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A STUDY OF HUMAN PILOTS' ABILITY TO DETECT ANGULAR MOTION WITH APPLICATION TO CONTROL OF SPACE RENDEZVOUS

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A STUDY OF HUMAN PILOTS' ABILITY TO DETECT ANGULAR MOTION WITH APPLICATION TO CONTROL OF SPACE RENDEZVOUS

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SUMMARY

Tests have been conducted to determine specific visual capabilities of human subjects performing guidance and control functions in space flight. Ability of pilots to detect the rate of motion of a light spot moving with respect to a star background was determined as a function of length of time of the observation. Ranges that were considered eliminated the ability to recognize how far away the object was and velocities normal to the line of sight were used which created a range of angular motions of the sight line. These angular motions varied from speeds beyond which recognition times did not change down to speeds slow enough to identify the lower threshold of dynamic visual acuity.

Results of the tests indicate that human visual resolution is suitable for performing rendezvous maneuvers and as a backup for onboard instruments to create a more flexible, adaptive error-sensing system.

INTRODUCTION

In airborne missions, one of the most important considerations has been the visual capabilities of the crew. Man's visual capabilities may also determine the success or failure of some space missions; therefore, it is desirable to know how well human vision can supplement and even replace system components that perform tracking tasks during space flight.

Most visual studies made in conjunction with air-crew duties have been directed toward determining man's ability to perceive objects that were relatively close by as a function of such parameters as the size and shape of the objects, lighting effects, color, and distance. References 1 and 2 are examples of studies aimed at isolating the basic capabilities of the human eye in identifying the size, shape, and binocular illusion of objects. Reference 3 presents a typical depth-perception study. References 4 and 5 represent medical approaches to the determination of the structure of the eye, and such reactions as the receptor process of color sensitivity and visual stimulation to different wavelengths of light. Reference 6 contains a comprehensive section on human vision in general.

Reference 7 presents a rendezvous study in which visual requirements are set forth. The relative motion between two vehicles in space creates an angular rate of the line of sight joining the two. Regardless of whether proportional navigation or orbital mechanics are utilized for control logic, this line-of-sight motion must be detected with resolution from 1 milliradian per second down to 0.1 milliradian per second, depending on control requirements. At the initiation of a space maneuver requiring this precise control, the target creating the angular motion is far enough away from the controlling vehicle to eliminate depth perception. For example, in reference 7 space rendezvous is proposed to begin at a separation of 50 miles, and only the component of relative motion normal to the line of sight is visually apparent. Visual techniques for controlling space rendezvous (ref. 7) utilize an identification light on the target vehicle with an inertial background and an optical sight for detecting and measuring this normal component of velocity. This concept of a point source of light moving relative to a stationary background reference is used in the present visual tests to determine whether the acuity simulated in the closed-loop study of reference 7 is valid.

In the present investigation, visual-acuity tests were conducted to establish thresholds of man's ability to detect relative angular motion such as would exist between vehicles in space. The tests were conducted in a 53-foot radome used as a planetarium at the Langley Research Center. Six subjects with normal vision were tested simultaneously. Time was allowed for all of the subjects' eyes to become dark-adapted prior to beginning each phase of tests. Results are presented by tests using light spots moving on a low-intensity star background.

APPARATUS

Figure 1 shows the 53-foot-diameter inflatable radome modified to serve as a planetarium facility for housing various simulation programs being carried out by the Langley Research Center.

Figure 2 is a photograph of the apparatus used in the series of light-on-dark tests to project a moving light spot on a star background on the inside wall of the planetarium. The star background was projected on the planetarium wall by a stationary slide projector not shown in figure 2. There were 106 stars on the 22° field, with random separation angles. The servomechanism that produced precise movement of the light spot was a two-axis drive system on which a 2-inch square mirror was mounted. The light spot was produced by an arc-lamp beam fed through a field stop and a lens system and reflected in the servoed mirror to focus on the star field. An analog computer commanded the mirror drive. Test subjects viewed the star motions from 25 feet for the tests. For horizontal right-left target motion, the line of motion connected the target and background reference star being used. For varying directions of target motion, the target was centered in a 3-star triangle or a 4-star square.

TEST PROCEDURE

Six engineers served as test subjects in the present acuity investigation. Time was allowed prior to beginning each test series for all six subjects to become dark-adapted. The subjects had normal vision and observations were made by all six at the same time to insure consistent test conditions in object spacing and orientation and in relative speed and direction of the objects. Each subject used a stop watch to measure the time he required to detect object motion; the watches were muffled under the participants' jackets or other suitable material so that each subject was unaware of his neighbor's observation time. Each also had a small red light so that he could record his observation time for each run and was instructed not to alert his fellow subjects, but to wait for several seconds after pressing his stop watch before switching on the light. At speeds greater than 1.6 milliradians per second, recognition time did not change and this fact determined the upper speed limit used. One group of tests was made beginning with zero motion between the objects and increasing to the 2-milliradian-per-second limit. Another group of tests was made in the opposite manner, beginning with fast motion. The objects were moved in various directions, and subjects were required to identify the direction of the motion as well as time of recognition. The initial position of the object was known, and target detection was not a task.

