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NAVSHIPS DISPLAY ILLUMINATION DESIGN GUIDE. SECTION II: HUMAN FACTORS

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13. ABSTRACT

Human factors guidelines are provided – supported by research data, tables, graphs, and charts – for general reference by those designers concerned with display illumination. Consideration is given to trade-offs between ambient illumination, local illumination for design areas, and self-emanating and projected displays. Sample specification materials are included.

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NAVSHIPS DISPLAY ILLUMINATION DESIGN GUIDE

Section II
Human Factors

By
Howard J. Heglin, Ph.D.

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SECTION II
HUMAN FACTORS

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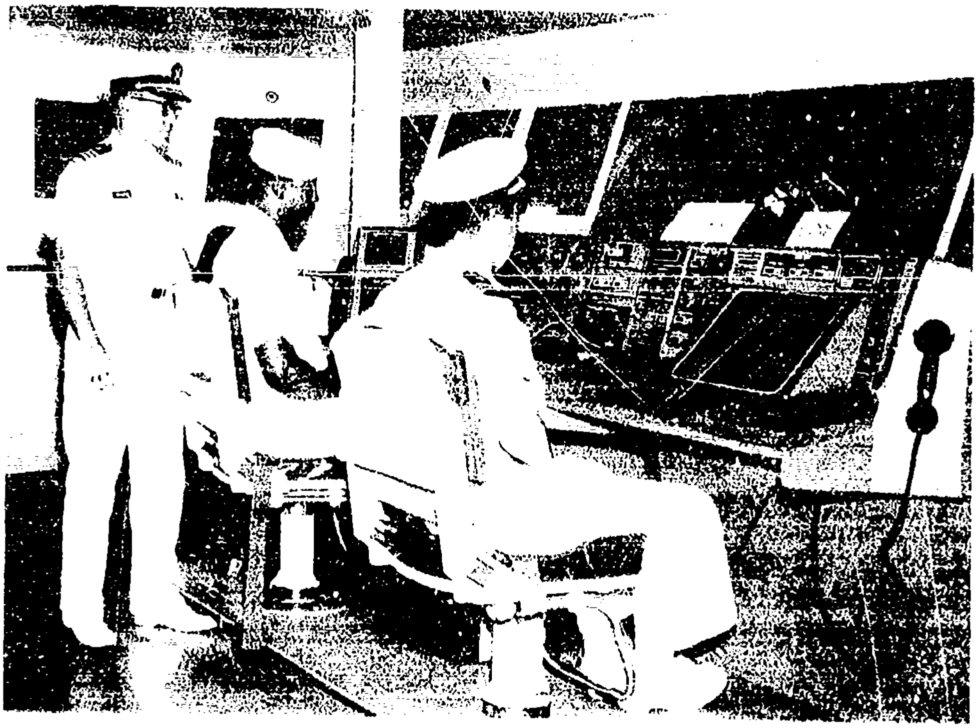

"Utilizing the Human Factors Evaluation Mock-Up of an Advanced Destroyer Concept — Ship's Bridge," NSRDL Report 335/65, J. Todd McLane et al.

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PREFACE

This technical document has been prepared for eventual publication as the second section of the Naval Ship Systems Command *Display Illumination Design Guide.*

When completed, the Guide itself will deal extensively with some of the special sorts of optical systems that have been developed for the internal illumination of indicating instruments and of control and monitoring panels and their color-coded signal devices. It is planned that there will also be a practical treatment of specification and design evaluation criteria.

The first section of the Guide, "Introduction of Light and Color," has been published by the Naval Ship Research and Development Center, Annapolis Laboratory. It is a highly summarized treatment that presents concepts to support a working understanding of the sections that follow.

The intent of this second section is to provide human factors guidelines for use in design of visual displays -- supported by research data, tables, graphs, and charts for general reference and followed by application specification materials that offer standards and tolerance limits. It is not possible in a work such as this to entirely support the various existing (and constantly changing) applicable military and industry standards and specifications. Where contracts demand departures from the guidelines given, this section's principal utility may be as a basis for evaluating related design or performance tradeoffs.

It was not feasible to bring all terminology of this edition of Section II into strict agreement with that of Section I, which was more oriented to physics and illuminating engineering. It is hoped that in an early revision many differences will be resolved.

Human-factors-oriented design of illuminated displays must consider the merits of at least four types of illumination -- some antagonistic to the others:

1. *Ambient illumination* in the display area. This can vary from completely controlled, uniform, nonglare illumination, such as that available in a windowless submarine control center, to that of a cockpit in an air- or spacecraft with widely varying incident light and practical illumination control restraints.

2. *Local illumination* for the display area itself, such as flood lighting.

3. *Self-emanating (transilluminated) illumination displays*, such as rear-illuminated legends and graphics, directly viewed electroluminescent elements, and light-emitting diode patterns; cathode ray tubes; and television raster scan tube devices. This category includes "edge-lighted," tungsten-lamp-equipped displays.

4. *Projected displays*, small and large scale.

A rather wide area beyond strict illumination requirements is covered in this section. This will allow the illumination designer to adequately consider interaction with other related design requirements and constraints, such as layout, legibility of characters, pointer size, coding options, etc. Also, particularly in the first chapter on human vision, display user-operator capabilities, limitations, habit patterns, and natural preferences are discussed since they are basic to effective use of illumination.

Maintenance and accessibility are not emphasized because guidelines for these are generally available in other references. Basically, any light source which requires frequent replacement should be readily accessible and easily replaced with conventional or readily available special tools.

Safety is relevant but also assumed to be covered in other references and standards. Any illumination scheme shoud, of course, present minimal hazard to the display user or maintainer with adequate protection from high-voltage, chemical, or radiation hazards or breakage in the intended environment.

Some chapters of this section of the NAVSHIPS *Display Illumination Design Guide* have aircraft or other nonshipboard design origins, but the principles involved are nevertheless valid.

ADMINISTRATIVE INFORMATION

Section II, Human Factors, has been prepared by H. J. Heglin, of the Human Factors Technology Division, Code 3400, Naval Electronics Laboratory Center, San Diego, California, Technical Document 223 of July 1973. The several sections of the Guide are now in various stages of preparation and publication by the Naval Ships Research and Development Center, Annapolis, Maryland, for NAVSHIPS under the sponsorship of G. N. Graine, Assistant for Human Factors Coordination, Code 03H. NELC and NSRDC funding was primarily under Element 62755N, Task Area SS 55525001.

ACKNOWLEDGMENTS

The material in this section is almost entirely excerpted from other references, but selected to provide a relatively concise, integrated source of human factors data and technology of interest to those concerned with display illumination. The principal sources are Woodson (1963), Woodson and Conover (1964) for Chapters I and II, Meister and Sullivan (1969) for most of III through VII, and MIL-STD-1472A (1970) for IX through XII. The balance of the material was gathered from diverse sources, which are all referenced in context. Woodson also provided valuable review of the original draft.

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CHAPTER I

HUMAN VISION CAPABILITIES AND LIMITATIONS

This chapter attempts to impart to the reader some insight into some aspects of this visual system directly relevant to display illumination. It is assumed that those using the NAVSHIPS Display Illumination Design Guide are familiar with basic vision anatomy and physiology to some extent and that Section I of this Guide, "An Introduction to Light and Color," has provided the other introductory material required.

The following presentation of special vision phenomena is excerpted from Woodson and Conover (1964), with minor deletions and additions by the author of this document.*** This source provided an excellent and concise coverage that would not benefit from paraphrasing.

"VISION"

Visual impressions depend upon light and upon its receptor, the eye. The visual processes enable us to perceive form, color, brightness, and motion. It has been estimated that 80 percent of our knowledge comes to us by way of the eye.

The light-sensitive part of the eye is generally conceded to be an extension of the brain and its neural network is nearly as complex as that of the brain. Before the visual impression is attained, light energy must set off a chain of chemical, neural, and "mental" processes. The impressions transmitted through the eyes are carried to the visual centers of the brain for integration, evaluation, and interpretation.

ACCOMMODATION

Accommodation is the action of focusing the lens on near or distant objects. Because the lens loses its elasticity with age, a child, who can focus on an object as near as 2.4 inches, will grow into an adult of, say, 40, who generally cannot focus on an object nearer than 6 inches. (This increase of minimum focusing distance with age is shown in figure I-1.) This hardening-of-the-lens condition which occurs with increasing age and prevents normal accommodation is known as presbyopia. Objects at distances of about 20 feet or more are essentially at optical infinity and no accommodation is necessary to focus on them. (The accommodation mechanism is given in figure I-2.)

The size of the retinal image of an object may readily be calculated by means of the equation $AB/ab = An/an$ when the size of the object and its distance from the eye are known. Take an as 0.8 inch. Image sizes, however, are usually given in terms of visual angle, in this case, angle α.

*See REFERENCES AND BIBLIOGRAPHY

**For uniformity of presentation, minor editorial changes are also made in material quoted in this and subsequent chapters.

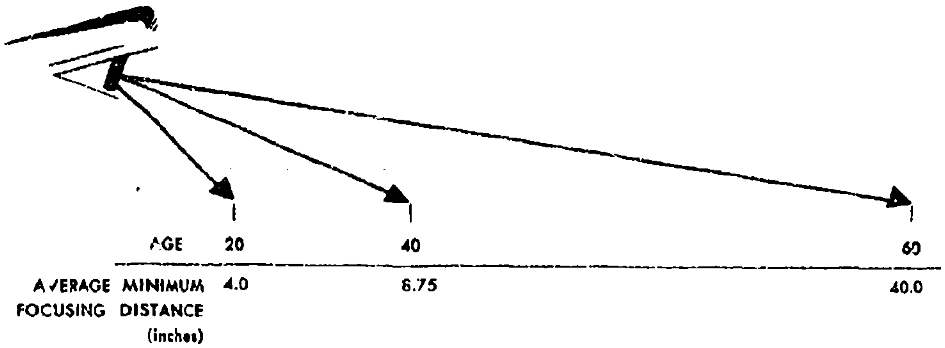


Figure I-1
Amplitude of Accommodation

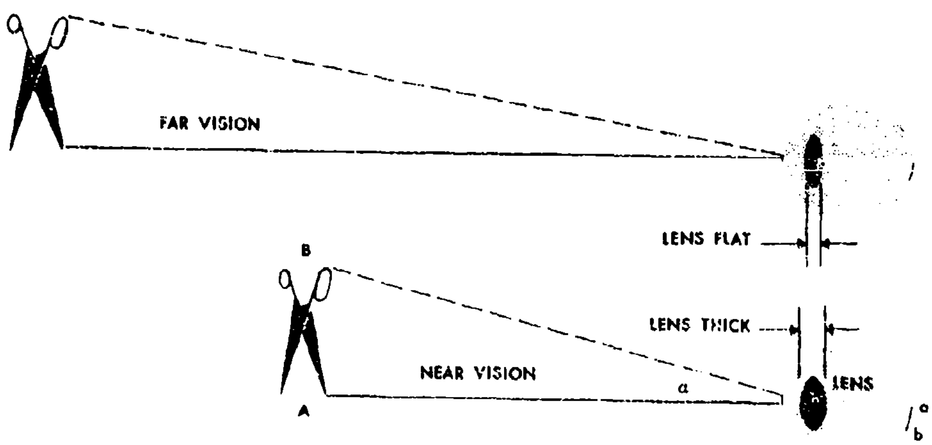


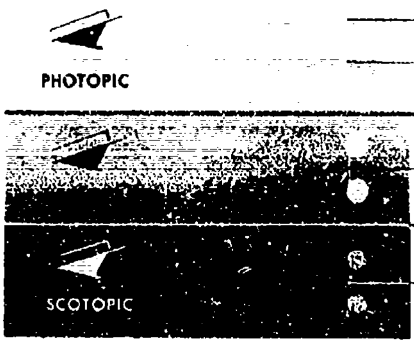
Figure I-2
Accommodation Mechanism

INTENSITY RELATIONSHIPS

The minimum intensity of light that can be seen, after complete dark adaptation, is called ABSOLUTE THRESHOLD of vision. It takes only an extremely minute quantity of light to excite the eye -- roughly only 1/1,000,000,000 of a lambert. It has been theoretically calculated that as few as half a dozen quanta, or less, of light reaching the retina have a good probability of yielding a visible sensation. The absolute threshold, however, is not of major concern here. The problem is that of detecting a light against a background of lower level. The ratio of light intensity to background intensity is the CONTRAST RATIO. The minimum ratio at which the light can be seen is called the CONTRAST THRESHOLD.

A light of low intensity may be clearly seen against a dark background. To be seen against a bright background, however, the light must have much higher intensity, as shown by table I-1.

TABLE I-1
CONTRAST AND VISION



LOG OF ILLUMINANCE JUST VISIBLE AT EYE (FT-C)	LOG OF BACKGROUND LUMINANCE (mL)
−5	4
−6.25	2
−7.60	0
−8.3	−2
−8.0	−4
−9.6	−6
−9.8	TOTAL DARKNESS

Visibility of light depends not only on contrast between field and background luminances, but upon area (visual angle) of the light surface being observed. Table I-2 (Blackwell, 1946) shows the effect of field size on its visibility when the background is completely dark. The numerical values shown are for different diameters (given in minutes of arc) of surface at the same distance from the eye.

TABLE I-2
ILLUMINANCE AND SIZE

As brightness diminishes, size must increase to be seen.

JUST VISIBLE BRIGHTNESS (LOG FT-L)	-2.2	-2.7	-3.25	-4.5	-4.75	-5.6	-5.8
DIAMETER OF SURFACE (MIN OF ARC)	0.3	0.6	1	6	10	60	100

Figure I-3 (Sloan, 1947) shows the sensitivity of different parts of the retina at night. The greatest sensitivity is shown to be about 40 degrees from the fovea on the nasal side of the retina and about 20 degrees from the fovea on the temporal side.

In order to see short flashes of light we must have much more intense light than we need to see longer flashes. Below 0.10-second duration, isolated flashes are equally visible if they contain equal energy.

Threshold visibility for a short flash of light depends on the total energy in the flash: the intensity of the flash multiplied by the duration. Thus the shorter flash must be at a greater intensity than the longer one in order to be visible. This reciprocal relationship between intensity and time, however, holds only up to a critical duration of about 0.1 second. For flashes longer than 0.1 second, threshold visibility depends on intensity alone and is independent of time. In figure I-4 the horizontal line shows the range of durations within which the product of intensity and time is constant. (Graham and Margaria, 1935)

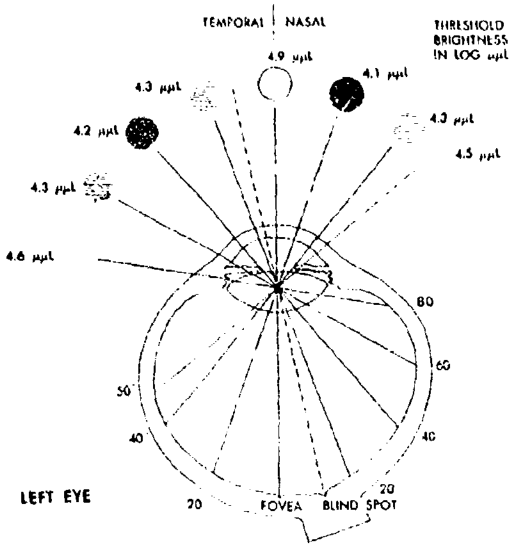


Figure I-3
Retina Night Sensitivity

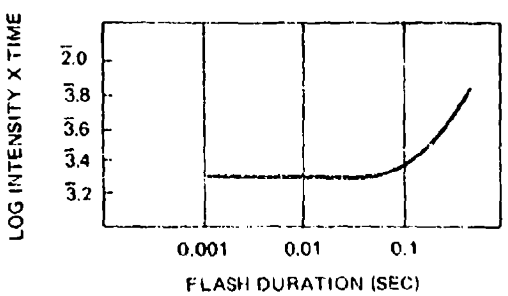


Figure I-4
Flash Intensity and Duration

The intensity of the dimmest light which can just be seen is shown in figure I-5 as a function of time in the dark following the original exposure periods to red and white light of the brightnesses indicated (Hecht and Hsia, 1945). Data are for the averages of ten subjects. The subject exposed to red light regains his response to fainter light sources more quickly than does the subject exposed to white light and reaches the level of "complete" adaptation much sooner also.

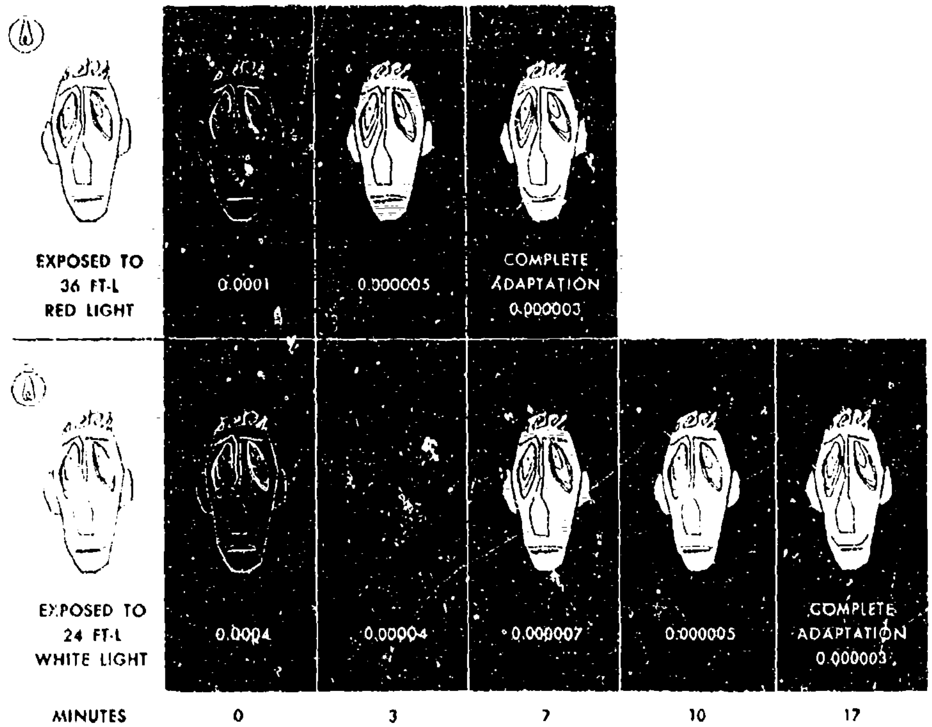


Figure I-5
Luminance of Just Visible Light (FT-L) (indicated in rectangles)

The just noticeable difference (JND) between two intensities is termed the DIFFERENCE THRESHOLD. The magnitude of this threshold depends somewhat on the wavelengths of the lights for which luminosity-difference judgments are being made. It depends more, however, on the intensity of the standard with which another intensity is being compared. In the normal intensity range, contrast sensitivity improves when light levels are raised.

Glare recovery times and flash recovery times are shown in figures I-6 and I-7. (In figure I-7, recovery time is given for visual task performance following brief (0.1 sec) exposure to various light intensities. The solid curve indicates visual task performance with object luminance of 0.07 ft-L and the dotted lines indicate performance with higher luminances. The flash intensity is indicated in the ordinates.)

The ratio between the brightness of a central display field and the brightness of an area surrounding it has an important effect upon brightness discriminations for fine details of the visual task within the display field (Coerman, 1941). As the surrounding-area brightness approaches that of the display field, brightness difference sensitivity within the display field improves. Best differential brightness sensitivity for traces on a cathode ray tube (scope), for example, is obtained when the brightness of the area surrounding the scope is about equal to that of the scope itself. When surround brightness exceeds scope brightness by a factor of more than ten, differential brightness sensitivity on the scope is impaired. The same effect holds, although to a considerably smaller extent, when surround brightness is less than that of the scope. These effects apply to any display which requires fine differential brightness judgment.

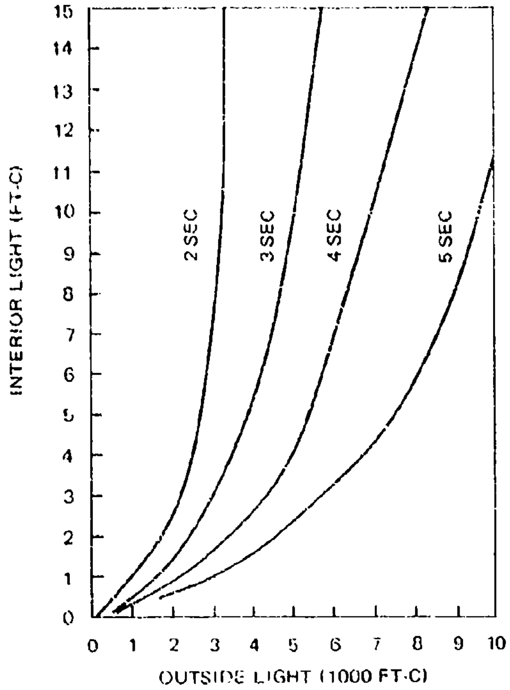


Figure I-6
Glare Recovery Times for Map Reading After 5-minute Exposure to Outside Light*

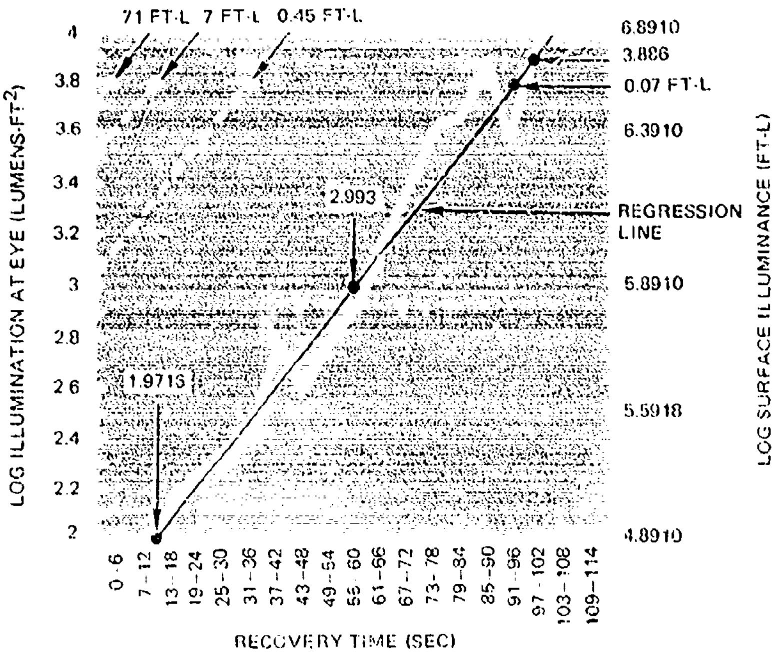


Figure I-7
Flash Recovery Times for Various Intensities*

*This illustration did not appear in Woodson and Conover; it was excerpted from Kubakawa et al (1969).

FLICKER-FUSION FREQUENCY is the point at which successive light flashes blend into a continuous light; it increases with increasing flash intensities and with decreasing proportion of the light-dark cycle occupied by the flash. It reaches 50 to 60 cycles per second at high intensities. When a flickering light -- on 50 percent of the time, off 50 percent -- flashes at the rate of 10 cycles per second, it appears to be twice as bright as a steady light of the same intensity. This phenomenon is of interest because it occurs at the same frequency as the brain's alpha-rhythm, a fluctuation around 10 cycles per second in the brain's electrical potential. The brightness enhancement may possibly be due to synchrony of impulses from visual stimuli with brain alpha waves (Bartley, 1939). Figure I-8 indicates the brightness of a flickering light with a light-dark time ratio of 1 to 1 and at rates of 0 to 20 cycles per second, as compared with the brightness of a steady light, and also shows the relationship of the 10-cycles-per-second point with the alpha-rhythm pattern.

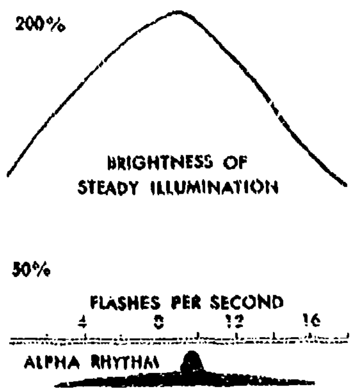


Figure I-8
Flicker Fusion and Brightness

ACUITY

Visual acuity can be defined and measured in several ways, with different results, depending upon the conditions of its measurement. One of the more commonly used standards is that acuity is the reciprocal of the visual angle in minutes subtended by the smallest discriminable visual detail at the nodal point of the eye, for all practical purposes the center of the lens.

The resolving power of the eye is the ability of the eye to detect small objects and distinguish fine detail. It varies greatly, depending upon the object, spectral distribution of radiant energy, luminosity of background, contrast between object and background, duration of the visual stimulus, and the criterion used to determine whether the object is or is not seen.

There is a marked relationship of visual acuity with the number of rods and cones and their distance from the fovea (figure I-9). Because the fovea (the central area of the retina, on which light from fixated objects falls) contains only cones, acuity is best there under photopic light conditions and poorest there under scotopic seeing conditions (Osterberg, 1935; Wertheim, 1894).

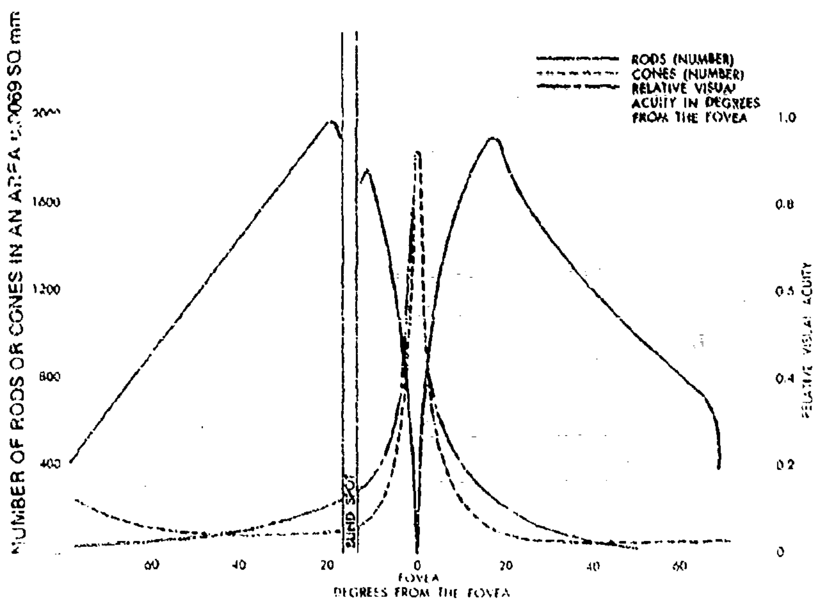
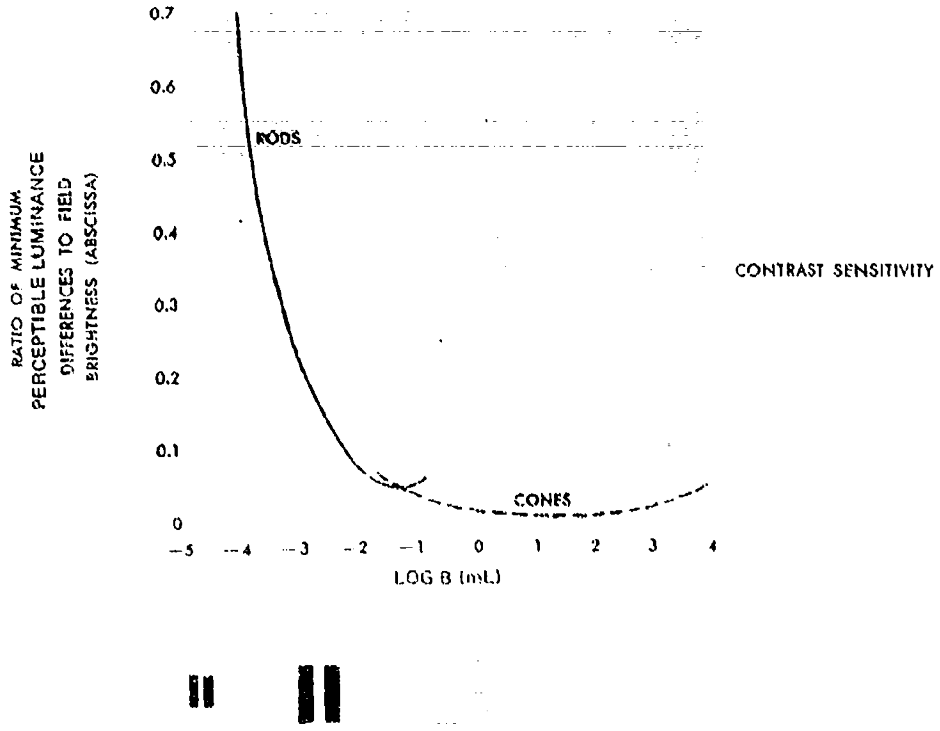


Figure I-9
The Relationship of Visual Acuity to the Distribution of Rods and Cones

The relationship between field brightness and minimum perceptible brightness difference (which is, in fact, a measure of acuity) for the rods and cones, is shown. Note that there is no appreciable change in sensitivity of the cones, which are used in daylight, while extreme change occurs in the sensitivity of the rods, used in darkened situations (Hecht, 1943).

At lowest intensities of light, the eye can just see a line whose thickness subtends a visual angle of about 10 minutes, while at high intensities, the just-resolvable line subtends less than 1 second of visual angle – less, in fact, than the width of an individual cone in the retina. All experimenters are agreed on the increase of visual acuity with increased illumination. Speed of recognition increases with increased illumination as well. When rapid discrimination of very small objects is required, high intensities of light and large contrast between background and object are necessary.

The relationship between contrast and size for threshold visibility of a standard parallel-bar test object under a brightness level of 30 millilamberts is indicated in figure I-10. As contrast is increased, minimum size and spacing between parallel bars may be decreased without rendering the spacing invisible. As contrast is decreased, size must be increased, especially for lower contrast percentages, in order to maintain threshold acuity.



PER CENT CONTRAST	45	8	5	3	2.8
VISUAL ANGLE MINUTES	1	2	4	10	16

Figure I-10
Acuity as a Function of Size and Contrast

An experiment of a threshold nature was conducted to determine whether the amount of increase in visual acuity, with increase of brightness on targets, differs more for persons with initial subnormal acuity than for those with initial normal acuity. The subjects located checkerboard targets under six levels of target luminance varying from 3.16 to 1000 foot-lamberts. It was found that the subnormal group gained significantly more in visual acuity terms with an increase in target luminance than did the normal group. The data show that adequate light for seeing detail is between 10 and 30 foot-lamberts for those with normal vision, somewhere between 30 and 40 foot-lamberts for subnormal subjects. All twelve subjects in each group, age 20 to 25 years, were tested monocularly (Kuntz and Sleight, 1949).

Visual acuity has been tested under different spectral illuminants, as shown in figure I-11. C-figures were used, with exposure times of 1 second (Ferree and Rand, 1931). In this study, yellow illumination was found to permit the best acuity. Given adequate ambient illumination, however, there is negligible relationship between the illuminant color and acuity for black-and-white figures. Luminance contrast, color contrast, illumination level, and exposure time are much more important factors in acuity than color of illuminant.

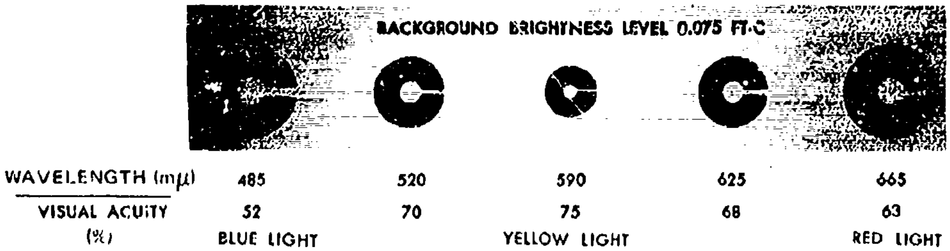


Figure I-11
Wavelength and Visual Acuity

When a visual image passes over successive receptor elements of the retina, that stimulus is perceived to be in motion. Visual acuity, for Landolt-ring test stimuli moving on a horizontal plane around the observer's head, decreases with increasing angular velocity of the test object. Figure I-12 shows that the gaps must increase in size in order to be distinguished at the higher speeds (Ludvigh, 1948). It was also shown that an object such as the Landolt ring seen 30 degrees from the line of vision is perceived only 60 percent as well when in motion as when stationary.

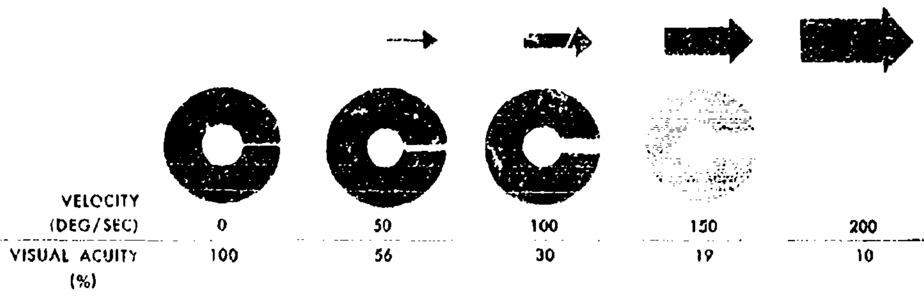


Figure I-12
Velocity and Visual Acuity

OTHER FEATURES OF SEEING

Summation and Interaction

The retina is composed of complex neural interconnections which may produce a summation effect between closely adjacent receptors (retinal summation). Thus, two test patches of light, either of which is below the threshold of vision, may become visible if presented simultaneously to adjacent parts of the retina. The threshold of a light may be lowered by increasing its area, because more interconnected receptors are stimulated. Another type of interaction may take place between the two eyes (binocular interaction) as a result of processes occurring in higher neural centers, including the brain. This phenomenon accounts for the slightly increased probability of binocular detection of small amounts of light as compared with monocular detection of the same amount of light. These and similar phenomena may alternatively be explained by physical optics, the mechanics of the eye, or probability theory.

Stereoscopy

When an object is fixated, a different view of it is seen in each eye. This feature of binocular vision is a major cue for the perception of depth. In the instrument known as the stereoscope, views of the object as seen by each eye are presented separately to them (figure I-13) Both two-dimensional views may then be fused, resulting in three-dimensional perception of a single object. Very fine differences between views can give this depth impression.

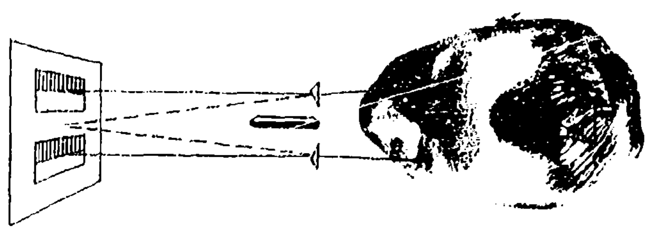


Figure I-13
Stereoscopic Vision

Single and Double Images

When an object is fixated, it is, of course, seen as a single image. Most other features of the visual field are, however, "seen" double, although our experience has taught us to disregard this impression. Many people are not even aware of the existence of double images. One can easily demonstrate them, however, by fixating on a pencil held in front of the eyes. A second pencil held behind the first is seen double.

For every fixation point in the horizontal plane there is a circle passing through that point and through the optical centers of the two eyes (figure I-14); with the exception of points very close to the eyes any point on or near this circle, including, of course, the fixation point, is seen singly (Boring, 1942). Points off the horizontal plane may also be seen singly; these points fall on rather complex curves with reference to the fixation point. Points on the plane but not on the circle are seen as double.

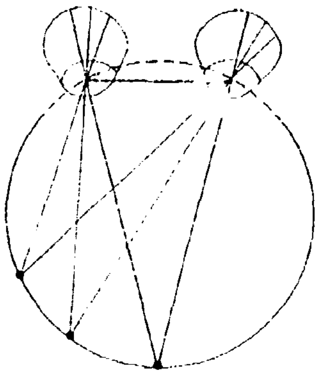


Figure I-14
Double Image Viewing

Apparent Motion

Lights presented in succession at the proper time interval, distance from each other, and intensity, give the impression of movement from one to the other.

If the second flash is more intense than the first, a backwards motion from the second to the first flash may be seen.

With alternate presentation of certain shapes in appropriate positions, the object may appear to move through three dimensions.

These effects, known as APPARENT MOTION (figure I-15), are utilized in motion pictures.

Figure I-15
Apparent Motion

After-Images

It has been known for many years that visual activity continues after stimulation of the retina has ceased. In positive after-images, the black areas will appear as black and the white areas as white. In negative after-images, however, the colors will be reversed; in the case of other colors, negative after-images will produce colors which are complementary to those of the actual picture.

Relevant Physical Variables

The features discussed above and other related physical variables are summarized in table I-3.

TABLE I-3

VARIABLES WHICH MUST BE CONTROLLED WHEN MEASURING SOME OF THE PRINCIPAL KINDS OF VISUAL PERFORMANCE (WULFECK ET AL, 1958)*

TYPE OF VISUAL PERFORMANCE	VARIABLES TO BE CONTROLLED												
	Level of Illumination	Region of Retina Stimulated	Stimulus Size	Stimulus Color	Contrast between Test Object and Background	Adaptive State of Eye	Duration of Exposure	Distance at which Measured	Number of Cues Available	Movement	Other Objects in Field	Monocular vs. Binocular	Stimulus Shape
Visual acuity	X	X	(MV)[1]	X	X	X	X	X		X			X
Depth discrimination	X		X	X	X	X	X	X	X	X	X	X	
Movement discrimination	X	X	X	X	X	X	X	X	X	(MV)[1]	X		X
Flicker discrimination	X	X	X	X	X	X	X						
Brightness discrimination	X	X	X	X	(MV)[1]	X	X			X		X	X
Brightness sensitivity		X	X	X	(MV)[1]	X	X			X			X
Color discrimination	X	X	X	(MV)[1]	X	X	X	X	X		X		

[1] Variable being measured

*Table excerpted from Kubakawa et al (1969).

COLOR

Light can be defined as physical energy in the form of electromagnetic radiations. The eye is sensitive to only a relatively narrow band of these radiations -- wavelengths from 400 to 720 millimicrons, approximately. The light travels through the lens and is focused on the retina, where it is absorbed in quantal units of energy.

The solar spectrum (radiation from the sun) contains all the visible wavelengths. Physical objects selectively absorb this radiation, so that the energy they transmit or reflect has a different energy distribution per wavelength than that of the original light. This difference provides the key to color vision.

The central nervous system of man is able to classify the distributions of light energy that fall upon his eyes; these classes of distribution are seen as colors. There are an infinite number of distributions of light energy which may be experienced as the same color. The eyes do not analyze out the separate wavelengths, as does a prism. The nervous system simply classifies impulses from groups of wavelengths and labels them colors from experience. Color is a psychological experience; it is not a property of the electromagnetic energy we see as light, but a perceptual response of the human being to that energy.

Sensitivity Zones

Not all zones of the retina are equally sensitive to color. Toward the periphery, objects can still be distinguished while their color cannot. Some colors are recognized at greater angles away from the fovea than others. Figure I-16 shows the limits of the retinal zones in which the various colors can, under normal illumination, be correctly recognized.

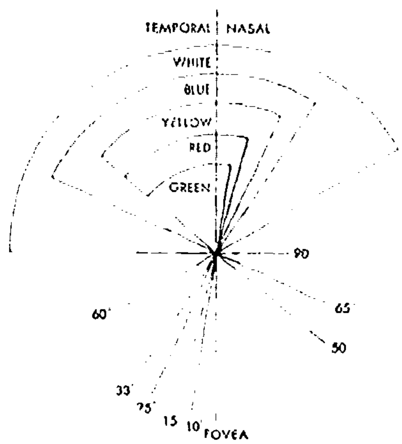


Figure I-16
Retina Color Sensitivity

Formation

Normal color vision is called trichromatism because any one of the 160 or more distinguishably different hues may for the most part be produced by variously mixing three independently adjustable primary colors, such as red, green, and blue. Mixing colors is often confused with mixing pigments. The former is an additive combination while the latter is subtractive.

When yellow and blue lights in proper proportion are thrown on a screen, the mixture appears white (figure I-17); the yellow and blue are said to be complementary colors.

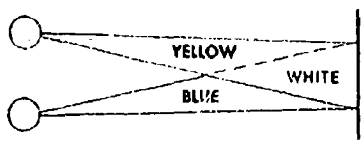


Figure I-17
Light Color Mixture

Color mixing may also be accomplished by using a "color wheel." The colors to be mixed occupy different sectors of the wheel, which when rotated at sufficient speed produces new colors in accordance with the rules of additive color mixture. This principle has been applied in experimental color-TV systems.

When artists mix yellow and blue pigments, however, a green results (figure I-18). This is done by double subtraction. The yellow pigment absorbs certain rays, while those remaining give it its yellow color. The same applies to the blue pigment. The light remaining after the yellow and blue pigments have both absorbed their respective wavelengths may be so balanced as to give a sensation of green.

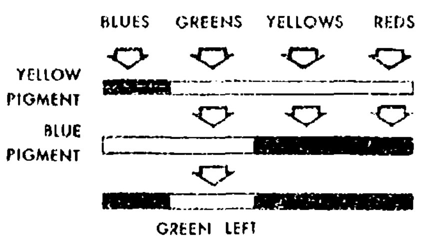


Figure I-18
Pigment Color Mixture

Color Abnormalities

The term "color blindness" is one frequently misused in connection with color abnormalities. In the absolute sense, color blindness should refer to a complete absence of psychological color experience. Because the so-called "color-blind" person usually does experience certain colors, it is suggested that the term "color deficient" be more applicable in most cases.

Trichromatism is usually considered normal color vision (Chapanis, 1951). (See figure I-19.) There are color-weak individuals, however, even among the trichromats; their impairment may be so slight that only very sensitive tests will reveal it. The largest proportion of color-deficient people have this type of color weakness, which is called "anomalous trichromatism." Though resembling normals in that they require three primaries to match spectrum colors, they may need them in abnormal amounts. Color deficiency is almost always hereditary in origin, present to some degree in about 8 percent of the male population. Females, however, are seldom afflicted.

The next most common form of color deficiency is red-green dichromatism. Dichromats have been divided into two principal subgroups – protanopes (red blind) and deuteranopes (green blind). For all dichromatic observers, color is restricted to two basic color groups, yellows and blues, which are not confused with each other. Dichromats can usually match all spectral colors, as they see them, by suitable combinations of the two independently adjustable primaries.

There are several important differences between protanopes and deuteranopes. For protanopes, the red end of the spectrum, seen as yellow, is foreshortened, whereas deuteranopes are able to see hue (though again yellow) out to normal limits of the spectrum. In figure I-19, the colors seen by a protanope are compared with those seen by a normal trichromat. The protanopes have a gray band centered around 493 millimicrons and cannot distinguish red or blue-green from gray; deuteranopes, on the other hand, have a neutral point around 500 millimicrons but cannot distinguish green or reddish-purple from gray. These differences are small but reliable and serve as one means of distinguishing between the two types of dichromats.

Monochromatic vision is extremely rare. Observers with this deficiency see only in terms of shades of gray. Acuity is poor in monochromats; their vision approximates black and white photography with poor definition.

Color and Illuminance

Satisfactory color selection can be made only if it is done under the proper illuminance conditions. Colors selected under an incandescent light will not appear the same if they are inspected under a fluorescent luminaire. (See tables I-4 and I-5.)

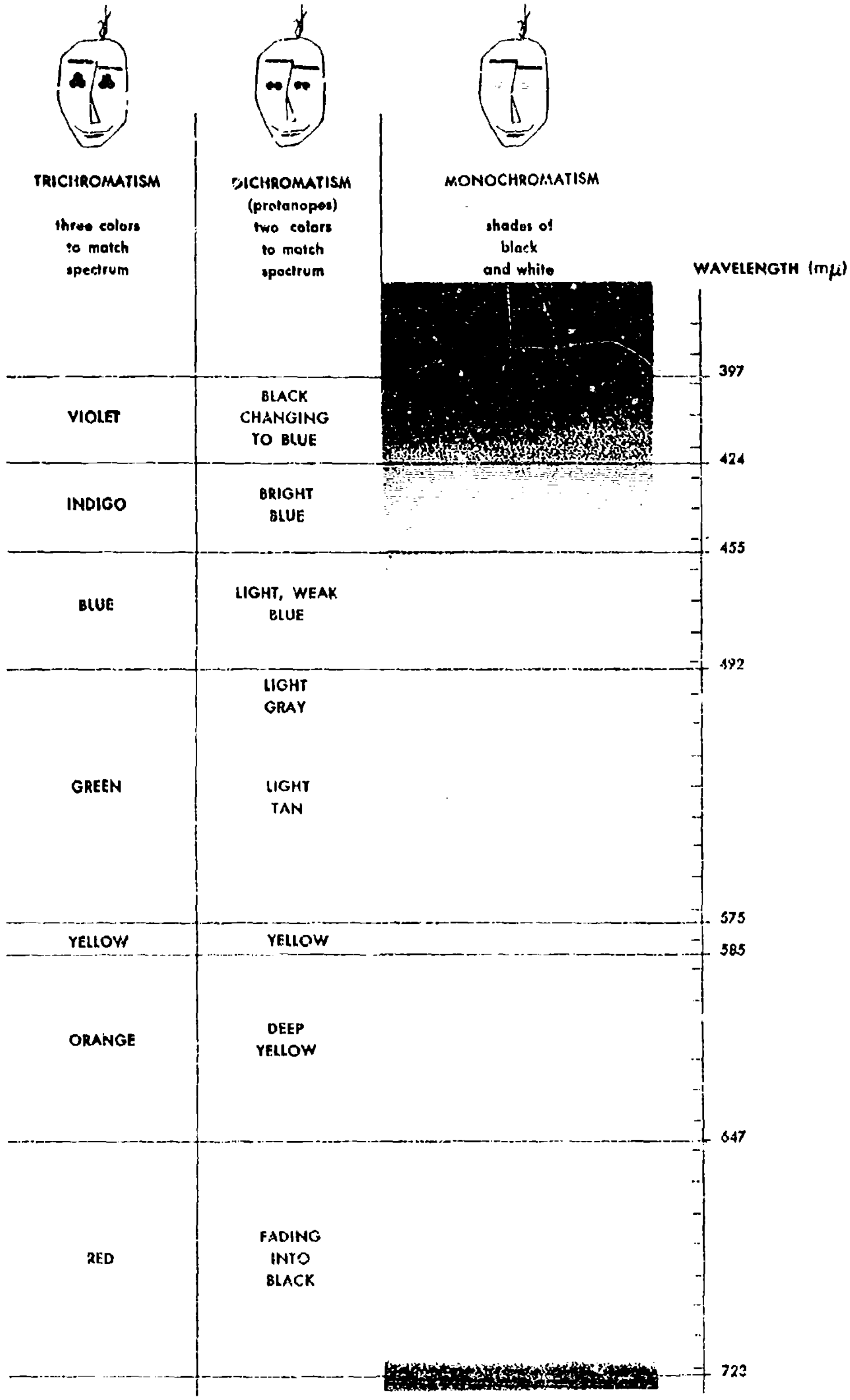


Figure I-19
Color Perception Abnormalities

TABLE I-4

APPEARANCE RATINGS OF TYPICAL COLORS UNDER ARTIFICIAL LIGHT SOURCES (DEPARTMENT OF THE NAVY, NAVDOCKS DM-1, 1962)

	FLUORESCENT LAMPS					
COLOR	DAYLIGHT	STANDARD COOL WHITE	DELUXE COOL WHITE	STANDARD WARM WHITE	DELUXE WARM WHITE	INCAN-DESCENT LAMPS
Maroon	Dull	Dull	Dull	Dull	Fair	Good
Red	Fair	Dull	Dull	Fair	Good	Good
Pink	Fair	Fair	Fair	Fair	Good	Good
Rust	Dull	Fair	Fair	Fair	Fair	Good
Orange	Dull	Dull	Fair	Fair	Fair	Good
Brown	Dull	Fair	Good	Good	Fair	Good
Tan	Dull	Fair	Good	Good	Fair	Good
Golden yellow	Dull	Fair	Fair	Good	Fair	Good
Yellow	Dull	Fair	Good	Good	Dull	Fair
Olive	Good	Fair	Fair	Fair	Brown	Brown
Chartreuse	Good	Good	Good	Good	Yellowed	Yellowed
Dark green	Good	Good	Good	Fair	Dull	Dull
Light green	Good	Good	Good	Fair	Dull	Dull
Peacock blue	Good	Good	Dull	Dull	Dull	Dull
Turquoise	Good	Fair	Dull	Dull	Dull	Dull
Royal blue	Good	Fair	Dull	Dull	Dull	Dull
Light blue	Good	Fair	Dull	Dull	Dull	Dull
Purple	Good	Fair	Dull	Dull	Good	Dull
Lavender	Good	Good	Dull	Dull	Good	Dull
Magenta	Good	Good	Fair	Dull	Good	Dull
Gray	Good	Good	Fair	Soft	Soft	Dull

Good - Color appears most nearly as it would under an ideal white-light source, such as north skylight.

Fair – Color appears about as it would under an ideal white-light source, but is less vivid.

Dull – Color appears less vivid.

Brown – Color appears to be brown because of small amount of blue light emitted by lamp.

Yellowed – Color appears yellowed because of small amount of blue light emitted by lamp.

Soft – Surface takes on a pinkish cast because of red light emitted by lamp.

TABLE I-5
EFFECT OF SOME VARIETIES OF COLORED LIGHT ON SOME COLORED OBJECTS*

OBJECT COLOR	RED LIGHT	BLUE LIGHT	GREEN LIGHT	YELLOW LIGHT
White	Light Pink	Very Light Blue	Very Light Green	Very Light Yellow
Black	Reddish Black	Blue Black	Greenish Black	Orange Black
Red	Brilliant Red	Dark Bluish Red	Yellowish Red	Bright Red
Light Blue	Reddish Blue	Bright Blue	Greenish Blue	Light Reddish Blue
Dark Blue	Dark Reddish Purple	Brilliant Blue	Dark Greenish Blue	Light Reddish Purple
Green	Olive Green	Green Blue	Brilliant Green	Yellow Green
Yellow	Red Orange	Light Reddish Brown	Light Greenish Yellow	Brilliant Light Orange
Brown	Brown Red	Bluish Brown	Dark Olive Brown	Brownish Orange

PSYCHOPHYSICAL RELATIONS

Let us now point out the relation between certain physical, psychophysical, and psychological aspects of seeing which are often misunderstood.

The physical stimulus, light, is *radiant energy* (measured in physical units, such as the erg) usually distributed over a wide band of the spectrum. When this physical energy acts on the organism, *luminous energy* results. Its magnitude is not in one-to-one relationship to the radiant energy, but is a differential function of the spectral composition of that radiant energy. If, for example, radiant energy is all above 750 millimicrons, no luminous energy results. Luminous energy, then, is a psychophysical concept, measured in such units as the candle, the lumen, and the lambert. Given the spectral radiant energy distribution of light and the well established response curve of the "average" observer, it is possible to convert radiant to luminous energy. *Brightness* is the psychological counterpart of luminous energy but, again, is not in one-to-one relation to it. It is a sensation which depends, for example, on the eye's state of adaptation and on the background of the luminous object.

The relationship of wavelength to color is even less precise than the above. It has been pointed out that an infinite number of frequency distributions may yield the same color. On the other hand, any particular frequency distribution of light may give rise to the perception of a large number of colors, depending upon field conditions as well as on the person's set and adaptation. A distinction between sources of light and reflecting surfaces is helpful in deciding what colors will be seen. The perception of a source color is fairly well correlated with its spectral wavelength distribution. Reflecting surfaces will, for the most part, be seen as the color which they would appear under "normal" (white) illumination, regardless of the character of the light illuminating and being reflected from them. This phenomenon is called "color constancy." When the color of the illumination is unknown to the observer, this color constancy breaks down, and the color of a surface then does depend to a large extent on the kind of light reflected from it; that is, the surface is now seen as if it were a source.

The characteristics of vision are summarized in table I-6.

*From Kubakawa et al (1969)

TABLE I-6

CHARACTERISTICS OF VISION*

PARAMETER	VISION
Sufficient stimulus	Light-radiated electromagnetic energy in the visible spectrum
Spectral range	Wavelengths from 400 to 700μ (violet to red)
Spectral resolution	120 to 160 steps in wavelength (hue) varying from 1 to 20μ
Dynamic range	~ 90 dB (useful range) for rods = 0.00001 mL to 0.004 mL; cones = 0.004 mL to 10,000 mL
Amplitude resolution $\frac{\Delta I}{I}$	contrast = $\frac{\Delta I}{I}$ = 0.015
Response rate for successive stimuli	~ 0.1 sec
Reaction time for simple muscular movement	~ 0.22 sec
Best operating range	500 to 600μ (green-yellow) 10 to 200 ft-C
Indications for use	1. Spatial orientation required. 2. Spatial scanning or search required. 3. Simultaneous comparisons 4. Multidimensional material presented. 5. High ambient noise levels.
References	Baker and Grether, 1954 Chapanis, 1949 Woodson, 1964 Wulfeck *et al*, 1958

*From Kubakawa et al (1969).

CHAPTER II

ILLUMINATION, LAYOUT, AND VISUAL DISPLAYS

This chapter presents a collection of guidelines for display use which are basic to consideration of illumination designers. Woodson and Conover (1964) and Woodson (1963) have condensed considerable information on visual display human factor requirements into a few pages, which are excerpted below. The illumination aspects are direct in some applications -- e.g., hooded consoles to control incident light -- and interactive in others – e.g., scale-pointer indicator design -- where rationale for human factor design may place constraints on illumination design options. In some instances, "brightness" or luminance controls may be mandatory for a single instrument. In others, a single adjustment may be advisable for a complete panel.

ILLUMINATION AND LAYOUT CONSIDERATIONS*

Good illumination is necessary for most human operator tasks. It is not attained, however, merely by adding light in large quantities. The type of task that is to be illuminated, the speed and accuracy with which it must be performed, the length of time it is to be performed, and variations in operating conditions must be known before a suitable lighting system can be designed. There are several important factors that should be considered in the design of any lighting system:

1. Suitable illuminance for the task at hand.

2. Uniform illuminance (ft-C) on the task at hand.

3. Suitable illuminance contrast between task and background.

4. Lack of glare from either the light source or the work surface.

5. Suitable color rendering quality of illuminants and colors of illuminated surfaces.

It is difficult to specify exact levels and limitations for all the problems that may arise in designing an efficient lighting system, but analysis of the following recommendations will undoubtedly serve as a safe guide to better seeing for most applications. Design and placement of all lighting elements should facilitate maintenance and cleaning in order to retain optimum illumination characteristics.

Variations in the time of day or night (fig. II-1), bright or cloudy days, or complexity of the seeing task – such as looking out of an airplane cockpit alternating with observation of instruments within the cockpit – make illumination solutions extremely difficult. Don't assume that good lighting for a daytime operation is equally good for night operation – and vice versa.

The human eye adapts to general illumination levels, thus making it necessary to provide different lighting solutions – for example, daytime vs nighttime viewing (fig. II-2). To emphasize this point, try looking out of a window at night with a lighted bulb behind you. You will probably see nothing outside the window, and instead see only the light bulb reflecting brightly on the window surface. However, if you repeat this observation in the daytime, the brightness of the outside scene is raised to such a high level because of the sunlight that you are hardly aware of the light bulb reflecting on the window surface at all. It is practically impossible to compete with the brightness of the sun reflecting on a surface – even if the surface is painted a dull black color.

*From Woodson and Conover (1964).

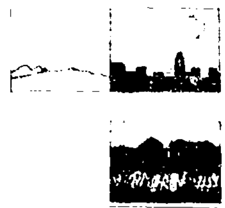


Figure II-1
Outside Lighting Effects

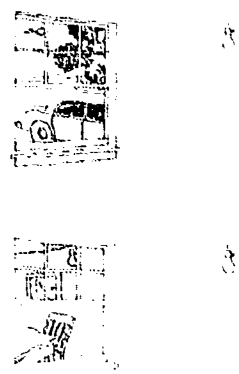


Figure II-2
Day-Night Contrast

A common error to avoid is direction of a light source at the observer instead of at the object to be illuminated (fig. II-3). Even a small amount of light so directed in the observer's eyes will change his adaptation level to the point that he will be unable to see the object you have tried to illuminate as well as you had planned.

Another illumination error to avoid is to plan a general lighting system for an interior area without regard to what will be built into the area after it is occupied. Partitions, large cabinets, and even people may absorb, obstruct, or shut off natural paths of light from the fixtures you have provided.

Some special activities are not at all appropriate to the general lighting approach. For example, a room where some of the occupants have to monitor displays which have low contrast characteristics, such as on cathode-ray presentations, must be reasonably darkened. In the meantime, other occupants in the same room may have to work on charts or colored maps and therefore require fairly high illumination levels (see figure II-4).

Figure II-3
Importance of Light Placement

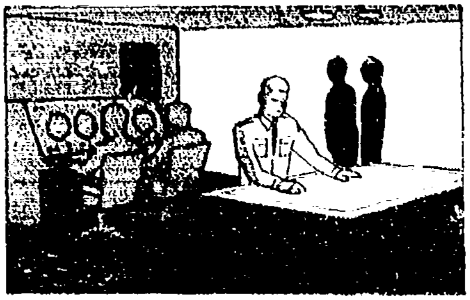


Figure II-4
Area Lighting

Adequate solutions to lighting problems such as the one just mentioned cannot always be worked out by the use of charts and illumination-level tables. Such problems call for an experimental approach. Use of portable luminaries with variable-intensity controls is suggested (fig. II-5). Such experimental lights are easy to move about and will allow measurements to be taken as well as give a chance to observe side effects, such as reflection and glare problems.

Figure II-5
Lighting Experimentation

Good lighting solutions cannot be obtained by concerning ourselves with the source only. We must also consider the interaction of surface texture, color, and the characteristics of objects which may be introduced into the "seeing task" (fig. II-6). For example, a glossy white sheet of paper viewed on a dark desktop in a dimly lit room becomes a disturbing glare source to the observer.

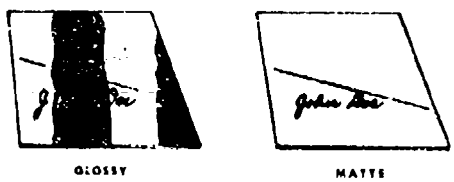


Figure II-6
Illuminated Surface Effects

Lighting is also a psychological tool. Mood lighting can create feelings ranging all the way from rest to excitement. Creating an "atmosphere" by means of lighting should, however, not be allowed to interfere with adequate "seeing" requirements.

