Chapter 8

SPECIAL PROBLEMS OF THE EYE

The problem of protecting the flier's eyes from blast, light, and trauma, always present in the past, has become more difficult with the advent of supersonic aircraft, high-altitude flight, and the use of nuclear warheads in the weapon systems. Physical factors, such as aircraft speeds exceeding that of sound, exceedingly high altitudes reversing the former environment of fliers, very low barometric pressures, cosmic radiation, and the flash from nuclear devices, are some of the problems facing the airman of today and tomorrow.

AFR 160-112 contains specific guidance concerning the Occupational Vision Program. This program basically covers the subjects of eye protection to personnel employed in hazardous environments, vision testing associated with placement of personnel, and the prescribing of safety glasses.

GENERAL EFFECTS OF ALTITUDE

Visual difficulties of the human organism at high altitudes are due to hypoxia, decompression, glare, and empty visual field.

Visual Effects of Hypoxia

The hypoxia which affects the flier as he ascends may cause several changes in his ability to see. These visual disturbances, and the ophthalmoscopically visible changes in the blood vessels which accompany them, are described in this chapter.

The range from sea level to 10,000 feet is known as the *indifferent zone,* because ordinary daytime vision is unaffected up to 10,000 feet. There is, however, a slight impairment of night vision, a fact which makes it imperative for night combat fliers to use oxygen equipment from the ground up.

The range from 10,000 to 16,000 feet is called the *zone of adaptation,* because even though visual functions are impaired, the flier is able to overcome the impairment sufficiently to carry on his duties. In this zone, the following changes occur, becoming progressively greater with increasing altitude: the retinal vessels become dark and cyanotic; the retinal arterioles increase 10 to 20% in diameter; retinal blood volume increases up to four times; the retinal arteriolar pressure increases along with systemic blood pressure; the intraocular pressure increases somewhat with the arteriolar pressure; the pupil constricts; there is a loss (at 16,000 feet) of 40% in night vision ability; accommodation and convergence powers decrease; the ability to overcome heterophorias diminishes.

All these changes are returned to normal by either administration of oxygen or return to ground level. Up to 16,000 feet, these effects remain *latent,* in the sense that physiologic compensatory reactions enable the flier to continue his task, unless this altitude is maintained for long flights without oxygen.

The region from 16,000 to 25,000 feet is called the *zone of inadequate compensation,* because one or several of the preceding changes becomes severe enough to produce visual difficulties which do interfere with maintenance of job proficiency. Visual reaction time is slowed; motor response to visual stimuli is sluggish; mental processes are all slowed; heterophorias are no longer compensated by fusion, and become heterotropias with resulting double vision; accommodation is weakened and convergence lost so that instruments are both blurred and double.

Dilatation of retinal vessels, with the accompanying pressure changes, continues to increase until circulatory collapse intervenes. Visual acuity is impaired by diplopia, loss of accommodation, and general retinal and cerebral malfunction; night vision is seriously impaired. All these changes are reversed by use of oxygen or return to sea level.

Above 25,000 feet is the *zone of decompensation*, or zone of lethal altitude. In this zone circulatory collapse occurs, the flier loses both vision and consciousness, and may suffer permanent damage to his retina and brain as a result of death of neurones from severe hypoxia and lack of circulation.

Effects of Acceleration on the Eyes

The pilot's vision while flying may be affected by radial and rectilinear accelerations. These forces have different physiological effects depending on the posture of the pilot in the aircraft. When centrifugal force is increased in the head-to-seat direction, a considerable stasis of blood in the splanchnic viscera and lower limbs results, progressively dilating the venous and arterial system. The quantity of blood returning to the heart is diminished as a result of this stasis. The heart continues to beat; but the diminution of the volume of the systolic blood wave reduces the cardiac output and lowers the arterial tension, which may drop to zero at the carotids if acceleration is greatly increased.

When the carotid pressure is diminished by centrifugal force, a point is reached where it is impossible for retinal arterial pressure to exceed intraocular pressure. At this point, visual function is impaired. Effects vary on individuals, but in general, one may say that pilots will grey out at 4 Gs, black out at 5 Gs, and lose consciousness at 6 Gs, if they are unprotected.

Three methods have thus far been suggested for protection from head-to-seat forces. The first is a reclining seat which automatically tilts the pilot into a supine position when centrifugal forces exceed certain intensities. This, however, is impractical in combat. The second method is by enclosing the lower part of the body in a G-suit. A third method is placing the pilot in the prone position in which he can tolerate about 12 Gs before breathing becomes impossible.

Negative G forces, if prolonged, result in congestion of all vessels of the upper part of the body. Congestion of the face and violent headache may follow. A so-called "red-out" may occur. The actual cause of this phenomenon is unknown. It may be due to congestion of the orbital contents, or to cerebral and/or retinal congestion.

Effect of Glare at High Altitudes

The pilot who flies at altitudes in excess of 40,000 feet encounters the problem of glare from the cloud layer below his aircraft. The human facial contour is not formed to protect the eyes from glare coming from below the eyes. This situation causes the flier to develop a haziness of vision from the glare below him. One investigator has indicated that the cause of this subjective haze is probably the persistence of a positive afterimage of the bright cloud floor.

Other causes of this haziness of vision have been suggested and investigated. These include fluorescence of the crystalline lens caused by greater intensity of ultraviolet light at high altitude and intraocular scatter of light.

The cause of this subjective haze has not been clearly established. Possible solutions to the problem may be through use of the following type filters. These filters would, of necessity, vary in design due to the various aircraft configurations affecting visibility.

a. Maximum absorption in central portion with increasing transmission superiorly and inferiorly.

b. Maximum absorption in superior portion with a gradual increase in transmission towards the center and inferior portion.

c. A self-attenuating variable density filter.

This would be the ideal type of protection in that the transmission of light would be dependent upon the intensity of light incident upon the filter, constant transmission resulting at all times.

The glare from below and the sides in combination with the lack of light scatter in the environment at high altitudes may cause a relative shadow on the instrument panel. Since the external environment is bright and a relatively small amount of light diffuses into the cockpit, the instrument panel may appear to be in a shadow when the pilot turns his attention from outside the aircraft to his panel. The solution to this problem is the use of white light in the instrument panel. The brightness of the panel can then be equalized with environmental lighting by a rheostat controlling panel light intensity.

Effect of Space Myopia (Empty Visual Field)

At high altitudes, pilots may develop "physiological myopia" due to the normal ciliary muscle tone when the eye is at rest. At these altitudes, one may not have a distant object on which to fixate. In such an empty visual field, a reflex accommodation occurs, creating from 0.50 to 2.00 diopters of relative myopia. Theoretically, under this condition, an emmetropic individual would be incapable of detecting a target at his normal "far point."

For example, a pilot with normal visual acuity of 20/20 is able to discern an aircraft having a fuselage diameter of 7 feet at a distance of 4.5 miles. The same individual accommodating 0.50 diopter, would then be able to detect the same aircraft at a distance of only 3 miles. Another possible solution would be to use pilots who are slightly hyperopic.

Sunlight and its Effect on the Eyes

Light is part of the energy spectrum. The entire spectrum extends from the extremely short cosmic rays with wavelengths on the order of 10^{-12} centimeters to the long radio waves, several miles in length. Visible light consists of a small portion of the spectrum, from 380 millimicrons (violet) to about 760 millimicrons (red). A millimicron is a millionth of a millimeter. The neighboring portions of the visible spectrum, although not visible, have their effects on the eye and are therefore of interest.

Wavelengths of 360 millimicrons and shorter, down to 200 millimicrons are known as abiotic rays. Exposure of the eyes to this portion of the electromagnetic energy spectrum produces ocular tissue damage, the severity dependent upon intensity and time of exposure. Wavelengths longer than 760 millimicrons to the microwaves at about 1 mm are the infrared or heat rays. These rays, too, may cause ocular tissue damage depending upon intensity and exposure time. The infrared rays may affect all ocular tissues, whereas the ultraviolet have their effect chiefly upon the conjunctiva and cornea.

The light intensity in extraterrestrial space above 100,000 feet is approximately 13,600 foot-candles. At 10,000 feet on a clear day, it is about 12,000 foot-candles, and at sea level on a clear day, it is about 10,000 foot-candles. It is obvious that something in the atmosphere is absorbing light. Water vapor, dust particles, and air absorb light. In addition to absorbing light, water vapor also scatters light. This accounts for the unexpected sunburn on overcast days.

