RELATIVE EFFECTIVENESS OF TWO AND THREE DIMENSIONAL IMAGE STORAGE MEDIA

MR. B. C. KING, JR. AND DR. D. B. JONES
Martin Marietta Aerospace, Orlando Division

ABSTRACT

This paper describes experiments conducted to evaluate the ability of subjects to perceive the dimensionality of source material presented under dynamic conditions on a TV display. This source material includes a series of simulated military-type targets which are viewed in dive approaches and along selected constant altitude paths. Key results which summarize subject performance are presented, together with a discussion of the relative importance of motion-dependent cues to apparent depth.

INTRODUCTION

The purpose of this study was to acquire quantitative behavorial data to help resolve an important and persistent design issue in the development of visual simulation equipment for training systems. One of the key decisions to be made in the design of this type of equipment is the nature of the image storage medium; i.e., 3-dimensional terrain model, 2-dimensional transparency, or mathematical model (for computer-based displays). This is obviously a complex issue involving many engineering, human factors, economic, and mission considerations. One such consideration is the adequacy of the depth cues which can be derived from imagery based on 2- as opposed to 3-dimensional sources.

The various cues to depth can be classified in terms of their dependence on motion. That is, many of the most compelling cues such as inter-position, relative size, aerial perspective, etc., can be considered essentially static since they are present under both static and dynamic conditions. Others, however, such as movement parallax (relative target-to-background displacement) and vertical perspective change can only occur as a result of relative movement between the observer (sensor) and that which is observed. Although motion parallax and perspective change may be relatively minor cues to depth, they represent the essential difference between imagery derived from a 3-dimensional source as opposed to imagery derived from a 2-dimensional source.

This study was specifically designed to investigate the role of motion-dependent cues in the perception of apparent depth on a dynamic TV display. To accomplish this objective, it was first necessary to acquire simulated target imagery under a variety of experimental conditions for use as stimulus material in a series of behavioral tests.

These stimulus materials required the development of a special optical technique to provide sets of equivalent target runs differing only in the presence or absence of motion-dependent depth cues. This technique, which simulates a 2-dimensional image source by eliminating relative motion within the visual field, is described in a subsequent section.

It was considered desirable from the standpoint of potential application to utilize representative real-world conditions in terms of flight trajectory, sensor viewing geometry, and ground imagery. Therefore, both constant dive angle approaches (DA) and constant altitude approaches (CAA) were employed at simulated velocities consistent with operational training problems.

The primary objectives of this study were:

a. To evaluate the ability of subjects to perceive the dimensionality of the source used to generate dynamic target imagery on a TV display.

b. To identify the motion-dependent cues responsible for the illusion of depth on a 2-dimensional screen.

c. To determine the relative importance of certain selected variables in providing these cues.

METHOD

The Dive Approach tests were designed to determine the point at which subjects can perceive the dimensionality of imagery typical of the final flight path of a TV guided missile; i.e., from a simulated 10,000-foot slant range down to within 1,500 feet of impact. In these tests, the target area appears to expand radially from the aim point at the center of the display. The behavioral tests were based on recordings of target convergence runs made out-of-doors at the Martin Marietta Guidance Development Center (GDC) — see Figure 1 — using 3-dimensional and optically simulated 2-dimensional target areas. Prior to preparation of the video tapes used in the behavioral analysis, a pilot study was performed to select the most appropriate target runs in terms of realism, approach velocity, flight times, and illumination conditions. The Dive Approach runs which were selected were then dubbed from the master video tapes onto the final stimulus tapes in an irregular sequence. The Constant Altitude Approach tests were designed to investigate the ability to perceive motion-dependent depth cues as a function of altitude/slant range in simulated horizontal flight. As above, the behavioral stimuli were video recordings of selected target runs on the GDC terrain model. Both tests were conducted as complete factorial designs.

Dive Approach Tests - Experimental Design and Behavioral Test Procedures

The independent variables included in this test series were:

a. Target area

b. Approach velocity

c. Subject experience

d. Stored image dimensionality: 2-D and 3-D

e. Shadow condition

f. Display viewing distance

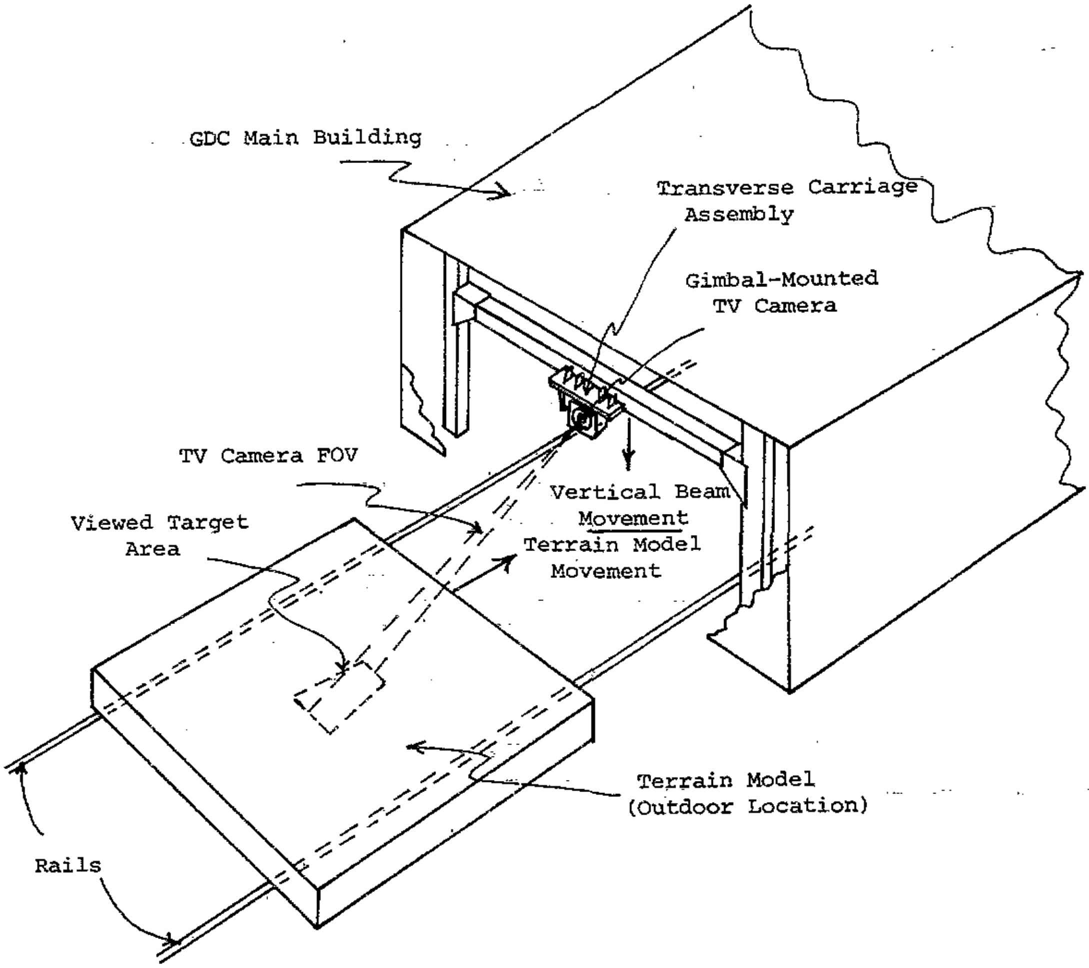
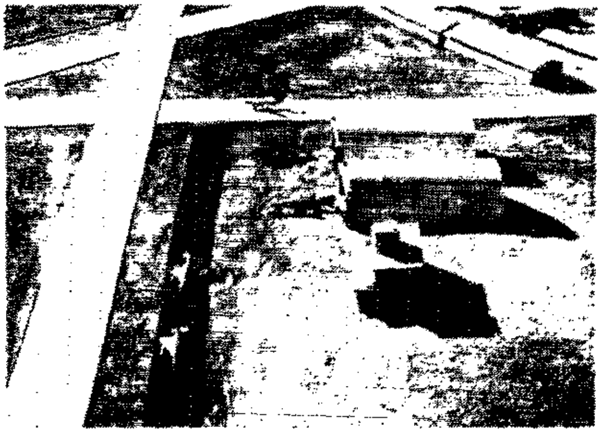
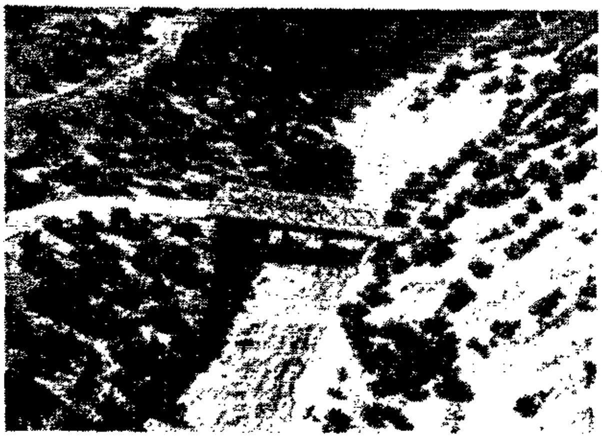


