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A LANDING DISPLAY FOR USE WITH A CONTACT FLIGHT SIMULATOR

(Human Engineering Systems Studies)

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Introduction

The usefulness of a synthetic flight trainer depends in a large part upon the number and variety of maneuvers that can be taught in it. A trainer that can be used to teach instrument flying, for example, is not as useful as one that can be used to teach both instrument and contact flying. The use of existing contact flight trainers is usually restricted to air work maneuvers because of the lack of adequate simulation of ground-derived cues. One of the most difficult maneuvers to learn in a contact flying syllabus, in terms of the time spent on it, is the approach to a landing. If this maneuver could be taught successfully in a synthetic trainer, the usefulness of the trainer would be greatly extended.

In order to teach contact landings using a synthetic flight trainer such as the 1-CA-2 SNJ Link, some device must be designed and constructed that will present sufficient visual cues for a pilot to perform a satisfactory landing. A previous attempt to do this has been reported recently by this laboratory.[1] In that study a tilting blackboard and screen were so arranged in front of a School Link trainer that the illusion of an approach and landing could be achieved in a crude fashion. The results of the study indicated that some transfer of training occurred. Students instructed with the device made fewer errors when learning to land a real aircraft than did students who were not so instructed. The difference between the two groups was significant.

The cues presented by the blackboard and screen represented an attempt to show the runway in perspective and in proper relation to the horizon, these functions being varied as the approach progressed. It was known at the time that the presentation was not geometrically correct. It was not known at the time, nor is it known now, that these perspective cues are the cues a pilot actually uses when performing an approach and landing. Nevertheless, the encouraging results of the first study have prompted the present analysis. It is hoped that with a geometrically correct display, which is now possible as a result of this analysis, results of practical importance will be obtained.

A mathematical analysis of the visual perspective cues during an approach to a landing.

This report presents a mathematical analysis of the visual perspective cues that occur during an approach to a landing and the application of this theory to the design of an actual training device.

To determine what a pilot sees when he views the runway during the final approach to a landing, some of the principles of perspective

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[1] Brown, E. L., Matheny, W. G., and Flexman, R. E. Evaluation of the School Link as an aid in teaching ground reference maneuvers. Port Washington, New York: U. S. Navy, Technical report SDC 71-16-7, December, 1950.

drawing are employed. It is assumed that the image the pilot sees can be duplicated on a "picture plane" that is placed between him and the runway (Figure 1).

All the rays of light reaching the pilot's eyes from the runway and the horizon pass through the picture plane. If the points of intersection are all marked, a picture of the runway and horizon will be formed on the picture plane. The primary assumption in this design is that this is indeed a true picture of the scene in question. Preliminary investigation has shown this to be so.

The drawing in Figure 1 contains the necessary information to determine the positions of the near and far ends of the runway with respect to the horizon. The picture plane is placed at a distance $\underline{k}$ from the pilot. This distance controls only the size of the picture produced.

The distance from the horizon to the near end of the runway is $\underline{H}$. This distance can be determined by using the two similar triangles, one with sides $\underline{H}$ and $\underline{k}$ and angle γ and the other with side $\underline{a}$ and $(\underline{d} - \underline{c})$ and angle γ.

Thus

$$\frac{H}{k} = \frac{a}{(d - c)} \quad \text{and} \quad H = k\frac{a}{(d - c)} \qquad (1)$$

The distances from the horizon to the landing spot and to the far end of the runway are found in a similar manner, and these are

$$h = k\frac{a}{d} \qquad (2)$$

and

$$f = k\frac{a}{(1 + d)} \qquad (3)$$

The value of $\underline{k}$, the distance from the pilot to the picture plane, is not necessarily a constant. There is some evidence that leads to the conclusion that the value of $\underline{k}$ should be larger for distant objects than near ones. It will be shown later that the value of $\underline{k}$ can easily be made a variable function of $\underline{d}$ when the equation for the variable has been determined.

Another variable not shown in Figure 1 is the "dip" of the horizon which will be called Δ. The horizon dip is a result of the curvature of the earth, and though it is negligible at low altitudes, it becomes quite apparent at 500 feet and higher.

If two lines are extended from the edges of the runway away from the pilot, they will appear in the perspective to meet at an infinite distance on a plane tangent to the surface of the earth at the runway. The dip of the horizon will, however, place this point somewhat above the visible horizon. This distance in the picture plane is determined in Figure 2. The quantity $\underline{e}$ is the distance of the pilot's horizon below the point of intersection of the runway edges. The distances computed for $\underline{H}$, $\underline{h}$, and $\underline{f}$ are measured down from this point of intersection as is the distance $\underline{e}$ to the pilot's horizon.

The angle between the edges of the runway in the picture is called θ. This angle can be expressed in several ways, but the one most convenient

