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John A. Perrone

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Visual Slant Misperception and the "Black-Hole" Landing Situation

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VISUAL SLANT MISPERCEPTION AND THE "BLACK-HOLE" LANDING SITUATION

John A. Perrone*

SUMMARY

A theory is presented which can explain the often-quoted tendency for dangerously low approaches during night-landing situations. The two-dimensional information at the pilot's eye contains sufficient information for the visual system to extract the angle-of-slant of the runway relative to the approach path. A theoretical system is developed which can carry out this analysis. It is dependent upon perspective information being available a certain distance out from the aimpoint, to either side of the runway edgelights. However, under "black-hole" landing conditions this information is not available, and it is proposed that the visual system use instead the only available information; namely the perspective gradient of the runway edgelights. An equation is developed which can predict what the perceived approach angle will be when this "incorrect" parameter is used. The predictions are in close agreement with existing experimental data.

INTRODUCTION

A great deal of recent research has been directed towards the so-called "black-hole" landing situation in which only runway lights are visible on the ground (refs. 10-15, 21). It has been established that visual illusions in the night-approach situation may directly cause low approaches during landing attempts. Several investigators have concluded that this is a problem concerning the misperception of the slant of the runway relative to the straight-ahead direction (refs. 11 and 23).

Wulfech et al. (ref. 23) concluded that shape/slant perception played an important role in the landing situation, but they were unable to find anything in the slant perception research of the time which offered a solution to the landing problem. Mertens (refs. 11-13) has consistently found evidence which shows that misperception of the optical slant of the runway is involved in the black-hole landing situation. He has attempted to explain this misperception by using Gogel's "equidistance tendency" theory (ref. 6).

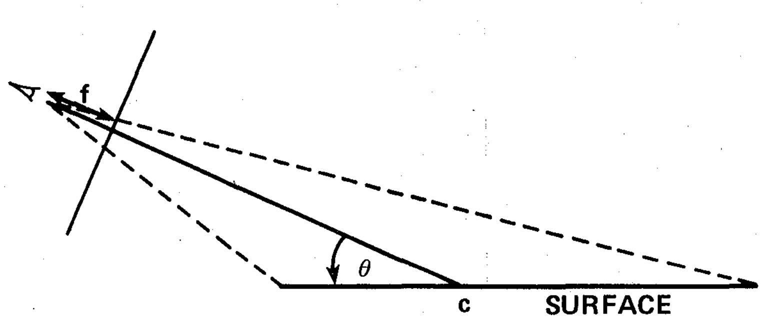
Perrone (refs. 18 and 19) provides a model of slant perception which has been successfully used to explain many cases of slant judgment error that occurred in past slant perception experiments. This paper attempts to show that this model can be used to explain low approaches during landing attempts under black-hole conditions.

A THEORETICAL SYSTEM FOR SLANT ESTIMATION

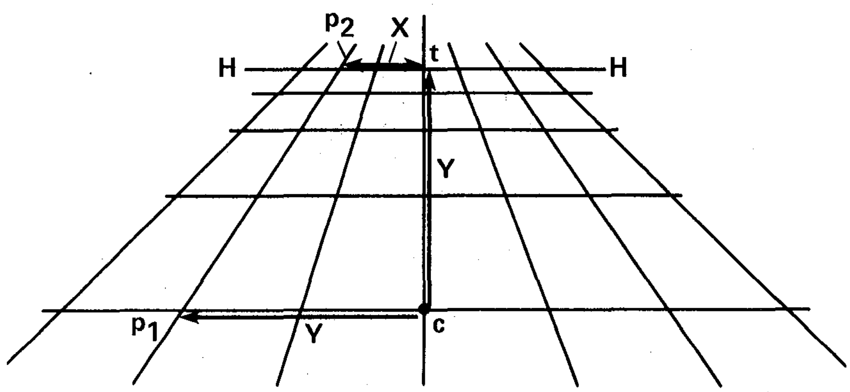
When a surface is slanted relative to the straight-ahead direction, it is possible to derive the angle-of-slant from the two-dimensional projection of the surface on the

*This research was carried out while the author was on a National Research Council Associateship.

retina. For simplification, a flat projection plane is used instead of the retina but this does not change the relationships between the projected elements. Several methods have been proposed for extracting the three dimensional slant angle from the two-dimensional projection (refs. 1,3,4,20). The method suggested by Perrone (refs. 18 and 19) measures off two equal distances from the center of the projection plane and finds the change in the projected width between parallel lines on the surface. Only two measures, X and Y, are required to find the slant angle (see figs. 1(a) and (b)).



