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⑥
DESIGN STUDY
FOR
RUNWAY LIGHTING ATTACHMENT
FOR AIRCRAFT FLIGHT SIMULATORS.

RHEEM MANUFACTURING COMPANY

⑮ AF 33(600)-29550

⑪ MARCH 1956

⑫ 24p.

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MARCH 1956

Contract No. AF 33(600)-29550

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by the Rheem Manufacturing Company at the Philadelphia Plant, under Air Materiel Command Contract No. AF 33(600)-29550, ~~Task No. 5-(6-6114)-61734~~, "Trainer Attachment for Runway Lighting, - Engineering Study, Services and Data Therefor". The work was administered under the direction of the Wright Air Development Center, Aeronautical Accessories Laboratory, Training Equipment Branch, with Lt. R. Gross acting as Project Engineer. This report covers Item 1 of the subject contract only.

ABSTRACT

Results [illegible]

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SECTION I

INTRODUCTION

A. Need for Night Landing Simulator

Night landing under clear sky conditions where the runway lights are visible from the normal glide path starting point is fairly safe procedure when performed by a skilled pilot, since he has a fair degree of ground vision after making the approach. Under poor visibility conditions, however, night landing becomes increasingly hazardous because of the fact that the runway may not be seen until the aircraft is within a few hundred feet of the ground. The pilot normally makes his glide path approach on instruments under such conditions, and remains on instruments until the runway is clearly visible.

The hazards involved in such bad-weather flying, as well as the operational costs and the use of already crowded field facilities, clearly indicate the desirability of a night landing simulation device. Because of the relatively small number of external visual stimulii required to be presented, it was felt that a suitable training device could readily be created by the attachment of a projection system to a conventional flight simulator. Furthermore, since the basic problem is limited primarily to the approach and landing, the equipment should be of a somewhat simplified nature in comparison to other visual projection systems. Results of a design study program devoted to solution of these requirements are presented herein.

B. Simulator Requirements

Operational requirements for a runway lighting attachment were established by the Air Force and presented in detail in Exhibit WCLEQ-3-17, "Attachment, Runway Lighting, for Aircraft Flight Simulator". The essential requirements, which were used as a basis for determination of the extent and direction of this study program, are restated here as a guide to the technical discussion presented in subsequent sections of this report.

The runway lighting attachment is intended to present to the pilot (and copilot, if any) of a flight simulator the visual effects of approaching a lighted runway at night under varying conditions of cloud ceiling and visibility. Design of the projection system should be such that the following operating features are provided:

1. Runway approach may be started from a point 6 miles out (maximum) and 3000 feet altitude (maximum).

2. Initial position of runway with respect to the aircraft path may be preset by the instructor within the limits of the system.

3. Cloud ceiling may be varied from 0 to 3000 feet altitude.

4. Instructor may cause the descending aircraft to emerge from the cloud ceiling on center or to right or left of center within the system limits.

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5. Go around shall be only upon verbal instruction and visual presentation shall fade out.

Analysis of these desired characteristics indicates that the visual presentation is required only when the aircraft is within the normal glide path or at a point from which recovery and a reasonably straight-in approach can be made. When the pilot reaches the end of the runway, or pulls up to go around, the presentation shall automatically fade out. The system concepts investigated during the course of the study program were based upon this interpretation of the Exhibit as written. All other detailed requirements have been considered in order to assure satisfactory fullfillment of the training requirements.

C. Study Program

The design study program for the Runway Lighting Attachment proceeded in four distinct but interrelated phases consisting of (1) investigation of special film projection techniques, point light sources, and discrimination of images by polarized light, (2) investigation of parallax and screen contour effects, (3) determination of basic part configuration for application to the ME-1 simulator, and (4) development of interconnection system between ME-1 flight coordinate data and runway lighting attachment.

Investigations devoted to the special film projection techniques and of point light sources were primarily concerned with correction of the image for glide path errors. Experience acquired in previous simulation development projects, using various other techniques, had indicated that the projector system proposed by Rucem-Philadelphia and described in Section IX was best suited to this application. The study was therefore concentrated upon determination of its feasibility. Parallax and screen contour effects are particularly important in view of the pilot position desired and the long straight lines presented in which deviations would be easily detected. The relative merits of curved and flat screens were evaluated with regard to both the accuracy and the adequacy or extent of visual presentation.

Attachment of the device to the ME-1 simulator and the pick-off of the coordinate flight data involve the more conventional design problems only. These portions of the study fall logically into place when the basic parameters have been established.

Section II summarizes the essential results of the study program and presents the recommendations of the contractor with regard to the proposed device. Section III through X presents the detailed analysis of the problem and describes the experimental procedures followed in arriving at these recommendations.

