THE EFFECTS OF RANGE-LINE SPACING
ON
RELATIVE DISTANCE ESTIMATES

Thesis

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ABSTRACT

Emphasis on low altitude high speed flight profiles has brought about a revolution in display system design for tactical aircraft. The present study deals with research on a new display system, currently being developed, which is called the Airborne Electronic Terrain Map System (AETMS). The AETMS perspective display is intended to provide the same information concerning the relationship between the aircraft and the terrain to be negotiated as is available in the out-of-the-cockpit visual scene. This information can be expressed in terms of maintaining appropriate spatial or depth relationships. Since maintenance of depth relationships is crucial in low altitude high speed flight, the present study was designed to empirically evaluate the cues to depth presently available in the AETMS perspective display.

The perspective display is generated by displaying lines that correspond to terrain altitude and shape at fixed distances from the aircraft. These lines are operationally termed range lines. Because they are displayed in perspective, the spacing between these range lines provides a potentially powerful cue to depth. Unfortunately, as the number of range lines increases, so does the time required to generate the visual scene. Real-time display generation and adequate perceptual cues are both absolutely essential. Consequently, when evaluating depth cues currently available in the AETMS display, emphasis was placed on the potentially salient cue provided by range line spacing.

A relative judgement task involving a modified paired comparison technique was utilized to assess the adequacy of depth cues. The task required observers to view two simultaneously presented still images of the AETMS display and indicate which scene appeared closer (or further). A hierarchical, within subjects, repeated measure design was employed in which the independent variables were range line spacing, relative distance between scenes, and absolute distance from the terrain feature.

The results of the experiment indicate that the AETMS perspective map display does provide cues to depth. Relative distance judgements were significantly above chance level. Relative distances as small as 1200 ft. and 600 ft. for the nearer and further absolute distances, respectively, could be accurately discriminated. Further, as might be expected, accuracy of estimates had a tendency to increase as the relative distance between the comparison scenes increased.

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Introduction

Emphasis on low altitude high speed flight profiles has brought about a revolution in display system design for tactical aircraft. Traditional sources of pilotage and navigation information have been found to be inadequate. The present study deals with research on a new system currently being developed to meet the demands imposed by low altitude, high speed flight.

The new system under development, the Airborne Electronic Terrain Map System (AETMS), uses an electronic, computer-mediated approach to real-time map generation. In addition to presenting a horizontal situational display, the AETMS also provides a forward looking perspective terrain map of the vertical situation. The perspective display is intended to provide the pilot with information similar to that available through out-of-the cockpit visual contact when adverse weather and night conditions mandate IFR (instrument flight rules) rather than VFR (visual flight rules). It is therefore imperative that the display provides the same information concerning the relationship between the aircraft and the terrain to be negotiated as the out-of-the window visual scene. This can be expressed in terms of maintaining appropriate spatial or depth relationships. Since maintenance of depth relationships are crucial in TA (terrain avoidance) flight, the present research effort was designed to empirically evaluate the cues to depth presently available in the AETMS perspective display.

In addition to providing some of the more traditional cues to depth (e.g. linear and size perspective and interposition), the

AETMS generates a detail perspective. The detail perspective is a result of encoding terrain relief information. Range lines, as they are operationally termed, are displayed at fixed intervals from the aircraft and are shaped to model corresponding terrain elevations. Because they are displayed in perspective the spacing between these range lines provides a potentially powerful cue to depth (see Figure 1). Unfortunately as the number of range lines increase, so does the time required to generate the displayed scene. In fact, the time it takes to generate each frame of imagery at the system imposed minimum range line spacing of 100 ft. is 1500% greater than when processing the maximum spacing (i.e. 600 ft.). An increase in processing time affects total system through-put which may significantly compromise real-time imagery generation. Consequently, when evaluating depth cues currently available in the AETMS display, heavy emphasis was placed on the potentially salient cue provided by range line spacing.

Background

Tactical strike missions are crucial in any large scale, conventional hostility. They permit friendly forces to transition from defense to counterattack by destroying enemy units approaching the forward edge of the battle area (FEBA) from reserve and assembly positions (Kuperman, et al 1980). Until 1973, these missions did not present overly difficult problems. During the war in Southeast Asia, U.S. tactical aircraft could penetrate the highly defended air space of North Vietnam at mediuim altitudes because of the limited variety and repetition of surface-to-air defenses and the effectiveness of electronic countermeasure (ECM) pods (Crawford, 1977).

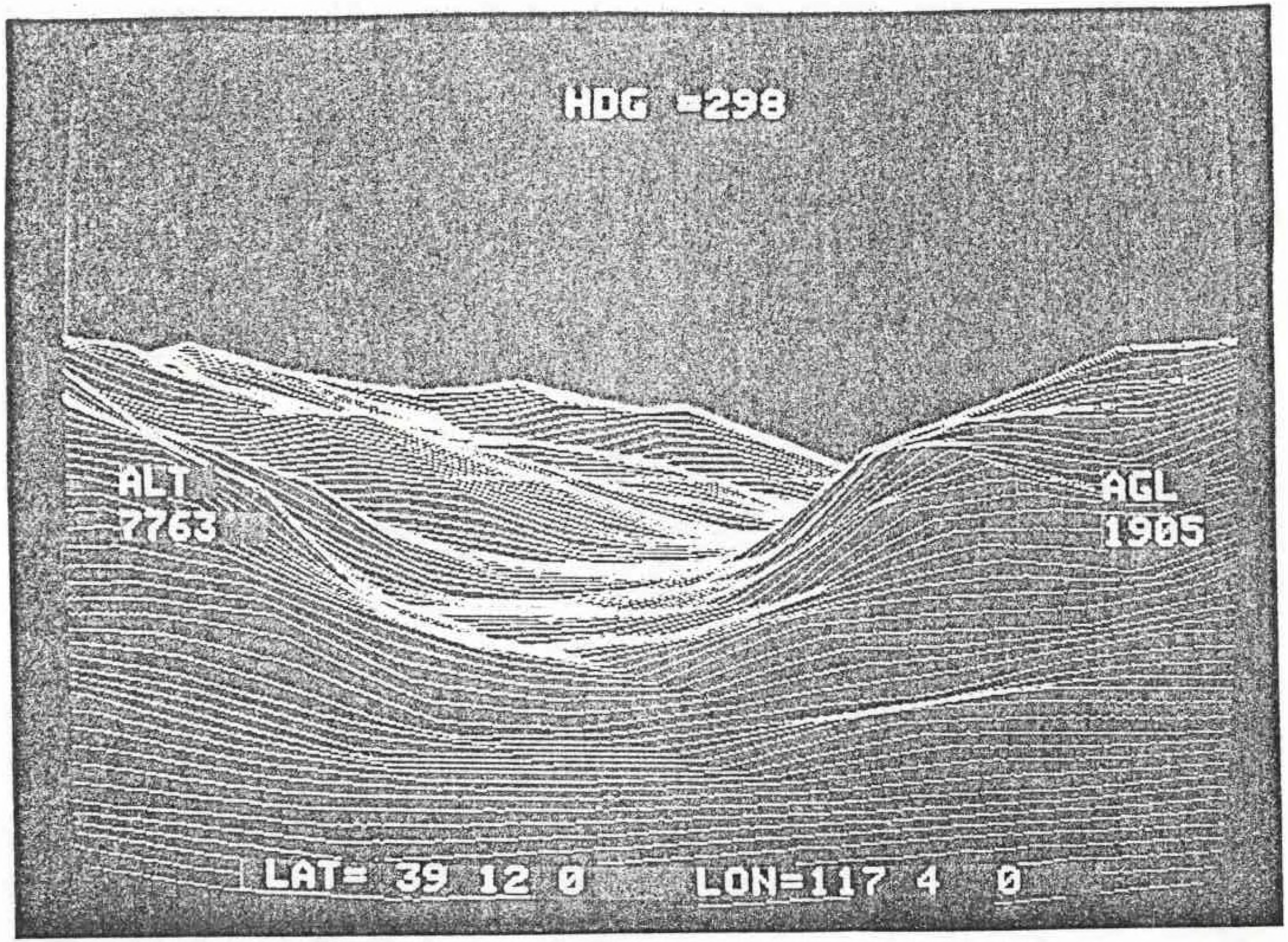

Figure 1. AETMS Perspective Display

These tactics, when employed by the Israeli Air Force in the 1973 Middle East War, had to be abandoned because of high attrition rates. The reduction in effectiveness appears to be due to the diversity and redundancy of Arab surface-to-air defenses. According to Crawford (1977), "Analysis of the 1973 Middle East War and the surface-to-air defenses present there, which are representative of those available to Warsaw Pact countries, leads to the conclusion that it may be extremely costly for present generation fighter aircraft to again penetrate highly defended air space at medium altitudes with a family of ECM pods (not yet available) and defense suppression techniques." In light of these facts, the United States Air Force is placing significant emphasis on low altitute high speed profiles (e.g. terrain avoidance) for tactical aircraft survivability (Kuperman and DeFrances, 1979).

Implementing low altitude, high speed profiles poses substantial problems. Figure 2 is an example of a low altitude strike scenario. The pilot must navigate, avoid ground fire, acquire the target and deliver munitions while trying to maintain the lowest possible profile (Kuperman, et al 1980 b). Pilotage and navigation problems are further compounded by the concurrent emphasis on all-weather and night operations.

There are three low altitude profiles currently available to the Air Force - terrain avoidance, terrain following, and terrain clearance. In terrain avoidance (TA) flight, the pilot must simultaneously maintain a constant altitude above the ground level (AGL) and make frequent heading changes so that hilltops and mountains may be flown over or around. The purpose of the heading

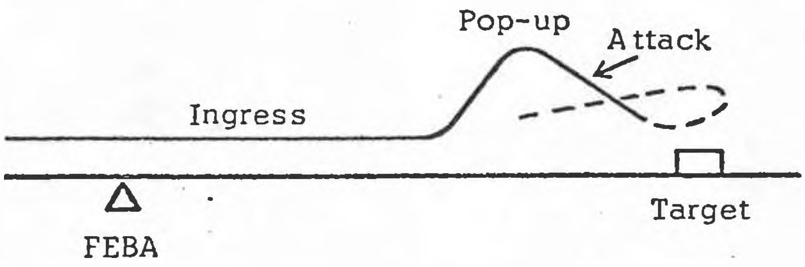

Figure 2. Example of Low Altitude Strike Scenario

changes is to take maximum advantage of terrain masking and to avoid threats and obstacles. A constant altitude AGL is also maintained in terrain following (TF), however, the aircraft flies a more or less straight flight path with heading changes made only for navigation purposes - not for obstacle and threat avoidance. TA and TF are similar in that a profile which parallels the contours of the terrain is maintained. They are both distinguished from terrain clearance (TC) in which an altitude sufficient to clear the highest terrain feature along the flight path is maintained.

Most threats such as surface-to-air missiles (SAM) and anti-aircraft artillery (AAA) defenses require a line-of-sight to the target. Since TA flight attempts to take maximum advantage of terrain masking, which denies line-of-sight, it is preferred over the other two profiles. Extended TA flight, in a heavily defended environment, however, represents one of the most stressful tasks to be attempted (Kuperman, et al, 1980 b).

Current Navigation and Pilotage Aids

In order to fly and navigate the aircraft while maintaining the lowest possible profile, the pilot needs information relating his current position to the terrain to be overflown and to the target area. Currently, there are a variety of aircraft systems which supply information to aid in piloting and navigation of the aircraft. Table 1 presents a summary of the characteristics of each system. The systems are typically classified according to their primary function (i.e. used for pilotage, navigation or both), field-of-view (FOV), whether they are predictive or descriptive, and whether they are active or passive. Each of these characteristics

Table 1. Characteristics of Current Navigation and Pilotage Systems

SYSTEMS	ACTIVE(A) PASSIVE(P)	FIELD OF VIEW HORIZONTAL X VERTICAL	PRIMARY FUNCTION PILOTAGE(P)/NAV(N)	PREDICTIVE(P) DESCRIPTIVE(D)
VISUAL	P		N/P	D
LOW LIGHT LEVEL TV	P	22.4 X 16.8^{o}	P	D
FLIR	P	20 X 15^{o}	P	D
TA RADAR	A	4 X 8^{o}	P	D
MAPS	P	NA	N	P/D
INS	P	NA	N	D
RADAR ALTIMETER	A	NA	N/P	D
AERIAL PHOTOGRAPHY	P	NA	N	P/D
AETMS	P		N/P	P/D

impacts total system effectiveness. Passive systems are preferred over active systems because active systems radiate some form of energy (e.g. radar) which can be detected by the enemy. The FOV affects the amount of the visual scene which is available to the pilot for decision making. Descriptive displays present only current status information, while predictive displays allow the pilot to see the potential ramifications of his actions before he is forced to make a decision.

Navigation Aides. The primary navigation aides are a radar altimeter, reporting current altitude (AGL); an inertial navigation system (INS), reporting current position in latitude and longitude; and topographic maps, reporting terrain shape and elevation as well as checkpoint and target information. The INS and radar altimeter provide only "time now" or "current status" information. The information from these subsystems must be used in conjunction with other systems (e.g. maps) to accomplish the navigation function. Integration of these discrete sources of information "has inherently high associated workload", (Kuperman, et al 1980 a).

Hand held topographic charts are the traditional source of cartographic information used for navigation purposes. They provide the pilot with gross present, target, and checkpoint location information as well as terrain elevations (i.e. relief). They suffer from the same limitations affecting the INS and radar altimeter - namely high associated workload because integration is lacking. The pilot must integrate the chart information with performance indices to determine the necessary pilotage actions to reach his destination. Integration of multiple sources of information is hindered by differential formating and location in the cockpit. The pilot must divide his attention between performance indices, the chart, as well as the outside world in an attempt to determine his present position and the appropriate flight control actions to reach his destination. Since the multiple sources of information are physically separated in space, the time necessary to scan the displays is substantially increased. "An increase in scan time undoubtedly increases head-down time, which is critical when flying 'on-the-deck'", (Kuperman and DeFrances, 1979). Additionally, there is differential eye accommodation and convergence for the hand held map and panel performance displays which increases head-down time and compounds transitions from in the cockpit to the outside world. Other limitations of hand held charts include inappropriate information content for specific mission segments and handling problems caused by the need to refold charts.

In an attempt to circumvent the limitations of hand-held charts and facilitate information integration (thereby presumably reducing workload), there has been a concerted effort to develop "automated" map displays. Since the map display is automated and can be used in conjunction with a frame of reference, operationally termed a "window", the pilot will be relieved of the burden of handling the map and scanning large areas of the map to determine position. Proper positioning of the display can reduce the physical distance between it and the performance displays, which will reduce scan time. Better yet, critical performance information can be incorporated in the map display itself.

Unfortunately, map displays have limitations. The principle limitation is the lack of steering information. The pilot must mentally "compute" the appropriate steering action, which increases workload. Another major drawback, is that map displays do not necessarily supply the appropriate information. "At certain times, excessive clutter increases the amount of time necessary to extract critical information. Under other conditions, insufficient information is presented." (Kuperman and DeFrances, 1979).

Pilotage Aides. There are three pilotage aides useful for low altitude flight: low light level television (L3-TV), forward looking infrared (FLIR) and terrain avoidance radar. Each has inherent advantages and disadvantages in terms of low altitude, all-weather, night capabilities.

With the incorporation of operational FLIR sensors into the Air Force inventory, opportunities for accomplishing sensor-aided TA flight segments were created. A design trade-off problem exists, however, in attempting to use FLIRs, which were originally developed for target acquisition, for terrain avoidance flight. The sensors were designed for target detection and recognition at "surveillance standoff distances." Since the targets of interest are tactical vehicles, the FLIRs have a narrow field of view ($\approx 12^{\circ}$). The resulting limited lateral coverage may substantially constrain performance in TA flight. Additionally, FLIR imagery is severely degraded when adverse weather conditions such as rain and fog prevail.

The B-52/G/H EVS (Electro-optical View System) includes both FLIR and low light television (L3TV) sensors. The L3TV augments FLIR by providing a TV imagery with a wider field of view. The FLIR and

L3TV imagery can be overlayed to produce a composite display. Problems exist however because of incompatibility in field of view between the two sensors (16.8 X 22.4^{o} for L3TV and 15 X 20^{o} for FLIR). Additionally, L3TV imagery is typically of poor quality. The contrast is very low and it is incapable of operating in fog or dense haze.

Terrain avoidance radar is a very effective pilotage aide. Either a sector in front of the aircraft is "mapped" or terrain elevation traces are displayed at a selectable range. These systems, however are extremely costly and may be subject to jamming. Since the system is "active" the probability of detection by the enemy may increase dramatically. Further, so called automatic terrain avoidance systems are in a truer sense, terrain following systems; that is, they maintain the aircraft at a fixed altitude above ground level (AGL) but require the pilot to make decisions concerning azimuth to maneuver laterally around terrain obstacles.

AETMS - A New System

All of the navigation and pilotage aides that have been discussed thus far have limitations which may significantly compromise tactical aircraft strike effectiveness and survivability. The System Technology Branch of the Air Force Wright Aeronautical Laboratories is presently developing a new pilotage/navigation system, called the Airborne Electronic Terrain Map System (AETMS), which attempts to circumvent the limitations of current systems. It incorporates much of the same information available through the more traditional displays but supplies it in an integrated format. Additionally, the system is totally self-contained and passive which will reduce detection probability. AETMS uses an electronic, computer-mediated approach to real-time map generation. It will be capable of providing an in-the-cockpit computer generated, wide area, terrain map display either of a forward looking perspective format or a planametric format.

The forward looking perspective format (Figure 1) provides the pilot with an out-of-the-cockpit view of the terrain over which he will be flying. It gives the pilot status-at-a-glance information concerning the relation between the aircraft and the terrain to be negotiated. Figure 3 demonstrates the information integration capabilities present in the perspective format. Performance and status information such as latitude, longitude, heading, airspeed, and altitude is integrated into a single display so that the pilot's attention can be more narrowly focused.

The planametric format (Figure 4) is similar to a topographic chart and will supply the pilot with information necessary to navigate and avoid known ground threats. With proper relief coding, it may also be possible to use this format for TA pilotage and route selection.