In addition, certain selective absorptions occur. The ultraviolet light shorter than 200 millimicrons is absorbed by dissociated oxygen as high as 400,000 feet. Below this level, these wavelengths are of no consequence. The ultraviolet light 200 to 300 millimicrons in wavelength is absorbed by the ozone layers in the atmosphere. This is very fortunate because the wavelengths from 200 to 300 millimicrons are the most damaging to the eye.

It is these wavelengths that produce the actinic conjunctivitis which welders receive when they fail to wear protective hoods. These wavelengths from 200 to 300 millimicrons are no problem until an altitude of about 125,000 feet is reached. This is about the height of the second ozone layer. Above this altitude, these ultraviolet wavelengths between 200 and 300 millimicrons will require consideration.

The rays of particular concern, therefore, are from 300 to 2,100 millimicrons in wavelength with an intensity varying between

10,000 foot-candles at ground level to about 13,000 foot-candles at presently attainable altitude.

Brightness of the Field of View

The amount of light reflected back to the eye determines the brightness of the individual's field of view. Snow, for example, may reflect back to the eye 85 to 90% of the light falling on it. White sand, coral, and white clouds may reflect as much as 75 to 80% of light. Grass and forests may reflect as little as 10% of light. The apparent "coolness" of green fields probably depends as much upon the fact that they reflect low percentages of light as it does upon any specific psychological effect of the color.

Insofar as the feeling of brightness in sunlight is concerned, then, there are two factors: the amount of light falling on a surface, and the amount of light reflected by the surface.

The Effect of Light on the Eye

There are certain specific effects which light may produce in the eye. First, consider ultraviolet radiation which produces its harmful effects externally. The short rays which do the damage are absorbed by the outer one-tenth of a millimeter of the eyeball. Hence, the effect of these rays is limited to this area of absorption.

Ultraviolet light produces a painful swelling accompanied by extreme sensitivity to light—photophthalmia, or so-called snow blindness—that one experiences in the Arctic. It is only produced after prolonged exposure to sunlight of high intensity, such as that reflected into the eyes by a snow field, the surface of water, or a bright desert. Ultraviolet burns do not produce permanent damage to the eye, although pain is severe.

Both infrared and visible light contain a great deal of energy. If an individual looks directly at the sun with inadequate eye protection (all so-called sunglasses are inadequate for this purpose), the lens system of the eye will concentrate this energy on the retina like a burning glass and will produce an actual burn of the retina. This happens so frequently during observation of an eclipse of the sun that it is called "eclipse blindness." It is a permanent eye injury and clinically is manifested by a macular scar. There will be present a central scotoma as demonstrated on the tangent screen. Vision may be 20/70 or less.

Infrared is also reputed to cause chronic redness of the eyes, chronic conjunctivitis, and pterygium. Its role in these eye conditions is still not completely determined.

Effects of Sunglasses and Other Ophthalmic Filters on Light

Plain crown glass as used in spectacles will eliminate most of the ultraviolet. Thus, if an individual wears spectacles which have large enough lenses to prevent ultraviolet light from entering his eyes around their periphery, he is protected to a great extent against snow blindness. Glare may bother him but he will not develop photophthalmia. Plastic lenses, if clear, transmit ultraviolet unless made from one of the new special plastics. Current aircraft plastic canopies do transmit ultraviolet. In general, dark-tinted plastics do not transmit ultraviolet, but there are exceptions.

If sunglasses with glass lenses are being considered, then one must be chiefly concerned with what these lenses do to visible and infrared light. All these wavelengths pass through crown glass with only about an 8% reduction. (Magnesium fluoride coated lenses absorb only 4% of light and allow 96% to pass through.)

Sunglass lenses of all types filter light. There are four types of sunglass lenses in common use:

Colored filters	Reflecting filters
Neutral filters	Polarizing filters

They all have in common the fact that only a certain percentage of the total amount of light gets through to the eye. They produce this effect differently. The colored, neutral, and polarizing filters achieve this effect by absorbing some of the light and allowing the rest to pass.

Colored Filters. The reason that a green sunglass looks green is that it absorbs a higher percentage of the other colors than it does of the green. It allows the green to pass through. The same is true of other colored sunglasses. They permit different amounts of light of different wavelengths to pass. Yellow or amber sunglasses, for example, absorb all the blue light and most of the green and allow only red, orange, yellow, and a little of the green to reach the eye.

Neutral Filters. On the other hand, neutral filters absorb approximately equal amounts of all wavelengths of light—as much of the red as of the green, the blue, or any other color. For this reason they appear gray. (However, all gray-appearing filters are not necessarily neutral.) They darken a scene without changing its colors.

Reflecting Filters. Reflecting filters allow a certain percentage of light to pass to the eye and reflect the remainder back in the general direction of its source. They act very much like partially silvered mirrors, and when worn, they resemble small mirrors. The silver-colored coating on the upper part of certain "graded density lenses" is such a filter. It is usually a thin coat a mixture of chrome and nickel. As a rule, these reflecting filters are nearly neutral in that they reflect an approximately equal percentage of all wavelengths.

Polarizing Filters. Polarizing filters transmit only light that is vibrating in a certain direction. They absorb light vibrating in other directions. They are not neutral in that they pass more light of certain wavelengths than of others. Polarizing filters pass about 30% of light unless they are polarized in one particular plane. For this reason, they require combination with other types of filters to be effective as a general-purpose sunglass.

They have an additional disadvantage in that the polarizing film is made up of very minute crystals. This film is quite delicate and must usually be placed between two layers of glass, to protect it. It also produces a certain amount of peripheral distortion and is subject to deterioration after a time. In addition, the lamination required makes it expensive to produce curved lenses or those in which corrections can be ground.

Filters used for sunglass purposes have their density described in terms of the amount of light they transmit. Thus, a 15% filter will allow 15% of the visible light falling on it to pass through. If it is a neutral filter, this will be 15% of each wavelength of visible light. If it is a colored filter, it may be only 1 or 2% of one wavelength and as much as 30 or even 40% of another wavelength.

It is emphasized that colored lenses do not "add yellow" or "add green" to the light. They cannot add anything. They only make things appear to be certain colors because they subtract other wavelengths of light by absorption or reflection.

Most ophthalmic filters transmit rather large percentages of infrared radiation, especially the near infrared source. Manufacturers of sunglass lenses are prone to show the fine infrared absorption of their lenses around 4,000 millimicrons. If it is recalled that sunlight has almost no infrared longer than 2,100 millimicrons, it can be readily seen that this characteristic has no significance for wear in sunlight. There are a few sunglass lenses, however, which do have a low infrared transmission.

Reduction in the total amount of light may aid one's ability to see when the total brightness is so high that one cannot adapt to it by the normal eye mechanisms. If retinal adaptation, small pupil, and partially closed lids do not sufficiently reduce the amount of light entering the eye, the person will be unable to see well. This may happen when flying just above a dense sunlit overcast or flying over snow or over water into the sun. The use of a filter lens will reduce the over-all brightness to a level that can be tolerated and will allow the individual to see properly.

Glare. It is frequently stated that filter lenses will reduce glare. This statement is usually scientifically incorrect. Glare is caused by a difference in brightness between various parts of the visual field. The eye is dazzled by a lighter object because it is adapted for the darker portion of the field. Glare is then present. Putting on the usual filter lens reduces the brightness of all objects by the same amount, so that it does not change the ratio between the brightest and the darkest areas. Therefore, glare is still present.

These filters can reduce glare when the bright area consists of polarized light, such as the sun path on paving, snow, water, or similar surfaces, and the filter used is a polarizing one which will, then, selectively reduce this brighter area more than its background. Polarizing lenses have certain disadvantages previously mentioned which limit their use. These disadvantages will be discussed below. Polarizing lenses are further limited in their usefulness due to the small portion of polarized light in the daily environment. In general, then, it can be said that sunglass lenses do not reduce glare.

Color Perception. It is quite obvious that colored sunglass lenses will distort color perception to varying degrees. The degree of distortion will depend upon the amount of the various wavelengths absorbed by the lenses. Carefully designed experiments will show some degree of color perception error induced by any colored lens. Only with a true neutral filter is color vision entirely normal.

Visual Acuity. The ability to distinguish small objects at long distances is essential for the flier. The amount of light during the day is in excess of that required for maximum acuity. For this reason, it can be reduced considerably by a filter lens without reducing ability to see distinctly. A lens of about 10 to 15% transmission has been shown to be the most useful. (This is true, provided that the lens is somewhere near a neutral lens.)

A slightly darker lens could be tolerated under conditions of extreme brightness, but the lens of 10 to 15% transmission is adequate. On sunlit days, this density will not reduce acuity. The lenses should be removed if the illumination falls below bright sunlight, or acuity will be decreased. This is particularly true at dusk and at dawn.