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3. Screen Shape

For a single image projection system, it is recommended that a flat screen be used. With this type of screen the distortions in the image are linear and can be minimized to an acceptable amount. The flat screen is capable of azimuth coverage up to 90 degrees (± 45 degrees). This is sufficient to cover the normal field of view through the windshield.

4. Limits of System Variables

Since the specification, WCLEQ 3-17, does not specify the limiting values of the system variables such as the visual field, pitch, roll, and heading, a logical basis for establishing each limit was constructed. It is recommended that the limits given in Section IV be accepted as meeting the requirements of the specifications and the scope of this program.

5. Connection with the ME-1 Flight Simualtor

The only difficulty involved in making electrical and mechanical connections to the ME-1 Flight Simulator is in increasing the length of the electrical cables from the cockpit to the simulator computer racks. This involves considerable labor, which can be performed at this plant.

6. Recommended Procedure

On the basis of these findings, it is recommended that the base of the study contract be broadened sufficiently to permit the analysis of alternative projection systems before contemplation of construction of any hardware. This procedure appears to be in the best interest of the government at this time.

SECTION III

FILM SYSTEM CONCEPT

A. Visual Cues and Landing at Night

The image of the lighted runway as seen from the cockpit of an airplane can take many subtle shapes and orientations. It is these subtleties of shape and orientation which give the experienced pilot information necessary to guide the aircraft to a successful landing. For the purpose of developing a projection system to simulate the instantaneous image of the runway, it will be necessary to resolve these quantities into their major components.

Considering the runway as a flat fixed rectangular plane and the aircraft as a completely free body, the appearance of the runway will be a function of the six degrees of freedom of the aircraft. Let the earth coordinates x,y,z be defined as follows:

x - The distance along the extension of the runway center line.

y - The distance transverse to the runway center line.

z - The distance above the earth's plane (altitude).

When the aircraft is directly on the accepted glide path, the image will be symmetrical with the two sides converging toward one another. The amount of convergence is a direct function of the x distance. The size of the image and the convergence is the major indication of distance to the touchdown point.

The altitude affects mostly the total height of the image in connection with the x distance: if the altitude is zero the image compresses into a straight horizontal line; where the altitude is very high the image is elongated vertically in comparison to the x distance. These two image variables have no absolute references in the aircraft, and the pilot is therefore compelled to resort to memory and experience in judging the altitude and ground distance.

The transverse coordinate, y, affects the symmetry of the image. For distances off the center line of the runway the image is skewed accordingly. This represents an absolute reference for the pilot and consequently can be reduced to zero with average flying skill.

The pitch, heading, and roll degrees of freedom effect the position of the image with respect to the windshield. The rolling motion rotates the image, the heading motion locates the image along the base of the wind shield, and the pitch motion locates the image along the vertical of the windshield. These effects are absolutely referenced in the cockpit, and consequently can be adjusted to exactly the correct values by the skilled pilot.

These six effects represent the basic elements to be simulated by the projection system in connection with the coordinate data generated by the flight simulator and pilot's control motions.

B. Basic Concept of Film Projection

From the preceding discussion it is evident that the six degrees of freedom of the image must be generated in the projector. The advantage of motion picture film is that its length can represent one of the degrees of freedom. In this case the logical choice is that the x coordinate be represented by the length of the film since this changes most in a typical landing. The pitch, roll, and heading motions can be direct and analogous motions of the film projector. That is, the film projector can be mounted on a double gimbal and each axis driven by a direct electrical connection with the roll, pitch, and heading angles developed in the flight simulator. The projected image will then roll and will be displaced in azimuth and elevation in accordance with the pilot's control motions.

The remaining degrees of freedom must be developed in the optical system used to project the image from the film to the screen. That is, the effects on the image due to displacement of the simulated aircraft along the y and z coordinate axes must be developed in the projector by distorting the image on the film in accordance with the geometric requirements. The exact method by which this is accomplished depends on the nature of the image on the film.

To develop the concept of film projection further, the geometry involved in making the individual film frame exposures must be discussed. Consider a point P, on the ideal glide from which the runway is being observed (See Figure 1).

The line connecting the eye point and each individual point on the runway are shown. At the instant represented by Figure 1, there will be a film frame exposed by these rays. The orientation of the film plane with respect to the ground will determine the form of the image on the frame. Of the film frame orientations possible, the one parallel to the earth, and the one normal to the ideal glide path are of interest for study. Examination of the film frame parallel to the earth revelas that the image of the runway on the film is a rectangular pattern exactly equal to the plan view of the runway. This is significant in that no matter what the glide path angle, G, is the image is the same. That is, for example, if G were 90 degrees with the point P directly above the touchdown point, the image on the film would be the same as in the case shown. The same conclusion is arrived at when considering the point P displaced in the Y direction. Therefore, the film frame parallel to the earth is of a universal nature and does not depend on a specific glide path. If the orientation geometry is maintained as shown in the figure and if a lensless projector is used, the projection of the runway image to a screen will be perfectly accomplished with no distortion for any analogous value of x, y, and z.

