted as heading changes and heading changes as course deviations.

With this display the prime source of slope-deviation information was the section of the pathway at the bottom of the screen, which was a considerable distance ahead of the aircraft because of the limited vertical view (18°) and the offset of the pathway 50 feet (15.24 m) below the glide slope. As a result, slope deviations were difficult to detect. Furthermore, changes in pitch attitude could be misinterpreted as slope deviations, since the pathway width changed with both pitch attitude and slope deviation. Thus, whenever the pathway width changed, the pilots were forced to check the position of the horizon line to determine whether the change in pathway width indicated a pitch change or a slope deviation. The use of the inclined pathway for slope control, therefore, was found to require scanning of the screen and considerable concentration on the part of the pilot.

As noted previously, the ground grid appeared to move with aircraft motion underneath the pathway tip. This relative movement of ground grid and pathway tip was considered by the pilots to detract considerably from the realism of the display. Despite the difficulties in the use of the display for course and slope controls, the pilots became sufficiently proficient toward the end of the familiarization flights to keep the pathway on the screen throughout most of an approach and to generally fly above the pathway and thereby avoid pathway inversion.

Because of the pilots' concentration on course and slope control, their control of airspeed was often erratic. On the other hand, their control of roll and pitch attitude was generally satisfactory presumably because of the relatively long horizon line and the 1:1 relationship with the real horizon.

In spite of the many shortcomings of the information presentation of the contact analog of the present tests, the pilots were of the opinion that the combined presentation of attitude and guidance information in a simple, perspective format represented an improvement over the separated vertical- and horizontal-situation presentations of the cross-pointer display of reference 1 and the moving-map display of reference 2. The combination of information in naturalistic form allowed the pilots to better coordinate their control actions in performing two or more control corrections simultaneously.

Performance Tests

In his performance tests with the display, the project pilot flew 10 consecutive approaches in quartering winds of from 6 to 10 knots. The course and slope tracks for these approaches are plotted in figure 9. Also plotted are the 50-foot (15.24-m) breakout height and the ±100-foot (±30.48-m) lateral limits within which the pathway remains on the monitor screen. Note that the course-deviation and height scales in this figure are five times the range scale, a scaling difference that produces an exaggeration of the actual deviations from course and slope. With the exception of one excursion between a range of about 5000 feet (1524 m) and 6000 feet (1829 m), all of the course tracks were within a lateral distance of 100 feet (30.48 m) from the course center line. The slope tracks in all the approaches were above the display pathway, with the exception of one excursion toward the end of one of the approaches.

In the performance tests by the other three pilots, all of whom had less experience than the project pilot in the use of the display and in the operation of the helicopter, the excursions from slope and course were generally greater and more erratic than those of the approaches in figure 9; in addition, the breakout heights of these pilots were higher and less consistent than the 50-foot (15.24-m) breakouts of the project pilot. The slope and course tracking in figure 9, therefore, represents the best that was achieved in the present tests of the contact-analog display.

This slope and course tracking with the contact-analog display can be compared in a general way with the tracking with the moving-map display of reference 2, since the two displays were comparable in that both presented slope and course guidance in the form of displacement information. Such a comparison shows that under comparable wind conditions, slope tracking with the contact analog was for the most part less precise than with the conventional slope-deviation indicator used with the moving-map display. Course tracking, on the other hand, was somewhat better with the contact analog, but this can be attributed, at least in part, to the fact that with the contact analog the pilot was constrained to fly within a narrower course path.

In an assessment of the overall performance of an approach task, the control of attitude and speed must be considered along with the control of guidance. As noted previously, the control of attitude with the contact analog was generally satisfactory, but the control of speed was often erratic. An indication of the magnitude of the speed variations in the approaches with the contact-analog display is given in figure 10, which shows time histories of the airspeeds for the 10 approaches of figure 9. These plots show that on a number of the approaches the airspeed varied from the nominal approach speed by more than 10 knots, a variation considerably greater than the speed variations that were experienced with the moving-map display.

The lateral and longitudinal positions of the aircraft at breakout for the approaches of figure 9 are plotted in figure 11. The lateral deviation for all approaches are less than 25 feet (7.62 m), a figure that compares favorably with the lateral deviations at the 50-foot (15.24-m) breakout with moving-map display. The longitudinal deviations from the prescribed range for the 50-foot (15.24-m) breakout height, however, vary from 50 feet (15.24 m) long to 490 feet (149.4 m) short. This variation compares with values of 50 feet (15.24 m) long to 140 feet (42.67 m) short for the breakouts with the moving-map display. These longitudinal deviations from the prescribed breakout range are a measure of the slope deviation at breakout and provide another indication that the control of slope with the inclined pathway of the contact analog was less precise than with the slope-deviation indicator of the moving-map display.