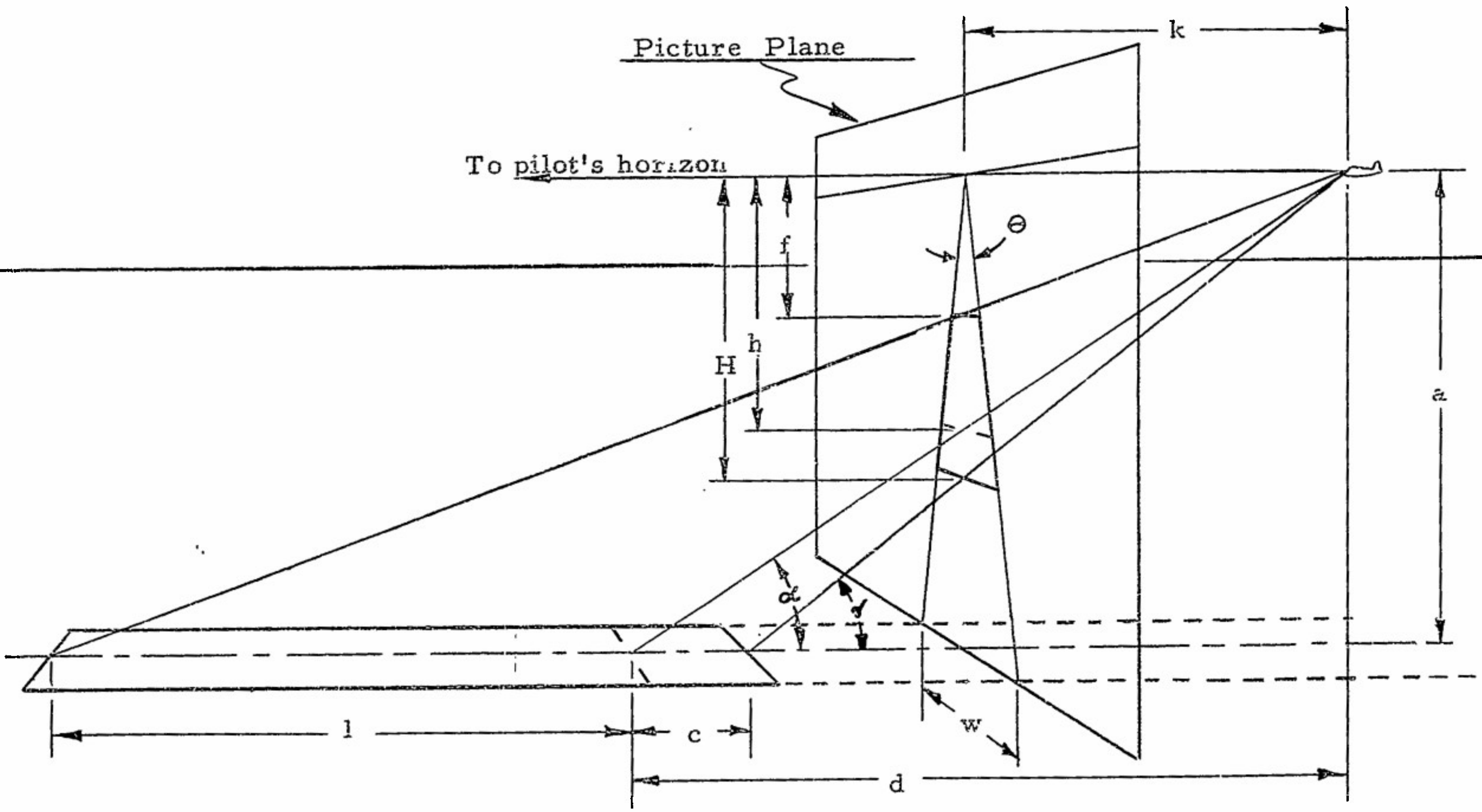
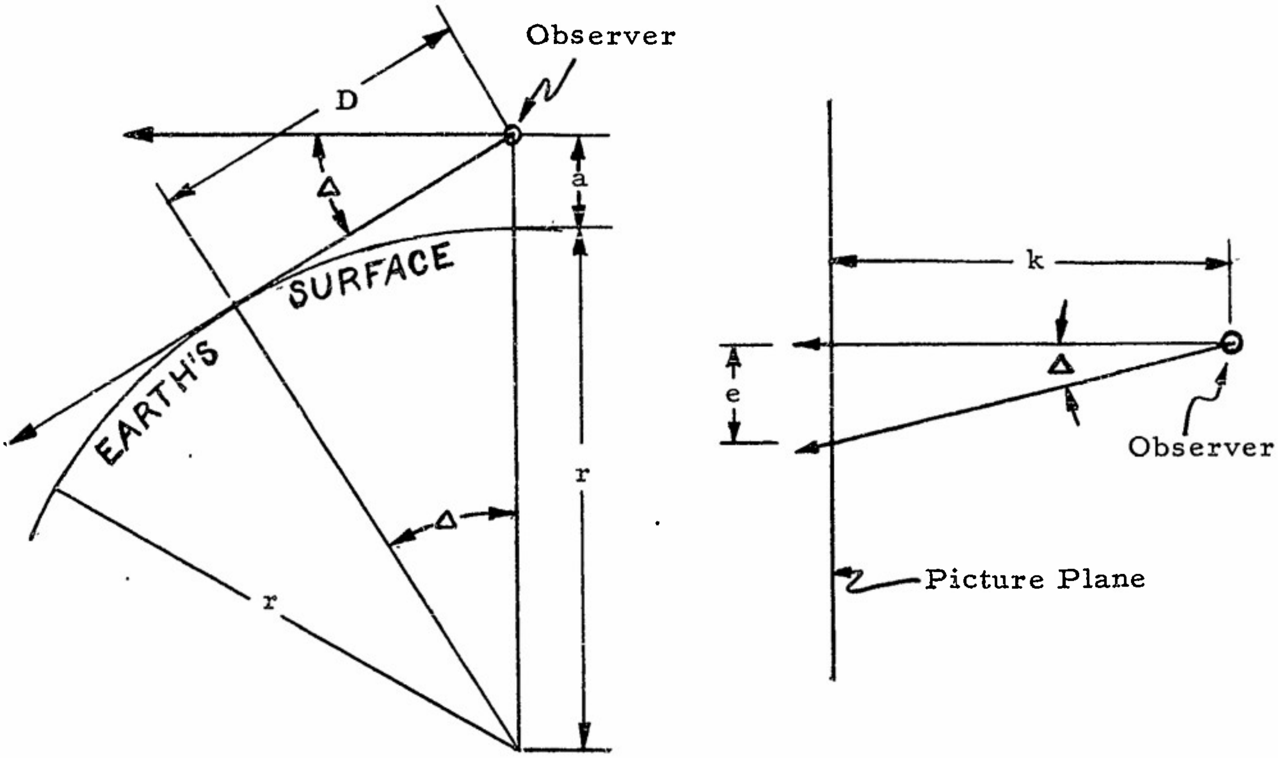


