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VISUAL SIMULATION REQUIREMENTS  
FOR AIRCRAFT ASPECT RECOGNITION  
AT REAL WORLD DISTANCES

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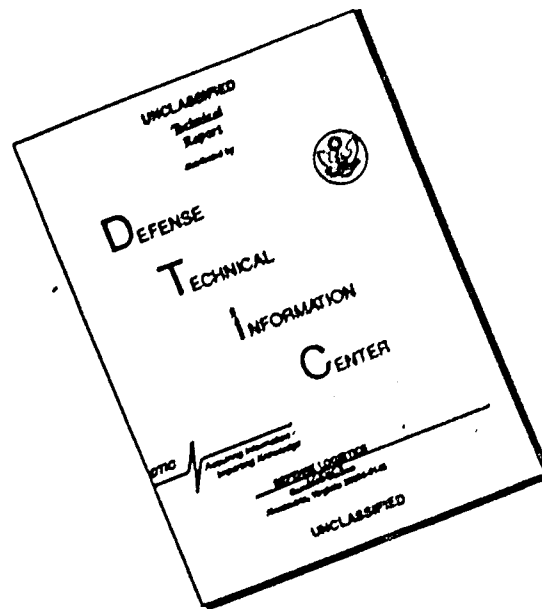
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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>A research program is underway whose goal is to provide engineering guide-<br>lines on target image sufficiency for training tactics and maneuvering skills<br>in ground-based flight simulators. The experiment examined aspect recogni-<br>tion sensitivity, i.e., the distance at which subjects could determine the<br>orientation of another aircraft. The aspect recognition task was simplified<br>in the following ways: a) only 16 stationary target orientations of a TA4J<br>aircraft were presented; b) targets had essentially the same length/width |                                      |                                                                                     |

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ratio; c) subjects made binary up/down judgments; and d) a staircase method provided percent detection thresholds for aspect recognition range.

In Phase I, four different target luminances and three background luminances were combined with four different levels of projector resolution in a partial parametric study to assess the relative effects of contrast, resolution, and brightness on aspect recognition. In Phase II, motion and direction of view were varied. Phase III replicated Phase I to determine whether sequence effects occurred in this repeated measures study. Through a series of mini-studies, Phase IV examined subsidiary effects (viz., different aircraft, different perceptual judgments, difficulty level of the silhouette stimuli, and poorer resolution). In Phase I, all main effects were found to be significant and resolution was the most persistently significant. In the best experimental condition, average aspect recognition thresholds occurred at > 4 miles (a 5.5 arc minute target), whereas the most degraded condition showed average thresholds at 1.5 miles (a 14 arc minute target). These are comparable to distances known to be typical in outdoor training ranges and in combat. In Phase II, a) motion (5 degrees/second) not coincident with the orientation did not degrade performance, but aided slightly. b) Direction of view (side vs straight ahead) had no effect on performance. In Phase III, practice effects were nil.

The following results were found in Phase IV. a) Larger aircraft were seen at greater distances than smaller aircraft with recognition occurring when large and small aircraft were of equivalent retinal sizes. However, the aircraft with the highest aspect ratio (MIG 21) was seen at a greater distance than would be predicted from size alone. b) The distance at which left/right and up/down threshold determinations could be made was about equal but, on average, these determinations could be made at ten times greater distances than coming/going. c) The effect of higher probability values for detection threshold (e.g.,  $P(c) = .85$  vs  $P(c) = .67$ ) resulted in minor changes in threshold recognition distances and could be inferred from normal deviate tables. d) All target orientations were essentially equally difficult, although silhouettes with the vertical stabilizer visible were more confusable than those without. e) A small (25%) reduction in resolution had only a modest (10%) effect on performance, but a larger (50%) reduction had larger (50%) effects, suggesting that < 2.5 arc min/tv line pair is an important design criteria boundary for performance on this task.

An additional finding was that substantial subject differences (> 20% of the total accounted for variance) were reliable over the whole experiment. The four subjects in this study exhibited normal or better than normal vision by static and dynamic tests of contrast sensitivity, and there were individual differences in high spatial frequency sensitivity. Accommodation to the blank background field of the dome was also measured. Subjects' contrast sensitivity and their error in accommodation were predictive of their visual performance on this target aspect recognition task. This relationship held over most of the ranges of background luminance and contrast, but appeared to break down at target projector resolutions which were poorer than 1.5 arc min/tv line pair. Thus, while performance may have been eye-limited over most of the experimental conditions, it was system- or apparatus-limited for the poorest resolution condition. This finding illustrates the utility of investigation of individual subject differences as a paradigm for deriving eye-limited specifications for training equipment design.

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## SUMMARY

A research program is underway whose goal is to provide engineering guidelines on target image sufficiency for training tactics and maneuvering skills in ground-based flight simulators. The experiment examined aspect recognition sensitivity, i.e., the distance at which subjects could determine the orientation of another aircraft. Our objective was to determine how aspect (orientation) recognition sensitivity is affected by changes in target contrast, resolution, luminance, motion, orientation, practice, and other pertinent factors. We describe how we analyzed the aspect recognition task into its perceptual elements and explain why we emphasized spatial vision in this study. The preliminary experiment was carried out in the Naval Training Equipment Center's Visual Technology Research Simulator (VTRS), using computer-generated aircraft images displayed on a dome via a variable-resolution target projector. The aspect recognition task was simplified in the following ways: a) only 16 stationary target orientations of a TA4J aircraft were presented; b) targets had essentially the same length/width ratio; c) subjects made binary up/down judgments; and d) a staircase method provided percent detection thresholds for aspect recognition range.

In Phase I, four different target luminances and three background luminances were combined with four different levels of projector resolution in a partial parametric study to assess the relative effects of contrast, resolution and brightness on aspect recognition.

In Phase II, motion and direction of view were varied. Phase III replicated Phase I, to determine whether sequence effects occurred in this repeated measures study. Through a series of mini-studies, Phase IV examined subsidiary effects (viz., different aircraft, different perceptual judgments, difficulty level of the silhouette stimuli, and poorer resolution).

In Phase I, all main effects were found to be significant. Over the ranges studied, contrast accounted for the most variance and luminance the least. Resolution was the most persistently significant main effect. In the best experimental condition, average aspect recognition thresholds occurred at >4 miles (a 5.5 arc minute target), whereas the most degraded condition showed average thresholds at 1.5 miles (a 14 arc minute target). These are comparable to distances known to be typical in outdoor training ranges and in combat.

In Phase II: a) motion (5 degrees/second) not coincident with the orientation did not degrade performance but aided slightly. b) Direction of view (side versus straight ahead) had no effect on performance. In Phase III: a) the main effects of Phase I were replicated. b) Practice effects were nil.

The following results were found in Phase IV. a) Larger aircraft were seen at greater distances than smaller aircraft with recognition occurring when large and small aircraft were of equivalent retinal sizes. However, the aircraft with the highest aspect ratio (MIG 21) was seen at a greater distance than would be predicted from size alone. b) The distance at which left/right and up/down threshold determinations could be made was about equal but, on average, these determinations could be made at ten times greater distances than coming/going. c) The effect of higher probability values for detection threshold [e.g.,  $P(c)=.85$  versus  $P(c)=.67$ ] resulted in minor changes in threshold recognition distances and could be inferred from normal deviate tables. d) All target orientations were essentially equally difficult, although silhouettes with the vertical stabilizer visible were more confusable than those without. e) A small (25%) reduction in resolution had only a modest (10%) effect on performance, but a larger (50%) reduction had larger (50%) effects, suggesting that  $<2.5$  arc min/tv line pair is an important design criteria boundary for performance on this task.

An additional finding was that substantial subject differences ( $>20\%$  of the total accounted for variance) were reliable over the whole experiment. The four subjects in this study exhibited normal or better than normal vision by static and dynamic tests of contrast sensitivity, and there were individual differences in high spatial frequency sensitivity. Accommodation to the blank background field of the dome was also measured. Subjects' contrast sensitivity scores and their error in accommodation were predictive of their visual performance on this target aspect recognition task. This relationship held over most of the ranges of background luminance and contrast, but appeared to break down at target projector resolutions which were poorer than 1.6 arc min/tv line pair. In other words, persons with better vision performed no better than persons with poorer vision at resolutions which were coarser than this critical resolution. Thus, while performance may have been eye-limited over most of the experimental conditions, it was system- or apparatus-limited for the poorest resolution condition. This finding illustrates the utility of investigation of individual subject differences as a paradigm for deriving eye-limited specifications for training equipment design.

PREFACE

The authors are indebted to the persons who served as subjects (K. Thomley and C. Davis) and experimenters (K. Thomley, D. Sheppard, and B. Riner). These persons willingly gave of their weekends and evenings and performed at high levels in order to complete the lengthy experimental sessions.



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## SECTION I

## INTRODUCTION

Flight simulators for training air combat skills are among the most costly and potentially most useful of military training devices (Orlansky & String, 1979). Several such devices are presently in use, with many more likely to be developed in the next decade. The stringent requirements for visual simulation in such devices include wide-angle fields of view and high detail in one or more aircraft target images.

It has been reported (Ault, 1969; Campbell, 1970) that in air-to-air combat, extraordinary advantage is afforded by better visual performance, because first sighting tends to result in first firing, and the latter is considered to produce 95% success. Therefore, it follows that air combat scenarios which adequately train visual performance may serve to decrease the high attrition rates among fighter pilots in first combat encounters. Weiss (1966) estimates that less than 15% of pilots in WWI, WWII, and the Korean War had a better than even chance of surviving their first combat experience. It has been suggested (Ciavarelli, 1979; Ciavarelli, Williams & Brictson, 1981; Ciavarelli, Williams & Stoffer, 1981; Stoffer, 1981; Youngling, Levine, Mocharnuk & Weston, 1978) that as much as 90% of the fighter pilot's air-to-air work involving vision out of the cockpit occurs at distances within 3 miles. While verifiable detections can take place at greater distances, these occurrences are uncommon. Thus, such extreme distant detections are less reasonable requirements for simulator design. Given 35 ft x 35 ft as an estimate of aircraft size (comparable to an F-5 or A-4) 4 minutes of arc would be subtended at 5 miles. This distance may serve as an approximate specification for simulator design to permit detection. To the extent that aspect recognition is a more demanding perceptual task, a specification of a distance at which aspect recognition ought to be possible in a simulator ought to be less than for detection.

One might analyze the visual work performed on targets in air-to-air engagements into a series of operations: a) detection; b) localization; c) aspect recognition; and d) aircraft category identification. These visual "jobs" or "tasks" are performed, and are important, at different times. Detection and localization are necessary to begin the encounter and identification occurs prior to firing. Determination of aspect and heading are employed continuously throughout an operation and are fundamentally important for initial planning and preparation maneuvers.

We may characterize the visual stimulus features or cues utilized in the air-to-air engagement in terms of the distance at which they become salient. Ordinarily, detection occurs at greater distances than localization; localization at greater distances than aspect recognition; aspect recognition at greater distances than identification, etc. All of the cues for these operations are primarily spatial in nature, if we assume that there is only a moment available for observation.

We believed that it was necessary to decompose the aspect recognition task in terms of stimulus features. We studied it first at threshold distances (i.e., spatial sizes). After this simple situation was well understood, we would perhaps add other factors (or "channels," Regan, 1982) like translational motion, loom, parallax (Zegers, 1948), texture, blur (Harrington & Harrington, 1978a), and color. A later stage of investigation should compare whether the spatial determiners of aspect at profound distances (e.g., high spatial frequency information) could be augmented by the addition of other factors which are known to influence these determinations at shorter distances, such as lower spatial frequency information, blur patterns, shading, movement in depth (Regan & Beverley, 1979), motion parallax, etc.

While cues unrelated to angular size (visual angle) may be used in detection (e.g., glint, movement, contrast), these cues may be less relevant to determination of aspect. Almost any kind of motion may be a powerful aid to detection. Under some circumstances, motion might be an aid to aspect determination (e.g., when flight is straight and level, and the retinal motion of the target is coincident with its long axis). However, during an engagement, this cue may provide conflicting information and would surely be difficult to attend to given the vestibular inputs to the oculomotor system from aircraft kinetics. Were one able to correct for frame of reference as an extrinsic variable (the world itself or the aircraft), then the corrected retinal motion with one's own motion subtracted out would always be coincident with the aircraft's long axis. While this is logically possible, it is more likely that this form of information processing is employed during movement parallax determinations. We suspect that the relative movement of the aircraft against the background (even a relatively featureless background) is a powerful cue to aspect. It is intended that studies of these relationships will be performed later in the program.

Whether practice can improve performance on any of the visual tasks (detection, localization, aspect recognition, identification) is not known, but one may predict that the more "mediated" jobs would be more likely to profit by training. We recognize that the operations and procedures performed after

completion of these visual tasks within the air-to-air engagement are the more important elements (viz., energy management, communications, manual control, further visual exploration). Because these more mediated sub-skills are so demanding in terms of task complexity, workload, and reaction time, it is likely that flight trainers will achieve their greatest effectiveness through training these tasks. Nonetheless, spatial judgments of aspect can provide visual requirements for flight simulators.

