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Black hole landings : the effects of form ratio and runway marking cues on glide slope control

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Black Hole Landings: The Effects of Form Ratio and Runway Marking Cues on Glide Slope Control

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ABSTRACT

BLACK HOLE LANDINGS: THE EFFECTS OF FORM RATIO AND RUNWAY MARKING CUES ON GLIDE SLOPE CONTROL

by Martin F. J. Schwirzke

This thesis investigated the ability of pilots and nonpilots to utilize depictions of a runway form ratio image and a runway marking scheme to acquire and maintain a constant 3° glide slope under black hole conditions. Black hole conditions occur at night, when few visual cues are available in the runway scene during a visual approach.

An effect of runway size was apparent across all factors. Relative to a constant 3° glide slope, subjects acquired a higher glide slope to the shorter runways than to the longer runways. Pilots and nonpilots could not reliably use form ratio approach plates or runway markings as visual cues for glide slope control. In addition, the glide slopes generated by the pilots and nonpilots were complex curvilinear functions. These findings provide additional evidence that suggests glide slope is difficult to control under black hole conditions.

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Black Hole Landings: The Effects of Form Ratio and Runway Marking Cues on Glide Slope Control

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Running head: BLACK HOLE LANDINGS

Footnotes

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Abstract

This thesis investigated the ability of pilots and nonpilots to utilize depictions of a runway form ratio image and a runway marking scheme to acquire and maintain a constant 3° glide slope under black hole conditions. Black hole conditions occur at night, when few visual cues are available in the runway scene during a visual approach. An effect of runway size was apparent across all factors. Relative to a constant 3° glide slope, subjects acquired a higher glide slope to the shorter runways than to the longer runways. Pilots and nonpilots could not reliably use form ratio approach plates or runway markings as visual cues for glide slope control. In addition, the glide slopes generated by the pilots and nonpilots were complex curvilinear functions. These findings provide additional evidence that suggests glide slope is difficult to control under black hole conditions.

Black Hole Landings: The Effects of Form Ratio and Runway Marking Cues on Glide Slope Control

The purpose of this thesis is to examine the ability of pilots and nonpilots to use the form ratio depictions of a runway image and runway markings as visual cues in the acquisition and maintenance of a constant 3° glide slope. Glide slope is the angular declination of the intended touch-down point (relative to the horizontal) below the observer's location on the glide path (see Figure 1).

Investigations of the effects of reduced visual information during night landings (e.g., only runway lights visible) on pilots' perception of glide slope were initially conducted in the 1950's (Cocquyt, 1953; Lane & Cumming, 1956). Investigating commercial aviation accidents, Cocquyt concluded that many night landing incidents were the direct result of visual illusions (e.g., a false horizon) produced in the runway scene. Lane and Cumming surveyed Australian pilot opinions and practices on the approach to landing. They reported that the only visual cue given in instruction manuals on flight training for glide slope control during night landings was the separation of runway lights. That is, if the distance between the runway lights appeared equidistant, then the glide slope was correct. Yet, using this visual cue was deemed vague and unreliable since it was dependent on glide slope, brightness of the runway lights, and the linear separation between the runway lights (the amount of linear separation between runway lights had not been standardized).

In more recent investigations, some of the visual cues that have been examined include linear perspective (Mertens & Lewis, 1982; Naish, 1971) and form ratio (Braunstein, 1976; Johnson, unpublished; Mertens, 1981). Linear perspective can be defined as "the magnitude of the base angles of the trapezoidal runway image when the pilot's eye is

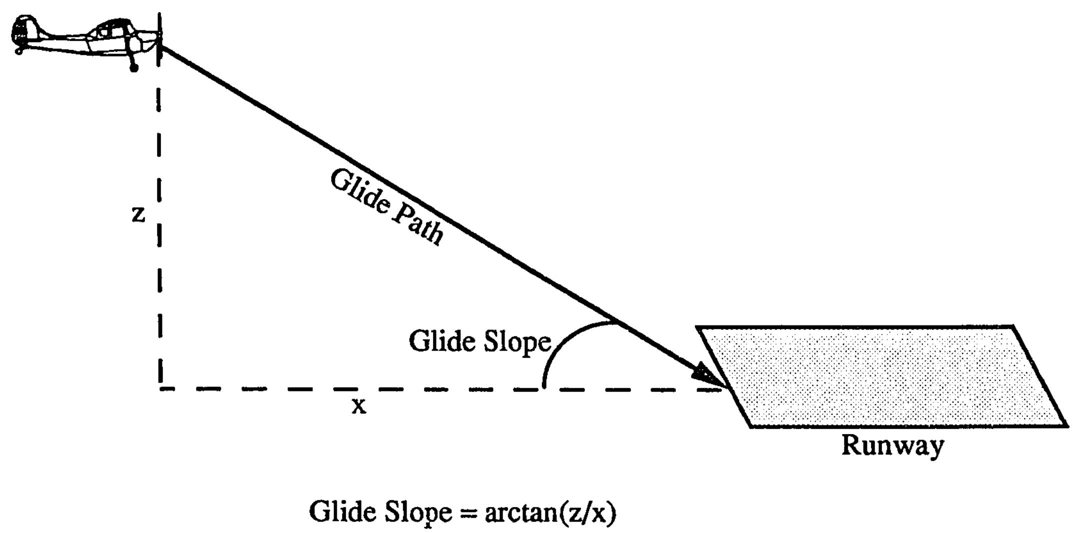

Figure 1. Definition of glide slope.

aligned with the extended centerline" (Mertens & Lewis, 1982, p. 469). Form ratio, based on the runway optical image, is the ratio of projected runway length to projected runway end width. Currently, it is not clear whether these cues can provide a pilot with useful glide slope information, especially on approach to an unfamiliar "black hole" runway.

The Black Hole Phenomena

During the approach phase, a pilot may encounter a potentially dangerous landing situation, namely black hole conditions (AOPA Air Safety Foundation, 1990). Black hole conditions occur at night, when few visual cues are available in the external environment. A visual flight rules (VFR) approach to a lit runway, without a visible horizon, and surrounded by dark terrain or water is an example of a black hole landing (Schwirzke & Bennett, 1991).

Kraft and Elworth (1969) provided an explanation for black hole landing accidents. They hypothesized that pilots maintain the visual angle subtending the runway at a constant value. Adopting a constant visual angle approach produces a "low-in-the-middle" or curvilinear glide path, and a low final approach. Alternatively, Perrone (1984) proposed that low approaches during black hole landings result from inadequate scaling information in the runway scene, making it difficult to use the runway perspective gradient for reliable glide slope estimation.

Additional evidence supports Kraft and Elworth's and Perrone's findings that pilots may overestimate their approach angle to the runway as a result of degraded visual conditions, and fly a lower than expected glide slope (Bennett, Schwirzke, & Tittle, 1990; Kraft, 1978; Lintern & Walker, 1989; Mertens, 1978, 1981; Mertens & Lewis 1982, 1983). Maintaining such a glide slope would result in dangerously low approach altitudes and consequently increase the risk of collision into terrain short of the runway threshold.

Visual Glide Slope Indicators. The visual glide slope indicator can be used to locate an aircraft's position in relation to a specific glide slope to the runway. One such system, the Visual Approach Slope Indicator (VASI), is the most commonly used lighting system (see Figure 2). A VASI may contain two or three light bars, depending on the size of the airport. These bars are linearly arranged, parallel to the side of the runway. In the case of the two bar system, the bars are referred to as the near bar and the far bar. The lights contained in these bars are either red or white, depending on the aircraft's approach angle. If both light bars are red, the glide slope is too low; if both light bars are white, the glide slope is too high. When the near bar is white and the far bar is red, the glide slope is correct. The glide slope is usually set at 3° on the VASI.

The Precision Approach Path Indicator (PAPI) is another glide slope indicator system (see Figure 3). This system is more precise in indicating to the pilot the aircraft's location along a 3° glide slope, and utilizes only one set of lights (Horonjeff & McKelvey, 1983). Two or four lights are installed in a linear arrangement, perpendicular to the left side of the runway. In the four-light configuration, if all the lights are red, the glide slope is low; if all the lights are white, the glide slope is high. The correct glide slope is indicated when both lights on the right are red, and both lights on the left are white.

These visual glide slope indicators are helpful in maintaining a constant 3° glide slope approach to a runway, especially under black hole conditions. Yet, these systems are not readily available at all airports due to the expense of the system and the constraints of small airport design. For example, a simple two-bar VASI system, purchased for a general aviation airport application, costs approximately $20,000. This does not include power

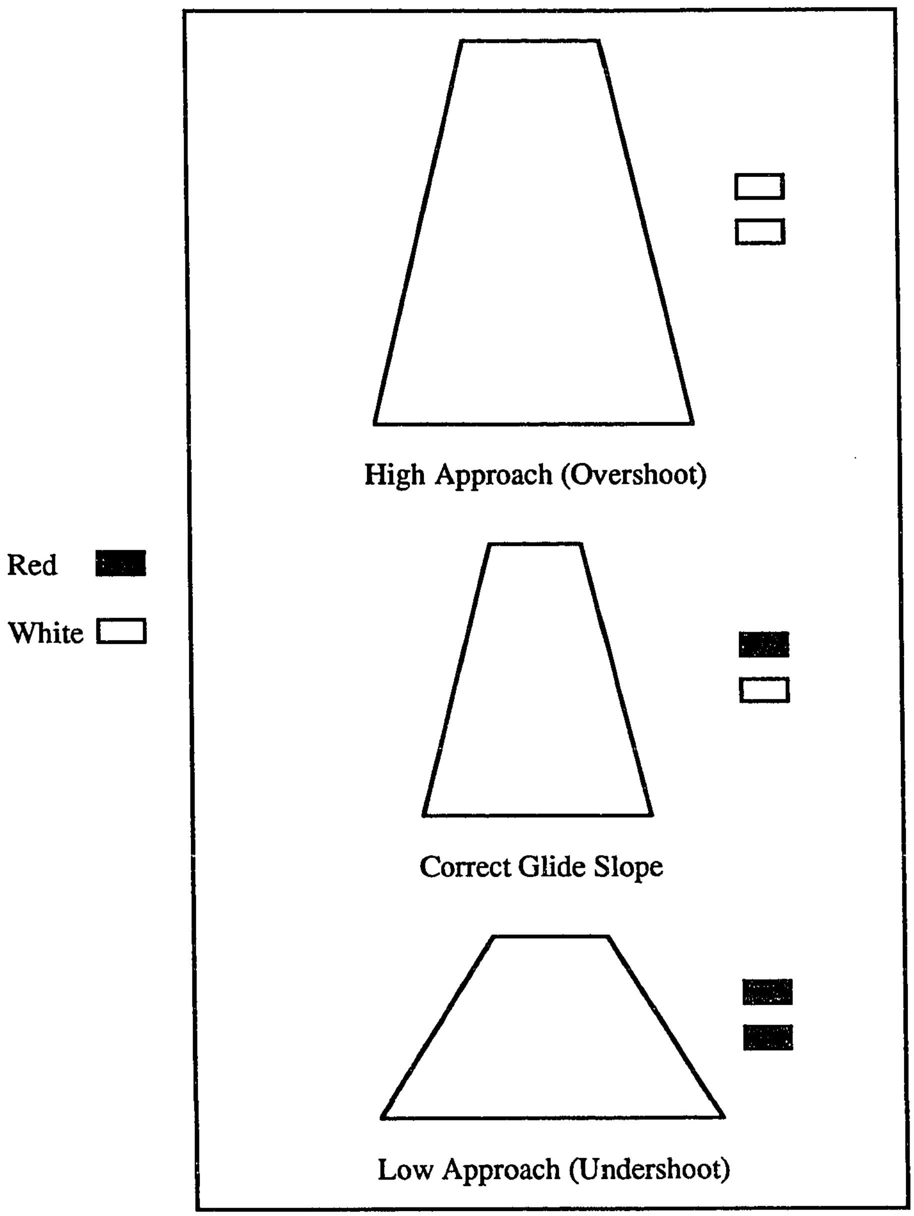

Figure 2. VASI (Visual Approach Slope Indicator) configuration.

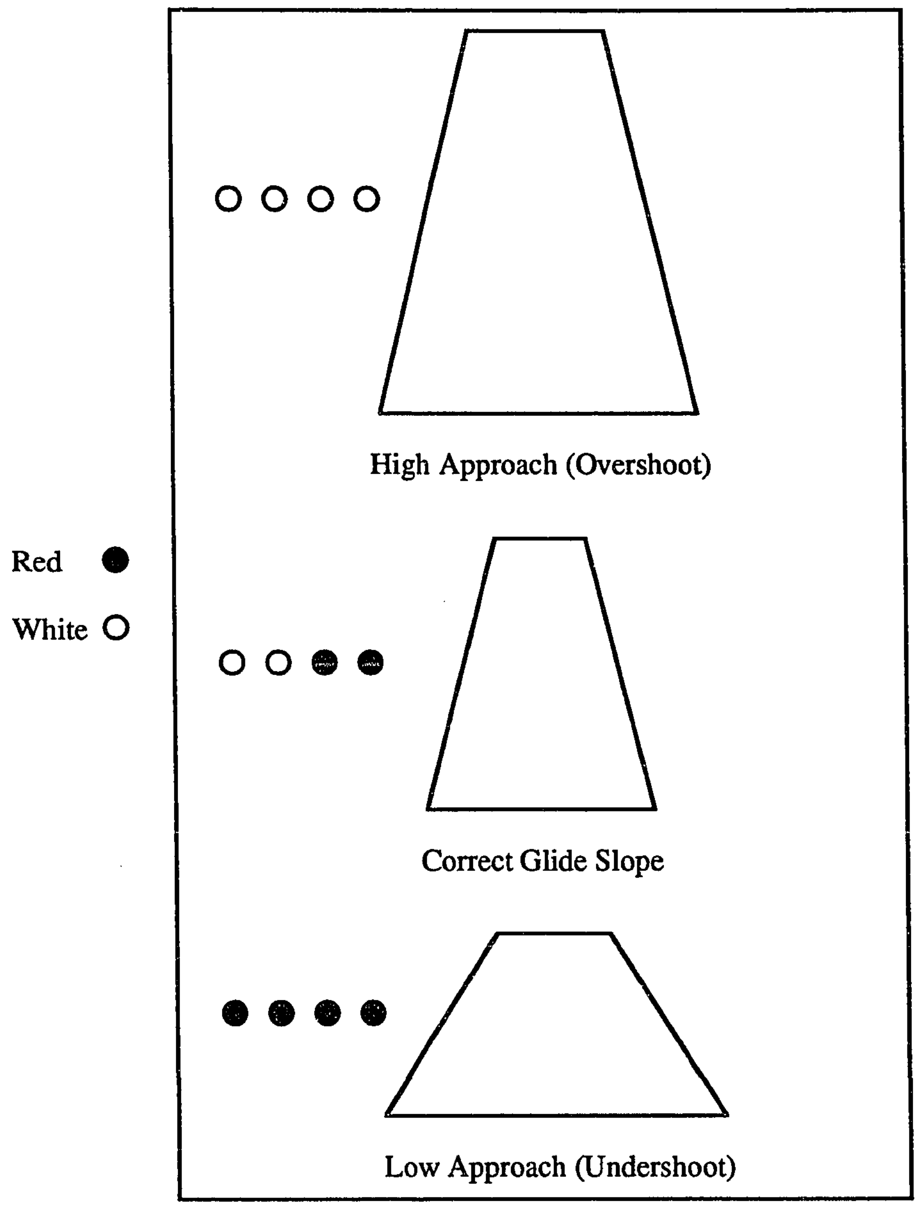

Figure 3. PAPI (Precision Approach Path Indicator) configuration.

hook-up or installation, which can cost approximately $60,000 (Hopkins, 1992). As a result, the hazards inherent in black hole landings still exist (AOPA Air Safety Foundation, 1990).

Sources Of Glide Slope Information

Linear Perspective. In accordance with the visual cue of linear perspective, a runway appears to the observer as an image with a set of lines receding in depth and converging at the horizon (Cutting, 1986; Riordan, 1974). In a mathematical analysis of the utility of runway features for flight path control, Naish (1971) derived quantitative optical equations relating the observer's position and motion, and perspective runway geometry. One cue, inclination of a ground line, is defined as inclination of the optical projection of a runway edge or centerline with respect to the vertical (see Figure 4). Naish found that ground line inclination can be used for lateral control by a pilot. At a constant distance from the runway, "apparent inclination of the ground line increases with the lateral offset of the observer..." (Naish, 1971, p. 168). Thus a pilot simply has to keep this inclination as small as possible. Alternatively, this inclination decreases with increases in the observer's altitude. However, vertical control is more difficult to assess than lateral control since it requires estimating the actual value of this inclination and then converting it into an altitude estimate.