CONCLUDING REMARKS

An evaluation has been conducted of an instrument display incorporating a contact analog as the principal source of attitude and guidance information. The contact-analog presentation included an inclined pathway, fixed in a ground-coordinate system, that provided information for slope and course guidance. The evaluation was conducted in landing approaches with a helicopter under simulated IFR conditions. The approaches were made at airspeeds of about 30 knots along a 6° glide slope that was set 50 feet (15.24 m) above the displayed pathway. From laboratory tests of the display and from flight tests by four research test pilots, the following conclusions are indicated:

1. With the limited horizontal view of the contact analog (24°), the pathway could be lost from view for heading changes of 12° and course deviations of about 100 feet (30.48 m); under these conditions the displayed scene was reduced to a uniform grid pattern with no distinguishing features.

2. Because of a deficiency in the pathway presentation for course deviation and the fact that the ground grid was not generated in true perspective, course deviations could be misinterpreted as heading changes and heading changes as course deviations.

3. Because of an inaccurate presentation of course deviation when the aircraft was below the pathway and in order to prevent frequent inversion of the pathway, it was necessary to set the pathway 50 feet (15.24 m) below the glide slope.

4. With the limited vertical view of the contact analog (18°) and the pathway offset of 50 feet (15.24 m) below the glide slope, the end of the pathway could be lost from view when the aircraft, inclined 3° nose down, reached a height of about 100 feet (30.48 m) along the 6° slope.

5. Because the section of the pathway at the bottom on the screen was a considerable distance ahead of the helicopter when the helicopter was 50 feet (15.24 m) above the pathway, slope deviations were difficult to detect and changes in pitch attitude could be misinterpreted as slope deviations since the width of the pathway changes with both slope deviations and pitch attitude.

6. Because the pathway was fixed in a ground-coordinate system and the ground grid moved with aircraft position rates (which were improperly generated in the contact analog tested), the ground grid moved relative to the pathway and thereby detracted from the realism of the display.

7. In performance tests with the display, each of the pilots flew 10 consecutive approaches to breakout heights of less than 100 feet (30.48 m); in the tests by the project pilot, the approaches were carried to a breakout height of 50 feet (15.24 m). For these 50-foot (15.24-m) breakouts, the lateral deviations were within 25 feet (7.62 m) and the

longitudinal deviations from the prescribed breakout point varied from 50 feet (15.24 m) long to 490 feet (149.4 m) short.

8. Despite the deficiencies in the contact-analog presentation, the pilots were of the opinion that the combined presentation of attitude and guidance information in a single, perspective format represented an improvement over the separated vertical- and horizontal-situation presentations of two of the displays previously tested at the Langley Research Center. The combination of information in naturalistic form allowed the pilots to better coordinate their control actions in performing two or more control corrections simultaneously.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., March 11, 1969,
721-05-00-01-23.

