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Range and Time Estimates of Dynamic Visual Targets

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13. ABSTRACT

This report presents the data based on field research by the Psychophysics Laboratory from 1 July 1971 through 30 June 1972. Previous data involving the ranging of aircraft by ground observers and of ground targets by aerial observers have been extended to the ranging of boat and marine markers by ground observers and aerial observers. Time estimates to impact by aerial observers are also reported.

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Security Classification

Range and Time Estimates of Dynamic Visual Targets

Introduction

The use of magnitude estimation techniques to generate psychological scales for a multitude of physical variables has increased our understanding of, and our ability to control and regulate, a variety of human judgments and choices (Stevens and Galanter 1957). For example, the psychological assessment of acoustic amplitude has made it possible to predict human response to changes in noise levels, and has helped to establish design parameters in voice transmission systems of various kinds (Stevens, 1962, Hillqist, 1967). At the theoretical level, these scaling techniques have enlarged our understanding of color vision, and have served to corroborate a general theory of the perception of color (Jameson and Hurvich, 1959). These scaling methods are now being used extensively to explicate and improve our understanding of taste and smell, and ultimately these scales may serve to measure various forms of food acceptability and palatability (Moskowitz and Meiselman 1972). But whereas the study of psychological scales of primary, modality specific, variables has proceeded apace, the techniques of magnitude estimation are only just now beginning to be applied to more abstract perceptual entities. Such work as the measurement of utility by magnitude estimation methods (Galanter 1972), and assessments of perceptual similarity independent of sensory mode (Carvellas 1971) are examples of these latter areas.

In the Psychophysics Laboratory, first at the University of Washington, and then at Columbia University, studies of complex human perceptual functions have been under examination with these methods. In particular some of the oldest problems in visual perception are being investigated by this new psychophysics. One of the problems of visual perception that we are reexamining is the explication of form and space perception. People can obviously negotiate effectively in three-space plus time; or four-space; they reach and lift, they run and catch, with great precision. However, just how information from the visual environment is processed to accomplish these tasks, is not well understood. Principles of binocularity and cues and clues for three-dimensional perception are not really satisfactory as explanations of these performances. Indeed, the first questions about these behaviors, <u>viz</u>. just what they are and how well they can be performed, have hardly been answered (Smith and Smith 1966). But the fact that people can move easily in a crowded room, and operate high speed vehicles in which four-dimensional information must be rapidly processed may not be the relevant target performances to be analyzed. First, we would argue, we should understand what the psychophysical dimensions of such skills are. So, for example, we may ask whether there is a psychological representation of physical distance, and if there is whether it is linear with physical space. If it is not linear, we then need to know whether this information is critical for performance of tasks involving translation in three dimensions. If it really is of importance in these tasks, we must recognize that such performances must include in their psychic organization a non-linear transform. On the other hand if such performance skills do not depend on the reduction of psychological representations of space and distance, but rather on other more easily processed variables, we may simply have wrongly construed the conception of such command and control activities.

This report will describe our most recent experiments and the data from them that, together with our past research yields a picture of the kinds of psychophysical functions that represent how people process visual information that is of importance in the perception of form and depth.

Past Results

Previous research conducted by this laboratory under contract 00 14-67-A-0108-0005 had shown that observers on the ground who were estimating the distance from their positions to aerial targets flying at low altitude, consistently over-estimated those distances. This result is not unusual and has been found consistently in past experiments (1962, 1968). However these previous results simply reported the physical magnitudes of the over-estimations that were observed when subjects ranged aerial targets at a few fixed distances. Our efforts were directed toward mapping the entire psychophysical function to determine the form of the function that described the over-estimation. Figure 1 shows data based on magnitude estimation scaling procedures used with two kinds of judgmental methods: a named standard with a modulus and no standard.

For this experiment observers were located on a missile launch pad on a beach front overlooking the Pacific Ocean, while an aircraft traversed a line perpendicular to their line of regard at various distances over many trials. The range of distances used was from 200 yards to 9,861 yards. The order of the transits relative to their distance was irregular. The direction of the passes alternated from trial to trial. Twelve observers who had been given one and one-half hours of training in making magnitude estimations of line lengths made magnitude estimation judgments of the distance of the aircraft on a signal from the range controller as the aircraft passed in front of them. The altitude of the aircraft was never greater than 200 feet above the water. The observer's eye level was approximately 40 feet above the water. Figure 2 shows how the observers were accommodated during the experimental procedures.