Figure 1. Basic Guidance Development Center (GDC) Test Stimulus Generation Setup

Five target areas, each containing typical military targets as well as varied terrain features, were used. These areas, plus a practice area, are shown in Figure 2. The target objects were selected to provide a wide range of representative sizes, orientations, vertical heights, and spacings. Average contrast levels and linear measurements of selected target features were recorded for each of the target areas. These measurements were then used in the calculations of angular displacement and percentage field of view (FOV) movement. In addition, an area was selected which provided obvious cues to dimensionality for the purpose of demonstration. This area is also shown in Figure 2 and consisted of a large suspension bridge, tall buildings, and critical street orientations relative to the buildings. Scaled heights of the principal objects in the five test areas ranged from 25 to 75 feet, and object-to-background contrasts from 20 to 90 percent (or more) in shadowed cases.



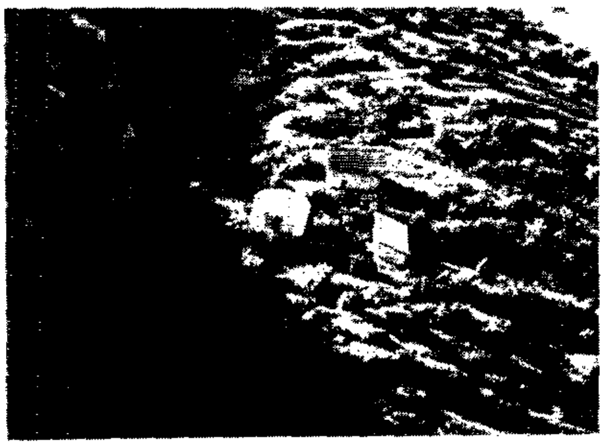
Airport



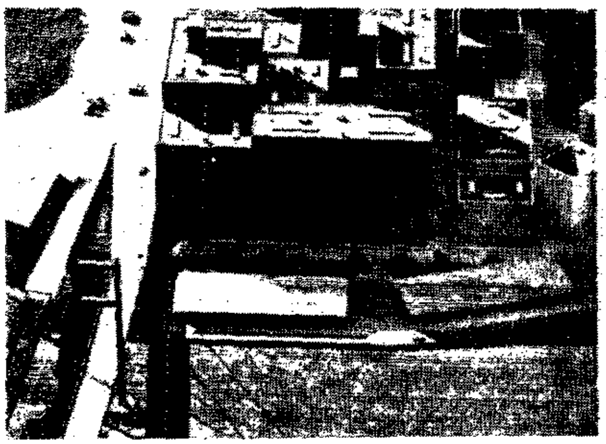
Truss Bridge

Industrial Area

POL Storage Facility



Mountain Storage Facility



Practice Area

Figure 2. Target Areas for Dive Approach Tests

Two realistic approach velocities were selected: 650 and 1100 feet per second (380 and 650 knots). This resulted in a recorded image sequence length of approximately 13 seconds for the lower and 8 seconds for the higher simulated approach velocity.

Two groups of subjects consisting of both operationally experienced pilots and naive college students were used.

The two types of stored image dimensionality were achieved as follows: Referring to Figure 3, in the 3-D runs, constant velocity closure was accomplished by decreasing the camera-to-target range at a constant rate; i.e., the terrain model moved longitudinally and the gimbal-mounted TV camera descended at the proper speed (under computer control) to simulate a diving trajectory. The approach geometry was defined by a 30-degree dive angle from a simulated 10,000-foot slant range down to 1,500 feet, with corresponding altitudes of 5,000 to 750 feet, respectively. In the 2-D runs, a zoom lens was used to simulate a constant velocity dive without relative motion within the visual field. This was done by positioning the gimbal-mounted TV camera at a fixed point along the descent path used for the 3-D stimulus generation and carefully aligning it with the same target aim points. The zoom lens focal length was adjusted under computer control to produce apparent closure at the same scaled velocities used for the 3-D cases. These differences in the 2-D and 3-D approach geometries resulted in the display of slightly different areas in the longitudinal axis. In addition, the 2-D aspect angle remained constant while the 3-D convergence runs produced small changes in aspect angles. Preliminary tests showed, however, that these minor differences were not detected by any of the subjects. The only usable cues to dimensionality then were those of motion parallax, and, to a much lesser degree, perspective change. The scale factor employed in these runs was 250:1.

Since useful depth information can often be derived from shadows, several target areas were studied under shadowed and nonshadowed conditions.

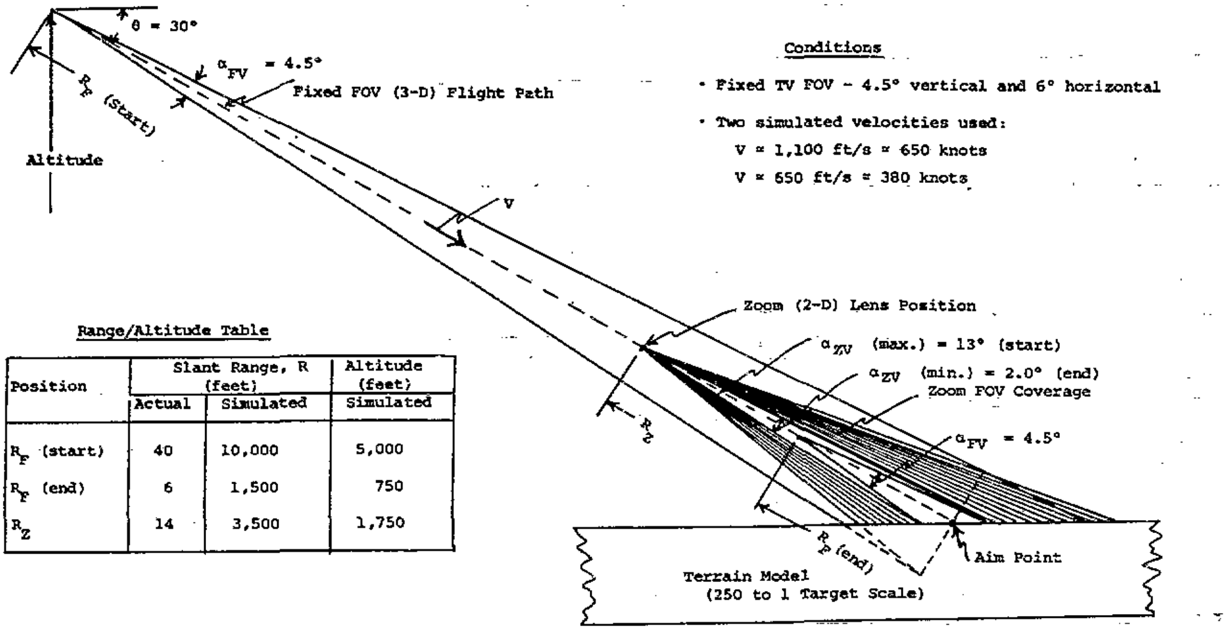
Two display viewing distances were used: 20 inches and 59 inches. The closer distance represented a normal subject-to-TV monitor separation for ease of viewing. The longer distance was used in a portion of the tests to achieve a display magnification* of unity. This was done in order to provide equivalence between the motion parallax values available via the TV display and those which could be directly observed on the terrain model.

The major independent variables were presented in a complete factorial design. Five target areas, two velocities**, two subject categories, and two types of imagery (2-D and 3-D) were used. Shadow and nonshadow conditions and the two display viewing distances were analyzed as subtests.

---

* Ratio of total displayed visual angle to TV camera fixed FOV in the 3-D runs.