AETMS Development. Identifying, organizing, integrating and displaying essential information to the pilot, in a readily comprehensible format, is a complex task requiring extensive research and experimentation. To aid in the AETMS development process, the Air Force Wright Aeronautical Laboratory/AAAT, Information Presentation and Controls Group, has developed an operational, interactive, non-real-time electronic terrain map system simulator. The system uses a PDP 11/45 (with RSX-11M) interfaced with a RAMTEK 9300 Series image

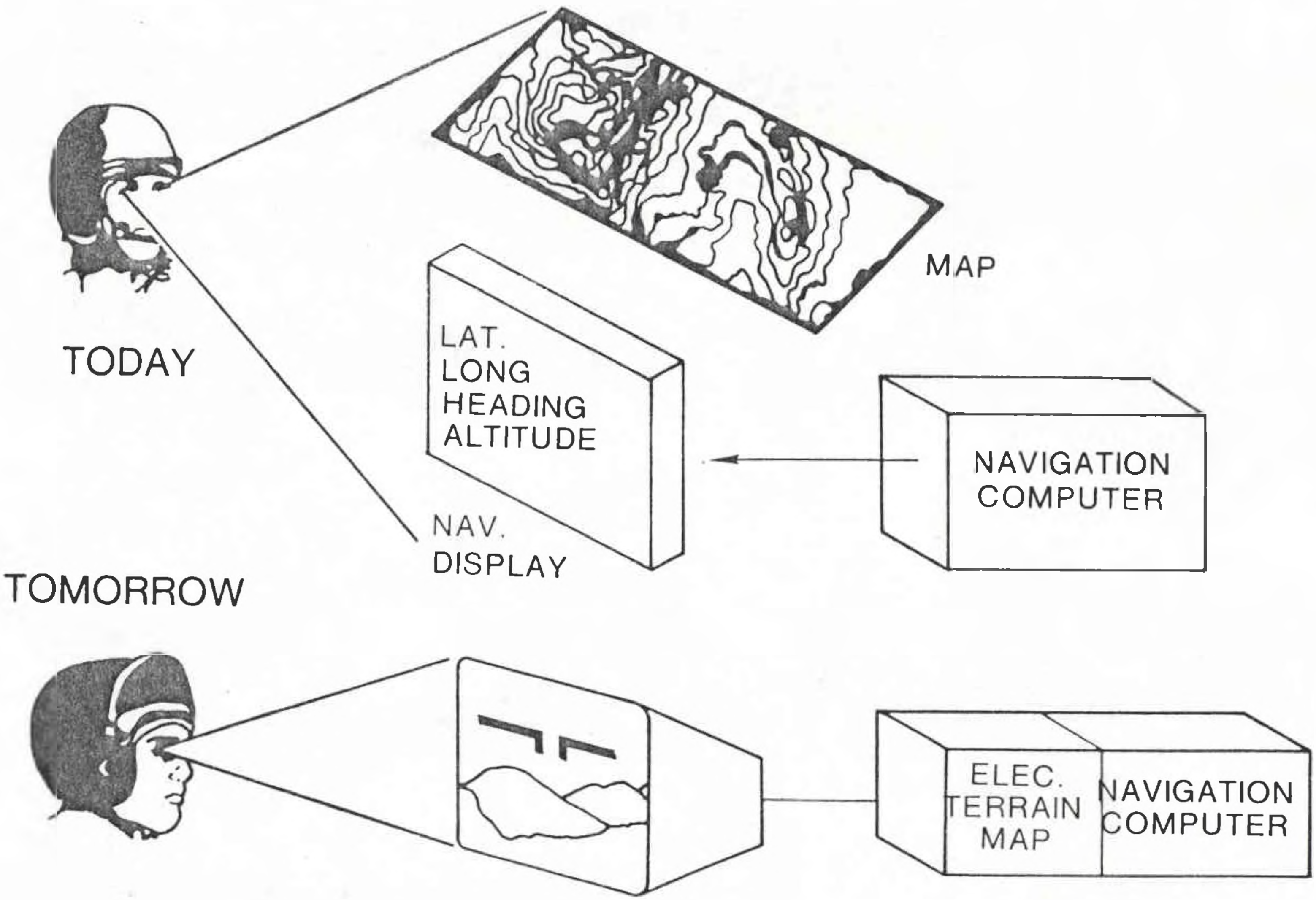

Figure 3. Information Integration Capabilities of AETMS Perspective Display

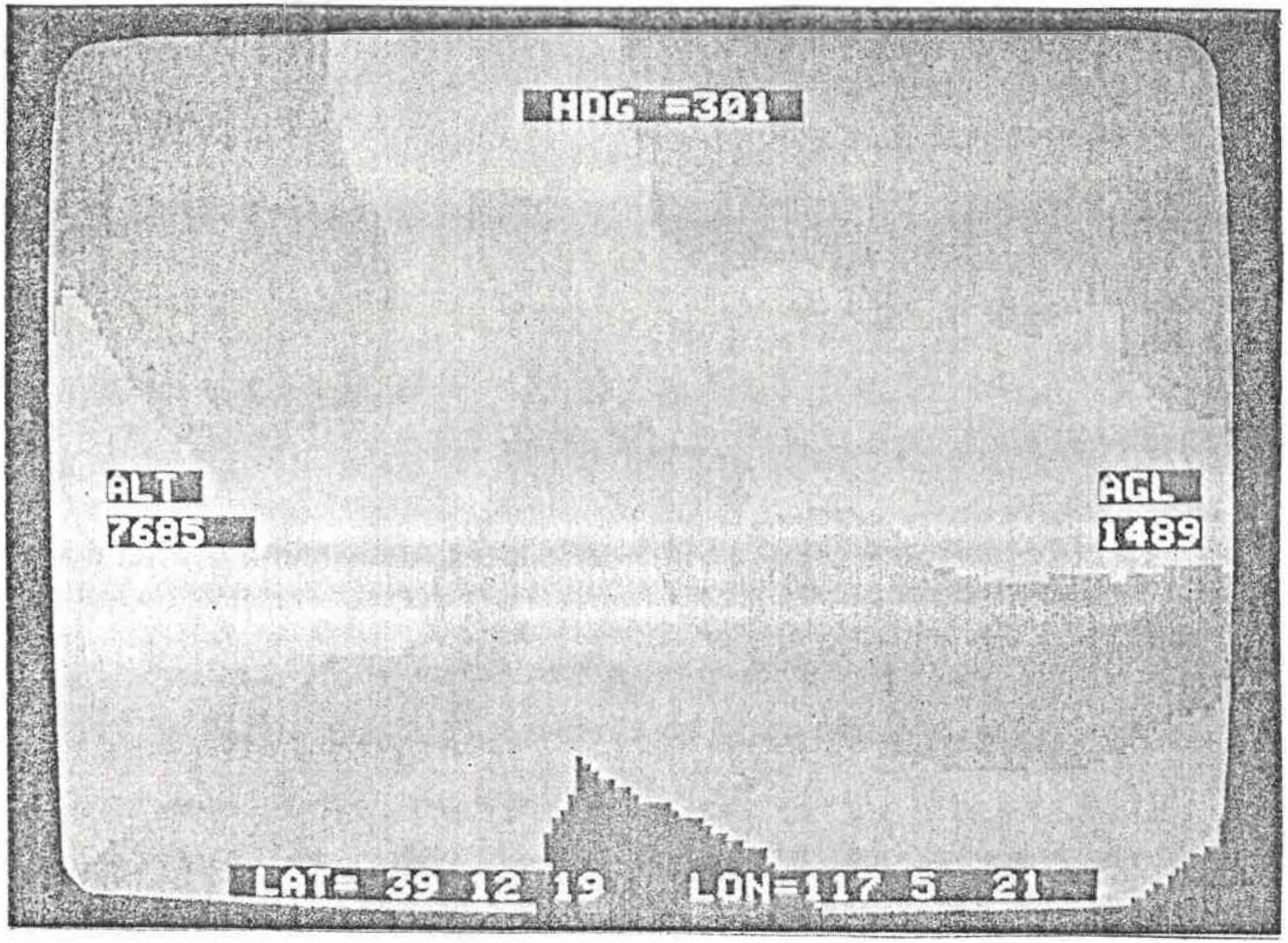

Figure 4. AETMS Planametric Format

generator. It is capable of producing full color perspective and planimetric terrain displays, including both flight control and navigation information at a rate of 3 seconds per frame.

The perspective display is generated by displaying lines that correspond to terrain altitude and shape at fixed distances from the aircraft. These lines are operationally termed range-lines. Flat-earth Euclidean projective geometry is used so that the range lines are displayed in perspective. Terrain interposition is also maintained so that nearer terrain features (range-lines) features mask more distant features.

The perspective display is unique because it provides information previously available only through out-of-the-cockpit visual contact and allows performance, navigation, and threat information to be integrated into a single display. This is expected to provide a significant increase in low altitude, high speed capabilities and reduce workload. All information is displayed in cockpit coordinates (i.e. referenced to the cockpit) which will reduce integration and interpretation time.

The perspective display is intended to supply the pilot with information similar to the out-of-the-cockpit visual scene when adverse weather and night conditions mandate IFR rather than VFR. It is, therefore, imperative that the the display provides the same information concerning the relationship between the aircraft and the terrain to be negotiated. This essentially translates into maintaining appropriate spatial or depth relationships. As mentioned earlier, the AETMS uses range lines to convey depth and terrain relief information.

As Table 2 illustrates, the range lines in the AETMS display provide most of the cues available through visual contact and the other information sources previously discussed. The only cues which are not represented are accommodation, convergence binocular disparity, aerial perspective, shadowing, and texture.

Accommodation, convergence and binocular disparity may be important cues to depth in three dimensional space where the distal stimulus is viewed directly and is in close proximity to the observer (0 - 12 ft.). In a cockpit environment, however, the distal stimulus is imagery on a two dimensional display at a more or less constant distance from the observer, and consequently these cues are not relevant. Even when directly viewing the visual scene from the cockpit, distance from the observer to the object of interest is typically too large to make use of these cues.

The utility of aerial perspective, shadowing and in the perception of depth is documented in the literature (Rock, 1975; Kaufman, 1974; and Gibson, 1950). The necessity of these cues as redundant or ancillary information when other cues are available, however, has not been established. Since algorithms for displaying these additional information cues will result in a signficant increase in processing time (and hence, may compromise real-time through-put) they should be implemented only if currently available cues, as provided by range lines, are found to be inadequate.

Present Study

The purpose of this study is to assess the effects of range-lines and range-line spacing on the perception of depth in the AETMS

Table 2. Depth Cues Available in Navigation and Pilotage Information Sources

++ highly effective + effective - does not apply	VISUAL	MAP	PASSIVE SENSOR (FLIR)	ACTIVE SENSOR (TA RADAR)	AETMS
ACCOMMODATION	-	-	-	-	-
CONVERGENCE	-	-	-	-	-
BINOCULAR DISPARITY	-	-	-	-	-
MOTION PARALLAX	+	-	-	+	+
AERIAL PERSPECTIVE	++	-	++	-	-
LINEAR PERSPECTIVE	++	-	++	-	++
SIZE PERSPECTIVE	+	-	+	+	+
SHADOWING	++	-		++	-
TEXTURE	++	-	+	-	-
INTERPOSITION	++	++	++	++	++

perspective display. Depth cues such as linear perspective, relative size and interposition are provided by range lines and the perspective geometry used to display them. Detail perspective results from the spacing between range lines. Although it is not known whether detail perspective is affected by range-line spacing, detail perspective spacing does affect display generation time. As range-line spacing decreases (i.e. the amount of information or number of range lines increases) display processing time increases. Real-time display generation and adequate perceptual cues are absolutely essential. Therefore, the primary emphasis in this study was to test the effects of detail perspective, as conveyed by range-line spacing, on depth perception and determine the largest range-line spacing which supports the perception of depth.

A relative judgement task involving a modified paired comparison technique was utilized in the present study. The task required observers to view two simultaneously presented still images of the AETMS display and indicate which scene appeared closer (or further away).

The basic assumption of this task is that, if relative distance estimates (i.e. closer or further) can be made between simultaneously presented scenes differing in distance from the aircraft, current display parameters must provide adequate depth information. Further by varying the distance from the aircraft to the two scenes to be compared, a measure of sensitivity can be made relating differences in distance between the two scenes (i.e. relative distance) to performance. Here relative distance is defined as the difference in distance between the two scenes to be compared. For example, if absolute distance from the "aircraft" to each scene is 12,152 ft. and 12,452 ft. respectively, the relative distance between the two scenes is 300 ft. A relative distance judgement was selected because, as Kaufman, 1974 pointed out, "these cues - relative size, detail perspective and linear perspective ... may well be only relative distance cues, for they do not of themselves allow one judge the absolute distance to an object." This premise appears to be supported by results obtained by Nelson and Ritchie (1976) and Aume, (1969), where judgement of absolute distance was overestimated by as much as 700%. The direction of the estimates was highly correlated with actual distance, however, absolute distance estimation was inaccurate.

The specific objectives of this research effort, then, are to:

1. Determine if the AETMS display provides cues to depth perception.
2. Test the effects of range line spacing on the perception of depth.
3. Provide recommendations on the minimum amount of information (i.e. largest range line spacing) which will support maximum depth perception.

These specific objectives were addressed by an experiment designed to answer the following five questions.

1. Can relative distance between displayed terrain features be discriminated using cues provided by range lines and range line spacing?

2. Does the spacing of range lines affect the relative distance that can be discriminated?
3. What is the smallest relative distance that can be discriminated?
4. What is the largest spacing between range lines that support the minimum discriminable relative distance?
5. Is the smallest relative distance that can be discriminated affected by absolute distance from the terrain feature?

Questions 1 through 4 follow directly from the stated objectives. Question 5 was posed to insure that the evaluation considered a prominent factor which may influence distance estimates - namely, absolute distance from the observer to relevant terrain features. Absolute distance is operationally defined as the distance from the "aircraft" to the closer of the two scenes. If, for example, the two scenes to be compared were 24,300 and 24,900 ft. from the aircraft, the scenes would be considered to be at an absolute distance of 24,300 ft., with a relative distance (i.e. separation) of 600 ft. As distance increases, size decreases; consequently, differences in size and distance become proportionately smaller.

METHOD

Design

A hierarchical, within subjects, repeated measure design was employed in which the independent variables were range-line spacing, relative distance between scenes, and absolute distance from the aircraft to the terrain feature. There were 60 major conditions in the experiment which were formed by nesting six relative distances within each of two absolute distances and then factorially combining absolute distance with each of 5 range-line spacings.

The five levels of range line spacing which were selected were based on current capabilities of the AETMS. Range line spacing was in even increments of 100 ft., ranging from 200 to 600 ft. inclusively.

Two absolute distances were selected based upon the climb characteristics of representative tactical aircraft and current capabilities of the AETMS. The absolute distances were at 2 and 4 nautical miles from the aircraft. The 2 mile point represents a critical decision point for initiating pull-up to safely clear most terrain features. Currently the AETMS has a 5.4 mile "display horizon", the 4 mile point was selected so that the feature of interest would be within the far edge of the horizon.

Twelve levels of relative distance (6 per absolute distance) were arbitrarily chosen. Relative distance was nested in absolute distance because, due to the projective geometry, as absolute distance increases, size decreases. If the judgement of relative distance is based on size alone, the difference in visual angle subtended decreases as distance increases and therefore differences in relative size become proportionately smaller. The relative distances used at the 2 mile absolute distance were 300 to 1800 ft. inclusive, in increments of 300 ft. At the 4 mi absolute distance, relative distances of 600 to 3600 ft (inclusive), in increments of 600 ft., were used. Three levels, 600, 1200, and 1800 ft. were crossed with absolute distance so that limited comparisons could be made across conditions.

The primary dependent variable was the percentage of correct trials. Reaction time was used as a secondary dependent measure. It was employed as a means to pace subjects and provide a "fine-tuning" mechanism in the event that the error anlaysis produced border-line results.

Stimuli

The terrain feature used in all imagery was Iron Mountain in Nevada (latitude 39^{o}, 18', 51" N; longitude 117^{o}, 23', 30" W). It was selected because it is surrounded by a relative flat plane, making it the predominate feature in the scene; thereby, reducing potential confusion between it and other features.

Perspective scenes were generated at the two levels of absolute distance to the East of Iron Mountain and at each corresponding relative distance. The "aircraft" heading was 270^{o} (due West) so that the aircraft was directly facing the mountain (see Figure 5). A mean sea level (MSL) altitude corresponding to that of the summit (8000 ft.) was maintained so that the summit was located at the center of the display regardless of aircraft position. Each scene

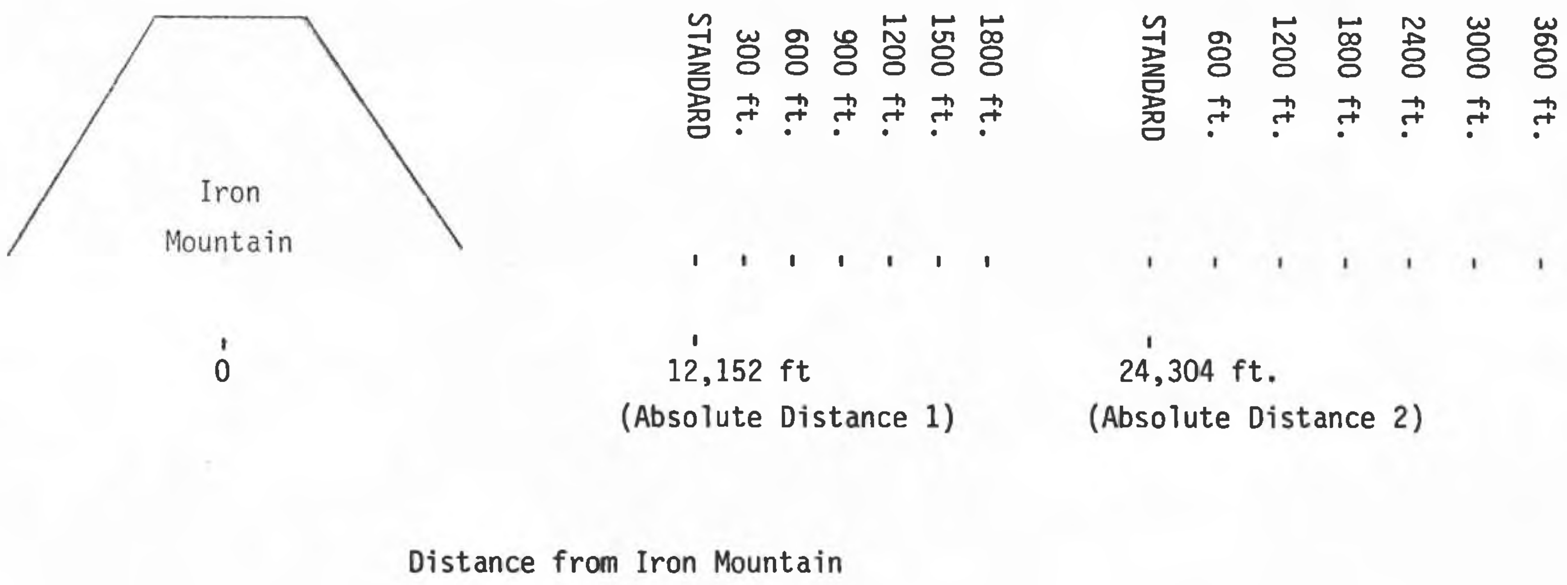

Figure 5. Aircraft Position Relative to Iron Mountain

was generated at every level of range line spacing. A total of 70 scenes were generated (2 standard distances X 5 range line spacings X 6 relative distances + 2 absolute distances X 5 range line spacing = 70 scenes).

