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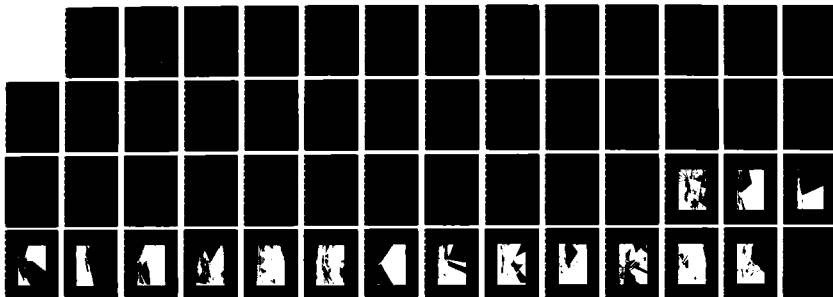
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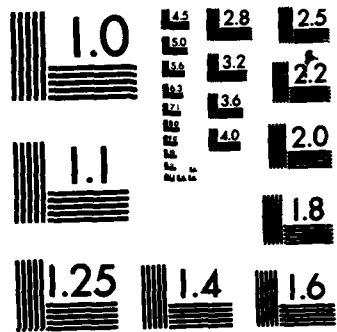
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PLAN FOR EVALUATION OF THE TRAINING  
POTENTIAL OF HELMET-MOUNTED DISPLAY  
AND COMPUTER-GENERATED SYNTHETIC IMAGERY

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## PREFACE

This report describes a plan of empirical research to evaluate the training effectiveness of a helmet-mounted display (HMD), and of computer-generated synthetic imagery (CGSI), for low-level flight, navigation, and target interaction. This HMD has been developed by the Advanced Simulation Concepts Laboratory of the Naval Training Equipment Center for use in the Navy Visual Technology Research Simulator (VTRS). Optics mounted on the pilot's helmet project a scene upon a retro-reflecting screen. Two computer-image generation (CIG) channels are incorporated which present a wide-angle, low-resolution, low-detail background and an area of interest (AOI) of high resolution and detail. Eye and head tracking are used to position the display so that the AOI is presented to the fovea. The goal of HMD is to present a scene to the pilot that is indistinguishable from the real world insofar as pilot performance is concerned.

The evaluation plan describes: potential training scenarios emphasizing low-level flight and ground interaction, response parameters used in measuring pilot performance, psychophysical experiments comparing the training efficacy of various aspects of HMD and CGSI, postsimulation subjective measures of pilot comfort, and the logistics of the research plan itself.



## SECTION I

### INTRODUCTION

Wide-angle, high-resolution, high-detail density simulation of the outside-the-cockpit visual environment for pilot training has been a major goal of the design efforts at the Advanced Simulation Concepts Laboratory. Such visual simulation should permit the pilot to perform maneuvers not currently possible in flight simulators employing conventional computer-generated imagery (CIG) such as flying close to scene surfaces. The improved flight performance capability should permit improved practice and training which, in turn, should result in transfer to real-world flight performance. Beyond providing practice of certain maneuvers that would be unavailable in less realistic simulators, realistic and veridical visual displays may have a more direct bearing upon training.

The visual environment during flight is unusual. For example, during a roll-turn, the ground surface is nearly upside-down at the very top of the field of view. Visual cues and features provide major control inputs for initiating, maintaining, modifying, and completing maneuvers. Learning to perceptually "select" those visual cues that are informative concerning particular flight tasks may be an important part of learning to fly. The change of the visual system so that unusual and even errant visual information appears normal and produces error-free responses is called "adaptation." Realism and fidelity may be necessary for visual cue selection and adaptation to occur. Rather than simply schooling the pilot response system (procedure training), realistic displays may enable perceptual learning to occur.

From this point of view, the recent concern over the occurrence of "simulator sickness" may be somewhat of an overreaction. There may be two sources for these symptoms: (1) symptoms based on the similarity of aircraft and simulator vision and motion dynamics (which should produce symptoms temporarily in novices); and (2) symptoms based on the dissimilarity of aircraft and simulation vision and motion dynamics (such as differential lags between visual, and physical motion between simulation and aircraft, which should produce symptoms in experienced pilots). Onset and cessation of symptoms resulting from the former circumstance may be viewed as an index of the degree of perceptual adaptation which has occurred. (Of course, certain anomalous displays, e.g., those depicting anomalous space, or two different and simultaneous paths of self-motion through a space, may produce sickness and undesirable kinds of perceptual adaptation.)

Realistic depiction demands high resolution and high detail in order to present texture gradients, cast shadows, and familiar objects. Texture gradients and cast shadows allow the surface shape of the ground plane to be perceived, while familiar objects permit distances among points on the ground and between points on the ground and the observer to be perceived. Perception of the size and shape of ground surfaces is critical during low-level flight, air-to-ground attack, and other ground-interaction scenarios.

A helmet-mounted display, the Visual Display Research Tool (VDRT), incorporating an area-of-interest has recently been developed at the Advanced Simulation Concepts Laboratory at NTEC for integration with the Navy's Visual Technology Research Simulator. This device may offer an alternative technology to more traditional multichannel simulation displays at a fraction of the cost but with the same or better spatial resolution and detail density. In this system, two CIG channels are displayed through a helmet-mounted projector onto the interior of a dome screen. One channel is a 25-degree square area-of-interest display; the other channel is a wide field (120-degrees horizontal) background display. The whole display may be slaved to the observer's eye or head, so that wherever the eye or head is fixated, a high level of detail will be seen. A two-channel display, so constructed, will effectively achieve the spatial resolution of a multichannel display but at much less cost (cost determined by the number of CIG channels). This device is a natural extension of the "target tracked" AOI display which has already been the subject of research at VTRS (Chambers, 1982).

A new image generation system being developed for integration with VTRS is computer-generated synthesized imagery (CGSI). Photographic material is presented on CIG surfaces allowing ecological texture of any level of detail to be presented. Such textures are seen as gradients of texture when observed from a particular location or motion path. Such texture gradients are powerful cues to surface shape. Familiar objects of high detail and depicted shadows may also be created with CGSI.

SECTION II  
TECHNICAL OBJECTIVES

The objectives of this effort are:

A. To define and describe training scenarios emphasizing low-level flight, low-level navigation, target acquisition, and ground attack.

B. To define and describe those parameters which are to be used to assess performance. Possible objective measures include targets acquired, deviations from ideal flight path, proximity to the earth, miss distance, and derivations of these measures. A visual environment model or data base must be selected which contains ample ground targets, disparate antiaircraft defenses, and variations in terrain height, in order to study training scenarios which will permit these factors to be investigated. The data base should involve enough difficulty in the flight paths and approaches so that differences between conditions will be apparent. We anticipate that with greater difficulty in the flight path, a greater range of scores will be obtained by the subjects. This can provide an opportunity for improved retest reliability which, in turn, can improve the sensitivity (power) of the experimental approach. The latter is likely to be advantageous in revealing differences between display conditions. Ground targets should have at least minimal depiction, if it's only a triangle, even in the low level of detail display region.

C. To define and describe a series of psychophysical experiments using different display conditions. Possible display configurations are permutations of the full-up VDRT display. The full-up VDRT includes eye-tracked inset and surround, a high-detail inset with a low-detail surround, and CGSI (texture or photographic imagery mapped onto CIG surfaces).

Variables

- Tracking: eye, head
- Inset/surround level of detail: high/low
- CGSI: yes/no

D. To define and describe subjective assessment questionnaires designed to elicit acceptability data regarding helmet weight, center of gravity, noise, distortion and illusions, simulator sickness, eye irritation, distractions such as popping, blending, laser speckle, and other display artifacts and overall suitability for training.

E. To specify the logistics of the experiments. Questions to be answered include: how many subjects will be run and who the subjects should be (for example: pilots, instructors, or students). Since the eye tracker has specifications such that in some number of individuals suitable recording and monitoring may not be accomplished, we need a way of pretesting subjects. How will we do this? What is the present estimate of accommodated percentage, etc?

## SECTION III

### TRAINING SCENARIOS

The training scenarios will emphasize low-level flight, low-level navigation, target acquisition, and air-to-surface attack.

Training scenarios which can be used in empirical investigations depend upon the availability of data bases with particular features. To investigate low-level flight and low-level navigation, a data base must be available depicting a terrain that varies in altitude and is of sufficient length to permit extended low-level flight. The simulated environment must be neither too easy nor too difficult to fly. Were a data base to be used which had objects all at the same height, this would permit easy flying at that level and most subjects would probably achieve similarly high scores. The range of scores between subjects would inevitably be small, and this restriction of ranges could lead to performances unaffected by equipment features regardless of their potential value. On the other hand, a data base presenting a very flat surface with no features giving scale information would also be unaffected by equipment or display features because all performances would be uniformly poor. In order to avoid these kinds of ceiling and floor effects, the data base for the VDRT investigations should include variety in altitude and surface definitions (Lintern, Thomley, Nelson, & Roscoe, 1984; Snyder, 1964; Vreuls & Sullivan, 1981).

Working closely with engineers and behavioral scientists at the Naval Training Equipment Center and Essex Corporation, we have attempted to define data base characteristics for the VDRT (cf. Appendix B). It is tailored for low-level flight, low-level navigation, target acquisition, and air-to-surface attack investigations. The proposed geography includes three data base regions arranged contiguously and continuously, so as to create a long thin data base. The first data base region is flat and includes a representation of the Norfolk Harbor area. The second region is rolling hills. The rolling hills region is approximately 50,000 feet wide and 75,000 feet long. The third data base region will include a very high feature, perhaps a 5000-foot mountain followed by a valley with a lake and waterfall. Thus, the geography depicted by the data base is long with rolling hills through most of it. There are intercept points (IP) at the end and there will be other targets throughout. At one end of the flight corridor the IP target is actually a target range on flat terrain similar to the one found in the twin-towns data base which has been used extensively in air-to-ground attack investigated at the Visual Technology Research Simulator (Westra, 1984). At the other end of the flight path corridor, the targets for air-to-ground

attack will require that one power over a large structure. Air-to-ground scenarios at this end of the data base would be similar to those required in the river valley data base.

Two kinds of extended missions involving air-to-ground attack may be flown. In one, the mission would start from the mountains, fly through the rolling hills, and then the attack would be on a target in the harbor area. It should be noted that the three regions are separated by 10-15 secs of no visible features. The other type of mission would start at sea, fly through the rolling hills, and attack the target after setting up the approach over the mountain. The mountain, followed by the lake, would provide not only a target at that end, but also the most interesting feature of the river valley. It would present an approach that is difficult to accomplish. The varying targets at each end of the data base would permit air-to-ground attack scenarios to be investigated.

The three data base regions present three levels of difficulty of low-level flying with each level of difficulty associated with a different kind of terrain. It is almost impossible to fly close to the flat terrain in the Twin-Towns data base in the current version of the VTRS simulator. This same type of flat terrain may exist in the Norfolk Bay data base. On the other hand, rolling hills and gorge models will give some cues for maintenance of low-level flying performance. Finally, the mountain followed by the waterfall, which is similar in some respects to the river valley of the earlier VTRS data base, may be easy to fly close to because of the presence of many side cues to altitude. The impact of any of the display or equipment features upon the performance of either novice or expert pilots may be expected to be measurable within some part of the data base.

The rolling hills data base region includes hills that are 300-900 feet in height and is expected to be useful for the investigation of low-level flight training scenarios because it presents an intermediate level of low-level flight difficulty. In addition, the length of the rolling hills data base region permits extended and continuous measurement. We believe these two features will enable the collection of stable and reliable measurements of low-level flying skills. In the absence of other workload factors (such as set-up for air-to-ground attack), extensive measurement of this type of performance may provide the best opportunity for the effects of equipment and display features to be determined.