(a) The two-dimensional information reaching the eye is analyzed on a theoretical projection plane an arbitrary distance f from the eye.



(b) The slant angle may be extracted from this information using equation (1). All measurements are made within the plane of the page.

Figure 1.- An example of two-dimensional information on a projection plane.

A length Y is set vertically upwards from the center of the projection plane (c) to t on a horizontal contour (e.g., HH). The same length Y is measured across, out from c (either left or right) to p_1. A perspective line at p_1 is traced back up until it meets the horizontal line HH at p_2. The length p_2t is equal to X. Let θ be the angle of slant, measured from the horizontal. The equation relating θ to the information on the projection plane is:[1]

$$\tan \theta = \frac{Y^2}{Y - X} \frac{1}{f} \tag{1}$$

[1]Derivation given in (refs. 17-19). Note, however, that a different convention is used for measuring the slant angle.

where f is a constant and it is the arbitrary distance from the eye to the theoretical projection plane used to analyze the array of light reaching the eye. The equation states that the change in projected width of elements on the surface, over a given area of the projection plane, is proportional to the angle of slant of the surface. It acknowledges that perspective is the most important source of slant information, and it assumes that sufficient surface detail exists to provide perspective lines.

This system for extracting the slant angle is independent of the distance, length, or width of the surface. It differs, therefore, from measures such as the form ratio (ref. 1), which requires the width and length of the original surface in the calculations for the slant angle. The information is there in the two-dimensional projection to extract the slant angle. It is likely, therefore, that the human visual system utilizes that information and performs an analysis using the same variables as the theoretical system.

One feature that must be assumed is that the system always sets the largest value of Y possible. A justification for this is that a large value of Y results in greater accuracy than a smaller one, and the difference between X and Y will be more easily detected. Of course, the limiting case is reached when Y equals the distance from the c to the horizon and X becomes zero.[2]

Note that equation (1) is a purely physical description of the relationship between various measurable elements in the pattern of light reaching the eye. It shows that under normal viewing conditions, the two dimensional stimulus contains sufficient information for veridical slant judgments to occur. However, under reduced viewing conditions observers tend to judge a surface to be closer to the front-parallel plane than it really is (e.g., refs. 2,5,7,22).

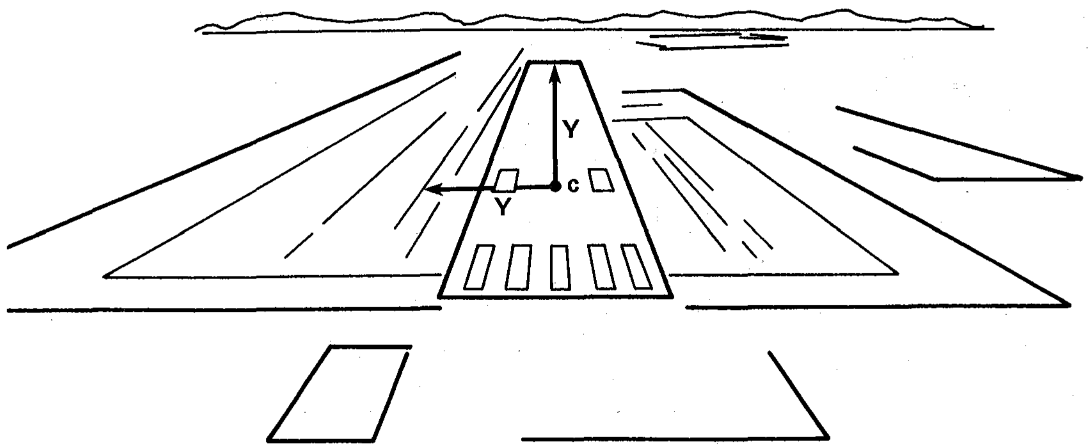
Perrone (refs. 18 and 19) has shown that if certain "incorrect" values of Y and X are used in equation (1), then a value of θ is obtained which closely predicts the errors made by human subjects when they judge the slant of a surface. The implication is that human observers use the same variables in the two dimensional array of light reaching the eye as does the theoretical system outlined above. The theory was developed in relation to surfaces slanted away from the vertical, but it can quite readily be adapted to the landing situation.