The runway image on the film frame normal to the glide path is a symmetrical trapezoid with the runway lights grouped close together at the upper end. This image is unique for the particular set of coordinates represented by the point P. Thus, if the glide path angle G were changed to a large value, such as 90 degrees, the image on the film would change extensively. As a result of this characteristic, projection of the film frame by the lensless point light source method will only approximate the true image when the simulated aircraft is off the glide path. That is, in normal operation the film frame corresponding to the instantaneous value of x will be exposed for a specific value of altitude, z, and zero y. The projected image will be true only when the simulated altitude is equal to the film altitude and y is zero. If this is not true, the point light source must be moved relative to the film frame to compensate for the difference in altitude and y. At best this method can only approximate the required change in image geometry over small errors in glide path coordinate.

The advantage of the film frame normal to the glide path over the film frame parallel to the earth is that it will permit light to be transmitted with a minimum of difficulty during projection. That is, since the film frame is perpendicular to the light rays radiated by the point source, the light rays will penetrate the glossy surface of the film and form the image on the screen. In the case of the film frame parallel to the earth's surface, however, the light rays are incident on the glossy film surface at an angle equal to the glide path angle, G, which is generally 3 or 4 degrees. At this low angle of incidence no light ray can penetrate the film surface and must be reflected. Consequently, although the image of the runway would be perfect in theory, no light will reach the screen. Optical techniques are available to obviate this difficulty but lead to difficult design and cumbersome operation.

C. Practical Problems Inherent in Projection Systems

1. Parallaxes

The most convenient place to locate the projector in the trainer is directly above the observer's head. Ideally, the projector optical center should be coincident with the observer's eye point. Since this is impossible, it is necessary to minimize the distance between the observer and projector and to estimate the effect of this parallax on the geometry of the projected image as a function of screen shape. That is, if the parallax distance were zero, the geometry of the image would not change with screen shape or aircraft attitude angles. Under this circumstance the shape of the screen can be chosen to meet other requirements.

The presence of a significant parallax distance, however, will introduce distortions in the projected image of the runway. In addition, these distortions will change as the projector is rotated in heading, pitch and roll. The problem then is to minimize these effects by minimizing the parallax distance, and, more importantly, by choosing the shape of screen which will give least distortion. In the case of a dual projector system, a horizontal parallax exists if the screen surface is curved. The horizontal parallax is a fixed value of two feet for the T-37 cockpit and can not be minimized. This will introduce extremely large distortions in the projected image which will vary as the projector rotates in heading, pitch, and roll. The only screen shape for which the distortion due to horizontal parallax is zero and the distortion due to vertical parallax is minimum is the flat screen. However, because of the effect of polarizing the screen for dual image projection, the spherical screen is necessary. Thus, the flat screen is best for the single projection system, and the spherical shape is needed for the dual projection system.

A concept to be considered in dealing with the parallax distortions is the use of back-projection techniques. That is, consider a system which employs a translucent screen with the projectors located behind the screen and the cockpit on the front side of the screen. If the projectors are as far behind the screen as the observers are in front of the screen, the vertical parallax can be reduced to zero. Obviously, the flat screen is the only shape applicable here. A major difficulty with this system is that it is applicable to a narrow visual field system because of the directivity of the translucent screen and the reflection rather than transmission of light at the back surface at large projection angles. In addition, this system is not adaptable to polaroid techniques because no known translucent screen will retain the polarization of the light waves after transmission.

2. Polarized Light

The only satisfactory method of discriminating between the pilot's and copilot's runway images is by polarized light. However, this system introduces certain deleterious effects on and restrictions of the system performance. The introduction of the transmitting and receiving polariod filters reduces the brightness of the image to 30% of its unpolarized value. This greatly weakens the image which is at best are acceptable in brightness. The acceptability of the resultant brightness can only be evaluated by placing the actual system in service for a length of time.

The polarized light system requires the use of a polarizing screen. Screens of this nature have the characteristic of scattering the incident light without altering the plane of polarization. As a consequence the scattering is not complete and the reflected light retains a directional effect. The resultant effect of the directivity of the reflected light is that an observer will experience a sharp decrease in spot brightness when observing the spot at angle greater than 20 degrees off from the direct ray. At 45 degrees from the direct ray, the spot of light appears to be almost extinguished. A more detailed description of these effects is given in Section VI.

