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Research and Analysis of Head-Directed Area-of-Interest Visual System Concepts

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Research and Analysis of Head-Directed Area-of-Interest Visual System Concepts

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"RESEARCH AND ANALYSIS OF HEAD-DIRECTED AREA-OF-INTEREST VISUAL SYSTEM CONCEPTS"

By John B. Sinacori

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

An analysis and survey with conjecture supporting a preliminary data base design is presented. The data base is intended for use in a Computer Image Generator visual subsystem for a rotorcraft flight simulator that is used for rotorcraft systems development, not training. The approach taken was to attempt to identify the visual perception strategies used during terrain flight, survey environmental and image generation factors, and meld these into a preliminary data base design. This design is directed at Data Base developers, and hopefully will stimulate and aid their efforts to evolve such a Base that will support successful simulation of terrain flight operations.

FOREWORD

This report was prepared for the United States Army Aeromechanics Laboratory, Research and Technology Laboratories, Aviation Research and Development Command (AVRADCOM) and the Ames Research Center, National Aeronautics and Space Administration (NASA). The study was performed under NASA contract NAS2-10934 and was accomplished in a 16-month period from March 1981 through June 1982. The technical monitor for the study was Col. Arlin Deel, Army Aeromechanics Laboratory.

1.0 Introduction

An effort to define out-the-window imagery needs for Nap-of-the-Earth (NOE) flight simulation has been completed.

The background for this study lies partly in the Army's commitment to advanced rotorcraft for future military missions. In implementing this commitment, the Army has concluded that it is the interest of the government to use NASA simulation facilities to aid in the development of advanced rotorcraft. To this end, the Army and NASA have entered into an agreement to modify existing NASA simulation facilities to include the capability of conducting NOE flight research.

The needs for the visual simulation subsystem for this facility are difficult to meet because of the large fields of view utilized and high ground detail characteristic of the NOE flight environment. A concept has emerged, however, that promises to meet this goal. It utilizeds a head-directed area-of-interest in which a relatively small field-of-view is maintained before the pilot's face. The purpose of this study is to define the imagery needs for this field-of-view and the corresponding data base used to generate it, using a computer-generated-imagery (CGI)-based system.

The initial part of the effort concentrated on evolving the method to be used in defining the imagery. Subsequently, a preliminary data base was created that is suitable for producing pictures using CGI hardware currently under development.

The rest of this report is organized into sections corresponding to the elements of the study approach. These elements are briefly summarized in the following paragraphs.

Flight within the Nap-of-the-Earth involves flying behind and/or below terrain features that afford masking from threat forces. It requires a tradeoff between masked time and speed. Generally, a slower speed permits more masked time. Because the crew workload is so high, visual scanning activity is theorized to be a key factor in determining imagery needs. The suspicion is that "there is no time for sight-seeing," and every pilot gaze has a purpose and is therefore related to the pilot's problem of perceiving the visual cues that are relevant to the successful progress of the flight. It is further theorized that the combined flight dynamic capabilities of pilot and rotorcraft some-how affect the visual scan activity. From a knowledge of the scan activity, it is assumed that the reason for each gaze may be determined, and then specific objects in the field-of-view can be defined that will facilitate the necessary perception at that time.

Next, object counts, array and quality factors may be determined for these gaze times considering the intended trajectory, real terrain properties and image generation, and presentation systems characteris-tics. If this process can be conducted for several typical but chall-enging NOE flight operations (areas and tasks), the assumption is that the result would be a preliminary data base map describing typical generation data such as object location, array, number and associated appearance factors with corresponding statistics, such as edge or poly-gon count.

This report describes the use of the method outlined above, in-cluding the assumptions made, the verification offered, and some preliminary research results to provide a description of a data base suitable for image generators that will permit effective NOE flight simulation, i.e., that which preserves the control strategy, workload and performance of real flight.

2.0 Probable Visual Scan Activity and Perception Strategies

The purpose of NOE flight is to make progress toward a local and/or a longer range destination, while utilizing the terrain to enhance survivability. The crew can consist of a pilot or an integrated team of at least pilot and co-pilot/navigator/gunner. In a multiple crew rotorcraft, the pilot's duties are primarily to fly while receiving navigational instructions from the co-pilot/navigator. Once a destination has been designated, the crew selects several routes that take advantage of terrain features for masking, while permitting a speed commensurate with the desired enroute time. If the average speed falls below that needed to arrive on time, the pilot may elect to "cut corners", i.e., to increase clearances in order to increase speed. Increasing clearances may take place at other times also; for example, to make a navigational survey, to facilitate communication, or to attack or evade attacking enemy forces. To the pilot, therefore, the primary visual task with respect to out-the-window imagery is to search for, find, and fly to suitable, immediate, i.e., close-by, masked areas along the route. This must be done while maintaining small, but safe, clearances from the immediate surroundings.

It is postulated that this task, as related to NOE flight, demands the highest image detail requirement. If the detail needed to accomplish this task can be provided, then there is sufficient detail for other phases where clearances are larger. In this study, therefore, we are concerned with the imagery corresponding to areas where small-clearance NOE flight is probable.

2.1 Pilot Visual Scan Activity

The structure and possible functions of eye movements have been studied extensively. While measurement of eye movements in flight is difficult, nevertheless, some results can be found in the literature. A survey of head and eye movements was made by the author, and the results and a bibliography of references used is contained in Ref. 1.

Eye movements can be classified into two broad groups:

Saccadic movements, the rapid flicks which reposition the eye to a new gaze point. A gaze point in the visual field is one whose image formed by the eye is placed on the fovea.

Vergences, glissades (pursuit) movements. These are the slower movements used to track objects in the visual field.

The number of saccadic movements per second is roughly two, and the duration of saccades is a function of their magnitude. For the average saccadic movement of about eight degrees, the duration of the movement is about 41 msec. Assuming that blinks of 100 msec. duration occur once each second and could occur during either a saccadic or a pursuit movement, the resulting time available per dwell for perception is about 400-500 msec. There is also the possibility that many dwells in the same general area may be required, resulting in staring.

How might these dwell periods of roughly ½ second be distributed over space and for what purpose? A clue to the answers to these questions may lie in the following factors:

1) The interactive kinematic performance potential of the rotorcraft and pilot

2) The features in the immediate surroundings

3) The basic mission motivations; i.e., avoid catastrophic collisions, move forward and remain masked

4) Pilot training

5) Physical state of the pilot

6) Ambient light conditions

The interplay of these first four factors and eye movements will be shown in the following paragraphs:

During training, a rotorcraft pilot learns to judge the performance potential of his craft and himself in many ways. For example, he learns the horizontal distance in which he can stop in at a given speed, and the minimum space within which he can turn. It is hypothesized that a three-dimensional boundary exists for any given speed, weight and atmosphere (air density and wind) that defines the space available to the pilot for maneuvering. This space is attached to the rotorcraft, but is not rolled with it, and projects mostly forward in the direction of movement. It is horn-shaped, with its sides being defined by the turning radius, its top surface by pull-up acceleration, and its bottom surface by descent performance. The forward-facing open end of the horn may be closed by the stopping distance boundary. Three examples of such a boundary, for three speeds, have been computed and renditions of their shapes (right side only) are shown in Figs. 1, 2 and 3, together with the kinematic assumptions used in the calculations for each.

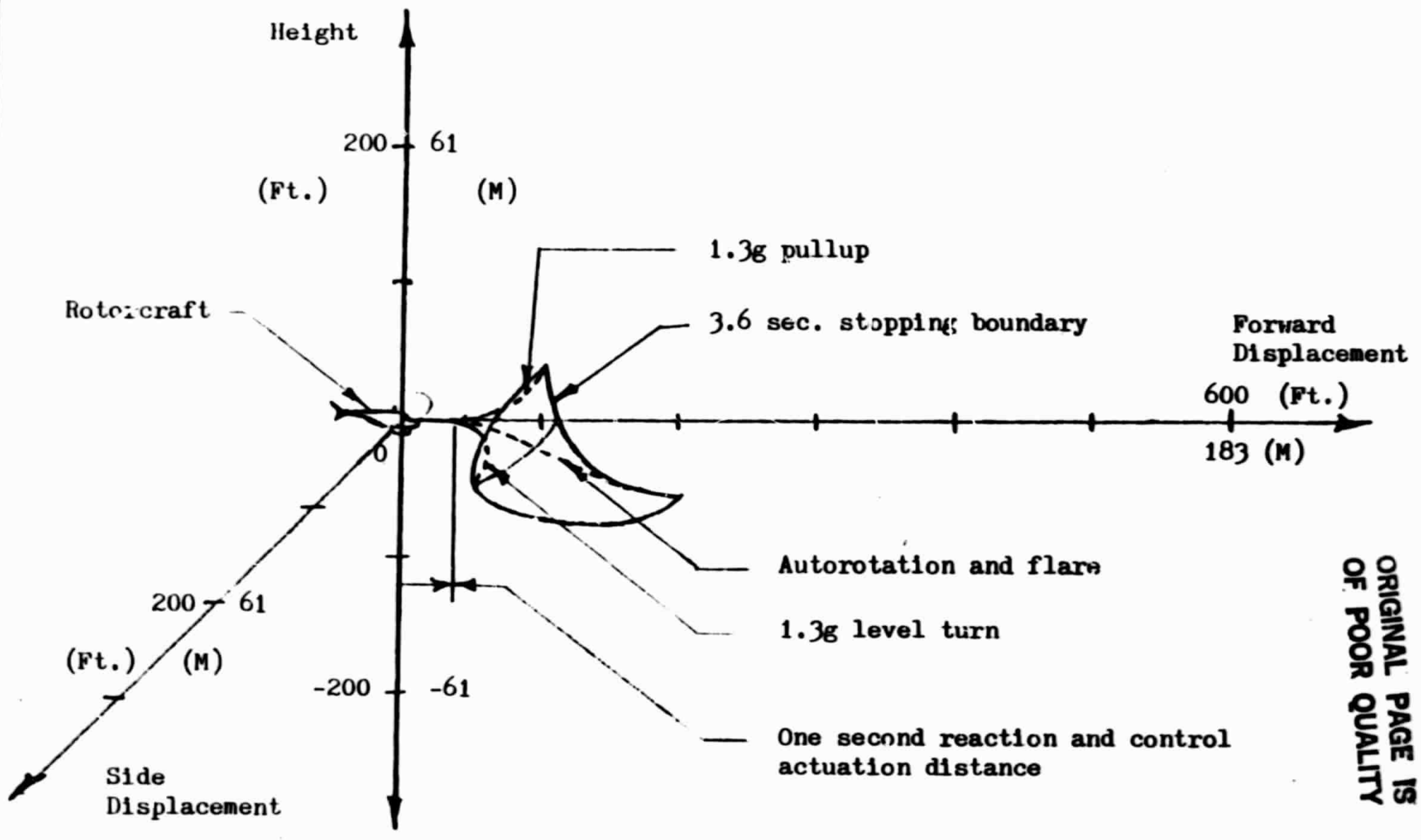

FIG. 1 Typical Rotorcraft Performance Boundary for a Speed of 25 Kts. (46.4 Km./hr.) (Right side only)

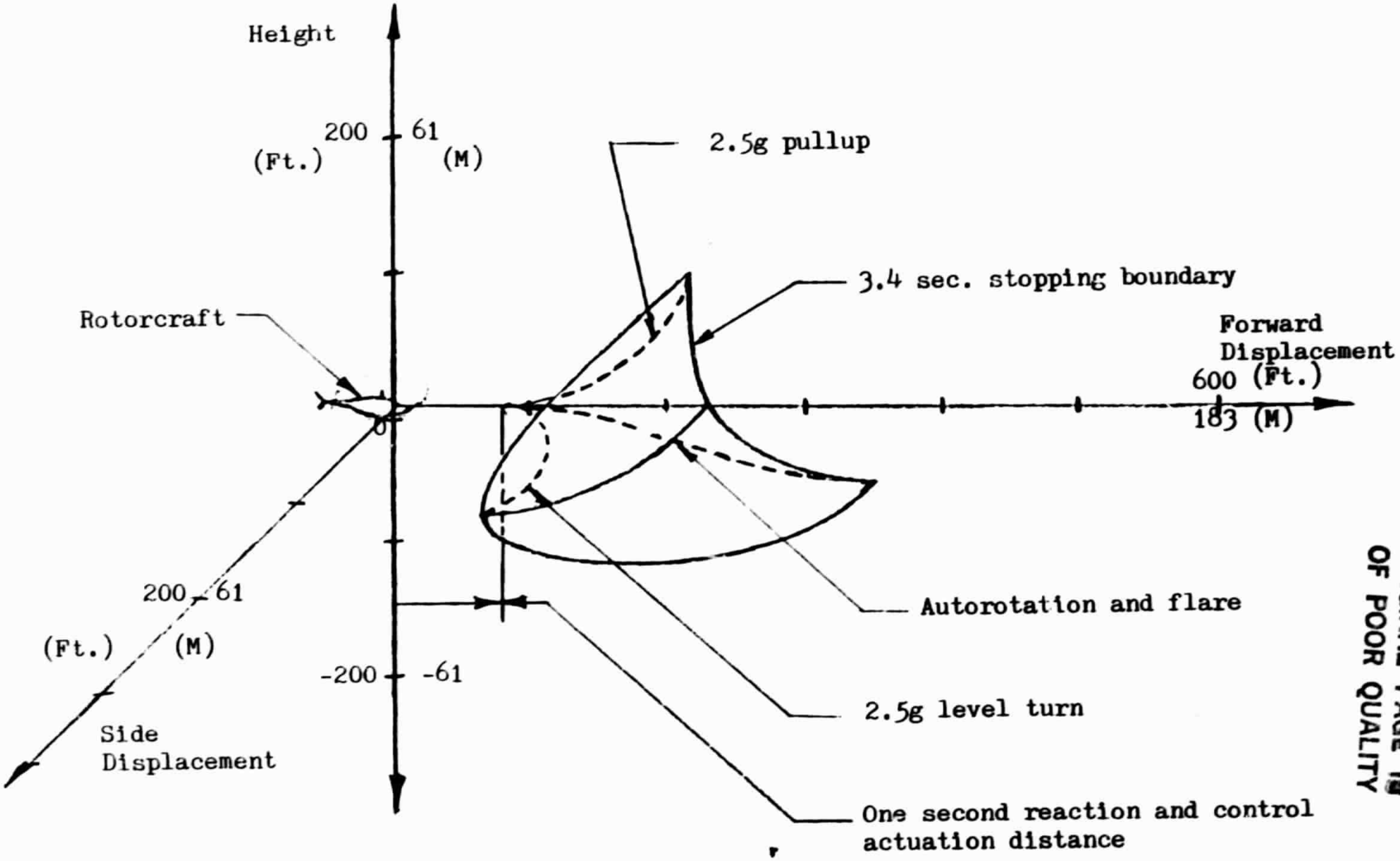

FIG. 2 Typical Rotorcraft Performance Boundary for a Speed of 50 Kts. (92.7 km./hr.) (Right side only)

