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by William Gracey, Robert W. Sommer, and Don F. Tibbs

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SUMMARY

An evaluation of an instrument display consisting of a television monitor; vertical-scale instruments for the indication of airspeed, vertical speed, and height; and a dial-type torquemeter has been conducted in simulated IFR (Instrument Flight Rules) approaches with a helicopter. The evaluation was made with three lenses having focal lengths of 12.5, 25, and 50 mm. Tests were also conducted under normal visual conditions and under restricted viewing conditions (both binocular and monocular) with the angular view of the 25-mm lens. The approaches were made along a 6° slope at speeds of about 40 knots.

The restricted-view tests with binocular vision showed that a view as small as 22.6° horizontal and 18.5° vertical has a detrimental effect on the control of longitudinal position at touchdown. The tests with monocular vision showed that the control difficulties increase with the loss of depth perception.

The tests of the television display showed that the difficulties in controlling attitude and position increased as the helicopter approached the ground. The determination of position and position-rate information (particularly range and height) was made difficult because of the restricted views of the lenses, the image magnification (about 0.35 to 1.4 for the tests), and the low resolution and lack of depth perception of the televised scene.

In a final series of performance tests, 20 landings were made with the 25-mm lens and 10 with the 12.5-mm lens. Despite the rather severe control difficulties in the terminal phase of the approach, the landings were completed with a fair degree of success and generally within a 100-ft-square (30.48 m) landing pad. The tests demonstrated that, with the television display augmented by height information, the pilots were able to execute low-speed, steep approaches with an angular view as small as 22.6° by 18.5° and an image magnification as small as about 0.35.

INTRODUCTION

Closed-circuit television systems with forward-looking cameras have been proposed as cockpit displays for the landing of aircraft. The television display has been considered primarily for the visual landing of high-performance aircraft providing inadequate visibility through the windshield. From a consideration of the possible development of satisfactory low-light television cameras, the use of the television display has also been suggested for night landings on fields without ground lighting. Flight evaluations of television systems have been conducted in landing operations under simulated IFR (Instrument Flight Rules) conditions with both conventional aircraft (refs. 1 and 2) and a helicopter (ref. 3).

In a National Aeronautics and Space Administration program to investigate the instrument display requirements for the landing of V/STOL aircraft (refs. 4 and 5), one of the display concepts to be evaluated is the "real world" presentation of the contact analog (a television-type display that presents a synthetic, perspective view of a stylized ground plane of the type described in ref. 6). Since the closed-circuit television presentation represents the most realistic form of contact analog display, tests of a television system have been conducted to gain knowledge and experience for the subsequent evaluation of the contact analog.

In the investigation of reference 3, the evaluation was made with one lens, with the camera at one of two positions and either fixed or rotatable in pitch. In the present investigation, evaluations were made with three lenses (12.5-, 25-, and 50-mm focal length), with the camera at one position and fixed at selected angles of pitch. In addition, tests were conducted under normal visual conditions and under restricted viewing conditions with an angular view the same as that of the 25-mm lens; the restricted-view tests were conducted with both binocular and monocular vision.

The tests were conducted in a helicopter and the tests of the television display were made under simulated IFR conditions. The approaches were made along a 6° glide slope at speeds of about 40 knots. The results of the tests are presented in terms of pilot evaluation of the display and pilot performance of the prescribed approach task.

GLOSSARY OF TERMS

Visual world – extended environment as seen by both eyes under normal viewing conditions

Visual field – angular view seen by both eyes with eyes fixed

Lens view angle – angular view, horizontal and vertical, projected by lens of given size

Pilot's viewing distance – distance from pilot's eyes to television screen

Pilot's visual angle – angle, horizontal and vertical, formed by size of television screen and pilot's viewing distance

Image magnification – ratio of pilot's visual angle to lens view angle

INSTRUMENT DISPLAY

The instrument display that was evaluated in the present investigation is shown in figure 1. The display consisted of a television monitor; vertical-scale instruments for the indication of airspeed, vertical speed, and height; and a dial-type torquemeter. For the initial evaluation of the display, the height indicators were not installed.

Television Equipment

The television equipment consisted of a standard, black-and-white, 525 raster-line camera and monitor. The camera and monitor were installed as a closed-circuit system.

Camera.- The camera was mounted on a bracket ahead of the cabin at about the pilot's eye level (fig. 2). The bracket could be tilted and locked at any angle between the horizontal and 35° down.

The focal lengths of three lenses used in the tests were 12.5 mm, 25 mm, and 50 mm. The view angles of the lenses as measured on the monitor screen are listed in figure 3. These measured angles are smaller than the nominal view angles because of an adjustment that was made to the raster coverage.

Monitor.- The screen of the monitor was 7 in. (17.8 cm) wide and 5.25 in. (13.3 cm) high. The distance from the screen to the pilot's eyes was about 24.5 in. (62.2 cm). For this viewing distance and screen size, the pilot's visual angle was 16.5° horizontal and 12.3° vertical. (Note that this visual angle applies to monocular vision.) For each of the three lenses, the image magnifications that result from the pilot's visual angle of the present tests are listed in figure 3.

The resolution of the television system (camera and monitor) was measured on a RETMA (Radio Electronic Television Manufacturers' Association) chart 1956. The horizontal resolution was 600 lines and the vertical resolution was 400 lines.

Vertical-Scale Indicators

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 in. (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 scale)	0 to 110 ft (0 to 33.53 m)
Height (coarse scale)	0 to 1100 ft (0 to 335.3 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 accelerometer element to compensate for the lag of the pressure element. The two altimeters indicated height above the runway plane as measured by a ground-based radar.

The hatched area at the bottom of the airspeed scale (fig. 1) indicates that the readings are unreliable in the range below 20 knots. The two white rectangles at the bottom of the 1100-ft-height (335.3 m) scale indicate the height at which the pilot should transfer his attention to the 110-ft-height (33.53 m) indicator.

RESTRICTED VIEW APPARATUS

For the visual tests with a restricted angular view, a channellike hood was installed on the right-hand side of the cockpit (fig. 4). The front end of the hood was fitted with interchangeable cutouts, one for binocular vision, the other for monocular. Both cutouts were sized for a 22.6° by 18.5° view (the same as that of the 25-mm lens) and were positioned vertically to provide a downward tilt of 4° (the angle of camera tilt used in the final tests of the 25-mm lens). The cutouts were located 19 in. (48.2 cm) from the pilot's eyes. A diagram showing the dimensions of the two openings is presented in figure 5. The hood allowed the pilot to see the standard flight instruments on the right-hand side of the cabin and to see outside only through the cutout panels.

TRACKING AND RECORDING SYSTEM

A ground-based radar, described in reference 4, was used to track the helicopter and provide continuous signals of range, course deviation, and height. These signals were used to record the horizontal and vertical tracks of the helicopter on two coordinate plotters. The height signal was also telemetered to the helicopter for actuating the two height indicators.

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. 4).

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:

	One sigma values
Range	10 ft (3.05 m) or 1 percent (whichever is greater)
Course deviation	3 ft (0.91 m) at zero range 8 ft (2.44 m) at 7000-ft (2134 m) range
Height	1 ft (0.31 m) at zero range 11 ft (3.35 m) at 7000-ft (2134 m) range

TEST AIRCRAFT

The test aircraft was a 10-place, turbine-powered, single-rotor helicopter that was not equipped with artificial stabilization equipment. As shown in figure 2, the helicopter was modified by the addition of a housing for test instrument displays and by the installation of a corner reflector to provide a point source for the reflection of the radar beam. For the tests of the television display, IFR conditions were simulated by covering the windshield with amber plastic and having the pilot wear a visor of blue plastic.

FLIGHT TESTS

The flight tests were divided into two series - evaluation and performance. For the evaluation tests, the display included the airspeed and vertical-speed indicators but not the height indicators. These tests were intended to allow the pilots to evaluate and become familiar with the television presentation without supplemental position information. For the performance tests, the height indicators were added to the display and a series of approaches was conducted in which records were made of the aircraft tracks and measurements were made of the touchdown positions. The tests were conducted by two NASA research test pilots.

Evaluation Tests

In the evaluation of the television system, tests were conducted with each of the three lenses. The evaluations were conducted throughout a complete flight regime – take-off with climb to 1000 ft (304.8 m), navigation around a race-track pattern, and an approach along a preselected course to a specified landing point. Evaluations were also made in vertical ascents to a height of about 10 ft (3.05 m), hovers for short periods of time, and descents to the ground. In both of these series of tests, the camera was fixed horizontally for some trials and tilted down at angles of as much as 30° for others. The evaluation tests were conducted during six 1-hour flights.

Performance Tests

In the performance tests, approaches were made (1) under normal visual conditions, (2) with restricted-view apparatus, and (3) with the television display. The approaches were started at altitudes from 500 to 700 ft (152.4 to 213.4 m), to one side of the selected course (a runway at the test airfield), and on a heading such that the runway was in view. After the pilot had lined up with the course, the safety pilot watched the glide-slope indicator (on the standard instrument panel) and advised the pilot when the aircraft was positioned on a 6° slope to the landing pad; thereafter, the pilot received no further glide-slope information. The approaches were made at an airspeed corresponding to a ground speed of about 30 knots. For the wind conditions during the tests, the airspeed was about 40 knots, or about 15 knots below the speed for minimum power for the test helicopter. In the final slowdown to hover, the pilot attempted to come to a stop over the center of the landing pad; however, if he brought the helicopter to a hover away from the center, he landed at that point instead of trying to reposition toward the center.

In an initial series of performance tests, the project pilot flew five consecutive approaches under normal visual conditions. In a second series, he flew 10 consecutive approaches for each of four test conditions: restricted-view binocular, restricted-view monocular, television display with the 25-mm lens, and television display with the 12.5-mm lens. Following these tests, a second pilot, who had flown as safety pilot for the tests by the project pilot, flew 10 consecutive approaches with the television display with the 25-mm lens.

RESULTS AND DISCUSSION

As a cockpit display, a television system provides a degraded representation of the visual world because of (1) limited field of view, (2) diminished clarity (due to the low resolution of the raster presentation), and (3) lack of depth perception (due to the two-dimensional projection of three-dimensional objects). Furthermore, unless the pilot's visual angle (angle formed by screen size and viewing distance) is the same as the angular view of the lens, the sizes of objects on the screen will be larger or smaller than they would be if seen visually (as a monocular view). The degree of degradation of a televised scene, therefore, depends on the size of the lens, the size of the screen, the raster-line content, and the pilot's viewing distance.