The tests were conducted with dim light spots on a black surface, and were estimated to have intensity equivalent to fifth-magnitude stars. The light spots subtended 1.7 milliradians, but definition was such that the outer annulus of about 0.2 milliradian was fuzzy. The moving spot was slightly brighter than the background stars. Runs were initiated with object-reference angular separations of 12.5, 27, 34, and 60 milliradians. The data at the 60-milliradian initial angle were not consistent; therefore, only data through 34 milliradians are included herein.

In addition to the tests of dynamic visual acuity as a function of the initial angular spacing of the object and reference, runs were made in the series of tests with the object and reference initially superimposed. The task in these runs was to identify precisely when the objects became separated as a check on the ability of the subjects to use range-finding or sextant-type instruments when the two light sources to be superimposed are in relative motion one to the other.

RESULTS

Results of the present tests are in terms of the time required to detect angular separation of a target from its background reference at various initial angles and motion rates. Such effects as the size of the initial separation angle, light intensity, and fatigue are indicated.

Figure 3 shows results of one series of the present visual acuity tests. Simple right-left motion was used for these tests, and the task of the six subjects was to detect the motion and identify its direction. The rate of motion is plotted against the overall average detection time for the six subjects. Spacing between the target object and reference was 12.5 and 34 milliradians, or about 7.5 and 20 target diameters, respectively. Figure 3 shows that, if the initial spacing is 12.5 milliradians, a pilot can detect an angular rate of 0.1 milliradian per second in about 10 seconds for a 1-milliradian traversed angle. Figure 3 also shows a tendency to recognize motion to the right more readily than motion to the left for the closest initial positioning of the objects.

Figure 4 is a typical cross plot of visual data from the present tests and shows the angle through which the object moves during the time required to detect the motion.

If the target moved across the reference background in random directions, the task of identifying both the existence and direction of motion became more difficult than just detecting motion in a predetermined plane. The time required for this task when only the correct estimates of the direction of object motion are used is described in figure 5.

Figure 6 is typical of results of how well subjects can detect separation from a superimposed condition at various speeds. The object and the reference both subtend 1.7 milliradians. The "detection" curve is parallel to the actual separation curve at speeds of separation above 0.1 milliradian per second. At 0.1 milliradian per second, separation required 17 seconds. At rates less than this, detection times converged on actual times required for the objects to separate, and reaction time was such a small percentage of the test time that its effect was secondary.

Up to this point, average values of results have been plotted. In figure 7, root-mean-square deviations for all subjects at each test condition are plotted. The upper threshold of this deviation for visual-rate detection at 12.5, 27, and 34 milliradians separation is defined. Some of the tests were made by beginning with slow rates, whereas other tests began with the fast rates first and the more difficult slow rates last.

In figure 8 the percentage of overall misses in identifying motion and direction correctly are plotted as error against the initial separation angles.

DISCUSSION

Results of the present visual-acuity tests indicate that a human pilot can detect angular motion accurately enough to control space rendezvous maneuvers by using only visual techniques.

Previous pilot-controlled simulation studies of visual rendezvous reported in reference 7 determined the visual requirements for each of two phases of the terminal rendezvous maneuver. The least demanding phase of the maneuver was the tracking or homing phase requiring close control of angular line-of-sight rates but not precise angular measurements. The second phase entailed precise measurement of angles on the order of 1 milliradian so that techniques for computing the range and range rate along the line of sight could also be applied.

The present tests indicate that the tracking task can be accomplished by the human pilot very readily. Therefore, space maneuvers where range and range-rate data are provided on instruments are easily possible for a human pilot to perform visually. In addition, a simple optical readout device (optically similar to a marine sextant) would allow the pilot to crank the images of the target and the reference together before observing their relative motion. This instrument would idealize the visual situation and insure that the pilot could perform both the tracking task and the range-finding phase of the terminal rendezvous maneuver visually. This is borne out by results of the present tests which show that if a pilot has a background reference close by the target he is homing on, then he can detect the precise angular line-of-sight motion required for computing range or distance values along the line-of-sight intercept.

The optical device would also permit the pilot to predetermine the plane of motion so that the subsequent visual task would be reduced to motion detection only. Thus pilot fatigue, which would affect his accuracy, would be reduced directly, since shorter detection times are required for contiguous tracking. Some of the tests began with slow rates, whereas other tests began with the fast rates first and the more difficult slow rates last. This procedure also showed that fatigue caused a deterioration in acuity, and relief cycles should be provided.

The low brightness difference between the stars and background utilized in the present tests showed that lighting intensity is not a primary consideration. This means that, with the aid of an optical device with a 3-inch lens, stars of the eleventh magnitude or brighter can be used as inertial tracking references. There are enough stars of the eleventh magnitude and brighter to give an average density of four stars per square degree at the galactic pole and four times as many at the galactic equator. Thus, the assurance of proper viewing conditions would only be a minor restriction in the planning of a rendezvous mission.

CONCLUDING REMARKS

Results have been presented of a study of human ability to detect angular separation and motion suitable for control of space rendezvous.

If the angular separation between a space target and an inertial reference is 12.5 milliradians, a human pilot can detect an angular rate of 0.1 milliradian per second by observing a 1-milliradian angle traversed in 10 seconds or less.

High brightness difference between moving objects and their background is not required for good angular detection. Visual-detection ability deteriorates with fatigue, and visual tracking tasks should include relief cycles.

