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Description of Path-in-the-Sky Contact Analog Piloting Display

Charles E. Knox and John Leavitt

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Charles E. Knox
Langley Research Center
Hampton, Virginia
and
John Leavitt
Sperry Rand Corporation
Hampton, Virginia

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SUMMARY

A contact analog display called path in the sky (PITS) integrates information on airplane attitude, airplane kinematic performance, navigation situation, and path prediction into one instrument. A rationale for and description of each component of the PITS display are presented. The coordinate systems used to generate the display and the magnitudes of pertinent geometric characteristics selected during the display development are discussed. Examples of the total PITS display are also included so that an understanding of how the individual display components interact could be related.

INTRODUCTION

Advances in the state of the art of cathode-ray-tube (CRT) technology and microprocessor design, increasing costs of initial purchase and annual maintenance of mechanical instrumentation, and the increased flexibility of display symbology have resulted in the increased use of electronic CRT displays in aircraft cockpit design. Advanced cockpit designs have utilized multiple CRT's for both peripheral and primary displays in numerous military aircraft (refs. 1 and 2). The flexibility offered by CRT displays has caused significant changes in display information presentation and content, cockpit layout, and pilot-crew procedures.

Contact analog display formats applied to the CRT may be significantly different from the formats utilized in mechanical instruments. Airplane attitude, navigation situation, and flight commands may be presented in an integrated manner with fewer displays. The potential therefore exists to reduce pilot work load by reducing the instrument scan and by simplifying instrument interpretation during complex flying tasks.

The path-in-the-sky (PITS) display format utilizes the flexibility of the CRT to integrate information on vertical and lateral navigation situation, airplane attitude, airplane kinematic performance, and path prediction into a single electronic attitude director indicator (EADI) that is placed in front of each pilot. By appropriately integrating this information, the pilot's scan can be substantially reduced to a single display while still perceiving navigation-situation information.

The purpose of this report is to describe the PITS display concept and dynamics and to specify the magnitudes of some of the pertinent geometric parameters. A brief description of how the display concept is implemented on a stand-alone graphics computer for evaluation purposes will also be presented.

SYMBOLS AND ABBREVIATIONS

CRT	cathode ray tube
EADI	electronic attitude director indicator
EFOV	effective field of view
FOV	field of view
PITS	path in the sky
X,Y,Z	Earth-fixed axes coordinates
X',Y',Z'	airplane-fixed moving axes coordinates
z_e	vertical deviation that airplane may be below path with pilot's eye looking directly at rear of shadow path (see fig. 7)
z_s	maximum height that airplane may be above path before shadow disappears from bottom of display (see fig. 7)

DISCUSSION

The purpose of the PITS display development is to develop an advanced piloting display that would give the pilot sufficient information on airplane attitude, performance, navigation situation, and prediction so that he could monitor or fly his airplane on a programed path. This information is to be presented on a single display in a simplified, understandable format that would allow a reduction in piloting work load and scan pattern.

Display Implementation

The PITS display is implemented on an Adage AGT/130 stand-alone graphics computer. The PITS program was written so that the display format could be modified as desired by the programer during a preliminary display dynamics evaluation. Geometric parameter modifications and some display format options may be changed by the program user without requiring that the program be recompiled; thus developmental time is saved.

Pertinent geometric parameters may be readily changed interactively through a peripheral set of dials and function switches; this allows the program user to observe the display as he changes the value of a parameter. These adjustable parameters include field of view (FOV), eye position relative to the airplane, path size, airplane shadow size, airplane symbol size, and airplane pitch and vertical displacement. The function switches allow the user to select a dashed-line or solid-line shadow symbol, a flight-path-prediction vector on the shadow, a display freeze, a roll scale, a digital readout display of various geometric parameters and speed, and a path initialization function.

The display dynamics and a simplified kinematic airplane model are computed in real time to assist the pilots and the engineers during the display development and evaluation. Control inputs to the simulated airplane are made with a two-axis control stick. The airplane's speed is controlled through a peripheral dial.

Display Symbology

The format of the PITS contact analog display shows airplane attitude information in the form of bank angle and pitch changes. Airplane performance information is shown in the form of airplane flight-path angle and flight-path acceleration (which may be used as thrust- or energy-management control). Both vertical and lateral path deviations during a tracking task are shown in pictorial form.

Path-tracking situation information is shown through a combination of an airplane symbol, a vertical projection of the airplane symbol with an extended center line drawn at the altitude of the path, a flight-path predictor, and a drawing of the programed path (fig. 1). These four pieces of symbology are drawn in a perspective display format as if the observer's eye were located behind and above the airplane.

The airplane symbol is a tetrahedron with a smaller tetrahedron at the tail to visually enhance pitch changes. The airplane's true position with respect to the path is at the symbol's apex. The symbol rolls and pitches about its apex in accord with the real airplane's attitude.

Altitude deviations from the programed path are indicated to the pilot pictorially by a vertical projection of the airplane symbol. The projection, drawn with dashed lines, may be thought of as a shadow; as shown in figure 2, it remains directly above or below the airplane at the altitude of the path. If the airplane is above the programed path, the shadow appears to be below the airplane symbol. If the airplane is below the programed path, the shadow appears to be above the airplane symbol.

Since the shadow is always drawn directly above or below the airplane symbol, the pilot may readily identify lateral tracking deviations when they are combined with a vertical tracking error. Figure 3 shows the perspective view of the shadow, the airplane symbol, and the path when the airplane is above and to the left of the path.

Altitude deviations from the programed path are also shown to the pilot in numerical form in a box in the upper right-hand corner of the display (fig. 4). The pilot is expected to use this information when the path and shadow are out of the display field of view, such as could occur during initial path captures.

A flight-path prediction vector (fig. 4) in the horizontal plane is attached to the shadow. The prediction vector, indicated by a dashed line, shows the airplane's predicted path for the next 10 sec based on the airplane's present bank angle and ground speed. An extended shadow center line drawn from the apex of the shadow in the direction of the present track angle, is also shown to aid the pilot with the lateral tracking task. Figure 5 shows the flight-path prediction vector and the present track indicator with the airplane in a left bank of 13°.

The programed path is drawn in a true perspective view from the observer's eye (behind and above the real airplane). The path disappears from the display when it is not within the horizontal and vertical field of view. A path consists of straight legs linked together by circular segments to form a continuous path. A set of vertical poles, one on each side of the path, is drawn between the straight and circular path segments so that the transition between curved and straight legs is clearly defined. Programed path altitude changes are drawn with a constant (straight line) slope between way points. A flight-path-angle scale is graduated in 5° increments with a range of ±20°. The zero flight-path-angle marks are elongated and centered on the airplane symbol. The flight-path-angle scale is fixed vertically but rotates with the airplane symbol about its apex during banking maneuvers. Figures 4 and 5 show the flight-path-angle scale dynamics with the airplane banking.

Twin L-shaped bars (fig. 4) that move vertically on the flight-path-angle scale provide the pilot with an Earth-referenced airplane flight-path angle. The flight-path-angle bars rotate with the flight-path-angle scale when the airplane is banked. Figure 5 shows the airplane below a programed ascending path of 3°. The pilot can see that he is correcting back to the path at a climb correction angle of 3° since his flight-path-angle bars are at 6° (3° steeper than the path).

A potential flight-path-angle box is drawn on the left-hand side of the flight-path-angle scale (fig. 4). The potential flight-path-angle box indicates acceleration in the direction of the airplane's flight path. The potential flight-path-angle box is drawn relative to the flight-path-angle bars so that the pilot can use the potential box in conjunction with the bars as a form of thrust- and energy-management indicators. Figure 5 shows the pilot that he will maintain his present ground speed since the potential flight-path-angle box is adjacent to the flight-path-angle bars. If the potential box were below the bars, the airplane would be slowing down; if it were above the bars, it would be speeding up.

The vertical angle of the programed path is graphically displayed to the pilot with a truncated triangle, as shown in figure 4. The programed path-angle indicator moves up and down on the left-hand side of the flight-path-angle scale and points to the programed path angle. Figure 5 shows that the displayed programed path angle is 3° up.