SECTION IV

LIMITS OF PROJECTION

A. Maximum Visual Field

The criterion for setting the maximum limits on the azimuth and elevation angles of the projected image is the visual field allowed by the windshield of the T-37 aircraft. Although an observer can see further from the side of the canopy, the visual field established by the windshield is of importance. On this basis direct measurements from the ME-1 drawing gives the following limits from the straight ahead position:

Azimuth ± 45 degrees,

Elevation ± 30 degrees.

B. Maximum Aircraft Attitude Limits

The ME-1 flight instrument trainer is capable of extreme limits in roll, pitch, and heading attitudes. However, since the aircraft will start initially at the beginning of a landing approach, the limits of these quantities will be a minimum of:

Heading ± 45°

Roll ± 45°

Pitch ± 30°

C. Maximum Coordinates

As given in the specification, the maximum ground range coordinate, x, and altitude, z, will be 30,000 feet and 3,000 feet respectively.

The maximum transverse coordinate, y, error developed in the ME-1 is ± 2000 feet. This should be increased to ± 3000 feet and linearly decreased with the x coordinate.

SECTION V

RUNWAY LIGHTING

The landing strip lighting to be simulated by the Night Landing Trainer is shown in Figure 2. This lighting covers a total of 8,000 feet divided into 3,000 feet of approach lighting and 5,000 feet of runway lighting. It is felt that 5,000 feet, while admittedly a compromise on the suggested 8,000 feet, would be sufficient for training. Once the student pilot reaches 5,000 feet beyond the threshold, the landing is a success or failure. To increase the runway to 8,000 feet would add 37-1/2% to the total lighted distance with the following result: Since the image is limited by a fixed film width, the 37-1/2% increase must be absorbed by the scale factor with a degrading effect on the image resolution.

Approach lighting has been patterned after Figure B of the National Standard on Approach Lighting, dated 20 July 1953. The approach distance is divided into two sections, both marked in Aviation Red Lights.

In order of occurrence, the first section of approach lighting consists of centerline bars, 14 to 20 feet long, at 100-foot intervals along the extended runway centerline. The last bar heading toward the runway is flanked by crossbars so that a total width of 100 feet is illuminated.

The second approach section, called the overrun area, is unsymmetrical in that the left hand units are made up of three lamps covering 14 to 20 feet perpendicular to the runway centerline while the right hand units are single lights. These are placed on 100-foot spacings along a line parallel to, but 100 feet out from, the runway centerline.

The Aviation Green threshold bars separate the overrun area and the runway proper. These are 40 feet long with their innermost edge in line with the overrun lights.

The runway proper is marked by Aviation White lights spaced at 200-foot intervals for 8,000 feet in line with the overrun lights (100 feet off runway center).

All lights stipulated as "bars" must appear as a single linear light when viewed from a distance of 1,500 feet.

SECTION VI

PARALLAX AND SCREEN SHAPE ANALYSIS

A. Vertical Parallax

Figure 3A illustrates the distortion of the image due to vertical parallax and various screen shapes. The lines EA and EB are the rays connecting the far end A and the near end B of the runway with the eye point. Thus, the angle AEB equal to V is the true vertical angle an observer would expect to see the image intercept from this position. If the film has been made without considering parallax, the rays PF and PD emanating from the center of the projector, P, will represent the rays

EA and EB. The projected rays PF and PD will diverge from the projector at an angle equal to V, the angle of the true rays.

From the intersection of these rays and the screen, the parallax distortion for each screen can be plotted and compared. In the case of the flat screen it is seen that PD intersects the screen at D a point considerable below G, the true intersection point. The result is that the observer at E sees a much longer and broader runway.

For the spherical screen, the ray PD intersects the screen at the point C closer to G than D. Thus, the elongation of the image is less than in the case for the flat screen. However, examination of the projected image reveals that straight lines representing the edges of the runway are seen as gentle curves from the eyepoint E (Figure 3B). To summarize, it is seen from the above discussion that both screens cause distortion in the image due to vertical parallax. Distortions due to the flat screen take the form of elongation and broadening of the image. The spherical screen has the same effect on the image to a smaller degree but with the added distortion of curving the image. The distortion of curving the image is by far the most objectionable. At wide angles when the aircraft is about to touchdown, this effect can be so great as to be unacceptable. Although the elongation and broadening of the image is less than for a flat screen, the smallest curvature of the image is easily detected by the observer. The linear distortion (elongation and broadening) due to the flat screen can be reduced by anticipating this effect when making the film. That is, if the film is made by photographing a model runway, an appreciable amount of counter-parallax can be inserted into the geometry.