A second cue, focus of expansion, is available through transformation of the runway outline as the observer approaches an aimpoint on the runway. This cue overlaps and, thus, specifies this aimpoint. However, subthreshold angular velocities of the runway elements, usually at distances in excess of 0.5 miles from the runway threshold, only support a crude estimation of the point of impact. In addition, Naish suggests that lateral

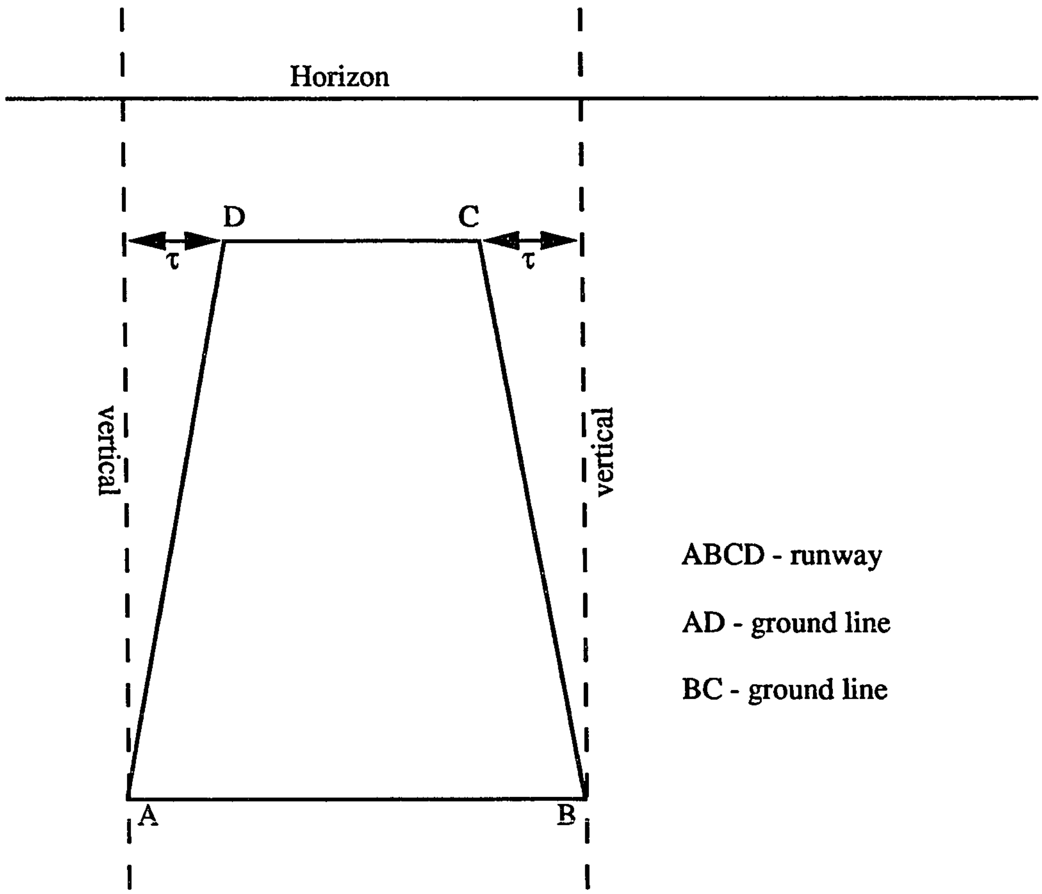

Figure 4. Definition of the inclination of a ground line. The runway perspective is based on an observer's view of a runway during a straight-on approach. The inclination of ground lines AD and BC are at an angle tau (τ).

and vertical control of the glide slope path using alignment mechanisms (e.g., inclination of a ground line and runway expansion) is also generally unreliable.

Mertens and Lewis (1982) provided additional evidence that suggests perspective cues do not provide adequate information for accurate visual perception of approach angle (glide slope). They had pilots fly simulated visual nighttime approaches in a fixed-base simulator to runways that ranged from 100 to 300 ft wide and from 3,000 to 9,000 ft long. The aircraft's generated flight path (altitude, distance, and heading) was recorded for each pilot.

Mertens and Lewis found the generated approach angles to the runway scenes were extremely variable within and between the pilots. As the ratio of runway length to width increased, the approach angles decreased on average. Also, giving pilots the runway dimensions prior to each flight did not affect approach angle performance. These data support the conclusion that the approach angles generated by the pilots are inconsistent and biased when using perspective cues (e.g., runway light separation and base angles) for visual approach information.

Form Ratio. Langewiesche (1944) advocated using the degree of foreshortening of the runway relative to the approach angle as a night visual approach cue. In aviation human factors, the cue is also known as form ratio (Braunstein, 1976; Mertens, 1981). Form ratio (see Figure 5) is defined as "the ratio of vertical height of the runway to width of the far end in the runway retinal image" (Mertens, 1981, p. 373).

Form ratio is an optical variable which informs the observer about the structure of the environment and the observer's relative location within that environment. The form ratio of a runway can be calculated using the equation:

$$\text{Form ratio} = \tan\theta(L/W)$$

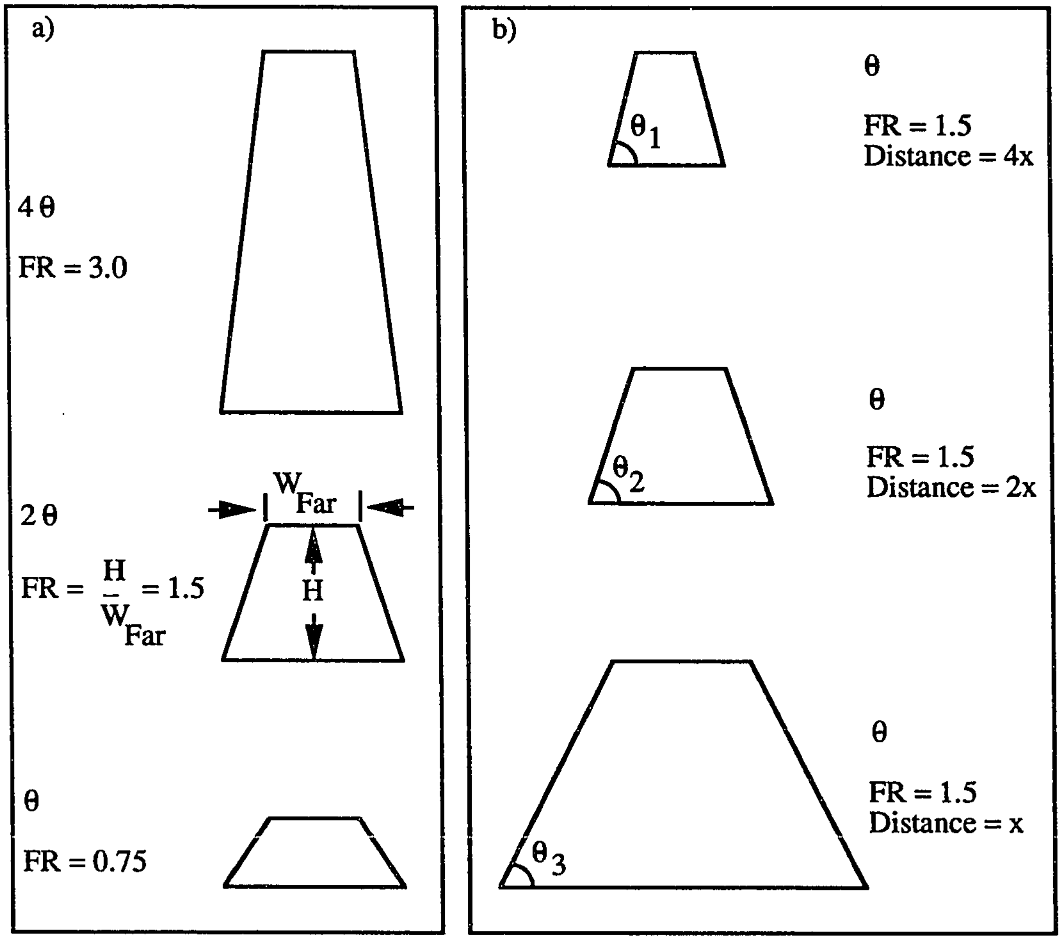

Figure 5. Definition of form ratio. a) Form ratio (FR) varies with approach angles as approach angles vary from θ to 4θ, and b) for a constant approach angle θ, form ratio remains constant as distance varies between x and 4x. Note. Adapated from "Perception of Runway Image Shape and Approach Angle Magnitude by Pilots in Simulated Night Landing Approaches" by H. W. Mertens, 1981, Aviation, Space, and Environmental Medicine, 52, p. 374.

The form ratio of a runway is equivalent to the tangent of the approach angle (θ) multiplied by the product of runway length (L) divided by runway width (W). The runway image transforms as the observer approaches the runway, changing the optical length and width of the runway image. Yet, by maintaining a constant form ratio of the runway image, the observer can maintain a constant approach angle. For additional information on the quantitative relationship between form ratio and the visual geometry of the runway during approach, see Appendix B.

Mertens (1981) examined the ability of pilots to make form ratio judgments using the runway image as a visual cue. Merten's interest in form ratio was based on its "simple relationship to approach angle, distance, runway size, and geographic slant of the runway, and because it is a potential cue in the critical nighttime 'black hole' situation..." (p. 373-374).

A physical model was constructed to simulate a 170 ft x 6,000 ft runway with strobe lights, and this model could be slanted in the vertical plane (Mertens, 1977). Simulated approach angles ranged from 0.3° to 10.7°, at intervals of 0.29°. Form ratios varied from 0.18 to 6.54. Pilots were asked to give verbal estimates of form ratio and approach angle after each simulated approach to the runway model.

There were substantial errors in the estimated form ratios. Subjects overestimated the stimulus form ratio in all conditions, inviting dangerously low glide slope approaches. Approach angle judgments were also inconsistent with the actual approach angle. Actual approach angles between 0.9° and 10.0° occasionally produced approach angle estimations of 3°. Mertens found that verbal estimates of visual form ratio were not predictive of the verbal estimates of approach angle. Therefore these could not aid in the approach angle estimates.

The effect of runway size on approach angle performance was investigated by Mertens and Lewis (1982). They hypothesized that approaches to runways of different widths and constant lengths would yield increasing approach angles as a function of runway width (Wulfeck, Weisz, & Raben, 1958).

Three male pilots flew 20 practice and an additional 20 experimental simulated visual approaches to a runway of a constant length (8,000 ft) and either 75, 150 or 300 ft wide. The subjects were required to fly a 3° glide slope approach and touch-down 1000 ft beyond the runway threshold. The generated approach angle was recorded as the dependent variable. Approaches to a narrow (75 ft) practice runway raised approach angles to subsequently wider test runways. Conversely, approaches to a wide (300 ft) practice runway lowered the generated approach angle to a narrow test runway. The closer the distance to the runway threshold, the greater the magnitude of the runway width practice effect.

Johnson (unpublished) examined the effects of different optical landing pad form ratios on the acquisition and maintenance of requested glide slopes. Subjects were asked to actively fly a 9°, 12°, or 15° glide slope approach to a landing pad, under simulated "black hole" conditions (no horizon was visible). The landing pad dimensions and assigned glide slope were varied randomly across trials. Based on his results, Johnson concluded that runway form ratio is a more salient cue than runway optical length in glide slope acquisition. Yet, these findings did not show form ratio to be the only information used in adopting an assigned glide slope since subjects did not generate a glide slope that reflected a single form ratio across all pad ratios. This suggests that other optical cues also influenced glide slope control. In conclusion, Johnson's results reflected the use of other unspecified optical cues in glide slope acquisition.

The Present Study

In this thesis, both form ratio depictions and runway markings were examined as potential glide slope control aids. Specifically, the utility of form ratio depictions and runway markings in the acquisition and maintenance of a constant 3° glide slope were investigated. These visual aids were designed to assist pilots attempting to land at an unfamiliar runway under black hole conditions. The advantage of utilizing these visual aids was their simple and economical design. A 3° approach angle was used in this study, as this is the standard approach angle recommended for fixed-wing aircraft on final approach (AOPA Air Safety Foundation, 1990; Boeing, 1975; Davies, 1967).

In a departure from previous research, the ability of subjects to use form ratio as a visual cue in glide slope control was evaluated using form ratio approach plates. Each approach plate (see Appendix C) contained a white paper runway image that had a specific form ratio (i.e., 1.0, 2.0, or 3.0), mounted on a black paper background. Each form ratio corresponded to that seen on a 3° glide slope approach at a constant distance from a runway threshold. By keeping the form ratio of the runway image on the projection screen identical to the runway form ratio provided on the approach plate, this cue may be used to acquire and maintain a constant 3° glide slope.

The runway marking manipulation was modeled after "runway-remaining lights" currently used at some airports. Runway-remaining lights are comprised of red runway edge and end lights that are incorporated on the last half, or last 2,000 feet, of the runway (depending on which distance is less) to inform pilots of the amount of runway remaining (Jeppesen Sanderson, 1990). The runway marking stimulus contains red lights integrated into the last half of the runway (see Appendix D). Since runway scaling information for glide slope control may be inadequate in a traditional runway light configuration, adding a runway marking that divides the runway length into two equal segments may provide additional scaling information.

The questions to be examined are: (a) Will runway size (i.e., length) have an effect on glide slope control? (b) Can subjects use approach plates as a visual cue in the acquisition and maintenance of a constant glide slope? (c) Can runway markings, providing more salient scaling information through modified runway light patterns, be used as supplemental information for glide slope control? (d) Will approaches generated by the subjects be low-in-the-middle?

Methods

Subjects

Twenty-four right-handed, male subjects between the ages of 18 and 40 participated in this study. Twelve subjects were general aviation pilots with a minimum of 125 total flight hours and a current instrument (IFR) rating. The remaining twelve subjects were nonpilots. Normal vision (20/20), or vision correctable to 20/20 vision was required. All participants were recruited and paid by Bionetics Corporation at NASA Ames Research Center. The treatment of the participants was in accordance with the ethical standards of NASA Ames Research Center and the San Jose State University Institutional Review Board.

Apparatus

The study was conducted at the Human Performance Research Facility at NASA Ames Research Center. The simulation was presented on a 183 cm high x 244 cm wide rear projection screen (see Appendix E). The metal screen frame and white laboratory walls were blacked out with black cloth, in order to minimize projection light reflection. The subjects sat in a chair with their eyes approximately 230 cm from the center of the screen. The visual angle of the screen in relation to the position of the subject was 43.6° (vertical) and 56.1° (horizontal).

The visual display and data collection was regulated at 30 Hz by a Silicon Graphics IRIS 3130 Workstation. An Electrohome projector (Model No. 38-B09880-71) projected the 768 x 1024 pixel image on the display screen. The dimensions of each runway image at the point of nominal glide slope acquisition are given in Table 1.

Due to the display limitations of projecting a runway image on a two-dimensional screen (Wickens, Todd, & Seidler, 1989), and to facilitate comparison with prior research (Kraft 1969, 1978; Mertens, 1981), subjects were required to keep their eyes fixed on the runway image while using a head rest.

The approach plates containing the runway figures were placed in a black binder that was mounted on a stand, directly in front of the seated subject at a height of approximately 60 cm from the ground. Each 9.0" x 11.0" paper approach plate was comprised of a black background and a white runway image (see Appendix C). Illumination of the approach plates was provided by a Maglite flashlight (3 volt). A red filter affixed to the flashlight allowed the subject to remain dark-adapted throughout each session.

The subject actively controlled the rate of change of the glide slope and the craft airspeed using a right-handed, spring-centered joystick. The pitch angle of the craft remained constant. To change the glide slope of the simulated craft, the stick had to be deflected. The rate of change in glide slope was then proportional to the amount of stick

Table 1

Runway Visual Angle and Pixel Size at Point of Nominal Glide Slope Acquisition. Craft Position = 10,560 ft (Distance) At 553 ft (Altitude).

Runway parameters				
Length (Feet)	Width (Feet)	Form ratio	Visual angle (Length x Width)	Pixel size (Length x Width)
3,816	200	1.0	0.8 x 0.8	13.7 x 13.7
7,632	200	2.0	1.3 x 0.6	22.3 x 10.8
11,448	200	3.0	1.6 x 0.5	27.4 x 8.9

deflection. When the stick was returned to the center position, the craft maintained the current glide slope. To increase the simulated speed of the craft, the stick was twisted to the left. To return to the craft's initial speed, the stick was released back into the default (untwisted) position. To decrease speed, the joystick was twisted to the right. The amount of change in craft speed was proportional to the amount the stick was twisted.