An airplane track-angle scale (fig. 4) moves left or right as the track of the airplane changes. A small triangle fixed to the center of the display just above the track-angle scale points to the airplane's present track.

The Earth's horizon is represented by a solid line in the upper third of the display. The horizon remains fixed at a specified position on the viewing screen. The horizon is not affected by roll, pitch, or yaw motions of the airplane.

A roll scale (fig. 4) is presented at the top of the display. Wings level, 10°, 20°, 30°, and 45° tic marks are fixed at the top of the display. A pointer moves under the roll scale in the direction of the bank angle. The roll pointer rolls with the airplanes symbol and with flight-path-angle scale during banking maneuvers. Figure 5 shows the airplane in a left bank of 13°.

Coordinate Systems

Figure 6 shows the coordinate systems used in the generation of the PITS perspective display. Two reference axes systems, one system fixed to the Earth and the other attached to the airplane's center of gravity, are shown.

The Earth-fixed axes system is an orthogonal system with the Z axis pointing towards the center of the Earth. The X and Y axes are tangent to the Earth's surface.

The moving reference axes system is also an orthogonal system attached to the airplane's center of gravity. The X' and Y' axes remain in a plane tangent to the Earth. The X' axis points in the horizontal direction of flight and the Z' axis points toward the Earth's center. The moving axes do not rotate because of airplane bank, pitch, or yaw angles.

The X' axis on the moving axes system was fixed tangent to the Earth's surface to simplify the computational requirements in the graphics computer. However, with this axes system, airplane maneuvers that include large flight-path angles (angles greater than 30°) could cause the display to be drawn in a discontinuous and confusing manner. However, for this initial effort and since the display is being developed for transport-type airplanes, it was felt that fixing the X' axis on a plane tangent to the Earth would not adversely affect the display development. In future simulations and when implemented for flight tests, the X' axis will point in both the vertical and horizontal direction of the flight path; this will enable the pilot to track a programed path with large flight-path angles (including loops with a vertical angle change of 360°).

The eye position, viewing screen, and programed path are also shown in figure 6. The eye position and viewing screen are held at the constant displacement along the X' and Z' axes of the moving reference system. The programed flight path is fixed with respect to the Earth-fixed reference system.

During the drawing of the perspective path, the graphics computer simulation program keeps track of the airplane's (moving reference system) position and direction with respect to the Earth-fixed axes. Internal computer algorithms perform the transformations required for drawing the perspective path on the viewing screen.

Geometric Parameter Adjustment

Figure 7 shows the geometric parameters that may be adjusted so that vertical and lateral navigation deviations, airplane pitch and roll changes, and the prediction vector are readily detected by the pilot. The selection of the magnitudes of these parameters is subjective in nature although the magnitudes of these parameters are a function of the required accuracy of the tracking task.

Each of the adjustable parameters has multiple effects on the perspective drawing of the display. However, with a few assumptions, the order of selection of these parameters and a range of magnitudes may be specified.

The field of view is selected first. The FOV is defined as twice the angle between the horizon line on the veiwing screen and either the top or bottom of the viewing screen, whichever is large. (In fig. 7, the FOV is twice the arc measured from the horizon to the bottom of the screen.) If the horizontal line is drawn other than at the vertical center of the viewing screen, a portion of the display will be clipped off and will result in a smaller actual FOV. The actual angle between the top and bottom of the viewing screen is called the effective field of view (EFOV).

Assuming that z_e and z_s remain constant, increasing the FOV moves the eye position closer to the viewing screen. This has two effects on the perspective drawing of the display. The first effect is an increase in the size of the path. Selections of the FOV should not depend on this effect, however, since the path may be varied in size independently of all other parameters, or the horizontal FOV may be changed independently of the vertical FOV. Both the horizontal and vertical FOV were the same throughout the initial display development.

The second effect of increasing the FOV is an adjustment of the eye position so that the pilot looks more on the top of the airplane symbol and path and less toward the rear of the airplane symbol. Eye position is important since it affects the distinguishability of both the lateral and vertical path deviations and the pitch and roll movements of the airplane symbol. During the development of the PITS display, it was found that the FOV of 60° (EFOV = 45°) resulted in good definition of vertical and lateral path deviations.

The magnitudes of z_e and z_s for a given FOV also vary the size of the airplane symbol, shadow, and path by moving the airplane closer or farther away from the viewing screen. They too can affect how much of the top and rear of the airplane symbol is displayed to the pilot. However, certain ranges of magnitudes are suggested by the required accuracy of the tracking task and tend to be the dominant factor in choosing the magnitudes of z_e and z_s.

The parameter z_s may be thought of as the maximum height that the airplane may be above the path before the shadow disappears from the bottom of the display. Though larger vertical deviations from the path would be presented in digital form in the altitude deviation box, the pictorial presentation of vertical deviation would b ost.

The parameter z_e is the vertical deviation that the airplane may be below the path with the pilot's eye looking directly at the rear of the shadow path. With this vertical deviation, the shadow and path will appear as a straight line parallel to the horizon and will give no lateral navigation-situation information. If the airplane deviates farther below the path, however, lateral guidance cues again become usable until the shadow disappears from the top of the display.

It was subjectively determined during the initial display development that the value of z_e can be 1 to 1.5 times that of z_s. The actual magnitudes of z_e and z_s are a function of the vertical-tracking-accuracy requirements. Depending upon the tracking task, their magnitudes should be selectable by the pilot during actual flight operations. A mode switch may allow the pilot to select path capture, en-route tracking, and approach tracking options. During en-route tracking, z_e and z_s should be approximately 150 to 300 m (492 to 984 ft); during approach tracking, 30 to 90 m (98 to 295 ft).

Path width is independent of all other geometric parameters. It must be specified so that the pilot has no trouble seeing the airplane, shadow, and path symbology interactions on the viewing screen. However, if the path width is too large, the shadow will appear to be within the path even though the airplane is off the path center line. The pilot will not be compelled to correct to the path center and decreased lateral tracking accuracy will result. Fortunately, when z_e and z_s are adjusted for high precision path tracking, the path widens in the screen. The path width may then be reduced to maintain proper proportioning on the viewing screen. The reduced path width will allow smaller path deviations to be detected.

The airplane symbol and shadow size are adjusted to fit the path width. If the shadow and airplane symbology are as wide as the path, an illusion of going outside the path during a turn occurs. This is caused by the aft end of the shadow and airplane symbol swinging outside the path while the apex (true airplane position) stays on the path center line. If the airplane and shadow symbology are drawn approximately two-thirds to three-fourths the width of the path, this illusion does not occur.

PITS Total Format

Figures 8 to 12 are included to show the symbology interaction of the total display. Various airplane attitudes and displacements from the programed flight path are shown. The pilot's actions to maneuver the airplane to the path are described through the display symbology.

The geometric parameters used for figures 8 to 12 are given in the following table:

FOV, deg	60
z_e, m (ft)	152.4 (500)
z_s, m (ft)	152.4 (500)
Path width, m (ft)	122 (400)

Figure 8 shows the airplane displaced to the right of the path. The present track pointer (the dashed line from the shadow extending straight ahead) indicates that the airplane is flying toward the path. However, the flight-path prediction vector indicates that the pilot is decreasing the intercept angle with a bank angle that will allow the airplane to fly tangentially to the center of the programed path. The airplane is at the proper altitude since the apex of the airplane symbol and the shadow are superimposed and the altitude deviation box is digitally indicating 0 vertical displacement. The flight-path-angle bars are indicating that the airplane is maintaining a zero flight-path angle (level flight). These bars coincide with the vertical angle of the programed path that is indicated by the programed path-angle indicator (truncated triangle). The airplane's current ground speed will be maintained since the potential flight-path-angle box is even with the flight-path-angle bars.