** Four target areas were tested at both velocities.



Range/Altitude Table

Position	Slant Range, R (feet)		Altitude (feet)
	Actual	Simulated	Simulated
R_F (start)	40	10,000	5,000
R_F (end)	6	1,500	750
R_Z	14	3,500	1,750

Figure 3. Profile of Basic 2-D, 3-D Dive Approach Geometry

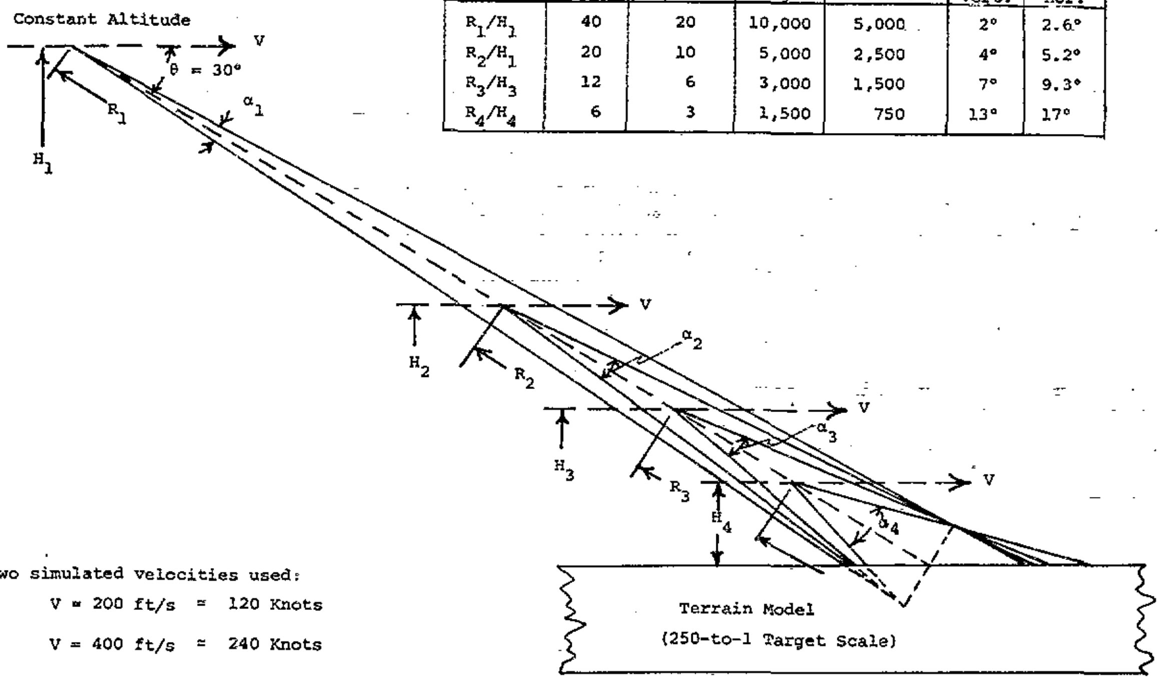
In the behavioral test phase, each subject was asked to respond verbally (2-D, 3-D, or Don't Know) as soon as he made his decision concerning the dimensionality of the particular presentation. This response was recorded concurrent with the video tape sound track call-outs, which provided slant range data. This data was then reduced by reviewing the audio tape and determining at what range (in thousands of feet) the subject made his determination.

Two dependent variables were used in this test: range at time of response, and accuracy of the subject's judgment. The subject was urged to make the earliest possible determination but was allowed to change his mind at the end of the run. The purpose of this approach was to encourage responses at the maximum ranges while maintaining a high percentage of correct final answers. At the end of the test, each subject was asked to identify and describe specific features of the target areas that provided cues to dimensionality.

Constant Altitude Tests - Experimental Design and Behavioral Test Procedures

This test was designed to evaluate the ability of subjects to detect the cues to depth which are present in a dynamic TV presentation as a function of altitude in simulated horizontal flight. Using many of the same targets employed in the Dive Approach tests, video tape recordings were made at four different altitudes. The fields of view (FOV) were adjusted by use of the zoom lens so that the camera recorded the same lateral dimension at each altitude. Under these conditions, the only cues present were motion parallax and perspective change as in the first test. Figure 4 is presented here as an aid in visualizing the technique. The TV camera was fixed at a 30-degree

Position	Actual Distance (feet)		Simulated Distance (feet)		TV-FOV, α (Approx.)	
	Range	Altitude	Range	Altitude	Vert.	Hor.
R_1/H_1	40	20	10,000	5,000	2°	2.6°
R_2/H_1	20	10	5,000	2,500	4°	5.2°
R_3/H_3	12	6	3,000	1,500	7°	9.3°
R_4/H_4	6	3	1,500	750	13°	17°



° Two simulated velocities used:

V = 200 ft/s = 120 Knots

V = 400 ft/s = 240 Knots

Figure 4. Profile of Constant Altitude Approach Geometry

depression angle, as in the previous test series, providing slant ranges equal to twice the corresponding altitudes. The terrain model was driven beneath the camera at the desired constant velocity. This test was designed as a supplement to the Dive Approach test to cover a wider range of operational conditions.

The independent variables in this test were:

a. Target area (flight paths)

b. Velocity

c. Experience of the subjects

d. Field-of-View/Slant Range/Altitude (FOV/SR/Alt) Combinations

Seven target areas were used. Figure 5 shows the entire terrain model* with the flight paths superimposed. An attempt was made to include all areas used as targets in the Dive Approach test so that direct comparisons could be made. The areas ranged from those containing predominantly manmade objects, to mountainous terrain, to flat featureless terrain containing almost no manmade targets.

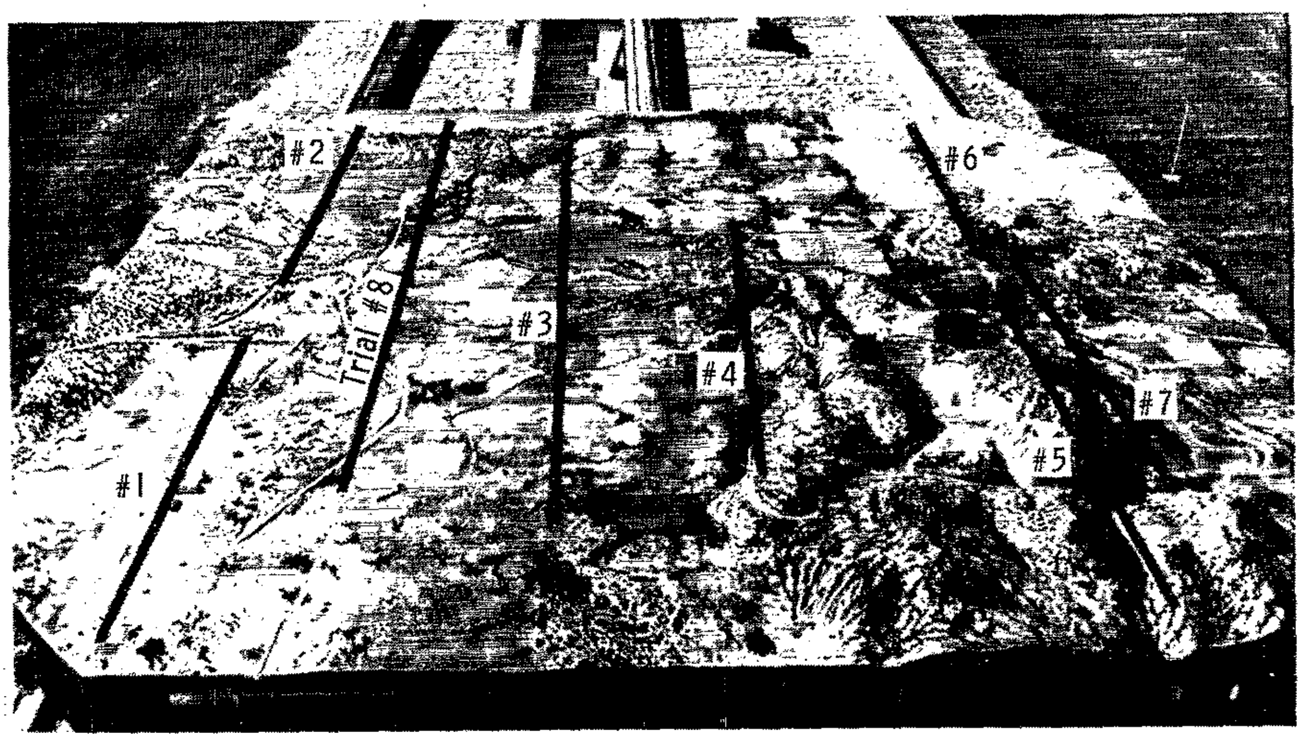


Figure 5. Terrain Model Ground Track Paths for Constant Altitude Approach Tests.

* The view is from an elevated position representative of that at which the TV camera was located. The terrain model is in the GDC outdoor test area and is illuminated by sunlight.

Two simulated flight velocities were used: 120 and 240 knots. These relatively slow velocities were chosen to provide minimum image smear on the TV display. The slower velocity was used in the factorial analysis of all target and FOV/SR/Alt combinations and the faster velocity was tested over two target areas and at two FOV/SR/Alt conditions.