Figure 1

Perspective view of the aircraft, the runway and the picture plane showing how the picture is formed.



r = radius of the earth

a = altitude of observer

D = distance to visual horizon

Δ = dip angle

e = distance of horizon dip on picture plane

$$(r + a)^2 = r^2 + D^2$$

$$r^2 + 2ra + a^2 = r^2 + D^2$$

$$D = r \tan \Delta$$

$$a^2 + 2ra - r^2 \tan^2 \Delta = 0$$

$$\tan^2 \Delta = \frac{a^2 + 2ra}{r^2}$$

$$\tan \Delta = \frac{e}{k}$$

$$\left(\frac{e}{k}\right)^2 = \frac{a(a + 2r)}{r^2}$$

$$a \ll r$$

$$e = k \sqrt{\frac{2a}{r}} \qquad (4)$$

r = 3960 miles
= 20.91×10^6 feet

Figure 2

The dip of the horizon as a function of altitude.

to the design of the equipment is one that leads to an expression in terms of altitude only. In Figure 1 it can be seen that two lines extended from the edges of the runway to the bottom of the picture plane intersect at the ground with their images in the picture. Since they are a distance w apart and must meet at the true horizon which is a distance a up from the ground, an isosceles triangle is defined with base w and height a.

An expression for θ is then found using the information in Figure 3.

$$\tan \frac{\theta}{2} = \frac{w}{2a}$$

$$\frac{\theta}{2} = \tan^{-1} \frac{w}{2a}$$

$$\theta = 2 \tan^{-1} \frac{w}{2a} \qquad (5)$$

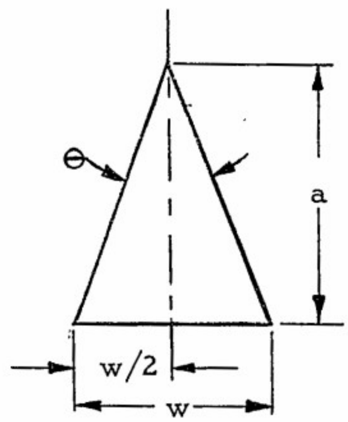


Figure 3. The Angle θ

All the equations necessary to describe the appearance of the runway and horizon on the picture plane have been developed. Before they are applied to the design of the display there are several interesting points that may be discussed.

Some perceptual phenomena.

First, the angle α from the pilot to the landing spot is known as the glide angle. The distance h in the picture can easily be expressed in terms of this angle. Since $h = k\frac{a}{d}$ and $\tan\alpha = \frac{a}{d}$,

$$h = k \tan \alpha \, . \qquad (6)$$

This means that when the glide angle α is held constant, h will be constant. The landing spot will not move with respect to the horizon as the pilot proceeds down this glide path. All points on the far side of the landing spot will appear to move away from the pilot toward the horizon and all points between the pilot and the landing spot will appear to move toward him.

The one point in the picture that remains stationary will be that at which the airplane will land if the glide angle is maintained. This also indicates that there is a unique distance h from the horizon to the landing spot for each glide angle. It is possible that this is a very important cue in a contact landing. It is a cue that does not depend on the appearance of objects on the ground but only on the glide angle of the aircraft.

It has been shown that for any width w of a runway, the angle θ is a function of altitude only. This implies that a pilot could estimate his altitude by the apparent angle between the edges of the runway if he were familiar with its dimensions. It is possible that this is another cue used in visual landings.