Figure 9 shows the airplane displaced 45 m (148 ft) below the path. The airplane is climbing at a flight-path angle of 7° to intercept the programed path. The path has an ascent of 3° that is indicated by the programed path-angle indicator. Hence, the airplane is correcting back to the path with a vertical intercept angle of 4° (the difference between the programed path angle and the airplane's flight-path angle). The airplane's present ground speed will be maintained since the potential flight-path-angle box is even with the flight-path-angle bars. The curved flight-path prediction vector shows that the airplane has the proper bank angle to remain laterally on the path during the programed turn.

Figure 10 shows the airplane displaced 30 m (99 ft) above the programed path. The airplane is descending to the level flight path (programed path-angle indicator pointing to zero) at an angle of descent of 3°. The potential flight-path-angle box is above the flight-path-angle bars, which indicates that the airplane's ground speed is increasing. The flight-path prediction vector shows that the bank angle is sufficient for the airplane to remain on the path during the turn.

Figure 11 shows the airplane displaced 48 m (159 ft) below and to the left of a turning, ascending (angle of 3°) programed path. The flight-path-angle bars indicate that the airplane is converging to the path at a vertical angle of 4°. The potential flight-path-angle box shows that the present bank angle will allow the airplane to capture the path tangentially.

Figure 12 shows the airplane displaced 12 m (40 ft) above and to the left of a path with an angle of ascent of 3°. The airplane is converging to the path with a vertical angle of 2° and ground speed is increasing. The flight-path prediction vector shows that the present bank angle is appropriate for the airplane to capture the path laterally.

CONCLUDING REMARKS

Advances in the state of the art of cathode-ray-tube (CRT) and microprocessor design technology have resulted in the increased use of the CRT in advanced cockpit design. The flexibility offered by the CRT displays makes possible significant changes to display symbology. Information required by the pilot to complete a flying task may be integrated into a more understandable manner so that the pilot's work load could be reduced.

The path-in-the-sky (PITS) concept is a contact analog display that gives the pilot information on airplane attitude, airplane kinematic performance, and navigation situation. The coordinate systems used to generate the PITS display allow the pilot to see his position relative to a programed flight path in a pictorial form. Predictive information is also presented in the form of a horizontal flight-path prediction vector.

All this information is integrated into one display in a simplified format. Hence, the potential exists to reduce pilot work load by reducing the required instrument scan and by making the interpretation of symbology easier. Pilot evaluation of the PITS display and its effects on pilot work load must be accomplished in simulation and flight.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
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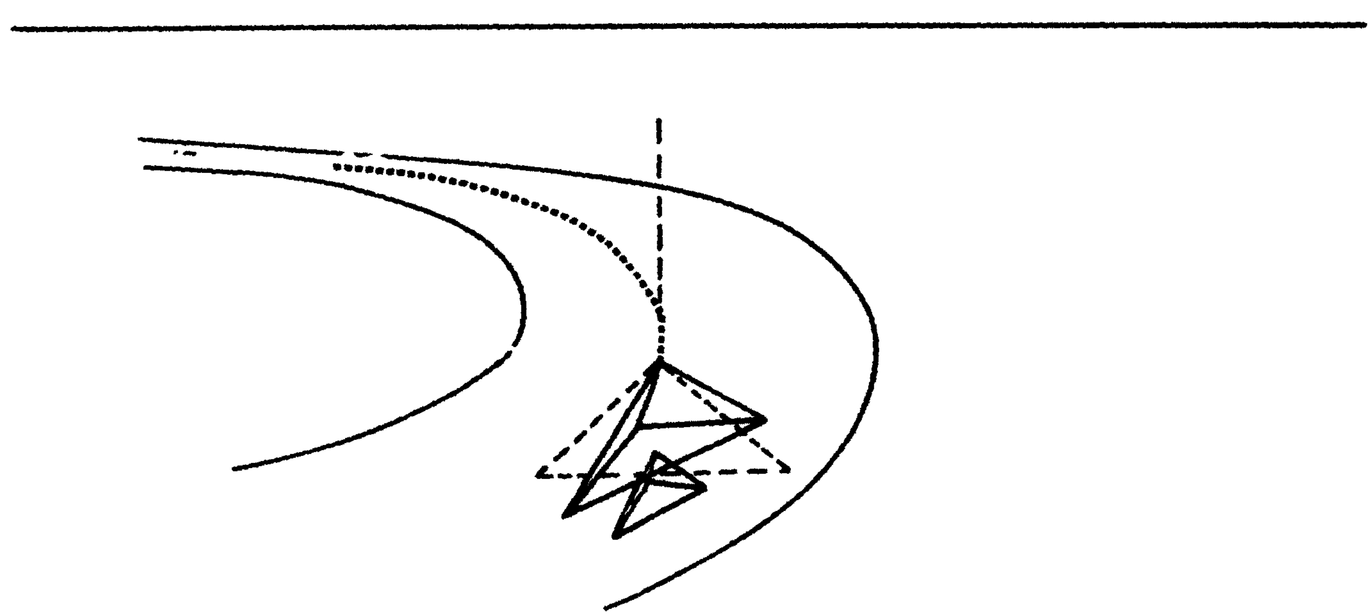
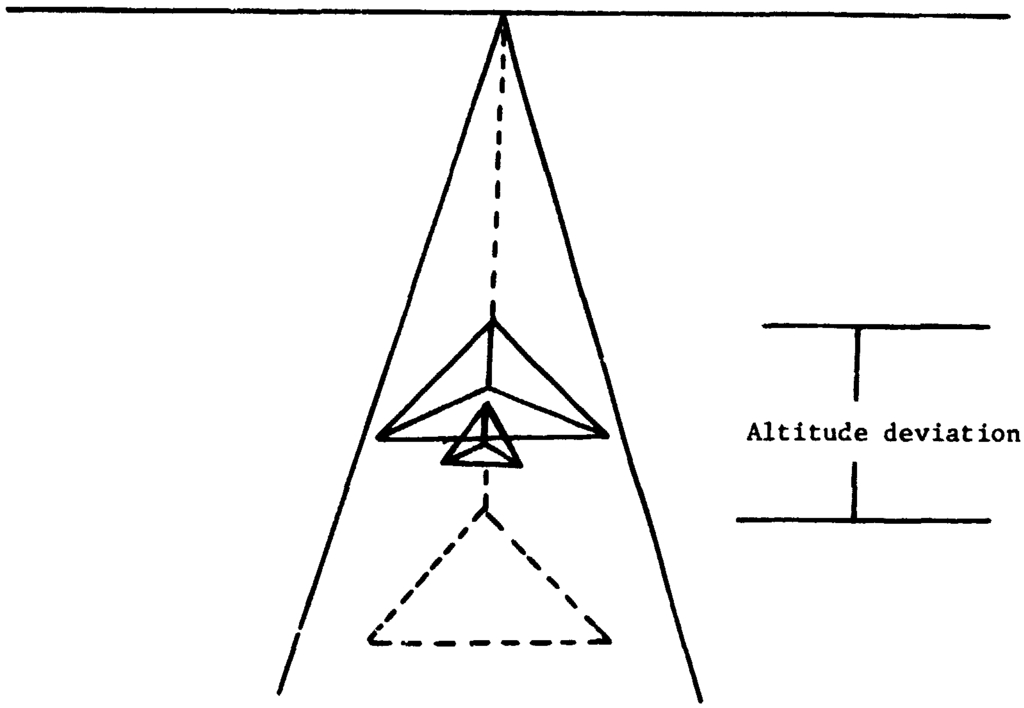
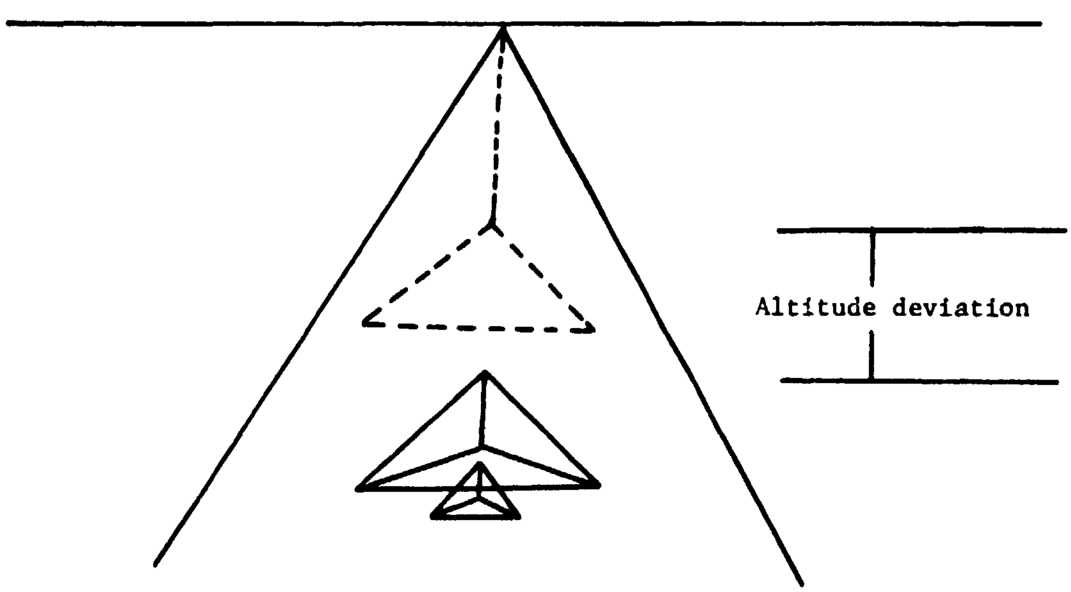


