COMPARISON OF THE VISUAL PERCEPTION OF A RUNWAY MODEL IN
PILOTS AND NONPILOTS DURING SIMULATED NIGHT LANDING APPROACHES

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16. Abstract

At night, reduced visual cues may promote illusions and a dangerous tendency for pilots to fly low during approaches to landing. Relative motion parallax (a difference in rate of apparent movement of objects in the visual field), a cue that can contribute to visual judgments of glide path angle, was studied for its effect on the nighttime approach problem in two experiments.

In the first experiment, 16 pilots and 16 nonpilots adjusted the slant of a model runway to make it appear horizontal under nighttime conditions on dynamic trials as the model approached them, and on static trials with the model stationary. In the second experiment, 12 pilots and 12 nonpilots performed the same task in dynamic trials while viewing the model in a dark field as before, and while viewing the model within a window which provided a stable visual frame of reference. Pilots also made supplementary judgments in which they verbally estimated magnitude of simulated approach angle in degrees or adjusted the model to produce a 3° approach angle.

Neither flying experience nor a visual frame of reference enhanced sensitivity to relative motion parallax. However, errors in horizontal adjustments were smaller in pilots, indicating that flying experience enhances other cues in the runway image. Direct judgments of approach angle magnitude indicated overestimation by an approximate factor of 2. These findings give further evidence of large visual illusions in the nighttime situation and indicate that the ineffectiveness of relative motion parallax may be an important part of the night approach problem.

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COMPARISON OF THE VISUAL PERCEPTION OF A RUNWAY MODEL IN PILOTS AND NONPILOTS DURING SIMULATED NIGHT LANDING APPROACHES

Introduction.

The dangerous tendency of pilots to fly too low during night visual approaches to landing has long been recognized as an important problem (21), but little research has been concerned with identifying the important visual cues for judgment of approach angle (17,30). In this context, relative motion parallax is one of the visual cues most frequently suggested as contributing to visual judgments of angle of approach (7,11,13,14,15,24,28,29). Relative motion parallax is defined as a difference in rate of apparent movement of objects in the visual field (4,9). In approaches to landing, all objects in the image of the ground plane appear to move directly away from the aim point in a complex pattern of apparent velocities which is a function of glide path angle and approach speed (7).

Several laboratory studies suggest that relative motion parallax can enhance the perception of slant or shape of a surface when other cues to orientation are present (2,3,22,26). These studies do not, however, provide data that might be used to predict whether relative motion parallax would be effective during approaches to landing, or if so, at what approach speeds and distances from the runway it would be an effective cue.

Kraft (17) has shown that the presence of low values of relative motion parallax that occur at distances greater than 4 miles from runway threshold did not prevent experienced pilots from flying below the proper glide path when upsloped terrain was behind the runway during simulated approaches. Mertens (21) studied the effectiveness of relative motion parallax due to both radial and vertical motion on the perceived orientation of a runway model by nonpilots in the segment of simulated approaches between 1.33 and 4.33 nautical miles from threshold. Again, no effect of relative motion parallax of practical significance was observed. He suggested that the effectiveness of relative motion parallax in judgments of the model runway orientation might be enhanced by the cockpit window and by flying experience. These variables were examined in the experiments described below regarding their relation to the effectiveness of relative motion parallax in the perception of the horizontal orientation of a moving runway model. Several other variables were studied in these experiments including direction of the model in the visual field and the psychophysical method by which perceived orientation was measured. Judgments of a stationary model were obtained in addition to those involving radial motion in order to assess the effect of relative motion parallax.

Judgments of horizontal orientation in the experiments described below concerned the geographical slant of the runway as distinguished from its optical slant (θ). Optical slant is defined as the slant of a surface relative to the line-of-sight to the surface; geographical slant is defined as the slant of a surface relative to gravity. The perception of geographical slant involves both perception of optical slant and perception of angular position (or height) in the visual field relative to the straight-ahead direction. Although judgment of optical slant is most similar to the pilot's visual task in judging approach angle, the accuracy of judgments of geographical slant should reflect the effects of stimulus variables on that component involving perceived optical slant. The task involving perception of geographical slant was first used for study of slant cues in the runway image by Wulfeck et al. (30). It has the very useful characteristic of having meaning to both pilots and nonpilots. That feature permits the use of nonpilots as subjects and allows direct comparison of responses of pilots and nonpilots.

EXPERIMENT I

This experiment compared the judgments of horizontal orientation of a runway model in pilots and nonpilots in order to evaluate the effect of flying experience on the effectiveness of relative motion parallax. Relative motion parallax was varied by presenting the runway model in both static and radial motion (dynamic) conditions. The psychophysical method of adjustment was used instead of the modified method of limits used previously (21). The method of adjustment simulated more stable approach conditions. Observations were made with the model approaching from two different angles below the straight-ahead direction in the visual field in order to study the effect of perceived direction in the visual field on adjustments of the model to the apparent horizontal orientation. Since relative motion parallax increases with optical slant when approaching a surface at a given approach speed, it might be more effective at the 12° viewing angle than at the 3° viewing angle.

Pilots also made verbal judgments of runway characteristics on a final static trial. Judgments of the magnitude of approach angles (θ) that were produced on this final trial were obtained to aid in interpretation of errors in horizontal orientation adjustments.

Method.

Subjects. Sixteen male pilots and sixteen male nonpilots served as subjects. All nonpilots and 10 pilots were paid an hourly wage. The other six pilots were volunteers who served without pay. The pilots were divided into two groups that were matched with respect to average total hours of flying time. The total flying hours of Group A ranged from 750 to 6,500 with a mean of 2,963 and a standard deviation of 2,197 hours. The total hours of pilots in the second group ranged from 800 to 5,800 with a mean of 2,831 and a standard deviation of 1,847 hours. The ages of pilots varied from 24 to 44

years. The ages of nonpilots varied from 18 to 29 years. Nonpilots were randomly divided into two groups. Nonpilots did not have experience as either student pilots or pilots. All subjects had at least 20/20 acuity, with correction if necessary.