However, there are immediate problems in implementing such training. It has been reported (Coward & Rupp, 1982) that existing flight simulators are seriously limited in their ability to depict the heading of potential target aircraft at distances greater than one mile. This limitation is a problem, because much of the activity within an air-to-air engagement takes place at greater distances (cf. Lee & Hughes, 1981). Specifically, although the target can be seen as a blob of light in these simulators, there appears to be insufficient spatial information to infer its direction. Yet, as was already mentioned (cf. Ciavarelli et al., 1981) much of the air-to-air (mostly visual) work occurs at distances of up to 3 miles. We have found no data for equivalent values for aspect recognition. Yet, to the extent that this task is spatially determined, it may be expected to occur at intermediate distances (i.e., visual angles) between detection (e.g., 1-3 arc min) and identification (e.g., >15 arc min).

The inability of these simulators to depict aircraft heading at real world distances is considered to be a serious shortcoming, since it may prevent the learning of proper maneuvering tactics. As a result, consideration is being given to specification of higher resolution levels for future trainers, perhaps to the extent of matching the resolving power of the human eye. The problem for design engineers is that very high target resolution can be extremely costly and can compromise other aspects of system performance. It was also not clear that increased target resolution alone would solve the problem.

Concern that visual simulators may compromise training by poor depiction of alien aircraft led us to compare the visual equipment factors cited in military standards and specifications which control the simulators, to determine whether they were in keeping with the visual requirements calculated on the basis of contemporary vision research. No specific section in Military Standard 1472C (MIL-STD 1472C, 1981) is devoted to the design of training equipment, nor to the design of simulators. However, visual luminance requirements for ground-based flight simulators presumably would be the same as those for Large Screen Optical Projection Displays (MIL-STD 1472C 5.2.6.6). Presently, 10 fL is considered optimum and 5-20 fL is acceptable. This document also lists that contrast, a presumed determiner of visual

performance, may be either light on a dark background or vice versa. Luminance Ratio (LR) (brighter/darker) is preferred in MIL-STD 1472 to more traditional contrast calculations (e.g., brighter minus darker/brighter plus darker) and the minimum LR specified is 5:1; but these limits are expected to be extended to 25:1 for animation. No special requirements for optical quality for large screen displays are called out in the standard, but axial resolution for optical instruments and related equipment (5.11.3) requires ".300 rad (1 arc min) divided by the magnification to provide an eye-limited instrument" (5.11.3.10.1). For target and alphanumeric detection, 20 minutes as a minimum for extraction of information from CRT displays is required.

From what we know about vision and visual perception, the design criteria listed in this document appear reasonable enough in specifying requirements (cf. Shurtleff, 1967). However, they do not appear to address the specific requirements of the design of flight simulators for air-to-air combat. In any event, they do not provide enough information to permit trade-offs between visual factors that are known to be determinants (e.g., contrast and luminance). No information is available for design criteria which deal with the temporal (e.g., motion) aspects of the stimulus.

It would seem that the study of how aspect recognition pertains to simulator design should address three main questions: a) What are the determiners of aspect recognition? b) Is the perception of aspect modifiable? and, c) What are the visual simulator requirements necessary to permit the chain of events occurring in the real world to be practiced in a simulator and transferred to an aircraft? Stated differently, if the flight simulator is to be used to train an aviator to position his aircraft in prescribed ways, depending on the identified heading of the enemy aircraft, we must decide what must be trained. If aspect recognition is to be taught as a separable subskill, then a part-task trainer which embodies those sensory, perceptual, and information processing operations could be created. If, however, the many sequentially dependent operations necessary to effect appropriate setup for missile or gun attack after the recognition of aspect, then training in aspect recognition may be instrumental to the subsequent training activities. A situation where these were combined into one simulator may appear very realistic and so gain pilot acceptance, but may not prove to be cost effective. Regardless of whether veridical or not, were real-world aspect recognition taught as a separable subskill, it would be desirable to have the ability to present target depiction sizes that imply distances like those found in the real world. Such depictions should support aspect recognition at the same levels of certainty at the same distances as in the real world combat situations.

The main purpose of the present study was to begin addressing question (a) by developing a workable test procedure and examining a few important factors. Question (b) is of particular concern to those interested in pilot selection, while (c) is of interest from the standpoint of the possible development of a part-task trainer to improve visual performance during air combat. The latter two issues were examined, although they were of lesser concern to us. A fourth question, not dealt with here, would be whether other methods than accurate depiction may be as useful in training. Techniques other than presenting highly realistic aircraft imagery might provide aspect information sufficient for the pilot to learn the proper tactical skills which follow on those percepts.

The present study is only a beginning of the investigations that are needed in this area. We set as our goal the study of the part of the air-to-air engagement following initial target acquisition detection. In this experiment, we examined visual equipment factors with the purpose of determining their relative contribution to performance of aspect recognition in a simulator. This preliminary experiment used nonaviators with normal vision.

We defined normal vision as unremarkable contrast sensitivity scores across a range of frequencies from .50 to 22.8 cycles/degree. It is of more than passing interest that Hutchins (1978) found no relationship between ordinary screening tests of visual function and ranges at which targets are detected on the Navy's Air Combat Maneuvering Range. Since there were individual differences in performance in that study, one might infer that a) these differences are due to other visual functions not presently measured in induction physical examinations; b) the performances have been modified by practice; or c) insufficient sensitivity is available in the tests of visual function.

We examined visual equipment factors cited in military standards and specifications in order to determine their applicability to performance of aspect recognition in a simulator using persons with normal vision.

The primary goal of the present study was to develop a paradigm which could be used in our simulator to study aspect recognition performance at realistic distances. For our initial study we concentrated on the study of the spatial determiners of aspect. This experiment was the first in a program of research to examine the visual equipment features which influence the determination of aspect recognition and the prospective trade-offs one may introduce between these features in ground-based simulators. A secondary purpose was to determine whether any part of recognition performance was improvable by practice.

## SECTION II

## PHASE I

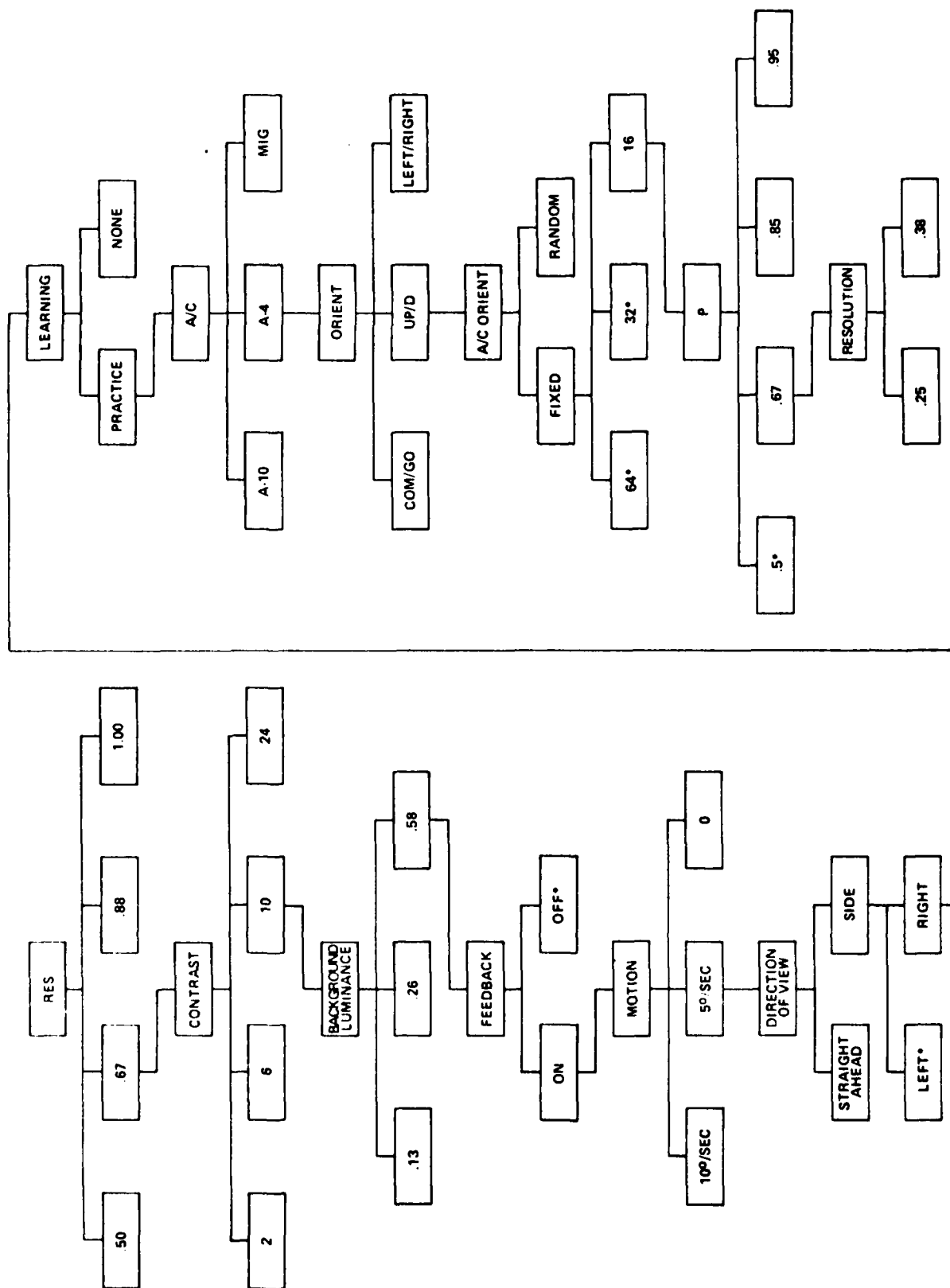
## INTRODUCTION

OVERALL EXPERIMENTAL PLAN. Figure 1 shows a schematic prospectus for the experiment as a whole. It shows the order in which we tested variables, the levels of those variables, and various decisions which we made about control variables shown as dead-ends. Tracing through the chart gives a good idea of how we proceeded. In the initial study (Phase I), resolution (RES), contrast and luminance were varied. To shorten the time required for the subjects to achieve stability on this task, feedback was provided after every determination. After those data were analyzed, motion was added as an experimental variable, although only one velocity was employed. Direction of view was kept constant in the first phase, but canopy bows restricted the field of view to stationary targets. Consequently, in Phase II, static trials out-the-side were compared with straight ahead, before motion and static out-the-side were studied. Practice effects were studied by comparing performance in Phase III with performance in Phase I. Several other variables of lesser importance were examined briefly in Phase IV in order to screen leads for future research where we intend to employ holistic designs (Simon, 1973, 1977).

SUBJECTS. Four paid volunteer subjects were used. There were three males and one female, ranging in age from 21 to 46. Detailed measurements of dynamic and static contrast sensitivity were made, and dark accommodation was assessed. Contrast sensitivity to vertical sinusoidal gratings was measured using a portable microprocessor system (Optronix Corp. Series 100 Vision Tester). Dark accommodation was tested by a modification of the procedure of Hennessy & Leibowitz (1980). These procedures and results appear in Appendices A and B. All subjects had average or better far vision.

APPARATUS. Data were collected in the VTRS, a flight simulator having a wide-angle, computer image generation (CIG) visual display system. This system (described more fully elsewhere, e.g., Collyer & Chambers, 1978) consists of a 10 ft radius spherical screen on which two projectors present images. In this experiment, a wide-angle background projector was used solely to provide uniform illumination over an area subtending 160 degrees horizontally by 80 degrees vertically.

A second projector presented static aircraft images directly in front of the subject. This target projector was a 1025 raster-line General Electric color light valve. A zoom



\*NOT DONE

Figure 1. Experimental Plan for Aspect Recognition Study

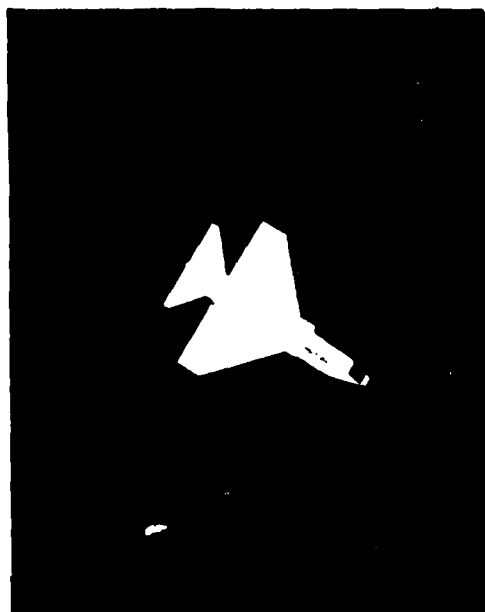
optics system provided the capability of varying the field of view (FOV) of the projected imagery, with a minimum FOV of 10.3 degrees horizontal by 8.2 degrees vertical. The targets for Phases I-III were achromatic (bluish-white) CIG images of a TA-4J aircraft (Figure 2) having a length of 35 feet and a wingspan of 27 feet.