The change in image size with view angle for the three lenses used in the present tests is illustrated in figures 6(a), (b), and (c). Each view is a picture of two 4- by 4-ft (1.22 by 1.22 m) squares at a distance of 100 ft (30.48 m) from the camera. Figure 6(d) shows the size and spacing of the squares as they would have appeared at the plane of the screen with monocular vision from the pilot's eye position of the present tests.

Evaluation Tests

In the evaluation tests of the television system, the pilots experienced the greatest difficulty in controlling the attitude and position of the aircraft when operating near the ground. The primary deficiency related to the restricted field of view. Even the largest view (i.e., the 45.1° by 36.8° field of the 12.5-mm lens) was believed to be only marginal. The field of the 50-mm lens was found to be so restrictive that, after a few flights, this lens was eliminated from further testing.

The horizontal views of the 12.5- and 25-mm lenses were found to be acceptable for heading control and guidance along a straight-line path, even in moderate crosswind conditions. The main difficulty with the limited horizontal fields of these lenses was experienced in turning through large angles, as when intercepting an approach course.

With the limited vertical fields of the 12.5- and 25-mm lenses, the near view of the ground (at the bottom of the picture) was a considerable distance ahead of the aircraft. To obtain a view of the ground nearer the aircraft (for better control of position at low heights), the camera was tilted down to an angle where the view above the horizon was still sufficient for the control of pitch attitude. For the 12.5-mm lens the selected angle was -9° and for the 25-mm lens, -4°. Even with these angles of tilt, however, the near view of the ground was still an appreciable distance in front of the aircraft. At a height of 10 ft (3.05 m), for example, the near point on the ground with the 12.5-mm lens was 35 ft (10.66 m); with the 25-mm lens, it was 67 ft (20.42 m). With regard to the problem of determining position from a view of a far field, the pilots suggested that the inclusion of a part of the aircraft in the picture would have provided a better aircraft-to-ground reference.

The control of aircraft position near the ground was made additionally difficult because of the lens magnification which, with the 12.5- and 25-mm lenses, made distances appear greater than actual and rates appear less than actual. The effect of the less-than-one magnification was more pronounced on range and height indications than on lateral displacement indications. These erroneous impressions of range and height were aggravated by the low resolution and two-dimensional nature of the television presentation.

The combined effects of limited vertical field, image magnification, low resolution, and lack of depth perception can also produce false position and rate information along one axis because of a displacement or rotation about another axis. As reported in reference 7, for example, when a pilot looks at a view of a far field, a change in height can create an erroneous indication of a fore and aft movement. Similarly, a change in pitch can be misinterpreted as a fore and aft translation unless reference is made to the position of the horizon. In this regard, it is of interest that the pilots looked at the bottom of the picture to obtain near-field position information and then looked up in the picture to check attitude. It is considered surprising that, even with a small screen, the pilots scanned the display to derive position and attitude information in a sequential manner.

The results of the evaluation tests showed the need for an altimeter to supplement the information derived from the television system. Even without separate height information, however, the pilots were able, toward the end of the evaluation tests, to control attitude and guidance with a fair degree of success throughout the landing approach. In light winds, they were able to bring the helicopter to a stop, to hover for a short period, and to descend to the ground. This experience indicated that the pilots could adapt, with sufficient learning, to angular views as small as those of the 25-mm lens and to magnifications as small as those of the 12.5-mm lens.

Performance Tests

The airfield at which the performance tests were conducted is shown in figure 7. The photograph was taken from a position about 1000 ft (304.8 m) from the landing pad and on a 6° slope to the landing pad. The field of view for the photograph was 28° by 22.8°, or about 12 percent larger than the field for the 25-mm lens. The landing pad was a 50-ft (15.24 m) circle in a 100-ft (30.48 m) square on a section of the runway where the surface was concrete divided in 12.5- by 15-ft (3.81 by 4.57 m) sections. The expansion joints of these squares provided a ground pattern that proved useful for attitude and position reference in operations close to the ground.

The results of the approach tests are presented in terms of tracking performance (figs. 8 to 13) and touchdown deviations (fig. 14). The plotted tracks of figures 8 to 13 are distorted graphs of the actual tracks because of the 5:1 difference between the range scale and the scales for lateral displacement and height. The wind-vector diagram in each of the figures shows the average speed and direction of the winds near the ground. Deviations from the vector values are noted beside the diagrams to indicate the degree of gustiness. The winds for most of the runs (90 percent) were 9 to 14 knots and fairly gusty.

Visual tests.- The tracks for five approaches under normal visual conditions are shown in figure 8. The slope tracks provide an indication of how well the pilot could fly a straight-line approach to the landing pad, at airspeeds below that for minimum power and using the visual scene as the only source for slope guidance. The touchdown deviations (both lateral and longitudinal) were all within 2 ft of the center of the landing pad (fig. 14(a)).

The tracks for 10 approaches under restricted viewing conditions with binocular vision are shown in figure 9. The slope tracks in the final 500 ft (152.4 m) were generally above the 6° slope and the descents to touchdown were made along a curved path from heights of about 25 ft (7.62 m). The pilot executed these approaches with a high level of confidence. In bringing the helicopter to a hover, however, he experienced momentary losses of attitude and ground-position reference when making large changes in pitch attitude. For this reason, he found it impossible to stop at the center of the pad and difficult to judge the last foot or so prior to touchdown. As shown in figure 14(b), the lateral deviations at touchdown were as much as 4 ft (1.22 m) and the longitudinal deviations as much as 32 ft (9.75 m). It is apparent from these results that restricting the pilot's angular view (particularly in the vertical direction) to 22.6° by 18.5° had a pronounced effect on his touchdown performance. How much his view was restricted may be indicated by the fact that the normal visual field in unrestricted viewing is about 180° by 150° (from ref. 8).

The tracks for the 10 approaches under restricted viewing conditions with monocular vision are shown in figure 10. The terminal slope tracking and descents to touchdown were about the same as in the binocular restricted-view tests. These approaches were made with less confidence than those with binocular vision, and the difficulties in controlling attitude and position began farther from the landing pad. The difficulties in control due to the restricted field of view were the same as with binocular vision but the control of position was made more difficult because of the lack of depth perception. Uncertainties in the estimation of height, for example, were experienced at positions 3 to 4 ft (0.91 to 1.22 m) above the ground. The results of these uncertainties are evident in the spread in the longitudinal touchdown deviations which, as shown in figure 14(c), are somewhat greater than those for the binocular restricted-view tests. It would appear from these results that the lack of depth perception had an additional detrimental effect on the pilot's touchdown performance.

Television tests.- The tracks for the 10 approaches by the project pilot using the television system with the 25-mm lens are presented in figure 11. The plots in figure 11 show that, in the final 2500 ft (762.0 m) of the approach, the course and slope tracking excursions were considerably greater and more erratic than in the monocular restricted-view tests. The slope tracks in this range were generally below the 6° slope. The difficulties in controlling position and height are particularly evident from the tracking uncertainties in the final 500-ft (152.4 m) range. In this region, the pilot brought the helicopter to a stop at heights of about 25 ft (7.62 m) and then, with continuous cross-checking of the height indicator with the scene on the screen, proceeded slowly and cautiously to a low hover position over the landing pad. He then concentrated on attitude control as the helicopter settled to the ground. Despite the tracking uncertainties toward the end of the approach, the pilot was able, with the exception of one run (the first of the series), to land within the 100-ft-square (30.48 m) landing pad. As in the restricted-view tests, the longitudinal deviations at touchdown (fig. 14(d)) were much greater than the lateral.

The tracks for the 10 approaches by the safety pilot with the 25-mm lens are presented in figure 12. The tracking excursions in these runs were generally of the same magnitude as those in the runs by the project pilot, and the slope tracks in the range from 500 to 2500 ft (152.4 to 762.0 m) were below the glide slope. In the final 500 ft (152.4 m), however, the tracks were more nearly on slope and, as shown in figure 14(e), the touchdown points were beyond the center of the pad in all cases.

In the tests of a television system with a 25-mm lens in reference 3, it was found that the pilots typically flew under the specified slope toward the end of the approach. In the present tests with the 25-mm lens, one pilot flew under the slope and generally landed short whereas the other pilot stayed on the slope and landed long. Both of these terminal profiles, however, differed markedly from the curved terminal path of the visual tests and, thus, confirmed a conclusion of reference 3 regarding the characteristic difference in television and visual landing profiles. It is also of interest that the tests of reference 3, like the present tests, showed the longitudinal deviation at touchdown to be much greater than the lateral.

The tracks for the 10 approaches by the project pilot with the 12.5-mm lens are presented in figure 13. With this lens, the pilot generally flew above the slope in the final 2500 ft (762.0 m) in contrast to his below-slope tracking with the 25-mm lens. Otherwise, the excursions in tracking, in course as well as slope, were about the same as with the 25-mm lens. There was a marked difference, however, in the pilot's control of the helicopter in the final 500 ft (152.4 m) of the approach. With the 12.5-mm lens, he brought the helicopter to a stop at a height of about 50 ft (15.24 m), then proceeded slowly to a second hover about 25 ft (7.62 m) above the ground and then descended, generally at a steeper angle than with the 25-mm lens. The greater uncertainties in lateral position and height control are clearly evident in the terminal tracks in figure 13. The increased difficulty in the control of position with the 12.5-mm lens was, of course, due to the very small image magnification (about 0.35). From the fact that the initial hover was farther from the pad than with the 25-mm lens, it would appear that the pilot tended to overcompensate in his estimation of distance with the small image magnification of the 12.5-mm lens. In his final positioning for touchdown, however, the pilot was able, as shown in figure 14(f), to overcome the distance-estimation problem sufficiently to land within the 100-ft-square (30.48 m) landing pad.

The tests with the 12.5- and 25-mm lenses showed that, with a television presentation supplemented by height indications, the pilots were able to execute low-speed, steep approaches to a landing with an angular view as small as 22.6° by 18.5° and an image magnification as small as about 0.35.