The error in identifying object motion varies directly with reference separation. To maximize a pilot's visual ability, an optical device that projects a space-fixed reference onto the target grid should be provided. If this optical device has at least a 3-inch lens, the human pilot can use stars as dim as eleventh magnitude as background inertial reference.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., August 10, 1962.

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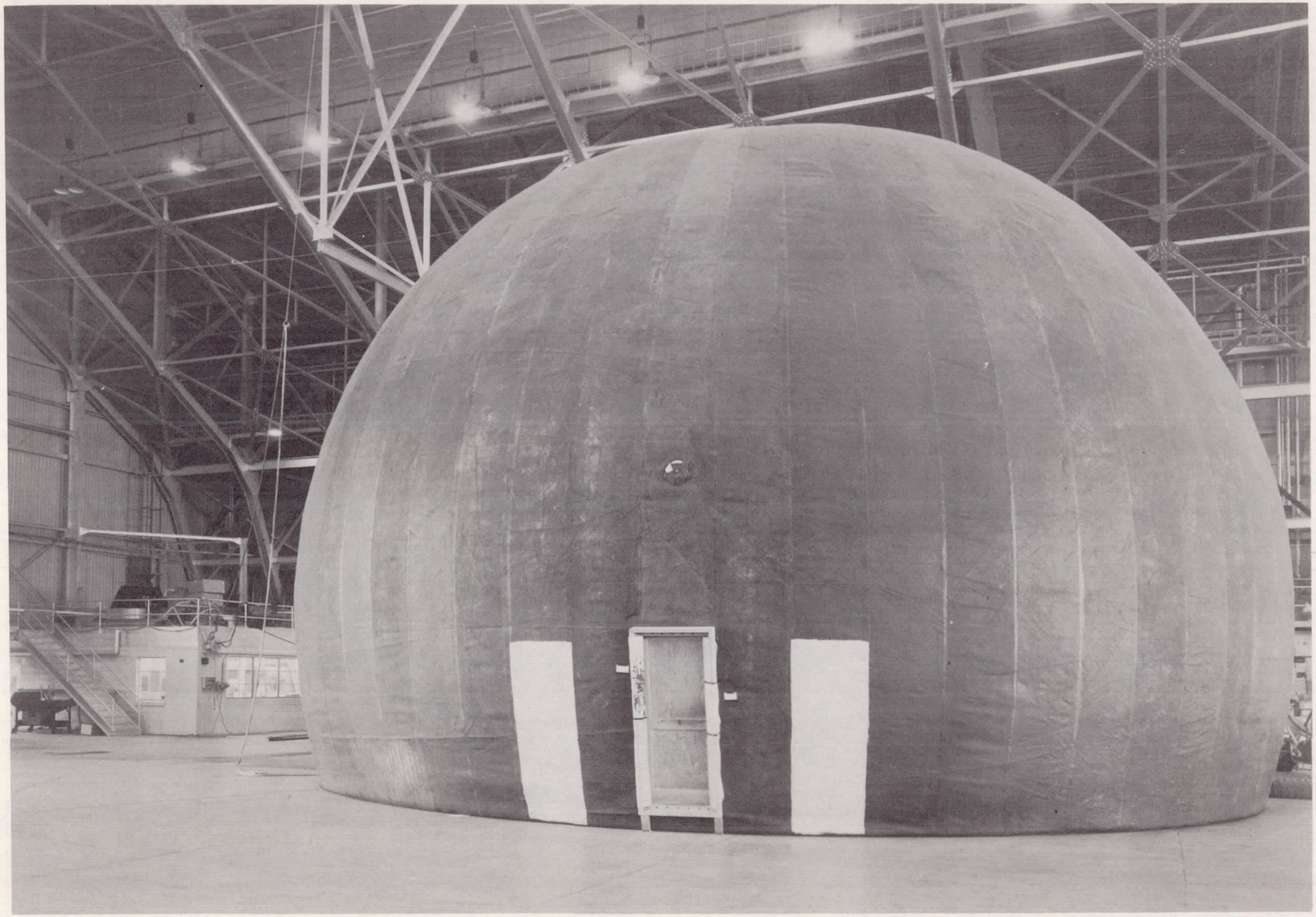