The rolling hills data base region includes several turns. The data base will include a number of permanent man-made ground features, such as buildings, towers, dams, and bridges, which may be used to score navigation through the data base, because these features will be permanent in this data base. Pilots may use them to navigate visually by using large man-made features as check points, when available. (See

Appendices A and B for a more complete discussion of the current development of the rolling hills data base.) Also included throughout the data base will be static air and ground targets which will be available for identification and possible attack. Thus, any and all training scenarios may include a target acquisition dimension. Such targets will show whether any "popping" (Berbaum, 1983) concomitant with the VDRT inset degrades acquisition.

While the data base modellers at NTEC are attempting to create a data base with an ecological geometry, their major concern is to provide the type of scenery that will advance the experiments testing AOI and CGSI imagery. Since the primary advantage of the AOI inset is presumed to be the presentation of a higher level of detail, special care must be taken in determining what scene features will be present in the high and low levels of detail. The low-detail data base can include only 16 models, each of which can include only 16 objects; while the data base for the high level of detail can include 16 models, each of which can include 16 objects. Due to the relative sizes of the AOI inset and low-detail surround, the detail density in the AOI will be 16 times that of the surround. Of course, an object may be a mountain, a hill, a tree, a house, or a simple surface feature (two-dimensional) such as a window or a door lying on the surface of a three-dimensional object. Two-dimensional and three-dimensional objects each count toward the 16 object limit that a model may include. Additionally, only part of the objects in each data base may have variable priority; that is, may be objects which can sometimes occlude other objects and sometimes not. The remaining objects must have fixed priority, which means that they must be two-dimensional surface features such as fields or windows or door frames.

Guidelines for matching details in high and low level of detail representations which minimize popping of scene detail have been described elsewhere (Berbaum, 1983). The additional detail in the AOI data base must be very carefully selected for its influence upon visual perception if a fair test of the efficacy of the area of interest display is to be achieved. Of course, increasing the detail of a scene by 16 times ought to improve perception of spatial surface shape somewhat, regardless of what two- and three-dimensional objects are selected. This is because the existing VTRS CIG will instill any added details with appropriate linear perspective, motion perspective, interposition, and motion parallax. However, several kinds of detail may be of particular importance in improving scene perception sufficiently so as to improve flight performance. These include familiar objects, texture gradients, and cast shadows.

Familiar objects and features may engage pattern recognition and size and shape constancy. Three-dimensional familiar objects may be depicted as barns, towers, bridges,

trees, trucks, people, etc. Such three-dimensional reference objects provide important scale and shape information relevant to interpreting the surrounding surfaces. An object of a known size will allow spatial extent of surrounding surfaces and their distance from the observer to be determined. Furthermore, given shadows attached to a familiar object, the three-dimensional shape of surrounding surfaces may be unambiguously interpreted from their shading gradients (Berbaum, Bever, & Chung, 1984a, b). Two-dimensional objects may be used to cover the surfaces of three-dimensional objects with sufficient detail to provide scale and shape definition for those surfaces. Familiar two-dimensional features can provide scale and/or shape information about the surfaces upon which they lie when the known size and shape of the feature is compared with the retinal image.

However, even unfamiliar two-dimensional features, if they are part of a pattern or texture in which features have similar size and shape and spacing, can provide information about surface definition. The features do not have to have a regular spacing as long as it is uniform. For example, if we were to place luminous disks at random over the surface of an otherwise unilluminated, irregularly crumpled blanket, gradients of texture would be generated when the disks were observed from a point and the shape of the blanket would be perceived. Whether the elements of the texture are two- or three-dimensional makes little difference and the shape and size of the elements would not be important so long as the size and shape of all elements was similar. The perceptual system assumes that elements whose size, shape, and spacing changes continuously are produced by elements of a constant size, shape, and spacing. Decreases in element size and spacing are interpreted as increasing distance and changes in element shape are interpreted as changes in the local orientation of the underlying surface. When the elements or the patterns of texture can be recognized as a familiar object, the absolute scale and distance information already discussed become available. The key to generating informative texture gradients for the AOI data base is to select a two-dimensional feature (an agricultural square or row) on a three-dimensional object (a tree) and present identically sized and shaped objects or features at approximately uniform spacing across the ground surface or surfaces. Textures that wrap around three-dimensional objects can provide shape information. Such two-dimensional objects can be made to wrap around and lie upon and across a series of three-dimensional object surfaces. CGSI imagery can place any kind of photographic texture pattern upon flat CIG surfaces. It will be of some interest to compare the relative efficacy of these two types of texturing, i.e., regular polygon texture patterns vs. photographic texture.

Illumination can play an important role in interpreting shading as shape (Berbaum, Tharp, Mroczek, 1983; Berbaum, Bever, Chung, 1984, a, b). If the direction of illumination



can be inferred from the pattern of shading on familiar objects or from the converging edges of cast shadows, their highlights and shadows attached to unfamiliar surfaces will permit their shapes to be perceived. A highlight will occur where a line perpendicular to the surface bisects the source-object-observer angle. However, while highlights improve surface depth perception (Berbaum et al., 1983), they will also move across surfaces as the observer moves, making them unsuitable for inclusion in the AOI data base. Shadows are attached to those surfaces facing away from the light source. Although the effect of sun-shadow is incorporated, the VTRS CIG will not generate shadows cast by an object onto another surface. Such shadows are very powerful cues to the relative locations of the object and shadowed surface. For example, if a form is suspended over a grand plain, the apparent distance of the form from the observer and the object's apparent size will depend upon the location of the shadow cast by the form upon the grand plain. Cast shadows also provide information about the direction of illumination. Cast shadows can be part of a texture gradient composed of three-dimensional objects and generate the same information as any other two-dimensional texture pattern.

Definition of the data base for VDRT investigations at an early stage has been necessary because the data base limits the kinds of training scenarios which are possible within the simulator experiments. This data base is designed to permit a wide variety of training scenarios to be tested, including low-level flight, low-level navigation, target acquisition, and air-to-ground attack. Preliminary experiments will be necessary in order to define the exact training scenarios which will be used in experiments determining the efficacy of display and equipment features. The rationale of the evaluation plan is that the simplest and least expensive experiments are completed first and used to guide more expensive, more time-consuming experiments which will be conducted in the later stages. By defining the data base in this way, the training scenarios can be adjusted to improve experimental precision and generality as experimentation progresses.

## SECTION IV

### RESPONSE MEASURES OF PERFORMANCE

Objective parameters, such as number of acquired targets, deviation from ideal flight path, minimum altitude, and average miss distance, are persistently considered to be the leading candidates for response measures. At this point, we propose no physiological measures, such as EEG, or nontask psychological measures (e.g., a secondary task). The proposed psychophysical experiments are embedded within approach and ground interaction scenarios. Thus, objective aircraft control measures serve as response measures. Essentially, the performance of the aircraft is the experimental subject's response.

Response measures are required for each of four types of performance. Low-level flying is most easily scoreable in the rolling hills. Variations in altitude through this slalom course, which includes several obstacles throughout the 18-mile length, make this ideal for measurement of low-level performance. The obstacles will be scoreable in terms of numbers of hits and misses. Three objective parameters for measurement of low-level flight will be airspeed, altitude, and number of errors. Of course, in any experiment, two of these should be held at constant values so that all variance goes into the third. If this is not done, it may be difficult to determine when the performance of one subject is better than that of another. For example, if one subject flies slowly at a high altitude and makes no errors, while another subject flies very rapidly and very low but hits several of the obstacles, it would be difficult to determine which pilot had the better performance. It is anticipated that much of the method and scoring protocols used by Westra (1982, 1984) and Westra, Simon, Collyer, and Chambers (1981) will lend themselves to simple modification for these purposes. We are selecting performance measures of obvious face validity and with which we are familiar. However, it will be our objective to focus on the retest reliability of whatever single score and/or composites that we settle upon. It will be necessary to run a pilot study with subjects in order to examine which scores to employ. Unreliable scores may indicate either poor measurement sensitivity, or poor selection of scoreable items, or instability of the task, or no variance between subjects. The latter is very unlikely to occur, but all of these except the latter will reduce the power and precision of the experiment (Cohen & Cohen, 1975; Cohen, 1977), particularly when we expect that some of the effects of interest are likely to be small. Inadequate attention to this problem (poor criterion reliability) in many applied experiments assures their failure even before they are begun, and we continue to be perplexed that very few experimenters address these issues before the

experiment. We propose to focus attention on the reliability of the criterion. Moreover, in our judgment, it is important to note that the cost, or amount, of data collected are not guarantees that they will be reliable. Reliability is an empirical question that needs to be answered prior to commitment of resources for testing equipment features.

For low-level navigation, several objective measures of performance are available. Average deviation from an ideal flight path is one possibility. Number of missed navigational checkpoints is a second measure. Finally, number of occasions that the pilot actually leaves the data base by flying off the edge is a third easily scoreable measure.

The simplest way of assessing target acquisition is to measure the number of targets observed by the pilot in flying the data base, since ground and air targets will be available throughout the data base. Target acquisition may be measured by asking or requiring subjects to report targets as they are observed. For the purpose of measuring target acquisition, it is not necessary for interaction with the target to be undertaken. The target acquisition task will emphasize detection of the presence of targets and latency rather than a recognition, discrimination, or other acuity-based decisions.

A parameter often used in assessing success in air-to-ground attack is average miss distance. It is the distance between the target and the impact of a fired weapon, and is a measure of the overall accuracy of the attack run. The problem with it is that it may be based upon too many factors to be a reliable/stable measure. It may be of value to devise measures of parts of an attack-run to achieve empirical precision. Deviation from the ideal positions and aircraft speed (and other motion factors) of firing may be of some value. Release point or the computer's solution of impact may also be good measures to use. We hope to benefit from lessons learned in previous VTRS studies where similar problems (and some solutions) are described.

## SECTION V

### PROGRAMMATIC RESEARCH METHODS

We propose a three-phase research effort of psychological experiments testing the training efficacy of helmet-mounted display features.

Phase 1 will be subjective analysis of the system. This will serve as a pilot study for Phase 2. An experienced pilot will fly the simulator using different display conditions. He will attempt an air-to-ground bombing run. He will attempt to report all targets in the slalom run. While objective measurements will be collected, our primary analysis in this pilot experiment will be from subjective reports. We have used formal questionnaires in the past (Kennedy, Frank, McCauley et al., 1984; Kennedy & Graybiel, 1965) with good success. The reliability of these reports and their validity (Wiker, Kennedy, Pepper, & McCauley, 1979a, b) has been demonstrated adequately. These are discussed in more detail in Phase 3. Comprehensive verbatim protocols will be collected concerning disorientation, vertigo, and motion sickness due to visually coupled displays, as well as illusions, eye irritation, distraction, unacceptability of the various conditions, etc. This will be a brief experiment, and indeed will be more in the form of a demonstration of feasibility of the simulation and of our planned approach. However, this phase will necessarily precede the development of an effective Phase 2 effort. It will also permit any design or methodological problems, problems in stimuli, or experimental conditions to be addressed before most of the data are collected. It will permit specific training scenarios to be defined and refined for Phase 2 and 3 efforts.

Between Phase 1 and 2, extensive preliminary work will be undertaken in 4-6 subjects in order to assure the reliability of the tasks and the elements which are scored. Some of this work may begin in Phase 1. Some information should be available from previous VTRS research, and liberal use of these data are recommended. Conceivably, a coordinated effort could be run between these task requirements and at-the-time ongoing VTRS research to constitute a combined or piggy-back experiment.