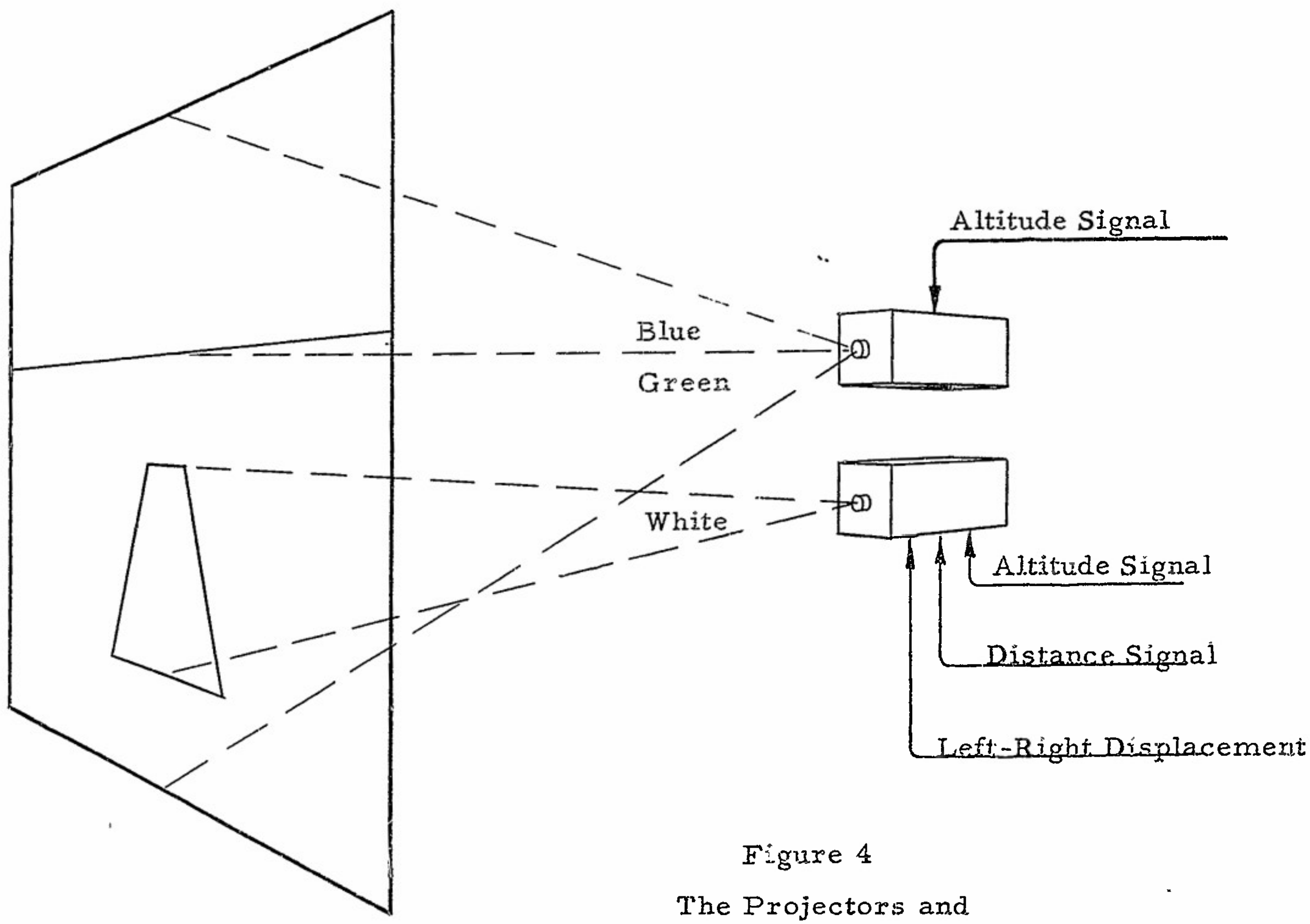


Figure 4

The Projectors and
Transducent Screen

In deriving equations (1) through (5) it has been assumed that the normal glide angle is less than ten degrees. This permits the assumption that the picture plane is vertical rather than perpendicular to the "line of sight." This assumption results in such a small error that it is unnecessary to take into account the actual slant of the picture plane. These equations are also based on the premise that the pilot is proceeding along the center line of the runway. Slight deviations from this path may be set into the display to be described, but these also must be no greater than ten degrees.

The application of the theory to the design of an actual training display for use with a contact flight simulator.

Employing the five equations just developed, it has been possible to design a functional contact landing display that can be used with any contact flight simulator that will provide the necessary signals. The display presents a constantly changing image of the landing runway and horizon. The changes in the image are made automatically in accordance with the simulated flight path of the trainer.

It seems wise to project this display on a screen because moving pieces large enough to give a suitable picture in front of a trainer would be cumbersome. Two projectors will be used. One will project the blue sky and green grass that surrounds the runway. The other will project the image of the runway. A gray runway image can be produced by projecting the complement of the green used to represent the grass field. A white runway can be produced more simply by projecting a white light sufficiently bright desaturate or "wash out" the green. Either will give the appearance of a runway surrounded by a grass field. The lights will be projected onto a ground glass screen from behind. The apparatus is shown schematically in Figure 4.

The sky and grass projector can be tilted slightly to show the horizon dip. The runway projector will contain suitable shutters to create the shape of the runway picture. See Figure 5.

The near and far ends of the runway will be positioned by shutters A and B and the edges of the runway by C and D.

These shutters can be moved by properly designed cams. The equations $H = k\frac{a}{(d - c)}$ and $f = k\frac{a}{(1 + d)}$ are hyperbolic, so the cams will be cut so that the radius is a hyperbolic, function of the angle of rotation. The motion of the cams can then be transmitted to the shutters by a suitable system of levers and cables. See Figure 6. Since the equations have been derived in terms of a and d, the equipment can be operated by altitude and distance signals taken from the trainer.