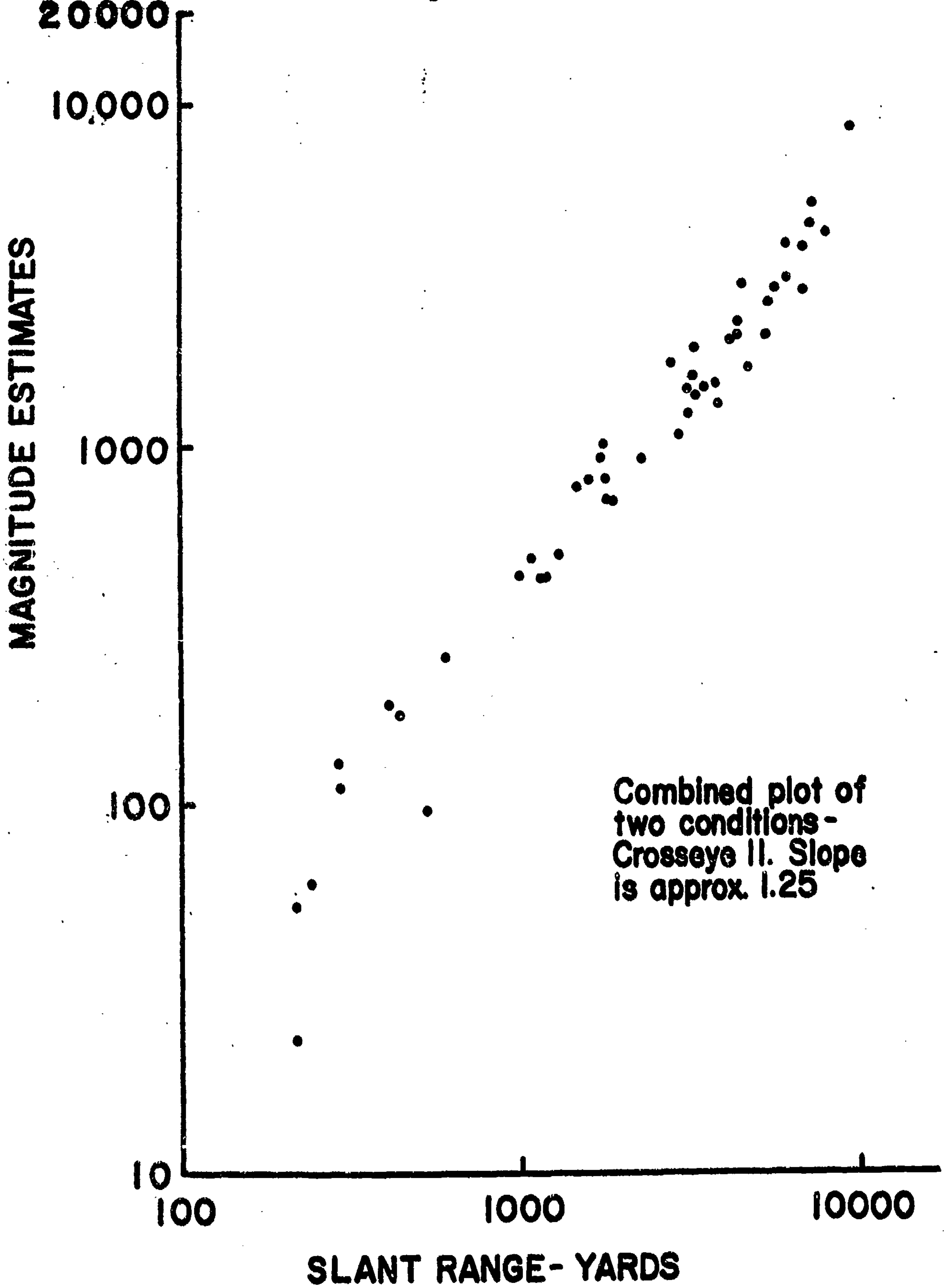
Each data point in the psychophysical function shown in Figure 1 represents the median of twelve judgments, one by each of the observers. The distance to the aircraft was determined by a digital radar (model AN/FPS16) and a real-time on-line computer, provided by the Pacific Missile Range, Point Mugu, California.[1] The data points shown here in log-log coordinates are adequately described by a power function of the form

$$\text{perceived distance} = (\text{actual distance})^n$$

The value of the exponent (n) for these data is 1.25, and the exponent has

26

Figure 1


20000
10,000
1000
100
10
MAGNITUDE ESTIMATES
100
1000
10000
SLANT RANGE- YARDS
Combined plot of two conditions - Crosseye II. Slope is approx. 1.25

2C

Figure 2

been consistently reproduced under these and similar experimental conditions. Other researchers (Künnapas 1960, Teghtsoonian and Teghtsoonian 1970) have obtained similar positively accelerated power functions.

Experiment 1

Whereas all of the preceding data seem to hang together pretty well, certain phenomenological observations and controlled experiments have suggested that such results may be a function of the angle of regard, and may possibly be contingent on the nature of the intervening terrain (or lack thereof). The source of the first concern about angle of regard is the phenomenon known as the moon illusion. It has been consistently observed both by psychologists and others (Holway and Boring 1940) that the horizon moon appears much larger, perhaps by a factor of two, than the zenith moon. A variety of theories have been proposed to account for these observations (Kaufman and Rock 1962), the most reasonable of which is that the distance to the horizon appears to be greater than the distance to the zenith; that is that the shape of the sky is a flattened bowl rather than a hemisphere. If this conjecture is true then the perceived distance to objects at the zenith should be different than what we have observed in our experiments, and what has been reported in the experiments of others. Consequently we engaged upon some experiments to provide data to answer this first question.

Eight observers (graduate students and technical personnel from the Psychophysics Laboratory at Columbia University) served in this experiment. All of them had had previous experience in making magnitude estimations of line lengths, and all of them understood the magnitude estimation procedure using a standard with a fixed modulus.

The target vehicle for the judgments was an aircraft (Beech, model V35) flown directly overhead at altitudes varying from 100 to 10,000 feet. The altitude for each pass was determined by a prearranged irregular schedule of altitudes. Observers were told to call the first pass 1,000. The aircraft for this pass traversed the observer's station at 500 feet. On each subsequent pass the observers were required to estimate the altitude of the aircraft relative to the standard that they called 1,000.

Figure 3 shows the psychophysical function relating magnitude estimations to the vertical distance of the target. Each data point represents two judgments by each of the eight observers for each altitude. Once again a power function is a reasonable description of the data. However, the exponent for these data when determined by the method of least squares is 0.8. This value is significantly different from the value observed in our earlier experiments for horizontal lines of regard, and also departs remarkably from all other reported values. In this experiment the observers consistently reported that the target was closer than it actually was. The unhappy choice of the modulus "1,000" against a physical standard of 500 feet makes this