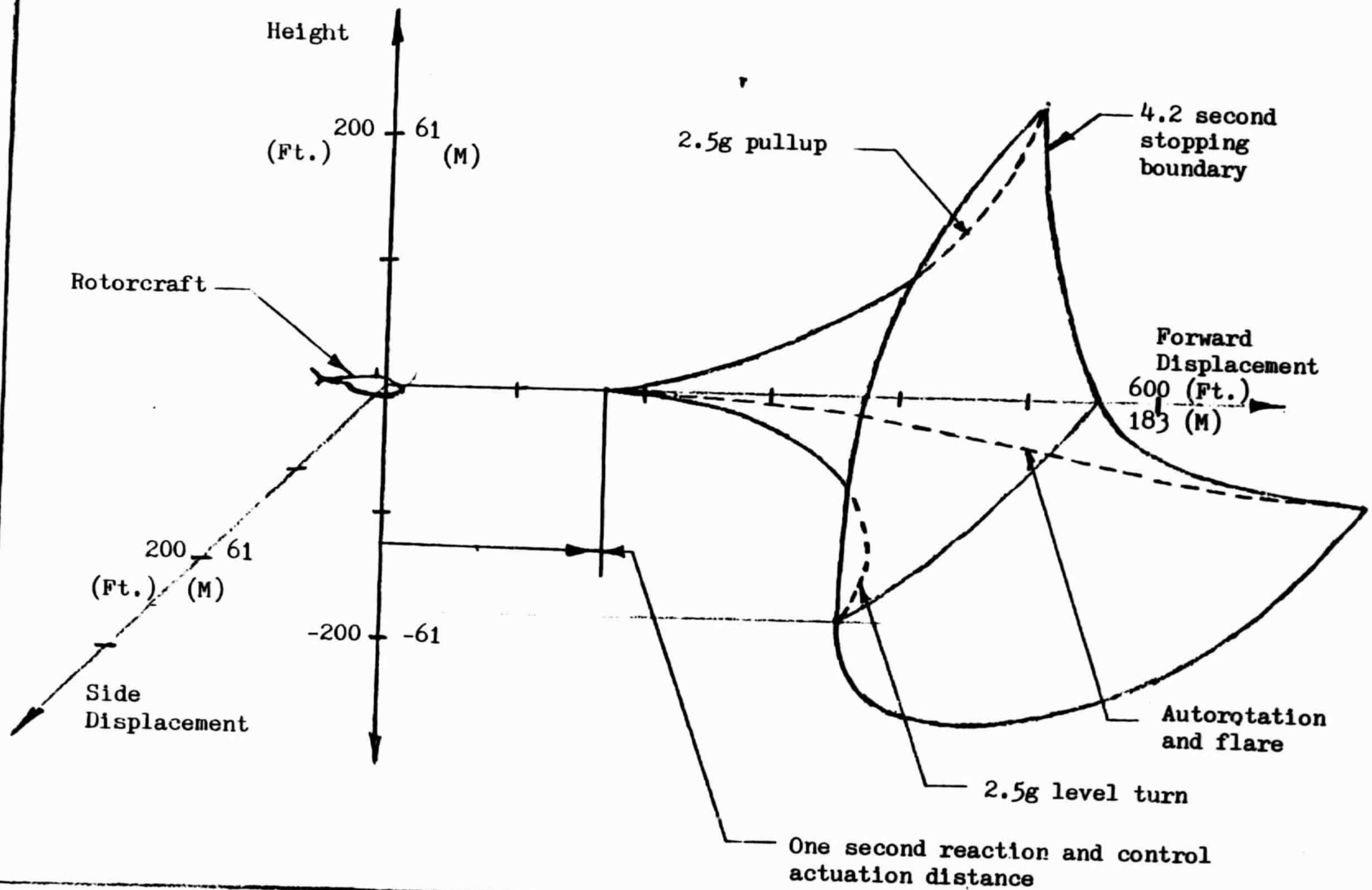

FIG. 3 Typical Rotorcraft Performance Boundary for a Speed of 100 Kts. (185.4 km./hr.) (Right side only)

The significance of these horn-shaped boundaries is that the space within it, and only within it, is available to maneuver in with an option to come to a hover at the forward face. This means that only the terrain features that enter this space are of any consequence to the flight progress, and indeed, any large object such as a hillside that enters it and fills the space between its sides, spells an imminent collision. There is another boundary of interest within the one described that is a forward extension of the rotorcraft's cross section, considering the present velocity and acceleration of the rotorcraft. Under acceleration, the latter boundary will extend forward and curve, intersecting the surface defining the stopping or hover boundary. This intersection defines the space where the rotorcraft will surely be soon, if some immediate action is not taken. If taken, the larger envelope defines the bounds of the possible places that the rotorcraft may be placed. As viewed from the initial point (pilot's eye point), the forward extremities of the boundaries define a field-of-view map that is of great interest to the pilot. For sake of reference, the field-of-view plot of the larger boundary defining the performance envelope will be termed the "envelope field," and the smaller one, the "impact field." Figure 4 shows these fields plotted for the corresponding boundaries defined in Figs. 1, 2, and 3. It is logical to expect most of the pilot gaze time to be concentrated about equally in these two fields, with the remainder diverted to outside navigational identifiers and inside displays. It is also logical to expect the pilot to prioritize his outside gaze time, mostly according to the nature of objects entering the envelope and

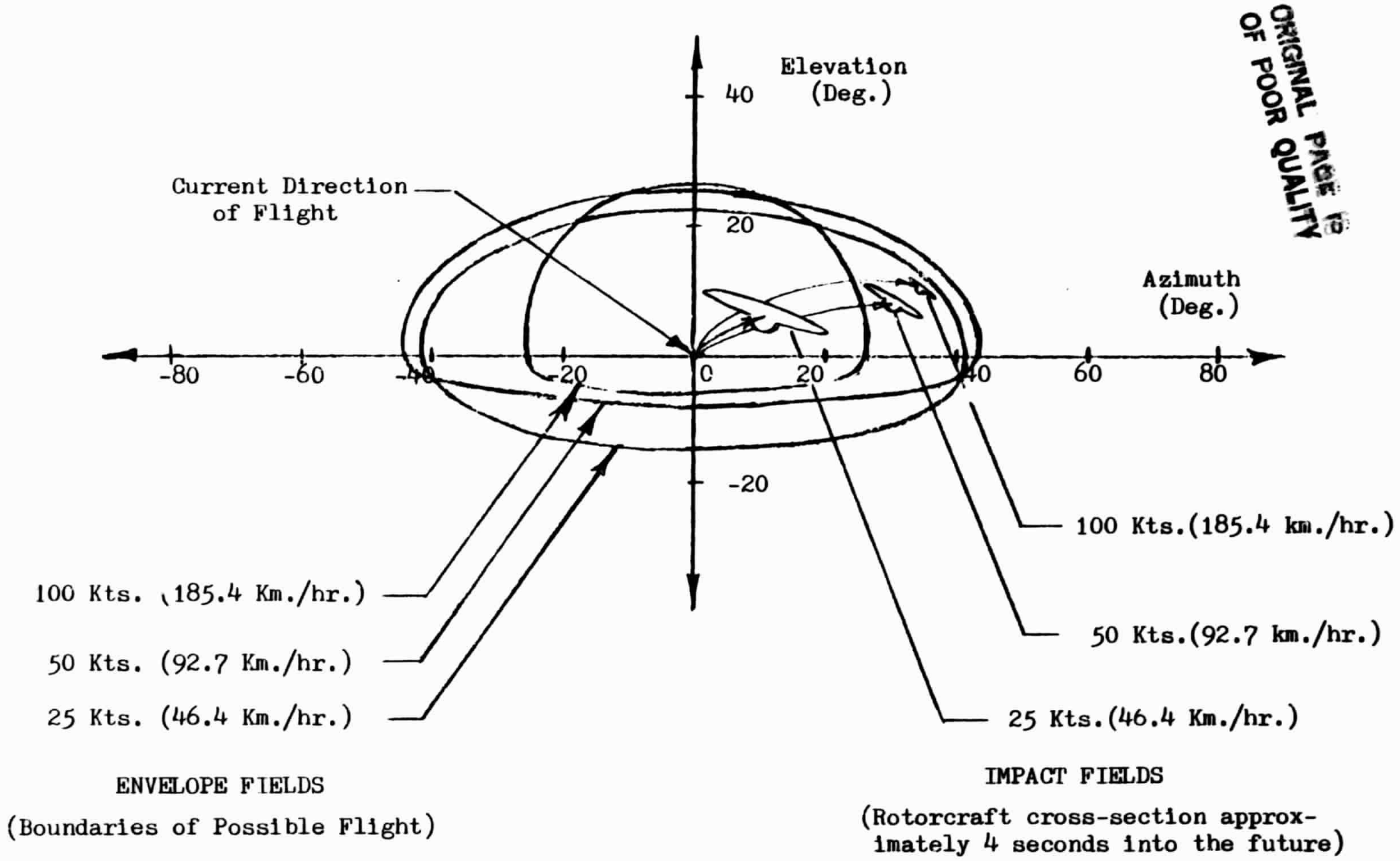

FIG. 4 Summary of Typical Rotorcraft Envelope and Impact Fields for Speeds of 25, 50 and 100 Knots (46.4, 92.7 and 185.4 Km./hr.)

Hypothesized Visual Scan Activity Model

1) First Highest Priority

Search the impact field for hazardous objects using peripheral vision to establish the impact field location, impact and passage times to objects, and clearances using motion perspective and foveal vision to detect, recognize and identify objects, if possible.

a) Closest objects
b) Tallest objects

Pilot	Co-pilot/Gunner
40%	20%
% Time	

2) Second Highest Priority

Search the envelope field for potentially masked areas in the general desired direction using foveal vision.

a) Behind ridges & rock outcroppings
b) Behind trees & vegetation
c) In depressions

Use peripheral vision and motion perspective to aid in the perception of impact and passage times to objects and clearances.

Pilot	Co-pilot/Gunner
40%	20%
% Time	

3) Third Highest Priority

Search the extra-envelope field for targets or potential threats and navigational fix features, using foveal and peripheral vision.

a) Near horizon
b) At edges of objects

Pilot	Co-pilot/Gunner
10%	35%
% Time	

4) Fourth Highest Priority

Fixate instruments and avionics displays.

a) Airspeed
b) Torquemeter
c) Radar Altimeter
d) Maps or map displays
e) Weapon panels & displays

Pilot	Co-pilot/Gunner
5 %	20%
% Time	

5) Blinks - 5% for each

FIELDS:

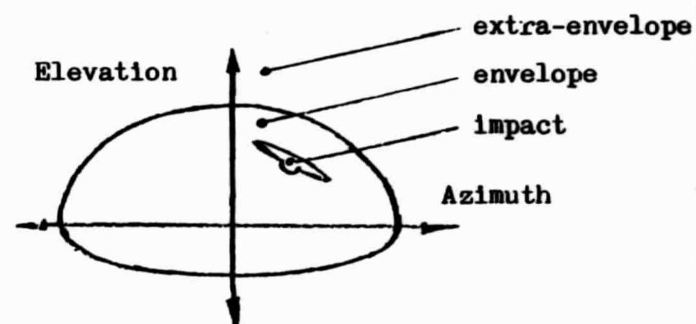

FIG. 5 Summary of a Theorized Crewmember Visual Scan Model for Point-to-Point NOE Flight

impact fields.

Figure 5 contains a plot of typical envelope and impact fields. It also shows the hypothesized dwell time the pilot will spend in each field, and the priority level he will give objects in that field. Priority level means that objects of higher priority will be fixated before objects of lower priority.

Figure 5 is essentially the hypothesized "set of rules" for determining the gaze patterns of pilots while flying NOE missions. Although of secondary concern here, the dwell times of the navigator are thought to be related to these boundaries, but complementary to those of the pilot. For a gaze time distributed uniformly over the solid angle visible from typical rotorcraft, the dwell times for navigators are those shown in the adjacent boxes. In determining the gaze pattern for a specific area, some note will be taken of experimental results reported in the literature. If necessary, the saccadic duration time as defined in Ref. 1 will also be used to account for transient times.

2.2 Perception Strategies

Because we <u>learn</u> to see, it is safe to assume that what we learn are methods for integrating visual stimuli into visual cues or visual interpretations. In the context of NOE flight, it is reasonable to expect that pilots also learn to perceive the necessary information. The more common methods thought to facilitate these perceptions may be found in the literature (Ref. 2) and are briefly summarized in the following table describing the basic mechanism, the input stimuli required, assumptions made, if any, and the resulting visual cue.

The viewpoint here is that visual perception is essentially information processing where the information is "encoded" in a spatially-unique array of light patches. These light patches may assume a variety of forms ranging from low-coherence texture* to high-coherence straight lines, and having a wide range of intensities and color. The essential information believed to be extracted from the stimuli are observer position (orientation) in space, velocity, and surface characteristics.

*Texture, as a component of appearance (of an image) is a spatial array of patches or spots with varying degrees of regularity in their size, shape, arrangement, distinctness, color and brightness. Texture gradients refers to systematic variations in the above factors over space.

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TABLE I - SUMMARY OF PERCEPTION MECHANISMS

MONOCULAR STIMULI/CUE RELATIONS			
MECHANISM	STIMULI	ASSUMPTIONS	CUE(S)
1. LINEAR PERSPECTIVE: Conversion of apparent size into relative distance and orientation[1]	An array of constant-size objects	Objects are all the same size	Shape of the array and relative orientation. Relative distance (distance of observer relative to object size)
2. AERIAL PERSPECTIVE: Conversion of object contrast into relative distance	Object contrast	Contrast variation with atmospheric scattering	Distance relative to visibility range
3. INTERPOSITION: Conversion of the view of occluded objects into object array shape and relative distance and orientation	An array of occluded objects	Non-transparency	Shape of the array, relative distance and orientation
4. SHADING: Conversion of object shadow images into object shape, relative orientation and distance	Shadows falling on the object and/or a nearby surface	Parallel rays of sunlight	Orientation of observer; orientation of object relative to surface and sun; relative distance
5. TEXTURE GRADIENT: Conversion of view of texture gradient into shape and relative distance	Array of texture on a surface	Texture properties invariant with distance and illumination	Shape of the surface orientation and relative distance
6. APPARENT/FAMILIAR SIZE: Conversion of the view of a familiar object into orientation and absolute distance	Any object or array of objects	Object is the recognizable entity it appears to be	Orientation and absolute distance

TABLE I , Cont'd.

MONOCULAR STIMULI/CUE RELATIONS			
MECHANISM	STIMULI	ASSUMPTIONS	CUE(S)
7. MOTION PERSPECTIVE, OPTIC FLOW, STREAMING, SHEAR: Conversion of the apparent angular velocity of objects into object array shape orientation and absolute time[2]	An array of objects	The array is on a rigid surface	Shape of the surface, orientation and absolute time
8. APPARENT/INTRINSIC BRIGHTNESS: Conversion of apparent brightness of point light into relative distance	An array of point lights	Intrinsic brightness of each light is the same	Shape of light array, orientation and relative distance
BINOCULAR STIMULI/CUE RELATIONS			
MECHANISM	STIMULI	ASSUMPTIONS	CUE(S)
9. ACCOMODATION/ CONVERGENCE: Conversion of eye focus and convergence responses to absolute distance	Any object	Knowledge of entrance interpupillary distance and focus relations	Absolute distance to object
10. STEREOSIS: Conversion of disparate retinal images into an impression of absolute depth	An object showing features of depth, e.g., sides	Knowledge of entrance interpupillary distance	Absolute distance to object

[1] While linear perspective pertains to cues of depth using actual or suggested lines that intersect in the background, the definition of the mechanism should be expanded to include cues resulting from any

Table I, Cont'd.

Footnote 1, Cont'd.

coherent image containing lines that involve a geometrical interpretation. This broader meaning is assumed in the rest of the report.

[2] Since the appearance of objects in a streaming optical flow field is that of an array of objects of differing angular velocity and angle, by comparing the two for an object, a sensation of time to pass each object is the result. Distances of objects, therefore, are probably perceived in terms of the absolute time remaining before passing them.

