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SUMMARY

In-simulator sink-rate performance at touchdown with a conventional-image distance profile is compared with performance with a profile tilted such that the lower portion of the display appears closer than the upper portion. The objective data revealed no significant differences between the untilted and the tilted conditions, although subjective opinions indicated increased depth cues for the tilted condition of a rudimentary Computer Generated Image (CGI) perspective-runway display. No such indications of apparent depth changes with tilt for a terrain model-board scene were obtained. The increased detail available from the terrain board, as suggested by an improvement in sink-rate performance over that obtained from the rudimentary CGI display, is assumed to provide depth cues that are not noticeably augmented by tilt effects.

Although subjective opinion was favorable for the tilted CGI image, the conclusion is that the increased effort involved to obtain the proper tilt profile is not warranted, as there is no resultant improvement in objective performance. This conclusion is based in part on the expectation that the subjective preference for the tilted CGI image would lessen or disappear if the additional runway details of a more sophisticated CGI system were available.

INTRODUCTION

Some of the factors affecting the quality of a flight simulator are the mathematical model of the flight vehicle and its environment; the cockpit hardware (such as instrumentation and force-feel system); and the motion, aural, and visual cues provided to the pilot. Although the general quality of current transport simulators is believed to be high, performance deficiencies are present, and particularly evident, in the area of flare and touchdown control. The importance of these deficiencies is increased as the civilian segment of air transportation relies increasingly on flight simulators for pilot training and proficiency maintenance.

These deficiencies have been attributed to each of the previously mentioned factors (ref. 1), with current emphasis placed on the motion factor (ref. 2) and, more commonly, the visual factor (refs. 3 and 4). Visual deficiencies are felt to be particularly prevalent in elementary Computer Generated Image (CGI) displays. The amount of detail in such displays is insufficient to provide performance equivalent to terrain model-board systems. The latter systems in turn do not provide performance equivalent to the real world (ref. 4).

One of the visual deficiencies prevalent in CGI system is the unrealistic presentation of binocular and visual-accommodation cues. This paper presents the objective and subjective data collected during a fixed-base evaluation of the visual effect of image tilt of a refractive-lens display system (ref. 5). The system was used to present a rudimentary computer-generated "out-the-window" scene to the pilot of a 737-100 simulator during approach, flare, and touchdown. It was expected that the tilt of the image surface would provide a more realistic simulation of the binocular cues involved in the landing task. The rationale for this expectation was the fact that the image orientation was adjusted by the tilting process to provide apparent-image distances which were closer at the bottom of the display, whereas the top of the display was collimated at infinity. Thus, the front portion of the runway during flare and touchdown appears to be nearer to the pilot-observer than the far end of the runway. In comparison, the conventional orientation yields apparent-image distances which are closer in the middle of the display, whereas the top and bottom of the display are collimated at infinity.

The rudimentary CGI scene was chosen for the initial evaluation of the tilt effect because the CGI scene has less apparent depth due to lack of detail than other available scenes. The tilt effect was expected to provide increased depth cues; thus, the increment in visual effect between the untilted and tilted cases for the CGI scene was expected to be the maximum possible and, therefore, should have been the easiest increment to detect.

Objective results from this study are presented as comparisons of sink rate at touchdown between performances for untilted and tilted displays. Sixty-four landings with each condition for a total of 128 touchdowns were made by 3 subjects. Subjective data from the evaluation utilizing the CGI scene are also presented. Other performance measures, such as the flare and touchdown footprints (ref. 4), were recorded and analyzed, but these measures provided less sensitivity than the traditional sink-rate measure.

The visual effect of the image tilt was also investigated for a terrain model-board scene. This comparison provided only subjective data. The original intention was to conclude the evaluation study with objective data for tilt with the terrain board scene, but the objective results with the CGI scene made this plan unnecessary.

The CGI sink-rate results of this study are also compared with the sink-rate results of a previous study (ref. 6) utilizing the same simulator and display system with the untilted terrain board scene to demonstrate the effect of the more detailed scene on touchdown performance.