The experimental stimuli were 35 mm color slides of the 70 scenes. Scenes were generated by the AETMS and displayed on a CONRAC Model color monitor. A PENTAX SP1000 camera with a 50 mm MACRO SUPER TAKUMAR lens and ECTACHROME EPT film was used to photograph the display. The slides were developed using E6 processing. Two duplicate sets of slides were produced from the originals using standard slide duplication film (Eastman Kodak). The two duplicate sets of slides were used for the experiment.

Apparatus

Presentation of stimuli and data collection was controlled by an INTEL SPC 80/20-4 microcomputer. The following equipment was interfaced through a SRL (SBC 80/20-4) I/O INTEFACE:

2 KODAK ECTAGRAPHIC RA960 random access slide projectors with MAST Model 140-6L1 keyset converters

2 UNIBLITZ MODEL 100 225L4A0X5 SERIES shutters with corresponding drive units (UNIBLITZ MODEL 122B).

1 TEXAS INSTRUMENT SILENT 700 ASR hard copy terminal

1 SRL RESPONSE BOX with 3 CL S K 8121 SPDT switches

The ETAGRAPHIC slide projectors provided the capability to randomly access up to 80 slides. Because it has the ability to perform bidirectional search based on "shortest-path calculations" the maximum search time was 3 seconds.

The UNIBLITZ shutters were used to guarantee that the two slides were presented "simultaneously". The rise time, which affects shutter control, was much smaller and more stable than standard slide projector (mechanical) shutters. The shutters were positioned over the F3/5, 4'6" focal length EKTANAR zoom lens supplied with the slide projector.

The Silent 700 was used to communicate with the INTEL and record subject responses. It was equipped with a digital tape recorder so that in addition to providing a hard-copy of subject response, it could also record data on tape.

A software driver program was written (see Appendix A) to control the experiment.

The slides were projected onto a DA-LITE DA-TEX rear projection screen. Screen measurements were 54 X 54 X .011 inches.

Set-up

All equipment was occluded by the projection screen and office dividers. Slides were presented side by side on the rear projection screen. Each projected image was 5 X 7 inches with a space of 3 inches between the two slides. Ambient illumination from the slide projectors was restricted by masking all but the projection area on the rear side of the projection screen with black cardboard. Light readings were taken before and after the experiment (see Figure 6) using a Minolta Luminance Meter 1 Degree hand held photometer.

The subject's chair was positioned so that, when seated, the observer would be 28" away from the screen and centered with respect to the two slides. A table was placed next to the chair and a padded arm rest and the response buttons were placed on the table. The height of the table and position of the armrest was adjusted so that, when sitting upright, the subject's forearm rested fully on the arm rest and the response buttons were at his/her finger-tips.

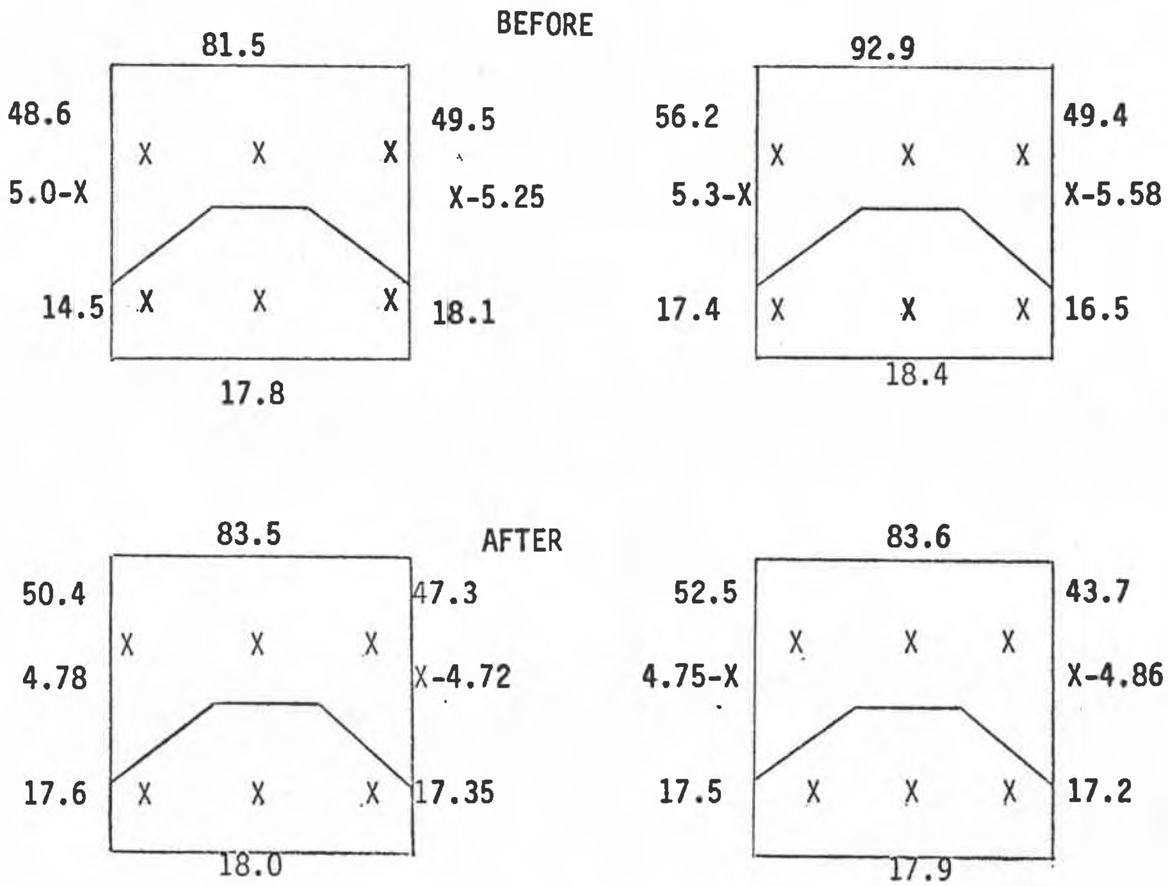

Figure 6. Before and after luminance readings (foot lamberts).

Subjects

Ten subjects were recruited from the AFAMRL (Air Force Medical Research Laboratory) paid subject pool. All were right hand dominant and had 20/20 vision (corrected or uncorrected). Eight male and two female subjects participated in the experiment.

Procedure

In individual sessions, ten subjects judged the relationship between two simultaneously presented color slides of computer generated imagery. Each subject participated in four 45 minute sessions at the same time of day on consecutive days. During two of the sessions each subject was asked to indicate the scene in which the mountain is closer to them and in the other two sessions indicate the scenes in which the mountain is further away. Further or closer judgements were consecutively alternated over the four sessions. Half of the subjects started judging the closer scene and half the further scene (see Appendix B). The subjects were randomly assigned to each condition.

Each session was composed of 150 experimental trials. On each trial, a standard scene was presented with a comparison scene. The standard scenes were always located at one of the two absolute distances (i.e. at 2 or 4 in miles). There was one standard for each range line spacing and standard distance combination (2 standard distances X 5 range line spacings = 10 standard scenes). The comparison scene could be the same standard; another scene at the same absolute and relative distance (differing in range line spacing); or a scene with the same range line spacing and absolute distance but a different relative distance. In other words, the two scenes to be compared differed (at most) along 1 dimension and comparisons were never made across absolute distances. The 150 trials were broken down as follows:

120 trials comparing scenes differing in relative distance
20 trials comparing scenes differing in range line spacing
10 trials comparing identical scenes
150 trials

The 120 trials comparing scenes differing in relative distance were derived from the combination of absolute distance, relative distance, range-line space and replication (2 absolute distances X 6 relative distances X 5 range line spacings X 2 replications = 120). The replication factor was essentially a counter balance because on half of the trials the standard scene was presented on the left and the other half on the right. This insured that probability of each response was equal (i.e. 50%).

The 20 trials comparing scenes differing in range-line spacing were created by the combination of range line spacing and absolute distance (((5 range-line spacings) !/2!(5-2)!)*2 absolute distances = 20). These trials were included to check for perception of apparent depth resulting from differential range-line spacing. The ten standards were used for the comparisons. These standards were also used for the 10 trials comparing identical scenes which were included as a check for response bias.

The 150 experimental trials were presented in a random order with an interstimulus interval of 5 seconds. Four randomized sequence blocks were generated so that a subject would receive the same sequence of trials only once in the four sessions. The blocks were presented to each subject in a random order.

During the first session, the experimenter introduced himself and asked the subject to read and sign a consent form which contained a brief introduction to the experiment (see Appendix C). The subject was then instructed to sit in front of the rear projection screen. Once seated, she/he was given a copy of instructions and asked to follow along as the experimenter read them aloud (see Appendix D/1 and D/2). Subjects were told that they were going to begin an experiment on relative distance estimation. They were to view pairs of 35 mm slides of terrain imagery which was generated by a map system being developed by the Air Force. Both slides would contain a mountain with a relatively flat summit and their task was to indicate in which scene the mountain was closer/further. Their response would be made by depressing the button corresponding to the scene containing the mountain that is closer/further. For example, if the left scene appeared closer/further depress the left button. If the right scene is closer/further depress the right button. If unsure they were to guess. They were further told: (1) to respond with their index finger and to rest it on the center button while waiting to respond; (2) they would have a maximum time of 3 seconds to view the scenes and make their response; and (3) although the scenes may differ in the number of lines used to generate the display there is no systematic relationship between the number lines and distance. The subjects were then given an opportunity to ask questions concerning their task. Questions about the criterion to be used in making their judgement were deferred until the debriefing session at the end of the experiment. The subject was given 20 practice trials to familiarize him/her with the task and again given a chance to ask clarifying questions. The 30 minute experimental session was then started.

On each subsequent session, the subjects were given an abbreviated instruction sheet (see Appendix D/3 and D/4) which was also read to them. They were instructed which judgement (further/ closer) they were to make and given 20 practice trials to refamiliarize them with their task. The 30 minute experimental session was then begun.

After the final session, each subject was debriefed.

RESULTS

The data was scored and broken down into three data sets termed range line spacing, distance, and check-bias. The range-line spacing data set contained all trials in which the two slides to be compared differed only in the range line spacing used to generate the scene (i.e. distance was the same). The distance data set was composed of data from all trials in which the range line spacing for the two slides was constant but distance from the mountain varied. Trials on which the two slides were identical in every respect comprised the check-bias data set.

Percent correct scores and mean reaction times were calculated (see Appendix E) for the distance data set by collapsing across the eight replications (4 sessions X 2 replications/session). These scores were used as dependent variables for all analyses. A mean percent correct score was calculated for each subject by collapsing across all cells in Appendix E. Each subject's mean percent correct score was compared to chance, using t-tests, to determine if responses were significantly greater than chance. As Table 3 shows, responses for all but one subject (i.e. subject 2) were greater than chance. The results of these analyses clearly show that 9 out of 10 subjects could judge relative distance significantly ($p < .01$) above chance level. Consequently, subject 2 was dropped from the experiment.

In an attempt to avoid task induced response bias, each set of comparison scenes (e.g. A, B) were presented in both left and

Table 3. Results of t-test Comparing Mean Percent Correct Scores For Each Subject Against Chance ($*P < .01$).

SUBJECT NUMBER	t
1	3.38 *
2	0.49
3	2.71 *
4	5.34 *
5	6.24 *
6	3.95 *
7	3.67 *
8	2.79 *
9	4.08 *
10	7.52 *

spatial orientations (e.g. A B and B A). In order to check for subject induced response bias, a frequency tabulation of responses for each of the remaining nine subjects was performed on the check data set. The check data set contained data from all trials where the two scenes to be compared were identical. If there was no subject induced response bias, the percentage of left and right responses should be equal. As Table 4 demonstrates, subjects 3 and 8 exhibited a strong response bias. Since this response bias was subject induced rather than task induced, subjects 3 and 8 were dropped from further data analyses.

An Analysis of Variance (ANOVA) was performed on the distance data set using percent correct scores and mean reaction time as dependent measures. Results for the ANOVAs using data from seven subjects are presented in Tables 5 and 6.[1] As mentioned in the method section, mean reaction time was a secondary dependent measure whose primary purpose was to pace the subject. Since the results for both dependent measures were identical and because mean reaction time was considered a secondary dependent measure, only analyses on percent correct scores will be discussed in the remainder of the Results section.[2] For the primary dependent variable, percent correct (Table 5), the main effects of absolute and relative distance were significant ($p < .01$).

The direction of the effects and other analyses which were performed will be discussed in context of the five questions posed in the introduction.

[1] Results for the ANOVAs on all 10 subjects are presented in Appendix F.

[2] Results for the ANOVAs and other analyses performed using mean reaction time as the dependent variable for 7 subjects presented in Appendix G.

Table 4. Frequency Tabulation of Each Subject's Response for Identical Scenes.

SUBJECT RESPONSE	% LEFT RESPONSE	% RIGHT RESPONSE	% NO NUMBER
1	52.7	47.3	0.0
3	78.3	19.8	1.9
4	53.5	45.8	0.6
5	47.9	51.9	0.2
6	46.0	52.1	1.9
7	51.5	48.3	0.2
8	28.7	71.3	0.0
9	50.8	43.3	5.8
10	52.3	47.5	0.2

Table 5. Analysis of Variance Summary Table Using Percent Correct Scores as the Dependent Variable.

SOURCE	df	MEAN SQUARE	F
Range-Line Spacing (RS)	4	0.0360	1.1520
Absolute Distance (AD)	1	3.9537	15.0775*
Relative Distance (RD/AD)	10	0.2862	12.0794*
Subjects (S)	6	0.1458	
RS X AD	4	0.1060	3.7161
RS X RD/AD	40	0.0267	1.3393
S X RS	24	0.0313	
S X AD	6	0.2622	
S X RD/AD	60	0.0237	
S X RS X AD	24	0.0285	
S X RS X RD/AD	240	0.0200	

Table 6. Analysis of Variance Summary Table using Mean Reaction Time as the Dependent Variable.

SOURCE	df	MEAN SQUARE	F
Range-Line Spacing (RS)	4	0.0575	1.3637
Absolute Distance (AD)	1	2.5303	34.3328*
Relative Distance (RD/AD)	10	0.3402	9.0530*
Subjects (S)	6	4.4875	
RS X AD	4	0.1357	4.015
RS X RD/AD	40	0.0349	1.0714
S X RS	24	0.0422	
S X AD	6	0.0737	
S X RD/AD	60	0.0376	
S X RS X AD	24	0.0338	
S X RS X RD/AD	240	0.0326	

1. Can relative distance between displayed terrain features be discriminated using cues presently available in the AETMS display?

Hypothetically, if the AETMS display did not provide depth cues, subjects would not be able to perform distance discrimination and, hence, their responses would be at a chance level (with two response choices, chance would be .5). Table 3 shows that responses for 9 out of 10 subjects were above chance. Therefore, it would appear that the AETMS display provides adequate depth cues to permit relative distance estimation. An overall mean and standard error was calculated using data from the seven subjects who were included in the ANOVAs. The resulting mean of .7726 was compared to chance (.5) using a t-test. The t of 12.170 ($t = (.7726 - .5)/.0224$) was found to be significant ($p < .01$). Relative distance between terrain features can be discriminated using cues presently available in the AETMS display.

2. Does the spacing between range lines affect the relative distance that can be discriminated?

The effects of range-line spacing on relative distance estimates can be determined by examining the interaction of the two variables in the ANOVA (see Table 5). The interaction of range-line spacing by relative distance produced an F ratio of 1.339 which was not significant ($p \geq .01$).

Relative distance is partially nested and partially crossed with absolute distance. In order to be able to further assess the interaction of relative distance and range-line spacing, and parcel out potential contamination due to the nested levels of relative distance, an ANOVA was performed using data only from the completely crossed levels of absolute distance, relative distance, and range-line spacing. Table 7 presents the results of the ANOVA using only the completely crossed levels of the variables. The results are identical to the results obtained in the ANOVA using both crossed and nested data (see Table 5).

The interaction of range-line spacing by relative distance produced an F of 1.119 which was still not significant ($p \geq .01$). Range-line spacing, therefore, does not appear to affect relative distance that can be discriminated.

3. What is the smallest relative distance that can be discriminated?

T-tests were performed to determine which relative distances could be discriminated above a chance level (i.e. 50%). A t-test was performed for each level of relative distance nested in absolute distance. Table 8 presents the results of the 12 t-tests. At the 2 mi. absolute distance, relative distances of 1200, 1500, and 1800 ft. could be discriminated above chance level. All relative distances (i.e. 600, 1200, 1800, 2400, 3000 and 3600 ft) could be discriminated above a chance level at the 4 mi. absolute distance. The smallest relative distance that can be discriminated (above chance) appears to be dependent upon absolute distance. The smallest relative distances that could be discriminated were 1200 ft. and 600

Table 7. Analysis of Variance Summary Table Using Only the Completely Crossed Levels of All Variables with Percent Correct as the Dependent Variable

SOURCE	df	MEAN SQUARE	F
Range-Line Spacing (RS)	4	0.02727	1.3620
Absolute Distance (AD)	1	0.7146	5.7486*
Relative Distance	2	0.3663	10.9685*
Subjects (S)	6	0.0875	
RS X AD	4	.0987	
RS X RD	8	0.0265	1.1189
AD X RD	2	0.0112	0.5428
S X RS	24	0.0200	
S X AD	6	0.1243	
S X RD	12	0.0334	
RS X AD X RD	8	0.0441	1.5308
S X RS X AD	24	0.0299	
S X RS X RD	48	0.0237	
S X AD X RD	12	0.0207	
S X RS X AD X RD	48	0.0288	

Table 8. Results of t-test comparing mean percent scores for each relative distance against chance. (* indicates $p < .01$)

ABSOLUTE DISTANCE	RELATIVE DISTANCE	t
Closer	300	.756
Closer	600	1.389
Closer	900	1.715
Closer	1200	2.159*
Closer	1500	4.464*
Closer	1800	3.753*
Further	600	3.560*
Further	1200	4.765*
Further	1800	5.392*
Further	2400	7.773*
Further	3600	8.069*

ft. for the closer and further absolute distances respectively.