CONCLUDING REMARKS

An evaluation of a closed-circuit television system has been conducted in simulated IFR (Instrument Flight Rules) approaches with a helicopter. The tests were conducted with three lenses having focal lengths of 12.5, 25, and 50 mm. Tests were also conducted under normal visual conditions and under restricted viewing conditions (both binocular and monocular) with the angular view of the 25-mm lens. The approaches were made along a 6° slope at speeds of about 40 knots. The tests were conducted by two NASA research test pilots.

The results of the binocular restricted-view tests indicated that a view as small as 22.6° horizontal and 18.5° vertical had a detrimental effect on the control of position just prior to touchdown. The vertical-angle restriction appeared to have the greater effect, as evidenced by the larger longitudinal deviations at touchdown (as much as 32 ft (9.75 m)). With monocular vision, the lack of depth perception increased the difficulty of distance estimation and resulted in greater uncertainties in longitudinal position control.

The tests of the television system showed that the angular view of the 50-mm lens was too restrictive for effective control of attitude and position throughout the approach. The views of the 12.5- and 25-mm lenses were satisfactory during the initial part of the approach, but the control of position and position rates became very difficult at heights below 50 ft (15.24 m) with the 12.5-mm lens and 25 ft (7.62 m) with the 25-mm lens. The difficulty of position control was increased by the image magnification (about 0.35 for the 12.5-mm lens and 0.70 for the 25-mm lens) which created false impressions of distance (particularly range and height). The estimation of distance was made additionally difficult by the inherently low resolution and lack of depth perception of the television presentation. Unique difficulties in position control were encountered when close to the ground, where changes in height and pitch could be misinterpreted as a fore-and-aft translation.

With the addition of height indicators to the display, one pilot flew 10 consecutive approaches with the 25-mm lens and 10 with the 12.5-mm lens. A second pilot flew 10 approaches with the 25-mm lens. The winds during these tests were generally 9 to

14 knots and fairly gusty. Although the terminal phase of the approach was executed with considerable caution and with a high level of difficulty, all the approaches were carried to touchdown. The touchdowns were generally within the 100-ft-square (30.48 m) landing pad and, as in the restricted-view tests, the longitudinal deviations were considerably greater than the lateral. These tests showed that, with a television presentation supplemented by height indications, the pilots were able to execute low-speed, steep approaches to a landing with an angular view as small as 22.6° by 18.5° and an image magnification as small as about 0.35.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 20, 1967,
721-05-00-01-23.

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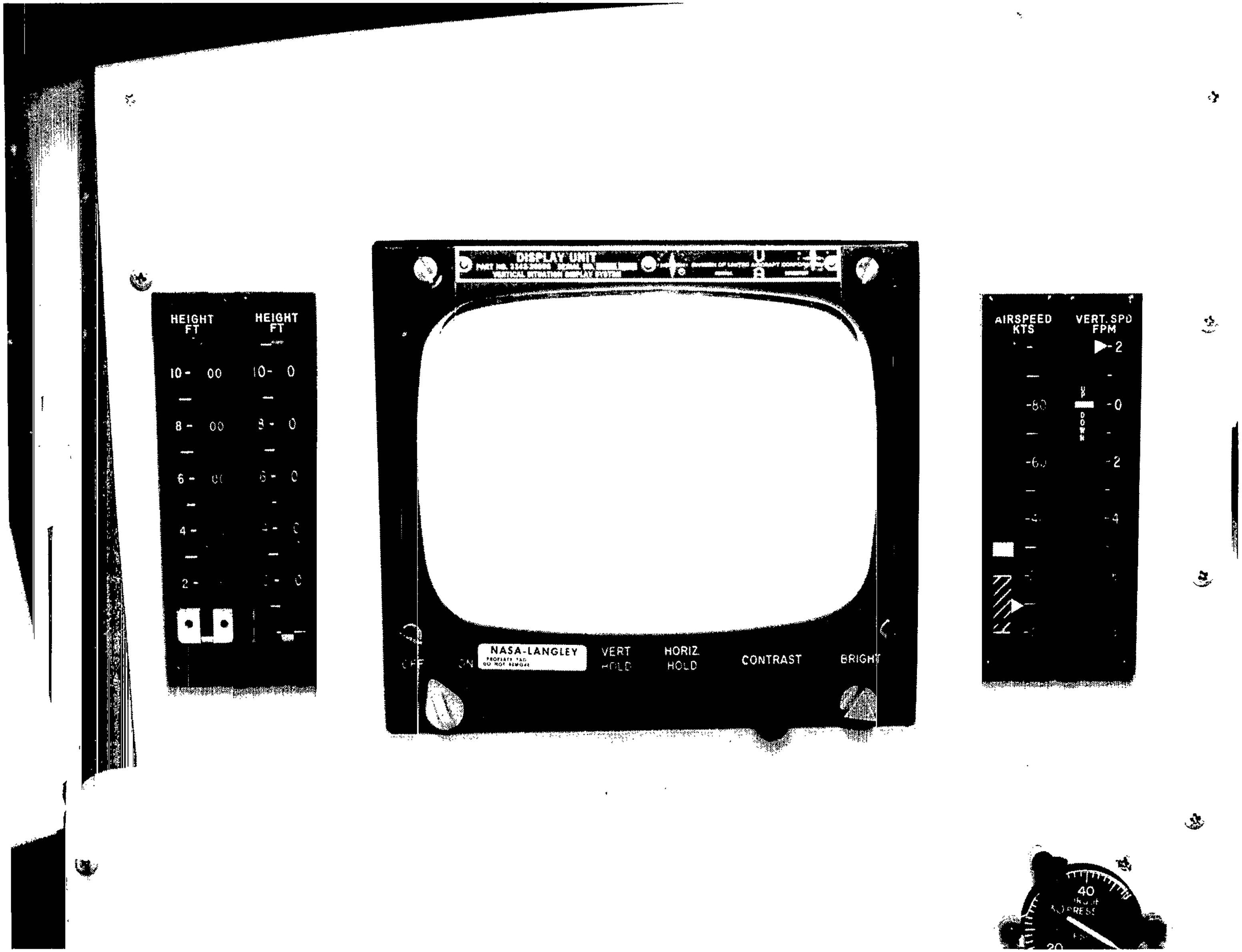
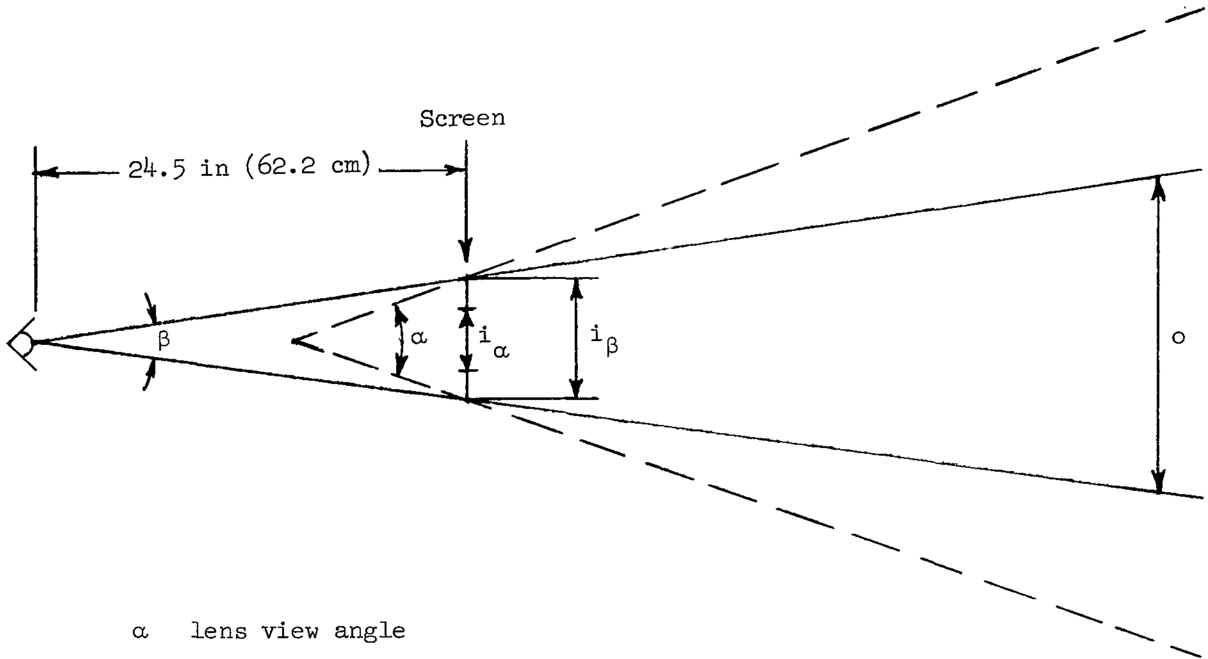


Figure 1.- Test instrument display.

L-67-1323

Figure 2.- Television camera installation.

L-67-1327

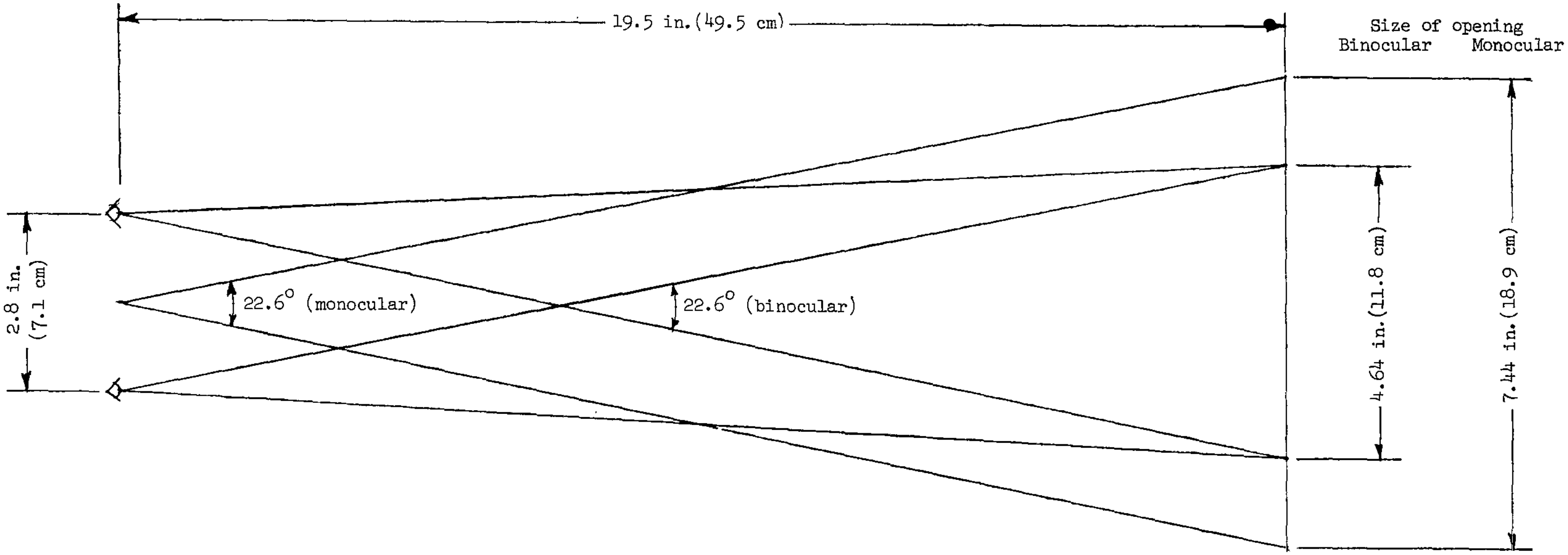


- α lens view angle
- β pilot's visual angle (16.5° horizontal, 12.3° vertical)
- o size of object
- i_β size of image at plane of screen for β
- i_α size of image on screen for α