Phase 2 will involve embedded performance tests of the system. Training scenarios involving approach and ground interaction tasks will be performed under the various display conditions. Experimental subjects will be pilots, and include equal numbers of instructors and students. Ten subjects at each level will be required. The display conditions will be treated as within-subject factors in this experiment, and each subject will participate in numerous replications of the

experiment, each of which will include all display conditions. In each replication, display conditions will occur in a random order of presentation. Sequential effects of experience with a scenario will be controlled by completing numerous replications of the experiment under each display condition. In one analysis, median performance values in a replication will be used as the subject's observations for that dependent variable. The data will be analyzed using multivariate and univariate analyses of variance. Potential of the VDRT for training low-level flight, navigation, and air-to-ground approach will be measured in terms of deviation from ideal flight path, minimum altitude achieved, and average miss distance. Some of the ground attack approaches may be sufficiently difficult that, under some display conditions, complete misses of the flight path will be attained, rendering scoring highly objective. Potential of the VDRT for target acquisition, particularly in air-to-surface scenarios, will be measured in terms of number and latency of targets acquired, evasion of anti-aircraft, and average miss distance. It is expected that in order to improve reliability, blocking (averaging) of trials may be necessary for some measures.

Though Phase 2 is essentially a performance study, it will include expert and novice pilots. Some information will be provided concerning the nature of transfer-of-training functions that are likely to be obtained in the Phase 3 quasi-transfer-of-training experiments. Performance studies have numerous advantages as preliminary research over transfer-of-training studies because the conditions of interest are within subjects, and differences between subjects are controlled. In any transfer-of-training experiment in which few subjects participate in each display condition, there is the possibility of individual differences compromising the validity of results. In our Phase 2 studies, large sample statistics can be employed. Design and interpretation of our Phase 3 transfer-of-training studies may depend in large part upon the results of this performance study.

Phase 3 will be a quasi-transfer-of-training study. Simulator to airplane transfer-of-training studies are often considered to be the final and definitive way of evaluating simulator training effectiveness. However, transfer studies are expensive, difficult to conduct properly, and occasionally present unacceptable risks to study participants. Most of the research studies performed at the Visual Technology Research Simulator (VTRS) are quasi-transfer studies (Lintern, Wightman, & Westra, 1984; Westra, 1982). These studies use between-subject repeated-measures designs, in which simulator equipment features constitute the experimental conditions. After completing a series of training trials in the various experimental conditions, all subjects complete a series of trials in a particular simulator configuration assigned as the criterion condition. The criterion condition is most often the simulator configuration which most closely resembles the actual

aircraft. Also, one of the simulator training conditions is usually the criterion configuration. This training condition allows inferences to be made about the efficacy of the various simulator configurations relative to actual inflight training. Quasi-transfer studies are often seen as a way of screening variables for transfer studies, since transfer studies will be more expensive and because scheduling and other difficulties are conducted at some risk of ever being completed. For this purpose, we believe quasi-transfer studies are preferable to transfer studies because we will have better control of non-experimental variables and conditions, and it will permit more reliable and valid measurement of performance. Thus, for some criterion tasks, the quasi-transfer paradigm may detect real differences in training methods that would be missed in a transfer study because of measurement problems. It is our judgment that the better precision of quasi-transfer studies will dictate that they be considered for Phase 3 and that transfer to an operational condition only be considered if stability and reliability of performance measurement metrics vastly exceed expectations.

The variables which would be investigated in the Phase 3 quasi-transfer studies would be those which have been shown to influence performance in the Phase 2 experiments. The rationale for this approach is that variables that do not affect performance of either novices or experts are unlikely to produce differential effects in a transfer-of-training paradigm (Westra, 1982; Simon & Roscoe, 1981; see also Jones, Black, & Johnson, in press, for related views concerning task analysis). Phase 3 experiments will be framed in the economical multifactor designs of Simon (1973, 1977).

## SECTION VI

### TRAINING EFFICACY EXPERIMENTS

#### COMPUTER-GENERATED SYNTHETIC IMAGERY (CGSI)

The potential of CGSI for training efficacy lies in its ability to present natural, photographic textures upon ordinary computer-image generated (CIG) surfaces. Presentation of texture gradients and global patterns of texture motion should, according to most perception theorists, improve the perception of surface shape, scale, and distance from the observer (Beverly & Regan, in preparation, 1985; Braunstein, 1968; Gibson, Gibson, Smith, & Flock, 1959; Koenderick & van Dorn, 1976; Owen, 1982; Owen, Wolpert, Hettinger, & Warren, 1984; Runeson, 1977; Ullman, 1979). A straightforward test of the efficacy of CGSI would compare flight performance over CIG surfaces presented without and with ecological texture (i.e., a corn field, a forest).

Care has been taken in designing the data base so that CGSI imagery may be inlaid upon surfaces which the pilot is attempting to fly close to. We expect that improved low-level flight performance may result from inclusion of ecological photographic textures, such as corn fields, ravine sides, barracks, forests, etc., and will provide better surface definition. One possible location for the CGSI is upon the two surfaces of a valley in one of the possible flight paths through the southernmost model in the flight corridor in the rolling hills data base. Unenhanced surfaces of these hills are difficult to fly close to because the distance of the hill surface to the observer is difficult to perceive. Thus, there is an excellent opportunity for CGSI texture to improve flight performance. Another possible location for CGSI imagery is upon the hill separating the town from the waterfall lake. This is an 850-foot structure containing three surface planes on each side. A third possible location for CGSI emplacement is the sides of the gorge. Another possibility is upon the surfaces of the most westerly model in the flight corridor, which includes high hills surrounding a target range. The forest surrounding the target itself is yet another possibility. The initial experiment on CGSI would probably test ecological rather than analytical types of texture so that for each location we would select an appropriate ecological texture. For the rolling hills we would select grass or corn; for the hill we would select terraced crops or rock; for the sides of the gorge we would select trees, rivulets, etc., and for the target range we would select hill textures or forest textures.

The major limitation of CGSI is that each surface in a data base so embedded with texture requires additional hardware and software. Thus, it becomes necessary to make the most of each CGSI-textured surface. In addition, some types of texture may be more efficacious than others. A systematic investigation of the effects upon low-level flight performance of texture size, regularity, and orientation, and of the dimensions of the surface (length and width) is required.

There is disagreement in the research literature concerning whether the visual system uses global or local texture to identify distance and surface shape (Gibson, 1950a, b, 1979; Stevens, 1980, 1981). However, there is little question that texture is a powerful cue to such perception. Fortunately, vision researchers studying the mechanisms of stimulus registration have provided very powerful ways of characterizing texture (Caelli, 1982; Caelli & Julesz, 1979; Julesz, 1962, 1981; Julesz & Caelli, 1979). The image variables can be described in terms of linear systems analysis (see Table 1). The importance of texture variables for flight simulation performance and training may be assessed empirically.

TABLE 1. TEXTURE VARIABLES AND LEVELS OF VARIABLES FOR CGSI EXPERIMENTS

<u>Variable</u>	<u>Conditions</u>
texture element	sine and square wave gratings:
size	1, 5, 15 cycles/degrees
contrast	.5, 1.0
texture orientation	gratings, oriented parallel, and perpendicular to flight path and crossed
importance of edge gradients	crossed sine vs square wave gratings
regularity of element placement	sine wave gratings vs structured noise (random phase)
horizontal extent of texture gradient	width of CGSI surface relative to flight path
vertical extent and texture gradient	length of CGSI surface relative to flight path



The eloquence of constructing texture using analytic functions is that the performance resulting from various texture conditions can be more clearly understood in terms of texture characteristics. Since naturally occurring textures can be qualified in terms of general characteristics as size (and as spatial frequency), edges, orientation and regularity, predictions about the efficacy of ecological textures follow from results obtained with analytic functions. (While inclusion of an ecological texture may enhance performance, it is not certain what characteristic(s) of the texture was important. Another ecological texture may not produce the same results.) Any type of naturally occurring texture -- corn fields, forests, orchards, etc., may be quantified. Thus, the results of the latter experiments can be readily generalized. (Of course, one aspect of ecological texture cannot be decomposed using analytic functions. If some feature of the texture pattern can be recognized as having a familiar size then absolute distance and scale may be perceived.)

Each of these variables should be investigated at many levels in separate Phase 1 experiments. In a Phase 2 performance study, the variables will only be included at 2 or 3 levels. The ultimate goal is to perform a definitive quasi-transfer-of-training study using a fractional factorial (or economical multifactor design, cf. Simon, 1983). Only those variables showing significant Phase 2 performance effects would be included in the Phase 3 study and at only two levels.

#### HELMET-MOUNTED DISPLAY (HMD)

Helmet-mounted area of interest (AOI) displays have been proposed as a way in which to present high-detail visual imagery only where the pilot is looking (Chambers, 1982). The HMD actually includes several constituents and may be implemented in several ways (Breglia & Spooner, 1982; Breglia, Spooner, & Lobb, 1981; Spooner, 1981). A large display field called the instantaneous field of view (IFOV) is projected from the helmet. In addition, a smaller display field called the area of interest (AOI) that is also projected from the helmet presents a part of the scene (data base) at high resolution and detail. Between these fields is a contrast-blend region. The AOI may contain the same or a higher level of detail than the IFOV. The AOI/IFOV is slaved to head or to eye movements. Thus, the configurations in Table 2 may be evaluated.

Of course, there are no control conditions in Table 2 that may be used to determine whether these implementations represent improvements over simpler implementations of the VTRS system (e.g., IFOV fixed to screen center, AOI fixed to particular targets). One way to include this condition once HMD is implemented and to match equipment across experimental conditions may be to mount the HMD helmet at a fixed location near the pilot's head. Such a condition (Condition 5) would not be identical to the current implementation of the VTRS CTOL

TABLE 2. CONDITIONS IN HMD EXPERIMENTS

<u>AOI Detail</u>	<u>AOI/IFOV Slaving</u>	<u>Condition</u>
1. high	eye	IFOV and AOI moves with the eye
2. high	head	AOI and IFOV moves with the head
3. low	eye	AOI has high resolution but not high detail. AOI/IFOV moves with eyes
4. low	head	AOI has high resolution but not high detail. AOI/IFOV moves with the head

which features a target tracking AOI. However, it may be determined whether various implementations of the HMD are improvements over fixed IFOV. It is possible that HMD implementations (1, 2, 3 in Table 2) lead to performance that doesn't differ from each other, but are better than a fixed IFOV. Such comparisons may be important in determining the relative success of helmet-mounted and servo-positioned AOI displays (Neves, 1984). The fixed location condition decouples the head from the display. Such decoupling is the major advantage of the servo-positioned AOI, because it affords greater control in coordinating display positioning and CIG computed positioning. This coordination may be difficult to achieve because of length and variation of CIG computed positioning (Ricard & Harris, 1978), but may be critical to the success of HMD (cf., Leibowitz & Post, 1982). Comparison of the fixed location condition with the condition in Table 2 would determine whether head coupling (helmet mounting), in the context of the HMD's current level of display/CIG positioning correspondence, leads to display artifacts that result in performance deficits. (The advantage of head coupling, of course, is that it produces the fastest display positioning of the IFOV (Murray, Olive, Roberts, & Wynn, 1984; Sinacori, 1981). However, the inherent speed of head-coupled display positioning obligates CIG computed positioning in similar rapidity so that display and CIG positions may be accurately matched (Chambers, 1982). Some consider that when this mismatch occurs, simulator sickness results (Kennedy & Berbaum, 1984).