#### METHOD

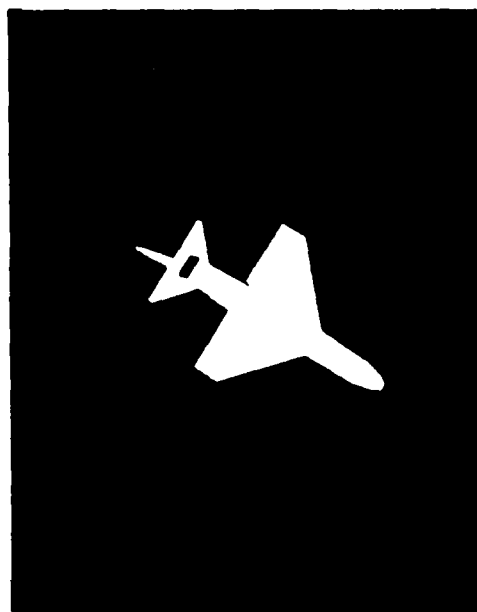
The stimulus set consisted of 16 target aircraft orientations. The following procedure was used to generate this set. Beginning with an aircraft on a heading of either 45, 135, 225 or 315 degrees (assuming a heading of 0 degrees for the simulated aircraft in which the subject was seated), the aircraft was then pitched either up or down 45 degrees. It was then rolled, a) either 45 degrees right or 135 degrees left, or b) either 45 degrees left or 135 degrees right. The selection of (a) or (b) depended on the particular yaw/pitch combination. The result was 16 images (4 headings X 2 pitch angles X 2 roll angles) all having nearly the same aspect ratio (ratio of projected length to projected wingspan). The stimulus set thus consisted of four different views of the aircraft, each of which could appear in one of four rotational positions relative to the subject's line of sight.

Figure 2 provides pictures of the aircraft targets showing the four unique views. In this case, all four are pointing up and to the right (the other three rotations being up and to the left, down and to the left, and down and to the right). The four orientations in the figure represent the bottom/rear, bottom/front, top/rear, and top/front viewpoints, respectively. The subject was seated in the simulator, normally 111 inches from the screen. The head was not fixed and may have permitted +/- 3 inches between and within subjects.

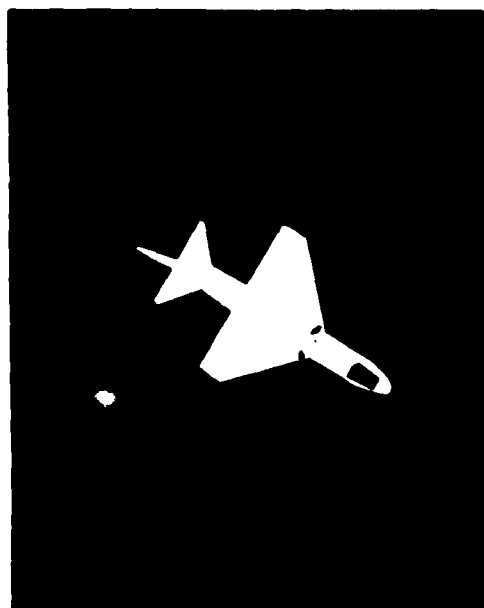
In a series of 100 trials, aircraft targets were presented at various orientations (randomized within 2 blocks of 50) and at various simulated distances from the subject. The first target was at a range of 4000 feet, a distance at which orientation was readily discernible. The subject's task was to press a switch either upward or downward to indicate his judgment whether the aircraft was climbing or diving. (Judgments of other stimulus dimensions--coming/going, inverted/non-inverted, left/right--were not required in this initial study.) If the subject's answer was correct, the distance to the aircraft on the next trial was increased by 5% of the distance at which the previous judgment was made. When incorrect, distance was decreased (size was increased) by 5% on each of the next two trials. This procedure was incorporated in order to minimize the bias of the up/down method (Blower, 1980a, b). Knowledge of results was provided after each response by causing the stimulus to be enlarged to a size subtending approximately 4 degrees.



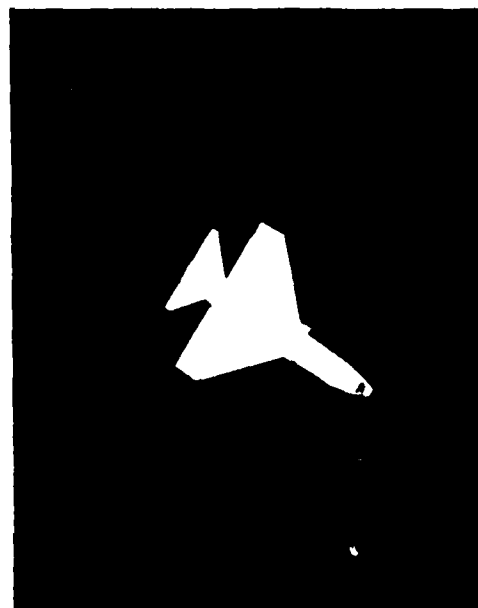
Bottom Front



Top Front



Bottom Rear



Top Rear

Figure 2. Four unique views of aircraft targets.

The variables examined were: a) maximum target luminance, b) background luminance, and c) target resolution. The combinations of target and background luminances studied, along with their resultant approximate luminance ratios, are presented in Figures 3-A, 3-B, and 3-C. Figure 3-A presents the luminances and luminance ratio that we had planned to use in the experiment. We used an incident light meter to adjust projector intensities based on the screen reflectance. Later, we collected luminance readings with a photometer. These actual target and background luminances and resultant luminance ratios are presented in Figure 3-A. Since target images were superimposed onto the background, only the combinations of luminances for which the target was brighter than the background were used. Average target luminances were .29, .67, 1.33, and 3.01 foot-Lamberts (fL) (somewhat different values being obtained at different background luminances). Background luminances were .13, .26 and .58 fL. Target luminances are the sum of target and background luminances.

The background and the target projectors were set using a light meter placed at the surface of the dome. Calibrations were made for each change in the target and background luminance (i.e., for each threshold determination). The light meter (illuminance measurement) was calibrated later using an SEI exposure photometer (luminance measurement). The latter was used because it is easily handled in the VTRS cockpit, so that measurements of various parts of the imagery can be easily seen through the windscreen and because the SEI employs matching to a standard to the image to be measured--the targets in the aspect recognition study being small. In our judgment, the SEI yields very accurate measurements, particularly in the hands of a trained user and, in our experience, the SEI is often used in preference to more expensive devices (e.g., Gamma, Spectra-Physics) in many vision laboratories. For the study reported here, the illuminometer was used for daily calibration. Most of the settings were performed by one person (KT) and all the calibrations with the SEI were performed by one person (KB). The latter were averages (medians) of five measurements taken on five occasions. Calibrations were always conducted at the center of a large (>10 degree) aircraft silhouette and background calibrations were performed at 1 foot from the target's edge.

The lack of complete regularity in these numbers and in the resulting luminance ratios (the negative diagonals of Figure 3-B) was due to the unavailability of the SEI equipment at the onset of the experiment and the slight difference in scaled values of the two devices. No bias was introduced by this approach, the one measurement being a linear transform of the other for our display.

The nine luminance combinations of Figure 3-B were studied at each of four levels of target image resolution. Resolution

# NAVTRAEQUIPCEN 81-C-0105-5

|                                      |    |    |   |   |
|--------------------------------------|----|----|---|---|
| AVERAGE LIGHT METER SETTING          | 2  | 2  | x | x |
|                                      | 4  | 4  | 2 | x |
|                                      | 8  | 8  | 4 | 2 |
|                                      | 16 | 16 | 8 | 4 |
|                                      | 1  | 2  | 4 |   |
| AVERAGE BACKGROUND LUMINANCE SETTING |    |    |   |   |

Figure 3-A. Planned luminance ratios for experiment based on light meter settings.

|                                               |      |       |       |      |
|-----------------------------------------------|------|-------|-------|------|
| AVERAGE ILLUMINOMETER READING (fL)            | 0.29 | 2.20  | x     | x    |
|                                               | 0.67 | 5.10  | 2.60  | x    |
|                                               | 1.33 | 9.70  | 5.90  | 2.10 |
|                                               | 3.01 | 24.10 | 11.10 | 5.20 |
|                                               | 0.13 | 0.26  | 0.58  |      |
| AVERAGE BACKGROUND ILLUMINOMETER READING (fL) |      |       |       |      |

Figure 3-B. Obtained luminance ratios based on illuminometer readings (in fL) of target and background luminances.

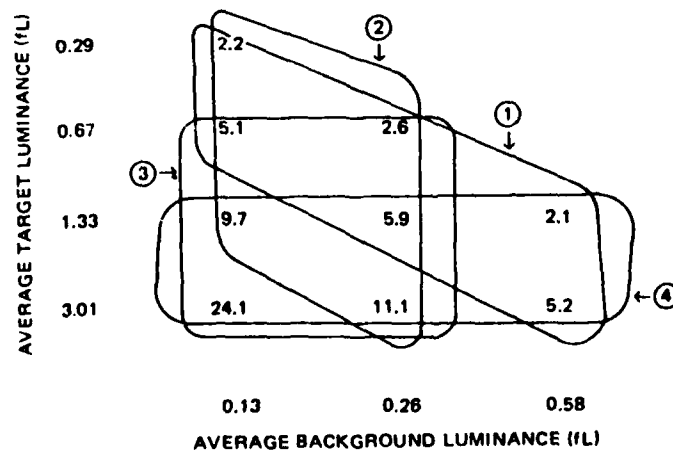


Figure 3-C. Schematic representation of luminance ratios (target/background) for nine target and background combinations resulting in four data subsets for repeated measures analysis of variance (ANOVA).

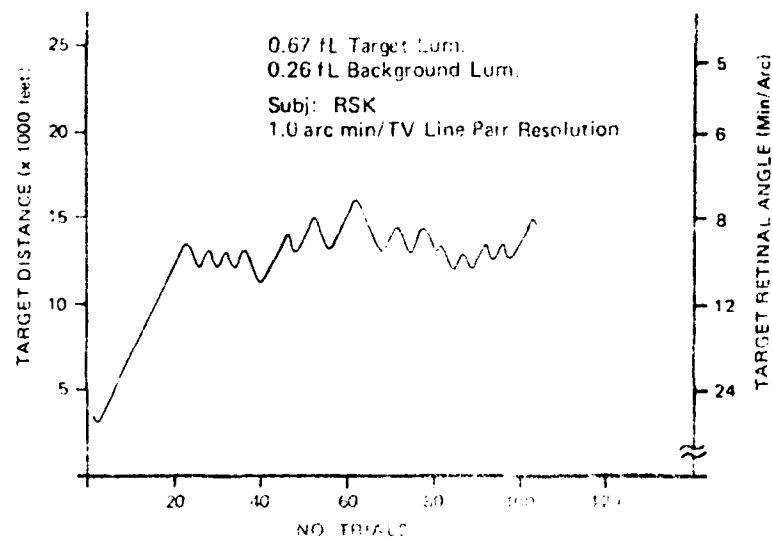


Figure 4 Representative curve for subject RSK for 0.67 fL target luminance and 0.26 fL background for 1.0 arc min resolution.

was varied by manipulating the field of view of the target projector. These manipulations of resolution were made while luminance was kept constant. The resulting levels of display resolution (measured as the visual angle of one just-resolvable TV line pair--i.e., the width of a black and white line pair of a square-wave wedge pattern) were 1.0, 1.3, 1.6 and 1.9 arc minutes per TV line pair. These values are averages for vertical and for horizontal resolution and are consistent with those reported by Fisher and Lyons (1977). Additional information concerning the engineering features of the visual system we used may be found in the subsystem design report (Fisher & Lyons, 1977).

To obtain a single threshold measurement required that, for each of the 36 experimental conditions, the subject make 100 judgments of aircraft orientation. This procedure took approximately 15 minutes. A one-hour experimental session permitted the testing of four conditions--in most cases, the four resolution levels for one target X background luminance combination. Figure 4 shows a representative curve for the .26 X .67 fL condition, at 1.0 arc min resolution. The score for each condition was obtained by finding the longest continuous string of trials for which the slope of a line, fitted by a least squares regression analysis, was not significantly different from zero. The midpoint of this line segment was taken as the estimate of the threshold.

## RESULTS

Four initial repeated measures analyses of variance (ANOVA) were performed. Each of these included factorial data subsets comprising two-thirds of the total data set. The data subsets for these analyses are depicted in Figure 3-C, which summarizes the experimental design for one resolution only. Each analysis also included resolution (number of line pairs) as a variable, although this variable is not depicted in the figure. The four analyses are indicated by the lines enclosing different subsets of data and are coded by the numbers in circles. Analyses 1 and 2 involve data along the major diagonals of the design, and therefore involve the variables "contrast" (ratio of target to background luminance) and "background luminance," as well as "resolution." Analyses 3 and 4 involve "target luminance," "background luminance" and "resolution" as variables.

Table 1 summarizes the results of these analyses in terms of all variables and interactions that were significant ( $p < .05$ ) or approached significance ( $p < .20$ ). As is clear, resolution, as a main effect, was always highly significant. Contrast was marginally significant in Analysis 1 when two levels were compared, and highly significant in Analysis 2 where three were compared. Luminance (which is related to contrast) was highly significant for both Analyses 3 and 4. Background luminance approached significance for three of the four analyses.