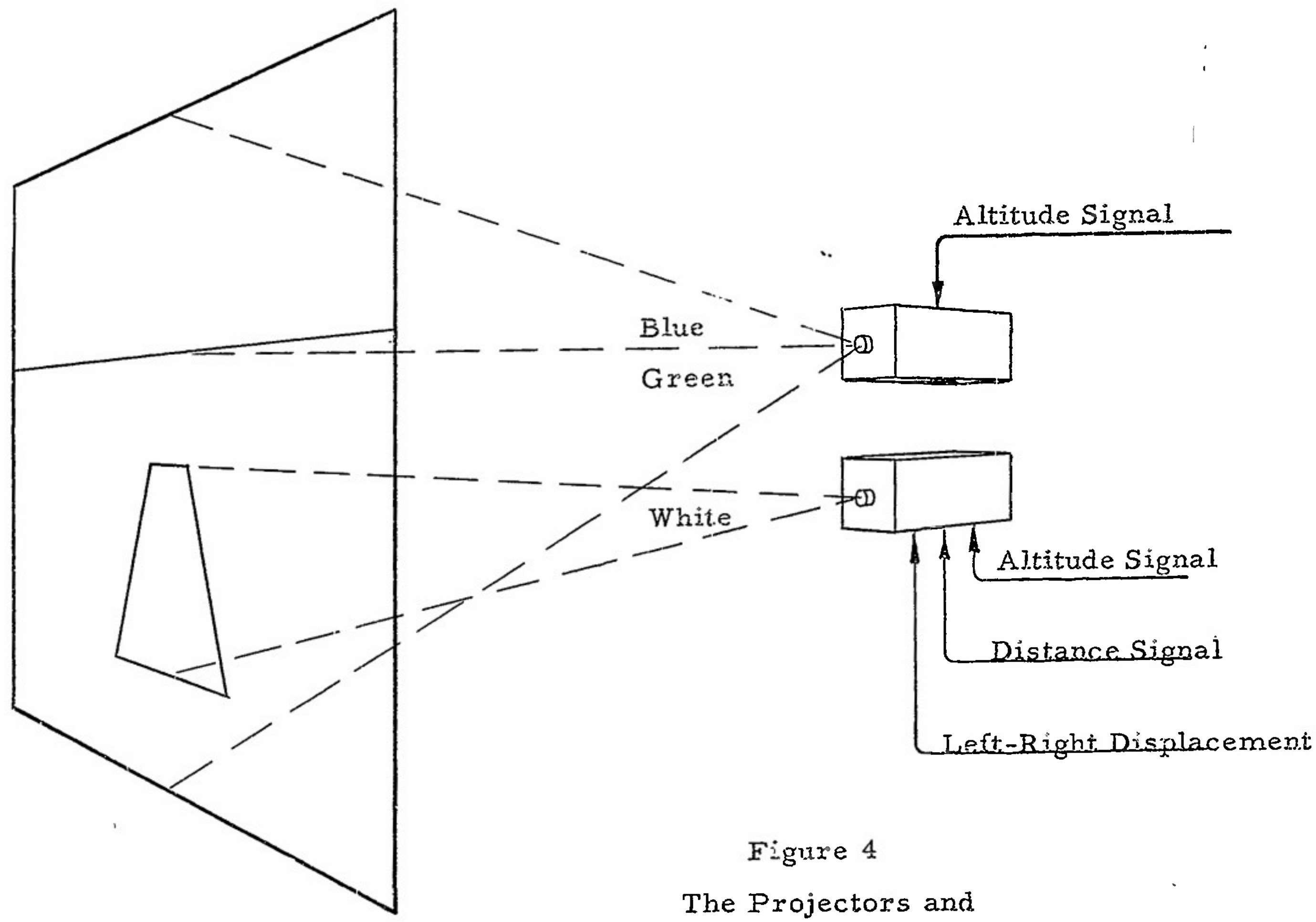


Figure 4

The Projectors and
Translucent Screen

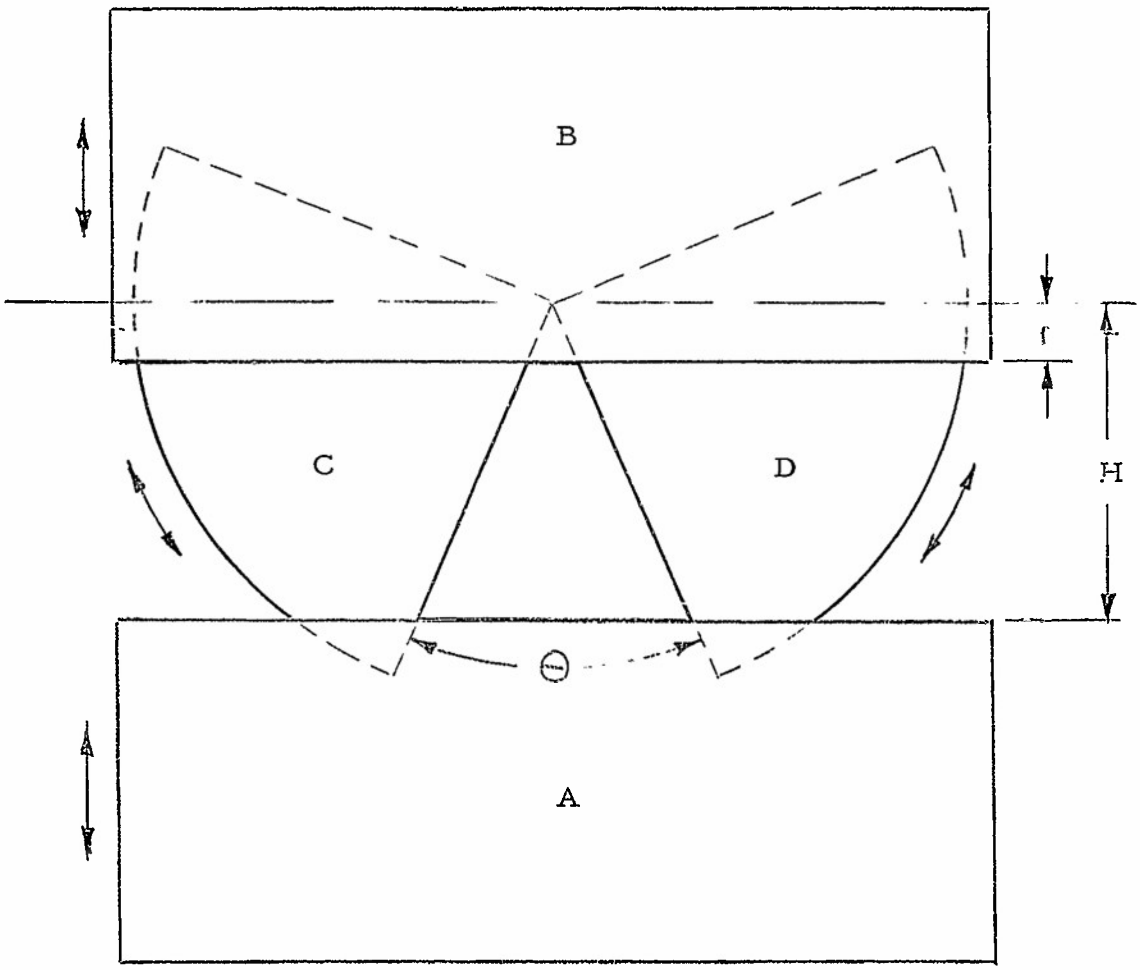


Figure 5

