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Optical Radiation Transmittance of Aircraft Windscreens and Pilot Vision

Van B. Nakagawara[1]
Ron W. Montgomery[1]
Wesley J. Marshall[2]

[1]Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

[2]U.S. Army Center for Health Promotion
and Preventive Medicine
Aberdeen Proving Ground, MD 21001

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16. Abstract

INTRODUCTION: Optical radiation can have acute and chronic effects on the tissues of the eye, especially if exposure levels exceed normal repair capabilities. In support of a Department of Homeland Security project, the transmittance properties of aircraft windscreens were measured at the FAA′s Civil Aerospace Medical Institute (CAMI) for both visible and invisible optical radiation. This paper focuses on windscreen transmittance in the ultraviolet (UV) (< 380 nm) and visible (380-780 nm) portions of the optical spectrum. **METHODS:** Transmission measurements were performed on eight aircraft windscreens. Three windscreens were from large commercial jets (MD 88, Airbus A320, and Boeing 727/737); two from commercial, propeller-driven passenger planes (Fokker 27 and the ATR 42); one from a small private jet (Raytheon Aircraft Corporation Hawker Horizon); and two from small general aviation (GA), single-engine, propeller-driven planes (Beech Bonanza and Cessna 182). The two GA aircraft windscreens were plastic (polycarbonate); the others were multilayer (laminated) composite glass. **RESULTS:** UV transmittance for both glass and plastic windscreens was less than 1% for UV-B (280-320 nm) radiation. In the UV-A portion (320-380 nm) of the spectrum, transmittance differences increased from 0.41% to 53.5%, with plastic attenuating more UV radiation than glass. For visible light, average transmittance from 400-600 nm (violet to orange) was similar (82.8% ± 4.6%) for both windscreen materials, while from 625 to 775 nm (orange to red), the difference in average transmittance increased from 9.1% to 40.0%, respectively, with plastic transmitting longer wavelengths more efficiently. **CONCLUSIONS:** Both types of windscreens blocked most of the more harmful UV-B radiation; however, glass laminate windscreens allowed higher levels of potentially damaging UV-A radiation to be transmitted than did plastic. Professional pilots who routinely fly at higher altitude for longer periods of time than private pilots should take special precautions to protect their eyes from UV exposure.

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Optical Radiation Transmittance of Aircraft Windscreens and Pilot Vision

INTRODUCTION

A pilot's most important physiological asset for maintaining control of an aircraft is his/her sense of vision. The importance of protecting this asset, therefore, is immeasurable. The aircraft's windshield (i.e., windscreen) is the first line of defense for protecting the pilot's ability to see what is happening outside the aircraft. A windscreen must be sturdy enough to deflect the environmental elements (wind, rain, sleet, snow, and hail) and sustain the occasional impact from airborne debris, including bird strikes, while maintaining a high level of transparency over the entire visible spectrum of light. How well a windscreen performs can affect the pilot's ability to maintain proper spatial orientation and avoid obstacles, such as changing terrain, adverse weather conditions, and other aircraft traffic, as well as to safely navigate taxiways around airports. The transmittance of a windscreen material is a property that can be measured throughout the electromagnetic spectrum for both visible and invisible wavelengths. The effective transmittance of the windscreen in each of these spectral bands may be determined by calculating the ratio of the total radiant or luminous flux transmitted by the material to the incident flux. A high ratio indicates that incident radiation is transmitted efficiently through the windscreen, while a low ratio denotes substantial attenuation.

