CRITICAL VISUAL REQUIREMENTS FOR NAP-OF-THE-EARTH (NOE) FLIGHT RESEARCH

H. OZKAPTAN
U.S. Army Research Institute for the Behavioral and Social Sciences

Introduction*

The helicopter pilot is more directly dependent upon his visual cues than the pilot of a fixed wing aircraft, and in some respects the operator of a land-based vehicle. Helicopter flight has the following basic peculiarities:

- flight often in the low altitude realm;

- rapid excursions within three-dimensional space;

- relatively higher angular velocities of the viewed scene;

- reduced frames of reference under low light levels;

- frequent non-correspondence between the visual line of sight and "seat of the pants" due to crabbed flighted conditions;

- surveillance of large rather than narrow fields of view.

The above, plus other considerations, lead to pilot problems of visual perception, geographical orientation, and the avoidance of obstacles. The helicopter pilot for these reasons can be considered as the busiest man in the air. The effectiveness and safety of helicopter flight, as a result, directly depend upon the adequacy with which the pilot perceives and responds to his visual cues, both in the natural world and on his displays.

A visual flight research laboratory is needed where the visual capabilities and requirements of the helicopter pilot in this unique visual environment can be determined, and where visual aids and display concepts can be tested. An increase in the mission capability and effectiveness of helicopter operations will be closely dependent upon the degree to which the pilot's visual capabilities are aided or augmented in the operating environment. Visual aids (including fire-control) may become the primary focal points about which future cockpits will be developed. Nap-of-the-Earth (NOE) flight under low illumination levels represents the primary research problem for such a facility.

For this purpose, a visual flight research facility (VFRF) is proposed rather than a conventional simulator for the conduct of the experimental studies. The requirements for such a facility will differ from those of a simulator designed for training or for specific equipment studies in the following basic ways:

- control and repeatability of system parameters (e.g., illumination levels, display gray scale control, etc.) to permit the precise replication of desired performance levels for the comparability of data.

- multiple levels of parameter control to permit a wide range of discrete and controlled stimulus conditions to determine performance thresholds.

- comprehensive interrelationship of parameters to enable the study of a wide range of stimulus interactions as they affect pilot performance.

- scope and latitude of potential studies to permit a wide range of planned studies, including unanticipated requirements in the visual area.

- flexibility of utilization to permit the rapid accommodation of different research needs.

- comprehensive performance measures and data recording technology to assure the valid and discriminative assessment of pilot performance.

As a visual research facility, the capability to comprehensively simulate the primary visual cues and stimuli will be of central importance. Several levels of simulation fidelity can be considered. These are physical, psychophysical and psychological.

<u>Physical Simulation</u>. This level of simulation attempts to replicate all variables as precisely as possible. The aerodynamic simulation of aircraft performance is a representative example. One-hundred percent accuracy is usually sought, including the simulated effects and interactions of such factors as wind, barometric pressure, rough air, and

*Special acknowledgment is made for the review and suggestions of Mr. J. Ohmart of the Martin Marietta Corporation.

icing. Similarly, the effects of fuel consumption on the aircraft's center of gravity and other internal aircraft state variables are taken into account. This level of simulation often attempts to replicate the fidelity of the internal system processes, in addition to the fidelity of the input/output processes.

Psychophysical Simulation. Early psychological experiments have shown that subjects do not react in a one-to-one fashion to the physical environment. According to Fechner's law, "The sensation is proportioned to the logarithm of the stimulus," (Woodworth 1950). In addition, there are stimulus thresholds for response and adaptation levels. For reasons such as these, human response ranges occur over relatively delimited physical stimulation ranges. For example, improvement in visual acuity levels off rapidly at about 100 fL, although in the real world we are exposed to much higher light ranges. (See Figure 6.) As a result, high brightness research can be conducted at the lower light levels, and this procedure can be expected to produce results which will closely approximate the visual performance levels achieved in the real world.

Psychological Realism. Psychological realism refers to the fact that a person can perceive events which cannot be readily substantiated by the physical event itself. This occurs in such phenomena as apparent brightness, motion, size, shape and color constancy (Gibson 1966). Brightness constancy, a common example, can be experienced when viewing a movie. The viewer has the impression of watching a daylight or high brightness scene when in fact the illumination of the screen is at twilight levels (e.g., 1-5 fL). The distinguishing difference, from a psychophysical relationship, is the fact that a subject's visual acuity will be less than the level which would occur under a higher or true brightness condition.

A research facility addressing problems in visual perception will need the latter two types of simulation fidelity, i.e., psychophysical and psychological. The VFRF requirements have been established on this basis, with the psychophysical being the primary consideration.

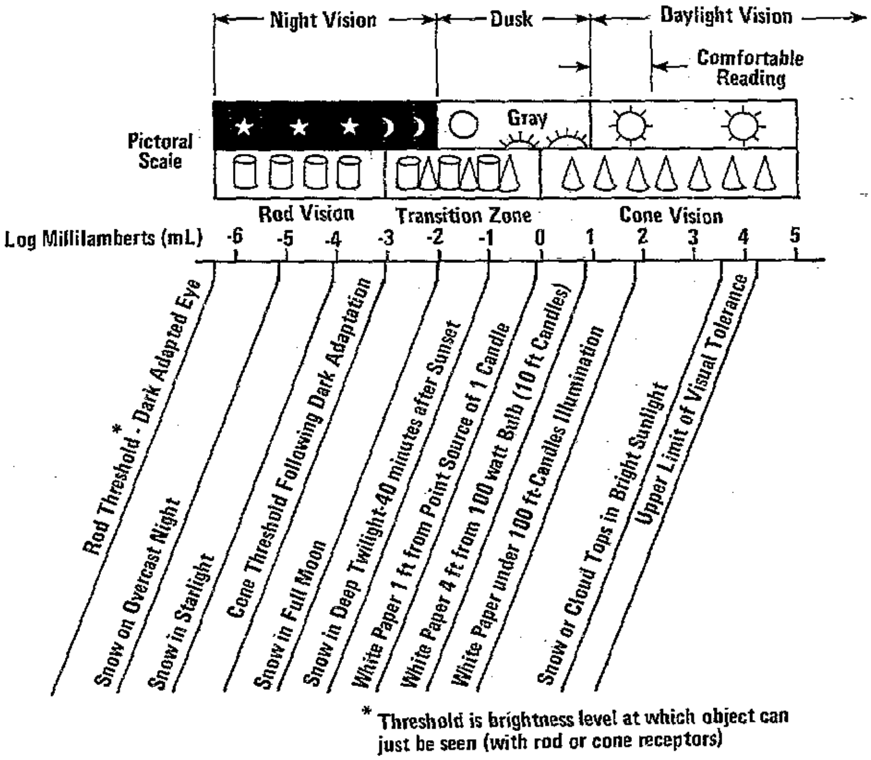


Figure 1. Luminance Under Various Natural Conditions of Illumination (from Wulfeck 1958)