Use of trade names or names of manufacturers in this report does not constitute an official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

THE FLIGHT SIMULATOR AND LANDING TASK

The various elements involved in the evaluation of the effect of image tilt are described in the following paragraphs.

Computer Implementation

The mathematical model of the aircraft and the simulation hardware drives were implemented on the Langley real-time simulation system. This system, which consists of a Control Data CYBER 175 computer with appropriate interface equipment, solved the programmed equations 32 times per second. The average time delay from input to output (1.5 times the sample period) was approximately 47 ms.

Aircraft Mathematical Model Characteristics

The mathematical model of a 737-100 aircraft included a nonlinear data package for all flight regions, a nonlinear engine model, and nonlinear models of servos, actuators, and spoiler mixers. The simulation of the basic airframe underwent extensive validation, including comparisons with actual aircraft response data and pilot evaluations. For the subject studies, the simulated aircraft was in the landing approach configuration with the approximate flight characteristics presented in table I. The flight-control mode was the manual mode rather than others available, such as control-wheel steering, navigation, or autoland.

Fixed-Base Cockpit

The transport simulator cockpit at the Langley Research Center was used for this study. The primary instrumentation consisted of an attitude director indicator (including active flight-director bars and speed bug but without flare guidance), vertical-speed indicator, horizontal-situation indicator, altimeter, airspeed indicators (both indicated and true), angles-of-attack and slideslip meters, and a turn and slip indicator. The control forces on wheel, column, and rudder pedals were provided by a hydraulic system coupled with an analog computer. The system allows for the usual variable-feel characteristics of stiffness, damping, Coulomb friction, breakout forces, and inertia. The force gradients were provided by the CYBER 175 computer. Selection of the parameters of the control loading system was included in the extensive validation process for the 737-100 flight simulator.

Refractive Display System

An out-the-window virtual image system with the triplet lens design of reference 5 was located nominally 0.79 m (2.58 ft) from the pilot's eye. It has a nominal field of view 48° wide and 36° high and uses a 525-line TV raster system. The display system provides a 46° by 26° instantaneous field of view. The system supplies a color picture of unity magnification with a resolution on the order of 9 minutes of arc.

Visual-Scene Generator

The visual scene used for the objective results of this study was generated by an Adage AGT 130 graphics computer.[1] The terrain board system was used only to obtain subjective opinions of the tilt effect on that type of system.

The CGI scene.- The perspective-runway image (fig. 1), drawn on a 30° by 40° field of view, included the basic outline of the runway and a centerline drawn from 1828.8 m (6000 ft) in front of the runway threshold to the horizon. The runway image represents a runway 1524 m (5000 ft) in length and 41.67 m (136.72 ft) in width. Four equally spaced lines were drawn perpendicular to the centerline in the plane of the runway at 304.8-m (1000-ft) intervals from the threshold. The mathematics necessary to draw the runway image are outlined in reference 7. The visual delay of the scene generator was less than 12 ms, which gave a total visual delay of less than 59 ms when combined with 47-ms delay of the central digital computer.

The terrain board scene.- A TV-camera transport system was used in conjunction with a terrain model board to provide a scene for display. The model board, 7.32 m (24 ft) by 18.30 m (60 ft), offers terrain and airport complexes at scales of 750/1 and 1500/1, complete with taxi lights, visual approach slope indicators, runway end identifier lights, etc. Provisions are made for day, dusk, and night scenes, including aircraft landing lights during night landings. The subjective data for the evaluation of image tilt were taken on the 1500/1-scale runway during daylight operation. The scaled runway width was 81 m (267 ft) and the length was 3.50 km (11 500 ft).

The approximate second-order transfer-function parameters for the camera transport system are presented in reference 8 and show translational lags of approximately 10 ms and rotational lags of approximately 20 ms. Total visual lag for the terrain board scene is thus less than 70 ms.

Effects of Image Tilt on Collimation

Figure 2 presents a stylized version of the untilted and tilted effects on the visual scene. The conventional or untilted orientation yields apparent image distances which are closer in the middle of the display, with the top and bottom collimated at infinity. In tilted orientation, the bottom of the display appears to be closer, with the top of the display collimated at infinity. Figure 3 presents the geometry necessary to produce the distance profiles; the POLYPAGOS ray tracing program of reference 5 was used for this design. The tilted image surface of figure 2 does more closely approximate the ideal surface relative to the line of sight during a typical landing approach than the untilted image surface.