Figure 1.- Path, shadow, flight-path predictor, and airplane symbology.



(a) Above path.



(b) Below path.

Figure 2.- Airplane symbol and shadow interactions during altitude deviations.

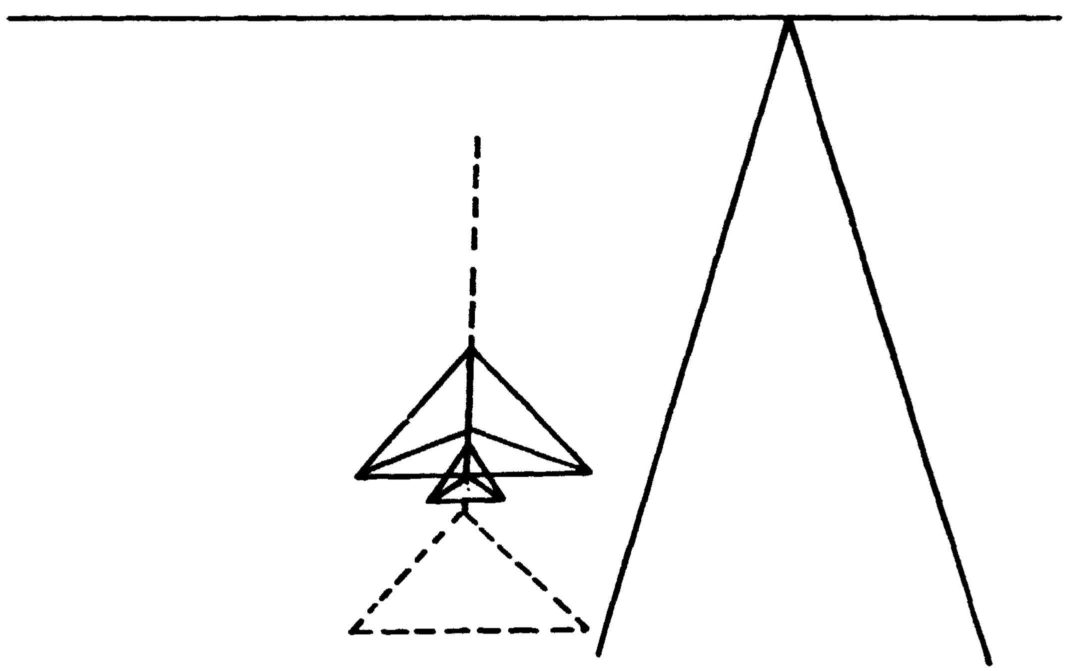


Figure 3.- Airplane above and to left of path.

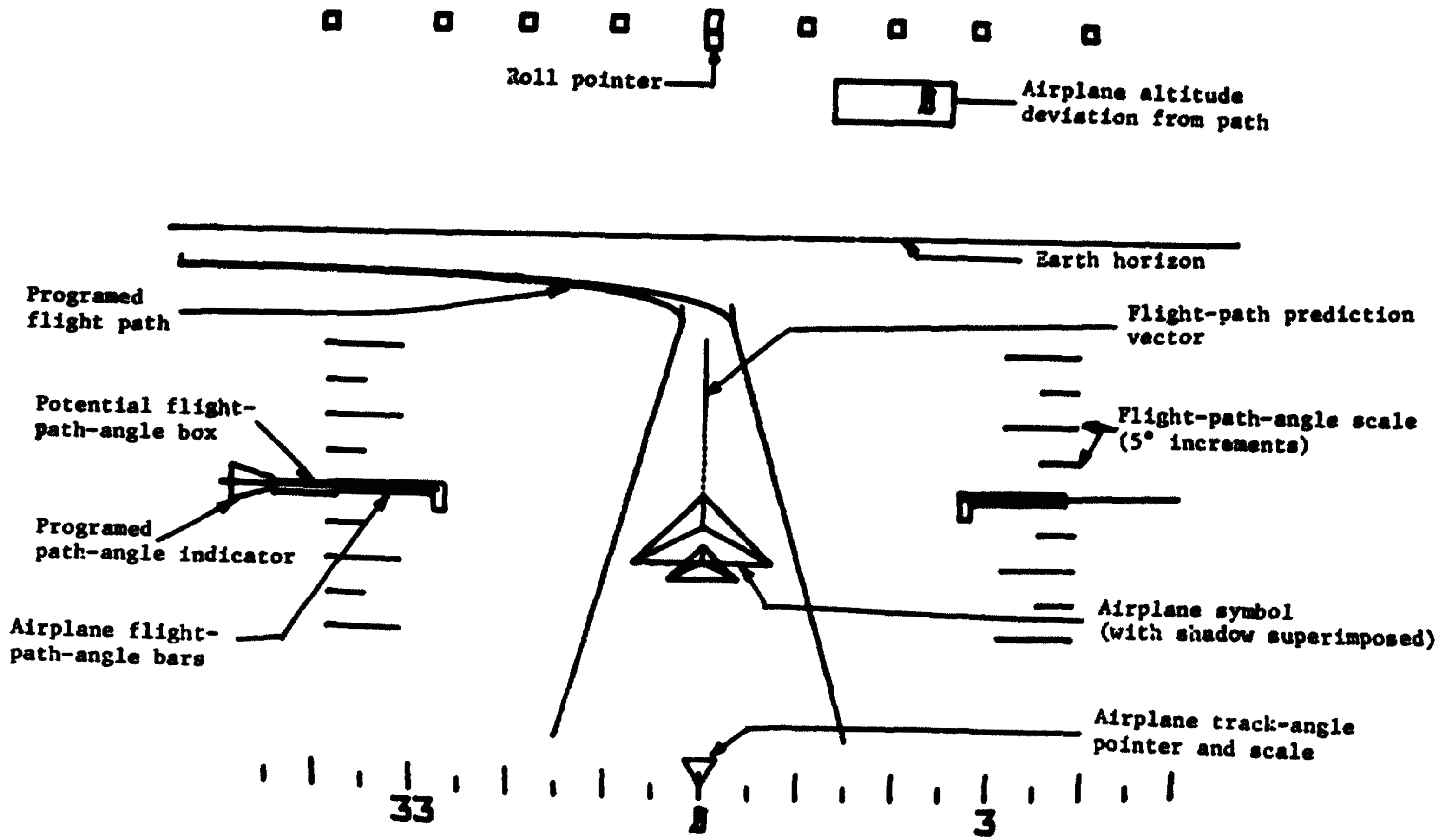


Figure 4.- The PITS contact analog display symbology.