During the following discussion on visual requirements, all luminance values are expressed as footlamberts (fL). When necessary and for convenience, millilamberts (mL) are considered as equivalent to fL since one mL equals 0.929 fL. Visual resolution will be specified as a subtended angle in terms of minutes of arc. The following night visual requirements are compared against a display resolution value of 5 arc min., which approximates the current state-of-the-art for camera-model systems with a monochromatic display.

Night Simulation Requirements

The following considerations are important for establishing the appropriate display parameters for night viewing:

- night luminance range

- visual resolution capabilities within this range

- the variation of visual resolution with scene contrast

- the effect of dynamic image scenes on visual resolution

Luminance. Most visual data for daylight viewing start at 1 fL. As shown in Figure 1, this light level represents dusk, just before sunset. However, the eye's ability to compensate, or the phenomenon of apparent brightness makes this level appear brighter than it is. In this respect, most simulated visual displays or movie screens are close to this level (e.g., 1-5 fL). Thus, while 1 fL would be a desirable starting point for a "night" system, it would be too close perceptually to daylight viewing conditions. From the same figure, it can be seen that with sunset, and full-moon conditions, the light level drops to 10^{-1} fL. For night NOE flight, this level appears to be an appropriate starting point. Both cone and rod vision are still active at this level. A consensus of the data appears to place rod vision alone, as starting at luminance levels of about 4×10^{-3} fL (see Figure 2) with full night vision starting at 10^{-2} fL (Figure 1).

Figure 1 shows 10^{-6} fL as the lower limit for night vision, and as the rod threshold for the dark adapted eye. Figure 2, however, shows that the practical limits of visual acuity are reached at 10^{-5} fL. This light level represents a no moon, starlight condition with ground reflection of snow, on an overcast night. As a result of the above considerations, it is reasonable to establish the luminance range for night NOE between 10^{-1} and 10^{-5} fL. Unlike day viewing conditions, where the phenomenon of "apparent brightness" operates, the luminance values in this range must be provided in a one-to-one fashion.

Visual Resolution Capabilities. The resolution capability of the eye at 10^{-1} fL is 1.2 arc min (Figure 2). This value is based on high contrast targets. The numerical value would increase (i.e., the resolution capability would decrease) if adjusted for lower contrast values as found in the real world. At 10^{-3} fL, the resolution capability of the eye is reduced to 10 arc min. Due to the rapid change of visual capabilities with illumination in this lower light region, a more reasonable visual resolution requirement would be 3 arc min. This would correspond to 10^{-2} fL at which time night conditions begin.

As noted earlier, 5 arc min. represents the current state-of-the-art for monochromatic displays. This will mean that the display will be eye limited when the visual resolution requirement is larger than 5 arc min., and will be display limited when the visual resolution requirement is smaller than 5 arc min. (e.g., 1.2 arc min at 1 fL). The crossover point in the illumination range between an eye and display limited windscreen presentation relative to a display resolution of 5 arc min. is 7×10^{-3} fL (Figure 2).

In Figure 2, visual acuity is shown for both the fovea (0° curve) and for off axis angular distances from the fovea (e.g., 4° and 30°). The takeover of rod vision can be noted at about 4×10^{-3} fL. Thus, rod and cone vision are operating at the crossover point of 7×10^{-3} fL. When the display is viewed 4° off axis, a visual capability of 5 arc min. is achieved at approximately 4×10^{-2} fL.

With foveal viewing alone, the luminance range above 7×10^{-3} fL represents approximately 32% of the total light range which is display limited. When viewing at 4° from the fovea, only 14% of the total luminance range is display limited. The true threshold may lie between these two values, on the premise that the line of regard should be shifting between them due to the lower light levels and fewer cones involved. However, 7×10^{-3} fL will be used as the reference point at which the display becomes eye limited with decreasing luminance levels (i.e., 68% of the luminance range). From Figure 1, it can be seen that this luminance region represents the major portion of night vision starting approximately below half-moon conditions.

It should be noted that color vision can still theoretically operate down to 4×10^{-3} fL levels of illumination and is readily apparent in dusk conditions between 10^{-1} and 10^{-2} fL. Pilots have also reported that color vision is not entirely lost during night flight, with greens and some browns being visible. As a result, the lack of color in this region may detract from the realism of the display as well as its apparent contrast.

Visual Resolution Capabilities when Adjusted for Contrast. The above resolution values were based on maximum contrast levels (e.g., 90-100%). Contrast values on the earth, however, vary from about .03 for damp earth to .9 for fresh snow. Average overall contrast is approximately .39 (Buddenhagen 1961). The contrast for NOE type terrain, heavily treed areas and open fields, should average about 24%. The average contrast level of the stimulus source can be established at this level with no loss in research validity.

The visual capability of the eye drops appreciably with reduction in contrast levels as well as illumination values. Figure 3 shows the variation in visual resolution as a function of contrast.

Resolution values associated with varying contrast values, as interpolated from Figure 3, are shown in Table 1. The values are assumed to be for foveal vision, since Figure 3 does not make a distinction between foveal and off axis viewing. From Table 1, it can be seen that the illumination value associated with 5 arc min. starts at 10^{-2} fL for 39.4% contrast, and approximately $5x10^{-2}$ fL for 24% contrast.