Optical radiation is defined as the part of the electromagnetic spectrum that includes ultraviolet (UV), visible, and infrared (IR) radiation. The Commission Internationalè de l'Eclairage (CIE) Committee on Photobiology has provided spectral band designations that are convenient for discussing biological effects. These divisions in the optical spectrum are illustrated in Figure 1 (CIE, 1970). Optical radiation can also be divided into two general regions with respect to their potential for eye damage: the retinal hazard region and the non-retinal hazard region. The wavelengths of the retinal hazard region include visible light (380-780 nm) and near IR (780-1400 nm), or IR-A radiation. The retinal hazard region identifies those wavelengths that are transmitted through the optical media of the eye (cornea, aqueous humor, crystalline lens, and vitreous humor) and focused onto the retina (Figure 2). The non-retinal hazard region refers to wavelengths that are mostly absorbed by anterior ocular tissues (cornea, aqueous humor, iris, and lens) without significant transmission to the retina. These spectral bands include UV radiation below 300 nm (UV-C and UV-B) and IR radiation greater than 1400 nm (IR-B and IR-C). The remaining radiation, wavelengths from 300 to 400 nm (primarily UV-A), is absorbed by the aqueous, iris, lens, and vitreous humor.

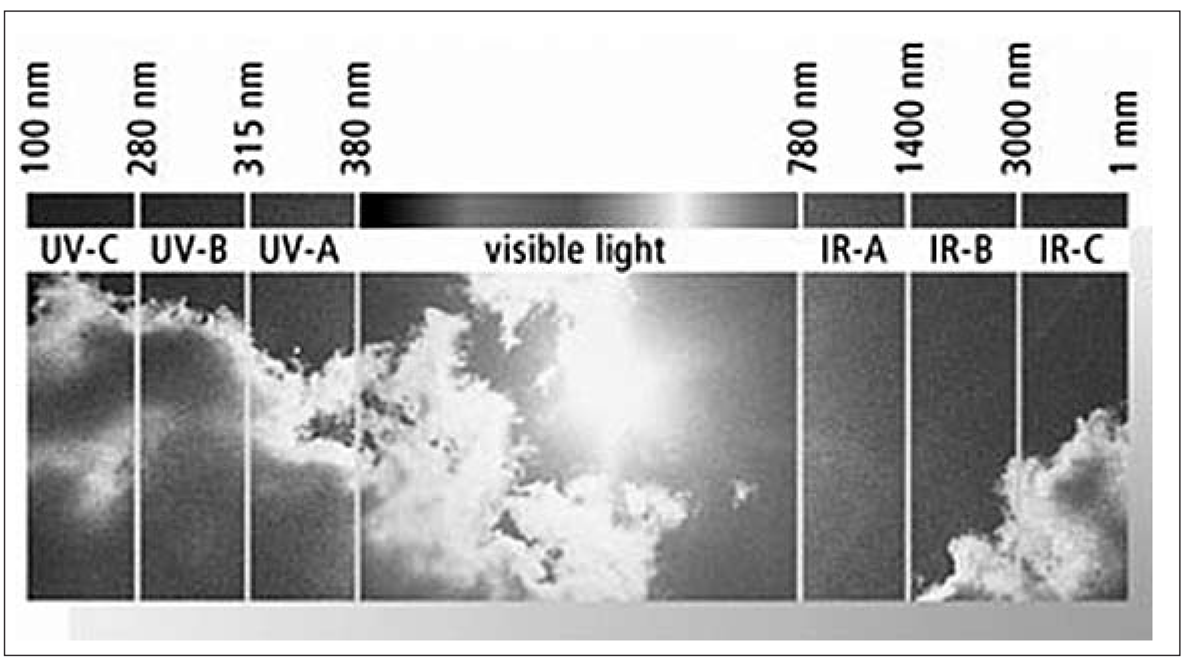

Figure 1. Optical radiation spectral bandwidths.