A THEORY OF SLANT MISPERCEPTION

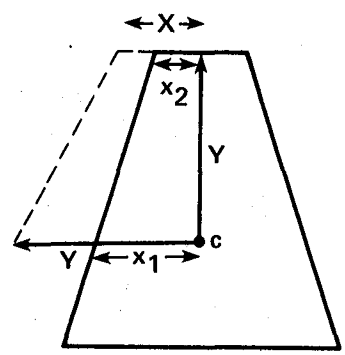
Figure 2(a) represents a daylight landing situation. From the two dimensional information at the pilot's eye it is possible to extract the approach angle θ, using the system described above. If the aimpoint (c) coincides with the touchdown zone, and if Y is taken up to the end of the runway, then in a normal situation there exists sufficient texture detail to the side of the runway to provide perspective lines a distance Y out from c.

However, now consider a black-hole landing situation with only the runway lights visible. (See fig. 2(b).) This time there is no perspective information available a distance Y out from c, and it is proposed that the visual system uses the only

[2]cf. the H-distance used by pilots as a guide to glide slope (ref. 16).



(a) Representation of a daylight landing situation. Perspective information is available a distance Y out from c and so veridical slant perception is possible.



(b) Representation of a black-hole landing situation with only the runway outline visible. No perspective information is available a distance Y out from c.

Figure 2.- Representations of landing situations.

information available. Hence, it uses the perspective lines defined by the edgelights of the runway. It will be shown that this leads to a misperception of the slant angle.

In order to obtain the correct approach angle from the two dimensional information using the system defined by equation (1), Y^2 should be divided by $Y - X$. (See dotted lines in fig. 2(b).) The theory states that instead, Y^2 is divided by $x_1 - x_2$. The lengths of x_1 and x_2 can be determined by trigonometry from the physical dimensions of the runway, the actual approach angle, and the distance from touchdown (see fig. 3). If the width of the runway is W, then:

$$x_1 = \frac{fW}{2D} \quad \text{and} \quad x_2 = \frac{fW[\tan\theta - \tan\alpha]}{2D\tan\theta} \tag{2}$$

where

$$\tan\alpha = \frac{L\sin\theta}{D + L\cos\theta}$$

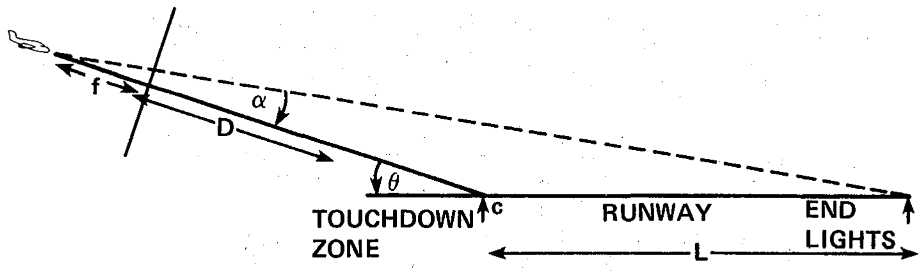


Figure 3.- Geometry of the landing situation for determining the two-dimensional information available to the pilot. Note that the value of L is not the total length of the runway.

These equations enable us to calculate the projected shape of the runway and, therefore, to define the two-dimensional information available to the pilot at a particular distance out from a runway of length L and width W with an approach angle equal to θ.