Figure 1.- Inflatable planetarium. L-61-3399

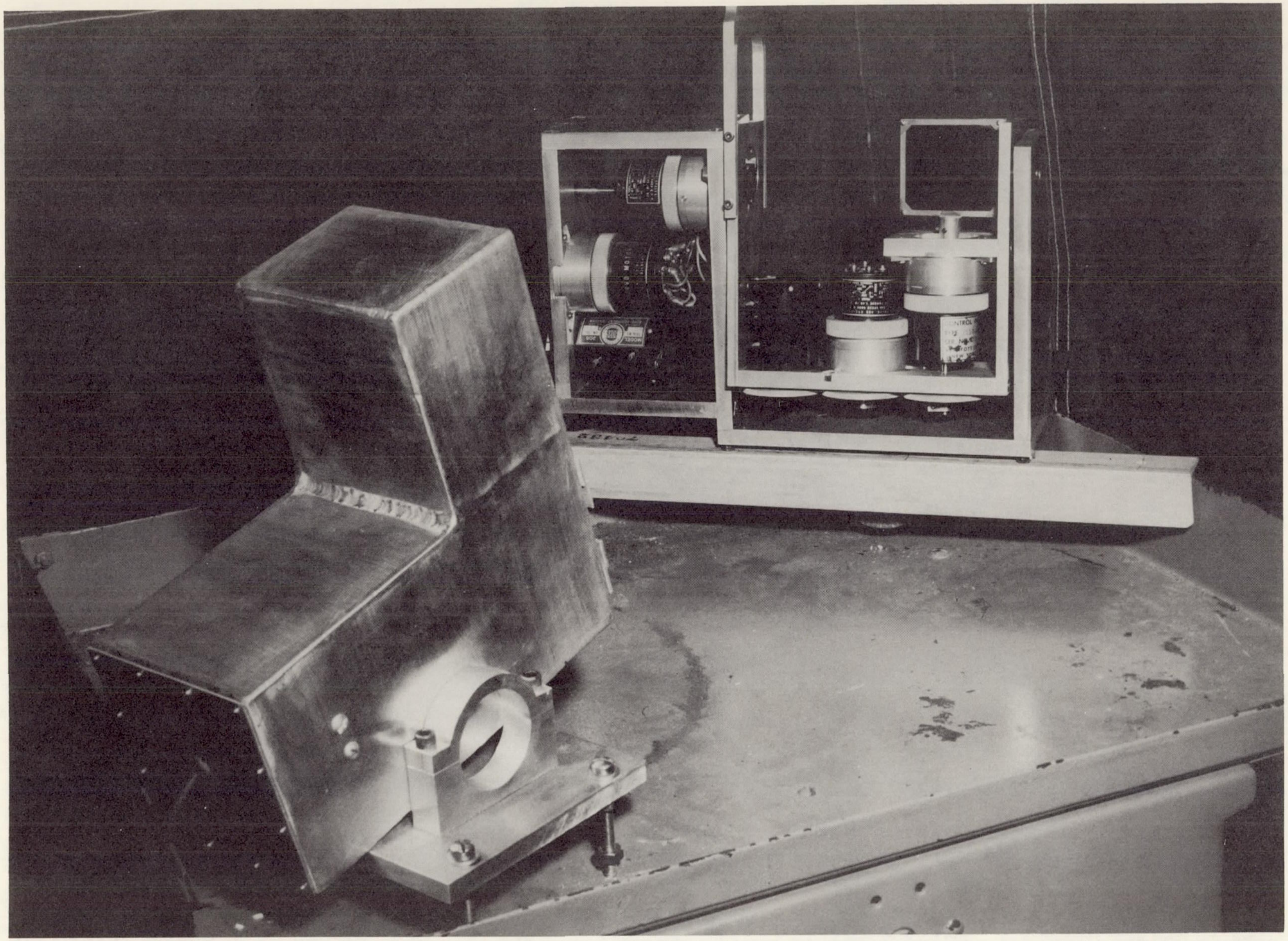


Figure 2.- Photograph of moving-target projector.   L-62-4534

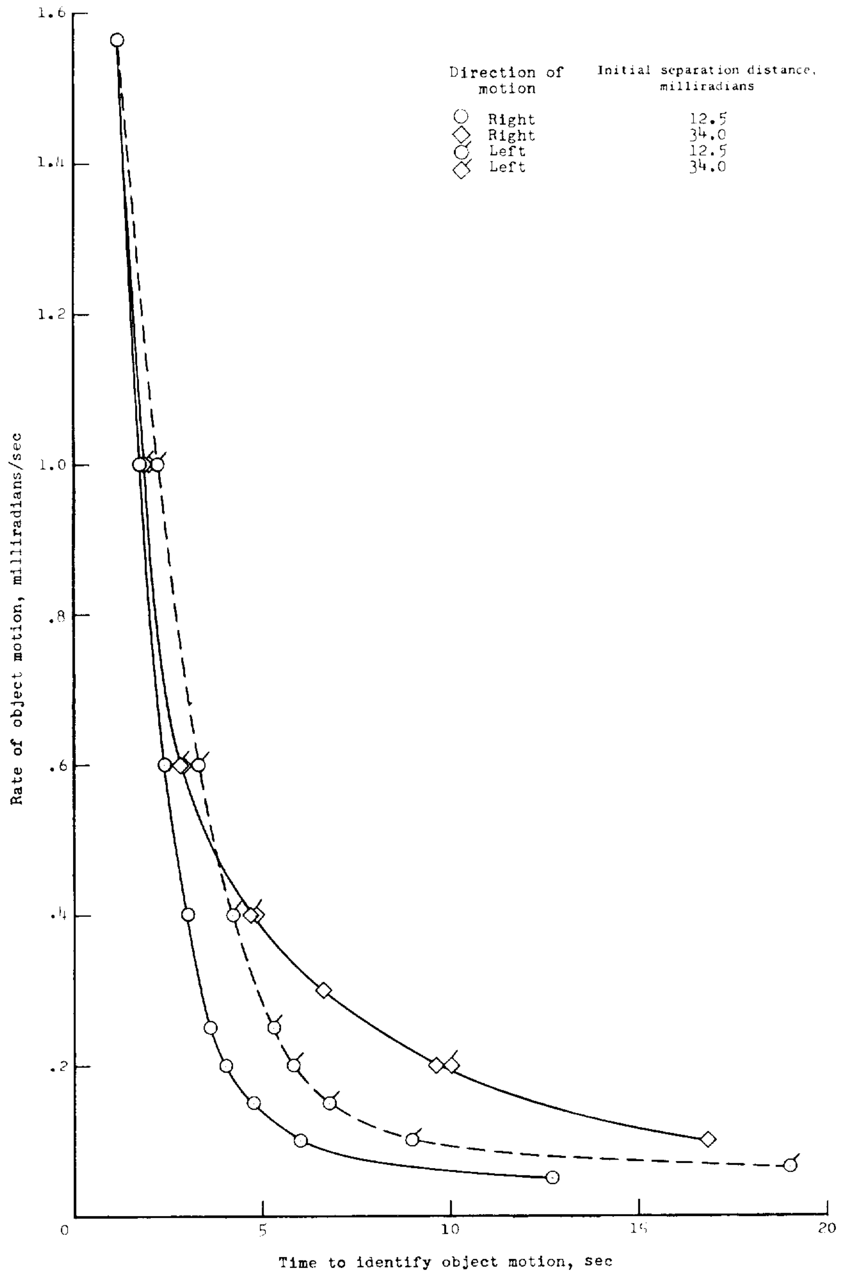


Figure 3.- Typical visual acuity showing effect of