With the exception of motion perspective, it is easy to see the bases for the monocular mechanisms in the physics of the visual world. The process that creates the visual world starts with illumination from various sources such as celestial and man-made objects. The objects being illuminated have characteristics of their own that modify the incident light, such as content, reflectivity, absorptivity and shading. The content can vary widely, ranging from complex objects with high coherence permitting linear perspective and interposition effects, to low-coherence objects, such as brush, that are associated with texture factors. The reflective and absorptive characteristics give rise to color and intensity of reflection and shading, depending on whether the incident radiation is parallel or diffuse. Finally, as the light leaves the objects on its journey to the observer's eye, the intervening atmosphere provides a myriad of additional effects permitting aerial perspective.

Motion perspective stands out of this physical milieu, as it appears to be able to convey depth information using the relative motion between observer and object.

Besides these ten methods of integrating visual stimuli into cues or interpretations, many other variations or combinations of the above exist that involve specialized stimuli and assumptions. For example, the simplest definition of linear perspective was included in the table; however, linear perspective should encompass a wide range of line arrays involving many complex but interpretable geometrical concepts and associated assumptions. Illusions occur when more than one set of assumptions are involved.

Note that most methods can provide cues as to shape, orientation and relative scale (size). Only one of the monocular methods can provide information about absolute scale or size (apparent/familiar size). This apparent dearth of methods for perceiving absolute distance is probably not true, and will be elaborated on later. Of the ten possible methods described previously, only those associated with monocular effects are considered useful, because binocular displays are not within the technology that will be applied to the Army-NASA facility modifications. This is not to say that binocular effects are unimportant to NOE flight. They may be, especially at extremely close range, say five feet from the tops of trees during a hover. Some insights into depth perception usefulness are given by Harker and Jones (Ref. 2).

Armed with the above concepts, a field study was made of a typical region where NOE flight could be conducted. This was done in order to gain insights into the perceptual strategies that could be used by pilots flying NOE missions.

The area chosen was Henry W. Coe State Park, located about twenty miles southeast of San Jose, California. The park is the former Coe homestead, and comprises an area of roughly twenty square miles. Due to relatively recent faulting, mountains have formed with ridges and valleys running generally parallel to the California coastline. The elevation of the peaks and valleys ranges from 3,000 feet to 2,000 feet, respectively, with the maximum large-area slope observed being about 40°. The coastal climate assures sufficient rainfall to support Oak and Madrone trees, Manzanita, a shrub, and a variety of grasses on a soil cover deep enough that few rock outcroppings are visible. The trees and shrubs are evergreen, but the grasses are seasonal, providing a rich, green carpet in the Spring, and suddenly fading to a golden brown about the middle of May. Cultural features are few. Besides the old homestead buildings, now occupied by the Park Service, there is a network of fire roads, hiking trails, campsites, and an occasional remnant of a fence, corral and stock loading ramp. The weather is usually sunny with clear skies and a variable visibility range. At these latitudes, the sun reaches a maximum altitude of 77° in June, and about 31° in December, so that in the winter, the steeper, northfacing slopes are always shaded.

Tactically speaking, the area is accessible enough so that large-scale battle operations could be carried out. The undulating nature of the terrain would enhance survivability during NOE flight, because the numerous interconnected gullies and small valleys, with some tree and shrub coverage, would provide a high degree of masking from hostile forces occupying neighboring depressions or the ridge tops.

The area was examined and re-examined at various times between the months of March through October, 1981, from the tactical, flight dynamic and perceptual points of view. The data sought were typical contours, slopes, tree and shrub size and distribution and appearance, cultural feature appearance, shading, color and contrast. The intent was not to examine the area to possibly mimic it as a NOE data base, but rather to understand the elements of the underlying perceptual process involved in flying over it. From the viewpoint of image generation, it is an area of moderate detail, i.e., not as rich as a desert with numerous rock features, but yet not as sparse as a snowscape. In many respects, the area is similar to Fort Hunter-Liggett Military Reservation, about 80 miles south, where NOE flight operations by the Army are routine. Therefore, it is to be expected that NOE flight in the Coe State Park would not be unusually difficult. The park is used occasionally by the National Guard for helicopter training exercises.

The important findings are summarized below:

1. Linear Perspective - In densely-wooded areas containing stands of Oak and Madrone trees and Manzanita shrubs, the appearance of the

crowns is that of "clumps" of green against other "clumps" of a darker or lighter green. Since the clumps vary widely in size, there is not a strong impression of terrain shape or depth. When individual trunks could be seen against a background of grass, the impression was stronger. In the few areas containing fence posts, dirt roads and trails, the usual commanding impression of shape and scale were evident. However, roads and trails were generally occluded by trees and shrubs, and unless viewed from nearly overhead, did not provide a strong impression of terrain shape or size. Only when hill slopes were high enough to require excavation for the road did any impression of shape or relative depth result.

2. Aerial Perspective - On most days examined, some impression of relative depth could be gained by comparing the contrast among closer features with that of more distant ones. The effect was apparent even in small gullies and valleys. It was difficult to calibrate, however, so that the judgement of relative distance was inaccurate. It is an excellent mechanism, however, for distinguishing near objects, such as trees, from more distant ones. The mechanism works at close range, provided that the visibility range is also short. For example, from a ridge-top viewpoint, it was readily obvious that the tops of shrubs on the nearby slope displayed higher contrast with their immediate neighbor's shadows than did those on the opposite slope, even when the sun appeared nearly overhead. It was not possible, however, to accurately judge the width of the valley using only these stimuli.

3. Interposition - The appearance of dense clusters of trees and shrubs on the sides of hills and in gullies was such that a low to

moderate impression of hill shape was apparent. The low contrast (color and luminance) between interposed trees and shrubs made the judgement of relative distance difficult in these areas. In more sparsely-populated hillsides and gullies, the impression of depth was moderate, as long as the contrast was high enough that individual trunks and crowns could be distinguished. This was especially true in the summer and fall months when the dark browns and greens of the tree trunks and crowns contrast with the background of light brown grass.

4. Shading - At high sun elevation angles, shadows are small and contrast highly with the brighter surroundings. For example, densely-wooded slopes contained trees and shrubs of a wide variety of sizes and shapes. This foliage showed a random-appearing array of shadows, which upon closer inspection were found to be due to the shadows of the lower portions of the crowns of Oak and Madrone trees that were exposed on the slope. The result is a definitely noticeable increase in shadowing on upward-going slopes, and conversely, a decrease in shadowing on level terrain or down-going slopes. This means that it could be expected that the shadowing of densely-wooded areas will increase when viewed from overhead, when sun elevation angles are high. It is not known whether this effect would be present for grassy areas. If so, then grassy areas should appear slightly darker when viewed from the same range, but a higher vantage point. The shadowing at low sun elevation angles was very apparent, and gave a definite impression of slope. Slopes at the sun's elevation angle, or higher, revealed deep shadows that did not change appreciably until the onset of twilight.

5. Texture Gradient - Texture gradients were sought in both open

and grassy and densely-wooded areas. Although "texture" associated with lighter or darker areas of grass, tree crowns and shrub tops was observed, no distinct gradients in these "texture" patterns could be detected. This was a surprising result, and closer scrutiny revealed some interesting patterns of light associated with illuminated vegetation.

The appearance of densely-wooded areas from an elevated viewpoint is that of an array of light patches of varying shape and angular size. This appearance is due to the shape of the tree crowns, i.e., the placement of individual branches and leaves relative to their trunks, and the variable spacing of the trunks themselves. Shrubs such as the Manzanita also had a varied appearance because of their wide range of shapes and sizes. It was concluded that no texture gradients were observed, because the texture element size varied too widely for the range of distances involved.

This notion was briefly tested by examining photographs of areas with easily-detected texture gradients. These photographs were of a rippled pond, a flower farm, a row crop and an orchard. The obvious texture gradients in these photographs suggest that for a gradient to be visible, the texture element size, e.g., average distance across the patch, should be nearly uniform for all patches. The texture element size of wild vegetation is too non-uniform to reveal gradients with distance. An exception to this exists for grass viewed at close range 1.52-15.2m (5-50 ft.). As long as individual blades of grass can be seen, the impression of depth due to the texture gradient was present, presumably because the grass was very nearly uniform in size.

6. <u>Apparent/Familiar Size</u> - The area was inspected for objects that could establish the perception of terrain size by the mechanism of apparent/familiar size. Besides the obvious cultural features, i.e., the homestead buildings left by the Coe family, a variety of fence posts and remnants of corrals and stock loading ramps were found. The latter give a strong impression of scale, because the fence posts are nearly uniform in height, ranging from four to five feet in height, with variable cross-section, as they were hewn out of the native trees. Other kinds were also found, for example, the familiar modern steel barbed-wire fence post with an "L" cross-sectional shape. Although small (about 1" wide) in size, they were always found with an occasional cross-sectional wooden anchor post whose cross-section varied from four inches by four inches to twelve inches by six inches.

Generally, the fences were placed in the open areas that are suitable for grazing. They seldom stood vertically, and their spacing was variable. Although watering troughs should be commonplace in semi-arid grazing areas, none were seen in Coe State Park. In similar areas, however, the author has seen troughs varying from home-built types to old bathtubs, washtubs and cut-down steel drums.

It was suspected that a sense of scale could be extracted by observing the vegetation, i.e., the Oak and Madrone trees, the Manzanita shrubs and the pasture grasses. Further examination, however, revealed a wide variation in the size and shape of the trees and shrubs. It was difficult to identify an "average tree" for any one locale, as they appeared to grow according to the supply of water and sunshine, the soil quality and the number of neighboring competitors. For example, large Oak trees were found mostly in gullies and drainage basins, but an occasional very large "loner" could be seen on the top of a ridge or hill.

The Madrone and Manzanita also grew to a wide range of sizes and shapes, e.g., four feet to sixty feet tall with a spreading, low crown, to short, vertical ones. There was no obvious correlation between shape and size. Also, it was difficult to observe a relative change in bearing by observing a single tree or shrub. They do not exhibit strong azimuthal appearance changes, unless they are severely wind-blown.

The tall pasture grass appeared to be of nearly uniform height, except on relatively steep (20-30°) slopes. It was concluded that only the few cultural features, i.e., fence posts, corrals and roads, gave an initial impression of absolute size. When they were not visible, it was difficult to judge the absolute size of gullies, small valleys and ridges. Estimates were often inaccurate by factors of two to three.

7. Motion Perspective - The area was negotiated on foot, therefore motion perspective was introduced slowly, over periods of minutes. Surprisingly, a powerful sense of scale was introduced by simply walking through an area such as a valley or gully. When nearer ridge tops could be seen against very distant ones, the absolute size of trees and shrubs on the near ridge could be easily and accurately estimated by walking a short distance normal to the line-of-sight to the object in question. When a distant background was not available, the impression of scale was simply more difficult to extract. For example, the width of a small valley could be estimated by selecting an object on each ridge that subtended an angle of 45° to the general direction of the valley center.

Then, by walking down the valley until the objects stood abeam of the observer, i.e., the angle of each increased to 90°, the width of the valley is then approximately twice the distance walked.

After some time in the area, it was obvious that a sense of scale became stronger, and more subtle stimuli-cue relations emerged. These will be discussed later.

8. Apparent/Intrinsic Brightness - This effect was not present, since the area was examined in daylight.

9.,10. Binocular Effects - These effects also were not explored, because the author does not possess normal binocular vision. It was observed, however, that individual leaves of trees and shrubs could be easily distinguished sometimes, if their shiny side was oriented so as to reflect sunlight to the observer. Normally, such details would not be visible due to their low contrast, but because of their relatively high reflectance, they stood out against darker backgrounds, giving a "Christmas tree light" effect that should result in stereoptic stimuli at distances of up to possibly 50 feet or more.

During the examination of Coe State Park, other perceptual mechanisms were discovered that involve more abstract perceptual assumptions and can result in the cues of absolute distance. It was noted that large trees sway differently in the wind than small ones. Apparently, the stiffness/inertia parameters of vegetation are such that they show the familiar decrease in natural frequency with size. It was obvious that a large tree or tree branch oscillated in the wind at lower frequencies than did a small tree or shrub. The observation of "average frequency" of oscillation in a wind could possibly be calibrated to yield the absolute size of the vegetation.

This observation immediately called to mind two other possible mechanisms. These are based on gravitational effects and relate to the appearance of falling objects, falling water, or rising smoke and fire. Since water and falling objects are scarce in Coe State Park, and fire is prohibited, these effects were scrutinized only in theory.

The principle is simple. Since we know the gravitational acceleration on the Earth's surface, we should be able to, with practice, make an absolute distance judgement by observing falling objects. An object such as fruit falling to the ground will require a definite time period to reach the ground. The observation of this time period and the apparent angle of the trajectory should theoretically be transformable into the cues of absolute size and distance to the tree.

Similarly, the appearance of small waterfalls is different from that of large waterfalls. The appearance of waves on lakes and the open sea should also be transformable into cues of absolute wave height, although the relations are complex.

Lastly, the appearance of smoke and fire is definitely size-dependent. A large fire undulates slowly, but a small one appears to flicker quickly. Large smoke puffs move differently than small ones. Presumably, the fire and smoke apparitions are due to the scale effects on thermally-induced buoyant forces relative to gravitational ones.

In summary, a search for the existence of "classical" perceptual mechanisms in a portion of the natural world revealed a lack of the corresponding stimuli. Although shape and orientation of the natural environment could easily be extracted through the use of several of the mechanisms, an accurate judgement of absolute size could not.

With repeated exposure to the area and the use of motion perspective induced by walking through it, the impression of absolute size began to emerge. In fact, it strongly appeared that some of the classical mechanisms, such as linear perspective and narrow-band texture, are associated mostly with cultural features. Furthermore, the mechanisms of aerial perspective, shading, and interposition are often absent or difficult to detect. The stimuli for the mechanism of apparent/familiar size is only readily found in cultured areas, and far more difficult to detect in natural terrain. We are inexorably drawn to the conclusion that pilots should not be able to perform NOE point-to-pointflight adequately over natural, random-appearing areas devoid of recognizable features. But, this is a ridiculous conclusion, as it is common knowledge that they can easily fly over unrecognizable terrain that they have never seen before! Either our concepts of the "classical" perceptual strategies are incorrect, or something else is being used.

The author believes that the latter is the case. The only recourse is to draw the conclusion that the dominant perceptual strategy used for NOE point-to-point flight is motion perspective augmented by the use of other mechanisms, such as linear and aerial perspective, interposition, shading, texture and apparent/familiar size; if and when their corresponding stimuli are available.

This means that pilots will be able to fly NOE over unrecognizable terrain upon first encounter, but will find it easier if some recognizable objects can be seen, or upon repeated exposure that allows them to "calibrate" the area. They will experience more difficulty (and therefore increase clearances and/or slow down) over terrain which lacks sufficient detail to induce motion perspective stimuli. Such terrain can be snowscapes, sand dunes and open, glassy water, for example. Obviously difficulty would also be encountered as twilight approaches, when the number of detectable objects decreases.

It was stated earlier that the motion perspective mechanism can only provide, at best, cues as to relative depth or distance. The mechanism was examined from a mathematical viewpoint, however, and this was found <u>not</u> to be true. In fact, the mechanism can provide a "depth map" directly by observation of several objects in the visual field. This is explained more fully in the next section, where the results of a preliminary analysis of the motion perspective mechanism can be found. The conclusions, statement of perceptual strategy, and implications for imagery design follow.