Claims have been made that certain lenses increase acuity—especially the yellow or amber lenses. This statement is usually based on the way light is scattered by haze or fog. It is known that the shorter wavelengths (blue and blue-green) are scattered more by haze and fog than the longer wavelengths (red, orange and yellow). On theoretical grounds, then, the elimination of the short wavelengths by a filter should increase the sharpness of an image. This would seem to be confirmed by the use of yellow filters in photographing distant scenes. Such filters absorb the short wavelengths and allow the long ones to pass. They do give sharper pictures of distant scenes.

Such yellow filters, when worn, give a subjective sensation of increased brightness (a false impression because the lens subtracts light; it does not add it). These yellow filters also give a subjective sensation of sharpening the image. However, all carefully controlled research experiments conducted to date fail to show an increased ability to see in haze and fog by using yellow filters.

The difference between the effect on the eye and the effect on film is readily explained by the relative sensitivity to blue light of the photographic film on one hand and the retina of the eye on the other. Photographic film is extremely sensitive to blue light. Scattering of blue light, therefore, gives a marked haziness to pictures. On the other hand the human eye has a very low sensitivity to blue light, so the scattering has very little effect on ability to see in haze or fog. We have not yet developed any sort of ophthalmic filter which will appreciably increase the ability of the eye to see in haze or fog.

Underwater Search. Certain types of sunglasses have been advocated from time to time for search of submerged objects, such as submarines. Polarizing lenses have been suggested because of their absorption of polarized light from the water surface. Extensive experimental tests have failed to demonstrate any superiority. This is probably true because, at the time polarized light is reflected from the surface of the water, it is also reflected from the curved surface of the submerged object.

The polarizing filter absorbs both sets of light rays equally so there is no advantage. When the line of sight is from other directions in which light is not polarized, the polarizing filter again has no advantage. For these reasons, polarizing sunglasses are only useful to reduce over-all brightness to a comfortable seeing level without any specific improvement in ability to locate submerged objects.

Selection of a Sunglass for Air Force Use

Selection of the best sunglass lenses for Air Force use must take the above factors into consideration. It has been determined that a lens with 15% transmission is most suitable for the level of brightness encountered in flying.

The elimination of electromagnetic radiation, which one cannot see and which may be damaging to the eye under certain conditions, presents no problem so far as ultraviolet is concerned. Glass lenses eliminate most of the abiotic wavelengths below 300 millimicrons. However, fluorescence of the crystalline lens may present a problem at high altitudes when lenses are used which transmit light in the region of 360 millimicrons.

The infrared rays are eliminated significantly better by the presently available neutral lens than by any of the colored lenses or the reflecting lenses. The ability to recognize colors without any impairment occurs only with neutral lenses—either absorbing or reflecting types. (Colored lenses distort colors.)

Visual acuity is as good through the neutral lenses as any of the colored type yet developed. It is not better, but is just as good. No lens has yet been shown to increase ability to penetrate haze or fog.

Careful review of these points shows the superiority of the neutral over the colored or polarizing lens. The neutral absorbing lens is superior to the neutral reflecting lens because of the infrared transmission of the reflecting lens and because the reflecting coat is rather susceptible to damage.

Use of Goggles

Goggles have lost their importance as protection against wind blast, oil droplets, flash fire, and so forth. Fighter pilots now use visors attached to the helmet. This visor, which can easily be pulled down or pushed up with one hand, protects the eyes against particles, oil spray, and the like. In addition, the visor protects the eyes against wind blast in bailouts at speeds less than supersonic. Speeds in excess of 500 knots cause the visor to be torn off by the wind blast.

Special goggles are valuable today as protection against flashblindness and chorioretinal burns in the case of nuclear detonations. A pilot who will be exposed to nuclear detonations, whether from his own or an enemy's nuclear devices, needs protection against the possible eye effects resulting from the intense light and thermal energy produced by atomic fireballs in order to have the best possible chance for successfully completing his mission. Several research programs have been instituted, to provide the answer to this problem.

One approach has been a goggle containing an electromechanical shutter. The eye piece consists of movable glass plates with series of alternately opaque and transparent lines. With the shutter open, the transparent lines are superimposed over one another, and since the opaque lines are narrower than the pupillary aperture, the pilot can see without any blind spot in his visual field.

When the flash detector senses the presence of unusual illumination above a preset level, it produces a signal which discharges one of four dimple motors. The dimple motor drives a wedge which moves one of each set of grids laterally. This causes an opaque line to cover a transparent line and an opaque lens results.

Another protective device which, if successfully developed, may be incorporated in a goggle, is a "variable density filter." This filter will contain a photochromic system (dye) which is sensitive to a specific amount of illumination. With a rise in the incident illumination to the specified light intensity, the filter immediately becomes opaque. This can be a reversible reaction, with clearing of the filter under reduced illumination. Research in the protection of eyes against nuclear flashes will continue into the future.

NUCLEAR DEVICES

The detonation of atomic bombs over Hiroshima and Nagasaki in 1945 marked the beginning of atomic warfare. Nuclear weapon development since that time has resulted in devices that are many times more devastating than the nominal 20 KT bomb. Explosion of such devices results in damage to the human body by concussion (blast), radiation, heat, and light. The concussion and radiation effects are limited to finite distances from the center of burst; these can be predicted from the yield and location of the detonation relative to the earth's surface. The radiant energy released at detonation of a nuclear bomb in the form of infrared and visible light causes damage to the human body at finite distances.

The eye is more susceptible to injury at far greater distances than other organs or tissues of the body. An eye, having a pupil of a given size, exposed to a nuclear detonation at a given distance, will result in a certain amount of energy distributed over the image area on the retina. If the distance from detonation is now doubled, the amount of energy passing through the same size pupil will be one fourth as great; the image area will also be one fourth as large. Therefore, the energy per unit area will remain constant irrespective of the distance, except for the attenuations due to the atmosphere and ocular media.

The potential danger of flashblindness and chorioretinal burns resulting from viewing atomic fireballs has now become of great concern to aircrew members, and has thus created new problems for the Flight Surgeon.

The chorioretinal burns that result from exposure to nuclear weapon detonations vary in size and severity depending upon distance from the center of burst, the more severe burns being sustained at positions closer to point of detonation. Persons exposed to atomic flash beyond the point where retinal burns occur may, nevertheless, be subject to flashblindness of several minutes' duration. Although this is of a temporary nature, it could result in inability to complete mission or actual loss of the aircraft.

Permanent loss in visual acuity and central field would result from a chorioretinal burn in the macular or perimacular area. A burn in the mid periphery would result in either a localized scotoma if the burn were minimal, or in a segmental field defect if the burn were severe. Suggestions have been proposed to protect the eyes from the effects of atomic flash. These include the use of shades, blinds, or the covering of one or both eyes. These may be of value in offensive operations, but, for obvious reasons, would be valueless in defensive tactics.

Adequate protection of the eyes from atomic flash would appear to be the only method of preventing flashblindness and chorioretinal burns. Research in this area has been devoted to the development of filters and shutters that would absorb or occlude the infrared and visible light released by atomic fireballs. This is to prevent flashblindness and retinal burns, and yet provide adequate visibility immediately before and after detonation.

Investigation is now under way, therefore, to develop a self-attenuating variable density filter which would transmit a constant amount of visible radiation, regardless of the intensity incident to the filter. Success in this area would provide a method for protection of the flier's eye from flashblindness and retinal burns associated with the detonation of nuclear weapons.

VISUAL PROBLEMS OF SUPERSONIC SPEED

It is evident that speeds of 3,000 mph will be commonplace in the future. Obviously, many problems will arise when pilots are subjected to such speeds.* Among these problems will be the visual difficulties encountered. Airflow, vibration, acceleration, temperature, and lag in human visual perception time will all be factors. First, however, it is necessary to discuss the physical conditions which exist at these speeds before considering the visual problems.

At sea level, the speed of sound is approximately 760 mph—varying with density of air, temperature, and other conditions. As the altitude varies so does the speed of sound. However, at any altitude, speed of sound is

* Text and illustrations adapted from Byrnes, Victor A., *Visual Problems of Supersonic Speed*, American Journal of Ophthalmology 34:2 (Feb 51). Used by permission. Copyright 1951.

called Mach 1—Mach derives its name from an Austrian physicist. At ground level Mach 1 is approximately 760 mph. At 40,000 ft, Mach 1 is roughly 660 mph. Speed ranges are subdivided as follows:

Subsonic	Up to Mach 0.8
Transonic	Mach 0.8 to 1.3
Supersonic	Mach 1.3 to 5.0
Hypersonic	Over Mach 5.0

The same characteristic which regulates the speed of sound produces the compressibility phenomenon. Below sonic speeds, air particles are able to get out of the way of a moving body. Above Mach 1, air particles begin to pile up in front of it. As these particles of air bump against each other, they produce compression in the air. This is the phenomenon that enables sound to be transmitted. A wave front is built up before bodies moving faster than Mach 1. This wave front lying rather far ahead of the moving body is not very dense. The wave forms a more acute angle over the nose of the body as speed increases and it becomes denser. The nose of the plane is never able to pierce this compression wave (see figure 8–3).