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[1]Manufactured by Adage, Inc.

Flare and Touchdown Task

The simulated aircraft was trimmed in a 3° descent on the glide slope and localizer at a range of 3.22 km (2 miles) from the runway threshold and an airspeed of 120 knots. The aim point on the runway was 304.8 m (1000 ft) beyond the threshold. The task was to maintain the 3° glide slope, execute the transition to flare, and then land while controlling speed. Although sink rate at touchdown was the primary performance measure, the goal was to make a normal touchdown with conventional techniques. No simulated turbulence or winds were present.

Experimental Subjects

Three experienced subjects (two nonresearch pilots and one simulation engineer) made a total of 128 landings, equally divided between the CGI untilted and tilted scenes. Static viewing and several landing approaches provided subjective data for the evaluation with the terrain board scene.

EXPERIMENTAL PROCEDURES AND RESULTS

In order to evaluate the effect of CGI image tilt on pilot/simulator landing performance, each of the three subjects involved in the study was allowed to familiarize himself with the characteristics of the simulator. (Landings were allowed during this period.) Forty-eight approaches and landings were then completed by each of 2 subjects, and 32 were completed by the third subject. Untilted and tilted conditions for each subject were randomized to eliminate learning and fatigue effects.

After the data were collected for the CGI scene, each subject made several approaches and landings in the simulator with the terrain board scene in both untilted and tilted conditions. Each subject also observed the terrain board scene for both conditions in a static display at flare position. None of the subjects felt there was any static or dynamic visual difference between the untilted and tilted display of the terrain board scene.

The subjective opinions of other observers of the static scenes also revealed a lack of differentiation between the untilted and tilted displays of the terrain board scenes. The depth cues already available from the finer details of the terrain board without tilt seem to explain this lack of differentiation. Conversely the differentiation was quite pronounced for all observers with the CGI scenes.

Objective CGI Tilt Results

Table II presents the results of an analysis of variance of the sink-rate performance with and without tilt of the CGI scene. Figure 4 presents the means and standard deviations of the data used in this analysis. The results in table II reveal no significant differences in tilt conditions, subjects, or the interaction of these factors. Since no differences were detected for the CGI scene, the case in which the tilt effects were expected to be the maximum possible, the objective evaluation for the terrain board scene was not carried out.

Comparison of CGI and Terrain Board Results

The sink rates from the 128 touchdowns for the CGI scene of this study were averaged to yield a single mean and standard deviation for comparison with a terrain board mean and standard deviation based on 30 touchdowns reported in reference 6. Table III presents the statistical comparisons of these data. As expected, the terrain board results demonstrate superior performance to that obtained with the rudimentary CGI display. (See fig. 4.)

CONCLUDING REMARKS

There were no significant differences in objective performance for the tilted and untilted conditions of the CGI display, though the subjective opinions indicated increased depth cues for the tilted case. Subjective opinions revealed no such indications of apparent depth changes with tilt for a terrain model-board scene. The increased detail available with the terrain board, as evidenced by the significant improvement in sink rate compared with the rudimentary CGI display, is assumed to provide depth cues that are not noticeably augmented by tilt effects.

Although subjective opinion was favorable for the tilted CGI image, the conclusion is that the increased effort involved to obtain the proper tilt profile is not warranted, since there is no resultant improvement in objective results. This conclusion is based in part on the expectation that the subjective preference for the tilted CGI image would lessen or disappear if the additional runway details of a more sophisticated CGI system were available.

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August 27, 1979

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TABLE I.- LINEAR APPROXIMATIONS OF THE

737-100 FLIGHT CHARACTERISTICS

Weight, N (lb)	400 340 (90 000)
Center of gravity	[a]$0.31\bar{c}$
Flap deflection, deg	40
Landing gear	Down
Damping ratio for:	
Short period	0.562
Long period	0.089
Dutch roll	0.039
Period for:	
Short period, s	6.30
Long period, s	44.3
Dutch roll, s	5.12

[a]Indicates 0.31 mean aerodynamic chord.