TABLE 1. SUMMARY OF PROBABILITY VALUES OF FOUR INITIAL REPEATED MEASURES ANOVAS

|                     | <u>1</u>     | <u>2</u>     | <u>3</u>     | <u>4</u>     |
|---------------------|--------------|--------------|--------------|--------------|
|                     | <u>RxCxB</u> | <u>RxCxB</u> | <u>RxCxB</u> | <u>RxCxB</u> |
| Resolution (R)      | .0008        | .0006        | .0001        | .0001        |
| Contrast (C)        | .0613        | .0100        | ----         | ----         |
| Target Lum. (T)     | ----         | ----         | .0006        | .0059        |
| Background Lum. (B) | .0962        | .1982        | ns           | .0527        |
| RC                  | ns           | ns           | ----         | ----         |
| RT                  | ----         | ----         | ns           | ns           |
| RB                  | .1011        | ns           | ----         | ----         |
| CB                  | ns           | ns           | ----         | ----         |
| TB                  | ----         | ----         | ns           | .1569        |
| RCB                 | ns           | ns           | ----         | ----         |
| RTB                 | ----         | ----         | ns           | ns           |

None of the two-way interactions was significant. However, three of these interactions approached significance--each on one out of four analyses. The two-way interactions for purposes of the current analysis were considered to be type 1 error and were not included in the subsequent nonorthogonal regression analysis. The ANOVAs had low power due to the use of only four subjects in the current experiment. In order to inform plans for future studies (particularly fractional factorial designs), the two most suggestive interactions are depicted in Figures 5 and 6 to elucidate trends that might surface in larger studies. It appears from Figure 5 that, although threshold aspect recognition distance increases monotonically with background luminance at high resolution, threshold distance reaches a ceiling relative to background luminance (0.26 FL level) with lower resolution.

Figure 6 again shows that target luminance also has less impact with lower resolution; in this case high target luminance increases threshold most at the higher two resolutions. The interaction of target X background luminance in ANOVA 4 was examined, but was not found easily interpretable.

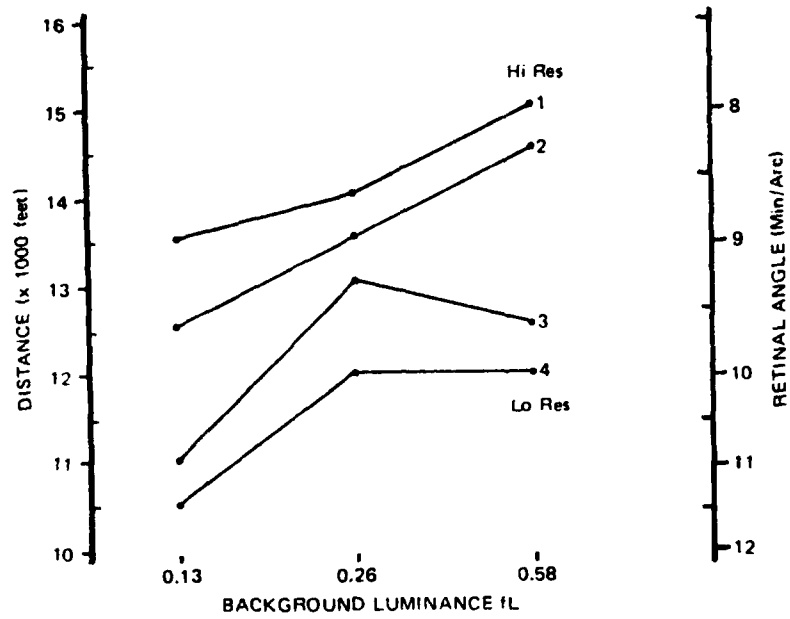


Figure 5. Resolution by Background Luminance Interaction from ANOVA 1 (Contrast Equal).

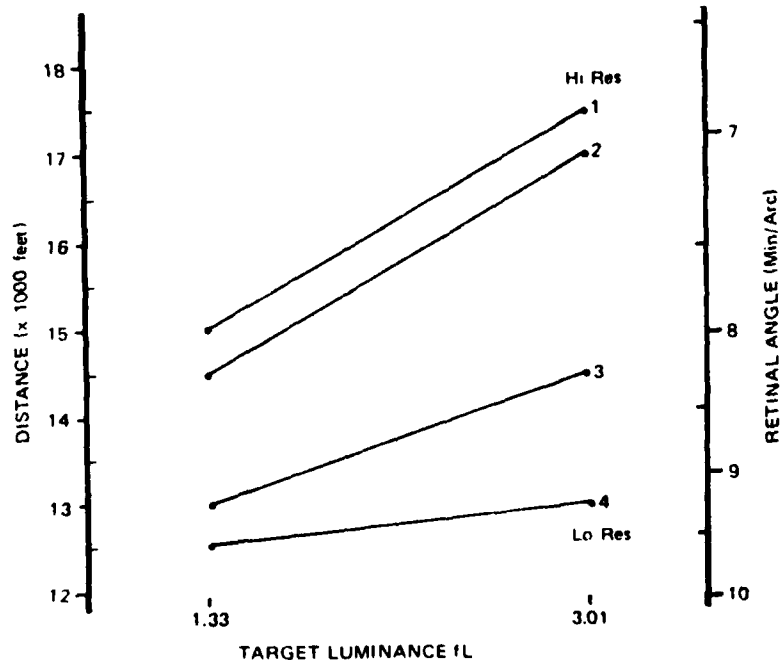


Figure 6. Resolution x Target Luminance Interaction from ANOVA 4.

In Figures 7 and 8, the scores for the four subjects have been combined. These figures are presented in order to illustrate the main effects of contrast (Luminance Ratio) and resolution. In the case of LR 2.3 and LR 5.4 the scores from the three stimulus conditions have nearly the same LR values and were averaged; two scores were averaged for LR 10.4 and one was used at 24.1. The threshold distances obtained were plotted against resolution and appear in Figure 7. Individual scores (not shown) exhibit the same relationships as the group curves and are discussed further below. The main effects of both variables were significant ( $p < .001$ ). The highest LRs resulted in threshold distances that were 40% greater than those at the lowest LRs. Threshold distances were slightly more than 20% greater for the resolution (i.e., least arc minutes per TV line) than for the lowest resolution studied. There is a suggestion that at the highest resolution and the highest LR, a tapering off of the resolution effect occurs. Figure 8 compares the relationships of background luminance and contrast (LR) on aspect recognition threshold. The data have been arranged so that all performances with constant backgrounds (e.g., .26 fL) were summed over the four resolutions. It may be seen that different LRs (where background is constant) result in the expected monotonic improvement in performance, a difference that was statistically significant ( $p < .001$ ). Moreover, all backgrounds of .58 fL result in better performances than .26 fL, and .26 fL is likewise better than .13 ( $p < .01$ ). In this experiment, a LR of 24.1 for a background of .13 fL is as detectable as a LR of 10.4 for a background of .26 fL.

**REGRESSION ANALYSIS.** In an attempt to model all of the data at once, and to provide some notion as to the proportions of variance accounted for by the major independent variables in this study, a regression analysis was performed where the distance thresholds were predicted from log background luminance, log contrast, and number of lines of resolution, as well as dummy predictors, to account for overall differences between subjects. All F ratios reported are based on complete versus reduced model tests using the REGRAN program (Veldman, 1967). Thus, each represents the independent contribution of a variable, controlling for all other variables. Since the design was a within-subjects design, and because subject differences were removed by employing dummy codes, the resulting F tests are equivalent to standard Fs using pooled error terms.

The overall multiple R was .8352, thus accounting for 70% of the variance in distance thresholds. Figure 9 displays the relative contributions of each source of variance, along with F-tests for their significance. As can be seen, Contrast, Resolution and Background account for more than 50% of the variance, and differences between subjects account for about 20%. Equation (1) describes the relationships.

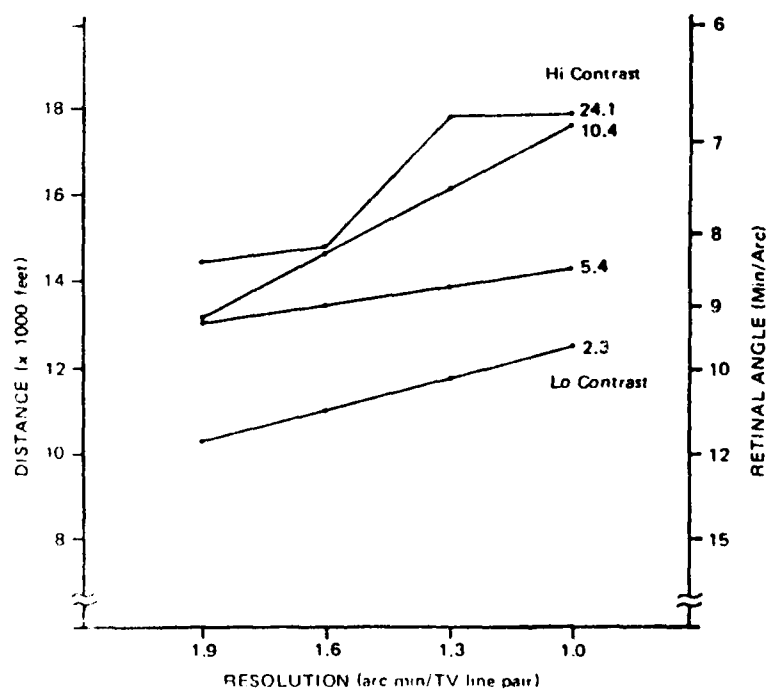


Figure 7. Comparison of Four Luminance Ratios at Four Display Resolutions for Four Subjects.

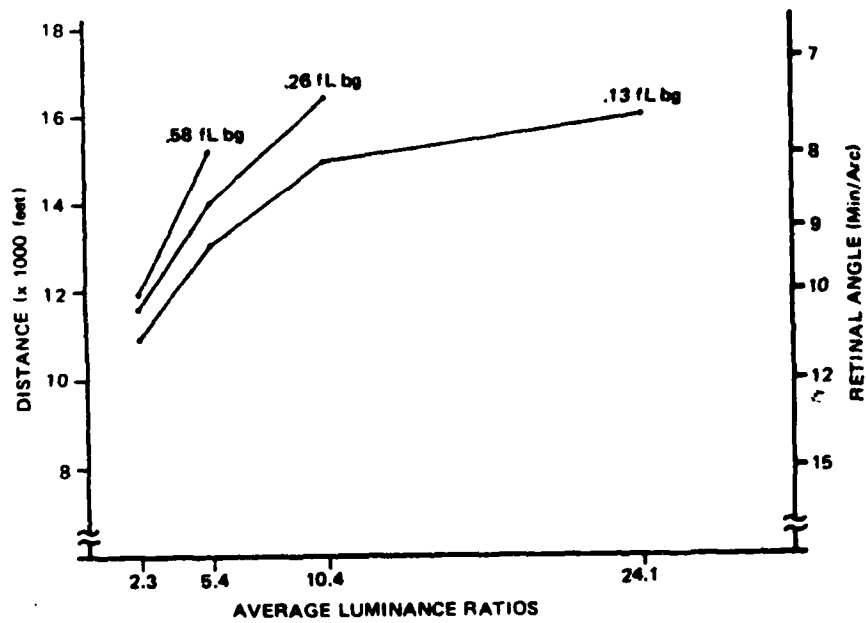


Figure 8. Effects of Background Luminance on Average Luminance Ratio for Four Subjects.

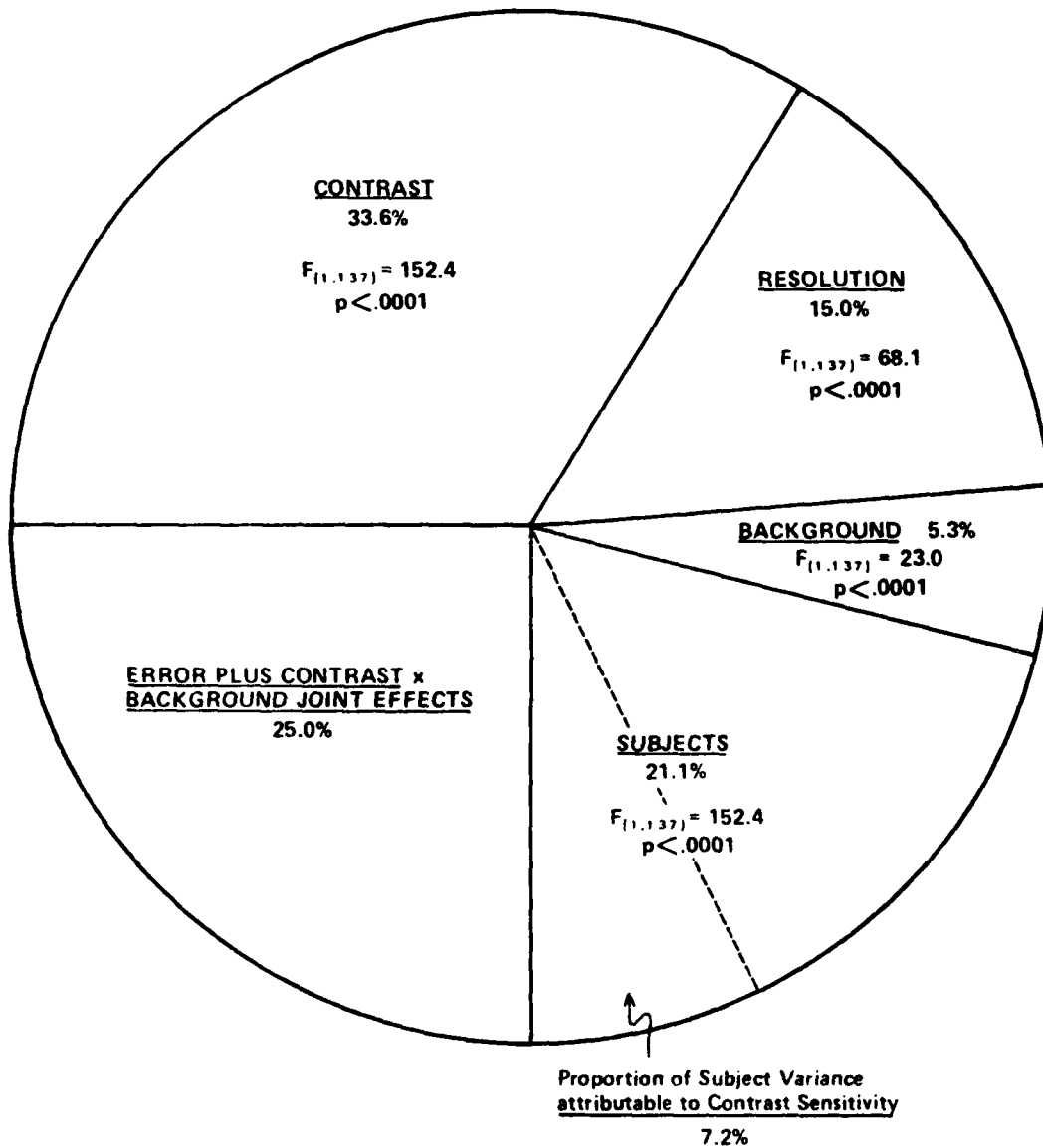


Figure 9. Proportion of Variances Accounted For

$$S = 1.79BG - 2.02R - 1.04T \quad (1)$$

Where:

Retinal Size (S) [in minutes of arc] =

+ 1.79 x Background Luminance (BG) [in foot Lamberts]

- 2.02 x Resolution (R) [in arc min/line pair]

- 1.04 x Target (T) Luminance Ratio [in foot Lamberts] + 12.08

The subject variance can be further partitioned by using individual scores of contrast sensitivity at 22.5 cycles/degree (the highest cycle/degree setting available). These contrast sensitivity scores account for 7.2% of total variance, or 34.1% of the between-subject variance in threshold determinations. Since the dark accommodation scores correlated perfectly with the contrast sensitivity scores at 22.2 cycles/degrees they added no unique variance.