Shutters to Create the Shape of the Runway Picture

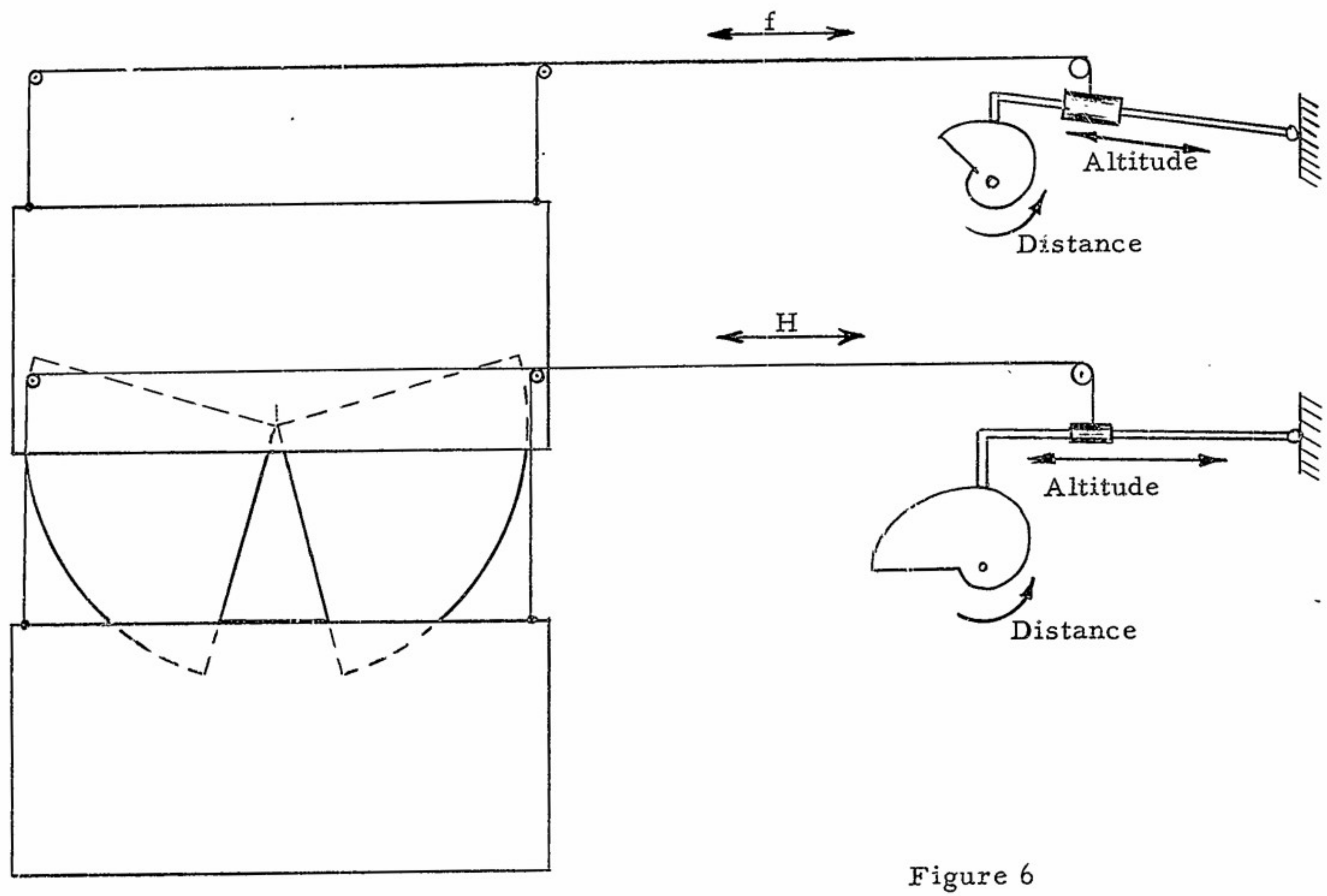


Figure 6

Cams and levers to operate shutters.