reference separation and direction of motion (right and left). Slow speeds tested first.

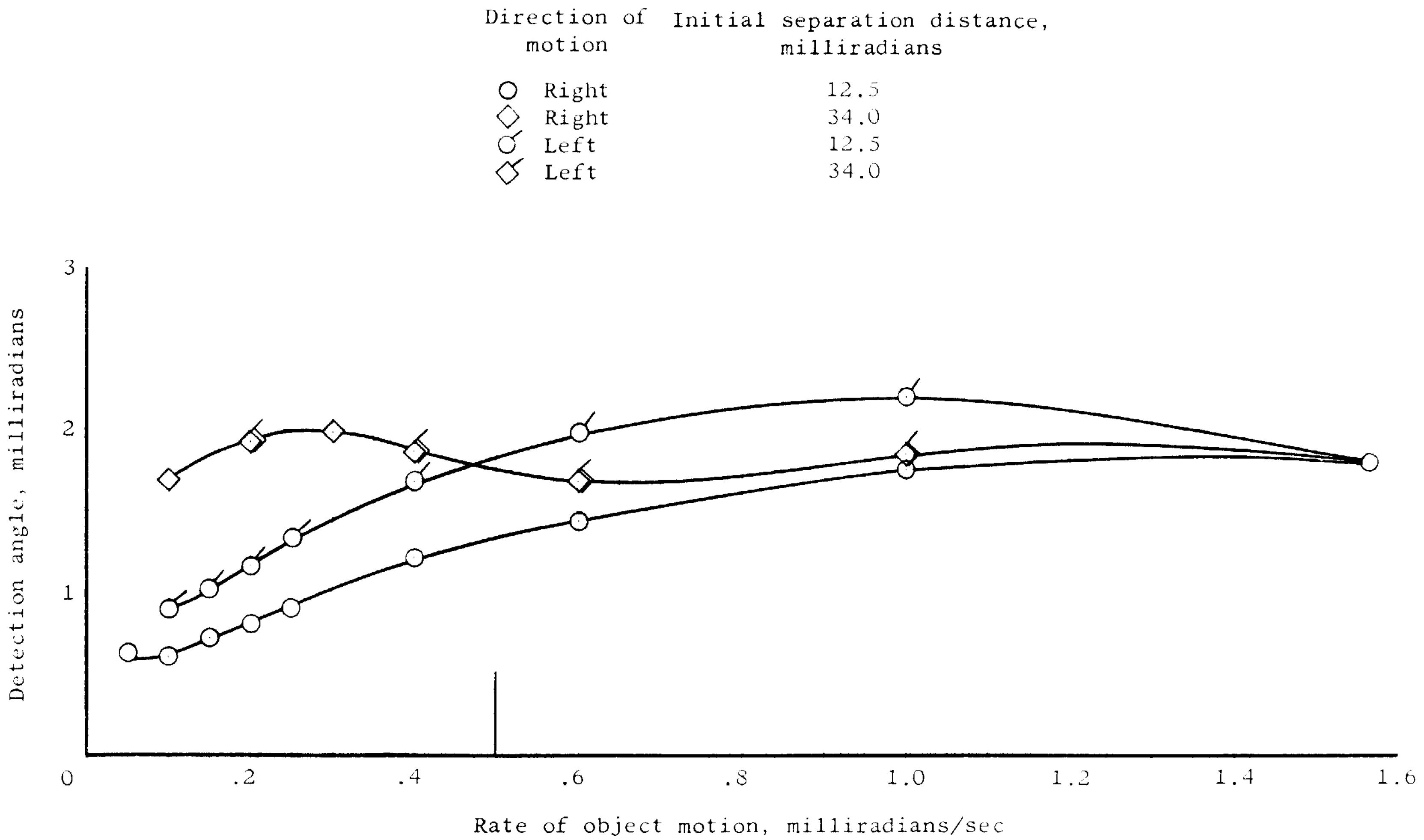


Figure 4.- Detection angle against rate showing similar tracking capability above 0.5 milliradian per second.