Apparatus. The apparatus has been described in detail previously (20) and is shown schematically in Figure 1. The runway model (R) was the same as that used in the previous experiment. The model simulated the lighting of a 170-ft by 6,000-ft runway with an ALSF-2 approach lighting system without sequenced strobe lights. The center of the model (F) moved toward the observation point (O) along an apparent path (Q) such that the center of the model was always at a constant visual angle (β) below the straight-ahead direction (H) in the visual field. That angle β will hereafter be called the viewing angle and was 3° on half the trials and 12° on the rest. An optical system composed of two mirrors (M1 and M2) was used to accomplish the change in viewing angle. The slant of the model (θ) was varied by rotation in the vertical plane and was measured accurately to the nearest 0.1°. Only runway and approach lights were visible in the scene. The intensity of these lights was adjusted to appear subjectively realistic to two experienced pilots who did not otherwise participate in the experiment. Viewing was monocular to eliminate binocular disparity, which is not normally an effective cue during approaches to landing (24). The viewing aperture was 12 mm in diameter.
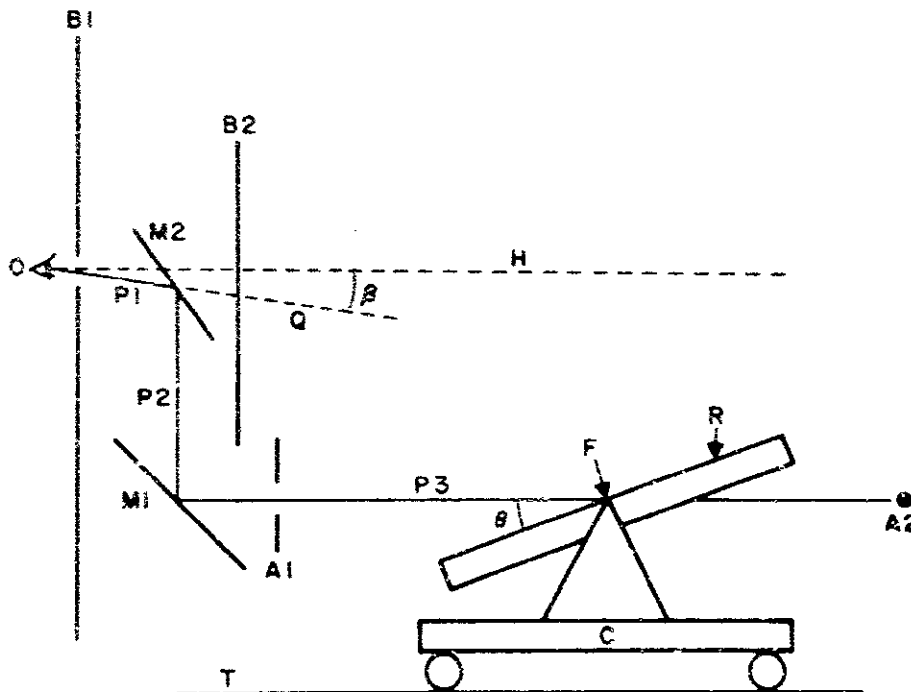

FIGURE 1. Schematic diagram of apparatus (A1 and A2, removable targets for aligning optical system; B1, baffle; B2, baffle in Experiment I, light box in Experiment II; C, cart; F, rotation axis; H, horizontal line of sight; M1 and M2, mirrors; O, eye position; P1, P2, P3, segments of optical axis; Q, apparent axis of radial motion; R, runway model; T, track; β, viewing angle; θ, model slant).

A chin rest and head rest were used to position and steady the subject's head during observations.

Procedure. The subjects adjusted the model to appear horizontal using the method of adjustment. When the subject pushed a toggle away from himself, the model rotated away from him (far end downward), and when he pulled the toggle toward himself, the model rotated toward him (near end downward). The model rotated as long as the toggle was actuated and stopped rotating immediately when the toggle was released. Eight of the pilots and eight of the nonpilots adjusted the model to appear horizontal with the 3° viewing angle. The other half of the pilot and nonpilot groups adjusted the model to appear horizontal with a 12° viewing angle. All subjects made adjustments in both static and dynamic observation conditions. In the dynamic condition, the model was visible as it moved toward the observer at a constant simulated speed of 140 knots over a range of simulated distances from 4.33 to 1.33 nautical miles from runway threshold. During slant adjustments in both static and dynamic conditions, the model rotated in the vertical plane at a constant rate of 10° per minute. At the beginning of both dynamic and static trials, the orientation of the model was slanted with respect to the observer's line-of-sight to the model's center (and axis of motion P) by either 0.25^O or 3°. The center of the model corresponded to a simulated distance of 1,500 ft from threshold and was located at the middle of the simulated touchdown zone lighting system. It was determined prior to the experiment that for both viewing angles most observers would see the model as horizontal within this range of slants. Following practice in the dynamic condition, four test trials were given with starting angles alternating between 3° and 0.25^O. The order of starting angles was reversed for half the subjects. Following practice in the static condition, two trials were given with each of the two starting slants at each of the three distances. Twelve static test trials were given each subject in blocks of three trials with the distances given in descending order in each block. The same two starting slants were used in static trials and were again alternated from trial to trial. Half the subjects in each viewing-angle condition had all dynamic adjustments before beginning static adjustments. The order was reversed for the remaining subjects.

When pilots had finished all adjustments to the horizontal orientation in static and dynamic conditions, the model was set at the 1.33-nautical-mile distance and at the 3° starting angle. The lights of the model were then turned on and the pilots were asked to adjust the model to appear horizontal. Next, they were asked to make several verbal judgments concerning characteristics of the simulated runway. These included (i) the simulated approach angle, i.e., the magnitude in degrees of the angle between the line-of-sight to the runway threshold and the plane of the runway, (ii) the simulated distance to runway threshold in feet or miles, (iii) the altitude above the ground plane in feet, and (iv) the simulated runway length in feet. These instructions may be characterized as "objective" instructions, as discussed by Carlson (1). Nonpilots did not make verbal judgments.