The theory states that the pilot's visual system, when faced with an impoverished visual field, will use the wrong variables in the two-dimensional pattern of light reaching the eye. Given that the visual system is using an analysis similar to that defined by equation (1), we can predict what the perceived approach angle will be when the incorrect variables are used.

If we call the predicted perceived approach angle β, then we have:

$$\tan \beta = \frac{Y^2}{x_1 - x_2} \frac{1}{f} \tag{3}$$

substituting in the values for x_1, x_2, and Y gives:

$$\tan \beta = \frac{2DL \sin \theta \tan \theta}{W[D + L \cos \theta]} \tag{4}$$

This is the main equation of the theory and it predicts the amount of slant misperception that will occur when black-hole conditions exist. Note that the presence of θ, D, L, and W on the right side of the equation does not imply that the pilot's visual system requires knowledge of these three-dimensional parameters to find β. These values have been substituted for the two-dimensional variables to enable predictions to be made by an experimenter using measurable features of a particular landing situation. The angle β could also be obtained from the two-dimensional pattern on the retina of the pilot's eye.

PREDICTIONS OF THE THEORY

According to the theory, the important variables that determine the (misperceived) approach angle are the actual width of the runway and the actual length of the runway from the aimpoint to the endlights. The aimpoint may vary slightly from pilot to pilot and be dependent upon other factors, but for the purpose of this analysis it will always be taken as coinciding with the touchdown zone.

For a 200 ft wide by 7000 ft long runway (with the touchdown zone 1000 ft from threshold, i.e., L = 6000 ft) the theory predicts that at a distance of 10,000 ft a 3° approach angle will be perceived to be equal to β where:

$$\beta = \tan^{-1}\left[\frac{2 \times 10{,}000 \times 6{,}000 \times \sin 3° \quad \tan 3°}{200 \times [10{,}000 + 6{,}000 \times \cos 3°]}\right] = 5.9° \qquad (5)$$

In other words, it is predicted that the pilot will overestimate his approach angle. The pilot will perceive his altitude to be approximately twice his actual altitude (see fig. 4).

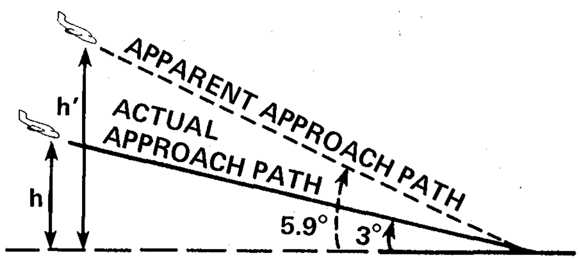


Figure 4.- When the approach angle is overestimated, the apparent altitude is above the true altitude.

In order for the runway to appear slanted by as much as it does during a normal daytime 3° approach, the pilot would have to fly a 2.14° approach (eq. (4) gives a value of $\beta = 3°$ when $\theta = 2.14°$). The theory can predict the type of errors that have typically been reported in relation to black-hole landing attempts.

The theory is unique in the sense that its predictions are based on measurable physical properties of the environment; equation (4) contains no phychological variables. However, the predictions are based on an "ideal" observer and so individual differences are expected to generate variation in performance about the theorized values.

Figure 5 is a plot of the predicted perceived approach angles for given actual approach angles, when W = 200 ft, L = 6,000 ft, and D = 10,000 ft. Whenever the curve is above the straight line, the theory is predicting misperception of the approach angle; the approach angle is seen to be greater than it really is. As the approach angle increases, the theory predicts the error to increase rapidly.

The area below the straight line represents slant underestimation and it is predicted to occur at very small actual approach angles. Slant underestimation means that the approach angle is seen to be less than it really is, and the altitude above the runway is underestimated. The dotted lines show the actual approach angle that must be flown by the pilot if the slant angle is to appear the same as a normal 3° approach. This only applies to the particular runway dimensions and distances specified above.

For a smaller value of D (e.g., 5,000 ft), the curve is flatter and the generated approach angle is expected to be closer to 3°, but still less than 3°. The situation improves as the plane gets closer to threshold.