Two groups of subjects were selected to provide a basis for generalizing the results: experienced ex-military or active reserve pilots and a naive group consisting of company secretaries.

Five FOV/SR/Alt combinations were used: 2°/10,000/5,000 ft., 4°/5,000/2,500 ft., 7°/3,000/1,500 ft., 13°/1,500/750 ft., and 13°/3,000/1,500 ft. The first four FOV's were chosen to provide approximately the same amount of terrain area exposure for each altitude. The last FOV/SR/Alt combination was selected to evaluate response at a given altitude with different FOV's: 13°/3,000/1,500 ft. vs 7°/3,000/1,500 ft. When not referring to this particular case, these combined parameters are considered only in terms of slant range/altitude values; i.e., the subjects were responding to dimensionality effects primarily associated with viewing range and altitude, not FOV.

In the behavioral test phase, the subjects responded at the end of each run by stating either "2-D", "3-D", or "Don't Know". The responses were recorded by the test conductor. At the end of each complete test, the subjects were reshown each area and asked to describe what particular features offered them clues to the dimensionality of the image source. These comments were recorded for later comparison with performance.

RESULTS

Dive Approach Tests

Results of the analysis of variance (AOV) performed using both slant range and average correct response showed that subjects were unable to distinguish between the 2-D and 3-D presentation. The performance of the experienced pilot group was not significantly different from that of the naive college sophomores. Average slant range from the targets was about 2,800 feet when response was made (Figure 6), and even at this close range, the subjects' judgments were only approximately 50 percent correct. Figure 7 illustrates this correct response percentage as a function of target area.

While the target effect was not significant overall, there was a significant difference between the slant ranges at which responses were obtained for the Industrial and Airport areas compared to the Mountain Storage and Bridge areas (Figure 6). This does indicate a trend in the subjects' responses (although still only chance statistically) which can be related to the target characteristics and relative sizes. While the subjects were able to respond at a greater slant range, their answers were not significantly different from their responses at the closer ranges. This is illustrated in Figure 7.

The effect of velocity was significant at the 0.05 level for the slant range variable. The essentially constant differences in response ranges at the two velocities can probably be accounted for on the basis of simple reaction and/or decision time. That is, the subjects probably perceived target dimensionality at the same slant range for both velocities, but with an essentially constant response time, the higher approach speed resulted in a shorter slant range at the time of response. This appears to be the most likely explanation for the observed effect.

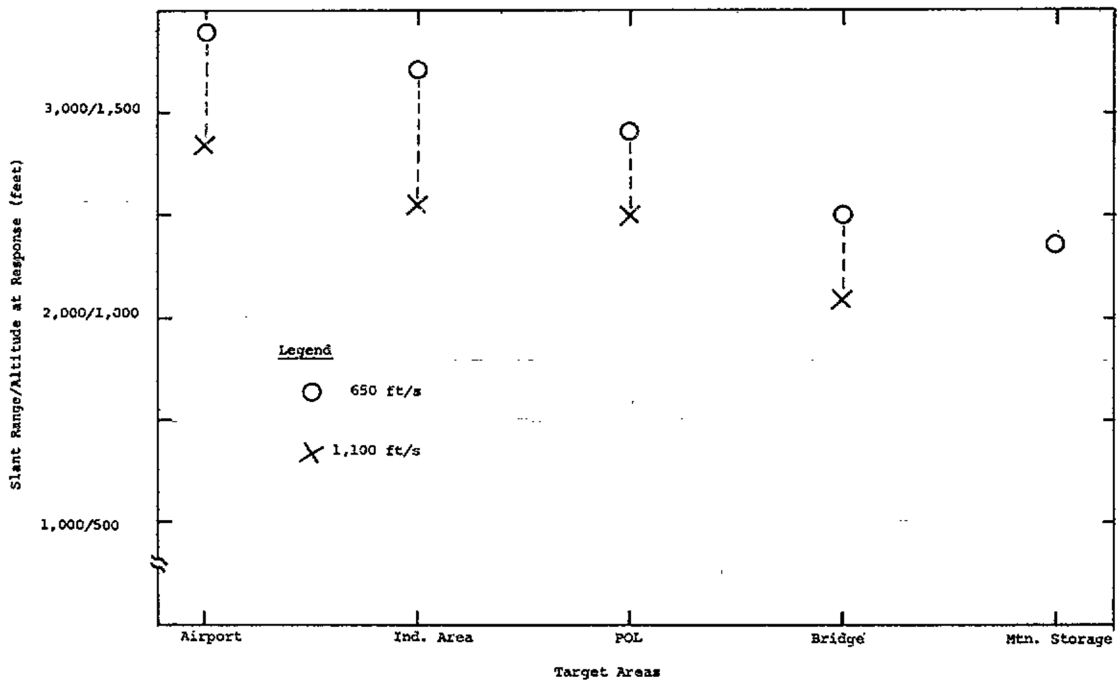


Figure 6. Slant Range/Altitude at Response as a Function of Target Area for 650 and 1,100 Feet per Second Velocities for Pilot Subjects: Dive Approach Test

Two areas, the POL Facility and the Airport were presented under both shadow and non-shadow conditions. This variable was not significant. While the non-shadowed imagery was consistently responded to at a greater distance than its shadowed counterpart, the differences in response distance were not statistically significant.

For the two display viewing distances used, 20 inches and 59 inches, there was no measurable difference in performance between the two. This indicates that the fidelity of the image displayed via TV was the limiting factor in both cases.

At the end of each test, the subjects were asked what aspects of the target areas aided them in making their decisions. For the most part, the subjects were unable to identify the specific target characteristics responsible for their decisions.

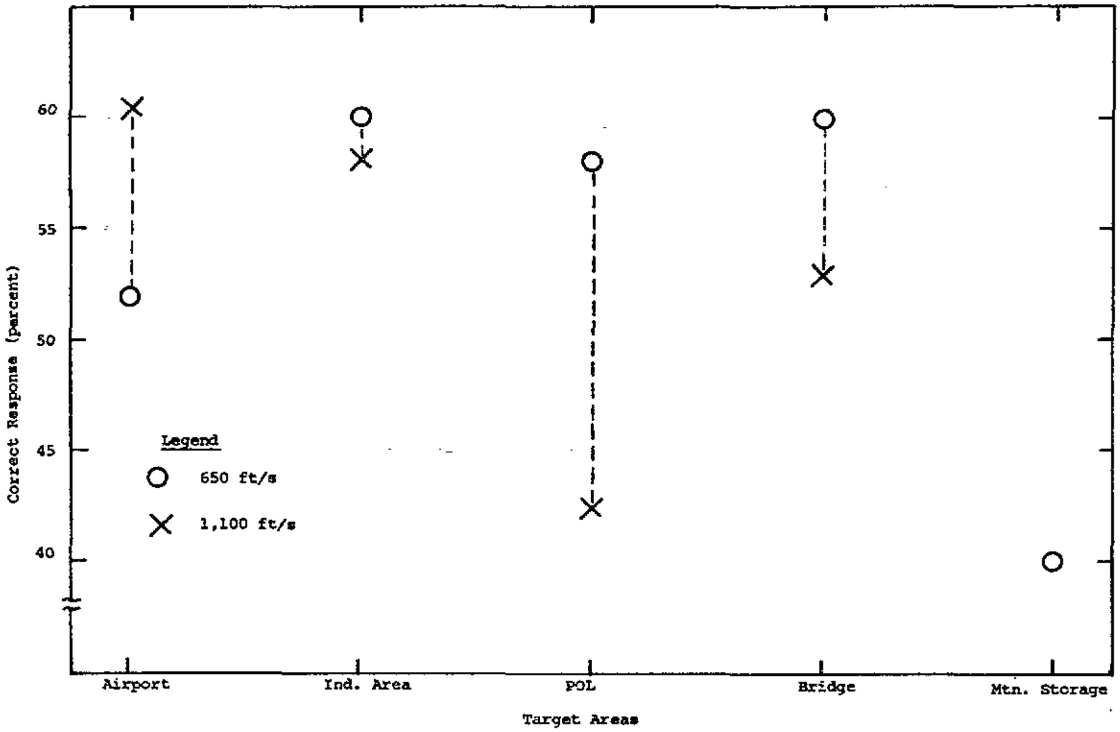


Figure 7. Percent Correct Response as a Function of Target Area for 650 and 1,100 Feet per Second Velocities for Pilot Subjects: Dive Approach Tests

Constant Altitude Tests

Complete factorial analyses of variance (AOV) of this experiment were performed. Both the target areas and FOV/SR/Alt values were significant at the 0.01 level along with the interaction of experience and FOV/SR/Alt. The experience factor,(i.e., pilots versus female secretarial help) was significant at the 0.05 level, indicating a difference in responses to the stimuli between the two groups.