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Results.

Adjustments to Horizontal Orientation. The adjusted slant of the model with respect to the axis of radial motion (angle θ in Figure 1) when the model appeared to be horizontal was the dependent variable and will be referred to as generated approach angle (3θ). For purposes of analysis, generated approach angle measurements were obtained from chart records of dynamic trials for the specific simulated distances of 1.33 and 2.33 nautical miles from threshold for comparison with static judgments at the same distances. Data for the 3.33-nautical-mile distance position were not analyzed since on many trials of the dynamic condition, the model had not yet been adjusted to the apparent horizontal orientation by the time it had reached that distance.
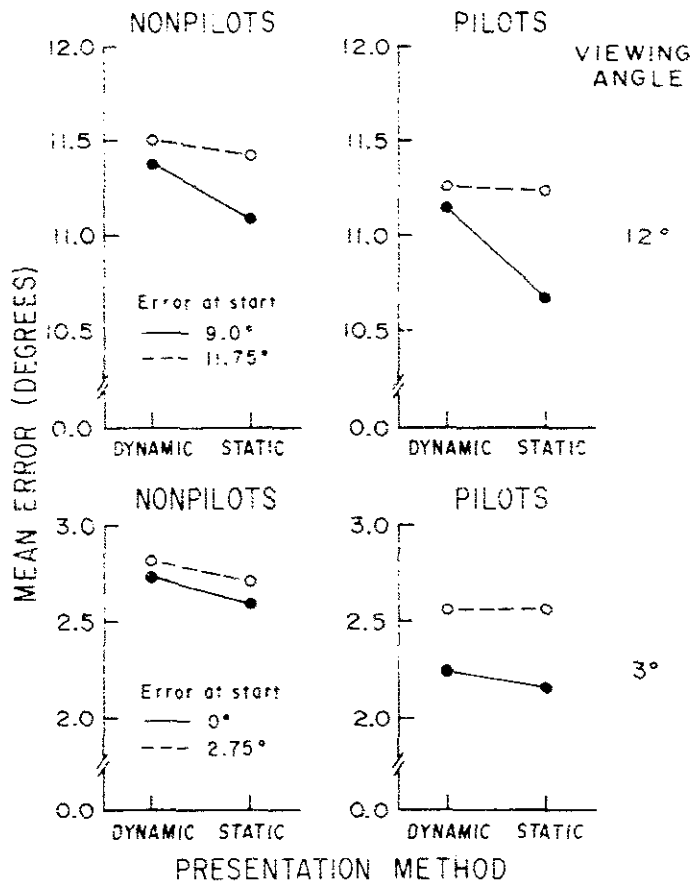

FIGURE 2. Errors in judgments of horizontal orientation as a function of flying experience, presentation method, viewing angle, and starting angle.

At the 3° and 12° viewing angles, generated approach angles of 3° and 12°, respectively, would have indicated accurate perception. Error scores were calculated for generated approach angle responses by subtracting

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response values from the values that would have indicated accurate perception. Values of 0 used as starting angles (0.25° and 3°) are identified in Figure 2 in terms of the error magnitudes they represented. At the 3° viewing angle, the 0.25° and 3° starting angles represent errors of 2.75° and 0°, respectively. At the 12° viewing angle, the corresponding errors are 11.75° and 9°. A split-plot factorial analysis of variance was used to assess the effects of flying experience, viewing angle, distance, presentation method (dynamic vs. static), and starting angle. The effects of these variables excluding distance, which had little effect, are illustrated in Figure 2.

The tests of greatest interest with regard to the possible effectiveness of relative motion parallax were the main effect of presentation method, comparing the responses in static and dynamic conditions, and the interaction of flying experience with presentation method. The main effect of presentation method was significant ($p < .05$) and indicated that errors in static adjustments were significantly smaller by 0.15° on the average than those in the dynamic condition. That finding is contrary to the expectation that if relative motion parallax in the dynamic condition were an effective cue it would reduce errors. This effect is on the same order of magnitude as the error of measurement inherent in responses (0.1°) and therefore may not be of practical significance. Furthermore, the interaction of flying experience with presentation method was not significant, suggesting that pilots did not have greater sensitivity to relative motion parallax than did nonpilots.

The main effect of flying experience was significant ($p < .01$) with pilots adjusting the model to appear horizontal with errors 0.3° less than nonpilots on the average. The main-effect viewing angle was also significant ($p < .01$). The increase in errors at the 12° viewing angle was approximately equal to the 9° difference in viewing angle between the 3° and 12° conditions. Only a small difference (0.33°) in the generated approach angle which was seen as horizontal resulted from a relatively large 9° change in viewing angle. The main effect of starting angle was also significant ($p < .01$) with errors averaging 0.26° less with the 3° starting angle than with the 0.25° starting angle. All but one of the significant interactions in the present analysis involved this variable. Starting slant had a significantly greater effect in pilots than in nonpilots ($p < .05$) and in static judgments ($p < .01$) than in dynamic judgments. The second order interaction of starting angle, viewing angle, and presentation method was also significant ($p < .05$) and reflects a greater interaction of presentation method and starting angle at the 12° viewing angle than at the 3° angle.

The only significant ($p < .05$) effect involving distance was the small interaction of viewing angle with distance. At the 3° viewing angle, mean errors increased by 0.07° as distance decreased from 2.33 to 1.33 nautical miles from threshold, and at the 12° viewing angle mean errors decreased by 0.03° over the same distance interval. The magnitude of this interaction, although statistically significant, does not seem to be of practical

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significance. The main effect of distance was small and insignificant. Generated approach angle errors were 0.02° less at 2.33 nautical miles than at 1.33 nautical miles from threshold.