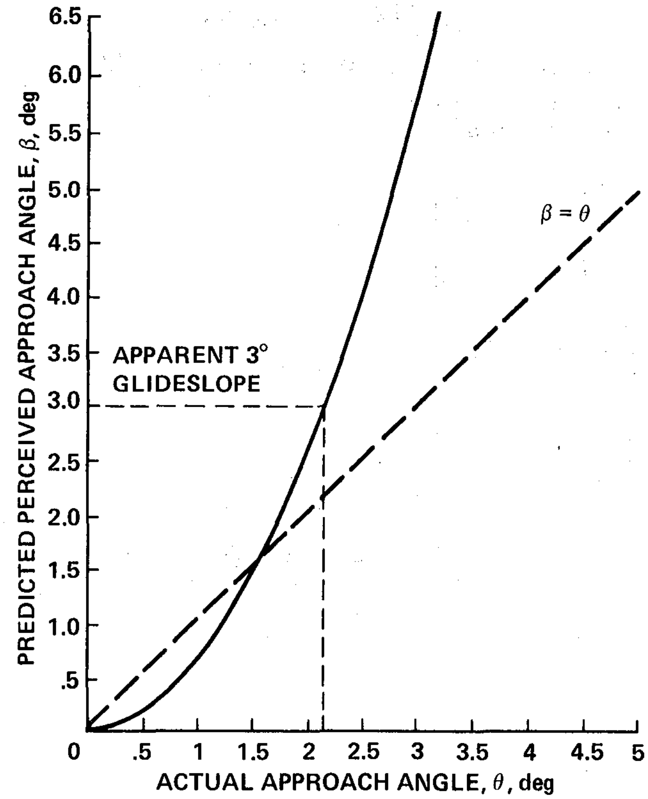


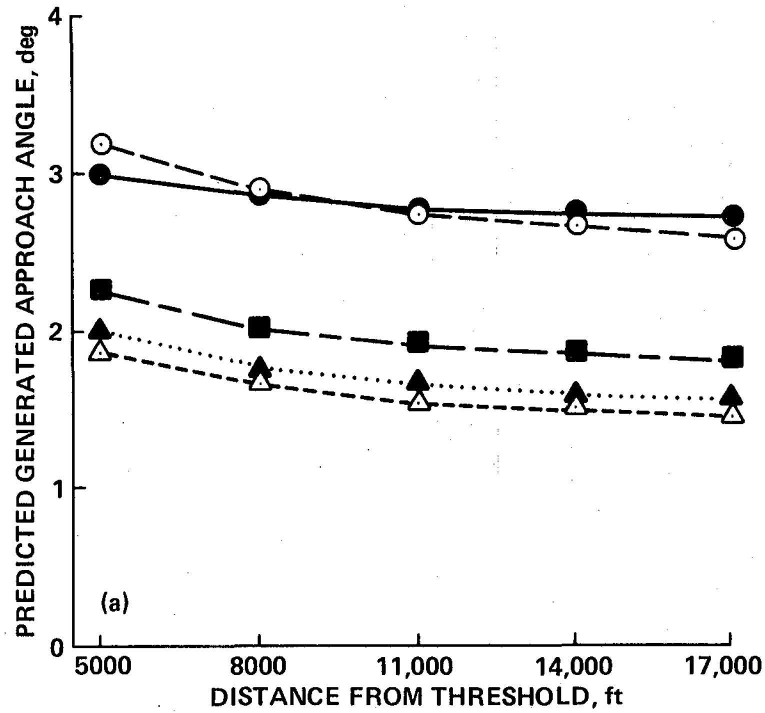
Figure 5.- Predicted perceived approach angle as a function of actual approach angle, for $L = 6{,}000$ ft, $W = 200$ ft, and $D = 10{,}000$ ft.

The dimensions of the runway affect the predicted perceived approach angle, and the greater the length-to-width ratio, the greater the predicted error. According to the theory, a runway would need to have a length-to-width ratio of approximately 16:1 if a 3° approach is to appear as a 3° approach at 10,000 ft. However, this value changes as the distance changes. If the theory proves to be correct, it can offer specific solutions to landing and approach problems, and quantitative changes can be suggested to existing runway features.