## SECTION VII

### POSTSIMULATION MEASURES

#### MEASURES OF POSTEFFECTS

In a series of studies which set out to survey the incidence of simulator sickness in the US Navy (Kennedy, Dutton, Ricard & Frank, 1984), there have been reports of postural disequilibrium following some exposures (cf. e.g., Crosby & Kennedy, 1982).

We propose that in order to test the subjects for possible postural disequilibrium resulting from exposure to the various simulation display conditions (Frank, Kennedy, McCauley, & Kellogg, 1983; Kennedy & Frank, 1983; Kennedy, Frank, McCauley, Bittner, Root, & Binks, 1984), experimental subjects be tested for ataxia. The tests we recommend include standing and walking. One of these, the stand-on-nonpreferred-leg (SONL) test, should be taken after each block of simulation trials. The SONL was selected from the Fregly-Graybiel battery of ataxia tests based upon its brevity, relatively high reliability, and sensitivity to high transitory effects (Thomley, Kennedy, & Bittner, 1984). Postsimulation scores will be compared to presimulation scores for each experimental condition. If time permits, one or two other tests (a standing and a walking [gait] test) will also be given (cf., Thomley et al., 1984).

If posteffects are present following termination of all simulation exposure, then the subject should be followed regularly until the posteffects subside. Previous literature suggests that whatever effects are present will be explainable on the basis of the exposure stimulus. We believe that exposure duration, field of view, magnitude of kinematics and degrees of inertial freedom are the chief determiners. We believe it is unlikely that large effects will follow short (X45 minute) exposures.

A one-page form which inquires into the severity and incidence of more than 40 signs and symptoms of motion sickness is available for use. This motion sickness symptomatology has been used with success at sea (Kennedy, Graybiel, McDonough, & Beckwith, 1968; Wiker, Kennedy, McCauley & Pepper, 1979b); in aircraft hurricanes (Kennedy, Moroney, Bale, Gregoire, & Smith, 1972); aerobatics (Kennedy & Graybiel, 1963); zero gravity (Kellogg, Kennedy, & Graybiel, 1965); and in studies of simulator sickness (Frank, Kennedy, McCauley, et al., 1984; Kennedy, Dutton, Ricard, & Frank, 1984). A scoring key is available which has predictive validity and high test-retest reliability (Wiker, Kennedy, McCauley, & Pepper, 1979a). These

questionnaires should be administered immediately after exposure and if scores greater than two (on a seven-point scale) are obtained, the individual should be followed until subsidence and for up to 24 hours. Pilots who have flown simulators have reported flashback symptoms which have persisted far after the stimulus (the simulation has been withdrawn). An automatically administered questionnaire with possibilities for branching logic is programmed on a NEC PC 8201A and is available so that subjects could be expected to test themselves at home. A hotline could be used to monitor scoring should it be deemed necessary in order to monitor the time course of subsidence.

We believe that control of exposure duration can minimize these problems, but it is considered prudent to plan for a worst case.

A Motion History Questionnaire (Kennedy & Graybiel, 1963) has been developed for use with student pilots and responses have been related to: likelihood of success in flight training (Hardacre & Kennedy, 1963); seakeeping in the Israeli Navy (Keinan, Friedland, Yithaky, & Moran, et al., 1984). We will administer this questionnaire before any simulator exposure and use the responses to interpret subsequent symptoms.

#### Subjective Debriefing Form

1. By viewing the imagery, could you tell where you were in space? Did you notice any apparent distortion of the scene space?

2. Did you find that you need different strategies for examining the scene: a) with the eye-tracking AOI; b) with the center field AOI; c) without the AOI; d) with the helmet off?

3. Did any of the display conditions seem to produce "stomach awareness" or sickness? Which conditions? Any other discomforts?

4. Was the helmet weight and center of gravity:

Not Noticeable	Noticeable But Not Detrimental	Detrimental	Very Detrimental?
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5. Did you find the projection system noisy? Was this distracting or detrimental?

6. Did the oculometer or other apparatus irritate your eyes? Please describe.

7. Was the laser speckle:

Distracting                      Very Distracting                      Not Distracting

8. The depiction of scene objects changes as they enter and exit the AOI. Did you find these changes:

Not Noticeable              Noticeable but Not Detrimental              Detrimental & Distracting              Very Detrimental & Distracting

9. Was the AOI:

Steady                      Sometimes Shaky                      Noticeably Shaky                      Very Shaky

10. Was the AOI shake:

Not Noticeable              Noticeable but Not Detrimental              Distracting              Very Distracting

11. Under what conditions did the AOI shake?

12. Was the delay between eye motion and AOI?

Not Noticeable              Noticeable but Not Detrimental              Detrimental              Very Detrimental

13. Under most display conditions, when you move your head, the display moves with it. Did you ever notice that the scene itself moved when you moved your head? If so, how often did this happen? Did you find this scene motion disturbing or distracting in any way?

## SECTION VIII

### LOGISTICS

#### SUBJECTS.

One highly experienced pilot will be required for Phase 1 studies. For Phase 2, ten student pilots and ten instructors (or other experienced pilots) will be required. The number of pilots required for Phase 3 experimentation will depend on how many of the Phase 2 conditions are judged to be important for further study. However, at least two subjects will be required per group in the Phase 3 economical multifactor, fractional factorial quasi-transfer design. Between Phase 1 and 2, 4-6 subjects will need to be tested to ascertain stability and reliability of all the stimulus conditions. We would like to suspend judgment about this part of the study until Phase 1 is well underway and the data from ongoing VTRS studies are fully analyzed and have been discussed with us.

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## APPENDIX A

### CURRENT DEVELOPMENT OF THE ROLLING HILLS DATA BASE

The data bases which will be used in VDRT experimentation are currently under development by Allen Mathews and several others at NTEC. These data bases are designed so as to fit within the VTRS coordinate system which is arranged to encompass the Norfolk Bay area. One of these two data bases was nearing completion at the time of this report. The other data base, which will abutt the west side of the first data base, will be a generally mountainous environment and will include the large structures already mentioned, i.e., the mountain followed by the lake and reservoir dam. Both of these data bases will be designed so as to capitalize upon a new VTRS-CGSI feature which will allow the same data base to be loaded into consecutive coordinates. Thus, for example, the same data base could be repeated nine times in a three-by-three matrix, permitting continuous flight across a much larger area.

The data base currently under development, henceforth referred to as the "rolling hills" data base, is 75,000 feet long in the north-south direction, and 50,000 feet wide in the east-west direction. The rolling hills is designed so that the principal flight paths run through approximately 75,000 feet of the data base. Thus, there is a corridor of high-detail imagery which begins at the south end of the data base, runs north for perhaps 50,000 feet, and then turns west for another 20,000 feet. The corridor itself is 10,000 feet wide. Three rectangular areas outside of this corridor are west and south of the corridor, east of the corridor, and north of the corridor. Each of these areas is represented by a single model which depicts low hills ranging from zero to 500 feet in height. (A data base may contain 16 separate models, each of which occupies a rectangular area of the data base. Within each model there may be 16 different objects, either two- or three-dimensional. Thus, there are approximately 16 hills in each of the three areas bounding the central L-shaped flight corridor.) The three areas surrounding the flight corridor will be presented as fields in the high level of detail data base. The L-shaped flight corridor is represented by 13 consecutive data base models. For convenience, we will follow the flight path starting at the south end, but the data base permits equally useful flight scenarios from the opposite end. Beginning at the south end, the first model depicts low hills ranging from 200-300 feet in elevation variation. The next data base further north depicts a town lying at the northeast end of a valley. There is also a small lake in this valley and a house on a hill on the west side of this data base. The town includes a church in the middle of a square and four houses. The third data base includes a tall structure, 800 feet above the valley, followed by a lake which is bounded on each side by

taller structures. It is bounded on the right by forest and is followed by a waterfall which drops approximately 400 feet to a small river which winds around several objects in the valley below.

The lake, waterfall, and river flow north. The lake, the forest, the waterfall, and the winding river are bounded on each side by 500-800 foot hills. The next section of the data base has been called the gorge because it includes a river which cuts through the hills within that part of the data base. The flight path is assumed to follow the river through this part of the data base. The gorge makes two sharp turns so that it first runs northeast, then turns west, then turns south and finally turns toward the west. The gorge actually includes two rivers that meet in the middle of the gorge between the gorge's turn west and its turn south at a watercourse that flows directly north through the hills into a lake. This watercourse is the confluence of the river flowing northeast and turning west and the river flowing east, turning north and then east again. The gorge's final turn west is around a hill, 400-500 feet high, which has a house at the top. There is a road running from this house down into the gorge and then the road lies parallel to the river which flows east. Further east there is a farmhouse and barn between the river and this road. The road then crosses the river by way of a 100-foot high bridge. Next, there is a waterfall, followed by another bridge by which the road turns and continues on north. At this point, a turn south would allow us to follow the river toward its source which is a lake. However, the flight path is assumed to continue on west. The final model in the flight path corridor depicts a valley surrounded by high hills, 900 feet in height. At the north end of this flat valley floor is a target range which is surrounded by trees on the east and west sides. In the next data base, which includes the mountain range, will continue the flight path as it leaves the west side of the rolling hills data base.

APPENDIX B

DESIGN AND SCHEMATIC OF PROPOSAL DATA BASE

The following diagrams depict various parts of the rolling hills data base.