Verbal Judgments of Runway Characteristics. On one final trial given only to pilots, verbal judgments of the runway were made after they adjusted it to appear horizontal. Means, medians, and standard deviations are given in Table 1 for the approach angles to threshold that pilots generated in the horizontal adjustments, for verbal judgments of the magnitude of those generated approach angles, and for error scores obtained by subtracting the magnitude of the generated approach angle produced by each pilot from his verbal judgment of magnitude of that angle.

TABLE 1.   Generated Approach Angles and Corresponding Verbal
            Judgments of Angle of Approach to Runway Threshold
            as a Function of Viewing Angle

Viewing Angle		Generated Approach Angle (A)	Verbal Judgment (B)	Error (B-A)
3°	Mean	1.17°	2.72°	1.55°
	σ	0.74°	1.03°	
	Median	0.71°	2.50°	1.79°
12°	Mean	1.99°	3.65°	1.66°
	σ	0.69°	2.76°	
	Median	1.96°	2.75°	0.79°

In horizontal orientation adjustments, it was shown above that errors were much greater at the 12° viewing angle. Mean judgments of approach angle as indicated by verbal responses show no significant increase in errors at the 12° viewing angle, and median values show a decrease. This finding illustrates the independence of errors in adjustments to horizontal orientation and judgments of approach angle. Verbal judgments also consistently overestimated the physical magnitude of generated approach angles.

Judgments of simulated altitude, distance, and runway length are summarized in Table 2 and are presented along with a summary of the actual simulated values of altitude that were produced when observers adjusted the model to appear horizontal on the same trial. In agreement with judgments of approach angle, judgments of altitude overestimated the simulated values that were produced when pilots adjusted the model to appear horizontal. Errors in judgments of altitude were greater at the 3° viewing angle, as was the case with medians of verbal judgments of approach angle. Variability of responses

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TABLE 2. Verbal Judgments of Distance From Threshold, Altitude Above
Ground, and Runway Length as a Function of Simulated Values

Viewing Angle		Altitude(feet)		Distance(feet)		Length(feet)	
		Generated Altitude	Verbal Judgment	Simulated Distance	Verbal Judgment	Simulated Length	Verbal Judgment
3°	Mean	163	275	8,000	3,660	6,000	6,250
	σ	103	85		1,320		1,773
	Median	153	300		3,000		6,000
12°	Mean	279	325	8,000	7,560	6,000	6,500
	σ	96	210		7,320		1,414
	Median	272	322		5,340		6,000

was also greater at the 12° viewing angle in both altitude judgments and
judgments of approach angle. Judged distance of the runway threshold from
the pilot was greatly underestimated at the 3° viewing angle. Although
judgments of distance were considerably closer to the simulated value at the
12° viewing angle, responses were more variable. Judgments of runway length
appear to be more accuate and less variable than other verbal judgments, and
variability is not increased at the higher viewing angle.

Discussion.

The results of the present experiment confirm previous findings in this
laboratory (21) that relative motion parallax in the runway image has little
or no effect on the perception of orientation of the runway model at simu-
lated distances as near as 1.33 miles from runway threshold and at simulated
approach speeds up to 140 knots. It was further determined that the flying
experience of pilots does not enhance their sensitivity to relative motion
parallax. Since pilots did, however, have significantly fewer errors than
nonpilots in both the static and dynamic conditions, it must be concluded
that their flying experience did have an effect on use of some other cue in
the runway scene. Other cues that might be involved are size cues, including
image shape and linear perspective, and the intensity gradient in the image
of the runway and approach lighting. Runway image shape has been shown to be
important in a study by Wulfeck et al. (30). The importance of intensity
cues in the runway image has been demonstrated by Kraft (18).

The relatively small effect of variation in viewing angle from 3° to 12°
on generated approach angles and consequent large increase in errors at 12°
suggest that direction of the runway in the visual field is not perceived

accurately in the present viewing conditions in which no extra runway geographic references, such as the horizon, were simulated. The fact that verbal judgments of approach angle on the final trial show no increase in errors with increasing viewing angle also suggests that the increase in error of horizontal orientation adjustments was due mainly to increased error in perceived position of the model in the visual field. Just how variation in viewing angle and optical slant of the stimulus affect the perceived direction of the horizon and whether variation in perceived direction of the horizon can influence judgments of approach angle should be examined further. In the present experiment, error in judgments of approach angle was independent of viewing angle.

The relatively constant magnitude of perceived approach angle errors, which indicated overestimation of approach angle by an approximate factor of 2, is of a very serious magnitude in the context of the aircraft landing approach situation. Overestimation of optical slant of the runway might occur as a consequence of a perceptual organizing process called the equidistance tendency (8,9). The equidistance tendency has been shown to make objects appear at the same distance to the extent that effective visual cues indicating a difference in distance are absent. Gogel (8) has cited several examples of reduction in apparent slant of stimuli with respect to a vertical reference plane as a function of cue reduction. Such effects are in the same direction as overestimation of slant with respect to a horizontal reference plane. Future research should measure the perceived direction of the runway relative to the apparent direction of the horizon and apparent magnitude of the generated approach angle in order to discriminate between overestimation of approach angle due to the equidistance tendency and errors due to misjudgment of visual direction. E. R. Wist (personal communication) has suggested that the hypothesized operation of the equidistance tendency in the night approach situation would be supported if errors in approach angle judgments increased with viewing time as has been found to be the case in errors due to the equidistance tendency in the perception of depth in a slanted line (23) or between objects (8).

The significant effect of starting angle on generated approach angle was present in the responses of both pilots and nonpilots, but was greater in pilots and with the 12° approach angle. Starting angle had no significant effect in a previous experiment (21) in which the perceived horizontal orientation of the runway was measured by a modified method of limits rather than the method of adjustment. A possible relation of the effect of starting angle to perceptual events in the situation is suggested by the comments of some subjects during debriefing that the apparent height of the model in the visual field appeared to decrease as they decreased its optical slant. It is possible that the optical slant of the model perceived initially on a given trial determined the perceived direction of the model in the visual field. Since the model would be seen as lower in the visual field with the 3° starting angle, it would be adjusted to a greater value of optical slant by the observer in order to make it appear horizontal. This possibility could be checked by measuring both the perceived position of the model in the visual

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field and direct judgments of approach angle in the two viewing angle conditions. Why the effect of starting angle should be greater in pilots is unexplained. Perhaps the errors of pilots in perceiving direction in the visual field were smaller than those of nonpilots.