Stimuli

Three runways of different dimensions were used as stimuli: (a) 3,816 ft x 200 ft, (b) 7,632 ft x 200 ft, and (c) 11,448 ft x 200 ft. At a constant 3° approach angle each runway has a unique form ratio: (a) Form ratio = 1.0 for the 3,816 ft x 200 ft runway, (b) form ratio = 2.0 for the 7,632 ft x 200 ft runway, and (c) form ratio = 3.0 for the 11,448 ft x 200 ft runway. Two runway variations were presented. In one variation, each runway contained a centerline and edge lights composed of ten white dots in length and five white dots in width, ensuring an identical number of dots in each configuration. In the other variation, red dots replaced the white dots located at the back half of the runway (see Appendix D).

The initial craft distance, relative to the runway threshold, was: (a) 19,378 ft, (b) 26,400 ft, or (c) 31,440 ft. Initial craft altitude was at a constant 553 ft for each trial. The initial craft distances were randomly assigned (within block) to all levels of runway dimension. Initial craft speed for each trial was 150 knots. The initial craft positions were varied in order to insure that the image of each runway spanned a range of similar optical dimensions at the beginning of each trial (see Table 2). This was done to reduce information about runway configuration within initial scene content.

Table 2

Initial Craft Position and Corresponding Runway Optical Dimensions.

Runway parameters			
Length x Width (ft)	Initial craft alt. (ft)	Initial craft dis. (ft)	Optical dim. (deg)
3,816 x 200	553	19,378	0.27 x 0.50
7,632 x 200	553	19,378	0.46 x 0.42
11,448 x 200	553	19,378	0.61 x 0.37
3,816 x 200	553	26,400	0.15 x 0.38
7,632 x 200	553	26,400	0.27 x 0.34
11,448 x 200	553	26,400	0.36 x 0.30
3,816 x 200	553	31,440	0.11 x 0.32
7,632 x 200	553	31,440	0.20 x 0.29
11,448 x 200	553	31,440	0.27 x 0.27

Design

Display information, runway size, segments, and flight experience were examined in a two (flight experience) by three (display information) by three (runway size) by three (replications) mixed factorial design. Flight experience was a between-subjects variable. Replications were collapsed across the independent variables in the analyses. The flight experience factor had two levels: (a) General aviation pilots and (b) nonpilots. Pilots and nonpilots participated in all experimental conditions (within-subjects). Each subject participated in a total of 39 trials (27 experimental and 12 practice trials)

The display information factor contained three levels: (a) None (baseline condition), (b) runway marking, and (c) matching form ratio. The none, runway marking and matching form ratio conditions were presented in blocks (Latin Square design). In the none condition, the subject received instructions to acquire and maintain a constant 3° glide slope to the runway threshold. There were nine trials comprised of three replications of three trial sets in each block, with each of the runways presented in each of these sets. The subject was instructed that the runway dimensions would vary between trials, and that the initial craft position was at an unknown distance and altitude from the runway.

In the runway marking condition, in addition to the above instructions provided in the none condition, a runway marking was added to each of the three runways (see Appendix D). Finally, in the matching form ratio condition, form ratio approach plates (see Appendix C) were presented to the subject. Each of the three approach plates presented a perspective view of a runway with a form ratio of 1.0, 2.0, or 3.0. The subject was informed that these plates could be utilized as a visual cue in the acquisition and maintenance of a 3° glide slope, and that this could be accomplished by keeping the appearance of the simulated runway image similar to the runway image on the approach plate. Aside from overall size, the form ratio of the image on the approach plate was the same as that of the optical image which the subject observed when on the correct glide slope.

Runway dimension was manipulated by presenting three different runways with a constant width and variable length: (a) 3,816 ft x 200 ft runway, (b) 7,632 ft x 200 ft runway, or (c) 11,448 ft x 200 ft. In order that the appropriate runway form ratio could be maintained, subjects were asked to use the runway threshold as an aimpoint. That is, the runway threshold was selected as the aimpoint in order to standardize the touch-down point and avoid extraneous effects that might be introduced with the presence of a touch-down mark beyond the runway threshold.

The approach path generated by the subject was divided into 10 equal-length segments, from point of glide slope acquisition (segment 1) to runway threshold (segment 10). The mean generated glide slope (in degrees), craft altitude (ft) and craft distance (ft) from the runway threshold were calculated for each segment. These segments were used in the analysis of glide slope maintenance and generated approach path.

Procedure

Before each session, subjects received instructions that their task was to acquire and maintain a constant 3° glide slope to the runway threshold. They were informed that the craft would initially fly on a level (horizontal) trajectory. The subjects were asked to get to the glide slope acquisition point as quickly and as accurately as possible, and then return the speed control to its initial default value (i.e., the joystick is not twisted) once the correct glide slope was acquired. When the subject believed that the craft had reached the correct point to acquire a constant 3° glide slope, the subject was required to turn-down onto this glide slope. The subject learned the procedure in the initial six practice trials. The dependent variables were the average position and glide slope generated by the subject. These were measured in the ten segments, with the first segment beginning at the point glide slope exceeded 0.25° (the operational definition of glide slope acquisition).

At the beginning of each nine trial block, the subject received specific written instructions relative to the display information condition being presented. At the end of each trial, feedback was displayed on the projection screen that indicated if the mean generated glide slope was too "high" or "low" relative to a 3° glide slope.

At the start of the session, the subject was seated in front of the projection screen and instructed on how to control the craft's movements with the joystick located on the right-hand side of the chair. Twelve practice trials were conducted in order to allow the subject to gain familiarity with the task. The first six trials started at the point at which the subject should turn onto the glide path for each of the assigned runways. At the beginning of each trial the subject was asked to immediately begin the descent directly towards the runway, and to carefully observe how the runway image looked during the descent. The remaining six practice trials were randomly sampled from the none information experimental conditions in which the subject was asked to fly forward and turn-down onto a constant 3° glide slope.

This practice session was followed by 27 experimental trials. Upon completion of the 27 trials, the session was concluded, and the subject was debriefed.

Results

Glide Slope Acquisition

A three-way mixed Analysis of Variance was conducted on the mean glide slope (in degrees) generated at the point of glide slope acquisition (segment 1). There were two within-subject factors (display information and runway size) and one between-subjects factor (flight experience). The display information factor contained three levels (none, runway marking, and matching form ratio) and the runway size (required form ratio) factor had three levels (1.0, 2.0, and 3.0). The two levels of the flight experience factor were pilot and nonpilot. The "F"-ratios and "p"-values of the omnibus ANOVA are summarized in Appendix F. The mean glide slopes and standard deviations for the nine display information and runway size conditions in each of the two flight experience groups are presented in Table 3.

Flight Experience Effects. The main effect of flight experience was not significant [$F(1,22) = 0.14$, $p < .715$].

Runway Size Effects. A significant main effect of runway size was present across the display information and flight experience factors [$F(2,44) = 52.51$, $p < .001$]. In absolute terms, acquisition of a 3° glide slope was best in the 2.0 runway condition. Subjects overflew (i.e., late turn-down onto glide slope) the point of acquisition in the 1.0 runway condition, whereas they underflew (i.e., early turn-down onto glide slope) their approach in the 3.0 runway condition. These findings suggest that as runway length increases, the subjects turn-down earlier, producing a low glide slope approach. This is in accord with the presumed influence of form ratio and runway dimensions.

Display Information Effects. There was no main effect of display information [$F(2,44) = 0.15$, $p = .860$], but display information interacted significantly with runway size [$F(4,88) = 4.39$, $p < .001$] (see Figure 6). This interaction shows that glide slope acquisition was more similar for the none and matching form ratio conditions, and showed

Table 3

Means and Standard Deviations of Display Information and Runway Size Glide Slopes (in Degrees) for Levels of Flight Experience.

			Flight Experience	
Display Info.	Runway Dimension	Form Ratio	Pilot	Nonpilot
None	3,816 x 200	1.0	3.29 (0.56)	3.06 (0.74)
	7,632 x 200	2.0	2.73 (0.39)	2.84 (0.64)
	11,448 x 200	3.0	2.61 (0.46)	2.52 (0.45)
Runway Marking	3,816 x 200	1.0	3.63 (0.76)	3.29 (0.86)
	7,632 x 200	2.0	3.00 (0.64)	2.94 (0.49)
	11,448 x 200	3.0	2.21 (0.42)	2.30 (0.35)
Matching Form Ratio	3,816 x 200	1.0	3.58 (0.80)	3.46 (1.44)
	7,632 x 200	2.0	2.67 (0.64)	2.60 (0.75)
	11,448 x 200	3.0	2.42 (0.81)	2.46 (0.71)

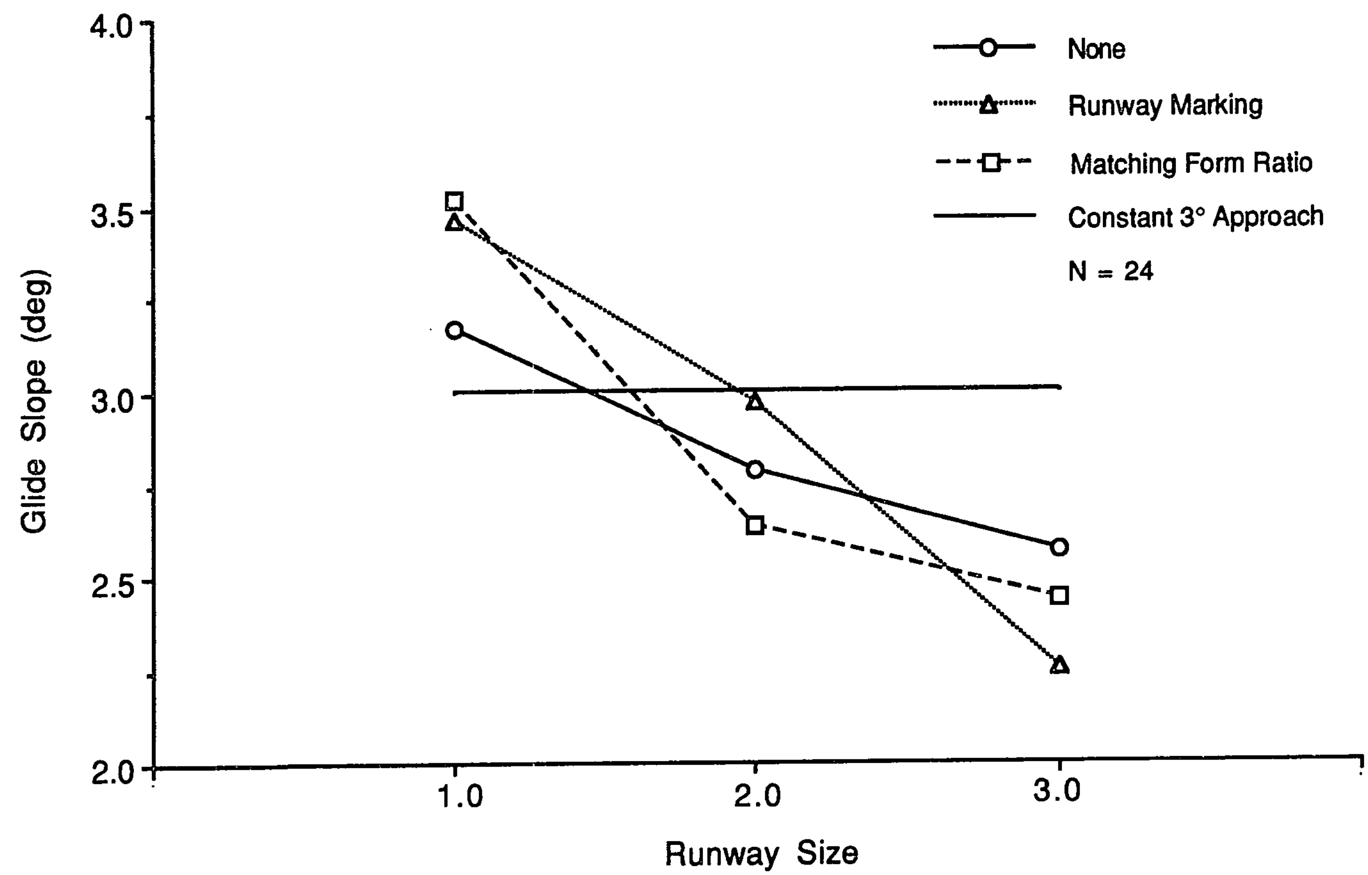

Figure 6 . Glide slope (acquisition) as a function of runway size and display information.

less influence of runway size than did the runway marking condition. For the none and matching form ratio conditions, the average change in glide slope acquisition between runway conditions 1.0 and 3.0 was about 0.8°, while it was about 1.2° for the runway marking condition.

Glide Slope Maintenance

A four-way mixed Analysis of Variance was performed on the mean glide slope (in degrees) generated from the point of acquisition to the runway threshold (segments 1-10). There were three within-subject factors (display information, runway size, and segment) and one between-subjects factor (flight experience). The "F"- ratios and "p"-values of the omnibus ANOVA are summarized in Appendix G. The mean glide slopes and standard deviations for the nine display information by runway size conditions (collapsed across the 10 segments) in each of the two flight experience groups are presented in Table 4.

Flight Experience Effects. There was no main effect of flight experience [$F(1,22) = 1.03$, $p = .321$].

Runway Size Effects. There was a significant main effect for runway size [$F(2,44) = 46.45$, $p < .001$], similar to that found for glide slope acquisition. Maintenance of a constant 3° glide slope was best approximated in the 2.0 runway condition. The glide slope generated in the 1.0 runway condition was overshot, and undershot in the 3.0 runway condition.

Display Information Effects. The main effect of display information was not significant [$F(2,44) = 1.27$, $p = .290$], but again there was a significant interaction between the display information and the runway size factors [$F(4,88) = 4.98$, $p < .001$] (see Figure 7). A post hoc pair-wise comparison was performed in order to determine

Table 4

Means and Standard Deviations of Display Information and Runway Size Glide Slopes Collapsed over Segments (in Degrees) for Levels of Flight Experience.

			Flight Experience	
Display Info.	Runway Dimension	Form Ratio	Pilot	Nonpilot
None	3,816 x 200	1.0	3.80 (1.76)	3.48 (3.20)
	7,632 x 200	2.0	3.19 (1.87)	3.17 (1.64)
	11,448 x 200	3.0	3.04 (1.67)	2.74 (1.33)
Runway Marking	3,816 x 200	1.0	4.52 (2.43)	4.14 (2.73)
	7,632 x 200	2.0	3.87 (2.38)	3.35 (2.19)
	11,448 x 200	3.0	2.75 (2.45)	2.35 (1.67)
Matching Form Ratio	3,816 x 200	1.0	4.60 (2.37)	4.11 (3.40)
	7,632 x 200	2.0	3.35 (2.67)	2.86 (1.98)
	11,448 x 200	3.0	2.80 (2.77)	2.64 (1.92)

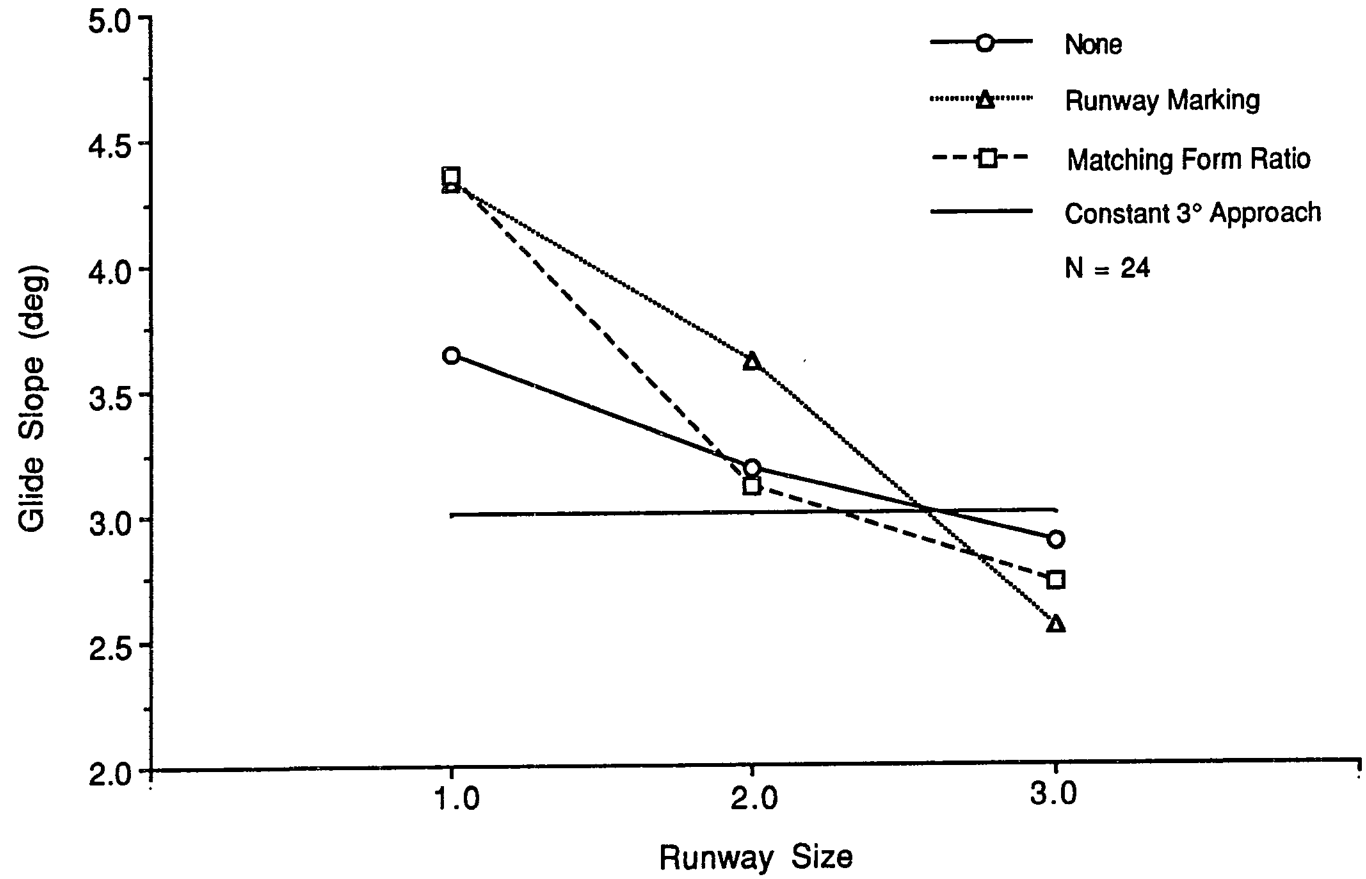

Figure 7 . Glide slope (maintenance) as a function of runway size and display information.

significant differences across runway size for each of the none, matching form ratio, and runway marking conditions (see Table 5). Both the runway marking and the matching form ratio conditions were found to be significantly different for all three pair-wise comparisons. The none condition was not significantly different for two of the three pairwise comparisons.