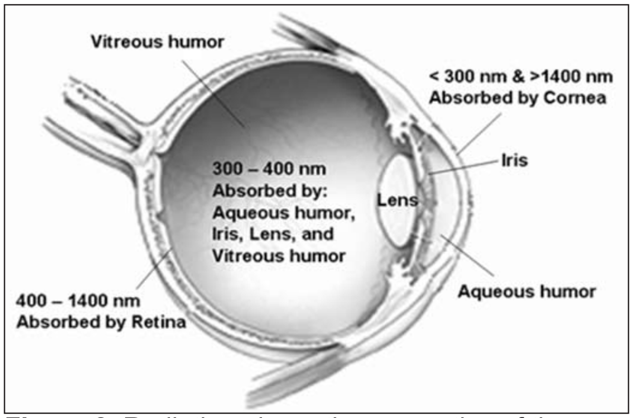

Figure 2. Radiation absorption properties of the human eye.

Excessive exposure to optical radiation is of concern to industrial hygienists, safety engineers, and public health officials for its potential as a hazard to health and safety. Aside from natural sources of radiation, such as the Sun and cosmic background radiation, many man-made sources of optical radiation exist and are becoming increasingly accessible to the general public. Excessive exposure to these sources can also lead to adverse physiological consequences. Examples of these sources include lasers, tanning beds, mercury-vapor and xenon halogen lamps, welding devices, infrared lamps, and germicidal lamps. These sources are frequently found in office settings, water treatment plants, hospitals, research laboratories, photo-etching production lines, graphic arts facilities, machine shops, tanning salons, and even in homes. Harmful effects produced by these sources include erythema (sunburn), photokeratosis, skin cancer, de-pigmentation, conjunctivitis, and temporary or permanent loss of vision. Conjunctivitis affects the membranes lining the insides of the eyelids and covering the cornea that become inflamed and can result in discomfort. Photokeratitis is an inflammation of the corneal tissue that results in an aversion to bright light, often accompanied by severe pain. The severity of these conditions depends on the duration, intensity, and wavelength of exposure. Symptoms may appear 6 - 12 hours after exposure and disappear gradually after 24 - 36 hours, leaving no permanent damage. Unlike the skin, the eyes do not develop a tolerance to repeated exposure to ultraviolet radiation. The absorption of UV-A radiation in the lens of the eye is thought to produce progressive yellowing with time and contribute to the formation of cataracts, causing partial or complete loss of transparency (1).

At the request of the Department of Homeland Security (DHS) Counter-Man Portable Air Defense System (C-MANPADS) Special Project Office (SPO), the Civil Aerospace Medical Institute's (CAMI) Vision Research Team was asked to assist in the evaluation of a proposed airborne missile countermeasure system to protect civilian air transport aircraft from possible terrorist attack. The C-MANPADS system uses laser radiation to disrupt the guidance system of an oncoming missile. The evaluation of transmission for optical radiation through aircraft windscreens was part of CAMI's contribution in support of the laser safety assessment for the C-MANPADS and a planned FAA Ocular Hazard Mitigation project. The FAA project will primarily study the threat that laser exposures pose to pilots. This report documents the direct transmittance measurement of optical radiation for a sample set of windscreens collected from both air transport and general aviation aircraft. While infrared radiation was measured to approximately 4000 nm, this paper will focus on transmittance issues specific to the UV-B, UV-A, and visible regions of the optical spectrum.

METHODS

Several aircraft windscreens were shipped from various aircraft maintenance facilities to CAMI's Vision Research Laboratory. Eight windscreens were selected from those available for testing. Three windscreens were from large commercial jets (MD 88, Airbus A320, and Boeing 727/737), one was from a smaller private jet (Raytheon Aircraft Corporation Hawker Horizon), two were from commercial propeller-driven passenger planes (Fokker 27 and the ATR 42), and two were from smaller single-engine propeller general aviation planes (Beech Bonanza and Cessna 182). The windscreens from the latter two were full windshields and appeared to be made of a single-layer polycarbonate material, rather than the laminated glass that comprised the other six.