## SECTION III

## PHASE II

## INTRODUCTION

EXPERIMENTS ON MOTION AND DIRECTION OF VIEW. In the first phase of this experiment, we defined aspect recognition as a spatial job and sought to examine the relative contribution of those elements known from the literature to affect spatial vision. In addition to spatial information, motion, color, texture, and perhaps other visual features (e.g., blur, loom), may contribute to aspect recognition in the real world. Our next step was to find out whether motion of the target would change threshold values obtained from the stationary images.

## METHOD

PROCEDURE. Apparatus and subjects were the same as in Phase I, and the procedure was as follows: The same 16 target aircraft orientations were employed following the same psychophysical task. However, the targets were presented to the side of the cockpit through the portion of the canopy without bows or struts. The viewing distance from the eye was the same. The plexiglass of the side canopy was slightly more transparent than that of the forward-looking one used earlier, although it was of a poorer grade and contained some distortion. The area of the dome on which the target was presented was illuminated by the background projector in a slightly less uniform manner. The overall number of experimental conditions was abbreviated in that four contrast levels (at .13 fL) and three contrasts with different average luminances (.13/.29, .26/.67, and .58/1.33 fL), and two resolutions (1.0, 1.9 arc minutes per tv line) were studied. Comparisons were made between sideward and straight ahead viewing of static targets and between moving and stationary targets viewed sideways. Essentially the same procedure for straight ahead viewing was repeated in the sideward static trials. Motion trials were similar to static trials except that only 8 seconds were available for viewing the target. That procedure was as follows: The target projector was slewed to its greatest extent to the right (approximately 90 degrees from the cockpit's nose) and began to move from right to left at 5 degrees per second. After 15 degrees of travel, the target was turned on, and the subject made a determination with his response key within 10 seconds. Ordinarily, a determination was made prior to the target reaching its fullest extent (90 degrees from the start), and this extinguished the target, after which a new trial was begun. The target was only viewable as it travelled over 65 degrees of extent, although the last 25 degrees of this travel was behind canopy bows. When a

determination could not be made (a rare occurrence), the trial was repeated.

Table 2 (similar to Figure 3) shows the luminance levels and luminance ratios used. There were eight comparisons (i.e., moving versus static, straight ahead versus sideward--each at high and low resolution).

TABLE 2. LUMINANCE RATIOS FOR VARIOUS BACKGROUND AND TARGET LUMINANCE SETTINGS PERFORMED OVER TWO RESOLUTIONS, WITH AND WITHOUT MOTION FOR SIDEWARD AND STRAIGHT AHEAD VIEWING

| Target<br>Luminance | <u>Background Luminance (fL)</u> |      |      |
|---------------------|----------------------------------|------|------|
|                     | 0.13                             | 0.26 | 0.58 |
| 0.29                | 2.2                              | -    | -    |
| 0.67                | 5.1                              | 2.6  | -    |
| 1.33                | 9.7                              | -    | 2.1  |
| 3.01                | 24.1                             | -    | -    |

ANALYSIS. Two comparisons were made. A one-way analysis of variance was performed each for the four incremental contrast conditions and the three isocontrast conditions, so that the .13/.29 condition appears in both analyses.

#### RESULTS

Tables 3 and 4 contain the ANOVAs for contrast and isocontrast (luminance), respectively. In both analyses, differences between side versus straight ahead were not significant, and resolution had a significant but weak effect. Unlike Phase I, only two resolution levels were studied in this phase. In Table 3, contrast shows a strong effect. In Table 4, performance for the three luminance isocontrasts were not significantly different. The resolution by direction of view interaction was not significant in one comparison (.1094) and weak but significant (.0464) in the other. The lower resolution was slightly better out the side than straight ahead, and the higher resolution was better straight ahead than out the side. This effect is so small that speculations concerning its basis may be counterproductive.

Because these tests showed sideward viewing of the aircraft targets afforded no significant disadvantage from straight ahead, studies of motion out the side could proceed and comparisons could be made with straight-ahead viewing.

TABLE 3. ANOVA FOR SIDE VERSUS STRAIGHT AHEAD,  
FOR FOUR CONTRASTS AND TWO RESOLUTIONS

| <u>Source</u> | <u>df</u> | <u>F</u> | <u>Prob.</u> |
|---------------|-----------|----------|--------------|
| Side/straight | 1,3       | 0.00     | .9497        |
| Resolution    | 1,3       | 13.17    | .0360*       |
| SxR           | 1,3       | 5.09     | .1094        |
| Contrast      | 3,9       | 18.43    | .0003*       |
| SxC           | 3,9       | 0.12     | .9473        |
| RxC           | 3,9       | 0.93     | .4664        |
| SxCxR         | 3,9       | 0.38     | .7682        |

TABLE 4. ANOVA FOR SIDE VERSUS STRAIGHT AHEAD FOR  
THREE LUMINANCES AND TWO RESOLUTIONS

| <u>Source</u> | <u>df</u> | <u>F</u> | <u>Prob.</u> |
|---------------|-----------|----------|--------------|
| Side/straight | 1,3       | 0.80     | .4362        |
| Resolution    | 1,3       | 11.26    | .0439*       |
| SxR           | 1,3       | 10.76    | .0464*       |
| Luminance     | 2,6       | 0.20     | .8266        |
| SxL           | 2,6       | 0.18     | .8392        |
| RxL           | 2,6       | 2.75     | .1419        |
| RxLxS         | 2,6       | 0.63     | .5637        |

Tables 5 and 6 show the ANOVA's for the two motion conditions. Again, as in sideward versus straight ahead, the four contrasts were analyzed separately from the three levels of luminance combinations with the same contrast. In Table 5 it may be seen that motion afforded some advantage, so that smaller aircraft targets (greater distances) could be seen when the target moved at 5 degrees per second, even though the movement of the target was not coincident with its aspect. Two other effects in Table 5 (contrast and motion by resolution interaction) were only marginally significant. The data from Phase II were slightly less regular than Phase I data and retrospective reports from the subjects indicated that they found this a slightly more difficult perceptual task than when the targets were stationary. No effect in Table 6 was significant.

TABLE 5. ANOVA FOR MOTION AND NO MOTION CONDITIONS  
AT FOUR CONTRAST LEVELS AND TWO RESOLUTIONS

| <u>Source</u> | <u>df</u> | <u>F</u> | <u>Prob.</u> |
|---------------|-----------|----------|--------------|
| Motion        | 1,3       | 26.42    | .0143*       |
| Resolution    | 1,3       | 6.73     | .0808        |
| MxR           | 1,3       | 9.64     | .0531        |
| Contrast      | 3,9       | 3.59     | .0594        |
| MxC           | 3,9       | 0.81     | .5174        |
| RxC           | 3,9       | 0.35     | .7929        |
| MxRxC         | 3,9       | 0.28     | .6334        |

TABLE 6. ANOVA FOR MOTION AND NO MOTION AT THREE  
LUMINANCE AND TWO RESOLUTIONS

| <u>Source</u> | <u>df</u> | <u>F</u> | <u>Prob.</u> |
|---------------|-----------|----------|--------------|
| Motion        | 1,3       | 0.01     | .9267        |
| Resolution    | 1,3       | 3.76     | .1480        |
| MxR           | 1,3       | 0.57     | .5050        |
| Luminance     | 2,6       | 0.70     | .5311        |
| MxL           | 2,6       | 1.87     | .2343        |
| RxL           | 2,6       | 1.76     | .2497        |
| RxLxM         | 2,6       | 1.23     | .3561        |

The results of this phase supported previous conclusions that contrast, resolution and, to a lesser extent, luminance, were important variables; and that motion, if anything, aids in judging aspect in a simulator. Although this latter effect was small, it is difficult to explain. Perhaps nonuniformities in the background illumination are responsible for improved recognition during motion. Slightly higher contrast between target and background may have existed at some point in the path of the target motion than was available at the static target position. No particular importance is attached to the finding that no differences were found between judgments of static targets viewed straight ahead, versus out-the-side of the canopy. The finding merely enabled a procedural requirement to be met (viz., comparing motion and no-motion conditions). Possibly, the increased variability in the motion condition may have reduced the precision of the experiment. It is also possible that the nonuniform background contributed to the outcome. For example, we calibrated at the midpoint of the

transit of the aircraft target and so earlier sightings would have higher luminance ratios, but later would have lower. In our opinion, motion could not have negated contrast effects because there is no motion x contrast interaction.

## SECTION IV

## PHASE III

## INTRODUCTION

In the course of collecting the data for Phases I and II, four subjects received many more trials of practice in the judgment of aspect than is ordinarily available in empirical investigations (about 25 hours of experimentation spread over four months). The subjects were more confident in their determinations after all this practice than earlier. Therefore, a partial replication of the first experiment was performed, both to replicate the original findings, and to determine whether the extended practice afforded improvement in performance.

## METHOD

The experimental paradigm was the same as in Phase I. Four resolution levels were studied as in Phase I, but only six experimental levels of target and backward luminance combinations were employed (as in Table 3).

## RESULTS

Tables 7 and 8 show the main findings of the two ANOVAS where practice effects were tested. Practice did not show a significant advantage in either analysis, although resolution was significant, and contrast was highly significant where it was examined. The three luminance levels with isocontrast conditions (formed by differing target/background combinations) were not statistically different from each other. There was a significant practice by resolution interaction, so that after extended practice, higher resolution resulted in much less facilitation. This finding should be replicated.

TABLE 7. EFFECTS OF PRACTICE, CONTRAST AND RESOLUTION  
IN A TARGET ASPECT RECOGNITION TASK

| <u>Source</u> | <u>df</u> | <u>F</u> | <u>Prob.</u> |
|---------------|-----------|----------|--------------|
| Practice      | 1,3       | 0.43     | .5577        |
| Resolution    | 3,9       | 31.95    | .0000*       |
| Contrast      | 3,9       | 30.82    | .0000*       |
| PxR           | 3,9       | 4.41     | .0362*       |
| PxC           | 3,9       | 0.82     | .5127        |
| RxC           | 9,27      | 0.84     | .5854        |
| RxCxP         | 9,27      | 1.14     | .3691        |

TABLE 8. EFFECTS OF PRACTICE, LUMINANCE AND RESOLUTION  
IN A TARGET ASPECT RECOGNITION TASK

| <u>Source</u> | <u>df</u> | <u>F</u> | <u>Prob.</u> |
|---------------|-----------|----------|--------------|
| Practice      | 1,3       | 0.84     | .4260        |
| Resolution    | 3,9       | 14.37    | .0009*       |
| Luminance     | 2,6       | 1.06     | .4036        |
| PxR           | 3,9       | 0.72     | .5629        |
| PxL           | 2,6       | 0.70     | .5339        |
| RxL           | 6,18      | 1.27     | .3204        |
| PxRxL         | 6,18      | 1.16     | .3698        |

\* Significant Effects

## SECTION V

## PHASE IV

## INTRODUCTION

To summarize the findings of phases I, II, and III there were no sequence effects, and a substantial portion (70%) of the variance was accounted for by main effects and correlates of individual differences; yet several subsidiary questions remained. Therefore, a series of mini-studies were undertaken whose purpose was to screen ranges of expected main effects in order to prepare for a future larger study, using pilots as subjects and employing the holistic design of Simon (1973, 1977; Westra, 1982).