Segment Effects. There was a significant main effect of segment [$F(9,198) = 33.64$, $p < .001$]. The mean generated glide slope appears to be curvilinear, and is low (relative to a 3° glide slope) in the initial seven segments after acquisition, but rapidly increases in segments 8, 9, and 10 (see Figure 8). The increasing values in segments 8, 9, and 10 suggest subjects are using aimpoints that are located beyond the runway threshold.

The segment factor interacted significantly with the display information factor [$F(18,396) = 2.73$, $p < .001$]. Since this interaction is nested in a higher order interaction involving all three factors [$F(36,792) = 1.76$, $p < .001$], only the higher order interaction will be examined. In the none condition, the subjects acquired a nearly average 3° glide slope in the 1.0 runway condition, and a shallow glide slope in the 2.0 and 3.0 runway conditions (see Figures 9 and 10). While all descents appear to have similar complex curvilinear forms, follow-up trend analyses showed different components to be significant for different runways (Appendix H). However, visual inspection shows all three to have gradual decreasing and then increasing (low-in-the-middle) glide slopes. The 2.0 and 3.0 functions have significant quadratic trends.

In the runway marking condition, the subjects acquired a good approximation of a constant 3° approach in the 2.0 runway condition (see Figures 11 and 12). In addition, the glide slope in the 1.0 runway condition is higher overall, and the glide slope in the 3.0

Table 5

Pair-Wise Comparison of the Display Information by Runway Size Conditions.

Factors	F	df	p
None/1.0 - 2.0 Runway	6.99	1,23	.014
None/2.0 - 3.0 Runway	3.13	1,23	.090
None/1.0 - 3.0 Runway	16.25	1,23	.001
Runway marking/1.0 - 2.0 Runway	13.11	1,23	.001
Runway marking/2.0 -3.0 Runway	33.80	1,23	.001
Runway marking/1.0 - 3.0 Runway	49.85	1,23	.001
Matching form ratio/1.0 - 2.0 Runway	17.07	1,23	.001
Matching form ratio/2.0 - 3.0 Runway	4.59	1,23	.043
Matching form ratio/ 1.0 - 3.0 Runway	33.14	1,23	.001

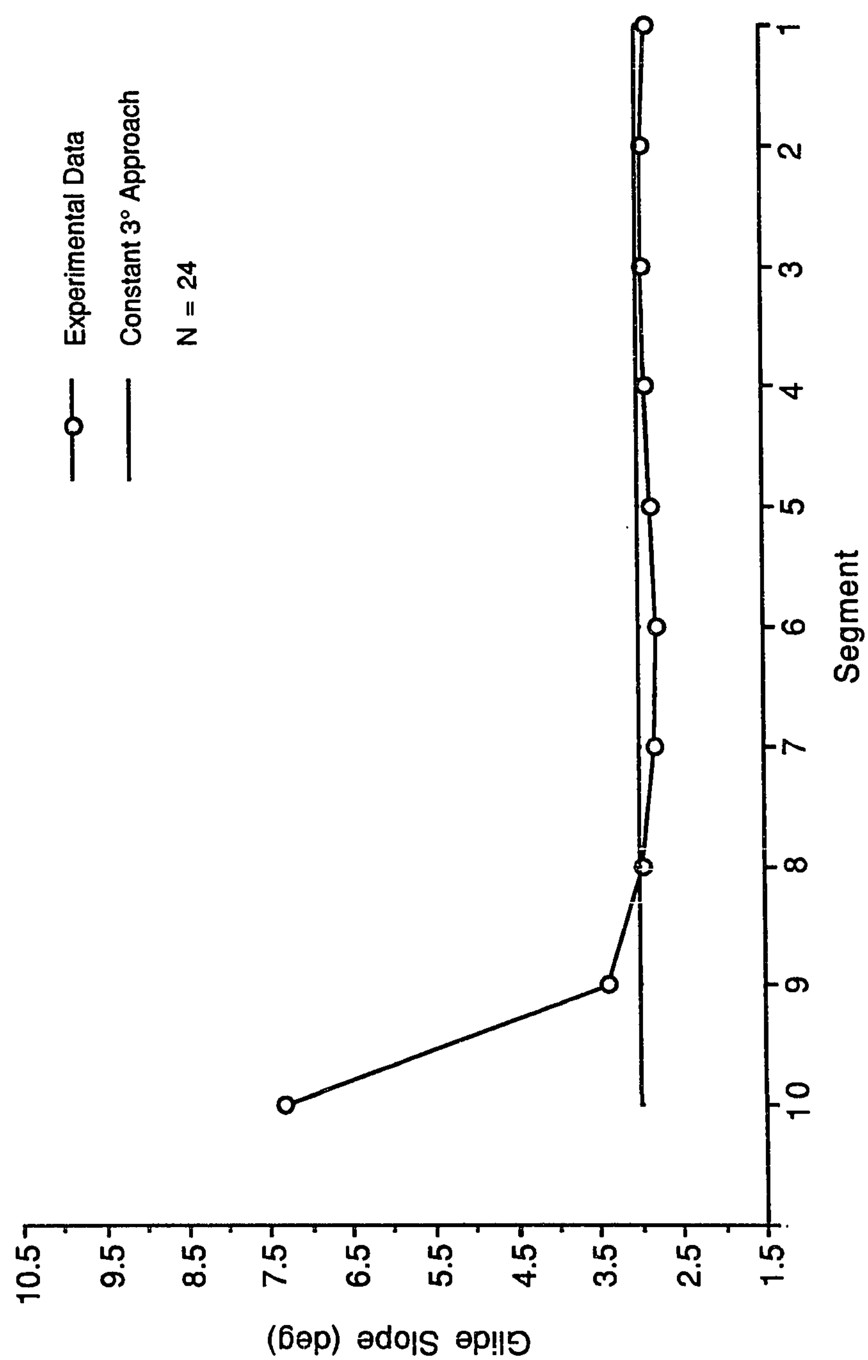

Figure 8 . Glide slope as a function of segment.

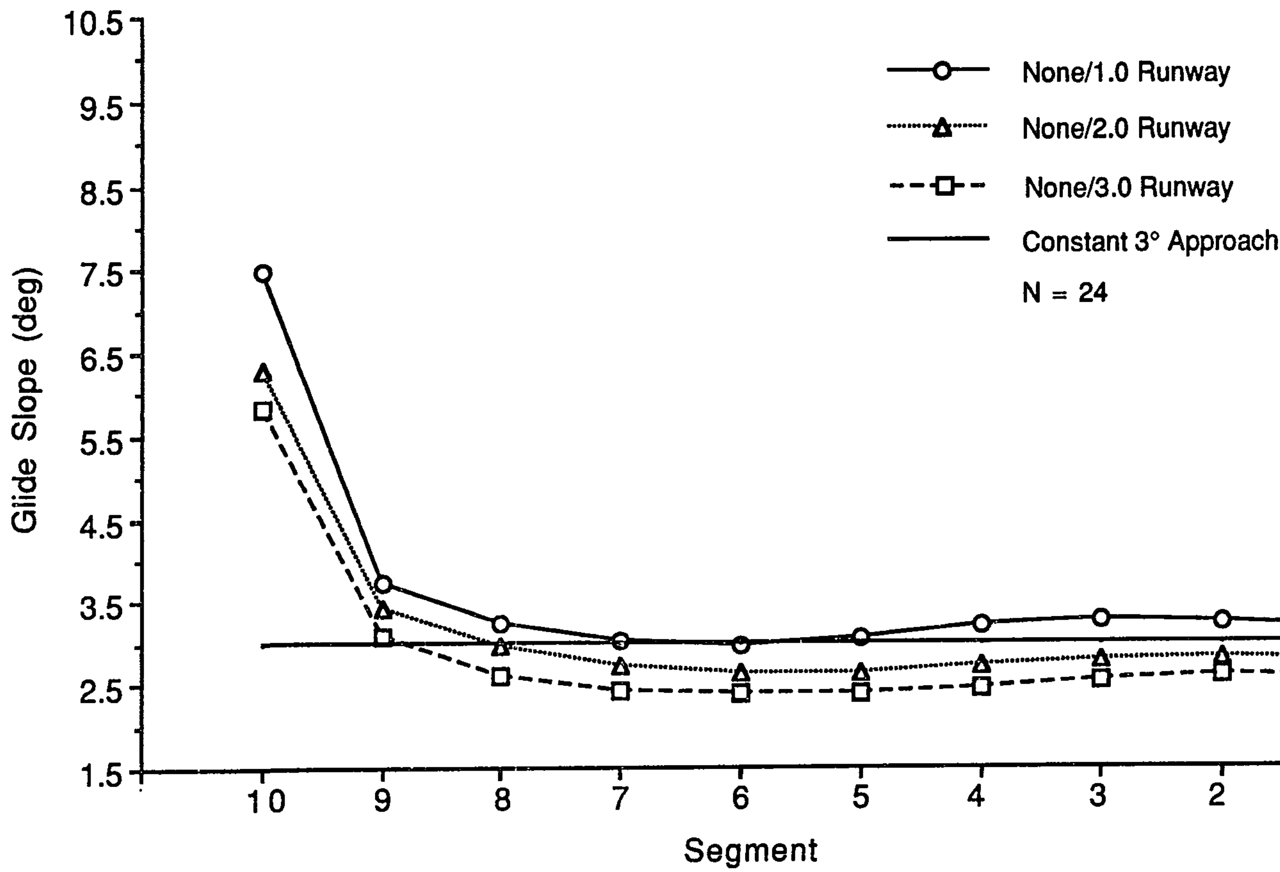

Figure 9. Glide slope as a function of segment and runway size for the none condition.

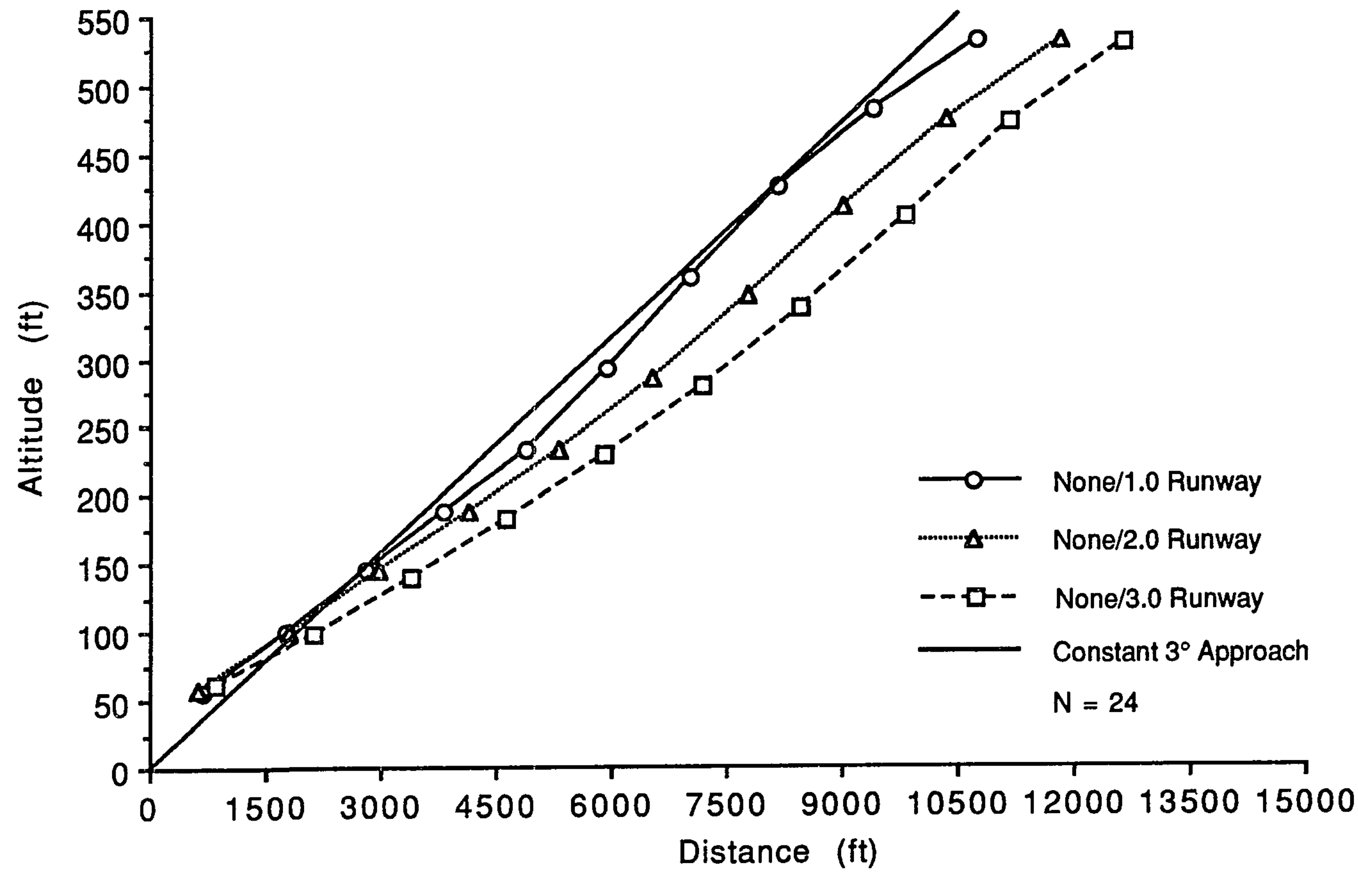

Figure 10 . Generated approach path for the none condition.