General Recommendations for Ambient Illumination*

1. Provide uniform lighting for all indicators and control panel areas.

2. Avoid direct view of light sources or spectral reflectances from these sources. Arrange direct light source so viewing angle of visual work area is not equal to angle of incidence from the source. Use diffuse light sources and provide matte finish (rather than glossy) on all surfaces in the field of view.

3. Where equipment is used in enclosures and not subject to blackout requirements, ambient illumination levels should be between 25 and 50 ft-C.

Maximum allowable luminance ratios are given in table II-1.

TABLE II-1
MAXIMUM ALLOWABLE LUMINANCE RATIOS

RATIO	CONDITION
5:1	Between task and adjacent surroundings
7:1	Between dimmest and brightest instruments
20:1	Between task and remote surfaces
40:1	Between light source (or sky) and surfaces adjacent to it
80:1	Between the immediate work area and remainder of the environment

Note: In the illumination of work areas, sharp gradients (ratios of 10:1 or greater) should be avoided.

*From Woodson (1963).

General Recommendations for Specific Station Illumination*

1. Light sources (or reflection from these) should not be visible to the operator in his normal working position.

2. Cover glass on instruments should be antiglare coated.

3. Lamp replacement should be from the front, without need for special tools.

4. Transilluminated markings should be sharply defined and readable when viewed at any angle up to and including 60° from the normal to the plane of the front face of the panel.

5. Sufficient control circuits should be provided to allow operators to "balance" various panels for apparent equal brightness.

Lighting recommendations for work place, instrument panel, and living spaces are shown in table II-2.

TABLE II-2
LIGHTING RECOMMENDATIONS FOR WORK PLACE, INSTRUMENT PANEL, AND LIVING SPACES

CONDITION OF USE	LIGHTING SYSTEM	LUMINANCE (FT-L)	ADJUSTMENT
General area illumination	White flood, indirect and/or diffused	15 minimum	Fixed
Chart reading and other printed material inspection	White flood, direct -- diffused	15 to 50	Continuous
Instrument panel (no integral lighting available)	White flood, diffused	0 to 100 (or above if possible)	Continuous
Integral panel lighting (transillumination)	White	0 to 100	Continuous
Integral instrument lighting	White	0 to 100	Continuous
Warning indicators:			
KILLER	Red	150	Fixed
Warning	Red	150 (bright) 75 (dim)	Adjustable
Caution	Amber	(Same as warn)	Adjustable
Other	Other	100 (bright) 50 (dim)	Adjustable

*From Woodson (1963).

Chromaticity Considerations*

It is necessary to regard each console signal light as a complex optical system in which each component interacts with the other. The signal in turn becomes part of a console or other control equipment that is immersed in the general illumination of the control room. (Figure II-7 shows a Navy console mockup used for lighting evaluation.) This environment not only interacts physically with the signal, but it also sets the pattern for the visual response of the (also immersed) observer -- his luminance and chromatic adaptation.

In order to describe the stimulus for the sensation of color which results from lighting an indicator, the light reflected by the indicator diffusing screen and the light transmitted through the diffusing screen must each be weighted for their individual contributions. The chromaticity which can be plotted in the CIE system by treating these two components as additive is an accurate description of the chromaticity of the light emanating from the indicator. It is not, however, an accurate description of all the relevant elements of the luminous environment and cannot be expected to permit an accurate prediction of how the color of the indicator will be perceived. The difference between the response to a color which includes reflected ambient light and the same color composed of only source light is due to the observer's ability to appreciate, to some extent, the contribution of the ambient illumination to the total brightness of the indicator. He is apparently able to report the indicator color somewhat independently. Aside from chromatic adaptation there is a degree of color constancy which is a function of the observer's ability to structure his visual field and of his familiarity with the color of the general illuminant.

For example, confusion between some "pale" colors and the achromatic condition of the indicator (off or white) are considerably more frequent than confusions resulting from desaturation of colors caused by the ambient illumination.

For this reason, chromaticity calculation which includes the reflected ambient illumination can only be considered as a description of indicator chromaticity in this particular situation and for purposes of demonstrating the difference between indicator elements, such as different diffusing screens.

Assuming the ability to discriminate a stimulus as a particular luminous color under given environmental conditions to be a function of its luminance and chromaticity, an adequate specification of minimum brightness for indicator lights must take into account both of these parameters. The practical restraints on the design of the experiment did not permit the parameters to be varied systematically to synthesize an accurate general model for minimum brightness.

The following considerations are important in the interpretation of the data and in considering the differences in the present data and the data of previous studies . . . :

1. Responses were restricted to predesignated categories. This is important inasmuch as some colors may have been highly distinguishable as orange, blue-green, etc.; but since these responses were not allowed, such colors were necessarily classified, although with less confidence, in one of the acceptable categories.

2. The color categories selected were those already adopted for the Fleet Ballistic Missile (FBM) system largely to take advantage of inherent meaning associated with such colors as red, green, and yellow, rather than to take advantage of maximum color spacing.

*From Winterberg (1962).

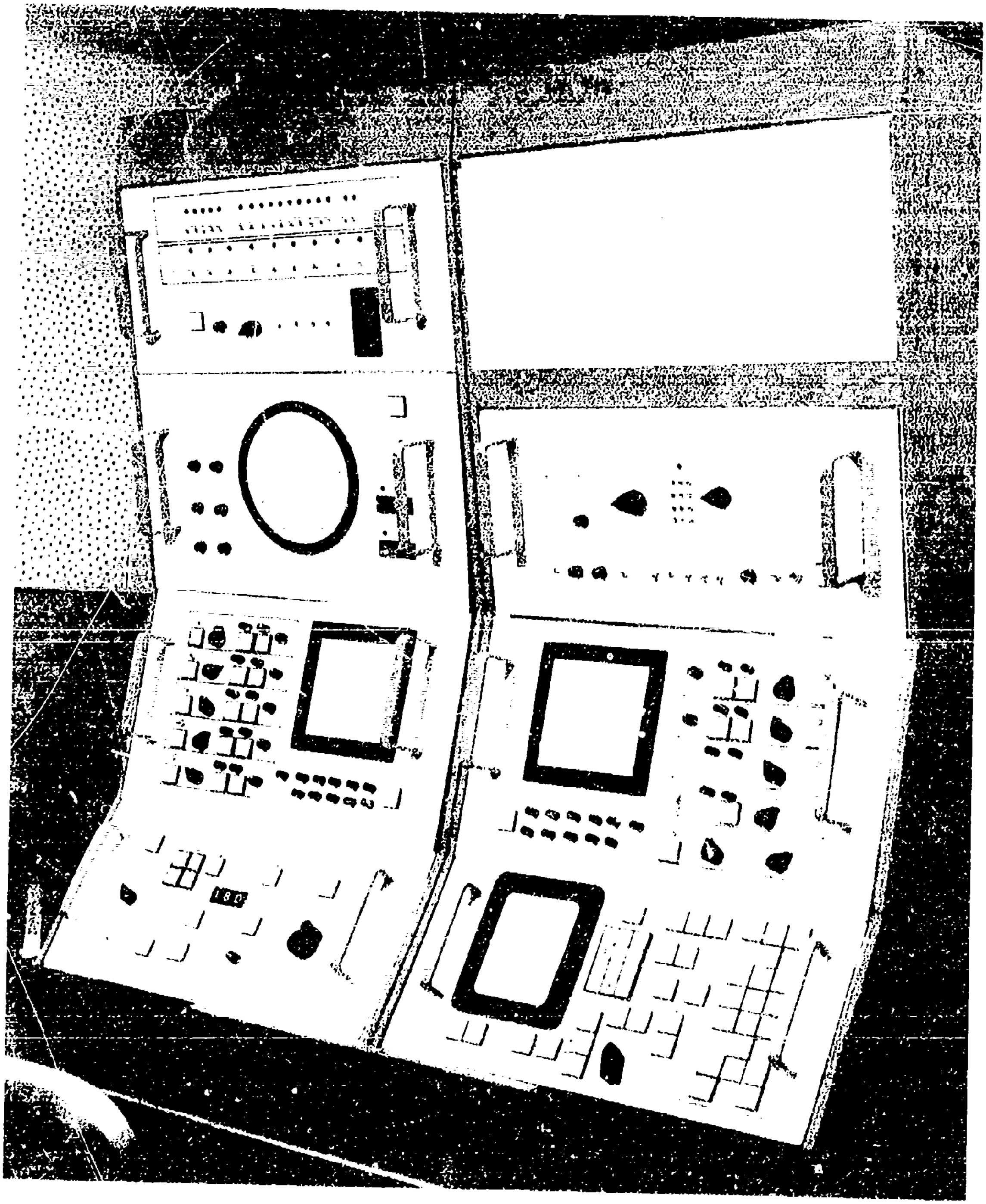


Figure II-7
Navy Console Mockup Permitting Lighting Evaluation

3. Neither luminance, nor chromaticity (in the sense of variation of purity, or dominant wavelength) were varied systematically. Because of this, precise formulation which takes these variables into account is not possible.

These considerations are believed to account for the differences between these experimental data and what might be expected from an inspection of existing outdoor colored light standards. Furthermore, they are the basis on which these data will be interpreted in posing new preliminary standards and implying areas needing additional refinement study...

From the results of this study, it is possible to define chromaticities representing five console signal light color categories which can be distinguished from one another and can also be distinguished from the "failed" or "not-lighted" condition under the ambient conditions of interest. Such a selection of chromaticities would be applicable to ambient conditions...: not less than 72 FT-L white screen signal luminances (darkroom determined) and not more than 7.2 FT-L of screen luminance caused by the reflections of ambient light in the actual working environment.

This study also suggests that the ratio of 11 to 1 for white-screen-signal to no-signal luminance will result in satisfactory recognition of the not-lighted condition as distinguishable from the lowest luminance colored light signals in a selected set of colors. The minimum limiting ratio was not established but it was found that a ratio of 4.3 to 1 was inadequate. It should be emphasized that the colored-signal/no-signal luminance ratios associated with the presentation of colors obtained by the use of color filters of low luminosity factors would be very much lower. While the results of this study do not support a simple explanation of these luminance ratio values, it appears that the minimum luminance ratio would vary as some function of the chromaticity of the colored signal...

USE AND CONTROL OF NATURAL DAYLIGHT*

Proper use and control of natural daylight is desirable not only from the standpoint of economy, but also for the sake of the general efficiency of people. Some people become irritable when they are shut off from the outside sunlight for very long.

It is desirable to consider the position of the sun in orienting a new building. Take advantage of the natural light. This means that one must consider the path of the sun for the particular latitude and even altitude of the building site.

The construction of buildings should be considered in terms of how best to introduce natural light into the work area.

In addition, consideration should be given to transparent and/or translucent materials in terms of filtering and equalizing the distribution of natural light.

Certain design configurations may create shadow difficulties — e.g., excessively deep window headers or sills. These should be avoided whenever possible.

Temporary light-control devices can also be added. These devices may create maintenance problems if they are not designed carefully to simplify the job of adjustment and cleaning.

The reflectance characteristics of internal walls, floors, and ceilings should be considered along with the design of the window openings. For example, a dark wall around a bright window will cause glare because of the extreme contrast between the wall and the window area. In general, light reflecting colors are recommended for most applications. Shiny surfaces, however, should be avoided.

*From Woodson and Conover (1964)

One exception that must be considered, in terms of light interiors, is that case where a night operation requires the worker to see out the window. In this case, a light interior is a potential source of reflectance on the window glass and is quite difficult to control.

PROBLEMS OF GLARE*

Glare is the most harmful effect of illumination. There is a direct glare zone which can be eliminated, or at least mitigated, by proper placement of luminaries and shielding, or. if luminaries are fixed, by rearrangement of desks, tables, and chairs. Overhead illumination should be shielded to about 45 degrees to prevent direct glare. Reflected glare from the work surface interferes with most efficient vision at a desk or table and requires special placement of luminaires.

Eyeglasses cause disturbing reflections unless the light source is 30 degrees or more above the line of sight, 40 degrees or more below, or outside the two 15-degree zones, as shown in figure II-8.

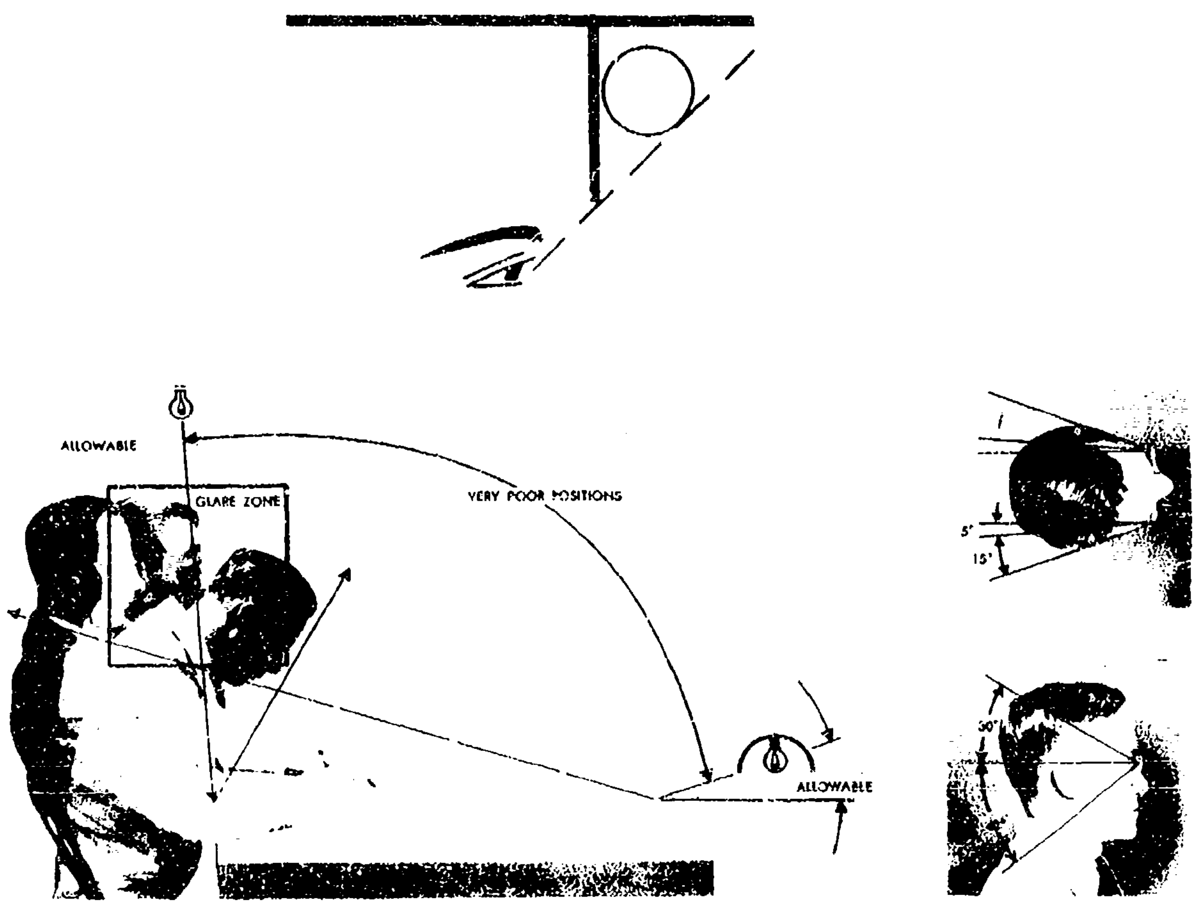


Figure II-8
Glare from Light Placement

*From Woodson and Conover (1964).

Instruments are normally protected by a glass cover. This glass cover often becomes a source of glare -- making it practically impossible to see the markings on the instrument face. The worst situation occurs on panels which are used in high ambient-light conditions, such as in the cockpit of an airplane. Here the sunlight illuminates the pilot's shirt front to the point that if it is reflected in the glass cover of the instruments in front of the pilot, he cannot read the indications at all. Although it is recommended as a general rule that instruments should be normal to the line of sight, this actually creates the worst situation for self-reflection (figure II-9). Therefore it is desirable to slope the instrument faces slightly off the normal line of sight, as shown in figure II-10.

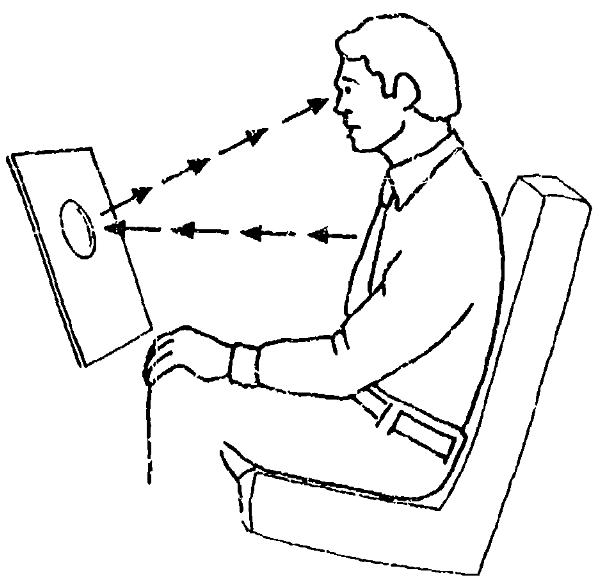


Figure II-9
"Self" Reflection

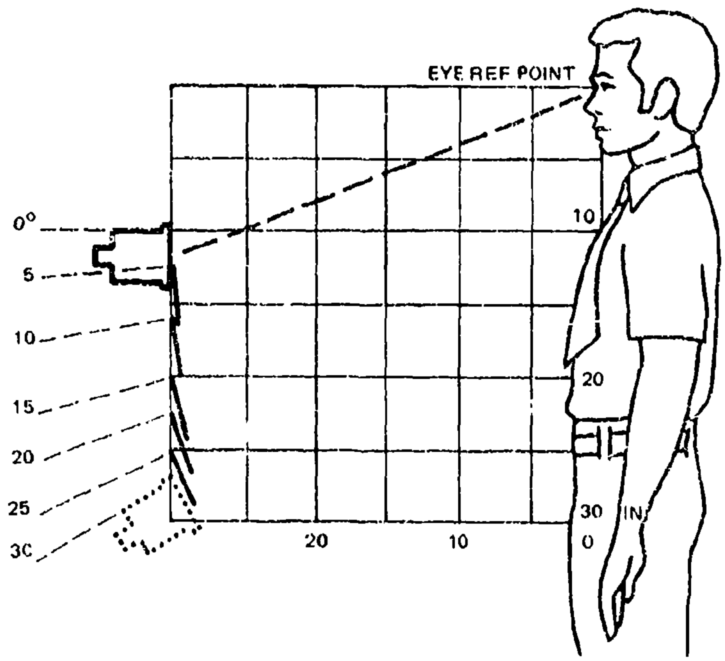


Figure II-10
Slope of Instrument Faces
to Avoid Self-Reflection

PANEL LAYOUT *

Some manufacturers develop a standard panel design in order to make their equipment appear distinctive. This also has the advantage of making it simple to group several equipments together and yet make them look as though they were designed as a complete unit. Modular panel-design techniques increase the discriminability of functional groups of displays and controls. For example, a dark-colored module contrasted against a light-colored background produces an association among the components within the module.

A typical modularized panel specification is shown in figure II-11.

The panel titles are centered at the top of each panel. The panel modules are located in an area ½ inch from the top of the panel, 1 inch from the sides, and 3/16 inch from the bottom of the panel. The module title is also centered within the module, as shown. Naturally, space limitations may sometimes require modifications, but the manufacturer attempts to maintain the specifications as nearly as possible in each new layout.

Figures II-12 through II-14, from Woodson (1963), summarize panel layout considerations.

* From Woodson and Conover (1964).

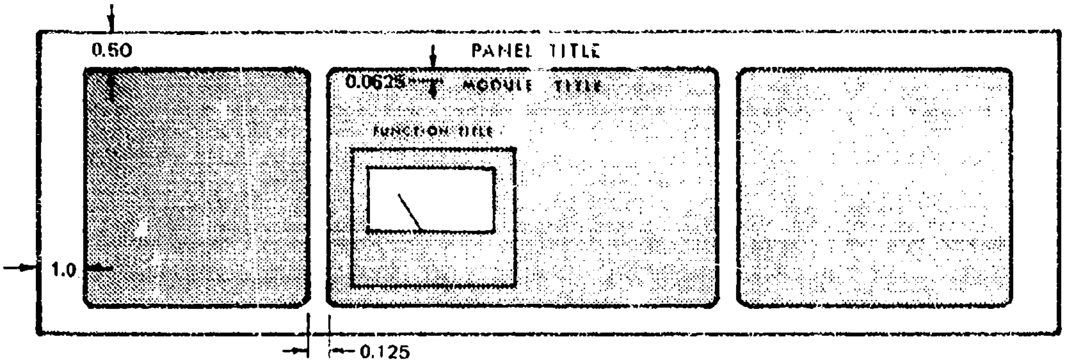


Figure II-11
Dark-Light Module Effects

In addition to the general layout, color specifications are usually provided in order that all equipments may maintain a uniform color scheme -- even when newer equipments are added at a later date. Table II-3 is a typical color specification.

Lettering styles and sizes are also specified and usually a style guide of type fonts is made a part of the specification.

Finally, control types are specified, generally related to a given manufacturer's line of knobs. Colors, sizes, methods of mounting, etc., are all included in the specification.

CAUTION: Although the basic objective of standardization is commendable, the designer is reminded not to be led astray by aesthetic or "arty" concepts which destroy good human-engineering practices. Remember that a bad standard is worse than no standard at all! First analyze your present and future needs, then apply good human-engineering principles in developing a standard. The end result *can* be beneficial both to the operator and the reputation of the company.

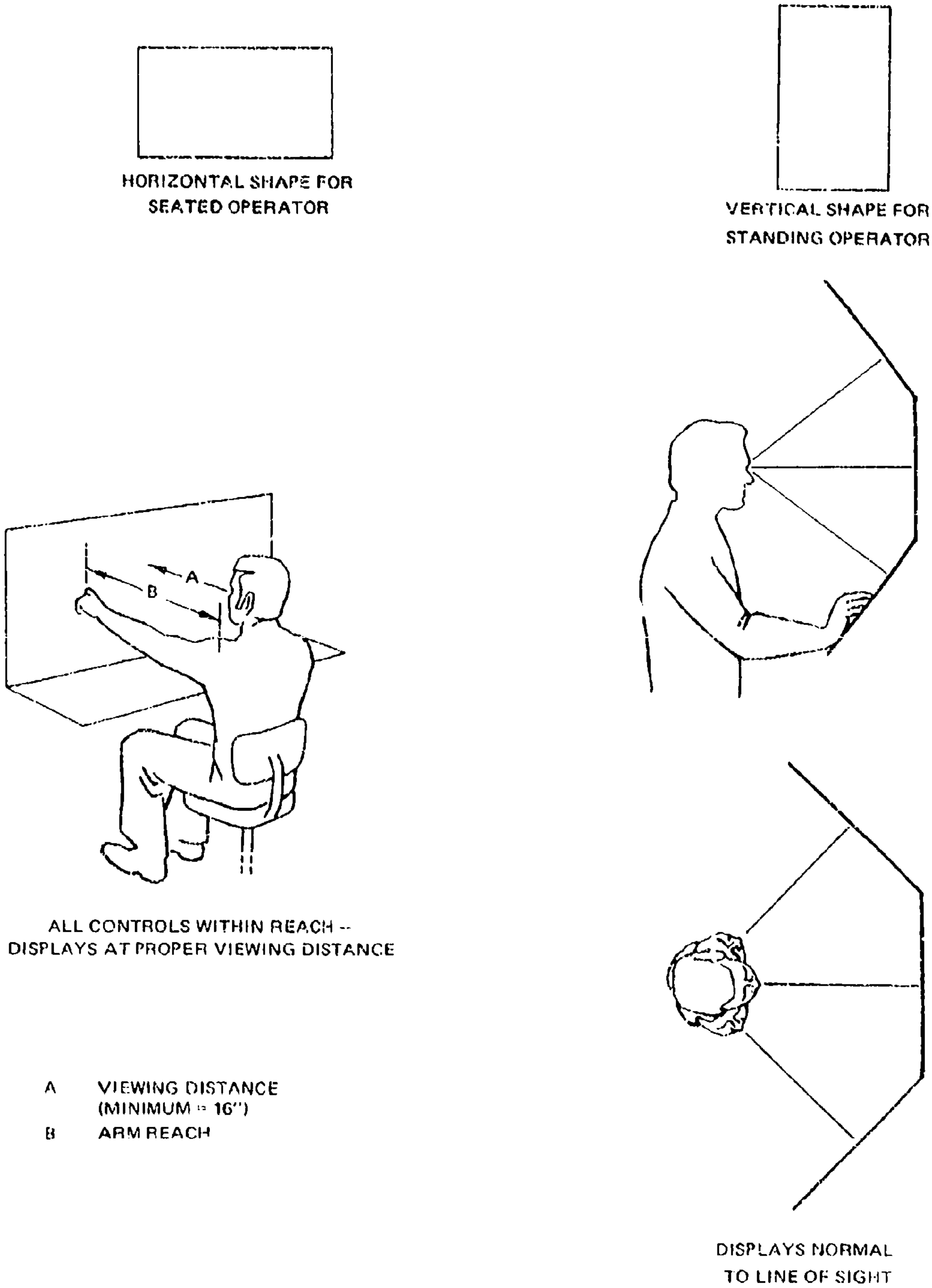
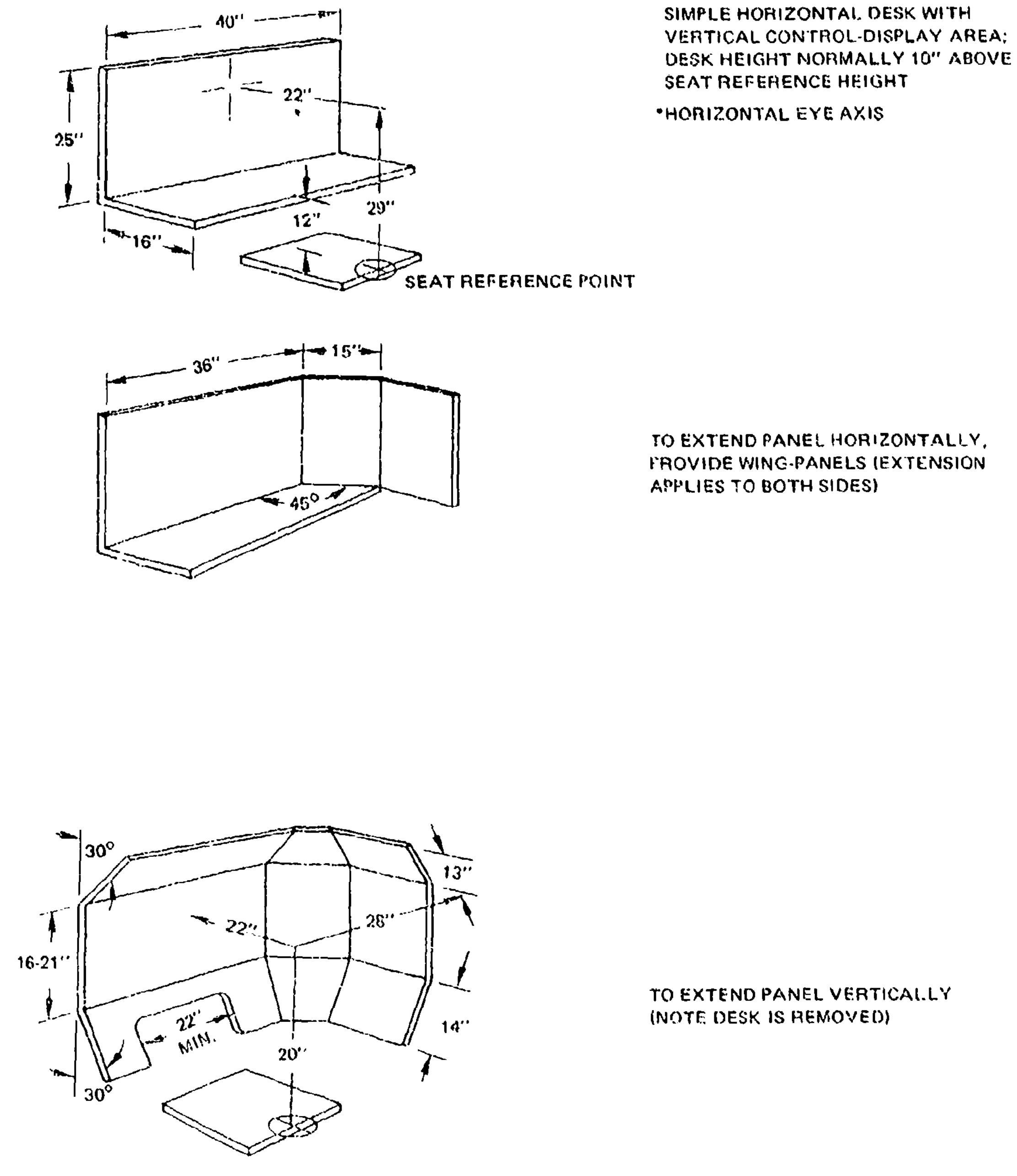
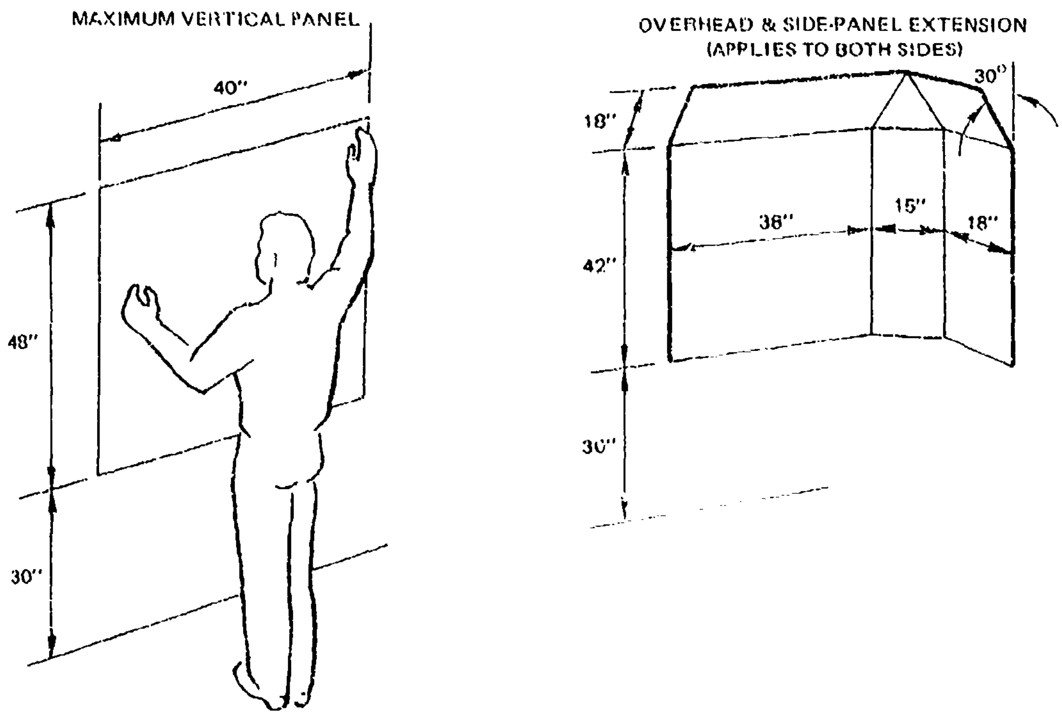


Figure II-12
Panel Shape, Size, and Orientation



NOTE: ALL DIMENSIONS ARE APPROXIMATE. FINAL DIMENSIONS SHALL BE DETERMINED BY MOCKUP EVALUATION

Figure II-13
Seated Operator Station



NOTE: ALL DIMENSIONS ARE APPROXIMATE. FINAL DIMENSIONS SHALL BE DETERMINED BY MOCKUP EVALUATION.

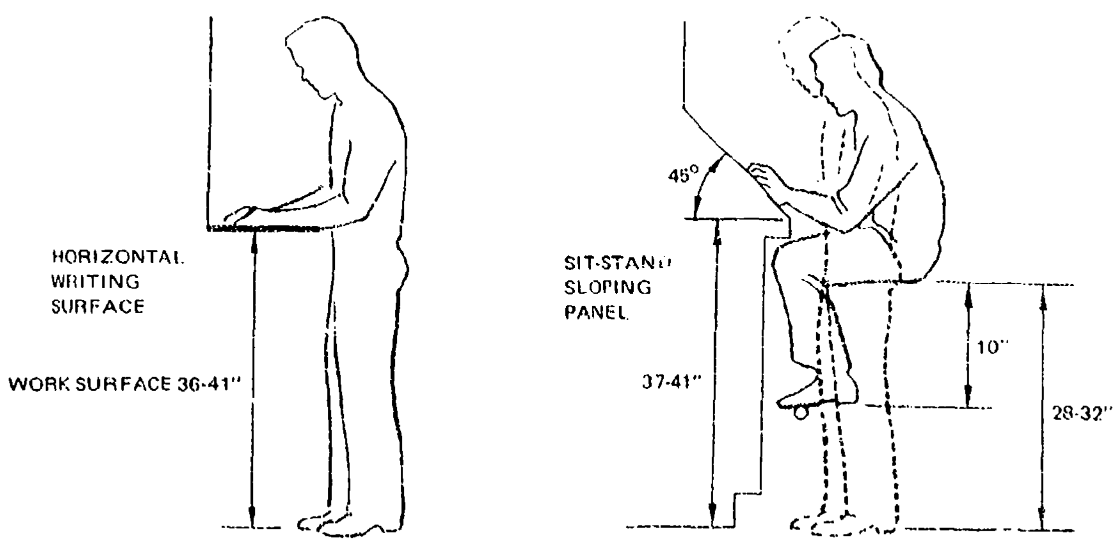


Figure II-14
Standing Operator Station

TABLE II-3
TYPICAL MODULAR-PANEL COLOR SPECIFICATION

UNIT	COLOR	FEDERAL STANDARDS 595
Basic panel	Light gull gray	36492
Noncritical module	Dark gull gray	36231
Emergency or critical-operation modules	Red	31136
Lettering on modules	White	37875
Lettering on panel outside modules	Dark gull gray	36231

PANEL FINISH TREATMENT AND PANEL ILLUMINATION*

Finish

All panel finishes should be such as to minimize spectral reflectance.

Glare from Transparent Materials

Transparent display covers are a serious source of light reflection, and require consideration of the following:

1. Antireflection coating.

2. Proper mounting with respect to the operator's line of sight (i.e., instrument glass cover should not be exactly perpendicular to the line of sight if there is a possibility of "operator self-reflection").

3. Avoidance of a single, large-area transparent cover over several instruments. This requirement also affects safety.

Illumination

Panel color, finish, and illumination should be considered as a system problem in order to effect the best trade-offs between visibility and power.

General Appearance

Extraneous, visible panel elements, such as screws, fasteners, instrument bezels, handles, etc., should be treated to minimize their distracting influence on the operator's attention from principal operating elements of the panel. This may be accomplished by eliminating extended screw heads, painting items the same color as the basic panel, and by location of such items in inconspicuous places wherever possible. Care should be taken, however, not to amplify maintenance difficulties.

*From Woodson (1963).

VISUAL DISPLAY APPLICATIONS*

Design or selection of visual displays is one of the most important problems to face the designer in developing an efficient man-machine system. Since the human eye is the medium through which man receives the greater share of his information about the world in which he lives, effective transfer of this information is vital to his operational efficiency. The following general recommendations are presented as an aid in the selection of the most suitable type of indicator for a given purpose. (Typical indicators are shown in figure II-15; table II-4 is a guide to visual display selection; and key operator/display system interactions are shown in table II-5.)

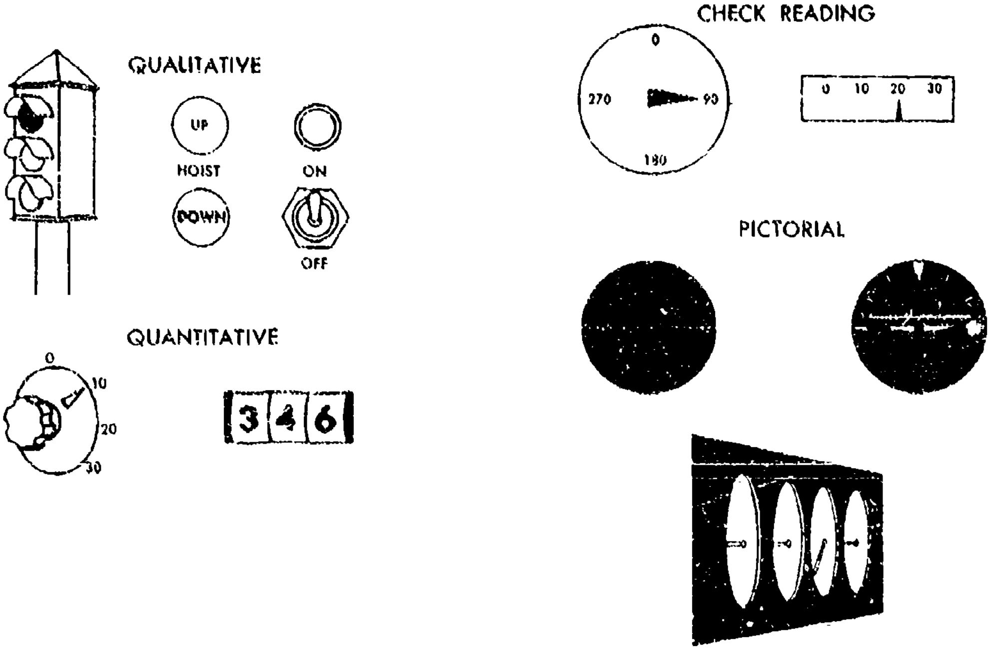


Figure II-15
Readout Variations

For a few, discrete conditions, use an indicator which presents large differences in position, brightness, or color. Use of two or more variables together normally increases operator reliability – e.g., color plus position.

For precise numerical values, with no need for interpolation between numbers, or for rate or directional indication, use a digital or counter indicator. Use a scalar indicator, however, when values are to be set into the equipment.

For numerical value plus orientation in time, space, magnitude, or rate, use a scalar indicator. Avoid multiple pointers or moving scales whenever possible. A pointer plus an adjacent counter is best when scale expansion is necessary.

For multidimensional information, use combinations of single-value indicators or composite graphic or pictorial representations.

For qualitative check reading, use a moving pointer against a fixed scale. If several dials are to be scanned rapidly, orient pointers so the "normal" position of the pointer is at 9 o'clock.

*From Woodson and Conover (1964).

TABLE II-4
GUIDE TO VISUAL DISPLAY SELECTION

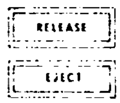
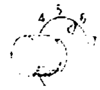
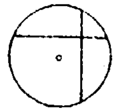
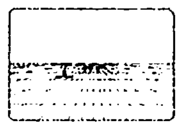
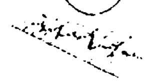
To Display	Select	Because	Example
Go, No Go, Start, Stop On, Off	Light	Normally easy to tell if it is on or off	
Identification	Light	Easy to see (may be coded by spacing, color, location, or flashing rate; may also have label for panel applications)	
Warning or Caution	Light	Attracts attention and can be seen at great distance if bright enough (may flash intermittently to increase conspicuity).	
Verbal instruction (operating sequence)	Enunciator light	Simple "action instruction" reduces time required for decision making	
Exact quantity	Digital counter	Only one number can be seen, thus reducing chance of reading error	52900
Approximate quantity	Moving pointer against fixed scale	General position of pointer gives rapid clue to the quantity plus relative rate of change	
Set-in quantity	Moving pointer against fixed scale	Natural relationship between control and display motions	
Data pick-off	Electronic "hook" or electromechanical pantograph over CRT target presentation; coordinates transferred to a digital counter automatically	Provides simple means for "pointing" at the position without interpreting or calculating actual values	

TABLE II-4
(CONTINUED)

To Display	Select	Because	Example
Tracking	Single pointer or cross pointers against fixed index	Provides error information for easy correction	
Vehicle attitude	Either mechanical or electronic display of position of vehicle against established reference (may be graphic or pictorial)	Provides direct comparison of "own position" against known reference or base line	
Geographical position	Plan-position analogue	Shows direct relationship to natural geographical features	
Command guidance	Analogue of "predicted" position or path	Allows observer to see or anticipate what is going to happen in advance	
Equipment-performance analysis	Meter	Single parameter simple to interpret	
	CRT (wave form)	Multiple parameter shows interrelationship	
	Pen recording	Provides permanent record for later analysis	

NOTE: Combinations of any of the above are possible and often desirable. Care should be taken not to introduce ambiguities, extreme complexity, or crowding, since these will increase operator-response time.

Checklist for a Good Visual Display

1. Can the display be read quickly in the manner required (that is, quantitative, qualitative, or check reading)?

2. Can the display be read accurately within the needs of the operator (preferably no more accurately)?

TABLE II-5

OPERATOR/DISPLAY SYSTEM INTERACTIONS*

DISPLAY SYSTEM PARAMETERS	IMAGE QUALITY: Image Resolution[1]	Image Luminance[2]	Image Contrast	Image Format Dimensions[3]	IMAGE MOTION: Apparent Motion of Image	CONTENT: Image Content[4]	TASK CHARACTERISTICS: Time Available[5]	Control Task Difficulty[6]
Frame Rate	Moderate	Moderate	–	–	Indirect	–	–	Slight
S/N Ratio	Large	Moderate	Moderate	–	–	Moderate	Moderate	–
Display Size	Large	–	–	Large	–	–	–	–
Display Aspect Ratio	–	–	–	Large	Indirect	–	–	–
Display Resolution	Large	Large	Large	–	–	Large	–	–
Display Gain (Luminance)	Moderate	Large	Large	–	–	Large	–	–
Number of Shades of Grey	Large	Slight	Large	–	–	Large	–	–
Display Contrast	Large	Large	Large	–	–	Large	–	–
Scan Type (Raster Composition or Orientation)	Slight	Slight	–	–	Slight	Slight	Indirect	–
Phosphor Type	Slight	Large	Moderate	–	–	–	Moderate	Slight
Phosphor Persistence	Indirect	–	–	–	Slight	–	–	–
WORKPLACE/JOB/OPERATOR PARAMETER								
Task Loading	–	–	–	Large	–	–	Large	Large
Operator Training and Experience	–	–	–	–	–	–	Large	Large
Visual Abilities	Moderate	–	–	–	Large	Slight	–	Slight
Display Viewing Distance	Moderate	–	–	Large	Moderate	Moderate	Moderate	Large
Viewing Time	–	–	–	Moderate	Large	–	Large	Large

– = Negligible or unknown influence
Slight = Weak interrelationship
Moderate = Significant interrelationship (second order effects)
Large = Very sensitive interrelationship (first order effects)
Indirect = Relationship not linear; other variables involved

NOTES:

1. Image Resolution includes noise, sharpness, definition, etc., across the entire image.
2. Image Luminance includes image highlight brightness, maximum and minimum useful luminance levels, gray level luminances etc.
3. Image Format Dimensions includes size, shape, aspect ratio, etc.
4. Image Content includes all those image parameters relevant to TV viewing which are descriptive of and/or bear information about the overall and detail characteristics of the displayed image.
5. Time Available refers to the duration during which an image is available, or within which a task must be completed.
6. Control Task Difficulty includes the response complexity, required response accuracy, type, frequency, and magnitude of items which must be nulled or tracked, type, frequency and magnitude of outside distractions, etc.

(Humes and Bauerschmidt, 1968)

*From Meister and Sullivan (1969).

3. Is the instrument design free of features which might produce ambiguity or invite gross reading errors?

4. Are the changes in indication easy to detect?

5. Is the information presented in the most meaningful form requiring the minimum of mental translation to other units?

6. Is the relationship of the required control movements natural to the expected instrument movement?

7. Is the information up to date with relation to the need?

8. Is the instrument distinguishable from other displays?

9. Will the operator be aware of an inoperative condition?

10. Is illumination satisfactory under all conditions of expected operation?

11. Is the display free of parallax or other potentially distorting characteristics?

Characteristics of Effective Displays*

1. Individual characters highly legible
2. Meaningful groups of characters (e.g., words) easily recognizable
3. Weak signals detectable at all display range scales
4. Characters readily discernible from each other
5. Display can be viewed equally well at any required viewing angle
6. Minimum loss of signal detectability at long and short ranges
7. Minimum fall-off in screen/scope brightness
8. Maximum contrast
9. Minimum image distortion
10. Fastest possible observer response time, where time is a factor in efficiency
11. Highest possible observer accuracy in performing visual function
12. No or very slight flicker
13. Display can be viewed efficiently in entire operating range of ambient illumination

*From Meister and Sullivan (1969).

14. Minimum equipment delay in responding to user's request for display (as in information-retrieval system)

15. Display parameters (e.g., luminance) adjustable by the user

INDICATOR LIGHTS – LEGEND*

Visibility

The brightness of an indicator should be sufficient to discern the "ON" condition under all expected ambient illumination conditions. When used under varying illumination conditions, a dimming control should be provided (the range being limited by means of an automatic "night/day" switching system) to insure visibility under the brightest ambient condition. Dimming should never be used for KILLER, Master Warning, and Master Caution lights, however. If indicators are subject to "outdoor" light, provisions should be made to prevent reflected sunlight from making the indicator appear "illuminated". It should not be possible to see the source of the light; i.e., the indicator screen brightness shall be as uniform as possible.

Fixture Design

1. A dual lamping system should be used for reliability (except for electroluminescent design).

2. Lamp replacement should be from the front of the panel.

3. Failure of a "flasher" should result in a steady light. Failure of an indicator should not cause failure of circuit being monitored.

4. Incandescent lamps should operate below rated voltage.

5. A method for lamp testing should be provided.

Legend Design

1. Use optimum letter/numeral design.

2. Use standard abbreviations only.

3. Use captive screens, coded keyways, etc., to prevent loss of, or inversion of legends.

4. Use dark lettering on light background for KILLER, Master Warning, and Master Caution indicators. Either dark or light lettering may be used for others. If dark adaptation is required, use light lettering to reduce over-all brightness of noncritical indicators.

5. Engraving should be resistant to wearing off or filling with dirt.

6. Legends should not be visible when the indicator is not lighted. That is, a legend such as "stop" should not be displayed unless the indicator is also the stop button. Other exceptions involve coding of colored lights to back-illuminate a visible legend such as "No. 1 Torpedo."

*From Woodson (1963).

WARNING LIGHTS*

When Should These Be Used?

To warn of an actual or potentially dangerous condition.

How Many Warning Lights?

Ordinarily only one. If several warning lights are required, use a master warning or caution light and a word panel to indicate specific danger conditions.

Steady State or Flashing?

Flashing lights should be reserved only for extreme emergencies, since they are distracting.

Flash Duration

If flashing lights are used, flash rates should be from 3 to 10 per second (4 is best), with equal light/dark intervals.

Warning Light Intensity

The intensity of the warning light should be at least twice as bright as the immediate background. The background should be dark in contrast to the display and should be in a dull finish. Make provision for dimming the warning light if it is to be used in dim surroundings.

Light Size

The warning light should ordinarily be 1½ times the size of other indicators on the console. A master warning or other extreme emergency light should be twice the size of other console indicators.

Warning Light Location

The warning light should be located within 30° of the operator's normal line of sight.

Color

Warning lights are normally red because red means danger to most people. Any other signal lights in the operator's vicinity should be of other colors.

Location and Identification

Warning lights become less effective as they are moved out of the center of the operator's field of vision; urgent warnings should always be within 30° of the operator's normal line of sight. For very urgent warnings the warning light should be supplemented by an auditory warning.

*From Meister and Sullivan (1969).

INDICATOR DETAIL*

Many seemingly minor details can affect the ease with which a visual display will be seen, read, and interpreted. Even the best choice of presentation type will suffer if the principles of this section are neglected. Frequently the designer feels that he has finished his job after specifying the general characteristics of the indicator face – leaving the details to a draftsman, artist, silk-screen specialist, or photo-lab technician. These details are extremely important to the designer, however, and he must see that they are recognized and followed if the results of his initial design are to be really effective.

IMPORTANT GENERAL CONSIDERATIONS
1. Distance of the observer from the display.
2. Position of the observer relative to the display.
3. Type, color, and amount of illumination available to the display.

Design of Numerals, Letters, and Indices -- General

In general, the larger the size of letters and numerals, the less we have to worry about backgrounds and illumination.

Capital letters are recommended for most panel labels, although upper- and lower-case letters are suggested for extended instructional material.

All labels should be normally oriented so that they can be read from left to right. Special cases of vertical orientation are permissible when the label is generally ignored and confusion might arise if it were adjacent to more critical labels.

If instruments or observers are subject to vibration, dials and markings must be larger than they would be otherwise. Dial detail should also be simplified.

Scale indices should be limited in number to the accuracy required and no more. The smallest readable division should never be finer than the probable error in the metering device. Indices may be spaced as close together as 0.04 inch, although the distance should not be less than twice the stroke width of a "light" index mark on a dark background nor less than one stroke width when the index is darker than the background (fig. II-16). A minimum of ½ inch is recommended for the distance between "major" indices. (Dimensions for major, intermediate, and minor indices are given in figure II-17.) These figures are for the normal instrument-panel reading distances, 14 to 28 inches. The number of graduation marks between numbered scale points should not exceed nine.

*From Woodson and Conover (1964).

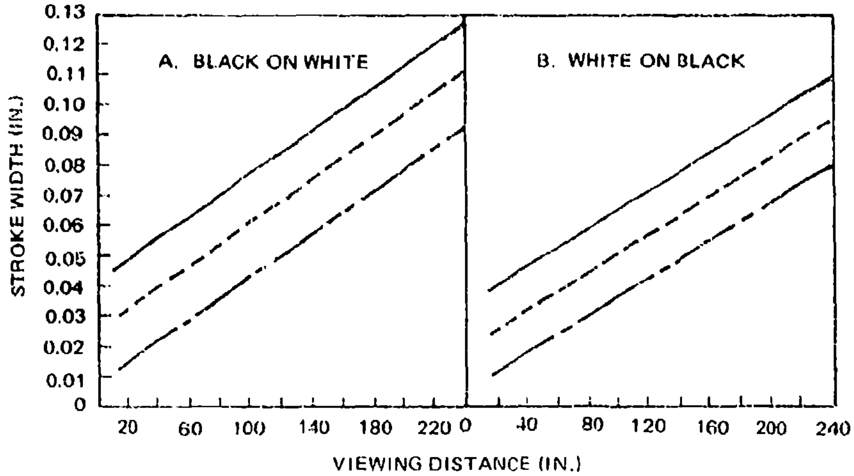
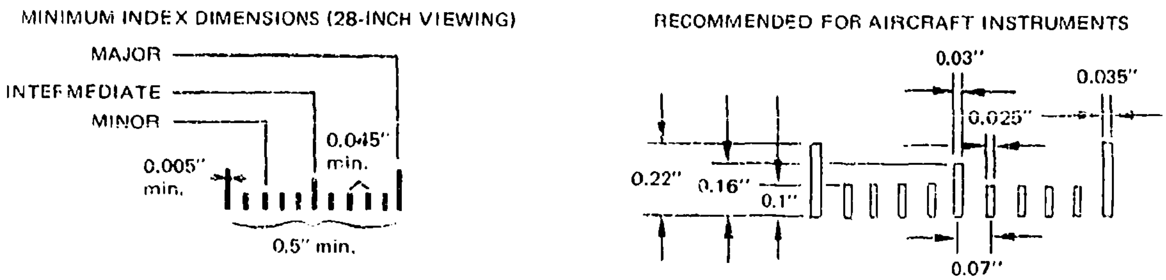


Figure II-16
Stroke Width and Viewing Distance



VIEWING DISTANCE (FT)	INDEX HEIGHT (IN.)		
	MAJOR	INTERM.	MINOR
1 2/3 or less	0.22	0.16	0.09
1 2/3 to 3	0.40	0.28	0.17
3 to 6	0.78	0.56	0.34
6 to 12	1.57	1.12	0.68
12 to 20	2.63	1.87	1.13

Figure II-17
Legend Readout Dimensions

Design of Numerals, Letters, and Indices – Specific* (See figure II-18 and table II-6)

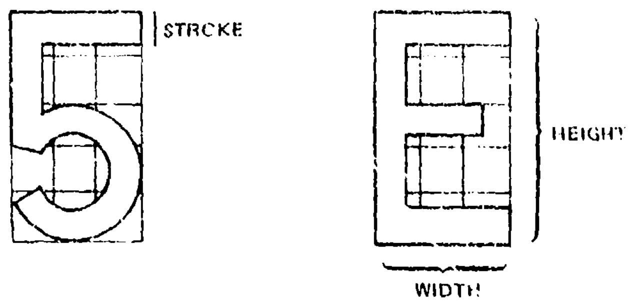


Figure II-18
Number/Letter Style and Size

TABLE II-6
NUMERAL/LETTER HEIGHT FOR 28-INCH VIEWING DISTANCE
(For other viewing distances, multiply the value by distance in inches/28.)

	HEIGHT OF NUMERALS AND LETTERS (IN.)	
	Low Luminance (down to 0.03 ft-L)	High Luminance (1.0 ft-L and above)
Critical markings -- position variable (numerals on counters and settable or moving scales)	0.20 to 0.30	0.12 to 0.20
Critical markings -- position fixed (numerals on fixed scales, control and switch markings, emergency instructions, etc.)	0.15 to 0.30	0.10 to 0.20
Noncritical markings (instrument identification labels, routine instructions, any marking required only for initial familiarization)	0.05 to 0.20	0.05 to 0.20

Style. Letters and numerals should be simple block type without serifs. (Do not use stencils.)

1. Typical fonts for engraving: Gorton Extended, Gorton Normal, and Gorton Condensed.

2. Typical fonts for printing: Airport Semi-Bold, Futura Demi-Bold, Vogue Medium, and Lining Gothic 66.

*From Woodson (1963). See also Chapter VIII, DISPLAY LEGIBILITY.

Height/Width Ratio. 3:5 to 1:1 (1:1 used for mechanical counters only).

Stroke Width.

1. Dark figure on light background = 1/6 of letter height.
2. Light figure on dark background = 1/8 of letter height.

Light/Dark Contrast. Contrast between figure and background should be 12 or greater. $C = \frac{B_2 - B_1}{B_1}$, where B_2 is brightness of light color, and B_1 is brightness of darker color.

READOUTS*

Introduction

The material included in this chapter deals with relatively small alphanumeric indicator displays, including the following general types:

1. Cold cathode glow discharge
2. Electroluminescent
3. Projected image (incandescent)
4. Electro-mechanical (incandescent)
5. Edge-lighted (incandescent)
6. Spherical optic (incandescent)

Maximum Viewing Distance

This is defined as the maximum distance at which observers are able to correctly read a given readout 90% of the time. Figure II-19 indicates that for character heights up to approximately 3 inches, all readouts exhibit a linear increase to a maximum viewing distance. Therefore, character height (visual size) more than any other parameter determines the maximum viewing distance in normal ambient light. Brightness alone has little or no effect on viewing distance: cold cathode (300 ft-L), electro-mechanical (30 ft-L), and projected image (50 ft-L) all have approximately equal viewing distance limits.

Brightness

Because of contrast considerations display brightness is important in high ambient illumination. Electromechanical readouts which depend on reflected light for viewing are most readable under these conditions. Cold cathode, electroluminescent (EL), and incandescent readouts start washing out as ambient light increases. A bright readout, however, can be read in high ambient light easier than one with low brightness.

*From Meister and Sullivan (1969).

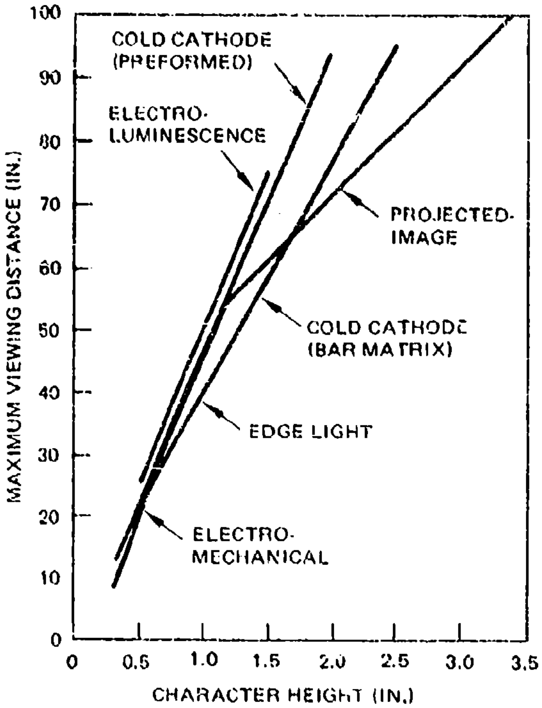


Figure II-19
Maximum Viewing Distance vs Character Height

Electro-mechanical readouts which depend on external lighting are difficult to see in low ambient illumination. Cold cathode types and other light emitting devices retain about the same viewing distance as in normal lighting.

Some readouts which use bulbs or EL fade with use; the glow discharge type does not. More brightness can be achieved with incandescent bulb readouts by increasing lamp voltage, but this shortens lamp life.

Stroke Thickness

A good ratio of stroke to height is 1/6 of the character height. If the stroke is too wide, the characters tend to run together. If too thin, the characters tend to break as viewing distance increases.

Viewing Angle

Viewing angle is approximately the same for all readouts except for electro-mechanical and edge-lighted types. For these two types intensity and contrast diminish as viewing angle increases above 30°, and at large viewing angles ambient light reflections obscure the readout.

For cold cathode displays the maximum viewing angle is determined by the requirement that characters near the bottom of the stack be visible over the next tube in the display. A maximum viewing angle of 135-160° is possible.

PICTORIAL INDICATORS*

Pictorial indicators (fig. II-20) are useful for clarifying spatial relationships. They are miniature representations of the world outside the cockpit or control room. They may be either electronic or mechanical in design.