3 L

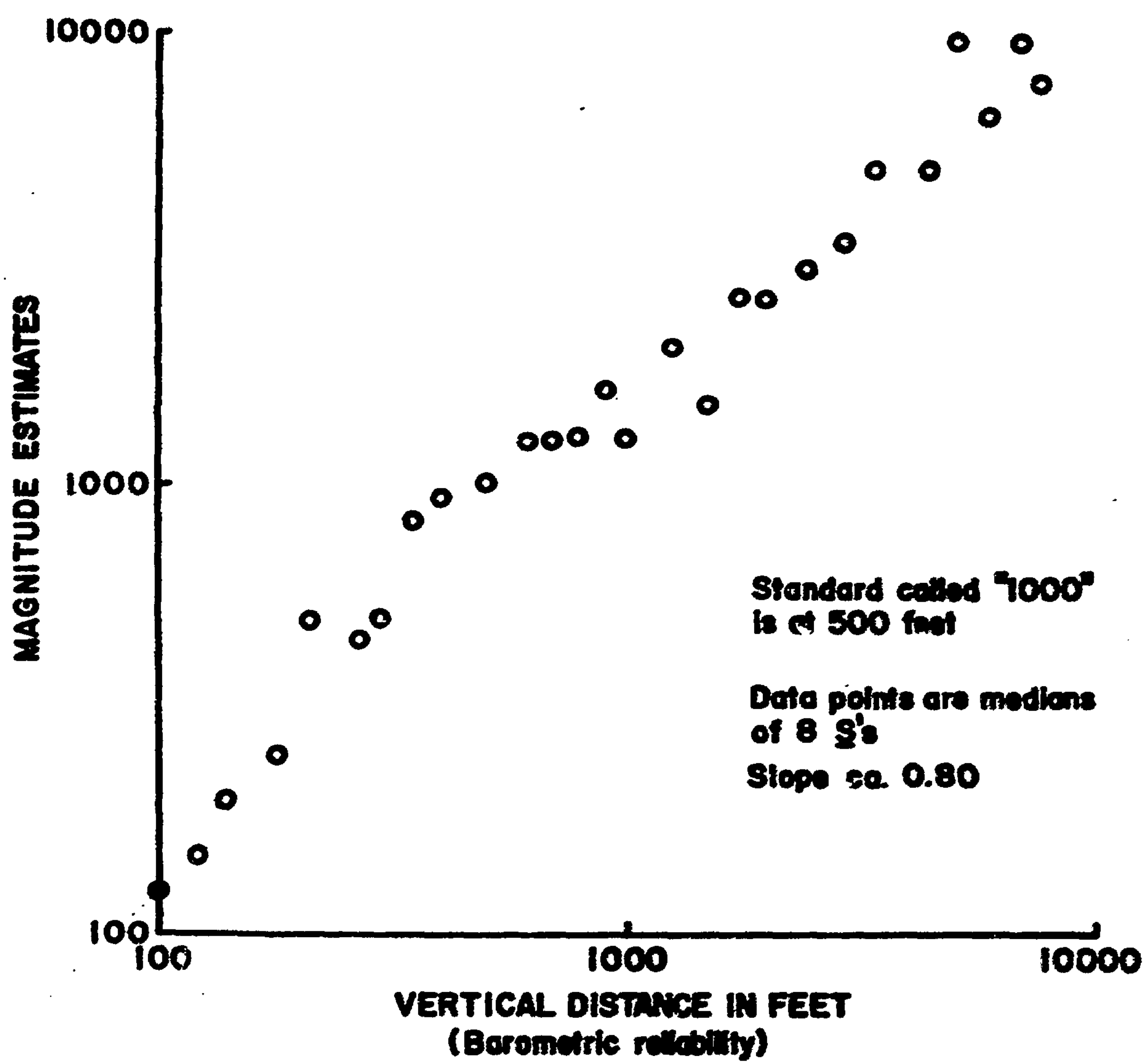

MAGNITUDE ESTIMATES
10000
1000
100
100
1000
10000
VERTICAL DISTANCE IN FEET
(Barometric reliability)
Standard called "1000"
is at 500 feet
Data points are medians
of 8 S's
Slope ca. 0.80

Figure 3

feature of the data less obvious than it would otherwise be. Furthermore the slope of the function is made to appear steeper than it is by the three lowest data points which rise more sharply than the rest of the data. This result is common in magnitude estimation judgments in many modalities (Galanter and Messick 1961) and represents the source of the consistently reported need to modify the usual power function formula to include an additive constant.

Experiment 2

In order to determine whether the horizontal and vertical lines of regard are special and unique, a second experiment was performed to obtain the psychophysical function of perceived distance against the physical range at an angle of regard somewhere between the horizontal and the vertical. In this experiment fourteen observers (enlisted seamen familiar with aircraft operations) were used to make the judgments. This time, as the aircraft made passes perpendicular to the line of regard at different distances, it was also at different elevations. The distances and altitudes were adjusted by the pilot so that the aircraft maintained an angle of regard to the observers of approximately 12°. The distances and elevations were monitored by an instrument landing system radar sweep with the glide slope antenna angle toggled to 12°. The values of the physical variable of this experiment are less precise than they were in the previous study, but to compensate partially for this lack of precision in the physical variable each of the observers made ten judgments at each of the distances used. For this experiment no fixed standard was used. Because of the number of judgments in this experiment it was run on four different days. There were slight variations in weather conditions on these days, however days were chosen when weather conditions provided at least 7 miles of reported visibility, and the cloud cover was at most scattered at 5,000 feet or higher.

Observers made their judgments on command of the range commander when the aircraft was abeam the observer's station. The range commanders "mark" was also transmitted to the radar operator who recorded the range and the angular accuracy of the run. If the run departed from 12° by more than the glide slope radar sweep excursion, the trial was discarded. Observers used their own standards, and the data were reduced by minimizing the overall variability of the judgments.

Once again the results graphed in Figure 4 can be described as a power function, albeit a degenerate one insofar as the slope has a value very near 1. Thus the distance judgments made by these observers in this experiment conform very well to the actual distances between them and the aircraft.

From these data, and the results of earlier experiments we may safely conclude that the perceived distance of a target is (to a first approximation) a power function of the physical distance of the target. However, the two experiments reported above indicate that the parameter of the power function—the value of exponent—is contingent upon the angle of regard (or something correlated with the angle of regard) through angles ranging from the horizon (0°) to the zenith (90°). The most reasonable conjecture to describe