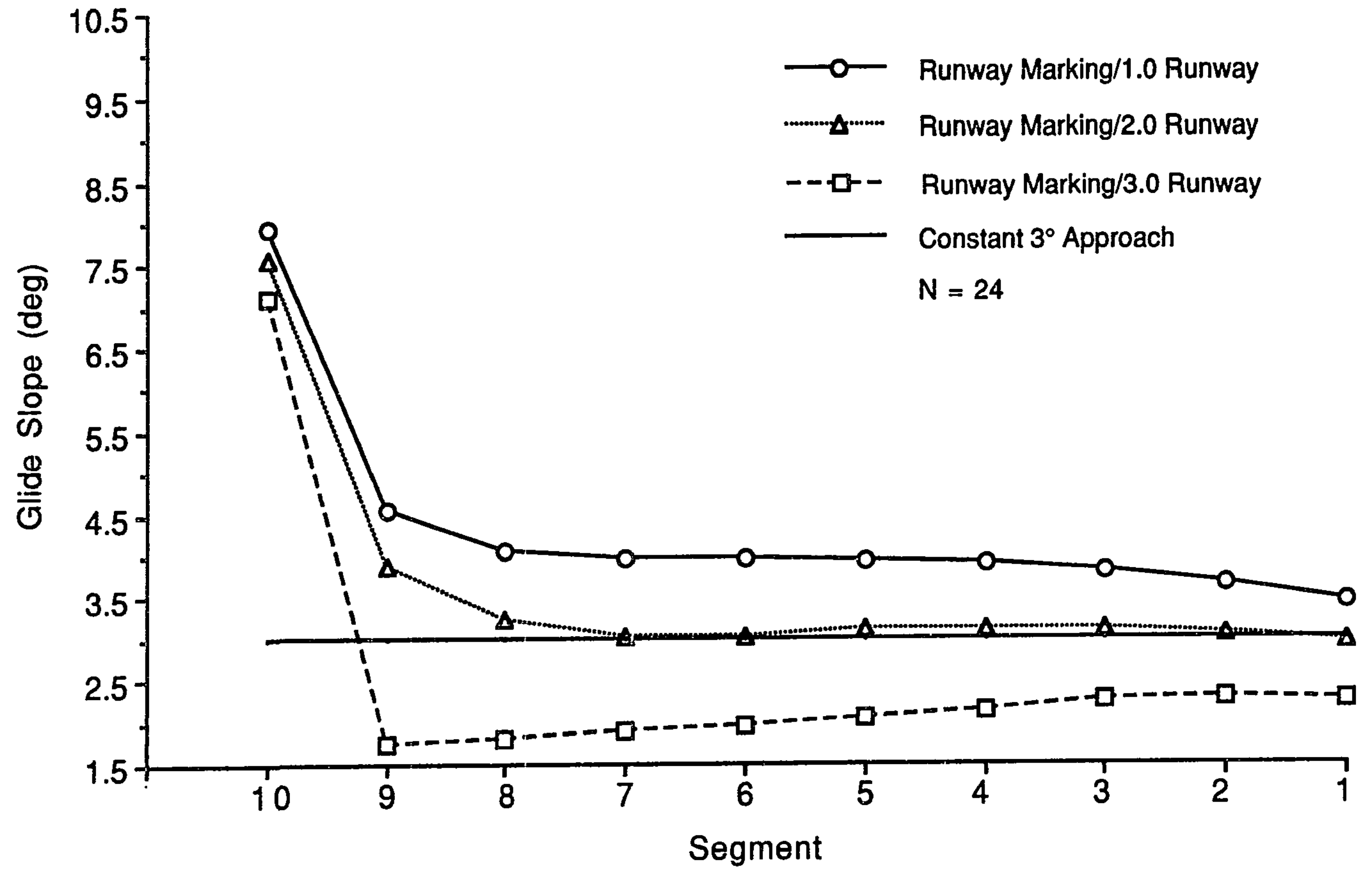

Figure 11. Glide slope as a function of segment and runway size for the runway marking condition.

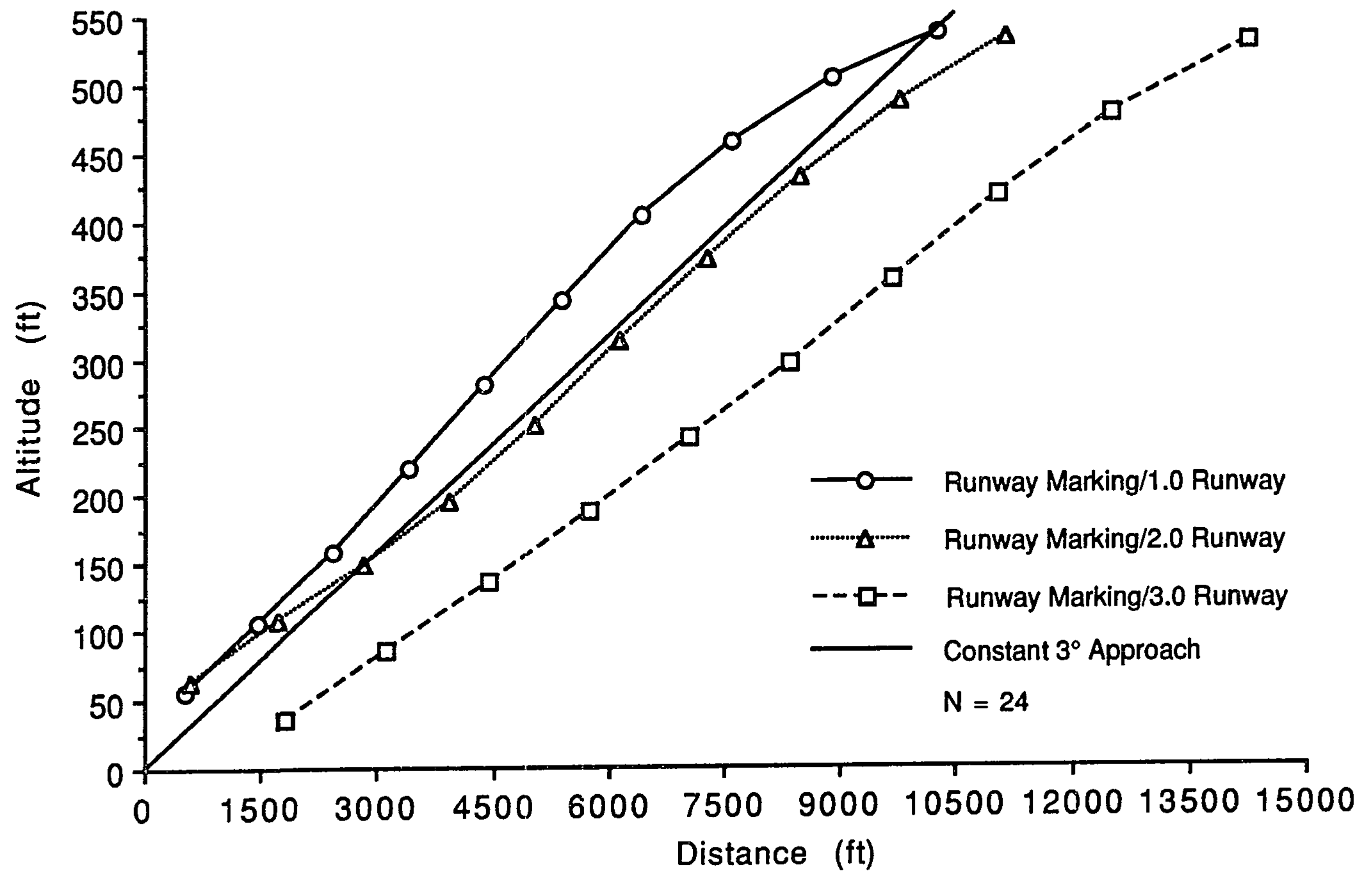

Figure 12 . Generated approach path for the runway marking condition.

runway condition is lower overall. In fact, for segments 7-10 in the 3.0 runway condition, 91% of the generated glide slopes were lower than 3°. However, none of these trajectories appear to have a low-in-the-middle structure. The approaches in the 1.0 and 2.0 conditions were complexly curvilinear (quadratic and cubic trends -- see Appendix H). The function produced in the 3.0 runway condition was linear. This linear trend may reflect noisy data, masking any apparent non-linear trends.

In the matching form ratio condition, subjects overflew the glide slope in the 1.0 runway condition, whereas they underflew the glide slope in the 2.0 and 3.0 runway conditions (see Figures 13 and 14). However, the follow-up trend analysis showed significant curvilinearity only for runway condition 3.0 (see Appendix H). Like the none display information condition, the 1.0, 2.0, and 3.0 runway condition functions appeared to be low-in-the-middle. This suggests that although the generated glide slopes were extremely variable in all display information conditions, the approaches conducted in the matching form ratio condition were the most linear. Yet, as in the runway marking condition, this apparent linearity may be attributed to noisy data that obscured any non-linear trends. Also, it is important to note that these approaches, in absolute terms, were still low relative to a 3° glide slope.

Visual Angles

The craft distance (ft) and altitude (ft) generated across the three levels of the display information and the three levels of the runway size factors were used to calculate the corresponding visual angles subtended by the runway length (see Appendix I). These visual angles were calculated using the equation:

$$l = \arctan(z/x) - \arctan[z/(x + L)],$$

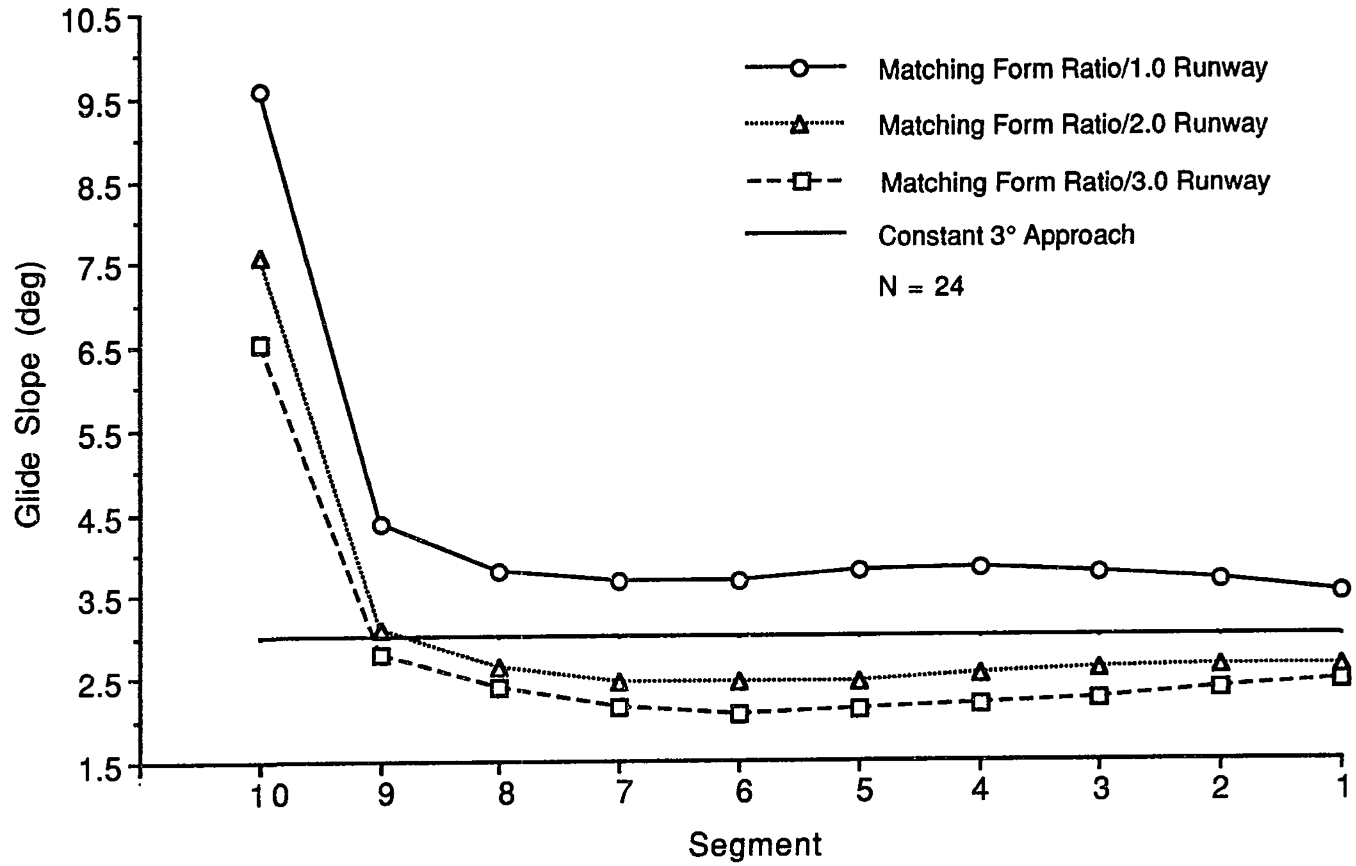

Figure 13 . Glide slope as a function of segment and runway size for the matching form ratio condition.

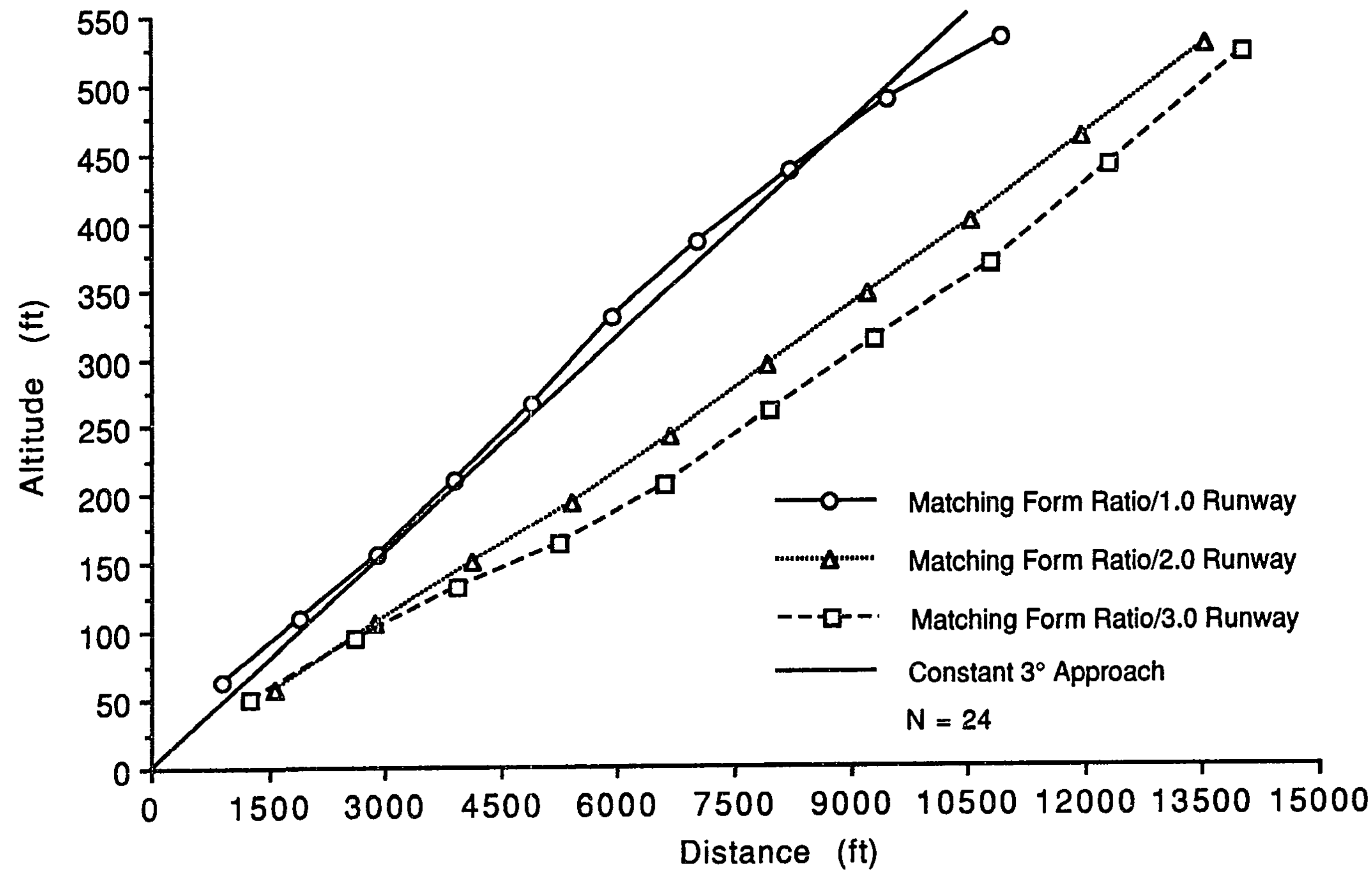

Figure 14 . Generated approach path for the matching form ratio condition.

where L = runway length, z = craft altitude, and x = craft distance from the runway threshold. The visual angles in eight of the nine conditions increased by factors of two to three over the first nine segments. As the subjects approached the runway, they acquired constantly expanding visual angles subtending the runway. The single exception occurred in the runway marking/3.0 runway condition, where the generated approaches approximated a constant visual angle. Overall, these findings do not support Kraft and Elworth's (1969, 1978) constant visual angle hypothesis which proposed low-in-the-middle black hole approaches were a consequence of maintaining a constant visual angle of the runway length during the approach.