Dunn mean comparison tests on relative distances at each absolute distance (see Tables 9 and 10) show that, in general, as relative distance increases, discrimination (as measured by percent correct) increases. At the 2 mi. absolute distance, the percentage of correct scores for relative distances of 1500 and 1800 ft. were significantly greater than for 300 and 600 ft relative distances. A relative distance of 1500 ft. was also discriminated more accurately than the 900 ft. relative distance. At the 4 mi. absolute distance discrimination of relative distances of 2400, 3000 and 3600 ft. were significantly better ($p < .01$) than for 600 ft; and judgements of 3000 ft were significantly better than 1200 ft.

4. What is the largest spacing between range-lines that support the minimum discriminble relative distance?

As noted in question 2, the interaction of range-line spacing and relative distance was not significant ($p \geq .01$). The main effect of range-line spacing was also not significant ($p \geq .01$). The largest range line spacing (i.e. 600 ft.) used in the experiment, therefore, appears to be adequate in supporting the minimum discriminable relative distance.

5. Is the smallest relative distance that can be discriminated affected by absolute distance from the terrain feature?

Table 9. Results of Dunn Mean Comparison Test for Relative Distance at the Closer (2 mi) Absolute Distance

Relative Distance		Mean
300	=	.55714
600	=	.61071
900	=	.64286
1200	=	.67143
1500	=	.80000
1800	=	.77143

	300	600	900	1200	1800	1500
300					.01	.01
600					.01	.01
900						.01
1200						
1800						
1500						

Table 10. Results of Dunn Mean Comparison Test for Relative Distance at the Further (4 mi) Absolute Distance

Relative Distance		Mean
600	=	.73214
1200	=	.81071
1800	=	.86071
2400	=	.91429
3000	=	.96429
3600	=	.93571

	600	1200	1800	2400	3600	3000
600				.01	.01	.01
1200						.01
1800						
2400						
3600						
3000						

The results obtained in question 3 above seem to indicate that the smallest relative distance that can be discriminated is dependent upon absolute distance. The smallest relative distance that could be discriminated at the absolute distances of 2 mi. and 4 mi. were 1200 ft and 600 ft, respectively. The interaction of relative distance by absolute distance, however was not significant in the overall ANOVA or the ANOVA using only the crossed levels of relative distance (see Tables 5 and 7).

Other Considerations

The main effects of absolute distance was significant ($p < .01$) for the overall ANOVA and ANOVA using only the completely crossed levels of all variables. The percentage of correct judgements were significantly better for the 4 mi. absolute distance than for the 2 mi. distance (see Table 5 and 7). The difference between the two absolute distances does not appear to be due to the nested levels of relative distance because, as Table 7 shows, ANOVAs using only the crossed levels of relative distance produced results which were identical to those of the overall ANOVAs.

To evaluate the effects of range-line spacing on apparent distance, a frequency tabulation was performed on the range-line spacing data set. Subject responses were tabulated against differences in range-line spacing between the two scenes (recall that both scenes were at the same absolute and relative distances). Results are presented in Table 11. The negative indices in the Table indicate that range line spacing in the right scene was less than in the left scene. A Chi Square test on the tabled results indicates that range-line spacing affects the impression of apparent depth.

Table 11. Frequency Tabulation of Responses for Scenes Differing Only in Range Line Spacing

	Difference in Level of Range Line Spacing Between the 2 Scenes							
	-4	-3	-2	-1	1	2	3	4
Left	8	19	18	40	86	75	55	28
Right	32	59	98	119	71	42	24	12
Did Not Respond	0	2	4	1	3	3	1	0

DISCUSSION

The results of the experiment indicate that the AETMS perspective map display does provide cues to depth. Relative distance judgements were significantly above chance level. Relative distances as small as 1200 ft. and 600 ft. for the nearer and further absolute distances, respectively, could be accurately discriminated. Further, as might be expected, accuracy of estimates had a tendency to increase as the relative distance between the comparison scenes increased.

A somewhat surprising finding in this present study concerned the effects of absolute distance. As absolute distance increased, subjects were significantly more accurate in discriminating smaller differences in relative distance. Intuitively, you would expect the opposite to be true. As Figure 7 illustrates, as absolute distance from the terrain feature increases the magnitude of the subtended visual angle decreases. It would, therefore, follow that differences in size between the two scenes to be compared would become increasing less as distance increases. If differences in relative distance were discriminated using the relative size cue, the results should have shown an inversely proportional relationship between relative and absolute distance. Obviously, the subjects did not use differences in subtend visual angle as a cue to depth. Either these differences in visual angle were too small to detect in the time allotted to make a decision, or there was a more salient cue present in the display.

A plausible interpretation for the above apparent anomaly may center on the relationship between the terrain feature and the field-of-view of the AETMS display. As you can see in Figure 8, the

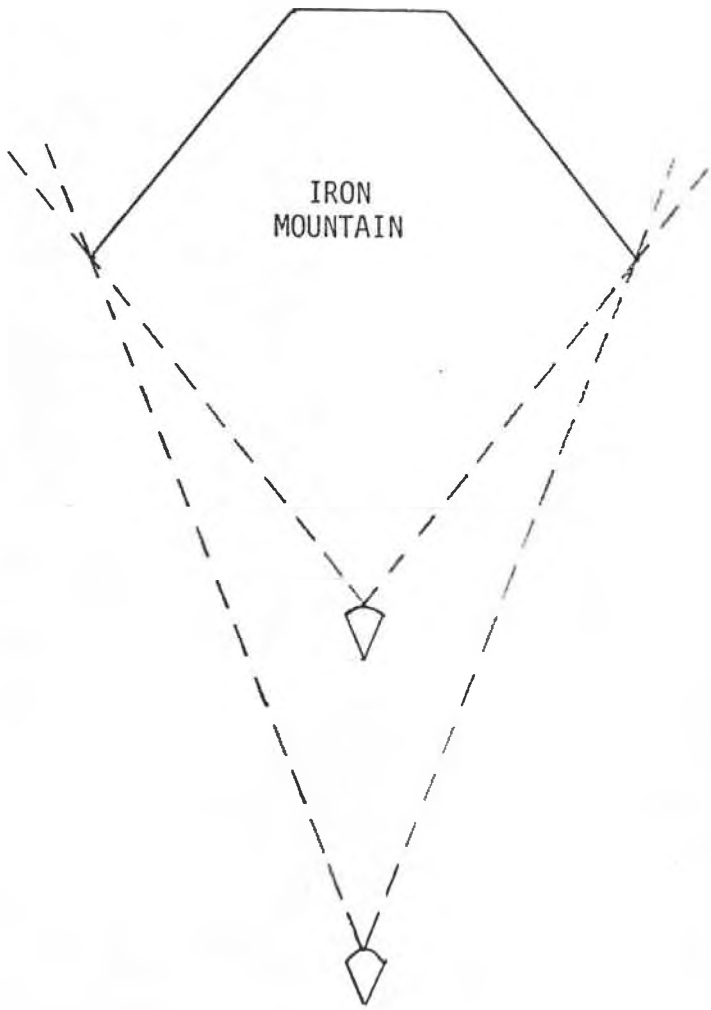

Figure 7. Differences in visual angle resulting from absolute distance from the terrain feature

predominant feature at the closer absolute distance encompassed almost the entire field-of-view and masked much of the background and peripheral information. However, this information was available at the greater absolute distance (Figure 9). James Gibson (1950) has argued that the perception of the world as three-dimensional depends upon "the perception of planes receding into depth." The closer scene which masked much of the ground plane surrounding the terrain feature may have caused the display to appear more flat which may perceptually alter the apparent difference between the comparison scenes.

Another explanation for the more accurate discrimination at the greater absolute distance may involve texture created by range-lines and range-line spacing in the foreground. The regularity of the spacing between range-lines may give rise to the perception of a texture gradient. As numerous studies (Gibson, 1959; Wohlwill, 1962; Baunstein, 1968) have demonstrated, texture increases the perception of depth. Again referring to Figures 9 and 10, notice the difference in foreground information (or texture) between the two scenes. At the closer absolute distance (Figure 8) one is too close to the terrain feature to make use of the "texture gradient" formed by range lines and the spacing between them. The relatively steep slope of the mountain further reduces linear perspective cues provided by the range lines themselves. Consequently the impression of depth is not as great as it is for the further scene (Figure 9).

The results indicate that range-line spacing has no effect on relative distance estimates. This is a significant finding to the operational community. Display processing time is highly dependent upon the amount of information that must be manipulated and displayed. Since

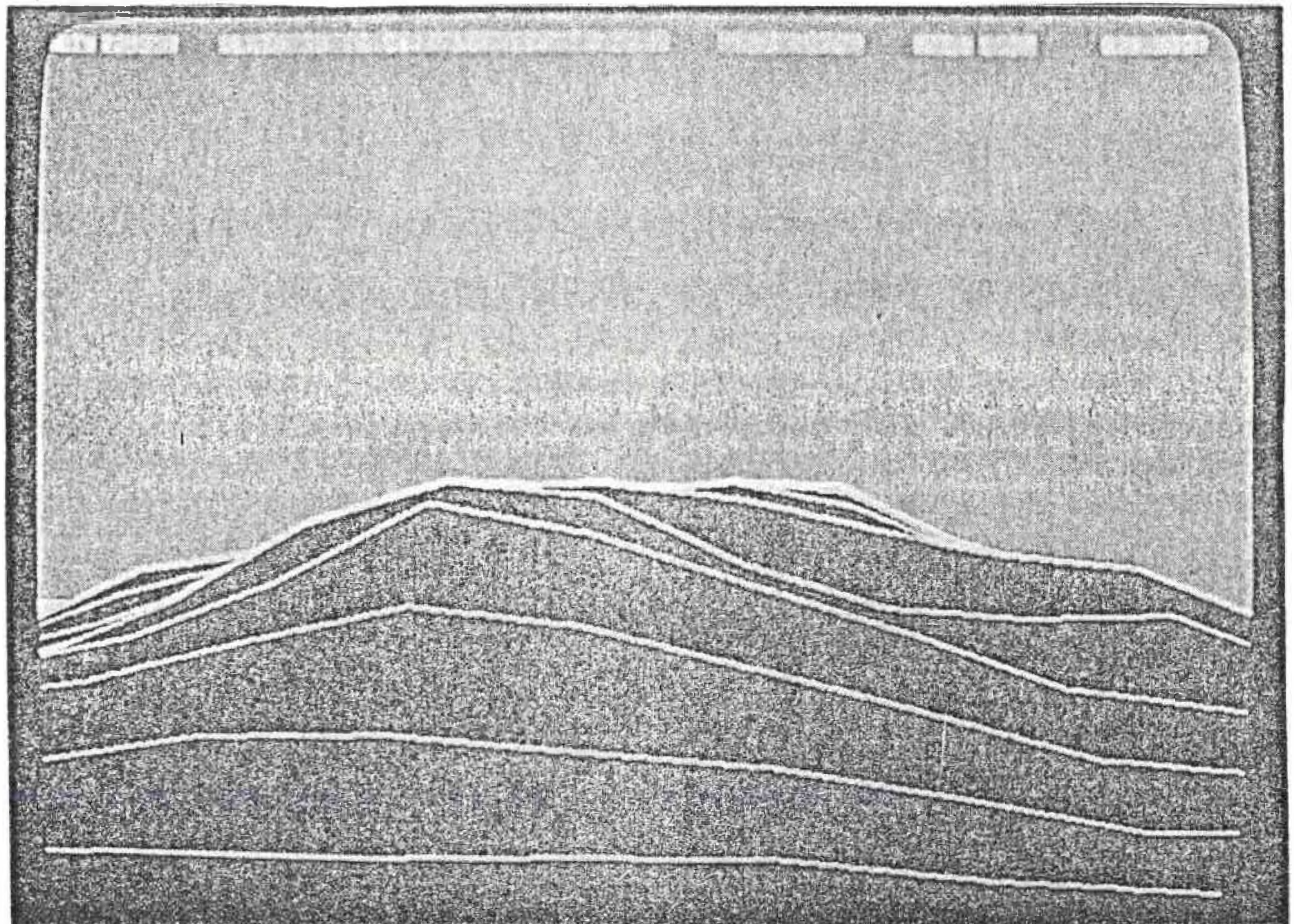

Figure 8. Representative Scene at the Closer (2 mi) Absolute Distance

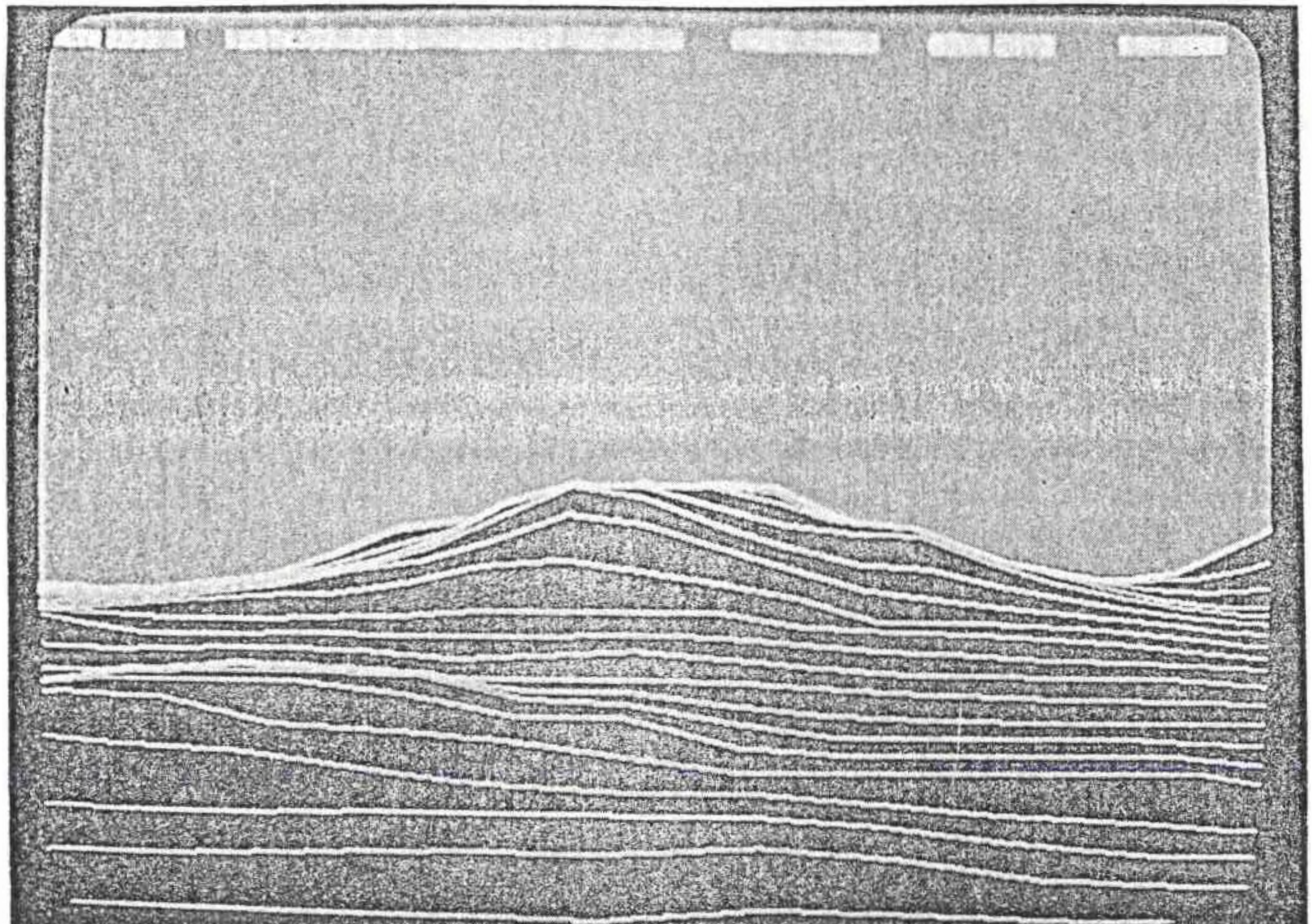

Figure 9. Representative Scene at the Further (4 mi) Absolute Distance

range-line spacing did not affect relative distance estimates, this implies that a large range-line spacing can be used to generate the display. As the spacing between range lines increases, the number of range lines and hence, the amount of information that must be processed can be reduced. This will result in an overall decrease in processing time which may facilitate real-time display generation.

Although the above results indicate that a large range-line spacing may be sufficient for the perception of depth, other factors must be considered. In addition to conveying depth information, range lines are the only source of terrain relief and shape information in the AETMS display. If a pilot is required to use the AETMS at extremely low altitudes to follow the contours of the terrain it may be necessary to increase the amount of terrain information (i.e. increase the number of range lines by reducing range-line spacing). Further, it may also be necessary to increase the amount of terrain relief and shape information if the display is going to be used for navigation purposes. For example, a representative navigation function would be check-point identification. This task requires a pilot to visually locate an out-of-the-cockpit feature and correlate it with information provided by his displays so that either the navigation computer can be updated or a course correction can be made. If the information provided by the AETMS display does not bear a close resemblance to the out-of-the-cockpit visual scene the pilot may become disoriented; dismiss the display as being unreliable or unrealistic; or miss the check-point because he cannot identify it. Intuitively, it would be logical to assume that as the resemblance between the two sources of information increased, so too would the probability of correct recognition. Again, this can be accomplished by decreasing range-line spacing, thereby increasing the number of range-lines which convey shape information. Considerable experimentation is necessary in this area to test this assumption and completely resolve the range-line spacing issue. The results of this present study, however, at least eliminates one of the important factors that must, otherwise, be taken into consideration in future evaluations of range-line spacing, that is, their effects on the perception of depth.

Generalizations from the results of this study must be made carefully. The task the subjects were required to perform was highly artificial in nature. In a real world environment, the pilot does not necessarily have a reference scene with which to compare the display. Also, the effects of imagery motion or movement was not examined. Kaufman (1974) and Rock (1975) for example, stress the importance of motion in the perception of depth. Rock further stresses the possible interaction of the various cues to depth. Much research is needed to fully assess the effects motion may have on the cues currently available in the AETMS perspective map display.