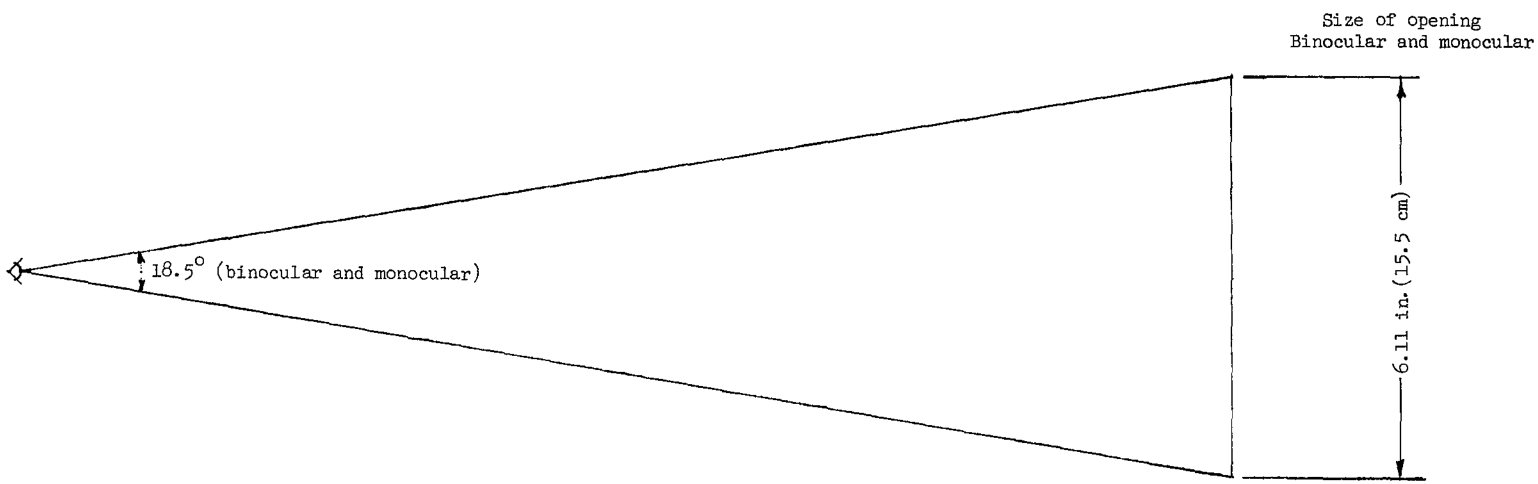
Lens focal length, mm	Lens view angles, deg		Image magnification, β/α, i_α/i_β	
	Horizontal	Vertical	Horizontal	Vertical
12.5	45.1	36.8	0.37	0.33
25	22.6	18.5	0.73	0.67
50	11.4	9.3	1.45	1.32

Figure 3.- Lens view angles and image magnifications.

Figure 4.- Hood used for restricted-view tests. L-67-1324

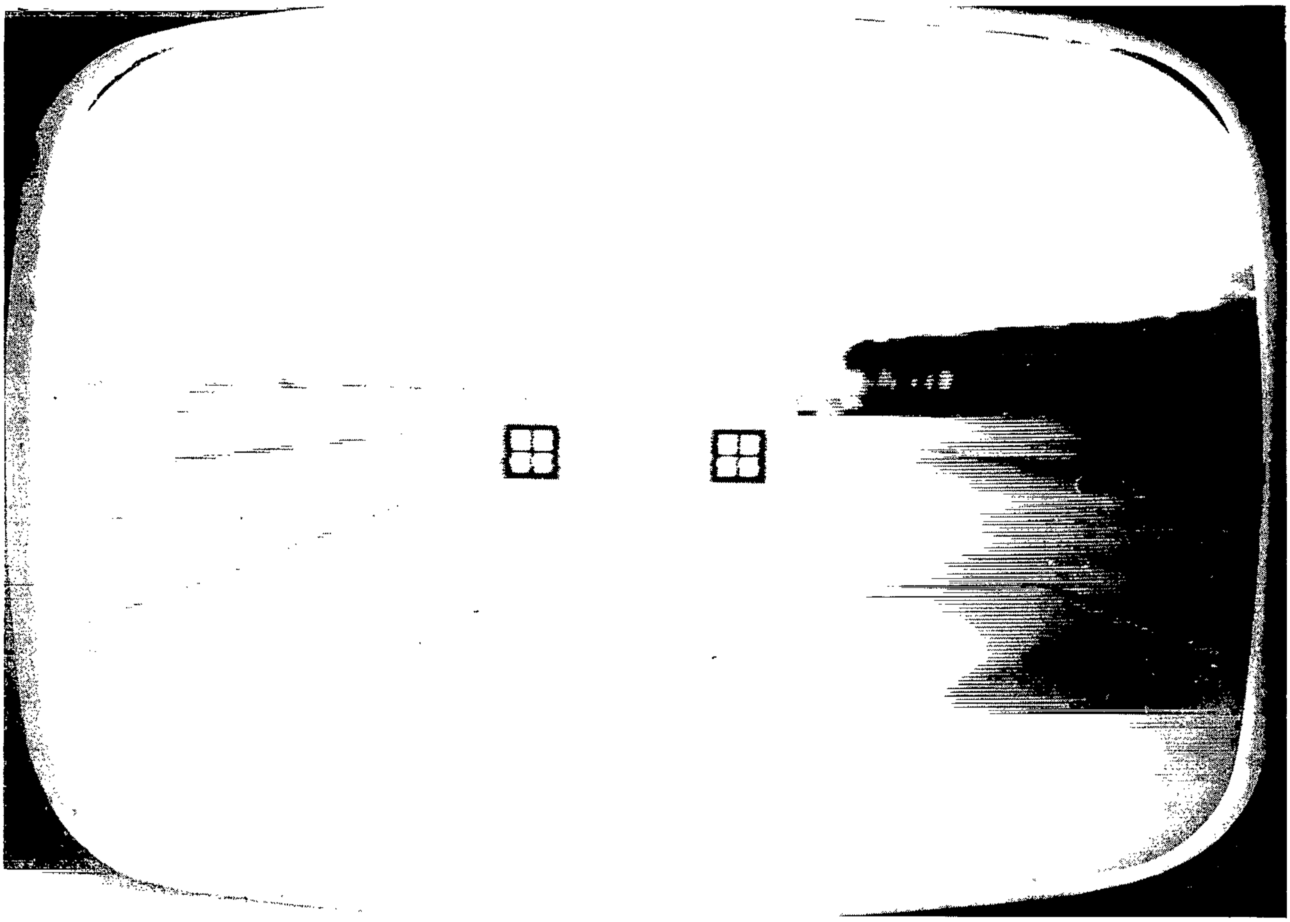


(a) Horizontal angular view.



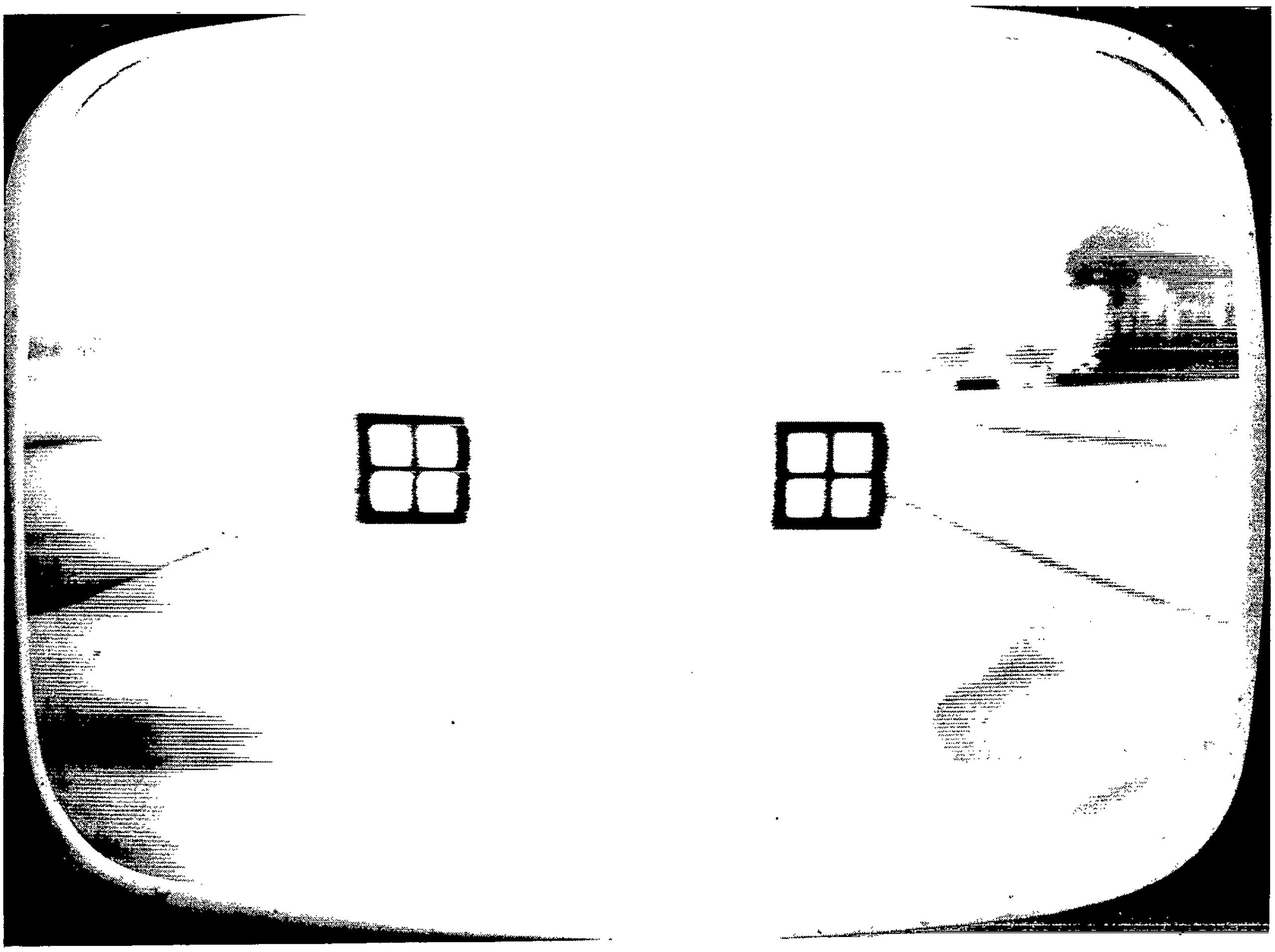
(b) Vertical angular view.