In each of the speed ranges, the air behaves differently. For instance, air passing through a venturi tube at subsonic speeds has increased velocity but decreased pressure at the constriction in the tube. At supersonic speeds there is increased pressure as well as increased velocity at the constriction. Air flowing over the wing surfaces behaves differently in each of the different speed ranges. There is considerable buffeting in the transonic range because of the mixture of the two types of airflow. Going through this speed range of mixed airflows is called "passing through the sonic barrier." The present century-series aircraft are not affected by this buffeting because of their design and great speed in passing through the sonic barrier (figure 8–4).

Effect of Slanting Optical Surfaces

To permit supersonic flight, the aircraft must be free from projections, and optical surfaces must be slanted to produce the least possible drag. It has been found that a wind-

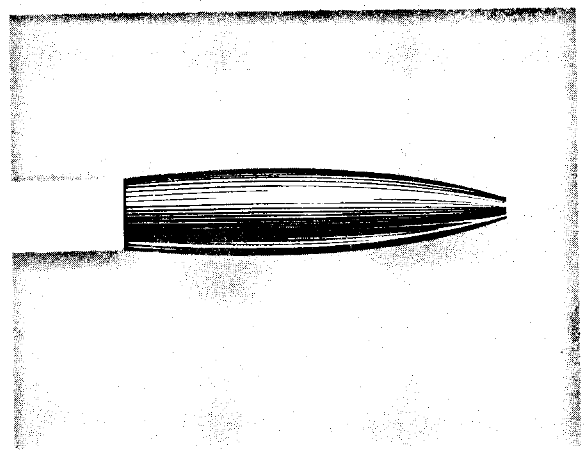


Figure 8–1. (Byrnes) Projectile Moving at a Speed of Mach 0.92 (700 MPH).

shield of bulletproof plate glass with nesa coating can be slanted to a 70° angle without producing measurable change in visual acuity or depth perception. No sizeable distortion occurs and it produces less than 3 minutes of deviation. However, the type of media used in the canopy will determine the angle at which the windshield can be slanted. There is a simple displacement of images produced by slanting surfaces in which emergent rays are parallel to incident rays. This, however, is not important.

Visual Effects Produced by Shock Waves

The air in shock waves is optically denser than normal air, producing a deviation of light rays which apparently displaces objects from their true position. This phenomenon varies with the speed between Mach 1 and Mach 4 and is entirely absent below Mach 1. The flow of air in the compression wave will obviously not be absolutely homogeneous and will probably produce mild rippling effects such as one sees in heat waves (figure 8–5).

Vibration

While the effect of vibration at supersonic speed has been a popular subject in the press, no vibrations of intensities great enough to harm human eyes have been produced by jets or rocket-propelled craft. One effect vibration may produce on the eye is resonation at its own frequency of about 40 cycles per second. However, it is more likely to be produced

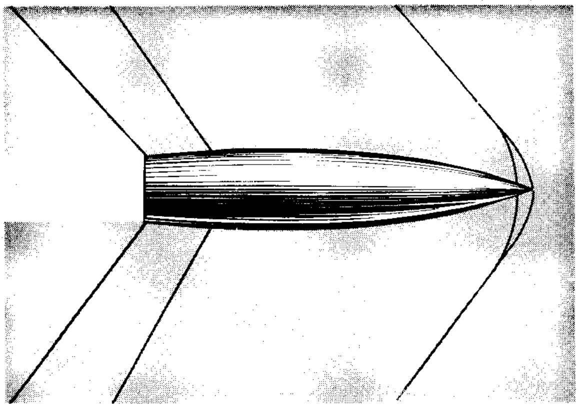


Figure 8–2. (Byrnes) Projectile Moving at a Speed of Mach 1.31 (1,000 MPH).

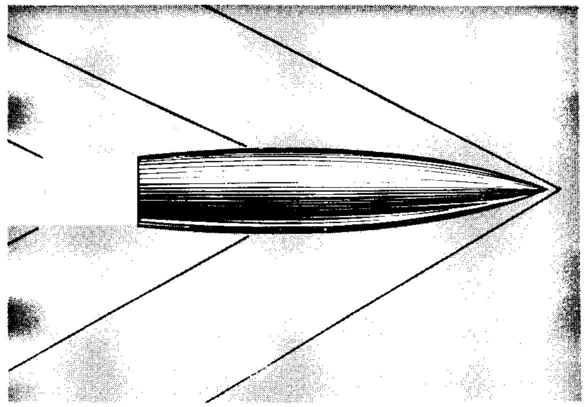


Figure 8–3. (Byrnes) Projectile Moving at a Speed of Mach 2.63 (2,000 MPH).

by low frequency vibrations of 10 to 40 cycles or 60 to 90 cycles than by high frequency vibration.

LAG IN VISUAL PERCEPTION

The length of time between an occurrence and the time a person sees it depends upon two factors: The length of time required for light to reach the eye, and the conduction time in the visual pathways and brain tracts. Because the speed of light is so fast, it is an unimportant factor; but the lag in the visual mechanism is appreciable and at supersonic speeds is important.

The latent period of perception varies with the individual, with his state of attention, with the part of the retina stimulated, and with the intensity of the stimulus. It may vary from 0.035 to 0.300 seconds. Sensory conduction times are important at supersonic speeds because of the distance travelled—for example, an individual flying 1,800 miles per hour is travelling approximately a mile every 2 seconds.

From the time an object appears in the peripheral visual field until the object is seen by central vision, about 0.400 second will have elapsed and the aircraft will have travelled 1,042 feet. At this point, the person has only seen the object—it has not been recognized.

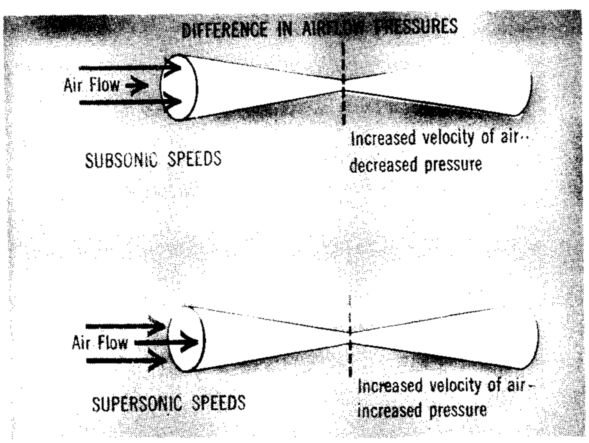


Figure 8–4. (Byrnes) Behavior Characteristics of Air at Subsonic and Supersonic Speeds.

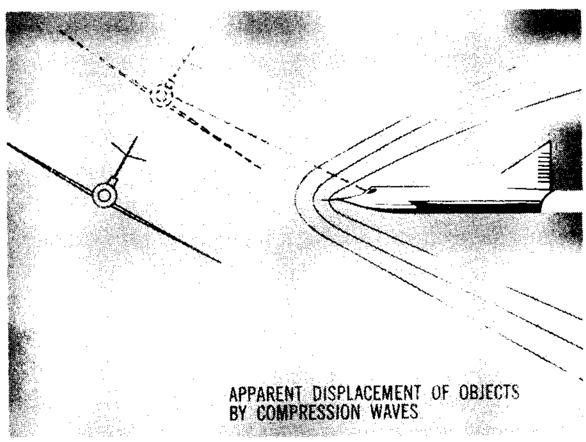


Figure 8–5. (Byrnes) Visual Effects Produced by Shock Waves.