Figure 8 shows the variability or range of responses across FOV/SR/Alt combinations. Responses ranged from a low of 28 percent judged correct at the closest SR/Alt for the General Terrain Area to 96 percent for both the Airport and Mountain Areas (#1 and #5). In the 10,000/5,000 foot case, less than 4 percent were judged as 3-D for Areas #2 and #4 (Harbor and Bridge Areas), up to 45 percent judged 3-D for the Mountain Area (#5). The single wide FOV condition in the 3,000/1,500 foot case resulted in an increase in the percentage judged to be 3-D for some of the target areas, notably Areas #4 (Bridge), #6 (POL), and #7 (Mountain Storage Area). The most dramatic increase was for the Mountain Storage Area, which went from 42 percent judged 3-D at the 7 degree FOV at 3,000/1,500 feet to 90 percent when a 13-degree FOV was used. The other two areas were not as dramatic in their changes, but were statistically significant at the 0.05 level of confidence. Analysis of the content of these areas revealed that in the wide FOV, new

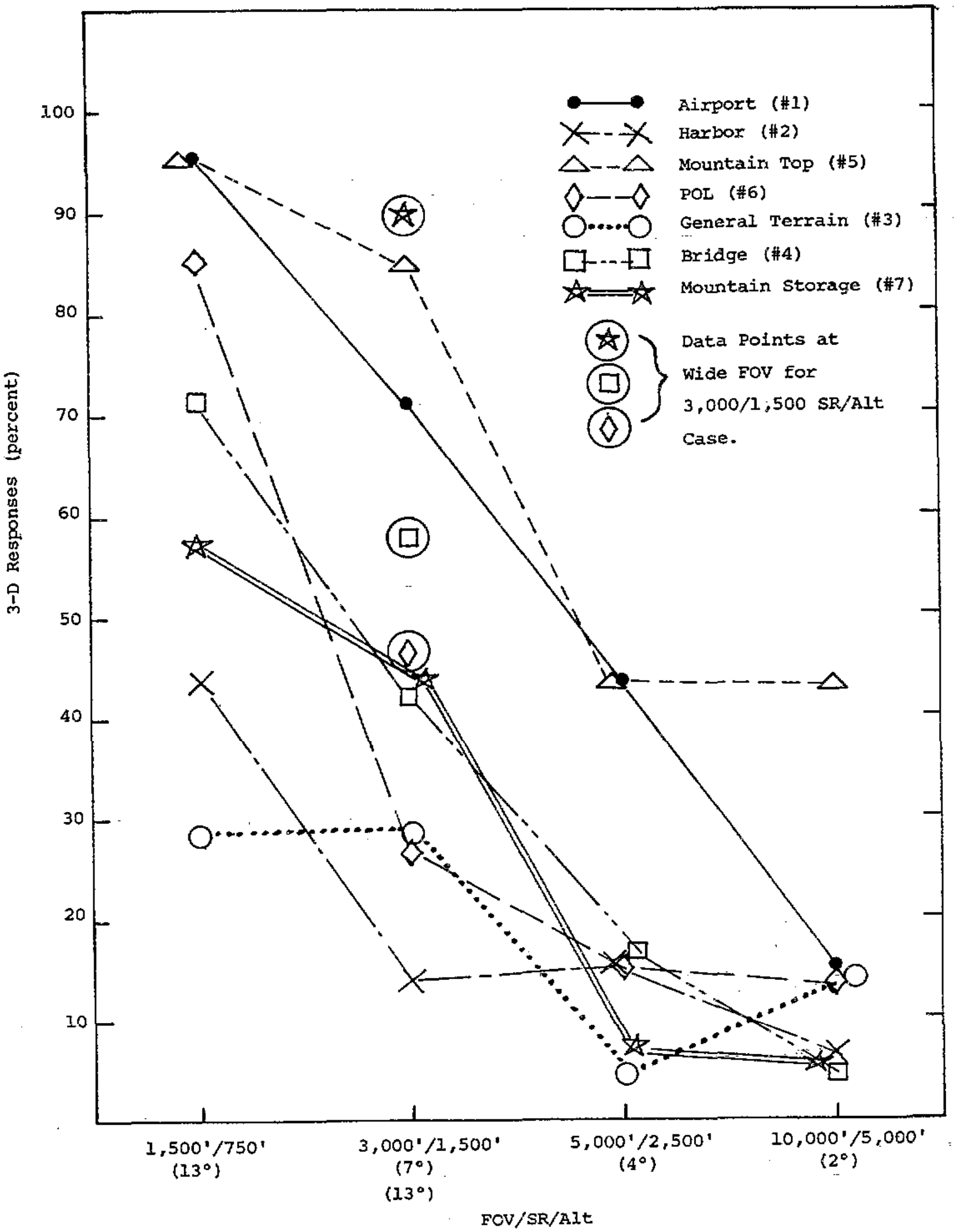


Figure 8. Percent Judged 3-D for Pilot Subjects: Performance on each area as a Function of FOV/SR/Alt - Constant Altitude Test

areas of terrain containing higher vertical elevations were available to be seen as compared with the smaller FOV. This increase in the terrain within the FOV (containing additional and more prominent cues to dimensionality) more than offset the effects of increased range/altitude.

Figure 9 shows the effects of altitude on the perception of source dimensionality. In the Constant Altitude Approach tests, FOV was systematically varied as a function of altitude in order to maintain the same lateral coverage. Therefore, the FOV's shown in this figure vary from 13 to 2 degrees. As the figure shows, with the same lateral terrain coverage, the percentage of trials judged to be 3-D decreased systematically with increasing altitude. The data points on this curve are the averaged values for all target areas at each altitude, and the range of values obtained as a function of target area is shown by brackets. The effect of FOV per se at one selected slant range/altitude combination (3,000/1,500 feet) is also shown on this same figure for the purpose of comparison. The high percentage of 3-D judgments obtained at the wide FOV (13 degrees) reflects the high values obtained on target areas 4, 6, and 7. It was, therefore, concluded that performance was not affected by the increased FOV unless additional cues to dimensionality are made available by the increase in area coverage.

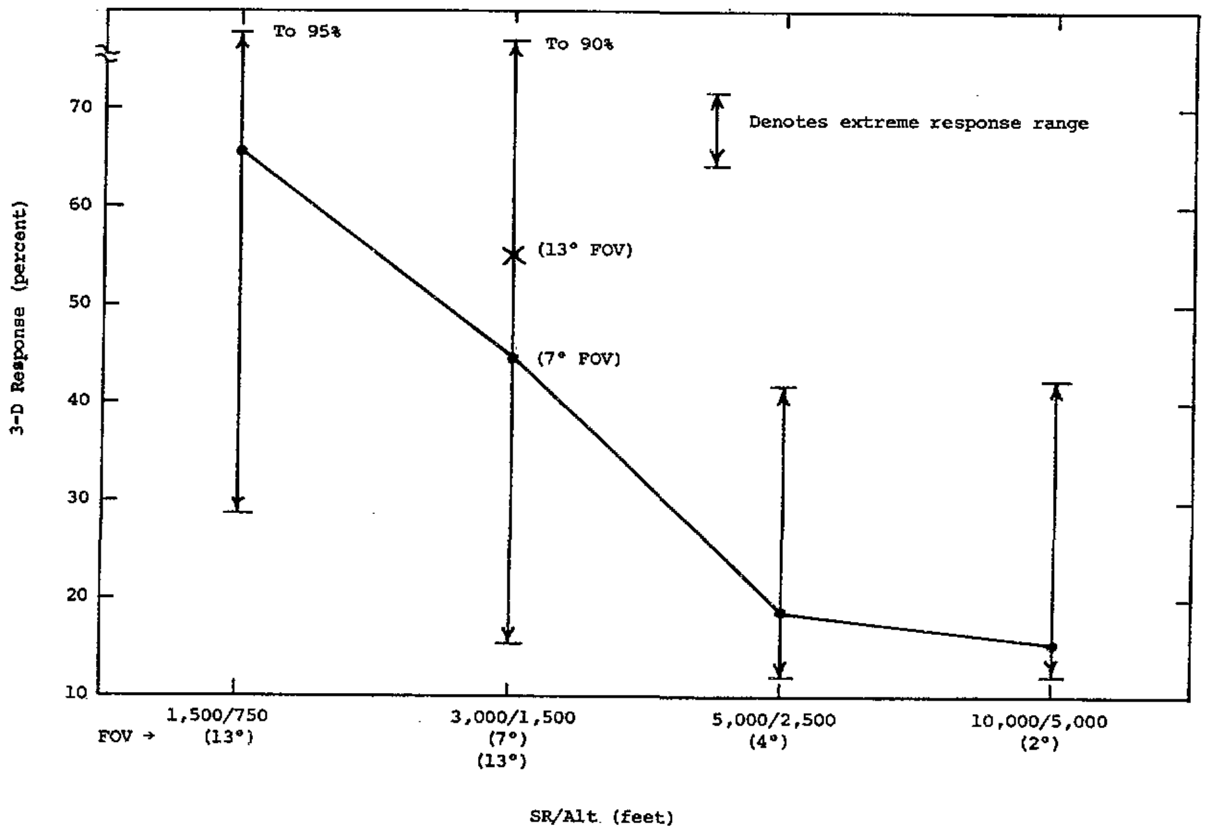


Figure 9. Percent Judged 3-D for Pilot Subjects: Averaged Over Areas as a Function of SR/Alt for the Constant Altitude Test