Three questions were addressed:

a) To what extent would resolution, poorer than we employed in earlier experiments, degrade performance? In the first three phases of this study we noted that performance was monotonically related to resolution. However, over the ranges that we studied, only about 20% improvement was found when our best resolution condition (1 arc minute per tv line pair) was compared with our poorest (1.9 arc minutes per tv line pair). This comprised the range over which engineers are currently interested. However, more inexpensive simulation systems might use displays with less resolution. To test the feasibility of this idea, we decreased the resolution by 25% and 50%. Twenty-five percent reduction in display resolution resulted in only 10% loss in aspect recognition sensitivity, whereas a 50% reduction resulted in a 30-50% loss. It would appear that for this type of task, resolution over the range (for our system approximately equal to 520 versus 1025 raster lines) that we employed in our main experiment, showed only a small drop in efficiency. The data from this probe suggest that our lower limit may be near the point where additional reductions in resolution may begin to have dramatic effects.

b) Did retinal size per se govern aspect recognition? During the course of our experiment we employed two other aircraft targets that were arrayed and depicted in essentially the same fashion as the TA4J, but one aircraft was of a different size (A-10), and the other was of different shape (MIG-21). The dimensions of these aircraft appear in Table 9 below, along with the ratio of their length to width (aspect ratio), and their relative retinal sizes at 13,500 feet.

TABLE 9. DIMENSIONS OF THE THREE TARGET AIRCRAFT

| <u>Aircraft</u> | <u>Length</u> | <u>Width</u> | <u>Square Root of<br/>Length x Width</u> | <u>Retinal Angle<br/>at 3 Miles</u> |
|-----------------|---------------|--------------|------------------------------------------|-------------------------------------|
| TA4J            | 26.5          | 35.0         | 30.5                                     | 6.6 min                             |
| A-10            | 57.0          | 52.8         | 54.9                                     | 11.9 "                              |
| MIG-21          | 26.5          | 35.0         | 33.9                                     | 7.4 "                               |

A series of trials was performed whereby the three aircraft were viewed in counterbalanced order, but with the same apparatus (contrast, luminance, resolution) setting. Aspect recognition for the largest aircraft (A-10) was possible at greater distances than the MIG-21 which, in turn, was recognized at a greater distance than the TA4J. However, when threshold determinations (in feet X 1000) were converted to retinal size (in minutes of arc), aspect recognition of the A-10 required larger targets. Additionally, when the MIG-21 and the TA4J were corrected for retinal size (either by the square root of length X width or the tangent of the longer axis), the aspect of the MIG-21 was generally recognized at greater distances than the TA4J (i.e., smaller retinal size). In attempting to discover some regularity in the differences, we arrived at a formula which follows the increment threshold equation (i.e., Long dimension minus Short dimension divided by Long). Multiplying threshold scores (in feet) by the ratio of L-S/L will result in a constant.

c) Were any differences in performance to be expected if the judgment to be made had to do with left versus right, or coming versus going, instead of the up/down we had employed until now? Early in the series of experiments, preliminary studies were conducted using determinations of up/down, left/right, and coming/going. In nearly all cases where comparisons were made, the threshold values for up/down were not markedly different from those for left/right. However, when threshold curves for coming/going were examined, it was found that those threshold values were approximately 10% of the threshold values for the other two. In other words, left/right and up/down thresholds were ten times better than coming/going.

## SECTION VI

1965). However, it may not be required for initial setup and in all combat situations.

## CONCLUSIONS AND RECOMMENDATIONS

Four subjects with normal vision served in a series of experiments in the 10-foot radius dome display of the VTRS. As a first step in a program studying requirements for simulating air-to-air engagements in ground-based flight trainers, our objective was to evaluate display design requirements for the task of recognizing the aspect of an opponent aircraft. We defined the task initially as a spatial task, and in Phase I the main effects of contrast, resolution, and luminance were examined. The data imply that with a range of contrast of 25:1, formed by different luminance ratios, more improvement in performance was available than in a range of 2:1 resolution. In general, the performance at the best contrast condition was 50-100% better than the poorest, and the highest resolution was about 20% better than the lowest.

Moreover, in Phase I, with three comparisons of isocontrast when viewing a static target, an effect of luminance was found (i.e., higher luminance levels with the same contrast resulted in better performance); however, this was a weak effect and was not found in Phase II under conditions of target motion.

Based on our pilot work, resolutions much below what was employed in the main experiment as our lowest level (viz., 1.9 arc min/line pair) are not recommended for this task (see Appendix C, Tables 12a, 12b and 12c, for equivalent values for retinal size, distance, and raster lines across the target). We would suggest that this finding could be generalized to similar tasks.

Phase II first studied the effects of sideward versus the straight ahead viewing. Since no differences were found, motion out the side (which could not be performed straight ahead because of canopy bow restrictions) was compared with results from straight ahead. A slight but significant improvement in performance (i.e., motion was better) was seen in one of the two comparisons. It is unlikely that this represents an improvement in sensitivity for the high resolution vision channels, which we feel mediate aspect recognition. This paradoxical outcome may be attributable to a variety of factors which may be clarified in future investigations.

Phase III showed that performance after 25 hours of practice was not much different from average performance over the first 9 hours. It should be noted that no test of practice effects was performed for changes which might have taken place within the first few experimental sessions. Indeed, the use of the feedback (knowledge of results) mechanisms we employed were

designed to get subjects' performances to stabilize as quickly as possible, and it could be argued that improvement in performance might have been missed by the present experimental design. We would agree that a fine-grained analysis of practice effects within the initial sessions which these subjects received might reveal learning. However, because the order of administration of conditions was counterbalanced, no useful post hoc analyses can be performed.

For the most part, results of this experiment are clear-cut. The findings agree well with the literature of spatial vision (Graham, 1965) and are in accord with television legibility studies (Shurtleff, 1967). We believe they can be used as guidance by simulator designers in their present form and can enable the ranges of the variables to be specified for future experiments (which is necessary for success using holistic designs). For example, the mean distance scores for aspect (as a function of resolution, target and background luminances) which appear in Appendix C and Tables 12a, 12b and 12c, show retinal sizes and mean number raster lines across the target for all experimental conditions. These numbers may be used as a first approximation, taking into account that pilots were not subjects, only one dimension of three coordinate space was judged at a time, and not all possible orientations were studied. Future studies should rectify these shortcomings.

It is our belief that the aspect recognition task (whether in the simulator or aircraft) occurs at its greatest distance when targets are beyond the sensitivity ranges of all but the spatial channel for visual information processing (cf. Regan, 1982, for a point of view concerning channels) and, perhaps, some motion parallax channel. In the air-to-air environment, loom or motion in depth (Regan, Beverley & Cynader, 1979), or blur patterns (Harrington & Harrington, 1978) may sometimes be used once an engagement is under way, but the threshold for size change that may be inferred from the literature (Beverley & Regan, 1979), is probably not exceeded when the other aircraft is more than 2 miles and moving at less than 1000 miles per hour. Color and texture, which are cues that could be employed to make determinations of aspect both directly and indirectly, probably cannot be picked up at distances greater than one mile, either in the simulator or in the real world. Aircraft moving across one's field of view at great distances (e.g., 3 miles), even at 850 miles per hour, are probably moving in the range of 5-10 degrees per second. In our study, translatory motion had a small facilitative effect; but in the real world, where aspect and direction motion are partially coupled, and with both aircraft being free to move, information provided about aspect by motion is unknown.

Motion parallax was not investigated in this study, but from casual observation and the literature, it may well be that this is a salient cue to the recognition of aspect (cf. Graham,

1965). However, it may not be useful at the great distances required for initial setup where aspect recognition is employed in air combat. Motion parallax within the engagement during close-in is probably a very important cue to aspect, as are size change (Regan, 1982), blur (Harrington & Harrington, 1978), and other cues. Yet, these may only be simulated with some difficulty and cost. It would seem that an operations analysis of the air-to-air task (one which dealt with the visual requirements for simulators) is necessary. In this respect, perhaps the earlier work of Ciavarella et al. (1981), could be expanded to include air combat simulators.

Ginsberg, Evans, Sekuler and Harp (1982) showed that an individual's contrast sensitivity threshold at the middle spatial frequencies was predictive of his ability to identify an aircraft on the runway in a simulated landing. In that study, the aircraft was depicted by a CRT pickup of an aircraft model. We found that high spatial frequency thresholds were predictive of overall performance in our task. The differences between image generation techniques (model versus CIG), the background fields (runway versus cloudless sky), and the task demands in the two experiments (identification versus aspect recognition) are the basis for the disparity in these outcomes.

We found two useful covariates of performance on this task in flight simulators which may be employed to improve power in future studies. It is not unlikely that relationships such as these may persist in the real world. Delineating visual functions which are predictive of air combat performance is a goal of research and development programs in USN and USAF (Hutchins, 1978; Kruk, Regan, Beverley & Longridge, 1981). It is possible that visual functions which support this activity in the simulator may also afford some advantage in outdoor target ranges. It is suggested that an attempt be made to replicate our findings in one of the air combat ranges (particularly the relationship of contrast sensitivity and performance.)

In this experiment, we found that greater contrast sensitivity for high spatial frequencies afforded better performance. Subsequently, a fine-grained analysis was performed to discover whether this relationship held to the same extent over all conditions. The outcome of this analysis was not clear-cut but suggestive: That while the subjects with better high spatial frequency acuity appeared to perform better regardless of background or target luminances, this was especially true for the high resolutions and the low contrasts. These relationships, while not insubstantial ( $r = .56$ ), were not significant ( $P = .10$ ). In other words, at the 1.9 arc min/tv line pair condition and the higher luminance ratio conditions, relationships were not evident between subject's overall rank order and performance. This implies that the task tends to be eye-limited for all of the experimental conditions but these. The latter, the poorest resolutions and highest contrasts

employed, do not result in as much improvement in performance by the "good" subject(s), and may thereby be considered apparatus limited. This implies that caution be used in applying pilot detection/recognition/identification performance data from simulator tests if displays are not eye limited. It is our view that further development of this approach would have merit in future studies of simulator requirements. It is plausible that such an analysis might embody a decision rule for how much fidelity is required. Stated differently, if changes in an underlying correlate of performance (e.g., usual acuity at high spatial frequencies) begins to result in the better subjects not performing any better in the simulator (e.g., less resolution), then that defines the point where further decreases in image quality may be considered to have adverse effects on performance and perhaps training.

#### A BEHAVIORAL ANALYSIS OF THE ASPECT RECOGNITION TASK

An air target produces a family of visual stimulus components which, if they fall within the bandwidth limitations of the human visual system, become available for analysis by channels specialized for color, pattern, disparity, motion and size change (Regan, 1982). Such analyses support complex perceptual activities such as detection, aspect recognition and identification. We assume, with many other investigators (Regan, 1982; Regan, Beverley & Cynader, 1979), that pattern recognition may be accomplished by various functionally and temporally independent channels. These channels correspond roughly to the classical domains within the study of sensation and perception.

One mode of perception of a target will be appropriate and sensitive within some range of distance; this range will overlap to a certain extent with the ranges of other modes (channels). As the distance of the target changes, one mode will take over from another as the target leaves the latter mode's range of sensitivity. We believe that channels can be characterized in terms of the distances at which they may register information (e.g., the distance at which a stimulus component enters the bandwidth of the channel).

What channels might be most appropriate for judgment of aspect? Considering an air target to be more distant than a mile eliminates a number of possibilities: color, accommodation, convergence, and static stereoptic disparity will not serve to define aircraft orientation at that distance. Many monocular depth cues are not very helpful because the target may appear on an unarticulated background where there is no interposition of objects between target and observer. If there is the possibility of interposition of target against background, relative motion would be of help in discovering up/down and left/right, but as for coming/going, it would be more helpful to know the airspeed of the air target. We

primarily studied spatial cues to aspect for two reasons. We were interested in recognition at the first moment after detection of a potential target, wherein recognition is entirely spatial and very rapid. If recognition occurs in this moment, there would be no necessity for continued time-dependent processing of motion. An additional reason for concentrating on spatial factors is that their translation into equipment design criteria is more readily achieved than other factors.

How then may we characterize detection and identification, but especially aspect recognition, in terms of spatial information channel? We consider the contrast sensitivity functions of our subjects to be a good description of response to angular size. (We further assume that that function is the result of a population of neural analyzers each selectively responsive to a range of spatial frequencies, which is a fraction of the range of the contrast sensitivity curve.) The more sensitivity to the high spatial frequencies, the more distantly will a target of a particular contrast be registered. The greater the high frequency roll off in sensitivity, the closer that a target would need to be in order to reach that part of the curve where sufficient sensitivity is available in order to be detected. Viewing the human senses in terms of this sensitivity function allows us to address several important questions. Why should detection be possible at greater distances than aspect recognition, and aspect recognition at greater distances than identification? Why should an air target have to be so much closer to tell coming/going from up/down or left/right? How is it that contrast and resolution influence aspect recognition? If we assume that the spatial properties (features) critical to detection, left/right and up/down recognition, coming/going recognition, and identification are successively smaller in linear extent, then answering the first two questions is straightforward. We might assume that detection is mediated by the aircraft's greatest extensity (length or wingspan) (cf. Lamar et al., 1947), that up/down and left/right requires the identification of the nose, and that coming/going is based on seeing some continuation of intakes, vertical stabilizer, and canopy.