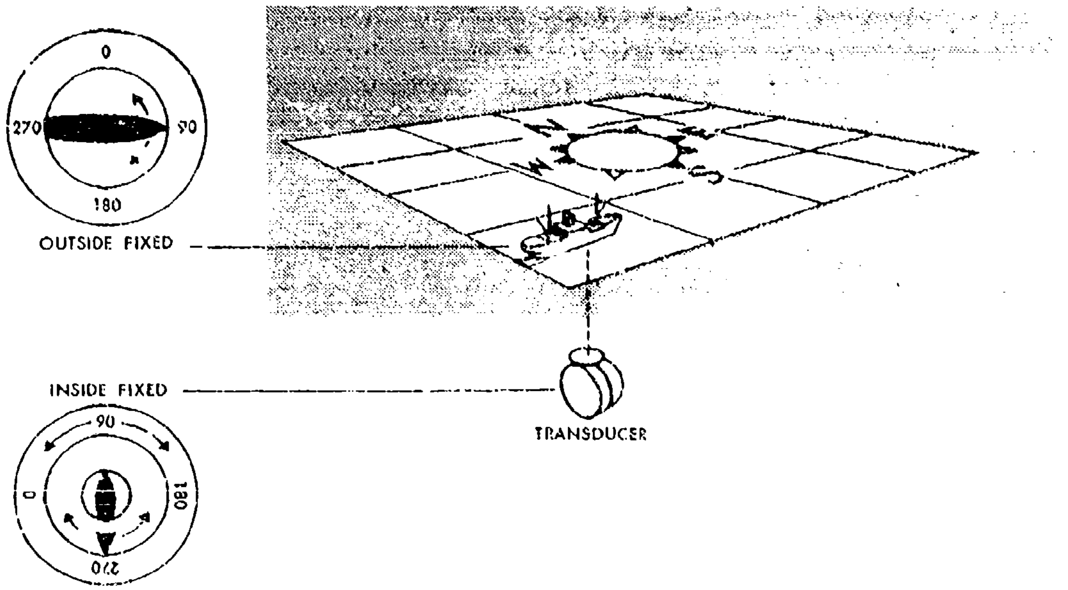


Figure II-20
Geographical Indicators

The design of mechanical as well as electronic pictorial displays poses the difficult question of which parts are to be fixed and which parts are to move. The problem is further complicated by the fact that natural visual-motor relationships enter into the picture if the operator affects the display by his own manipulative efforts. In general it can be said that, as an operator's vehicle moves about in space, he can best comprehend a display that gives a representation of his movement with the fixed portions of the instrument representing the space within which he has moved. Conversely, it is generally true that, when an operator is interested in the movement of some other object that is moving about him, he will best comprehend the display that gives his own representation as the fixed portion of the instrument, and the moving portions representing objects moving about him. Special care should be taken in the choice of these opposing points of view. It is especially important that the two opposing conditions do not appear on the same panel.

*From Woodson and Conover (1964).

COMBINED DISPLAYS

The combination of different types of visual displays within one instrument, or of several instruments into an array or within a single frame such as a projection or television screen, should be governed by the following principles:

1. Combine only those forms of information which bear a common relationship.

2. Keep the common factor of interpretation (fixed and moving parts, scale values, etc.) the same.

3. Minimize parallax between successive layers of overlays.

4. Do not confuse the operator by unnecessary information.

Single-Instrument Combinations

The single frame of one instrument for more than one item of information saves the operator time which would be taken in locating parts of a total picture (fig. II-21A).

Scale range may be increased by combining pointers and counters. The total range may be increased by extension (pointer plus counter) or the range may be given with more precision (pointer plus subdial and pointer) (fig. II-21B).

NOTE: This type of scale expansion is to be used only when some qualitative information relative to rate or normal operating range is needed. The counter is best when only quantitative information is needed.

Do not use multiple-pointer displays with more than two pointers (fig. II-21C).

Typical combined instrument displays for aircraft are shown in figure II-22.

FACTORS TO CONSIDER IN DECIDING WHETHER THE SCALE OR POINTER (INDEX) SHOULD BE THE MOVING ELEMENT IN YOUR DISPLAY

1. In general, a pointer moving against a fixed scale is preferred.
2. If you wish to have a numerical value readily available, however, a moving scale appearing in an open window can be read more quickly.
3. If numerical increase is typically related to some other natural interpretation, such as *more or less*, or *up or down*, it is easier to interpret a straight-line or thermometer scale with a moving pointer because of the added cue of pointer position relative to the zero or null condition.
4. Normally you should not mix types of pointer-scale (moving element) indicators when they are used for related functions — to avoid reversal errors in reading.
5. If a manual control over the moving element is expected, there is less ambiguity between the direction of motion of the control and the display if the control moves the pointer rather than the scale.
6. If slight, variable movements or changes in quantity are important to the observer, these will be more apparent if a moving pointer is used.

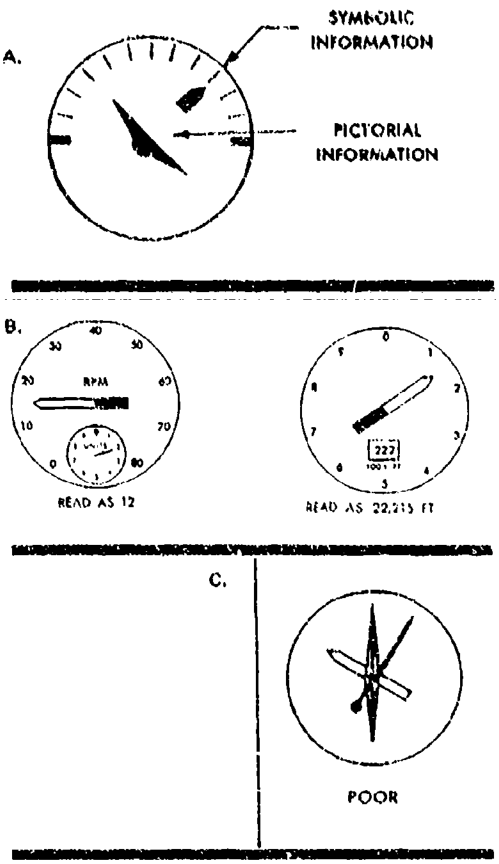


Figure II-21
Combined Instrument Displays

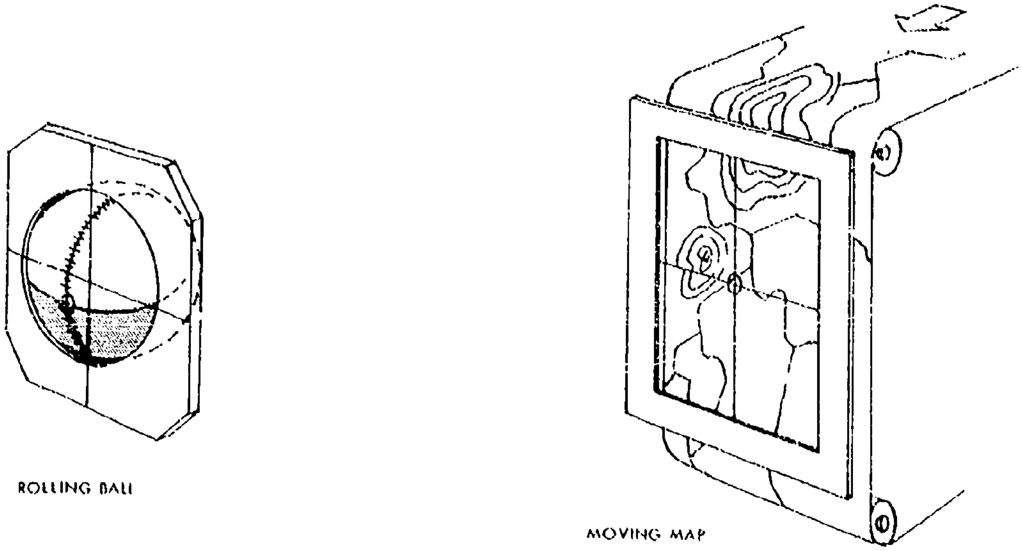


Figure II-22
Rolling Ball and Moving Map Displays

The Whole-Panel Concept

The instrument panel should always be considered as a whole (fig. II-23). In many cases this can be accomplished by simple analysis of the operational sequence and arrangement of available instruments to reduce scanning distances and "backtracking." The ideal approach, however, is to analyze the functions to be accomplished and develop an integrated instrumentation layout. This approach quite often leads to entirely new displays and usually reduces the actual number of instruments required.

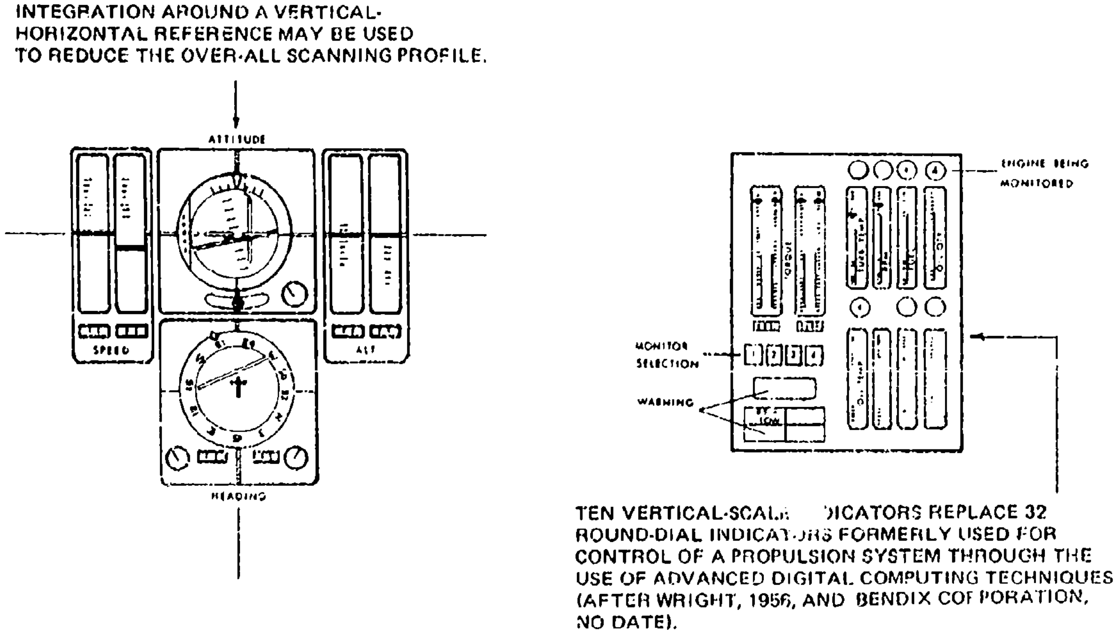


Figure II-23
Whole-Panel Concept

Frequently it is desirable to provide semi-permanent overlays with scales or quantitative symbology to be referenced to a CRT display. Owing to the disparity between the plane of the CRT and the overlay, extreme parallax can become a severe problem for the observer. This can be overcome by the use of an arrangement of independently lighted plates which are reflected in a half-silvered plate mounted 45 degrees to the line of sight. This makes the image from the edge-lighted overlay appear at the same plane as the surface of the CRT.

A combination of permanent, semipermanent, and dynamic elements can be displayed simultaneously by means of back-projection techniques. This is particularly good from the observer's point of view since there is no parallax between elements. Careful control of contrasts and ambient glare is required, however.

Closed-circuit television systems are an excellent solution to the problem of bringing a picture of a remote operation into the crew work-area. When operator panel space is limited, and certain instruments are referred to only intermittently these instruments can be mounted elsewhere and called into view on the TV screen as required. The closed-loop TV technique is especially useful for observing remote hazard-areas, such as may occur with nuclear engines, or for control of "slave" manipulators in atomic research laboratories.

A principal consideration in all of the above types of display techniques is proper control of ambient lighting conditions at the operator's viewing screen. Since the illuminance of these indirectly viewed images is not high, ambient light should be filtered or blocked from the screen wherever possible.

Design Considerations Associated With Combined Displays

Most of the combination displays discussed in this section have a serious problem with reflected light because of the necessity for large areas of glass which cover the faces of the instruments.

Hoods may be used to prevent direct ambient light rays from falling on the display cover glass (fig. II-24). Such hoods should be painted dull black on the inner side.

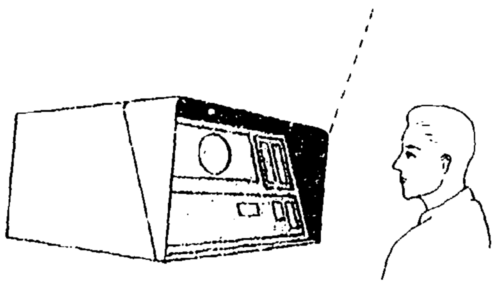


Figure II-24
Hood for Eliminating Ambient Reflection

Panels which have a great amount of glass are prone to reflect the operator's face, and if he is wearing light-colored clothing, this too will interfere with his seeing the display. Although we emphasize mounting instruments normal to the line of sight, this actually creates the worst condition for "self reflection." Therefore, instruments should be mounted at angles slightly off the normal line of sight.

Integrally lighted instruments, because of the differences in amount of reflecting or energized markings, tend to appear unevenly bright to the observer. This, in addition to large glass-covered areas, suggests use of other than black instrument-face backgrounds. Medium gray tends to help maintain an over-all balance in the brightness emitted from the several displays.

Some integrated displays have the problem of symbols appearing over more than one shade or color of background. It is important to recognize this and take steps to create a symbol that is equally visible under all conditions. In figure II-25 note that the airplane symbol has been outlined so that it can be seen in either the dark or light background.

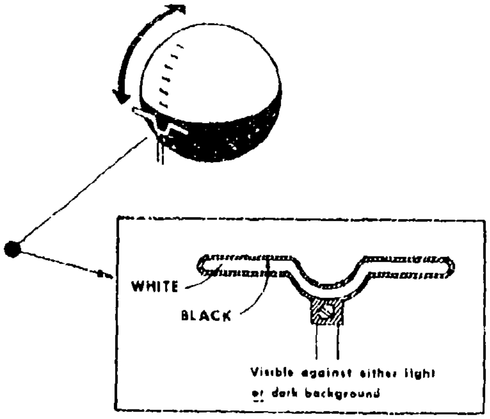


Figure II-25
Integrated Display Contrast

When using off-the-shelf instruments from different manufacturers on the same panel, be sure there are no inconsistencies between them. A good case in point occurs with combination instruments which use a pointer with digital-counter insert. In figure II-26A, on one instrument the counter presents gross value with vernier on the scale, while on the other the arrangement is reversed.

Integrated instrument designs usually involve more than one type of pointer, and these are generally coded by shape, size, color, or other special scheme of marking. Care must be taken to maintain a constant code throughout the panel. In other words, a command marker should appear in the same configuration on each instrument.

The importance of pointers, index markers, and lubber lines varies with different instruments (fig. II-26B). Care should be taken to make this difference apparent. Variation in size and stroke width are the most acceptable methods for accomplishing this.

There is a tendency when combining or integrating instruments to create a severe maintenance problem owing to the necessity for miniaturization and dense packaging. Modularizing techniques are recommended to alleviate this problem. Avoid use of large numbers of screws if possible. Special fasteners for quick release are desirable — as are quick-disconnect cable connectors.

Integrally lighted instruments are fine when they are operating. However, special care must be taken in the design of the instrument for lamp replacement (fig. II-27). Proper selection of long-life lamps operated slightly below rated voltage often provides sufficient lamp reliability to outlast the required life of the instrument. Electroluminescent materials are suggested also. This approach reduces the problem of uneven illumination, and will not be subject to "all at once" loss of light.

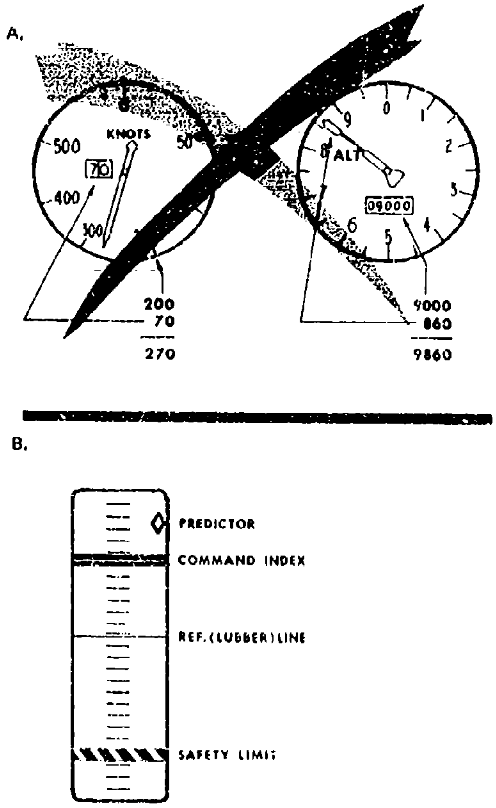


Figure II-26
Combined Displays

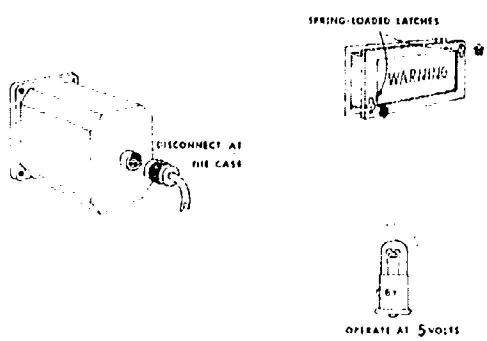


Figure II-27
integral Lighting Access

GRAPHIC PANELS

A graphic representation of a complex control system can be made to convey operational status to an operator more clearly than the typical array of abstract meters and controls. The graphic panel, as it is called, pictorializes the salient features of a system directly on the panel, so that the operator has a better appreciation for the parts, direction of flow, and subsystem relationships. The extent to which the elements of the display are static or dynamic will depend, of course, upon how much the designer has to spend on the panel. In the simplest case, elements of the system can merely be painted on the panel. For more complex or exotic renditions, the elements, including flow lines, can be made to appear dynamic by means of illuminated indicators, edge- or back-lighted lines, or by use of electroluminescent panels and strip elements. Color coding is quite useful in segregating various subsystems or for emphasizing certain critical elements of the display. Another technique which is useful is the flashing light for attracting attention to important elements of the display – especially when it is important for the operator to react to the signal quickly.

A typical application used aboard submarines is the panel which displays open or closed hatch conditions. In figure II-28A, the circles (when illuminated) indicate that a particular hatch is still open. Not until all bars are illuminated can this command be given to submerge.

In figure II-28B, missile tubes are pictorialized, showing when the hatch is open and also when a missile tube is being flooded. Electroluminescent panels are very useful in making up displays of this type.

Combinations of edge-lighted lines, areas, symbol and indicator lights, annunciators, or illuminated instruments are useful in developing a graphic layout of complex systems (see figure II-29).

In the design of graphic panels using edge-lighting techniques, it is important to control the spread of light in the plastic transilluminating medium. Barriers must be provided between elements to avoid having stray light from one part of the graphic affect another. Also, it is important to position the lamps in such a way that there is a good balance among various parts of the display. If it is impossible to locate the lamps in an optimum position, it is sometimes possible to balance the illumination by means of filters.

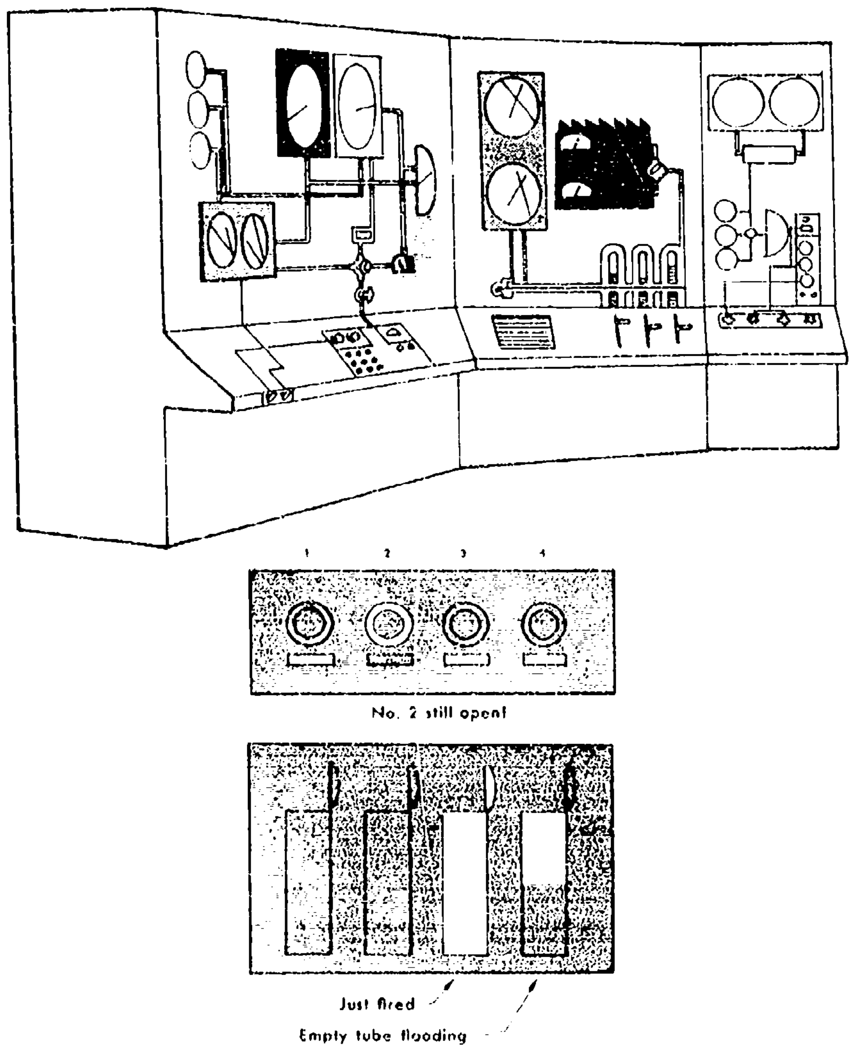


Figure II-28
Graphic Panels

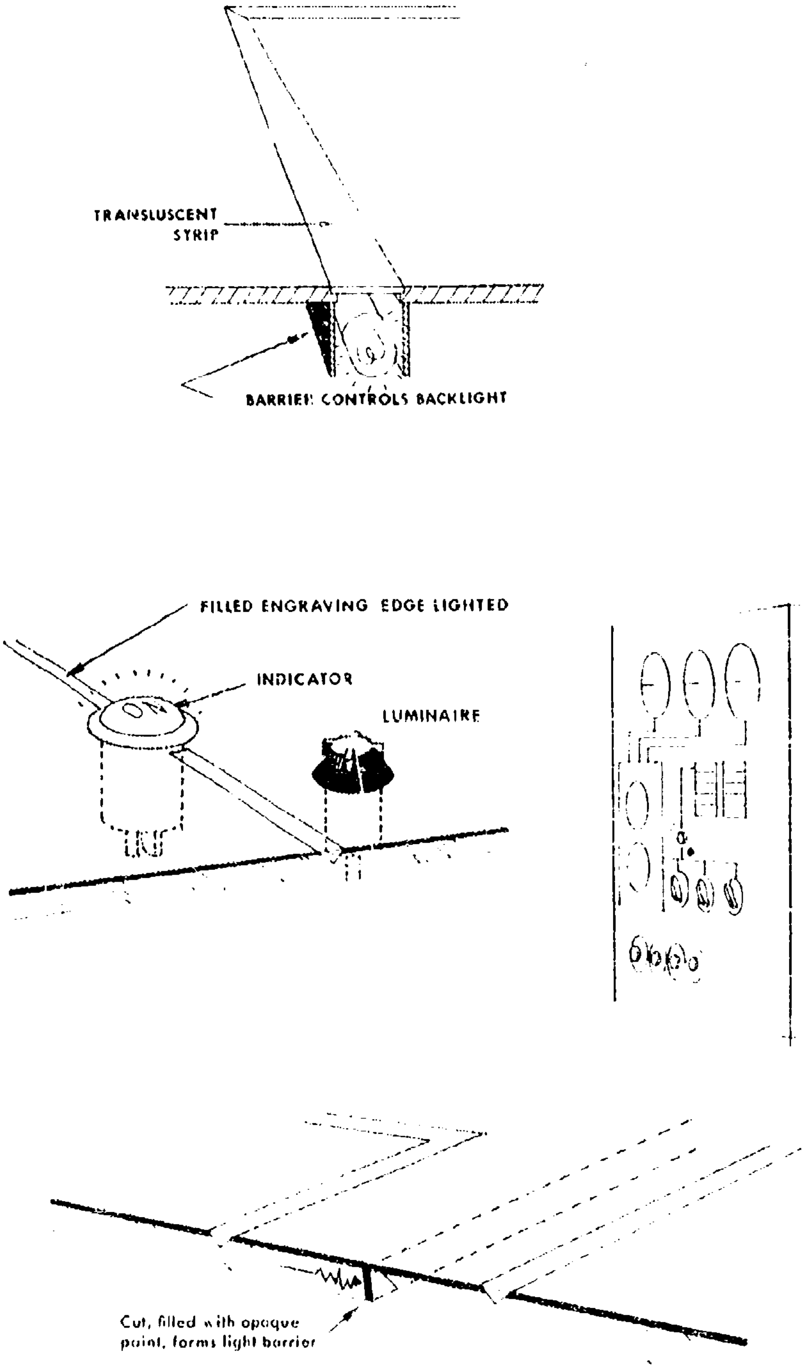


Figure II-29
Graphic Panel Lighting

AUTOMATIC PRINTERS AND GRAPHIC RECORDERS

Design of chart paper to be used in automatic pen-recording equipment should consider visibility and legibility. Under normal lighting conditions, the paper should be white, graph lines black, and pen tracing red, green, or some other color which shows up well against the black graph lines.

Pen-recording devices should be designed so that the pen assembly covers no more of the chart than is absolutely necessary.

Captive-paper storage should be provided so that the operator isn't required to provide some make-shift method for collecting the paper as it comes from the machine. The method for reloading chart paper should be made as simple as possible.

Pen assemblies should be designed so that they are easy to refill and do not leak or lead to spillage because the operator did not adjust the assembly properly.

Recording devices should be designed so that it is possible for the operator to make notes directly on the chart. Continuously variable paper-speed control is recommended. Manual controls should be placed so that the operator does not cover the tracing as he adjusts the control knobs.

Provide a simple, sure method for tearing or cutting off finished chart-paper segments.

For single-sheet chart systems, the pen should always move from left to right. For moving-chart systems, the paper should move from right to left. For printers (e.g., teletype), the paper should move from bottom to top.

NAVY UYA-4 STANDARD CONSOLE

A standard console for multiple applications in shipboard use is shown in figure II-30. It incorporates a large CRT, direct readouts (DRO), quick action controls, and selectable display modes.

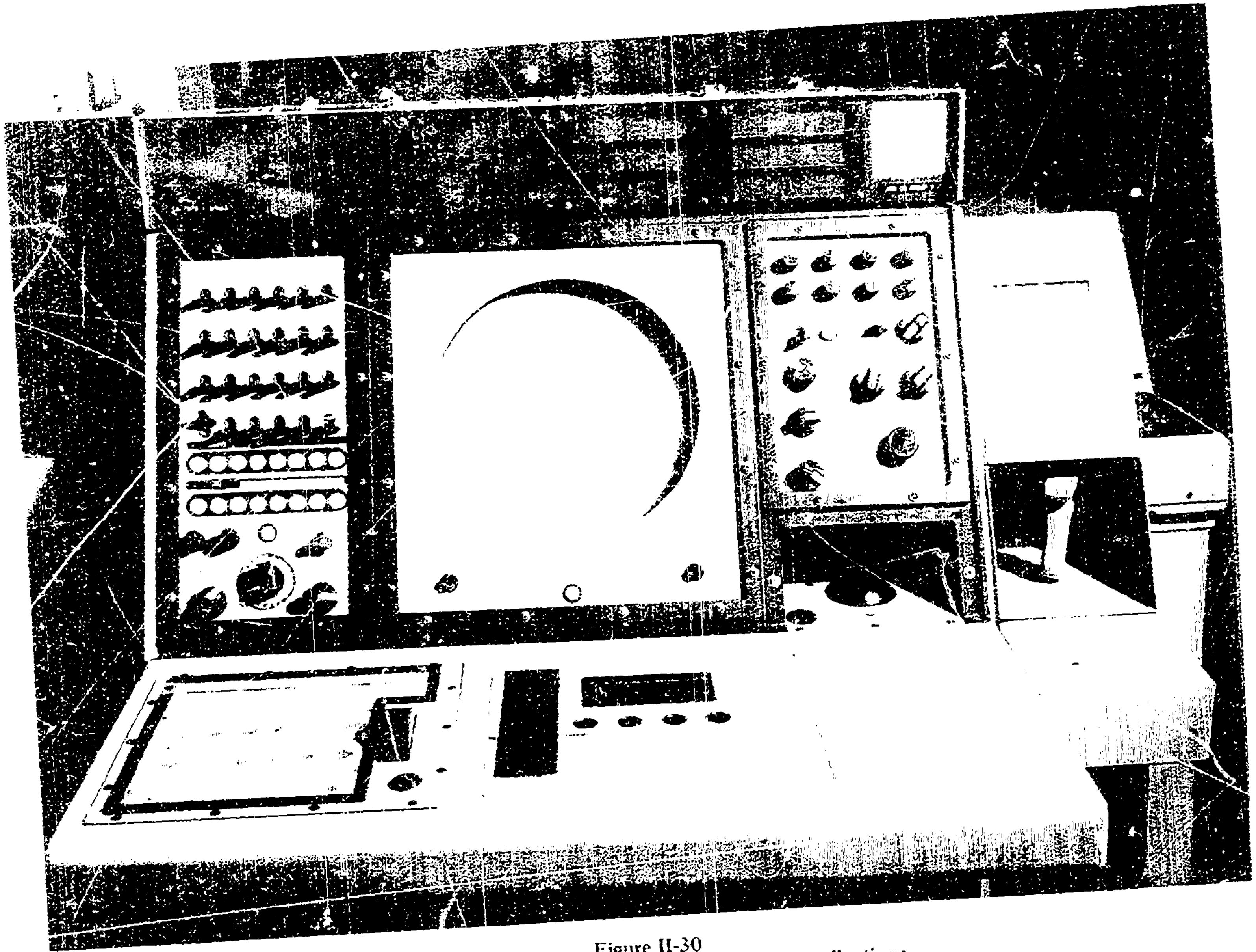


Figure II-30
Standard UYA-4 Console for Multiple Navy Applications

UNDERWATER DISPLAY ILLUMINATION

It is common knowledge that the human eye is incapable of focusing properly when immersed in water. This is primarily due to the fact that the normal air-cornea interface is replaced by a water-cornea boundary. Since the cornea and water have similar densities, little refraction occurs and the lens cannot adequately focus.

Most underwater display vision, however, will involve viewing through a facemask. This allows focusing but adds refraction at the water-air interface. The refraction index of water is 1.34 as compared to 1.0 for air. The apparent distance from a viewed object would be 1/1.34, or 0.75 times its true distance. Vision should therefore be clearer since the image is magnified 25 to 30 percent. However, underwater viewing capability is limited due to scattering of particles between the light source and the object viewed, causing reduction in contrast. Both refractive and reflective particles are involved, particularly in coastal waters where microscopic marine organisms, debris, and sediments are stirred up by tidal action near shores.

The facemask structure also is limiting. Incident light is totally reflected at approximately 48.6° (the critical angle). This sets a limit for the cone-of-vision, about 48.6° half angle and 97.2° total, as compared with a 135° vertical and 188° horizontal field of view in air without a mask.

Even in perfectly clear water, mask fogging tends to reduce visual resolution capability.

Another consideration is that, when the image is magnified, its total area is increased and thus luminance of any one part viewed is reduced. Increased area equals $(1.34)^2$, or 1.8, and luminance of a viewed object is decreased 1/1.8, or 0.55.

Color differences are also significant. Beam and Shannon (1967) tested subjects viewing displays with white, red, and green lighting. Subjects generally preferred green but, although green produced faster response time than white, it also generated the greatest number of errors. They found that red provided a lower error rate than green, the same reaction time as green, and had the added advantages of preserving operator dark adaptation for external viewing (important for swimmer-diver vehicle (SDV) mission functions such as rendezvous and docking with a transport submarine). Green also required more electrical power than red or white. However, it has the advantage that, in water "highly contaminated with suspended particles," green would be the least attenuated and absorbed.

Beam and Shannon concluded that, in general, white illumination should be used for underwater display, but indicated further study should be made.

Chapters III through VII are excerpted from Meister and Sullivan (1969). Their guide was intended for ease of use by designers and yet is thorough in backing recommendations with referenced empirical evidence to assure user confidence. Meister and Sullivan state that they are writing to meet the following criteria:

"1. Emphasis on substantive design-relevant data

2. Minimal verbal material

3. Emphasis on pictorial illustrations and graphs

4. Inclusion of equipment factors affecting display parameters

5. Simplified presentation"

Although style differences from Woodson and Conover will be apparent, they are attempting to accomplish the same goals – ready reference and clear communication. As it happens, the chapters selected for inclusion here supplement the Woodson and Conover selections quite well, with minimal need for additions, deletions, paraphrasing, or transitional material.

Chapters III through VII deal only with visual displays of the command control type – that is, displays commonly used in:

1. Detection, identification, and tracking of targets

2. Weapons assignment and firing

3. Strategic and tactical planning

4. Transmission of command information

5. Status of equipments and forces

6. Communications

7. Logistics

The following types of display devices are described:

1. Plan position indicators (PPIs) of the cathode ray tube (CRT) type (A and B scan devices and their characteristics have not been considered due to the lack of substantive data in this area.)

2. Console-type televised or projected displays

3. Large screen televised or projected displays

4. Warning signals

5. Readouts

CHAPTER III

CATHODE RAY TUBE DISPLAYS (PPI)

INTRODUCTION

This chapter describes certain human characteristics and their interrelationships with CRT-type display devices. Most of the performance data and the display characteristics referred to in this chapter are based on PPI-type displays. This is due entirely to the lack of data about human performance on A-scan, B-scan, and other types of devices.

The data presented here can, where applicable, be applied to scan types other than PPI's, but only with extreme care and judgment.

The design questions covered in this chapter deal with the *detection* function only.

1. How large should:

   a. The PPI scope be
   b. The display be
   c. The target pip be

2. What is the most desirable:

   a. Scanning rate
   b. Viewing distance
   c. Viewing angle

3. What is the effect on pip visibility of:

   a. Display brightness
   b. Background brightness
   c. Target brightness
   d. Target duration
   e. Contrast
   f. Noise
   g. CRT bias
   h. Ambient illumination

4. What phosphors are the best to employ.

5. Operator performance and equipment characteristics.

HOW LARGE SHOULD THE SCOPE BE?

No single recommendation is very safe. All the evidence indicates that optimal size for detection is *7 inches* diameter.

Figure III-1 shows search time as a function of search area under conditions comparable to real-world display conditions.

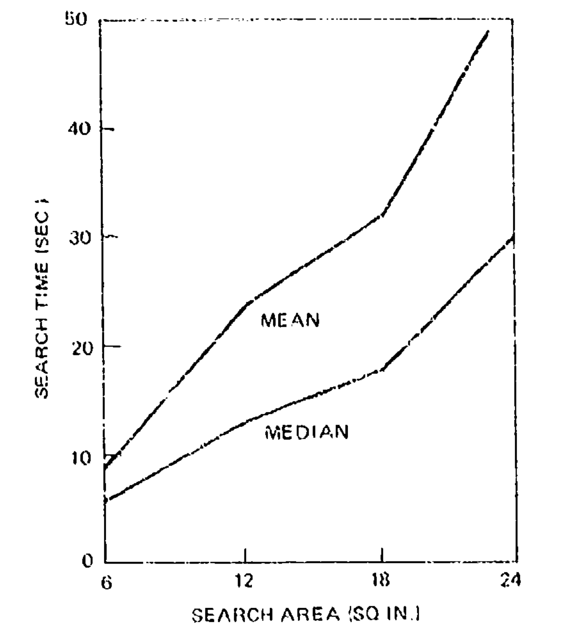


Figure III-1
Search Time vs Search Area

Figure III-2 shows that the 7" scope is superior to a 10", and 10" to a 14" scope *at outer ranges* (best for long-range detection). Detection is degraded as search area is increased. Ranking is reversed at inner ranges (Baker, C.H., 1962). Additional evidence suggests that detection on a 6" or 9" display is superior to either a 3" or 12" and 14" display (fig. III-3) (Horowitz, P., 1965).

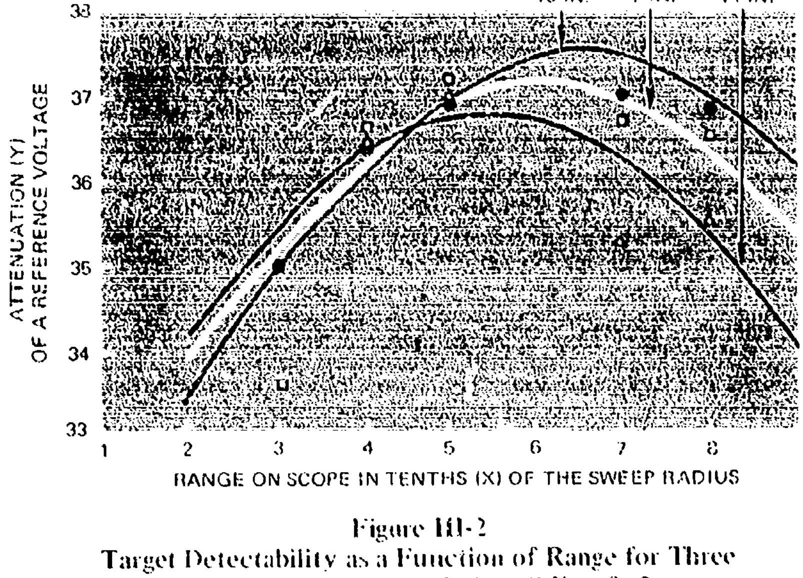


Figure III-2
Target Detectability as a Function of Range for Three Sizes of Radar Scope (Baker, C.H., 1962)

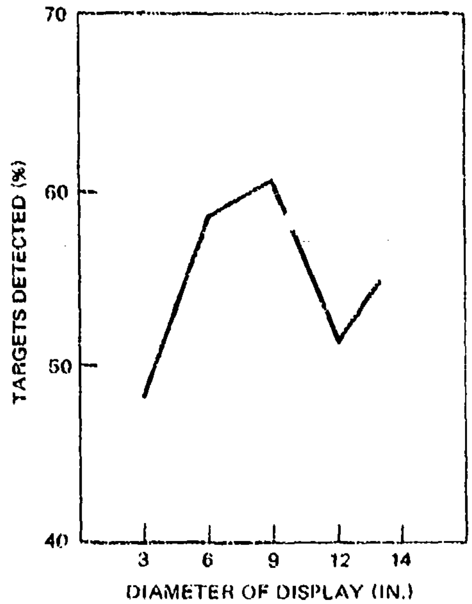


Figure III-3
The Percentage of Targets Detected on Each of Five Sizes of Displays (Baker and Earl)

Considerations -- The 7" recommendation applies only when smaller target sizes (2-8 mm) are used. When larger target sizes (12-16 mm) are used, the advantage of the 7" scope disappears (fig. III-4).

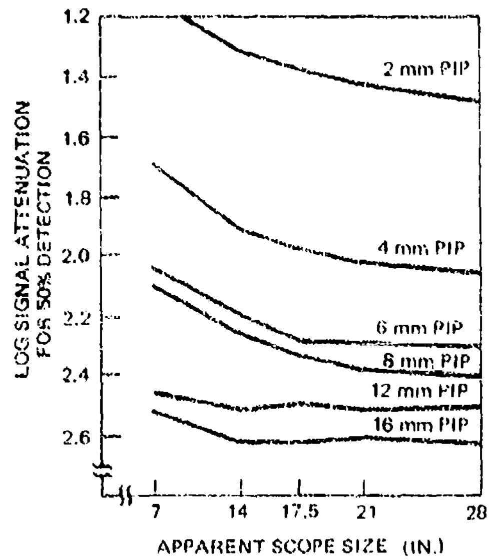


Figure III-4
Signal Requirements for 50% Detection as a Function of Apparent Scope Size for All Pip Sizes (Williams et al, 1955)

The tradeoff is between pip size and scope size. Radar detection improves as pips get larger up to about 60 minutes of visual angle, but decreases continuously as the scope gets larger. The practical tradeoff suggests a scope size of 17.5 to 28 inches. Probably the 7" scope would still be the best for different detection functions, but only if the pip could be enlarged without enlarging the scope.

Best Guess – As long as pip size is between 12 and 16 mm, *the best size is in the range 12 to 16 inches diameter*, differences in this range being unimportant. The larger CRT scopes, which atuomatically magnify pip size, appear to be more effective for detection. There are also techniques for electronically amplifying pip size.

Predicting Detectability from Display Geometry

Pip detectability thresholds, usually expressed in terms of decibels attenuation of a reference voltage, can be predicted from display geometry using the regression equation below; adding regression terms for scope area and pip size does not improve the overall prediction.

$$Y = 26.02 + 3.33x - 0.22x^2 - 0.46xz + 2.09z$$

where:

Y = mean detectibility threshold in decibels of attentuation of a reference voltage

x = target range in tenths of PPI radius

z = usable display diameter in units of 7 inches (Baker, C.H., 1962)

HOW LARGE SHOULD THE PIP BE?

Pip size is governed by a large number of factors which are ordinarily outside the control of the display designer. Primary among these are

1. Pulse length
2. Target extent (along the axis of the beam) in range
3. Target extent in bearing
4. Scan rate
5. Echo level
6. SNR
7. Bandwidth
8. Phosphor characteristics
9. Resolution requirements

Within the constraints imposed by these factors, figure III-5 suggests that the *minimum target size for recognition is 12 minutes of arc.* This assumes high contrast and ideal viewing conditions. To design *operational* equipment, a safer bet is that the minimum visual angle should be approximately *20 minutes.*

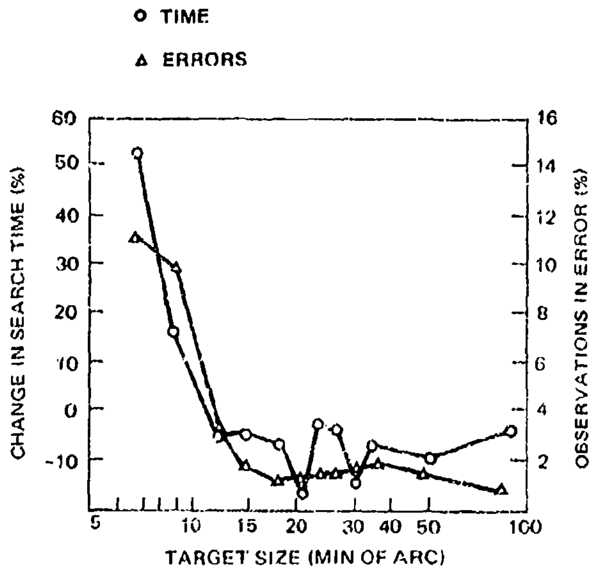


Figure III-5
Relative Increase or Decrease in Search Time and Errors as a Function of Target Size

Within the range of 7 to 28 inches of scope diameter and 2 to 16 mm of pip diameter, the larger the pip, the less important is scope size. *Medium and small scopes can be at least as efficient as large scopes* at the same level of resolution. (Colman et al, 1958.)

The minimum detectable separation between targets is one minute of arc, which is beyond the capabilities of most present tubes.

Assuming a 12-inch viewing distance from the target, a target must have a minimum size of 0.042 inch as displayed in order to expect relatively accurate and rapid recognition. Given these values (visual angle of 12 minutes, viewing distance 12 inches), one can plot display size against target size in accordance with the following formula.

$$\text{Display size in inches} = \frac{\text{ground range}}{\text{target size}} + 0.042$$

(see figure III-6). Example: if the smallest target one needs to recognize is 1000 feet in its greatest dimension, and the system displays (a target range) an analogue of a strip of ground 40 miles wide, the display must have one dimension of not less than 10.2 inches (Steedman and Baker, 1960).

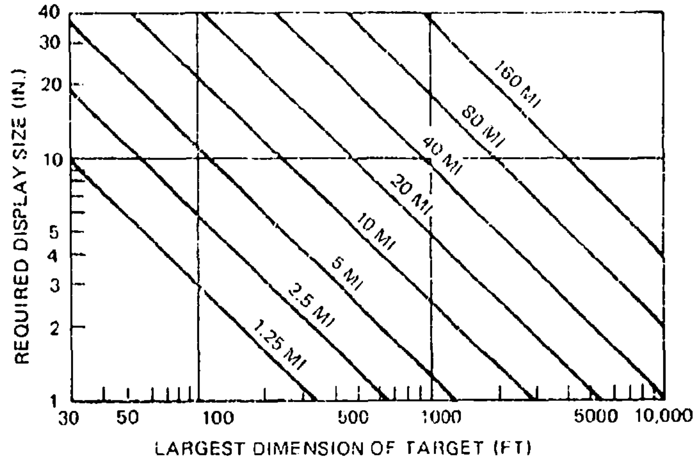


Figure III-6
Required Display Size Plotted Against Target Size for Various Ground Ranges Displayed to the Observer (Bendix Corp., 1959)

Considerations Detectability varies with the size of the signal. From signals of approximately 1 mm^2 to those of approximately 2 cm^2, the slope of the size-detectability relationship is essentially linear (fig. III-7). Beyond signals of 2 cm^2, the slope levels off. This is true for both bright and dim background luminance (Deese, 1954).

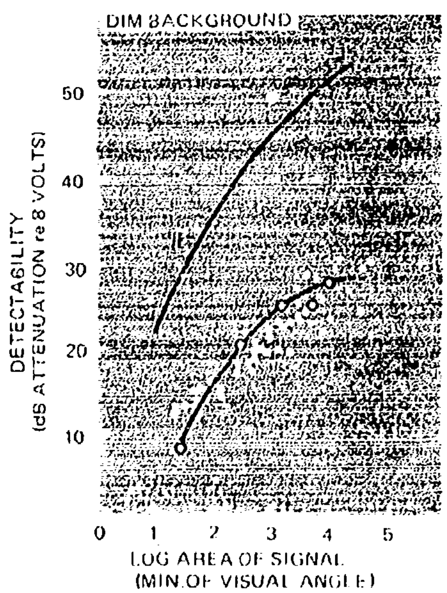


Figure III-7
Detectability as a Func on of Signal Size for a CRT Bias of 2 V below VRI* (-22 V). The background luminance is approximately 0.01 millilamberts at 10° behind the sweep. A similar curve is found for a CRT bias of 10 V below VRI (-16 V) (Deese, 1954)

*VRI = Visual reference index, defined as "a dim screen, on which the sweep line is barely visible" (Baker, C.H., 1962).

HOW PERSISTENT SHOULD THE PIP BE?

In order for the eye to detect the presence of a signal on a CRT, the signal must be sufficiently bright (see luminance), large enough (see preceding section) or be present for a long enough period of time. For detection of weak signals on a CRT, the signal must appear for a minimum of 0.1 second. Maximum visual sensitivity of the eye occurs between 0.2 and 0.3 seconds of observation time. Figure III-8 indicates that for detection of relatively weak signals, 0.1 second is the minimum level of acceptable exposure time (Mirabella and Goldstein, 1967).

For every increase in unit log area visual angle of signals, one can expect about 8-dB increase in detectability. By doubling the area of a display, assuming resolution is constant, one gets about a 2-dB increase in detectability for all but the very largest signals (Baker, C. H., 1963).

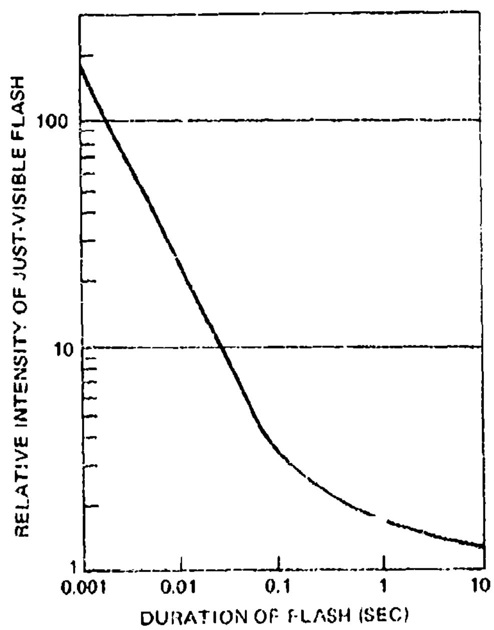


Figure III-8
Signal Persistence

WHAT IS THE MOST DESIRABLE SCANNING RATE?

The PPI scanning rate for the optimal 7″ tube in a radar application should be not less than 12 rpm, preferably higher (Kober, 1952). However, data on larger tubes are lacking.

WHAT IS THE MOST DESIRABLE VIEWING DISTANCE?

For console viewing, *18 inches is the recommended viewing distance.* Performance has been acceptable in the range of 14 to 18 inches; however, viewing distances of less than 16" are not recommended due to eye strain and fatigue effects. Arm reach (28" max.) is an important consideration when the operator must use controls on the console surface. This determines maximum viewing distance.

WHAT IS THE MOST DESIRABLE VIEWING ANGLE?

Optimally, the most desirable is at *right angles (90°)** to the PPI screen. Viewing angles up to 30° from optimum can be tolerated, if necessary, but result in some loss of pip visibility. Between 90° and 60° visibility is unimpaired. At 45° there is a drop off of 3 dB, and at 30° a further drop of 3 dB (Kober, 1952).

LUMINANCE

For a dark adapted area, *scope luminance* should be between *10 and 100 ft-L*, depending on the type of display and ambient illumination. The ideal background scope luminance for high ambient illumination should be about *100 ft-L* (Dyer and Christman, 1965).

Considerations -- The visibility of the radar pip increases with display luminance. This indicates that, as background liminance increases, the visual angle which can be resolved becomes smaller and smaller.

Data more specific to the CRT pip is shown in figures III-9 and III-10, which indicate that not only is the visibility of the pip increased with luminance, but also the range at which it is detected (Baker, C. H., 1962).

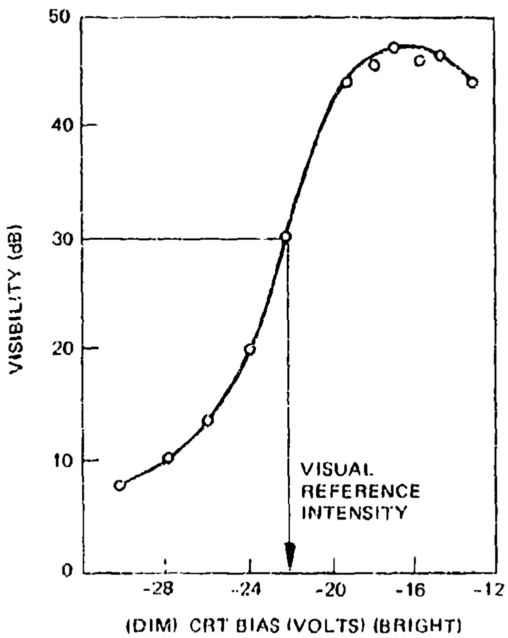


Figure III-9
Pip Visibility Threshold and Display Luminance (CRT bias) on a PPI (Williams, 1949)

*This is only theoretically true. Since antireflective coatings have not been perfected, viewing normal to the scope surface will most probably present the observer's own reflection. Viewing slightly off from 90° reduces this problem.

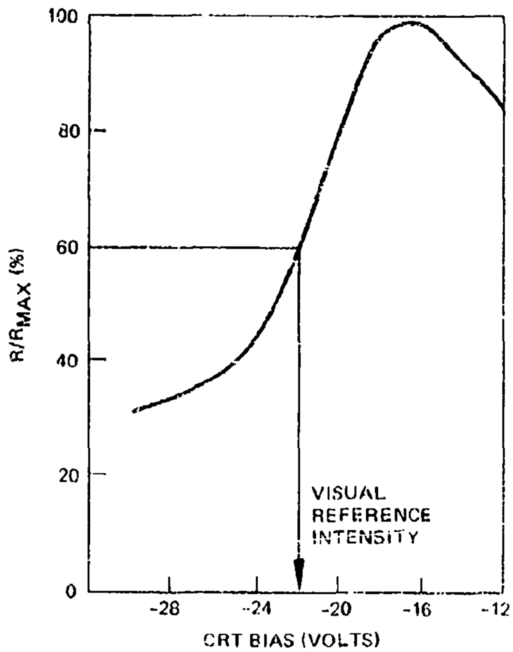


Figure III-10
Percentage of Maximum Range at Which a Pip is Visible as a Function of Display Luminance (data translated from figure III-6) (Thornton, 1954)

VISIBILITY, CRT BIAS, AND GAIN

The most effective pip visibility occurs with a low to moderate gain, as shown in figure III-11 (Baker, C.H., 1964).

Optimum detectability -- i.e., detection of weak pips -- occurs at an intensity and bias in the middle range of values (Grant et al. 1961).

Investigation of B-scan bias levels indicates that optimum bias level is independent of noise.

Considerations – In general, the higher the beam current, the longer the visual persistence of the strong signals. Maximum visibility of a signal during the first 7 seconds after excitation is obtained with a CRT bias in which the sweep is fairly dim yet clearly detectable. For images having decayed more than 7 seconds, best visibility occurs at a higher bias furnishing a less bright sweep (Baker, C.H., 1962). These effects are shown in figure III-12.

Luminance Adjustment - Operators are commonly allowed to adjust the brightness setting of their displays. There is evidence, however, that they cannot do this efficiently (figure III-13). Analytically determined luminance adjustments give better pip visibility. A simple technique which is recommended is to use a light filter of such a density that making the sweep line just visible through it provides optimum luminance or noise level. Such a filter would be specific to a particular scope (Baker, C.H., 1963).

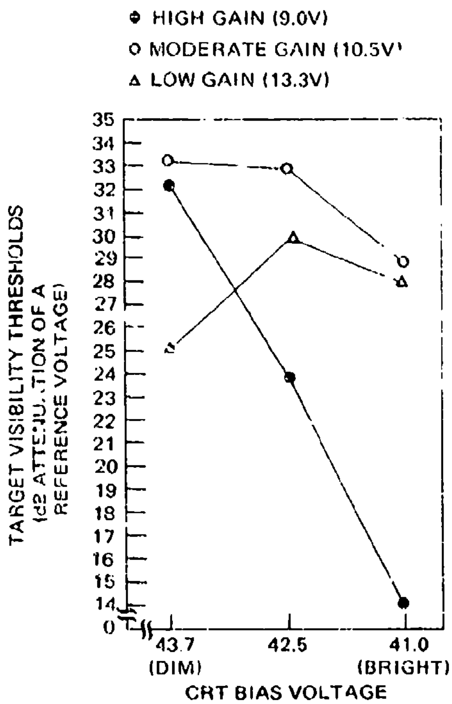


Figure III-11
Target Visibility Thresholds and CRT Bias for Three Levels of Gain (Baker, C.H., 1963)

There is a gradient of scope luminance in the radial dimension on a PPI. Detectability threshold signal/noise ratios are a function of radial range. Because of this, the setting of optimum luminance should be made with reference to that radial position which is of greatest importance in detection. In early warning radars optimum brightness should be set near the periphery of the scope. Whenever radar range scales are changed, scope luminance changes and therefore must be reset to restore optimum luminance. The grid voltage required to generate optimum luminance changes as the CRT ages; hence luminance must be adjusted periodically (Baker, C. H., 1962).

Figure III-14 shows that a reduction in any one factor -- background luminance, symbol size, or contrast -- may be compensated for by an increase in one or more of the others. As an example, the chief effect of reducing contrast is a shift of the curve upward in the direction of increased target size for a given probability of detection (Lovelace Foundation, 1968).

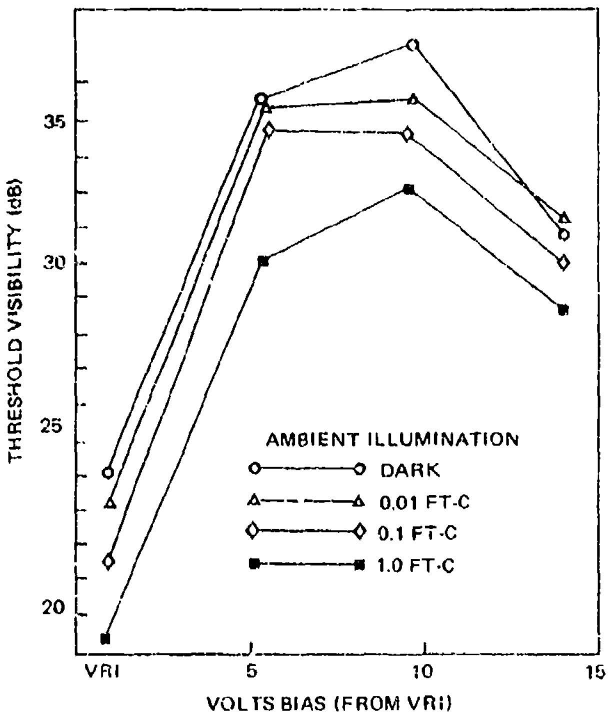


Figure III-12
Target Visibility as a Function of CRT Bias

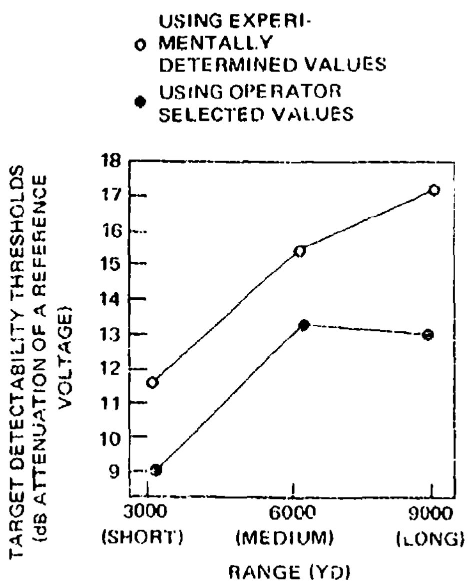


Figure III-13
A Comparison of Target Detectability Thresholds

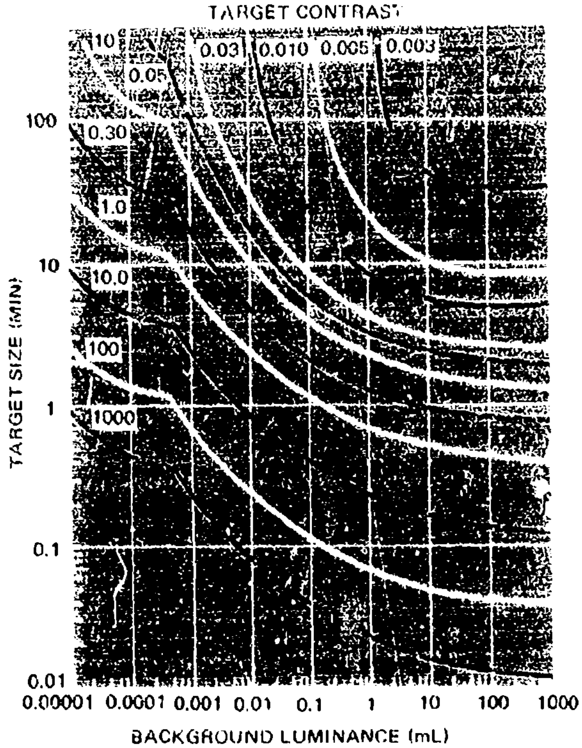


Figure III-14
Relation Between Target Size, Threshold Background Luminance, and Contrast (Lovelace Foundation, 1968). Thresholds are at the 50% probability of detection level; multiplying the values by 2 (log 0.3), the values can be converted to about the 95% probability of detection.