B. Horizontal Parallax

Figure 4 illustrates the distortion of the image due to horizontal parallax. The points E and E_2 represent the eye points of the first and second observers. The light rays are drawn for only the observer, E_1. The vertical parallax is not seen in this view but is represented by the superposition of points E_1 and P_1 for the first observer and points E_2 and P_2 for the second observer. The ray P_1A and P_2B are the true rays projecting the two lower corners of the image. It is seen that the flat screen has no particular effect because of its shape, whereas the spherical screen, because of the assymmetry, will distort the image more on one side than the other.

C. Effects Due to Polarized Screens

Rays of light incident upon polarized screens will be scattered without altering the plane of polarization. The scattering of the light is not as complete as in the case of ordinary white screen surface. The result is that the scattered rays are grouped together as shown in Figure 5 for the polarized screen. Comparing the two reflective patterns of the figure, it is seen that an observer walking around the point of incidence from right to left will, in the case of the white screen, see the point of incidence at all angles. In the case of the polarized screen, however, the observer will at first barely detect the presence of light at the right. As the point A is approached, the point of incidence becomes progressively brighter. At the point A, the brightness is about 3.5 times brighter than the white screen. Passing beyond the point A to the left, the brightness again declines to a weak value. It is seen that the highest brightness range is in the vicinity of the direct reflected ray direction. Within ± 25 degrees of this direction the brightness is at least as bright as the white screen, while beyond these limits the brightness declines rapidly.

The effect of the directivity pattern is illustrated in Figure 6. Shown is a plan view of a flat screen and a spherical screen with its center at C. The two observers' eye points are E and E_2 with the respective projector centers P_1 and P_2 directly over the eye points. Consider the ray PA emanating from the first projector at P_1. In the case of the flat screen, the ray of light is scattered away from the observer at E_1. If the angle E_1AB is less than 20 degrees, the image will appear bright. However, as the angle increases to the value shown (approximately 90 degrees), image brightness declines to an almost imperceptible value as viewed from E_1.

In the case of the spherical screen, the ray from P_1 is incident at D. The consequent scattering is directed back in the general direction of the observer. In general, the direct reflected ray will be directed at E_2. Consequently, the angle E_1DE_2 is never greater than 20 degrees approximately for the parameters shown. Therefore, the image will always be within the required brightness tolerance.

SECTION VII

LENSLESS PROJECTION AND POINT LIGHT SOURCES

A. Maximum Magnification

Lensless projection techniques generally employ an extremely intense light source and a film transparency upon which the desired angle is fixed. In application, the transparency is placed between the light source and the screen. The rays of light emanating from the light source pass through the film in regions of transparency and are absorbed or blocked in opaque regions. A magnified image of the transparency is thus projected to the screen, with the magnification dependent on the distance from the light source to the film and from the film to the screen. The theoretical advantages of this technique in addition to its simplicity are: (1) regardless of the magnification, the image is always in focus on the screen, and (2) the image is always in focus regardless of the orientation of the film with respect to the lamp and screen.

B. Resolution of Projected Image

Certain practical considerations restrict these theoretical advantages. The strength of the light source in comparison with the area of its radiating surface is the most important consideration, for if a lamp were of sufficient strength to produce a bright enough image and if the area of the radiating surface were infinitely small, the full theoretical performance of lensless projection would be realized. However, real lamps of sufficient strength have an appreciable radiating area. The direct and overall result of this condition is that the maximum magnification of the system is limited. Or, in another sense, the maximum realizable scale factor of the image on the film is limited.

Figure 7 illustrates the operation of a practical lensless projection system. The arc lamp in the left has a finite arc length, x. The film is opaque except for the transparent hole, F_1 F_2 of diameter d. The screen is located a distance V from the film and receives the projected image at $S_1 S_2$ of diameter D. The upper edge A_1 of the arc will project the lowest ray $A_1 F_2 S_2$ through the hole. The lower edge A_2 of the arc will project the upper most ray $A_2 F_1 S_1$ through the hole. The diameter D of the magnified image on the screen is a function of the parameters shown, where $D = d\,(V/u + 1) + x\,(V/u)$. That is, the diameter of the spot is increased by the factor $\frac{V}{u}\,x$ due to finite arc length, x.

The factor V/u in this equation may be defined as the magnification. Thus, if the maximum allowable spot diameter, D, is specified and if the minimum values of d and x are set by the Fresnel effect, the maximum magnification can be computed by $m = (D/d) + x$.

The minimum practical value of d and x are 0.010 and 0.011 inches respectively.

The maximum value of D must be set by the nature of the problem. For example, when the runway is at far range, the spots on the screen are close together. This requires then that the spots be small in diameter so that they can be resolved. Let D equal 1/2 inch at long ranges. When the runway is at close range, the spots are far apart and need not be small. Let D equal 6 inches at short range. Then the maximum allowable long range and short range magnifications are 25 and 300 respectively. These factors are used in Section VIII to determine the geometric dimensional parameters of the two film systems.