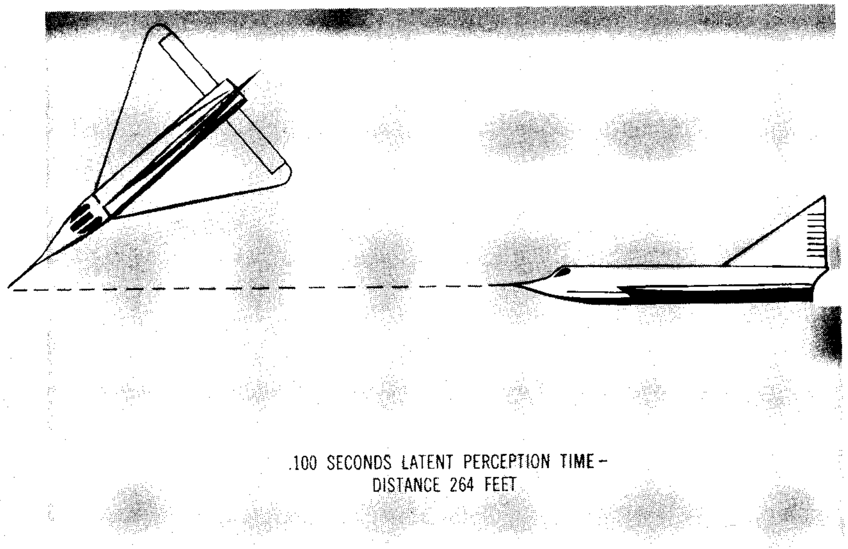


Figure 8–6(A). (Byrnes) Latent Perception Time at 1,800 Miles Per Hour.

If an object appears in the visual field it will be roughly 0.1 second before the pilot is aware that an object is present. During this period he will travel 264 feet.

Recognition time varies between 0.65 and 1.50 seconds, so an average would probably be 1.0 second during which time an additional 2,640 feet will have been travelled.

This means that from appearance to recognition the plane has travelled 3,683 feet. The time required to make a decision to do something about it and the motor reaction time to move control surfaces is not included. Obviously, therefore, if two aircraft came out of the clouds 3,000 feet apart and were coming toward each other, they would collide before the pilots could do anything about it.

To move the eye from clear distance vision to read a dial with recognition and return to clear vision takes about 2.39 seconds. During this time, the plane would move 6,336 feet. The time of accommodation increases with age and is an important factor in selecting pilots for high-speed craft. Because of this high-speed, it is also important that instrument dials be set up for maximum readability (figure 8–6 (A) through (F)).

Lag in visual perception is a very important factor in supersonic aircraft. It is obvious from the above discussion that the human visual apparatus is unable to cope with the demands placed on it by supersonic

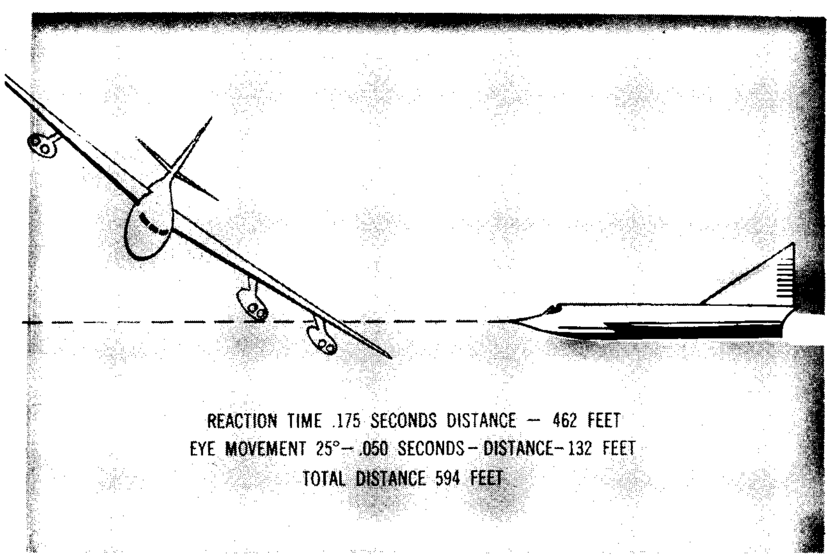
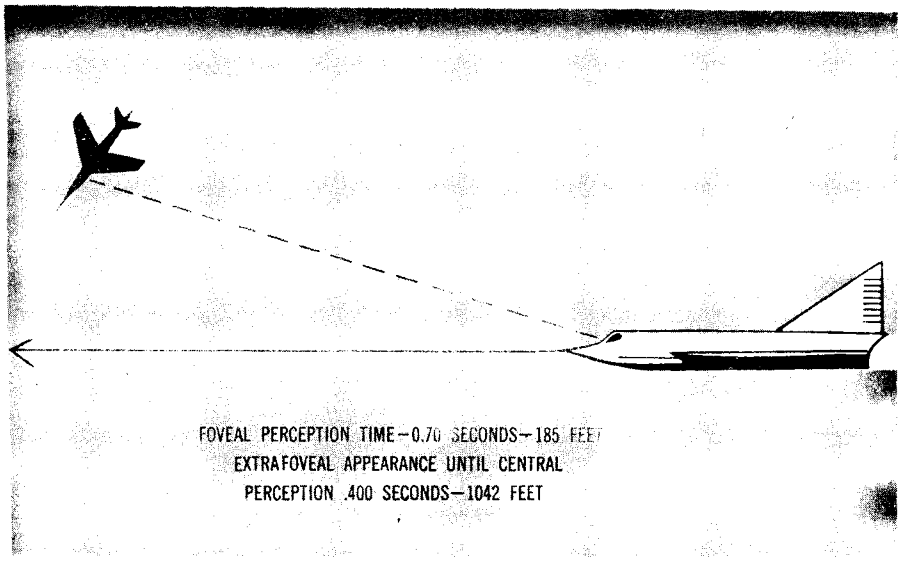


Figure 8–6(B).

After perception of an object in the peripheral field, in order to see it centrally a motor reaction time of 0.175 second is required to prearrange the eye movement. The eye movement itself requires 0.050 second. Distance travelled — 594 feet.

Figure 8-6(C).



After the visual axis is fixed on the object to be viewed, foveal perception requires 0.070 second. Total time, then from extra-foveal appearance to central perception is 0.400 second. Distance travelled — 1,042 feet.

speeds. For this reason, the current century-series aircraft and future aircraft, whether jet or rocket-propelled, will require the use of electronic devices which can detect aircraft or other objects in space before the unaided human eye can possibly see them, and allow the pilot to take offensive or evasive action.

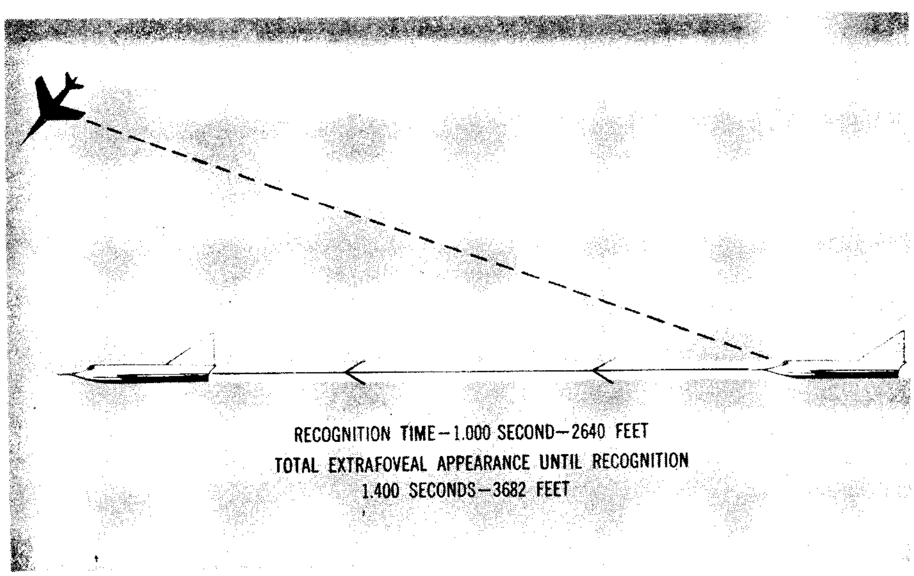
Acceleration

Forces of 6.0 Gs will cause practically every upright observer to black out unless he is wearing a very good G-suit. Turns which produce 6.0 Gs at various speeds have been computed to give an idea of the limiting effect which this phenomenon has on high-speed flight. Turns of the following radii would each produce 6.0 Gs.