Figure III-15 shows that with large targets on bright backgrounds (curves for 121 and 360 minutes of visual angle), the brightness contrast can be low and still provide a high probability of detection. (The curves in the figure are the contrast required for 50% detection probability.)

Contrast enhancement by edge sharpening techniques which tend to increase both resolution and contrast has been found to increase probabilities of detection, recognition, and designation, and to increase the speed with which these events occur (Humes and Bauerschmidt, 1968).

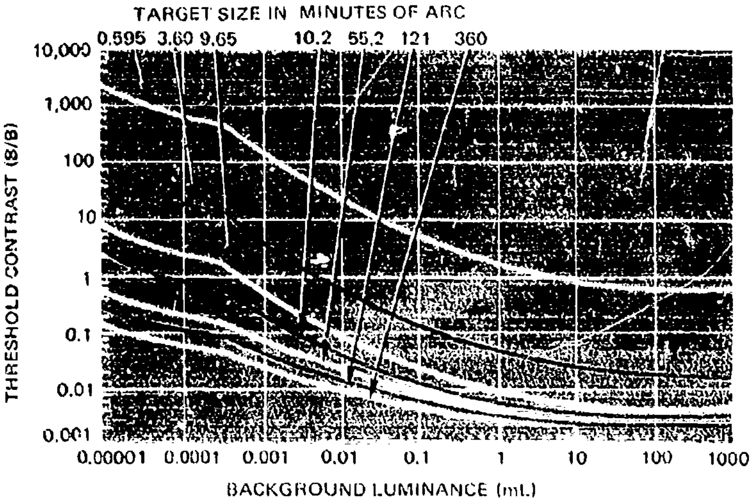


Figure III-15
Contrast Thresholds for Different Target Sizes and Background Luminances (Lovelace Foundation, 1968). Thresholds are at the 50% probability of detection level; multiplying the values by 2 (log 0.3), the values can be converted to about the 95% probability of detection

NOISE EFFECTS

The effect of gaussian noise on pip visibility is shown in figure III-16. Noise reduces the amount of improvement found in operating at optimum luminance, but the improvement still persists (Baker, C.H., 1962).

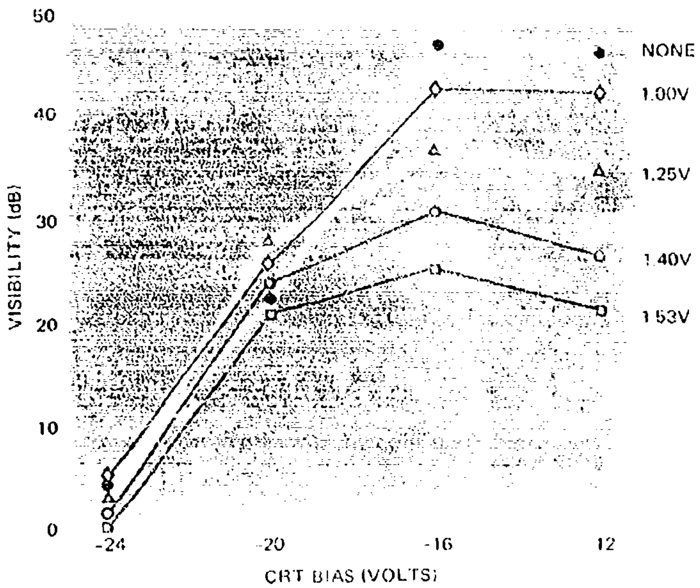


Figure III-16
Effect of Noise on Pip Visibility (Williams, 1949)

CRT detection is degraded, as one would expect, with an increase in display noise. Figure III-17 indicates that at optimum scope brightness noise impairs visibility, but with dim scope it actually adds visibility, since the noise adds needed luminance to the scope (Baker, C.H., 1962).

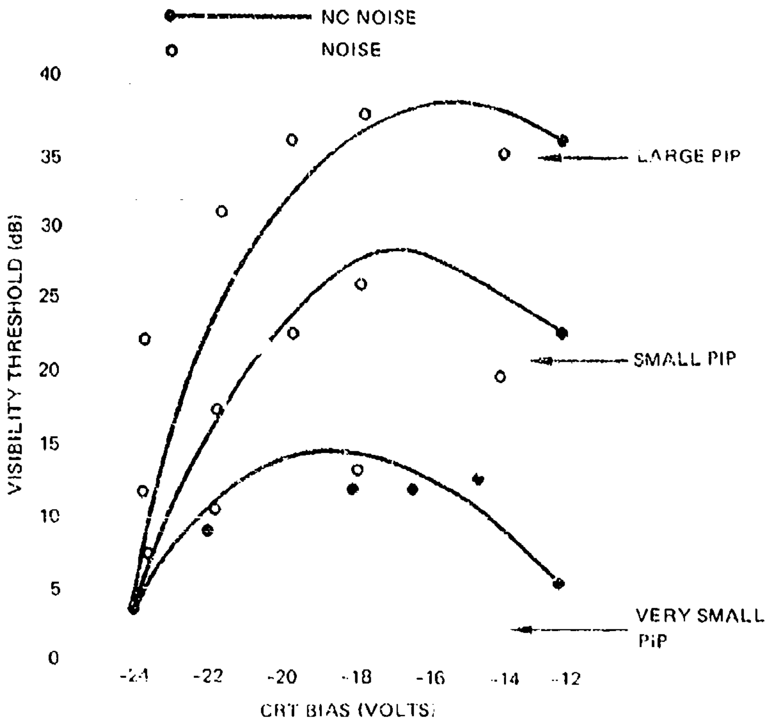


Figure III-17
Pip Visibility Threshold and Scope Luminance for Pips of Three Sizes Under Noise and Noise-Free Conditions

Detection and localization performance as a function of S/N ratio and ambient illumination for several common phosphors is shown in figure III-18 (Sonn and Carr, 1967). The curves presented show a strong dependence for detection probability with S/N ratio.

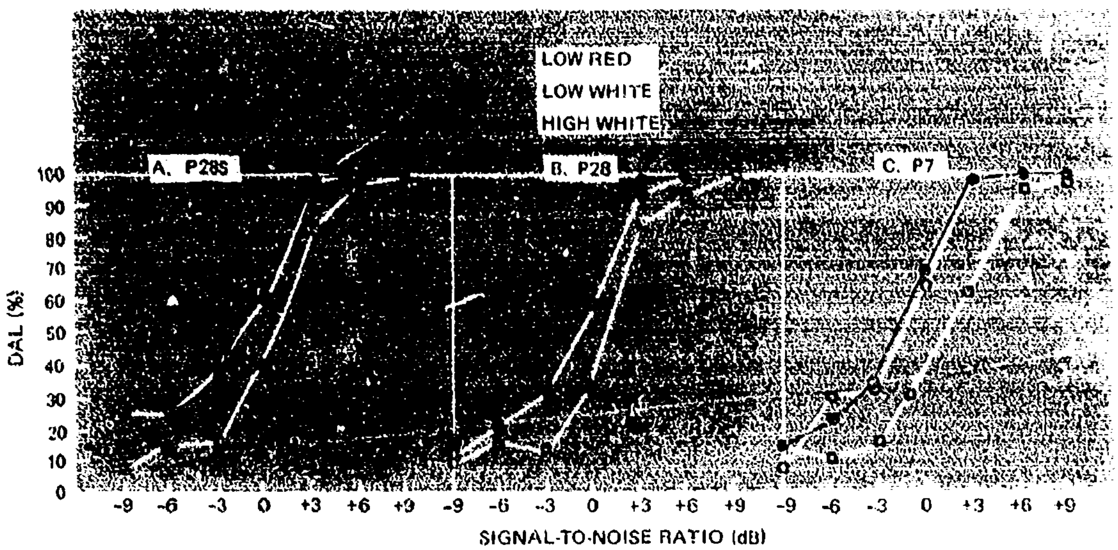


Figure III-18
Detection-and-Localization (DAL) Accuracy as a Function of Signal-to-Noise Ratio with Ambient Lighting as the Parameter

TARGET SYMBOLS

The ability to *identify* (as opposed to detect) different target shapes on a PPI scope varies as a function of the shape used. Table III-1 shows accuracy of identification of common geometric shapes under conditions of low and high noise (Baker, C.H., 1962).

TABLE III-1
ACCURACY OF IDENTIFICATION OF GEOMETRIC SHAPES UNDER LOW/HIGH NOISE CONDITIONS

Target Shape	Correct Identification (%)	
	Low Noise	High Noise
Triangle	88 (1)	56 (1)
Square	29 (4)	35 (2)
Circle	76 (2)	27 (3)
Cross	---	22 (4)
Trapezoid	70 (3)	---
Rectangle	37 (5)	---
Ellipse	30 (6)	---

Another study showed that the following four symbols are most legible:

At viewing distances up to 10 feet, symbols should be 0.4 inch or larger - i.e., fit into a square 0.4 X 0.4 inch. Stroke width-to-height ratios should be between 1:6 and 1:10. The symbols should subtend at least 22 minutes of arc at the observer's eye. (Baker, C. H., 1962).

The above data should be applicable to the selection of symbols for such equipments as air traffic control radar where aircraft must be identified and tracked.

AMBIENT ILLUMINATION

Ambient illumination up to a level of 0.1 footcandle does not impair pip visibility. Illumination of higher than this does impair detectability (see figures III-19 and III-20) (Adler et al, 1953). This applies regardless of the color (e.g., red) of the ambient lighting.

Scope brightness should be adjusted so that the higher levels of illumination that must be tolerated are not more than 100 times the average scope brightness. Except for radar used in aircraft, the brightness levels of the scope and the physical surroundings should be similar (Baker, C.H., 1962). This is often difficult to accomplish.

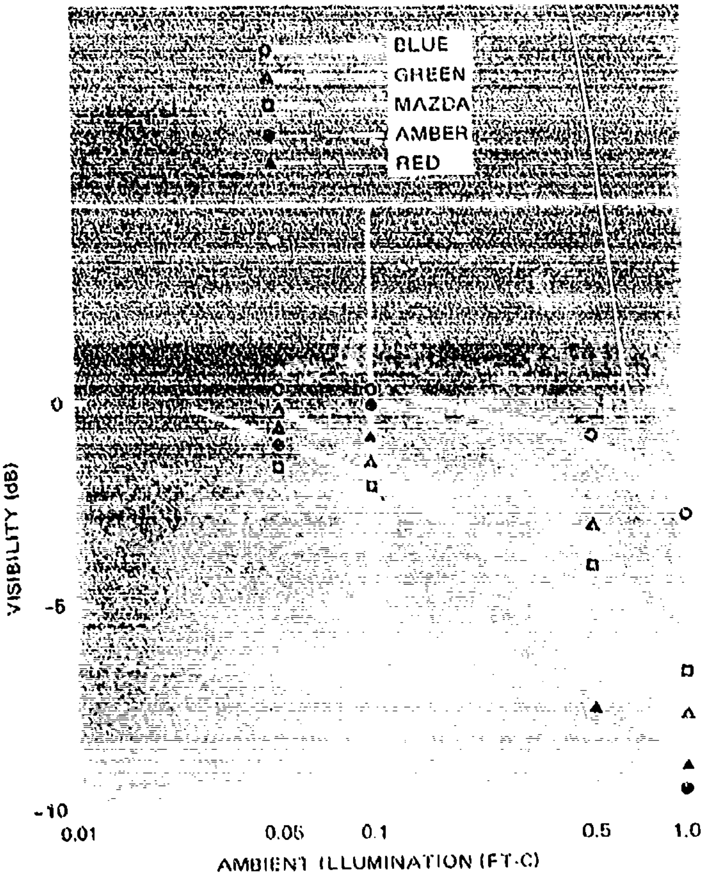


Figure III-19
Visibility and Ambient Illumination (Baker, C.H., 1960)

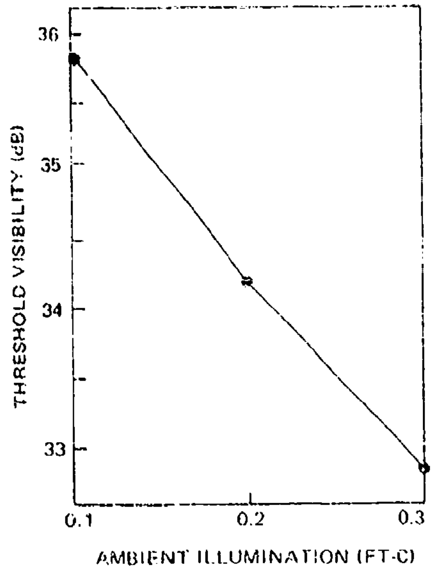


Figure III-20
Decrease in Target Visibility at Higher Light Levels (Baker, C.H., 1960)

PHOSPHORS

Table III-2 presents information on the characteristics of phosphors available for display applications (Luxenberg and Kuehn, 1968; Gould, 1968).

TABLE III-2

PERSISTENCE CHARACTERISTICS AND CRITICAL FLICKER FREQUENCY (CFF) OF PHOSPHORS COMMONLY USED ON DISPLAYS (GOULD, 1968)

Phosphor	Residual Light (%) after		Persistence to 10% (sec)	Empirically Determined CFF for Various Ambient Illumination Levels					
	1/30 sec	1/60 sec		10 ft-L	32 ft-L	50 ft-L	100 ft-L	10 mL	50 mL
P 28	85	90	550×10^{-3}	34	40	31.4	46		
P 19	80	90	220×10^{-3}			17.5			
P 12	70	85	210×10^{-3}	25	29		32		
P 7 (Y)	45	80	400×10^{-3}	32	38	29.8 (B&Y)	43		
P 1	4	23	24.5×10^{-3}	33	38	29.2	43	32	38
P 4 (y) silicate	1.3	7	60×10^{-6}	35	41	33.5 (B&Y)	47	36	43
P 31	1	1	38×10^{-6}	37	44	32.4	51		
P 20	1	1	50×10^{-6} to 18×10^{-3}	40	47	32.7	54		

OPERATOR PERFORMANCE CHARACTERISTICS

1. There are large individual differences among operators in detecting targets on PPI displays.

2. The requirement to search the entire PPI scope results in about 13% fewer detections on the average than when the operator is alerted to the target's probable bearing.

3. Detection of targets at midrange on the PPI is more rapid than at close or far range.

4. Repeated presentations of a target (up to 5 echoes) are often necessary to elicit valid detection reports.

5. The range between 10% and 90% probability of detection on a PPI is only about 4.5 dB.

6. Setting the PPI scope brightness at the visual reference intensity (VRI), as often recommended, adversely affects target detection. The optimum brightness for detection is well above this setting.

7. Operators typically do not adjust CRT bias and gain optimally for detection. Weak signals can be detected much more frequently using experimentally determined optimum settings than when the operator uses his own setting.

8. Signals can be missed even when the eyes are fixated on the PPI.

EQUIPMENT CONSIDERATIONS

1. Pulse length: Increasing pulse length of short pulses improves detection very markedly, the effect on longer pulses is not as significant.

2. Antenna rotation rate: If the rotation rate is sufficient to paint a uniform background on the scope, detectability is essentially independent of rotation rate. If the background is discontinuous and "grainy," the slower rotation rates are slightly advantageous, over a range of about 1 to 70 rpm.

3. Sweep rotation rate: The slower the sweep rotation rate, the higher the detectability of the signal.

4. Beam width: The beam width of the antenna largely determines the angular dimension of the pip. From 2 to 12 degrees, detection improves as the 2/3 power of beam width.

5. Video bandwidth: No effect of video bandwidth on detection has been found.

6. Sweep direction: No significant difference between clockwise and counterclockwise direction of movement of the sweep line.

7. The higher the video gain, up to maximum, the easier it is to detect the target (lowered detectability threshold) within a device's dynamic range.

8. Interaction between gain and CRT bias: a more positive bias can help compensate for low gain, and a high gain can help compensate for low bias.

9. Pulse repetition frequency (PRF): This is a measure of the frequency with which the electron beam excites the CRT phosphor. The probability of detection increases with increases in PRF.

CHAPTER IV

RANDOM POSITION AND TELEVISION TYPE DISPLAYS (SINGLE OBSERVER VIEWING)

INTRODUCTION

This chapter discusses random position and raster scan displays of the console type (single observer viewing).

The following topics are covered:

1. Minimal acceptable symbol resolution

2. Minimal acceptable symbol size

3. Relation between symbol size and resolution

4. How to determine acceptable symbol size

5. How to determine the number of symbols that can be presented

6. Effect of signal bandwidth on symbol identification

7. Viewing distance

8. Alphanumerics

   a. Recommended character height as a function of viewing distance
   b. Types of symbols
   c. Special character shapes
   d. Aspect ratio

9. Effect of TV quality on legibility

10. Light/dark contrast

11. Viewing angles

12. Flicker

Summary of Recommendations

1. Luminance ratio: 2:1 (display: surround)

2. Symbol resolution (minimum): 10 TV lines

3. Symbol size (minimum): 12-15 minutes of arc

4. Symbol aspect ratio: 5:7 or 2:3

5 mbol stroke width: 1/6 to 1/10 character height

6. Geometric distortion: not more than 2-5% of picture height

7. Acceptable bandwidth: 4.5 MHz at least

8. Viewing distance (average): 18 inches

9. Screen luminance (acceptable): 50% fall off

10. Direction of light/dark contrast: not important for legibility

11. Viewing angle: not smaller than 45°

12. Frame rate: not less than 30-35 Hz, depending upon phosphor

13. Signal-to-noise ratio: 35 dB

SYMBOL RESOLUTION

Performance studies indicate that for 99.5% accuracy of character recognition the minimal acceptable vertical symbol resolution is 10 TV lines per symbol height (fig. IV-1 and IV-2) (Kinney, G.C., 1965).

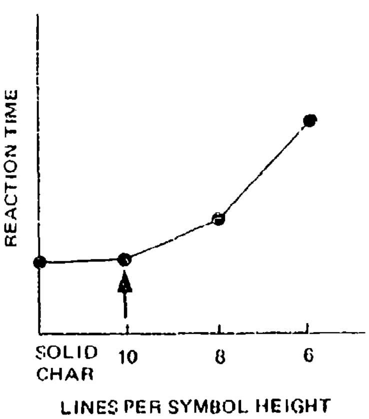


Figure IV-1
Speed of Operator Response as a Function of Number of Scan Lines

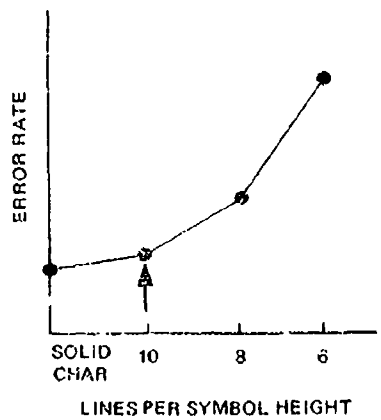


Figure IV-2
Operator Error as a Function of Number of Scan Lines

The percentage of correct responses to be expected as a function of scan lines is shown in figure IV-3.

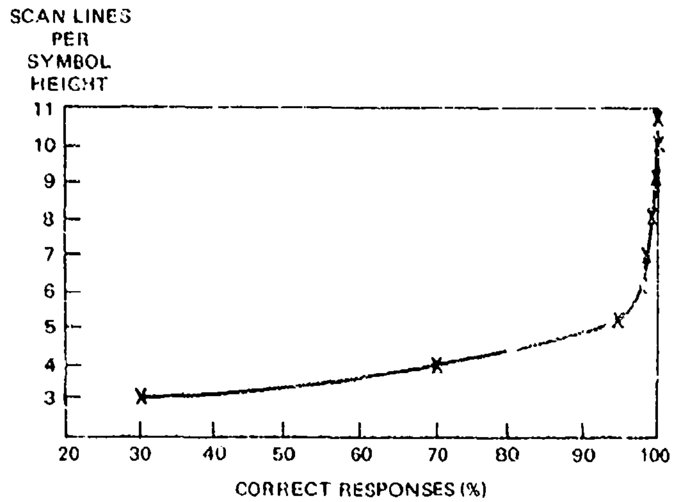


Figure IV-3
Accuracy of Character Recognition as a Function of Scan Lines (Davis, J.A., 1967)

SYMBOL SIZE

The accepted visual size for viewing televised symbols is between 12 and 15 minutes of arc (Shurtleff, 1967). This is shown by figures IV-4, IV-5, and IV-6, which show the accuracy of identification as a function of visual size and symbol resolution.

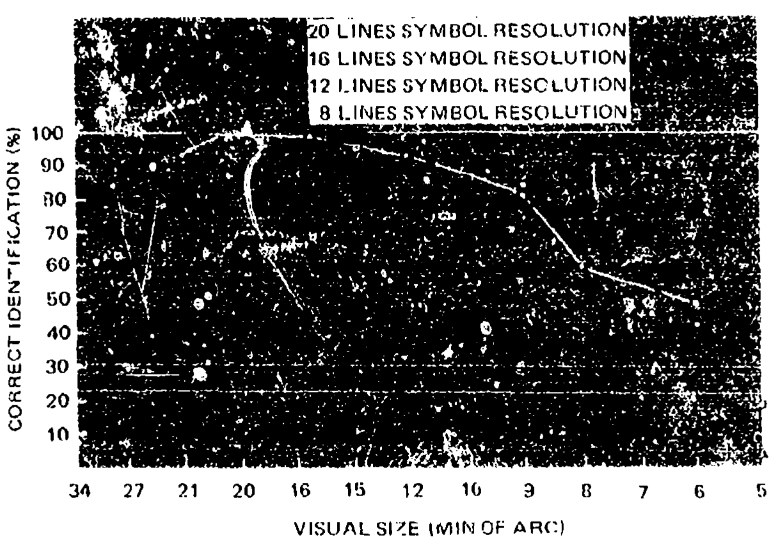


Figure IV-4
Accuracy of Identification as a Function of Visual Size and Symbol Resolution (Shurtleff, 1966)

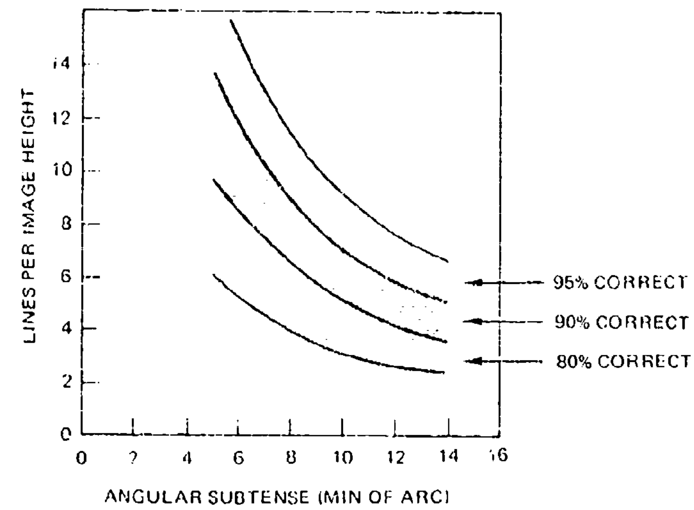


Figure IV-5
Trade-off Bands for Angular Subtense vs Line Number
for Three Levels of Performance (Ericksen, R.A., 1964)

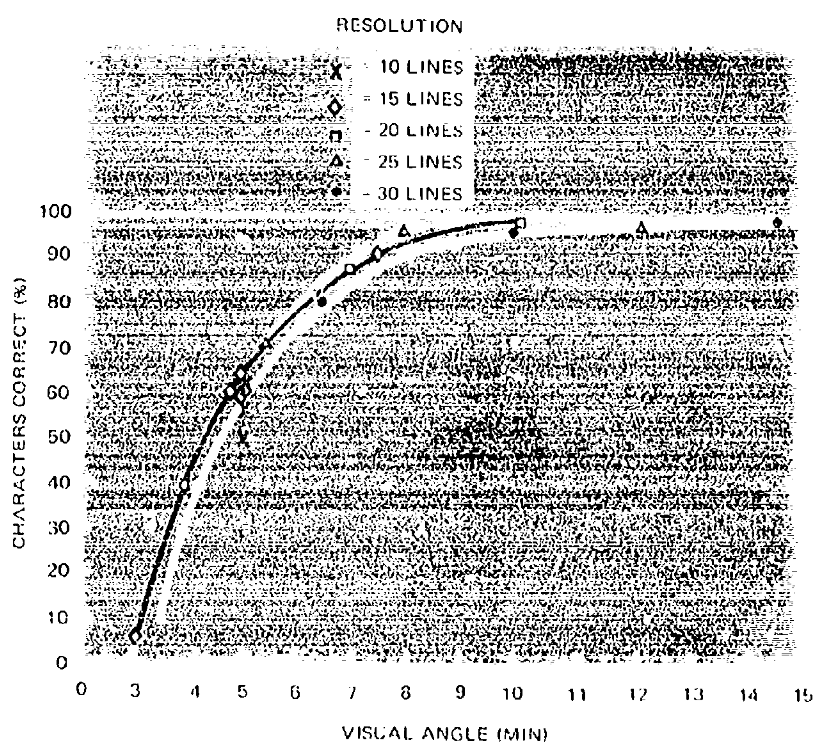


Figure IV-6
Relationship Between Visual Angle And Resolution

Note that where resolution is inadequate (8 lines), all visual sizes above 12 minutes of arc give essentially the same performance for acceptable resolution.

SYMBOL RESOLUTION

	No. of Lines		
	10	8	6
Standard Leroy	13.15*	12.82	35.97
Revised Leroy	13.37	15.09	30.08

Determining the Size of the Display Element

The size of the display resolution element, in terms of its maximum dimension, and the maximum viewing distance D at which two adjacent elements can be discriminated is given by the formula:

Character Height = H

$$H = 0.003D$$

Where the display format is comprised largely of symbology, the relationship of symbol size to screen height is shown in figure IV-7. Symbols 3 to 5 times the minimum size of 10 minutes of arc are usually acceptable, but will degrade the maximum display data capability.

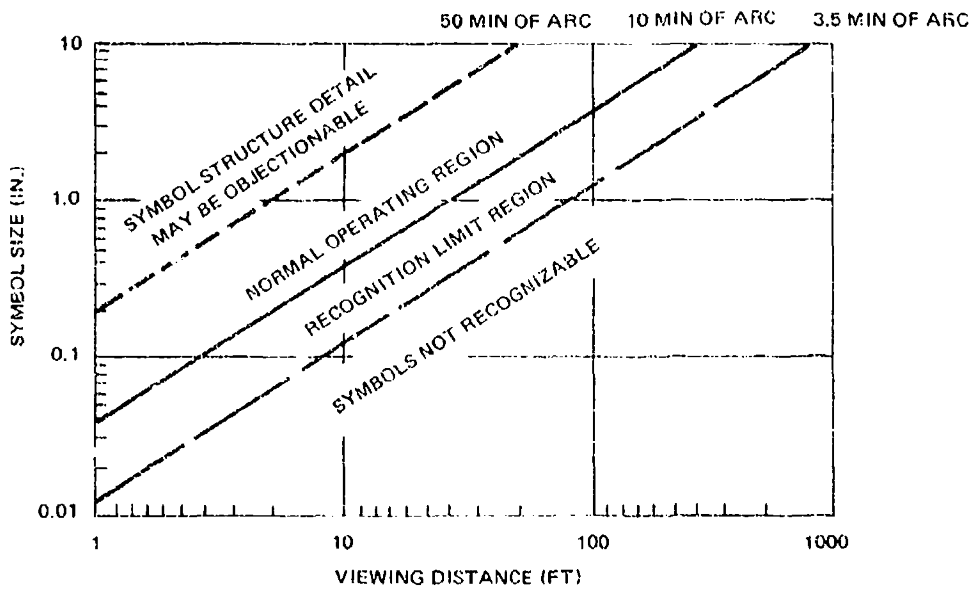


Figure IV-7
Relation of Symbol Resolution to Viewing Distance
(Whitham, 1965)

*Size of symbol in minutes of arc required for 99% accuracy of identification.

It is also possible to determine maximum element size from the number of vertical elements or raster lines and the display screen height (fig. IV-8). Example: For 500 line TV screen with a height of 15 inches, the maximum element size is 25 mils, which is consistent with the spot size of normal TV CRTs.

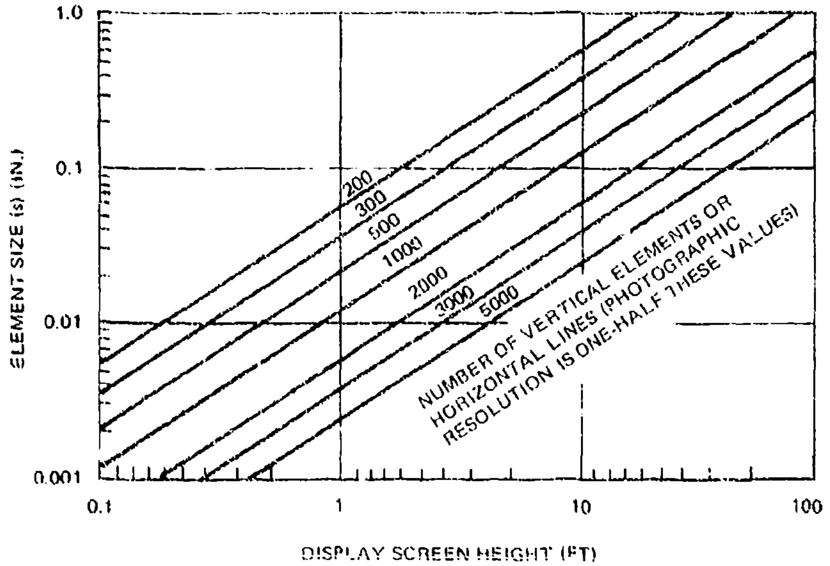


Figure IV-8
Relation of Screen Height to Element Size and Number of Vertical Elements or Horizontal Lines (Whitham, 1965)

HOW TO DETERMINE THE NUMBER OF SYMBOLS THAT CAN BE PRESENTED

The number N of characters of limiting resolution which can be accommodated for a square screen having a side dimension S is given by the equation:

$$N = \frac{D^{-2}}{S} \times 10^5$$

where D = the viewing distance and S = screen size.

If character height visually subtends 10 minutes of arc for limiting conditions, then the total symbol area will subtend 7.5 by 15 minutes of arc.

If square adjacent symbols, which visually subtend 10 minutes of arc for each side, are used, the maximum number is given by the equation:

$$N = \frac{D^{-2}}{S} \times 1.1 \times 10^5$$

Practical limits for the value of D/S normally lie in the range between 1 and 5. Plots of the equations above are given later in figure IV-11, which demonstrates that the maximum symbol populations are between 4×10^3 and 10^5 for normal values of D/S.

GEOMETRIC DISTORTION

The combined effects of all geometric distortion should not displace any point on the projected display from its correct position by more than 2-5% of picture height.

The projector should be capable of correcting keystone or trapezoidal distortion within a range of ± 15 degrees off center.

EFFECT OF SIGNAL BANDWIDTH ON SYMBOL IDENTIFICATION

As long as the visual size of the alphanumeric is 10 minutes of arc or more, there appears to be no appreciable loss in identification accuracy as a function of reducing video bandwidth, within the range 4.0 to 1.0 MHz. There is, however, a sharp drop in performance between 100 MHz and 750 kHz. The effect is most pronounced for alphanumerics of less than 10 minutes of arc (see figure IV-9 below).

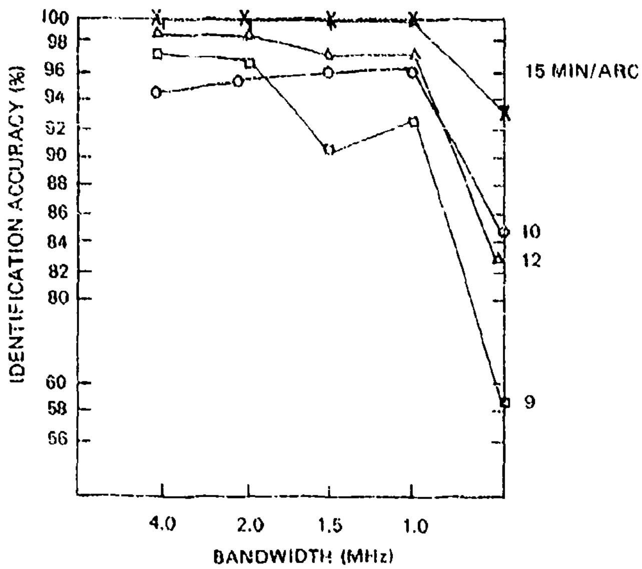


Figure IV-9
Effect of Bandwidth on Identification Accuracy (Shurtleff, 196?)

The type of symbol is important here. For nonmeaningful symbols (e.g., Landoldt rings) the reduction in bandwidth from 8 MHz to 2 or 1 MHz is much more pronounced. See tables IV-1 and IV-2 below, which describe the percentage of target identification accuracy lost.

TABLE IV-1
EFFECTS OF VIDEO SIGNAL BANDWIDTH ON TARGET IDENTIFICATION ABILITY (SHANAHAN, 1964)

Video Signal Bandwidth	Target Contrast Ratio		
	100%	81%	27%
8 to 2 MHz	23%	24%	15%
8 to 1 MHz	54%	52%	42%

TABLE IV-2
EFFECTS OF TARGET CONTRAST RATIO ON TARGET IDENTIFICATION VELOCITY (SHANAHAN, 1964)

Target Contrast Ratio	Video Signal Bandwidth		
	8 MHz	2 MHz	1 MHz
100 to 81%	7.4%	7.9%	3.8%
100 to 27%	26%	18%	6.6%

VIEWING DISTANCE

Average viewing distance from the console is assumed to be 18 inches, in which case the minimum element size would be 0.15 inches. Figure IV-10 can be used to determine optimum element size as a function of viewing distance. The relationship among size of display screen, acceptable viewing distance, and amount of detail or number of characters which can be displayed is shown in figure IV-11. This figure shows that for a given viewing distance, display size must be increased if the amount of detail displayed is to be increased.

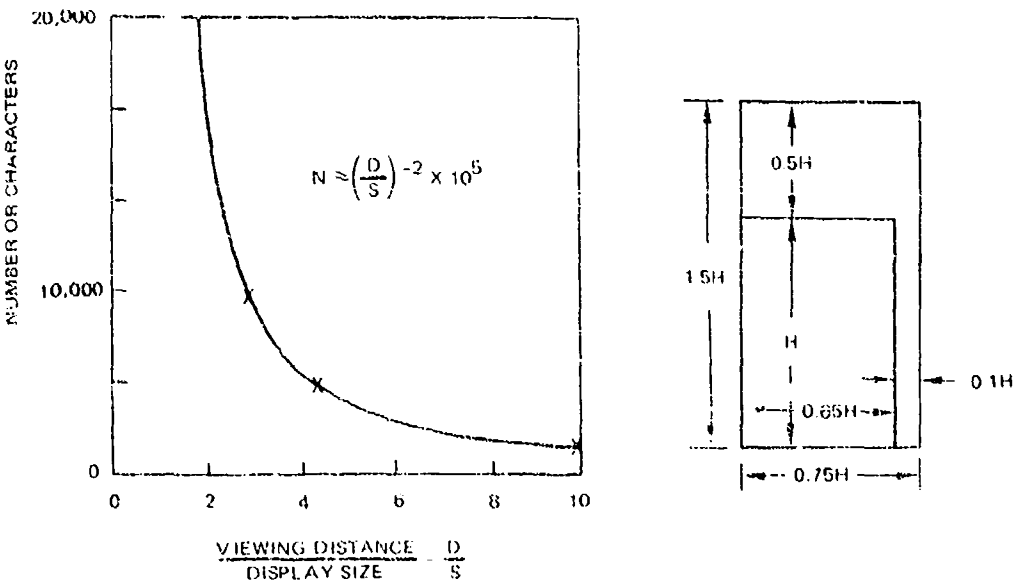


Figure IV-10
Relationship Between Display Detail (N), Display Size (S), and Viewing Distance (D)* (Whitham, 1965)

*CONDITIONS:
1. Square display
2. Character slot as shown
3. Character height, H, subtends 10 min of arc at viewing distance, D (H = 0.003D)
4. Increased viewing distance at display edges is neglected
5. Adequate brightness and contrast exist
6. Viewing distance, D, is greater than 13 inches
7. No margin allowed at display edge

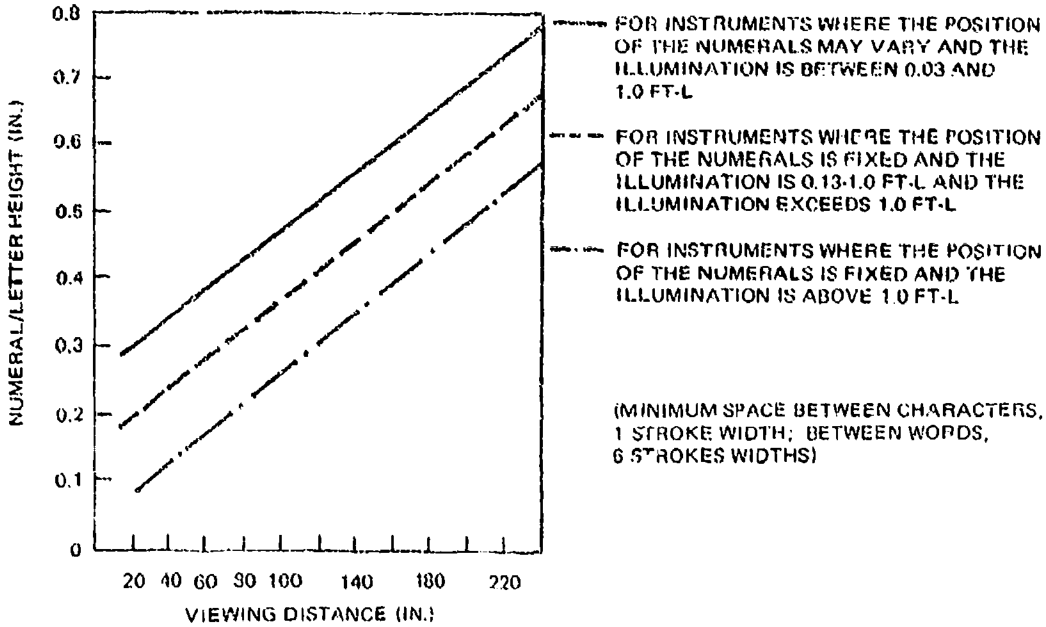


Figure IV-11
Letter Height vs Viewing Distance and Illumination Level
(Barmack, et al. 1966)

SYMBOL CHARACTERISTICS

Recommended Character Heights for Alphanumerics

TABLE IV-3

RECOMMENDED MINIMUM ALPHANUMERIC CHARACTER HEIGHTS AS A FRACTION OF VIEWING DISTANCE (SMITH, S.L., 1962)

Type of Displayed Information	High Display Luminance (Down to 1.0 ft-L)	Low Display Luminance (Down to 0.03 ft-L)
Critical Data Position on Display Variable	0.0045 to 0.007	0.007 to 0.011
Critical Data, Position Fixed	0.0035 to 0.007	0.0055 to 0.011
Noncritical Data (Labels, etc.)	0.002 to 0.007	0.002 to 0.007

The optimum size of letters, and numerals on CRT displays is a function of viewing distance, illumination, and movement of numerals. Figure IV-11 shows these relationships, although the data are based on conventionally printed displays, not CRTs. Considering 18 inches as the typical viewing distance, CRT letters should be from about 0.08 inches to 0.28 inches (Barmack,et al, 1966).

Dot Mosaics – The coarsest mosaic that is capable of providing easily legible alphanumeric symbols is a 5 by 7 dot mosaic (fig. IV-12). Only 35 decoded lines are required. If only numerics and a limited number of symbols are required (e.g., -, -, 1, etc.), some elements are not required, and the number of do may be reduced to 27, as shown in figure IV-13. Characters generated in 5 X 7 dot matrices are probably marginal in comparison to those generated in larger matrices.

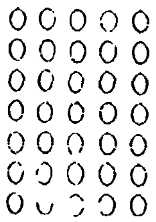


Figure IV-12
Full 5 X 7 Dot Mosaic (35 elements – full alphanumeric) (Luxenberg and Kuehn, 1968)

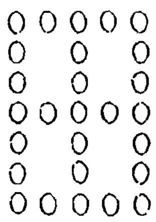


Figure IV-13
Reduced 5 X 7 Dot Mosaic (27 elements – numeric only) (Luxenberg and Kuehn, 1968)

Stroke Mosaics – The bars, strokes, or segments are arranged in a pattern similar to that shown in figure IV-14. The segments may be electroluminescent strips, electrochemical cells, or cathodes in a glow discharge tube, or they may be back lit or edge lit by neon or incandescent lamps The characters are nearly as legible as those made from a 5 by 7 dot mosaic, but logic (switching) requirements are reduced from 35 inputs for the full 5 X 7 matrix to 16, 14, 9, or 7, depending on the type of font style chosen. The same height/width/stroke ratios apply as for shaped characters. 16 and 23 segment fonts have been found to be more legible than 17, 27, or 38 segment fonts (Stephenson and Schiffler, 1968).

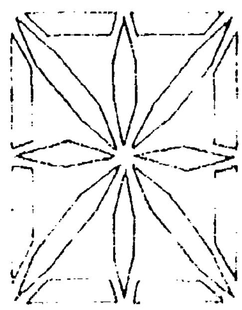


Figure IV-14
Stroke Mosaic (16 elements)

Recommended Symbol Size (other than alphanumerics)

Highly skilled operators can accurately distinguish typical military map symbols at a resolution of 14 lines. However, for the identification of symbol detail, a resolution of 17 lines is recommended; this will allow interior detail of the symbol to resolve 3-4 lines, and represent a visual size of 5 to 6 minutes of arc (Marsetta, et al, 1966).

Confusion Among Alphanumerics

Observers most commonly confuse the following alphanumerics (Kinney and Showman, 1967):

Mutual	One-Way
O and Q	C called G
T and Y	D called B
S and 5	H called M or N
I and L	J, T called I
X and K	K called R
I and 1*	2 called Z*
	B called R, S, or 8*

Accuracy of Identification of Common 5-Letter Words

It is possible to use as few as 7 lines per word height and still retain 98% accuracy of word identification. This is shown by table IV-4.

TABLE IV-4
IDENTIFICATION ACCURACY AS
A FUNCTION OF RESOLUTION

Resolution			
Solid stroke	10 lines	7 lines	5 lines
100%	99%	98%	97%

*These three often comprise 50% or more of the total confusions.

ASPECT RATIO

Aspect ratios of 5:7 or 2:3 (width to height) are recommended for greatest legibility. Stroke width should be in the range of 1/6 to 1/10 character height with the thinner widths used for illuminated characters on a dark background (Poole, 1966). A wide stroke width should be used for lower symbol resolution (Shurtleff, 1966).

VARIATIONS IN TV QUALITY

At resolutions of 8, 10, and 12 lines, quality of TV equipment appears to have no significant effect on accuracy and speed of identification of standard Leroy symbols (most commonly employed alphanumeric). At 6 lines, identification is superior for better quality TV (945 lines). Even high-quality TV requires a minimal resolution of 10 lines (Shurtleff, 1966). See figure IV-15 below.

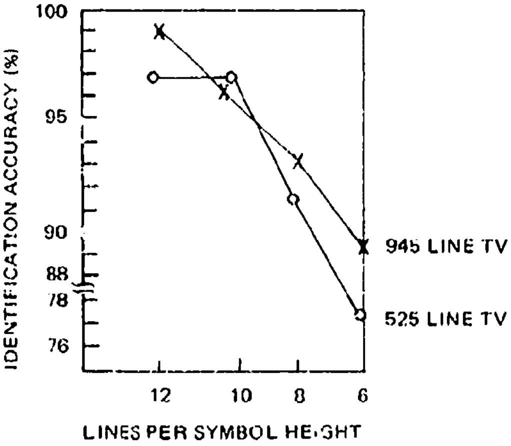


Figure IV-
Accuracy of Symbol Identification for Good-Quality vs Low-Cost TV (Shurtleff, 1966)

RATIO OF ACTIVE TO INACTIVE EL...

Where symbol resolution is lowered (5-7 lines), the ratio of widths of inactive TV to active TV elements should be no more than 1:1. Ratios greater than these increase errors of identification as well as produce a raster which requires especially careful registration of scan lines (Shurtleff, 1965).

LIGHT/DARK CONTRAST

Light symbols on a dark background are recognized more accurately under low ambient lighting. Dark symbols on a light background are recognized more readily under medium and high ambient illumination (table IV-5). For intermediate values of symbol and background brightness, the direction of contrast is not significant in legibility (Blackwell, 1959). Under high ambient illumination, identification accuracy is so poor (66-73%) that the D/L condition would not be used anyway (Shurtleff, 1967).

TABLE IV-5

ACCURACY OF IDENTIFICATION IN PERCENTAGE CONTRAST FOR TWO DIRECTIONS OF CONTRAST AND THREE VALUES OF AMBIENT ILLUMINATION

Direction of Contrast	Ambient Illumination		
	0.026 ft-C	186.4 ft-C	638.4 ft-C
D/L	88%	81%	73%
L/D	93%	77%	66%

Contrast Ratio

Contrast ratio should be maintained at 90%.

DISPLAY FORMAT

Vertical vs Horizontal Arrangement

The effect of vertical vs horizontal arrangement of coded symbols is negligible (Coffey, 1961).

Spacing

At low brightness (1 ft-L) spacing of characters (25% of character dimensions) does not affect acuity. At higher brightness (20 and 40 ft-L) wider spacing (200% of character dimensions) produces better acuity. Wider spacing produces better acuity for L/D symbols than for D/L symbols (Shurtleff, 1967).

VIEWING ANGLE*

Errors and reaction time in recognizing briefly exposed common 5-letter words increase gradually as the viewing angle is reduced from 90° (straight on) to 45°. At 30° the error rate cannot be accepted (fig. IV-16) (Kinney, 1965).

Recommendation: Optimally, no viewer should be seated at a viewing angle smaller than 30° or at a distance from which the height of the smallest symbol is smaller than 16 minutes of arc. (See also figure IV-20) (Colman, et al, 1958).

For 99% accurate identification, table IV-6 presents the minimum required visual sizes, in minutes of arc, for five viewing angles and two levels of symbol resolution.

TABLE IV-6

VISUAL SIZES** REQUIRED FOR VIEWING TV DISPLAYS AT VARYING ANGLES

Symbol Resolution in Lines	Viewing Angle				
	90°	75°	60°	45°	30°
10	20	24	28	36	63
8	24	28	32	44	--

*Angle subtended at the viewer's eye from the center line of the display.

**In minutes of arc.

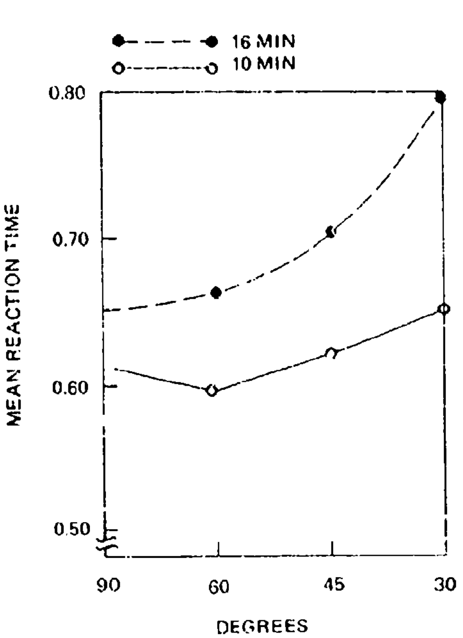


Figure IV-16
Mean Reaction Time Plotted Against
Viewing Angle for Two Symbol Sizes

EXPOSURE DURATION

Minimum exposure duration for maximum visual acuity is about 0.2 sec., with no appreciable increase in acuity beyond this (Crumley et al, 1961).

FLICKER

The curves in figure IV-17, represent the critical flicker frequency (that value which is lowest frequency which can be perceived as anything but a steady light) for several common phosphors as a function of display luminance (brightness).

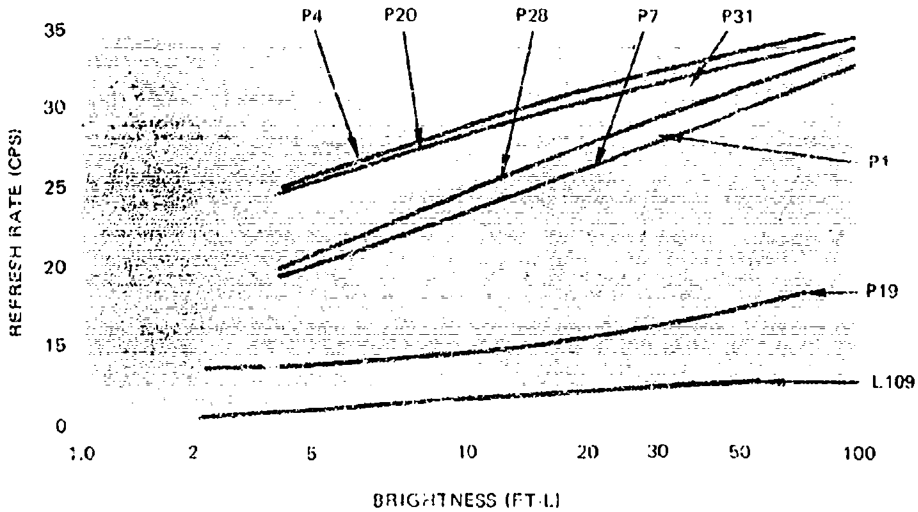


Figure IV-17
Flicker Threshold of Average Observer (Bryden et al, 1969)

For character displays, the pulse rate should be greater than 30-40 Hz so that the characters do not appear to blink. Flicker can be eliminated from most electronic displays if the pulse rate is 35 Hz or more (Barmack et al, 1966). Some flicker is noticed with average display brightness unless repetition rate is at least 50 Hz. Displays under 20 Hz are usually quite annoying to the observer (Poole, 1966).

Flicker in TV cannot be noticed at 60 fields per second unless display brightness exceeds 180 ft-L. 50 fields per second is acceptable if display brightness drops to 30 ft-L.

THE EFFECTS OF SURROUND LUMINANCE ON VISUAL COMFORT

Figure IV-18 presents mean values of surround brightness preferred by viewers of broadcast television for three surround areas at each of five values of peak screen luminance (Shurtleff, 1966).

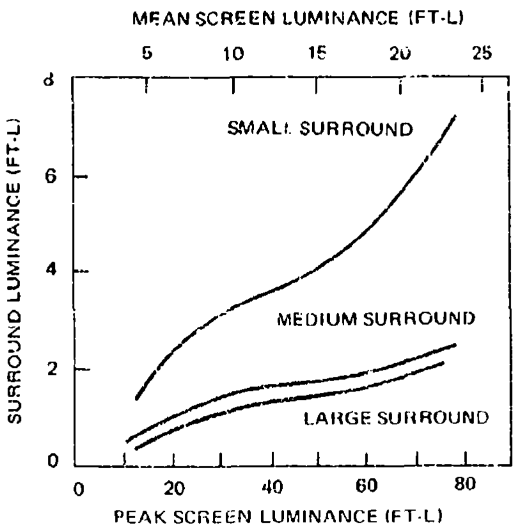


Figure IV-18
Mean Value of Surround Luminance Preferred by Viewers of Broadcast Television. Plotted for three surround areas at each of five values of peak screen luminance (Shurtleff, 1966).

TV display = 9° vertically, 12° horizontally
Small surround area = 12° vertically,
14° horizontally
Medium surround area = 17° vertically,
23° horizontally
Large surround area = 23° vertically,
32° horizontally

THE EFFECTS OF SIGNAL-TO-NOISE RATIO

One aspect of display quality affecting display acceptance and operator performance is the signal-to-noise ratio of the display. Quality of presentation has been judged satisfactory at 10:1, good at 30:1, and excellent at 50:1 (Bogatov, 1966).

In table IV-7 the percentage of comments in a specific category vs signal-to-noise ratio is given (Altman, M., et al, 1968).

TABLE IV-7

PERCENTAGE OF COMMENTS IN A GIVEN CATEGORY VS SIGNAL-TO-NOISE RATIO

S_{BW}/N_{rms}	50 dB	45 dB	40 dB	35 dB	30 dB
Impairment only slight (if at all)	98%	90%	65%	35%	10%
Not objectionable	99% to 100%	96%	85%	60%	30%
Somewhat objectionable	---	4%	10%	20%	25%
Definitely objectionable	---	---	5%	20%	45%

CHAPTER V

TELEVISION DISPLAYS FOR GROUP VIEWING

INTRODUCTION

This chapter discusses the parameters most important for group viewing of *TV* displays. *Parameters not discussed here will be found in Chapters III and IX.*

Summary of Recommendations

1. Symbol size - At least 10 minutes of arc at the eye of the observer in the worst position in the viewing area. This will give 95% accuracy. For 98% accuracy a visual angle of 14 minutes is required.

2. Viewing angle – Maximum off-axis angle of 30°.

3. Resolution – 15 lines per character height

4. Bandwidth – 2.5 MHz

5. Viewing distance – See section on choosing the maximum viewing distance from the screen

6. Determination of screen size and number of characters as a function of viewing distance – See 5. above.

7. Request response time – 1-3 seconds

8. Display generation response time – 1-2 seconds

9. Screen luminance – Not more than 35 ft-L for normal ambient lighting

10. Brightness contrast – 90%

11. Registration accuracy – 10 seconds of arc at the nearest observer

SYMBOL SIZE

In a group viewing situation, letters must be large enough to produce at least 8 minutes of visual angle (preferably 14 minutes) at the eye of the observer in the worst position in the viewing area (30° off-axis). This should produce 95% accuracy of identification of random characters (Neal, 1968).

VIEWING ANGLE

Under conditions where resolution (lines per character) and symbol size produce at least 90% identification accuracy at 0 degrees off-axis (90° straight on), there is no decrement in legibility until the off-axis angle becomes 40°. Under less favorable size and resolution conditions, the effect of the off-axis angle is more severe, reducing legibility significantly at 20° (fig. V-1) (Neal, 1968). *The maximum off-axis angle should be 30°.*

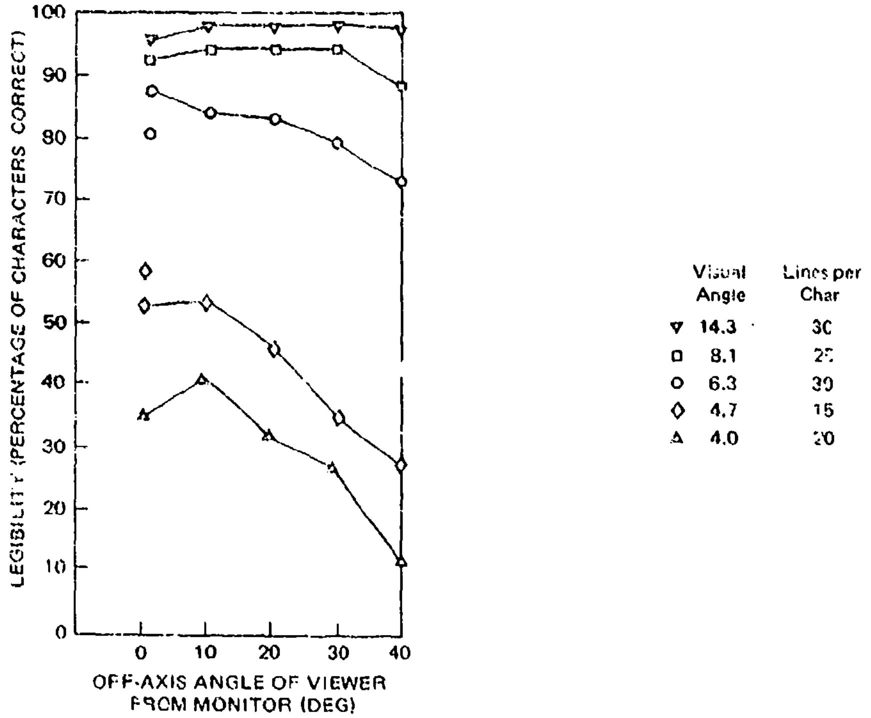


Figure V-1
Average Legibility as a Function of Off-Axis Angle for Five Representative Test Conditions

The adverse effect of oblique viewing is not a straight conic projection from the screen, but rather is geometrically described by "the surface of a sphere tangent to the plane of the display." The diameter of that sphere equals the recommended viewing distance for that particular display size. Figure V-2 presents the locus of marginal legibility for a constant visual angle (Luxenberg and Kuehn, 1968).

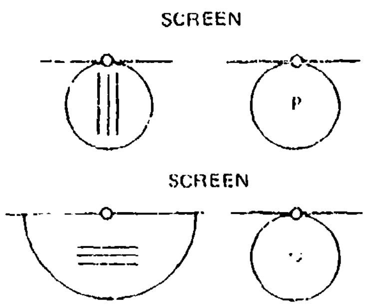


Figure V-2
Loci of Marginal Legibility for Resolution Bars and Letter P. The symbols are displayed at eye level on a vertical screen: above in upright position, below turned horizontal. The locations of the symbols are indicated by the small circles.

RESOLUTION

For group viewing, a minimum vertical resolution of 15 lines per character height is recommended when small visual angles are involved. At 15 lines per character, the ratio of the character height to the total display height is 1/33, and 16 rows of characters can be put on the screen (as long as the screen is small enough to keep the visual angle within 8 min of arc) (Neal, 1968). (See figure V-3 below; see also figure IV-7 and RECOMMENDED SYMBOL SIZE in chapter IV.)