The choice of these spot diameters is based on the absolute maximum which will allow sufficient clearance between spots to represent the area between runway lights. In reality, the runway lights will appear as infinitely small points at all ranges up to touchdown. At touchdown and ground roll, the real runway lights will subtend very small angular area with respect to the pilot's eye. In comparison with the large angles subtended by the spot sizes given above, it is seen that the projected image of the runway is only an illusion in which luminous spots are formed on the screen in a pattern analogous to the pattern formed by the points of the true scene.

C. Projection Lamps

Lamps used in lensless projection systems are usually of the electric arc type in which large electric currents form a small but intensely luminous arc between two electrodes. The total amount of light radiated from the arc determines the candle power of the lamp. By definition, the candle power of a lamp is equal to the lumens radiated divided by 4   for an omnidirectional radiation. If the luminous radiation favors one direction, the candle power is greater in that direction.

Intrinsic brightness of a lamp is the ratio of the candle power to the area of the radiating arc. Thus, if a lamp is of 400 candle power and the arc is 2 millimeter square, the intrinsic brightness is 100 candle power per square millimeter. The parameters of lensless projection systems depend to great extent upon the intrinsic brightness of the lamp to be used. For example, the maximum allowable magnification is inversely proportion to the diameter of the light source. If the diameter were zero, the magnification would be limited only by the Fresnel effects, the ideal operating condition. However, the smallest light source of domestic make with the highest possible intrinsic brightness is the high pressure short mercury arc.

These lamps are sold in large sizes and rated at 500 candle power per square millimeter. The smallest lamp made is 1000 watts with an arc length of 3 millimeter. This is much too large for instrument applications, and must be reduced in scale by demagnification. Figure 8 illustrates the optical technique used to demagnify the electric arc. The glass bulb is silvered on the left side in order to double the intrinsic brightness of the arc in the direction of the optical system. This increases the intrinsic brightness to 1000 candle power per square millimeter. The copy lens images the arc in space with a magnification of unity. The objective lens then refocuses the space image of the arc to a diameter of 0.011 inches and a resultant candle power of 100. The objective lens is a low power microscope objective which is optically corrected for an application such as this. With this type of lens, the rays of light forming the demagnified image of the arc diverge at an angle greater than 90 degrees, which is required for wide angle projection.

SECTION VIII

GLIDE PATH IMAGE CORRECTIONS

A. Corrections for Glide Path Errors

The element of major importance in the projection system is the simulation of image changes due to the aircraft being off course in its glide path. If the aircraft is too high or too low in altitude for a given ground range to touchdown, the image should be elongated or compressed accordingly. Likewise, if the aircraft is to the right or left of the runway centerline, the image should skew to the right or left respectively. In order to create these effects with photographic film projection, it is necessary to obviate the fixed optics of ordinary projectors and substitute the free and flexible lensless projection technique. Two types of film geometry were considered for this purpose, and the major difficulties of each are presented below.

1. Film Frame Normal to the Glide Path

In this system the plane of the film frame is oriented normal to the glide path during exposure. Each film frame represents a discrete point along the ideal glide path. The resultant image on each frame is an array of transparent spots surrounded by an opaque area. The dots represent each light on the runway and approach, and form a symmetrical trapezoid pattern.

To simulate the effects of glide path errors (altitude and off-centerline errors), it is necessary to change the geometry of projection. That is, when the simulated aircraft is on the proper glide path, the projector elements are in their normal positions and the projected image is normal. When the simulated aircraft develops glide path errors, it is necessary to move the projector elements relative to one another in order to simulate the changes in the image.

One method of accomplishing this would be to move the whole projector great distances in the space about the cockpit. To be in accord with the scope of this program and to achieve wide angle projection; however, it is necessary to hold the projector fixed in space except for rotations about its own center. Therefore, the alternative course of action is to develop subtle motion within the optical elements of the projector.

The simplest motions possible which could be analogous to the two glide path errors are shown in Figure 9. Rotation of the film frame about the horizontal axis could be analogous to altitude error. That is, if the simulated altitude is lower than the ideal altitude, the vertical size of the image must be compressed. In Figure 9A, the image on the film frame is represented by the arrow. This is projected to the arrow on the screen. If the arrow head is rotated to the right, the angle intercepted by the light rays will be smaller and the image on the screen will be compressed. Although the compression is not perfect for all points, the major effect, that of compressing the image, is accomplished.

On the other hand, if the altitude is too high, the image of the runway must be elongated. This is not accomplished in the system of Figure 9 unless certain changes are made in the initial film character. Instead of exposing the film frames along the ideal glide path, the path of exposure is chosen twice that of the ideal glide path. This will represent a constant bias angle in the system. Thus, if no simulated altitude error exists during projection, the film frame will be rotated to the left to correct the image. Now, if the simulated aircraft should develop an altitude greater than the ideal glide path, the film frame can be rotated to the left. This will produce the desired effect of elongating the projected image.