As in the Dive Approach tests, both experienced and naive subjects were employed. There was an interaction between this experience factor variable and the FOV/SR/Alt variable. This interaction is shown graphically in Figure 10. T-tests performed at each level show that at the 13°/1,500/750 and 7°/3,000/1,500 FOV/SR/Alt combinations the performance of the pilot subjects was consistently better ($p < .05$) than that of the inexperienced subjects. There was, however, no difference in performance between the two groups at the 5,000/2,500 and 10,000/5,000 foot distances. At 3,000/1,500 feet with the larger FOV, the differences between the two groups were even more marked ($p < .01$). Evidently, the experienced pilots made more (or better) use of the additional information available to them in the wider fields than did the naive subjects.

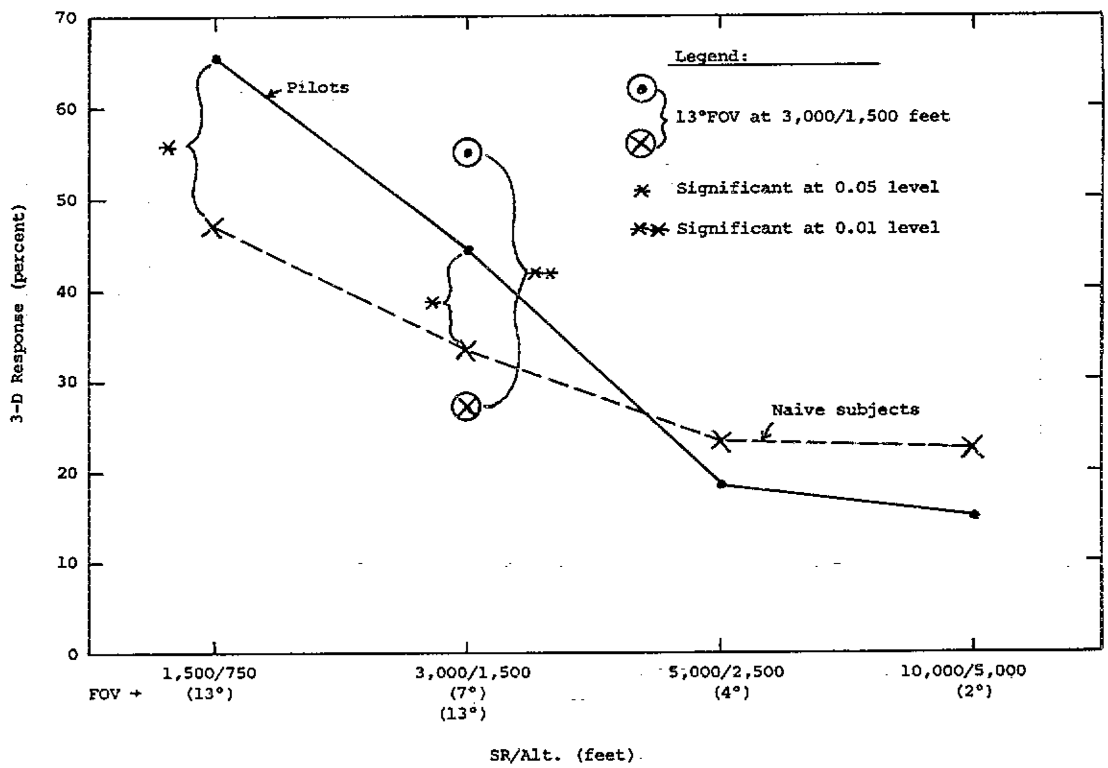


Figure 10. Pilot-Naive Subject Interaction as a Function of FOV/SR/Alt Averaged Over All Areas for Constant Altitude Test

The results of this test show that the ability to perceive the dimensionality of the source material is closely related to piloting experience at the lower values of slant range/altitude. At SR/Alt values in excess of 3,000/1,500 feet, however, the differences in performance attributable to piloting experience are insignificant.

Two simulated airspeeds were used on Areas #1 and #2 (Airport and Harbor). These velocities were 200 and 400 ft/s, scaled to the 250-to-1 ratio used in this study. These relatively slow speeds resulted from the desire to (1) maximize the viewing time available on each target run, and (2) minimize image smear on the TV monitor. These velocities (120 and 240 knots) allowed the subjects ample search time. An AOV was performed and the effect of velocity was determined to be not significant.

RELATED ANALYSES

Comparisons Between Dive Approach and Constant Altitude Tests

The Dive Approach and Constant Altitude tests employed several common target areas to facilitate direct comparison of data differing only in respect to viewing conditions. Significant differences were obtained between the two viewing modes. In summary, it was found that the differences in response to identical targets in the DA and CAA tests could not be satisfactorily explained in terms of either angular image displacement, per se, or the rate of change of angular image displacement.

However, consideration of the approach geometries involved shows that the two series of tests presented the observer with two essentially different perceptual tasks — not in terms of the cues available, but in terms of their temporal characteristics. Also, for a given target and altitude combination, the Constant Altitude Approach produced approximately two times greater image movement than the Dive Approach. This additional image movement combined with the additional time available to detect and respond to whatever differential movement existed is probably responsible for the superior performance in the CAA tests.

Comparisons with Other Psychophysical Data

Earlier work by many scientists has shown that threshold values for the perception of movement parallax can be obtained as low as 1 to 2 arc minutes per second. The corresponding data from this study is well above this range (4.5 to 10 arc minutes per second), but in view of the problems inherent in applying basic laboratory findings to real-world problems, the observed differences are not unreasonable. There are, of course, many sources of variability in the applied data which can be precisely controlled in the laboratory. In this case, one of the most important sources of uncertainty is in determining whether or not any individual subject was attending to the critical portions of the displayed imagery at the proper time; i.e., the time (measured in fractions of a second) at which the most prominent motion-dependent cues to dimensionality were available to him. Another factor which tends to degrade the obtained threshold values relative to these reported in the basic literature is the limitation imposed by the TV system. In effect, the TV system constitutes a spatial filter which limits the displayed image detail available to the subject.

Notes on Perspective Change

Perspective change (principally foreshortening of vertical height) is another motion-dependent cue to dimensionality. It apparently plays a relatively minor role in the perception of apparent depth, however. In debriefings following both the DA and CAA tests, the subjects consistently indicated that they did not find that perspective change provided a major clue to dimensionality. Related calculations support these observations. It was found that for a given target viewing geometry, target/background movement parallax displacements were approximately four times as great as the corresponding perspective shift values.

SUMMARY OF PRINCIPAL RESULTS

For the Dive Approach (DA) tests the dimensionality of the original source material could not be reliably determined from a TV displayed image even at the minimum combination of scaled slant range/altitude (i.e., 1,500/750 feet).

In the CAA tests, subjects were able to correctly identify dimensionality of the average image source in only 45 percent of the trials at a 1,500 foot altitude. This value increased to 65% at the minimum altitude of 750 feet.

Motion parallax was the most important cue to dimensionality. Although some target perspective change (vertical foreshortening) undoubtedly occurred in the runs, the effect was minor and was masked by the much larger effect of movement parallax.

In both the DA and the CAA tests, several variables considered potentially important in the perception of image source dimensionality via TV were shown to have no significant effect. These include:

a. Display viewing distance - Viewing distance was not an important parameter, apparently because the TV display system was performance-limited under the conditions of this experiment.

b. Displayed target/background contrast - A wide range of inherent contrasts was included (estimated 20 to 70 percent, and even higher with shadow conditions).

c. Video signal-to-noise ratio (SNR) - SNR levels ranged from an estimated 35 dB to 20 dB.

d. Shadow effects - No apparent enhancement resulted from the use of shadows.

e. Velocity - For the range of velocities used in these tests, no significant effect on the perception of source dimensionality was noted.