TABLE II.- COMPUTED F-VALUES FOR THE ANALYSIS OF VARIANCE

Factor	Degree of freedom	Computed F-value	Tabulated F-values for significance level of -	
			0.05	0.01
Tilt	1	1.42	3.92	6.85
Subjects	2	1.02	3.07	4.79
Tilt-subject interaction	2	.10	3.07	4.79
Error	122			
Total	127			

TABLE III.- STATISTICAL COMPARISON OF RUDIMENTARY CGI AND TERRAIN BOARD PERFORMANCE

(a) Comparison of means and standard deviations

Scene generator	Sink rate, m/s		Sample size	Computed t-test of means	Computed F-test of variance
	Mean	Standard deviation			
Rudimentary CGI	1.655	0.674	128	[a]2.64	[b]1.98
Terrain model board	1.320	.341	30		

[a]Indicates significance at the 1-percent level.
[b]Indicates significance at the 5-percent level.

(b) Tabulated one-tailed t- and F-values

Test	Degrees of freedom	Value at significance level of -	
		0.05	0.01
t	156	1.658	2.358
F	127, 29	1.700	2.140

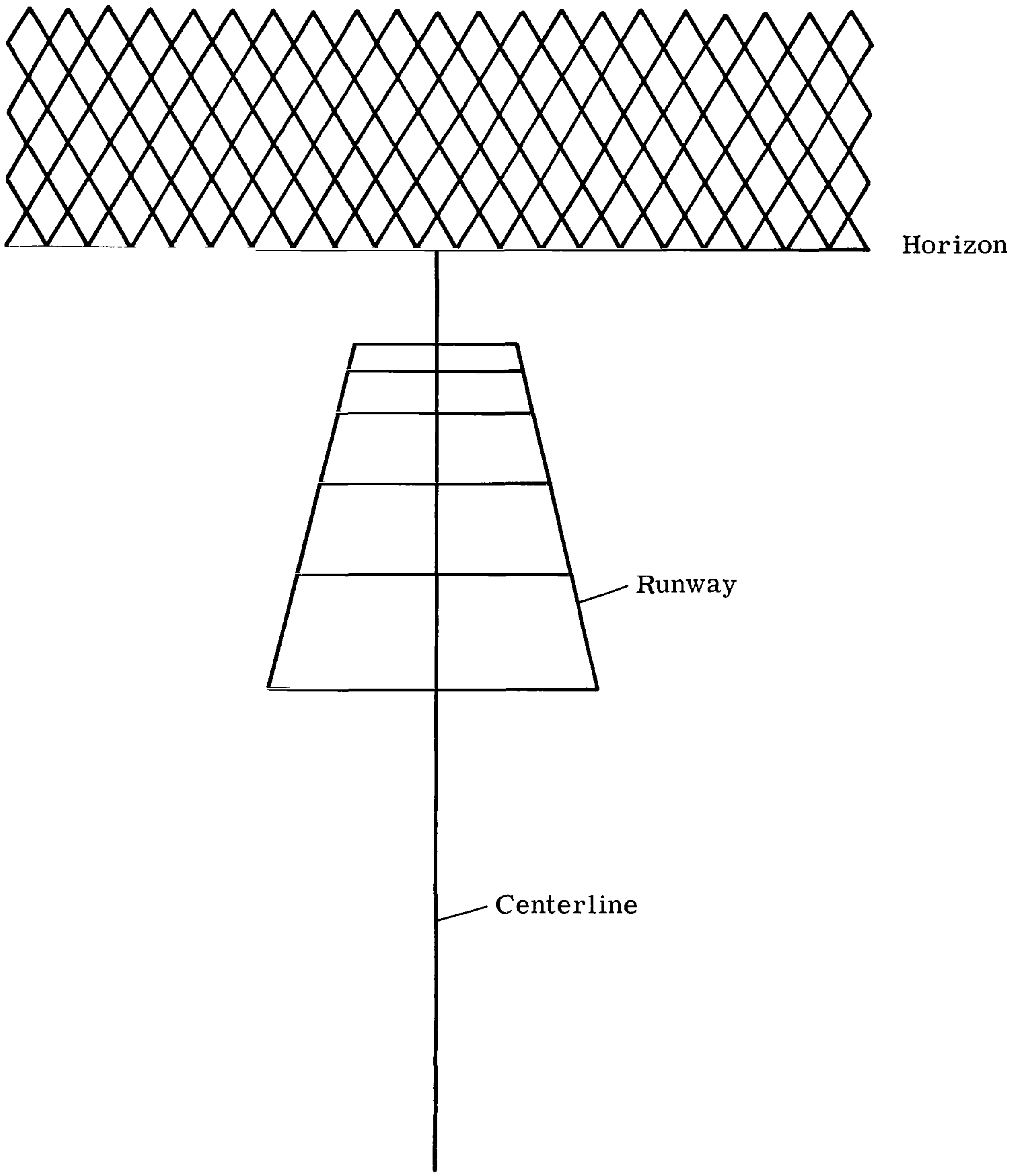

Figure 1.- The rudimentary CGI perspective runway.