The aircraft must be successively closer for decreasingly smaller properties to achieve the angular size necessary to be detected by the high spatial frequency band of the human visual system. The answer to the question of how contrast and resolution influence aspect recognition is also straightforward. For an individual with poor contrast sensitivity, more contrast is required to register a pattern. As contrast is increased, the lower sensitivity, higher spatial frequency channels can register the patterns. With lower contrast, the relatively higher sensitivity, lower spatial frequency part of the curve must perform the work. The lower the spatial frequency of the analyzer, the less contrast is required, but the greater the angular extent of the target. Resolution of the display system

generally limits the fineness of detail that may be presented. Of course, a low resolution display system will still present high spatial frequency, provided that it presents edges. Resolution will limit the highest spatial frequency fundamental (corresponding to size) that may be presented. This limit will be important. Relative spatial extent of parts of a pattern are what are necessary for a particular perceptual job. We believe that the effect of the decreased resolution is to limit the ability of the highest spatial frequency analyzers to register such information. The lower the spatial resolution of a display system, the lower will be the spatial frequency tuning of the analyzers that mediate aspect recognition. For our experiment, using generally high resolution, the frequency sensitivity of subjects correlated with aspect recognition. Had a lower resolution system been employed, we would predict that subjects' medium spatial frequency sensitivities would have correlated with their performance. This is in line with the findings of Ginsburg et al. (1982). Thus, both contrast and resolution affect recognition, but in slightly different ways.

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## APPENDIX A

MEASUREMENT OF CONTRAST SENSITIVITY  
IN AIR TARGET ASPECT RECOGNITION

## INTRODUCTION

In a recent study, Ginsburg, Evans, Sekuler, and Tharp (1982), studied the relationship of contrast sensitivity scores (across the usual range of spatial frequencies) to the identification of an object as an aircraft at the end of a runway during a simulator landing study. They found that threshold scores for their subjects at the middle spatial frequencies were predictive of the range at which this target was identified. Mean values corresponded to a 12-minute target and the image was formed by an optical pickup of an aircraft model. Coincident with our study of aspect recognition, we examined the contrast sensitivity functions of our subjects because of the possibility that such sensitivity may mediate aspect recognition.

## METHOD

**STIMULI.** All stimuli were presented on the viewing screen of an Optronix Vision Tester, which is described in detail elsewhere (cf. Optronix Operating Manual 1981). The average luminance of the screen was 100 cds/sq. m. and the peak contrast of the patterns was .5 (set using the Optronix internal photometer). Six spatial frequencies of vertically oriented gratings varying sinusoidally in contrast were used in these investigations. Spatial frequencies were .5, 1.0, 3.0, 6.0, 11.4, and 22.8 cycles per degree of visual angle. Stimuli were viewed foveally from a distance of 3 meters. This is approximately the same viewing distance as that used in the experiment.

**APPARATUS.** Stimuli were presented on the viewing screen of an Optronix 200 Vision Tester which incorporates a microprocessor to control a modified 525 line video monitor. This device permits automated determination of threshold contrast sensitivity for various spatial frequencies. Preprogrammed psychophysical procedures and measures were used and, wherever possible, viewing conditions and stimulus variables were those recommended by the manufacturer. The viewing screen of the Optronix 200 Vision Tester is 22cm wide and 29.2cm in height.

Calibration of brightness and contrast was accomplished using a semiautomatic procedure and the photometer which is provided with the Optronix. The values selected by the internal photometer were checked using a photometer manufactured by SEI. Calibrations were performed before each session.

PROCEDURE. The four subjects (KB, BK, KT, CD) were tested individually using the von Bekesy psychophysical method. A single experimental trial consisted of eight measurements of sensitivity to a spatial frequency. Each trial began with a preview of the waveform of interest at peak contrast (.5) for two seconds. The contrast then went to zero and was slowly increased at the rate of zero to peak contrast in 30 seconds. Subjects pressed a response key as soon as they could detect the pattern of interest, held the key down so long as they could still detect the pattern, and released the key as soon as the pattern was no longer visible. Each depression and release of the response key reversed the direction of the change in contrast. The stimulus contrast at the point of reversal was used as a measure of threshold. Eight such measures (reversals) were collected and averaged for each trial. Each subject completed two practice trials using .5 and 6 cycle per degree gratings. Next, three blocks of six trials, one trial for each spatial frequency, were completed. Thus, for each of the six spatial frequencies, eight measurements were averaged to get a trial score, and then the scores for the three trials were averaged to yield a subject's contrast sensitivity for each spatial frequency.

#### RESULTS AND DISCUSSION

The contrast sensitivities of the four subjects for the six spatial frequencies are shown graphically in Figure A-10. These values are the reciprocal of log threshold contrast and may be considered to be normal or better than normal.

Table A-10 contains average aspect recognition scores (distance in feet X 1000) for four subjects for each of the four resolutions and each of the four contrasts, as well as a grand mean for the experiment as a whole. In general, the subjects maintained their same order of performance with KB's scores the poorest and either KT or CD best. These differences were relatively consistent across the four resolutions and were relatively more obvious (e.g., 50% versus 20%) at the lower contrasts.

Also in Table A-10 may be found the correlations between the contrast sensitivities of the four subjects at the two highest spatial frequencies and the average aspect recognition scores. These correlations, while based only on four subjects, are of interest because of their consistency with some theoretical predictions. All correlations between performance and contrast sensitivity at 22.8 c/d are around  $r = .55$ , with one exception, and all correlations for 11.4 are nearer zero, with one exception. The one exception is a correlation at the lowest contrast (luminance ratio) studied. The correlation for 22.8 c/d at this comparison is the highest. Admittedly, these differences lack statistical significance, but are suggestive of two things; high spatial frequency neural analyzers, in

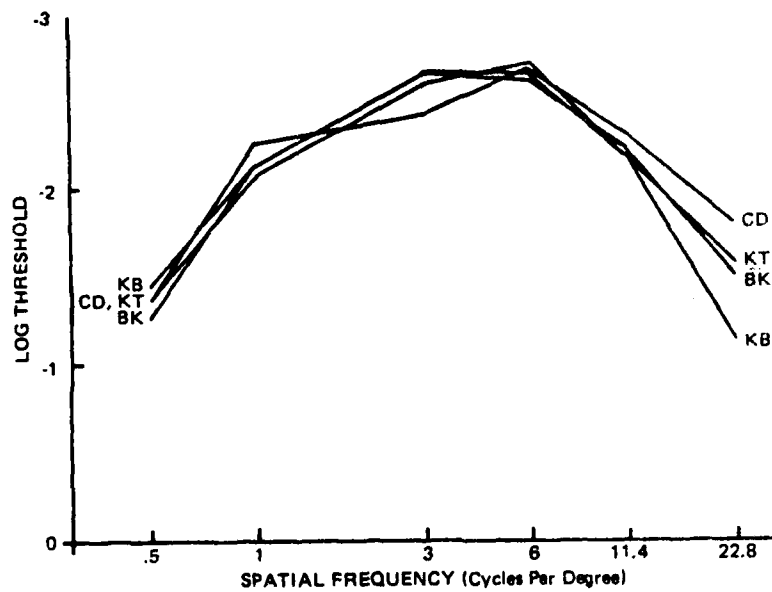


Figure A-10. Contrast Sensitivity for Four Subjects

general, may mediate aspect recognition, but as the contrast of targets is decreased successively, lower spatial frequency analyzers become involved.

TABLE A-10. MEANS AND CORRELATIONS OF CONTRAST SENSITIVITY AND ASPECT RECOGNITION AT FOUR LEVELS OF CONTRAST AND FOUR LEVELS OF RESOLUTION

a) Pearson product moment correlations between contrast sensitivity and aspect recognition for four disparate levels of contrast (range of luminance ratios = 24.1 - 2.3) and four levels of resolution (range in arc minutes/t.v. line pair = 1.9 - 1.0).

CORRELATIONS

| <u>11.4 c/d</u> |                |               |                | <u>22.8 c/d</u> |                |               |                |
|-----------------|----------------|---------------|----------------|-----------------|----------------|---------------|----------------|
| Resolu-<br>tion | Pear-<br>son r | Con-<br>trast | Pear-<br>son r | Resolu-<br>tion | Pear-<br>son r | Con-<br>trast | Pear-<br>son r |
| 1.9             | .02            | 24.1          | .24            | 1.9             | .45            | 24.1          | .40            |
| 1.6             | .38            | 9.7           | .24            | 1.6             | .70            | 9.7           | .60            |
| 1.3             | .15            | 5.1           | .42            | 1.3             | .59            | 5.1           | .06            |
| 1.0             | .12            | 2.3           | .61            | 1.0             | .55            | 2.3           | .90            |

Total (all levels of  
contrast and res.)  $r = -.08$

$r = .56$

(cont'd)

TABLE A-10. MEANS AND CORRELATIONS OF CONTRAST SENSITIVITY  
AND ASPECT RECOGNITION AT FOUR LEVELS OF CONTRAST  
AND FOUR LEVELS OF RESOLUTION (cont'd)

b) Means of contrast sensitivity (at 22.8 & 11.4 c/d) and aspect  
recognition distance in feet X 1000 at four disparate levels of  
contrast and four levels of resolution.

| <u>Subject</u> | <u>Contrast Sensitivity Threshold Scores</u> |          |
|----------------|----------------------------------------------|----------|
|                | 11.4 c/d                                     | 22.8 c/d |
| KB             | 151.4                                        | 13.5     |
| BK             | 170.8                                        | 33.2     |
| KT             | 147.9                                        | 34.2     |
| CD             | 196.7                                        | 61.0     |

| <u>Subject</u> | <u>Distance for Resolution Levels</u> |       |        |       |
|----------------|---------------------------------------|-------|--------|-------|
|                | Highest                               |       | Lowest |       |
| KB             | 12.30                                 | 12.14 | 10.74  | 10.54 |
| BK             | 16.00                                 | 15.39 | 13.31  | 12.61 |
| KT             | 17.56                                 | 15.51 | 13.33  | 12.38 |
| CD             | 15.18                                 | 15.18 | 13.33  | 12.38 |

| <u>Subject</u> | <u>Distance for Contrast Levels</u> |       |        |       |
|----------------|-------------------------------------|-------|--------|-------|
|                | Highest                             |       | Lowest |       |
| KB             | 13.35                               | 12.65 | 12.63  | 8.72  |
| BK             | 17.35                               | 16.35 | 14.49  | 11.81 |
| KT             | 17.05                               | 16.78 | 16.78  | 12.22 |
| CD             | 15.53                               | 15.75 | 13.26  | 13.10 |

| Total |       |
|-------|-------|
| KB    | 11.42 |
| BK    | 14.33 |
| KT    | 15.29 |
| CD    | 14.02 |

## APPENDIX B

MEASUREMENT OF ACCOMMODATION  
IN AIR TARGET ASPECT RECOGNITION

## INTRODUCTION

When we discovered a correspondence between contrast sensitivity to high spatial frequencies and aspect recognition in CRT projections of air targets (reported in the main body of this paper), we did not know whether this correlation was based upon causality or whether both variables were influenced by a third, as yet uninvestigated, variable. We wondered whether our subjects' ability to accommodate to the CRT test screen and VTRS dome may have determined their ability to resolve high spatial frequencies and the air-target detail. Considering that the viewing conditions of the air-target experiment may constitute an impoverished stimulus for accommodation, this hypothesis merits consideration if only in a preliminary way. Therefore, we conducted an experiment to discover 1) whether the experimental observers in the air-target study were accommodated to the viewing screen or to the dark focus point (relaxed accommodation), and 2) whether observer variation in accommodation to the air-target background field corresponded to aspect recognition performance.

## METHOD

We used the procedure described by Hennessy and Leibowitz (1970; also see Hennessy & Leibowitz, 1972) to measure the accommodation of the four primary observers in the air-target experiment to the background field of that study. This extensive (120 x 80 degrees), nearly featureless, blue field was displayed at .44 fL. (The color and intensity of the field are visibly nonhomogenous, and the raster scan lines between image elements are also visible.) The diverged beam of a low-power helium-neon 6328-A laser was directed to the center of the VTRS dome viewing screen. Each subject, participating individually, sat in the VTRS cockpit and viewed the laser beam image foveally by looking over the windscreen framework. The viewing distance was 111 inches. A number of experimental trials were conducted in which the subject moved his head from side to side and reported whether the granularity of the laser light moved in the same or opposite direction, or whether no motion of the granularity pattern obtained (cf. Hennessy & Leibowitz, 1970). A set of lenses of refractive power ranging between -3 and +3 diopters in quarter diopter steps were used to discover accommodative distance. By appropriately choosing lens strengths that bracketed the reversal of motion, a lens strength that nulled the motion of the granularity was discovered for

as we have already noted, the background field is not featureless; the raster lines between image elements are within the range of human spatial resolution at the 10-ft viewing distance. The raster pattern is a low-contrast grating of unequal duty cycle oriented along the vertical and horizontal dimensions. The pattern has spatial frequency components between 15 and 25 cycles per degree. Thus, for our experiments, it may be that subjects with greater sensitivity to high spatial frequencies were able to use the high frequency pattern present in the background to accommodate more closely to the screen than subjects with less sensitivity. If this is so, then sensitivity to high spatial frequency may determine both aspect recognition and the ability to accommodate, with the correlation between these latter two variables being fortuitous.