Figure 5.- Dimensions of openings in hood used for restricted-view tests with binocular and monocular vision.



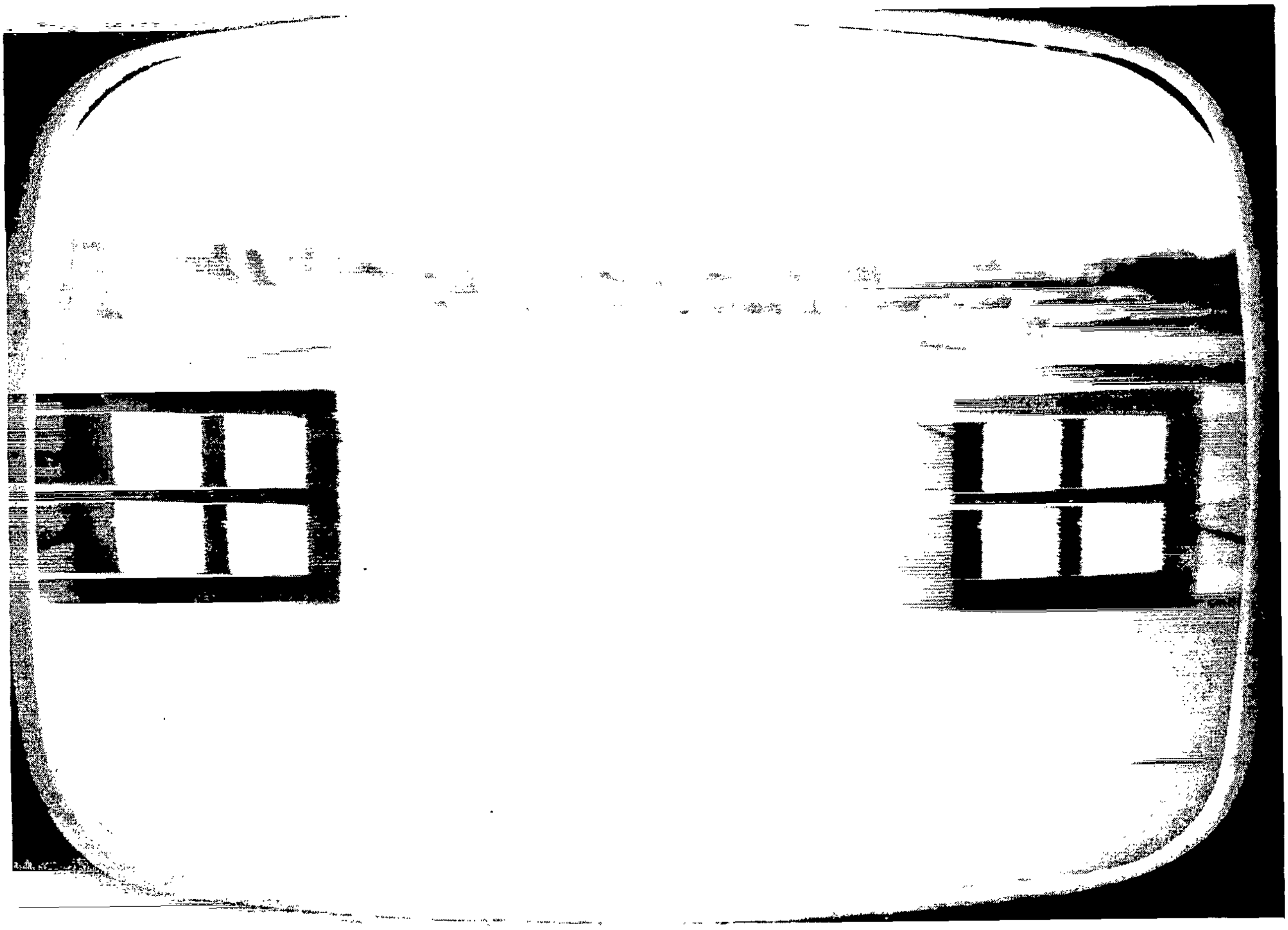
(a) With 12.5-mm lens. L-67-1135

Figure 6.- Illustrations of view angles and image magnifications of three test lenses and of correct view angle and image size for present tests. Objects are 4- by 4-ft (1.22 by 1.22 m) squares 100 ft (30.48 m) ahead of camera.



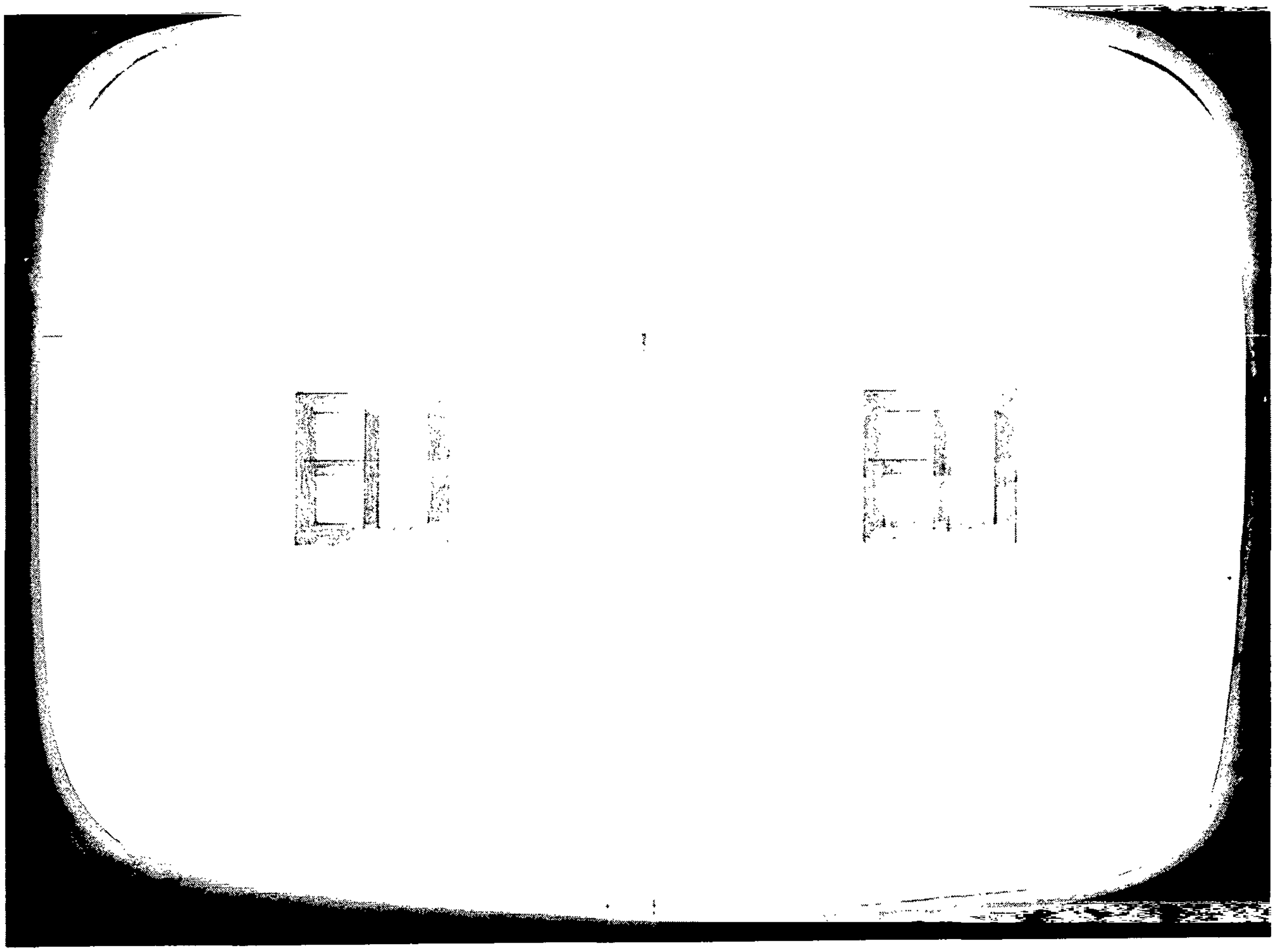
(b) With 25-mm lens. L-67-1136

Figure 6.- Continued.



(c) With 50-mm lens. L-67-1137

Figure 6.- Continued.



(d) Appearance at plane of screen with monocular vision from the pilot's eye position.

Figure 6.- Concluded.