Although the flight geometries are defined in terms of slant range/altitude combinations, for a given target the factor primarily responsible for the amount of movement parallax displayed on the monitor is the altitude of the sensor. This is true for both the Dive Approach and the Constant Altitude Approach tests. That is, motion parallax varies inversely with altitude, and for a given altitude, is not greatly affected by slant range (i.e., by sensor dive angle or depression angle).

Only in the case of pronounced target or terrain heights, as in the mountainous region on the GDC terrain model, is the subject capable of perceiving dimensionality at a reasonably high altitude, i.e., > 85 percent correct judgments at 3,000/1,500 feet. However, even in these extreme areas, accuracy falls below the 50 percent correct level when the altitude is increased to 2,500 feet.

The sensor FOV has only a minor influence on movement parallax cues derivable from a given target/background complex. Although the total scene viewed by the sensor will increase with increasing FOV, the image is compressed within the fixed limits of the TV monitor, resulting in the same percent target image shift. That is, the image size decreases as the FOV increases, essentially negating the effect of increased viewing angle. This, of course, would not be true in a direct viewing case. An exception to the above occurs when there is a major change in the nature of the total scene with changing FOV. If a wider FOV encompasses target areas having more prominent cues (e.g., taller building or greater terrain elevations), then the new target area can considerably alter the ability of the subjects to perceive the dimensionality of the image source.

APPENDIX A

Optical Zoom Simulated 2-D Dive Approach

As previously noted, 2-dimensional source material can take the form of photographic transparencies (or prints). However, for this particular study where 2-D and 3-D versions of the same scenes were to be critically observed in a given test sequence, a more flexible approach was selected to provide simulated 2-D source imagery. This approach had to satisfy the following criteria.

a. No cues specific to a 3-D source (movement parallax and/or perspective changes in projected vertical dimension of target) would be present.

b. Each run would exhibit, within the perceptual tolerance of the subjects, the same dynamic image growth and image fidelity (resolution, grey scale, dynamic range, video SNR) as its 3-D based counterparts.

c. No artifacts sufficiently obvious to identify the source as 2-D would be present.

The zoom technique selected for simulating 2-D target approaches can be explained by reference to Figure 11. The upper portion of this illustration shows the normal 3-D Dive Approach geometry in plan view. Here, the TV camera with a fixed field of view (FOV) approaches targets identified as elements A and B. These targets are separated in the longitudinal direction and offset from the approach path. From the start to the end of the run, the TV camera coverage decreases from width W_i to W_f, and the line of sight (LOS) to elements A and B undergoes a shift (element A LOS shifts from the light portion of element B to the shaded portion). This angular shift is termed "movement parallax," and it is the primary cue (perspective shift being secondary) which permits a subject viewing a TV display of this imagery to perceive the source material as 3-D. The lower diagram of this figure shows the TV camera FOV as it is zoomed over the focal length range which provides the same change in viewed widths, W_i to W_f. In this case, the image is magnified and the general effect is similar to physical closure on the targets. The significant difference between the two conditions, however, is that the TV LOS to target element A relative to element B remains fixed throughout the simulated convergence run. Therefore, no movement parallax or perspective change occurs. To produce equivalent dynamic closure effects (same apparent image growth rates) it is necessary to control the zoom focal length as a function of run time. This was accomplished by GDC analog computer control.

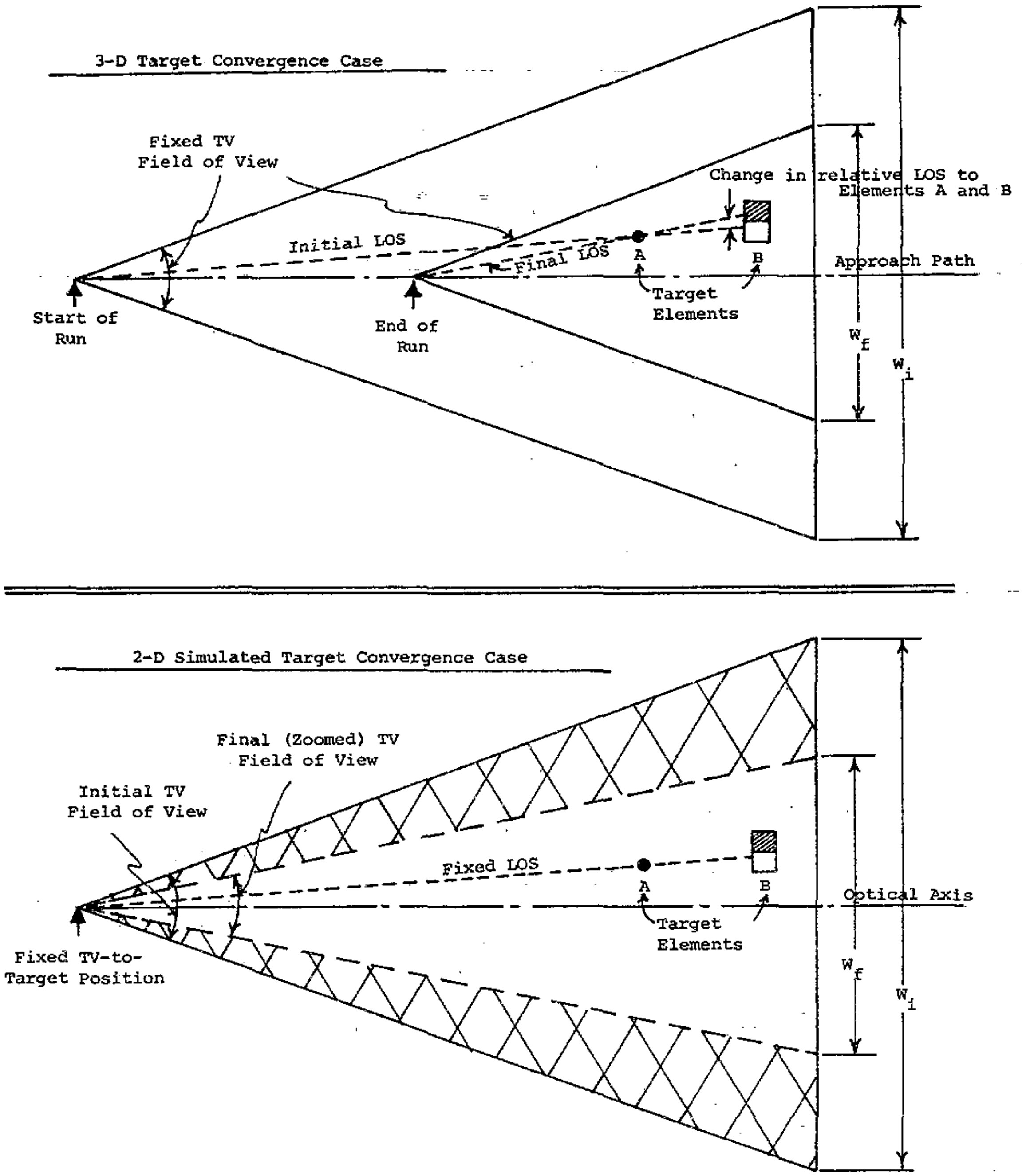


Figure 11. Comparison of 2-D and 3-D Target Convergence Geometries (Vertical View)

Test Facilities and Equipment

The 2-D and 3-D target stimulus material (video tapes) were produced at the Martin Marietta Guidance Development Center. Behavioral tests were performed in a separate room in the Engineering Research laboratory area.

Principal elements used to generate the video taped stimulus runs for the Dive Approach and Constant Altitude tests consisted of (1) the GDC optical simulation facility, (2) TV camera and display subsystem, and (3) video recording equipment.

GDC Facility

The elements of this facility which were utilized in this experiment are shown in Figure 12. They consist of the terrain model (including the new 250-to-1 scale targets), the computer-controlled precision movement subsystem within which the TV camera was mounted, and the computer laboratory.

The terrain model is 40 feet on a side and it contains a wide range of topographical features together with a variety of manmade targets. The basic scale factor is 600 to 1; however, by substituting the 250-to-1 scale targets at selected areas on the model, those areas were redesignated as 250-to-1 scale areas for purposes of these tests.

The model is driven logitudinally on rails, and its position and velocity are accurately controlled by an analog computer. The drive system is capable of providing a wide range of velocities up to a maximum of 10 feet per second. As implemented in the Dive Approach tests, model movement provided one component of dive convergence. At the 250-to-1 scale factor used, the maximum rate required was approximately 3.8 feet per second.