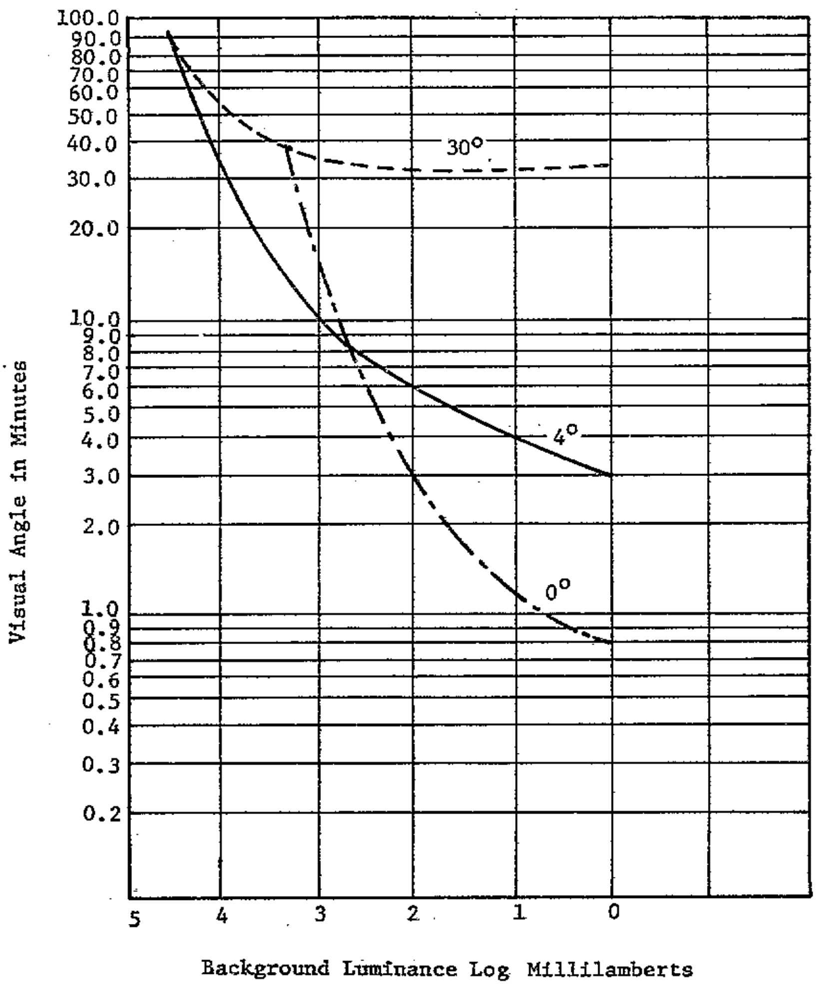


Figure 2. Visual Angle of Smallest Discriminable Detail as a Function of Background Luminance (from Wulfeck 1958)

Table 1
VISUAL RESOLUTION (ARC MIN) RELATIVE TO CONTRAST AND ILLUMINATION

	Contrast		
Illumination (fL)	92.9%	39.4%	24.4%
10^{-1}	1.2	2.2	2.5
10^{-2}	2.8	5	10
10^{-3}	6.6	16	33

The illumination crossover point relative to a visual display resolution of 5 arc min. is summarized in Table 2 for the range of contrast values discussed above. It is apparent that the luminance threshold values shift to the right as contrast levels are reduced. It should be noted that the threshold for 24% contrast is comparable to the threshold for high contrast targets when viewed 4° off axis. In view of this comparability, it would appear reasonable to set the luminance threshold value at 4×10^{-2} fL as the approximate light level where 5 arc min. resolution is achieved, whether with rod vision (off axis viewing of high contrast targets) or more direct viewing of low contrast targets. This threshold value would account for 85% of the luminance range where the display will be eye limited.

Table 2
ILLUMINATION THRESHOLD VALUES (fL) RELATIVE TO VISUAL ANGLE OF 5 ARC MIN. AND CONTRAST

	Contrast		
Viewing angle	95%	34.4%	24.4%
Fovea	7×10^{-3}	10^{-2}	5×10^{-2}
4°	4×10^{-2}	--	--

If the 34.4% contrast value is used, the light threshold falls to 10^{-2} fL, which is the beginning of full night vision (Figure 1) although still above the rod-cone crossover point of 4×10^{-3} fL. At this value, 75% of the luminance range will provide an eye limited display. This latter value would represent a more conservative reference point. Thus, when resolution values are adjusted for contrast, the eye limited portion of the display increases to 75% from 68% (i.e., from 7×10^{-3} to 10^{-2} fL). The area of night vision starting just after dark, with less than full-moon conditions (i.e., 10^{-2} to 10^{-5} fL) will represent the primary area of interest for night NOE studies and represents the critical area where sensor aids may be used.

The implications of contrast control during simulation are also worth considering. As implied by the above data, higher contrast is needed to see the same visual angle as illumination decreases (or with decrease in illumination visual resolution degrades at the same contrast level). The interaction between contrast, illumination and visual angle is illustrated in Figure 4. As can be seen, at the lower illumination levels, contrast sensitivity drops with greater contrast steps between each visual angle. This fact implies that the control of contrast levels can be relaxed at the luminance levels proposed. Control of contrast at higher luminance levels (e.g., above 10 fL) has always been a difficult and critical requirement. On the other hand, the control of luminance values at low light levels becomes more critical since visual angle is much more dependent upon light levels. The reverse is true for the simulation of daylight scenes.