An alternative possible "explanation" of the effect of starting angle is in terms of adaptation-level theory. The effect of starting angle seems related to the stimulus series order effect in the perception of a slanted disc found by Smith (27). He observed that apparent slant with respect to the frontal (vertical) plane was significantly greater when the stimulus series was presented in order of increasing slant with respect to the frontal plane than when the stimulus series was presented in order of decreasing slant. Smith interpreted this finding in terms of the repellant effect of anchoring at extremes of the stimulus series. Anchoring effect refers to the shift in adaptation level caused by extreme stimuli, which in the present experiment would correspond to the starting angle (optical slants of 3° and 0.25°). The greater effect of starting angle in pilots as compared with nonpilots might be explained by adaptation-level theory through the residual effects of past flying experience on adaptation level. Although pilots have a different task when trying to generate the ideal approach angle, their visual experience with runways, especially in night approaches, might have an effect on adaptation level that would generalize to the present experimental task by virtue of the similarity of stimuli produced in real and simulated runways. The pilot's past experience would most probably have been with generated approach angles close to 3° on the average due to greater information, including sources other than natural cues in the visual scene in the real approach situation. This would increase their adaptation level, thereby causing their generated approach angles to be greater than those of the nonpilots who had no such prior experience. Furthermore, the effect would be greatest at the 3° starting angle because of its closer proximity to the adaptation level.

A third possible "explanation" of the starting angle effect might be in terms of the equidistance tendency, mentioned above, operating in conjunction with another perceptual organizing process called the adjacency principle (8). According to the adjacency principle, the equidistance tendency operating between objects such as near and far ends of the runway would vary inversely with their directional separation in the visual field. The result in the present situation would be an increase in apparent (optical) slant of the model with respect to the line-of-sight due to the equidistance tendency which would be greater with the 0.25° than with the 3° starting angle. This interpretation assumes that strength of relative size cues would not change significantly with change in starting angle.

The greater accuracy and lower variability in verbal judgments of runway length suggests that these judgments were relational judgments involving known size as well as relative size cues in the image. The known standard size of approach zone and touchdown zone lighting could have been used in conjunction with the relative image size of the runway edge lighting

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to enable greater accuracy in length judgments. In contrast, there were no
reference objects in the scene that had known altitude, distance, or
orientation that would have permitted those judgments to be made on a similar
relational basis. The importance of "known size" in length judgments might be
determined in judgments of length by two groups of nonpilots, one group given
information about the length of the touchdown zone lighting system and the
other group not given that information. Judgments of runway length would be
expected to be much more accurate and less variable in the group given size
information.

As mentioned above, Kraft (18) found that highly experienced pilots flew
below the proper glide path when upsloped terrain was behind the runway during
simulated approaches. Kraft interpreted that finding as the result of pilots'
attempting to maintain a constant visual angle height in the retinal image of
the city lights behind the runway. The present findings suggest another
contributing factor. In the present study it was shown that the geographic
orientation of runways is not perceived accurately. Pilots may learn to
produce the proper approach angle in nighttime approaches, therefore, by
judging the optical slant of the runway rather than geographic slant. Since
most runways are level, that would not cause a problem until a geographically
slanted runway is encountered. Then a pilot unfamiliar with sloped runways
might attempt to use the same optical-slant criterion used previously with
level runways since he would not perceive geographical slant accurately. That
would cause a low approach with an upsloped runway or a high approach with a
downsloped runway in agreement with anecdotal reports in the literature (24).

The most important finding of the present experiment was that verbal
judgments of approach angle and altitude as well as horizontal orientation
adjustments indicated perceptual overestimation of position relative to the
generated approach path. That finding reinforces the suggestion that there
is a direct perceptual basis for the documented tendency of pilots to fly
lower approaches at night. Additional responses involving adjustment of the
model to produce a 3° approach angle also indicated overestimation of approach
angle in the following experiment.

EXPERIMENT II

The second experiment examined the effects of a visual frame, simulating
the cockpit window, on the effectiveness of relative motion parallax in the
task of adjusting the runway model to appear horizontal as it approached the
observer. It was thought that relative motions between lights of the runway
and the stable window might make relative motions between points within the
runway image more salient and thereby enhance the motion parallax cue, since
thresholds for perception of relative motion are smaller than thresholds for
absolute motion (10,12). In addition, the effect of flying experience was
reexamined with regard to its possible interaction with the presence of a
visual frame. Two psychophysical methods were also compared. One was the
modified method of limits used in an earlier experiment (21) and the other was
the method of adjustment that was used in Experiment I. This variable was

added to the present experiment to permit further study of the significant interaction of starting angle with psychophysical method that occurred in the above experiments.

In Experiment I, pilots' verbal judgments of approach angle greatly overestimated the angle of approach. An additional task was added in the present experiment for pilots in order to reexamine this finding in a task that would be more "natural." Pilots were asked to adjust the model to appear "like a runway does when on a 3° glide path during an approach to landing." Since pilots learn to identify acceptable angles of approach and 3° is a common glide path setting for Visual Approach Slope Indicators, it was reasoned that this instruction would have similar meaning to different pilots and would assess errors at that point on the continuum of perceived approach angle where judgments should be most accurate. Any large illusions observed with this instruction would reinforce the previous suggestions that perceptual errors may cause low approaches at night when vertical guidance is entirely under visual control.

Method.

Subjects. Twelve male pilots and twelve male nonpilots served as subjects and had at least 20/20 acuity, with correction if necessary. The nonpilots were paid an hourly wage. The pilots were all professional pilots in the employ of the FAA and participated during duty hours. Their total hours of flying experience ranged from 1,350 to 13,750 hours of flying time, with a mean of 9,360 hours and a standard deviation of 3,416 hours. The ages of nonpilots ranged from 19 to 29 years. The ages of pilots ranged from 39 years to an estimated maximum of about 60 years.