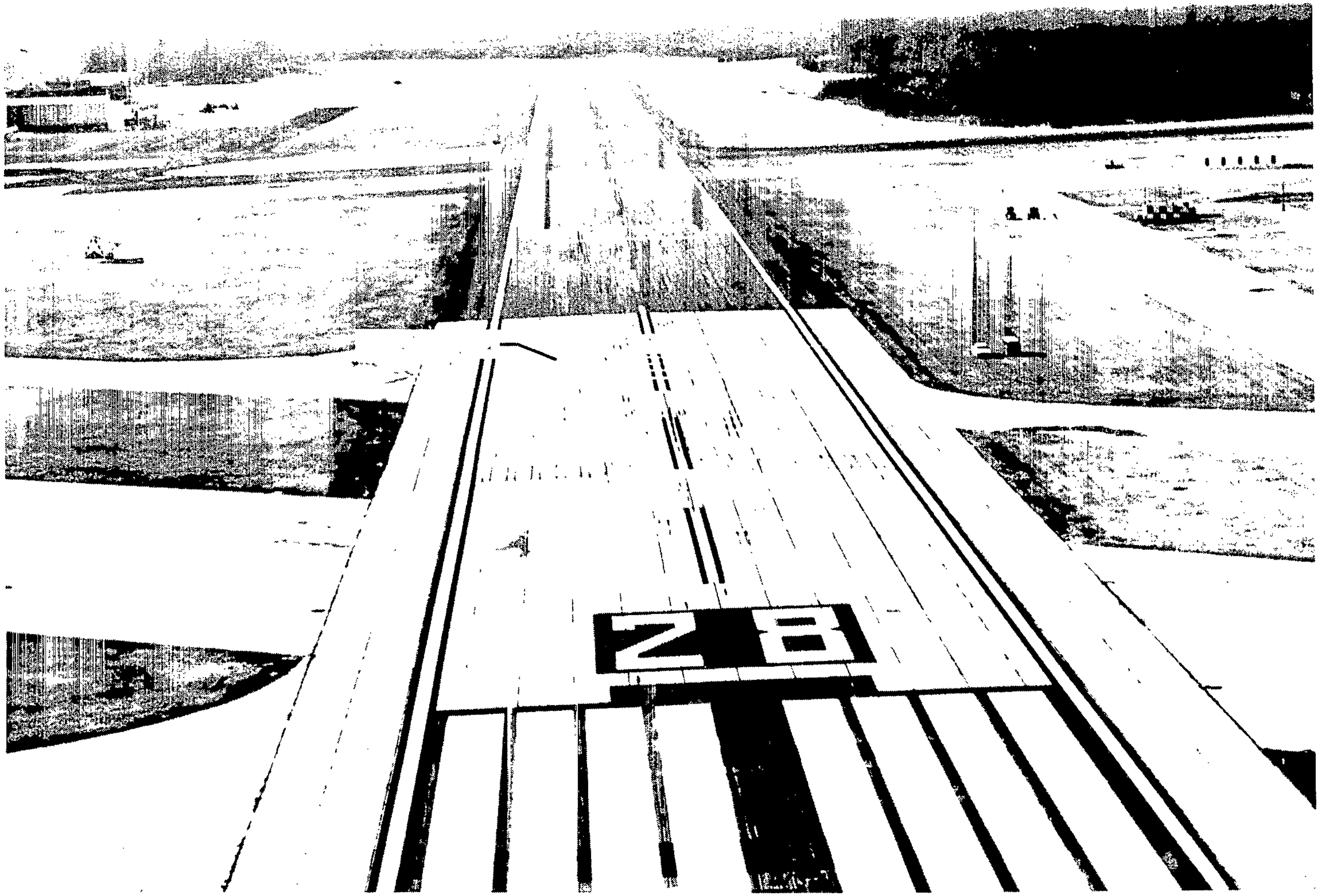


Figure 7.- Aerial view of test airfield. L-67-3

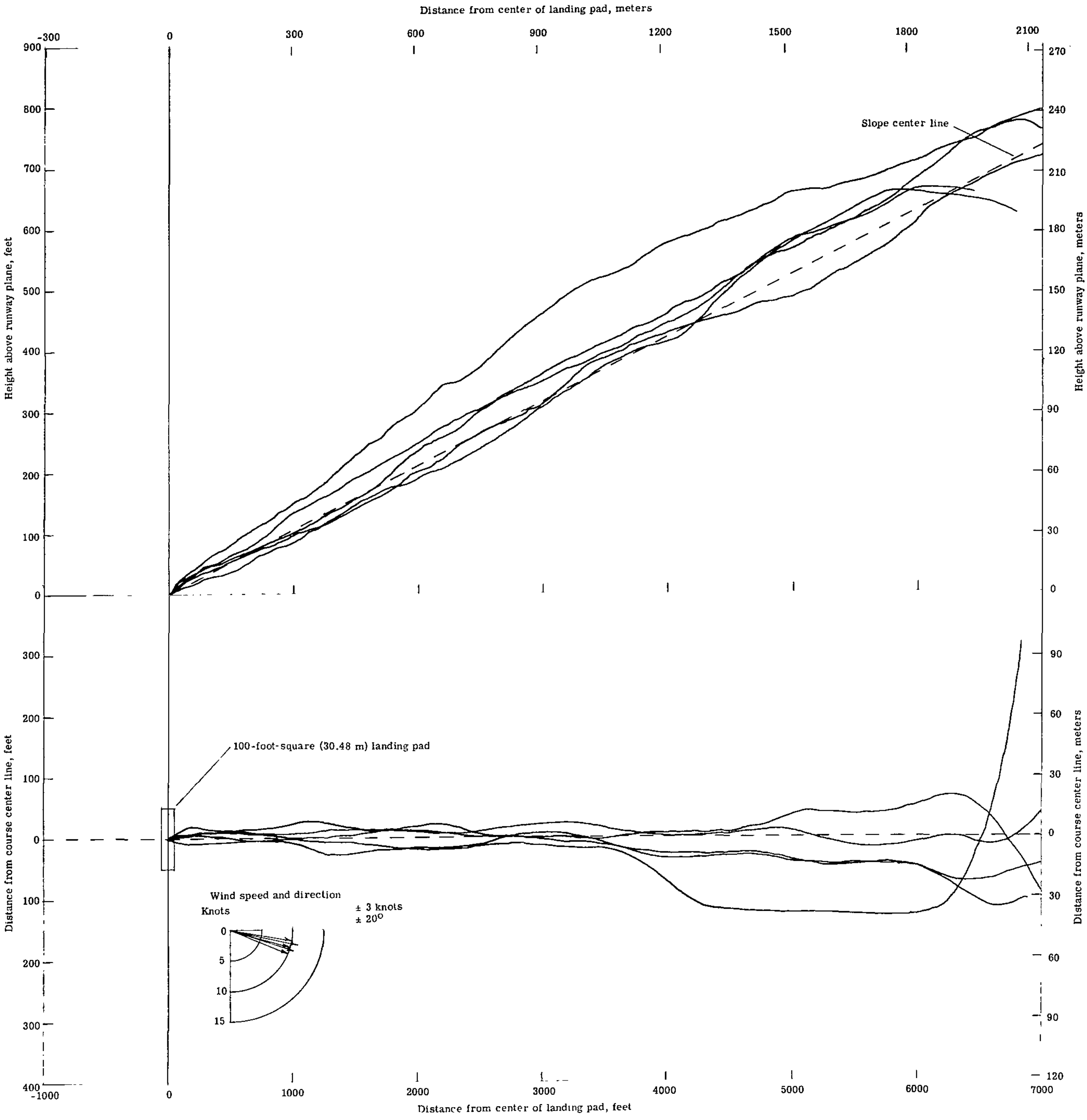


Figure 8.- Course and slope tracks for five approaches under normal visual conditions. Project pilot.

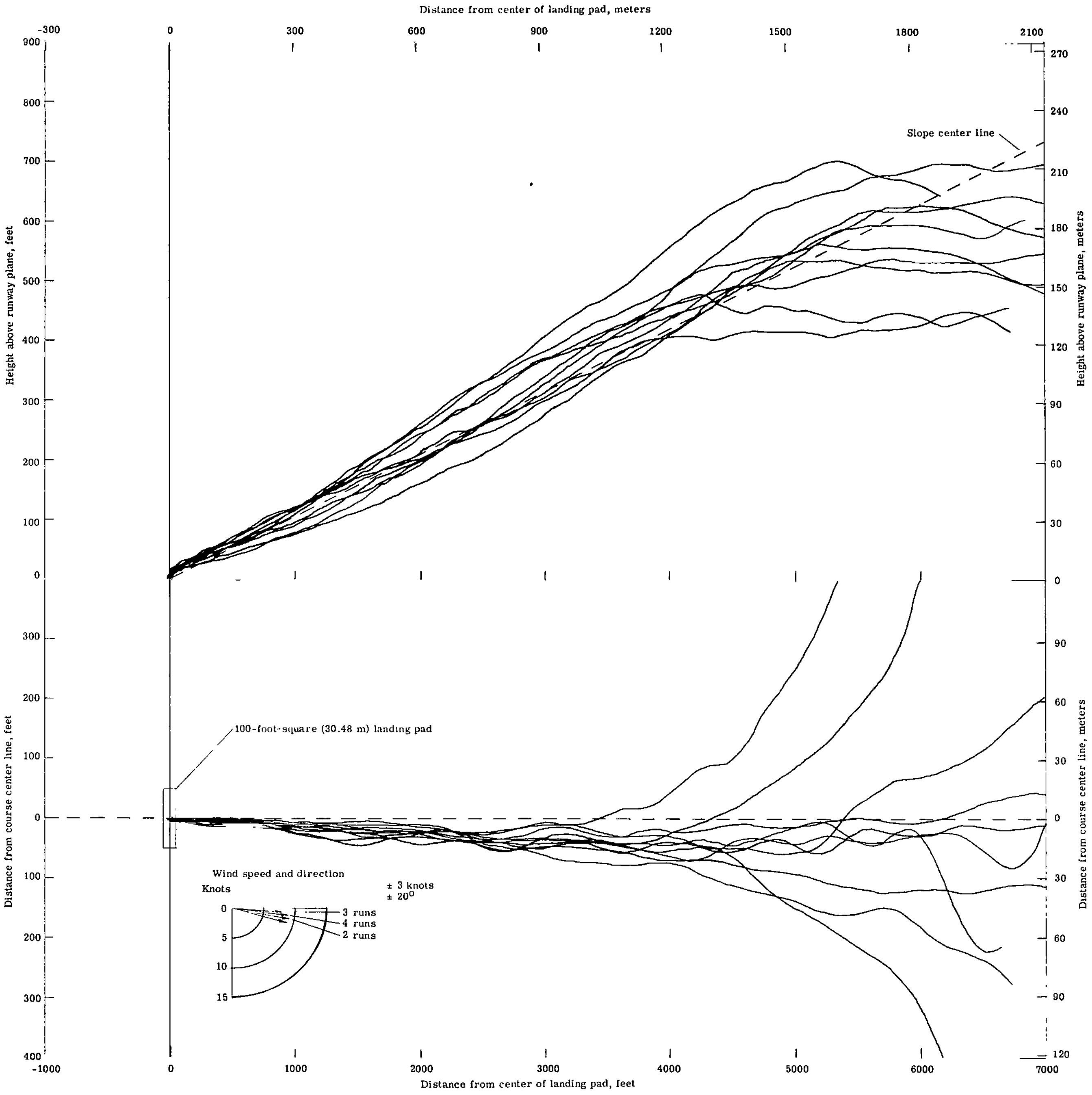


Figure 9.- Course and slope tracks for 10 approaches under restricted viewing conditions with binocular vision. Project pilot.