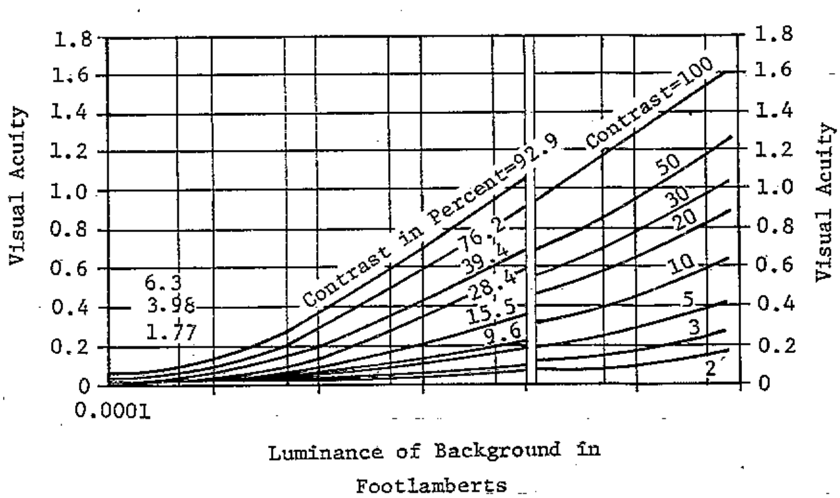


Figure 3. Visual Acuity as a Function of Contrast (from Wulfeck 1958)

The camera-TV display chain should, nevertheless, have a 10-step logarithmic gray scale over a brightness range of 5-50 fL (at the windscreen). The low windscreen brightness levels of 10^{-1} to 10^{-5} fL can be achieved by placing appropriate neutral density filters over the CRT display. By using this technique, no system degradation will take place by forcing the TV system to operate at low signal to noise ratios due to low CRT current levels.

Impact of Angular Velocities on Resolution. The impact of angular velocity on the resolution capability of the human eye should also be taken into account. As can be seen from Figure 5, appreciable degradation occurs at angular velocities of 20 deg/sec. and particularly at the lower light levels such as 10^{-1} and 10^{-2} fL. For example, a visual resolution capability of 1.2 arc min. at high contrast levels and under 10^{-1} fL of illumination (Table 1) will degrade to 4 arc min. at 20 deg/sec. angular velocity and to approximately 5.2 arc min. at 50 deg/sec. angular velocity. *In this respect, the loss of visual resolution* is proportionately greater relative to increased angular velocity than it is to lower contrast values (as shown in Table 1). Angular velocity and lower contrast values may also interact to produce even greater visual degradation. Data, however, are not available to show such interaction.

The potential range of angular velocities at aircraft velocities between 5 and 60 knots are shown in Table 3. In reading this Table, the pilot's line-of-sight is at 90° so that 85° represents 5° from this axis. As can be seen, angular velocity increases with speed, angular deviation and with reduced viewing range (decreasing "R" values). At night, NOE velocities will be about 20 knots. The pilots maximum viewing angle will be about 40°. For an "R" value of 200 and 400 (the normal distance between the target and flight path) the viewing or slant range will equate to approximately 240 and 480 feet* respectively. These latter values represent realistic viewing ranges under no moon conditions. The associated angular velocities with these conditions are 3.69 and 1.82 deg/sec., respectively. A 40° viewing angle represents a worst case condition. As angular deviation decreases from 40°, the drop in angular velocity is rapid, with 3.69 deg/sec. representing the worst case at the viewing ranges selected. At closer viewing ranges, such as 60 to 120 feet,** and at the same angular deviation and airspeed, the angular velocity increases to 14.6 and 7.3 deg/sec., respectively. At these lesser viewing distances, however, the aircraft's velocity would be slower.

An angular velocity of 3.69 deg/sec. at a viewing range of 240 feet (the probable worse case) will only lead to a degradation of visual resolution of less than .5 arc min. at 10^{-1} fL As a result, visual degradation due to angular velocities should be minimal during night NOE. Any degradation that may occur will tend to shift the light threshold value further to the right, making a still higher percentage of the display eye limited. As a minimum, it increases the validity of the threshold value selected (i.e., 10^{-2} fL).

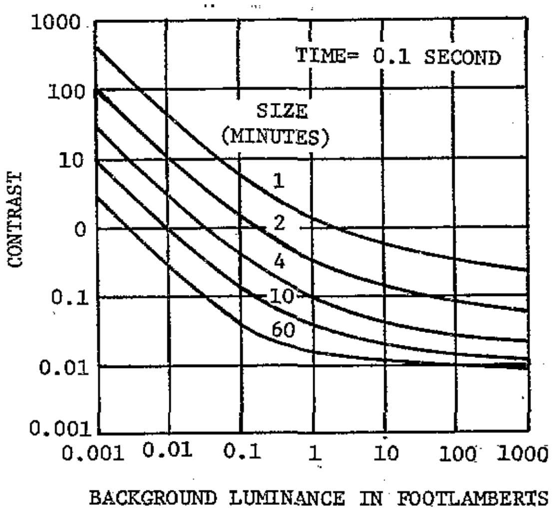


Figure 4. Relationship between Threshold Contrast and Background Luminance for Various Object Sizes (from Kaufman 1966)

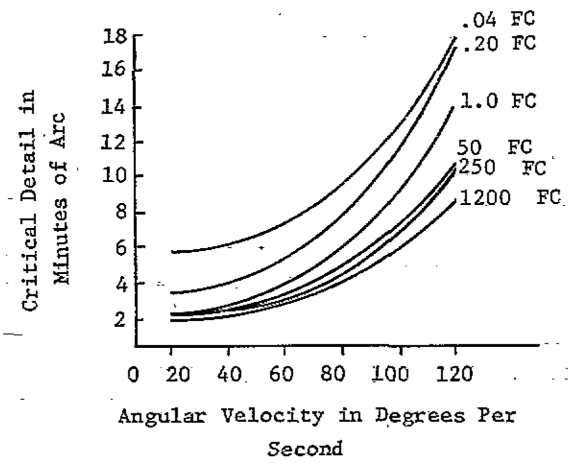


Figure 5. Acuity as a Function of Angular Velocity (from Miller 1958)

*When divided by the tangent of the viewing angle, to solve for the hypotenuse of the triangle or viewing range.

**Calculated from "R" values of 50 and 100'.

Practical Implications of 5 Arc Min. Visual Resolution. As noted above, a display resolution value of 5 arc min. leaves approximately 25% of the display above 10^{-2} fL as display limited. The practical implications of this limitation at NOE altitudes may be minimal due to the relatively short viewing ranges involved. The pilot scans approximately 500-1000 feet during daylight conditions with an occasional scan to 1500 to 3000 feet at an average flight speed of 40 knots. At night, the speed range drops to 10-20 knots with a viewing range between 250-500 feet. The impact of these closer viewing ranges, relative to different object sizes and visual resolution limits, has been plotted in Table 4.