3.0 Preliminary Analysis of Motion Perspective

The first thorough description of motion perspective cues to distance was provided by H. Helmholtz (Ref. 3), as cited by Harker and Jones (Ref. 2). Although the subject has been extensively studied by Gibson, et. al. (Ref. 4) and others, it has remained an odd sort of mechanism thought to provide some cues to relative depth. The mechanism has been associated with other names, e.g., optic flow, streaming, monocular movement parallax, shear and motion parallax. All relate to the basic idea that any visual field contains movement patterns dictated by the relative motion between observer and the outside world.

Briefly stated, if relative motion can be characterized by two quantities, a translational and a rotational motion vector that are defined relative to coordinates in the outside world, then the appearance of the outside world during such movements takes on definite patterns. For pure translational movement toward an impact point, all objects in the visual field will stream outwards from this point. For a pure rotation, however, the pattern is circular, arching around the point corresponding to the axis of rotation. As we move through the fixed outside world, the vector combination of these two patterns are impressed on the retinas of our eyes.

It is suspected that these patterns are learned and used by the human infant following its first attempts at hand, head and eye coordination, and the reflex is further refined by the time it is crawling and walking. It is probably very well-developed in the young child, permitting it to move gracefully and perform amazing feats of balance and locomotion.

For persons who drive automobiles and fly aircraft, the subliminal integration of the movement patterns of many objects in the visual field into the visual cues of angular and translational velocity is probably highly developed.

The integration of these patterns does not appear to depend on the gaze point relative to the direction of movement or rotation, however, it could be expected that the streaming patterns corresponding to translational movement are probably most accurately interpreted by the visual sense when the gaze point is near (within 90° of) the impact point or direction of translation.

The mathematical expression for the absolute angular velocity of any object in the visual field is given below:

1) Angular movement:

$$\omega_p = -\Omega \sin P \qquad (1)$$

2) Translational movement:

$$\omega_T = \frac{V \sin \theta}{R} \qquad (2)$$

ω_p = Apparent angular velocity of an object in the visual field due to observer rotation. (rad./sec.)

Ω = Observer angular velocity (rad./sec.)

P = Angle between the direction of rotation and the direction to the object.

ω_T = Apparent angular velocity of an object in the visual field due to observer translation. (rad./sec.)

V = Observer translational velocity (ft./sec.)

θ = Angle between direction of translational movement and direction to the object.

R = Distance from observer to object (ft.)

The idea of motion perspective is that many objects in the visual field will be sampled and the impressions will be integrated into the perception of observer angular velocity and distance to the object. The observer angular velocity perception process is straightforward, and is demonstrated by re-writing equation (1) thus:

$$\Omega = \frac{-\omega_P}{\text{SIN } P} \quad \text{- - - - - - - - - - - - - -} \quad (3)$$

The observer's angular velocity is simply the apparent angular velocity of an object divided by the sine of the angle between the direction of rotation and the direction to the object. The perception of the angle (P) requires the sampling of several objects not near the axis of rotation, so that the angle (P) of each may be determined.

The corresponding situation for translational movement requires some interpretation. In this case, a similar re-writing of equation (2) results in the following:

$$\frac{R}{V} = \frac{\text{SIN}\,\theta}{\omega_T} \quad \text{- - - - - - - - - - - - - -} \quad (4)$$

The first interpretation can be seen by dividing R and V by D, a characteristic dimension of the rotorcraft like its rotor diameter. The new equation would be the following:

$$R/D = (V/D)\ \frac{\text{SIN}\,\theta}{\omega_T} \quad \text{- - - - - - - - - - -} \quad (5)$$

The formula implies that if the rotorcraft's velocity were known in terms of rotor diameters per second (V/D), then the distance to the object can be inferred (in terms of rotor diameters) if the angular velocity of the object is observed and a sufficient number of object angular velocities are sampled in order to perceive the angle θ to each. Several objects must be sampled in order to determine the observer's aim point, so that the angle θ may be determined from this point to each object.

The second interpretation requires no knowledge of flight speed in terms of a characteristic dimension D, but rather yields a direct perception of distance to the object in terms of time to impact (assuming the observer were traveling straight toward it). This may be seen by considering the left side of equation (4) as the time-to-impact, namely R/V directly. This means that a depth map may be directly perceived in terms of time-to-impact each object in the visual field by sampling the angular velocity of each object and the pattern of movements for several objects in order to perceive the angle θ to each.

The mathematics suggest that a minimum number of objects must be simultaneously seen in the visual field for the mechanism to work. Zacharias (Ref. 5) provided a vigorous mathematical treatment of the general equations in vector form, and has concluded that a minimum of <u>three</u> objects is required in order to make the number of equations equal to the number of unknowns, thereby yielding a solution for the impact time-depth map for those three objects, considering translation only.

To illustrate the use of the motion perspective mechanism in a perceptual process, the following example is offered. Consider a rotorcraft pilot approaching a hill. For the sake of simplicity, let us make the hill a two-dimensional one similar to one cycle in a corrugated roof. Let us assume that two points will be placed on the surface, one above the impact point, and one below it as shown in Fig. 6.

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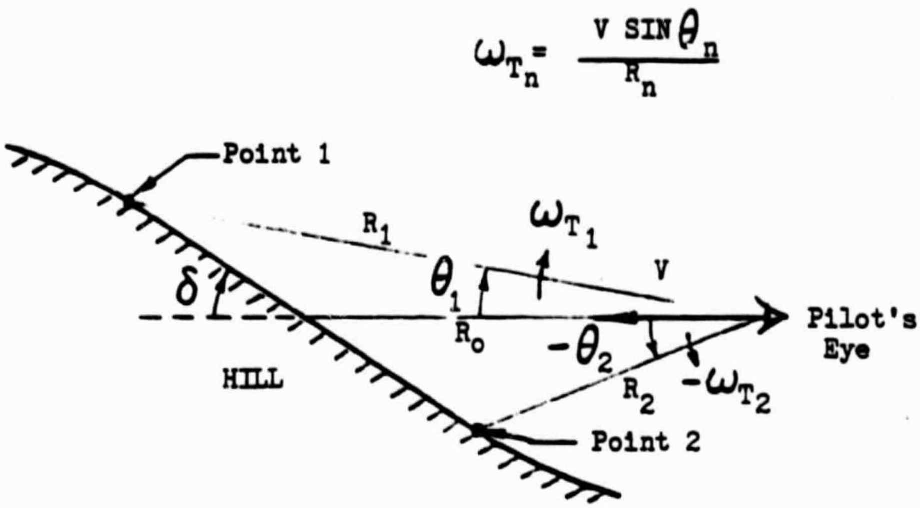

FIG. 6 - Motion Perspective Parameters for the Approach to an Inclined Flat Plane

The equation for the apparent angular velocity of each point is given by the following equation:

$$\omega_{T_n} = \frac{V}{R_o} \frac{\sin \theta_n \sin(\delta - \theta_n)}{\sin \delta} \quad \text{- - -} \quad (6)$$

θ_n - Elevation angle of the point n

δ - Slope angle of the plane containing points 1 and 2

V - Rotorcraft velocity (ft.sec.)

R_o - Horizontal distance to slope (ft.)

Re-writing equation (6) for time-to-impact:

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$$T = \frac{R_o}{V} = \frac{\sin\theta_1 \sin(\delta - \theta_1)}{\omega_{T_1}\sin\delta} = \frac{\sin\theta_2 \sin(\delta - \theta_2)}{\omega_{T_2}\sin\delta} \qquad (7)$$

Equation (7) is the key to the interpretation of the time-to-impact depth map, since if T can be determined for the impact point, the time-to-impact for any other point may be computed by the relation:

$$\frac{R_n}{R_o} = \frac{\sin\delta}{\sin(\delta - \theta_n)} \qquad (8)$$

The solution of equation (7) is straightforward. First, two points are required as a minimum, so that an equation for the slope angle may be formed from the two right components of equation (7), namely:

$$\frac{\sin(\delta - \theta_1)}{\sin(\delta - \theta_2)} = \frac{\omega_{T_1}}{\omega_{T_2}} \frac{\sin\theta_2}{\sin\theta_1} \qquad (9)$$

Equation (9) is solved for δ following the observation of the angular velocities ω_{T_1} and ω_{T_2}, and the angles θ_1 and θ_2; the result is then used in equation (7) to compute the impact time T.

If a third point is used, then it will be obvious that it should be possible to define the time-to-impact depth map for a plane formed by those three points. Hence the conclusion that, mathematically-speaking, only three points are required to effect the perception of observer orientation relative to the plane and time-to-impact to the three points; for that matter, any point in the plane, including the actual impact point.

Some preliminary calculations were performed to see what the accuracy of the time-to-impact and slope angle estimates would be, assuming errors in the perception of the angular velocities ω_{T_1} and ω_{T_2}, and their corresponding elevation angles θ_1 and θ_2 (relative to the impact point). A true slope of 32° and a time-to-impact of four seconds were chosen for the calculations. The corresponding true angular velocities for two points, one at $\theta_1 = -10°$ and the second at $\theta_2 = -40°$, were also calculated.

The assumption was then made that the perceived angles (absolute value) were too high by five per cent, and the perceived angular velocities (absolute values) too low by 10 per cent, yielding a worst case based on the minimum number of points and reasonable threshold errors. The results showed a perceived slope angle of 31.5 degrees, and a perceived time-to-impact of 4.73 sec., approximately in error by -1.6 and 18.3, per cent, respectively.

It could logically be expected that the use of more points would only improve the accuracy in a way similar to the improvement in a celestial navigational fix when more sightings are taken. In the motion perspective case, the perceptual thresholds would be distributed about a mean of zero, thereby making the distribution of impact time also cluster about the true value. The use of many points, therefore, simply averages out the error! Consider that the human eye has thousands of receptors to apply to the sampling of perhaps hundreds, even thousands of objects in the visual field. Perhaps one of the functions of the many photoreceptors in the parafovea of the eye is the sampling of object stimuli so as to allow the accurate perception of movement using averaged perceptions based on the motion perspective mechanism.

Further thoughts on the subject of motion perspective have been developed based on observations of scenes produced by computer-image generators at the U.S. Air Force's Aerospace Medical Research and Human

Resources Laboratories and the Evans and Sutherland Computer Corp., and by personal communications with Dr. Greg L. Zacharias of Bolt Beranek and Newman Inc.

These thoughts are partly the result of an Air Force-funded research effort to model visual and motion cue effects on pilot performance. Since the detailed findings of that effort will include a rigorous analysis of motion perspective, only the findings important to the present work will be highlighted.

First, on the analytical side, Zacharias has analyzed the motion perspective mechanism applied to a randomly-distributed texture field on a flat surface, and has found that the theoretical minimum number of texture elements required for the perception of self-motion is three for translational motion only, and five for a combination of translational and rotational motion. His analysis included imperfect (noisy) perceptions of texture element angular velocity, and consequently demonstrated that the error in the perception of aim point (impact point) decreased with an increasing number of texture elements. From the convergence properties of the computer solution, he also infers that a number of points greater than the theoretical minimum is required to obtain a solution for estimated aim point; a typical value being twenty or more texture elements.

Secondly, on the experimental side, insights into the question of how many texture elements are required were gained by observing electronically-generated pictures of surfaces containing arrays of texture elements or points. The eyepoint corresponding to these pictures was moved through or over the texture field in order to see if the shape of the underlying supporting surface could be perceived. The surface shapes more commonly investigated were flat and inclined to the direction of translational movement or sections of two-dimensional sinusoids similar to a piece of corrugated roof. The conclusion of the author is that, for a given density of random texture, a certain amount of time was required to perceive surface shape. Zacharias stated it another way by saying, "It is like solving the sampling theorem in three dimensions." While the nature of the complex interaction between estimated surface shape and observer velocity, time allotted for perception, surface shape and surface decoration (texture density) is the subject of the Air Force work, a preliminary "best estimate" based on the observations is a mean texture spacing of one eyeheight for a randomly distributed array on a nearly flat surface.

One more point should be made about the perception of a translational flow field under conditions of high rate rotations. The streaming translational flow field seemed to disappear during high-rate rolls, suggesting that a relatively stable retinal image is required to perceive the impact time depth map and aim point information contained in a translational visual field.

4.0 Conclusions

1) Natural terrain contains few, if any, stimuli that could be integrated into visual cues of absolute size. Those that are present require specialized knowledge of the distribution of size, shape and appearance of vegetation, or of the dynamic nature of falling water, vegetation, smoke or fire.

2) Because pilots are able to fly rotorcraft and aircraft at low altitudes over natural terrain devoid of cultural features, it is concluded that upon first encounter, the primary perceptual strategy in such areas is the use of motion perspective.

With repeated exposure to the area, the appearance of consistently-encountered objects such as trees and shrubs is "calibrated" by the pilot so that faster, more accurate judgements of distance, based on the apparent/familiar size mechanism, may be made to supplement the motion perspective cues. If available, the stimuli for other mechanisms, such as aerial perspective and shading, may be used.

Perceptual Strategy:

For low-level or terrain flight operations over natural terrain devoid of cultural features, the primary initial perceptual mechanism used is motion perspective. This is supplemented by other relative-size mechanisms such as aerial and linear perspective and the absolute size mechanism, apparent/familiar size, through a "calibration" process akin to acquiring "air sense" knowledge of the specific terrain.

The motion perspective mechanism used may be interpreted in two ways. In the first, the observance of the absolute angular velocity of several objects and their position relative to the impact point permits the pilot to perceive a "time-to-impact" depth map of the visual field. In the second interpretation, the pilot uses the same observations, but from a knowledge of his velocity in terms of a relevant vehicle dimension per second; he perceives a depth map in terms of this dimension. For rotorcraft, the velocity could be sensed in terms of rotor diameters per second, and the perception of depth in terms of rotor diameters.

The Integration of Perceptual Strategy and the Performance Envelope:

The pilot constantly reconciles his knowledge of "where he can go" with his perceptions of "where he is going" and "what is out there" to achieve the desired clearances and speeds, while allowing himself some margins for safety. This means that he will superimpose a mental image of the current performance envelope onto his perception of the terrain shape ahead, and adjust the controls so as to place his future trajectory in places affording him desired clearances, masking, and adequate safety margins. The performance envelope must never be completely "filled with terrain," as this spells imminent impact, but yet to achieve close clearances, the envelope must be nearly filled. Since the region of intense interest is the envelope and impact regions, the corresponding eye fixations are concentrated in these regions where foveal vision is used to search for identifiable objects and optimum places to go, and peripheral vision complements foveal vision to mediate the perception of surface shape and impact times. The corresponding eye movement activity is concentrated in the vehicle impact field and surrounding envelope field which are dictated by a knowledge of the performance capability of the pilot and vehicle.

The relationships among workload, clearances and speed should be affected by the nature of the terrain being flown over. Generally, there is a direct relation between clearances and speed; a lower speed being associated with smaller clearances. The associated workload, however, may vary with both speed and clearances. It should also depend on the complexity of the terrain, a hilly terrain being more difficult to fly over than a flat one. The nature and number of the features that lie on the surface also should cause the workload to vary. Areas with sparse, low vegetation under low, diffuse illumination should demand high visual workload, possibly even staring. Areas with many taller, more differentiated features, such as loosely-spaced trees under direct illumination with shading effects, should be easier, since surface shape perceptions should be possible in shorter times. Finally, areas with cultural features that can be readily recognized or identified should reduce workload further.

5.0 Implications for Imagery Design

5.1 Philosophy

Because it is imperative that the visual cues presented to the pilot and associated workload in the NOE simulator be similar to that in the real world, the simulated scenes require that the visual scan pattern (gaze point distribution and dwell times) and perceptual strategy also be similar.