Instrumentation for testing included:

1) EG&G model 580 spectro-radiometer systems (with UV, visible, and IR gratings and housings); order sorting filters; photodiode detectors, models 580-22A, 580-23A, and 580-25A; and Palentronic model AR582F indicator unit.
2) International Light Model 1700 radiometer with SED 623 broadband detector.
3) Ophir LaserStar radiometer system, with model 3A-P-SH thermopile detector.
4) Narrow pass filters: 1450 nm, 1540 nm, 1940 nm, 2050 nm, 2100 nm, 2200 nm, 2300 nm, and 2380 nm.
5) Long pass filters: 1600 nm and 2500 nm.
6) Sapphire window: transmission from UV to 4000 nm.
7) Light sources: deuterium lamp, 100-watt incandescent light, 250-watt heat lamp.
8) Light box and aircraft windscreen movable dolly.
9) Miscellaneous laboratory mounts, filters, filter holders, and equipment.

10) Perkin Elmer UV/VIS/NIR model Lambda 900 spectrometer system.
11) Cold mirror and extended-range hot mirror.

Measurements of direct transmittance were performed in a semi-darkened room. Two large tables were used: one for the light sources and the other for the various optical detectors. A custom-made windscreen cart (Figure 3) was used to slide the windscreens in and out of the beam path between the two tables separating the light sources and detectors. Three monochromator systems were placed side-by-side and aligned with the appropriate light source, which was placed in a metal enclosure (Figure 4). For each windscreen and each spectral region, a baseline measurement was made with the windscreen moved to one side and then repeated with the windscreen placed between the light source and the detector. The two polycarbonate (plastic) windscreens were cut for easier measurement, and these samples were also measured in a Lambda 900 spectrometer. An attempt was made to cut a sample from one of the composite glass windscreens, but crazing of the sample made transmission measurements impossible.

For UV transmission measurements (< 400 nm), a deuterium lamp was used as an optical source. The EG&G spectro-radiometer system had a quartz diffuser as the beam input optics, rather than glass, so that UV radiation could pass through the diffraction grating in the monochromator housing to the Model 580-25A detector. Appropriate order-sorting filters were placed in a filter holder attached to the front of the beam input optics.

For visible and near-infrared transmission (400 – 1250 nm) measurements, an ordinary 100-watt incandescent light bulb was sufficient for an illumination source due to the high transmission of the windscreens for visible and near IR radiation. The EG&G Model 580-22A detector was used for measurement in the spectral region from 400 nm to 800 nm, and the Model 580-23A detector was used in the spectral region from 800 nm to 1250 nm. A thermopile detector, in conjunction with narrow-pass and long-pass filters, was used for longer wavelengths.

Due to the weight of the windscreens and the need to reposition the detectors and light source for various spectral regions, a single baseline was not practical. Therefore, a new baseline was usually created for each set of measurement conditions for each windscreen. Measuring two of the windscreens under both field and laboratory conditions served to validate the measurement method used on-site for all windscreens measurements and also to identify potential problem areas.

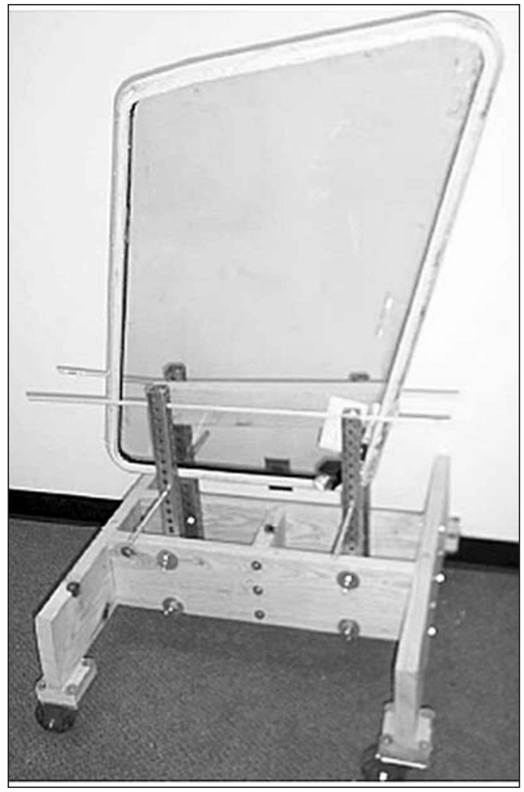

Figure 3. Custom-made windscreen cart for manipulating aircraft windscreens.