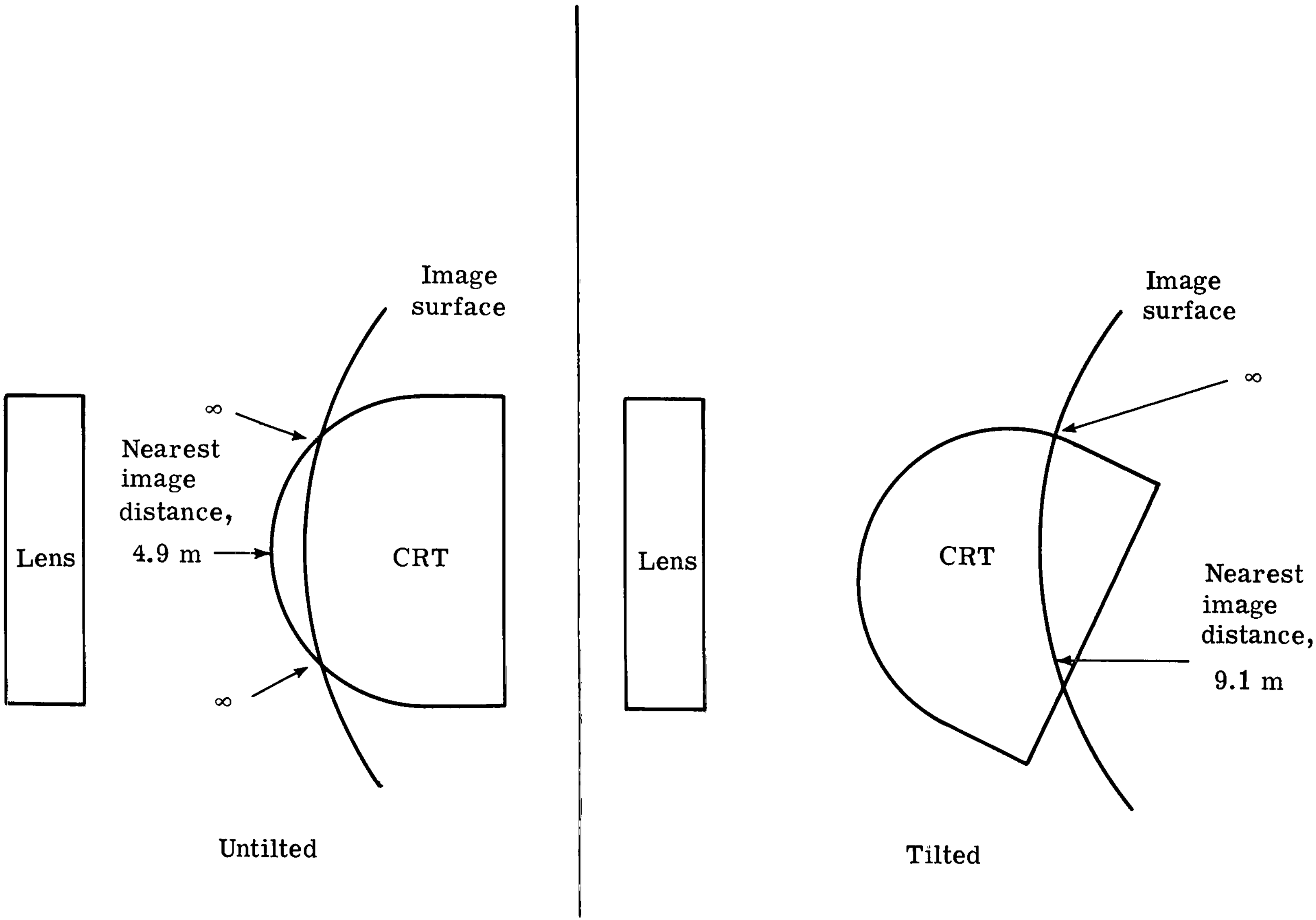

Figure 2.- Stylized effect of collimation and image tilt on visual scene.