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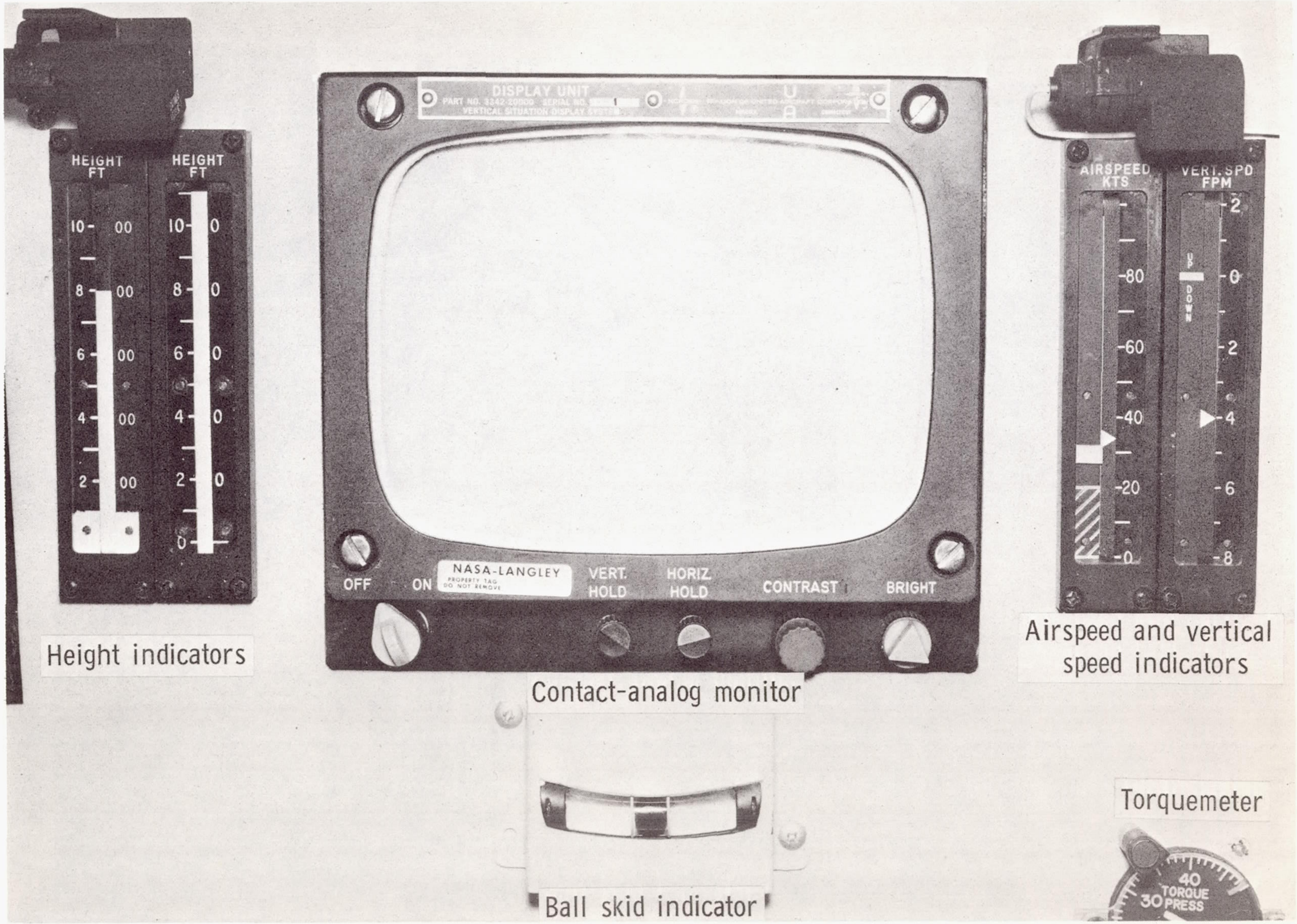
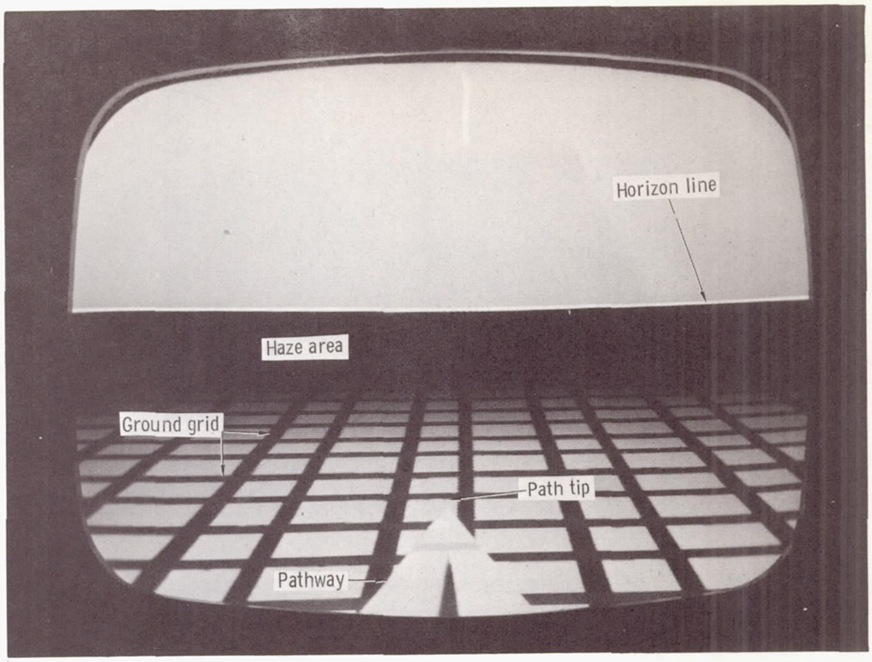


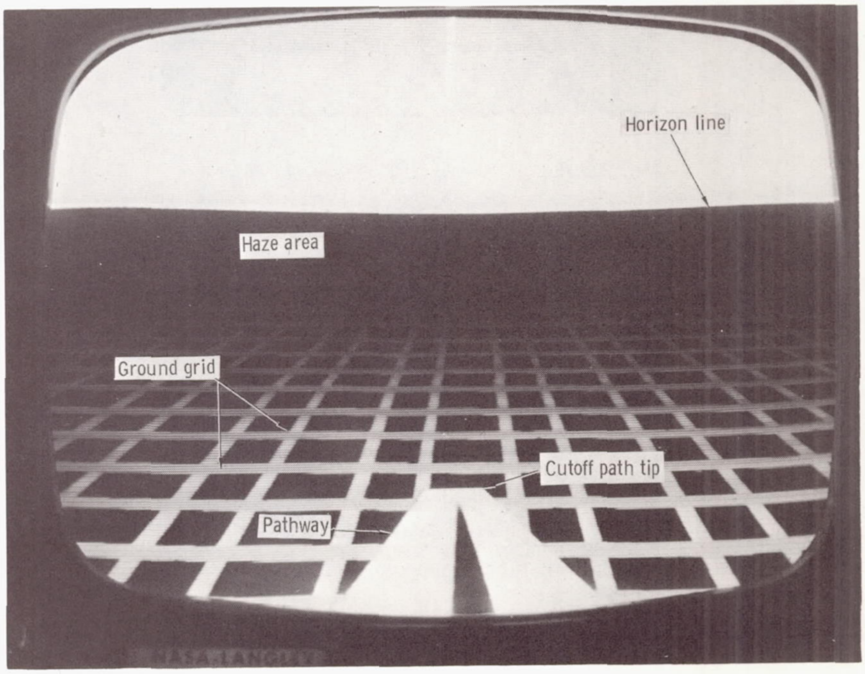
Figure 1.- Test instrument display.