Figure 9B illustrates a method of skewing the image for off-runway centerline error in the simulated aircraft position. The film frame is rotated about the vertical axis clockwise or counterclockwise for a left or right runway centerline error. This will cause some skewing of the trapezoidal image because the vertical axis of rotation is not in the plane of the film. While the skewing is not as great as need be, no improvement can be made in this effect without changing the film geometry completely. A film geometry of this nature is considered below.

2. Film Frame Parallel to Runway Plane

In this system the plane of the film frame is parallel to the plane of the runway. The film and the light source are directly analogous to the runway and pilot observer. The image on the film is a scaled down plan view of the runway and the position of the projecting light source with respect to the film frame is directly analogous to the simulated aircraft in space.

Figure 10 illustrates the geometry of projection of this system. In the side view (A), it is seen that the distance of the lamp above the plane of the film is analogous to the instantaneous altitude of the simulated aircraft. This distance is equal to the simulated altitude divided by the scale factor of the runway image on the film. The distance of the lamp from the touchdown point on the film is equal to the ground range divided by the scale factor. In the plan view (B), the indicated motion of the lamp is analogous to the distance off the centerline of the simulated aircraft.

This system will yield a perfect image of the runway but is impractical because of the size of the film and the surface reflectivity. Because the maximum magnification is limited, the size of the image of the film frame cannot be smaller than 32 inches long and 6.8 inches wide. The normal mechanisms used in motion picture projectors cannot be adapted to this size of film. Indeed, because the film frame is so large, it is advisable not to change range by discreet film frames, but to have one single frame and move the lamp toward the film to simulate decreasing ground range. However, this would lead to one extremely complex and expensive projector.

The surface reflectivity of the film will not permit transmission of the light under ordinary circumstances. In order to obviate this difficulty two thick plates of glass must be used. The glass plates would be as long and several times wider than the film. The glass plates should be placed one on top of the other with the film in between. The glass will then provide a medium for transmitting the light through the film. The addition of the glass blocks further complicates the system.

8. Summary of Lensless Projection

Using the film frame normal to the glide path type of projection system would result in the simplest mechanical projector. However, the correction of the glide path error would be imperfect and insufficient in magnitude. On the other hand, using the film frame parallel to the runway type of projection system would result in a single film frame projector. The resultant mechanical complications make the projector prohibitively expensive.

SECTION IX

RUNWAY LIGHTING ATTACHMENT CONFIGURATION

The basic arrangement chosen for the night landing trainer is shown in figures 11, 12, 13 and 14 and places the cockpit in a light tight enclosure, one surface of which comprises the projection screen. The total space required is an area 30 by 30 feet including enclosure bracing and simulator cabinet access space. Since this access is required on both sides of the simulator cabinets, the cockpit must be shifted out to provide sufficient clearance for the light tight enclosure. This requires additional wire duct and cable to cover about six more feet, plus an air duct connecting the cockpit air conditioner to the area outside the enclosure.

The light tight enclosure is constructed of plywood panels in an aluminum frame. These panels, of standard plywood sizes, are bolted together through the aluminum frame with the plywood facing inside. The roof of the enclosure is made from canvas. The panel bases are fitted with leveling fittings, to compensate for any floor irregularities, and plastic gasketing for light leaks. Access to the enclosure is by a door in the rear by the pilot's side of the cockpit.

Two screen types are shown; a flat figures 11 and 12 screen and a segment of a sphere, figures 13 and 14. Both take approximately the same setup space, although the enclosed area of the spherical type is quite less. The flat screen is for single projector application and the spherical type for dual projection polarized applications.

The spherical screen is of fiberglass impregnated with polyester resin construction with a 10 foot inside radius. It is horizontally symmetrical in front of the cockpit and is centered about a point 18 inches above the middle of a line connecting the pilot and copilot's eyes. The aluminized screen surface covers a total of 90° in the horizontal direction and 30° above and 30° below the horizontal plane. This gives an enclosure ceiling height of 12 feet.

The flat screen utilizes the plywood panels, suitably braced to support a regular white matte projection screen 14 feet high by 20 feet wide. This is held taut by lacing around the edge to a rigid frame. The flat screen is centered about the projector pivot point at a perpendicular distance of 10 feet.