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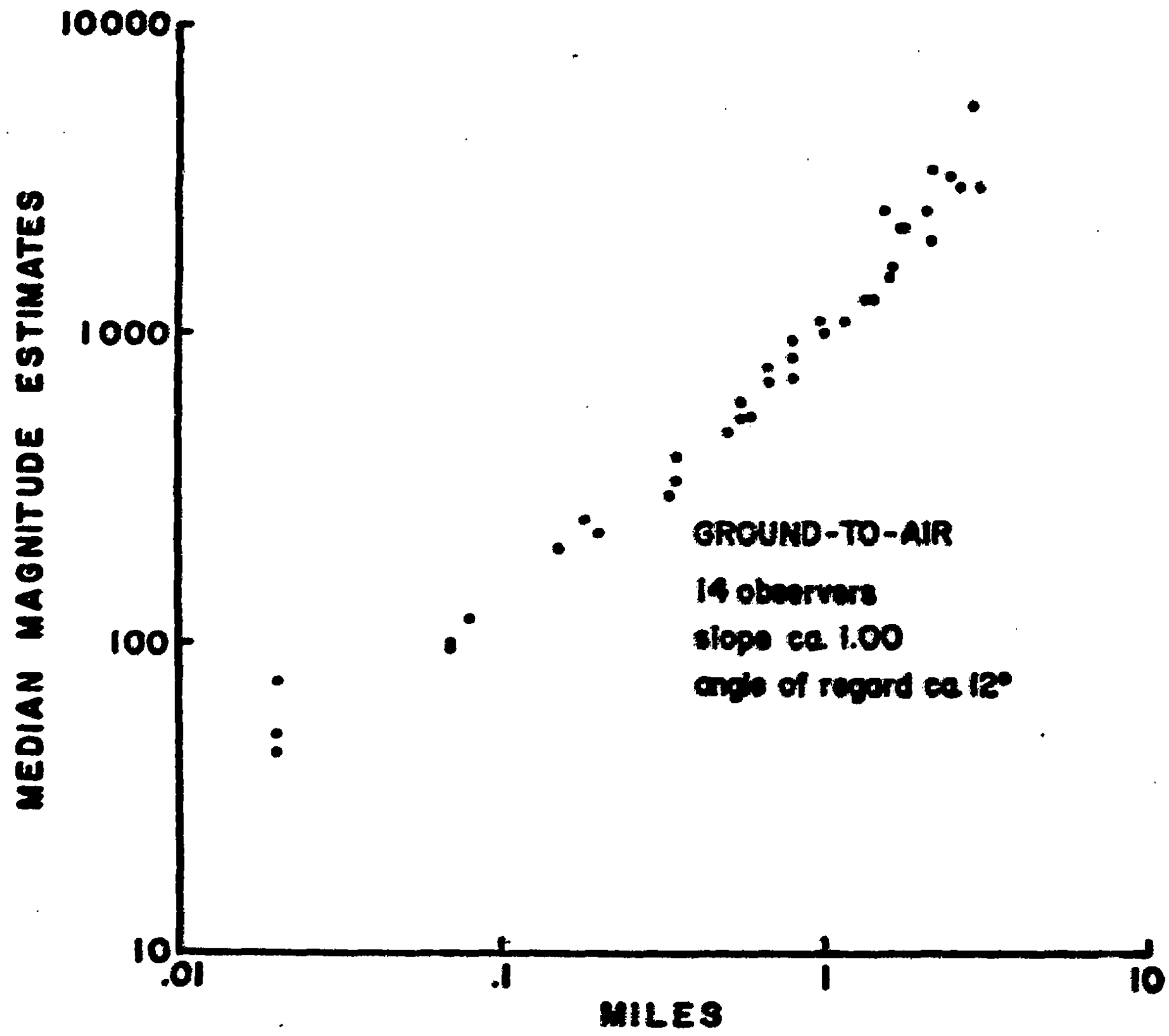

MEDIAN MAGNITUDE ESTIMATES
10000
1000
100
10
.01
.1
1
10
MILES
GROUND-TO-AIR
14 observers
slope ca. 1.00
angle of regard ca. 12°

Figure 4

this parametric change is that the perceived distance at the horizon consistently over-estimates the actual distance, the perceived distance at the zenith consistently under-estimates the actual distance, and in between there is probably a smooth transition, with reduced over-estimation as the angle of regard increases until finally under-estimation begins and reaches its maximum at 90^{0}. Such a labile distance function, contingent as it seems to be upon the angle of regard, does not speak well for it as the psychological determiner of complex psychomotor tasks.

However it still remains to be seen whether this distance function may stabilize under certain sets of conditions. In particular, in the experiments described so far the target is an aerial target, that is the target is suspended or located against a background of indeterminate structure, the sky. Our next experiment was designed to find out whether the perceived distance function was altered if the target object was imbedded in an environment with some continuously graded micro-structure. Although these conditions were found in the earliest studies of distance estimation, an exact comparison is difficult to make because of the methods of data reduction that were employed in the earlier studies. Consequently Experiment 3 was conducted to try to determine whether range estimation of maritime objects conform to the general law of the psychophysical function that we had observed for aerial targets.

Experiment 3

This experiment required that observers on the shore of a large bay estimate the range of a small boat passing on a line perpendicular to their line of regard at varying distances. For this experiment Great Bay, New Jersey was used with a 26 foot inboard cruiser serving as the target vehicle. A tall mast was erected on the aft end of the vessel to provide easy rangefinder ranging. The ranging of the vessel was accomplished with an ND4 Mark 2 U. S. Navy rangefinder with a one meter base. The dynamic range of this rangefinder is 200 to 10,000 yards. At distances less than 200 yards a small Edmund Scientific Corporation split-image rangefinder was used. This small rangefinder was calibrated up to 300 feet with a surveying tape. During its runs, the boat maintained a constant compass course (or its reciprocal) but varied its distance from the observation point according to an irregular schedule of qualitative distances, e.g., very far, near, fairly near, etc.

Nine observers, employees from the National Aviation Facilities Experimental Center in Atlantic City volunteered to make the observations. They were all given thirty minutes instruction in magnitude estimation methods with line lengths as stimuli. They were instructed to make their judgments without an experimenter-determined standard. The vessel was in communication with the range commander by radio. On each run the range commander called "mark" as the vessel passed abeam of the observers. This designated that a judgment was to be made. The range of the vessel during its transit was taken by an assistant at the observation post and recorded at the call of "mark". If the range could not be determined at the "mark", the assistant reported a mistrial and the results were struck from the data records. Observers completed a total of 31 observations. Median values were determined and the results graphed in Figure 5. Observe that the slope of the function is approximately 1.27, quite close to the observed function for low angle aircraft. It need hardly be added that the function itself is a power function as is found in all of our previous studies. We draw the conclusion that imbedding the vehicle in a background with a texture gradient--water--in no way changes the nature or value of the psychophysical judgments of distance.