In conclusion, the present study has demonstrated that the AETMS does provide cues to depth. The cue of detail perspective was not affected by range-line spacing. Either detail perspective was not a salient cue to depth or the degree of detail perspective provided by the largest range-line spacing was sufficient in conjunction with the other cues of linear perspective and interposition to produce the perception of depth.

APPENDIX A

Software Program for Experiment

```
CP/M MACRO ASSEM 2.0      #001     STATIC RANGE SOFTWARE PACKAGE  - MAY 31, 1980 -

                                TITLE 'STATIC RANGE SOFTWARE PACKAGE  - MAY 31, 1980 -'
                                PAGE 58
                        ;*****************************************************************
                        ;
                        ;       S T A T I C   R A N G E   S T U D Y
                        ;
                        ;       STATIC.ASM                MAY 31, 1980
                        ;       BY RON SPICUZZA
                        ;       SYSTEMS RESEARCH LABS INC.
                        ;
                        ;THIS PROGRAM PRESENTS A SEQUENCE OF SLIDES FROM
                        ;TWO PROJECTORS TO A SUBJECT. DATA COLLECTED REPRESENTS
                        ;THE REACTION TIME FROM STIMULUS ONSET TO A KEYPRESS.
                        ;THE CORRECT RESPONSE IS ALSO CHECKED AND INCLUDED IN
                        ;THE OUTPUT. WHEN THE TASK IS COMPLETE THE EXPERIMENTER
                        ;IS REQUIRED TO WRITE THE DATA TO A CASSETTE TAPE.
                        ;
                        ;
                        ;*****************************************************************
                        ;
                        ;
                        ;
                        ;
                        ;
3000                            ORG     3000H
                        ;
                        ;
0307 =                  CO      EQU     0307H   ;CONSOLE OUTPUT ROUTINE CHAR IN C REG
02F4 =                  CI      EQU     02F4H   ;CONSOLE INPUT ROUTINE CHAR IN A REG
0312 =                  CONST   EQU     0312H   ;GET CONSOLE STATUS, A=0 IF NO CHARACTER.
0312 =                  CRLF    EQU     0312H   ;CARRIAGE RETURN TO CONSOLE
0081 =                  MODE1   EQU     81H     ;MODE WORD FOR SLIDE PROJECTOR I/O PORT
00E7 =                  CNTL1   EQU     0E7H    ;SLIDE PROJ #1 CONTROL WORD PORT
00EB =                  CNTL2   EQU     0EBH    ;SLIDE PROJ #2 CONTROL WORD PORT
0080 =                  MODE2   EQU     080H    ;I/O PORT1 MODE WORD, OUTPUT PORT
00F7 =                  CNTL3   EQU     0F7H    ;I/O PORT1 CONTROL WORD PORT
009B =                  MODE3   EQU     09BH    ;I/O PORT1 MODE WORD, INPUT PORT
00FB =                  CNTL4   EQU     0FBH    ;I/O PORT1 CONTROL WORD, INPUT PORT
00F4 =                  SHUTER  EQU     0F4H    ;OUTPUT PORT FOR SHUTTER
00F8 =                  KEYS    EQU     0F8H    ;INPUT PORT FOR RESPONSE KEYS
0001 =                  POSLTR  EQU     01H     ;FLAG FOR POSITIVE LETTER
0000 =                  NEGLTR  EQU     00H     ;FLAG FOR NEGATIVE LETTER
00FF =                  OFF     EQU     0FFH    ;BYTE TURNS SHUTTER OFF
000D =                  CR      EQU     0DH     ;CARRAGE RETURN
000A =                  LF      EQU     0AH     ;LINE FEED
0189 =                  WDATA   EQU     0189H   ;WRITE CASSETTE - H&L=START ADD, D&E=END ADD
02C6 =                  BREAK   EQU     02C6H   ;FOR BREAK USE THE ESC KEY.
                        ;
                        ;
                        STARTER:
3000 31B53E                     LXI     SP,STACK        ;INIT STACK POINTER
3003 3E81                       MVI     A,MODE1
3005 D3E7                       OUT     CNTL1   ;SLIDE PROJ 1
3007 D3EB                       OUT     CNTL2   ;SLIDE PROJ 2
3009 3E80                       MVI     A,MODE2 ;I/O PORTS MODE WORD
300B D3F7                       OUT     CNTL3   ;
300D 3E9B                       MVI     A,MODE3 ;INPUT PORT MODE WORD
300F D3FB                       OUT     CNTL4   ;CONTROL WORD PORT
```

```
 3011 3EFF              MVI     A,OFF    ;
 3013 D3F4              OUT     SHUTER   ;TURN SHUTTER OFF, TAPE CONTROL LOW
 3015 CD1203            CALL    CRLF     ;START WITH CARRIAGE RETURN
 3018 217C32            LXI     H,MSG0   ;POINT TO MESSAGE
 301B CD7431            CALL    PMSG
                  ;
                  ER:
 301E AF                XRA     A        ;ZERO ACC
 301F 32B035            STA     LINE     ;UPDATE LINE POINTER
 3022 21FC32            LXI     H,MSG1   ;POINT TO MEGGAGE 1
 3025 CD6131            CALL    GETCHR   ;PRINT MESSAGE, GET RESPONSE
 3028 FE37              CPI     '7'      ;IS RESP > 6
 302A D21E30            JNC     ER       ;YES GET ANOTHER
 302D FE30              CPI     '0'      ;IS RESP < 1
 302F CA1E30            JZ      ER       ;YES, GET ANOTHER
 3032 FE31              CPI     '1'      ;IS RESP 1?
 3034 CA6930            JZ      DBLK1    ;YES, SKIP
 3037 FE32              CPI     '2'      ;IS RESP 2?
 3039 CA6330            JZ      DBLK2    ;YES, SKIP
 303C FE33              CPI     '3'      ;IS RESP 3?
 303E CA5D30            JZ      DBLK3    ;YES, SKIP
 3041 FE34              CPI     '4'      ;IS RESP 4?
 3043 CA5730            JZ      DBLK4    ;YES, SKIP
 3046 FE35              CPI     '5'      ;IS RESP 5?
 3048 CA5130            JZ      DBLK5    ;YES, SKIP
                  DBLK6:
 304B 21663E            LXI     H,BLOCK6          ;POINT TO BLOCK SIX
 304E C36C30            JMP     START    ;SKIP
                  DBLK5:
 3051 21293E            LXI     H,BLOCK5          ;POINT TO BLOCK FIVE
 3054 C36C30            JMP     START    ;SKIP
                  DBLK4:
 3057 210C3C            LXI     H,BLOCK4          ;POINT TO BLOCK FOUR
 305A C36C30            JMP     START    ;SKIP
                  DBLK3:
 305D 21EF39            LXI     H,BLOCK3          ;POINT TO BLOCK THREE
 3060 C36C30            JMP     START    ;SKIP
                  DBLK2:
 3063 21D237            LXI     H,BLOCK2          ;POINT TO BLOCK TWO
 3066 C36C30            JMP     START    ;SKIP
                  DBLK1:
 3069 21B535            LXI     H,BLOCK1          ;POINT TO BLOCK 1
                  START:
 306C 22B335            SHLD    DPTR     ;SAVE DATA POINTER
                  ER1:
 306F 21EC33            LXI     H,MSG2   ;POINT TO MESSAGE 2
 3072 CD6131            CALL    GETCHR   ;PRINT MESSAGE, GET RESPONSE
 3075 FE0D              CPI     CR       ;CHECK FOR CARRAGE RETURN
 3077 C26F30            JNZ     ER1      ;WRONG, TRY AGAIN
 307A 2100D0            LXI     H,DBUFF  ;POINT TO DATA BUFFER
 307D 22B135            SHLD    DBFPTR   ;SAVE POINTER
 3080 CDF630            CALL    RSCLOCK  ;RESET CLOCK TO ZERO
                  ;
                  ;SUBROUTINE TASK IS THE MAIN PROGRAM LOOP.
                  ;ALL ROTINES ARE CALLED AND RETURNED TO THIS
                  ;LEVEL.
                  ;
                  TASK:
```

```
 3083 2AB335          LHLD    DPTR     ;POINT TO SEQUENCE
 3086 7E              MOV     A,M      ;GET SLIDE POSITION
 3087 FEFF            CPI     0FFH     ;END OF DATA?
 3089 CA0931          JZ      FINUP    ;YES, EXIT TASK
 308C E5              PUSH    H        ;SAVE DATA POINTER
 308D CD8031          CALL    SLIDE1   ;SET PROJECTOR TO SLIDE
 3090 E1              POP     H        ;RESTORE DATA POINTER
 3091 23              INX     H        ;NEXT SLIDE POSITION
 3092 7E              MOV     A,M      ;GET IT
 3093 E5              PUSH    H        ;SAVE DATA POINTER
 3094 CDA331          CALL    SLIDE2   ;NEXT PROJECTOR
 3097 E1              POP     H        ;RESTORE DATA POINTER
 3098 23              INX     H        ;RESPONSE TYPE
 3099 46              MOV     B,M      ;GET RESPONSE TYPE
 309A 23              INX     H        ;NEXT SLIDE POSITION
 309B 22B335          SHLD    DPTR     ;SAVE DATA POINTER
 309E CDC430          CALL    PRESENT  ;PRESENT STIMULUS, GET RESPONSE
 30A1 C5              PUSH    B        ;SAVE RESPONSE TYPE
 30A2 CD2631          CALL    PRDATA   ;PRINT RESPONSE AT CO
 30A5 C1              POP     B        ;RESTORE RESPONSE TYPE
 30A6 2AA635          LHLD    CLOCK    ;GET RESPONSE TIME
 30A9 7C              MOV     A,H      ;MOST SIG BYTE
 30AA B0              ORA     B        ;ADD IN RESPONSE TYPE
 30AB 67              MOV     H,A      ;RESTORE BOST SIG BYTE
 30AC CDFD30          CALL    STDATA   ;SAVE RESPONSE DATA
 30AF CDF630          CALL    RSCLOCK  ;RESET TIME TO ZERO
 30B2 CDC602          CALL    BREAK    ;CHECK FOR BREAK
 30B5 D28330          JNC     TASK     ;
 30B8 214935          LXI     H,MSG8   ;PRINT BREAK MESSAGE
 30BB CD6131          CALL    GETCHR   ;PRINT MESSAGE, GET RESPONSE
 30BE CD1203          CALL    CRLF     ;SEND CRLF TO CONSOLE.
 30C1 C38330          JMP     TASK     ;PRESENT NEXT SLIDE
                 ;
                 ;
                 ;SUBROUTINE PRESENT, PRESENTS SLIDES TO THE
                 ;SUBJECT AND COLLECTS THE RESPONSE TIME DATA. THIS
                 ;ROUTINE CHECKS FOR RESPONSE ERRORS AND RETURNS WITH
                 ;A=0 FOR CORRECT, A>0 FOR INCORRECT RESPONSE.
                 ;
                 PRESENT:
 30C4 AF              XRA     A        ;ZERO ACC
 30C5 D3F4            OUT     SHUTER   ;TURN SHUTTERS ON
                 RESLOOP:
 30C7 CDD331          CALL    T1MS     ;WAIT 1 MSECOND
 30CA 2AA635          LHLD    CLOCK    ;GET TIM
 30CD 23              INX     H        ;ADD 1 MSEC
 30CE 22A635          SHLD    CLOCK    ;SAVE TIME
 30D1 7C              MOV     A,H      ;CHECK FOR 5 SECONDS
 30D2 FE0C            CPI     0CH      ;ACTUALLY 3072 MSECONDS
 30D4 CAEC30          JZ      TIMOUT   ;NO RESP, TIME >5 SECONDS
 30D7 DBF8            IN      KEYS     ;CHECK  RESPONSE
                 ;    CMA              ;MAYBE ACTIVE LOW?
 30D9 00              NOP
 30DA E607            ANI     07H      ;APPLY MASK
 30DC CAC730          JZ      RESLOOP  ;INPUT ZERO, NO RESPONSE
 30DF F5              PUSH    PSW      ;SAVE RESPONSE
 30E0 3EFF            MVI     A,0FF    ;BYTE TURNS SHUTTERS OFF
 30E2 D3F4            OUT     SHUTER   ;DO IT
```

```
30E4 F1                 POP     PSW     ;RESTORE RESPONSE BYTE
30E5 0707070707         RLC!RLC!RLC!RLC!RLC     ;SHIFT TO MOST SIG 3 BITS
30EA 47                 MOV     B,A     ;RESPONSE GOES IN B
30EB C9                 RET
                TIMOUT:
30EC CDF630             CALL    RSCLOCK ;NO RESP, ZERO CLOCK
30EF 3EFF               MVI     A,0FF   ;SHUTTER S OFF
30F1 D3F4               OUT     SHUTER  ;TURN EM OFF
30F3 0600               MVI     B,0     ;ZERO IN B MEANS TIMEOUT
30F5 C9                 RET
                ;
                ;
                ;SUBROUTINE RSCLOCK, RESETS CLOCK TO ZERO
                ;
                ;
                RSCLOCK:
30F6 210000             LXI     H,0000  ;LOAD ZERO
30F9 22A635             SHLD    CLOCK   ;SAVE IT IN CLOCK
30FC C9                 RET
                ;
                ;
                ;SUBROUTINE STDATA, SAVES RESPONSE TIME IN MEMORY
                ;ALSO FORMATS PRINT OUT AT CONSOLE
                ;
                ;
                STDATA:
30FD EB                 XCHG            ;PUT DATA IN D&E
30FE 2AB135             LHLD    DBFPTR  ;GET DATA POINTER
3101 73                 MOV     M,E     ;SAVE LOW BYTE
3102 23                 INX     H       ;NEXT LOCATION
3103 72                 MOV     M,D     ;SAVE HIGH BYTE
3104 23                 INX     H       ;NEXT LOCATION
3105 22B135             SHLD    DBFPTR  ;SAVE POINTER
                        ;INSERT PRINTOUT ROUTINE HERE
3108 C9                 RET
                ;
                ;
                ;SUBROUTINE FINUP, IS CALLED TO PRINT OUT INSTRUCTIONS
                ;SOTHE EXPERIMENTER CAN WRITE THE DATA TO A CASSETTE
                ;TAPE.
                ;
                ;
                FINUP:
3109 210E34             LXI     H,MSG3  ;POINT TO MESSAGE
310C CD6131             CALL    GETCHR  ;PRINT MESSAGE, GET RESPONSE
310F FE0D               CPI     CR      ;IS RESP A CR
3111 C20931             JNZ     FINUP   ;NO TRY AGAIN
3114 2AB135             LHLD    DBFPTR  ;GET END OF DATA
3117 2B                 DCX     H       ;SUBTRACT LAST TWO
3118 2B                 DCX     H       ;BYTES, POINT TO END OF DATA
3119 EB                 XCHG            ;IN D&E
311A 2100D0             LXI     H,DBUFF ;POINT TO START OF DATA
311D CD8901             CALL    WDATA   ;WRITE DATA BUFFER TO CASSETTE TAPE.
3120 CDF402             CALL    CI      ;GET A RESPONSE FORM THE CO
3123 C31E30             JMP     ER      ;RESTART TASK
                ;
                ;
                ;SUBROUTINE PRDATA, PRINTS THE REACTION TIME AND RESPONSE
```

```
                 ;TYPE AT THE CONSOLE.
                 ;
                 ;
                 PRDATA:
3126 CDDC31              CALL    BINDEC  ;CONVERT RT TO ASCII
3129 CD6D32              CALL    PRINT   ;PRINT IT AT CONSOLE
312C E1                  POP     H       ;SAVE RETURN ADDRESS
312D C1                  POP     B       ;GET RESPONSE TYPE
312E C5                  PUSH    B       ;SAVE IT
312F E5                  PUSH    H       ;RESTORE RETURN ADDRESS
3130 78                  MOV     A,B     ;IN A FOR CHECK
3131 FE20                CPI     20H     ;CHECK FOR GREATER
3133 211535              LXI     H,MSG4  ;LOAD MESSAGE
3136 CA4C31              JZ      TYPE    ;SKIP AND PRINT
3139 FE40                CPI     40H     ;CHECK FOR SAME
313B 212235              LXI     H,MSG5  ;LOAD MESSAGE
313E CA4C31              JZ      TYPE    ;SKIP AND PRINT
3141 FE80                CPI     80H     ;CHECK FOR LESS
3143 212F35              LXI     H,MSG6  ;LOAD MESSAGE
3146 CA4C31              JZ      TYPE    ;SKIP AND PRINT
3149 213C35              LXI     H,MSG7  ;LOAD TIMOUT MESSAGE, DEFAULT
                 TYPE:
314C CD7431              CALL    PMSG    ;PRINT MESSAGE
314F 3AB035              LDA     LINE    ;GET LINE POSITION
3152 3C                  INR     A       ;ADD NEXT POSITION
3153 32B035              STA     LINE    ;SAVE IT
3156 FE04                CPI     04H     ;IS IT >4
3158 C0                  RNZ             ;NO RET
3159 AF                  XRA     A       ;
315A 32B035              STA     LINE    ;SAVE NEW LINE POINTER.
315D CD1203              CALL    CRLF    ;SEND CARRAGR RETURN
3160 C9                  RET
                 ;
                 ;
                 ;SUBROUTINE GETCHR, PRINTS MESSAGE POINTED TO BY
                 ;H&L AND GET A RESPONSE AT THE CONSOLE.
                 ;
                 ;
                 GETCHR:
3161 CD7431              CALL    PMSG    ;PRINT MESSAGE
3164 CDF402              CALL    CI      ;GET A RESP CHARACTER
3167 E67F                ANI     7FH     ;MASK PARITY
3169 4F                  MOV     C,A     ;READY FOR OUTPUT
316A C5                  PUSH    B       ;SAVE CHAR
316B CD0703              CALL    CO      ;PRINT RESP AT CONSOLE
316E CD1203              CALL    CRLF    ;CARRAGE RETURN TO CONSOLE
3171 C1                  POP     B       ;RESTORE CHAR
3172 79                  MOV     A,C     ;PUT CHAR IN A REG
3173 C9                  RET
                 ;
                 ;       SUBROUTINE PRINT MESSAGE, PRINTS THE
                 ;       MESSAGE POINTED TO BY H&L AT THE CONSOLE.
                 ;
                 PMSG:
3174 7E                  MOV     A,M
3175 FE24                CPI     '$'
3177 C8                  RZ
3178 4F                  MOV     C,A
```

```
 3179 CD0703            CALL    CO
 317C 23                INX     H
 317D C37431            JMP     PMSG
                  ;
                  SLIDE1:
 3180 E67F              ANI     7FH      ;MASK SEARCH BIT
 3182 D3E4              OUT     0E4H     ;LOAD SLIDE LOCATION
 3184 F5                PUSH    PSW      ;SAVE LETTER
 3185 21F401            LXI     H,1F4H   ;DELAY COUNT
                  DL1:
 3188 CDD331            CALL    T1MS     ;WAIT ONE MSEC
 318B 2B                DCX     H        ;DECREMENT COUNT
 318C 7C                MOV     A,H      ;
 318D FEFF              CPI     0FFH     ;
 318F C28831            JNZ     DL1      ;WAIT SOME MORE
 3192 F1                POP     PSW      ;RESTORE LETTER
 3193 F680              ORI     80H      ;SET SEARCH BIT
 3195 D3E4              OUT     0E4H     ;SLIDE PROJSECOR IN SEARCH MODE
 3197 E67F              ANI     7FH      ;MASK SEARCH BIT
 3199 D3E4              OUT     0E4H     ;TURN SEARCH OFF
                  WAIT1:
 319B DBE6              IN      0E6H     ;GET PROJ STATUS
 319D E601              ANI     01H      ;CHECK FOR FINISH
 319F C29B31            JNZ     WAIT1    ;WAIT SOME MORE
 31A2 C9                RET
                  ;
                  ;
                  SLIDE2:
 31A3 E67F              ANI     7FH      ;MASK SEARCH BIT
 31A5 D3E8              OUT     0E8H     ;LOAD SLIDE LOCATION
 31A7 F5                PUSH    PSW      ;SAVE LETTER
 31A8 21F401            LXI     H,1F4H   ;DELAY COUNT
                  DL2:
 31AB CDD331            CALL    T1MS     ;WAIT ONE MSEC
 31AE 2B                DCX     H        ;DECREMENT COUNT
 31AF 7C                MOV     A,H      ;
 31B0 FEFF              CPI     0FFH     ;
 31B2 C2AB31            JNZ     DL2      ;WAIT SOME MORE
 31B5 F1                POP     PSW      ;RESTORE LETTER
 31B6 F680              ORI     80H      ;SET SEARCH BIT
 31B8 D3E8              OUT     0E8H     ;SLIDE PROJSECOR IN SEARCH MODE
 31BA E67F              ANI     7FH      ;MASK SEARCH BIT
 31BC D3E8              OUT     0E8H     ;TURN SEARCH OFF
                  WAIT2:
 31BE DBE9              IN      0E9H     ;GET PROJ STATUS
 31C0 E601              ANI     01H      ;CHECK FOR FINISH
 31C2 C2BE31            JNZ     WAIT2    ;WAIT SOME MORE
 31C5 210014            LXI     H,1400H  ;5120 MSECOND TIME CONSTANT
                  WAT2:
 31C8 CDD331            CALL    T1MS     ;ONS MSEC TIME DELAY
 31CB 2B                DCX     H        ;DECREMENT TIME COUNT
 31CC 7C                MOV     A,H      ;
 31CD FEFF              CPI     0FFH     ;IS IT DONE
 31CF C2C831            JNZ     WAT2     ;NO
 31D2 C9                RET
                  ;
                  ;
                  ;**************************************************
```

```
                    ;
                    ;       ONE MILLISECOND TIME DELAY
                    ;
                    ;
                    ;**************************************************
                    ;
                    T1MS:
 31D3 C5                    PUSH    B       ;SAVE B REG
 31D4 068B                  MVI     B,8BH   ;LOAD B WITH 1MSEC TIME CONSTANT, ADJUST IF NEEDED
                    T1MS1:
 31D6 05                    DCR     B       ;DECREMENT COUNT
 31D7 C2D631                JNZ     T1MS1   ;NOT DONE
 31DA C1                    POP     B       ;RESTORE B REG
 31DB C9                    RET
                    ;
                    ;
                    ;*************************************************************
                    ;
                    ;       SUBROUTINE BINDEC CONVERTS A 16 BIT BINARY
                    ;       NUMBER TO DECIMAL. THE NUMBER IS STORED
                    ;       UPON ENTRY IN CLOCK. RESULTS ARE STORED IN
                    ;       AREA.
                    ;
                    ;*************************************************************
                    ;
                    ;
                    BINDEC:
 31DC 2AA635                LHLD    CLOCK   ;LOAD RT IN H AND L
                    BNDEC1:
 31DF 11A035                LXI     D,AREA  ;6 BYTE RESULT ADDRESS
 31E2 CDE631                CALL    DCNV    ;CALL DOUBLE BYTE CONVERT
 31E5 C9                    RET
                    ;
                    DCNV:
 31E6 0620                  MVI     B,' '   ;ASCII PLUS SIGN
 31E8 7C                    MOV     A,H     ;HALF OF BINARY TO A
 31E9 B7                    ORA     A       ;SET FLAGS
 31EA F2FA31                JP      H3      ;SKIP IF POSITIVE
 31ED 0620                  MVI     B,' '   ;ASCII MINUS TO B
 31EF 7D                    MOV     A,L     ;FETCH LOW HALF
 31F0 2F                    CMA             ;FORM ONES COMPLEMENT
 31F1 3C                    INR     A       ;AND THEN INCREMENT
 31F2 6F                    MOV     L,A     ;RETURN RESULT TO L
 31F3 7C                    MOV     A,H     ;FETCH HIGH HALF
 31F4 2F                    CMA             ;ONES COMPLEMENT, HIGH ORDER
 31F5 C2F931                JNZ     H2      ;NO CARRY IF LOW ORDER NONZERO
 31F8 3C                    INR     A       ;PROPAGATE CARRY
                    H2:
 31F9 67                    MOV     H,A     ;RETURN RESULT TO A
                    H3:
 31FA 22A835                SHLD    DATA    ;SAVE NUMBER TO BE CONVERTED
 31FD 3E20                  MVI     A,' '   ;BLANK TO A
 31FF 12                    STAX    D       ;SAVE IN AREA
 3200 78                    MOV     A,B     ;FETCH ASCII SIGN
 3201 32AA35                STA     SIGN    ;SAVE IT
 3204 EB                    XCHG    ;SWAP REG TO GET RESULT ADDRESS IN H AND L
 3205 22AC35                SHLD    ADR     ;SAVE RESULT ADDRESS
 3208 AF                    XRA     A       ;ZERO A
```

```
 3209 32AE35          STA     FLAG      ;ZERO SIGNIFICANCE FLAG
 320C 01F0D8          LXI     B,-10000D        ;HIGEST POWER OF TEN(-) TO B AND C
 320F CD3A32          CALL    DFL8      ;EXTRACT NUMBER OF 10,000'S
 3212 CD4A32          CALL    STC0      ;SAVE GENERATED CHARACTER
 3215 0118FC          LXI     B,-1000D         ;-1000 TO B AND C
 3218 CD3A32          CALL    DFL8      ;EXTRACT 1000'S CHARACTER
 321B CD4A32          CALL    STC0      ;SAVE IT
 321E 019CFF          LXI     B,-100D ;-100 TO B AND C
 3221 CD3A32          CALL    DFL8      ;EXTRACT 100'S CHARACTER
 3224 CD4A32          CALL    STC0      ;SAVE IT
 3227 01F6FF          LXI     B,-10D  ;-10 TO B AND C
 322A CD3A32          CALL    DFL8      ;EXTRACT 10'S
 322D CD4A32          CALL    STC0      ;SAVE TENS CHARACTER
 3230 3AA835          LDA     DATA      ;GET DATA
 3233 F630            ORI     '0'       ;MERG WITH ASCII ZERO
 3235 5F              MOV     E,A       ;MOV TO DFL8 RESULT REG
 3236 CD4A32          CALL    STC0      ;STORE UNITS DIGIT
 3239 C9              RET
                ;
                ;
                ;     SUBROUTINE DFL8 ADDS THE NUMBER IN B AND C TO THE NUMBER IN DATA
                ;     AND DATA + 1 UNTIL THE RESULT IS NEGATIVE. ALSO IT KEEPS TRACK
                ;     OF THE NUMBER OF SUCCESSFUL SUBTRACTIONS IN THE E REGISTER
                ;
                ;
                DFL8:
 323A 2AA835          LHLD    DATA      ;FETCH NUMBER TO H AND L
 323D 1E00            MVI     E,0       ;CLEAR E REG
                DF1:
 323F 09              DAD     B         ;SUBTRACT POWER OF TEN IN B AND C
 3240 7C              MOV     A,H       ;MOVE HIGH DIFFERENCE
 3241 B7              ORA     A         ;SET FLAGS
 3242 F8              RM                ;FINISHED IF MINUS
 3243 1C              INR     E         ;INCREMENT SUB COUNT
 3244 22A835          SHLD    DATA      ;SAVE UPDATED NUMBER
 3247 C33F32          JMP     DF1       ;DO IT AGAIN
                STC0:
 324A 2AAC35          LHLD    ADR       ;FETCH RESULT STRING ADDRESS
 324D 3AAE35          LDA     FLAG      ;FETCH SIGNIFICANCE FLAG
 3250 B7              ORA     A         ;SET FLAGS
 3251 C26432          JNZ     STC3      ;SKIP IF ALREADY NONZERO
                STC1:
 3254 83              ADD     E         ;ADD NEW DIGIT TO FLAG
 3255 32AE35          STA     FLAG      ;SAVE
 3258 C26032          JNZ     STC2      ;SKIP IF DIGIT IS NONZERO
 325B 3E20            MVI     A,' '     ;OTHERWISE SUBSTITUTE A BLANK
 325D C36732          JMP     STC4      ;AND SKIP TO STORE SEQUENCE
                STC2:
 3260 3AAA35          LDA     SIGN      ;FETCH SIGN
 3263 77              MOV     M,A       ;PLACE SIGN IN STRING
                STC3:
 3264 3E30            MVI     A,'0'     ;ASCII ZERO FRAME TO A
 3266 B3              ORA     E         ;MERG WITH BCD DIGIT
                STC4:
 3267 23              INX     H         ;INCREMENT POINTER
 3268 77              MOV     M,A       ;PLACE DIGIT IN STRING
 3269 22AC35          SHLD    ADR       ;RESTORE STRING ADDRESS
 326C C9              RET
```