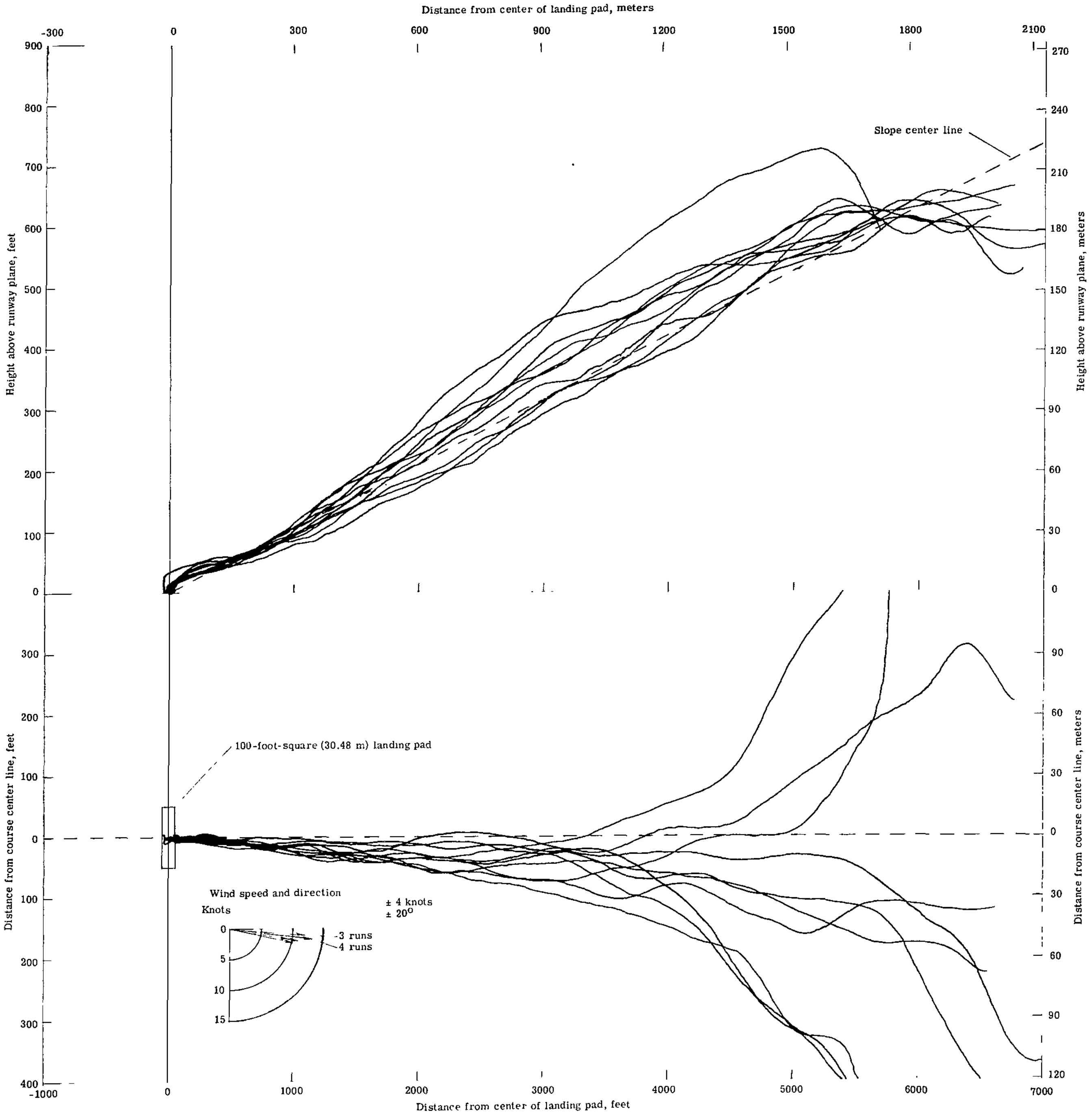


Figure 10.- Course and slope tracks for 10 approaches under restricted viewing conditions with monocular vision. Project pilot.

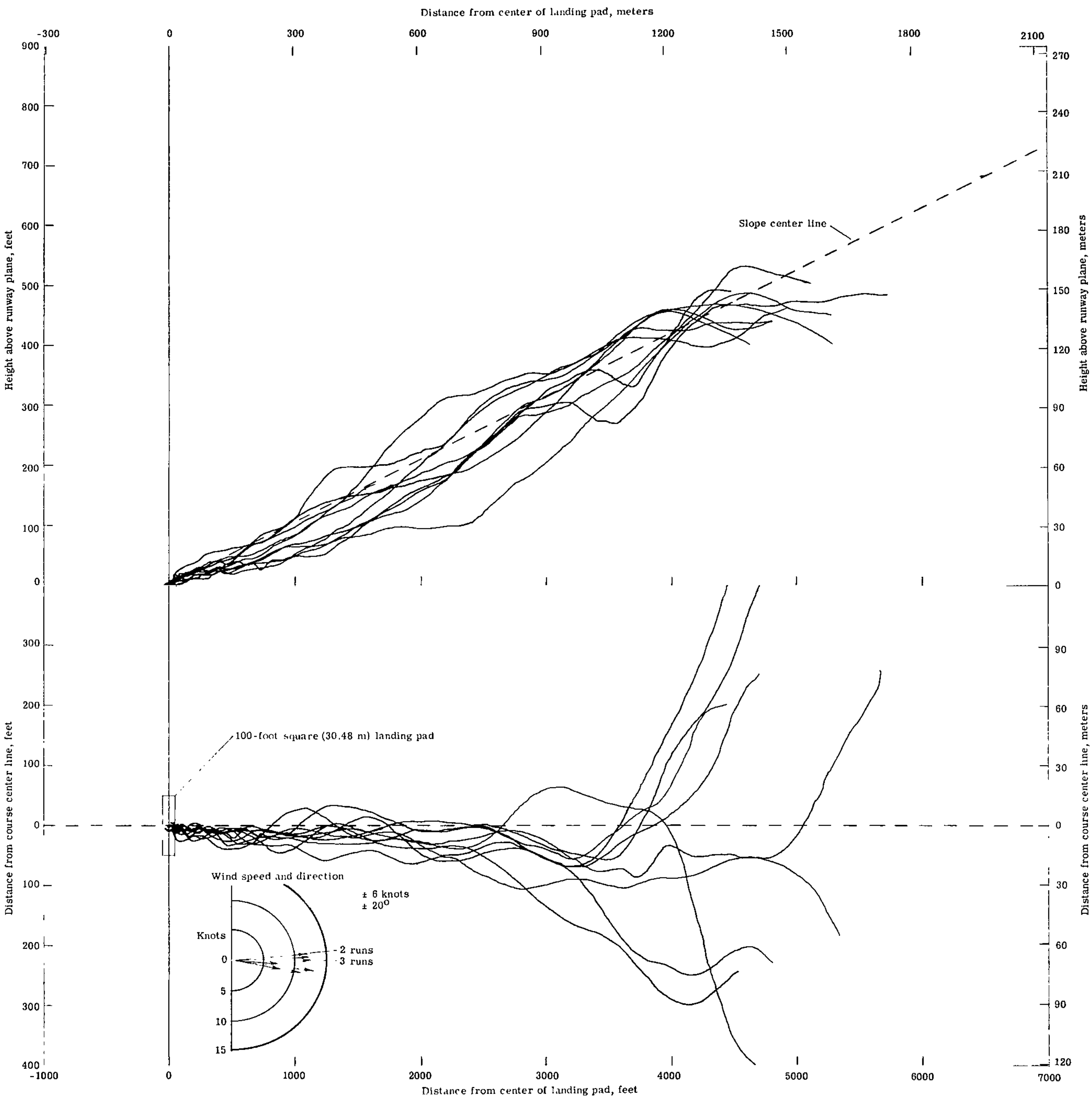


Figure 11.- Course and slope tracks for 10 approaches with television system with 25-mm lens. Project pilot.