A case was made earlier, based on flight dynamic concepts, that the pilot's gaze points are distributed mostly in the immediate impact field from three to five seconds ahead, with nearly all the remaining fixations contained in the surrounding envelope field. This field is comprised of azimuth angles of approximately ±60 degrees, and elevation angles of ±30 and -15 degrees.

Furthermore, a case was also made, based on a review of perceptual mechanisms and a survey of some terrain samples, that the only reliable, i.e., always available, mechanism useful to the pilot for perceiving terrain shape and depth is motion perspective. This is because the terrain most likely to be overflown during NOE flight is natural, i.e., it appears as randomly distributed incoherent patches of light attached to the earth's surface with weak texture gradients. This kind of terrain, therefore, offers few, if any, means of establishing distances by the observation of familiar objects, and sporadic opportunities to use other mechanisms such as aerial and linear perspective, shading and interposition.

5.2 A Case for Texture

If imagery for NOE flight simulation were composed only of texture elements randomly-distributed on the terrain surface, the necessary perceptions of terrain shape and depth would be made using motion perspective. This will work even if the distribution of texture element size on the surface is so great that no obvious texture gradients are visible during static viewing. There are areas of the earth's surface that have this appearance; for example, highly-eroded canyons containing mostly bare rock formations and individual rocks of many sizes and shapes. Each rock is visible, depending on distance and illumination, but because they vary so widely in size, shape and color, they are unidentifiable and called "trash" by some pilots. Distances to unidentifiable features are extremely difficult to judge under static conditions, but while moving, the observer can ascertain the underlying terrain shape and distance to each feature using motion perspective, as long as enough of them are visible. The question of "How much is enough" is, of course, the main question here.

A limited number of "observational tests" performed using various computer-generated scenes has revealed a rough rule of thumb. This rule states that for terrain shape and depth to be perceivable in a few seconds or less, that <u>the mean spacing of texture elements decorating the terrain be one eyeheight* or less</u>. This value of texture density has been found to be adequate in facilitating the perception of terrain shape under dynamic conditions. The reader is cautioned that this estimate is preliminary. The problem is complex, as the elements include

* An eyeheight is the distance between the pilot's eye and a point on the terrain surface or feature directly below.

the dynamic perception of terrain shape given a density of texture decoration, the surface itself, and the observer's motion. There is considerable room for improvement of this estimate, and some suggestions of how to do this are described in Section 5.4.

5.3 Suggested Imagery Details

In areas to be overflown, a texture decoration with a mean texture element spacing of one eyeheight is deemed a minimum texture level needed to reveal surface shape using motion perspective. This means that a spacing of five feet is adequate for areas where hovering operations, including landing, are to take place. Over other areas where higher-speed NOE flight is conducted, a spacing of 15-20 feet should be adequate. The texture may be composed of irregularly-shaped polygons in the surface of the terrain. The array size should appear random, as does natural texture in the real world. This may be accomplished by using five different sizes of polygons where the ratio of the largest to the smallest is about ten to one. (The size of a polygon is defined as the diameter of a circle having the same area.) Such an array of texture elements should begin to show texture gradients for distances greater than ten eyeheights.

The surfaces decorated as suggested above should be the most difficult to fly over at altitudes above ground level (AGL) of one mean texture element spacing or less. This is because considerable attention must be paid to the streaming texture pattern in order to perceive the surface shape ahead. The gaze can be expected to be drawn to objects near the impact or aim point, and dwell times may be long, i.e., one-half to two seconds. An amount of texture less than that suggested above should result in increasing workload and a reduction in height-holding performance to where an impact is certain.

To make the areas easier to fly over, one would think that more texture elements are needed. This is probably false, however, and the addition of more texture elements should not significantly reduce workload or improve height-holding performance. What should reduce workload and/or improve performance is the addition of coherent objects that more easily facilitate a static perception of terrain surface shape and observer position relative to that surface.

The addition of vertical objects should also reduce workload and/or improve height-holding performance. Vertical objects such as poles or renditions of trees (tetrahedrons, triangles, etc.) permit a static perception of height relative to the object height and orientation under the assumption that the object is vertical. The perceptual mechanism was pointed out by Harker and Jones (Ref. 2). The observer's eyeheight relative to the vertical object's height is simply the ratio of the vertical angle formed by the horizon and the bottom of the object to the angle subtended by the object itself.* In order to fly just at treetop level, one has to only fly so as to maintain the treetops silhouetted against the horizon. The perception is relatively easy to make, but becomes increasingly inaccurate when the horizon line position is occluded by nearby hills or trees, and consequently has to be estimated by means other than direct viewing.

It should be remembered, however, that trees vary in height and shape so that the use of tree renditions requires that they also vary

*Valid only for a flat earth

in height and shape. This simply means that the use of closely-spaced trees distributed in height will induce pilots to fly near the surface formed by the treetops, which forms a convenient and soft earth reference. When trees are widely-spaced so that a rotorcraft can pass between them, the eyeheight is probably perceived using the angle subtenses previously cited, and the spacing between trees, by the use of motion perspective. It is also obvious that actual trees do not offer cues to relative azimuth (bearing) owing to the random appearance of their crowns. Their "transparency," i.e., the fact that the crown is not a solid mass, but a complex array of leaves and branches, permits the detection of relative movement when viewing trees aligned in depth against a bright background.

The use of trees and other vertical objects should ease the workload required to fly close to the ground or improve height-holding performance. They need not show changes with relative bearing, and should be distributed in size and shape so that static perceptions of absolute size are difficult. As an example, a survey of a stand of Oak trees containing twenty-six specimens revealed variations in height and maximum crown width of from 1.2m to 24.4m, and 1.2m to 17.1m (four to eighty feet, and from four to fifty-six feet), respectively (see Fig. 7).

It is tempting to suggest that trees be distributed similarly to texture, but trees are not uniformly distributed in nature. Since it is desirable, from an image generation viewpoint, to use the minimum number of features, the trees should be sparse like they are in semi-arid regions. This means that they should be distributed mostly in

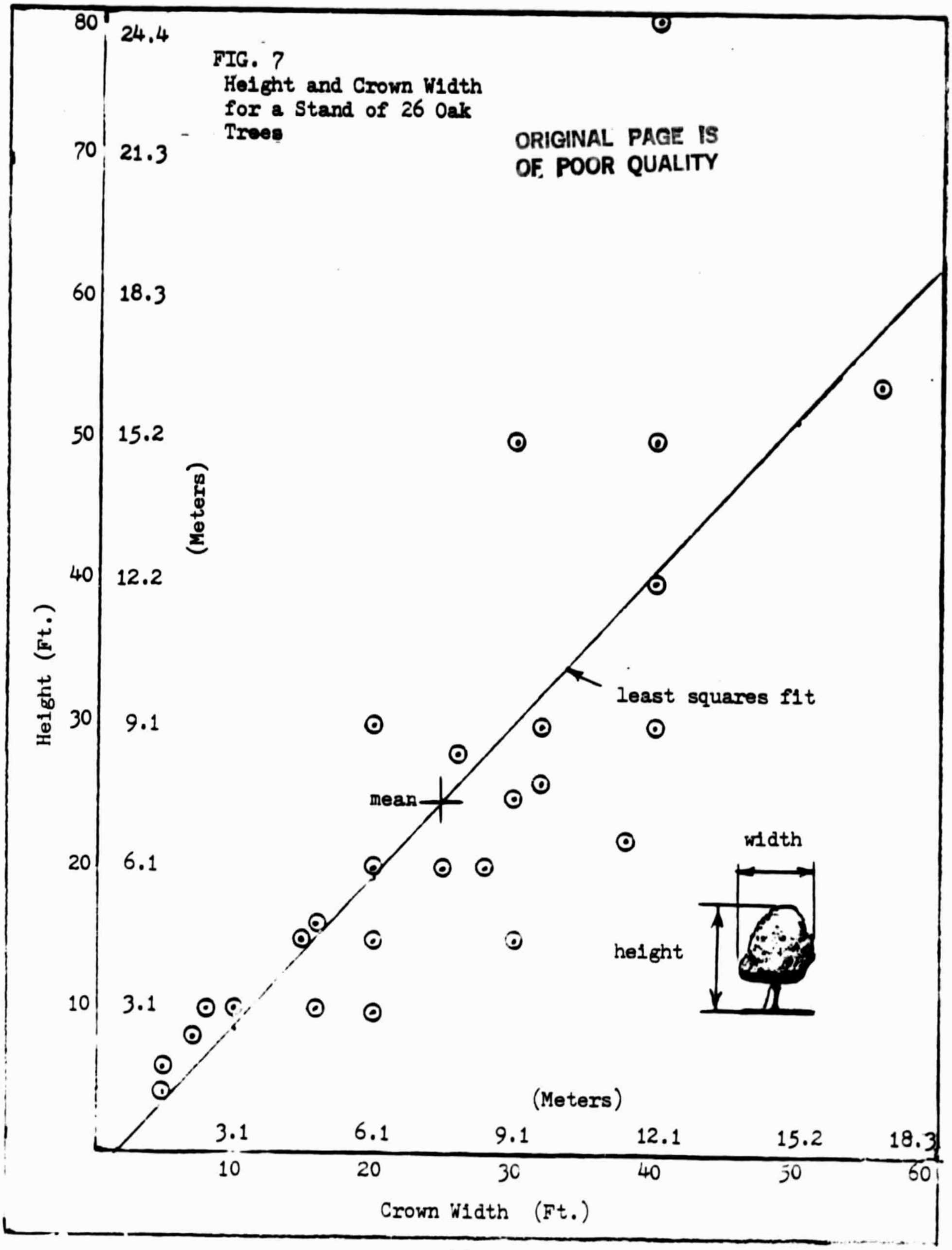

FIG. 7
Height and Crown Width
for a Stand of 26 Oak
Trees
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Height (Ft.)
(Meters)
80
24.4
70
21.3
60
18.3
50
15.2
40
12.2
30
9.1
20
6.1
10
3.1
least squares fit
mean
width
height
(Meters)
3.1
6.1
9.1
12.1
15.2
18.3
10
20
30
40
50
60
Crown Width (Ft.)

gullies and valley floors with a few on ridge tops to help facilitate ridge crossings. Also, it is not necessary that they be three-dimensional or can be seen through.

Although an estimate of the mean texture element spacing was made, at this time it is not possible to determine an equivalent number for vertical objects such as trees. A suggested starting point for tree density is a value that results in a mean spacing of from three to five eyeheights for vertical objects of average height equal to an eyeheight.

As a final note, highly-coherent texture, such as a checkerboard pattern, should ease workload and/or improve height-holding performance. The use of these features, however, is not recommended because they permit the use of the linear perspective and apparent/familiar size mechanisms to perceive terrain shape. This is akin to the cues provided by runways, orchards, row crops and vineyards, and should result in lessening workload and/or improving height-holding performance.

5.4 Ways to Improve Imagery Need Estimates

Because terrain shape perception is dependent on shape itself, surface feature appearance and distribution, and observer movement, the numbers quoted are preliminary; they were obtained by simple observational tests conducted by the author and image generator suppliers, and Air Force researchers who fit these tests into their busy schedules using whatever hardware was available.

During these tests, a number of methods emerged that could be the basis for more rigorous experiments into the subject of orientation and surface shape perception, and surface decoration. Four of these experiments are outlined on the next page.

The following experiments are some of the ones used in the observational tests that led to the preliminary estimates. Many others are possible, particularly when one begins to think about a two-dimensional surface that is representative of actual terrain.

1) Title: HORIZONTAL APPROACH TO AN INCLINED FLAT SURFACE

Task: Pullup without striking the surface

Performance Measures: Eyepoint clearance normal to the plane

Vehicle Dynamics: Vertical incremental acceleration of 1.5 g's for full deflection of a pitch joystick; speed, 10-100 knots

Surface: Flat, infinite plane; inclination 0-40°

Surface Features: Flat texture or vertical objects, or both

Field-of-View Shape and Size: Nearly square or round, up to five steradians, vehicle-referenced

Application: Terrain (contour) flight; low-level terrain following, landing; straight-in autorotation

2) Title: APPROACH TO AND FLIGHT OVER A HILL

Task: Maintain constant height above the surface

Performance Measure: Eyepoint height above the surface

Vehicle Dynamics: Same as above

Surface: Initially flat followed by a one-dimensional hill formed by an inverted cosine function

Surface Features: Same as above

Field-of-View: Same as above

Application: Terrain (contour) flight; low-level terrain following

3) Title: FLIGHT OVER AND THROUGH A DEPRESSION

Task: Fly into and out of a channel-like depression; fly into a channel-like depression, turn, and continue down the channel centerline

Performance Measure: Eyepoint height above the surface

Vehicle Dynamics: Same as above, except with coordinated roll/turn capability. Roll joystick deflection commands roll rate with a sensitivity of 1 radian/sec. for full deflection

Surface: One-dimensional depression formed by a cosine function

Surface Features: Same as above

Field-of-View: Same as above

Application: Same as above. Ridge crossing may be studied if another cosine wave cycle is added to the first

4) Title: APPROACH TO TWO TREES

Task: Approach two tree lines followed by flight between, over, or around them, depending on the observer's judgement that the vehicle either can or cannot fit between them

Performance Measure: Same as above, and vehicle lateral clearance from trees

Vehicle Dynamics: Same as above, except with velocity controlled by pitch attitude permitting a deceleration to a hover

Surface: Flat; of infinite size

Surface Features: Texture, especially in the approach area. Two tree-like features of unequal height, whose absolute size cannot be perceived and that offer no cues to relative bearing

Field-of-View: Rectangular, 60° vertical angle by up to 180° horizontal angle; a size of up to 6.28 steradians

Application: NOE flight

6.0 Preliminary Data Base Design

The following paragraphs contain a description of a Preliminary Data Base design that could be used in the image generation subsystem of a rotorcraft research and development simulator.

The Data Base elements are based on typical missions, and the intent here is to provide a starting point and guidelines for the detailed design tasks. The sections that follow describe a typical NOE mission and Data Base portions that could support such a mission, together with some statistics that will aid the selection, sizing and programming of the image generator.

6.1 A Typical NOE Mission

A typical air cavalry NOE mission has been planned and laid out on charts showing map data for the Hunter-Liggett Military Reservation in Central California. Figure 8 gives an overview of the assumed battle area with the following major data items:

1) The approximate latitude and longitude of one point
2) The approximate boundary between friendly and enemy-controlled territory
3) Major physical features such as towns, major highways, mountain ranges and valleys
4) The planned NOE flight routes
5) Approximate boundaries of three more detailed maps (Figures 9 a, b, and c)

Figure 9 a, b, and c show portions of the overview map. They are based on a Defense Mapping Agency topographical map entitled, "Hunter-Liggett Special"(Ref. 6). The contour interval is 6.1 meters (20 ft.)