TABLE B-11. ACCOMMODATION OF AIR-TARGET  
ASPECT RECOGNITION SUBJECTS\* IN  
EXPERIMENT VIEWING ENVIRONMENT

| <u>Subject</u> | <u>Lens Required<br/>to Null Motion</u> | <u>Lens Power<br/>Corrected for<br/>Color**</u> | <u>Distance<br/>accommodated<br/>(v.d.=3.05m)</u> |
|----------------|-----------------------------------------|-------------------------------------------------|---------------------------------------------------|
| KB             | 1.0                                     | 1.5                                             | 0.67 m                                            |
| BK             | 0.5                                     | 1.0                                             | 1.00 m                                            |
| KT             | 0.0                                     | 0.5                                             | 2.00 m                                            |
| CD             | -0.5                                    | 0.0                                             | inf.                                              |

\* Error of measurement = plus or minus .125 diopters.

\*\* Corrected to 560 nm. It is not clear exactly what value our figures should be corrected to, since the blue background field for the air-target experiment is actually a rather broadband stimulus, so that the amount of correction is difficult to determine (LeGrand, 1967).

## APPENDIX C

TABLE C-12a. MEAN DISTANCES (IN FEET X 1000) FOR FOUR  
SUBJECTS FOR ASPECT RECOGNITION OF TA4J AIRCRAFT  
AT 36 COMBINATIONS OF TARGET AND BACKGROUND  
LUMINANCE AND PROJECTOR RESOLUTION

| Target<br>Lum. | <u>Background<br/>Luminance</u> |       |       | Target<br>Lum. | <u>Background<br/>Luminance</u> |       |       |
|----------------|---------------------------------|-------|-------|----------------|---------------------------------|-------|-------|
|                | 0.13                            | 0.26  | 0.58  |                | 0.13                            | 0.26  | 0.58  |
|                | <u>1.0 arc min/ln.pair</u>      |       |       |                | <u>1.3 arc min/ln.pair</u>      |       |       |
| 0.28           | 12.08                           |       |       |                | 11.02                           |       |       |
| 0.58           | 14.85                           | 12.90 |       |                | 13.92                           | 12.22 |       |
| 1.76           | 17.45                           | 14.40 | 13.05 |                | 15.12                           | 15.42 | 12.80 |
| 3.55           | 17.72                           | 17.87 | 16.80 |                | 17.80                           | 17.70 | 16.42 |
|                | <u>1.6 arc min/ln.pair</u>      |       |       |                | <u>1.9 arc min/ln.pair</u>      |       |       |
| 0.28           | 10.22                           |       |       |                | 9.73                            |       |       |
| 0.58           | 12.02                           | 11.00 |       |                | 11.53                           | 10.35 |       |
| 1.76           | 13.50                           | 15.02 | 11.03 |                | 13.03                           | 13.80 | 11.00 |
| 3.55           | 14.62                           | 15.30 | 14.28 |                | 14.43                           | 13.18 | 13.08 |

TABLE C-12b. MEAN VISUAL ANGLE (IN MINUTES) FOR FOUR  
SUBJECTS FOR ASPECT RECOGNITION OF TA4J AIRCRAFT  
AT 36 COMBINATIONS OF TARGET AND BACKGROUND  
LUMINANCE AND PROJECTOR RESOLUTION

| Target<br>Lum. | <u>Background<br/>Luminance</u> |      |      | Target<br>Lum. | <u>Background<br/>Luminance</u> |       |      |
|----------------|---------------------------------|------|------|----------------|---------------------------------|-------|------|
|                | 0.13                            | 0.26 | 0.58 |                | 0.13                            | 0.26  | 0.58 |
|                | <u>1.0 arc min/ln.pair</u>      |      |      |                | <u>1.3 arc min/ln.pair</u>      |       |      |
| 0.28           | 8.67                            |      |      |                | 9.50                            |       |      |
| 0.58           | 7.05                            | 8.12 |      |                | 7.52                            | 8.57  |      |
| 1.76           | 6.00                            | 7.27 | 8.02 |                | 6.92                            | 6.79  | 8.18 |
| 3.55           | 5.91                            | 5.86 | 6.23 |                | 5.88                            | 5.92  | 6.37 |
|                | <u>1.6 arc min/ln.pair</u>      |      |      |                | <u>1.9 arc min/ln.pair</u>      |       |      |
| 0.28           | 10.24                           |      |      |                | 10.76                           |       |      |
| 0.58           | 8.71                            | 9.52 |      |                | 9.08                            | 10.12 |      |
| 1.76           | 7.76                            | 6.97 | 9.49 |                | 8.03                            | 7.58  | 9.52 |
| 3.55           | 7.16                            | 6.84 | 7.33 |                | 7.25                            | 7.94  | 8.00 |

TABLE C-12c. MEAN NUMBER OF LINE PAIRS  
ACROSS THE TARGET FOR FOUR SUBJECTS  
FOR ASPECT RECOGNITION OF TA4J AIRCRAFT  
AT 36 COMBINATIONS OF TARGET AND BACKGROUND  
LUMINANCE AND PROJECTOR RESOLUTION

| Target<br>Lum. | <u>Background<br/>Luminance</u> |      |      | Target<br>Lum. | <u>Background<br/>Luminance</u> |      |      |
|----------------|---------------------------------|------|------|----------------|---------------------------------|------|------|
|                | 0.13                            | 0.26 | 0.58 |                | 0.13                            | 0.26 | 0.58 |
|                | <u>1.0 arc min/ln.pair</u>      |      |      |                | <u>1.3 arc min/ln.pair</u>      |      |      |
| 0.28           | 8.67                            |      |      | 7.31           |                                 |      |      |
| 0.58           | 7.05                            | 8.12 |      | 5.79           | 6.59                            |      |      |
| 1.76           | 6.00                            | 7.27 | 8.02 | 5.33           | 5.22                            | 6.29 |      |
| 3.55           | 5.91                            | 5.86 | 6.23 | 4.52           | 4.55                            | 4.91 |      |
|                | <u>1.6 arc min/ln.pair</u>      |      |      |                | <u>1.9 arc min/ln.pair</u>      |      |      |
| 0.28           | 6.40                            |      |      | 5.66           |                                 |      |      |
| 0.58           | 5.44                            | 5.95 |      | 4.78           | 5.32                            |      |      |
| 1.76           | 4.85                            | 4.37 | 5.93 | 4.23           | 3.99                            | 5.01 |      |
| 3.55           | 4.48                            | 4.28 | 4.58 | 3.82           | 4.18                            | 4.21 |      |

## APPENDIX D

SOME NOTES ON DARK FOCUS:  
CONCERNING THE DIFFERENCES DUE TO MAXWELLIAN VIEW,  
DIRECT VIEW, AND OPTICAL INFINITY

Arthur P. Ginsburg

"Dark focus" is defined as the resting state of accommodation visual situation where no stimulus for accommodation is present. Two general misconceptions exist about dark focus: Firstly, that the resting point is at optical infinity; and secondly, that the eye accommodates accurately. In general, accommodation is extremely individualistic. Because an individual's accommodation is not a steady state and will change depending upon different stimuli, it is necessary to measure in real time the moment-to-moment accommodation, with a device such as the infrared, optometer device. Unfortunately, infrared optometers provide only relative dioptic measures. Other types of devices which provide accurate measures of accommodation are laser and vernier optometers. These devices present another difficulty, in that interrupting the viewing conditions may have a disturbing effect if other experimental questions are being studied. Unfortunately, neither technique provides an optimum measure of accommodation.

Accommodation depends in general on three factors: 1) the attributes of the target to which one is accommodating, 2) the attributes of the visual surround (i.e., texture or horizon), and 3) observer variables--age, oxygen supply, instructions, ability to change accommodation, contrast sensitivity threshold functions.

Another accommodation factor is the depth of focus field, the distance over which satisfactory definition of the target is obtained when the lens is in focus for certain distances. The depth of focus is a function of four general factors: 1) the criterion one adopts for what is considered the best focus image, 2) target distance, 3) the focal length of the lens (in this case the eye), and 4) the relative aperture or pupil size, which will change as a function of luminance. In general, the depth of focus will increase with the increased distance of the target, and it will decrease when the focal length increases, as well as when the aperture increases in size.

The degree to which one is accommodated on a stimulus is complex. In general, the literature indicates that only at lower spatial frequencies--less than approximately 10 cycles per degree (cpd)--is it reasonable to say that one accurately accommodates on the target. At higher spatial frequencies accommodation is poorer. Even under the best conditions for accommodation (for example, high contrast letters) focus is at

only about 80% of the distance it should be. In general, the literature shows that the state of accommodation is somewhere between the individual's dark focus and where that person should be accommodating.

Different consequences occur under conditions of Maxwellian view, direct view and optical infinity. Typically, in a Maxwellian view system, the last stage of the optics focuses the image at the retina of the eye. So conceivably, that particular optical configuration should be near optimal. However, it is not known whether a particular individual's dark focus (for which the equipment may be set up) is an average for all other subjects. Hence, many Maxwellian view systems may be providing stimuli supposedly accommodated for the right distance, but actually accommodated only for the correct distance of the experimenter. For example, on one occasion, a very large CRT with very low frequency gratings was found with a lens diopter calculated to have provided the clearest low frequency image on the screen, but it did not at all, and it became necessary to determine empirically which lenses would provide the clearest images.

In general, for Maxwellian view systems where one is creating an optical system such that the last stage of the optics provides an in-focus image, unless the observer provides different lenses for different observers, the degree of focus of the image may vary considerably. For the direct view condition, one has the extreme range of accommodation available to the observer to bring to the task. Depending upon distance, an individual's resting state will determine the degree of accommodative accuracy. For conditions where the image is at optical infinity, it seems that the further dark focus will provide the most in-focus or best focus image. One would expect that under these conditions of visibility the individuals whose dark focus is furthest out should have the clearest image. Though again we are reminded that under all these conditions there are other factors, such as the particular target to be accommodated, as well as the texture or surround (i.e., the environment) that will also enter into the final degree of accommodation.

In terms of simulator studies, it would seem that observers with the farthest dark focus (e.g., the elderly types) should have a clearer image of the target than those whose dark focus is closer to the observer. (Keeping in mind, of course, that older observers take longer to accommodate.) Therefore, the degree of effect of the individual dark focus on the particular task will really have to do with the task itself. For example, if one is just detecting a target, then perhaps such factors as superior acuity, if the target is quite small, or superior contrast sensitivity over the lower frequencies, if the target is larger, will have more of an effect on the visibility than on accommodation, per se. However, as one gets into determinations

such as direction of motion, aspect angle and identification, then depending upon the particular cues that an observer employs, the relatively higher frequencies required for those tasks may place a higher premium on a clearer (i.e., better in-focus or optimally accommodated) image. It would seem, therefore, that one's knowledge of the spatial frequency distribution of relevant target information would play an important role in determining the importance of accommodation.

In particular, an important study by Charman & Tucker (1977) found that more accurate accommodation tended to occur at spatial frequencies of about 10 c/d. Accommodating to low spatial frequencies was quite similar to the empty field or "dark focus" state. These results were obtained from subjects instructed to obtain the best possible focus. They found that accommodation was most accurate at distances ranging from about 0.25 to 0.50 meters for spatial frequencies less than 10 c/d. For distances greater than 0.50 meters, accommodation was most accurate for high spatial frequency targets. These findings are similar to others where the most accurate accommodation was at empty field conditions. Leibowitz & Owens (1982) found that contrast sensitivity and accommodation were optimum at around peak frequency from 3 to 5 c/d, when subjects were instructed for natural viewing. The implication was that sharp edges were not required for the natural task. Bour (1980 & 1981) found similar results, even though he instructed his subjects to obtain clear images of gratings. By using dynamic response measures he found that accommodation was degraded for spatial frequencies greater than about 8 cpd. So, in general, these results suggest that if relevant target information is larger than approximately 10 c/d, the effect of dark focus will be minimized. As the spatial relevant target information required becomes smaller than about 10 cpd, the individual's "dark focus" (i.e., pushing the focus out further) will have, or should have, a greater effect on the visual task.

It should be noted that the above results are with sine wave gratings, which are spatially pure stimuli. Also, it must be kept in mind that the textural effects (i.e., the Mandlebaum effect) may play a role under certain viewing conditions. However, for a simulator study (such as may be undertaken in the Visual Technology Research Simulator) where one is looking at a target in the clear sky, projected on a dome several feet away, the textural effects are nil. Studies by Charman & Heron (1979) and Charman & Tucker (1977) found that given a new target to fixate and focus, only the lower spatial frequencies may be above visual threshold. Since, at an individual's "dark focus" viewing conditions, the least affected are the lowest spatial frequencies, the most affected target information would be the highest spatial frequencies. So here, too, the consideration of uncertainty is raised. It seems that in an uncertain visual environment where a new target is just coming through threshold, the visual system will be at its resting state, unless it is

pulled out by texture or other things. Unless the system is already in good focus, as the target emerges, it will typically filter through the relatively lower spatial frequencies of the visual system. Here we can see the value of having the resting state of accommodation as far out as possible in order to create a better focused image at the instant of detection.

There is another factor that should be considered; namely, that accommodative latencies are greater for older subjects. So there may be some subtle but interesting trade-offs between an older individual having a far dark focus, yet having a longer latency with which to accommodate.

In summary, the accommodative effect of the state of the observer in the three different conditions of Maxwellian view, direct view and optical infinity, will depend upon a complex interrelationship of the target, the background and individual differences. There does not seem to be any simple way of measuring the actual accommodative state of the observer, either accurately or without interfering with the experiment itself.

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