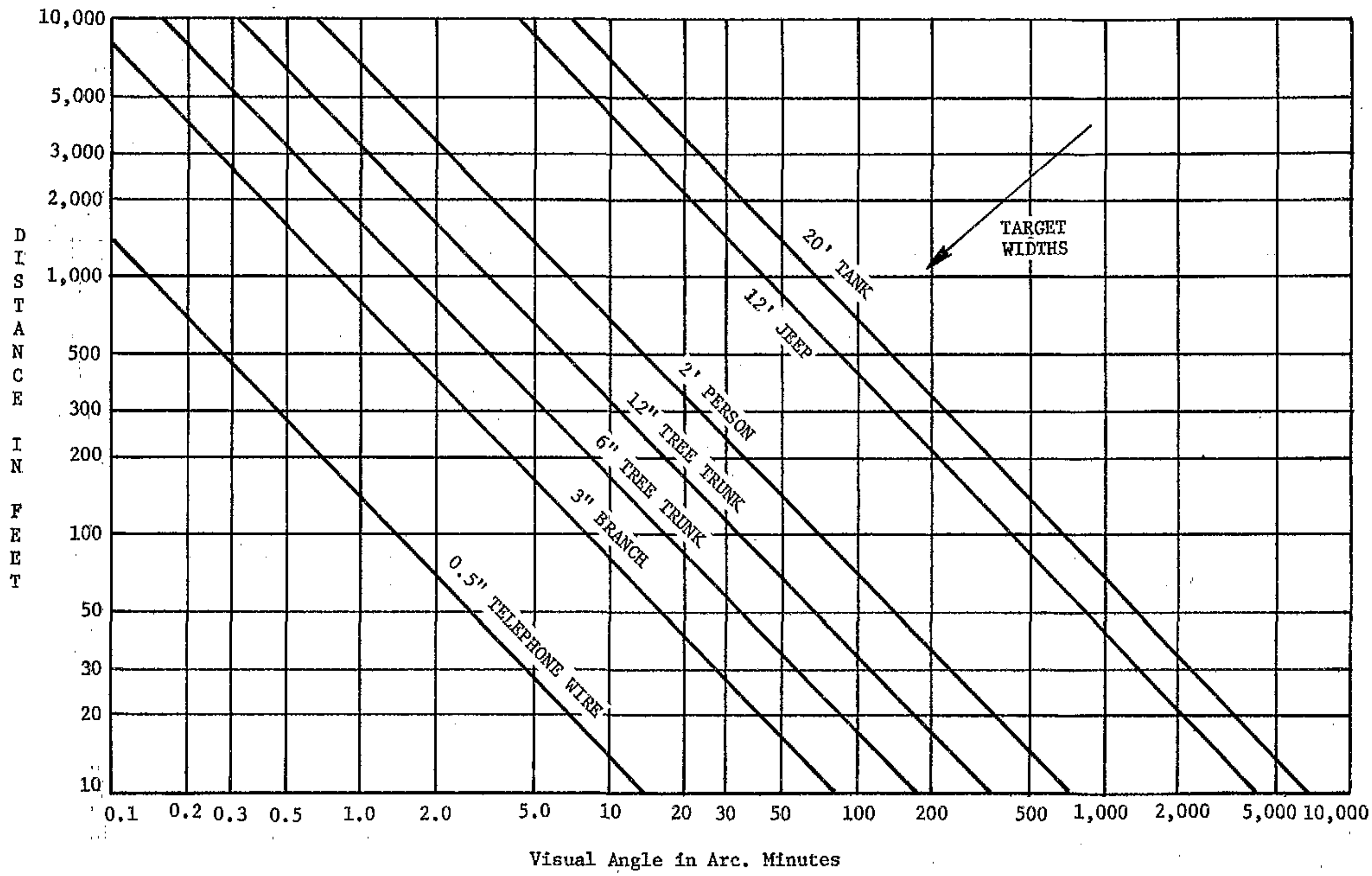
It can be seen from this Table (which assumes high contrast objects) that with 5 arc min. resolution, a 4.5" wide object detail can be resolved to 250'. A 9" wide object can be seen up to 500', and an 18" object, which is about the width of a large man, can be seen up to 1000'. A tank would be just resolvable at approximately 10,000'. Thus, in the region of dusk and full-moon conditions, at 250-500' viewing ranges, objects of 4.5" to 9" in width would be discernable. These sizes can represent large leaves, limbs, tree trunks. Details of this size and larger tree shapes and ground objects would be discernable (i.e., a whole image size comparable to detection of an object). In effect, while we would be display limited in the upper light region, the display would still have some research value from a practical point of view.

Brightness Adaptation. As noted earlier, illumination control becomes a critical consideration during the simulation of night scenes. Corresponding to this requirement is the importance of a subject's dark adaptation to assure his appropriate visual response at the light levels simulated. As a result, lighting control in the cockpit becomes an important consideration, as well as a potential experimental parameter.

Table 3
ANGULAR VELOCITY (DEG/SEC) AS A FUNCTION OF DISTANCE "R" FROM THE TARGET NORMAL TO THE PROJECTED FLIGHT PATH, AND THE ANGLE BETWEEN THE FLIGHT PATH AND THE TARGET