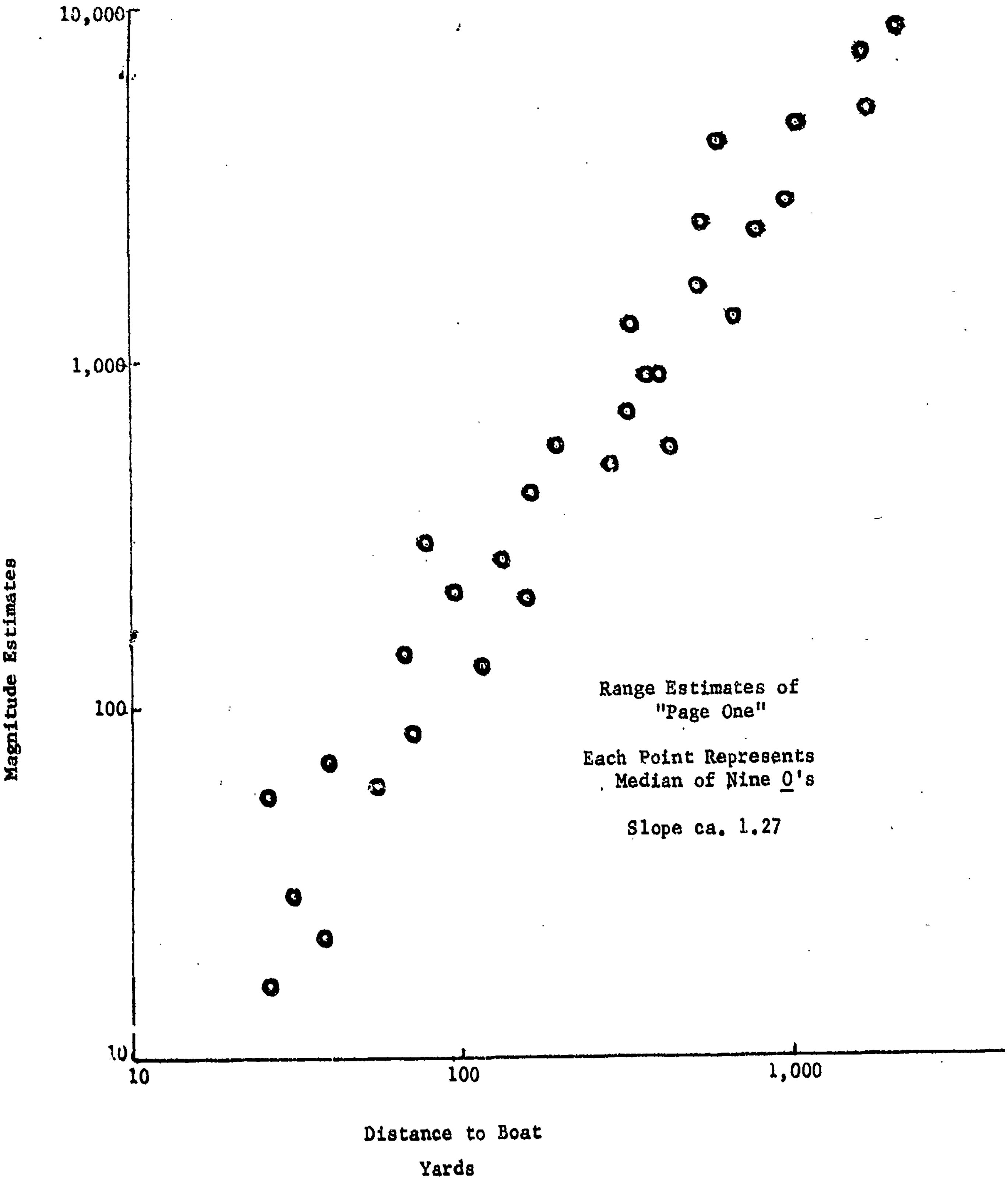
Experiment 4

The previous results tend to show that the psychophysical function relating physical distance to perceived range is a power function whose exponent depends, not on variables such as atmospheric transmissivity or background texture, but rather on angle of regard. However there is a specific feature of all the previous experiments that may be relevant, and that is that the observer is stationary. The normal form of human interaction with environmental events involves movement of the person. Perhaps the static observer in the preceding experiments induces the non-linearity in the psychophysical functions. The moving observer may transmute the judgments that would be made under static conditions in such a way as to reveal to us linear percepts on which the control of his activities may depend. Additionally, in the experiments reported above, the angles of regard ranged over, at most, 100°. We did no ranging from high vantage points. Therefore, to round out our understanding of these phenomena we decided to examine the perceived distance function when the observer was undergoing dynamic translations, and the targets remained fixed in the perceptual sense of that term. That is to say, the distal targets in the perceptual field were stationary relative to the surface of the earth.

In the first part of this experiment six observers, untrained and unsophisticated ground personnel at the Naval Air Station, Lakehurst, New Jersey who had no experience in light aircraft, served as observers. They worked in groups of three. Three of the observers would board the experimental aircraft (Beech Model V35) and the aircraft would fly at altitudes between 200 and 500 feet over a prearranged course. As the aircraft crossed a known landmark the observers were required to range an easily identifiable target on the ground. The observers had been given experience in the magnitude estimation of line lengths and they did the ranging with no standard established by the experimenter.

The physical distances between the landmarks that were overflown and the targets that were ranged by the observers were determined by a combination of electronic, photogrammetric, and topographical survey techniques. Each target was physically measured from the overflown landmark by at least two independent metric procedures. Several times in the course of the experiment observers became airsick because of the uncomfortable turbulence at low altitude. When this occurred the runs were cut short and the aircraft returned to home base. Repeated experimental sessions were conducted on days when weather conditions were as similar as possible. The weather during

Figure 5 62


10,000
1,000
100
10
Magnitude Estimates
10
100
1,000
Distance to Boat
Yards
Range Estimates of
"Page One"
Each Point Represents
Median of Nine O's
Slope ca. 1.27

the experiment was clear with visibility of 7 miles. The temperature in the aircraft often reached above 90^{o}, and consequently the conditions of the experiment for the observers would not normally be expected to lead to high quality data.