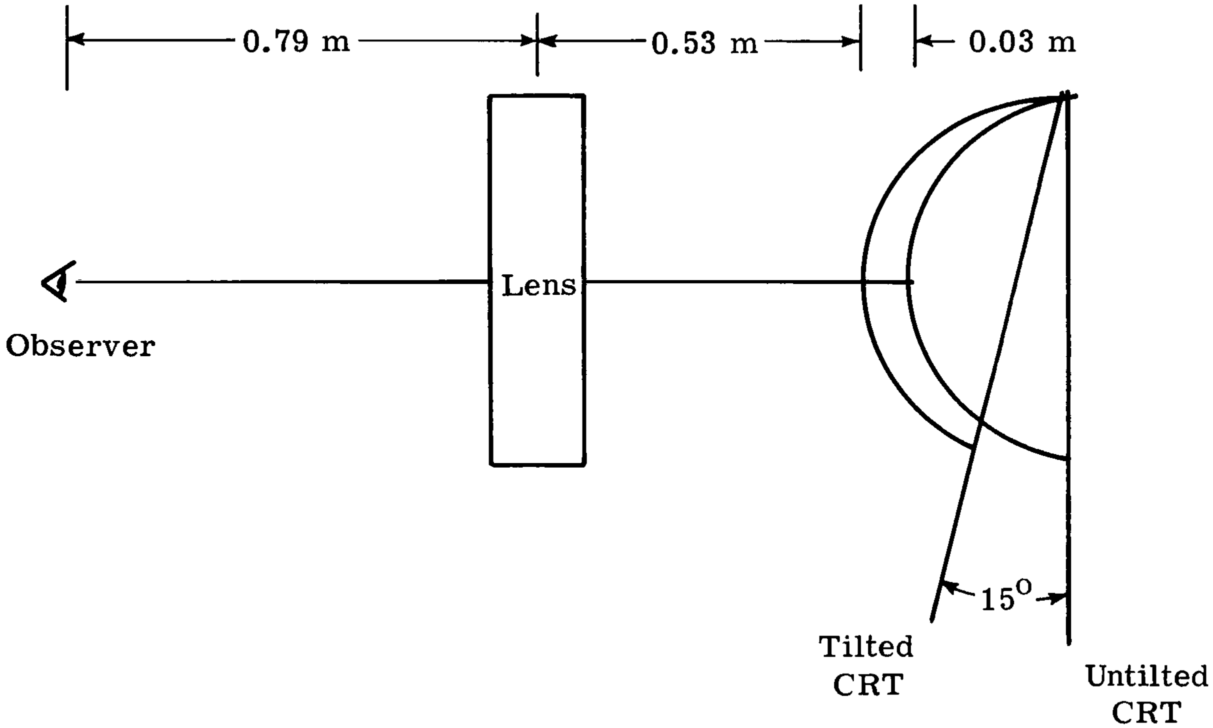

Figure 3.- Geometry necessary to obtain image distance profiles.