ANGLE TO TARGET	VELOCITY M.P.H.	DISTANCE "R" IN FEET					
		50	100	200	400	800	1500
85°	5	.73	.36	.18	.09	.04	.02
	10	1.46	.73	.37	.18	.09	.05
	20	2.92	1.46	.73	.36	.18	.09
	40	5.84	2.92	1.46	.73	.36	.19
	60	8.76	4.38	2.19	1.09	.55	.29
80°	5	1.43	.72	.36	.18	.09	.05
	10	2.87	1.44	.72	.36	.18	.09
	20	5.75	2.87	1.44	.71	.36	.18
	40	11.50	5.70	2.87	1.44	.72	.36
	60	17.40	8.70	4.35	2.17	1.08	.57
70°	5	2.70	1.35	.67	.33	.16	.09
	10	5.40	2.70	1.35	.67	.33	.18
	20	10.80	5.40	2.70	1.35	.67	.36
	40	21.60	10.80	5.40	2.70	1.35	.72
	60	32.41	16.20	8.10	4.05	2.03	1.08
60°	5	3.64	1.82	.90	.45	.22	.12
	10	7.27	3.64	1.82	.90	.45	.25
	20	14.60	7.30	3.64	1.82	.90	.48
	40	29.10	14.60	7.30	3.64	1.82	.97
	60	43.70	21.80	10.90	5.50	2.73	1.46
50°	5	4.14	2.07	1.03	.51	.26	.14
	10	8.27	4.14	2.07	1.03	.51	.28
	20	16.54	8.27	4.14	2.07	1.03	.55
	40	33.10	16.54	8.27	4.14	2.07	1.03
	60	49.65	24.80	12.40	6.20	3.10	1.66

Table 4. Target Distance versus Subtended Visual Angle



F.O.V. The visual field-of-view (F.O.V.) is another important consideration. During high altitude flight, the pilot generally scans a limited F.O.V. at a considerable slant range from the aircraft (e.g., 10-40,000 feet). During NOE flight, the pilot's maximum viewing range is roughly 3,000 feet. This fact, plus the lower flight speeds, both require and permit the NOE pilot to scan a larger F.O.V. A 120° F.O.V. is almost the minimum the pilot must scan to adequately survey the scene in front of his windscreen. A 120° F.O.V. is also consistent with a person's normal viewing area (Kaufman 1966). There is some evidence that the lack of peripheral vision, in a normally wide F.O.V. situation, could induce uneasiness due to the lack of general attitudinal reference acquired by peripheral vision. The pilot has a vertical F.O.V. of approximately 55° in the UH-1H. Of this, at least 30-40° represents the primary viewing envelope.

Special Effects. Night overcast conditions must also be considered, which will affect visibility in terms of both illumination and contrast. Lunar glare also represents an important consideration, with pilots reporting adverse effects due to shadows and night blindness, and the loss of dark adaptation when transitioning back to displays.

In summary, a luminance range of 10^{-1} to 10^{-5} fL is required as the representative and useful range for simulated NOE flight at night. This range will vary from dusk to starlight conditions. A visual display with a resolution of 5 arc min. will permit valid visual experiments between the illumination range of 10^{-2} to 10^{-5} fL, as the resolution capability of the eye is poorer than this value at these light levels. This luminance region represents the primary light region under which night NOE will be conducted and where special sensors and visual aids will be employed. In the remaining light range, 10^{-1} to 10^{-2} FL, human visual resolution capabilities are better than 5 min. of arc. This represents the light range associated with dusk, just after sunset and during full moon. The effect of this display limitation is minimized, however, in view of the factors mentioned above which reduce or negate high resolution requirements. The lack of color in the limited region of 10^{-1} to 10^{-2} fL represents a potential loss of realism.

DAY VISUAL REQUIREMENTS

The following primary variables must be addressed to assure the simulation of a visual display that will permit valid daylight psychophysical studies:

- maximum illumination range for effective visual acuity

- display resolution comparable with real world (i.e., NOE) acuity requirements

- appropriate visual cues for depth perception and visual perspective

- simulation of a reasonable spectrum of chromatic cues.

Illumination. In most visual display systems, "apparent" brightness is generally sufficient for the intended objectives (e.g., training). A luminance of 1-5 footlamberts, for example, is adequate to provide an "apparent" daylight scene. At this light level, however, a subject's visual acuity is reduced. Figure 6 shows the relationship between visual

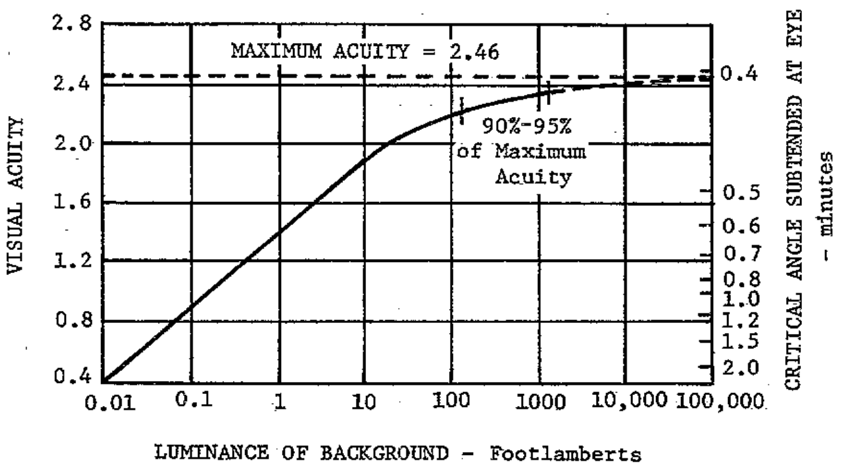


Figure 6. Variation in Visual Acuity and Visual Size with Background Luminance for a Black Object on a White Background (Kaufman 1966)

acuity and light levels. Near maximum visual acuity occurs at about 100 FL where the slope of the subsequent improvement begins to level off. "Even though we must grant that visual acuity continues to increase beyond this luminance level, it is apparent that the sensory response of the human eye and the related perceptual response of the human observer changes very little. In terms of perceptual fidelity, it may be concluded that visual fields with more than 100 millilamberts luminance are approximately perceptually equivalent, and that relative to visual acuity, a simulation display technique that is capable of generating 100 millilamberts, possesses almost 100 percent perceptual fidelity." (Buddenhagen 1961.)

The practical implication of higher luminance levels for simulation was evaluated by Harris (1974) relative to the influence of illumination on probability of detection at varying viewing ranges. Figure 7 shows the probability of detection when illumination and viewing range are taken into account. It shows performance to be comparable or identical at 100 and 50 fL, due primarily to the fact that with reduced illumination, performance is lost primarily at the more distant ranges and less at the more close-in ranges. The author states that "the acceptable tolerance in scene luminance depends upon the specific experiments to be performed and the precision desired in the experimental results. It would be expected, however, that differences in performance between 50 fL and 100 fL scene luminance will be lost in the noise of individual differences and other experimental factors." Thus, it would appear that maximum luminance levels can be less than the desirable 100 fL relative to specific experimental conditions. One-hundred fL, however, represents the ideal requirement.