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                  ;
                  ;         SUBROUTINE PRINT PRINTS CONTENTS OF AREA
                  ;         IN ASCII ON SYSTEM CONSOLE
                  ;
                  ;
                  PRINT:
 326D 21A035               LXI     H,AREA   ;POINT TO DECIMAL BUFFER
 3270 1E06                 MVI     E,6      ;SET DIGIT COUNTER
                  PRINT1:
 3272 4E                   MOV     C,M      ;GET DIGIT
 3273 CD0703               CALL    CO       ;PRINT IT
 3276 23                   INX     H        ;NEXT DIGIT
 3277 1D                   DCR     E        ;DECREMENT COUNTER
 3278 C27232               JNZ     PRINT1   ;GET ANOTHER DIGIT
 327B C9                   RET
                  ;
                  ;
 327C 2A2A2A2A2AMSG0:      DB      '******** S T A T I C  R A N G E  S T U D Y ********',CR,LF
 32B1 0D0A535953           DB      CR,LF,'SYSTEMS RESEARCH LABS INC.',CR,LF
 32CF 3238303020           DB      '2800 INDIAN RIPPLE RD.',CR,LF
 32E7 444159544F           DB      'DAYTON, OHIO 45440',CR,LF,'$'
 32FC 0D0A4F4B20MSG1:      DB      CR,LF,'OK DEFRANCES, THIS IS YOUR SHOW.',CR,LF
 3320 0D0A53454C           DB      CR,LF,'SELECT ONE OF THE FOLLOWING DATA BLOCKS.',CR,LF
 334C 0D0A202020           DB      CR,LF,'          1.     BLOCK 1'
 3363 0D0A202020           DB      CR,LF,'          2.     BLOCK 2'
 337A 0D0A202020           DB      CR,LF,'          3.     BLOCK 3'
 3391 0D0A202020           DB      CR,LF,'          4.     BLOCK 4'
 33A8 0D0A202020           DB      CR,LF,'          5.     BLOCK 5'
 33BF 0D0A202020           DB      CR,LF,'          6.     BLOCK 6'
 33D6 0D0A454E54           DB      CR,LF,'ENTER YOUR CHOICE: $'
 33EC 0D0A544F20MSG2:      DB      CR,LF,'TO START TASK, TYPE RETURN      $'
 340E 0D0A544F20MSG3:      DB      CR,LF,'TO SAVE DATA:'
 341D 0D0A202031           DB      CR,LF,'  1. INSEART CASSETTE TAPE.'
 343A 0D0A202032           DB      CR,LF,'  2. PRESS REWIND, THEN LOAD'
 3458 0D0A202033           DB      CR,LF,'  3. PRESS RECORD SW, (TOP ROW) WHEN READY LITE COMES ON.'
 3493 0D0A202034           DB      CR,LF,'  4. PRESS RECORD CONTROL SW, (MIDDLE ROW) TO "ON".'
 34C8 0D0A202035           DB      CR,LF,'  5. TYPE RETURN'
 34DA 0D0A202036           DB      CR,LF,'  6. WHEN FINISHED TURN RECORD SW TO OFF AND TYPE G3000.$'
 3515 2020204C45MSG4:      DB      '   LEFT      $'
 3522 2020205341MSG5:      DB      '   SAME      $'
 352F 2020205249MSG6:      DB      '   RIGHT     $'
 353C 2020205449MSG7:      DB      '   TIMEOUT   $'
 3549 0D0A2A2A2AMSG8:      DB      CR,LF,'********************** B R E A K **********************' -
 3580 0D0A0D0A54           DB      CR,LF,CR,LF,'TO CONTINUE TYPE ANY KEY.  $'
                  ;
 35A0             AREA:    DS      6
 35A6             CLOCK:   DS      2
 35A8             DATA:    DS      2
 35AA             SIGN:    DS      2
 35AC             ADR:     DS      2
 35AE             FLAG:    DS      2
 35B0             LINE:    DS      1
 35B1             DBFPTR:  DS      2
 35B3             DPTR:    DS      2
                  ;*****************  D A T A  B L O C K S  *************************
                  ;
 35B5 150F040F13BLOCK1: DB         21,15,4,15,19,4,64,64,0,22,24,4,64,65,4,55,64,1
 35C7 0F14043C39           DB      15,20,4,60,57,4,52,50,4,61,57,4,36,42,4,59,57,1
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 35D9 1617041 61B      DB    22,23,4,22,27,4,55,50,4,62,57,4,1,4,0,36,43,1
 35EB 1D1D003240       DB    29,29,0,50,64,4,32,29,4,19,15,4,44,43,4,20,15,1
 35FD 1B1604402B       DB    27,22,4,64,43,4,48,43,4,29,22,4,57,62,4,2,1,1
 360F 1D0F042B2C       DB    29,15,4,43,44,4,39,36,4,6,1,4,64,70,4,1,7,1
 3621 2B2B00080A       DB    43,43,0,8,10,4,57,63,4,29,35,4,43,49,4,49,43,1
 3633 160104160F       DB    22,1,4,22,15,4,29,31,4,58,57,4,51,50,4,70,64,1
 3645 393A040106       DB    57,58,4,1,6,4,41,36,4,8,13,4,8,9,4,64,50,1
 3657 161600211D       DB    22,22,0,33,29,4,43,46,4,64,64,0,10,8,4,1,3,1
 3669 2424003940       DB    36,36,0,57,64,4,15,17,4,43,45,4,15,8,4,57,60,0
 367B 393D042429       DB    57,61,4,36,41,4,15,22,4,1,5,4,36,37,4,15,18,0
 368D 4440043932       DB    68,64,4,57,50,4,50,55,4,43,50,4,8,15,4,50,57,1
 369F 0101002427       DB    1,1,0,36,39,0,15,1,4,14,8,4,64,68,4,1,15,1
 36B1 2432043235       DB    36,50,4,50,53,0,13,8,4,38,36,4,53,50,4,63,57,1
 36C3 393900393C       DB    57,57,0,57,60,4,15,18,4,15,21,4,3,1,4,36,57,1
 36D5 0701042B40       DB    7,1,4,43,64,4,37,36,4,35,29,4,46,43,4,43,46,0
 36E7 100F042427       DB    16,15,4,36,39,4,28,22,4,36,40,4,56,50,4,36,38,1
 36F9 1716041D20       DB    23,22,4,29,32,4,50,53,0,22,25,4,50,51,4,57,59,1
 370B 1816042B24       DB    24,22,4,43,36,4,45,43,4,66,64,4,22,28,4,8,11,1
 371D 1D22041D20       DB    29,34,4,29,32,0,1,29,4,31,29,4,8,11,0,15,16,1
 372F 4042044024       DB    64,66,4,64,36,4,57,36,4,8,22,4,43,47,4,29,33,1
 3741 3235041A16       DB    50,53,4,26,22,4,50,56,4,8,14,4,34,29,4,8,12,1
 3753 4043042A24       DB    64,67,4,42,36,4,22,29,4,1,1,4,69,64,4,15,29,1
 3765 0102044039       DB    1,2,4,64,57,4,64,69,4,29,1,4,30,29,4,40,36,1
 3777 0116042B30       DB    1,22,4,43,48,4,9,8,4,50,43,4,15,18,0,54,50,1
 3789 0C08044340       DB    12,8,4,67,64,4,8,11,0,29,8,4,57,43,4,47,43,1
 379B 081D04161A       DB    8,29,4,22,26,4,25,22,4,22,25,0,1,4,1,50,54,1
 37AD 1D1E042440       DB    29,30,4,36,64,4,8,1,4,17,15,4,43,57,4,22,8,1
 37BF 3224040501       DB    50,36,4,5,1,4,18,15,4,50,52,4,1,8,4,11,8,1
 37D1 FF               DB    0FFH
 37D2 1D1D000108BLOCK2: DB   29,29,0,1,8,4,22,25,0,36,39,4,8,11,0,7,1,1
 37E4 393C04161D       DB    57,60,4,22,29,4,36,50,4,46,43,4,8,14,4,64,70,1
 37F6 080C04312B       DB    8,12,4,49,43,4,64,69,4,15,29,4,66,64,4,22,26,1
 3808 2425040301       DB    36,37,4,3,1,4,34,29,4,26,22,4,28,22,4,22,25,1
 381A 0101004440       DB    1,1,0,68,64,4,1,15,4,36,42,4,2,1,4,19,15,4,10,8,1
 382F 0F0F003235       DB    15,15,0,50,53,0,15,20,4,58,57,4,1,4,0,45,43,1
 3841 3232003238       DB    50,50,0,50,56,4,70,64,4,43,45,4,1,3,4,63,57,1
 3853 0F10040809       DB    15,16,4,8,9,4,43,46,0,23,22,4,8,29,4,50,57,1
 3865 081604302B       DB    8,22,4,48,43,4,43,36,4,39,36,4,29,1,4,1,1,1
 3877 3235044039       DB    50,53,4,64,57,4,36,57,4,64,68,4,24,22,4,56,50,1
 3889 0B0804080A       DB    11,8,4,8,10,4,36,41,4,15,21,4,50,55,4,37,36,1
 389B 4032042428       DB    64,50,4,36,40,4,32,29,4,1,22,4,50,54,4,15,18,0
 38AD 161B040908       DB    22,27,4,9,8,4,36,39,0,64,43,4,52,50,4,8,11,1
 38BF 1D1D000102       DB    29,29,0,1,2,4,1,29,4,29,32,4,57,62,4,43,48,1
 38D1 150F041D0F       DB    21,15,4,29,15,4,43,64,4,16,15,4,22,15,4,1,6,1
 38E3 2B2E042B2F       DB    43,46,4,43,47,4,42,36,4,53,50,4,15,17,4,51,50,1
 38F5 3939003940       DB    57,57,0,57,64,4,15,22,4,69,64,4,15,8,4,50,36,1
 3907 282404080D       DB    40,36,4,8,13,4,50,51,4,57,43,4,31,29,4,22,24,1
 3919 1D22044040       DB    29,34,4,64,64,0,22,28,4,36,43,4,29,35,4,64,36,1
 392B 2C2B041617       DB    44,43,4,22,23,4,43,46,0,29,22,4,50,52,4,54,50,1
 393D 010704393A       DB    1,7,4,57,58,4,15,19,4,50,43,4,14,8,4,33,29,1
 394F 080F042B31       DB    8,15,4,43,49,4,5,1,4,43,57,4,64,66,4,22,1,1
 3961 1D21040F12       DB    29,33,4,15,18,4,29,30,4,61,57,4,13,8,4,36,38,1
 3973 2B3204140F       DB    43,50,4,20,15,4,64,67,4,62,57,4,30,29,4,57,60,0
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 39A9 393F040105       DB    57,63,4,1,5,4,57,59,4,67,64,4,8,1,4,36,39,0
 39BB 3C3904080B       DB    60,57,4,8,11,0,36,64,4,64,65,4,17,15,4,18,15,1
 39CD 3240042924       DB    50,64,4,41,36,4,64,64,0,65,64,4,15,1,4,12,8,1
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 39EE FF                  DB    0FFH
 39EF 0B08040108BLOCK3:   DB    11,8,4,1,8,4,50,52,4,18,15,4,5,1,4,50,36,1
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 3A13 3236040104          DB    50,54,4,1,4,1,22,25,0,25,22,4,22,26,4,8,29,1
 3A25 2F2B04392B          DB    47,43,4,57,43,4,29,8,4,8,11,0,67,64,4,12,8,1
 3A37 3632040F12          DB    54,50,4,15,18,0,50,43,4,9,8,4,43,48,4,1,22,1
 3A49 2824041E1D          DB    40,36,4,30,29,4,29,1,4,64,69,4,64,57,4,1,2,1
 3A5B 0F1D044540          DB    15,29,4,69,64,4,1,1,4,22,29,4,42,36,4,64,67,1
 3A6D 080C04221D          DB    8,12,4,34,29,4,8,14,4,50,56,4,26,22,4,50,53,1
 3A7F 1D21042B2F          DB    29,33,4,43,47,4,8,22,4,57,36,4,64,36,4,64,66,1
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 3AB5 393B043233          DB    57,59,4,50,51,4,22,25,4,50,53,0,29,32,4,23,22,1
 3AC7 2426043832          DB    36,38,4,56,50,4,36,40,4,28,22,4,36,39,4,16,15,1
 3AD9 2B2B002E2B          DB    43,43,0,46,43,4,35,29,4,37,36,4,43,64,4,7,1,1
 3AEB 2439040301          DB    36,57,4,3,1,4,15,21,4,15,18,4,57,60,4,57,60,0
 3AFD 3F39043532          DB    63,57,4,53,50,4,38,36,4,13,8,4,50,53,0,36,50,1
 3B0F 010F044044          DB    1,15,4,64,68,4,14,8,4,15,1,4,36,39,0,1,4,0
 3B21 323904080F          DB    50,57,4,8,15,4,43,50,4,50,55,4,57,50,4,68,64,1
 3B33 0F0F002425          DB    15,15,0,36,37,4,1,5,4,15,22,4,36,41,4,57,61,1
 3B45 3939000F08          DB    57,57,0,15,8,4,43,45,4,15,17,4,57,64,4,36,39,0
 3B57 0103040A08          DB    1,3,4,10,8,4,64,64,0,43,46,4,33,29,4,22,25,0
 3B69 4032040809          DB    64,50,4,8,9,4,8,13,4,41,36,4,1,6,4,57,58,1
 3B7B 4640043332          DB    70,64,4,51,50,4,58,57,4,29,31,4,22,15,4,22,1,1
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 3B9F 0107044046          DB    1,7,4,64,70,4,6,1,4,39,36,4,43,44,4,29,15,1
 3BB1 020104393E          DB    2,1,4,57,62,4,29,22,4,48,43,4,64,43,4,27,22,1
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 3C0B FF                  DB    0FFH
 3C0C 1916041D1FBLOCK4:   DB    25,22,4,29,31,4,27,22,4,43,44,4,57,61,1
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 3C63 1616003732          DB    22,22,0,55,50,4,29,8,4,1,4,1,47,43,4,22,8,1
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 3C87 2426040D08          DB    36,38,4,13,8,4,61,57,4,29,30,4,15,18,4,29,33,1
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 3CBD 3632043234          DB    54,50,4,50,52,4,29,22,4,43,46,0,22,23,4,44,43,1
 3CCF 4024041D23          DB    64,36,4,29,35,4,36,43,4,22,28,4,64,64,0,29,34,1
 3CE1 1618041F1D          DB    22,24,4,31,29,4,57,43,4,50,51,4,8,13,4,40,36,1
 3CF3 3224040F08          DB    50,36,4,15,8,4,69,64,4,15,22,4,57,64,4,57,60,0
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 3D17 010604160F          DB    1,6,4,22,15,4,16,15,4,43,64,4,29,15,4,21,15,1
 3D29 2B3004393E          DB    43,48,4,57,62,4,27,32,4,1,29,4,1,2,4,29,32,0
 3D3B 080B043432          DB    8,11,4,52,50,4,64,43,4,36,39,0,9,8,4,22,27,1
 3D4D 0F0F003236          DB    15,15,0,50,54,4,1,22,4,32,29,4,36,40,4,64,50,1
 3D5F 2524043237          DB    37,36,4,50,55,4,15,21,4,36,41,4,8,10,4,11,8,1
 3D71 3832041816          DB    56,50,4,24,22,4,64,68,4,36,57,4,64,57,4,50,53,1
 3D83 0401041D01          DB    4,1,4,29,1,4,39,36,4,43,36,4,48,43,4,8,22,1
 3D95 323904081D          DB    50,57,4,8,29,4,23,22,4,43,46,0,8,9,4,15,16,1
 3DA7 3F39040103          DB    63,57,4,1,3,4,43,45,4,70,64,4,50,56,4,50,53,0
 3DB9 2D2B040104          DB    45,43,4,1,4,0,58,57,4,15,20,4,50,53,0,15,18,0
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CP/M MACRO ASSEM 2.0      #012       STATIC RANGE SOFTWARE PACKAGE  - MAY 31, 1980 -