L-67-8918.1

Figure 2.- Airborne guidance equipment. L-66-8797.1

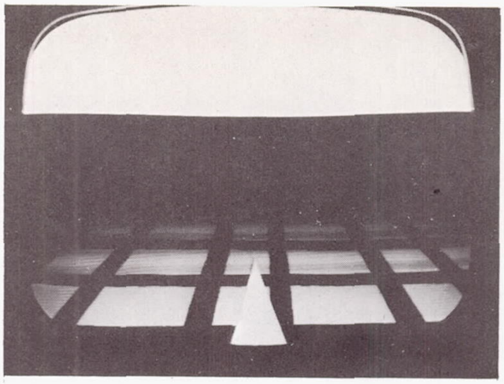


(a) Configuration at heights above 200 feet (0° pitch). L-67-4101.1

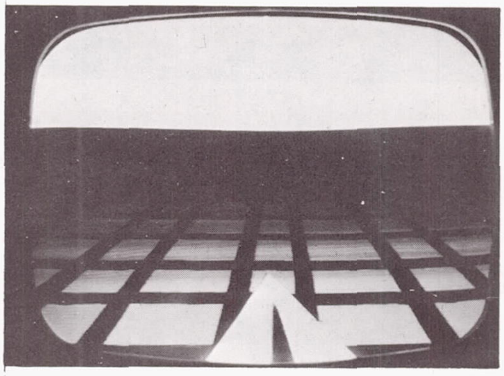


(b) Configuration at heights below 200 feet (3° pitch down). L-67-9559.1

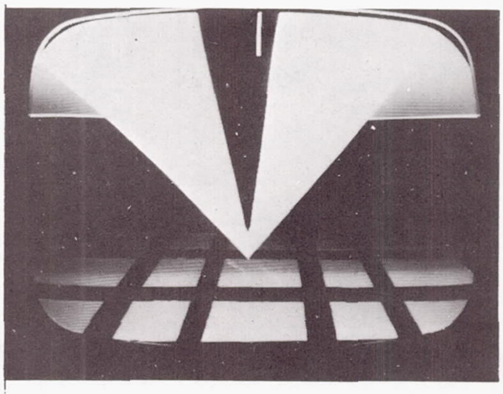
Figure 3.- Symbol configuration of contact analog.



(a) Aircraft 100 feet (30.48 m) above pathway.

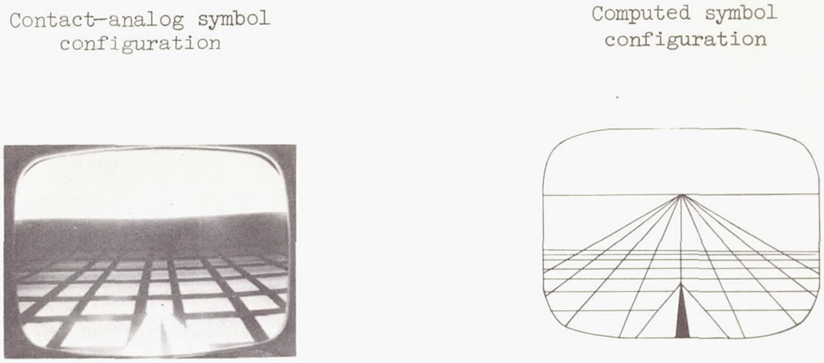


(b) Aircraft 50 feet (15.24 m) above pathway.

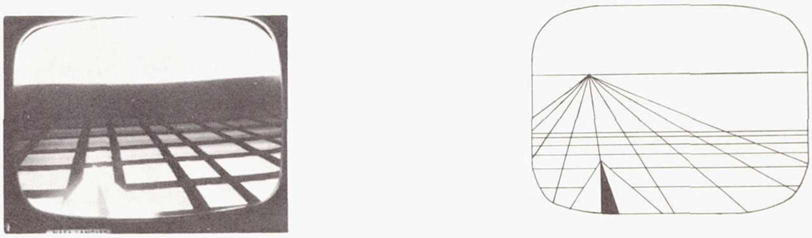


(c) Aircraft 10 feet (3.05 m) below pathway.

Figure 4.- Pathway indication of slope deviation.

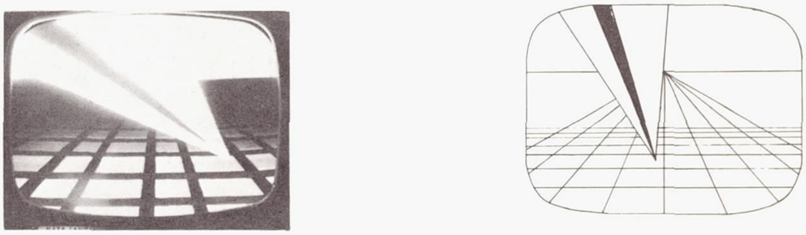


(a) Aircraft on course with 0° roll, 2° pitch down, 0° heading, and 50 feet (15.24 m) above pathway.