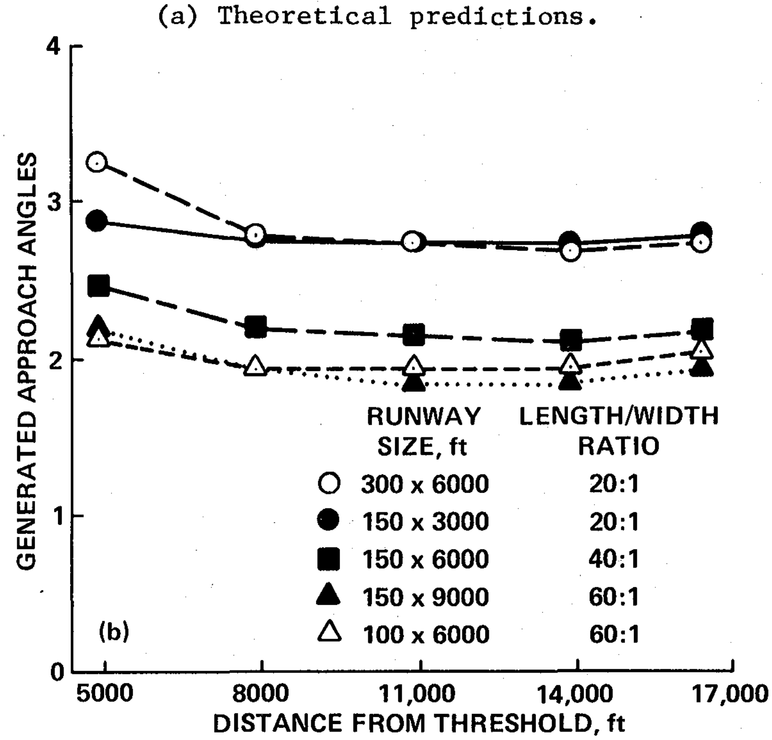
EXISTING EVIDENCE FOR THE THEORY

There are many predictions arising from the theory that can be actually tested and there already exists some experimental evidence to support it. Using existing experimental evidence to test a theory represents the ultimate in impartiality; no arguments of experimental bias can apply. Mertens and Lewis (ref. 14) carried out an experiment (exp. 2, ref. 14) in which pilots controlled the slant of a moving runway model during simulated night visual approaches. Five different models simulated runways from 100 ft to 300 ft wide and 3,000 ft to 9,000 ft long. The approach angle was the dependent variable and it was measured at 3,000 ft intervals from 17,000 ft to 5,000 ft from threshold.

By using equation (4) values of θ can be calculated which produce a value of $\beta = 3°$ (given the various runway dimensions and distances used by Mertens and Lewis, ref. 14). The resulting theoretical predicted approach angles have been plotted in figure 6(a). The value for L was taken to be the length of the runway minus 1,500 ft, since Mertens (ref. 12) described his model as having a touchdown zone at a simulated 1,500 ft from threshold.



(a) Theoretical predictions.



(b) Actual data values obtained by Mertens and Lewis (ref. 12).

Figure 6.- Generated approach angle as a function of distance from threshold and runway dimensions.

Figure 6(b) represents the actual data values obtained by Mertens and Lewis for 40 pilot subjects. The theory can explain the decrement in performance with changes to the width to length ratio of the runway. It can also predict the "overestimation" obtained by Mertens and Lewis for the 300 ft by 6,000 ft runway at 5,000 ft. More importantly it can make absolute predictions as to the approach values that would be obtained under the various conditions, and these predictions are in close agreement with the experimental data values. Experiments are presently being carried out to further test the parameters of the theory.

DISCUSSION

Motion cues have not been directly considered in the theory, although it is appreciated that extra information can be obtained from optical flow patterns. For the true black-hole situation, motion manifests itself in the theory only as a change in the value of D. In other words, we can analyze the situation as a series of discrete slant judgments over a range of distances. Mertens (ref. 12) demonstrated that motion did not have an effect on generated approach angles over the range tested and the errors were the same as for a static display. At small distances from threshold, it is expected that motion perspective will play a larger role.