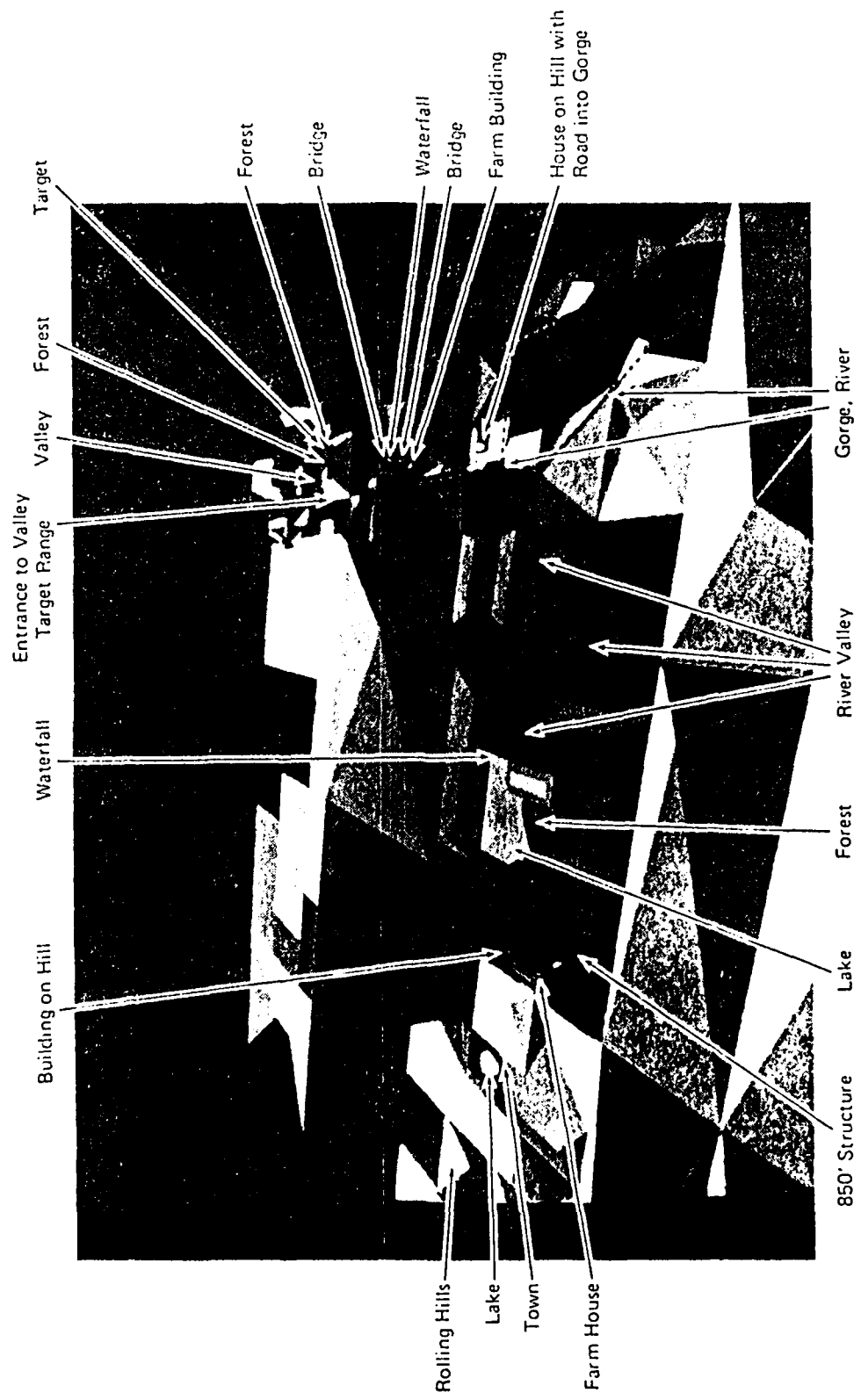


Figure B-1. The Rolling Hills Data Base - Plan View



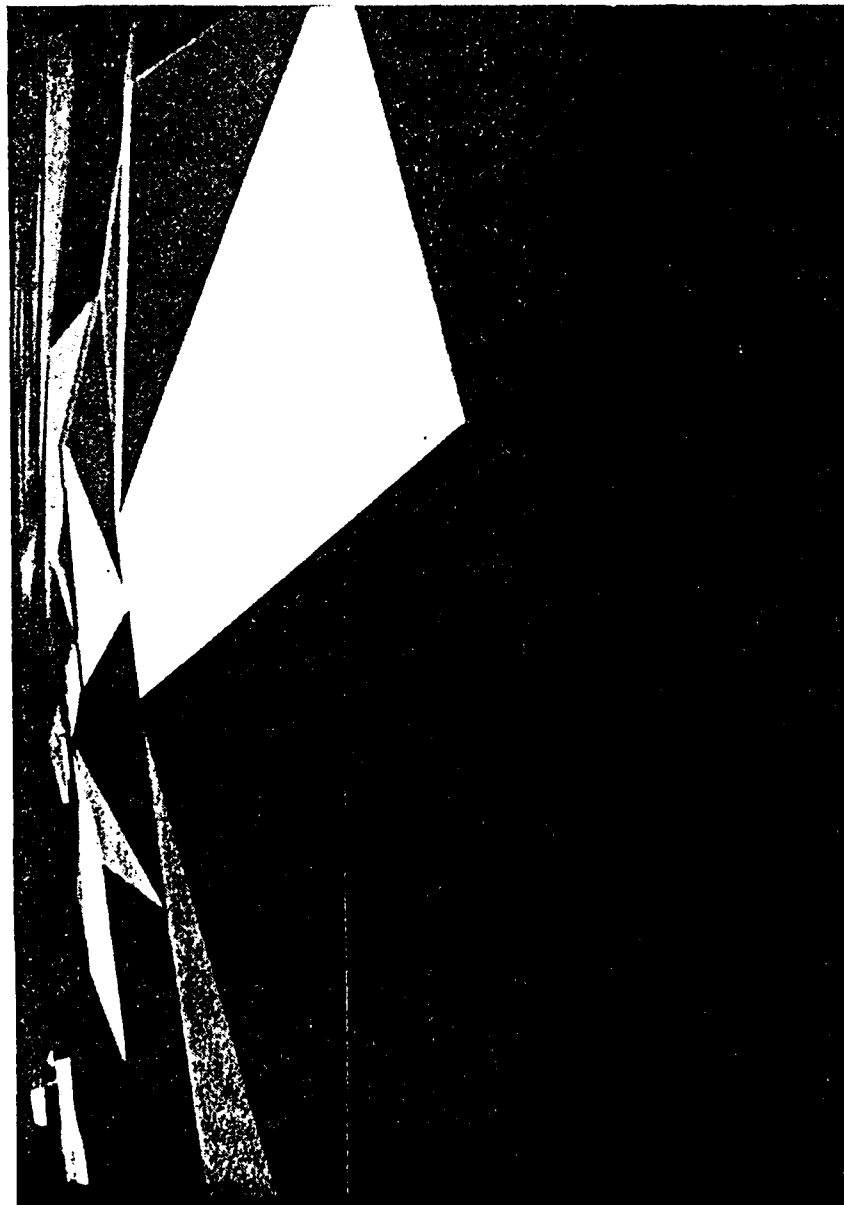


Figure B-2. Rolling Hills Data Base. The View Looking North Over the Rolling Hills Model.



Figure E-3. Rolling Hills Data Base. The View Looking North  
in the Rolling Hills Model.

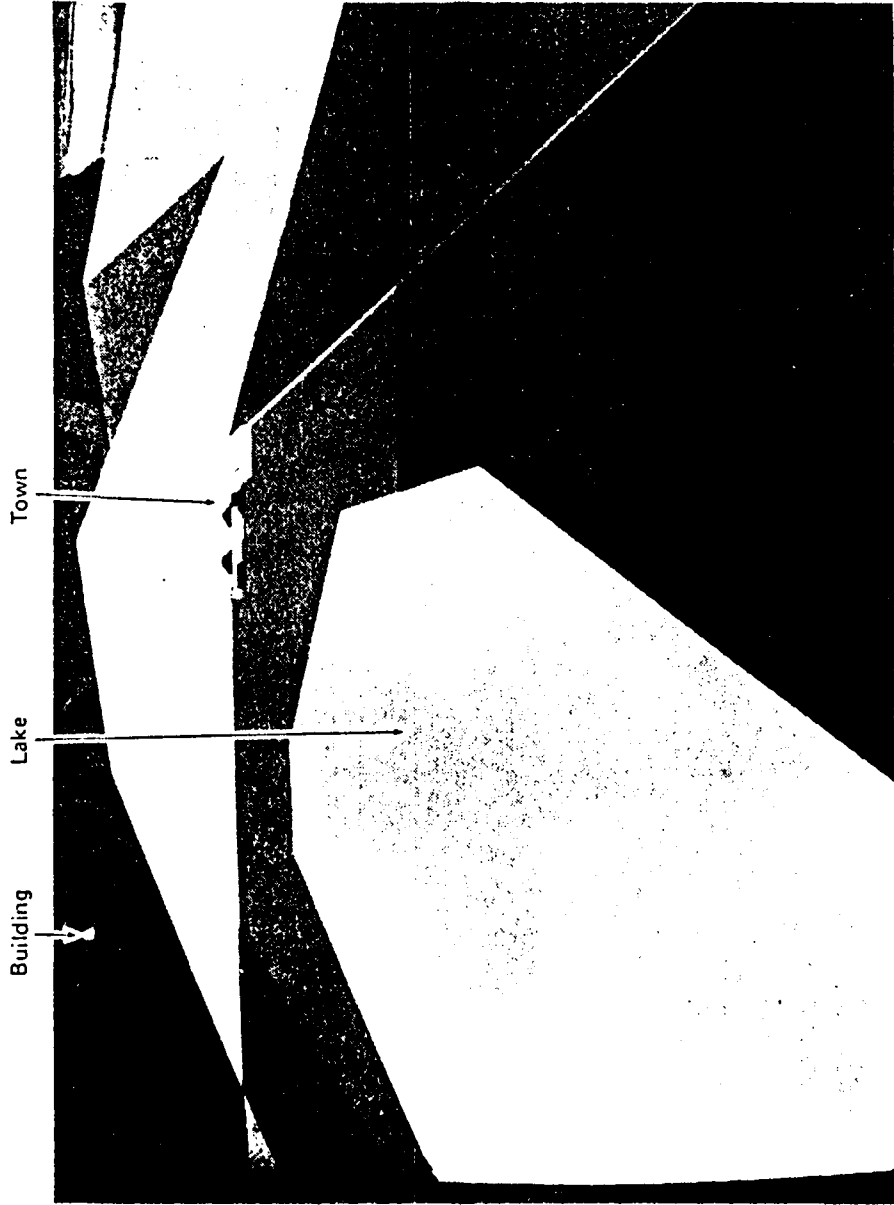


Figure B-4. Rolling Hills Data Base. The View Looking North  
Of the Lake, Town, and House on Hill.

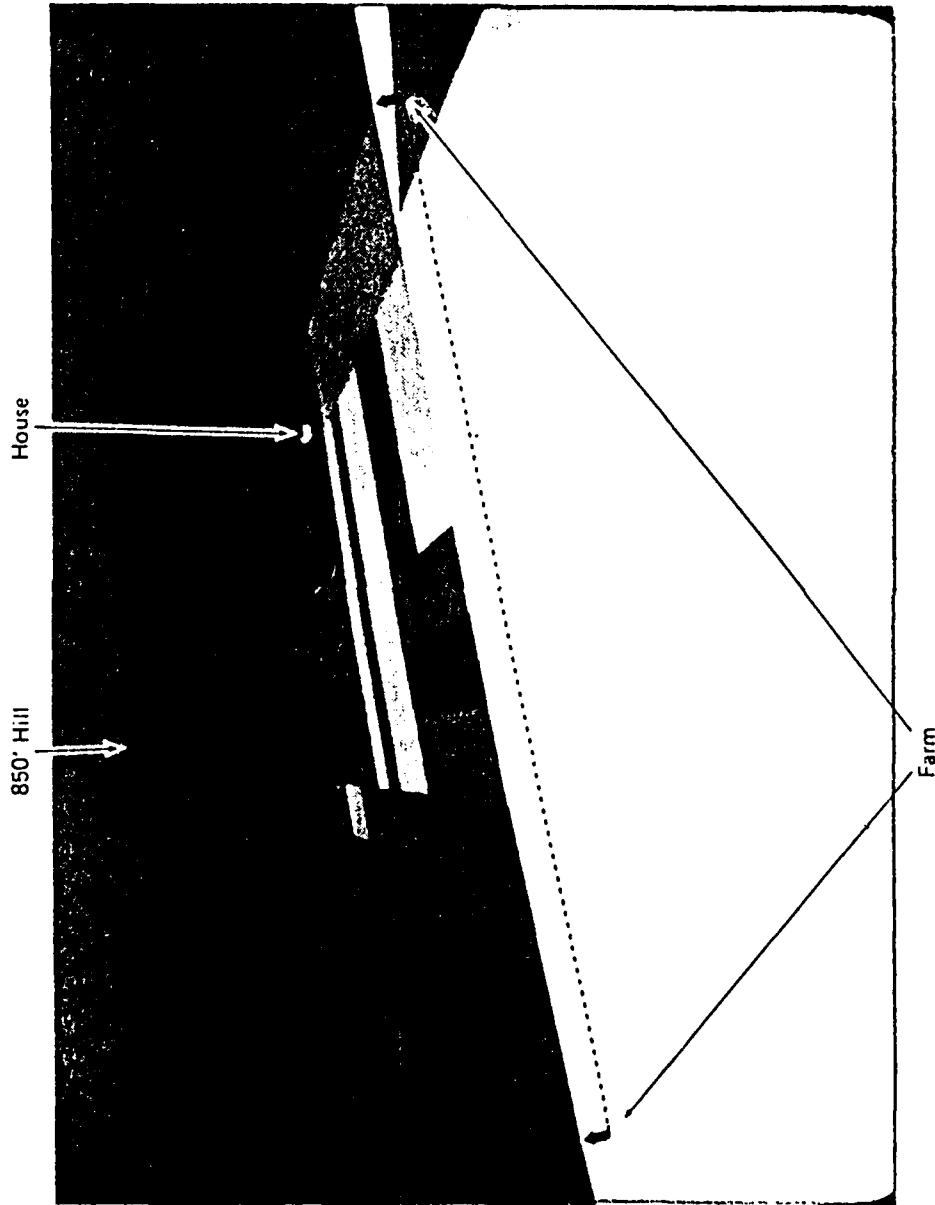


Figure B-5. Rolling Hills Data Base. View Looking North of the Farm, Farmhouse, and 850 Degree Hill.