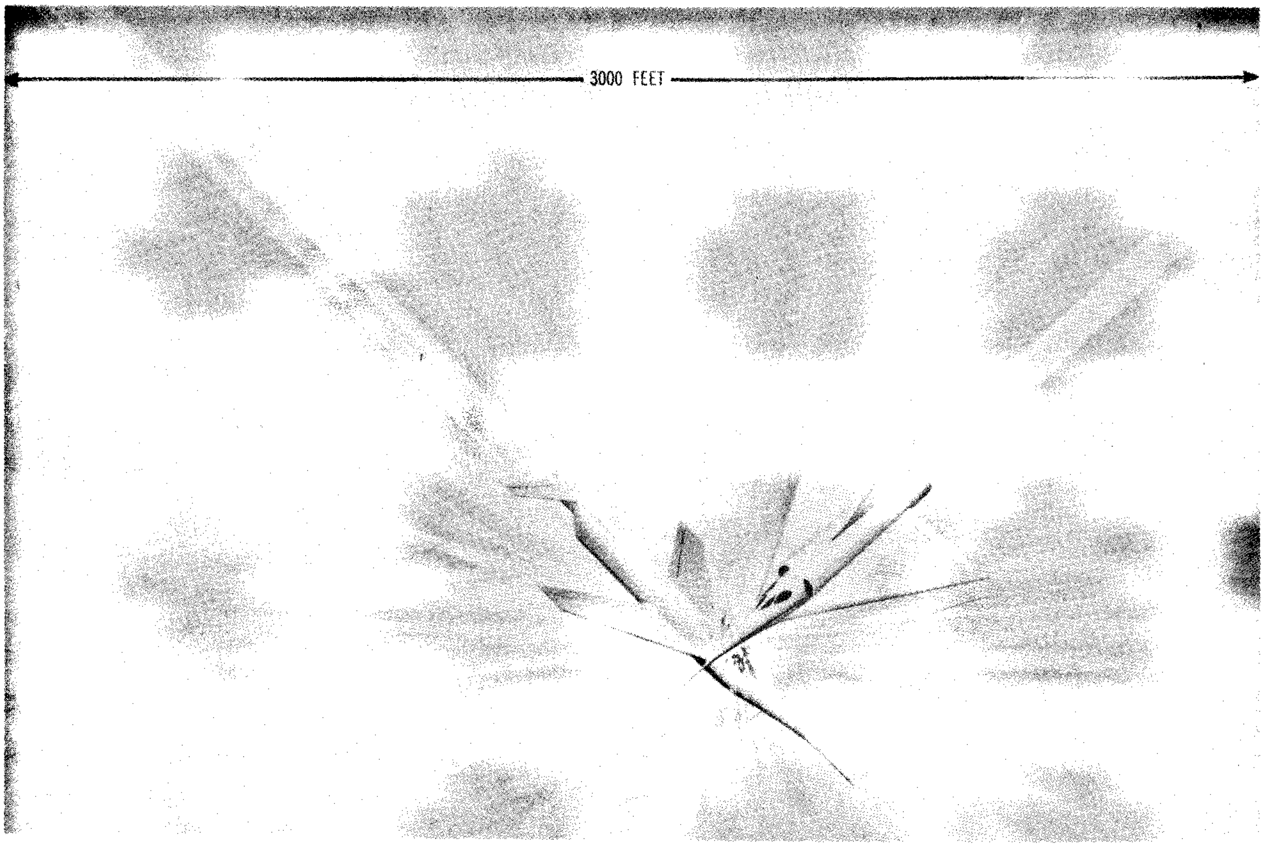
250 mph	686 feet
500 mph	2,740 feet
750 mph	6,170 feet
1,000 mph	11,132 feet
1,500 mph	25,074 feet
2,000 mph	44,530 feet

Thus, at a speed of 2,000 miles per hour the pilot could not turn a circle smaller than 18 miles in diameter. And he would black out all

Figure 8-6(D).



Speed of recognition varies from 0.65 to 1.50 seconds, average about one second.



If two pilots emerged from clouds 3,000 feet apart on a collision course, they would crash before they could do anything about it. If the distance were only 500 feet, they would collide without either pilot seeing the other.

Figure 8–6(E).

the way around the circle unless he were wearing a good protective suit or assuming a position other than upright.

Temperature at Supersonic Speed

Aircraft travelling 2,000 miles per hour can develop a surface temperature above 600° C. Efficient insulation and refrigeration must be used for aircraft to operate at such speed. This is an engineering problem which has been solved in the small satellites sent into space, as well as in the case of the X–15.

The eyes can withstand dry air of at least 240° F which is the highest a human can breathe—an absolute tolerance at 240° F being about 23 minutes. Actually, the eyes can tolerate any temperature which the body can withstand.

Ejection at Supersonic Speeds

There have been several reports of pilots ejecting from aircraft at speeds in excess of Mach 1. The pilots involved suffered severe damage to the body as a whole and to the eyes. At the present time, there is no adequate protection for the eyes on ejections at speeds greater than 550 miles per hour when using conventional helmets. The solution lies in using a closed capsule-type ejection apparatus.

NIGHT VISION

There are two types of sensory end organs in the retina—the rods and the cones. According to the widely accepted duplicity theory of vision, the rods are responsible for vision at very dim levels of illumination (so-called scotopic vision), while the cones function at the higher illumination levels (photopic vision). The cones alone are responsible for color vision. There is a common misconception that the rods are used only at night and the cones only during the day. The cones, as will be pointed out later, function at all levels of illumination down to their threshold. The same is true of the rods.

Mesopic Vision

There is a transition zone between photopic and scotopic vision where the level of illumination ranges between .01 foot-candle and 1 foot-candle. For comparison purposes, the light on new snow from the full moon would measure about .01 foot-candle and the 1 foot-candle would fall on a white sheet of paper at a 10-foot distance from a 100-watt bulb. Both the rods and cones are active at dusk when the level of light spans these limits, and the perception experienced is called mesopic vision. Neither the rod or cone network operates at peak efficiency. Central vision would be markedly reduced in the lower right ranges and rod detection capability would be severely hampered at the upper levels.

Reaction Time	.175	seconds	462 feet
Eye Movement	.050	seconds	132 feet
Foveal Perception	.070	seconds	185 feet
Accomodation	.500	seconds	1320 feet
Recognition	.800	seconds	1952 feet

Figure 8–6(F).

Below the intensity of moonlight (the cone threshold), the cones cease to function and the rods alone are of value to an individual under these circumstances.

Thresholds

The dimmest light in which the rods can function is about 10^{-6} millilamberts, the rod threshold. The dimmest light in which the cones can function is about 10^{-3} millilamberts which is equivalent to the light from the half moon. This is the cone threshold. A white light which can just barely be seen by the rods must be increased in brightness 1,000 times before it becomes visible to the cones.

Eccentric Fixation

The portion of the retina responsible for keenest visual acuity is the fovea which corresponds to the center of the visual field, and which is used constantly to fixate objects. The fovea is composed entirely of cones. This means that at luminance levels below 10^{-3} millilamberts, a blind spot develops in the center of the visual field (figure 8–7).

Rods begin to appear outside the macula and gradually increase in numbers, finally reaching their maximum concentration at a point some 20° from the fovea. Since the rods have a much lower threshold than the cones, they are much more sensitive to light. A person attempting to see in illumination dimmer than moonlight has to depend entirely on his rods. To utilize the rods under such circumstances, the individual must look slightly to one side, above, or below any object which he wishes to see. This is known as *eccentric fixation.*

Proper indoctrination is, therefore, essential for maximum use of vision at night. Men are taught to look slightly above, below, or to either side of a night target, and to employ a roving gaze. Training and repeated practice is necessary in this maneuver if the flier is to use his visual powers to their fullest extent during operations at night (figure 8-8).

Dark Adaptation

Both the rods and cones contain photochemical substances which are bleached on exposure to light. This process of bleaching is thought to initiate visual impulses in the retina. The photochemical substance in the rods is visual purple or rhodopsin; in the cones it is believed to be visual violet or iodopsin. These substances are broken down or bleached by light. During "dark adaptation" there is a maximum regeneration of the photochemical substances.

The rods and cones differ in their rate of dark adaptation, the rods requiring some 30 minutes or longer in absolute darkness to attain almost their maximum sensitivity after exposure to bright light, while the cones attain maximum sensitivity in about 8 minutes. The amount of light energy absorbed by visual purple determines the extent to which it is bleached. An intense light will bleach it fairly rapidly and completely while a dim light will bleach it to a small extent only. In the light-adapted retina, sensitivity to light is diminished.

Photochromatic Interval

Visual purple does not absorb light of a wavelength greater than about 650 millimicrons (the red portion of the visible spectrum). The rods contain visual purple and are almost completely insensitive to red lights. This is not true of the cones. This fact is easily demonstrated. If the intensity of a red light is slowly decreased until the cone threshold is reached, not only the color red but the light itself will disappear. If the same procedure is repeated with any color except red—*for example,* violet light—the violet color will disappear at the cone threshold, but the light will still be perceived by the rods as grey, or dim white light.