(b) Aircraft on course with 8° heading to right.

(c) Aircraft at 0° heading and 75 feet (22.86 m) to the right of prescribed course.



(d) Aircraft at 0° heading and 75 feet (22.86 m) to the right of prescribed course below the pathway.

Figure 5.- Comparison of contact-analog and computed symbol configuration for selected combinations of aircraft attitude and position for aircraft altitudes greater than 200 feet (60.96 m).

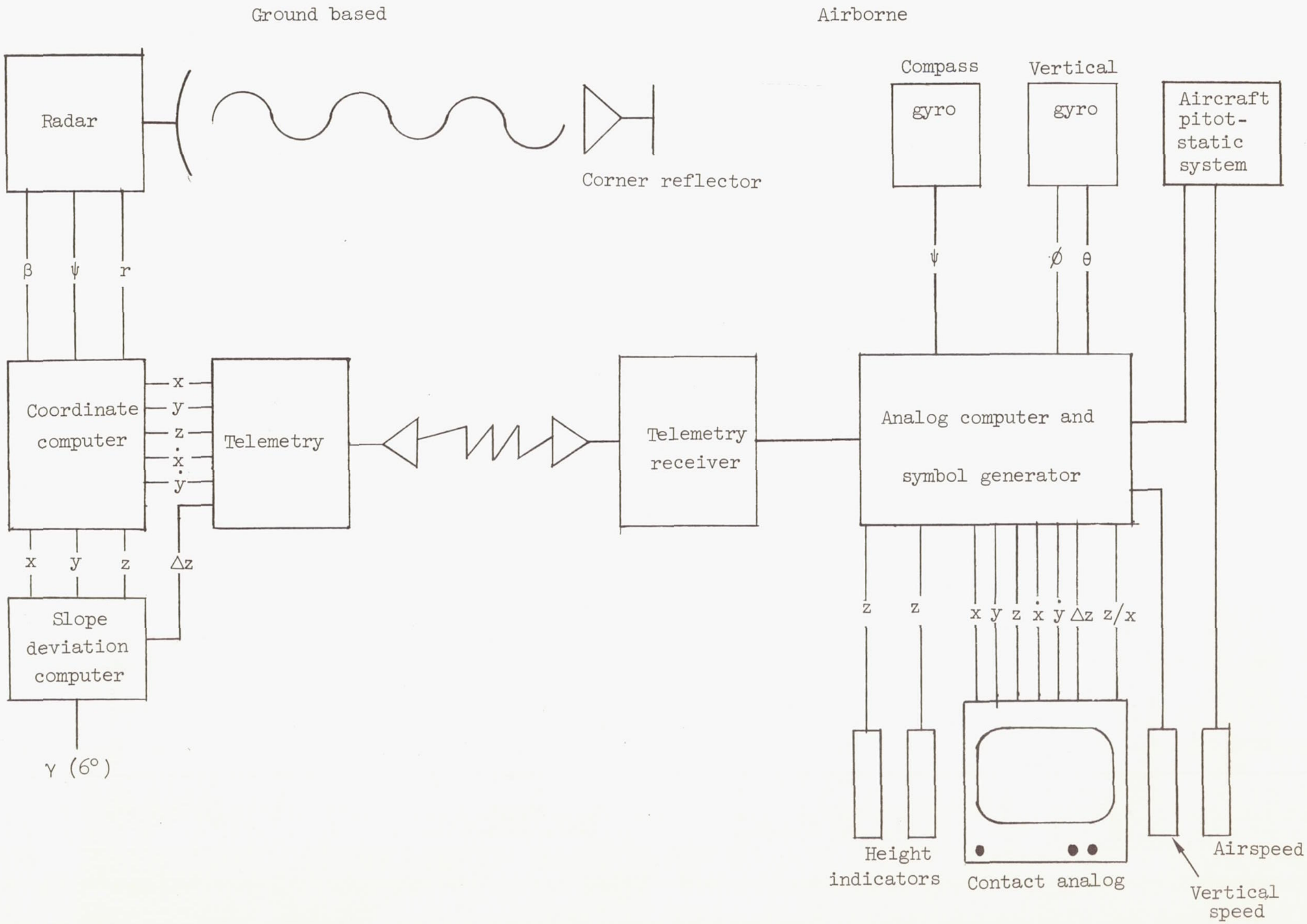


Figure 6.- Diagram of guidance and display system.

Figure 7.- Test helicopter.