Visual Resolution. Basic human visual resolution is generally accepted to be 1 arc min. In this respect, the visual resolution chart is referenced to a 1 min. of arc visual capability (i.e., 20/20 vision). Visual resolution, however, varies considerably with contrast and luminance as shown in Figure 8, and with position on the retina, in terms of distance from the fovea. (Reference Smith 1966.)

Under dynamic viewing conditions, visual resolution or the visual angle at which targets can be detected, recognized and identified is appreciably less. "A rough guideline for target acquisition capabilities of the human eye is as follows: target-detection--when target subtends an angle of 2 to 5 arc minutes; target recognition--at an angle subtended of 4 to 10 arc minutes, and target

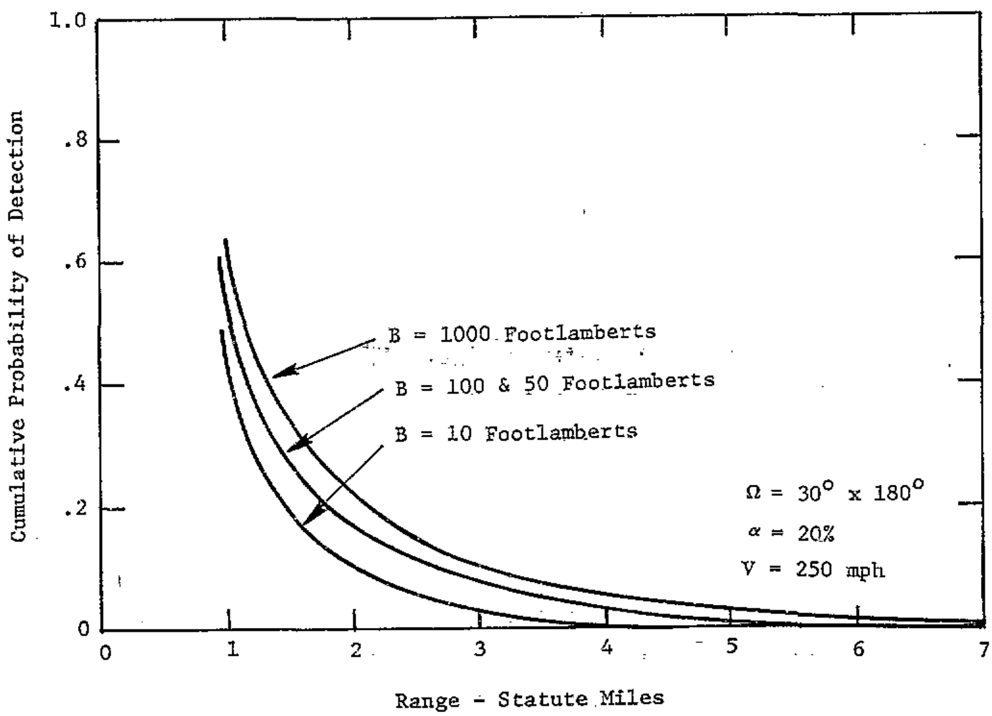


Figure 7. Probability of Detection Relative to Range and Illumination (from Harris 1974)

identification--at an angle subtended of 8 to 16 arc minutes." (Bailey 1974.) These values are influenced by many variables, in addition to visual capabilities.

One way to establish a visual resolution requirement is to determine the minimum discriminable feature that one would like to see. For day NOE flight, objects as small as 6" in diameter at a 500' viewing range would appear to be an acceptable criterion, with a 12" diameter at 1000' (i.e., tree limbs and branches). An analysis has indicated that NOE pilots generally view objects between 500 and 1000'. By means of Table 5, it can be seen that a 3 arc min. display would be necessary to view a 6" and 12" diameter object at 500 and 1000', respectively. Three arc min. is also compatible with target detection data. For example, 3 arc min. is needed to detect a target with 20% contrast (Fowler 1972). Three arc min., as a result, can be established as a reasonable resolution requirement for day NOE visual studies. The impact of angular velocities on this value is negligible. As shown in Table 3, the highest angular rate is 2.07 deg/sec. at 45° from center, at an 800-foot viewing range and 40k airspeed. The impact of higher speed is offset by the longer viewing ranges. In addition, the eye minimizes blur by tracking the target. A wide angle F.O.V., high brightness display, however, with a 3 arc min. resolution is difficult to achieve at the present time.

<u>Depth and Visual Perspective.</u> The illusion of depth will be important to assure scene perspective and visual orientation during NOE flight. The pilot relies on depth perception to assess his altitude above the ground and treetops. Some visual theorists (e.g., Gibson 1950) argue that the predominant factor in depth perception is the receding textural gradient of the viewed scene. This is seen as the explanatory basis for visual phenomena such as size constancy due to the fixed ratio of magnitudes of the stimulus gradients. According to Gibson, the important visual determinants of depth perception are:

- receding textural gradient
- linear perspective
- aerial perspective (haze)
- motion parallax
- realistic horizon or vanishing point

The implication of these considerations is that, to the extent feasible, a true analog and distortionless representation of the real world is needed in both the stimulus source (e.g., terrain model) and visual display (e.g., virtual image). Another associated consideration will be the maintenance of scene perspective during pilot head movements. An important feature of a virtual image display, in this respect, is that it permits the impression of motion parallax (i.e., the apparent motion of objects relative to each other as the observer moves his head).