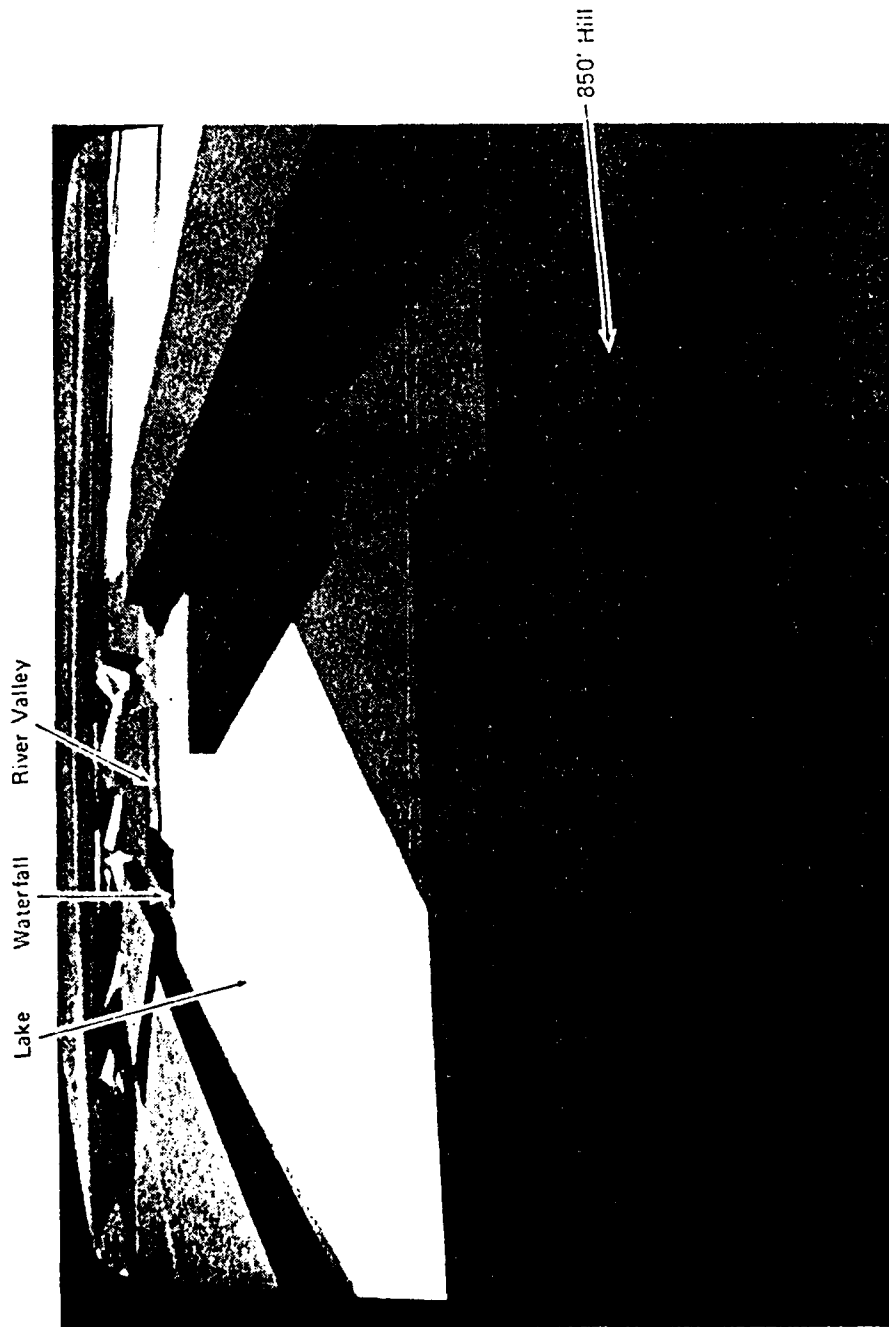


Figure B-6. Rolling Hills Data Base. The View Looking North Over the 850 Degree Hill of the Lake, Forest, and Terrain Beyond the Waterfall.

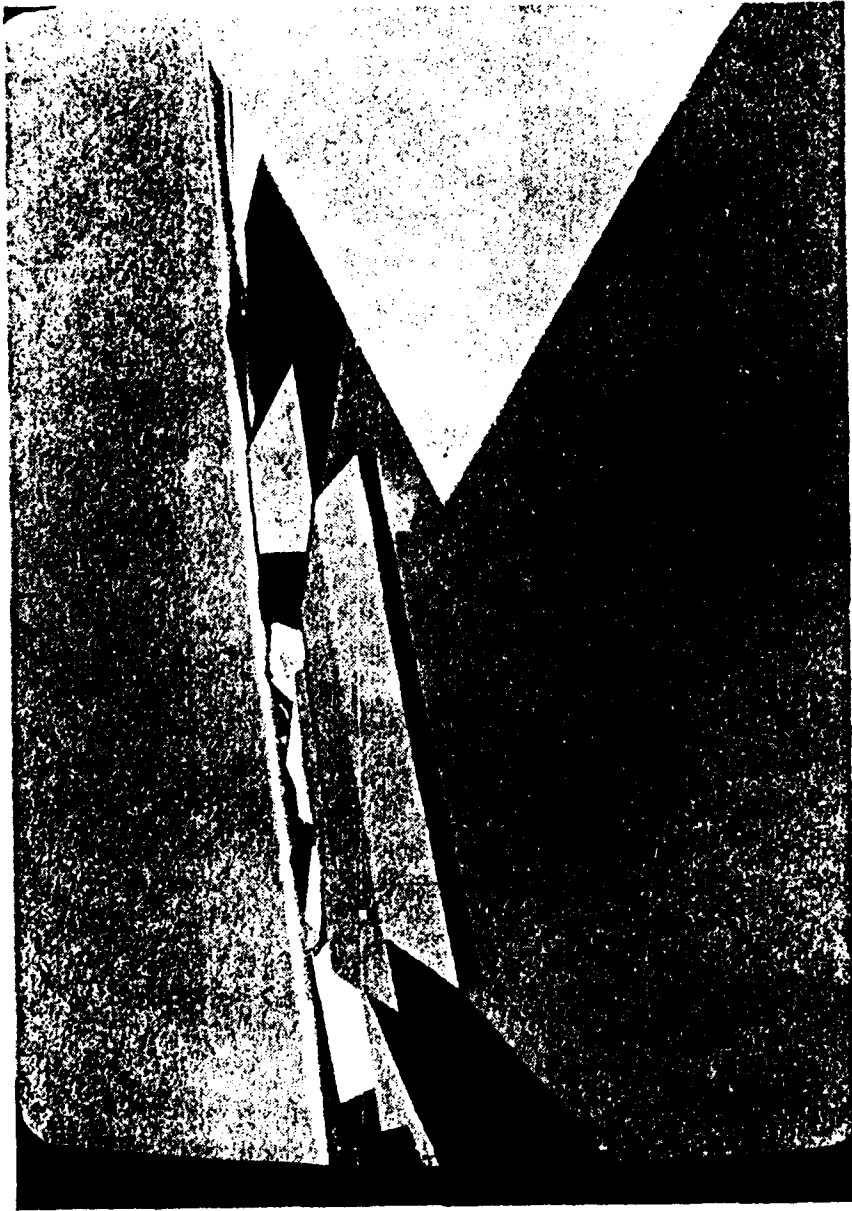


Figure B-7. Rolling Hills Data Base. View from Beyond the Waterfall, Looking North at the River Valley.



Figure B-8. Rolling Hills Data Base. View from North of the Waterfall of the River Valley and Gorge Entrance.



Figure B-9. Rolling Hills Data Base. View Looking South of the River Valley, the Waterfall, Lake, and South Corridor Structures.



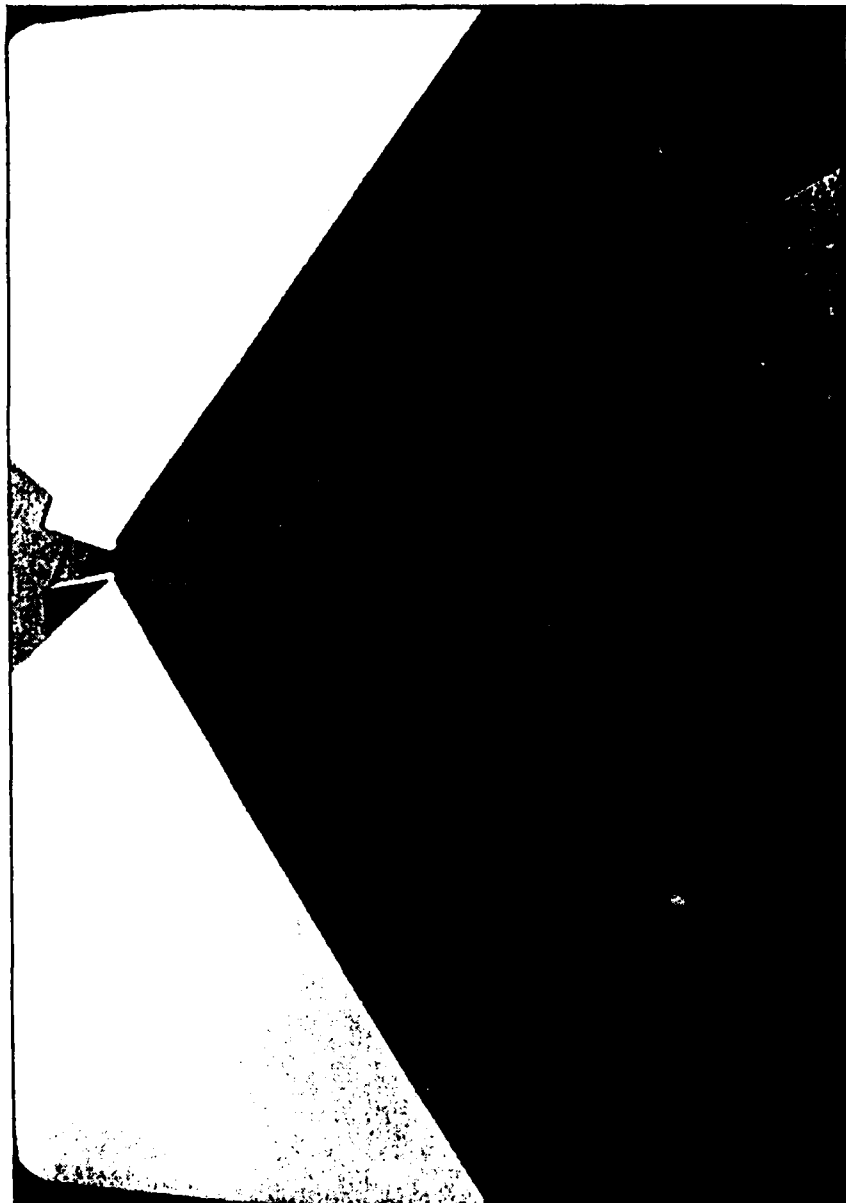


Figure B-10. Rolling Hills Data Base. The View Looking Northeast into the Gorge/River.