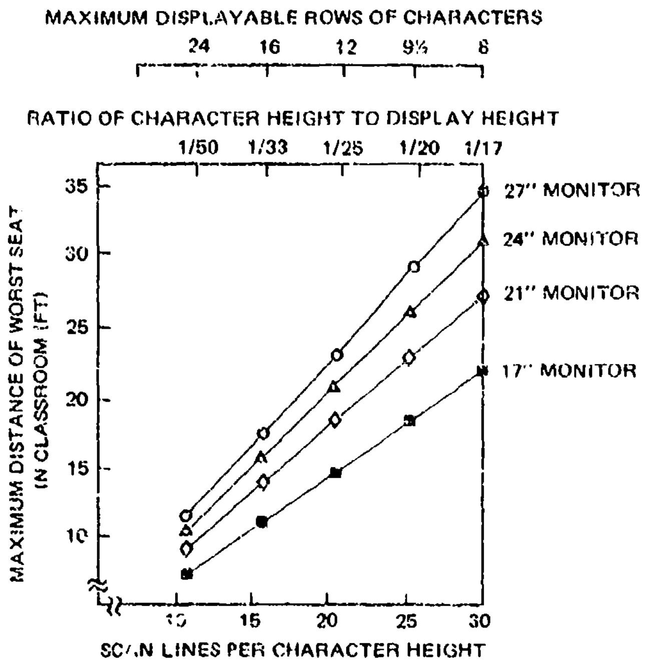


Figure V-3
Maximum Viewing Distance for Worst Seat in Classroom
(maintaining a minimal 8 minutes visual angle at the eye)
(Neal, 1968)

BANDWIDTH

For group viewing of a large television screen (17 inches or more) a bandwidth of approximately 2.5 MHz is recommended. There is no improvement above this point but decrement below it.

CHOOSING THE MAXIMUM VIEWING DISTANCE FROM THE SCREEN

Figure V-3 above shows the maximum viewing distance from various size monitors calculated to maintain the recommended minimum visual angle (8 minutes). For a symbol resolution of 15 lines, the recommended maximum distances for various monitor sizes are:

27-inch monitor – 18 feet
24-inch monitor – 15 feet
21-inch monitor – 13 feet
17-inch monitor – 11 feet

Another way to increase the maximum viewing distance is to choose larger characters, although this will reduce the total number of characters that can be placed on the display. For example, figure V-3 shows that as the character height increases from 1/33 of screen height (15 scan lines) to 1/17 (30 lines) the maximum viewing distance increases from 18 feet to 35 feet from a 27-inch monitor or from 11 to 22 feet from a 17-inch monitor. However, the maximum number of rows of characters that can be placed on the screen decreases from 16 rows with the smaller characters to 8 rows with the larger (Neal, 1968).

RESPONSE TIME

Response time is the major, if not the only, justification for automating display systems. The faster a requested display becomes available upon request, the greater the impact the display has on system operations. Request response time should be on the order of *1 to 3 seconds* (RADC, 1965).

Display generation response time is defined as the time from intitiation of computer output until the complete display is available to the user. *1 to 2 seconds is desirable.*

LUMINANCE

Luminance ratios required for comfortable viewing of large screen displays may be determined by locating two values: (1) the minimum ratio required for adequate viewing and (2) the maximum measure of luminance without annoying aftereffects. The maximum luminance for group displays should not be more than 35 ft-L. Higher luminance may produce afterimages if the display is viewed for an extended period of time. An increase in luminance over 15 ft-L up to the 35 ft-L maximum contributes little to acuity.

An optimum luminance distribution on the surface of the display is approximately 17 ft-L measured from central axis, and not less than 13 ft-L measured at the largets angle of view off-center. Assuming an ambient light level of 1 ft-C on the display, this permits viewing in about 10:1 contrast for symbols with regard to background.

Luminance contrast should be maintained at 90%.

AMBIENT ILLUMINATION

To minimize glare, light sources should not be located within 60° of the viewer's central visual field. Light should be diffused and distributed evenly over the work area. The ratio between light and dark portions of work surfaces should not exceed 7:1.

REGISTRATION ACCURACY

The maximum symbol registration accuracy considered necessary is 10 seconds of arc with respect to the nearest observer. Registration requirements more accurate than this are unnecessary, since an observer cannot appreciate the difference.

CHAPTER VI

CODING

INTRODUCTION

This chapter discusses the following topics:

1. When coding is required

2. Advantages and disadvantages of available codes

3. Types of codes best for particular applications

    a. Color
    b. Alphanumeric
    c. Shape
    d. Size
    e. Flash
    f. Special codes

4. Amount of improvement produced by coding

5. Coding in indicator displays

Definition

Coding is putting information in symbolic form to increase the amount of information supplied while minimizing display space. In figure VI-1 the shape of the symbols indicates the type of airport facilities available.

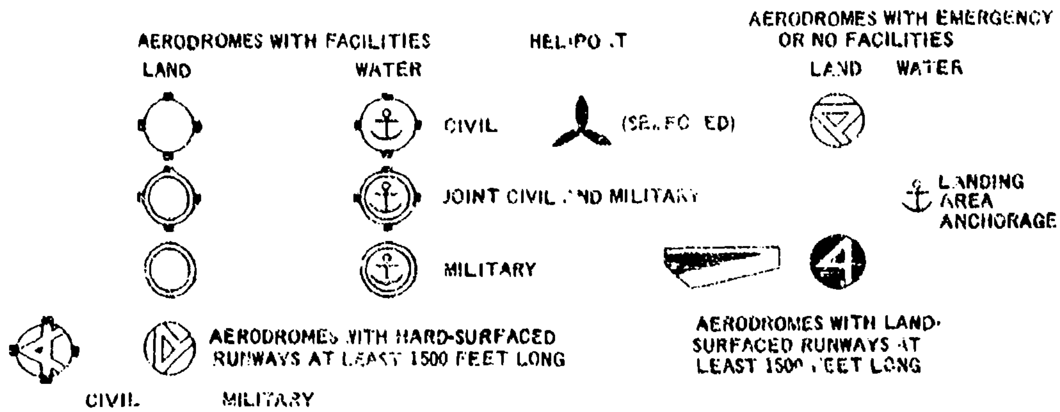


Figure VI-1
Sample Coding (military map symbols)

Coding Requirements

Coding requirements differ for:

1. Projected displays: CRT and slide projected displays

2. Indicator displays: indicators, legend lights, and meters

and as a function of mission requirements.

Coding should be used:

1. When much information must be presented in a single display (100 or more characters)

2. When the observer's task may be difficult (10% complexity – percent of characters which must be discriminated)

3. When he must respond quickly:

   a. In less than 10 seconds – coding is required

   b. Within 10-20 seconds – coding is desirable

   c. Over 20 seconds – coding is not necessary

Coding Criteria

Codes should be:

1. Visible

2. Legible

3. Discriminable (observers must be capable of distinguishing between two or more characters)

4. Compatible (see figure VI-2)

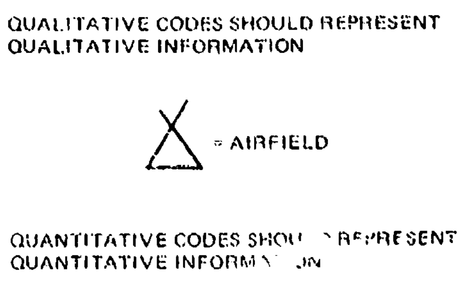


Figure VI-2
Compatible Coding Requirements

Coding Categories

Codes may be divided into the following categories:

1. Single coding

   4 = 400 knots

2. Redundant coding

   4 = 400 knots (both numeral and square indicate 400 knots)

3. Compound coding

   4 = 400 knots (numeral means 400 knots; triangle means jet powered aircraft)

ADVANTAGES AND DISADVANTAGES OF AVAILABLE CODES

Figure VI-3 indicates most and least used codes.

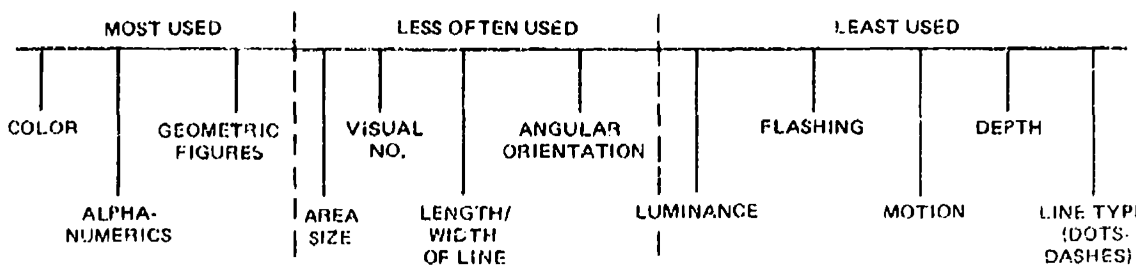


Figure VI-3
Most and Least Used Codes*

At any given time the observer is capable of identifying about seven (± two) alternatives along a single coding dimension. As the number of alternatives increases, speed and accuracy decrease in a linear manner (Howell et al, 1966).

*Does not imply a scale of desirability, only frequency of use.

DESIGN ANALYSIS

When Should Coding be Used?

<u>**How Many Data Points Must the Display Have Before Coding is Necessary?**</u> Factors to be considered are:

1. Density – Number of characters/data points in display (100 or more).

2. Complexity – Percent of characters irrelevant to observer's task. (The designer may not be able to define complexity in detail in advance of design. Where it is suspected, however, that as many as 10% of display characters may have to be disregarded by the observer, coding should be employed.)

3. Speed of updating – The faster displayed information must be updated, the more coding of that information is required. However, quantitative information on speed requirements is not available.

As density and complexity increase, observer accuracy is reduced and coding becomes important. Figure VI-4 illustrates accuracy in updating information. Figure VI-5 illustrates percent of observational cycles (trials) in error when *counting* characters. Note that these graphs and others in this chapter represent data gathered under relatively ideal laboratory conditions.

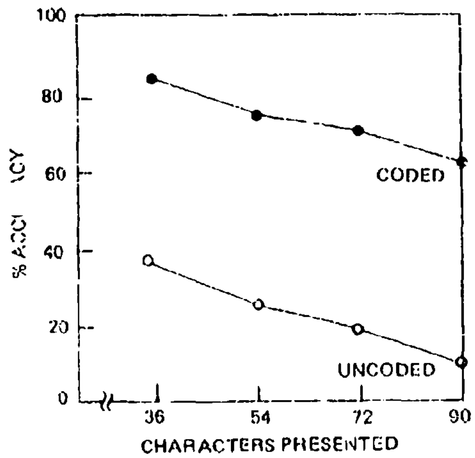


Figure VI-4
Accuracy of Updating Displayed Information
as a Function of Density (Hammer and Ringel, 1966)

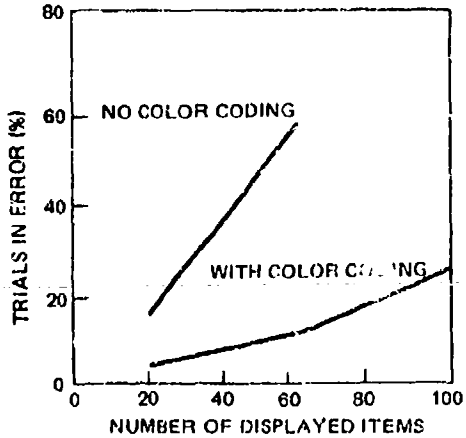


Figure VI-5
Counting Errors as a Function of Display Density
With and Without Color Coding (Smith, S. L., 1963)

Figure VI-6 shows how correct identification of alphanumerics decreased as complexity increases (percent of task irrelevant characters) (Dyer and Christman, 1965).

How Short Must Display Exposure Time be Before Coding is Necessary? As display exposure time is reduced, observer accuracy decreases correspondingly. Figure VI-7 demonstrates that the curve of correct observer performance is almost a perfect linear relationship with exposure time.

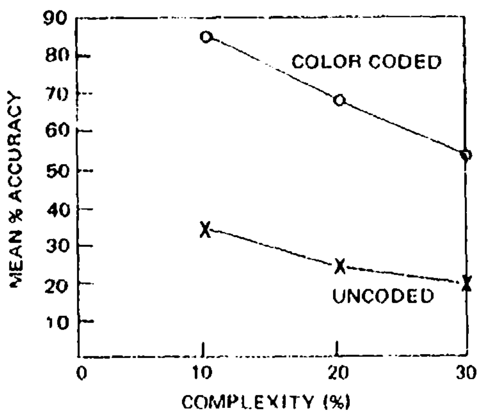


Figure VI-6
The Effect of Complexity on Accuracy
(Dyer and Christman, 1965)

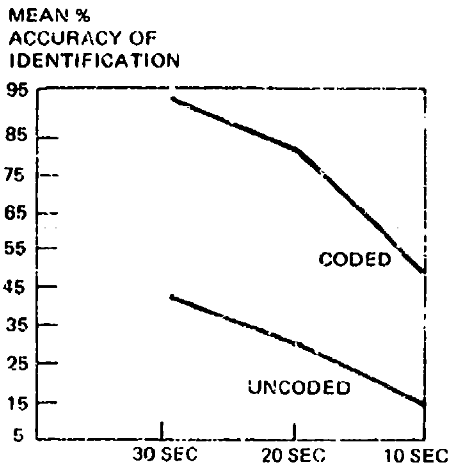


Figure VI-7
The Effect of Display Exposure Time on
Accuracy of Identification (Smith, S. L., 1963)

What Type of Coding is Best for Particular Applications?

The designer must consider:

1. Code type (e.g., color, shape, alphanumeric)

2. Code characteristic (e.g., if color, which color; if geometric figure, which figure?)

3. Observer's task (locating, counting, identifying, updating)

Available information is incomplete. Comparisons have been made between color and three shape codes (military symbols, geometric forms, and aircraft shapes) for *counting*. The codes used in this study (Wolf and Zigler, 1959) are shown in figure VI-8.

Average counting time for these codes is shown in figure VI-9, and percent of trials in error is shown in figure VI-10. Color is superior at all density levels to even the best of the shape codes. *This applies, of course, only to counting or searching for characters.*

Recommended Practice --

1. Use alphanumerics when identification is most important.

2. Use color when *searching* or locating is most important.

3. Use symbols/shapes when qualitative objects are represented.

COLOR (MUNSELL NOTATION)	MILITARY SYMBOLS	GEOMETRIC FORMS	AIRCRAFT SHAPES
GREEN (2.5G 5/8)	RADAR	TRIANGLE	C-54
BLUE (5BG 4/5)	GUN	DIAMOND	C-47
WHITE (5Y 8/4)	AIRCRAFT	SEMICIRCLE	F-100
RED (5R 4/9)	MISSILE	CIRCLE	F-102
YELLOW (10YR 6/10)	SHIP	STAR	B-52

Figure VI-8
Codes Used in Code Comparison Study

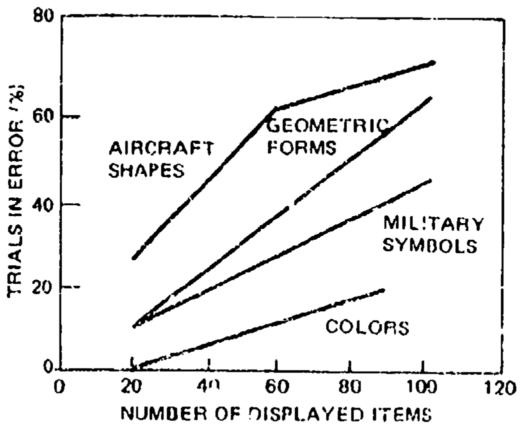


Figure VI-9
Counting Errors as a Function of Display Density,
Comparing Color Coding With the Three Shape Codes
(Wolf and Zigler, 1959)

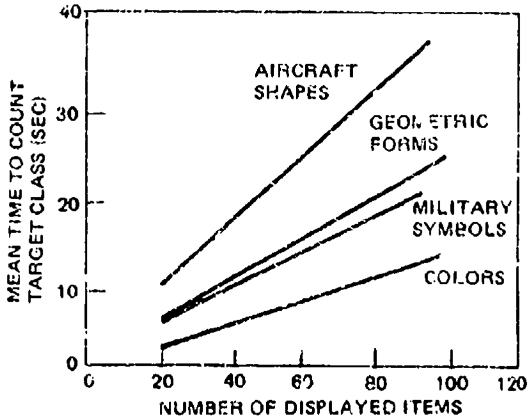


Figure VI-10
Average Counting Time as a Function of Display Density, Comparing Color Coding with the Three Shape Codes (Wolf and Zigler, 1959)

Individual vs Group Displays

There is some evidence that individual displays are slightly superior to group displays when *updating uncoded* displays. However, this difference becomes insignificant when displays are coded (fig. VI-11).

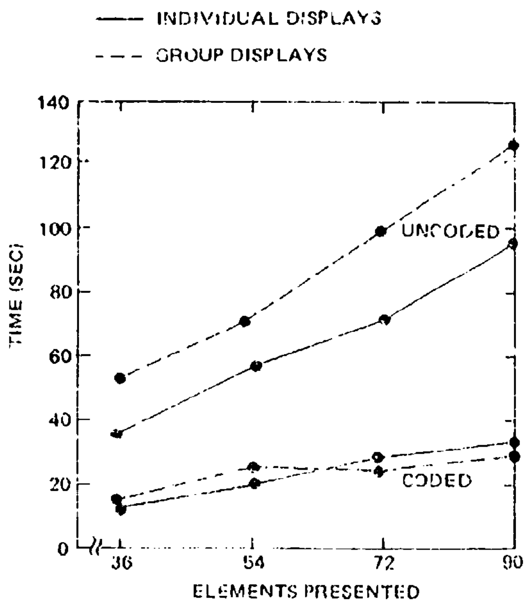


Figure VI-11
Mean Time for Coded and Uncoded Charts at each Level of Elements Presented (Allusi and Martin, 1958)

Should Single, Redundant or Compound Coding be Used?

There is some evidence (Allusi and Martin, 1958) that redundant coding is slightly more effective than single coding.

How Many Coding Levels Should be Employed?

Coding level -- Values within each code type (e.g., color) which are equally identifiable (e.g., red, yellow, green).

General rule -- Use as few coding levels as necessary. Code steps in table VI-1 are maximum values under laboratory conditions. For operational use, it is desirable to *halve* these values. The effect of increasing code levels on operator performance is to reduce observer accuracy (fig. VI-12).

TABLE VI-1
ADVANTAGES AND DISADVANTAGES OF AVAILABLE CODES
(Baker and Grether, 19[illegible])

Code	Maximum No. Code Steps*	Evaluation	Advantages/Disadvantages
Color	Slides – 5-7 CRT – 3-5 Paint – 7-11	Good	Little space required. Objects easily identified, low training requirement.
Alpha-numerics	Unlimited combinations	Good	Little space required if good contrast and resolution. Longer identification time than color.
Shape (geometric figures)	10-100 pictorial	Good	Little space required if good resolution.
Area/Size	3	Fair	Requires considerable display space.
Length/width of line	4-5	Fair	Clutters display.
Visual no.	6	Fair	Requires considerable display space.
Angular orientation	8	Fair	95% of estimates will be in error by less than 15°.
Luminance	3-4	Poor	Poor contrast reduces visibility. Difficult to distinguish between any two brightness ratios.
Flash rate	3	Poor	Distracting and fatiguing. Difficult to distinguish between more than two flash rates unless the rates are very different. Extremely useful as an alerting or warning signal.

*Generally will give overall accuracies of 95% or better. All figures given are for laboratory conditions. For operational displays, it is better to be conservative.

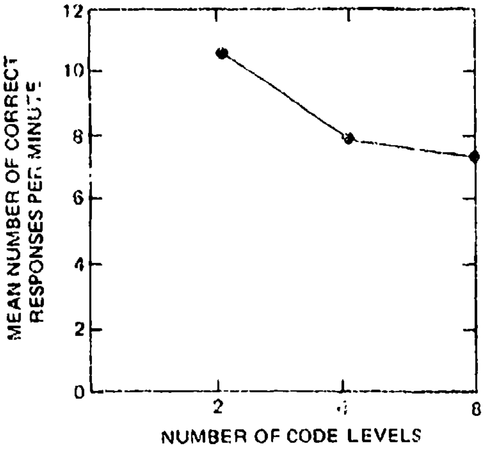


Figure VI-12
Effect of Number of Code Levels on Observer Performance (Anderson and Fitts, 1958)

HOW MUCH IMPROVEMENT IN OBSERVER PERFORMANCE CAN ONE EXPECT WITH CODING?

Table VI-2 indicates that coding produces marked improvement in observer performance.

TABLE VI-2
IMPROVEMENT IN OBSERVER PERFORMANCE WHEN DISPLAYS ARE CODED

Original Displays	Code Type	Observer Function	% Accuracy Improvement	% Response Time Improvement
Alphanumerics	Color	Locating	44	
Alphanumerics	Color	Counting	86	72
Alphanumerics	Size	Update	50	65
Map	Conspic-uity (border)	Information assimilation and extraction	97 & 57	
Alphanumeric and Shape	Color	Search and count	15 53	5-25
Alphanumeric	Size	Update	49	

ADDITIONAL FACTORS TO BE CONSIDERED

Which codes to use and how depends in part on display parameters discussed in earlier sections. Any parameter which reduces display visibility increases display difficulty level and the need for coding. The following factors are especially important.

Display Brightness/Resolution/Contrast – If display brightness or resolution are expected to be significantly less than levels recommended earlier, alphanumeric coding is preferable to color or shape (geometric figure) coding. If alphanumeric coding can't be used, then shape coding is preferable. (See also figure VI-3 and table VI-1.)

For the display of color coded points or small symbols, an empirical spacing of at least three lines is required to prevent color fusing (Wolf Research and Development, 1968).

The optimum range for display contrast when a seven-color display is being used is 20-30:1. But, acceptable levels of performance have been recorded at as low as 10:1 for an additive color display (Rizy, 1967).

Display Formatting – In formatted displays, characters are distributed by rows, columns, or quadrants; in unformatted displays, characters are distributed randomly. Coding is more likely to be required in unformatted displays.

The following sections present detailed information on each of the major code types.

COLOR CODING

When Color Coding Should Be Used

Use particularly when the observer must *search for* or pick out one or more characters from a matrix of displayed characters. On the other hand, for *identification* of characters (i.e., recognizing their meaning) an alphanumeric code is more useful (Avakian, 1964).

Which Colors Should Be Used

The number of chromatic colors which can be absolutely identified is 9-11 (paint chips). However, one would not use more than 3-5 colors for CRTs and 5-7 for projected slide displays. The nine chromatic and achromatic colors in common use are presented in table VI-3.

Color Usefulness

For a three-category color code for CRTs, use red, yellow-orange, and green or green-blue (Rizy, 1967).

For projected displays the colors of greatest effectiveness, with regard to observer performance, are shown in figure VI-13.

Several "less-than-seven" color systems might be employed in specialized circumstances wherein the full seven color complement is not required.

For example, a six-color subtractive display (without yellow) might be used. The same recommendations for apparent size and contrast would hold.

TABLE VI-3A
RECOMMENDED CHROMATIC COLORS

Color Name	Munsell Book Notation	Chromaticity Coordinates	Dominant Wavelength (nm)	Federal Spec 595 Equivalents (paint chips)
Purple	1.0 RP 4/19	x - 0.2884 y - 0.2213	430	27144
Blue	2.5 PB 4/10	x - 0.1922 y - 0.1673	476	15123
Green	5.0 G 5/8	x - 0.0389 y - 0.8120	515	14260
Yellow	5.0 Y 8/12	x - 0.5070 y - 0.4613	582	13538
Orange	2.5 YR 6/14	x - 0.6018 y - 0.3860	610	12246
Red	5.0 R 4/14	x - 0.6414 y - 0.3151	642	11105

TABLE VI-3B
RECOMMENDED ACHROMATIC COLORS

Color Name	ISCC-NBS Symbol	Munsell Value	Chromaticity Coordinates	Federal Spec 595 Equivalents
Black	Bk	N1.0 or lower	x - 0.3151 y - 0.3425	17038
Gray	Gy	–	x - 0.3100 y - 0.3160	16187
White	White	N9.0 or higher	x - 0.3137 y - 0.3222	17886

A five-color additive system might be employed, omitting blue and red, where optimum contrast cannot be maintained.

A four-color additive system, using white, yellow, red, and magenta (where small symbol sizes, below 26 minutes of arc, must be used), could also be employed (Rizy, 1967).

Disadvantages of Color Coding

__Brightness/Resolution/Contrast.__ Reading performance for color coded displays deteriorates when contrast levels drop below 10:1, particularly for colors at the blue end of the spectrum (Baker and Grether, 1954). Above this level, the use of color coding tends to reduce the overall contrast level required for the display.

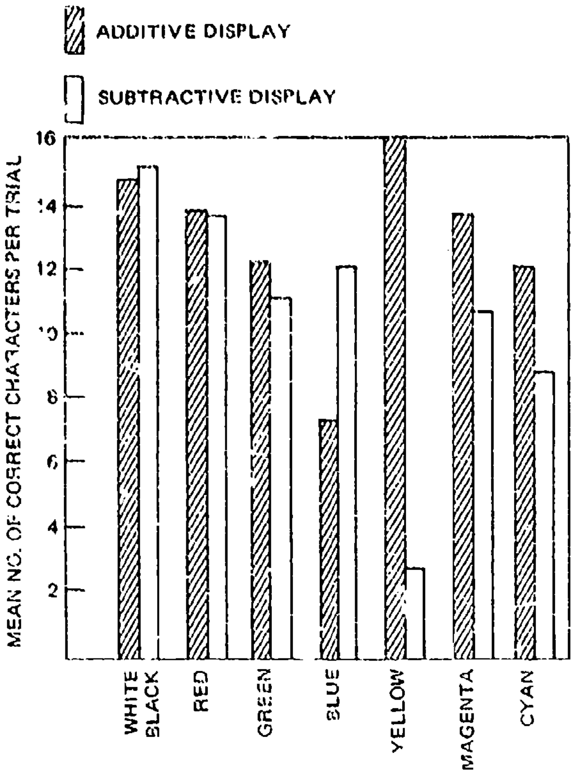


Figure VI-13
Relative Readability of the Seven Color Code in Additive and Subtractive Displays (Rizy, 1967)

Reading performance for color coded displays is affected by the angular size and color of the symbology as shown in figure VI-14 (Rizy, 1967).

Capabilities. CRTs are presently not capable of producing more than four colors, where 100% reliability of judging color is required. In addition, character size should be as large as possible (up to 20 minutes of visual angle) since color perception tends to degrade as fisual angle decreases. Blue is seen as purple and purple as yellow, etc.

Color Weakness. Where color weakness is considered to be important, use only "aviation red," "aviation green," and "aviation blue," as they are highly discriminable for surface colors on white background at moderate distances (Army-Navy Aeronautical Specification AN-C-56) (Bendix Corp., 1963).

Misregistration (Rizy, 1967). In displaying color additive displays, misregistration should not exceed 65% of stroke width (see fig. VI-15). This, however, is under relatively ideal laboratory conditions. For operational use, a more suitable value would be 50%. The greatest impact of misregistration occurs with blue and green (fig. VI-16).

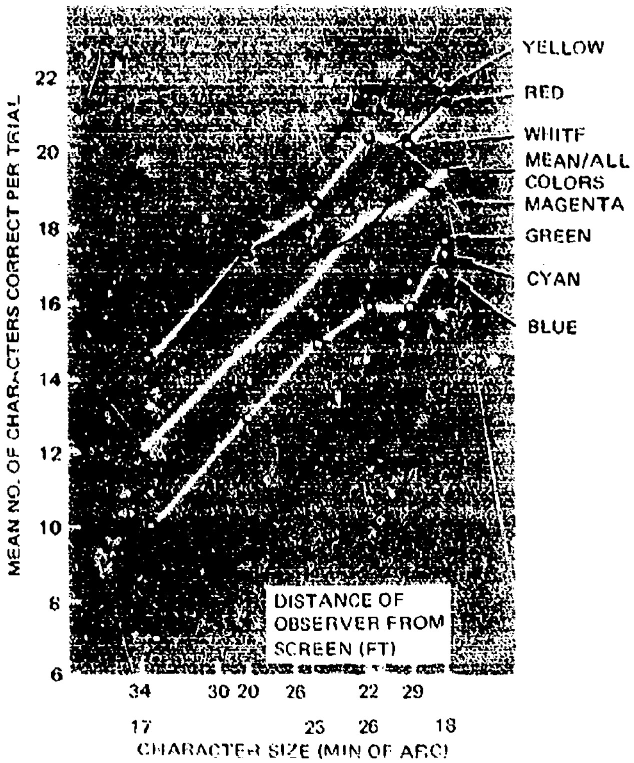


Figure VI-14
Subject Performance in Reading Color-Coded Alphanumerics as a Function of Size and Color (Reed, 1951)

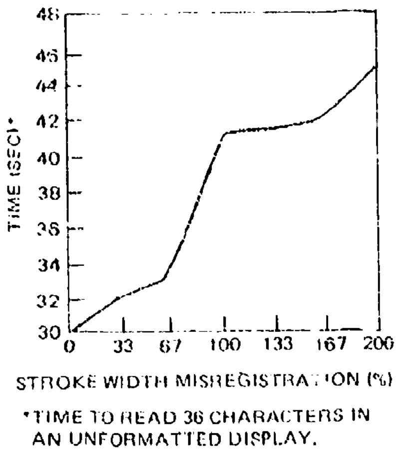


Figure VI-15
Response Time as a Function of Misregistration (Snadowsky et al, 1964)

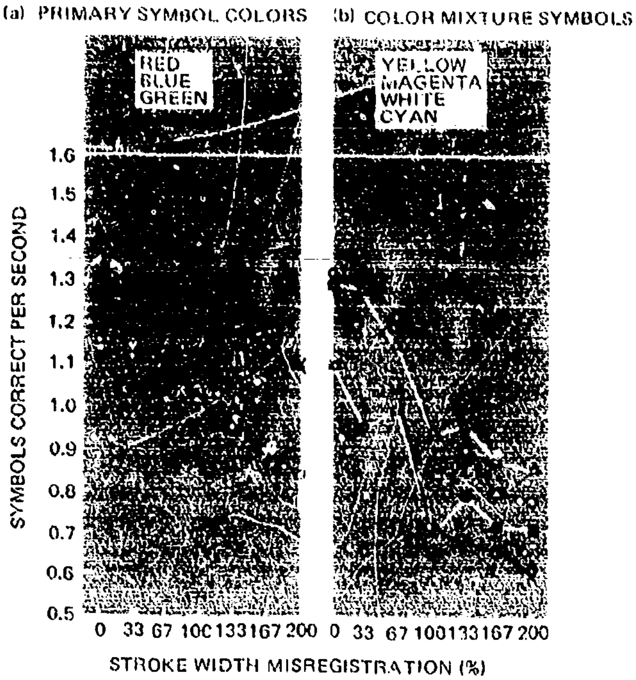


Figure VI-16
Viewer Performance as a Function of Misregistration and Symbol Color (Shadowsky, et al, 1964)

Anticipated Performance With Color Coding

The performance to be expected from color coding as a function of density and display exposure time is shown in figure VI-17 (Dyer and Christman, 1965). For the relationship between complexity and color coding, see figure VI-6.

Recommended Practice

From the results shown in figure VI-17, color is recommended for coding alphanumeric displays under any of the following single or combined conditions:

1. Density: 100 or more characters

2. Display exposure time: 10 seconds or less

3. Complexity: 10% or more

Although the data pertain only to alphanumeric displays, in the absence of anything else, it is recommended that the same standards be applied for other display types.

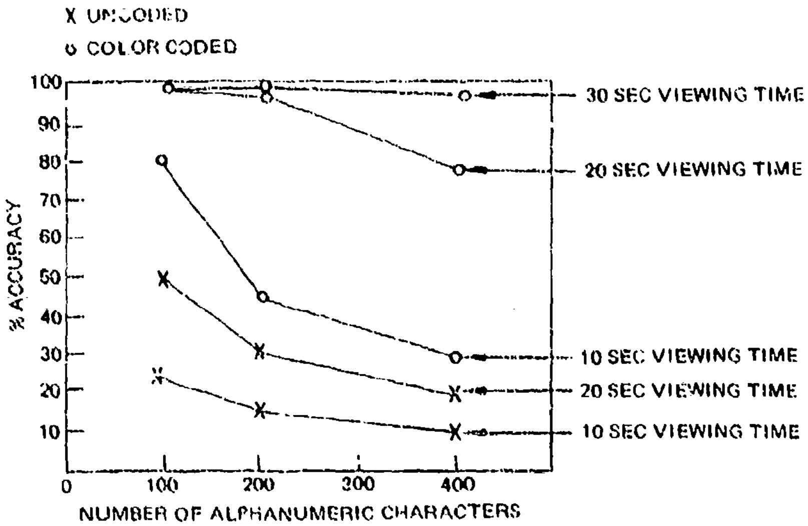


Figure VI-17
The Effect of Density and Display Exposure
Time on Accuracy (Dyer and Christman, 1965)

OTHER RELATIONSHIPS

1. Color would seem to place constraints on acceptable symbol size. A lower limit of 16 minutes of arc was found to be inadequate for a reading task. 26-27 minutes of arc is recommended for color coded alphanumeric characters (Rizy, 1965).

2. Low ambient (0.001 ft-C) or chromatic illumination causes general observer performance decrement with surface colors. For example, green appears black under red ambient light.

3. For map type group displays, if the background is mottled or patterned, use:

a. A color which contrasts most with all colors in background

b. A brightness which differs maximally from the background

c. A fluorescent color

d. As large an area of solid color as possible (stripes and checkerboards tend to blend at distances and lose configuration)

e. If the background color cannot be predicted, a target divided into two areas of solid contrasting color has increased chance of being visible. Suggested color pairs for two-toned targets are:

white-red
bright yellow-blue
bright yellow-black
bright green-red (Leibowitz, 1967)

ALPHANUMERIC CODING

When Alphanumeric Coding Should be Used

Alphanumeric coding is particularly useful when the observer's task is largely *identification* of a character set. Outside of the particular advantage color codes have for locating the desired character set (shorter search time), alphanumerics are about as effective as color codes (see table VI-4). In addition, they are much less expensive and technically difficult to display than color codes.

TABLE VI-4
THE EFFECT OF CODING METHODS ON OPERATOR TASKS

	Rank Order of Code Categories				
Tasks	1	2	3	4	5
Identify	Numeral 13.64*	Letter 13.02	Shape 12.53	Color 12.34	Configuration 11.77
Locate	Color 8.46	Numeral 7.42	Letter 7.25	Shape 6.94	Configuration 4.03
Count	Numeral 12.60	Color 12.22	Shape 11.49	Letter 11.11	Configuration 7.07
Compare	Numeral 6.85	Color 6.72	Shape 6.56	Letter 6.33	Configuration 4.76
Verify	Numeral 10.01	Color 9.95	Shape 9.50	Letter 9.05	Configuration 6.60

Alphanumeric Code Levels

Unlike other forms of display coding (where levels within the code category are highly restricted), there is no practical upper limit to the number of alphanumeric combinations which can be used by the designers. Search time, however, increases with an increased number of alphanumerics (see Smith, S. L., 1963 and figures VI-5 and VI-6).

Recommended Practice

Best use of letters and numbers is in short code words for items which represent one of a kind (e.g., three-letter code names for cities).

For other alphanumeric recommendations, see Chapter IV.

SHAPE (GEOMETRIC FIGURES) CODING

When Shape Codes Should be Used

Shape coding should be used when color is not feasible or too expensive, and particularly to represent qualitative objects.

*All scores reported in terms of mean correct response per minute.

Recommended Practices

Select shapes or symbols which are associated with the real objects they represent (e.g., airplanes for aircraft, ships for ships). Only those symbols should be used which are: simple, symmetrical, have a continuous contour, relatively large enclosed area, are familiar to observers, and have a sharp angle or simple curves. The symbols shown in figure VI-18 (Silver and Cruikshank, 1965) have been found to be identified 100% of the time if their maximum dimension subtends a visual angle of 10 minutes of arc and if contrast and definition are near optimal. These symbols are for slide projected displays only. For CRT symbols, see Chapter III, TARGET SYMBOLS section.

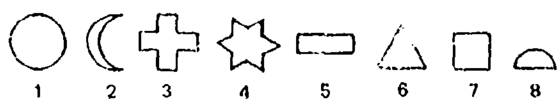


Figure VI-18
Common Geometric Symbols

Ten different symbols are a good upper limit; however, the fewer shapes used, the more easily they are recognized. Under adverse display conditions, no more than six should be used.

The circle, rectangle, cross, and triangle are the most distinctive common geometric forms. Squares, polygons, and ellipses should be avoided. Variations of a single geometric form, such as sets of round, pointed, and triangular characters, should be avoided.

Stroke width/height ratios of 1:6 to 1:10 and symbols 0.4 inch or larger are best for viewing up to seven feet (see table VI-5).

TABLE VI-5
MINIMUM SATISFACTORY SIZES FOR VISUAL SYMBOLS USED ON CRT DISPLAYS (HEL, 1965)

Symbol	Description	Dimension (in.)
Spots and Circles	Diameter	0.02
Squares and Rectangles	Length of short side	0.02
Lines	Width	0.005 (for bright line on dark background)
		0.01 (for dark line on bright background)

OTHER CODES

Other codes are not recommended unless color, alphanumeric, and shape codes are not feasible. The available information concerning these codes is as follows:

Size Coding

Size coding is infrequently used. A safe upper limit on number of sizes is 3. Beyond that number, errors become unacceptable. Steps coded in logarithmic progression are more easily discriminated than steps coded in linear progression (fig. VI-19) (Baker and Grether, 1954).

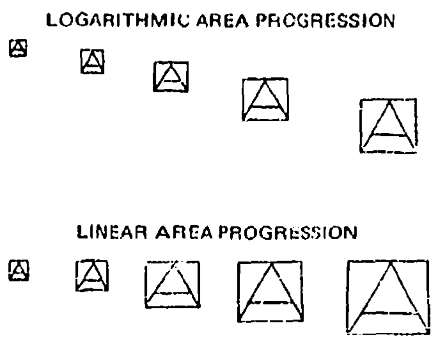


Figure VI-19
Steps Coded in Logarithmic Progression Are More Easily Discriminable Than Steps Coded in Linear Progression

Size can also be used in combination with alphanumerics. That is, in matrix-type alphanumeric displays, a larger type face can be used to emphasize particular characters or items of information (Hammer and Ringel, 1964; see figure VI-20).

When size is used in this way, the mean time to locate coded, updated information is 65% less than for uncoded updates, and errors of omission are reduced by 50%. As the number of characters is increased from 36 to 90, the mean time to locate coded updates is increased 100%, but that of uncoded updates is increased 150% (fig. VI-4).

Flash Rate Coding

This type of coding has been used primarily as an *attention-getting* device and should be reserved for emergency situations only.

Using several levels of flash rate information results in poor observer performance (Newman and Davis, 1962). Three flash rates should be the limit in any practical situation. These rates are: 0, 1.0/sec, 2.5/sec, and 5.0/sec, assuming a 50% on-off ratio.

FRIENDLY TACTICAL UNITS STATUS					
UNIT	ACTIVITY	EFF STRENGTH	TERRAIN	ARMOR STATUS	WEATHER
23	LANDING	77	FARMLAND	92	DAMP
72	REBUILDING	96	LOWLAND	85	ATTACKING
57	ASSEMBLING	87	RIVERS	91	SNOW
82	WITHDRAWING	78	JUNGLE	82	HUMID
53	ASSAULTING	80	MARSHLAND	76	RAIN

Figure VI-20
Example of Size Coding Updated Alphanumeric Information (Allusi and Muller, 1956)

Brightness Coding

Brightness coding is most effective when limited to *two* steps (dim and bright). It is not ordinarily recommended because (1) observer cannot reliably discriminate more than two levels; (2) ambient illumination may "wash out" the brightness display.

Special Codes

In radar-type displays, when the information to be displayed is *bearing, angular orientation* has been employed. With this coding, 50% of the course estimates were in error by less than 15°.

Inclinations of 0, 90, 180 and 270 degrees can be identified accurately. Inclinations of 45, 135, 225, and 315 degrees may be used if more bearing information must be displayed. Line length should be between 0.2 and 0.3 inches (HEL, 1965; see figure VI-21).

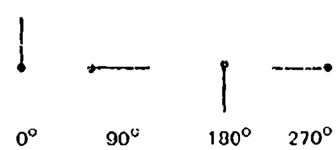


Figure VI-21
Inclination Coding

Angular orientation coding may also be used with banks of identical indicators in which direction of the pointer for normal operation has been standardized. Deviations from this normal direction indicate an abnormal condition. Minimum deviation of 45° from normal orientation is required for high probability of detection, 90° preferred (fig. VI-22).

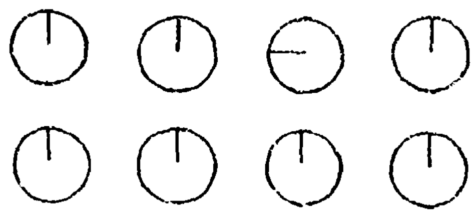


Figure VI-22
Angular Orientation Used with Indicators

Location Coding

Location coding may be accomplished by color coding different locations or by outlines around each unique displayed object or group of displays. An intensive border has also been used particularly with map displays (Hammer and Ringel, 1964)

This type of coding improved observer performance 97% when response time was limited, 57% when response time was unlimited, over unaided performance.

Coding Combinations

No more than two codes should be combined where rapid, accurate reading of the display is required.

Potential combinations of coding techniques (compound coding) are summarized in table VI-6.

TABLE VI-6

SUMMARY OF POTENTIAL COMBINATIONS OF CODING TECHNIQUES

	Color	Numeral and Letter	Shape	Size	Brightness	Location	Flash Rate	Line Length	Angular Orientation	Stereoscopic Depth	Pattern and Configuration
Color		X	X	X	X	X	X	X	X	X	X
Numeral and Letter	X			X		X	X				
Shape	X			X	X		X				X
Size	X	X	X		X		X				X
Brightness	X		X	X							
Location	X	X							X		
Flash Rate	X	X	X	X							X
Line Length	X								X		
Angular Orientation	X					X	X				
Stereoscopic Depth	X										
Pattern and Configuration	X		X	X			X				

CHAPTER VII

OPTICAL PROJECTION DEVICES

INTRODUCTION

This chapter discusses the display characteristics of projected images (i.e., slides, films, remotely projected CRT displays, etc.).

The following topics are covered:

1. Seating area and screen size
2. Image luminance
3. Ambient illumination
4. Projection screen types
5. Legibility of projected data

Summary of Recommendations

1. Symbol size -- 10-15 minutes of arc resolved at the viewer's eye
2. Aspect Ratio -- 1.33 to 1.48
3. Symbol stroke width -- 1/6 to 1/10 character height
4. Viewing distance -- 4 x image width
5. Viewing angle -- 20° to 30° (from the centerline of the display)
6. Image luminance -- 10 ft-L
7. Direction of light/dark contrast -- not important for legibility
8. Ambient light -- 0.02 ft-L (impinging on the center of the screen)
9. Contrast ratio -- 500:1 (measured with no film in the projector)

SYMBOL SIZE

The acceptable visual size for viewing projected alphanumeric characters is between 10 and 15 minutes of arc resolved at the viewer's eye. (Baker and Grether, 1972) This follows from essentially the same performance determined from research for TV displays (see Chapter IV, SYMBOL SIZE section).

ASPECT RATIO

Aspect ratios of between 1.33 and 1.48 are recommended (height/width) for greatest legibility. Stroke width should be in the range of 1/6 to 1/10 character height. Figure VII-1 presents screen dimensions as a function of aspect ratio.

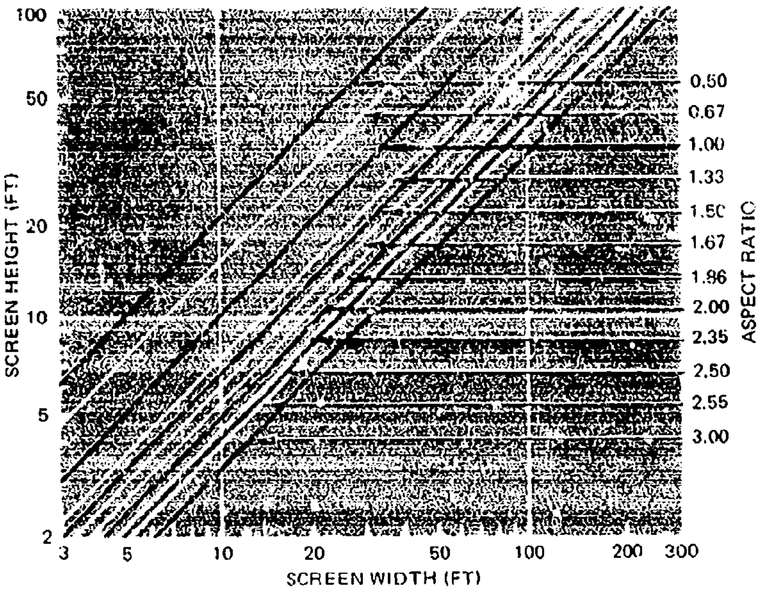


Figure VII-1
Screen Dimensions as a Function of Aspect Ratio (IES, 1959)

VIEWING DISTANCE

Viewing distance for projected displays is determined by a number of factors including resolution of picture detail, limitations of graininess and sharpness in the projected image, etc. Recommended viewing distances for small viewing areas (CICs, etc.) and auditoriums etc. are found in table VII-1 (IES, 1959).

TABLE VII-1
RECOMMENDED VIEWING DISTANCES (IES, 1959)*

	Small Rooms	Auditoriums
Front Row of Seats	3.0	1.2
Minimum Viewing Distance*	3.0	1.2
Maximum Viewing Distance	5.0	8.0

VIEWING ANGLE

The maximum recommended viewing angle for group viewing of slides and motion pictures is between 20-30° off the centerline of the display (Baker and Grether, 1972). Objectionable geometric distortions of the image on a *flat screen* become apparent at angles beyond approximately 30° off-axis to the screen.

*Dimensions given are in multiples of screen height

The adverse effect of oblique viewing is not a straight conic projection from the screen, but rather is geometrically described by "the surface of a sphere tangent to the plane of the display." The diameter of that sphere equals the recommended viewing distance for that particular display size. Figure V-2 (Chapter V) presents the locus of marginal legibility for a constant visual angle (Luxenberg and Kuehn, 1968).

IMAGE LUMINANCE

Screen luminance levels (measured with no film in the projector) are approximately 10 times the average luminance level of the images projected from normal film. Illumination falls off from the center as a function of screen type, decreasing as much as 20 to 40% at the screen's edge. The recommended screen luminance for small rooms is 10 ft-L with the recommended luminance for auditoriums and theaters being 10^{+4}_{-1} ft-L (IES, 1959).

Luminance variation across the screen should be held to 1.5 for:

$$\frac{\text{Maximum Illumination}}{\text{Minimum Illumination}}$$

(see projection screen types, below, for screen characteristics.)

DIRECTION OF LIGHT/DARK CONTRAST

Direction of contrast has not been proven to have any appreciable effect on detection performance.

CONTRAST RATIO

The recommended contrast ratio for viewing optically projected displays is 500:1, measured with no film in the projector. (Maximum image highlight brightness will normally be 25-60% of screen brightness.)

PROJECTION SCREEN TYPES

One of the primary factors responsible for the performance of optically projected systems is the type of projection screen used. Screens can be classified generally as *reflective* or *translucent*, depending upon whether the projected image is viewed from the same side as the projector (reflective) or from the opposite side (translucent). Reflective types may be either directional or non-directional depending on whether or not brightness changes with viewing angle (IES, 1959).

Mat Screens

Such screens are practically non-directional. Screen brightness is essentially the same at all viewing angles. Practical reflective mat screens have surfaces of high reflectance, but since the light is distributed throughout a complete hemisphere the maximum attainable brightness is limited. Most mat screens are about 85-90% efficient (IES, 1959).

Lenticular and Metallized Screens

Reflective or translucent screens incorporating uniformly shaped and spaced lens elements and/or metallized surfaces control the direction of light reflection so that maximum brightness will be obtained within certain specified viewing angles. The highest brightness for a given incident illumination is obtained with screens having lenticulated surfaces. Gain is typically 1.5 to 2.0 (IES, 1959).

Beaded Surface

This may be either a reflective or translucent screen; such a screen will appear the brightest when viewed along the axis of projection and will darken quite rapidly as the viewing angle increases away from the axis. Gain is typically 1.5 to 3.0 (IES, 1959).

Figure VII-2 presents the efficiency of various types of screens as a function of viewing angle.

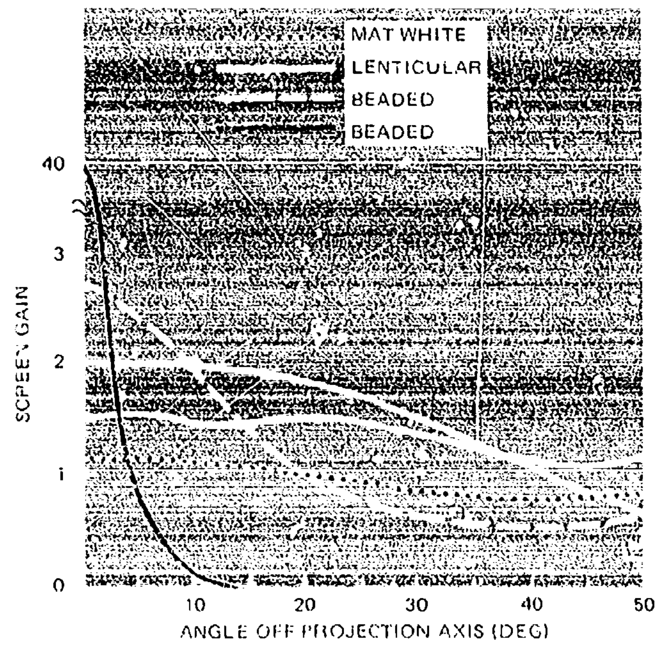


Figure VII-2
Gain vs Viewing Angle for *Typical* Front Projection Screens
(Baker and Grether, In Press)

AUDIENCE SEATING*

The modern trend for auditorium design is toward special treatment for each type of presentation, ranging from small lecture rooms to the huge sports arena. We are here limiting our recommendations to the lecture room and theater situations.

Inasmuch as slide and movie projectors are important elements of class or lecture rooms and theaters, the criteria for optimum viewing of the projection screen should govern the planning of seating arrangements.

1. DISTANCE from the screen — maximum and minimum. Optimum distances for viewing small screens are given in Table VII-2. Large screen viewing distances are shown in Figure VII-3.

* From Woodson and Conover (1964)

2. ANGLE at which the screen can be viewed — maximum.

3. STAGGERING or stepping (or both) of seats so that each person has as nearly unobstructed view of the screen as possible.

TABLE VII-2
SMALL SCREEN VIEWING DISTANCE

TELEVISION

TV Screen	Viewing Distance
9 in.	18–30 in.
15–17 in.	30 in.–6 ft
17–19 in.	6–10 ft
19–23 in.	10–20 ft
21–30 in.	20–30 ft

MOVIES

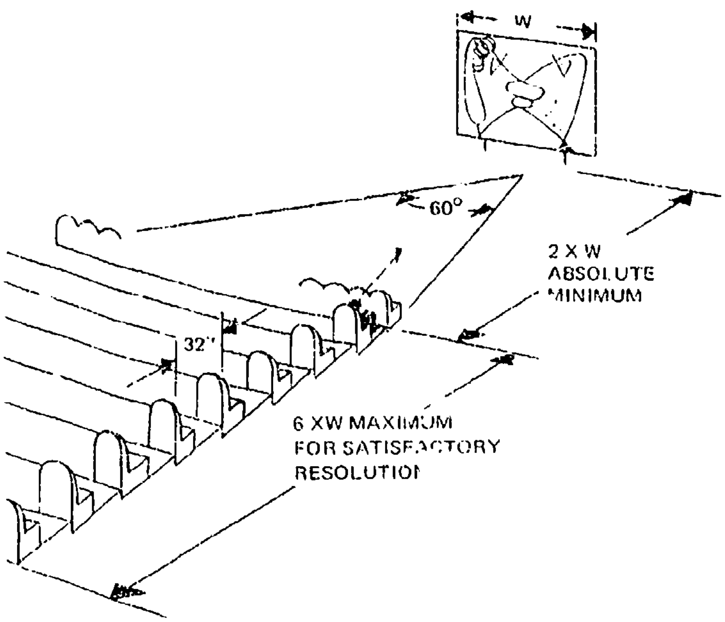


Figure VII-3
Large Screen Viewing Distance

SUMMARY OF TV AND PROJECTED DISPLAY DATA*

The following is a compilation of key performance characteristics and typically accepted numerical values for TV and projected displays.

1. Symbol size (minimum visual angle) -- 12-15 minutes of arc

2. Resolution (minimum number of TV scan lines per height of symbolic characters for adequate recognition) -- 10

3. Stroke width to height ratios for symbols -- 1:6 to 1:10

4. Character width to height ratio -- 0.75; should be closer to 1.0 if display is to be viewed at large acute horizontal angles

5. Misregistration (maximum acceptable for additive color mixing) -- ±65% of strokewidth

6. Minimum frame rate for display of continuous motion -- 7½-15 frames per second

7. Geometric distortion - displacement of any picture element should not exceed 1-2% (optimum) of picture height from true position; *acceptable* geometric distortion is defined by display application

8. Linearity -- ± x 1% acceptable, 0.2% desirable (depending upon application)

9. Display aspect ratio - commercial TV standards call for 4:3 width-to-height ratio; 5:7 or 2:3 are recommended for greatest legibility

10. Acceptable bandwidth -- 4.0-10 MHz

11. Viewing distance (for individual displays) - 18-20 inches. Also sometimes given as 28 inches, because this is average arm reach. For 28 inches the size dimensions of an optimal console display would be height -- 13 inches above eye level, 20 inches below; width - 20 inches on either side of the seat centerline

12. Viewing angle - not less than 30° off perpendicular axis. For console displays, 30° down from horizontal; 15° either side of direct line of sight.

13. Flicker -- display pulse rate should be compatible with CFF for the particular phosphor and driver combination being utilized

14. Display brightness -- line brightness of 50 ft-L in normal ambient lighting (lower intensities will be required for very low ambient light levels)

15. Contrast ratio: 90% (optimal)

16. Equipment response time -- should be in the range of 2-6 seconds; most desirable would be less than 3 seconds at the display station

* From Meister and Sullivan (1969)

CHAPTER VIII

DISPLAY LEGIBILITY

The material for this chapter was excerpted primarily from a rather old but thorough study conducted by human factors personnel at the Bendix Aviation Corporation, Radio Division, (Bendix, 1959). Once again a change in style is evident since this was primarily written as a research report rather than a design guide. However, the selected material provides a well-balanced handling of an area in which considerable confusion has prevailed. Its link to illumination is direct in that there are increased requirements for luminance and/or contrast with decreased display legibility. Furthermore, in suboptimal environments, such as aircraft cockpits, simultaneous attention to legibility and illumination is necessary for optimum viewing.

Material excerpted from other sources is so indicated.

DEFINITIONS

It has been repeatedly found that confusion in meaning causes much information to be lost in efforts to communicate ideas concerning legibility of displays between the customer, prime contractors, subcontractors, and vendors. The following terms are the worst offenders and, hence, are here defined:

1. Visibility — the quality of an item which makes it separately visible from its surroundings. An example may be taken from the alphabet. The letter "B" has three horizontal strokes, with two spaces between, making five elements in height to be seen. Likewise, it has vertical strokes at each side and a space between which makes three elements in width to be seen. If these three width elements and five height elements can be distinguished, we may say that the elements of the letter are visible. This example is a good indication as to why the popular nominal width-to-height ratio of type is given as 3:5. Normal human vision under average lighting can see an object subtending a visual angle of 1 minute. It follows then that a letter to be visible as a letter must be 5 minutes of visual angle in height. This is about 1/64th of an inch at normal reading distance. (This is a threshold, not a recommendation.)

2. Legibility — the quality of a letter or numeral which enables the observer to positively and quickly identify it to the exclusion of all other letters and numerals. In figure VIII-1 it can be clearly seen that different type styles possess different degrees of absolute legibility.

3. Readability — Figure VIII-2 was prepared originally as an illustration of a study of the shortcomings of available digital indicators in the matter of readability. In essence, readability may be defined as those qualities which contribute to easy recognition of words and whole numbers. Note that the small numerals of the lower right hand group are most easily readable as a whole number. Among the many factors involved are spacing of the individual characters, spacing of words, spacing of lines, and ratio of character area to background area.

Figure VIII-3 shows the distinction between readability and legibility in that the quality of readability is mainly determined by the dimensions of surroundings of the individual characters in relation to other characters, whereas the quality of legibility is mainly determined by the dimensions and style of the character itself.

4. Gothic type — A composite or a summary of dictionary definitions of the word "Gothic" will disclose that, in America, it means "any character which is of uniform stroke width and whose strokes terminate without decorations or embellishments called 'serifs'." In printer's parlance, it also includes styles which have very minor serifs designed to provide very sharp terminations. (This is a reference to Copperplate Gothic styles.) This American definition is spelled out here and there in government

Airport Black	ABCDEFGHIJK 1234567890
Franklin Gothic	ABCDEFGHIJKLMNO 1234567890
Square Gothic	ABCDEFGHIJKLMN 1234567890
Futura Demibold	ABCDEFGHIJKLMNOPQRSTUVW 1234567890
Futura Medium	ABCDEFGHIJKLMNOPQRSTU 1234567890
Tempo Medium	ABCDEFGHIJKLMNOPQ 1234567890
News Gothic Condensed	ABCDEFGHIJKLMNOPQRSTUVWXYZ 1234567890
Tempo Bold Condensed	ABCDEFGHIJKLMNOPQRSTUVWXY 1234567890
Gothic Medium Condensed	ABCDEFGHIJKLMNOPQRSTUVWXYZ 1234567890

Figure VIII-1
Comparative Legibility

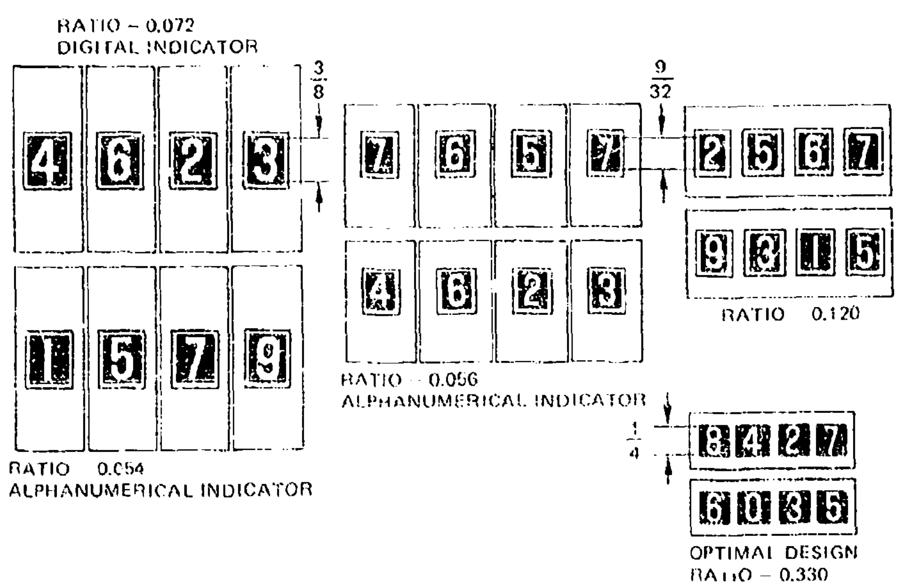


Figure VIII-2
Readability of Digital Indicators. A Typical Display Problem

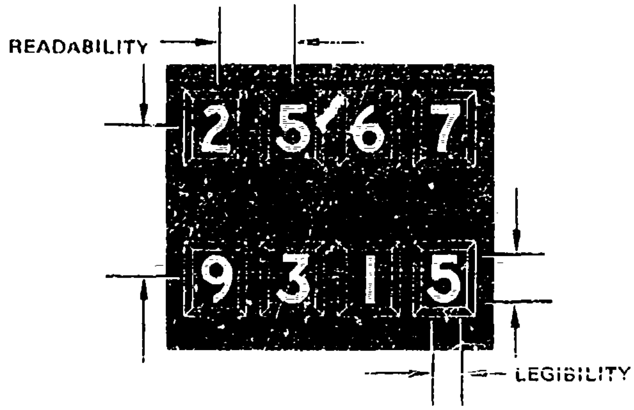


Figure VIII-3
Dimensions Which Affect Readability and Legibility

specifications. Unfortunately, however, there is another older, traditional definition. In the traditional definition used both in America and Europe, Gothic means just about everything that the specification definition does not. In this old definition, the strokes are not uniform, the strokes never terminate in a rectangular form, and serifs are all over the letters. The old English Gothic is our familiar Christmas style Much confusion has resulted from such a loose description of Gothic, but many earnest and competent equipment designers have gratefully accepted the design latitude that such looseness has provided them in solving difficult design problems.