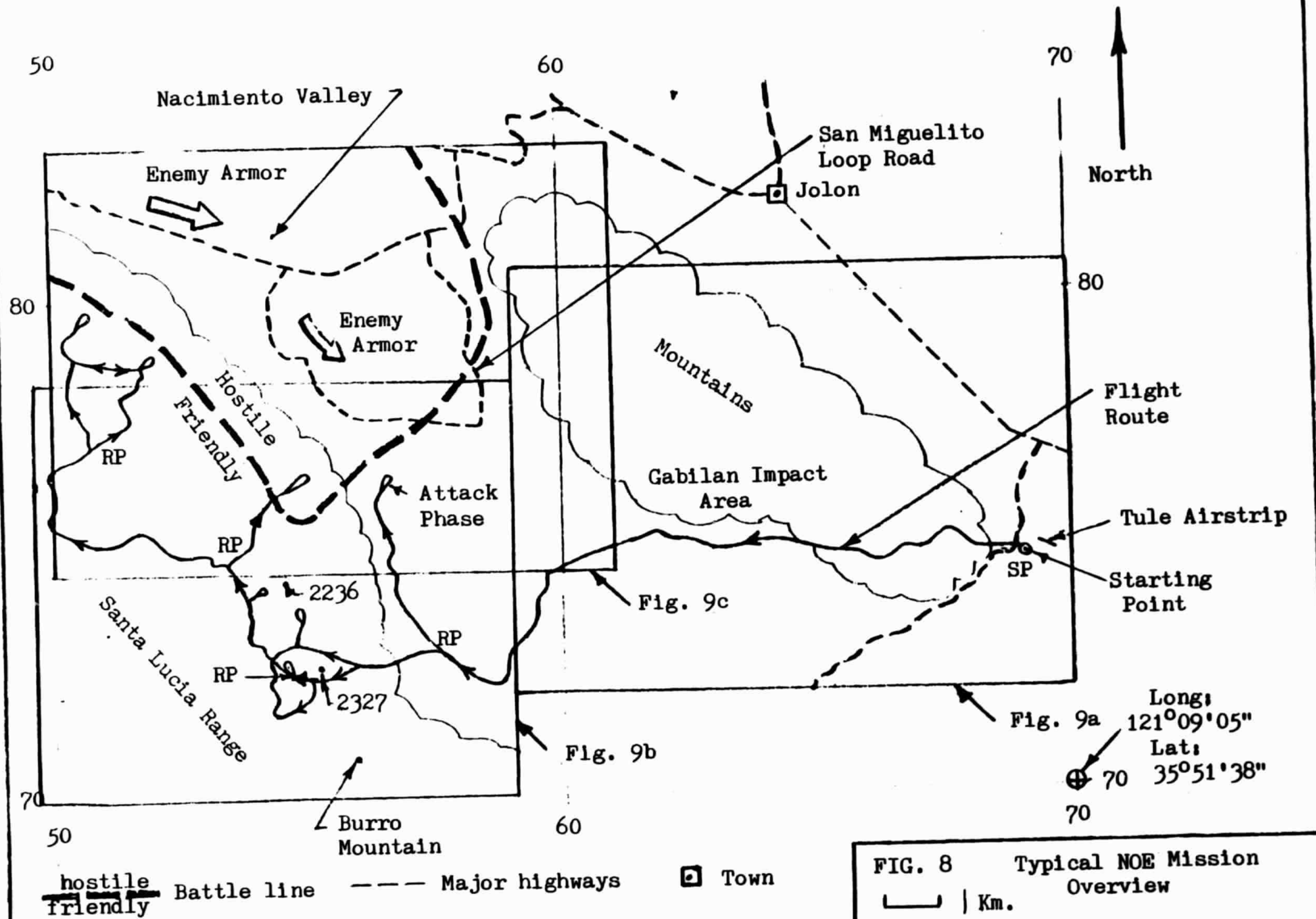

FIG. 8 Typical NOE Mission Overview

| Km.

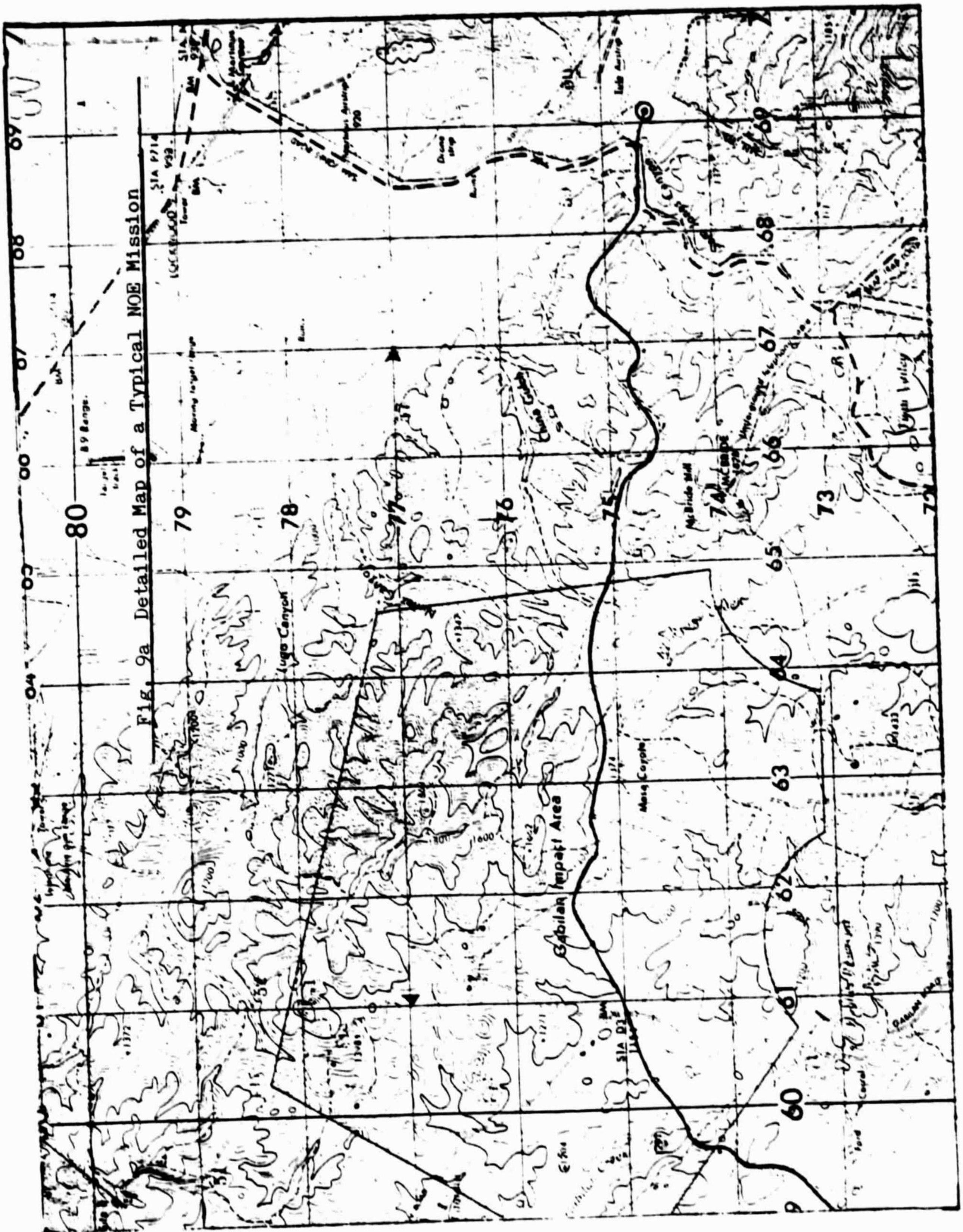

Fig. 9a Detailed Map of a Typical NOE Mission

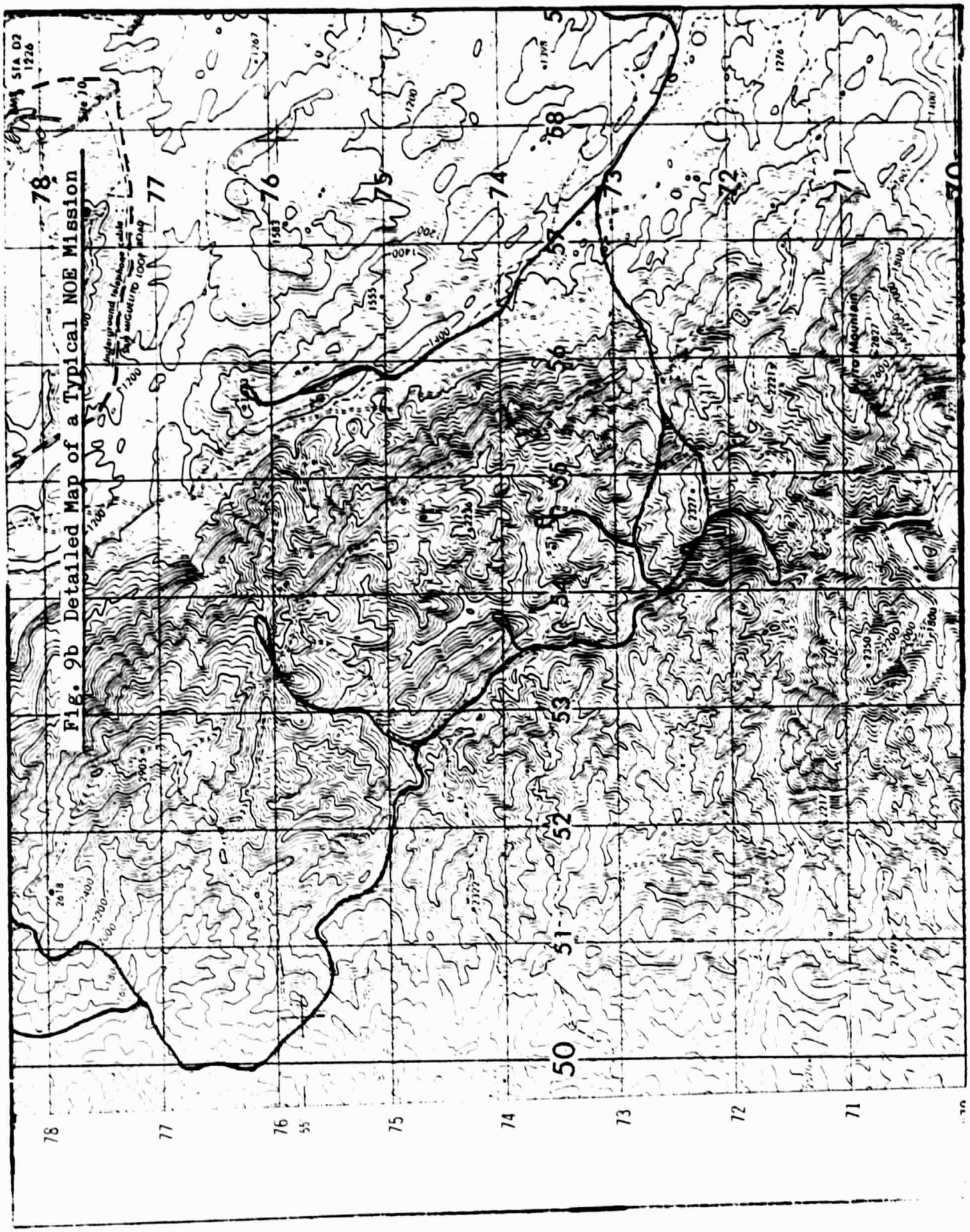

Fig. 9b Detailed Map of a Typical NOE Mission

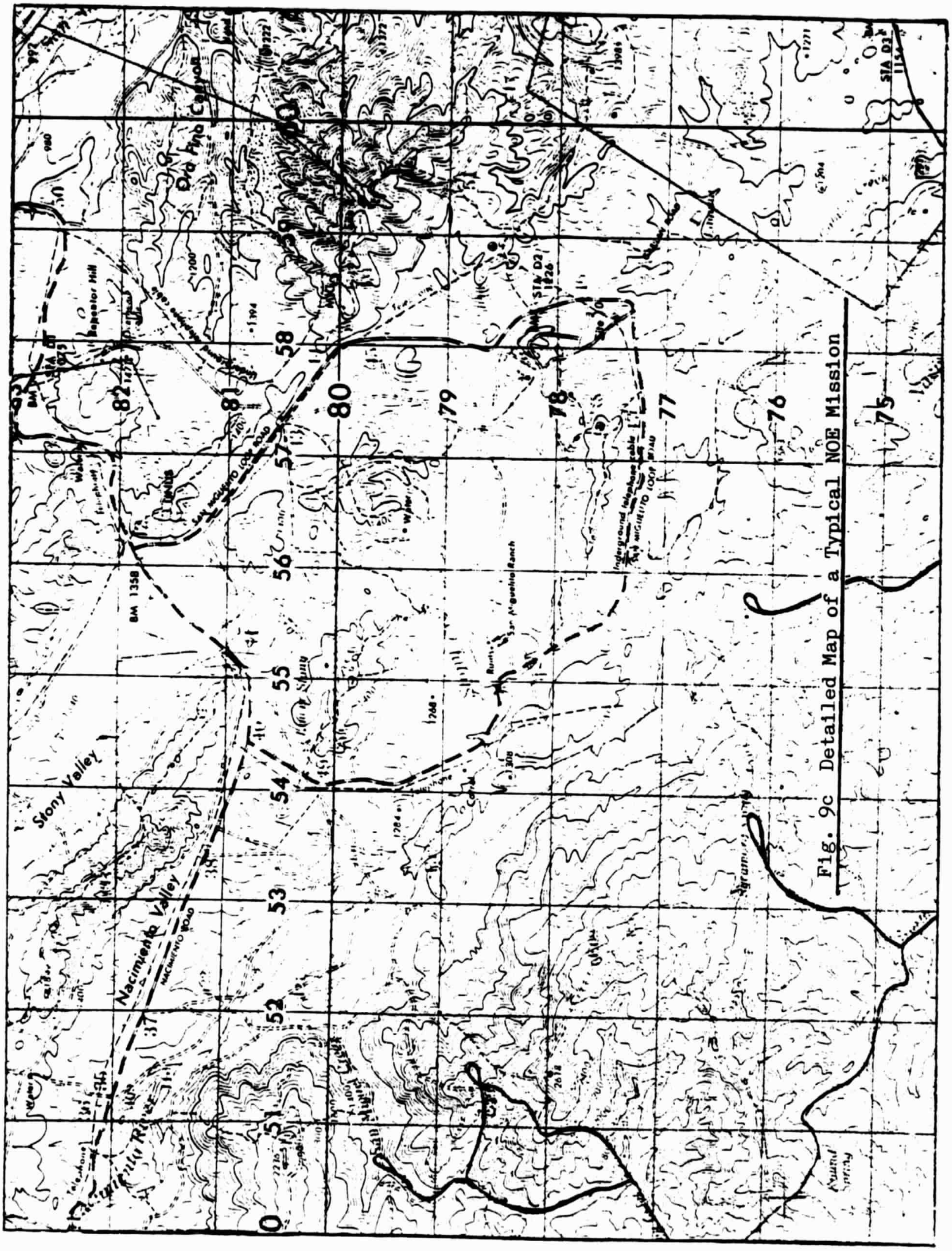

Fig. 9c Detailed Map of a Typical NOE Mission

and the grid network is in blocks of one square kilometer each, with North toward the top. The data are from several sources; the Geological Survey, the Coast and Geodetic Survey, the Defense Mapping Agency and the San Francisco District Engineers. The scale is 1/50,000. Additional maps of the area are the "Alder Peak" and "Jolon" quadrangles available from the U.S. Geological Survey. These maps are at a scale of 1/24,000 with a contour interval of 6.1 meters (20 ft.), but with no grid.

Referring again to the overview map, Figure 8, it can be seen that the hypothetical battle scenario centers around an enemy armor advance down the Nacimiento Valley for an assault on the town of Jolon. Friendly forces massed to the Southeast plan a major counter-attack from the South and East, supplemented by harassing attacks from the mountains forming the Southern boundary of the Nacimiento Valley. Air cavalry teams formed by several gunships, scout and utility helicopters mass at the Tule airstrip staging area. Their crews plan to mount a synchronized attack on the advancing column from several vantage points in the mountains overlooking the valley. Also, they plan to resupply advanced units placed in the mountains earlier.