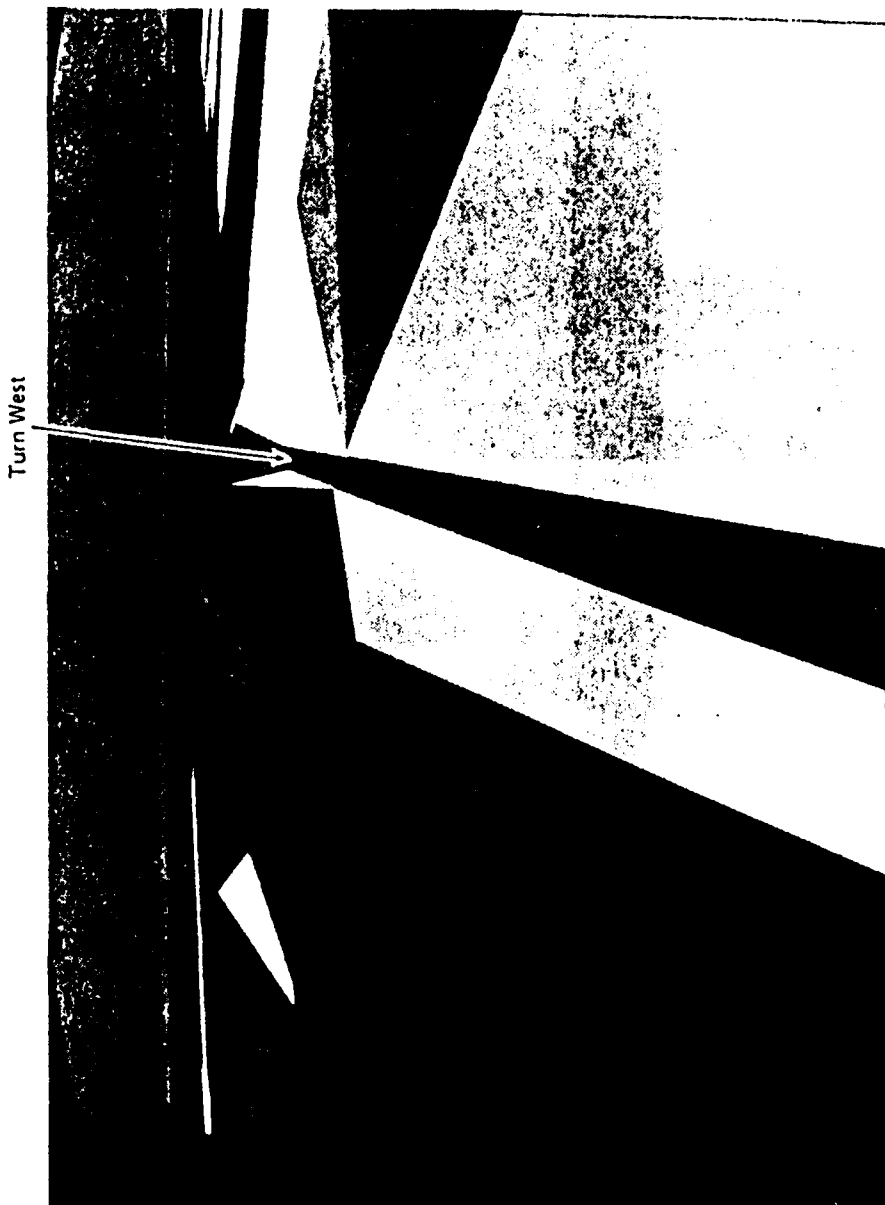


Figure B-11. Rolling Hills Data Base. The View Looking North of the Gorge Showing the Turn West.

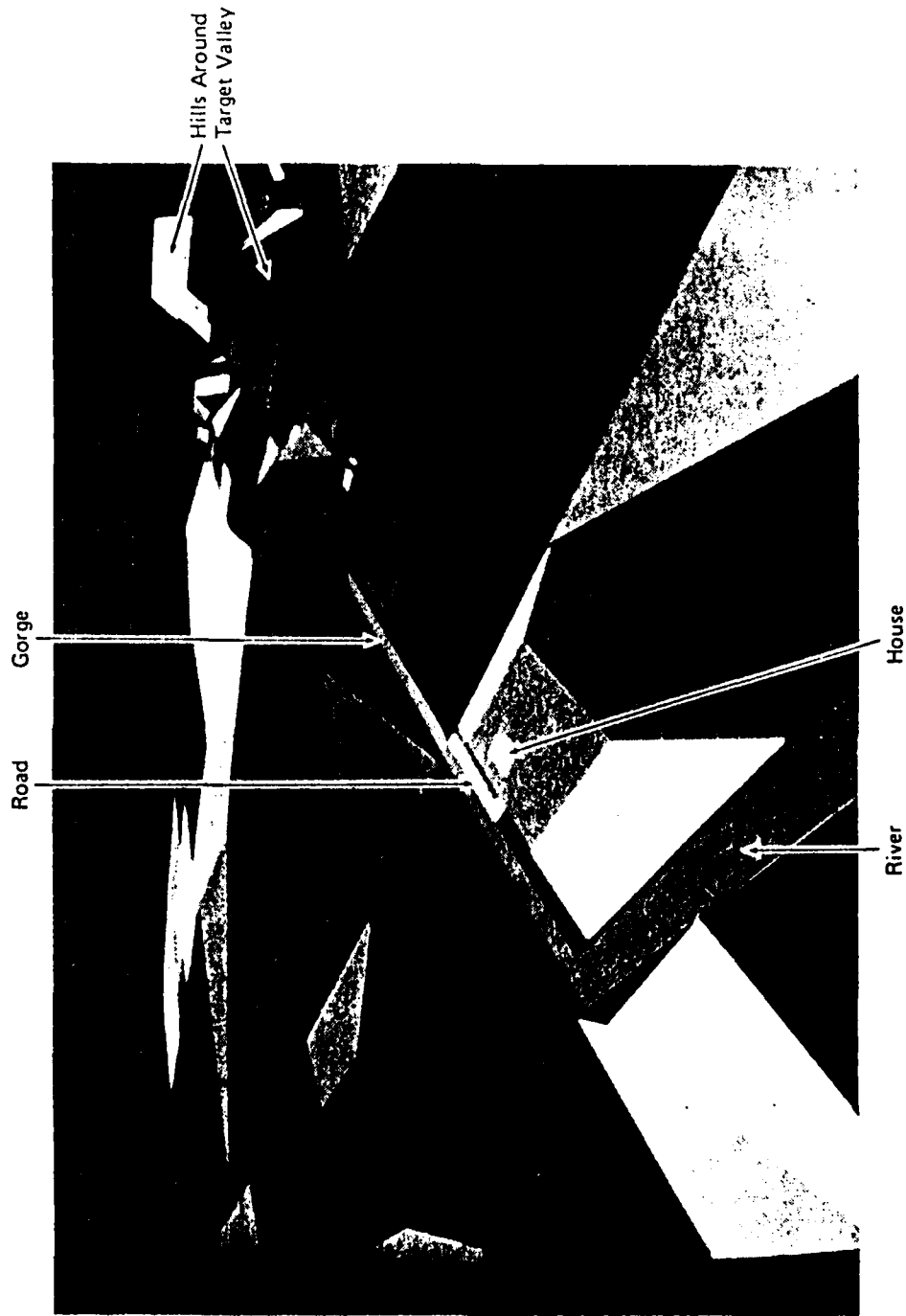


Figure B-12. Rolling Hills Data Base. View Looking Southwest of the Gorge and River, Hill House, Farm Building, and Target Valley.

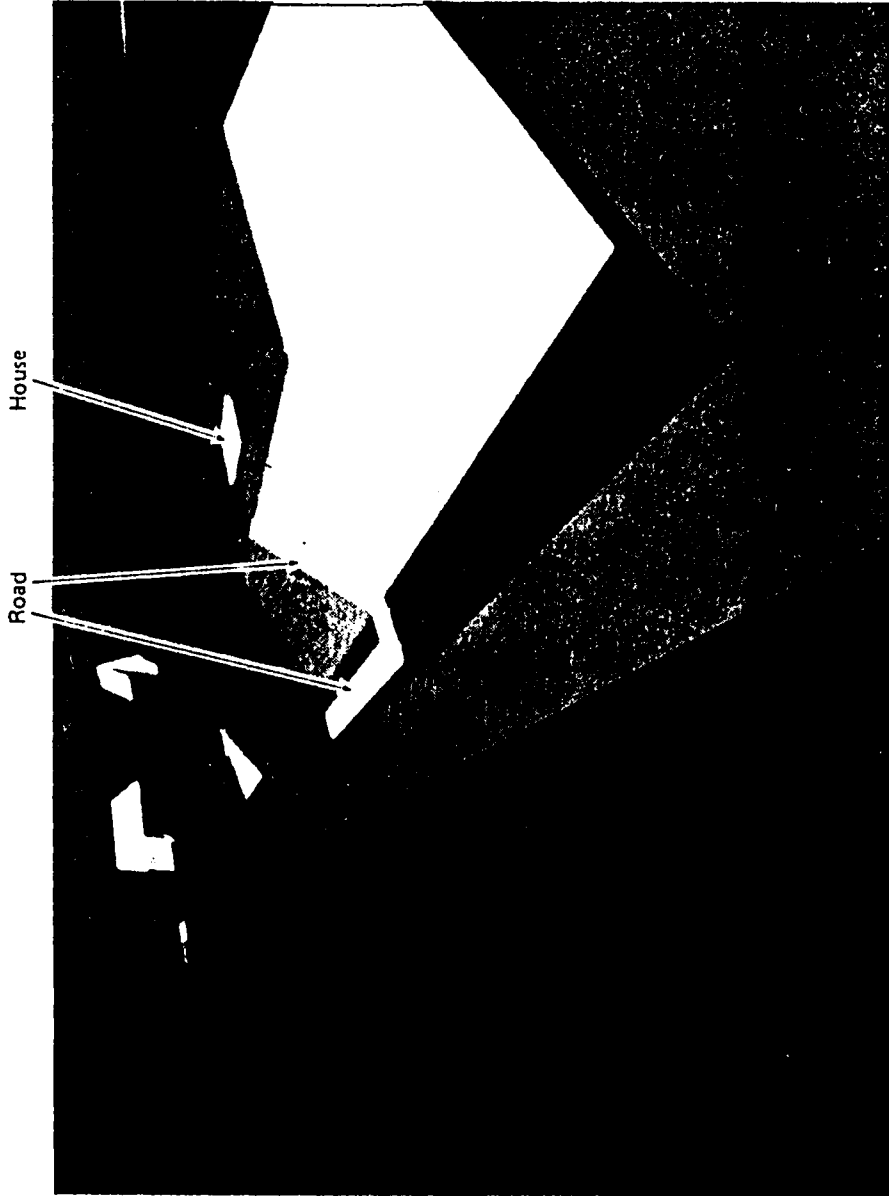


Figure B-13. Rolling Hills Data Base. View Looking West of the Hill House and Gorge.