Discussion

The four main findings of this thesis were: (a) Runway size (i.e., length) affects glide slope acquisition and maintenance; (b) Form ratio approach plates did not prove useful in acquisition and maintenance of a constant 3° glide slope; (c) The runway marking was not effective as supplemental scaling information for glide slope acquisition and maintenance; and, (d) In general, the glide slopes generated to the three different-sized runways under the three display information conditions were complexly curvilinear approaches. These results will be discussed in further detail below.

Runway Size Effect

The runway size effect was evident across all levels of the display information factor. In absolute terms, subjects overshot the approach in the 1.0 runway condition, undershot (closest approximation of a constant 3° glide slope) the glide slope in the 2.0 runway condition, and undershot the approach in the 3.0 runway condition to an even greater degree. These findings suggest that the subjects' ability to acquire and maintain a constant

3° glide slope was influenced by runway length, and that the effect of the feedback caused the subjects to adopt a strategy that, on average, tended to yield a 3° glide slope. Given that the runway size manipulation biased their performance, it is not unexpected that they would adopt a strategy based on the average runway size (i.e., the 2.0 runway).

The runway size effect was also evident in investigations performed by Mertens and Lewis (1982) and Wulfeck, Weisz, and Raben (1958). Based on a survey of pilots' experience, Wulfeck et al. suggested that a pilot, after a few landings, learns the length-to-width ratio of the runway outline that will provide the correct glide slope information. If the pilot then flies to an unfamiliar runway that is longer, the resulting approach will be too low. Mertens and Lewis examined the effects of different runway sizes simulated under night conditions on pilot performance. The mean generated approach angles to the 3,000 ft x 150 ft, 6,000 ft x 150 ft, and 9,000 ft x 150 ft runways were 2.74°, 2.23°, and 1.96° respectively. Therefore, as runway length increased, generated approach angles decreased. Mertens and Lewis suggested that at least three cues may have had an effect on approach angle performance to runways of different lengths and widths: (a) linear perspective, (b) runway image height, and (c) the form ratio of the runway image.

Approach Plates

Glide Slope Acquisition. No evidence was found that supported the hypothesis that approach plates, each depicting a runway image with a specific form ratio (i.e., 1.0, 2.0 or 3.0), aided subjects in the acquisition of a 3° glide slope. There was no main effect of display information, and the greatest standard deviation (mean = 0.85°) of the mean acquired glide slopes occurred in the matching form ratio (i.e., approach plate) condition.

In the interaction between runway size and display information, the mean glide slopes generated in the none condition, across the levels of runway size, were closer to a constant 3° glide slope than in the matching form ratio condition. This also suggests that the approach plates interfered with the use of runway outline information. Yet, it is important to note that acquired glide slopes in the none condition were also extremely variable (mean = 0.54°).

There are several explanations for the non-significant effect of the matching form ratio condition on glide slope acquisition. The presentation of the approach plates may be one factor. The approach plate is comprised of a single runway image. This runway image is matched to one of the three different runway sizes used in this thesis, each image in turn representing a form ratio of 1.0, 2.0 or 3.0. The runway image selected for each of the three approach plates was derived from a central point on the 3° glide slope, 5,280 ft from the runway threshold and at a altitude of 277 ft. The problem that arises from the selection of these three runway images, on a specific point along the glide path, is that as the craft approaches the runway the form ratio remains constant, yet the base angles change. At the point of acquisition, the base angles of the runway image are large, resulting in a tall and narrow runway image. At points closer to the runway threshold, the base angles of the runway image decrease, resulting in a shorter and wider runway image. That the subjects were unable to utilize the approach plates in glide slope acquisition suggests that they were influenced by the base angles, or other changing aspects of the runway image.

In informal post-experiment interviews, most subjects responded that they found it difficult to match the form ratio on the approach plates to the simulated runway image. This also supports the conclusion that the approach plates did not provide subjects' with useful visual information for glide slope acquisition.

Another factor that may have influenced subject performance in the matching form ratio condition was the experimental method. In order to minimize the effects of demand characteristics and experimenter expectations, subjects did not receive a detailed definition of form ratio. In written instructions provided to the subjects, they were informed that the "approach plates may be utilized as a visual cue in acquiring and maintaining a constant 3° glide slope. This may be accomplished by keeping the appearance of the simulated runway image similar to the runway image on the approach plate. The image on the approach plate will, except for overall size, be the same as the optical image". This last sentence, in particular, was probably poorly phrased.

Glide Slope Maintenance. Approach plates also did not help subjects maintain a constant 3° glide slope, and again there was no main effect of display information. Also, again, the matching form ratio condition (mean = 2.52°) exhibited the greatest standard deviation of mean generated glide slope when compared to the none (mean = 1.92°) and runway marking conditions (mean = 2.31°).

In the significant interaction of display information and segment, the matching form ratio and none conditions were similar complex, curvilinear functions. This suggests that the approach plates did not improve the ability of the subject to maintain a constant 3° glide slope. Also, the matching form ratio condition, like the none and runway marking conditions, was also influenced by the runway size effect. In approaches in the 1.0 runway condition, the glide slope was generally overshot, whereas the glide slope in the 3.0 runway condition was undershot. If the approach plates were aiding the subject in glide slope maintenance, runway size should have had less effect upon glide slope performance than in the none condition.

As in the case of glide slope acquisition, the presentation of the runway form ratio on the approach plate and withholding the definition of form ratio from the subjects may have adversely influenced glide slope performance. This evidence is consistent with Mertens' (1981) findings. Mertens examined the ability of pilots to make form ratio judgments using the runway image as a visual cue. Subjects overestimated form ratio and glide slope in all conditions. Mertens suggested that judgments of form ratio as a visual cue were not useful in minimizing the variability of glide slope estimations.

Runway Marking

Glide Slope Acquisition. There was no evidence that a runway marking provided additional runway scaling information to the subject that could be used in glide slope control. Although subjects reported that the runway marking seemed to be the most helpful visual aid in glide slope control, the approaches generated by the subjects suggested otherwise. The standard deviation in generated glide slope in the runway marking condition (mean = 0.58°) was more extreme than in the none condition (mean = 0.54°). This suggests that the runway marking did not provide any additional visual information that could be used by the subject in glide slope acquisition.

In the interaction between the display information and runway size factors, the glide slope acquisition in the runway marking condition was the least accurate, relative to a 3° glide slope, in both the 1.0 and 3.0 runway size conditions.

Glide Slope Maintenance. The runway marking did not improve the subjects' ability to maintain a constant 3° glide slope. The standard deviation in generated glide slope was more extreme in the runway marking (mean = 2.31°) than in the none condition (mean = 1.92°). In addition, in the display information by runway size interaction, the runway marking condition provided the worst (relative to a constant 3° glide slope) generated glide slope across the three runway sizes.

The scaling information provided by the runway marking did not serve as a useful visual cue in either the acquisition or maintenance of a constant 3° glide slope. This finding did not support Perrone's (1984) analysis of black hole landings, in which low approaches were proposed to be the result of the observer's inability to turn the runway perspective gradient into a correct glide slope estimate due to inadequate scaling information in the runway scene. Yet, it is important to note that only one type of runway marking was investigated in this thesis. Therefore, inadequate scaling information in the runway scene may continue to be a contributing factor to low approaches under black hole conditions.

Low-In-The-Middle Approaches

The generated glide slopes in the three different-sized runways conditions across the three display information conditions were generally complex functions of distance from the runway (see Appendix H). Kraft and Elworth (1969, 1978), Johnson (unpublished), Mertens (1981, 1982), and Perrone (1984) found that approaches performed under black hole conditions tended to be low-in-the-middle, but did not report the range of complexity found here.

These approaches may be the attributed to the inherent difficulty in controlling the vertical directional component based on the reduced visual information available in the runway scene. Naish (1971) derived quantitative optical equations relating the observer's position and motion, and perspective runway geometry. Naish concluded that vertical control of the glide slope using alignment mechanisms (e.g., inclination of a ground line and runway expansion) is generally unreliable. If this lack of vertical control is due to the subthreshold angular velocities of the runway elements, at distances in excess of 0.5 miles from the runway threshold, this may account for these approach profiles. Specifically, generated low-in-the-middle approaches (those showing quadratic trends) may be the result of a dual-processing model of glide slope control. The lack of dynamic visual cues (e.g., runway deformation) further away from the runway threshold may directly influence the subject to take a lower than normal (3°) glide slope. As the subject approaches the runway threshold, these visual cues are more salient, allowing the subject to make the necessary adjustments to maintain a constant glide slope. However, the more complex trends also found in the present data remain unexplained.

Flight Experience

There was no main effect or interaction of flight experience for glide slope acquisition or maintenance. This suggests that: (a) The pilots (minimum 125 flight hours) may not have had enough actual flight experience to perform significantly better than the nonpilots, and/or (b) differences between actual flight conditions and this simulation were great enough to negate any difference in flight experience (all 24 subjects had either flight simulator or video game flight simulator experience).

Future Research

First, the runway size effect should be thoroughly investigated. Since pilots continually encounter runways of different lengths and widths, studying the runway size effect would have a practical impact on: (a) How runways should be designed in order to minimize the runway size effect, and (b) pilot training issues (i.e., awareness of the runway size effect). Second, the presentation of the form ratio stimuli could be modified to more accurately assess form ratio in glide slope control. In one case, three form ratio runway images would be presented on each approach plate, in which each runway image would represent one phase of the approach (e.g., acquisition, maintenance, and landing). Another modification of the form ratio stimulus could be in the form of a Heads-Up-Display (HUD). The form ratio of the runway image could be presented as a HUD on a simulated aircraft windscreen, and the subject would match the HUD runway image with the actual runway as the subject approaches the runway. Finally, the form ratio runway image could be presented on approach plates in a "T" configuration (i.e., only the centerline and far end width displayed). This would eliminate the conflicting image characteristics (e.g., changing base angles).

Conclusions

The length of the runway has an effect on glide slope acquisition and maintenance under black hole conditions. As runway length increases, the subjects turn-down earlier, producing complexly curvilinear approaches. Since the 2.0 runway represents an average of the 1.0 and 3.0 runways, subjects tended to acquire the closest approximation of a 3° glide slope approach in the 2.0 runway condition. Approach plates or a runway marking, as presented in this thesis, did not have a positive effect on glide slope acquisition and maintenance. In general, approaches conducted in the none, runway marking, and matching form ratio conditions were complex functions of distance from the runway. This may be attributed to the design of the visual aids (i.e., approach plates and runway marking) and/or that form ratio and additional scaling information are only salient at distances closer to the runway threshold as outlined in the dual-processing model.

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Appendix A

Signed Approval Forms

SJSU SAN JOSE STATE UNIVERSITY

A campus of The California State University

College of Social Sciences • *Department of Psychology*
One Washington Square • San José, California 95192-0120 • 408/924-5600 • FAX 408/924-5605

February 12, 1992

TO: Martin Schwirzke, MA candidate

FROM: Kevin Jordan, MA Coordinator

RE: Design and analysis review

Drs. Alvarez and Fox have read your thesis proposal for the Design and Analysis Committee; their comments are attached. Based on their comments, the thesis proposal is approved. As you can see, both reviewers are pleased with the writing style and the organization of the paper. Make sure that you include a clear, up-front definition of glide slope early in the final version of the thesis.

Based on this committee's approval, the collection of data for your thesis is approved contingent on documentation of compliance with university policy regarding the use of human subjects in research. University policy requires approval of your project by the Human Subjects Institutional Review Board. Please provide me with a file copy documenting such approval as soon as you receive it. After that copy is part of your file, you may begin collecting data.

Congratulations on your progress to date! We look forward to the continuation of your fine performance in the program.

cc:

Alvarez
Cooper
Fox
Johnson (NASA-ARC; give to Jordan)
Jordan
file

SJSU SAN JOSE STATE UNIVERSITY

A campus of The California State University

Office of the Academic Vice President • Associate Academic Vice President • Graduate Studies and Research
One Washington Square • San Jose, California 95192-0025 • 408/924-2480

To: Martin F. J. Schwirzke, Psychology
972 Apricot Avenue
Campbell, CA 95008

From: Serena W. Stanford
AAVP, Graduate Studies and Research

Date: January 30, 1992

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

"Black Hole Landings: The Effects of Runway Marking and Form Ratio Cues on Glide Slope Control"

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The Board's approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Dr. Serena Stanford immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

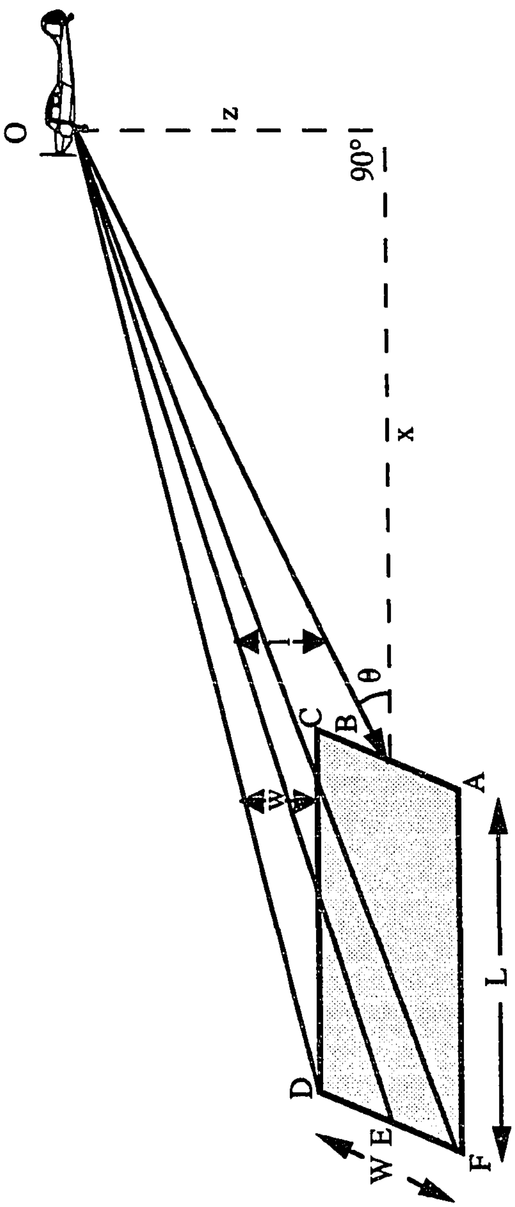
Please also be advised that each subject needs to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate or withdrawal will not affect any services the subject is receiving or will receive at the institution in which the research is being conducted.

If you have questions, please contact me at 408-924-2480.

CC: Kevin Jordan, Ph.D.