Apparatus. The apparatus was identical to that used in Experiment I with the exceptions that mirror M1 was replaced with a mirror having 70-percent reflectance and 10-percent transmittance, and a light box was placed at the position of baffle B1 to produce a luminous square frame with a dark area in the center of which the model was seen during experimental trials. The center of the runway model appeared 3° below the center of the square. The center of the square window was in the straight-ahead direction from the observation point. The height and width of the dark area in the center of the frame was 18°. The distance of the frame from the observer's eye was 61 cm.

Procedure.

a. Judgments of Horizontal Orientation. In both psychophysical methods, subjects controlled the model to make it always appear horizontal as the model approached the observation point. The method of adjustment was identical to that of Experiment I. The procedure for the method of limits was identical to the procedure used by Mertens (21). In the latter procedure, the model was constantly rotating in the vertical plane as it approached the observation point. The subject's task was to control the direction of

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rotation to make it appear horizontal by reversing the direction of rotation with a pushbutton every time the model appeared to be rotating away from the horizontal orientation in either direction. The model was again visible as it approached from a simulated distance of 4.33 to 1.33 nautical miles from threshold at the same approach speed and rate of rotation that were used in Experiment I. All trials with a particular psychophysical method were given before trials with the other method were begun. The order in which the two methods were given was reversed for half the subjects. With both psychophysical methods, two practice trials were given and followed by four test trials. Either the first two test trials or the last two test trials were given with the visual frame of reference present. The order of trials in which the frame was present was the same for both psychophysical methods in a given subject. Half the subjects had the frame present on the first two test trials with each psychophysical method and the other half of the subjects had the frame present on the last two test trials. For the two trials in a given condition of psychophysical method and visual frame, one trial was given with a 3° starting angle and one trial was given with a 0.25° starting angle. These two starting angles were alternated from trial to trial throughout the experiment. Viewing was monocular with the right eye.

b. Judgments of 3° Approach Angle. After all judgments of horizontal orientation had been completed, the pilots were asked to adjust the model as it approached them on two trials so that it looked "like a runway does when on a 3° glide path during an approach to landing." This instruction was designed to elicit the learned perceptual criterion that a pilot uses in flying night approaches. The 3° value seemed appropriate for this group of pilots since the Visual Approach Slope Indicator and the Instrument Landing System at the base airport for these pilots were set to define 3° and 2.9° approach paths, respectively.

Results.

As in Experiment I, the adjusted slant of the model with respect to the approach path, angle θ, was the dependent variable and was measured continuously as a function of distance over the range of simulated distances from 4.33 to 1.33 nautical miles. Since no static condition was involved in this experiment, rather than measuring generated approach angle at two specific distances, the mean generated approach angle values were averaged over both 1-nautical-mile segments between 3.33 and 1.33 nautical miles from threshold to increase the reliability of measurements. The method of scoring chart records has been described previously (21). The mean of the two values for an individual in each experimental condition was subtracted from 3° to obtain an error score for each distance segment. A response of 3° would have indicated accurate perception in both judgment of horizontal orientation and judgment of the 3° approach angle.

Adjustments to Horizontal Orientation. A split-plot factorial analysis of variance was used to assess the effects of flying experience (pilots vs. nonpilots), visual reference condition (frame vs. no frame), psychophysical

method (limits vs. adjustment), model slant at the start of a trial (starting slant errors of 0° or 2.75°), and distance interval (1.33-2.33 nautical miles and 2.33-3.33 nautical miles). All generated approach angles were less than 3° when the model was adjusted to appear horizontal. The visual frame had no significant effect and did not interact with other variables as can be seen in Figure 3. The mean generated approach angle errors for pilots and
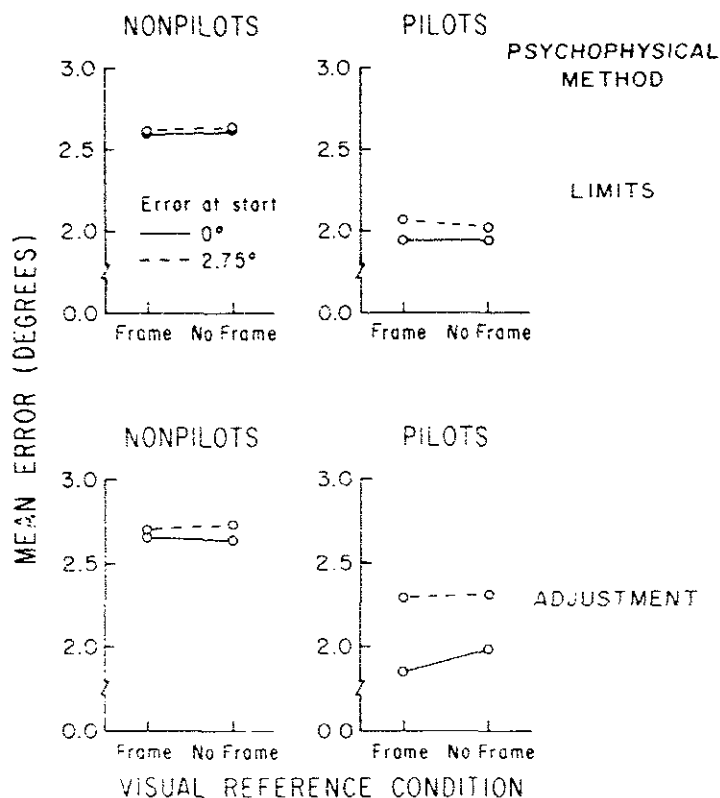

FIGURE 3. Errors in judgments of horizontal orienta-
tion as a function of flying experience, visual
reference condition, psychophysical method, and
starting angle.

nonpilots were 2.06° and 2.66°, respectively. This 0.60° difference in generated approach angle errors between pilots and nonpilots was statistically significant ($p < .01$). The only other statistically significant ($p < .01$) main effect was due to starting angle. Generated approach angle errors were on the average 0.14° greater when the starting angle was 0.25° rather than 3°. Several interactions of starting slant with other variables were significant. These included the first order interactions of starting slant with flying experience ($p < .05$), with psychophysical method ($p < .01$), and with distance ($p < .01$). Second order interactions involving starting slant were its interaction with flying experience and psychophysical method ($p < .05$) and its interaction with flying experience and distance ($p < .05$).