 3DCE 0A0804130F          DB        10,8,4,19,15,4,2,1,4,36,42,4,1,15,4,68,64,4,1,4,0
 3DE0 1719041C16          DB        23,25,4,28,22,4,26,22,4,34,29,4,3,1,4,36,37,1
 3DF2 171A044240          DB        23,26,4,66,64,4,15,29,4,64,69,4,49,43,4,8,12,1
 3E04 404604080E          DB        64,70,4,8,14,4,46,43,4,36,50,4,22,29,4,57,60,1
 3E16 070104080B          DB        7,1,4,8,11,0,36,39,4,22,25,0,1,8,4,29,32,0
 3E28 FF                  DB        0FFH
 3E29 242700201DBLOCK5:   DB        36,39,0,32,29,4,50,56,4,26,22,1
 3E35 1D2204322B          DB        29,34,4,50,43,4,43,44,4,58,57,1
 3E41 1D22041D20          DB        29,34,4,29,32,0,1,29,4,31,29,4,8,11,0,15,16,1
 3E53 4042044024          DB        64,66,4,64,36,4,57,36,4,8,22,4,43,47,4,29,33,1
 3E65 FF                  DB        0FFH
 3E66 3224041D20BLOCK6:   DB        50,36,4,29,32,4,43,36,4,36,38,4,13,8,4,64,57,1
 3E78 1D1D000107          DB        29,29,0,1,7,4,48,43,4,8,22,1
 3E84 FF                  DB        0FFH
 3E85                     DS        30H
 3EB5             STACK:  DS        1
                  ;
                  ;==================================================================
                  ;
                  ;       D A T A   S T O R A G E   B U F F E R
                  ;
                  ;==================================================================
                  ;
                  ;
 D000                     ORG       0D000H
                  ;
                  ;
 D000             DBUFF:  DS        STACK-BLOCK1+10 ;DATA BUFFER
                  ;
                  ;
 D90A                     END
```

APPENDIX B

Experimental Session Sequence

SESSION NUMBER	SUBJECT NUMBER	JUDGEMENT	RANDOMIZED BLOCK NO.
1	1	Closer	3
1	2	Further	2
1	3	Closer	2
1	4	Further	4
1	5	Closer	3
1	6	Further	1
1	7	Closer	1
1	8	Further	1
1	9	Closer	1
1	10	Further	4
2	1	Further	4
2	2	Closer	1
2	3	Further	3
2	4	Closer	1
2	5	Further	4
2	6	Closer	3
2	7	Further	1
2	8	Closer	4
2	9	Further	2
2	10	Closer	2
3	1	Closer	1
3	2	Further	3
3	3	Closer	1
3	4	Further	3
3	5	Closer	2
3	6	Further	2
3	7	Closer	4
3	8	Further	3
3	9	Closer	4
3	10	Further	1
4	1	Further	2
4	2	Closer	4
4	3	Further	4
4	4	Closer	2
4	5	Further	1
4	6	Closer	4
4	7	Further	2
4	8	Closer	2
4	9	Further	3
4	10	Closer	3

APPENDIX C

Subject Consent Form

CONSENT FORM

I, ______________________________________, having full capacity to consent, do hereby volunteer to participate in a research study entitled, "Airborne Electronic Terrain Map System Display Format" under the direction of Mr. Gilbert Kuperman and Mr. William Kama and Lt Donald Sander. The implications of my voluntary participation, the nature, duration, and purpose, the methods and means by which it is to be conducted, and inconveniences and hazards which may reasonably be expected have been explained to me by ______________________ and are set forth on the reverse side of this agreement, which I have initialed. I have been given the opportunity to ask questions concerning this research project, and any such questions have been answered to full and complete satisfaction. I understand that I may at any time during the course of this project revoke my consent, and withdraw from the project without prejudice; however, I may be required to undergo certain further examinations, if in the opinion of the attending physician, such examinations are necessary for my health or well-being.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

AM
PM

Signature Date Time

I was present during the explanation referred to above, as well as the volunteer's opportunity for questions, and hereby witness the signature.

Signature Date

I have briefed the volunteer and answered questions concerning the research project.

Signature Date

ADDENDUM TO THE CONSENT FORM

AIRBORNE ELECTRONIC TERRAIN MAP DISPLAY FORMAT

You are invited to participate in an experiment entitled, "Airborne Electronic Terrain Map Display Format". We hope to study and measure the capability of a new low altitude simulator system.

If you decide to participate, you will be asked to view rear projected images onto a standard commercial screen. One half of the screen will have a reference photograph of a terrain. The other half will display a similar terrain. You will be asked to decide whether the latter image appears closer, farther, or the same perceived distance in comparison to the reference.
A computer will analyze your response time and accuracy. Each session will last approximately 30 minutes and you will be asked to participate in 4 sessions. There are no medical risks anticipated.

Your confidentiality as a participant in this program will be protected. Your name will not be revealed without your written permission. Statistical data collected during the test program may be published in scientific literature without identifying individual subjects.

Monetary benefits will be according to Air Force and Systems Research Laboratory agreements.

No alternative means exist to obtain the required information. Your decision to participate will not prejudice your future relations with the Air Force Aerospace Medical Research Laboratory. If you decide not to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice. If you have any questions, we expect you to ask us. If you have additional questions later, Mr. Gilbert Kuperman (255-4820) or Capt George Wolf (255-6623) will be happy to answer them.

YOU WILL BE GIVEN A COPY OF THIS FORM TO KEEP

DATE VOLUNTEER'S INITIALS

APPENDIX D

Instructions to the Subjects

Today we are going to begin an experiment on relative distance estimation. We will present scenes to you in pairs. The scenes are 35mm slides of terrain imagery which was generated by a map system being developed by the Air Force. Both slides contain a mountain with a relatively flat summit. It will be located in approximately the center of both slides. Your task is to indicate in which scene the mountain is closer to you. The scenes may differ in the # of lines used to generate the display; however, there is no systematic relationship between the number of lines and distance. Your response will be made by depressing the button corresponding to the scene containing the mountain that is closer to you. For example, if you think the left scene is closer, depress the left button. If you think the right scene is closer, depress the right button. If you are unsure - guess. We ask that you respond with your index finger and that you rest your finger on the center button while you are waiting to respond. This will assure that you start in the position for each trial. You have a maximum time of 3 seconds to view the scenes and make your response. Please respond as accurately and quickly as possible.

Do you have any questions?

We are going to give you 20 practice trials to familiarize you with the task. If you are ready we will begin.

(AFTER PRACTICE)

The next block of trials will last approximately 30 minutes. Are you ready? OK, I will start the sequence.

Today we are going to begin an experiment on relative distance estimation. We will present scenes to you in pairs. The scenes are 35mm slides of terrain imagery which was generated by a map system being developed by the Air Force. Both slides contain a mountain with a relatively flat summit. It will be located in approximately the center of both slides. Your task is to indicate in which scene the mountain is further away from you. The scenes may differ in the # of lines used to generate the display; however, there is no systematic relationship between the number of lines and distance. Your response will be made by depressing the button corresponding to the scene containing the mountain that is further away from you. For example, if you think the left scene is further, depress the left button. If you think the right scene is further, depress the right button. If you are unsure - guess. We ask that you respond with your index finger and that you rest your finger on the center button while you are waiting to respond. This will assure that you start in the position for each trial. You have a maximum time of 3 seconds to view the scenes and make your response. Please respond as accurately and quickly as possible.

Do you have any questions?

We are going to give you 20 practice trials to familiarize you with the task. If you are ready we will begin.

(AFTER PRACTICE)

The next block of trials will last approximately 30 minutes. Are you ready? OK, I will start the sequence.

Today we are going to continue the experiment on relative distance estimation. Your task will be the same as yesterday's except that today we would like you to depress the button corresponding to the scene which is further away from you. If you are unsure - guess. Again there is no systematic relationship between the number of lines used to generate the display and distance. Remember, respond with your index finger. Rest it on the middle button while you are waiting to respond. You have a maximum time of 3 seconds to view the scenes and make your response.

We are going to give you 20 practice trials as a warm-up. If you are ready, we will begin.

(AFTER PRACTICE)

The next block of trials will last approximately 30 minutes.

Today we are going to continue the experiment on relative distance estimation. Your task will be the same as yesterday's except that today we would like you to depress the button corresponding to the scene which is closer to you. If you are unsure - guess. Again there is no systematic relationship between the number of lines used to generate the display and distance. Remember, respond with your index finger. Rest it on the middle button while you are waiting to respond. You have a maximum time of 3 seconds to view the scenes and make your response.

We are going to give you 20 practice trials as a warm-up. If you are ready, we will begin.

(AFTER PRACTICE)

The next block of trials will last approximately 30 minutes.

APPENDIX E

Percent Correct and Mean Reation Time Scores

SUBJECT NUMBER	RANGE-LINE SPACING	ABSOLUTE DISTANCE	RELATIVE DISTANCE	REACTION TIME	PERCENT CORRECT
1	1	1	1	1.474	0.500
1	1	1	2	1.658	0.250
1	1	1	3	1.384	0.500
1	1	1	4	1.612	0.750
1	1	1	5	1.570	0.500
1	1	1	6	1.619	0.625
1	1	2	7	1.869	0.750
1	1	2	8	1.754	1.000
1	1	2	9	1.750	1.000
1	1	2	10	1.473	0.875
1	1	2	11	1.427	1.000
1	1	2	12	1.524	1.000
1	2	1	1	1.432	0.125
1	2	1	2	1.784	0.250
1	2	1	3	1.639	0.625
1	2	1	4	1.917	0.625
1	2	1	5	1.791	0.625
1	2	1	6	1.691	0.875
1	2	2	7	1.640	0.750
1	2	2	8	1.512	0.875
1	2	2	9	1.507	1.000
1	2	2	10	1.580	1.000
1	2	2	11	1.382	1.000
1	2	2	12	1.443	1.000
1	3	1	1	1.942	0.375
1	3	1	2	1.634	0.500
1	3	1	3	1.746	0.625
1	3	1	4	1.914	0.375
1	3	1	5	1.478	0.625
1	3	1	6	1.511	0.625
1	3	2	7	1.908	0.625