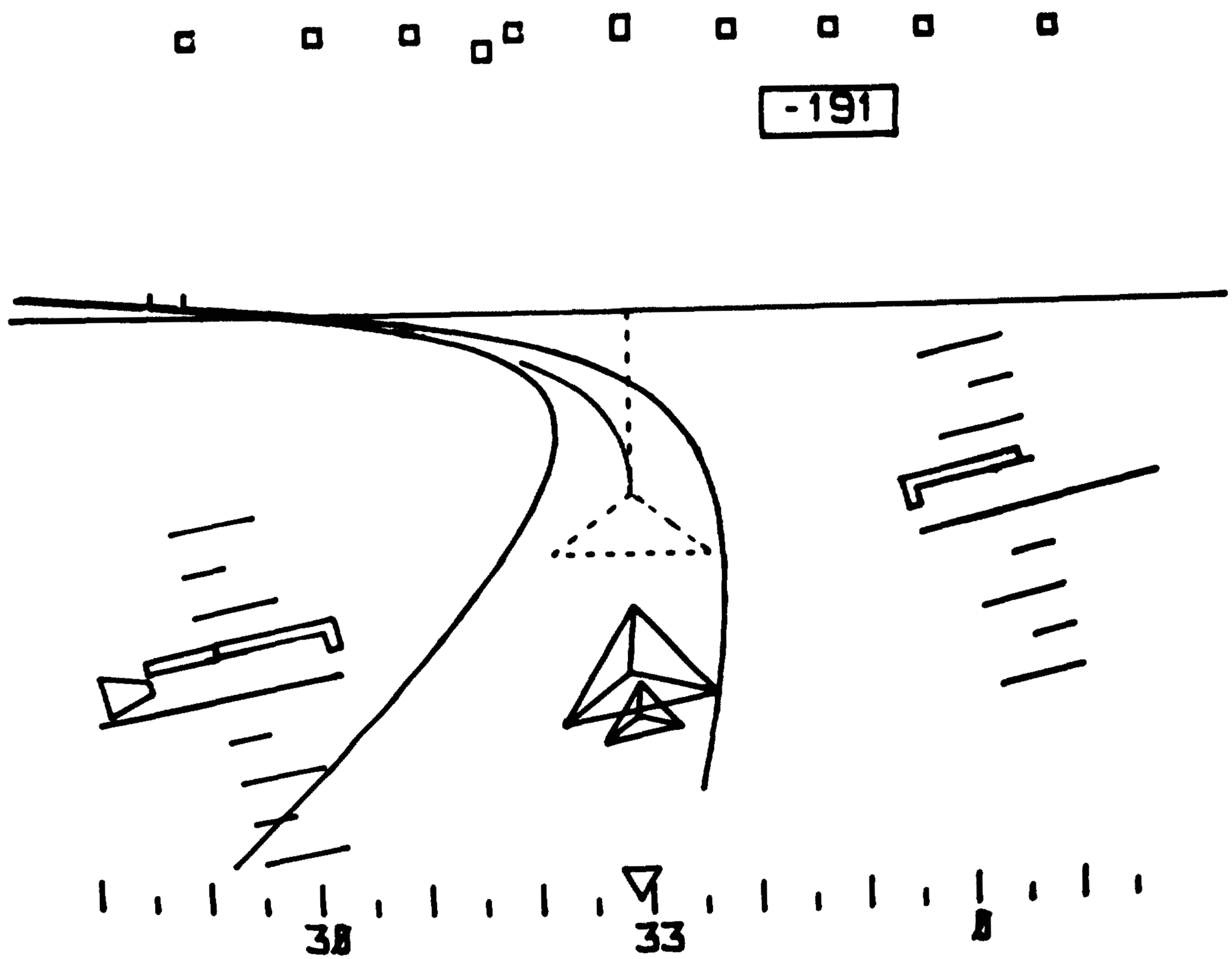


Figure 5.- The PITS display concept showing airplane below path and climbing in a left bank of 13°.

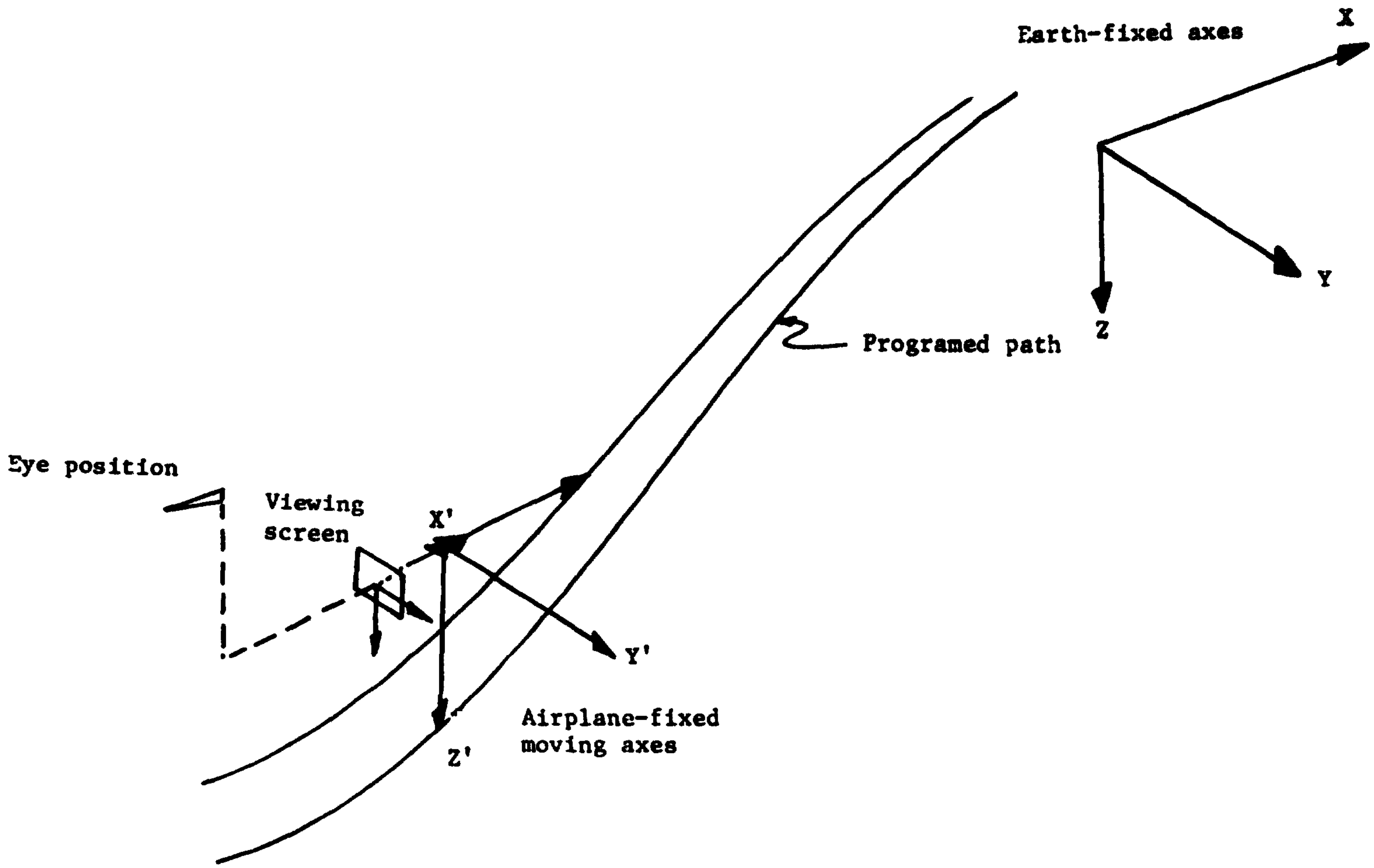


Figure 6.- Reference coordinate systems.