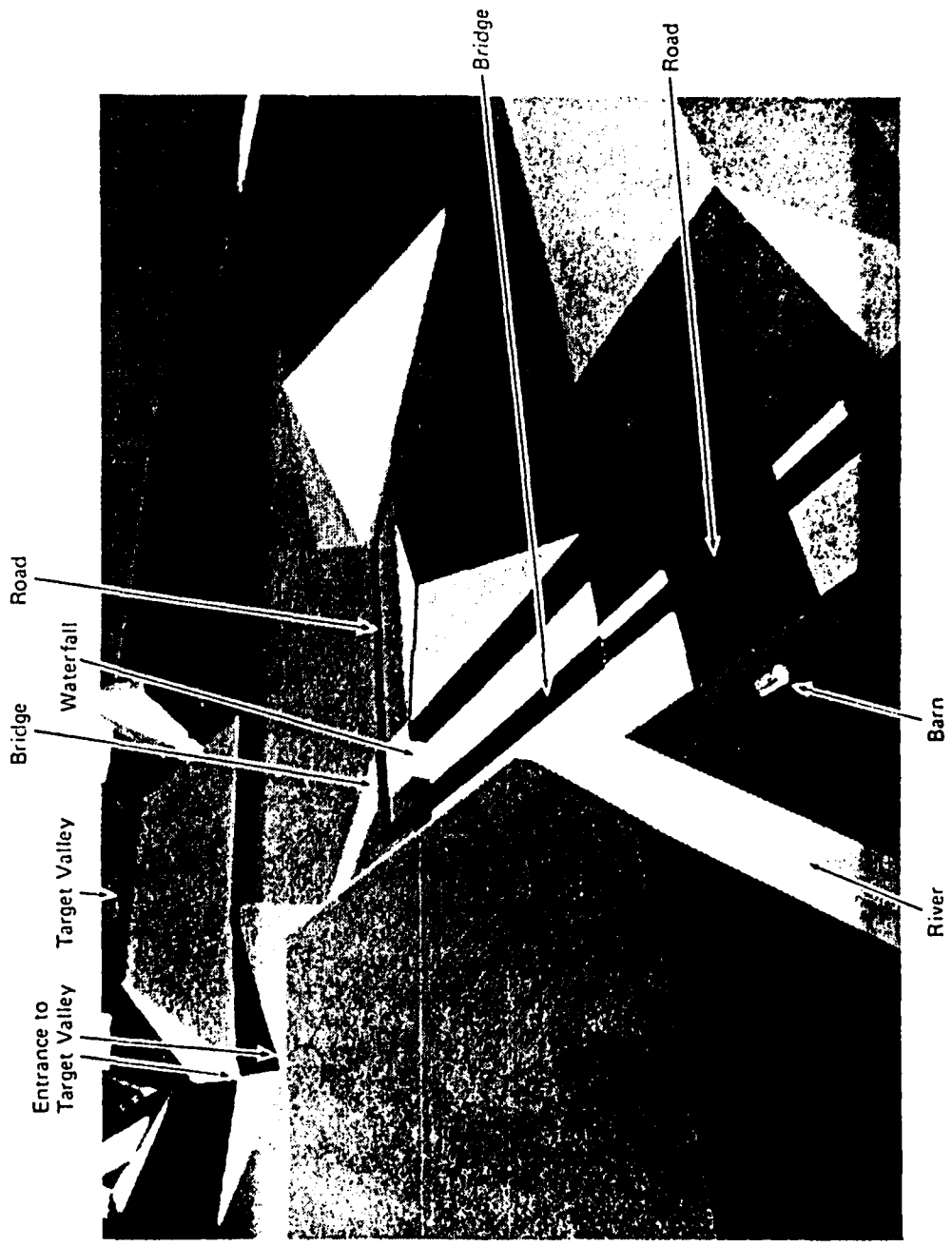


Figure B-14. Rolling Hills Data Base. The View Looking West of the River, Town Building, Bridge, Waterfall, Bridge and Target Valley.

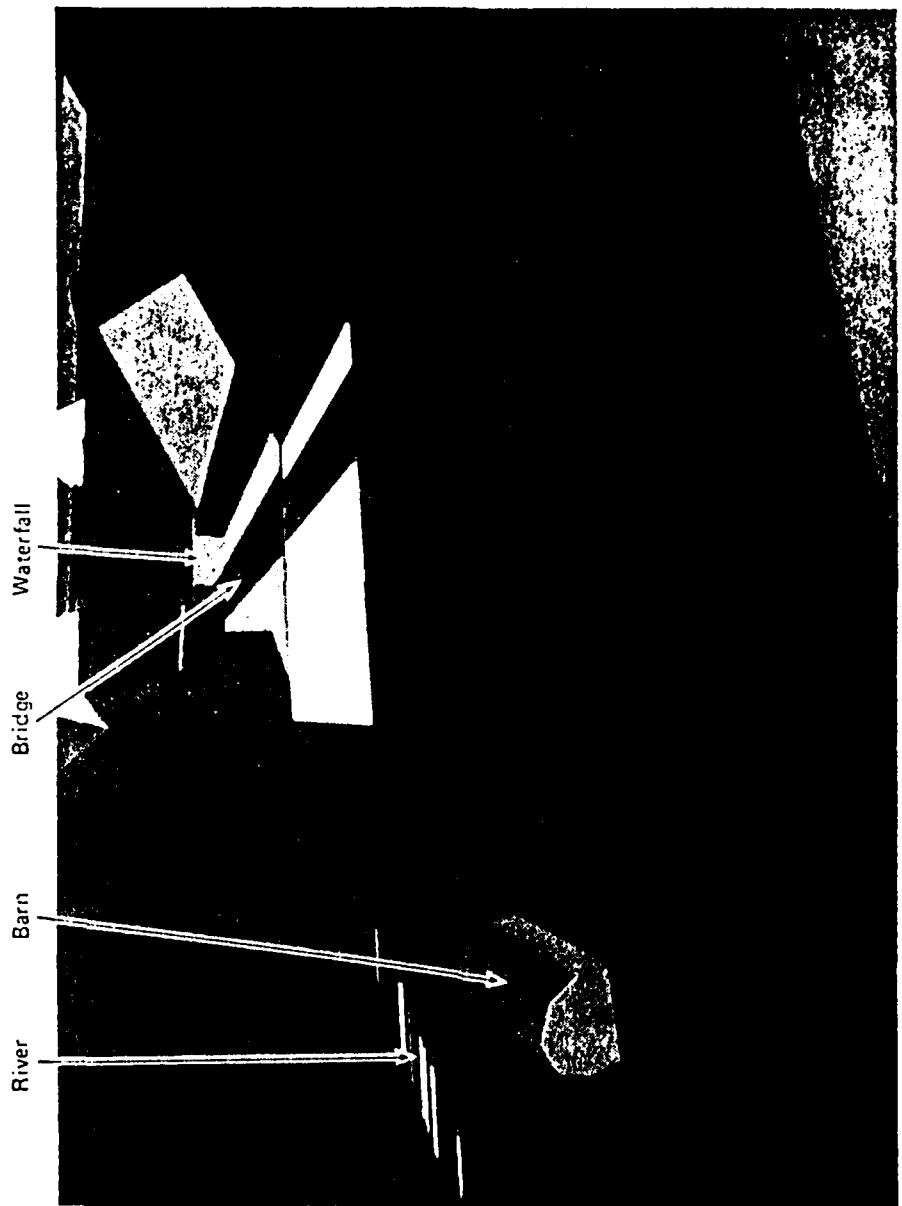


Figure B-15. Rolling Hills Data Base. View Looking West of the Barn, Bridge, and Waterfall.

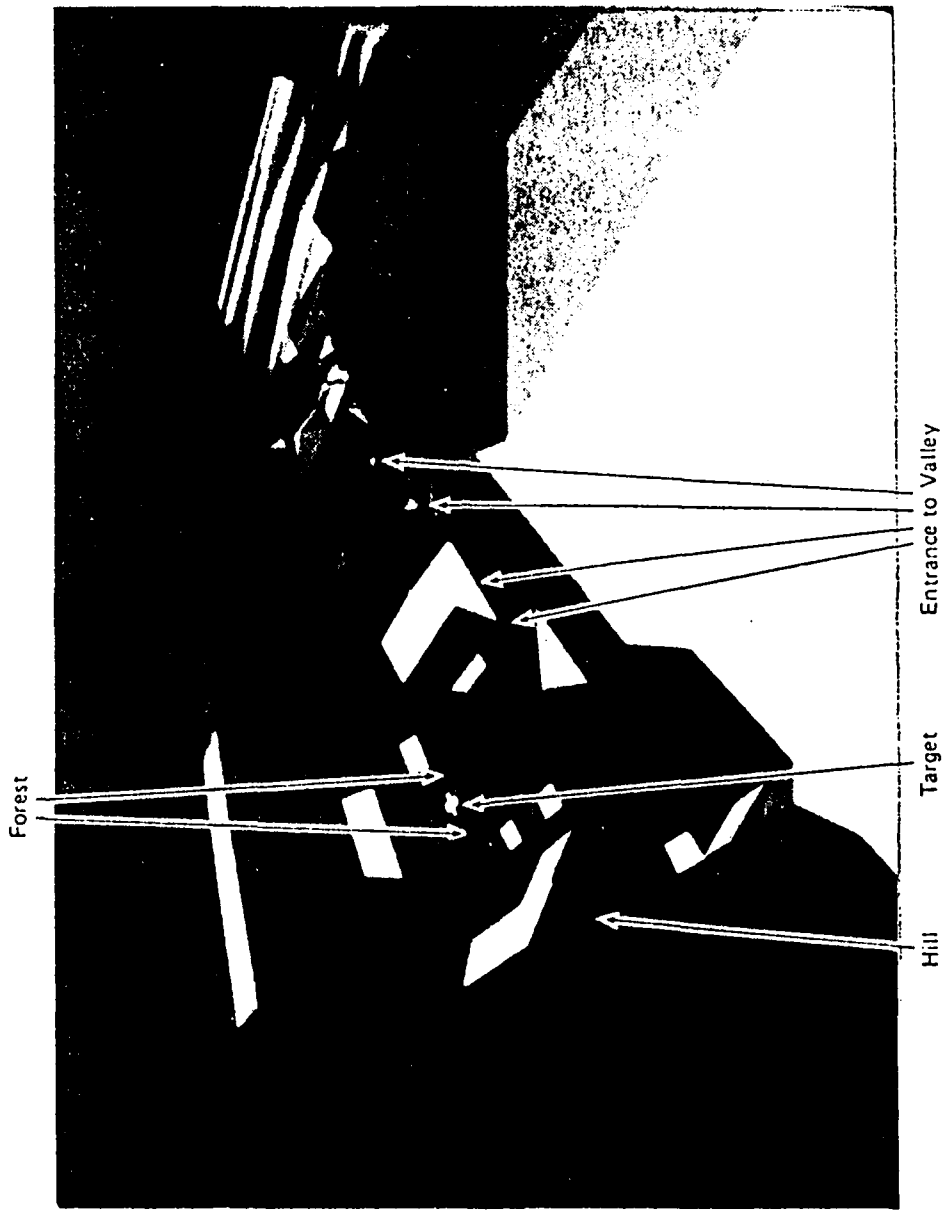


Figure B-16. Rolling Hills Data Base. View Looking East, North-east of the West Leg of the Flight Corridor, Showing the Valley Target Range.

## APPENDIX C

### A DESIGN RECOMMENDATION

The problem of popping (potentially distracting appearance and disappearance of objects between levels of detail) could be a problem when high-detail area-of-interest and low-detail surround are used. This sort of problem would show up in the objective measures between various implementation conditions. The design of the area of interest blending could be amended to more completely eliminate the problem. (This would involve temporally ramping in and out the area of interest before and after it changes location, rather than simply spatially ramping the area of interest.)



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