The theory is applicable to those situations in which the outline of the runway is discernible, and the perspective information is detectable by the human visual system. It cannot be directly applied therefore to the situations discussed by Kraft (ref. 9) in which the plane is 20 miles from threshold. The theory makes predictions for that part of the approach path which begins after the farthest point considered by Kraft (ref. 9, 4.5 miles).

The daytime landing situation need not be exempt from the same problems predicted by the theory for the night-landing case. If the terrain surrounding a runway is relatively uniform and featureless, and if a pilot relies mainly on the outline of the runway for slant information, then it would be expected that slant misperception will also occur. Experiments need to be carried out to determine what constitutes "inadequate" textural information.

One important variable in the theory is the projected length of the runway. This leads to the following seemingly paradoxical prediction: If the visible length of the runway is diminished by fog, then because the length-to-width ratio of the runway is less, the amount of slant misperception will be less. Approach angles should be closer to the desired 3°.

This counter-intuitive prediction has support from experimental findings. Mertens and Lewis (ref. 15, exp. 2) covered up the upwind half of their runway model and reduced the simulated length from 6,000 ft to 3,000 ft. They obtained an unexplained increase in the generated approach angles of 0.5° when only half of the runway was visible. (Approach angles were still below 3°.)

In another experiment, Mertens and Lewis (ref. 15, exp. 1) measured the generated approach angles for situations with and without approach lighting. The mean generated approach angle over all subjects was 2.13° without approach lighting, and 1.9° with approach lighting. Again this paradoxical finding can be explained by the theory, if one assumes that the presence of the approach lighting somehow brings the position of the aimpoint closer to the threshold, thus increasing the value of Y. An increase in Y would explain the decrement in performance with the addition of approach lights.

Investigations are presently being carried out to see just how features such as approach lighting can affect the parameters of the theory.

CONCLUSIONS

The "landing-short" accident problem has been well documented (ref. 8), and there is a stated need to isolate the factors which cause this problem. The theory of slant misperception presented in this paper offers a starting point for experimentation on the approach and landing problem. There already exists sufficient evidence (both in slant perception studies and in actual landing studies) to conclude that the variables specified by the theory play an important part in the problem. This paper offers guidelines for future research into a problem that has for too long suffered from "too many factors."

If the human visual system uses the same variables as the proposed theoretical system, then the black-hole landing situation is, in fact, a case of "lack of visual information." The theory can specifically pinpoint the lack of information to the absence of perspective lines a certain distance out from the runway edgelights. The problem reduces down to the fact that humans are not very good at judging the slant of long narrow rectangular surfaces. Pilots must believe their instruments and not their eyes.

REFERENCES

1. Braunstein, M. L.; and Payne, J. W.: Perspective and Form Ratio as Determinants of Relative Slant Judgements. Journal of Experimental Psychology, vol. 81, 1969, pp. 584-590.

2. Clark, W. C.; Smith, A. H.; and Rabe, A.: Retinal Gradients of Outline as a Stimulus for Slant. Canadian Journal of Psychology, vol. 9, 1955, pp. 247-253.

3. Flock, H. R.: A Possible Optical Basis for Monocular Slant Perception. Psychological Review, vol. 71, 1964, pp. 380-391.

4. Freeman, R. B., Jr.: Function of Cues in the Perceptual Learning of Visual Slant. Psychological Monographs: General and Applied, vol. 80, no. 2, 1966, pp. 610.

5. Gibson, J. J.: The Perception of Visual Surfaces. American Journal of Psychology, vol. 63, 1950, pp. 367-384.

6. Gogel, W. C.: Equidistance Tendency and Its Consequences. Psychological Bulletin, vol. 64, 1965, pp. 153-163.

7. Gruber, H. E.; and Clark, W. C.: Perception of Slanted Surfaces. Perceptual and Motor Skills, vol. 16, 1956, pp. 97-106.