If the intensity is further decreased until the rod threshold is reached, the light will disappear entirely. The difference between the level of illumination at which the color of a light disappears (the cone threshold) and that at which the light itself disappears (the rod threshold) is known as the *photochromatic interval.* There is a photochromatic interval for every color of the spectrum except the longer wavelengths of red.

PRACTICAL PROBLEMS IN NIGHT VISION

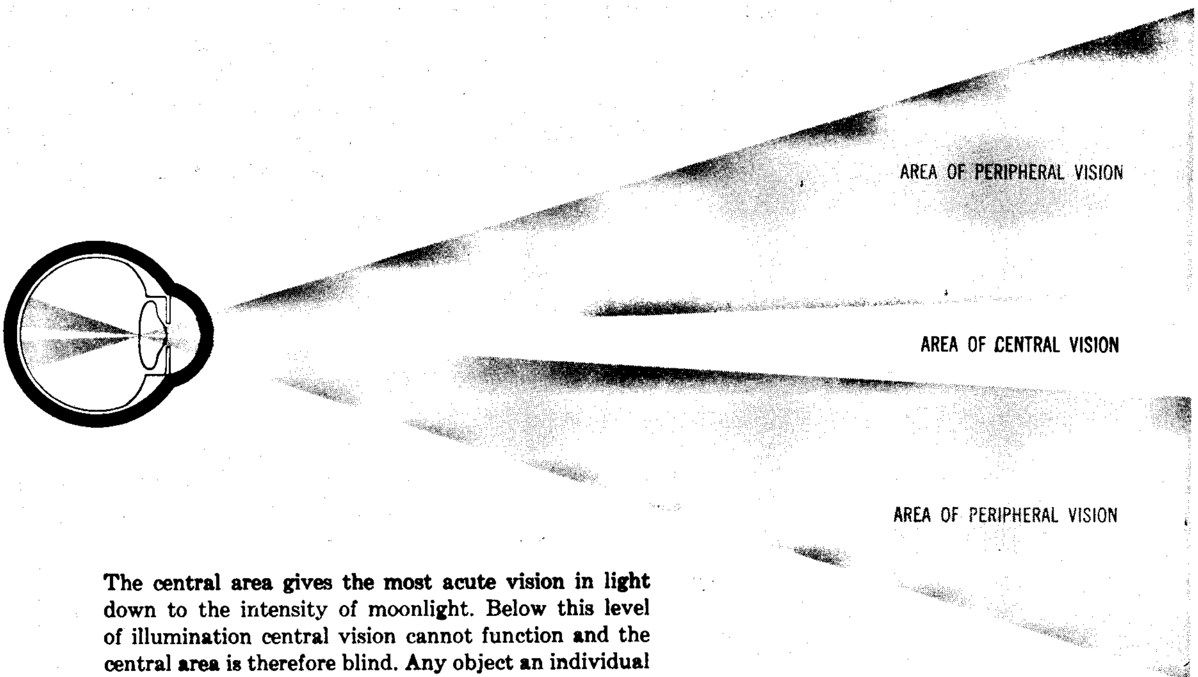
Contrast Discrimination. Objects are seen at night only by being either lighter or darker than their backgrounds. These contrast differences are reduced by light reflected from windshield or goggles, by fog or haze, and by scratched or dirty windshield or goggles. Any transparent medium through which the flier must look should, therefore, be spotlessly clean for night operations. Contrast differences are used by pilots to aid in the discovery of enemy planes while hiding their own ships. Hence, when flying over dark areas, such as land, they should fly below the enemy; when flying over white clouds, desert, moonlit water, or snow, they should fly above the enemy.

Under conditions of low illumination, additional aid may be obtained by following enemy planes either from above or below rather than from directly behind. The retinal image is much larger from the former positions than from the latter and there is less likelihood of losing the enemy in the darkness.

Night Myopia. A person who may be otherwise emmetropic will have a shift toward myopia when under extremely reduced illumination. The exact cause of this myopia is still controversial, but there is good evidence to show that it is made up of two components: a portion due to spherical aberration produced by the widely dilated pupils, and a portion due to slight involuntary accommodation. These portions apparently vary in their importance with different people. Regardless of the cause, it does exist and must be considered in night operations.

The largest group of persons will have about .75 diopters of night myopia.

Preservation of Dark Adaptation. Even in modern warfare, circumstances can arise which may require maximum utilization of night vision. If 30 minutes are spent in a



The central area gives the most acute vision in light down to the intensity of moonlight. Below this level of illumination central vision cannot function and the central area is therefore blind. Any object an individual looks at directly will not be seen.

Figure 8-7. Area of Central Vision.

dark room, the pilot's eyes will be satisfactorily dark-adapted. To overcome this drawback, flying personnel are instructed to wear red goggles to facilitate dark adaptation in fairly bright illuminations which does not interfere with their ability to read maps, magazines, or newspapers, and to see others to whom they wish to talk.

To explain why red filters are used to achieve dark adaptation it is necessary to examine the relative positions of the photopic and scotopic luminosity curves on the wavelength scale of the spectrum. If a filter with a cutoff at about 620 millimicrons is used, a greater portion of the scotopic curve (rod) is eliminated as compared to that portion of the photopic curve (cone) that is eliminated. In effect, approximately 1/10 of the light reaching the cones is effective on the rods.

In other words, for white light to be made equal in brightness to the red light transmitted through the red filter, the white light would have to be reduced to 1/10 its intensity. The cones will become dark-adapted in about 8 to 10 minutes after a pilot steps into the dark, while his rods, by virtue of the red goggles, are already fully adapted. On a dark night, the cone adaption is unimportant since they are incapable of functioning in starlight illumination.

Dark adaptation of the rods develops rather slowly over a period of 30 minutes but can be lost in a second or two of exposure to bright lights. The night flier must, therefore, be taught to avoid bright lights. He must know his airplane so thoroughly that no light is required to locate the controls. He should memorize his route so well that he need seldom refer to his maps. He must keep his instrument panel illuminated at the lowest level consistent with safe operation, and must avoid looking at the exhaust flame or the gun flashes. If he must use light, it should be as dim as possible and used for the shortest possible period.

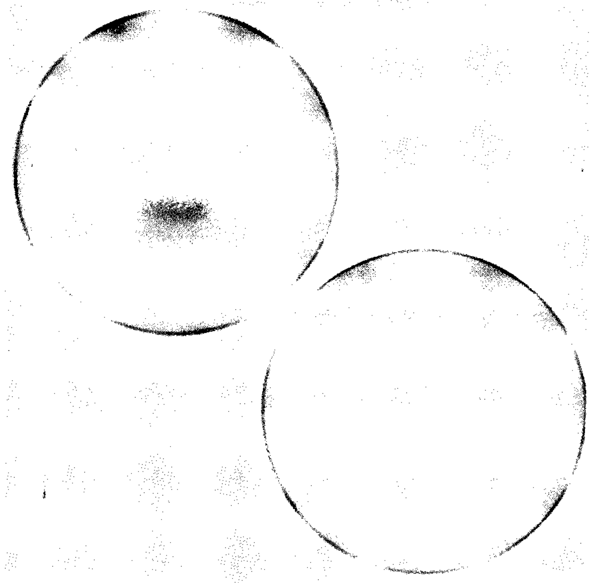
Dark adaptation is an independent process in each eye. Even though a bright light may shine in one eye, the other will retain its dark adaptation if it is protected from the light.

This is a useful bit of information because if a flier must use light for some purpose or is caught in the beam of a searchlight, he can preserve the dark adaptation in one eye by simply keeping that eye closed or by covering it.

Cockpit Illumination. The use of red light having a wavelength greater than 630 millimicrons for illumination of the cockpit is desirable from the viewpoint of dark adaptation. Red lighting of cockpit instruments has been traditional since World War II, and the intent was to retain the greatest rod sensitivity possible while permitting an effective illumination for foveal vision. With the increased use of electronic devices for navigation and enemy aircraft and target detection, the import of man's unaided visual system for these purposes in high-performance aircraft has diminished. Low intensity, white cockpit lighting is presently advocated which will afford a more natural visual environment within the aircraft without degrading the color of objects that are not self-luminous. The disadvantage of red light is that red markings on aerial maps are invisible when viewed in red light.

Ultraviolet light has a disconcerting side effect if directed or reflected into the eye. These radiations produce a fluorescence of the crystalline lens in the eye, giving the pilot the sensation that he is flying in a sea of fog. This annoyance may be avoided by proper adjustment of the ultraviolet lamps and rheostatic reduction of their intensity. These radiations are not injurious to the eyes, for at highest intensities they are still far less than those present in sunlight.