5. Printer's terms of measurement -- It is not necessary to go into all the terms of measurement used by printers, but one term, the "point," has caused much loss of information in communication between interested parties in the field of displays in equipment design. The printer's "point" is 1/72nd of an inch. When used as a unit of measure it means just that, but when used as a measure of type size it means the size of the slug upon which the character is cast. Figure VIII-4 shows that the point measurement of the slug makes provision for lower-case characters to descend below the base line of the capitals and also provides spacing between lines. It can be stated as a general rule that a close approximation of character height expressed in points may be made by considering the point as being 1/100th rather than 1/72nd of an inch.

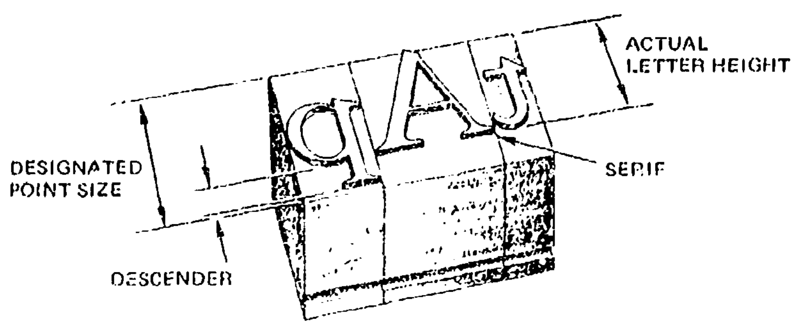


Figure VIII-4
The Meaning of the "Point" as Used in Defining Type Size

PREFERRED GOTHIC STYLES

A few of the Gothic styles are very archaic and should never be used. A tentative selection of preferred styles may be made, and such a selection is shown in figure VIII-5. A number of different names have been given to identical type styles by various type founders and manufacturers of machines and materials for various methods of preparation of copy for displays. Figure VIII-5 includes a preliminary study of such equivalents. A complete and accurate tabulation of this data on equivalents should be made for guidance of procurement and inspection personnel. Many man-hours and dollars are being lost by lack of this concise information, and more important, rejection of excellent work has been known to cause delay, in order to procure less desirable work, all because of lack of clear definitions of specification terms such as Gothic, point, width-to-height ratios, etc.

VERY LIGHT STYLES	
Futura Light	ABCDEFGHIJKLMNOP 1234567890
Futura Light; Headliner No. 48	
Lining Metrothin	
Metrolite	ABCDEFGHIJKLMNOPQRS 1234567890
Sans Serif Light	A B C D E F G H I J K L M 1 2 3 4 5 6 7 8 9 0
Tempo Light	ABCDEFGHIJKLMNOPQRSTU 1234567890
Vogue Light	ABCDEFGHIJKLMNOPQR 1234567890
LIGHT STYLES	
Futura Book	ABCDEFGHIJKLMNOPQRST 1234567890
Spartan Book	
Sans Serif Medium	ABCDEFGHIJKLMNOPQ 12345678
Sans Serif Medium Condensed	ABCDEFGHIJKLMNOP 1 2 3 4 5 6 7 8 9 0
Tempo Medium	ABCDEFGHIJKLMNOPQ 1234567890
MEDIUM STYLES	
Futura Medium	ABCDEFGHIJKLMNOPQRST 1234567890
Airport Gothic; Headliner No. 50; Spartan Medium	
Futura Medium Condensed	MEDIUM CONDENSED abcdefghijklm 608
Sans Serif Bold	A B C D E F G H I 1 2 3 4 5 6 7 8 9 0

Figure VIII-5
Tentative Selection of Preferred Styles (equivalents indented)

There are occasions when wide characters should be used. A typical example is a digital indicator using a wheel or tape to carry the characters to a position in a window. Generally, wheel diameter or tape length is restricted. This means limited character height, but space in width is usually available. It is undoubtedly because of nonavailability of legible extended numerals that specification MIL-P-7788 suggests extended styles for letters, but wisely suggests nonextended styles for numerals, even though extended (wide) numerals *could* be superior.

DESIGN OF TRANSILLUMINATED NUMERALS AND LETTERS*

Transilluminated types of displays require special height-width and stroke width specifications. . . . Special care must also be taken in engraving the sandwich materials, for the slightest variation in the engraving depth makes a great difference in the brightness of the emitted light. Designers are warned that the thickness of commercially available plastic sheets varies considerably and the engraving techniques ordinarily used will not give satisfactory results. *Engraving depth must be measured from the opaque top surface.*

Letters should be all capitals, similar to Futura Demibold type or Groton Extended engraving. Numerals should be similar to Futura Medium or Tempo Bold type or Groton Condensed engraving. For stroke width and height-width ratios, see figures VIII-6 and VIII-7.

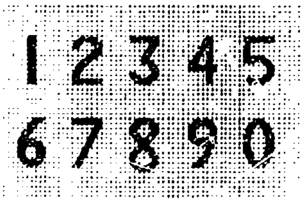


Figure VIII-6
Recommended Numerals for Engraved Legends

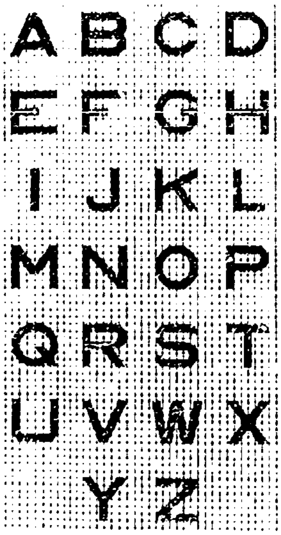


Figure VIII-7
Recommended Letters for Engraved Legends

Letters may be reduced in size to a height-width ratio of 5:3 when there is not sufficient space for the 1:1 ratio shown.

* Excerpted from Woodson and Conover (1964).

EXPERIMENTAL PSYCHOLOGY FINDINGS

Common sense would normally suggest that, once the most legible type style has been generated (for example, Futura Demibold), it would be best for all conditions and environments. The stroke width-to-letter height ratio of Futura Demibold is about 1:6. Is this optimum for all types of display? Experiments by Berger disclose some interesting information. . . .

Using a series of stroke widths, Berger found that a 10-mm stroke was best for black letters on a white background. This is a 1:8 ratio of stroke to height. Further, Berger found that, when the characters were white on a black background, the greatest distance for reading was achieved with a stroke width of 6 mm, approximately 1:13. However, before concluding that the 1:6 ratio of Futura Demibold for white letters on black recommended for airborne control panels is incorrect, many other factors must be considered. Berger 's experiments dealt with optimal conditions of lighting. Military aircraft depart deliberately from optimal lighting, primarily because there is an enemy. Commercial pilots also have an "enemy" and deviate from optimum conditions of cockpit lighting to preserve their visual acuity for night flying . . . .

This phenomenon of white letters on black requiring a narrower stroke than black letters on white is a familiar one; white areas look bigger than dark areas. Darkness cannot spread into light areas, but light can be dispersed into dark areas. Every factor — such as bad eyesight; air, dust, or smoke intervening between the display and the observer; vibration; nervous stress; etc. — causes the light areas to appear larger than they are. This effect is more enhanced as the intensity of the light is increased. . . .

Just as it can be shown that very thin strokes are required for very highly luminous characters, it can also be demonstrated that very thick strokes are preferred for black letters on a very highly luminous background. This can be illustrated easily with projection slides, but not on the printed page. . . .

A typical case of highly luminous background is a warning light having its label engraved directly on the lens. Here, thick strokes are desirable, but there is a practical limit.

LOW LEVELS OF ILLUMINATION AND CONTRAST

As illumination (or contrast) is reduced, thick letters become relatively more readable than thin ones. This is true for both black-on-white or white-on-black. . . .

It has been determined that, for optimal levels of illumination, white letters on black should have a thinner stroke (1:13) than black letters on white (1:8) and that this difference should increase as the light intensity is increased from 1:5 to 1:100 (a 20-to-1 range). However, as the illumination is reduced from optimum and the consequent contrast is reduced, a new rule comes into effect. There seems to be a common meeting point at very low levels of illumination and contrast of an optimum stroke width for both white-on-black and black-on-white characters. The complete answer has not yet been found, but it is expected that the answer is in the experimental data which have been accumulated. There are good reasons to expect that the data will disclose that, for very low contrast or very low levels of illumination, the most important factor controlling legibility is area — the maximum legibility being achieved when the character area is approximately equal to the immediately surrounding background areas. . . .

LEGIBILITY AT GREAT DISTANCE OR WITH SMALL-SIZE CHARACTERS

There are good reasons to expect the data to disclose that, although stroke width is important, the most important factor governing legibility of distant or very small type is geometric form. Somewhat as with low illumination or contrast, smallness of size is a visibility problem. That is, can the separate elements of the character by which it is distinguished still be seen? It is obvious that, as size is reduced to the point where the eye can no longer separate the five elements in height and the average of three elements in width, there is still a pattern of geometric form left wherein it becomes difficult to make sharp distinctions between individual characters, but words can still be recognized. If the individual characters can be made sufficiently distinctive in geometric form, the downward range of legible size can be extended.

WIDTH-TO-HEIGHT RATIO

Sincere effort has been expended by experimental psychologists to determine an optimum width-to-height ratio. This effort has been rewarded with a valid finding that available styles are too narrow. The experimentally derived optimum width for certain characters appears to be of the order of 1.3:1.0 (greater in width than in height). This is partly because many displays must be viewed from an unfavorable angle, which artificially reduces the apparent width, and is also partly due to the fact that there is opportunity to emphasize the distinctive features of some characters by extension of the geometric patterns in width.

In matters of proportion, the modern designer bows in admiration of the designers of 2000 years ago. The classic Roman alphabet shown in figure VIII-8 has never been surpassed for beauty. In general, the vertical strokes were made thick in order that they would remain visible at wide viewing angles. With careful artistry, when successive vertical strokes occur, the most significant were selected for thickening. A natural pattern was followed. If you will visualize yourself as tracing the characters from A to Z, you will find that the natural pen or brush strokes you would make in an upward direction, and laterally, are thin, and the natural downward strokes are thick. Thus, the Romans enhanced the legibility of their architectural inscriptions without sacrificing one bit of their classic beauty.

Figure VIII-8
Classic Roman, and the "Thick and Thin" Design

Getting back to width-to-height ratios, one should be very skeptical of accepting fixed notions that this or that ratio is best for all characters of an alphabet. . . . *The most poorly legible styles are often* the result of an attempt to "horse" the design into a standard ratio and all of the most legible type styles are the result of pursuing good geometric expression, utterly ignoring any concept of fixed ratios.

The character "O" cannot be made more legible by departing from a perfect circle. The characters "A" and "V" cannot be made more legible by departing from the proportions of an equilateral triangle. The characters "C," "D," and "B" are recognized by their semicircular construction. Some gain in legibility is possible by widening these characters as required to preserve the semicircular appearance over a wide viewing angle.

COMMENTS ON SOME PROPOSED STYLES

The NAMEL style of numerals was based partly upon a study by Mackworth in which an old and a proposed new style were compared (see figure VIII-9). Mackworth altered the geometric form to gain higher legibility. With Mackworth's new style reading errors were reduced to about 50 percent of the reading errors with the old style. It is fair to note, however, that the old style used for comparison was rather poor.

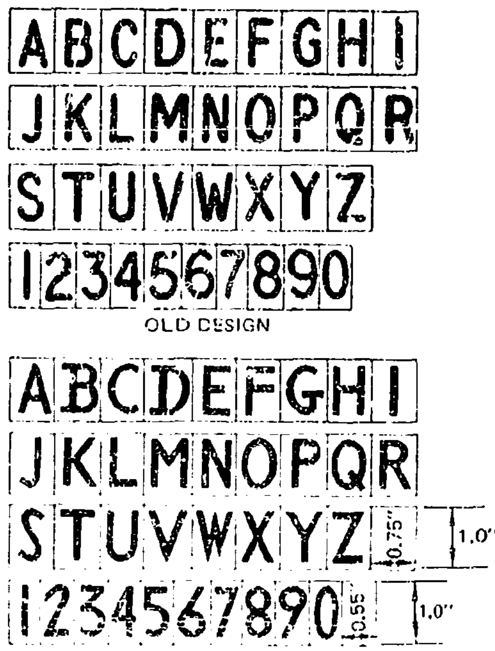


Figure VIII-9
Mackworth's Experiment

Another experiment used numerals of very radical design. Typical forms are shown in figure VIII-10. With this design, errors were reduced to near zero. As an experiment this was a notable one.

Figure VIII-10
A Radical Departure in Geometric Form

The principles of legibility used in this experiment were sound, but to our present sensibilities, the characters are rather shocking. . . . It is felt that the principles of this experiment can be used to develop pleasing, acceptable numerals with a very high degree of legibility.

EXPERIMENTAL METHODS

We believe that the foregoing sketchy discussion of the problem and a few of the many experiments which have been performed will show that legibility cannot be maximized using only one style of lettering, however good, for all applications. For example, no evidence has been discovered so far to indicate that the Futura styles recommended for airborne control panels are anywhere near optimal. Yet, other valid experiments, not discussed, show that there is nothing commercially available which is any better for the peculiar conditions of both day and night flying. This is just a single fact and does not in any sense indicate that Futura is therefore optimal for all displays. . . .

It can be shown that legibility and beauty are not synonomous, but it also appears that they should be close companions. A desirable goal is to demonstrate how a style as highly legible as studies have shown is possible can be generated and still be attractive and acceptable as a pleasing example of modern type design. Figure VIII-11 represents a start in this direction.

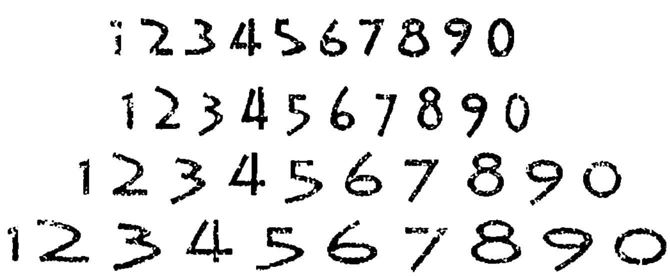


Figure VIII-11
A Start Toward Higher Legibility

SPECIFICATIONS

If you wish to look at the detailed requirements of the various specifications . . . you will find perhaps that you would like to change a few words or add some clarifying notes on the basis of the content of the foregoing discussions. This is not because of errors to be found in the specifications, but rather that some erroneous inferences could easily be made from what is said. For example, MIL-P-7788 appears to imply that numerals should have a thinner stroke width than letters. The experimental data show that white characters on black should have thinner strokes. Therefore, it would be desirable that the letters also be thinner. But, unfortunately, the available thinner style letters have a fault. The A, M, N, V, and W have pointed stroke terminations, causing poor apparent alignment which, due to shortcomings in the printing processes, often causes very poor results. This specification also appears to be saying that letters should be wide, 1:1 ratio, and numerals should be narrow, 3:5 ratio. Experimental data show that all characters should be relatively wide for maximum legibility. What MIL-P-7788 is really saying is that there are wide letter styles available which are satisfactory, but in general, existing wide numeral styles have poor legibility. MIL-P-7788 further appears to be implying that *uniform* width-to-height ratios are desirable. If so, it is a mistake, due probably to the ambiguous nature of some expermental data and due to the fact that uniform width characters "look" more orderly. . .

MIL-E-4158A, *General Specification for Ground Electronic Equipment,* says, on the subject of lettering, "Vertical Gothic, minimum height 3/64-inch. . . ." Experience has shown that such a low minimum is absolutely necessary in many cases. This is quite a "touchy" question. Design engineering organizations must meet some very complex problems and, in order to meet customer needs, must get equipment out on the shipping platform. It is a human engineering objective to put sufficient information before procurement officers, design engineers, and government inspection officers to allow them to determine if the customer needs have been met. However, some idea may be gained of how words look when they are made up of 3/64 inch letters from the fact that this is the size of the smallest type shown in the book of sample readings an oculist will hand you to read with your new glasses.

In spite of the work that has been done, there is still room for improvement in type design. The word Gothic should never be used in specifications when it is desired to define a certain type face. Use of the term point should be avoided, with letter heights specified in inches instead. There is nothing to be gained by specifying width-to-height ratios; specification of a suitable style is a much more productive step Perhaps most important of all, stroke width should be determined on the basis of contrast or of one of the factors interrelated to it – illumination, size, or time of exposure – the manner shown in table VIII-1.

TABLE VIII-1

RECOMMENDED PRINT STYLES AND STROKE WIDTHS

Condition	Variety of Style	Stroke Width
Low level of illumination	Bold	1:5
Low contrast with background	Bold	1:5
Contrast value of 1:12 and up		
Black letters on white	Medium bold – medium	1:6 to 1:8
White letters on black	Medium – light	1:8 to 1:10
Dark letters on illuminated background	Bold	1:5
Illuminated letters on dark background	Medium – light	1:8 to 1:10
Highly luminous letters	Very light	1:12 to 1:20
Characters to be read at great distances or of below optimum size	Bold – medium bold	1:5 to 1:6

Letter height as a function of viewing distance and illumination level is given in figure VIII-12.

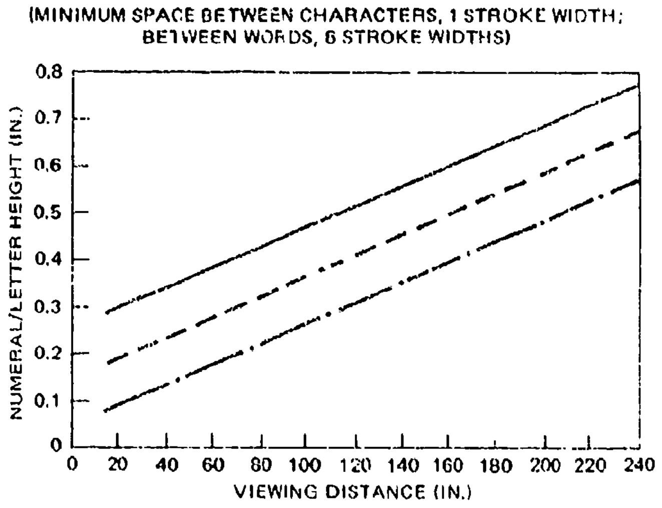


Figure VIII-12
Letter Height vs Viewing Distance and Illumination Level*

—— FOR INSTRUMENTS WHERE THE POSITION OF THE NUMERALS MAY VARY AND THE ILLUMINATION IS BETWEEN 0.03 AND 1.0 FT-L.

- - - FOR INSTRUMENTS WHERE THE POSITION OF THE NUMERALS IS FIXED AND THE ILLUMINATION IS 0.3-1.0 FT-L, OR WHERE POSITION OF THE NUMERALS MAY VARY AND THE ILLUMINATION EXCEEDS 1.0 FT-L.

—— · —— - FOR INSTRUMENTS WHERE THE POSITION OF THE NUMERALS IS FIXED AND THE ILLUMINATION IS ABOVE 1.0 FT-L.

* From Kubakawa et al (1970).

Chapters IX through XII present "specifications" covering human factors aspects of visual displays. They are almost entirely from MIL-STD-1472A.* For applications where that specification is not called out, these excerpts may provide useful benchmark data of interest to display designers in emphasizing proper man-machine interface.

*See REFERENCES AND BIBLIOGRAPHY.

CHAPTER IX

VISUAL DISPLAYS – GENERAL SPECIFICATION REQUIREMENTS

GENERAL

Visual displays should be utilized to provide the operator with a clear indication of equipment or system conditions for operation under any eventuality commensurate with the operational and maintenance philosophy of the system under design (see table IX-1).

TABLE IX-1
RECOMMENDATIONS FOR DISPLAY LIGHTING

CONDITION OF USE	LIGHTING TECHNIQUE	BRIGHTNESS OF MARKINGS (ft-L)	BRIGHTNESS ADJUSTMENT
Indicator reading, dark adaptation necessary	Red flood, indirect, or both, with operator choice	0.02-0.1	Continuous throughout range
Indicator reading, dark adaptation not necessary but desirable	Red or low-color-temperature white flood, indirect, or both, with operator choice	0.02-1.0	Continuous throughout range
Indicator reading, dark adaptation not necessary	White flood	1.0-20.0	Fixed or continuous
Panel monitoring, dark adaptation necessary	Red edge lighting, red or white flood, or both, with operator choice	0.02-1.0	Continuous throughout range
Panel monitoring, dark adaptation not necessary	White flood	10.0-20.0	Fixed or continuous
Possible exposure to bright flashes, restricted daylight	White flood	10.0-20.0	Fixed
Chart reading, dark adaptation necessary	Red or white flood with operator choice	0.1-1.0 (on white portion of chart)	Continuous throughout range
Chart reading, dark adaptation not necessary	White flood	5.0-20.0	Fixed or continuous

Display Illumination

When the degree of dark adaptation required is not maximum, low-brightness white light (preferably integral), adjustable as appropriate, shall be used; however, when the maximum degree of dark adaptation is required, low-brightness red light (greater than 600 nm) shall be provided (nm = nanometers).

Information

Content. The information displayed to an operator shall be limited to that which is necessary to perform specific actions or to make decisions.

Precision. Information shall be displayed only to the degree of specificity and precision required for a specific operator action or decision.

Format. Information shall be presented to the operator in a directly useable form. (Requirements for transposing, computing, interpolating, or mental translation into other units shall be avoided.)

Redundancy. Redundancy in the display of information to a single operator shall be avoided unless it is required to achieve specified reliability.

Combined Information. Information necessary for performing different activities (e.g., operation and troubleshooting) shall not simultaneously appear in a single display unless they are comparable functions requiring the same information.

Display Failure Clarity. Displays shall be so designed that failure of the display or display circuit will be immediately apparent to the operator.

Display Circuit Failure. Failure of the display circuit shall not cause a failure in the equipment associated with the display.

Unrelated Markings. Trademarks and company names or other similar markings not related to the panel function shall not be displayed on the panel face.

Location and Arrangement

Accuracy. Displays shall be located and designed so that they may be read to the degree of accuracy required by personnel in the normal operating or servicing position

Access. Ladders, supplementary lighting, or other special equipment should not be required in order to gain access to or to read a display.

Orientation. Display faces shall be perpendicular to the operator's normal line of sight whenever feasible and shall not be less than 45° from the normal line or sight (fig. IX-1). Parallax shall be minimized.

Reflectance. Displays shall be constructed, arranged, and mounted to prevent re action of information transfer due to the reflectance of the ambient illumination from the display cover. Reflection of instruments and consoles in windshields and other enclosures shall be avoided. If necessary, techniques (such as shields) shall be employed to insure that system performance will not be degraded.

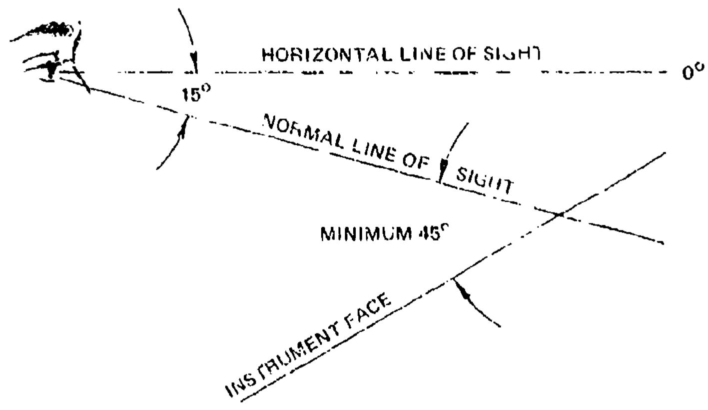


Figure IX-1
Lines of Sight

Vibration. Vibration of visual displays shall not degrade user performance below the level required for mission accomplishment.

Grouping. All displays necessary to support an operator activity or sequence of activities, shall be grouped together.

Function and Sequence. Displays shall be arranged in relation to one another according to their sequence of use or the functional relations of the components they represent. They shall be arranged in sequence within functional groups whenever possible to provide a viewing flow from left to right or top to bottom.

Frequency of Use. Displays used most frequently should be grouped together and placed in the optimum visual zone (fig. IX-2).

Importance. Very important or cirtical displays shall be placed in a privileged position in the optimum projected visual zone or otherwise highlighted.

Consistency. The arrangement of displays shall be consistent in principle from application to application, within the limits specified herein.

Maximum Viewing Distance. The viewing distance to displays located close to their associated controls is limited by reach distance and shall not exceed 28 inches (71 cm). Otherwise, there is no maximum limit other than that imposed by space limitations provided the display is properly designed. NOTE: A 30-inch (76 cm) clearance is required when using ejection seats

Minimum Viewing Distance. The effective viewing distance to displays, with the exception of cathode ray tube displays (see CATHODE RAY TUBE (CRT) DISPLAYS section below) and collimated displays, shall never be less than 13 inches (33 cm) and preferably not less than 20 inches (51 cm).

Aircrew Station Signals. Signals for aircrew stations shall be in accordance with MIL-STD-411.

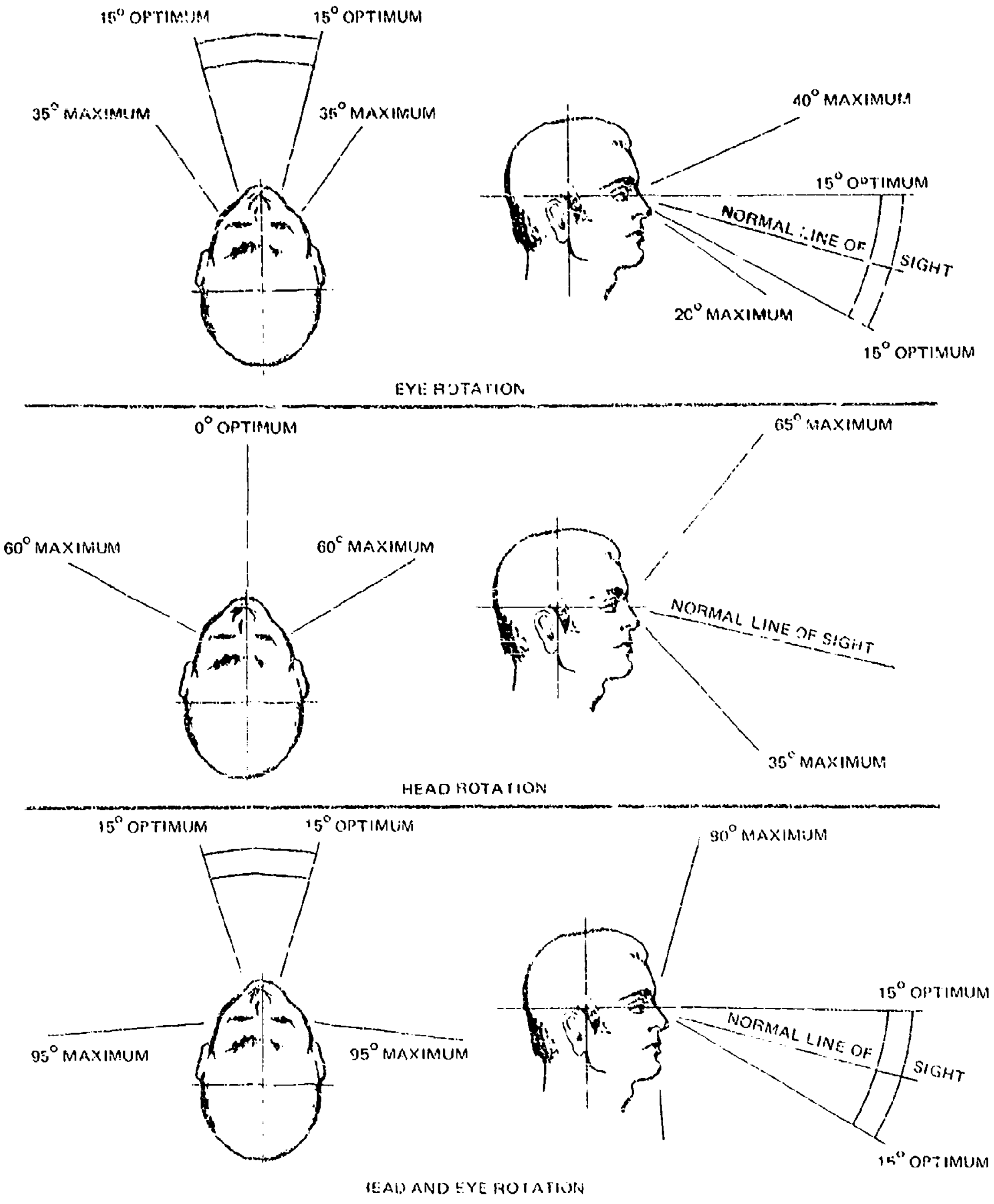


Figure IX-2
Vertical and Horizontal Visual Field

Coding

Techniques. Displays shall be coded by color, size, location, shape, or flash coding, as applicable.

Objectives. Coding techniques shall be used to facilitate:

1. Discrimination between individual displays
2. Identification of functionally related displays
3. Indication of relationship between displays
4. Identification of critical information within a display.

Standardization. All coding within the system shall be uniform and shall be established by agreement with the procuring activity.

TRANSILLUMINATED DISPLAYS

General

The following three general types of transilluminated displays should be considered:

1. Single- and multiple-legend lights, which present information in the form of meaningful words, numbers, symbols, or abbreviations.

2. Simple indicator lights, such as pilot, bull's-eye, and jewel lights.

3. Transilluminated panel assemblies, which present qualitative status or system readiness information.

Use. Transilluminated indicators should be used to display qualitative information to the operator (primarily, information that requires either an immediate reaction on the part of the operator or that his attention be called to an important system status). Such indicators may also be used occasionally for maintenance and adjustment functions.

Equipment Response. Lights, including those used in illuminated push buttons, shall display equipment response and not merely control position.

Information. Lights and related indicators shall be used sparingly and shall display only that information necessary for effective system operation.

Positive Feedback. The absence of a signal or visual indication shall not be used to denote a "go-ahead," "ready," or "in-tolerance" condition, nor shall such absence be used to denote a "malfunction," "no-go," or "out-of-tolerance" condition; however, the absence of a "power on" signal or visual indication shall be acceptable to indicate a "power off" condition. Changes in display status shall signify changes in functional status rather than results of control actuation alone.

Grouping. Master caution, master warning, and summation lights used to indicate the condition of an entire subsystem shall be set apart from the lights which show the status of the subsystem components, except as required under the LOCATION, CRITICAL FUNCTIONS paragraph below.

Location. When a transilluminated indicator is associated with a control, the indicator light shall be so located as to be immediately and unambiguously associated with the control and visible to the operator during control operation.

Location, Critical Functions. For critical functions, indicators shall be located within 15° of the operator's normal line of sight (see figure IX-2). Warning lights shall be an integral part of, or located adjacent to, the lever, switch, or other control device by which the operator is to take action.

Maintenance Displays. Indicator lights used solely for maintenance and adjustment, and referred to infrequently, shall be covered or nonvisible during normal equipment operation, but shall be readily accessible when required

Brightness. The brightness of transilluminated displays shall be compatible with the expected ambient illumination level, and shall be at least 10% greater than the surround brightness; however, the indicator brightness shall not exceed 300% of the surround brightness.

Reflection. Provision shall be made to prevent direct and/or reflected sunlight from making indicators appear illuminated when they are not, or to appear extinguished when they are illuminated.

Brightness Control. When displays will be used under varied ambient illumination, a variable control shall be provided. The range of the variable control shall permit the displays to be legible under all expected ambient illumination.

Contrast Within the Indicator. The brightness contrast of the figure-ground relationship within the indicator shall be at least 50 percent.

Lamp Redundancy. For incandescent displays or for other than airborne applications, lamps shall be provided that incorporate filament redundancy or dual bulbs, so that when one filament or bulb fails, the intensity of the light shall decrease sufficiently to indicate the need for lamp replacement, but not so much as to degrade operator performance.

Lamp Testing. When indicator lights are installed on a control panel, a master-light test control shall be incorporated. When applicable, design shall allow testing of all control panels at one time. Panels containing three or fewer lights may be designed for individual press-to-test bulb testing. Whenever practicable, circuitry should be designed to test the operation of the total indicator circuit. If dark adaptation is a factor, a means for reducing total indicator circuit brightness during test operation shall be provided.

Lamp Removal, Method. Where possible, provisions shall be made for lamp removal from the front of the display panel without the use of tools, or by some other equally rapid and convenient means.

Lamp Removal, Safety. Display circuits shall be designed so that bulbs may be removed and replaced while power is applied without causing failure of indicator circuit components or imposing personnel safety hazards.

Indicator Covers. Legend screen or indicator covers shall be designed to prevent inadvertent interchange.

Color Coding. With the exception of aircrew station signals, which shall conform to MIL-STD-411, and Air Force training equipment, which shall conform to MIL-T-27474, transilluminated incandescent displays shall conform with the following color coding scheme, in accordance with Type I Aviation Colors of MIL-C-25050:

1. RED shall be used to alert an operator that the system or any portion of the system is inoperative and that a successful mission is not possible until appropriate corrective or override action

is taken. Examples of indicators which should be coded RED are those which display such information as "no-go," "error," "failure," "malfunction," etc.

2. FLASHING RED shall be used only to denote emergency conditions which require operator action to be taken without undue delay, to avert impending personnel injury, equipment damage, or both. The flash rate shall be within 3 to 5 flashes per second with approximately equal amounts of ON and OFF time. The indicator shall be so designed that, if it is energized and the flasher device fails, the light will illuminate and burn steadily.

3. YELLOW shall be used to advise an operator that a condition exists which is marginal. YELLOW shall also be used to alert the operator to situations where caution, recheck, or unexpected delay is necessary.

4. GREEN shall be used to indicate that the monitored equipment is in tolerance or a condition is satisfactory and that it is all right to proceed (e.g., "go-ahead," "in-tolerance," "ready," "function activated," etc.).

5. WHITE shall be used to indicate system conditions that do not have "right" or "wrong" implications, such as alternative functions (e.g., Missile No. 1 selected for launch, etc.) or transitory conditions (e.g., action or test in progress, function available), provided such indication does not imply success or failure of operations.

6. BLUE may be used for an advisory light, but preferential use of BLUE should be avoided.

Legend Lights

Use. Legend lights shall be used in preference to simple indicator lights except where design considerations demand that simple indicators be used.

Color Coding. Legend lights shall be color coded in conformance with the COLOR CODING paragraph above and, where applicable, shall be further coded as to function by location, size, and flash coding. Legend lights required to denote personnel or equipment disaster (FLASHING RED), caution or impending danger (YELLOW), and master summation – go (GREEN) or no-go (RED) – shall be discriminably larger, and preferably brighter, than all other legend lights. . .

Visibility and Legibility. In other than aircrew stations, and with the exception of warning and caution indicators, the lettering on single legend indicators shall be visible and legible whether or not the indicator is energized.

Multiple Legends. Multiple-legend indicators (legend plates stacked one behind another) shall be designed to conform with the following:

1. When a rear legend is illuminated, it shall not be obscured by the front legends.

2. Rear legend plates shall be so placed as to minimize parallax.

3. Rear legends shall be equal in apparent brightness to front legends, and the contrast between rear legends and background shall be equal to that of front legend and background.

Matrix Displays. Matrix displays may be used when the symbology presented does not lead to ambiguity in interpretation.

Simple Indicator Lights

Use. Simple indicator lights should be used when design considerations preclude the use of legend lights.

Spacing. The spacing between adjacent edges of simple round indicator light fixtures shall be sufficient to permit unambiguous labeling, indicator interpretation, and convenient bulb removal.

Coding. Simple indicator lights shall be coded in conformance with table IX-2; however, the different sizes shown are intended only for the attention-getting value that larger lights provide in relation to indicator lights of lesser importance.

TABLE IX-2

CODING OF SIMPLE INDICATOR LIGHTS

SIZE/TYPE	COLOR			
	RED	YELLOW	GREEN	WHITE
½-INCH (12.7 mm) DIAMETER or SMALLER/STEADY	Malfunction; action stopped; failure; stop action.	Delay; check; recheck.	Go ahead; in tolerance; acceptable; ready.	Functional or physical position; action in progress.
1-INCH (25.4 mm) DIAMETER or LARGER/ STEADY	Master summation (system or subsystem).	Extreme caution (impending danger).	Master summation (system or subsystem).	
1-INCH (25.4 mm) DIAMETER or LARGER/ FLASHING (3 to 5/sec)	Emergency condition (impending personnel or equipment disaster).			

Transilluminated Panel Assemblies

Transilluminated panel assemblies, which present whole patterns of information, should be considered for presentation of data flow and complicated data organization.

CATHODE RAY TUBE (CRT) DISPLAYS

Signal Size

When a target of complex shape is to be distinguished from a nontarget shape that is also complex, the target signal shall subtend no less than 20 minutes of visual angle.

Viewing Distance

A 16-inch (41 cm) viewing distance shall be provided whenever practicable. When periods of scope observation will be short, or when dim signals must be detected, the viewing distance may be reduced to 10 inches (25 cm). Design should permit the observer to view the scope from as close as he may wish. A degree of resolution consistent with the operator's needs should be provided. Displays which must be placed at viewing distances greater than 16 inches (41 cm) due to other considerations shall be appropriately modified in aspects such as display size, symbol size, brightness ranges, line-pair spacing, and resolution.

Screen Brightness

The ambient illumination shall not contribute more than 25% of screen brightness through diffuse reflection and phosphor excitation.

Faint Signals

When the detection of faint signals is required and when the ambient illumination may be above 0.25 ft-C, scopes shall be hooded, shielded, or recessed. (In some instances, a suitable filter system may be employed.)

Brightness Range

The brightness range of surfaces immediately adjacent to scopes shall be between 10% and 100% of screen background brightness. With the exception of emergency indicators, no light source in the immediate surround shall be brighter than scope signals.

Ambient Illumination

The ambient illumination in the CRT area shall be appropriate for other visual functions (e.g., setting controls, reading instruments, maintenance, etc.), but shall not interfere with the visibility of signals on the CRT display.

Reflected Glare

Reflected glare shall be minimized by proper placement of the scope relative to the light source, use of a hood or shield, or optical coatings or filter control over the light source.

Adjacent Surfaces

Surfaces adjacent to the scope shall have a dull matte finish. The reflectances of these surfaces shall be such that the resultant brightnesses will be consistent with the criteria established above.

LARGE-SCALE DISPLAYS

Design

The design of large-scale displays intended for group observation shall conform with the basic visual criteria in other paragraphs of this standard, and the additional requirements below.

Legibility

The height-to-width ratio, stroke width, size, and spacing of display symbols shall be such that all characters will be legible at the maximum viewing angle and distance.

OTHER DISPLAYS

Counters

Illumination. Counters shall be self-illuminated whenever practicable.

Finish. The surface of the counter drums and surrounding areas shall have a dull finish so as to minimize glare.

Contrast. Color of the numerals and background shall provide high contrast (black on white, or converse, as appropriate).

Plotters

Use. Plotters should be used when a visual record of continuous graphic data is necessary or desirable.

Visibility. Plotting points shall be readily visible and shall not be obstructed by the pen assembly or arm.

Contrast. A minimum of 50% contrast shall be provided between the plotted function and the background on which it is drawn.

CHAPTER X

CODING, LEGEND, AND LABELING SPECIFICATIONS

CODING

Methods and Requirements

The selection of a coding mode (e.g., size and color) for a particular application shall be determined by the relative advantages and disadvantages for each type of coding. Where coding is selected for the purpose of differentiating among controls, application of the code shall be uniform throughout the system. (See table X-1 for advantages and disadvantages.)

TABLE X-1
ADVANTAGES AND DISADVANTAGES OF VARIOUS TYPES OF CODING

ADVANTAGES	TYPE OF CODING					
	LOCATION	SHAPE	SIZE	MODE OF OPERATION	LABELING	COLOR
Improves visual identification.	X	X	X		X	X
Improves nonvisual identification (tactual and kinesthetic).	X	X	X	X		
Helps standardization.	X	X	X	X	X	X
Aids identification under low levels of illumination and colored lighting.	X	X	X	X	(When trans-illuminated)	(When trans-illuminated)
May aid in identifying control position (settings).		X		X	X	
Requires little (if any) training; is not subject to forgetting.					X	
DISADVANTAGES						
May require extra space.	X	X	X	X	X	
Affects manipulation of the control (ease of use)	X	X	X	X		
Limited in number of available coding categories.	X	X	X	X		X
May be less effective if operator wears gloves.		X	X	X		
Controls must be viewed (i.e., must be within visual areas and with adequate illumination present).					X	X

Location Coding

Controls associated with similar functions should be in the same relative location from panel to panel.

Size Coding

No more than three different sizes of controls shall be used in coding controls for discrimination by absolute size. Controls used for performing the same function on different items or equipment shall be the same size.

Shape Coding

Control shapes shall be both visually and tactually identifiable and shall be designed to be free of sharp edges.

Color Coding

Choice of Colors. Controls shall be black (17038) or gray (26231). If color coding is required, only the following colors identified in FED-STD-595 shall be selected for control coding:

1. Red, 11105
2. Green, 14187
3. Orange-Yellow, 13538
4. White, 17875
5. Blue, 15123, shall be used if an additional color is absolutely necessary.

Relation to Display. When color coding must be used to relate a control to its corresponding display, the same color shall be used for both the control and the display.

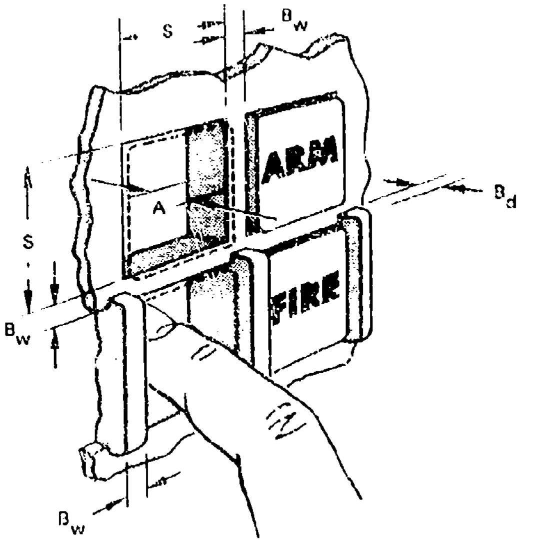
Control Panel Contrast. The color of the control shall provide contrast between the panel background and the control.

Ambient Lighting and Color Coding Exclusion. Prior to selection of color code, consideration shall be given to anticipated ambient lighting coordination throughout the mission. Color coding shall not be used as a primary identification medium if the spectral characteristics of ambient light during the mission, or the operator's adaptation to that light, varies as the result of such factors as solar glare, filtration of light, and variation from natural to artificial light. If red lighting is to be used during a portion of the mission, controls which would otherwise be coded red shall be coded by orange-yellow and black striping.

LEGEND SWITCHES

Dimensions, Resistance, Displacement and Separation

Dimensions, resistance, displacement, and separation between adjacent edges of legend switches shall conform to the criteria in figure X-1.



	S Size (in.)	A DISPLACEMENT (in.)	BARRIERS* (in.) B_w	 B_d	RESISTANCE (oz)
Minimum	3/4	1/8	1/8	3/16	10
Maximum	1-1/2	1/4	1/4	1/4	45

* Barriers will have rounded edges.

Figure X-1
Legend Switch

Barrier Height

Barrier height from panel surface shall conform to the criteria in figure X-1.

Other Requirements

1. For positive indication of switch activation, the legend switch shall be provided with a detent or click.

2. The legend shall be legible when only one lamp is operating within the switch.

3. There shall be a press-to-test or dual lamp/filament reliability.

4. Lamps within the legend switch shall be replaceable from the front of the panel by hand and the legends or covers shall be keyed to prevent the possibility of interchanging the legend covers.

5. There shall be a maximum of three lines of lettering on the legend plate.

LABELING

General

General Requirements. Controls, displays, and any other items of equipment that must be located, identified, read, or manipulated shall be appropriately and clearly labeled to permit rapid and accurate human performance. No label will be required on equipment or controls whose use is obvious to the user (e.g., aircraft control stick).

Label Characteristics. The characteristics of the labeling to be used shall be determined by such factors as:

1. The accuracy of identification required
2. The time available for recognition or other responses
3. The distance at which the labels must be read
4. The illumination level and color characteristics of the illuminant
5. The criticality of the function labeled
6. Consistency of label design within and between systems

Prototype and Production Equipment Labels. Labels for both prototype and production equipment shall meet the criteria specified herein. Labels for production equipment shall be designed to meet the criteria specified for the duration of equipment use. Since frequent design changes may be anticipated in prototype equipment, labels for such equipment shall be designed so that they may be simply and easily affixed, altered, and removed.

Orientation and Location

Orientation. Labels and information thereon should be oriented horizontally so that they may be read quickly and easily from left to right. Vertical orientation shall be used only when labels are not critical for personnel safety or performance and where space is limited. When used, vertical labels shall read from top to bottom.

Location. Labels shall be placed on or very near the items which they identify, so as to eliminate confusion with other items and labels. Labels shall be located so as not to obscure any other information needed by the operator. Controls shall not obscure labels.

Standardization. Labels shall be located in a consistent manner throughout the equipment and system.

Contents

Equipment Functions. Labels should primarily describe the functions of equipment items. Secondarily, the engineering characteristics or nomenclature may be described.

Abbreviations. Standard abbreviations shall be selected in accordance with MIL-STD-12, MIL-STD-411, or MIL-STD-783. If a new abbreviation is required, its meaning shall be obvious to the intended reader. Capital letters shall be used. Periods shall be omitted except when needed to preclude misinterpretation. The same abbreviation shall be used for all tenses and for both singular and plural forms of a word.

Irrelevant Information. Trade names and other irrelevant information shall not appear on labels or placards.

Qualities

Brevity. Labels shall be as concise as possible without distorting the intended meaning or information and shall be unambiguous. Redundancy shall be minimized. Where the general function is obvious, only the specific function shall be identified (e.g., frequency as opposed to frequency factor).

Familiarity. Words shall be chosen on the basis of operator familiarity whenever possible, provided the words express exactly what is intended. Brevity shall not be stressed if the results will be unfamiliar to operating personnel. For particular users (e.g., maintenance technicians), common technical terms may be used even though they may be unfamiliar to nonusers. Abstract symbols (e.g., squares and Greek letters) shall be used only when they have a commonly accepted meaning to all intended readers. Common, meaningful symbols (e.g., - and +) may be used as necessary.

Visibility and Legibility. Labels and placards shall be designed to be read easily and accurately at the anticipated operational reading distances, vibration/motion environment, and illumination levels, taking into consideration the following factors:

1. Contrast between the lettering and its immediate background
2. Height, width, stroke width, spacing, and style of letters and numerals
3. Method of application (e.g., etching, decal, and silk screen)
4. Relative legibility of alternative words
5. Specular reflection

Access. Labels shall not be covered or obscured by other units in the equipment assembly.

Label Life. Labels shall be sharp, have high contrast, and be mounted so as to minimize wear or obscurement by grease, grime, or dirt.

Design of Label Characters

Black Characters. Where the ambient illumination will be above 1 ft-C, black characters shall be provided on a light background.

Dark Adaptation. Where dark adaptation is required, the displayed letters or numerals shall be visible without interfering with night vision requirements. Where possible, markings shall be white on a dark background.

Style. Style of label characters shall conform to MIL-M-18012. Labels shall be prepared in capital letters, except that extended copy (e.g., instructions) shall be in lower-case letters.

Label Size vs Illumination. The height of letters and numerals shall be determined by the required reading distance and illumination. With a 28-inch (71 cm) viewing distance, the height of numerals and letters shall be within the range of values given in table X-2 for "low" and "high" control display brightness conditions.

Label Size and Viewing Distance. For general dial and panel design, with the brightness normally above 1 ft-L, character height should approximate the values given in table X-3 for various distances.

TABLE X-2
LABEL SIZE VS ILLUMINATION

	Height (in.)	
	Low (below 1 ft-L)	High (above 1 ft-L)
For critical markings, with position variable (e.g., numerals on counters and settable or moving scales)	0.20-0.30 (5.1-7.6 mm)	0.12-0.20 (3-5 1 mm)
For critical markings, with position fixed (e.g., numerals on fixed scales, controls, and switch markings, or emergency instructions)	0.15-0.30 (3.8-7.6 mm)	0.10-0.20 (2.5-5.1 mm)
For noncritical markings (e.g., identification labels, routine instructions, or markings required only for familiarization)	0.05-0.20 (1.3-5.1 mm)	0.05-0.20 (1.3-5.1 mm)

TABLE X-3
LABEL SIZE AND VIEWING DISTANCE

DISTANCE (in.)	HEIGHT (in.)
20 (51 cm) or less	0.09 (2.3 mm)
21-36 (53-91 cm)	0.17 (4.3 mm)
37-72 (94-183 cm)	0.34 (8.6 mm)
73-144 (185-366 cm)	0.68 (17.3 mm)
145-240 (368-610 cm)	1.13 (28.7 mm)

Letter Width. The width of letters shall preferably be 3/5 of the height, except for the "I," which shall be one stroke in width, and the "M" and "W," which shall be 4/5 of the height*

Numeral Width. The width of numerals shall preferably be 3/5 of the height, except for the "4," which shall be one stroke width wider, and the "1," which shall be one stroke in width.

* It is recognized that these arbitrary callouts are debatable in some situations, as indicated in Chapter VIII. However, they do reflect current specification requirements.

Wide Characters. Where conditions indicate the use of wider characters, as on a curved surface, the basic height-to-width ratio may be increased to 1:1 in accordance with MIL-M-18012.

Stroke Width, Normal. For black characters on a white (or light) background, the stroke width shall be 1/6 of the height.

Stroke Width, Dark Adaptation. Where dark adaptation is required or legibility at night is a critical factor, and white characters are specified on a black background, the stroke width of the characters shall be from 1/7 to 1/8 of the height (i.e., narrower than specified for normal daytime vision).

Character Spacing. The minimum space between characters shall be one stroke width.

Word Spacing. The minimum space between words shall be the width of one character.

Equipment Labeling — Assemblies, Components, and Parts

General Requirements. Each assembly, component, and part shall be labeled with a clearly visible, readable, and meaningful name, number, or symbol.

Location. The gross identifying label on an assembly or major component shall be located:

1. Externally in such a position that it is not obscured by adjacent assemblies or components
2. On the flattest, most uncluttered surface available
3. On a main chassis of the equipment
4. In a way to minimize wear or obscurement by grease, grime, or dirt
5. In a way to preclude accidental removal, obstruction, or handling damage

Terms. Components, circuits, or assemblies shall be labeled with terms descriptive of the test or measurement applicable to their test points (e.g., demodulator rather than crystal detector and power amplifier rather than bootstrap amplifier).

Other Criteria. In addition to the criteria herein, equipment labels and placards shall conform to MIL-STD-129, MIL-STD-130, MIL-STD-195, MIL-STD-411, MIL-STD-783, and MIL-STD-1247, as applicable.

Equipment Labeling -- Controls and Displays

General Requirements. Controls and displays shall be appropriately and clearly labeled with the basic information needed for proper identification, utilization, actuation, or manipulation of the element

Simplicity. Displays and controls shall be labeled in the simplest and most direct manner possible. Abbreviations may be used when they are familiar to operators (e.g., psi).

Functional Labeling. Each control and display shall be labeled according to function, and the following criteria shall apply:

1. Highly similar names for different controls and displays shall be avoided.

2. Instruments shall be labeled in terms of what is being measured or controlled, taking into account the user and purpose.

3. Control labeling shall indicate the functional result of control movement (e.g., increase) and may include calibration data where applicable. Such information shall be visible during normal operation of the control.

4. When controls and displays must be used together (in certain adjustment tasks), appropriate labels shall indicate their functional relationship.

Location. The following criteria shall apply to the location of control and display labels:

1. Ease of control operation shall be given priority over visibility of control position labels.

2. Labels should normally be placed above the controls and displays they describe. When the panel is above eye level, labels may be located below if label visibility will be enhanced thereby.

3. The units of measurement (e.g., volts and psi) shall be located on the panel.

4. Labels shall be used to identify functionally grouped controls and displays. The labels shall be located above the functional groups they identify. When a line is used to enclose a functional group and define its boundaries, the label shall be centered at the top of the group either in a break in the line or just below the line. When colored pads are used, the label shall be centered at the top within the pad area.

5. Label location throughout a system and within panel groupings shall be uniform

Size Graduation. To reduce confusion and operator search time, labels shall be graduated in size. The characters used in group labels shall be larger than those used to identify individual controls and displays. The characters identifying controls and displays shall be larger than the characters identifying control positions. With the smallest character determined by viewing conditions, each label shall be at least approximately 25 percent larger than the next smaller label.

CHAPTER XI

LAYOUT SPECIFICATIONS

STANDING OPERATIONS

Display Placement, Normal

Visual displays mounted on vertical panels and used in normal equipment operation shall be placed in an area between 41 inches (104 cm) and 74 inches (188 cm) above the standing surface.

Display Placement, Special

Indicators that must be [illegible] precisely and frequently shall be placed in an area between 50 inches (127 cm) and 69 inches (175 cm) above the standing surface.

SEATED OPERATIONS

Work Surface Width

A lateral workspace of at least 30 inches (76 cm) wide and 16 inches (41 cm) deep shall be provided whenever practicable.

Work Surface Height

Desk tops and writing tables shall be 30 inches (76 cm) above the floor, unless otherwise specified.

Writing Surfaces

Where a writing surface is required on equipment consoles, it shall be at least 16 inches (41 cm) deep and should be at least 23 inches (61 cm) wide.

Display Placement, Normal

Visual displays mounted on vertical panels and used in normal equipment operation shall be placed in an area between 6 and 48 inches (15 and 122 cm) above the sitting surface

Display Placement, Special

Indicators that must be read precisely and frequently shall be placed in an area between 14 and 37 inches (36 and 95 cm) above the sitting surface and no further than [illegible] inches ([illegible] cm) laterally from the centerline.

Warning Displays

For "sit" consoles requiring horizontal vision over the top, critical visual warning displays shall be mounted at least 22.5 inches (57 cm) above the sitting surface

CHAPTER XII

AMBIENT ILLUMINANCE SPECIFICATIONS

Where equipment is to be used in enclosures and is not subject to black out or special low-level lighting requirements, illumination levels shall be as specified by table XII-1 and shall be distributed so as to reduce glare and specular reflection. Capability for dimming shall be provided. Adequate illumination shall be provided for maintenance tasks. General and supplementary lighting shall be used as appropriate to insure that illumination is compatible with each task situation. Portable lights should be provided for personnel performing visual tasks in areas where fixed illumination is not provided.

TABLE XII-1

SPECIFIC TASK ILLUMINATION REQUIREMENTS

WORK AREA OR TYPE OF TASK	ILLUMINATION LEVELS (FT-C)* RECOMMENDED	MINIMUM
Assembly, missile component	100	50
Assembly, general		
Coarse	50	30
Medium	75	50
Fine	100	75
Precise	300	200
Bench work		
Rough	50	30
Medium	75	50
Fine	150	100
Extra fine	300	200
Business machine operation (calculator, digital, input, etc.)	100	50
Console surface	50	30
Corridors	20	10
Circuit diagram	100	50
Dials	50	30
Electrical equipment testing	50	30
Emergency lighting	--	3
Gages	50	30
Hallways	20	10
Inspection tasks, general		
Rough	50	30
Medium	100	50
Fine	200	100
Extra fine	300	200

*As measured at the task object or 30 inches above the floor

TABLE XII-1 (CONTINUED)

WORK AREA OR TYPE OF TASK	ILLUMINATION LEVELS (FT-C)* RECOMMENDED	MINIMUM
Machine operation, automatic	50	30
Meters	50	30
Missiles		
Repair and servicing	100	50
Storage areas	20	10
General inspection	50	30
Office work, general	70	50
Ordinary seeing tasks	50	30
Panels		
Front	50	30
Rear	20	10
Passageways	20	10
Reading		
Large print	30	10
Newsprint	50	30
Handwritten reports, in pencil	70	50
Small type	70	50
Prolonged reading	70	50
Recording	70	50
Repair work		
General	50	30
Instrument	200	100
Scales	50	30
Screw fastening	50	30
Service areas, general	20	10
Stairways	20	10
Storage		
Inactive or dead	5	3
General Warehouse	10	5
Live, rough or bulk	10	5
Live, medium	30	20
Live, fine	50	30
Switchboards	50	30
Tanks, containers	20	10

*As measured at the task object or 30 inches above the floor.

TABLE XII-1 (CONTINUED)

WORK AREA OR TYPE OF TASK	ILLUMINATION LEVELS (FT-C)* RECOMMENDED	MINIMUM
Testing		
Rough	50	30
Fine	100	50
Extra fine	200	100
Transcribing and tabulation	100	50

NOTES: 1. Some unusual inspection tasks may require up to 1,000 ft-C of light.

2. As a guide in determining illumination requirements the use of a steel scale with 1/64-inch divisions requires 180 ft-C of light for optimum visibility.