Appendix B

Visual Geometry of the Runway During Approach



Legend:

W = runway width
L = runway length
w = optical width
l = optical length
z = craft altitude
x = craft distance
O = observer
ABCDEF = runway
θ = approach angle

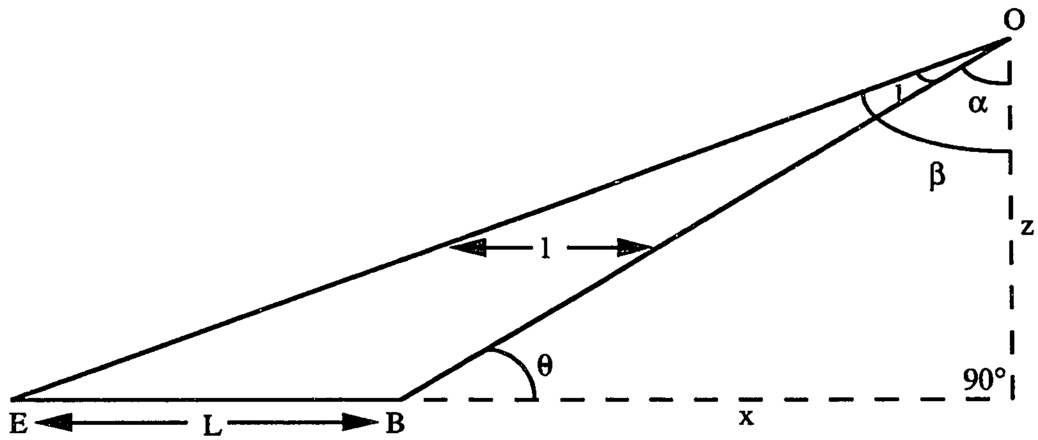
Form Ratio Equation:

$$\text{Form Ratio} = \tan(\theta)\,\frac{L}{W}$$

Approach Angle Equation:

$$\theta = \arctan\left(\frac{z}{x}\right)$$

Side View



Legend:

EB = runway
L = runway length
l = optical length
x = craft distance
z = craft altitude
O = observer

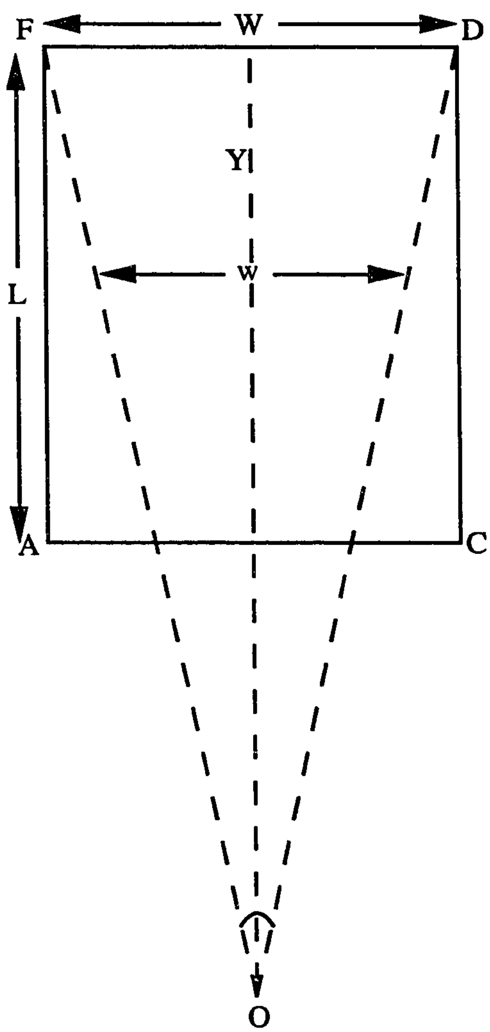
Optical Length (Degrees):

l = angle β - angle α

angle α = arctan(z/x)

angle β = arctan[z/(x+L)]

Top-Down View



Legend:

O = observer
W = runway width
w = optical width
L = runway length
ACDF = runway

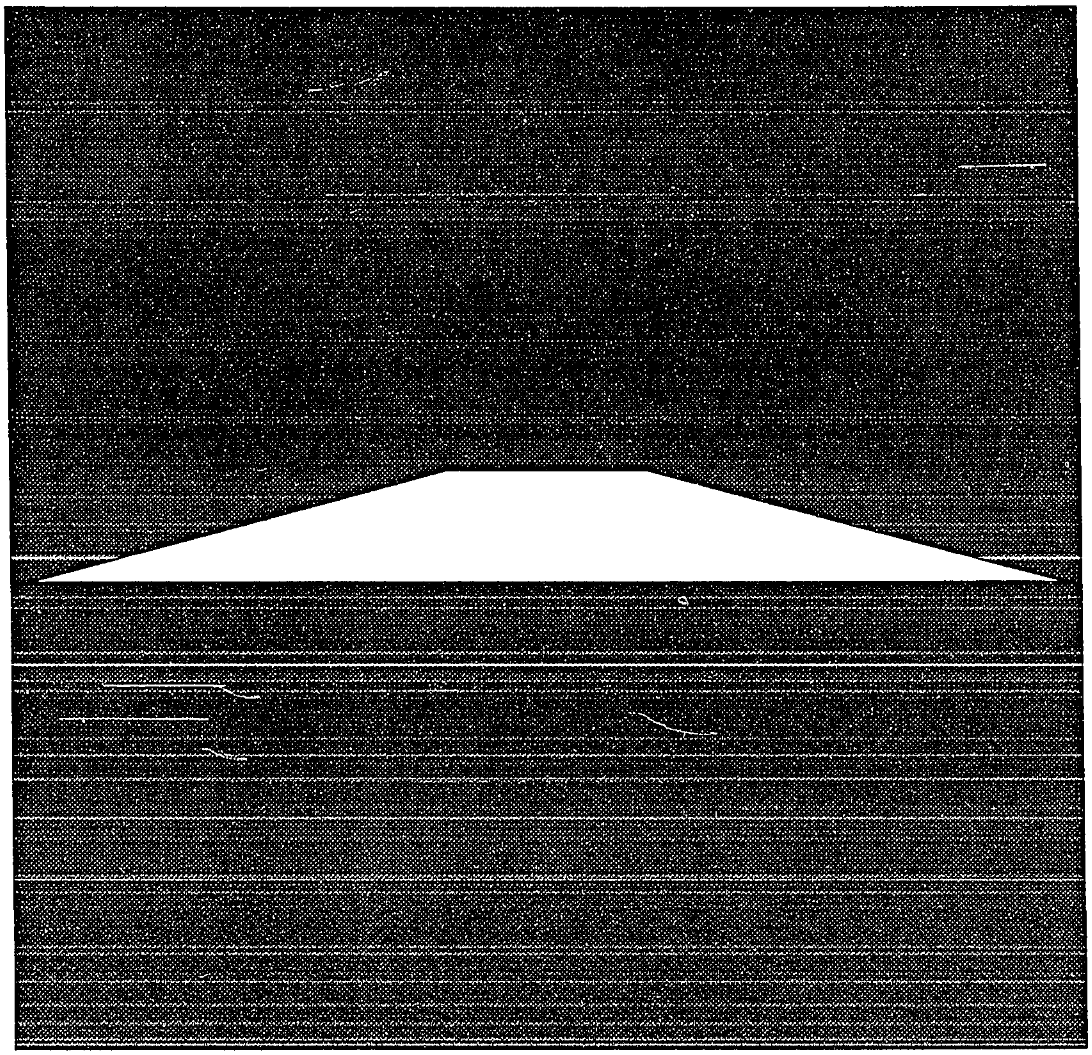
Optical Width(Degrees):