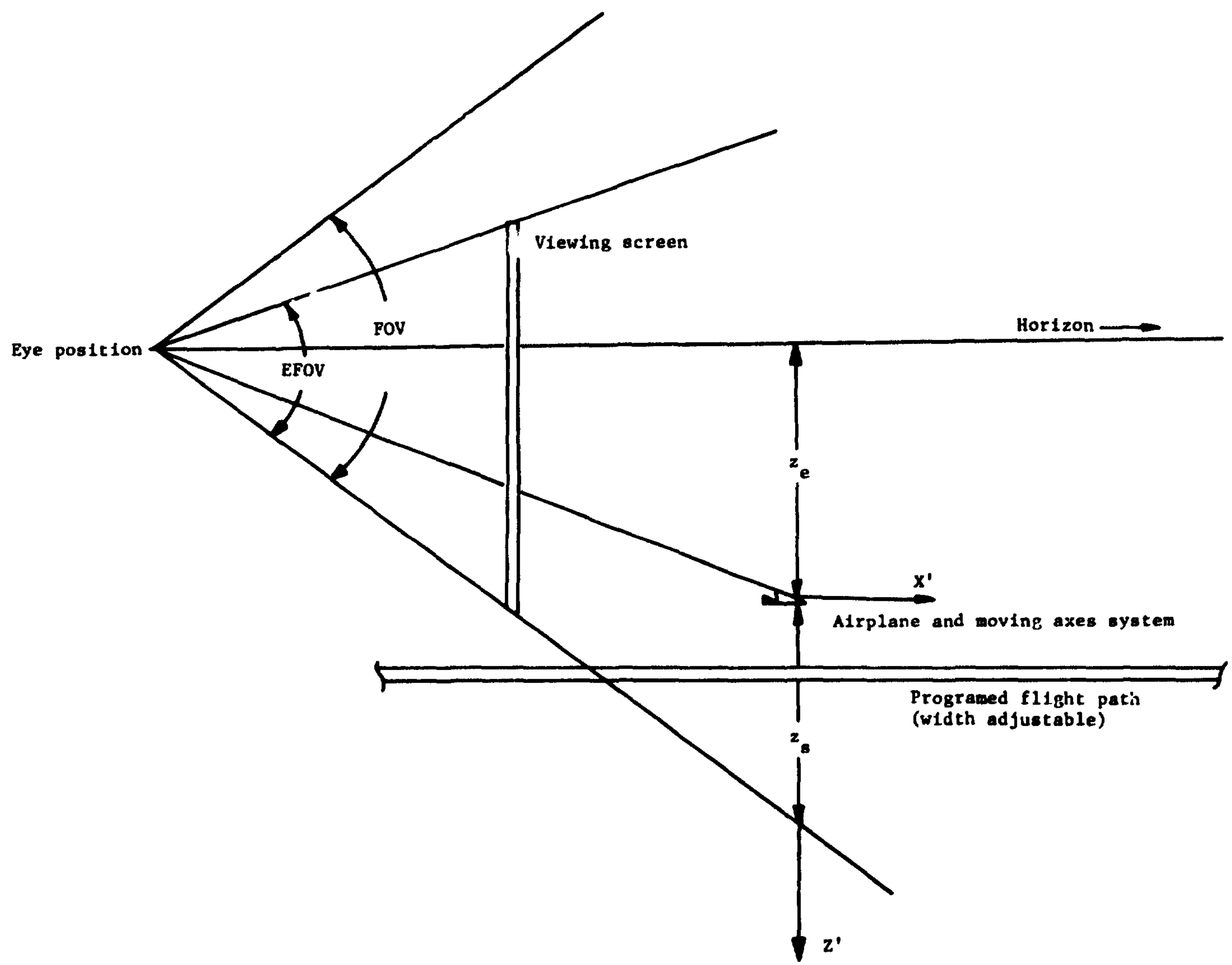


Figure 7.- Adjustable geometric parameters.

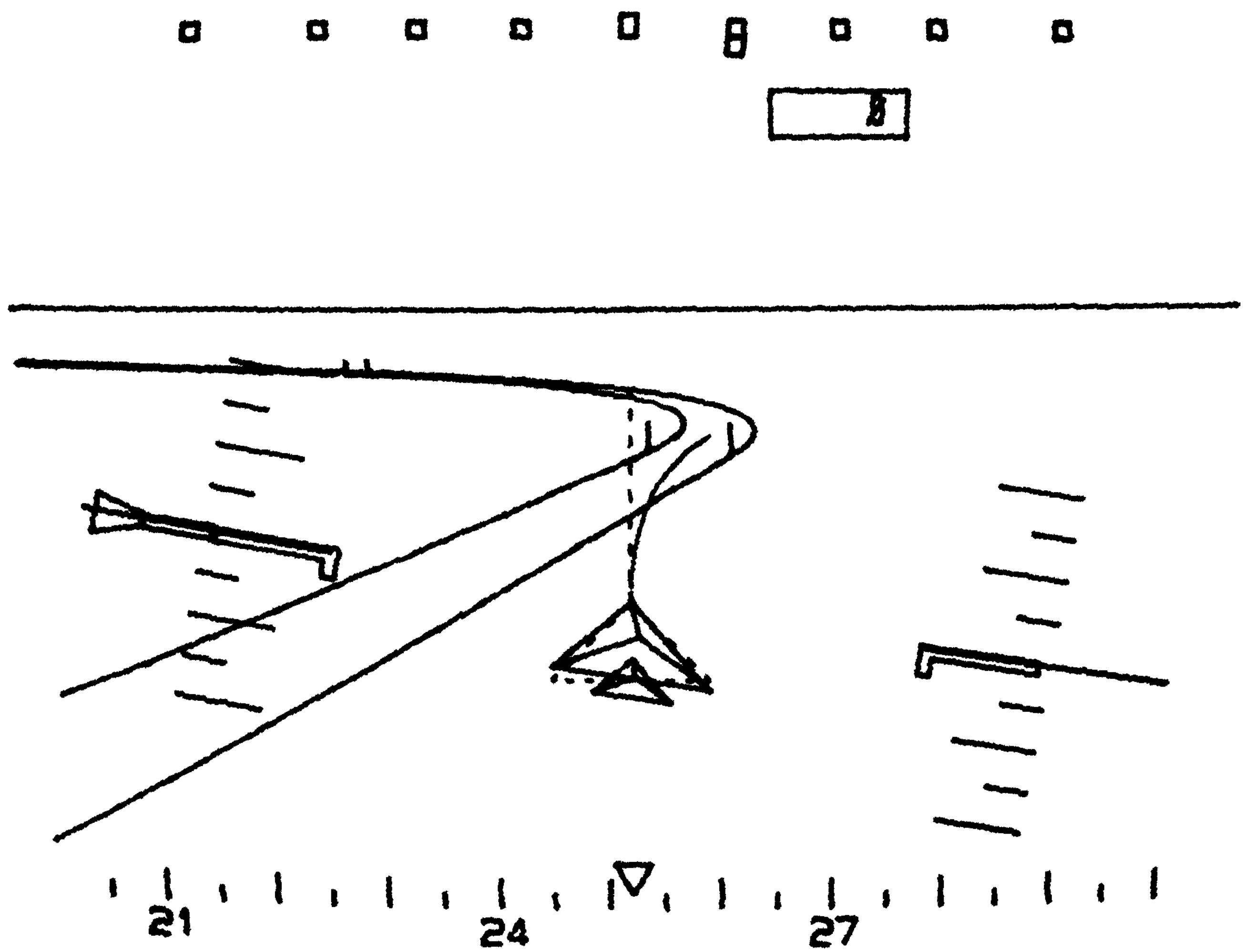


Figure 8.- The PITS display showing airplane displaced to right of path.