*As measured at the task object or 30 inches above the floor.

MILITARY REFERENCE DOCUMENTS (FOR CHAPTERS IX THROUGH XII)*

ARMY PUBLICATIONS

Regulations

AR 385-16	Safety for Systems, Associated Subsystems and Equipment

Pamphlets

AMCP 706-134	Maintainability Guide for Design

Design Criteria Handbooks

HEL STD-S-2-64	Human Factors Engineering Design Standard for Vehicle Fighting Compartments
HEL STD-S-3-65	Human Factors Engineering Design Standard for Missile Systems and Related Equipment
HEL STD-S-6-66	Human Factors Engineering Design Standard for Wheeled Vehicles
HEL STD-S-7-68	Human Factors Engineering Design Standard for Communications System and Related Equipment

NAVY PUBLICATIONS

Drawings

BUSHIPS Drawing 9000-65604-F-73687-K	Standard Dial Markings for Interior Communication Order and Indicating Systems

Reports

NAVSHIPS 94324	Human Engineering Guidelines for Maintainability

Design Criteria Handbook

NAVWEPS OD 18413A	Human Factors Design Standards for the Fleet Ballistic Missile Weapon System

AIR FORCE PUBLICATIONS

Manuals

AFM 127-201	Missile Safety Handbook

*From MIL-STD-1472A, 15 May, 1970

Specifications

MIL-M-18012B	Markings for Aircrew Station Displays and Design Configuration of, 20 July 1964

Technical Documentary Reports

WADD TR 58-474	The Effect of Team Size and Intermember Communication on Decision-Making Performance (AD 215 621)
RADC TDR-63-315	Criteria for Group Display Chains for the 1962-1965 Time Period (AD 283 390)
FDL TDR 64-86	Investigation of Aerospace Vehicle Crew Station Criteria (AD 452 187)

Air Force Systems Command Design Handbooks

Copies of Air Force Systems Command design criteria handbooks may be obtained by non-governmental organizations when compliance therewith is required by a Government contract, or when possession of the handbook will otherwise benefit the Government. Requests for the following handbooks should be directed to ASD/ASNPS, Wright-Patterson AFB, Ohio 45433:

AFSC DH 1-1	General Index and Reference
AFSC DH 1-3	Personnel Subsystems
AFSC DH 1-6	System Safety
AFSC DH 2-2	Crew Stations and Passenger Accommodations
AFSC DH 2-6	Ground Equipment and Facilities

ANSI

Copies of the following standards can be obtained at a nominal cost from the ANSI, 1440 Broadway, New York, New York 10018.

A11.1	Practice for Industrial Lighting
C1	National Electrical Code (NFPA 70)
C2	National Electrical Safety Code (NBS H30)
Z35.1	Specifications for Industrial Accident Prevention Signs

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APPENDIX A

SITUATIONAL AND ENVIRONMENTAL EFFECTS ON VISION AND DISPLAY VIEWING, WITH DESIGN IMPLICATIONS

The following appendix is an attempt to bring together information from diverse sources for reference use by those faced with the problem of establishing display resolution requirements. Two major areas are covered: environmental effects from the operational situation are reviewed, then total display system considerations are examined to allow assessment of summed effect on display operational needs.

Such reference material can never be complete since new studies are continuing to reveal useful relationships. Future studies in this area may require updating of material to facilitate systematic determination of display requirements for each application.

What display resolution must be made available for the operator in a particular operational situation? This sort of question arises frequently and is never easy to answer in simple terms. Naturally, it raises counter-questions as to what the total display-operator environment will be and how it will affect visual acuity as operationally measured. Effects of vibration, acceleration, oxygen level, general illumination, display brightness and contrast, etc., are touched on in the following sections, but overall cumulative effects can only be estimated for each operational situation as it is defined.

Extensive quotation from useful reference sources is included since they already represent concise review material and paraphrasing would not enhance their presentation.

VIBRATION

The curve in figure A-1, from Morgan et al.* shows the smallest Landolt-ring gap the eye can detect for different background brightness. As the amount of light is increased, the eye can detect smaller and smaller gaps. As a rule of thumb, the eye can detect a gap of 1 minute of visual angle at ordinary indoor light levels. (This assumes normal eyesight and high brightness contrast. It does not apply to white on black targets, white tends to blur.)

Mean decrements of visual acuity of 12 subjects during vertical sinusoidal vibration (sitting, restrained, without padding, in an airplane seat) are shown in figure A-2 (from Lange and Coermann**). Below 12 c/s decrements were mainly due to physiological stress produced in the body (especially in areas of resonance of whole body and organ complexes), and above 12 c/s decrements were mainly due to image displacement on the retina which had an increasingly blurring effect.

Drazin (1962)*** investigated the legibility of pointers on dials during constant-amplitude vibration of the test material at frequencies down to less than 1 c/s. He found that legibility was most adversely affected between 2 and 4 c/s, depending upon the angular-displacement amplitude (fig. A-3). Below 2 c/s, the eye can follow the vibrating object quite efficiently, so that the dial can be read continuously. At high frequencies of 8 c/s and above, the dial legibility is again good, because the subject can form a steady impression of the dial by fixating one of the nodal or maximum displacement positions of the target.

*Morgan, C. T., et al (Ed.), *Human Engineering Guide to Equipment Design*, McGraw-Hill, 1963.

**Lange, K.O., and Coermann, R.R., "Visual Acuity Under Vibration," *Human Factors*, vol. IV, no. 5, 291-300, October 1962.

***Referenced in Gillies, J. A. (Ed.), *A Textbook of Aviation Physiology*, Pergamon Press, 1965.

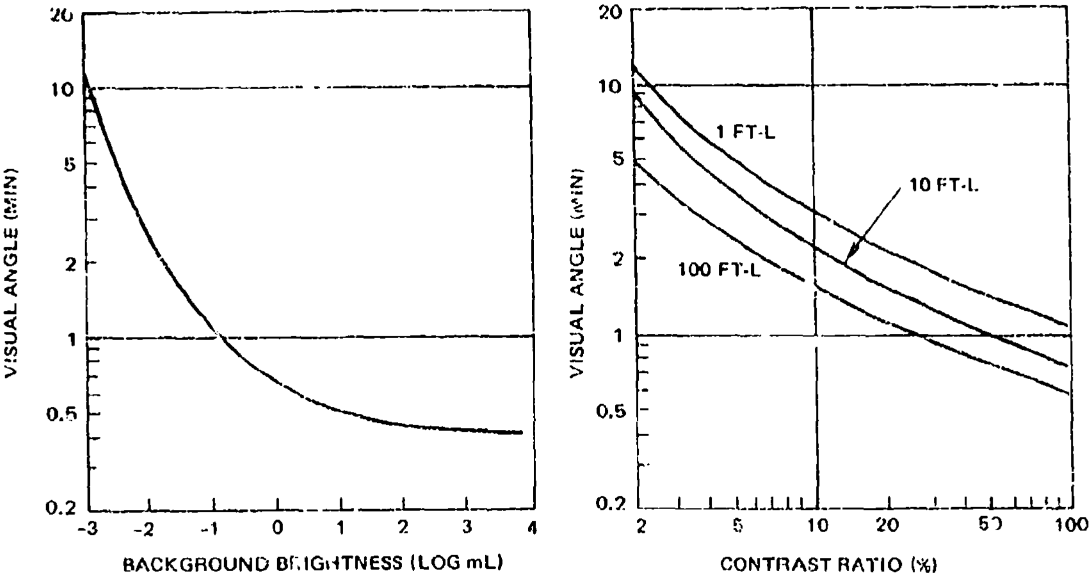

Figure A-1
Visual Acuity

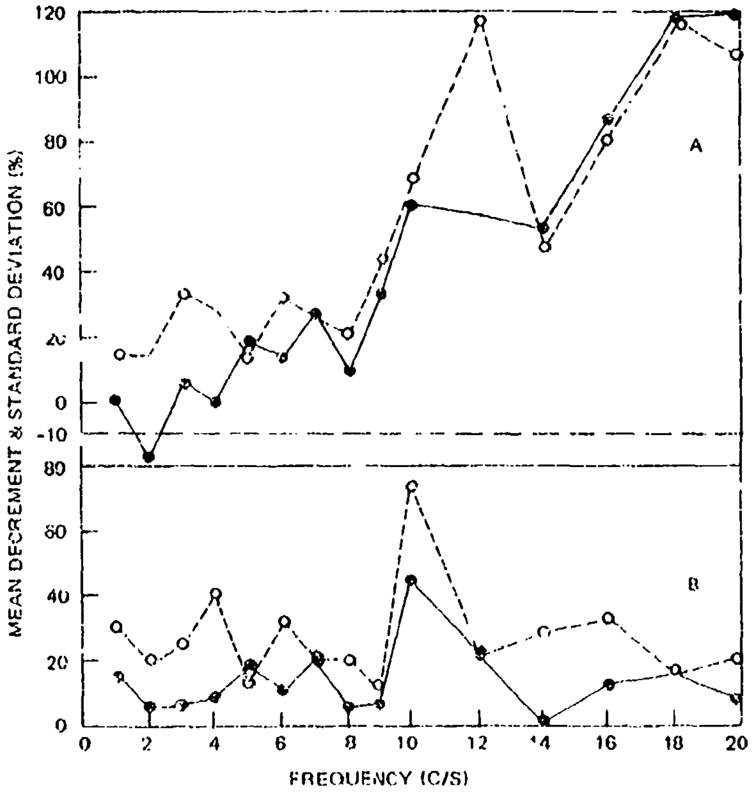

Figure A-2
Effects of Vibration on Visual Acuity

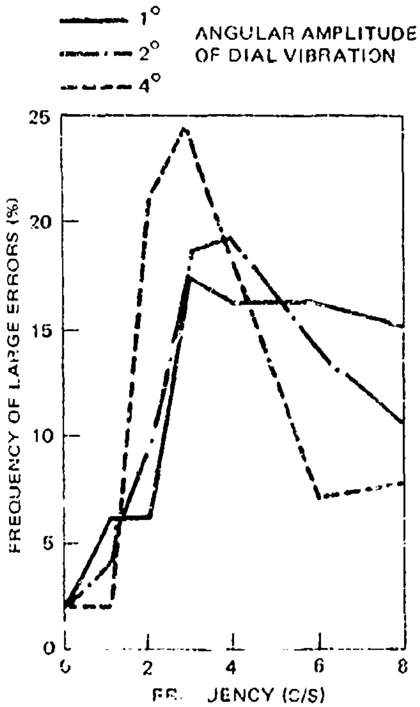

Figure A-3
Variation of Large Dial Reading Errors (Greater Than 0.5 Scale Division) With Frequency and Amplitude of Sinusoid?' Dial Vibration
(Drazin, 1962)

Dial legibility during vibration in the intermediate ... ncy range around 3 c/s is poor, because the oscillation of the target is too fast for the eye to ... ow and ... infrequent to produce nodal images which can comfortably be fused by the subject. Legib ... during vibration depends considerably upon the conditions of illumination, reading distance, a ... of the dial marks and pointer.

The curves shown in figure A-4 (from ... ... for different groups viewing Landolt rings and circles moved across a display area at various speeds. They show that visual acuity deteriorates with increased angular velocity. This is significant in decisions on whether to use a rolling display versus successive fixed frames in any particular sensor display application.

*Erickson, R. A., *Visual Detection of Targets: Analysis and Review*, NAVWEPS ... 8617. U.S. Naval Ordnance Test Station, China Lake, California, February 1965.

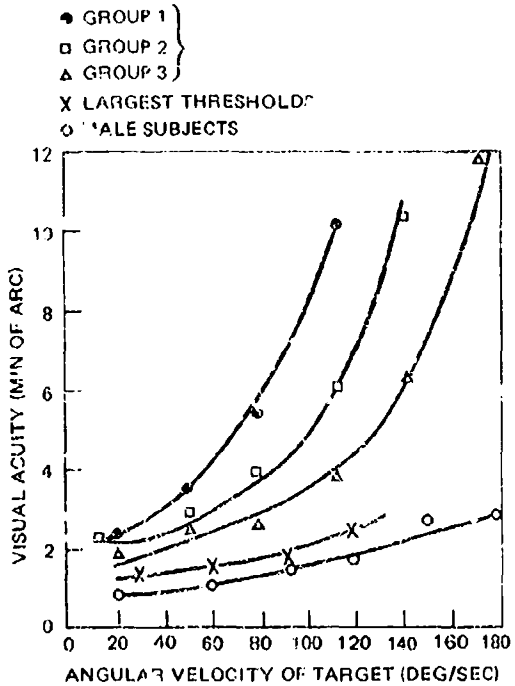

Figure A-4
Visual Acuity as a Function of Angular Velocity
(Targets on Display)

ACCELERATION

"In a series of studies on the relation between visual acuity and acceleration (White and Jorve, 1956*), it was found that visual acuity decreases progressively as the magnitude of the accelerative force is increased above 1 g, regardless of body position (fig. A-5). This suggests that cardiovascular effects are minimal, and the loss in acuity is attributed to displacement of the lens of the eye in the direction of the acceleration vector."**

The curves in figure A-6 (from Brown***) are averages from reaction time measures (button push-on light signal -- no hand or arm movement required) during last half of 10-second periods with differing g forces. Reaction time increased significantly. Effects were quicker for low illumination. For higher acceleration levels, dimming of vision was reported.

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*White, W. J., and Jorve, W. R., *The Effects of Gravitational Stress Upon Visual Acuity*, WADC Tech. Report 56-247, Wright Air Development Center, Wright-Patterson AFB, Ohio, 1956.

**Excerpted, with minor changes, from White, W. J., and Monty, R. A., "Vision and Unusual Gravitational Forces," *Human Factors*, vol. V, no. 3, June 1963.

***Brown, J. L., "Acceleration and Human Performance," in *Selected Papers on Human Factors in the Design and Use of Control Systems*, H. W. Sinaicko (Ed.), Dover Publications, 1961.

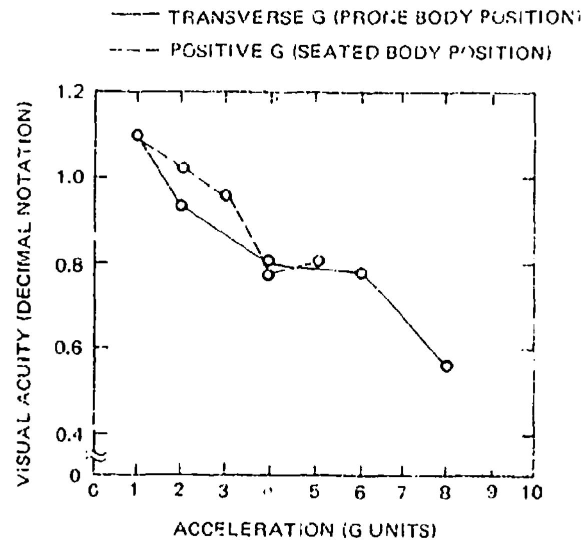

Figure A-5
Binocular Visual Acuity as a Function of Acceleration
(White and Jorve, 1956)

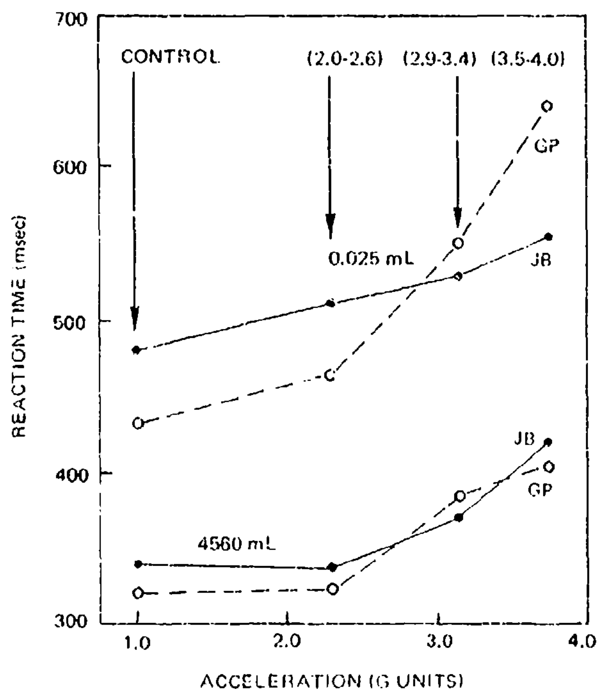

Figure A-6
Visual Reaction Time and Acceleration (Positive)

"White (1960)* utilized a Hecht adaptometer to study changes in the absolute threshold, attributable to positive acceleration. The results have been summarized in figures A-7 and A-8. Figure A-7 shows that foveal threshold measurements made while the subject was riding at 3 g are almost double those at 1 g. At 4 g, threshold had risen to a level where the intensity of the stimulus light had to be increased 3.4 times to be seen at the 50 percent probability level. Measurements made in the periphery of the retina showed similar changes with acceleration, differing only in the final level. For example, the rise in threshold at 2 g was 1.5; at 3 g, the factor was 3.0; and at 4 g, the factor was four times the 1 g value.

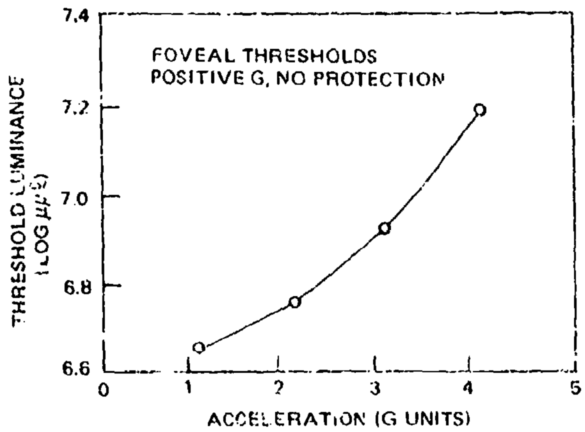

Figure A-7
Foveal Thresholds as a Function of Acceleration
(White, 1960)

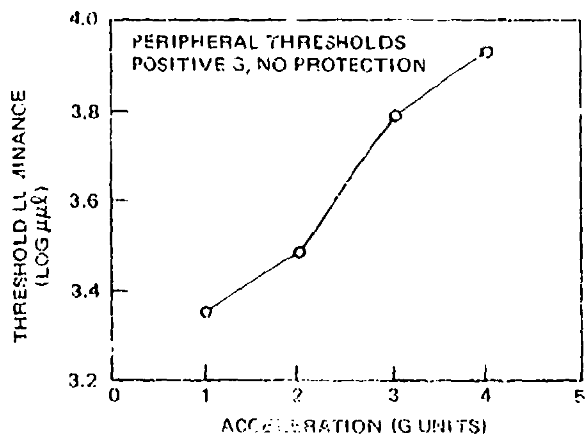

Figure A-8
Peripheral Thresholds as a Function of Acceleration
(White, 1960)

*White, W. J., *Variations in Absolute Visual Thresholds During Accelerative Stress*, WADC Tech Report 60-34, WADC, Wright-Patterson AFB, Ohio, 1960.

"White (1961)* studied the effects of positive acceleration on the relation between visual acuity and luminance level. Threshold was measured in terms of visual angle. It can be seen in figure A-9 that there was an interaction between the effects of g and the luminance level. In other words, the expected decrease in threshold with increasing luminance level was found to be a function of g level. Thus at 0.01 mL, the minimum angle increased from 4′ of arc at 1 g to 7.59′ of arc at 4 g. At 150 mL, the change in visual angle was 0.25′ of arc between these two values of acceleration. The curves drawn on the graph represent the best fit to the 1 g data. The curve has been transposed to the right to fit the data obtained at the 3 and 4 g levels. It is possible to think of the effects of acceleration as being equivalent to putting an optical filter before the pilot's eyes. At 4 g, for example, the decrease in sensitivity is almost equivalent to reducing illumination by one logarithmic unit."**

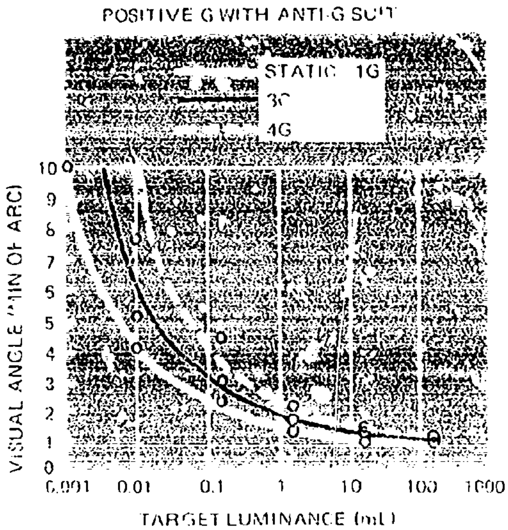

Figure A-9
Visual Acuity Decrement as a Function of Target Luminance and Acceleration (White, 1961)

Gillies (1965) presents a discussion on the effects of acceleration on vision. He includes figures A-10 and A-11 showing the onset of "grey-out" with positive g forces. Figure A-12 shows the last (foveal) area of vision before blackout.

The following comments are from this reference:

"There is a lag of 5-6 sec between the application of the acceleration and the development of signs of impaired acuity. This 'clear period,' to which reference will again be made later, strongly suggests a vascular origin. It is not unreasonable to suppose that capillary vessels of a similar size are

*White, W. J., "The Effect of Acceleration on the Relation between Visual Acuity and Luminance Level," *Aerospace Medicine*, 32, 252 (Abstract), 1961.
**From White and Monty (1963).

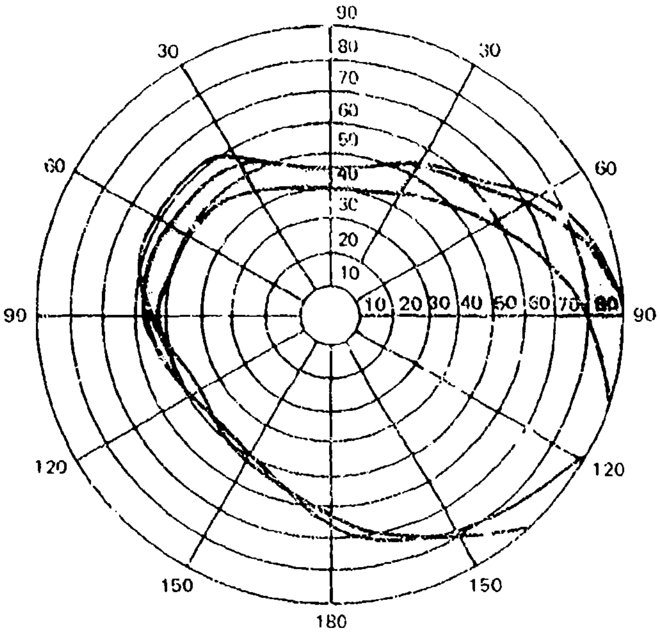

Figure A-10
The Decrement of the Visual Field During Positive
Acceleration at 2.6 G -- No Visual Symptoms

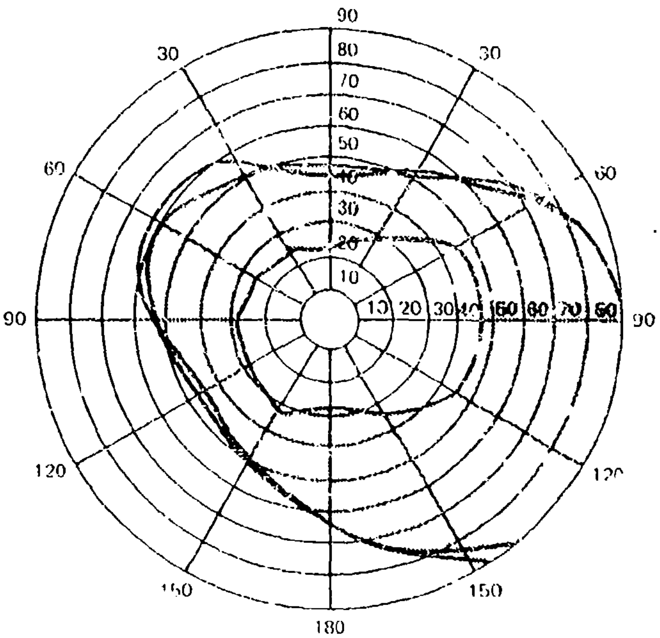

Figure A-11
The Decrement of the Visual Field During Positive
Acceleration at 3.0 G "Grey-Out" and Loss of Peripheral Vision

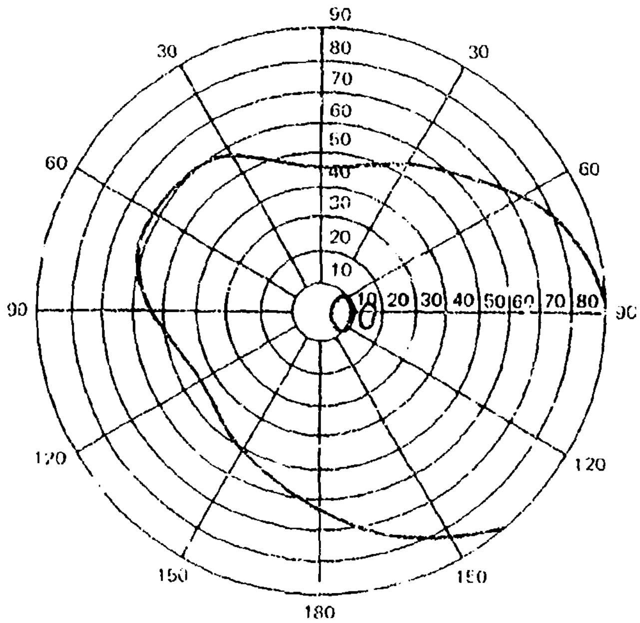

Figure A-12
The Location of the Last Remaining Area of Vision as Blackout is Approached

distributed throughout the retina and that a reduction in driving pressure will affect them all equally. It is only when failure of flow in the larger arterial branches becomes the critical factor that gross differentiation between peripheral and central vision is to be expected. The decrease in visual acuity demonstrable at very low g levels may therefore correspond to the sensation of 'veiling' or decreased contrast experienced by many subjects at an early stage in a centrifuge run.

"Variations in absolute visual threshold support this view. Howard and Byford* showed that a small red signal light in the center of the visual field behaved in the same way as a bright light, but at a much lower acceleration. If the light intensity were adjusted to be only 0.2 logarithmic units above the absolute foveal threshold at rest, an acceleration as low as 1.4 g could result in failure to perceive it, but only after an interval of 6-10 sec. There was some interchangeability between the acceleration at which a light of given brightness disappeared and the time of its disappearance, but the clear periods were never less than 6 sec (fig. A-13). A more comprehensive survey of the effects of acceleration on luminance thresholds was made by White.*

"From these and other experiments it may be postulated that (1) impairment of vision over the entire field can be demonstrated at very low values of acceleration; (2) the extent of the field is progressively reduced with increasing acceleration; (3) at some stage vision is lost completely, (4) there is a 'clear period' of at least 6 sec before the phenomena can be demonstrated; and (5) all the findings can be explained on the basis of a progressive failure of the retinal circulation. Of these (3) and (5) bear more critical evaluation. If central vision for dim lights is, in fact, impaired by

*Referenced in Gillies (1965).

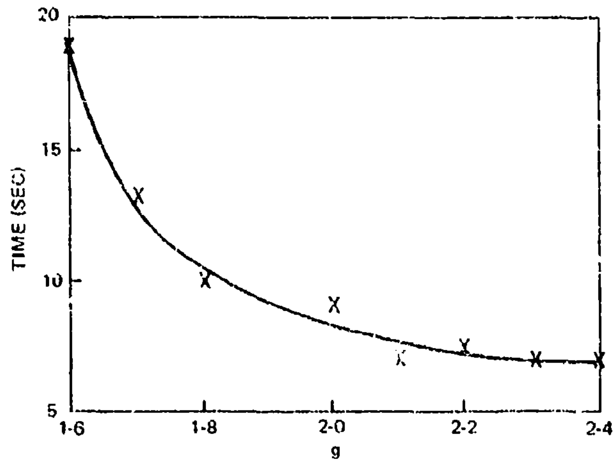

Figure A-13
Time to Extinction as a Function of G –
Target Brightness 0-6 Log Units
Above Absolute Threshold

accelerations far below the accepted blackout threshold, is it possible that, by increasing the brightness of the central light, blackout may be delayed? And again, can the 'clear period' be interpreted as a true physiological reserve time?

"The observation by Howard and Byford* that a disturbance of central vision for a dim target could be shown at very low accelerations suggested that there might be degrees of blackout. It was thought that a very bright light might be seen by a subject who was blacked out to a normal level of illumination. On the other hand, the fact that blood flow through the eye ceases at blackout suggested that no signal, however large, would be perceived by an anaemic retina. Steward* had noticed in aircraft experiments that even when he had lost central vision for a target light within the cockpit he was still conscious of a change in ambient brightness when the aircraft turned into the sun.

"A series of experiments on the centrifuge, using various levels of acceleration between blackout and unconsciousness, showed that a flash of light, provided that it was bright enough, could be seen by the subject however deep his state of blackout might be. No detail was discernible in the flash: the subject was merely aware of a sudden diffuse brightening of his visual field, which was at that time usually dotted with the 'retinal light' characteristic of pressure blindness and of deep blackout.

"These findings showed that retinal function persists to some extent even after normal vision has been lost, and they are supported by Lewis and Duane* who recorded the electroretinogram at various levels of acceleration up to and including blackout and found that, although there were minor variations in the form of the retinogram, no marked or constant change occurred with blackout."

*Referenced in Gillies (1965).

Gillies offers little quantitative data on the effects of negative g forces on vision:

"Loss of consciousness caused by negative acceleration only occurs apparently when the stress exceeds 3 g, and then only after the lapse of a considerable time. At greater accelerations, punctate haemmorhages, petechiae, or frank bleeding into the soft tissues of the head, or into the orbit and conjunctiva, precede the collapse, and although they may be harmless enough, they are an unacceptable penalty in the measurements of an end-point.

" 'Red-out,' or the 'red mist,' is a symptom analogous to 'blackout,' but it is as inconsistent as all the other visual disturbances which have been recorded during negative acceleration. From the descriptions given by various subjects, the time course of the impairment of vision is similar to that seen during positive g. Indistinctness or blurring is followed by grey-out, in which there is a uniform loss of fine detail and contrast. At a later stage vision disappears entirely, and it is in this phase that 'red-out' sometimes appears. In many subjects, however, the impairment of vision does not progress beyond the initial blurring, although a proportion report diplopia at the higher accelerations, and a few have remarked that bright objects seem to develop a halo, or surrounding ring of light.

"The detailed physiology of these symptoms has never been studied. It is probable that the cause of the grey-out is the same in both positive and negative accelerations; that is, a minimal interference with the blood supply to the entire retina and especially to its peripheral parts. The inconstancy of complete loss of vision makes this explanation less likely, and there is no obvious reason why the retinal blood supply should fail completely in negative g. While it will certainly do so if the asystole which commonly occurs is unusually prolonged, in that case consciousness and vision will be lost together. A more likely reason for the loss of vision is the mechanical occlusion of the eye by the lower lid gravitating up over the cornea. In favor of this view are the observations of Ryan et al* who noted that the loss of vision could be alleviated in most of their subjects by a deliberate effort to keep the eyes wide open. It is also significant that, although this form of blackout has been reported both in centrifuges and in aircraft, red-out has never been reliably reported in the centrifuge. This led Lombard et al* to suggest that sunlight shining through the lower lid which covered the eye in this way might have the same effect as placing a frosted red filter over the cornea, thus giving rise to the sensation of 'red-out.' A few experiments in which the lid was deliberately allowed to creep upwards during negative g, after which a photographic flash-bulb was fired at the eye, support this theory (Howard)*. It has also been suggested that the red visual field observed at higher accelerations may be due to staining of the lacrimal fluid with blood from the ruptured conjunctival vessels (Henry).*

"The appearance of a halo around brightly-lit objects is a symptom which sometimes occurs in cases of glaucoma and severe hypertension. The intra-ocular pressure is almost certainly increased during negative acceleration, and there is also considerable local hypertension at the level of the eye. It is possible that the cause of the flare is the same in the experimental situation as in the clinical case. On the other hand, a similar disturbance of vision takes place when the eyes are full of tears, and lachrymation is a common complaint of subjects exposed to negative g."

White (1960) has explored the effects of two different types of anti-g suits on visual thresholds. In the full pressure half-suit, the entire lower half of the body is encased in a pneumatic bladder which produces an even counterpressure when inflated. The other suit, the CSU-3/P, gives protection by applying pressure over five locations in the legs and abdomen. It can be seen in figure A-14 that the rise in peripheral threshold brought about by increased acceleration is, in part, compensated for.

*Referenced in Gillies (1965)

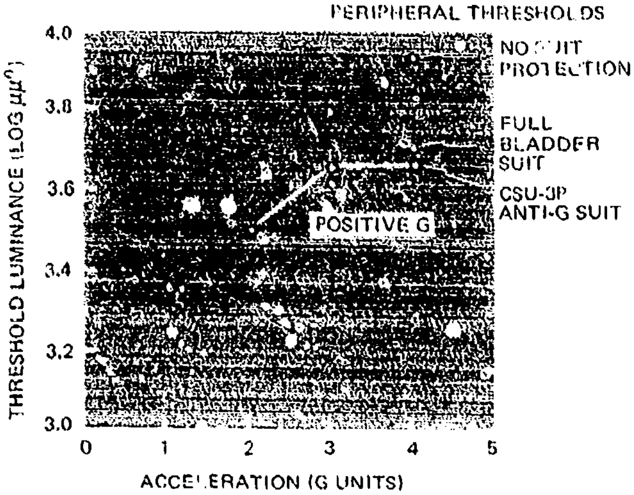

Figure A-14
Peripheral Thresholds as a Function of Acceleration With and Without Anti-G Suit Protection (White, 1960)*

"In a study of the ability of pilots to read aircraft instrument dials at positive accelerations of 1, 2, 3, and 4 g, White (1962)** and White and Riley (1958)*** included illumination level as a parameter. An instrument panel consisting of 12 dials was presented to the subjects. Performance in reading the dials was scored in terms of number of errors made and time taken to read the dials. The percent of readings in error as a function of g and luminance level are summarized in figure A-15. The data indicate that (1) at the highest luminance level there are no differences in the percentage of errors among the four acceleration conditions, (2) at the three highest levels, for values up to 3 g, there are no significant differences in the percentage of reading errors, (3) at the two lower luminance levels, errors are inversely related to luminance and directly related to acceleration, (4) at the 4 g condition, there is a systematic increase in errors with decreasing brightness, and (5) the 2 g level of acceleration cannot be distinguished from the 1 g or static condition. Reading time varied in a similar way."****

*Referenced in Gillies (1965).
**White (1962).
***White, W. J., and Riley, M. B., *The Effects of Positive Acceleration on the Relation Between Illumination and Instrument Reading*, WADC Tech Report 58-332, WADC, Wright-Patterson AFB, Ohio 1958.
****From White and Monty (1963).

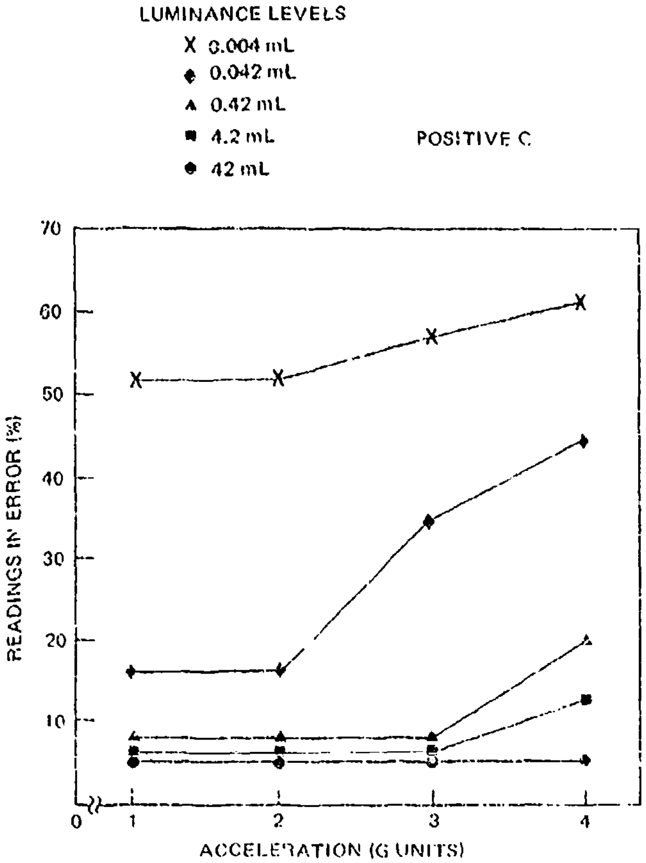

Figure A-15
Dial Reading Errors as a Function of Acceleration at Various Luminance Levels (White, 1962)*

ANOXIA

Gillies (1965) presents a discussion on the effects of anoxia on vision:

"Darkening of the visual field is a common feature of anoxia, although generally the subject is unaware of the change until a normal level of oxygenation is restored when there is then an apparent rise in the level of the illumination of the environment. Measurements of the retinal sensitivity in relatively bright light (photopic vision) have shown that no significant reduction in sensitivity occurs with mild degrees of anoxia, but it is decreased in subjects breathing air at above 18,000 ft — the reduction being proportional to the degree of anoxia. By contrast, there is the significant impairment of night vision (scotopic vision) produced by a very mild degree of anoxia, which effectively raises the threshold of absolute sensitivity for the fully dark-adapted eye. Even at a simulated altitude of 7,400 ft, McFarland and Evans** found that the brightness of a threshold test light had to be increased

*White, W. J., "Quantitative Instrument Reading as a Function of Illumination and Gravitational Stress," *Journal of Engineering Psychology*, vol. 1, (2) 133, 1962.
**Referenced in Gillies (1965)

by one-fourth so as to be still visible and that at 15,000 ft its intensity had to be increased by 1½ to 2 times. In aviation, the practical importance of the sensitivity of night vision to mild anoxia is emphasized by the experiments conducted by Goldie.* He determined the decrease in range of night vision produced by breathing air at various altitudes. His results, expressed in terms of reduction of pick-up ranges, are presented in table A-1.

TABLE A-1

DECREASE IN RANGE OF NIGHT VISION AS A FUNCTION OF ALTITUDE

ALTITUDE (FT)	AVERAGE PERCENTAGE DECREASE IN NIGHT VISION
4000	5
6000	10
8000	15
10,000	20
12,000	25
14,000	35
16,000	40

"The visual fields are restricted in moderate and severe anoxia. Anoxia induced by breathing air at 20,000 ft results in loss of peripheral vision for both form and color and also causes enlargement of the blind spot and development of a central scotoma. These effects increase with increasing anoxia until blindness."

*Referenced in Gillies (1962).

APPENDIX B

VISUAL ACUITY AND CONTRAST EFFECTS — DISPLAY SYSTEM CONSIDERATIONS

VISUAL ACUITY AND CONTRAST*

The detail discrimination threshold of the human eye, i.e., visual acuity, has been investigated exhaustively. Various types of acuity such as minimum detectable, minimum separable, vernier, and stereo have been defined. Minimum separable visual acuity applies in the case of shape recognition where, generally, closely spaced image details must be discerned. It is known to vary as a function of adaptation level, image brightness, contrast, exposure time, image motion, vibrations, spectral characteristics, angular position of the target relative to the line of sight, etc. Visual acuity is defined in terms of arbitrary regular test patterns with generally sharp edges, although some studies have been conducted with sine wave patterns.

Discrimination of imagery details differs from visual acuity measurements in that it requires detection of discontinuities characterized by diffuse edges and irregular intensity distributions. The published acuity data are statistics representing specified performance levels (usually 50% detection probability). Thus, they provide information in a probabilistic rather than in a deterministic sense. Therefore, in any specific instance, visual performance may fall far short, or exceed, predictions based on published data. In general, standard visual acuity data are modified by field factors to obtain realistic operator performance estimates under operational conditions. Unmodified data can be used to establish average expected limits of performance under ideal conditions.

A minimum contrast threshold visual acuity curve, taken from A. S. Patel**, is plotted in figure B-1. These data are for a sine wave test pattern with an average luminance of 100 ft-lamberts and viewed at 20 inches. This curve neglects image motion, exposure time, wave length, and vibration effects. The visual acuity curve sets the lower limit on useful system contrast. In order to be visually discernible, an image detail must exceed the threshold contrast of figure B-1. The resolving power of a sensor/display system is matched to visual acuity for a specified viewing distance at the point where the modulation transfer function (MTF) of the system crosses the corresponding visual acuity contrast threshold.

The use of the display modulation transfer function and the visual acuity contrast threshold to compare two alternative display systems is best shown by means of an example. Let us compare a 5-inch direct view storage tube (DVST) with a scan converter tube (SCT)/10-inch cathode ray tube (CRT) system. Suppose the DVST had a shrinking raster resolution of 120 lines per inch, and the display consisted of a 3-inch square format. The resultant MTF curve for this display is shown in figure B-2. The visual acuity contrast threshold is also shown in figure B-2 for a 20-inch viewing distance. The maximum usable resolution is 590 TV lines where the two curves intersect.

If we assume the SCT has 2,000 limiting TV lines per diameter and an inscribed square format is used, the resultant MTF for the scan converter is shown in figure B-3. The MTF for the CRT shown in figure B-3 assumes a 6-inch square display format and 120 shrinking raster lines per inch. The two MTF curves are multiplied together to provide the total SCT/CRT system response (the video bandwidth is assumed not to be a limiting factor). Again, the visual acuity contrast threshold is plotted in figure B-3 for a 20-inch viewing distance. In this case, the maximum usable resolution is 910 TV lines where the two curves intersect.

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*This section on visual acuity and contrast is excerpted from Slocum, G.H. et al, *Airborne Multi-Sensor Displays*, Hughes Aircraft Co., Culver City, California, July 1967. The material is quoted directly except for minor additions and deletions.

**Patel, A.S., "Spatial Resolution by the Human Visual System, The Effect of Mean Retinal Illuminance," *Journal of the Optical Society of America*, vol. 56, no. 5, 689-694, May 1966.

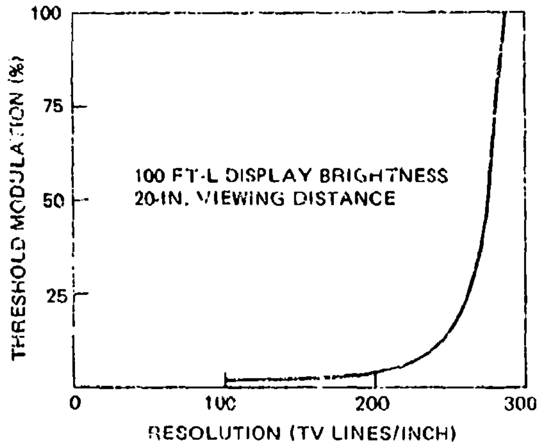

Figure B-1
Visual Acuity Threshold Modulation (Patel, 1966)

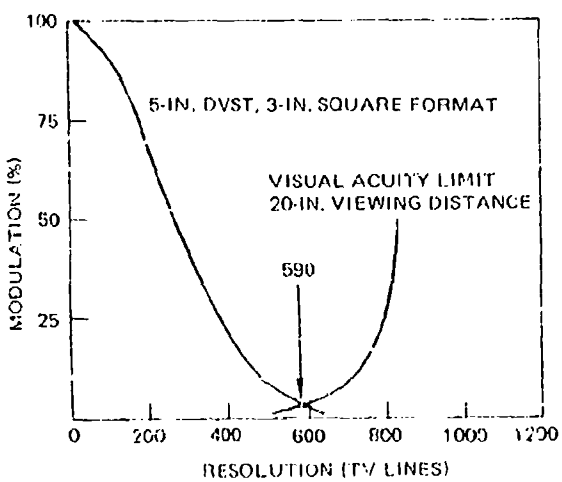

Figure B-2
Modulation Transfer Function and Visual Acuity Threshold for 5-inch Direct View Storage Tube

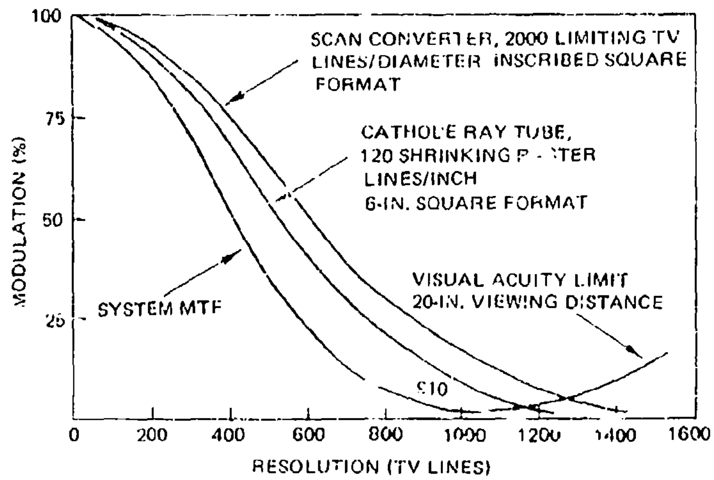

Figure B-3
Modulation Transfer Function and Visual Acuity Threshold for SCT/CRT Display System

DISPLAY SYSTEM CONSIDERATIONS

Carel* has developed the notion of "definition" of a target in order to make some generalized inference about different specific target types. It is defined as the number of resolution elements placed along the major axis of a compact target. A sensor system with a ground resolution of 2 ft looking at a tank 30 ft long exhibits a definition of 15. From studies by Jennings et al** of target identifiability at various levels of ground resolution for various types of aircraft, vehicles, weapons, etc., he assessed target reporting at three levels: (1) recognition (e.g., aircraft); (2) identification (e.g., transport aircraft); and (3) modified identification (e.g., C-54). He then plotted percent correct descriptions at the three levels against definition and derived a chart which tentatively indicates the relationship between definition and probability of recognition and identification (fig. B-4).

He hypothesizes that curves for radar imagery would be similar but displaced somewhat to the left since photographs need little transformation for recognition but radar imagery needs to be interpreted.

Carel discusses the relationship of resolution and scale. From Bennet et al***, he presents figure B-5 which shows that a given scale is useful up to the point "where with that scale the displayed resolution elements become much larger than the acuity limits of the eye. When the eye can resolve to the limit of the rest of the system it does no good to make the image larger by expanding the scale." He indicates Bennet et al recommend, as a generally desirable scale, about 750 times the resolution for displays viewed from about 12-18 inches with the unaided eye. Figure B-6 shows calculated relationships among display size, viewing distance, and resolution.

*Carel, W. L., *Pictorial Displays for Flight* (AD 627 669), Hughes Aircraft Co., Culver City, California, December 1965.

** Jennings, L. B., et al, *Ground Resolution Study*, Final Report, Contract AF 30(602)-2653, RADC-TDR-53-224, Minneapolis-Honeywell Regulator Co., West Covina, California, 29 November 1963.

***Bennet, C.A., et al, *A Study of Image Qualities and Speeded Intrinsic Target Recognition*, IBM No. 63-535-1, IBM, Federal Systems Division, Owego, N.Y., 5 February 1963.

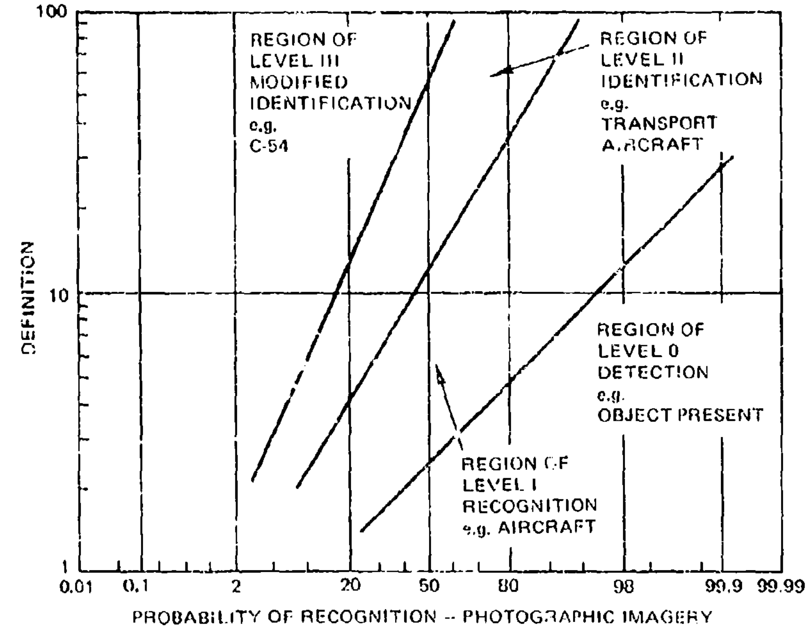

Figure B-4
Definition vs Probability of Recognition

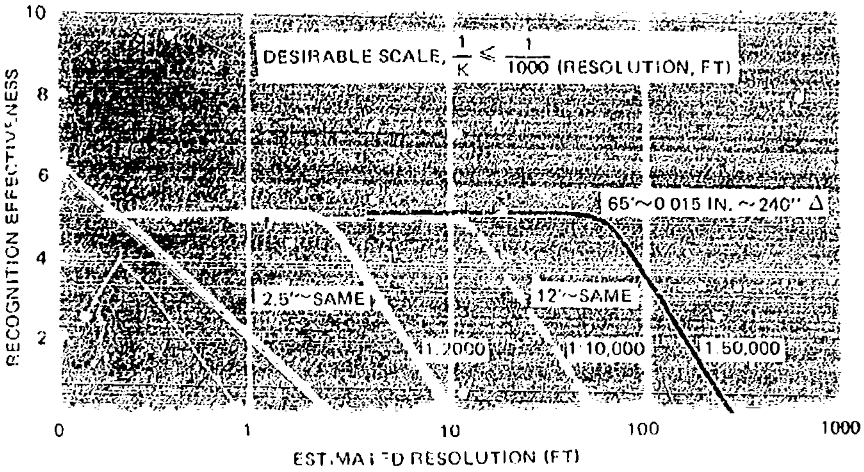

Figure B-5
Effectiveness as a Function of Resolution, by Scale

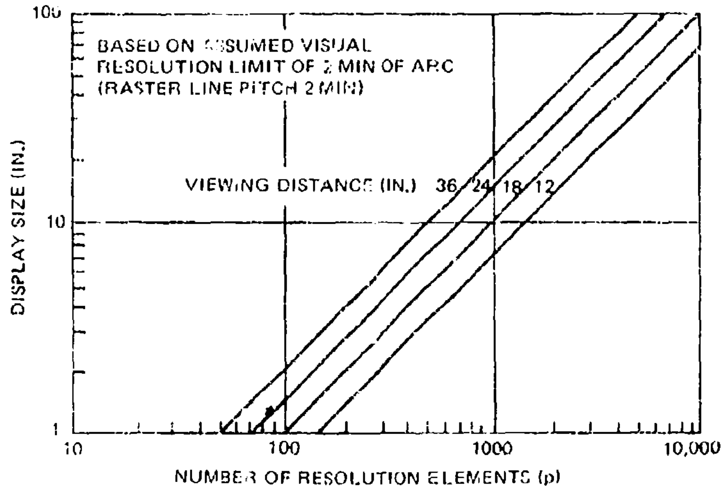

Figure B-6
Required Display Size

RESOLUTION*

Several different techniques exist for measuring and specifying resolution. These can result in widely different resolution numbers for the same device. The cascading of several devices in series such as a scan converter tube, video amplifier, and cathode ray tube creates additional complexities in specifying or predicting a total system resolution, especially when the resolutions of the individual devices are specified differently. Therefore a standard for comparing and combining resolutions of alternate devices must be established. This resolution standard may be arbitrarily selected but should be meaningful in application to sensor displays and should be capable of consistent measurement. The three major resolution measurements for display devices are shrinking raster, limiting television response, and spatial frequency response or modulation transfer function (MTF).

Shrinking Raster Resolution

Shrinking raster resolution is determined by writing a raster of equally spaced lines on the display and reducing or 'shrinking' the raster line spacing until the lines are just on the verge of blending together to form an indistinguishable blur. A trained observer normally determines this flat field condition at about two to five percent peak-to-peak light intensity variation. Since the energy distribution in a CRT spot is very nearly gaussian, the flat field response factor occurs at a line spacing of approximately 2σ, where σ is the spot radius at the 60 percent amplitude of the spot intensity distribution.

*Slocum et al (1967) have also written a useful discussion on the application of resolution and visual acuity measures in determining display requirements. It is presented in this section. Again, the material is quoted directly, except for minor changes.

Television Resolution

A television wedge pattern measures spot size by determining the point where the lines of the wedge are just detectable. The number of TV lines per unit distance is then the number of black and white lines at the point of limiting resolution. The wedge pattern is equivalent to a square wave modulation function, and therefore the TV resolution is often referred to as the limiting square wave response. (One needs to be careful to remember that, in television parlance, one cycle of the square wave produces a black interval and a white interval and is considered as *two* television lines.) Assuming a gaussian spot distribution, the limiting square wave response occurs at a television line spacing of 1.18 σ. Thus, there are approximately 1.7 times as many limiting television lines per unit distance as shrinking raster lines for a display with the same spot size.

Modulation Transfer Function

The sine wave response technique of O. H. Schade* analyzes the display resolution by the use of a sine wave test signal, rather than the square wave signals employed in a TV test pattern or the photographic patterns commonly employed in the optical field. The sine wave response test produces a curve of response called the modulation transfer function (MTF). This is shown in figure B-7. When several devices are cascaded such as a scan converter and CRT, the MTF's of the individual devices are multiplied together to provide the total system MTF. This capability for computing the system MTF from individual device MTF's is a major advantage of using the MTF resolution measurement. Another advantage of the MTF technique is the graphic capability it provides for determining the visual acuity limit of a given display system. The MTF response can be related to the other resolution measurements (shrinking raster and television) if a gaussian spot shape is assumed. This is done in figure B-7. For example, if a sine wave test signal were set on the display at a half cycle spacing corresponding to the shrinking raster resolution line spacing, the resultant observable modulation on the display would be approximately 29 percent. Table B-1 can be used to convert from one resolution measurement to another.

*Schade, O. H., "A Method of Measuring the Optical Sine-Wave Spatial Spectrum of Television Image Display Devices," *Society of Motion Picture and Television Engineers*, September 1958.

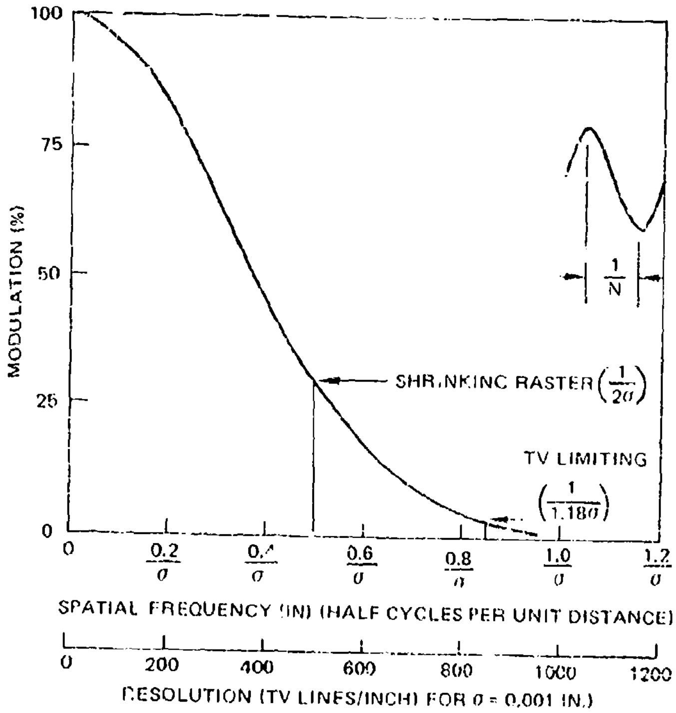

Figure B-7
Relative Modulation Transfer Function

TABLE B-1

CONVERSION TABLE OF VARIOUS MEASURES OF DISPLAY RESOLUTION*

FROM		TO							
		TV Limiting	10% MTF	TV_{50}	Shrinking Raster	50% Amplitude	50% MTF	Optical	Equivalent Passband
TV Limiting	1.18σ		0.80	0.71	0.59	0.50	0.44	0.42	0.33
10% MTF	1.47σ	1.25		0.88	0.74	0.62	0.55	0.52	0.42
TV_{50} (3 dB)	1.67σ	1.4	1.14		0.84	0.71	0.63	0.59	0.47
Shrinking Raster	2.00σ	1.7	1.36	1.2		0.85	0.75	0.71	0.56
50% Amplitude	2.35σ	2.0	1.6	1.4	1.17		0.88	0.83	0.66
50% MTF	2.67σ	2.26	1.8	1.6	1.33	1.14		0.94	0.75
Optical ($^{1}/_{c}$)	2.83σ	2.4	1.9	1.7	1.4	1.2	1.06		0.80
Equivalent Passband (N_e)	3.54σ	3.0	2.4	2.1	1.77	1.5	1.33	1.25	

*For example, to convert from TV limiting to shrinking raster resolution, multiply by 0.59.

APPENDIX C

DISPLAY VIEWING DYNAMICS

In the system design process, an analyst is continually faced with the problem of specifying display parameters and determining the implication of particular decisions. An example is provided by the question of how long it will take for an observer to find a target after it appears on a display. The answer to this may be expected to vary with the vigilance and qualifications of the observer, figure-ground contrast conditions for the target, resolution of the display system, display viewing environment conditions, and the total situation. Yet, in mission analysis and in decisions on design requirements, such questions legitimately are raised, calling for some sort of pragmatic answer. This appendix is a discussion and review of recent literature concerning means of finding such an answer.

Emphasis has been placed upon including design tools with a brief summary of related information. References are provided to ensure ready access to additional details, if desired. In the case of review articles, the liberty has been taken to quote extensively rather than paraphrase a well-written summary.

DISPLAY SEARCH TIME

Simon* points out that, theoretically,

$$\text{display search time} = \frac{\text{display area}}{\text{est. area of a fixation (1 sq in.)}} \times \underset{\text{(0.3 sec)}}{\text{approx time for a fixation}}$$

where:

1 sq. in. = about 5° of arc subtended from 12 in. viewing distance

0.3 sec is based on visual search study data

For a 12 X 12 inch display, $\frac{144}{1} \times 0.3 = 43.2$ sec search time. This seems high, but may apply as a sort of limit. It assumes the targets are reasonably recognizable once they are fixated.

Time Available

Time of image on display is related to ground speed, object size, display size, and scale factor (ratio of display area to area covered by sensor) (see table C-1).