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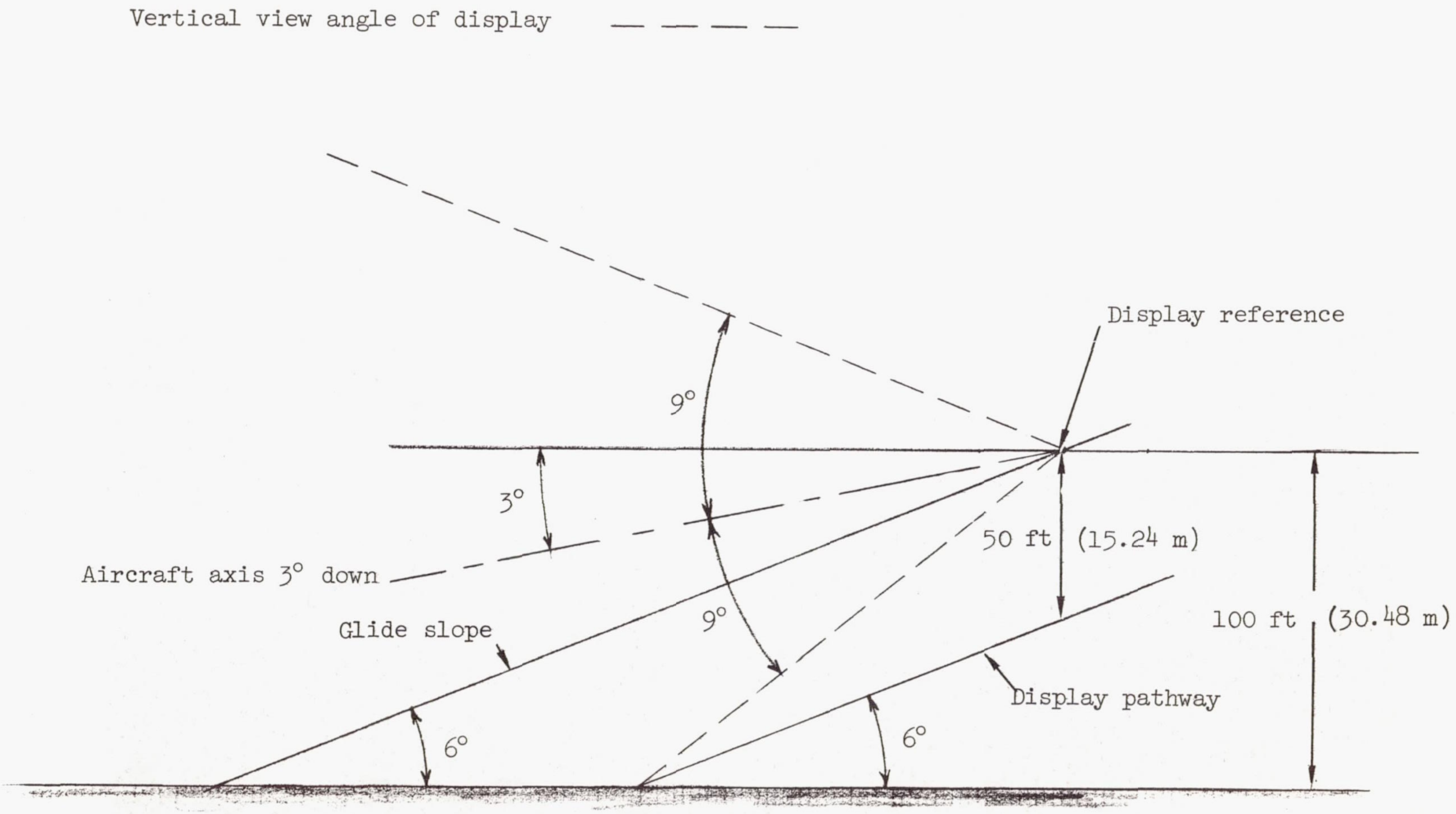

Figure 8.- Diagram showing glide slope, display pathway, and vertical view angle of display with aircraft in a 3° pitch-down attitude.