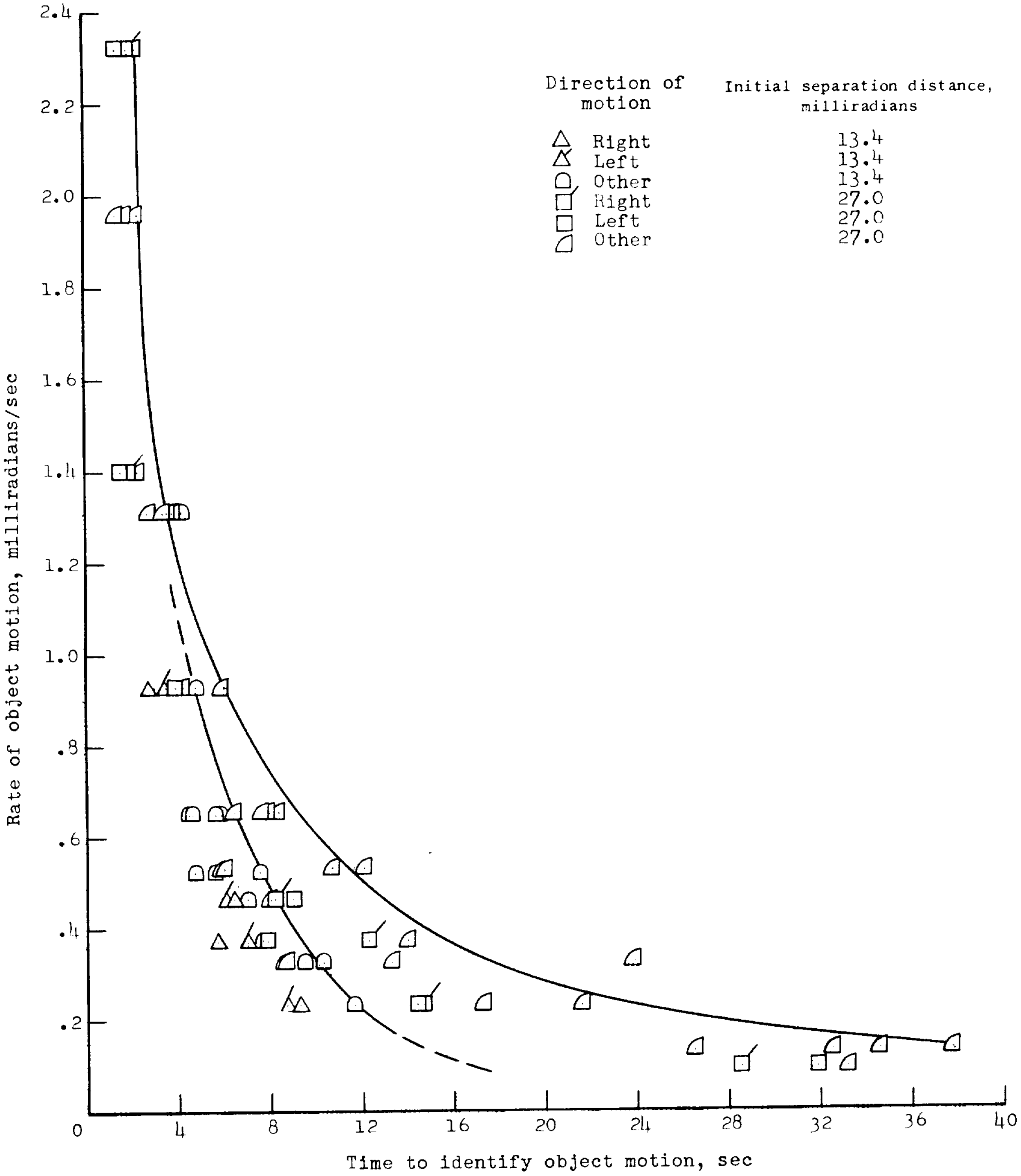


Figure 5.- Typical visual acuity showing boundaries for multiple-direction tests. Fast speeds tested first.