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The above-mentioned effects with the exception of the two involving distance are also illustrated in Figure 3. The first order interactions of starting slant and psychophysical method with flying experience reflect the much greater effect of starting angle in pilots and the greater effect of starting angle in the method of adjustment. The significant second order interaction of starting slant with psychophysical method and flying experience reflects the fact that by far the greatest effect of starting angle occurred in pilots who were responding with the method of adjustment. There was no significant main effect of distance, but the three significant interactions involving distance are illustrated in Figure 4.
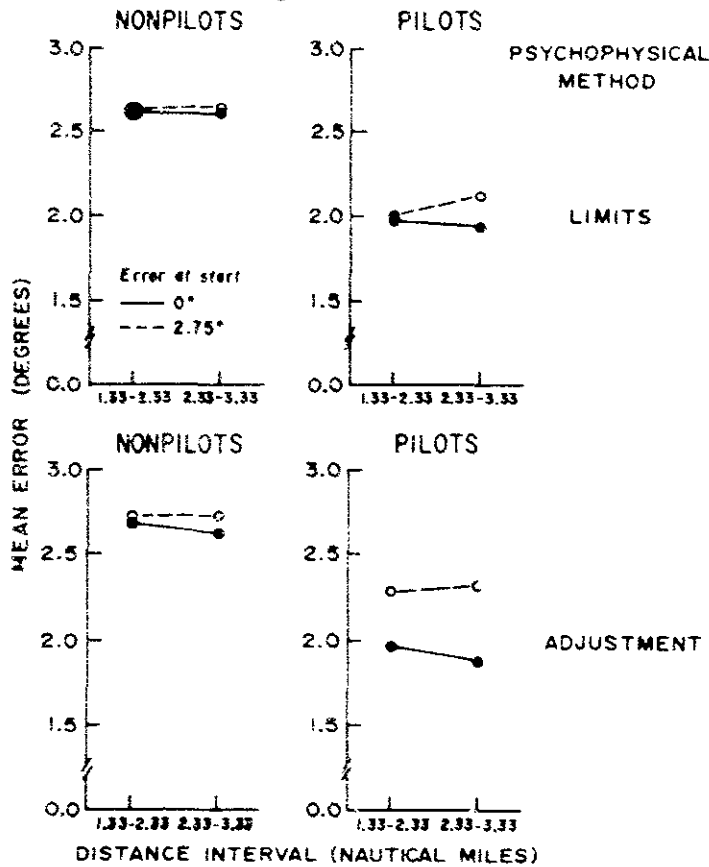

FIGURE 4. Errors in judgments of horizontal
orientation as a function of flying experience,
distance, psychophysical method, and starting angle.

The interaction of psychophysical method with distance is statistically significant (p < .05) although small. The significant (p < .01) interaction of distance with starting angle reflects a greater effect of starting angle at the farther distance. The significant (p < .05) interaction of distance and starting angle with flying experience reflects the fact that the interaction of distance with starting angle is larger in pilots. As can be seen in Figure 4, the significant interactions involving distance are of small magnitude and probably not of practical significance.

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Production of 3° of Approach Angles. Error scores of pilots for the 3° instruction were compared with error scores for the last two horizontal adjustment trials given under the same conditions. The variable concerning the visual frame was ignored for this analysis since preliminary analysis revealed that it had no effect. A split-plot analysis of variance was used with psychophysical method as a between-groups variable and three within-groups variables: type of response (3° approach angle adjustments vs. horizontal orientation adjustments), distance interval, and starting slant error. These data are illustrated in Figure 5.
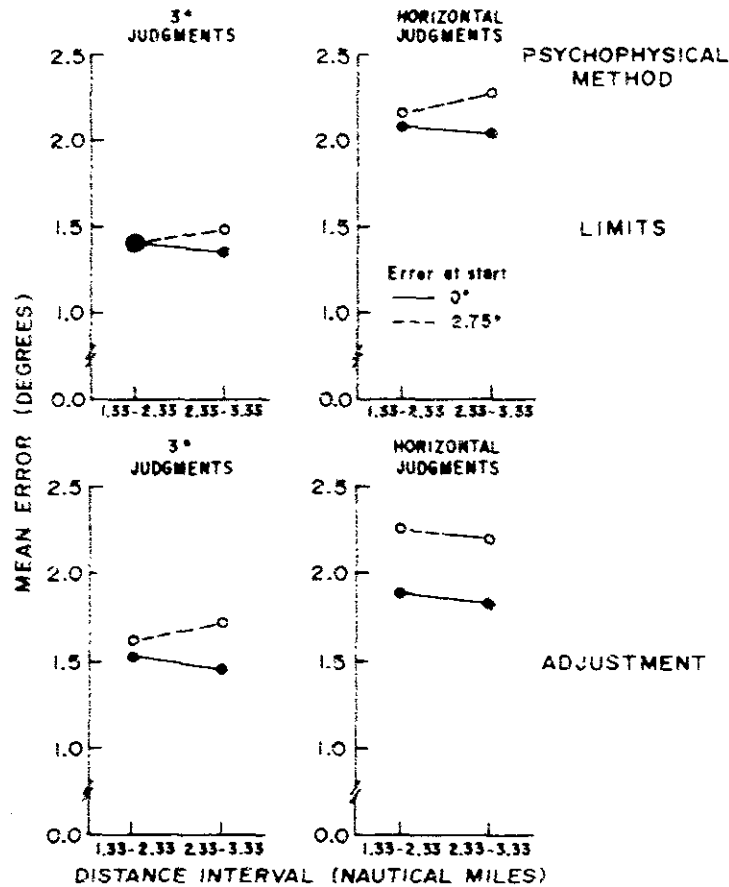

FIGURE 5. Errors in judgments of pilots of both 3° approach angle and horizontal orientation as a function of psychophysical method, distance, and starting angle.