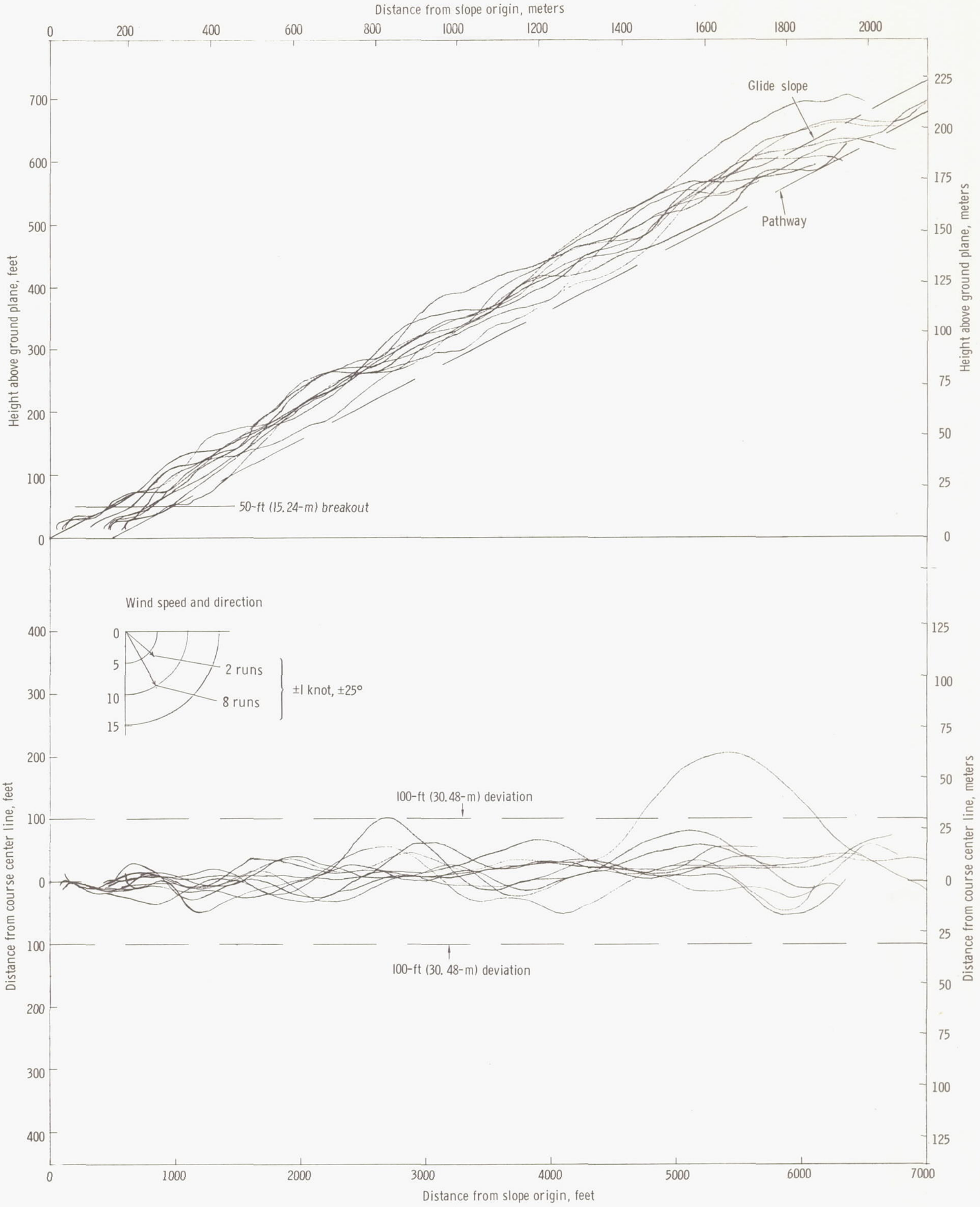

Figure 9.- Course and slope tracks for 10 approaches at a speed of 30 knots to a 50-foot (15.24-m) breakout height.