The pylon straddles the rear of the cockpit. Its prime function is to support the projector, although the base is convenient for housing the electronic rollouts and projector power supply. The structural members of the pylon support the projector by means of bearings carrying the roll axis shaft. This shaft is located parallel to and 36 inches above the pilot's forward visual axis. The pitch axis and yaw axis intersect the roll axis at a point directly over the pilot's eyes. These three axes are the basis of a gimbal ring giving the three angular motions to the projector. The screen area and projector-to-pilot distance are both dictated by the magnitude of these angles which are given in section IV. It is desirable to place the projector center as close as practical to the pilot's eye. However, the combination of these motions limits this vertical parallax distance to a minimum of 36 inches.

The electronic units housed in the pylon consist of the servo amplifiers and power supplies necessary to control the projector.

SECTION X

INTERCONNECTION WITH ME-1 FLIGHT INSTRUMENT SIMULATOR

The signals required by the Runway Lighting Attachment are electrical analogue data representing the simulated aircraft's flight. The data specifically required are pitch, roll, and heading displacement coordinates with respect to the runway, and glide path errors (up-down, left-right). Although the ME-1 Flight Instrument Simulator was not designed to supply data signals to the visual attachment, no particular difficulty will be experienced to accomodate this requirement. Some mechanical changes, such as the addition of synchro transmitters to some of the computer shafts will have to be applied to the ME-1. Electrically, the only changes will be the addition of wires to conduct the data signal to the runway lighting attachment. The required data and necessary adaptation to the ME-1 is given in the following paragraphs.

A. Displacement Coordinates

Figure 15 illustrates the ground coordinate system used in the ME-1. The range of the coordinates are 56 miles true north and 56 miles true east. The runway is arbitratilly placed in this area by locating the localizer station, S, at some point given by x and y in the figure.

At the point S, the magnetic north direction is arbitrarily chosen to establish the magnetic coordinate xm and ym. The simulated aircraft is made to fly in the magnetic coordinate system. The simulator has available voltages representing true north coordinates x, y, and true magnetic coordinates xm, ym.

The Runway Lighting Attachment requires coordinate data referenced to the runway center line. In the figure the point P represents the instantaneous position of the aircraft projected into the ground plane. This position is given in the required coordinate system with respect to the localizer station S, by the coordinates x_r and y_r, where x_r is the distance along the runway center line from the station S to the projection of P into the centerline, and y_r is the normal distance from the centerline to the point P. In ME-1 nomenclature, the coordinate x_r is designated as the range R, and the coordinate y_r is designated as the path error E. The limiting value of E is ± 2000 feet. These data are available as dc voltages proportional to the respective distances. These signals can be conducted directly into the x_r and y_r servo systems of the Runway Lighting Attachment.

B. Altitude Data

Altitude data required are the instantaneous altitude above the field and the glide altitude as a function of x_r. The altitude above the field is available as the dc output of the altitude potentiometer. The glide altitude as a function of x_r is available as a dc signal from a buffer amplifier. These signals can be directly conducted to the altitude servo of the Runway Lighting Attachment.

C. Pitch, Roll, and Heading

The pitch angle data is available as a dc signal from an electronic integrator within the ME-1. The signal is conducted to the pitch servo of the Runway Lighting Attachment.

Roll and Heading data are available as mechanical shaft positions in the roll and heading servos of the ME-1. The presently installed synchro transmitters are capable of driving one more control transformer each in addition to the present load. These control transformers are to be the follow-up devices on the roll and heading servos of the Runway Lighting Attachment. The synchro roll and heading data must be conducted from the ME-1 to the respective control transformers in Runway Lighting Attachment.

D. Reference Signals

Reference signals for both ac and dc operation will be conducted to the Runway Lighting Attachment.

SECTION XI

SUMMARY

The preceding sections have described the extent and direction of the Night Landing Simulator study program to date. Also presented are the results of the experimental development and analysis, as well as the methods and techniques employed.

The study program was pursued within the scope established by the applicable Exhibit, WCLEQ 3-17, and the scope of the contract. Results and recommendations presented are based upon careful application of accepted scientific principles.

The fundamental conclusion to be drawn from this study is that film presentation methods are not suited for the student-participation type of training device. Even though fairly complex projection techniques are employed to improve the inherent limitations of strip film with regard to aspect and perspective in the image, the amount of flexibility gained thereby is not sufficient to provide positive training in the task. For example, it is not possible to make landing procedure turns in a visual simulation device using strip film, unless the turn is programmed into the initial production of the film. Furthermore, it is not possible to deviate from the glide path by more than approximately 6° before serious difficulties are encountered in the quality of image.

Studies conducted recently at Aero Medical Laboratories at WADC have shown that the confusion created on the part of the student in trying to resolve the changes in image due to changes in aircraft bank angle as compared to changes due to spatial displacement from the glidepath, is so severe that negative training is produced.

In the light of all these considerations, this contractor feels that no recommendation for use of film presentation methods can be made. Instead, it is felt that an alternate method soon to be proposed will solve this problem in the best interests of the government.