The flight route begins with a combination of NOE and contour flight to the Gabilan Impact Area. Since the terrain along the route from the Impact Area to the Santa Lucia mountains is relatively flat and open, the crews receiving the latest intelligence reports elect to use low-level and contour flight to minimize exposure to enemy surveillance units known to be operating on the San Miguelito Loop Road.

Following entry into the Santa Lucia mountains just North of Burro Mountain, the team leader is told there may be an enemy surveillance and ground-to-air missile site atop a mountain labelled "2236." (Hereafter, a grid block containing a feature of interest will be denoted by the grid coordinates forming its Southeast corner; the longitude grid line first followed by the latitude grid line. Using this nomenclature, the block containing mountain "2236" is 55-74.)

While attempting to pass around mountain "2327" (block 55-72), the flight draws fire from an enemy site near "2236."

Cover is taken in the valley Southwest of 2327, while a revised plan is drawn up to attack "2236." The attack is mounted from the two attack positions located approximately one kilometer South and West of "2236." The loops indicate the rotorcraft track, while engaging on the enemy position. The enemy emplacement is taken and utility ships land atop "2236" to emplace a surveillance unit. A pinnacle approach is required to deploy observers.

The attack team resumes its original course toward the Nacimiento Valley, rendezvousing at the attack branch intersections indicated by "RP." The flight synchronizes its progress so that all gunships arrive at their attack positions (indicated by loops) simultaneously. The scouts acquire and designate the targets, and the gunships unmask and fire their missiles at the column while jinking to avoid return fire.

The progress into and out of the attack areas is made using NOE flight, due to the intense saturation of the overlying airspace by enemy surveillance radiation and air defense weapons.

Following the engagement, the flight regroups at the rendezvous points and returns to the Tule staging area using overwatch techniques to guard against attack by enemy fighters that have been called in to defend the armor.

The maximum ground track length for this mission is approximately 30 kilometers one-way. One hour is a reasonable enroute time considering the overwatching, synchronizing and contingency due to the enemy emplacement. Therefore, an average speed over the route of between 30 and 50 knots can be expected. This is approximately a traverse of one block per minute. This means that at the fastest speed and a visibility of one statute mile, that terrain ahead will become just barely visible about one minute before passage.

The mission described is considered to comprise a "skeleton" for possible mission scenarios that may offer specific challenges to future researchers interested in a particular weapon system topic. It is offered as an example of how terrain can be used for cover and is complex enough that specific variations may be added later. The area is often used in such military exercises, and range equipment and map data already exist to support operations there.

6.2 Gaming Area

For the purposes of establishing gaming area statistics, it is necessary first to define the areas around the flight routes that are likely to be scanned by the pilot. We have already estimated that fixations to the sides of the main track are likely to remain less than $\pm 60^{\circ}$ from dead ahead, or about $\pm$90m ($\pm$300 feet). If the visibility is maintained at about 1.6 km. (one mile), no terrain on either side of the track will be visible beyond this range. Furthermore, since most of the enroute track will be either in small valleys, gullies, or against hillsides, not much of the terrain beyond the immediate hilltops will be visible. Passage by side canyons or gullies, however, will be of great interest to the crews, because they are the areas where surveillance radiation or weapons fire may emerge. In the battle area itself, a larger gaming area will be necessary to accommodate the many possibilities of enemy weapon placement.

These thoughts prompt one to think that the gaming area should be comprised of two parts; a corridor leading to and from the battle area, and a larger gaming area offering enough space to accommodate future possibilities in hostile weapon arrangement and performance. Also, these two areas should require the full gamut of terrain flight operating modes, from low-level to NOE. The battle area should range from flat to mountainous and be approachable from both low-lying, relatively flat and open areas, to and from mountainous areas.

With these thoughts in mind, a gaming area was chosen consisting of a tessellated array of square kilometer blocks of terrain from the Hunter-Liggett area to the Southwest of the town of Jolon. The boundaries of the mosaic are shown in Fig. 10, together with a sketch of the track. Note that the total area is 174 square kilometers, which is equivalent to a square with a side of 13.2 km. or 8.2 miles. Approximately half of the total area is mountainous, and about one-fifth of it is considered to be held by hostile forces.

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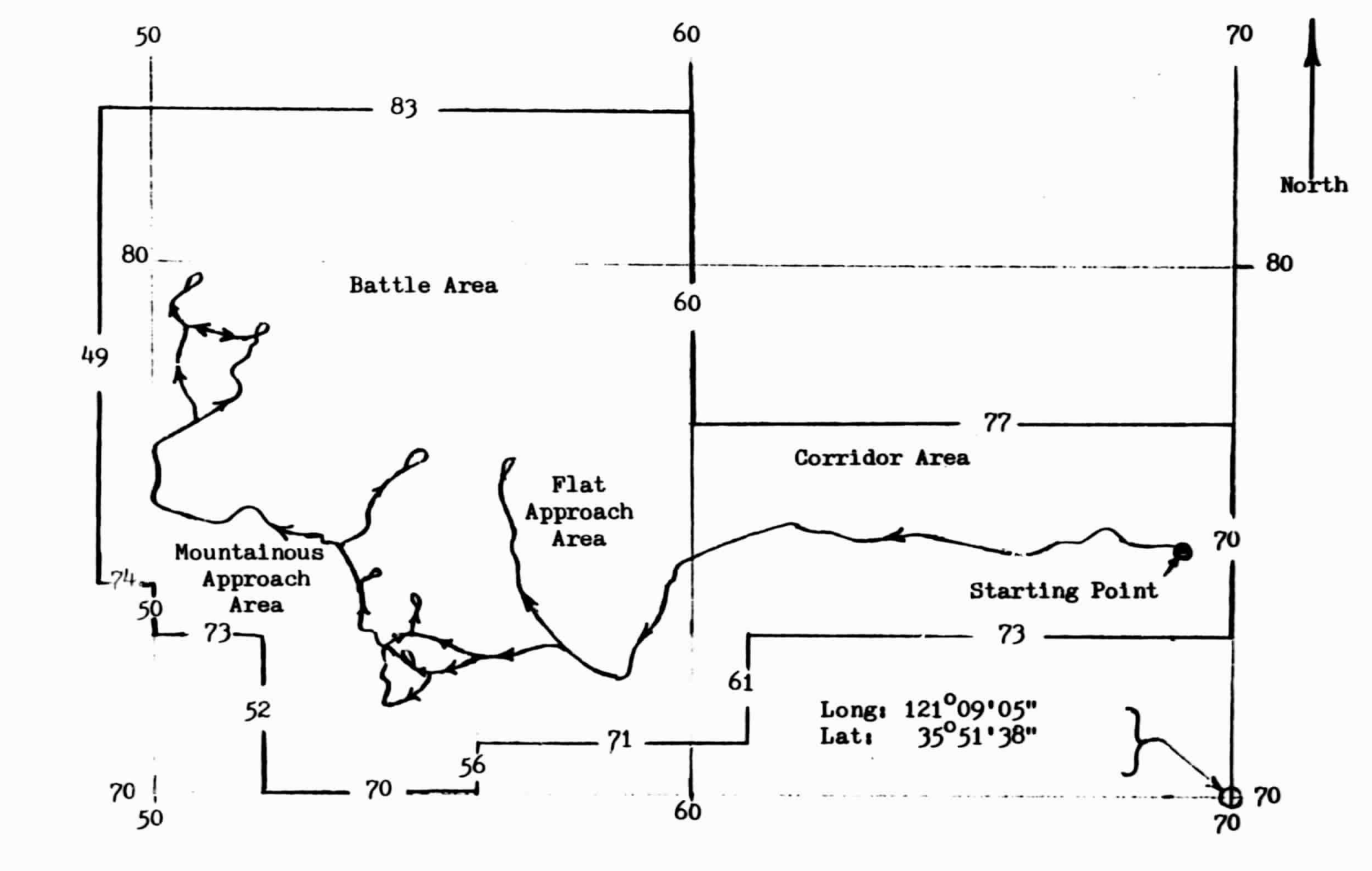


FIG. 10 Boundaries of the Gaming Area
(Grid reference from FIG. 8)

1 Km

Total Area:
174 Km^2
67.2 Mi^2

6.3 Data Base Buildup Guidelines

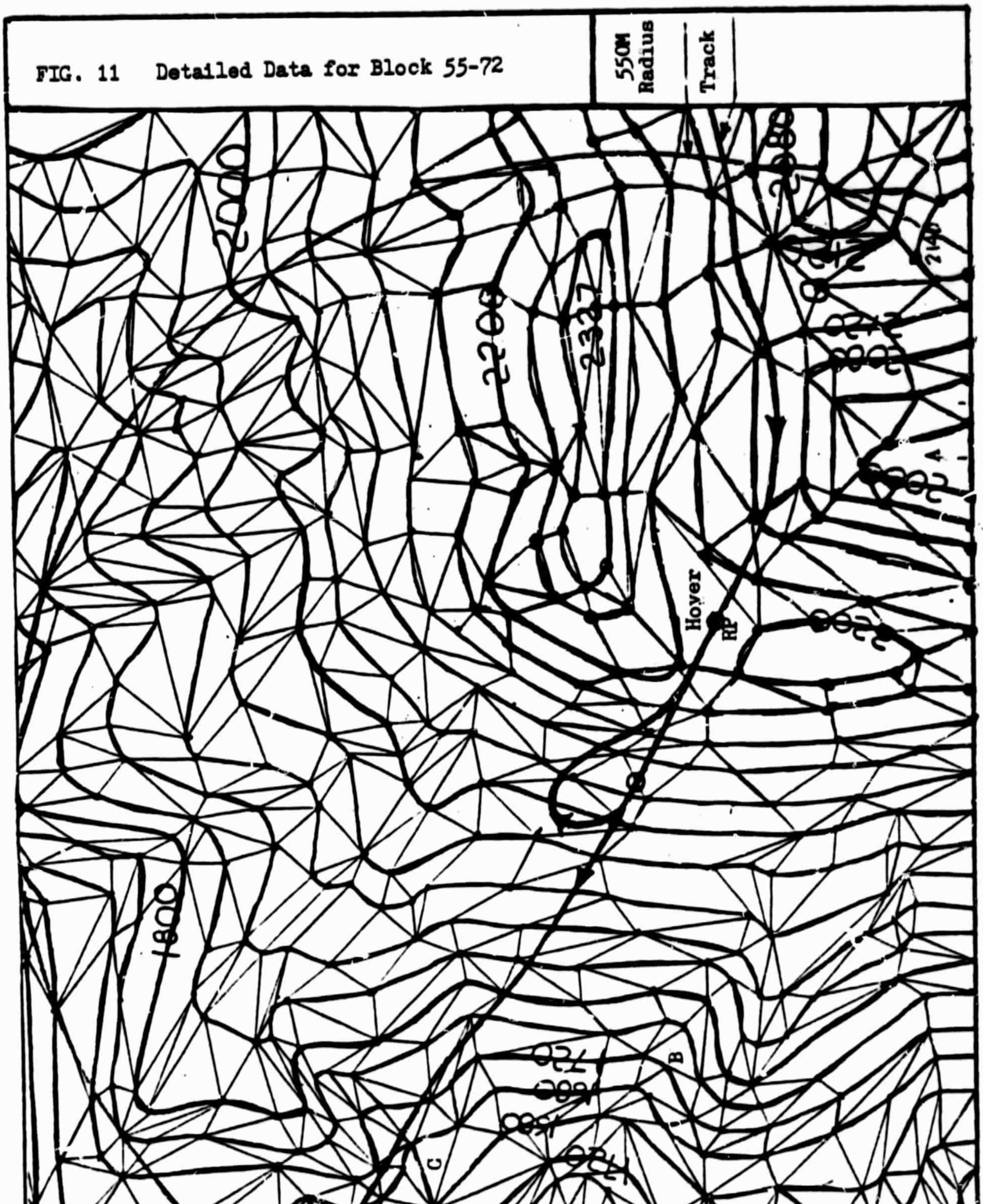
The data base of a computer-image-generator is usually built up of elementary geometrical forms. Edges and polygons are the most commonly-used, although some curved features such as circles are emerging in the "menus" of these generators. A certain amount of processing time and associated software is required to form the image data from a group of elements; hence the capacity of these systems may sometimes be expressed in terms of equivalent polygons or edges. Generally speaking, a polygon is equivalent to between two and three edges. These systems generally have an upper limit to the number of polygons or edges that may be maintained in an active or on-line memory from which the immediate picture is extracted, as well as a larger off-line memory containing the rest of the data. As the eyepoint moves over the data base, new data representing close objects may be brought into active memory, while old data not needed anymore may be erased. In this way, a level of density may be maintained if the data transfer rates can keep up with the eyepoint movements. The reader is referred to Ref. 7 for a more detailed review of CGI.

The problem at hand is basically one of constructing a data base that provides an adequate level of random-appearing image data for low-altitude operations, while not exceeding generator capacity limits or data transfer rates.

6.3.1 Polygon Fit

The first step in the buildup of the data base is the creation of a polygon array that fits the terrain. This is illustrated in Fig. 11. This is a magnified view of a portion of terrain block 55-72 at

FIG. 11 Detailed Data for Block 55-72



a scale of approximately 1:5000, showing a portion of the mission where a rendezvous is made, followed by an unmasking to survey hill "2236." An array of polygons, consisting of mostly irregular triangles on trapezoids, was fitted to the contour lines as shown. Within the limits of the graphical technique used, an attempt was made to ensure that the maximum deviation of a polygon edge from its adjacent contour line did not exceed 10 per cent of the local, average spacing between contour lines. This suggests that the maximum elevation deviation of the polygon approximation from the depicted terrain should also not exceed 10 per cent of the average local contour spacing. For some of the larger spacings of this block, this results in a possible error of as much as seven meters, or twenty-five feet. Of course, it is not possible to verify this estimate without elevation data between contours.

Similar polygon fits were made for blocks 55-73 and 55-74, and the resulting total number of polygons and edges were counted for all three. For the blocks in these mountainous areas, the average number of polygons and edges per square kilometer are 1,039 and 1,574, respectively. For these analyses, an edge was counted only once, although it was common to two adjacent polygons. The ratio of edges to polygons is 1.51. Multiplying this by two yields 3.03, which is indicative of the fact that most of the polygons fitted were triangles with a small percentage having more than three sides. Polygons with more than three sides, that are not trapezoids, are much more difficult to fit without discontinuities in the resulting elevation, and are therefore avoided.

If the terrain outlined in Fig. 10 is fitted to the degree described by the preceding statistics, then the total number of polygons would be 180,786, and the non-shared edges associated with these polygons would number 547,782. Since the flatter areas would require fewer polygons, the total could be expected to be less. At a peak density of 1,039 polygons per square kilometer, the total number of polygons and non-shared edges within a circle of one statute mile radius are 8,454 and 25,616, respectively. For an instantaneous horizontal field-of-view of 120°, it could then be expected that a maximum of 8,539 polygons and 25,872 associated non-shared edges might be potentially visible. If the eyepoint moved over the data base at a speed of 100 kts., then 62.5 seconds would be required before a completely new circle of data would be visible. This suggests a maximum data flow rate of 135 polygons/sec., or 410 edges/sec.