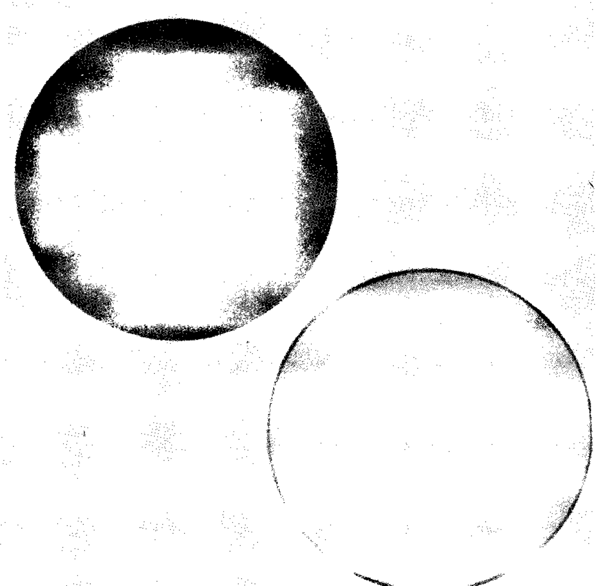
Visibility of Light to the Enemy. Light at the blue end of the spectrum is seen by the rods more readily than any other color; it is not seen as blue but is perceived as light. A blue light just visible to the rods as a colorless light would have to be increased 1,000 times in brightness before it could be seen as blue by the cones, and before any use of central vision could be made. If a pilot exposed himself to blue light bright enough to allow central vision, he would then have lost much of his dark adaptation (rods). Too, the



Left—The central blind spot present in very dim light makes it impossible to see the plane if it is looked at directly.

Right—The plane can be seen in the same amount of light by looking below (as is shown here), above, or to one side of it so that it is not obscured by the central blind area.

Figure 8–8. Eccentric Fixation.



Left—View seen by a person who is not dark-adapted.

Right—The same view seen by a dark-adapted person who is looking at a point above the plane.

Figure 8–9. Dark Adaptation.

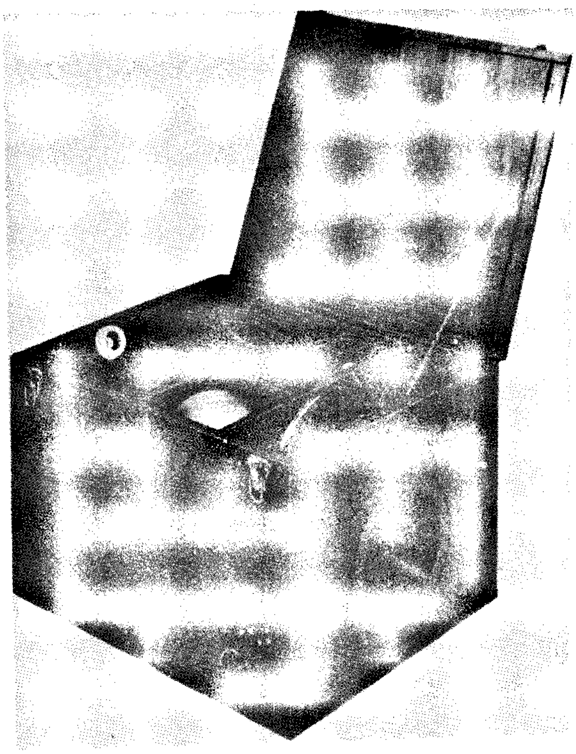


Figure 8–10. Night Vision Training Projector, Packed Box.

enemy could pick up a blue light in any position of his peripheral field with ease, whereas a red light of low intensity would be invisible unless viewed directly.

Drugs. The use of drugs systemically to improve normal night vision has been uniformly unsuccessful.

Hypoxia. The effect of hypoxia at altitude on night vision is primarily one of an elevation of the rod and cone threshold. The rise in foveal visual threshold at 4,000 feet is less than 0.05 log unit and at 8,000, it is less than 0.1 log unit. Since the pilot needs vision at the cone levels of adaptation for reading instruments, the actual decrement in acuity from hypoxia is minimal.

NIGHT VISION TRAINING

The use of a number of simulated training exercises form the basis of the Air Force night vision training program. These exercises are given in a completely blacked-out room. The artificial illumination is accurately controlled and adjusted to correspond closely with natural outdoor conditions.

The basic training device now used in the night vision program is termed "The Night Vision Trainer." This instrument is a projector which pictures typical night outdoor activities. They are projected on a screen at levels of illumination found at night. Silhouettes are used so that the various phenomena of dark adaptation and night vision, discussed by the night vision training instructor during the training session, may be practically demonstrated.

For complete details regarding night vision training, reference can be made to AFM 50–10.

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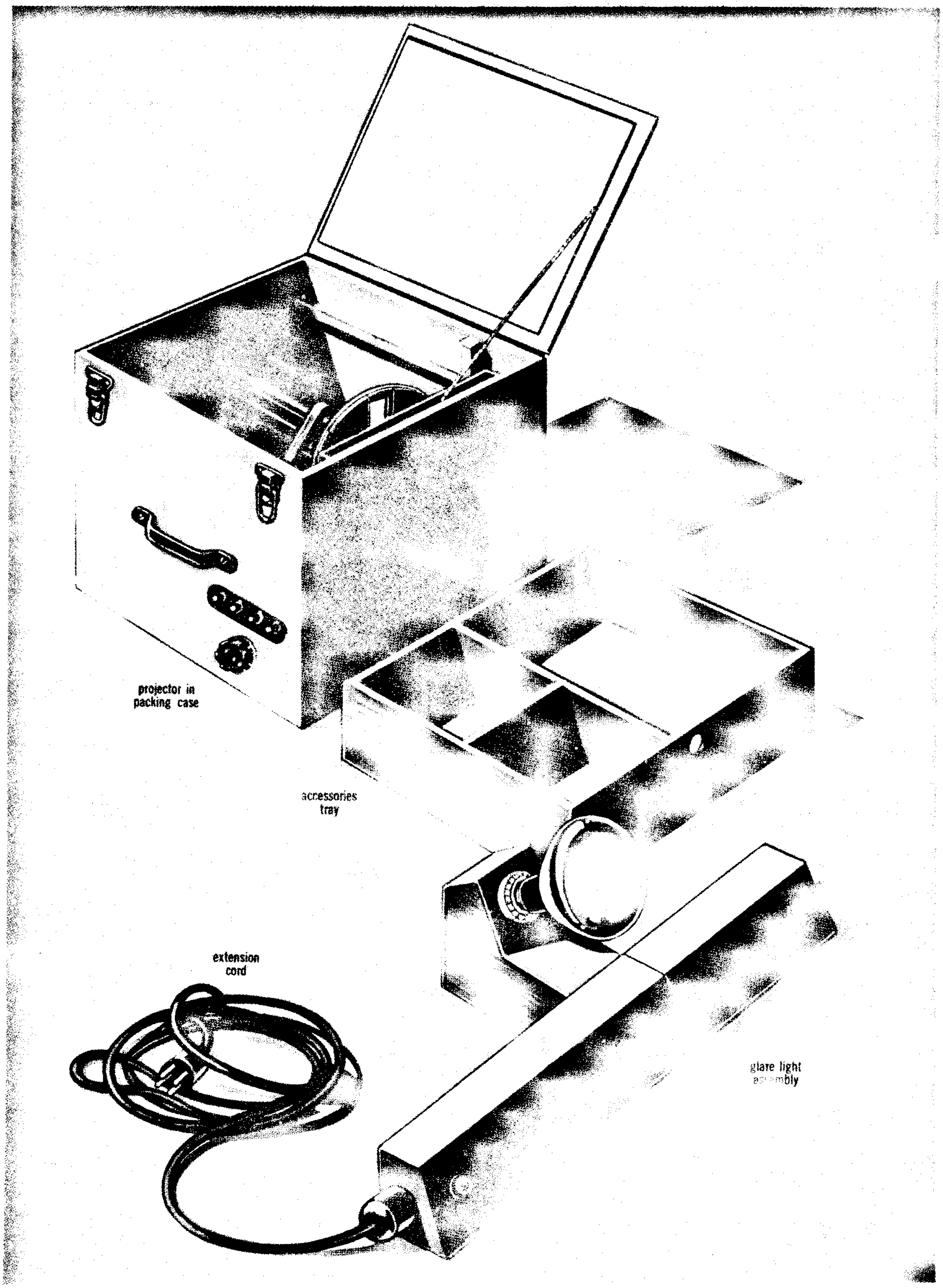
projector in
packing case
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tray
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cord
glare light

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