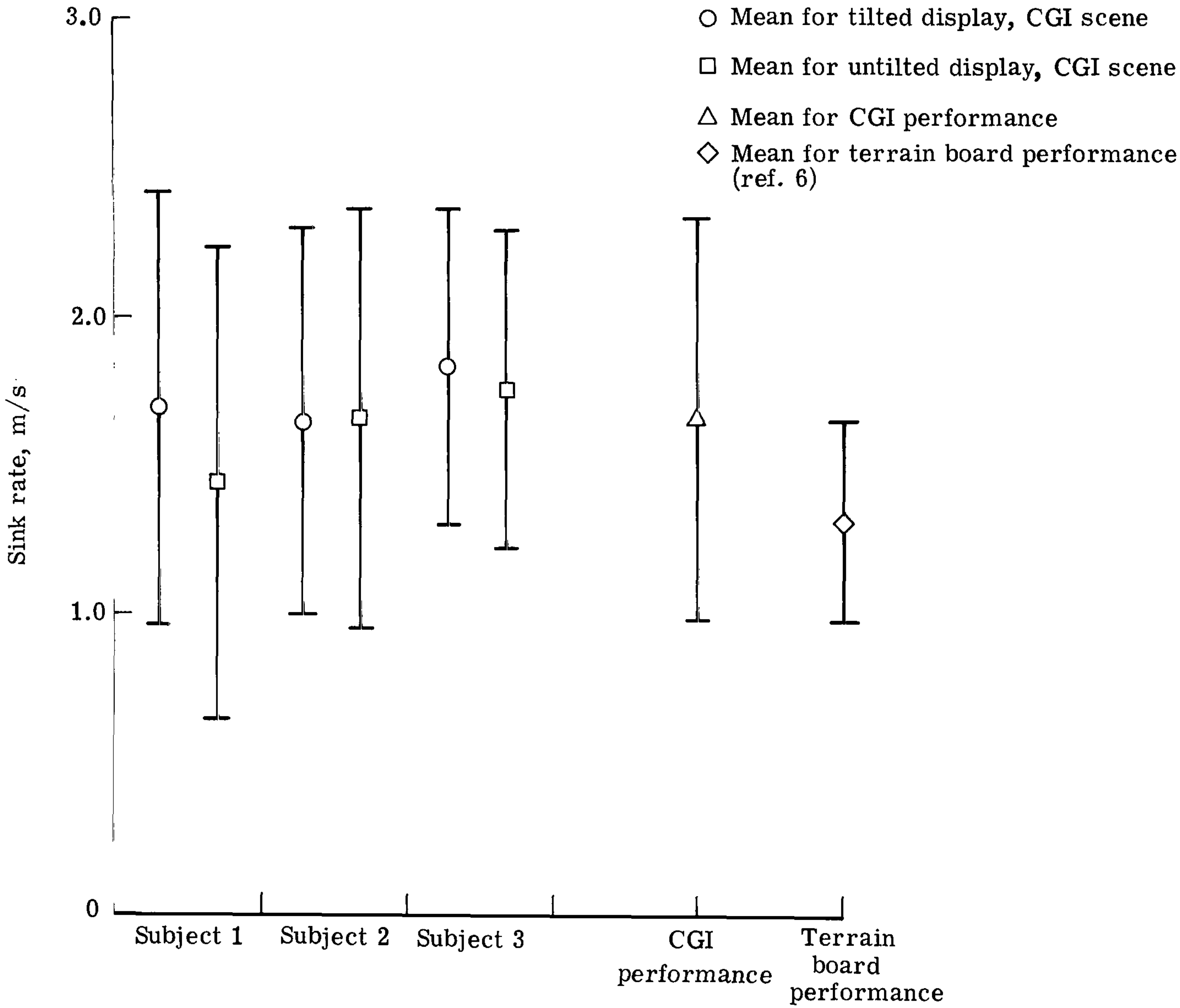

Figure 4.- Means and standard deviations of sink-rate performance.

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16. Abstract

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Although subjective opinion favored the tilted CGI image, the increased effort involved to obtain the proper tilt profile is not warranted, as there is no resultant improvement in objective performance. This conclusion is based on the expectation that subjective preference for the tilted CGI image would lessen if a more sophisticated CGI system were available.

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