1	3	2	8	1.718	0.625
1	3	2	9	1.508	1.000
1	3	2	10	1.454	0.875
1	3	2	11	1.444	1.000
1	3	2	12	1.462	1.000
1	4	1	1	1.851	0.500
1	4	1	2	1.514	0.125
1	4	1	3	1.855	0.375
1	4	1	4	1.897	0.625
1	4	1	5	1.588	0.875
1	4	1	6	1.692	0.750
1	4	2	7	1.729	0.750
1	4	2	8	1.803	1.000
1	4	2	9	1.646	0.750
1	4	2	10	1.575	1.000
1	4	2	11	1.331	1.000
1	4	2	12	1.480	1.000
1	5	1	1	1.764	0.375
1	5	1	2	1.772	0.625

SUBJECT NUMBER	RANGE-LINE SPACING	ABSOLUTE DISTANCE	RELATIVE DISTANCE	REACTION TIME	PERCENT CORRECT
1	5	1	3	1.725	0.500
1	5	1	4	1.903	0.750
1	5	1	5	1.687	0.875
1	5	1	6	1.563	0.375
1	5	2	7	1.660	0.625
1	5	2	8	1.807	0.625
1	5	2	9	1.478	1.000
1	5	2	10	1.538	0.875
1	5	2	11	1.530	1.000
1	5	2	12	1.395	1.000
4	1	1	1	1.652	0.625
4	1	1	2	1.868	0.750
4	1	1	3	1.974	1.000
4	1	1	4	1.591	0.625
4	1	1	5	1.326	0.750
4	1	1	6	1.538	0.875
4	1	2	7	1.963	0.500
4	1	2	8	1.488	0.875
4	1	2	9	1.420	1.000
4	1	2	10	1.337	1.000
4	1	2	11	1.394	0.875
4	1	2	12	1.053	0.625
4	2	1	1	1.810	0.625
4	2	1	2	1.799	0.750
4	2	1	3	1.690	0.875
4	2	1	4	1.499	0.500
4	2	1	5	1.593	0.875
4	2	1	6	1.495	1.000
4	2	2	7	1.384	0.875
4	2	2	8	1.350	0.875
4	2	2	9	1.235	1.000
4	2	2	10	1.137	0.750
4	2	2	11	1.047	0.875
4	2	2	12	1.069	1.000
4	3	1	1	2.279	0.375
4	3	1	2	1.299	0.500
4	3	1	3	1.615	0.875
4	3	1	4	1.390	0.750
4	3	1	5	1.407	0.750
4	3	1	6	1.560	0.750
4	3	2	7	1.306	0.375
4	3	2	8	1.510	0.875
4	3	2	9	1.312	1.000
4	3	2	10	1.319	0.750
4	3	2	11	1.210	0.875
4	3	2	12	1.234	1.000
4	4	1	1	1.325	0.750
4	4	1	2	1.350	0.750
4	4	1	3	1.330	0.875
4	4	1	4	1.396	0.625
4	4	1	5	1.403	0.875

SUBJECT NUMBER	RANGE-LINE SPACING	ABSOLUTE DISTANCE	RELATIVE DISTANCE	REACTION TIME	PERCENT CORRECT
4	4	1	6	1.374	1.000
4	4	2	7	1.064	0.625
4	4	2	8	1.473	0.875
4	4	2	9	1.537	0.750
4	4	2	10	1.448	1.000
4	4	2	11	1.100	0.875
4	4	2	12	1.048	0.750
4	5	1	1	1.460	0.375
4	5	1	2	1.474	0.750
4	5	1	3	1.648	0.750
4	5	1	4	1.535	1.000
4	5	1	5	1.676	0.750
4	5	1	6	1.474	0.875
4	5	2	7	1.695	0.500
4	5	2	8	1.555	0.625
4	5	2	9	1.645	0.625
4	5	2	10	1.446	1.000
4	5	2	11	1.160	1.000
4	5	2	12	1.395	1.000
5	1	1	1	1.204	0.625
5	1	1	2	1.285	0.750
5	1	1	3	1.351	0.625
5	1	1	4	1.418	0.875
5	1	1	5	1.228	1.000
5	1	1	6	1.073	1.000
5	1	2	7	1.352	0.750
5	1	2	8	1.514	1.000
5	1	2	9	1.315	0.750
5	1	2	10	1.552	1.000
5	1	2	11	1.100	0.875
5	1	2	12	1.326	1.000
5	2	1	1	1.399	0.500
5	2	1	2	1.157	0.500
5	2	1	3	1.303	0.750
5	2	1	4	1.369	0.750
5	2	1	5	1.214	1.000
5	2	1	6	0.993	0.750
5	2	2	7	0.974	0.875
5	2	2	8	1.205	0.875
5	2	2	9	1.016	0.875
5	2	2	10	1.243	1.000
5	2	2	11	1.153	1.000
5	2	2	12	1.035	1.000
5	3	1	1	1.177	0.625
5	3	1	2	1.562	0.750
5	3	1	3	1.822	0.750
5	3	1	4	0.959	1.000
5	3	1	5	1.201	1.000
5	3	1	6	1.318	0.750
5	3	2	7	1.215	0.875
5	3	2	8	1.358	0.500

SUBJECT NUMBER	RANGE-LINE SPACING	ABSOLUTE DISTANCE	RELATIVE DISTANCE	REACTION TIME	PERCENT CORRECT
5	3	2	9	1.050	1.000
5	3	2	10	1.269	1.000
5	3	2	11	1.070	1.000
5	3	2	12	1.104	1.000
5	4	1	1	1.806	0.375
5	4	1	2	1.128	0.625
5	4	1	3	1.415	0.750
5	4	1	4	1.430	0.750
5	4	1	5	1.307	0.875
5	4	1	6	1.265	0.875
5	4	2	7	1.242	0.625
5	4	2	8	1.321	0.875
5	4	2	9	1.299	1.000
5	4	2	10	1.204	0.875
5	4	2	11	0.961	1.000
5	4	2	12	0.898	0.875
5	5	1	1	1.361	0.500
5	5	1	2	1.394	0.625
5	5	1	3	1.497	0.875
5	5	1	4	1.181	0.750
5	5	1	5	1.253	0.875
5	5	1	6	1.034	1.000
5	5	2	7	1.038	0.750
5	5	2	8	1.124	0.750
5	5	2	9	1.345	1.000
5	5	2	10	1.223	0.750
5	5	2	11	1.245	1.000
5	5	2	12	1.021	0.875
6	1	1	1	2.363	0.125
6	1	1	2	2.055	0.500
6	1	1	3	2.341	0.375
6	1	1	4	1.915	0.375
6	1	1	5	1.705	1.000
6	1	1	6	1.831	0.750
6	1	2	7	2.067	1.000
6	1	2	8	2.172	1.000
6	1	2	9	1.926	1.000
6	1	2	10	1.657	1.000
6	1	2	11	1.524	1.000
6	1	2	12	1.374	1.000
6	2	1	1	1.924	0.625
6	2	1	2	2.400	0.125
6	2	1	3	2.528	0.250
6	2	1	4	2.090	0.500
6	2	1	5	1.991	0.375
6	2	1	6	1.971	0.625
6	2	2	7	2.154	0.750
6	2	2	8	1.777	0.875
6	2	2	9	1.786	0.750
6	2	2	10	1.625	0.875
6	2	2	11	1.563	1.000

SUBJECT NUMBER	RANGE-LINE SPACING	ABSOLUTE DISTANCE	RELATIVE DISTANCE	REACTION TIME	PERCENT CORRECT
6	2	2	12	1.242	1.000
6	3	1	1	1.965	0.875
6	3	1	2	1.936	0.500
6	3	1	3	2.397	0.250
6	3	1	4	1.833	0.625
6	3	1	5	1.616	0.750
6	3	1	6	1.410	0.625
6	3	2	7	2.018	1.000
6	3	2	8	1.758	0.875
6	3	2	9	1.713	0.750
6	3	2	10	1.441	1.000
6	3	2	11	1.454	1.000
6	3	2	12	1.440	1.000
6	4	1	1	1.782	0.750
6	4	1	2	1.890	0.750
6	4	1	3	1.895	0.625
6	4	1	4	2.071	0.625
6	4	1	5	1.890	0.750
6	4	1	6	1.899	0.875
6	4	2	7	1.932	0.750
6	4	2	8	1.530	0.750
6	4	2	9	1.933	1.000
6	4	2	10	1.689	0.875
6	4	2	11	1.692	1.000
6	4	2	12	1.480	0.875
6	5	1	1	1.949	0.375
6	5	1	2	2.117	0.875
6	5	1	3	2.130	0.625
6	5	1	4	2.032	0.375
6	5	1	5	1.785	0.750
6	5	1	6	1.996	1.000
6	5	2	7	1.867	0.750
6	5	2	8	2.040	0.875
6	5	2	9	1.868	1.000
6	5	2	10	1.820	1.000
6	5	2	11	1.356	1.000
6	5	2	12	1.508	0.875
7	1	1	1	1.669	0.500
7	1	1	2	1.484	0.625
7	1	1	3	1.504	0.750
7	1	1	4	1.800	0.875
7	1	1	5	1.594	0.750
7	1	1	6	1.428	0.750
7	1	2	7	1.443	0.875
7	1	2	8	2.010	0.625
7	1	2	9	1.889	0.875
7	1	2	10	1.716	0.875
7	1	2	11	1.572	1.000
7	1	2	12	1.615	1.000
7	2	1	1	1.848	0.875
7	2	1	2	2.118	0.375

SUBJECT NUMBER	RANGE-LINE SPACING	ABSOLUTE DISTANCE	RELATIVE DISTANCE	REACTION TIME	PERCENT CORRECT
7	2	1	3	1.811	0.375
7	2	1	4	2.857	0.250
7	2	1	5	1.780	0.625
7	2	1	6	1.690	0.750
7	2	2	7	1.635	1.000
7	2	2	8	1.602	0.625
7	2	2	9	1.375	1.000
7	2	2	10	2.105	0.875
7	2	2	11	1.414	0.875
7	2	2	12	1.459	1.000
7	3	1	1	2.115	0.500
7	3	1	2	2.046	0.375
7	3	1	3	1.959	0.125
7	3	1	4	1.233	0.750
7	3	1	5	1.842	0.625
7	3	1	6	1.672	0.250
7	3	2	7	1.673	0.500
7	3	2	8	1.671	0.625
7	3	2	9	1.535	1.000
7	3	2	10	1.754	0.625
7	3	2	11	1.522	0.875
7	3	2	12	1.496	1.000
7	4	1	1	1.273	0.750
7	4	1	2	1.698	0.750
7	4	1	3	1.815	0.875
7	4	1	4	1.471	1.000
7	4	1	5	1.759	0.750
7	4	1	6	2.007	0.750
7	4	2	7	1.976	0.750
7	4	2	8	1.889	0.875
7	4	2	9	1.968	0.750
7	4	2	10	1.415	1.000
7	4	2	11	1.416	1.000
7	4	2	12	1.567	0.875
7	5	1	1	2.416	0.625
7	5	1	2	1.371	0.750
7	5	1	3	1.777	0.250
7	5	1	4	1.669	0.125
7	5	1	5	2.001	0.625
7	5	1	6	1.718	0.750
7	5	2	7	1.921	0.750
7	5	2	8	1.520	0.875
7	5	2	9	1.483	0.625
7	5	2	10	1.439	1.000
7	5	2	11	1.634	0.875
7	5	2	12	1.233	1.000
9	1	1	1	2.163	0.625
9	1	1	2	1.938	0.750
9	1	1	3	2.310	0.375
9	1	1	4	1.714	0.625
9	1	1	5	1.719	0.750

SUBJECT NUMBER	RANGE-LINE SPACING	ABSOLUTE DISTANCE	RELATIVE DISTANCE	REACTION TIME	PERCENT CORRECT
9	1	1	6	2.184	0.500
9	1	2	7	2.253	0.500
9	1	2	8	2.210	0.875
9	1	2	9	1.833	0.625
9	1	2	10	2.121	0.875
9	1	2	11	1.854	0.875
9	1	2	12	2.311	0.875
9	2	1	1	2.594	0.375
9	2	1	2	2.671	0.375
9	2	1	3	2.464	0.250
9	2	1	4	2.124	0.375
9	2	1	5	1.742	0.625
9	2	1	6	1.891	0.500
9	2	2	7	1.758	0.750
9	2	2	8	2.042	1.000
9	2	2	9	2.009	1.000
9	2	2	10	2.085	0.875
9	2	2	11	2.160	1.000
9	2	2	12	1.979	1.000
9	3	1	1	2.139	0.625
9	3	1	2	1.819	0.375
9	3	1	3	2.161	0.750
9	3	1	4	2.129	1.000
9	3	1	5	1.703	0.750
9	3	1	6	2.113	0.625
9	3	2	7	1.930	0.625
9	3	2	8	1.813	0.625
9	3	2	9	2.047	0.750
9	3	2	10	2.001	1.000
9	3	2	11	1.753	1.000
9	3	2	12	1.924	1.000
9	4	1	1	2.023	0.750
9	4	1	2	2.033	0.750
9	4	1	3	1.852	0.750
9	4	1	4	2.001	0.750
9	4	1	5	1.983	1.000
9	4	1	6	2.012	0.875
9	4	2	7	2.195	0.625
9	4	2	8	1.935	0.875
9	4	2	9	1.745	0.500
9	4	2	10	1.862	1.000
9	4	2	11	1.857	1.000
9	4	2	12	1.763	0.750
9	5	1	1	2.401	0.250
9	5	1	2	2.115	0.875
9	5	1	3	2.051	0.750
9	5	1	4	2.028	0.500
9	5	1	5	1.961	0.875
9	5	1	6	2.061	0.875
9	5	2	7	1.778	0.750
9	5	2	8	2.145	0.750

SUBJECT NUMBER	RANGE-LINE SPACING	ABSOLUTE DISTANCE	RELATIVE DISTANCE	REACTION TIME	PERCENT CORRECT
9	5	2	9	2.069	0.875
9	5	2	10	2.005	1.000
9	5	2	11	1.772	1.000
9	5	2	12	2.045	1.000
10	1	1	1	1.434	0.875
10	1	1	2	1.380	0.625
10	1	1	3	1.449	1.000
10	1	1	4	1.628	0.625
10	1	1	5	1.352	0.875
10	1	1	6	1.293	0.875
10	1	2	7	1.571	0.750
10	1	2	8	1.536	1.000
10	1	2	9	1.289	0.875
10	1	2	10	1.291	0.750
10	1	2	11	1.382	1.000
10	1	2	12	1.150	0.750
10	2	1	1	1.413	0.625
10	2	1	2	1.386	0.750
10	2	1	3	1.250	0.875
10	2	1	4	1.414	0.750
10	2	1	5	1.392	1.000
10	2	1	6	1.341	1.000
10	2	2	7	1.500	0.750
10	2	2	8	1.378	0.750
10	2	2	9	1.196	0.750
10	2	2	10	1.472	0.875
10	2	2	11	1.184	1.000
10	2	2	12	1.160	0.875
10	3	1	1	1.453	0.750
10	3	1	2	1.636	1.000
10	3	1	3	1.387	0.875
10	3	1	4	1.441	0.875
10	3	1	5	1.305	1.000
10	3	1	6	1.246	1.000
10	3	2	7	1.713	0.875
10	3	2	8	1.196	0.750
10	3	2	9	1.062	0.500
10	3	2	10	1.310	0.875
10	3	2	11	1.436	1.000
10	3	2	12	1.157	1.000
10	4	1	1	1.489	0.875
10	4	1	2	1.535	0.875
10	4	1	3	1.247	0.875
10	4	1	4	1.443	0.750
10	4	1	5	1.415	1.000
10	4	1	6	1.314	0.750
10	4	2	7	1.307	0.750
10	4	2	8	1.245	0.750
10	4	2	9	1.283	0.875
10	4	2	10	1.269	0.875
10	4	2	11	1.399	1.000

SUBJECT NUMBER	RANGE-LINE SPACING	ABSOLUTE DISTANCE	RELATIVE DISTANCE	REACTION TIME	PERCENT CORRECT
10	4	2	12	1.055	0.750
10	5	1	1	1.671	0.500
10	5	1	2	1.499	0.875
10	5	1	3	1.531	0.750
10	5	1	4	1.407	1.000
10	5	1	5	1.417	0.875
10	5	1	6	1.425	0.750
10	5	2	7	1.389	0.875
10	5	2	8	1.414	0.750
10	5	2	9	1.334	0.875
10	5	2	10	1.343	1.000
10	5	2	11	1.148	0.875
10	5	2	12	1.198	1.000

APPENDIX F

ANOVAs on 10 Subjects

Table F.1 Analysis of Variance Summary Table on 10 Subjects Using Percent Correct as the Dependent Variable

SOURCE	df	MEAN SQUARE	F
Range-Line Spacing (RS)	4	0.0845	1.7034
Absolute Distance (AD)	1	3.1901	8.1020
Relative Distance (RD/AD)	10	0.3605	10.4785*
Subjects (S)	9	7.1312	
RS X AD	4	0.1291	3.8584
RS X RD/AD	40	0.0473	1.9187
S X RS	36	0.0496	
S X AD	9	0.3937	
S X RD/AD	90	0.0344	
S X RS X AD	36	0.0335	
S X RS X RD/AD	360	0.0212	

Table F.2 Analysis of Variance Summary Table on 10 Subjects Using Mean Reaction Time as the Dependent Variable

SOURCE	df	MEAN SQUARE	F
Range-Line Spacing (RS)	4	0.1261	2.7018
Absolute Distance (AD)	1	1.0329	3.0827
Relative Distance RD/AD	10	0.2653	5.8201*
Subjects (S)	9	7.1293	
RS X AD	4	0.1591	3.2397
RS X RD/AD	40	0.0414	1.1147
S X RS	36	0.0467	
S X AD	9	0.3351	
S X RD/AD	90	0.0456	
S X RS X AD	36	0.0491	
S X RS X RD/AD	360	0.0372	

APPENDIX G

Analyses on Mean Reaction Time

Table G.1 Analysis of Variance Summary Table using Mean Reaction Time as the Dependent Variable.

SOURCE	df	MEAN SQUARE	F
Range-Line Spacing (RS)	4	0.0575	1.3637
Absolute Distance (AD)	1	2.5303	34.3328*
Relative Distance (RD/AD)	10	0.3402	9.0530*
Subjects (S)	6	4.4875	
RS X AD	4	0.1357	4.015
RS X RD/AD	40	0.0349	1.0714
S X RS	24	0.0422	
S X AD	6	0.0737	
S X RD/AD	60	0.0376	
S X RS X AD	24	0.0338	
S X RS X RD/AD	240	0.0326	

Table G.2 Analysis of Variance Summary Table Using Only Completely Crossed Levels of all Variables with Mean Reaction Time as the Dependent Variable

SOURCE	df	MEAN SQUARE	F
Range-Line Spacing (RS)	4	0.0582	1.5589
Absolute Distance (AD)	1	0.1257	36.6947*
Relative Distance	2	0.2614	11.2107*
Subjects (S)	6	2.4524	
RS X AD	4	0.1964	6.6039*
RS X RD	8	0.0479	1.3242
AD X RD	2	0.0019	0.0987
S X RS	24	0.0373	
S X AD	6	0.0034	
S X RD	12	0.0233	
RS X AD X RD	8	0.0174	0.4402
S X RS X AD	24	0.0297	
S X RS X RD	48	0.0362	
S X AD X RD	12	0.0190	
S X RS X AD X RD	48	0.0394	

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