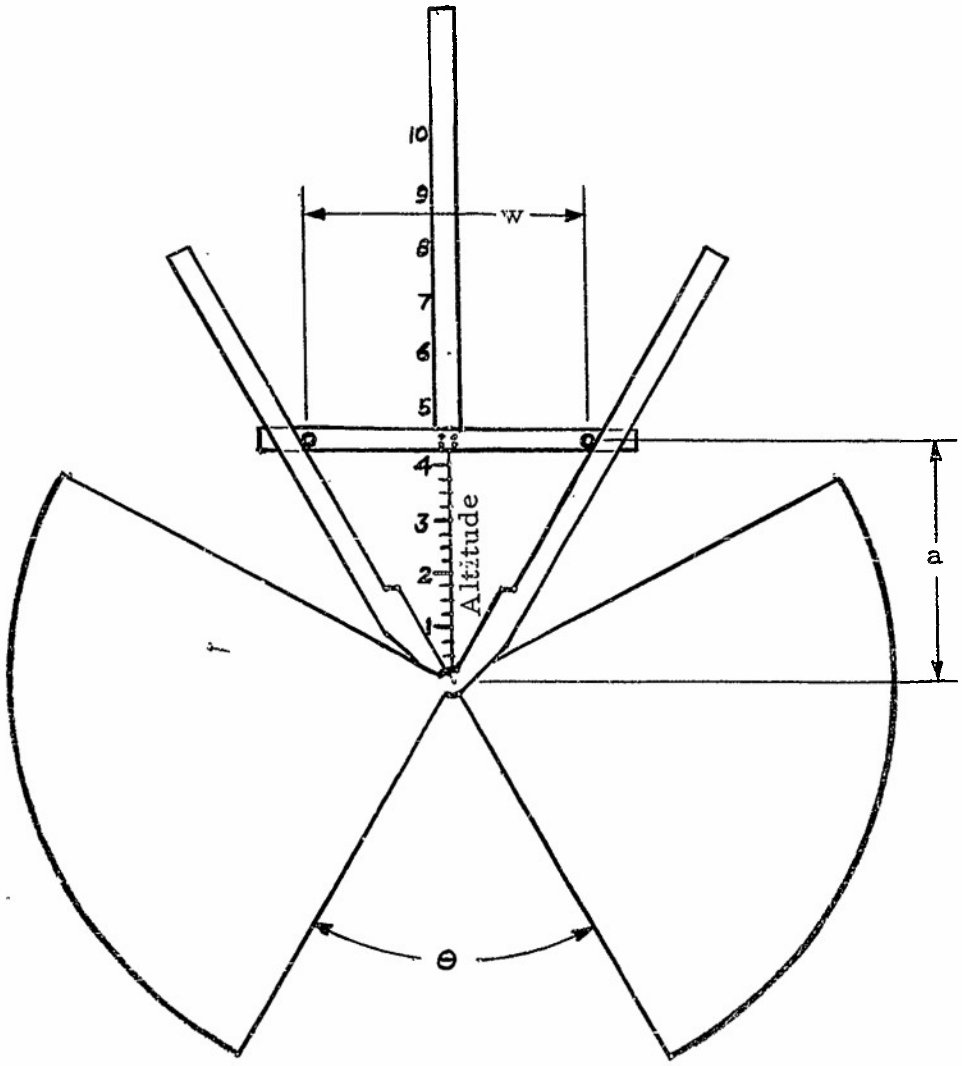


Figure 7

Apparatus to establish the angle between the runway edges.

Shutters C and D can be positioned in a very simple manner. Since the angle θ is determined by the constant w and the variable a, it can be produced in the machine by two pins a distant w apart and a distance a from the center of rotation of the shutters. If these pins were to run along the edges of the shutters the proper performance would result, but they would interfere with the light. They must, therefore, be placed above the shutters and run along two edges that are extensions of the edges of the shutters. See Figure 7.

It can be seen now that a deviation to the right or left of the center line of the runway can be simulated by a sideways motion of the pins that spread shutters C and D. This results in the type of picture shown in Figure 8.

If this deviation is less than ten degrees, a sufficiently accurate picture is produced. However, if the deviation is greater, the problem becomes far more complex. The pilot's line of sight is no longer parallel with the edges of the runway, and the single vanishing point at the intersection of these lines will no longer be sufficient.

When the line of sight makes a large angle with the parallel lines being viewed, two vanishing points must be used to construct the perspective picture. The position of these vanishing points varies with this angle. If the line of sight is parallel with the edges of the runway and perpendicular to the ends of the runway, one vanishing point is on the horizon ahead of the runway and the other at an infinite distance to the left or right. If the airplane flies off to the right far enough, the first vanishing point moves to the right, and the second starts in from infinity toward the left edge of the picture. See Figure 9. If a machine were to take this into account, the shutters would have to rotate about moving centers whose position depended on the left-right deviation from the glide path. It appears at this stage of the design that this refinement would result in complications too great for the value received. The right-left deviation from the center line will be limited to ten degrees.

If this display is used with a trainer that produces east-west and north-south distance signals, such as the 1-CA-2 SNJ Link trainer, all the necessary signals will be available. The north-south signal can be used to give the distance to the landing spot, and the east-west signal can give the right-left deviation from the runway center line. These signals and the altitude signal can be fed into suitable servo mechanisms that can drive the shutters.