A vertically moving I-beam provided the necessary freedom in the gimbal-mounted TV camera's vertical translation. Accurate positioning of the I-beam in height, together with longitudinal positioning of the terrain model, produced correct initial slant ranges to the targets in the Dive Approach tests. Then, under computer control, this assembly moved down to provide the vertical component of the dive convergence.

The analog computational equipment used in this study consists of an EAI 231 R-V console. This was programmed to provide precision control of the simulated flight paths for both the Dive Approach and Constant Altitude runs. The zoom lens focus and focal length servo drives were also operated under computer control in the 3-D Dive Approach runs to provide correct simulated convergence rates and continuous optimum optical focus.

TV Camera and Display Equipment

The TV equipment used in these tests was a composite of two Martin Marietta TV systems; (1) the standard GDC 1-inch vidicon camera and camera control[1],

---

1 Cohu Model 2004 camera and Model 3952 camera control.

and (2) the gamma control unit and high quality 8-inch TV display[1], which are elements of the Variable Parameter Research TV system. These latter items were needed to achieve and maintain a nominal unity gamma characteristic (system brightness transfer function) and thus provide an approximately one-to-one transfer of scene contrasts to displayed image contrast (within the dynamic range capability of the display — approximately 20 to 1).

A remotely controlled Angenieux 10-to-1 zoom lens, incorporating servo drive refinements, was used with the above TV camera. The range of camera FOV's employed in this program required use of a standard 2X extender lens which provided a maximum zoom focal length range from 30 to 300 mm.

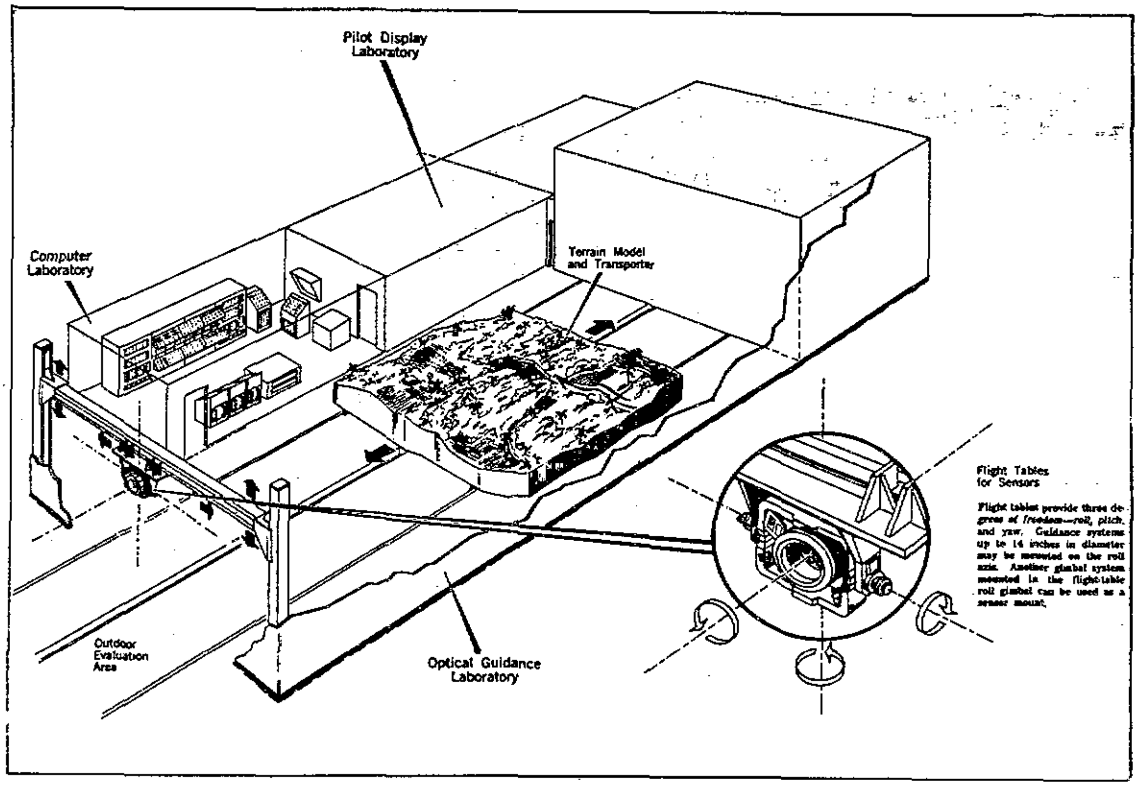


Figure 12. Martin Marietta's Guidance Development Center

---

1 Conrac Model CZB-8. This display incorporates a "keyed clamp" type dc restorer to maintain accurate black level control independent of changing scene content.

Table 1 provides a summary of the composite TV system operating characteristics (including the zoom lens, gamma control, and display performance). It should be noted, however, that the image degradation resulting from the sequential video recording/duplicating process used in producing the final stimulus tapes is not included in this table.

TABLE 1. TV SYSTEM OPERATING CHARACTISTICS SUMMARY

Characteristic	Performance
Horizontal scan rate	525 lines per frame, 2-to-1 interlace
Vertical scan rate	30 frames/60 fields per second
Limiting horizontal resolution (center)	600 TV lines (nominal) using EIA type wedge pattern
Video signal-to-noise (SNR)	>40 dB nominal peak video/RMS noise (estimated)
System gamma	Nominal value of unity
Grey scale response	9 shades of grey discernible using $\sqrt{2}$ type grey scale test pattern input

Video Recording Equipment

All runs on the GDC terrain model were recorded on a SONY helical scan type video tape recorder (VTR), Model PV-120U. The unit uses a 2-inch wide magnetic tape. This ensures high resolution reproduction together with a high video SNR. Its rated characteristics of special interest are:

- SNR
  - (1) Video — 42 dB
  - (2) Audio — 40 dB (two audio channels available)
- Video response — 3 dB down at 3.3 MHz
- Horizontal resolution (limiting) — Nominal 330 TV lines (using EIA standard chart signal input)

An irregular sequence of runs was used on the tapes employed in the behavioral tests for both the Dive Approach and Constant Altitude phases. Reordering of the basic VTR runs and rerecording (duplicating) them to form a master tape for each of the above tests required a second video recorder having an electronic edit capability. The electronic edit feature permits insertion of selected portions of external composite video signals (in this case the basic runs recorded on the PV-120U VTR) onto a second tape in any desired sequence, and ensures that the dubbed video sequences are recorded with the proper time relationships to avoid interruption of the vertical sync pulses. In this manner, smooth transitions are made from one run to the next without picture roll-over at the monitor.

A SONY 1-inch helical scan VTR, Model EV-320, was used for the above purpose. A summary of its rated performance characteristics is given below:

- SNR

(1) Video	43 dB
(2) Audio	40 dB (two audio channels available)

- Horizontal resolution (limiting) — Nominal 300 TV lines (using EIA standard chart signal input)

ACKNOWLEDGEMENTS

This study was funded under Contract N61339-70-C-0238, awarded to Martin Marietta by the Naval Training Equipment Center, Orlando, Florida.

ABOUT THE AUTHORS

MR. BARRY C. KING, JR., during his 13 years with Martin-Marietta Aerospace, has primarily been involved in the electro-optical area, with particular emphasis on advanced television sensor and display techniques. He has served as task leader on several Navy and Air Force missile advanced E/O guidance studies and development programs. As a Staff Engineer in the Electronics Division, he has been a technical contributor to various conceptual design studies, analyses and proposals employing TV techniques in air-to-ground target acquisition and airborne fire control, air-to-surface missile guidance, and tactical air defense missile guidance. He has served as principal investigator on two experimental TV simulation programs funded by the Naval Training Equipment Center (including the 2-D vs 3-D study reported herein). This human factors oriented work has included extensive use of Martin-Marietta Guidance Development Center (GDC) simulation facilities. Mr. King's previous experience in advanced E/O system analysis, design, and testing was obtained at EMR, Inc., Sarasota, Florida and at RCA, Camden, New Jersey. Mr. King received his B.S.E.E. in 1945 from the University of South Carolina.

DR. DANIEL B. JONES has over 26 years experience in human factors engineering, operations research systems analysis, and military operations. Currently he is responsible for Human Factors for Martin-Marietta Aerospace Orlando Division programs. Prior to joining Martin-Marietta in 1969, Dr. Jones was Chief of Human Factors Engineering for McDonnell Douglas Astronautics Company Western Division. He spent 20 years as an Army officer engaged in human factors technology research and development and operations analysis. Dr. Jones holds a PhD in Psychology and Statistics from the University of Missouri, Kansas City, an M.S. degree in Experimental Psychology from Tulane University, and a B.A.E. degree (with honors) from the University of Florida.