8. Hartman, B. O.; and Cantrell, G. K.: Psychological Factors in "Landing Short" Accidents. Flight Safety, vol. 2, 1968, pp. 26-32.

9. Kraft, C. L.: A Psychophysical Contribution to Air Safety: Simulator Studies of Visual Illusions in Night Visual Approaches. Psychology from Research to Practice, H. L. Pick, Jr., H. W. Liebowitz, J. E. Singer, A. Steinschneider, and H. W. Stevenson, eds., New York: Plenum Press, 1978, pp. 363-385.

10. Lewis, M. F.; and Mertens, H. W.: Pilot Performance During Simulated Approaches and Landings Made with Various Computer-Generated Visual Glidepath Indicators. Aviation, Space, and Environmental Medicine, vol. 50, 1979, pp. 991-1002.

11. Mertens, H. W.: Perceived Orientation of a Runway Model in Nonpilots During Simulated Night Approaches to Landing. Aviation, Space, and Environmental Medicine, vol. 49, 1978, pp. 457-460.

12. Mertens, H. W.: Comparison of the Visual Perception of a Runway Model in Pilots and Nonpilots During Simulated Night Landing Approaches. Aviation, Space, and Environmental Medicine, vol. 49, 1978, pp. 1043-1055.

13. Mertens, H. W.: Perception of Runway Image Shape and Approach Angle Magnitude by Pilots in Sinulated Night Landing Approaches. Aviation, Space, and Environmental Medicine, vol. 52, 1981, pp. 373-386.

14. Mertens, H. W.; and Lewis, M. F.: Effect of Different Runway Sizes on Pilot Performance During Simulated Night Landing Approaches. Aviation, Space, and Environmental Medicine, vol. 53, 1982, pp. 463-471.

15. Mertens, H. W.; and Lewis, M. F.: Effects of Approach Lighting and Variation in Visible Runway Length on Perception of Approach Angle in Simulated Night Landings. Aviation, Space, and Environmental Medicine, vol. 54, 1983, pp. 500-506.

16. Palmer, E. A.: Night Visual Approaches — Pilot Performance With and Without a Head-up Display. NASA TM X-62,188, 1972.

17. Perrone, J. A.: Slant Underestimation: A Model Based on the Size of the Viewing Aperture. Perception, vol. 9, 1980, pp. 285-302.

18. Perrone, J. A.: Visual Slant Underestimation. Ph.D. thesis, University of Canterbury, Christchurch, New Zealand, 1982.

19. Perrone, J. A.: Visual Slant Underestimation: A General Model. Perception, vol. 11, 1982, pp. 641-654.

20. Purdy, W. C.: The Hypothesis of Psychophysical Correspondence in Space Perception. Doctoral dissertation, Cornell University, Ann Arbor, Michigan: University Microfilms, no. 58-5594, 1958.

21. Roscoe, S. N.: When Day is Done and Shadows Fall We Miss the Airport Most of All. Human Factors, vol. 21, 1979, pp. 721-731.

22. Smith, A. H.: Gradients of Outline Convergence and Distortion as Stimuli for Slant. Canadian Journal of Psychology, vol. 10, 1956, pp. 211-218.

23. Wulfeck, J.; Queen, J. E.; and Kitz, W. M.: The Effect of Lighted Deck Shape on Night Carrier Landing. Technical Report No. 196-115, Dunlap and Associates, Inc., Inglewood, Calif., 1974.

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16. Abstract

A theory is presented which can explain the often-quoted tendency for dangerously low approaches during night-landing situations. The two-dimensional information at the pilot's eye contains sufficient information for the visual system to extract the angle-of-slant of the runway relative to the approach path. A theoretical system is developed which can carry out this analysis. It is dependent upon perspective information being available a certain distance out from the aimpoint, to either side of the runway edgelights. However, under "black-hole" landing conditions this information is not available, and it is proposed that the visual system use instead the only available information; namely the perspective gradient of the runway edgelights. An equation is developed which can predict what the perceived approach angle will be when this "incorrect" parameter is used. The predictions are in close agreement with existing experimental data.

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