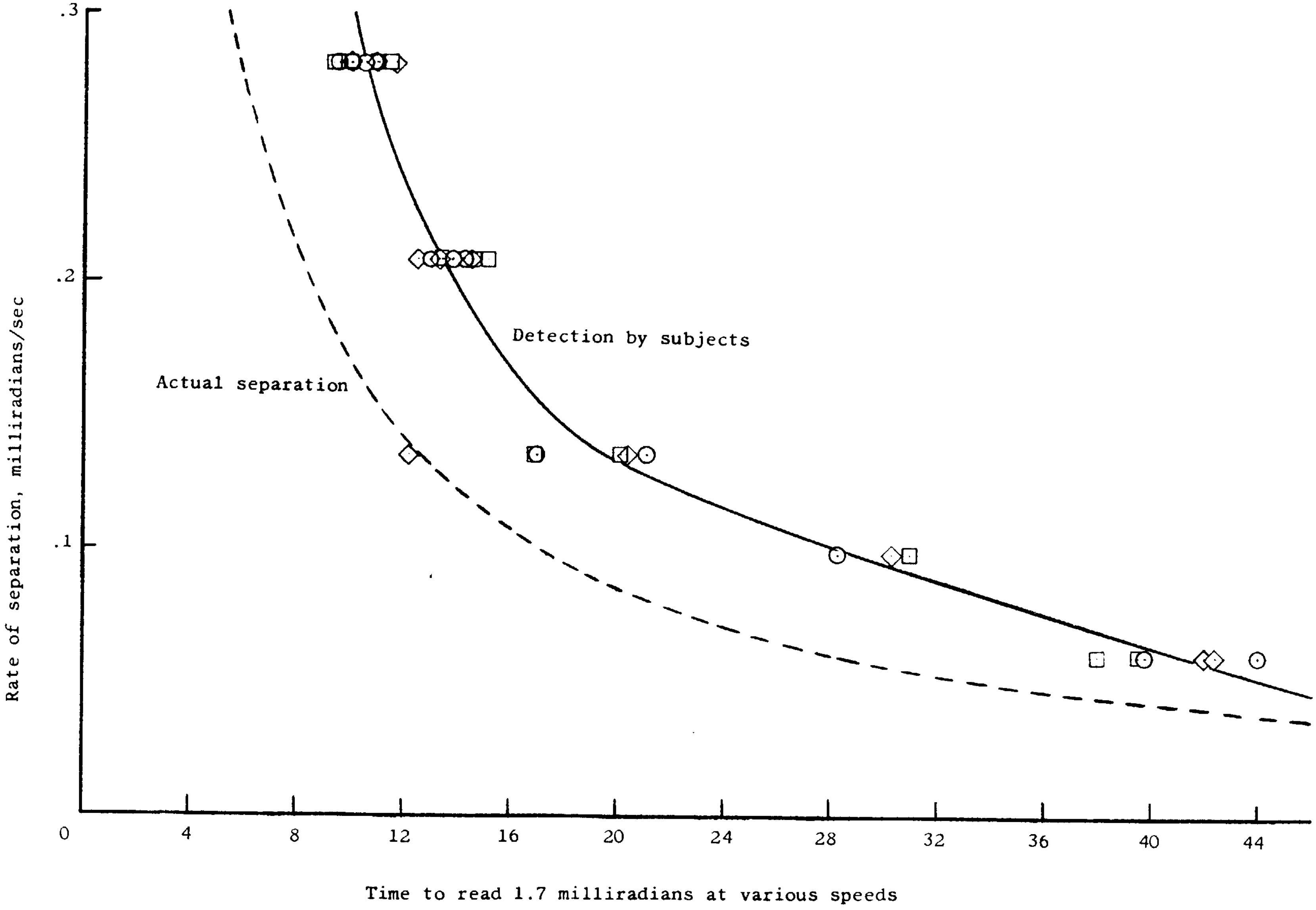
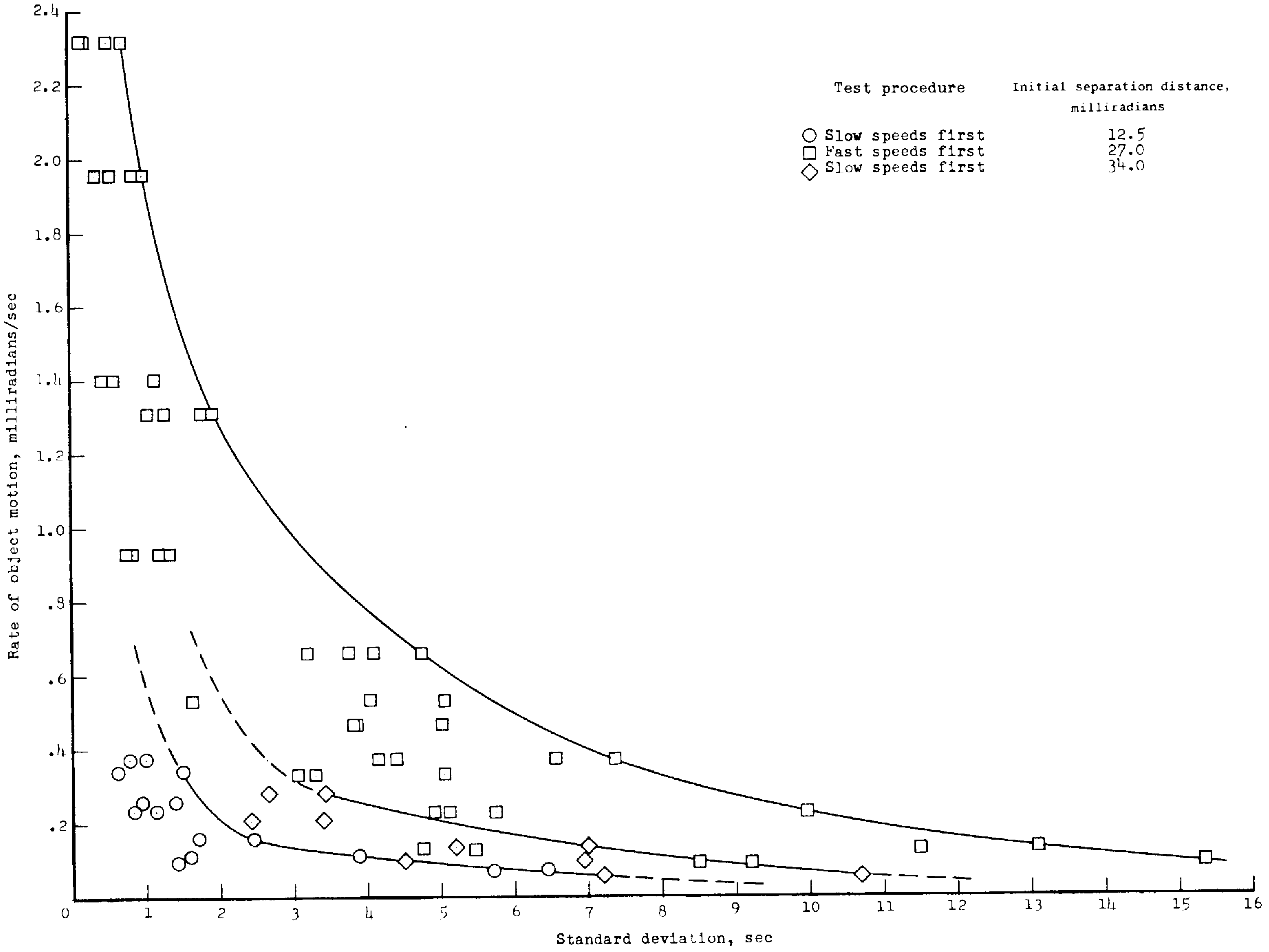