One may help by scanning with a smaller scale, increasing the scale factor to investigate any potential target detected, but this sacrifices seeing smaller targets. Also, multisensor cues may indicate a target which would not have been found by pattern recognition alone (e.g., infrared or radar emanations).

*Simon, C. W., "In-Flight Pictorial Interpretation," in *Visual Problems of the Armed Forces*, Whitcomb, A. Milton (Ed.), National Academy of Sciences, National Research Council, Washington, D.C., 1962 (AD 272 762).

TABLE C-1

TIME AND SPACE VALUES RELATED TO
TARGET SIZE AND EFFECTIVE SCALE FACTORS

Assume
Display size = 12 X 12 in.
Aircraft ground speed = 500 ft/sec

TARGET SIZE FOR REPRESENTATIVE TARGETS

	12.5 ft (track)	25 ft (tracked carrier & missile)	50 ft (fighter plane)	100 ft (large building)
SCALE FACTOR (20 min visual angle at 12 in.)	1/2,125	1/4,250	1/8,500	1/17,000
WIDTH OF TERRAIN STRIP DISPLAYED (miles)	0.35	0.7	1.4	2.8
MAXIMUM STUDY TIME PER OBJECT (sec) (at 500 ft/sec)	4.2*	8.5	17	34

Resolution

In a study by Williams et al,** subjects were to find airfields in photographs of varying resolutions corresponding to 13, 26, and 55 feet on the ground. As one measure, the time for correct designation of an airfield was recorded. When none was located after 60 sec, a score of 70 sec was given. Median times for 12 subjects receiving six trials each were averaged. The means of the medians were as follows:

55-ft resolution – 45.8 sec

26-ft resolution – 39.9 sec

13-ft resolution – 23.2 sec

The differences in time are statistically significant. This gives some feeling for the relationship of recognition time and picture resolution for one target type.

Angular Velocity

Williams and Borow*** used a moving display – up, down, right and left – at rates of 0, 2, 4, 8, 16, and 31 degrees/sec angular velocity. Subjects were to pick out letter triplets, one set at a time, from high-density or low-density search fields of other letters (10 X 10 and 18 X 18 character matrices in a 7.5-inch square). Viewing distance was about 15 inches, and the letters (typed capitals) subtended

*This time would permit analyzing only about 10% of the display.

**Williams, A. C., et al, *Operator Performance in Strike Reconnaissance*, WADC Tech Report 60-521, August 1960.

***Williams, L. G., and Borow, M.S., "The Effect of Rate and Direction of Display Movement upon Visual Search," *Human Factors*, vol. V, no. 2, April 1963.

about 27 minutes of arc. Through 8°/sec they found no significant effects in recognition due to angular velocity. These low rate measures (0, 2, 4, and 8 degrees/sec) were combined. There were also no appreciable differences for up and down or for right and left. These were combined for horizontal and vertical movement groups.

Figures C-1 and C-2 show the study results (24 male undergraduates with 20-20 vision, 106 trials each). They show that target recognition time is related to background density characteristics, angular velocity of displayed pattern, and direction of motion. Average time to recognition was 16.1 sec for low-density and 44.2 sec for high-density backgrounds.

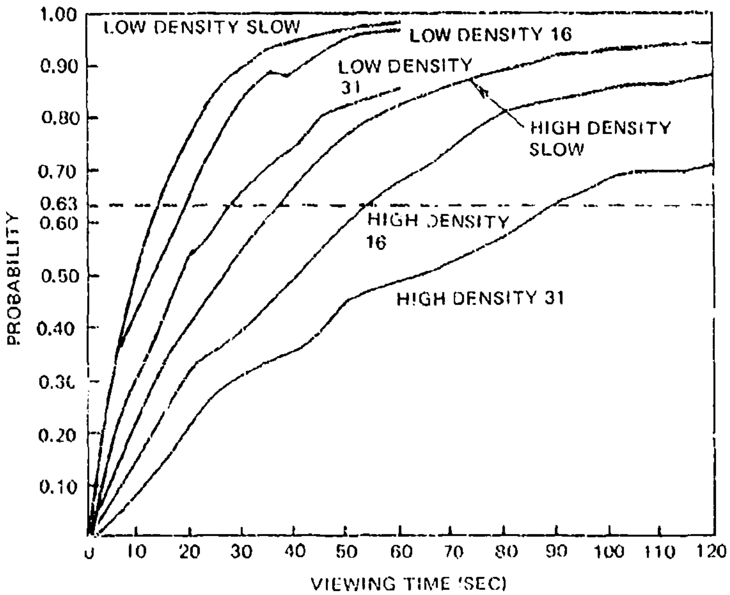

Figure C-1
Cumulative Probability for Each Speed at Each Array Density

Moving vs Static Displays

In another study by Simon,* 12 trained observers worked with 18 different displays showing eight typical military type targets in high-resolution, side-looking radar imagery on a rear-projection viewer. Pictures were moved continuously across the display half of the time and in a series of discrete, static steps during the other half. Two sizes of display were used (6 × 6 inches and 12 × 12 inches) with two area sizes representing 9- and 18-mile strips and three different observation times: 10, 20, or 40 seconds. Significantly less time was required to find a target on the moving display. Target recognition percentages may be regarded as typical for this kind of material except that the aircraft environments (vibration, noise, accelerations, etc.) were not simulated.

*Simon, C. W., "Rapid Acquisition of Radar Targets from Moving and Static Displays," *Human Factors*, vol. VII, no. 3, 185-206, June 1965.

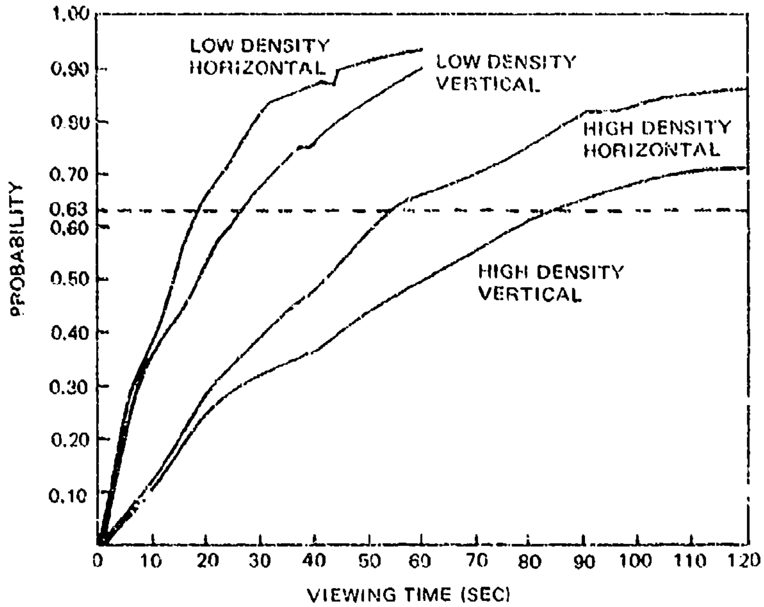

Figure C-2
Cumulative Probability for Fast Speed for the Two Directions at Each Array Density

Figure C-3 shows the percentage of targets recognized in relation to time allowed. This seems a fairly simple comparison. However, figure C-4 shows some of the different values within the above time averages when subgroup figures are considered, such as the kind of target and the display size. In this case, "interaction" refers to the effect of a third variable on the relation of two others. If one tries to generalize from any of these curves, there is danger of being misled. Percentage of targets recognized can only be a relative index of display viewing time requirements for a given situation.

Figure C-5A shows the median time taken to recognize the targets used in Simon's study for moving and static displays. These may be regarded as typical, but figures C-5B and C-5C show there is considerable variation possible if constraints are put on the sample. Recognition time could go to infinity if the target were small enough or could be limited only by visual reaction time if the target were large enough. Simon deduced that the subjects were faster with the moving display because they used a better, more systematic scanning technique, always checking the oncoming material.

Figure C-6 shows a similar effect for ranges of recognition times.

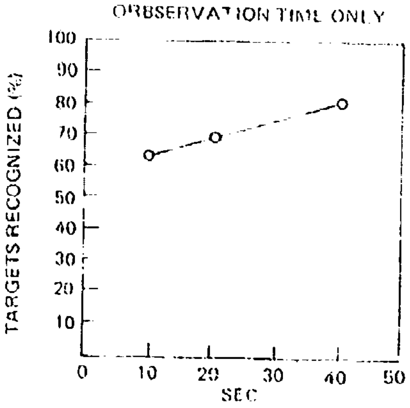

Figure C-3
Percentage of Targets Recognized for Three Times Levels Allowed

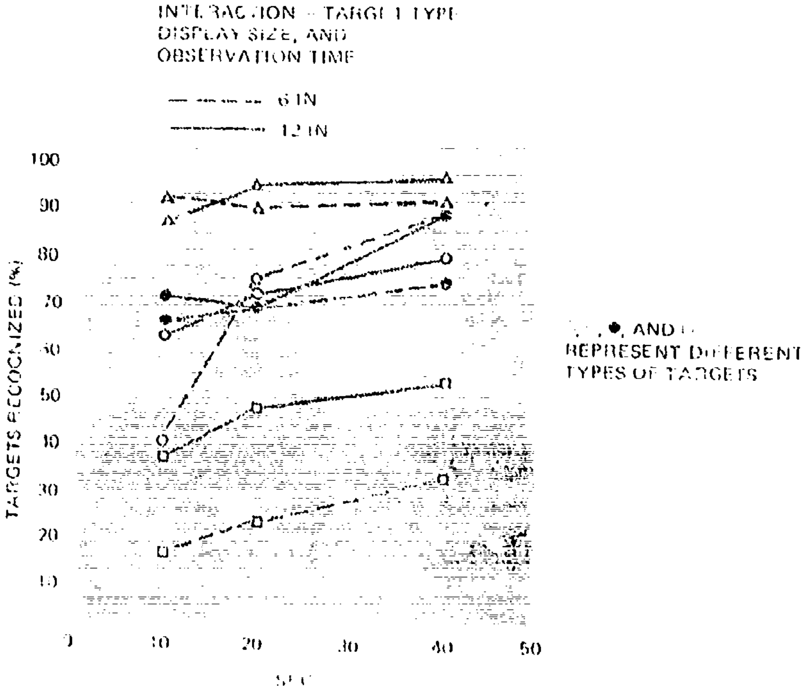

Figure C-4
Percentage of Targets Recognized for Three Time Levels Allowed With Different Target Types

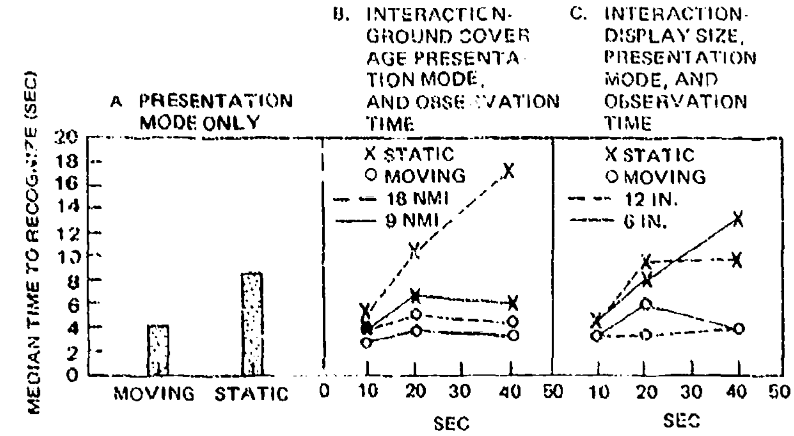

Figure C-5
Median Time to Recognize Targets

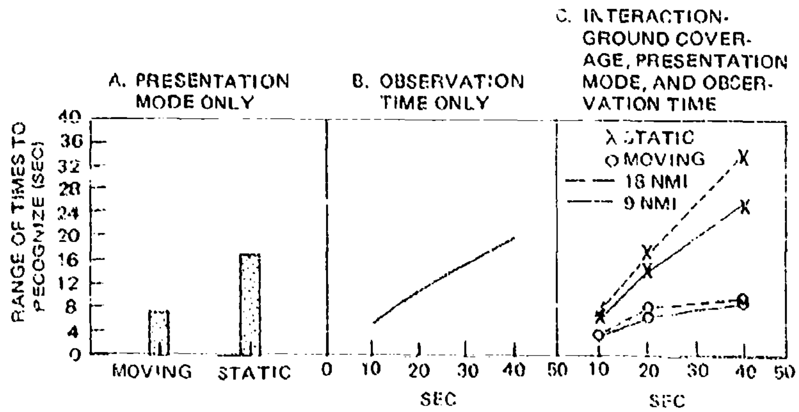

Figure C-6
Range of Times to Recognize Targets

Contrast

Figure C-7, from Hillman,* illustrates how requirements for object contrast change with respect to size depending on whether the visual task is detection or recognition. The detection curve is from Taylor.** The recognition data are from Boynton, Elsworth, and Palmer.*** The Taylor experiment

*Hillman, B., "Human Factors in Airborne Television Displays in Society for Information Display," *7th National Symposium Tech Session Proceedings,* October 1966.

**Taylor, J., "Visibility IV, Use of Visual Performance Data in Visibility Prediction," *Applied Optics,* 3, 562-569, 1964.

***Boynton, R., Elsworth, C., and Palmer, R., *Laboratory Studies Pertaining to Visual Air Reconnaissance, Part II,* April 1958.

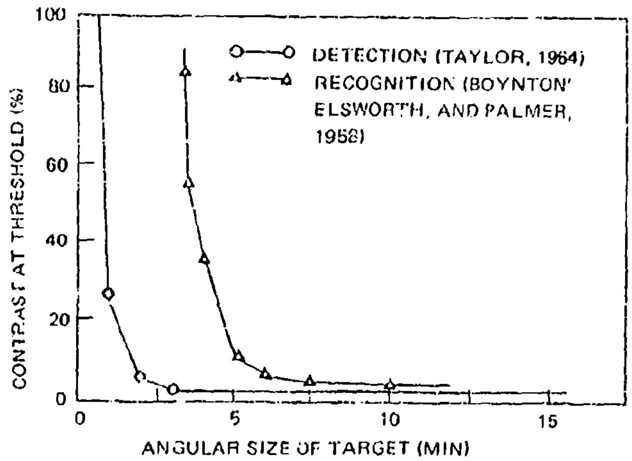

Figure C-7
Comparison of Detection and Recognition Thresholds

called for detection of a single form against a homogeneous field. Boynton required recognition of a particular form from a background of forms. The curves show how the size limit for recognition is greater and that, for target sizes below 10 minutes of arc, more contrast is required for threshold recognition than detection.

A 5-inch square display format (7-inch tube) would subtend 15° at the operator's eye with 18 inches viewing distance. If 6 minutes is required for detection, the limiting scale factor is determined from 0.10°/15° = 0 0067.

Field of View

Figure C-8 shows some ground coverage limits computed for four classes of targets. A 20° field of view reaches a given ground coverage at a lower attitude than the 5° field.

Some advantage is apparent for narrower fields of view when display format is limited.

Signal-to-Noise Ratio

Figure C-9 shows the results of an RCA study* on how much noise could be tolerated in images used for the extraction of navigational information. The subjects examined information in a degraded image of a sector to determine where the imaged area was with respect to a reference photo map. Performance was relatively constant at the noise levels measured, indicating that considerable noise can be tolerated in this situation. Mean response time varied only 0.2 second as the signal-to-noise ratio was increased from 10 to 30 dB.

*RCA Aerospace Systems Division, *Target Detection and Recognition Study*, Final Report, CR-588-90, September 1962.

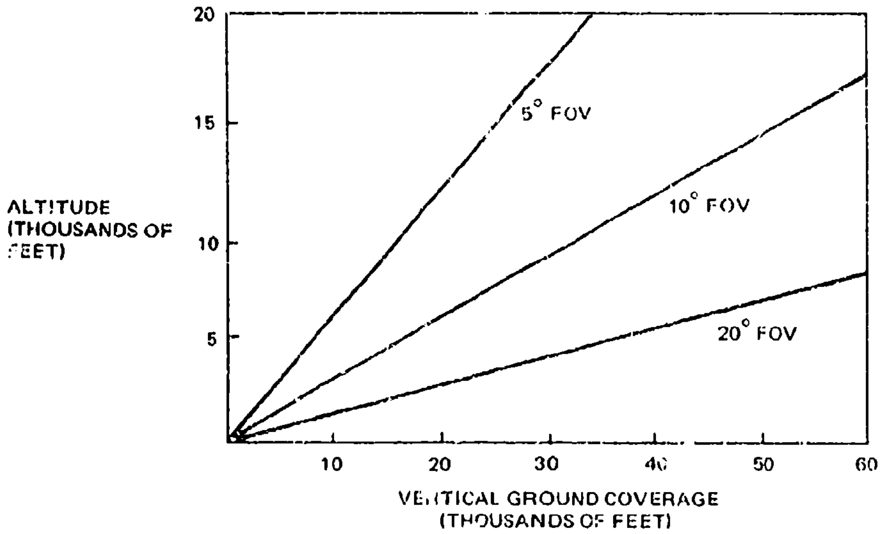

Figure C-8
Ground Coverage Limits (RCA, 1962)

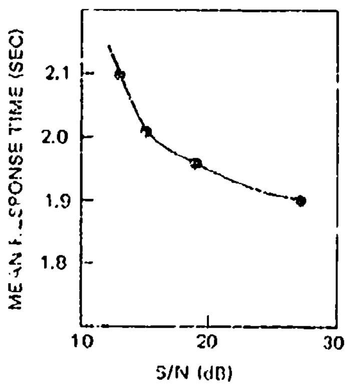

Figure C-9
Effects of Video Noise on
Terrain Recognition (RCA, 1962)

Target Search Time

Erickson* reports several studies on target search time. An excerpt from his discussion of this area is included below.

"In searching for ground targets from aircraft it is often necessary to search over a fairly large area and to make judgments on a number of objects. A number of laboratory experiments have been carried out requiring this kind of search.

"In the study of Boynton and Bush,** observers were asked to search for a specified target located among a number of irrelevant forms. The target and objects were located on a circular, back-illuminated glass plate as shown in figure C-10. Typical results are shown in figure C-11. Performance decreases as search time decreases and as the number of objects in the display increases.

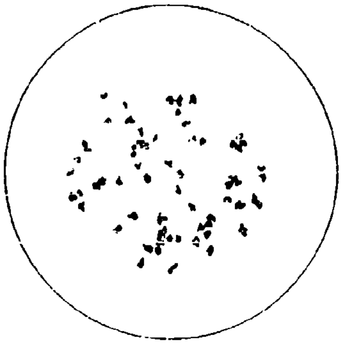

Figure C-10
Example of Field to Be Searched,
From Experiments of Boynton and Bush (1956)

"In the study described in Baker, Morris, and Steedman,*** observers were asked to search a circular field for a target (fig. C-12) located among a number of similar objects. Search time increased with search area size (fig. C-13). Since the number of forms on a search area was roughly proportional to the search area size, it was felt that the primary factor in the increase in search time was the increase in the number of irrelevant forms."

---

*Erickson, R. A., *Visual Detection of Targets: Analysis and Review,* NAVWEPS Report 8617, NOTS TP 3645, China Lake, California, February 1965 (AD 612 721).

**Boynton, R. M., and Bush, W. R., "Recognition of Forms Against a Complex Background," *Journal of the Optical Society of America,* vol. 46, no. 9, 758-764, 1956.

***Baker, C. A., Morris, D. F., and Steedman, W. C., "Target Recognition on Complex Displays," *Human Factors,* vol. 2, no. 1, May 1960, 51-61.

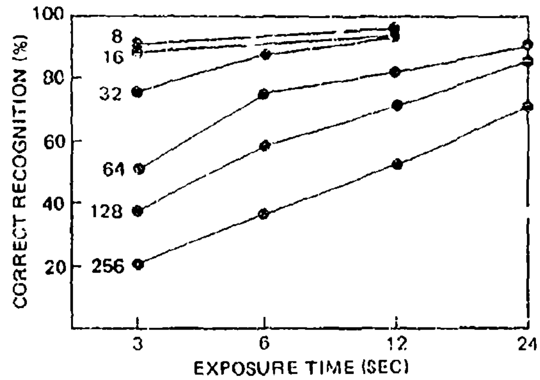

Figure C-11
Search Performance, From Experiments of Boynton and Bush (1962). Object density is shown on each curve.

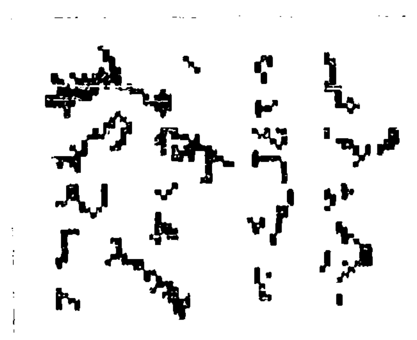

Figure C-12
Targets Used in Experiments by Baker, Morris, and Steedman, 1960. The figure above is not representative of the displays used, but only of the different objects used in the displays.

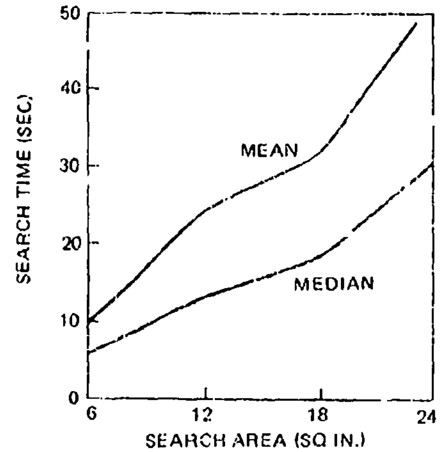

Figure C-13
Search Time vs Search Area for
Experiment by Baker, Morris, and Steedman, 1960

Eriksen reports one of his own experiments* in which a square white field was partitioned into equal sections by black lines. This field contained squares, diamonds, and triangles, the latter being the targets. He found that search time increased as the number of nontarget objects in the field increased. His results are shown in figure C-14. (Search time also increased with increased partitions, presumably due to added visual clutter.)

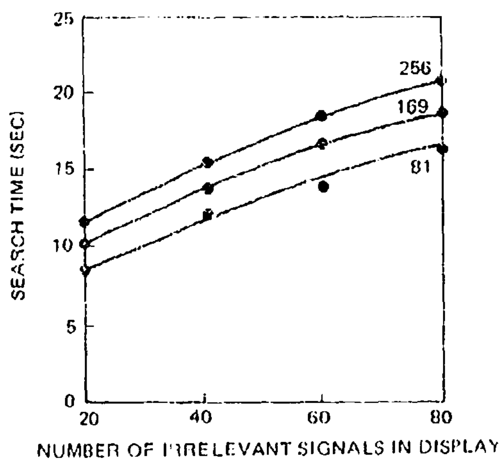

Figure C-14
Search Time as a Function of the Number of Signals
and Partitions. Number of partitions in display
are shown on each curve, Smith, 1961.

*Eriksen, C. W., *Partitioning and Saturation of the Perceptual Field and Efficiency of Visual Search*, WADC Tech Report 54-161 (AD 40730), Wright-Patterson AFB, Ohio, April 1954.

Eriksen also describes work by Smith* in which a circular display containing many small circular pseudo-targets and one designated target (a square, triangle, hexagon, or pentagon) was used in a search experiment. Typical results (for the square target) are shown in figure C-15. Smith also found that the triangle was the easiest target to find, and then in increasingly difficult order, a square, a pentagon, and a hexagon. In other experiments,** a peripheral discriminability of the targets was measured and compared to search time for that target (fig. C-16). It was found that the easier it is to discriminate the target peripherally, the quicker it can be found in a display containing other objects.

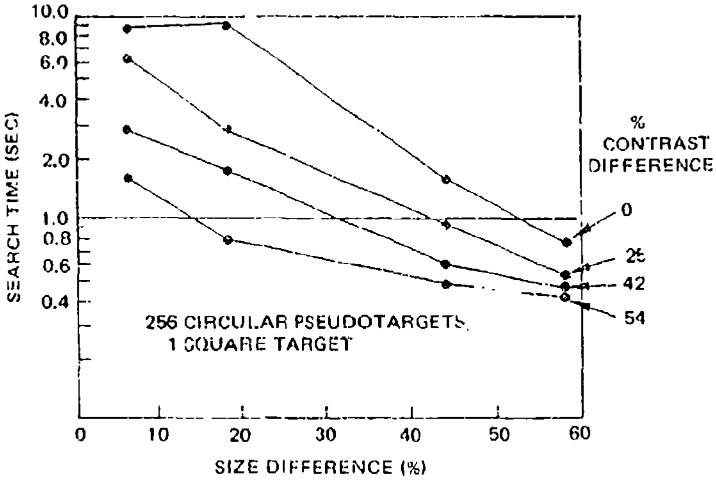

Figure C-15
Search Time as a Function of Target-Pseudotarget Size and Contrast Difference (Erickson 1954)

Erickson*** reports he obtained a peripheral visual acuity score for 16 subjects using a Landolt ring as the target. The time it took these subjects to find a target in a display containing other objects was also measured. Those subjects with the higher peripheral acuity (PA) scores tended to find the target quicker than those whose PA scores were lower. Two types of displays were used: one contained "blobs" and the other rings. Search time was longer and less affected by object density for the blob displays than for the rings. The search task was repeated using only ring displays as part of a second experiment, and the average search times were much the same as those measured in the first. A third experiment employed a linear cue in ring displays by adding a black line to the display.

*Smith, S. W., "Problems in the Design of Sensor Output Displays," in *Visual Problems of the Armed Forces*, M. A. Whitcomb (Ed.), National Research Council, Washington, D. C., 1962.

**Smith, S. W., "Visual Search Time and Peripheral Discriminability," *Journal of the Optical Society of America*, vol. 51, no. 12, 1,462, December 1961.

***Erickson, R. A., *Visual Search for Targets: Laboratory Experiments*, NAVWEPS Report 8406, NOTS TP 3328, China Lake, California, NOTS, October 1964.

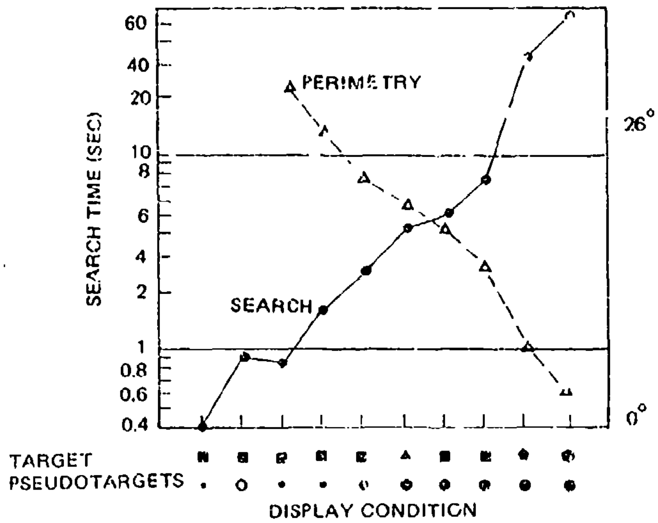

Figure C-16
Search Time vs Peripheral Discriminability, From Smith, 1961.
Peripheral location in the figure is the distance
from the point of fixation at which the target
could be discriminated from a pseudotarget
75% of the time (50% corrected for chance).

The target was located somewhere along this black line. Search time decreased greatly and was not as affected by object density as it was in the displays without the cue. These search times are shown in figure C-17.

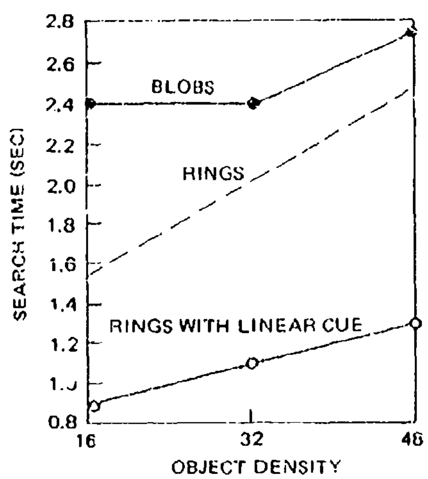

Figure C-17
Average Search Time on Static Displays

TARGET DETECTION AND IDENTIFICATION

Franklin and Whittenburg* provide an extensive reference source for direct visual air-to-ground target detection and identification. The parameters covered have a generally comparable effect when viewing a sensor display of the same scenes. For example, the relationship between illumination level and threshold detection range is indicated in figure C-18. It may be assumed that, as this threshold is approached, increased time will be required on the average before detection.

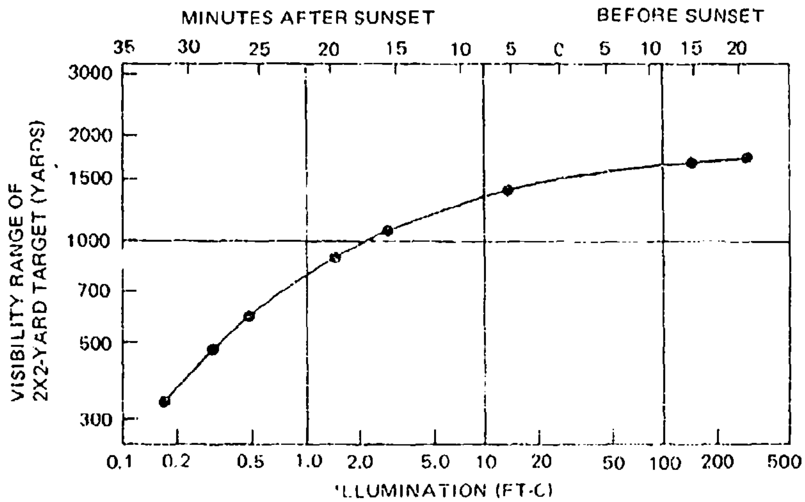

Figure C-18
Visibility Range as a Function of Illumination Level

The bearing of the sun with respect to aircraft line-of-flight is a related variable. Figure C-19 shows that detection range is greatest when this angle approaches 180° and lowest when line-of-flight is toward the sun. This variable also should affect average detection time.

The effects of terrain masking in terms of number of slope changes per unit area and average slope change on target viewing capabilities may be partially determined from figure C-20, which shows terrain effects from different altitudes. Rough hilly terrain tends to mask outlying areas.

*Franklin, M. E. and Whittenburg, J. A., *Research on Visual Target Detection, Part I, Development of an Air-to-Ground Detection/Identification Model*, HSR-RR-65/4-Dt (AD 619 275), Human Sciences Research, Inc., McLean, Virginia, June 1965.

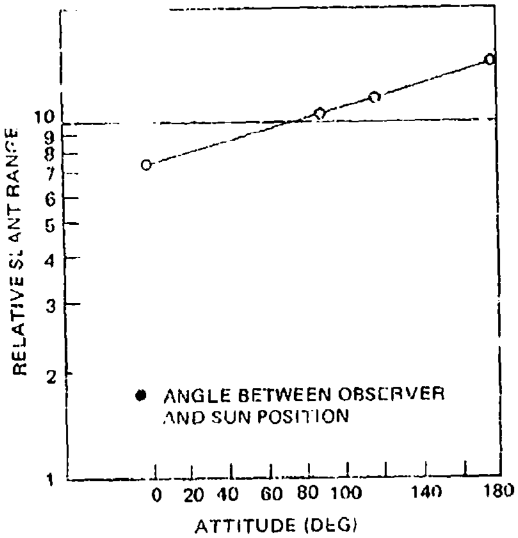

Figure C-19
Log Relative Recognition Slant Range as a Function of Flight Attitude (from Blackwell et al)*

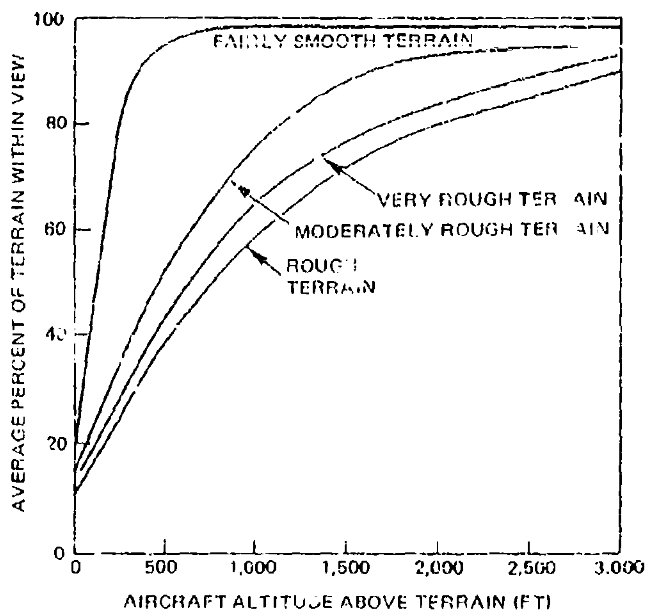

Figure C-20
Average Percentage of Terrain Seen From Aircraft as a Function of Type of Terrain and Altitude (Franklin and Whittenburg, 1965)

*Blackwell, H. R., Ohmart, J. G., and Harcum, E. R., Field Simulation Studies of Air-to-Ground Visibility Distance, Final Report, University of Michigan, Vision Research Labs, Ann Arbor, Michigan, December 1958. (Project MICHIGAN, Report 2643-3F; AD 211 131L).

The effects of vegetation in target detection/identification will vary with the different figure-ground relationships and extent of actual concealment. Figure C-21 shows the results of one study* for viewing from different altitudes.

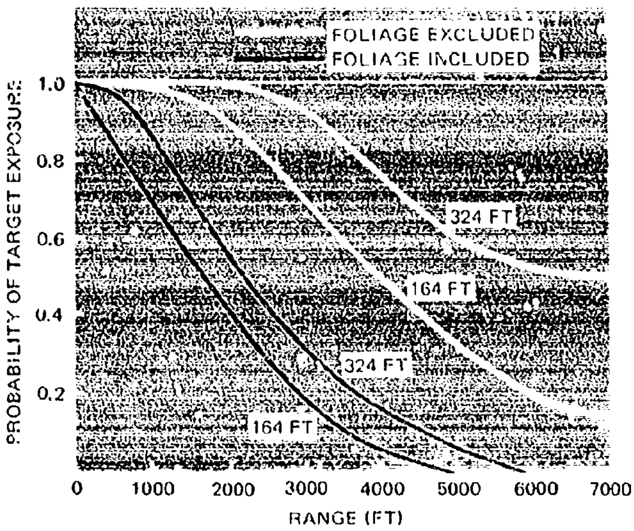

Figure C-21
Average Probability That a 7-foot Target is Exposed as a Function of Range and Altitude With Foliage Included and Excluded (redrawn from Ballistics Analysis Laboratory, 1959). Altitude is shown on each curve.

The effect of altitude itself is shown in figure C-22 to be characteristically a 'u'-shaped relationship with target recognition, since altitude affects both the amount of ground that can be seen at a given time and the apparent size of the target. As altitude increases above ground level, the masking effects of terrain and vegetation are reduced. However, apparent size becomes smaller, decreasing recognition probability. Also, at higher altitudes, atmospheric attenuation tends to reduce viewing effectiveness.

Similar effects are involved in the relationship between slant range and recognition probability. Figure C-23 shows typical ogive curves for comparisons with simulator and field tests.

*Ballistics Analysis Laboratory, *An Analysis of Results of a Ground Roughness Survey, III*, Johns Hopkins University, Institute for Cooperative Research, Baltimore, Maryland, May 1959. (Project THOR, Report No. 42; AD 217 514)

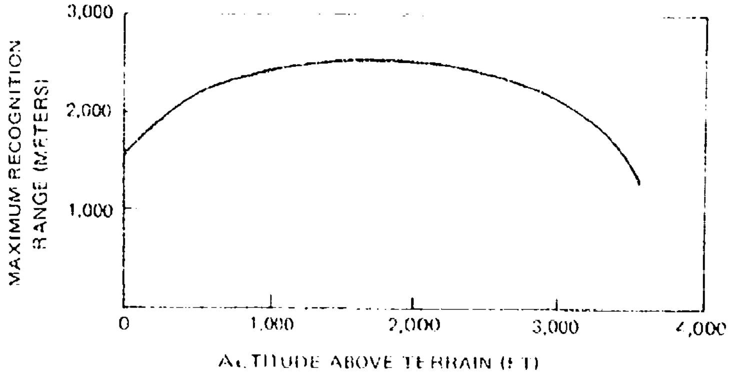

Figure C-22
Effect of Altitude on Maximum Recognition Range.
Conditions assumed: target-tank, visibility clear, terrain-rolling.

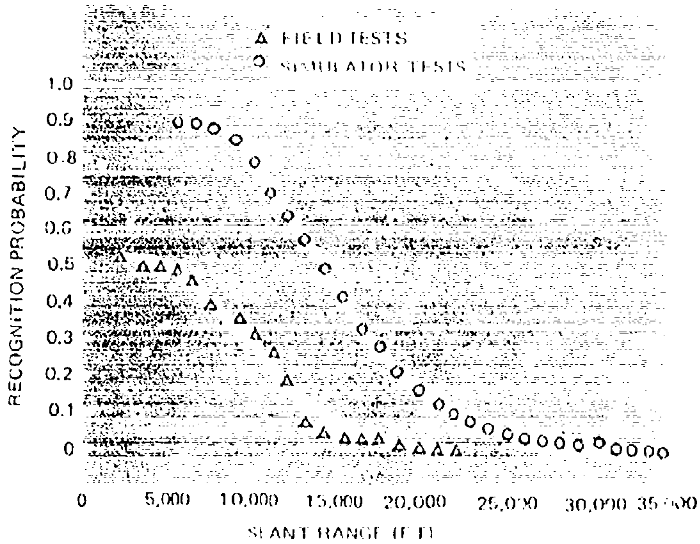

Figure C-23
Recognition Probability as a Function of Slant Range — Field and Simulator Data (from Blackwell et al, 1958)

TARGET RECOGNITION

Carel[2] has prepared a good summary coverage on target recognition which is so directly applicable that it is repeated here almost intact.

"As used in this context, target recognition implies the ability of the operator to classify or name an object or place on the grounds of the output of one or more of the sensors aboard the aircraft. In the first go around, only those sensors that map a contrast pattern are being considered. Such sensors include radar, IR, TV, and perhaps lasers....

"System resolution has been studied extensively. The upshot of these studies can be summarized as follows. Objects can be identified on the grounds of context as well as by shape. An interpreter may infer that a blob on the end of a runway is an aircraft. Such inferences are often erroneous for the context is often insufficient, and a system that yields finer grain data by increasing sensor resolution will increase the confidence that can be placed on any inference. In order that an object be correctly identified by its familiar shape when it is isolated and not embedded in a context, somewhere between 10 and 100 adjacent resolution cells must be 'placed' on the object.[1] For example, for an object 30 feet on a side to be recognized on the grounds of its visual pattern alone requires a contrast sensor with a minimum resolution of 3 to 10 feet.

"Most of the data on this topic has dealt with photo-interpretation and has been collected in the laboratory under noise-free, good contrast conditions. As an example of the relationship that holds between sensor resolution and object recognition, an examination of photographs made from the output of a high resolution IR detector AAR-9 (XA-2) was made. The sensor has a resolution of 0.3°, and the IR 'pictures' were taken vertically at 1,000 feet on a clear night. At this altitude the angular resolution of the sensor yields a ground resolution of about 5 feet. Large aircraft — KC-135, B-47 etc. — can be identified directly by shape. Smaller aircraft — F-89, F-100 — can be discriminated on the grounds of wing sweep and wing tanks. Still smaller aircraft (sic!) remain 'unidentified.' In plan view, fighter aircraft of the F-89, F-100 type can be contained in a square about 40 feet on a side. This implies that the sensor yield was approximately 64 resolution cells 'on the target.'

"Although the generalization is hazardous, as a working rule we assume the requirement for a resolution of 1/10 target size (linear dimension) for target recognition independent of context. The exceptions to this rule are long linear targets: roads, railways, rivers, etc.

"There are some secondary characteristics, secondary only in the sense that they are not subject directly to design control, that are so critical that their effect must and is being considered. These are:

1. The nature of the briefing or reference materials.

2. The complexity of the background in which the target is embedded.

3. The amount of time the operator has to examine the live sensor imagery.

[1] We presume recognition is direct in the sense that, if the real shape of the object is known to the observer, he will recognize it in the display. Nonpictorial or transformed target signatures may be learned, but the observer must be trained to associate the unique signature with the object.

[2] Carel, W. L., *Analysis of Pictorial Displays*, Third Quarterly Progress Report, JANAIR Contract NONr-4468(00), Hughes Aircraft Co., March 1965

"Numerous studies have shown the overriding importance of reference material when the operator's task is target recognition. In general, the more closely the reference material resembles the live display with respect to orientation, content, scale factor, grey scale, and resolution, the easier it is to identify and recognize the target. The importance of such briefing materials suggests the use of two displays: one for live and one for stored data. This topic will be explored more fully under display requirements.

"The complexity of the background and in particular the similarity of the background to the target will increase the number of alternatives from which the observer must select and will obviously affect recognition performance. A set of curves illustrating the effects of complexity on time to recognize a target is shown in figure C-24. These data . . . are meant to show the general nature of the function rather than to be used literally as a design aid.

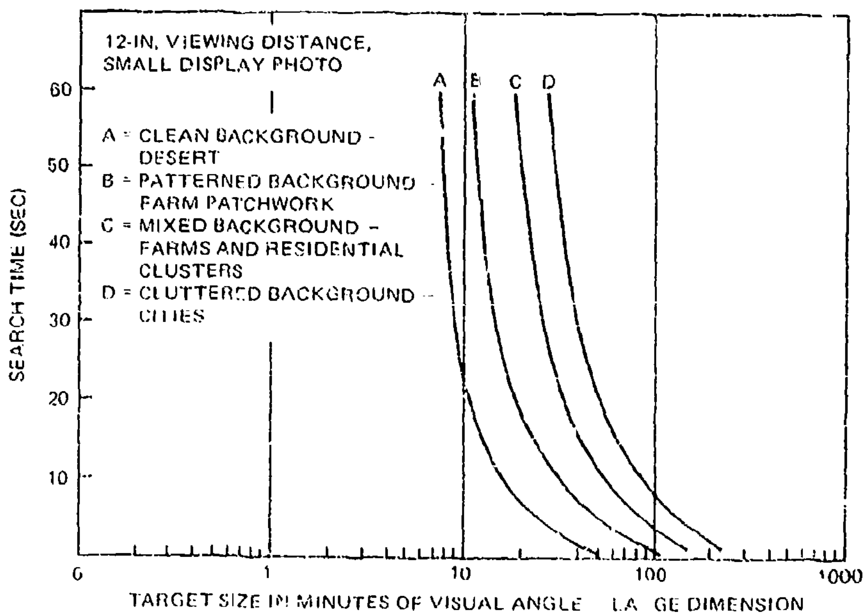

Figure C-24
Effects of Background Complexity on Time to Recognize a Target

"The time available to the operator to find and recognize the target is largely dictated by the nature of the mission and the speed of the vehicle. Where thorough briefing has occurred and access to good reference materials is at hand, the observer is able to do much better than might be expected because the reference material in effect directs his attention to critical parts of the live display with the consequence that the time available is spent only in examining these critical areas. There are, however, cases where briefing is inadequate, and it is of interest to know how much live data the operator can process.

"In the ideal display of sensor data, the dimensions of each sensor resolution cell as displayed should be at least twice as fine as the eye's resolution which results in a negligible loss of effective resolution.* In practice this ideal situation is usually compromised, and an effort is made to provide display resolution only equal to that of the eye. We have drawn a series of charts that illustrate the size of the display needed for the latter case if each displayed sensor cell is dimensioned to subtend 1, 5, or 10 minutes of arc at the observer's eye (see figure C-25). For example, a sensor with 5-foot resolution covering 10,000 feet on the ground requires a display 6.96 inches in diameter if viewed at 12 inches and each sensor cell subtends 1 minute of visual arc at the eye. For pattern sensors, the importance of matching the display resolution to the eye's resolution is tied to the operator's ability to recognize targets. As was previously stated, resolution is one of the key factors in target identification. Targets smaller than 10 times the resolution limit of the system will be difficult to identify except on the grounds of context. Let us now suppose the operator is looking for a very small target and has no a priori data about its probable position.

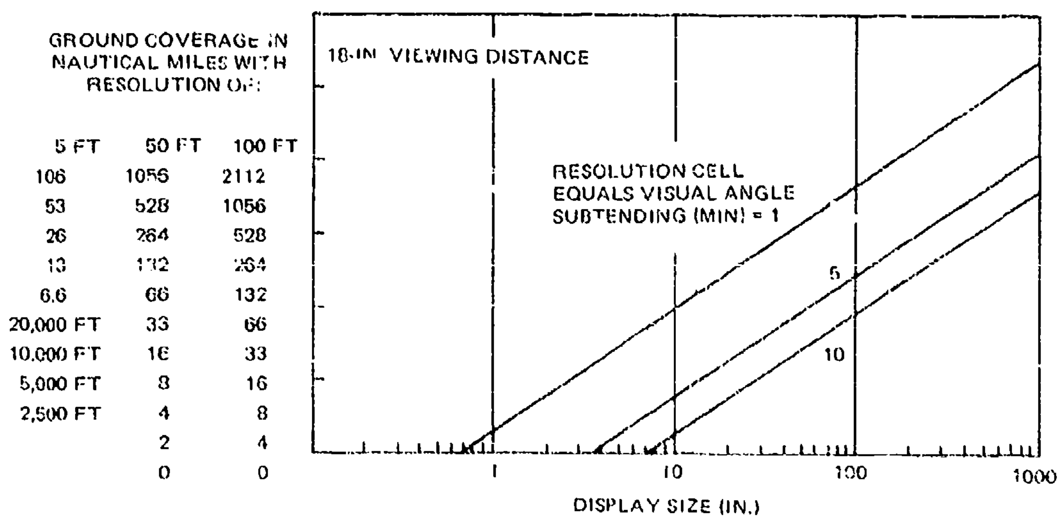

Figure C-25
Display Size, Coverage, and Ground Resolution

"It is possible to estimate the minimum time it will take a hypothetical observer to scan a display of any given size under these conditions if some simplifying assumptions are made. The image on the eye must be stationary if the observer is to see anything. Thus, in scanning a display, the eye dwells momentarily on a patch, then slews quickly to the next patch and so on until the display is visually scanned. In order to determine the time it will take to search a display, we need to know the patch size, the dwell time, the slew time, and the scan pattern. Patch size can be estimated by

*Carel uses twice the eye's resolution somewhat arbitrarily, but this should allow for the not unlikely case where there is 100% loss in resolution between the sensor and the final display as seen by the eye.

examining the acuity characteristics of the eye. Acuity varies with the distribution of retinal cones and thus with the angular distance of the observed target from the optical axis (fovea) of the eye, as shown in figure C-26. For purposes of this analysis, a value of plus and minus 3 degrees will be used as the limit of a useful cone of vision. Patch size will be computed by calculating the size of the square subtended by 6 degrees and will therefore vary with observation distance. Ford et al* found that the average dwell time on large displays is 0.28 second. Enoch** in a similar study found that dwell time varied with display size, but the data from the two studies are in fair agreement, and a dwell time of 0.33 second will be used in this analysis. Slew time is negligible, and the observer will look about three times per second. Scan patterns for real men vary with a host of factors. For our purposes, however, we assume that the man scans the display in a raster fashion, completely, with butted patches, and no overlap. With these assumptions, it is now possible to compute the time it takes to scan a display of any size from any viewing distance. The results of these computations are shown in figure C-27."

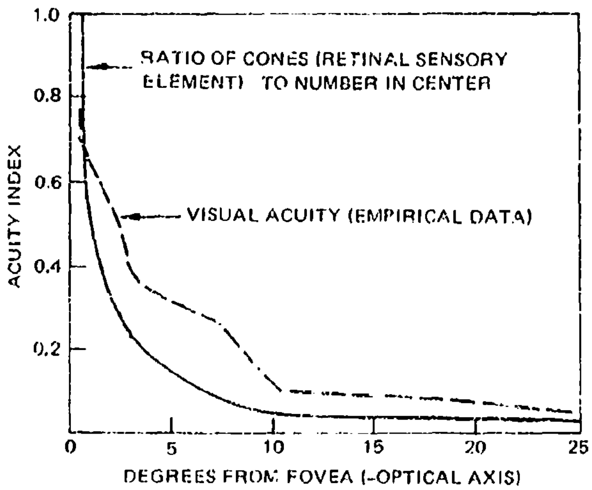

Figure C-26
Visual Acuity as a Function of Angle Off Optical Axis

Carel thus arrives at a similar approach to that of Simon (1962). His chart seems to lead to shorter time values than Simon's formula, although they have made very similar assumptions about patch size and dwell time. In either case, it is assumed that the entire display is scanned methodically as a photo-interpreter might scan, looking for any sign of a target in any part of the display. Actually, there are usually clues as to where targets may be expected in context, leading to more efficient search. And a clear target emerging anywhere on the display will be picked up by peripheral vision and then rapidly focused by a vigilant observer.

*Ford, A., Wh[illegible] T., and Lichtenstein, M., "Analysis of Eye Movements During Free Search," *Journal of the Optical Society of America*, vol. 49, March 1959.

**Enoch, J. M., "Effect of the Size of a Complex Display Upon Visual Search," *Journal of the Optical Society of America*, vol. 49, March 1959.

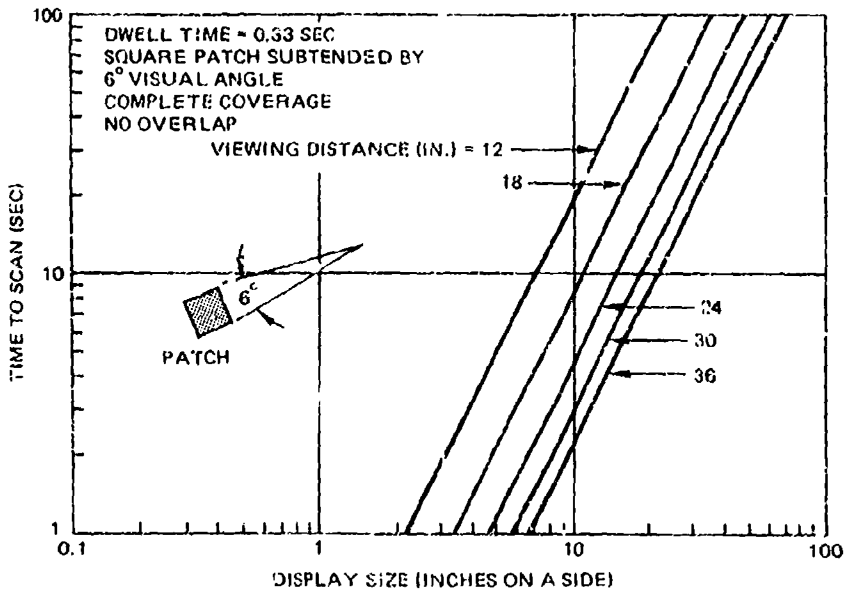

Figure C-27
Time to Scan a Display

Each target situation must be considered separately, but in doing so reference may be made to variables that have been indicated in this appendix. Target-background relationship is particularly critical (determined by contrast, resolution, and pattern effects). Moving, rolling window displays seem to offer quicker target recognition than static sequential displays. Altitude and slant range show predictable effects. Context can facilitate recognition, especially with good training or experience or with reference materials.

The diverse relationships of variables with detection and recognition time presented in this appendix may be useful as a partial design tool reference file. It may be expanded or revised later to provide an up-to-date source of sensor display information.

SUPPLEMENTARY REFERENCES

Figures C-28 through C-33 are from Kubakawa et al.* They present supplementary references on display viewing dynamics.

*Kubakawa, C., et al (Ed.), *Data Book for Human Factors Engineers*, vol. 1 and 2 (CR 114 271), by Man Factors, Inc., for NASA Ames Research Center, November 1969.

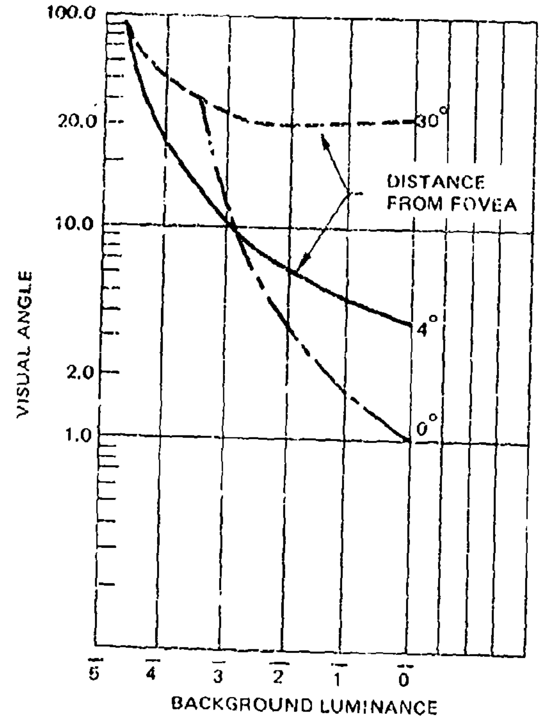

Figure C-28
Visual Angle of the Smallest Detail That Can Be Discriminated as a Function of Background Luminance

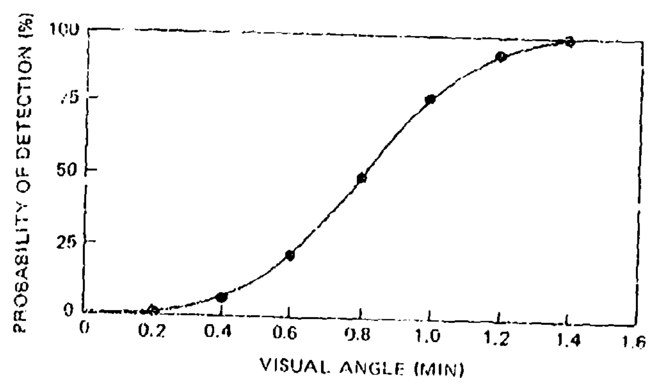

Figure C-29
Probability of Target Detection as a Function of Target Size (Visual Angle) When Target Is Known

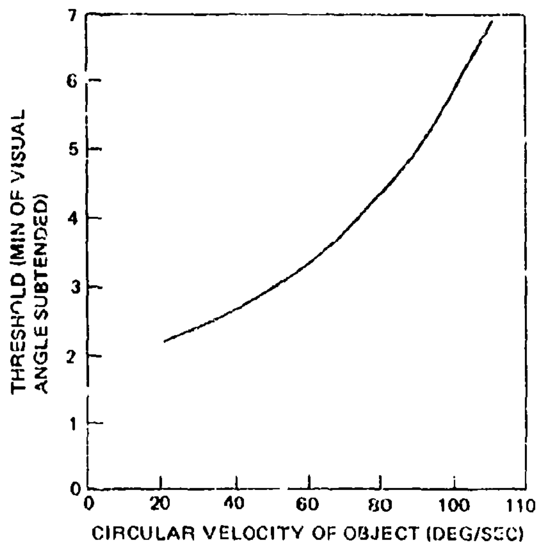

Figure C-30
Visual Acuity as a Function of
Relative Movement Between Observer and Target

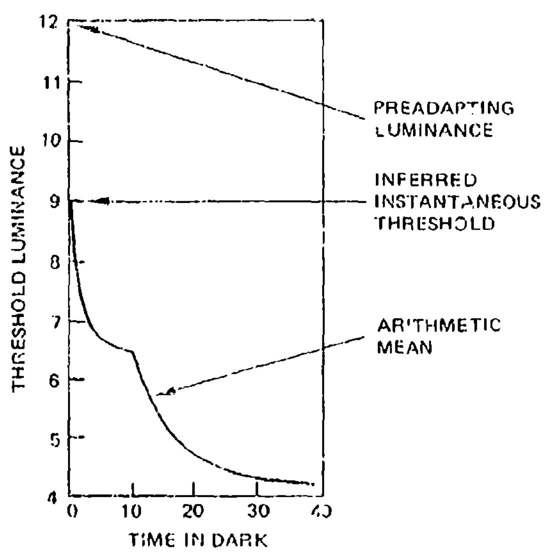

Figure C-31
Luminance That Can Just Be Seen
as a Function of Time in Darkness

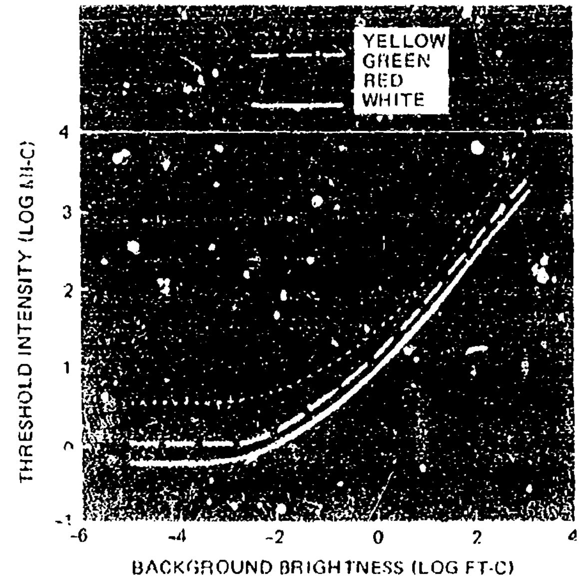

Figure C-32
Intensity of Point-Source Signal Light
of Various Colors When Viewed Against
Neutral Background of Various Brightness

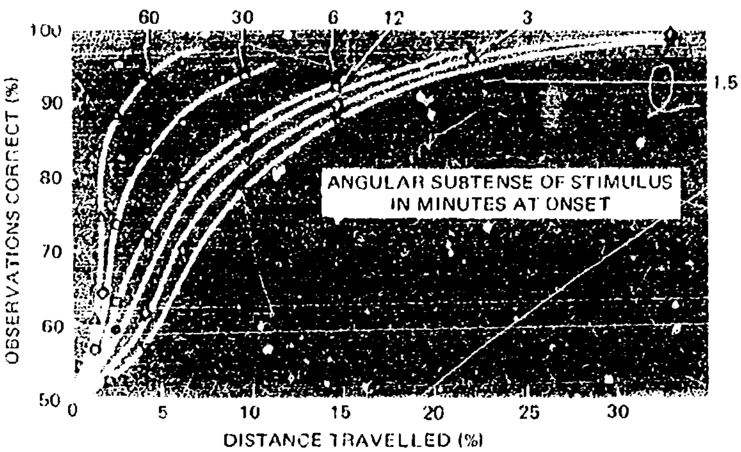

Figure C-33
Threshold Data for Visual Judgment of
Target Motion During Rendezvous

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