$$w = \arctan \frac{(W/2)}{Y} \times 2$$

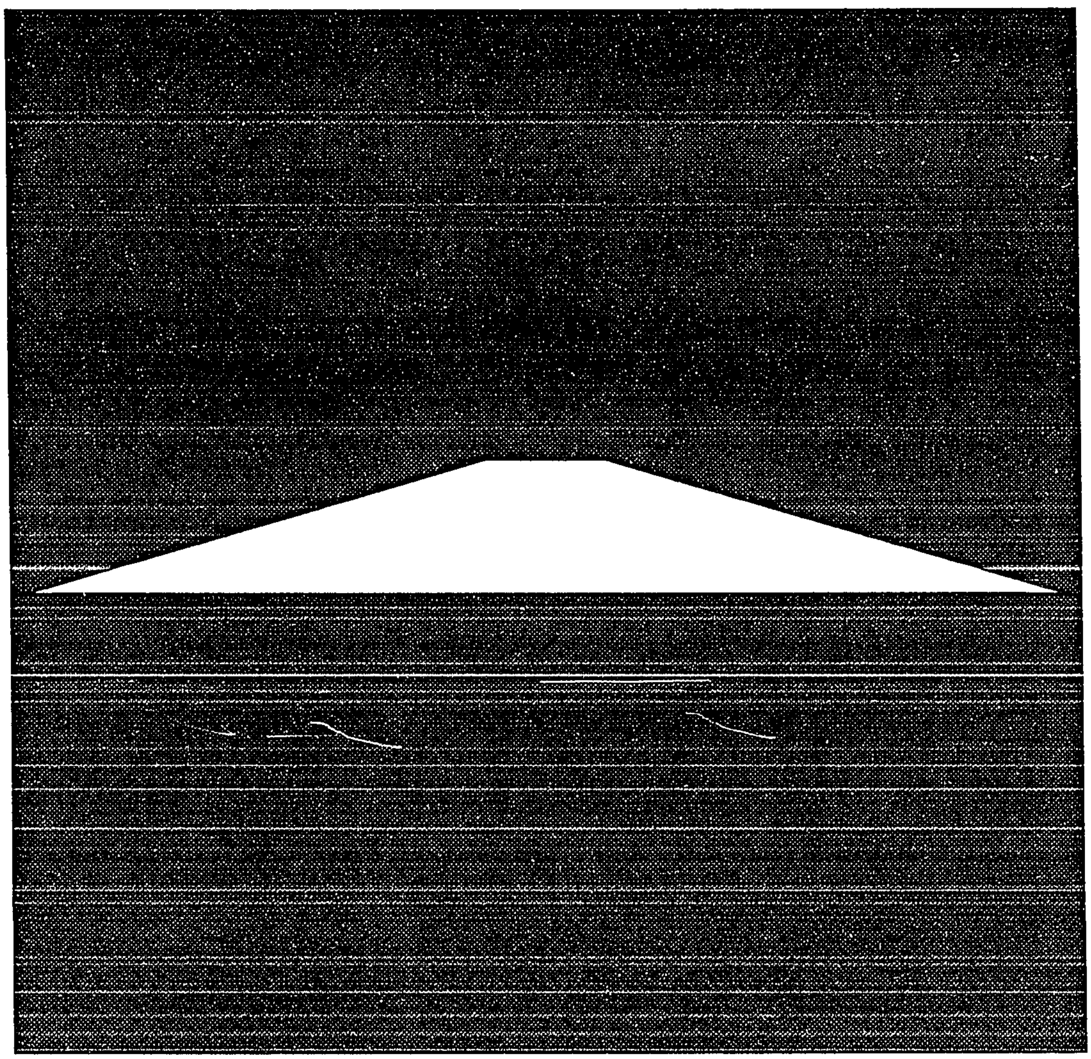
$$Y = \sqrt{(x + L)^2 + (z)^2}$$

Appendix C

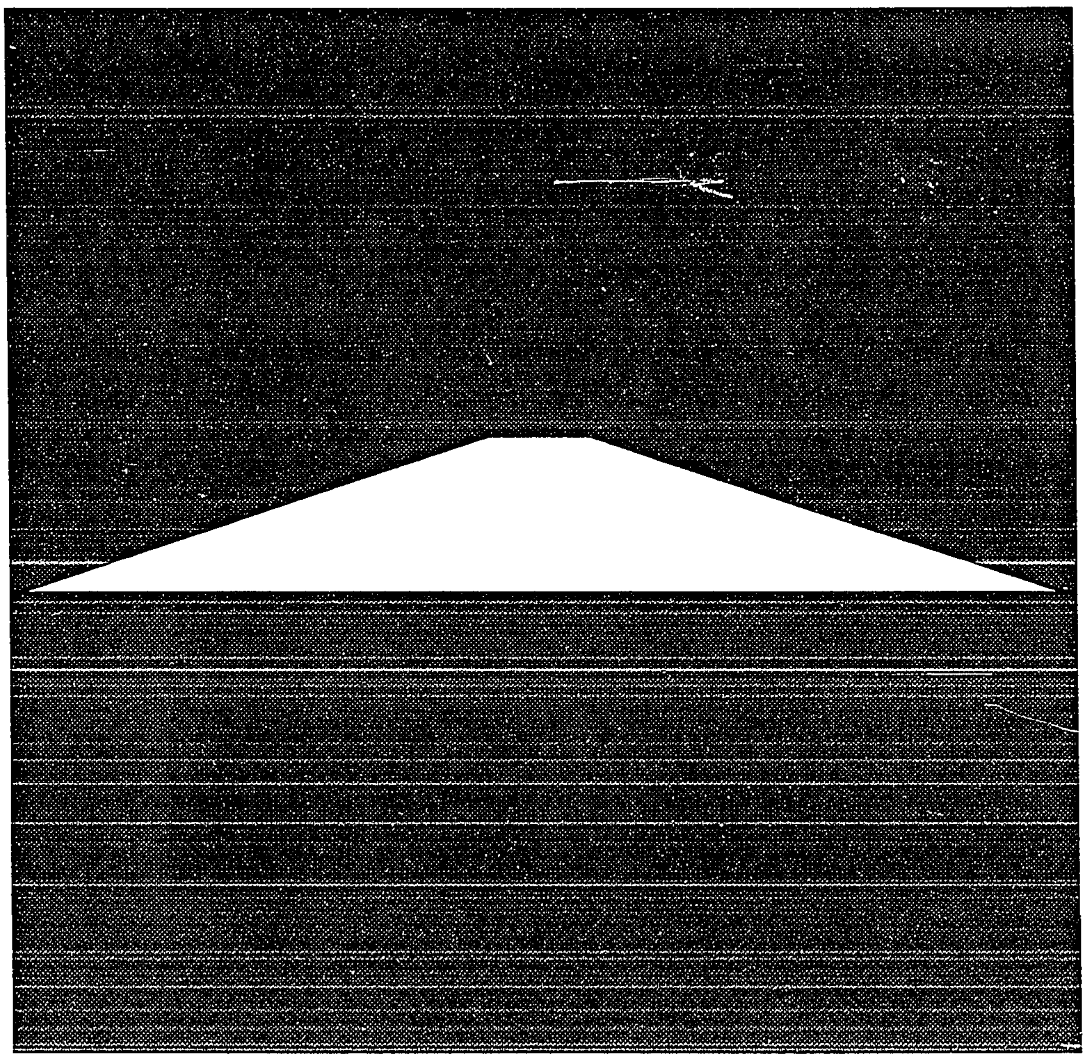
1.0 Form Ratio Approach Plate



2.0 Form Ratio Approach Plate

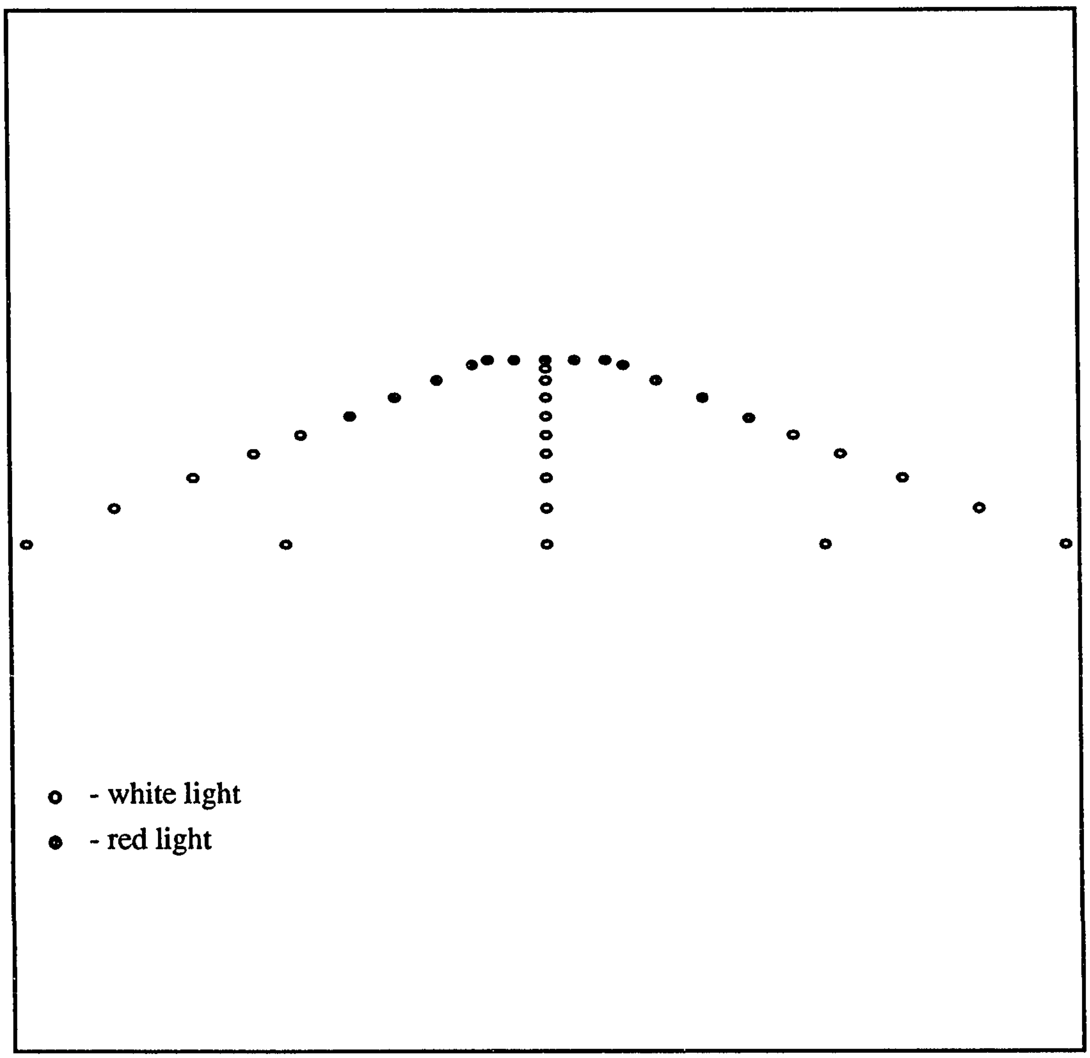


3.0 Form Ratio Approach Plate



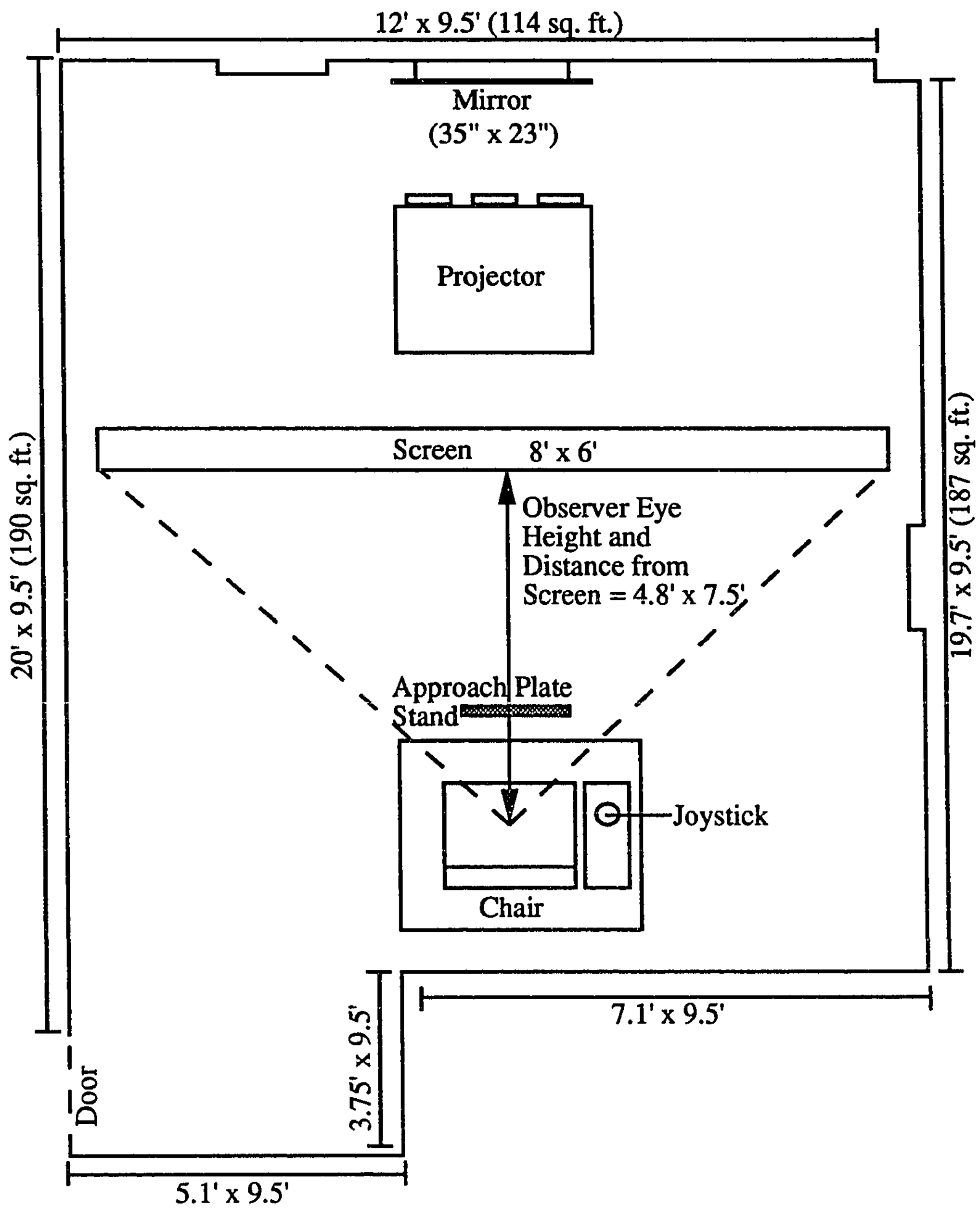
Appendix D

<u>Runway Marking Stimulus</u>



Appendix E

Apparatus and Laboratory



Appendix F

ANOVA Summary Table (Glide Slope Acquisition)

Factors	F	df	p
DI	0.15	2,44	.860
RS	52.51	2,44	.001
DI x RS	4.39	4,88	.001
FE	0.14	1,22	.715
DI x FE	0.04	2,44	.965
RS x FE	4.02	2,44	.370
DI x RS x FE	0.38	4,88	.819

Legend

DI = Display Information

RS = Runway Size

FE = Flight Experience

Appendix G

ANOVA Summary Table (Glide Slope Maintenance)

Factors	F	df	p
DI	1.27	2,44	.290
RS	46.45	2,44	.001
DI x RS	4.98	4,88	.001
S	33.64	9,198	.001
DI x S	2.73	18,396	.001
RS x S	0.49	18,396	.964
DI x RS x S	1.76	36,792	.001
FE	1.03	1,22	.321
DI x FE	0.25	2,44	.779
RS x FE	0.07	2,44	.934
S x FE	0.35	9,198	.956
DI x RS x FE	0.36	4,88	.840
DI x S x FE	1.18	18,396	.274
RS x S x FE	0.93	18,396	.539
DI x RS x S x FE	0.37	36,792	.999

Legend

DI = Display Information

RS = Runway Size

S = Segment

FE = Flight Experience

Appendix H

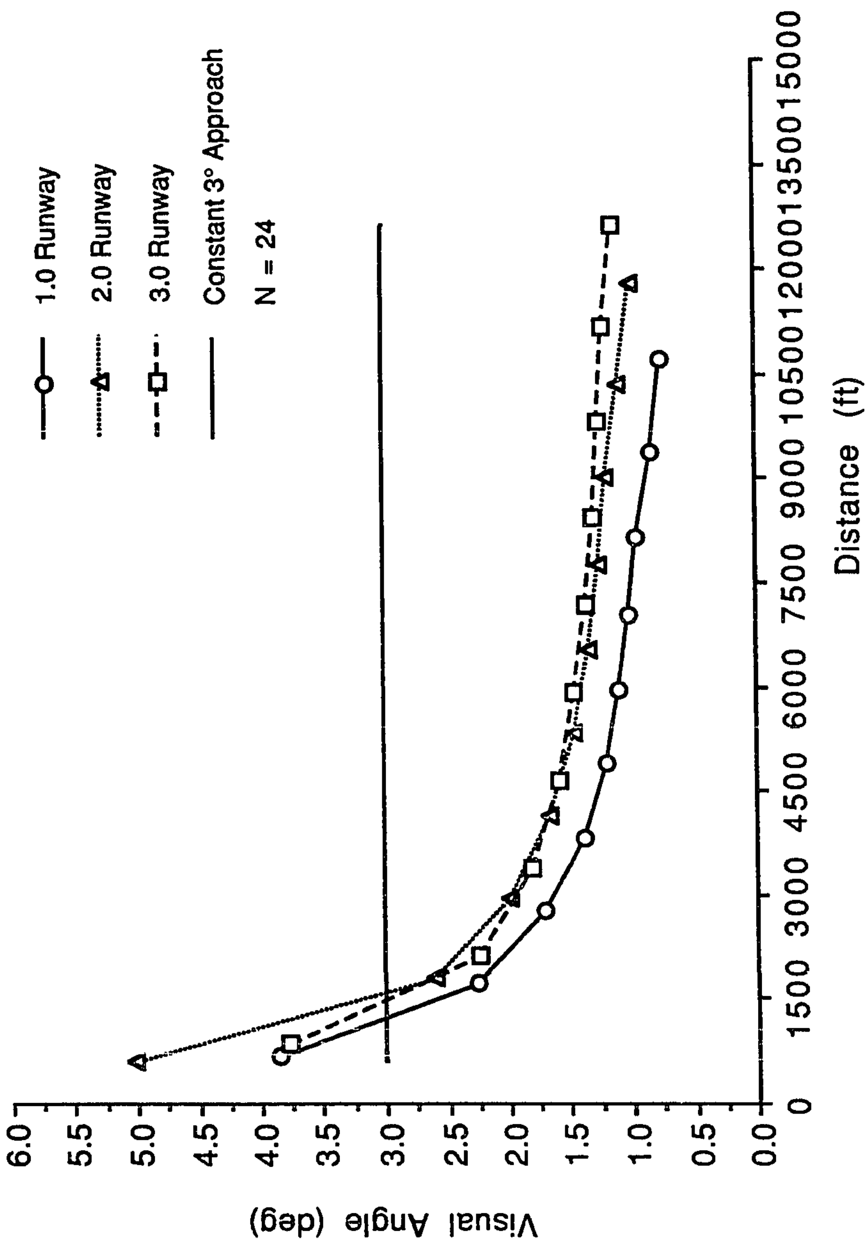
Trend Analysis Table

DISPLAY INFORMATION

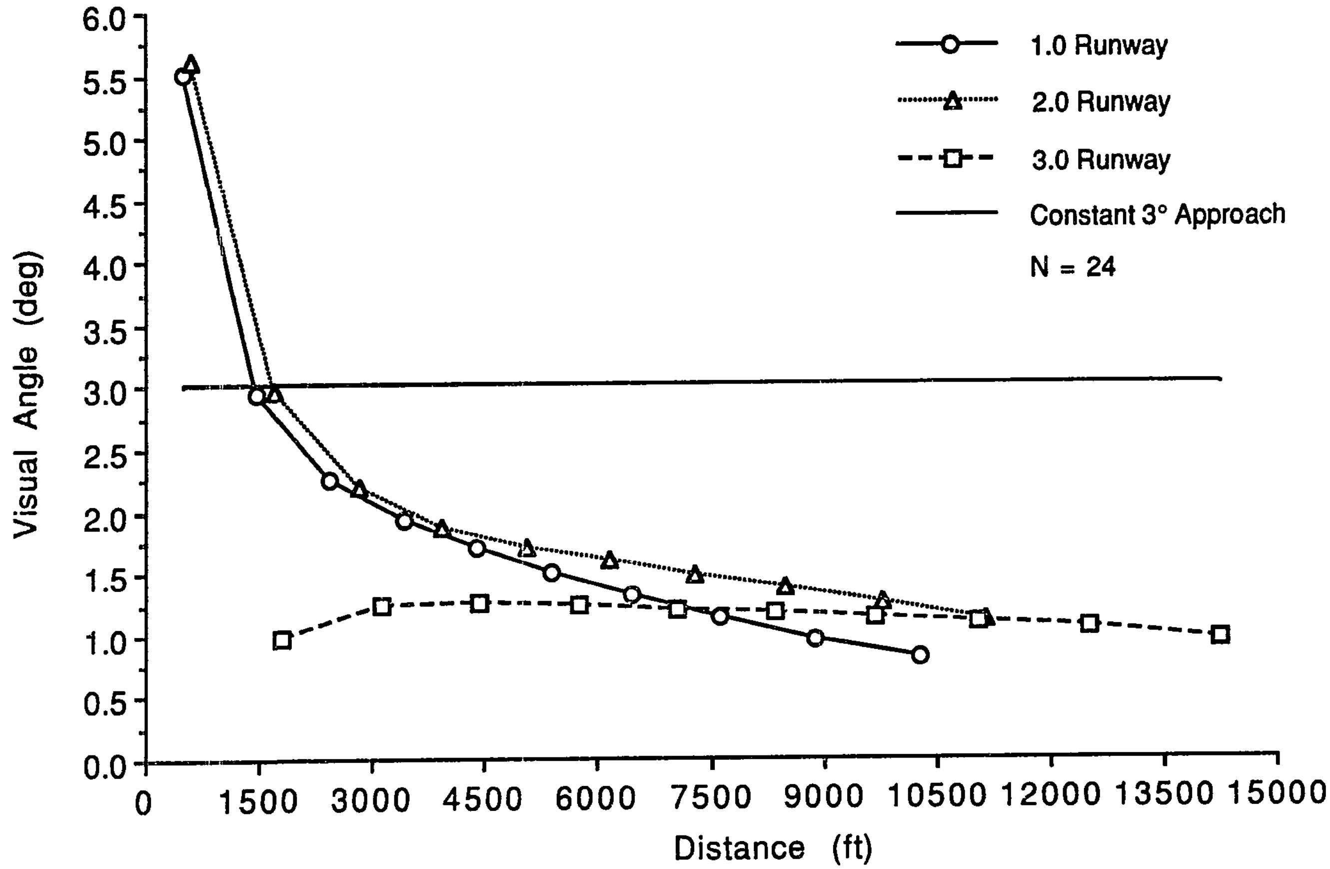
RUNWAY SIZE	None	Runway Marking	Matching Form Ratio
1.0	Altitude (z) = linear, cubic	Altitude (z) = linear, quad-ratic, cubic	Altitude (z) = linear
2.0	Altitude (z) = linear, quad-ratic	Altitude (z) = linear, cubic	Altitude (z) = linear
3.0	Altitude (z) = linear, quad-ratic, quartic	Altitude (z) = linear	Altitude (z) = linear, quad-ratic

Appendix I

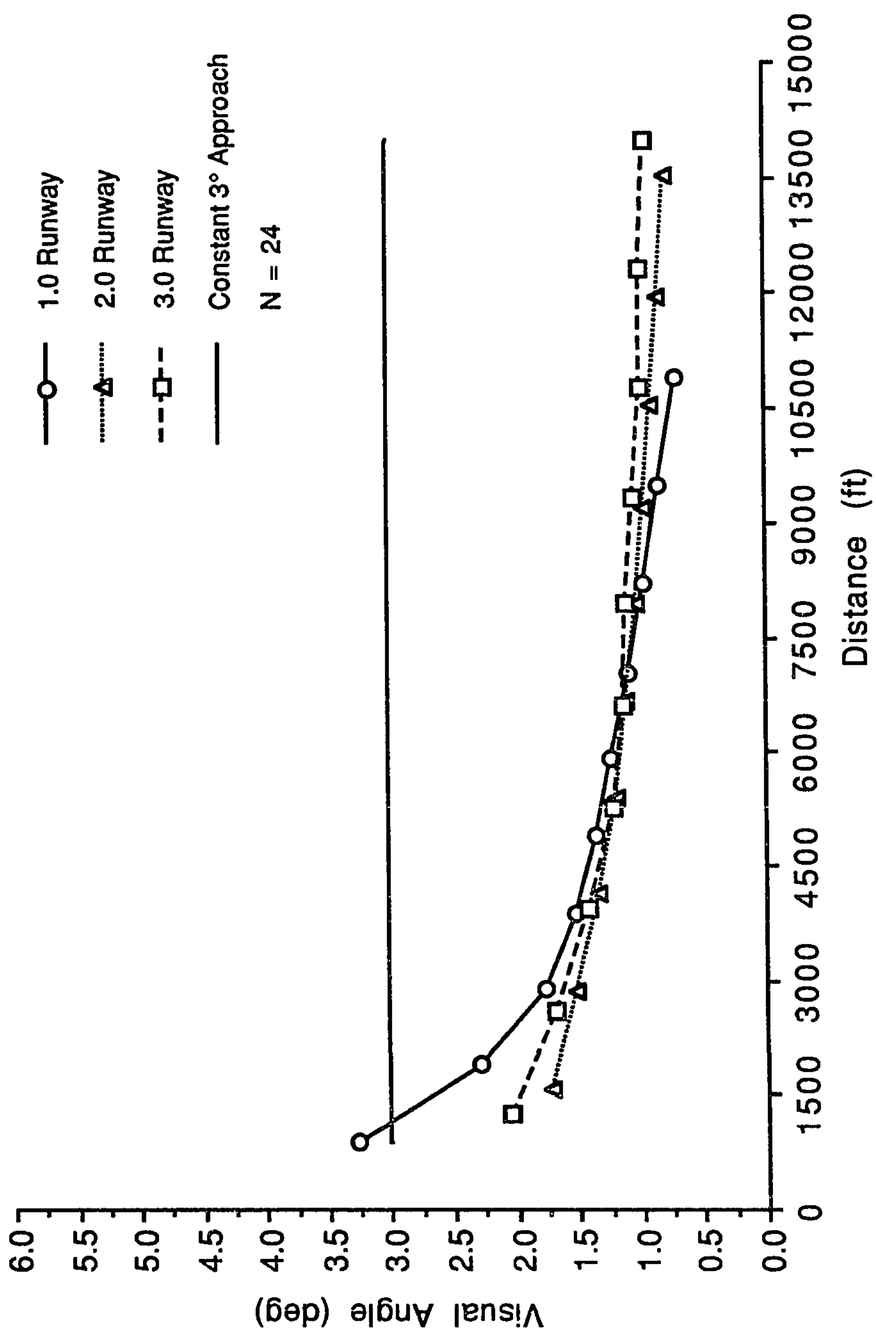
Visual Angle Graphs



Visual angles subtending runway length calculated from the generated approach path for the none condition.



Visual angles subtending runway length calculated from the generated approach path for the runway marking condition.



Visual angles subtending runway length calculated from the generated approach path for the matching form ratio condition.