Figure 6.- Typical plot of maximum separable acuity. 1.7-milliradian-diameter object initially superimposed on background reference of same size.



igure 7.- Standard deviation boundaries for three visual acuity tests. Direction of object motion included 8 points of the compass.

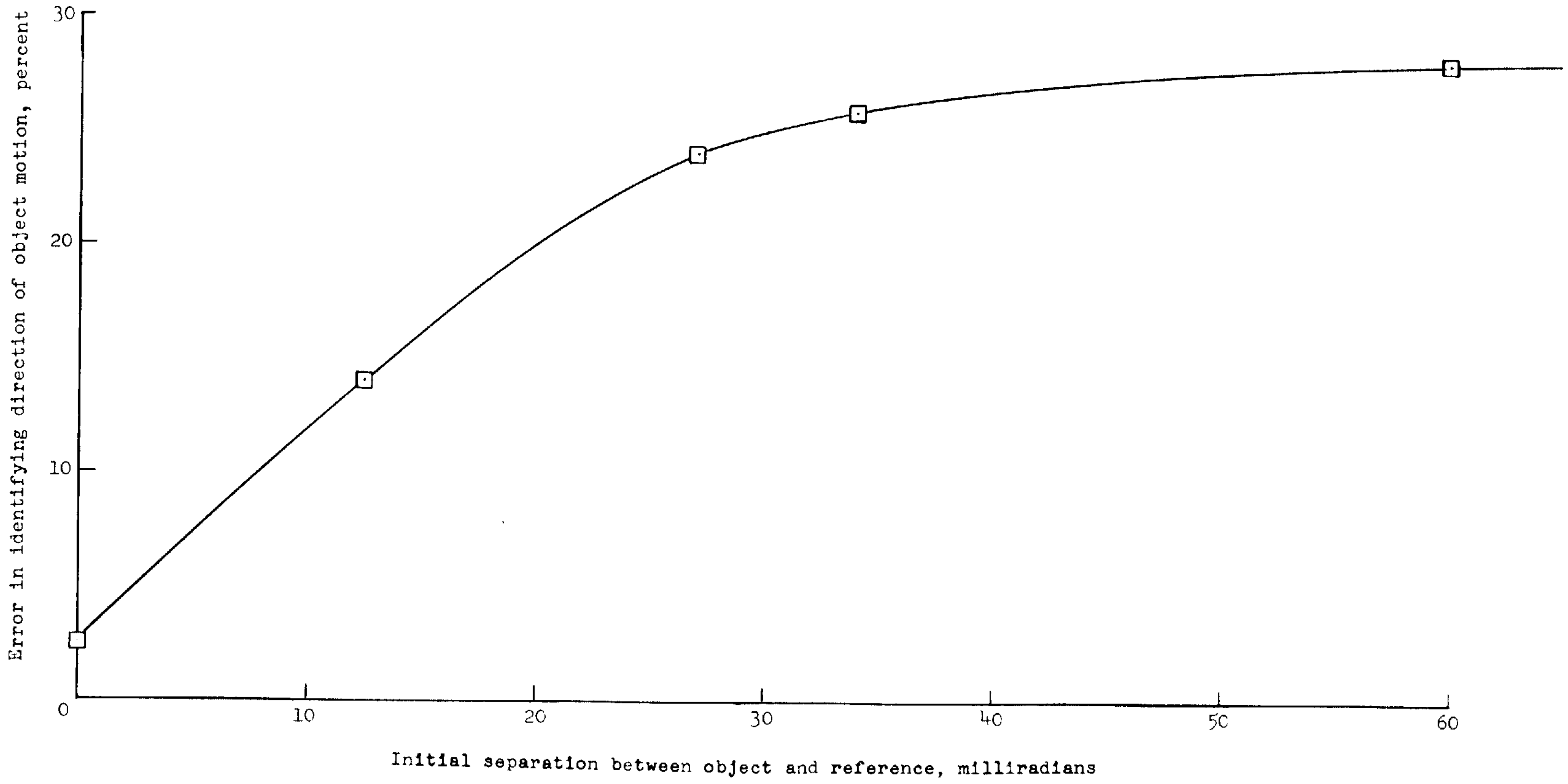


Figure 8.- Error in identifying a bias direction of motion plotted against reference separation. Directions used: 45°, 135°, 225°, and 315°.

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