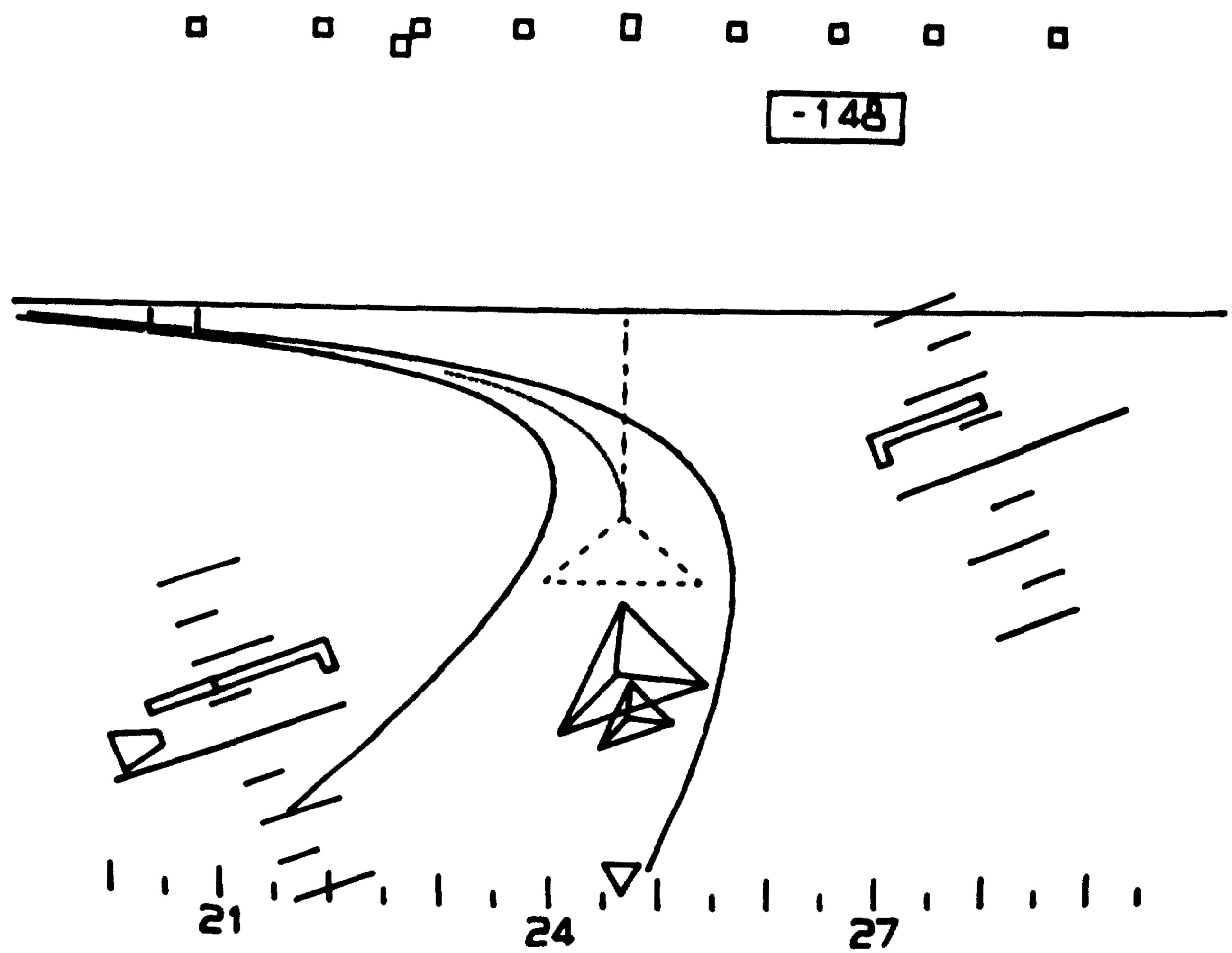


Figure 9.- The PITS display showing airplane displaced below path.

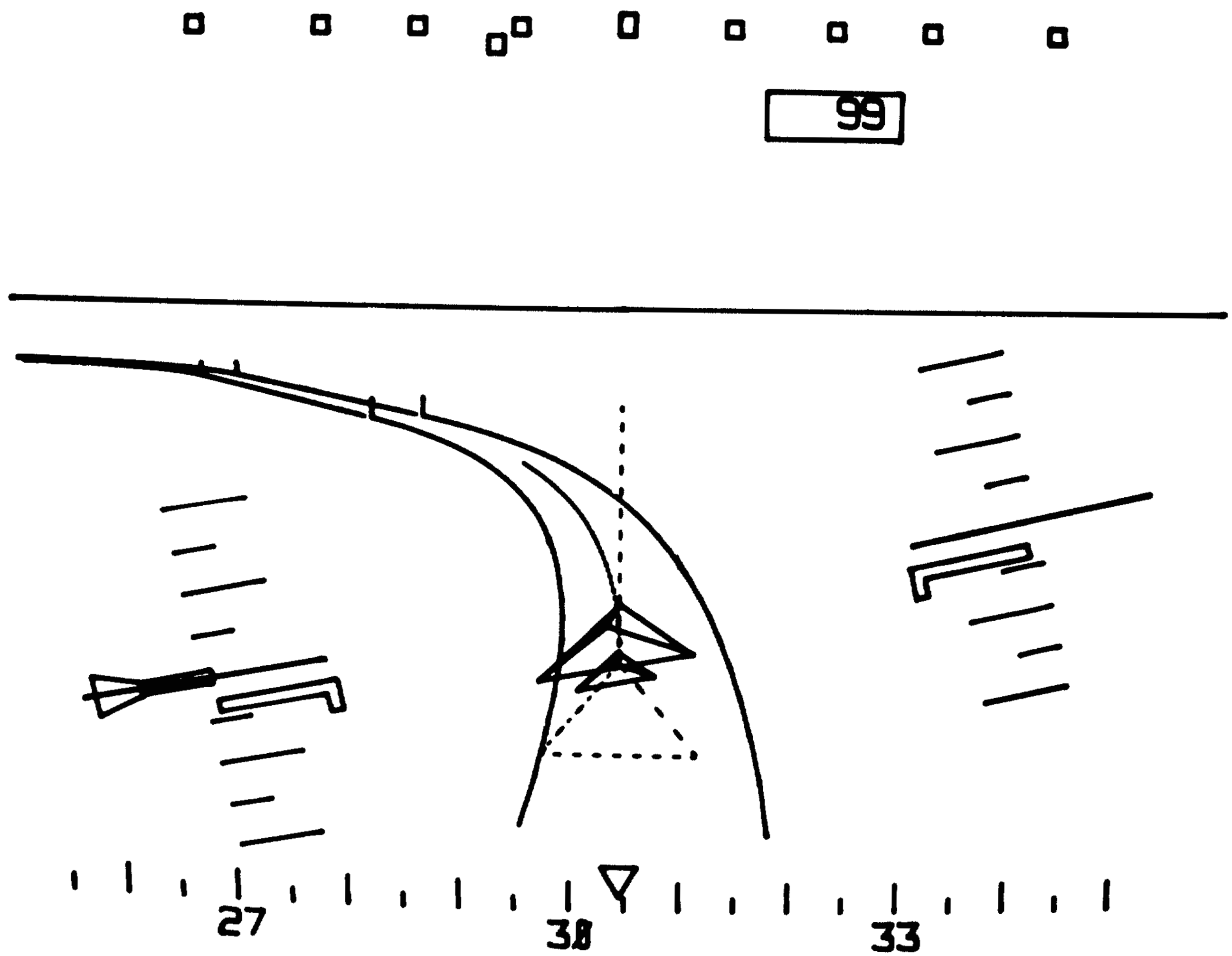


Figure 10.- The PITS display showing airplan: displaced above path.