Errors in 3° approach angle adjustments were significantly (p < .05) less than errors in horizontal adjustments. The mean error in the 3° task was 1.50° and in horizontal adjustments was 2.09°. The only other significant effect was the interaction of starting angle with distance. The effect of starting angle was significant in the distance interval between 3.33 and 2.33 nautical miles, but not in the nearer interval.

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Discussion.

The most important finding of Experiment II concerning the relative motion parallax in the runway image was that the presence of a stable visual frame did not enhance relative motion parallax as a cue for perception of runway orientation. That result adds to the evidence of previous experiments in this laboratory, which strongly suggests that relative motion parallax probably has no effect on perception of vertical position relative to the ideal approach path in night approaches when only runway lights are visible. The latter visual situation is commonly referred to as the "black hole" in aviation literature, and has long been considered the most dangerous approach-to-landing situation.

Another important finding of Experiment II was that pilots attempting to adjust the model to produce 3° approach angles under "objective" instructions (1) consistently overestimated approach angles by a factor of 2. That finding strongly suggests that the tendency toward low approaches at night is directly caused by overestimation at the perceptual level in judgments of approach angle. This interpretation assumes that the simulated approach scene in this laboratory contains essentially the same visual information that exists over the same distance range in the "real world" when only runway and approach lights are visible. This assumption should be tested by direct comparison of pilot judgments of approach angle under the same instructions in both simulated and real situations with similar lighting configurations.

Errors in adjusting the model to appear horizontal were lower in pilots than in nonpilots in Experiment II, corroborating a similar finding in Experiment I. The difference between responses of pilots and nonpilots, however, was 0.6° in Experiment II as compared to 0.3° in Experiment I. This greater effect of flying experience in Experiment II is possibly associated with a higher average total hours of flying experience in the pilots who served in Experiment II. The average total number of hours was approximately 9,000 in Experiment II as compared with 2,000 in Experiment I. This finding suggests that the effects of flying experience on judgments of approach angle should be studied more systematically with regard to the possible different use of visual information as a function of experience.

The effect of starting angle and the interactions of this variable with flying experience, psychophysical method, and distance were generally similar to previous results. The greatest effect of starting angle was again in pilots with the method of adjustment. The speculation given above concerning interpretation of starting angle effects in terms of adaptation-level theory is in agreement with the finding in Experiment II of a smaller effect of starting angle in the method of limits than in the method of adjustment. In the method of limits, the task required the subject to alternately adjust the perceived orientation to be above and below that orientation which appeared to be horizontal. The method of adjustment, in contrast, required only that the model be adjusted _to_ the orientation which appeared to be horizontal.

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The subject would, therefore, be more likely to see orientations farther from the starting position when using the method of limits and the starting position would have less influence on the adaptation level as a result.

The fact that starting angle effect was smaller in the 3° adjustments (0.12°) than in horizontal adjustments (0.27°) in Experiment II further supports the interpretation of starting angle effects (at least partially) in terms of effects on perceived direction, since perception of direction in the visual field would not be expected to affect judgments of optical slant (3° judgments) as much as judgments of geographical slant (horizontal judgments).

Conclusions.

The present findings corroborate earlier findings that relative motion parallax has little effect on the perception of the orientation of the runway model at simulated distances as near as 1.33 nautical miles from runway threshold, at simulated speeds of approach up to 140 knots, and with a visual frame of reference present which corresponds to the cockpit window. Furthermore, it was shown that the flying experience of pilots does not enhance sensitivity to motion parallax in this situation. Further research concerning relative motion parallax should direct attention to the possibility that higher values of relative motion parallax than achieved in these experiments may exceed thresholds for effectiveness of this cue. Higher values would occur at distances of less than 1.33 nautical miles from threshold or with the presence of extra lights in the nighttime scene outside the runway.

The present findings do not reflect on the value of the relative motion parallax cue for the judgment of aim point, or direction of flight path, during approaches. Hasbrook (14), Langewische (19), and others have suggested interesting techniques for use of relative motion parallax for this purpose. The limited existing experimental evidence that was obtained in simulated day and night aircraft carrier approaches suggests that judgment of aim point is variable and perceived direction of the aim point is displaced upward in the visual field at night (16). Errors in this direction would cause low approaches. More research on this topic is needed, especially on judgments of aim point in the reduced visual information conditions of night approaches.

The most important finding of this series of experiments is that pilots misperceived both the geographical and the optical slant of the model runway. Direct judgments of approach angle were overestimated by a factor of 2 on the average. This demonstrates the presence of large visual illusions in night approach conditions that do not involve reduced visibility due to atmospheric conditions. Reduced visibility could be expected to affect judgment of approach angle even more seriously. The inability to judge the geographical orientation of a runway corroborates warnings in the literature concerning the tendency to fly low on approaches to upsloped runways and high on approaches to downsloped runways. Installation of Visual Approach Slope Indicators at runways with significant geographic slope would seem especially

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desirable. As mentioned above, future research should attempt a direct determination of the relation between judgments of approach angle magnitude in real and simulated night approach situations, to corroborate the present findings which suggest a specific cause of problems in night approaches and to validate the present visual simulation technique as a basis for future experiments concerning relative motion parallax and other cues involved in judgments of approach angles. Pilots obviously can and usually do successfully correct for visual illusions because most VFR approaches are performed safely. We should continue to study the method by which this correction occurs to understand why this critical process occasionally but tragically fails. A series of experiments in this laboratory has indicated that the ineffectiveness of relative motion parallax as a cue when only runway lights are visible may be an important part of this problem.

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