Figure 6 plots the results obtained in this experiment from the six observers. The impressive consistency and regularity of the data speak not only of the seriousness with which the subjects engaged in their tasks, but also of the low variability with which the physical metric was established. The surprising result is the magnitude of the power function exponent, ca. 1.27. This is almost identical to ground-to-air estimates at horizontal lines of regard. That the angle of regard was fairly flat can be seen by the conditions of the observations. The average altitude of the aircraft was ca. 350 feet. The closest objects that were ranged were of the order of 250 yards, with the great bulk of data having been collected between 1 and 4 miles. It can be concluded that the angle of regard was rather low.

In order to check on the reliability of the observers, the research director himself served as an observer making repeated observations. Figure 7 shows the results of 43 observations per data point with an estimate of the variability of the physical metric given by the length of the horizontal line. For this single trained observer it is evident that the slope function although slightly flattened at 1.2, approximates what was observed for the untrained group of subjects.

We have now observed in a variety of experimental contexts that the judgments of visual distance into the third dimension by both practiced and unpracticed observers consistently generate non-linear psychophysical functions. If the perceptual information on which many kinds of human action are based is contingent upon perceptual data of the form that we have observed, then the control of such action must entail non-linear components. This of course is no high crime, except that it certainly complicates any attempt to explicate the nature of perceptual motor organization. Consequently, it behooves us to search for other features of the perceptual field that may be used to guide action, and that may be perceived as a linear function of their physical counterparts. The one candidate for such a role is the judgment of time relative to the anticipation of the consequences of action.

The final experiment in this series reports a recent result on the estimation of time to impact. This experiment is a field study that parallels laboratory simulations of time estimations to impact conducted under Army Contract DADA-17-70-C-0077 between Columbia University and the United States Army Medical Research and Development Command.

Experiment 5

In this experiment, segments of which are even now continuing[2], observers seated in a landing airplane, are required to estimate how much time will elapse between some point signaled by the experimenter during the approach,

Figure 6 72

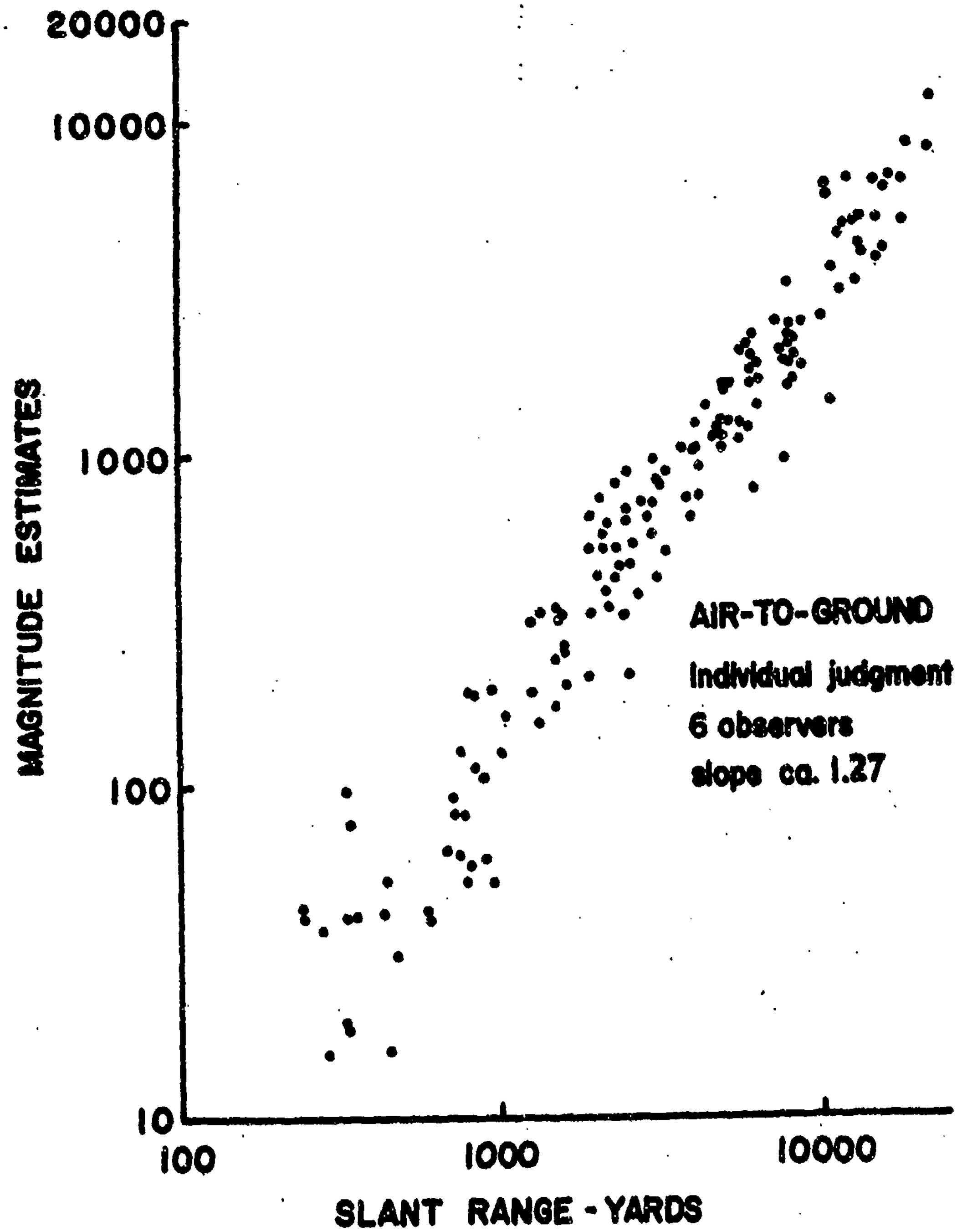
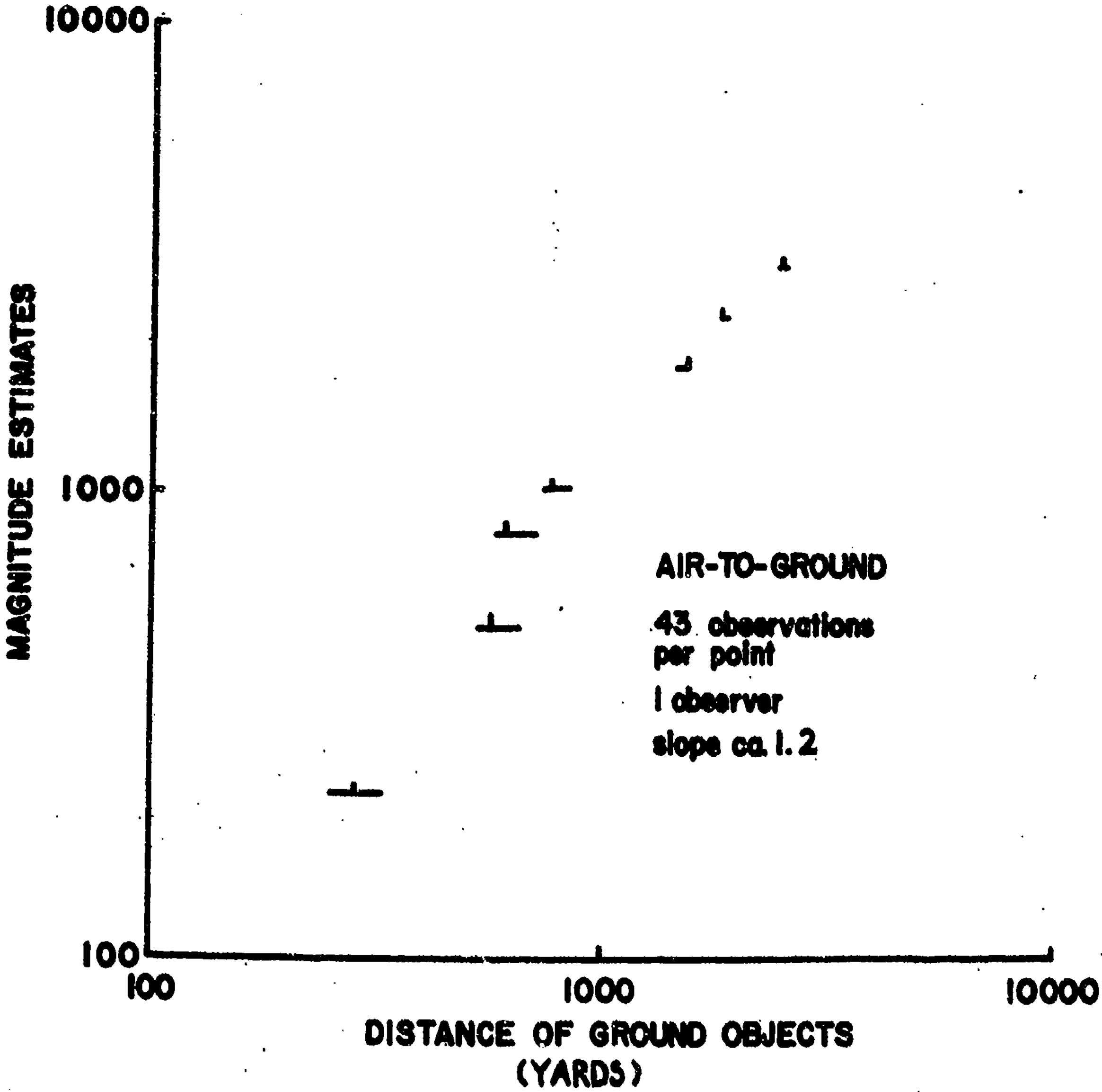