6.3.2 Texture

In order for the polygon approximation terrain to be visible and its shape perceived, it must be "decorated" with at least an array of texture elements dense enough to support the timely perceptions of impact and passage times from low altitude using motion perspective. This has been estimated to be a density that maintains an average spacing between texture elements of one eyeheight. This suggests that the mean spacing in hover areas should be 1.52m (five feet) and about 4.6m (15 feet) in areas to be overflown at speeds up to 100 kts. Furthermore, in order to provide weak texture gradients, the texture element size (diameter of a circle of the same area) should vary. Five different sizes are suggested, where the ratio of the largest to the smallest is ten to one. This form of texture should start to show a gradient for distances ranging beyond ten eyeheights. The approximate total number of texture elements per unit area are $.43/m^2$ ($.04/ft.^2$) and $.048/m^2$ ($.0044/ft.^2$) for the hover and fly-over areas, respectively. At the latter fly-over density, approximately seventeen million texture elements would be contained within a circle 1.6 km (one mile) in radius.

It is suggested that hover densities be used at rendezvous points, attack areas, the starting point, and the pinnacle of "2236." Density transition should be gradual, being accomplished within a linear distance of from 10 to 20m (33 to 66 feet).

6.3.3 Vertical Objects (Trees and Shrubs)

In Section 5.3, a value for tree density was given. This was a density that results from a mean tree spacing of between three and five eyeheights. For hover areas, this is a mean of between 4.6m (15 ft.) and 7.6m (25ft.). For fly-over areas, this value is between 13.7m (45 ft.) and 22.8m (75 ft.). At the higher fly-over density of $.0053/m^2$ ($.00049/ft.^2$, 13.7m, or 45 ft. spacing), a total of 43,300 trees would be contained within a circle 1.6 km. (one mile) in radius. As was pointed out in that section also, the trees and shrubs are found mostly in gullies, and are distributed in size and shape.

6.3.4 Distribution and Contrast

If the suggested densities of objects are to be maintained up to distances of 1.6 km. (one mile), the number of texture elements or tree/shrub-related polygons required is large (seventeen million, and over 40,000, respectively). Since typical capacities of Computer Image Generators are about 4,000 polygons (processed from the on-line memory providing image data for the current image), it is obvious that these levels of "decoration" are excessive.

In order to remain within reasonable capacity limits and still maintain an adequate density level, the elements will have to be distributed more effectively, particularly when it is realized that part of the available polygon capacity will have to be devoted to mission-specific objects, such as tanks and other cultural features. One solution to this problem is to limit the radius about the eyepoint within which the required density is maintained. It was estimated earlier that the immediate radius-of-concern to a NOE pilot extends only to 168m (550 ft.) at the highest speed (100 kts). If a texture density is maintained within this radius, that yields a total number of elements within it, of say 2,000, what is the resulting mean texture spacing? It is 6.65m (21.8 ft.). If this spacing were used, it could be expected that pilots will fly at eyeheights of this value, since flight below this level begins to reveal sparse ground detail. However, flight at a mean eyeheight of 6.65m (21.8 ft.) probably does not result in significant unmasking and workload reduction. Therefore, to start with, this level of mean texture spacing is a good way to stay within capacity limits.

The second suggestion is to decorate only gully areas with trees and shrubs with a mean spacing of 13.7m (45 ft.).

The third suggestion is to model the terrain with fewer polygons. If the polygon fit is made to a contour array with a contour interval of 12.2m (40 ft.) instead of 6.1m (20 ft.), then the polygons required within a given radius will be approximately one-fourth of that required with the smaller spacing. It should also be remembered that the polygon spacing will be larger, i.e., fewer polygons will be needed to approximate relatively flat terrain.

To illustrate the above points and demonstrate an example of polygon allocation, the relation between the number of elements N, mean element spacing S, and element density D was plotted in Fig. 12 as a function of R, the radius of the included circle. Two points are shown representing the choices of fly-over texture and terrain polygons. Referring again to Fig. 11, the detailed diagram of block 55-72, a hypothetical eyepoint has been represented by a 3mm (0.12 inch) circle within the loop forming the abort maneuver of the rotorcraft, while being fired upon from mountain "2236." A circle about this point has been drawn with a radius of 550m (1,804 ft.). Within the area formed by this circle, the following elements are contained:

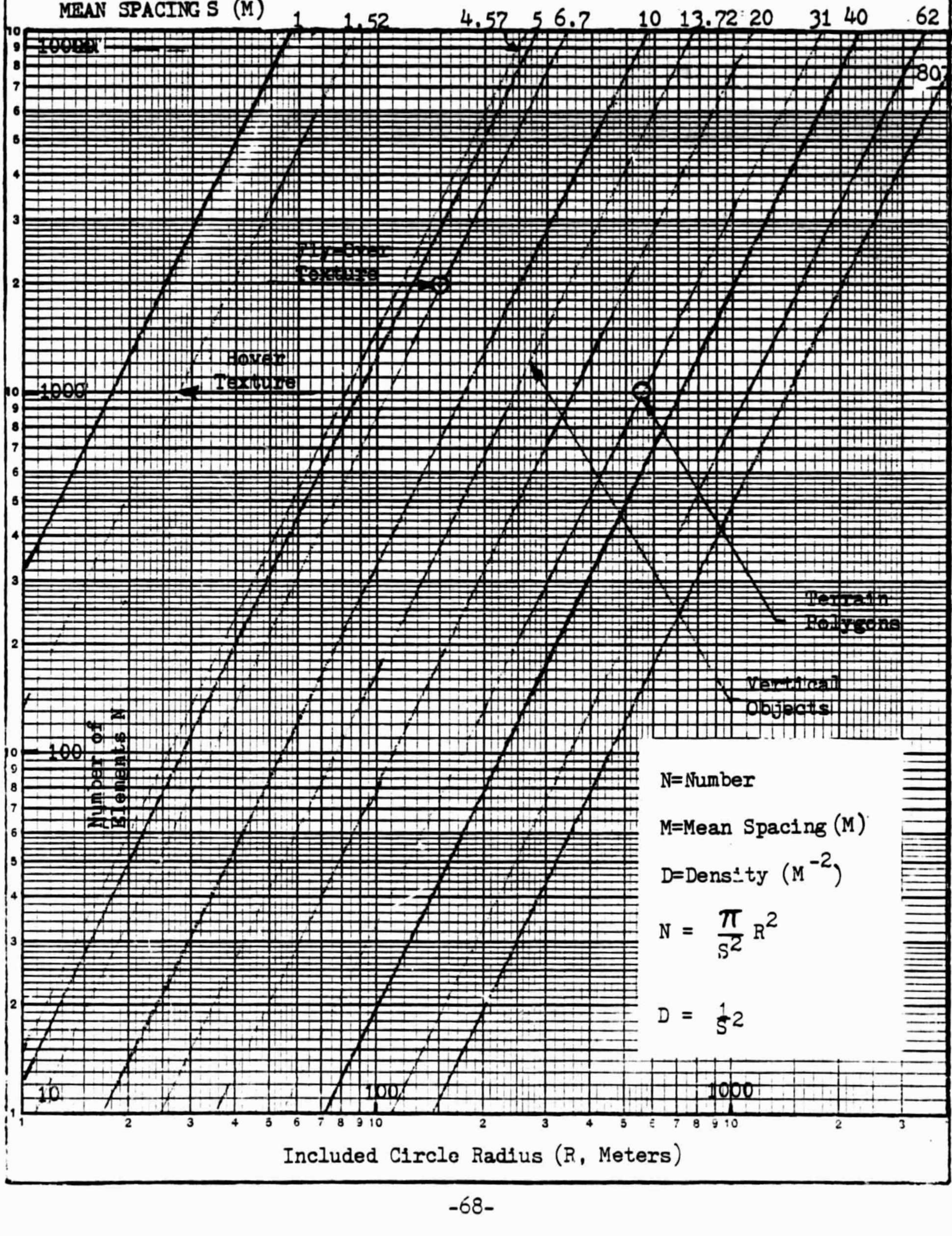
TERRAIN - 1,000 polygons at a mean spacing of 31m (102 ft.) approximating the terrain out to a radius of 550m (1,804 ft.)

FLY-OVER TEXTURE - 2,000 irregular polygons forming a fly-over texture array with a mean spacing of 6.7m (21.9 ft.) out to a radius of 150m (492 ft.)

VERTICAL OBJECTS (Trees/Shrubs) - 448 polygons (7 polygons/tree or shrub) or a total of 64 trees or shrubs decorating three areas of 4,000 m^2 (43,000 $ft.^2$) each at a mean spacing of 13.72m (45 ft.). These areas are approximately 20m by 200m (65.6 ft. by 656 ft.) in size and are placed at the areas labelled "A," "B" and "C" in Fig. 11.

FIG. 12

Relations Among Element Number, Mean Spacing, Density and Radius of the Included Circle



HOVER AREA TEXTURE - 97 irregular polygons forming a hover area texture array within an area approximately 15m by 15m (49 ft. by 49 ft.). The mean texture element spacing is 1.52m (five ft.), and the area is located at the rendezvous point marked "hover" in Fig. 11.

CULTURAL FEATURES (Targets, Roads, etc.) - 455 polygons devoted to mission-related features such as missile fire, sensor imagery, roads, wires poles or spent ordnance.

The total number of polygons included in the above analysis is 4,000. For a field-of-view that is 120° wide by 60° high, whose center is aimed at a heading of approximately 300°, it could be expected that approximately 1,330 polygons would have to be processed from on-line memory in order to form a picture from the loop area vantage point. This value is considered to be one of the worst cases that calls on the image generator to process a relatively large number of polygons. The corresponding densities of features and radius of "decoration" are considered marginal to support close NOE flight simulation, and where possible, ways should be sought to increase the radius of coverage. Although the texture in the above case is represented by polygons, it is hoped that texture can be introduced into current CGI systems without encroaching into their polygon processing capacity. Also, it should be remembered that the texture element recommendations imply that the surface texturing obeys the laws of linear perspective.

At the radii suggested, some thought will be necessary on the development of innocuous blending at the edge. At the relatively close range of 150m (492 ft.) for fly-over texture, and 550m (1,804 ft.) for terrain polygons and vertical objects, some form of object contrast function must be selected and applied to these features so that they will not appear to "pop in" or "pop out" of the scene at the "radius of decoration." An obvious way to handle the terrain and vertical object polygons is to simply limit the visibility to 550m (1,804 ft.). The fly-over texture could be handled differently. Since all polygons forming the terrain and texture will be smooth-shaded, i.e., their edges will not appear sharp. Instead, the luminance transition across each edge will be performed smoothly, i.e., over a perceptible distance. The contrast* level at an edge of a terrain polygon pair will necessarily reflect the result of diffuse illumination similar to the appearance at dusk under a low overcast with haze and some fog that limits the visibility to 550m (1,804 ft.) Under these conditions, typical contrast levels are 0.5 to 1.0. Under the same conditions, a lower contrast fly-over texture, when viewed at a distance of 150m (492 ft.), will have its contrast reduced to one-third of its maximum value due to aerial perspective (assuming an exponential decay of contrast with range). If the maximum contrast of the texture is made low to begin with, say 0.2 or less, then the contrast will fall to 0.33x0.2 = .066 at a range of 150m (492 ft.). At this range and contrast, eliminating the texture beyond 150m in a linear fashion, spread over about 10m (32.8 ft.), may well be innocuous.

*Contrast is defined as the higher luminance minus the lower luminance (or color difference) divided by the lowest luminance or "average" color.

A final note will be made regarding the distribution of image details in a head-directed field-of-view. It is likely that such a field format will be comprised of three separate fields arranged horizontally, each subtending a field of approximately 60° vertically by 40° horizontally. This means that the center field will be viewed using foveal vision; however, the two side fields will be viewed using only peripheral vision. One of the aims of this effort was to gain an insight into the level-of-detail that would be necessary in the two side fields relative to that in the central one. The hope here was to raise the possibility of using image generators for the two peripheral fields that modelled the terrain at, say, one-tenth the level-of-detail, as does the central field generator, thereby saving generation costs. A potential problem with this scheme, however, is the transition of imagery details at the two boundaries between the central and peripheral fields. For example, as a feature moved from the high-detail field into the lower-detail one, a feature such as a surface section containing twenty texture elements would switch to one with only two. The central question here is "Would this switching be innocuous or distracting to the pilot?"

To attempt to answer this question, a peripheral vision testing apparatus was assembled and used in tests with two subjects. The device presented a static display of random numbers approximately one degree high that were presented at a rate of one per second. The subjects were asked to fixate and read these numbers. While doing so, they were told to observe a 2°x2° square target that started at the number display and moved horizontally outward. At a preset eccentricity,* the square target, a 10 by 10 checkerboard (100 squares total) was switched to a blank one of the same luminance as the average checkerboard luminance. The luminance of the checkerboard/blank target was varied, as was that of the background screen. The subjects were asked if they could detect, with their peripheral vision, whether the target had switched to a blank one. The boundary defining the contrast+ above which the switching could be detected was defined as a function of switching eccentricity. The target horizontal sweep rate was set at 10° per second. The contrast level above which switching could be detected was found to be about 0.15 for a switching eccentricity of 35°. The curve extrapolated to a contrast of .08 for an eccentricity of 20°. These contrast values are so low that a preliminary conclusion from these brief tests is that the eye's peripheral detection potential is so high that such a dual-level-of-detail scheme will result in noticeable distractions to the pilot. For this reason, a variable-detail area-of-interest display of this kind is not recommended unless further testing can verify some potential benefit.

*Angle between the target and the central random number display

+Target luminance minus background luminance, divided by background luminance

7.0 REFERENCES

1. Sinacori, John B., "A SURVEY OF HUMAN HEAD AND EYE MOVEMENTS WITH APPLICATION TO A HEAD AND EYE-DIRECTED AREA-OF-INTEREST VISUAL SYSTEM FOR FLIGHT SIMULATORS," 26 November 1979; Prepared for American Airlines, Inc. Incorporated into a report entitled "AMERICAN AIRLINES SCANNED LASER, FINAL REPORT; SPECIFICATION AND MODIFICATION SUPPLEMENT." Prepared for the Naval Training Equipment Center, Orlando, Florida, under Contract N61339-77-C-0001, 20 December 1979.

2. Harker, George S. and Jones, Paul D., "DEPTH PERCEPTION IN VISUAL SIMULATION," August 1980, Performance Research Laboratory, University of Louisville, Louisville, Kentucky 40208; Final Report prepared for Air Force Human Resources Laboratory, Air Force Systems Command, Brooks Air Force Base, Texas 78235, AFHRL-TR-80-19.

3. Helmholtz, H. von (Treatise on physiological optics, v. III), J.P.C. Southall (Ed. and trans.) New York; Optical Society of America, 1925. (Originally published, 1910.)

4. Gibson, E.J., Gibson, J.J., Smith, O.W., & Flock, H., "MOTION PARALLAX AS A DETERMINANT OF PERCEIVED DISTANCE," Journal of Experimental Psychology, 1959, 58, 40-51.

5. Zacharias, Greg and Levison, William H., "DEVELOPMENT OF A MODEL FOR THE USE OF EXTRA-COCKPIT VISUAL CUES," Final Report, December 1980, Bolt Beranek and Newman Inc., Report No. 4562; Prepared for Systems Research Laboratory.

6. Hunter-Liggett Special, 1:50,000; Defense Mapping Agency Topographic Center, Washington, D.C. 20315, Series V795S, Edition 1-DMATC, Stock No. V795SHUNTERLI.

7. Gullen, Robert K., Cattell, Charles S. and Overton, Robert K., "THE COMPUTER IMAGE GENERATION - Applications Study," July 1980, Logicon, Inc., Tactical and Training Systems Div., 4010 Sorrento Valley Blvd., P.O. Box 80158, San Diego, Calif. 92138; Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio 45433, Report No. AFWAL-TR-80-3075.