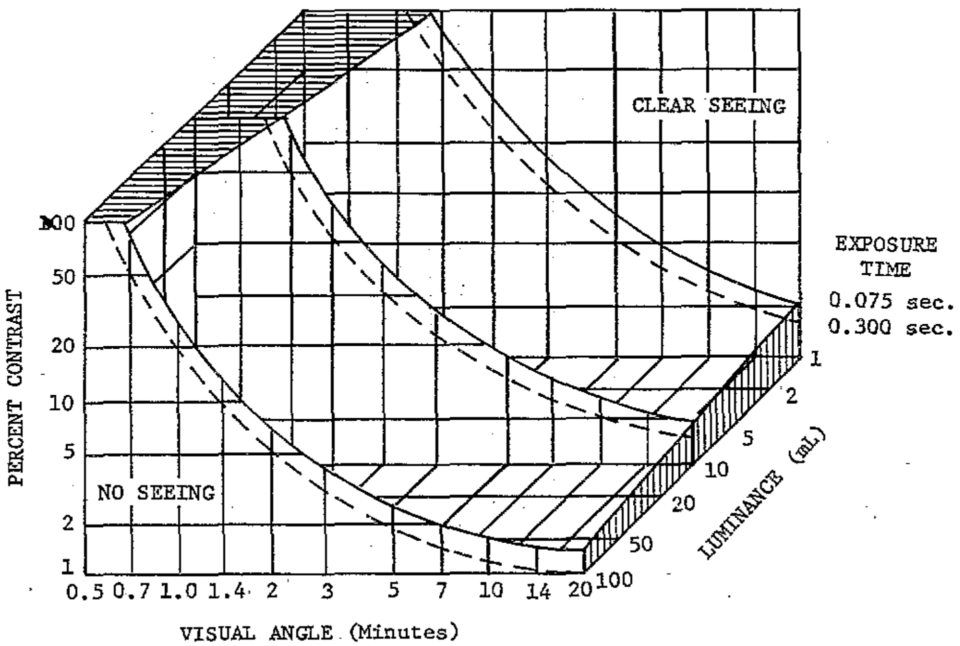


Figure 8. Background Luminance and Contrast Required for Bars Subtending Various Visual Angles Under Daylight Conditions (from Wulfeck 1958)

Contrast. At the higher illumination ranges, contrast sensitivity increases with visual angle. As can be seen in Figure 8, a 5 arc min. object can be seen at 2% contrast, a 3 arc min. object at 3.5% contrast and a 2 arc min. object at 5% contrast. This will have implications for NOE flight. Since viewed objects will generally be larger, they will need less contrast to be seen. This, in turn, will place a greater demand on low contrast sensitivity or rendition in the display. Some studies have reported contrast control to be limited to approximately ±2% utilizing a terrain table and a TV presentation (Ozkaptan 1968). At a very minimum, this demands that the camera TV display chain have a logarithmic 10 step gray scale over a brightness range of 10-100 fL.

Color. The use of color will add to the analog realism of the display. Unlike high altitude flight, it may have an important role in perception at lower altitudes, due to the nearness and prominence of the viewed scene, and the reduced attenuation of color by atmospheric haze. In addition, there is evidence that color adds to apparent contrast even at reduced illumination levels. Color will also aid the perception of depth at lower altitudes, and will tend to aid display resolution for recognition purposes. Color on a terrain table will also help produce the correct shades of gray for night monochromatic display, which otherwise would have to be determined by photometered values.

Haze and Sunlight. Both atmospheric haze and sun angle will represent important requirements to assure a realistic NOE environment. Atmospheric attenuation or haze plays an appreciable role in limiting visibility at long slant ranges. The simulation of sun angle is also an important variable, particularly in view of the effects of sun glare and shadow.

Table 5 summarizes the basic functional requirements of a visual display for day and night research studies at NOE flight altitudes.

Table 5
SUMMARY OF VISUAL REQUIREMENTS FOR NOE Research

	Day	Night
F.O.V.	Horizontal 120° Vertical 30-40°	same
Resolution	3 arc min.	same
Contrast	min. 10 shades of gray, logarithmic	same
Luminance	50-100 fL	10^{-1} to 10^{-5} fL
Chrominance	Full color	monochrome
Haze	0 to 20 miles	0 to 1 mile
Glare Simulation	Sun glare	lunar glare

References

Bailey, J.E. Design criteria for a weapons evaluation flight simulator. US Army Missile Command (EOSS Task Group). September 1974.

Buddenhagen, T.F., and Wolpen, M.P. Visual simulation techniques for astronautical flight training. Behavioral Sciences Laboratory, WPAFB. March 1961. (AD 260 093).

Fowler, F. Target acquisition studies. Martin Marietta Corp., Orlando, Florida April 1972.

Gibson, J.J. The perception of the visual world. Universal Press. 1950.

Gibson, J.J. The senses considered as perceptual systems. Houghton Mifflin Co. 1966.

Harris, J. Study to explore the relationship between visual senses performance and adaptation level. Scripps Institution of Oceanography, Visibility Laboratory. January 1974.

Kaufman, J.E., editor. I.E.S. lighting handbook, fourth edition. Illuminating Engineering Society. 1966. (Library of Congress Catalog No. 66-19818).

Miller, J.W. Study of visual acuity during ocular pursuit of moving test objects. Effect of direction of movement, relative movement, and illumination. Journal of the Optical Society of America. Vol. 48. November 1958.

Ozkaptan, H., et al. Target acquisition studies: Fixed television fields-of-view. ONR. NR 196-071. October 1968.

Smith, J.W. The design of optical systems. McGraw-Hill. 1966.

Woodworth, R.S. Experimental psychology. Henry Holt & Co. August 1950.

Wulfeck, J.W., et al. Vision in military aviation. Air Research & Development Command, WPAFB. November 1958. (AD 207 780).

ABOUT THE AUTHOR

MR. HALIM OZKAPTAN is a Principal Scientist and Work Unit Area Leader with the Army Research Institute for the Behavioral and Social Sciences. He is currently responsible for laboratory and field studies in the area of Human Performance Enhancement. He holds a Master's degree from Fordham University in Experimental Psychology. He was formerly the Director, Manpower Systems Research Division for the Navy Personnel Research and Development Laboratory, where he was responsible for research and development programs in the areas of manpower utilization and human performance. In earlier associations, he was Chief of Human Factors for the Martin-Marietta Corporation in Orlando; Head of F-111B Personnel Subsystems for Grumman Aircraft; a Research Scientist at Republic Aviation; and a Branch Head at the Naval Training Device Center (now the Naval Training Equipment Center). Mr. Ozkaptan has written over 30 publications in the field of human factors.