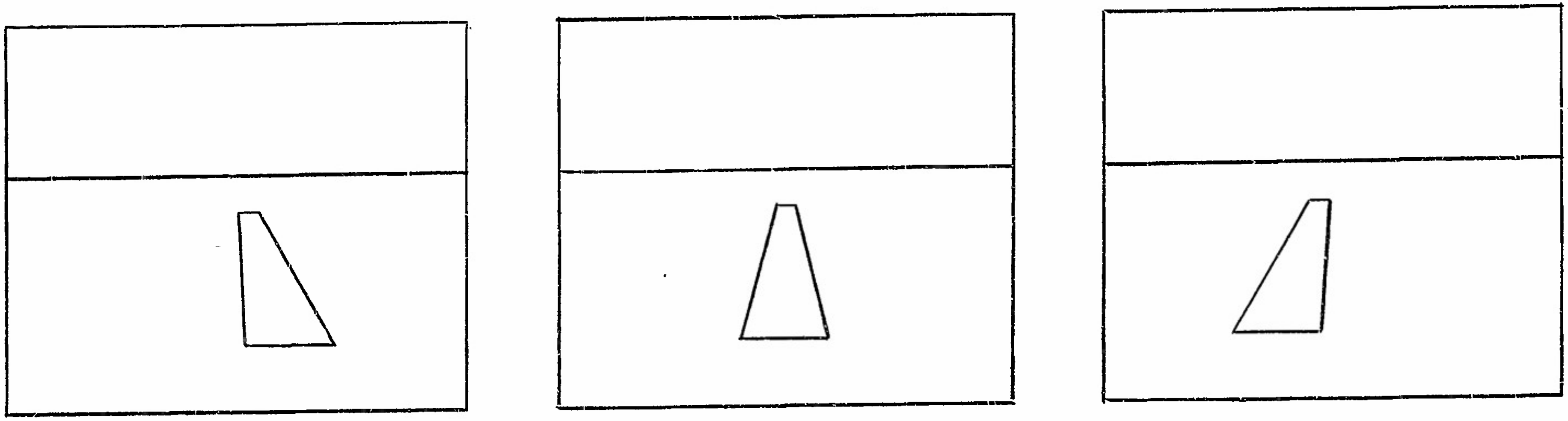


Figure 8

Changes in the runway picture due to small deviations to the left or right of the glide path.

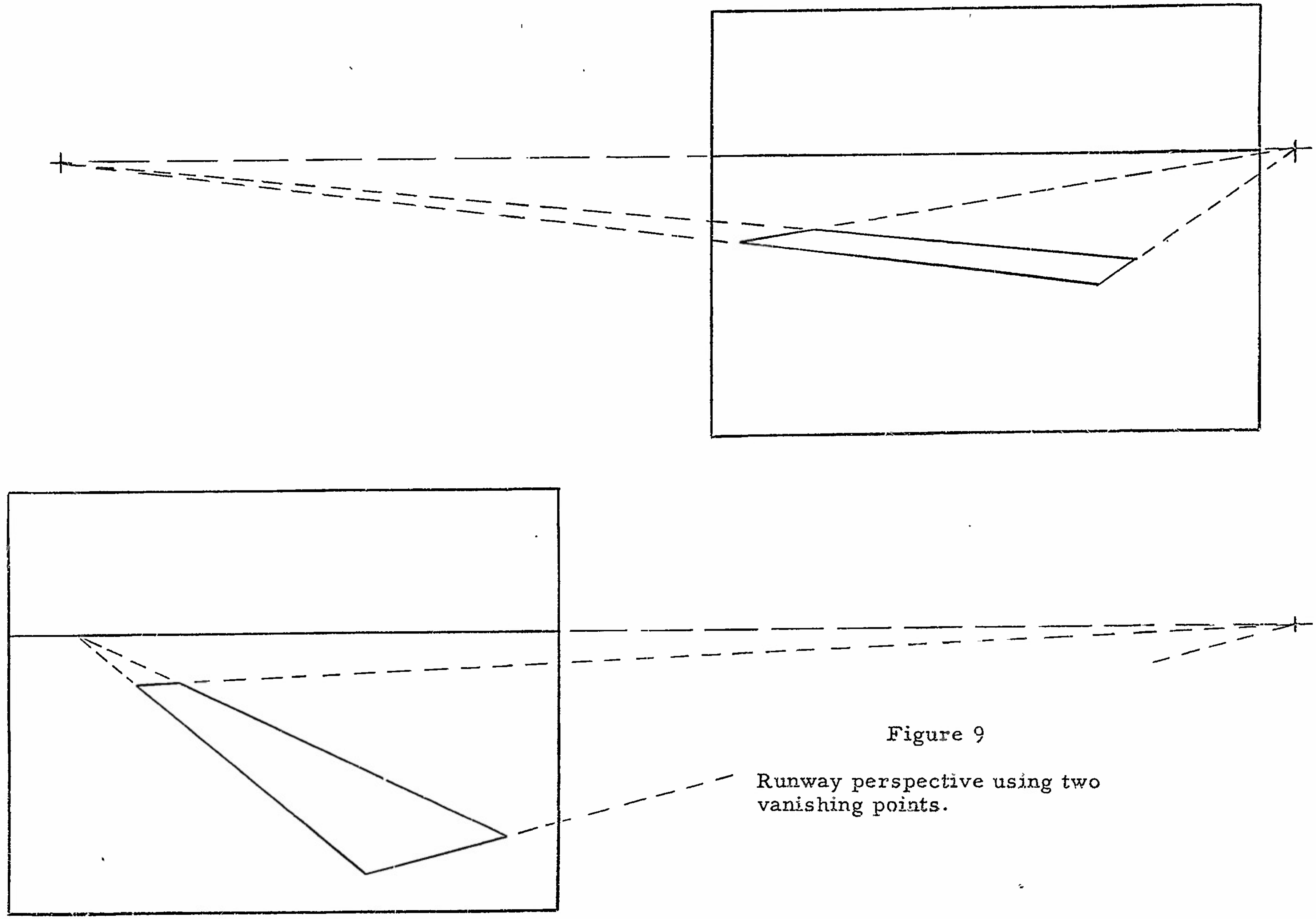


Figure 9

Runway perspective using two vanishing points.