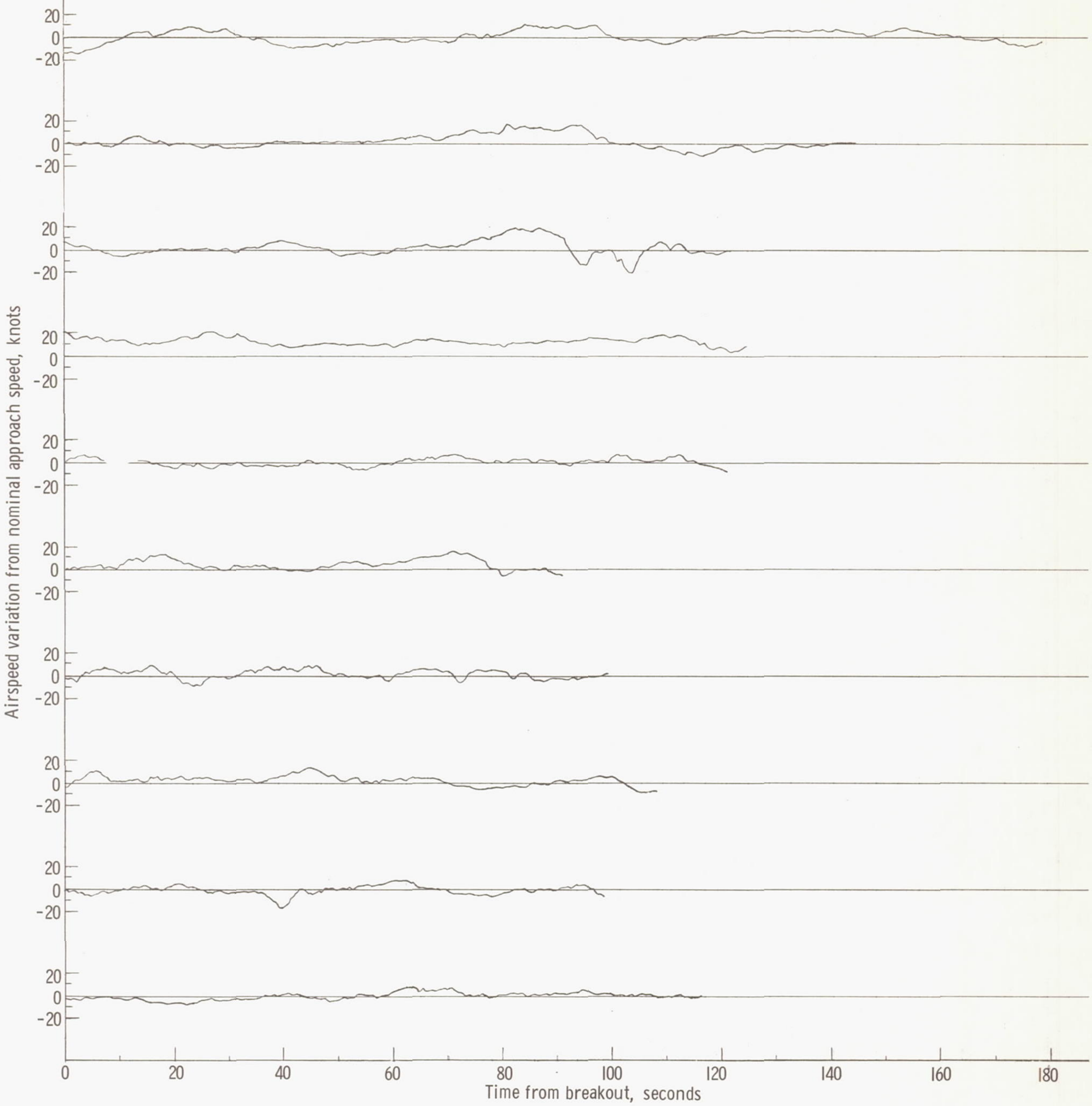

Figure 10.- Time histories of airspeed variations from nominal approach speeds of 30 knots.

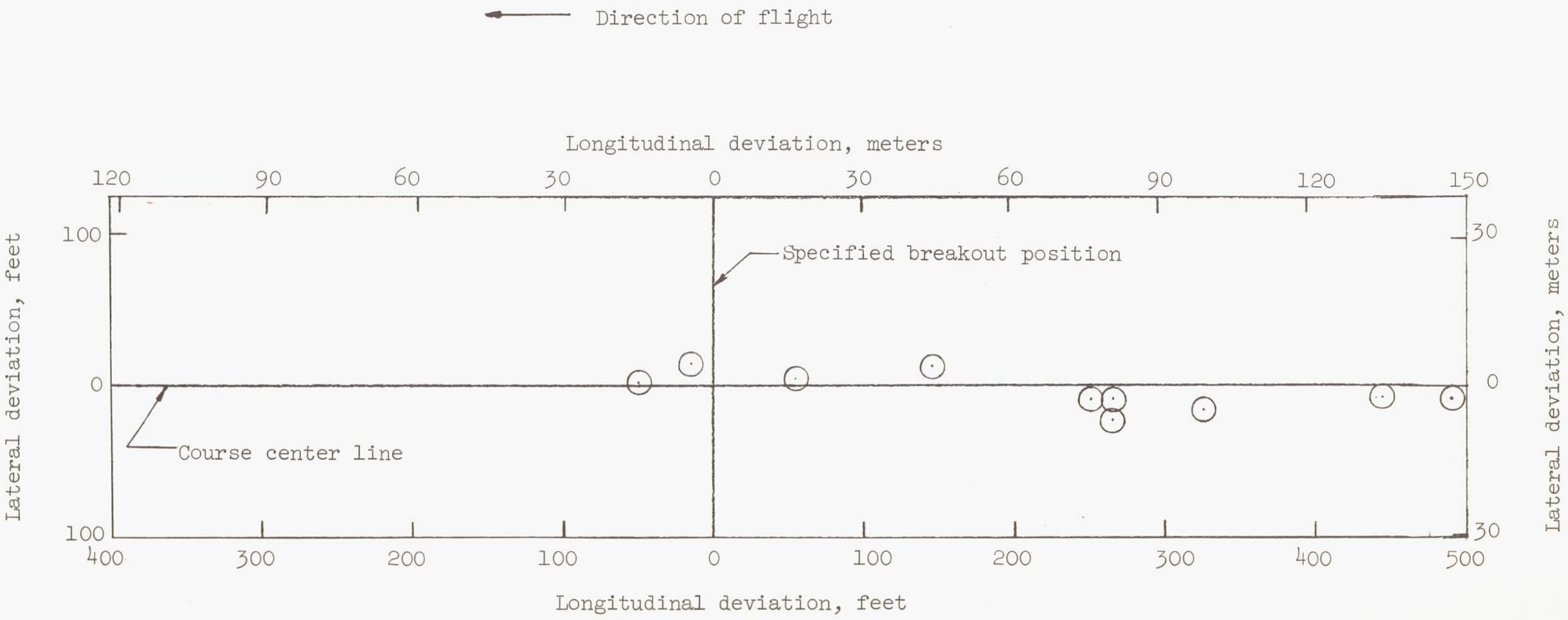

Figure 11.- Longitudinal and lateral deviation of aircraft at 50-foot (15.24-m) breakout height.

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