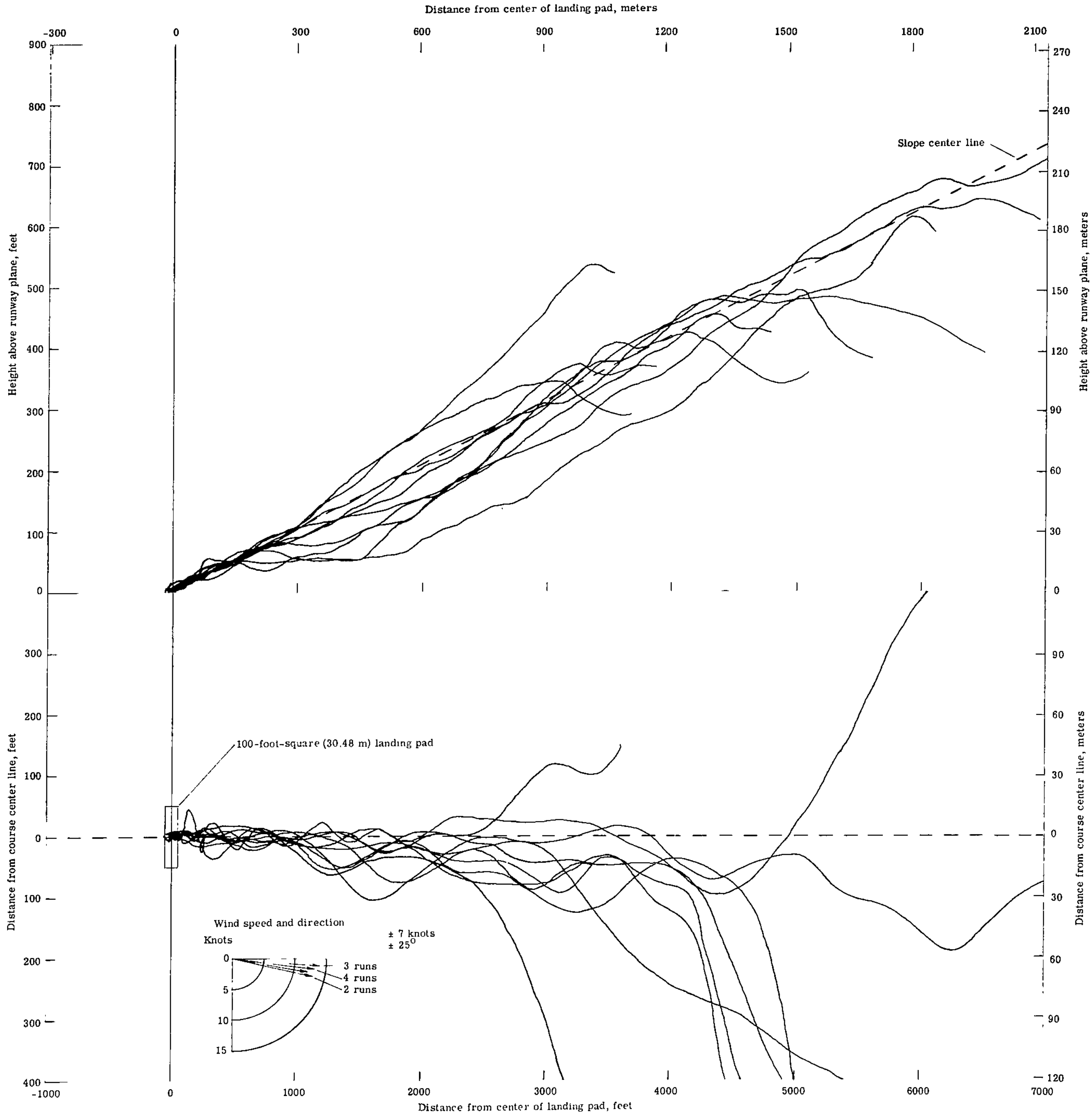


Figure 12.- Course and slope tracks for 10 approaches with television system with 25-mm lens. Safety pilot.

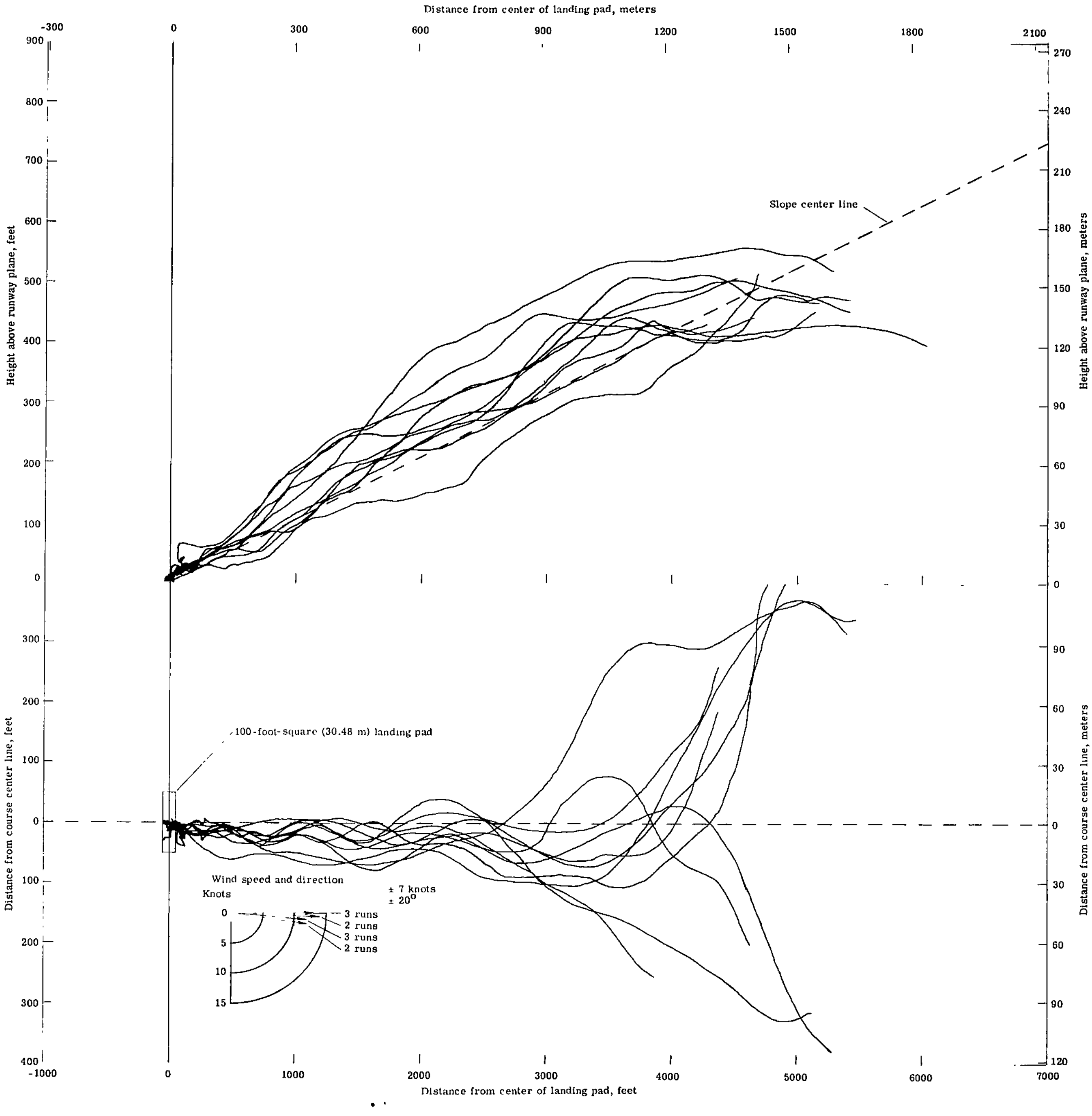
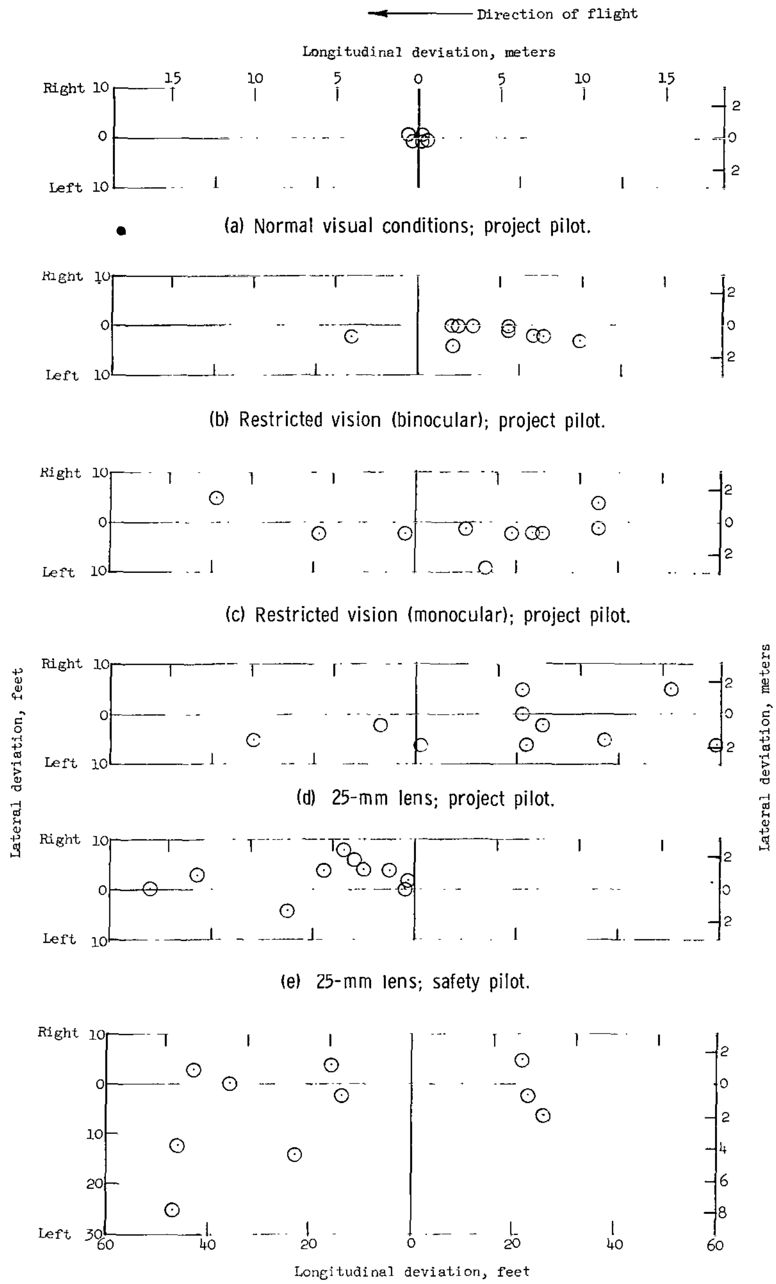


Figure 13.- Course and slope tracks for 10 approaches with television system with 12.5-mm lens. Project pilot.



(a) Normal visual conditions; project pilot.

(b) Restricted vision (binocular); project pilot.

(c) Restricted vision (monocular); project pilot.

(d) 25-mm lens; project pilot.

(e) 25-mm lens; safety pilot.

(f) 12.5-mm lens; project pilot.

Figure 14.- Touchdown deviations from center of landing pad.

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