20000
10000
1000
100
10
MAGNITUDE ESTIMATES
100
1000
10000
SLANT RANGE - YARDS
AIR-TO-GROUND
individual judgment
6 observers
slope ca. 1.27

Figure 7C 7C


10000
1000
100
MAGNITUDE ESTIMATES
100
1000
10000
DISTANCE OF GROUND OBJECTS
(YARDS)
AIR-TO-GROUND
43 observations
per point
1 observer
slope ca. 1.2

and the time the observer expects the aircraft to impact the runway.

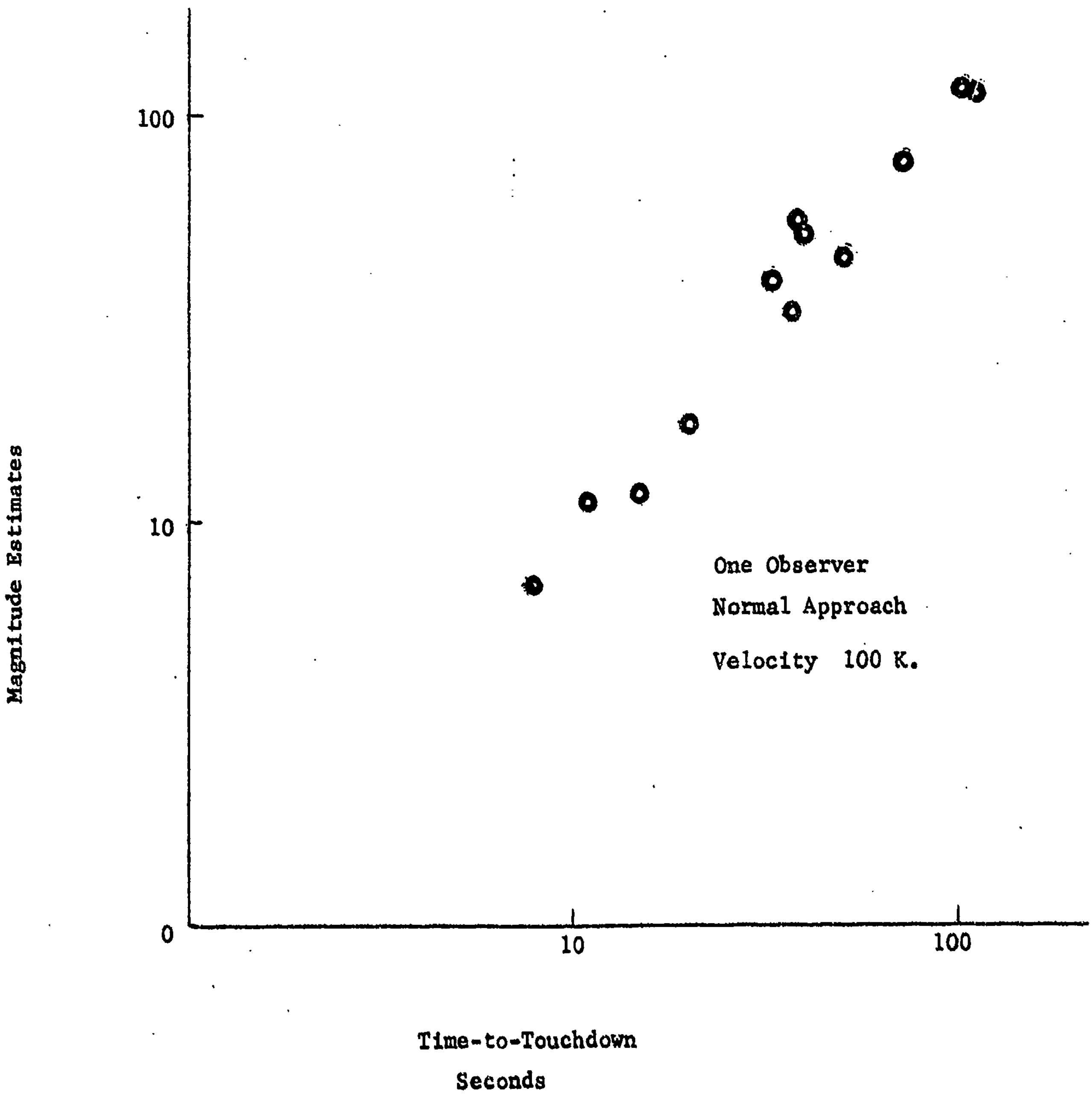
The observers were four highly trained pilots, two of whom were volunteers associated with the National Aviation Facilities Experimental Center in Atlantic City, and the other two a graduate student and a professor of psychology at Columbia University. The experimental task required the observer to ride in the pilot's seat of a light aircraft (Cessna Model 172) during an approach to a landing at a well marked runway. The experimenter, who piloted the aircraft from the right seat, engaged in a series of such approaches to runway 04 at NAFEC. The approaches all followed the localizer and glide slope of the instrument landing system. The observer wore a Psychophysics Laboratory designed "field tachistoscope" that could blank his vision electro-mechanically, or used the simple procedure of closing his eyes on command in order to block his vision from a "mark" point onward. The observer's task was as follows: during each approach the experimenter (using a preplanned schedule to locate the points) would operate the field tachistoscope or say "mark," and the subject would close his eyes. Simultaneously the observer would activate a stop watch to start timing the remainder of his, now imaginary, approach. He was instructed to stop the watch when he believed the aircraft had crossed the runway threshold. Twelve different "mark" points were selected within three miles of the runway threshold. At each "mark" the experimenter would start his own stop watch and stop it as the aircraft crossed the runway threshold. The runway threshold overflight was executed in such a way as to cause no abrupt changes in airspeed or sink rate. Consequently if the observer over-extimated the time-to-touchdown there would be no kinesthetic information available that he could use to make a correction. All the data from each individual observer have not yet been analysed, however preliminary examination shows small variability from one observer to another and consequently the data from one observer have been shown in Figure 8.

We used an algebraic procedure to convert the time judgments into an estimate of the slope of the presumed psychophysical power function. The data, averaged across the four observers yield a slope of 1.20. Again we observe a significant non-linearity in psychophysical judgments of a variable that could be used to control human performance. We remark in passing that this result differs from our findings using laboratory simulations. In those experiments the resulting psychophysical functions were close to linear. It was this result that led us to conjecture that time rather than distance may be the controlling psychophysical function in motor skills.

Conclusions

Although various aspects of the field research described in the preceding pages are still in progress, we can already draw some tentative conclusions based on the data shown here, and on the existing literature. First of all, naturalistic observation guarantees that normal people learn to negotiate very complex visual environments without injuring themselves or others in the first dozen years of their lives. The precision with which

Figure 8 8L


100
10
0
Magnitude Estimates
One Observer
Normal Approach
Velocity 100 K.
10
100
Time-to-Touchdown
Seconds

this type of performance occurs, and in particular when similar behavior involves the guidance of high speed vehicles later in the person's life, leads to questions about how this behavior can be guided and to questions about the mechanisms by which environmental information is processed for use in such guidance. The first and most obvious answer is that the appearance of the world as perceived by the person guides his actions. What the preceding experiments suggest is that the appearance of the world may have metric properties that are not linearly related to the metric properties of the physical world itself. This would mean that some non-linear transformation of the psychological information would have to take place if the person's behavior was expected to conform with the realities of the physical world. It is not impossible that such a transformation occurs; however such non-linearity certainly suggests that alternative hypotheses to explain the guidance of skilled performance are not out of order.

The currently accepted view of motor skills, tracking, and sensory motor performance is still the response shadowing concept first introduced in the early part of the second world war to serve as a basis for analysis of flexible gunnery and other pursuit-type tasks. These theories all presume that stimulus information guides responses with linear fidelity, except for a remanent attributable to error factors (Bilodeau and Bilodeau 1969). The alternative characterization that we would propose to account for human performance and guidance in dynamic situations is a variant of the proposal suggested in Plans and the Structure of Behavior (1960). Such a model interprets components of the skilled performance as "psychologically" ballistic. The model requires only that after the completion of some act it must be possible for the person to check the results of his act against internally stored perceptually based information. His task is now to determine whether new information, arriving as a consequence of the ballistic act itself, conforms to the expectations based on the stored information. In the context of such a model, non-linearities in the actual perceptual structure of the environment would have no complicating consequences. The development and tests of explicitly formulated models based on this conceptualization as alternatives to the linear tracking theories are continuing in the Psychophysics Laboratory.

Footnotes

1 We extend our sincere thanks to Mr. Robert Maples and Mr. Ray Morton, range operation officers at the Pacific Missile Range for their invaluable assistance in the conduct of this research.

2 This experiment is being conducted in two phases, aboard aircraft and on shipboard. We report only the results for the aircraft phase, and compare it with the results obtained from motion picture simulations of aircraft engaged in similar translations in space.

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