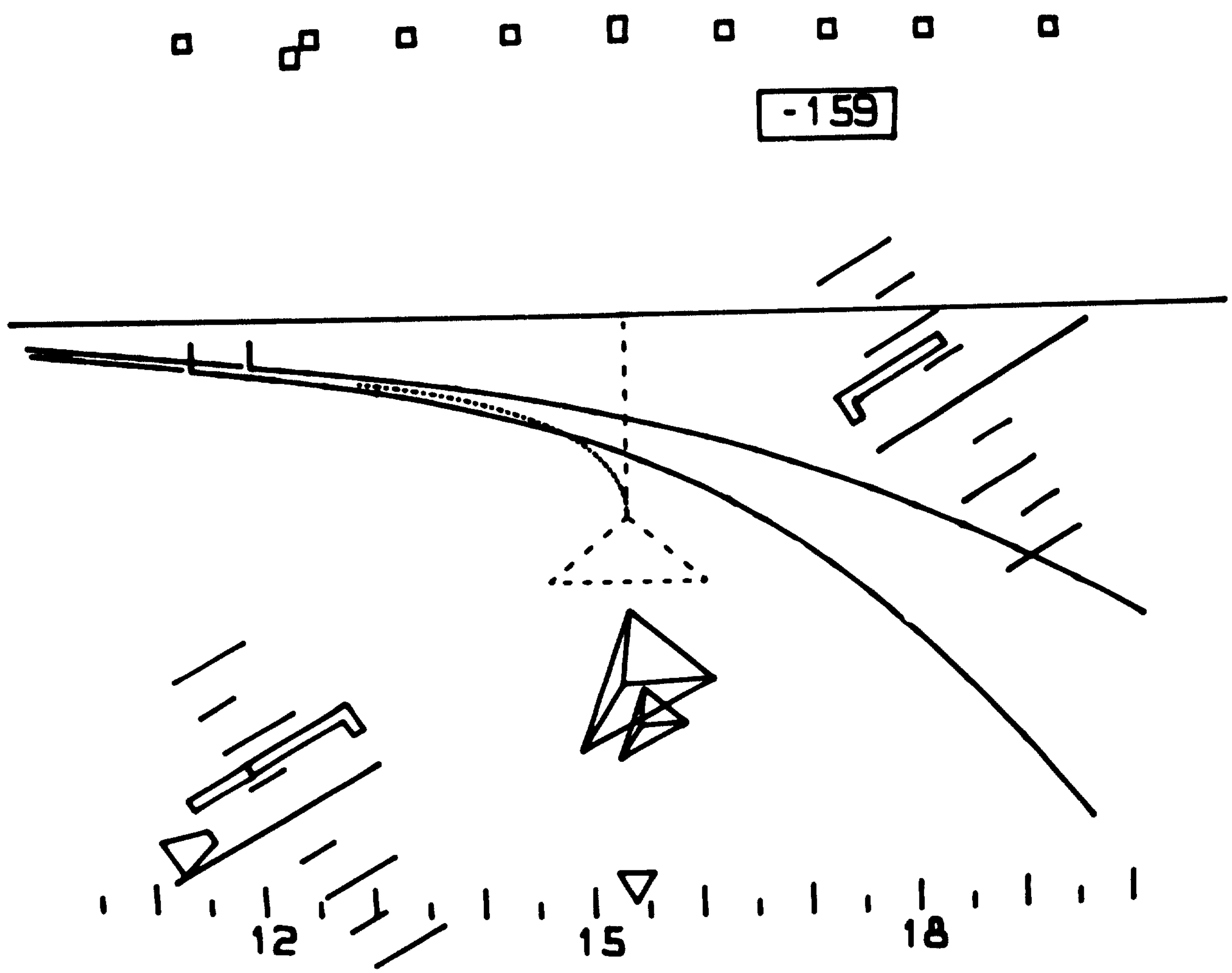


Figure 11.- The PITS display showing airplane displaced below and to left of path but correcting back.

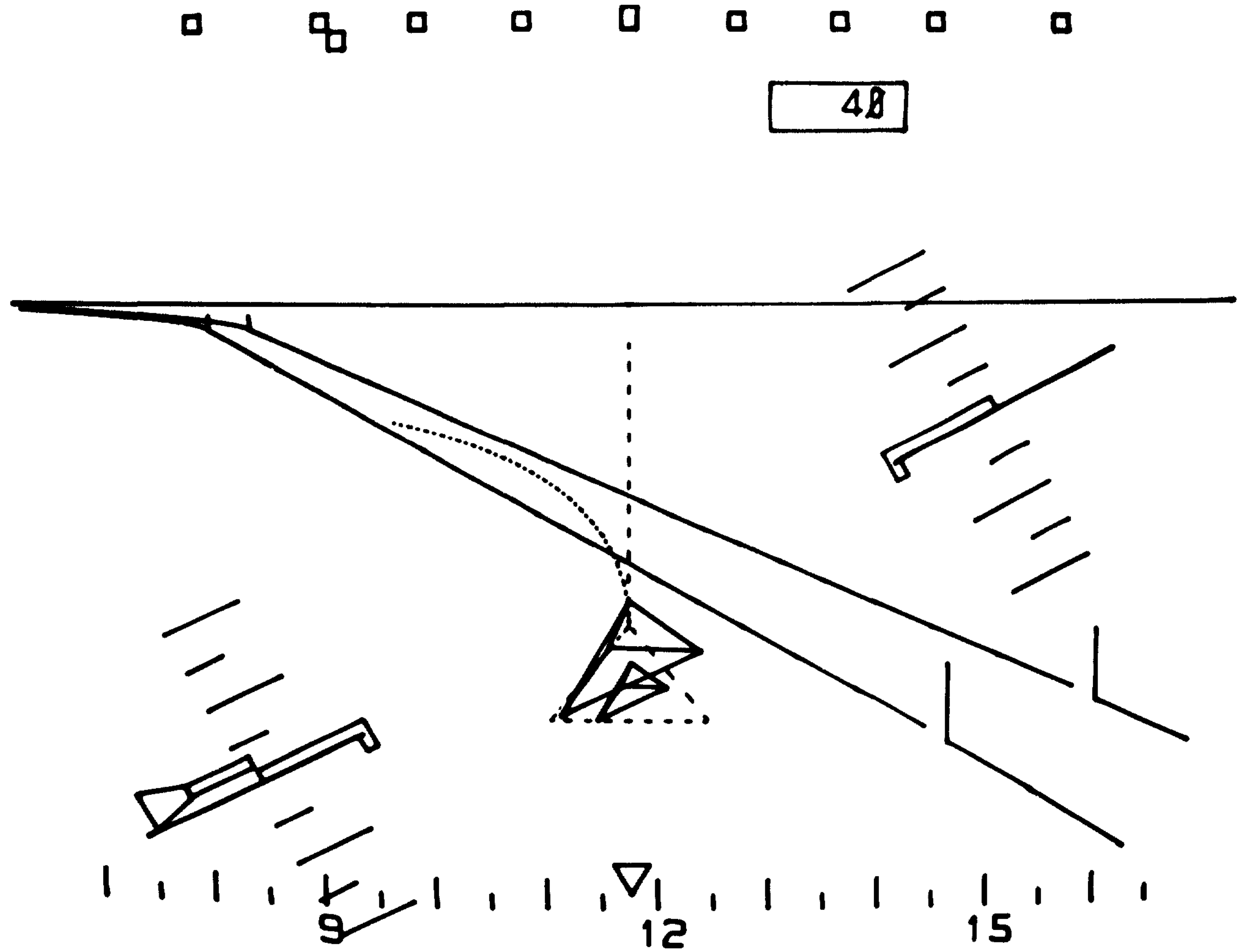


Figure 12.- The PITS display showing airplane displaced above and to left of path but correcting back.

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15. Supplementary Notes

John Leavitt: Sperry Rand Corporation, Hampton, Virginia.

16. Abstract

A contact analog display called path in the sky (PITS) integrates information on airplane attitude, airplane kinematic performance, navigation situation, and path prediction into one instrument. The pictorial format utilized in the PITS display concept was designed to reduce the required instrument scan and to simplify interpretation of information with the objective of reducing pilot work load. This report describes the symbology of the PITS display, the coordinate systems used to generate the display, and the magnitudes of pertinent geometric characteristics selected during the display development. Also included are examples of the PITS display generated on a stand-alone graphics computer.

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