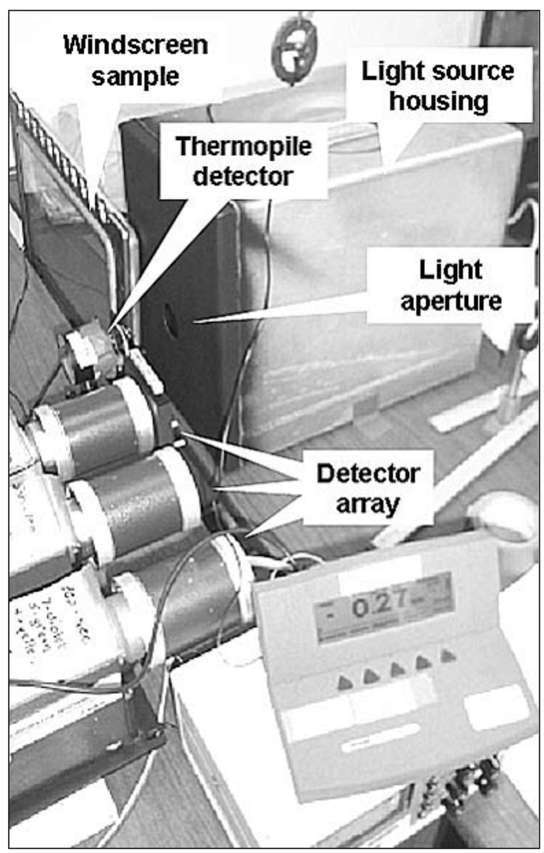

Figure 4. Detector and light source configuration.

RESULTS

The transmittance values for individual glass laminate windscreens are summarized in Figure 5, and those for the two plastic windscreens are provided in Figure 6. The average transmittance data for both glass laminate and plastic windscreens are plotted in Figure 7. UV transmittance for both glass and plastic windscreens was less than 1% for UV-B (280-320 nm) radiation. In the UV-A (320-380 nm) portion of the spectrum, transmittance differences increased from 0.41% to 53.5%, with plastic being the superior UV absorbing material. Within the visible spectrum, between 400 and 600 nm, the average transmittance was similar (82.8% ± 4.6%) for both windscreen materials. However, from 625 to 775 nm (orange to red), the difference in average transmittance increased from 9.1% to 40.0%, respectively, with plastic transmitting longer wavelengths more efficiently.

DISCUSSION

The spectral data for visible wavelengths measured in this study were likely higher than the actual transmissions as a result of multiple reflections between the windscreen samples and the optical detector due to the cramped measurement arrangement. Figure 8 illustrates the average difference in transmittance between the glass laminate and plastic windscreens tested in the study throughout the ultraviolet and visible spectrum. The areas in the top portion (positive percent difference) of the chart represent greater transmittance for glass over the specified bandwidths, while the areas in the lower portion (negative percent difference) are indicative of higher transmittance for plastic windscreens. Glass laminate exhibited a higher average transmittance (approximately 1-3% higher) around the human eye's inherent peak visual sensitivity (2) (i.e., dark-adapted [507 nm] and light-adapted [555 nm]), while plastic material maintained greater clarity (up to 40% higher at 780 nm) throughout the longer wavelengths of the visible spectrum (560-780 nm). Contrary to previous reports (3,4), glass windscreens allowed a considerable amount of UV-A radiation to be transmitted, beginning at 320 nm and peaking at 380 nm (54%). In contrast, plastic material blocked almost all UV-A and UV-B up to the shortest wavelengths of the visible spectrum (380 nm). These results suggest that plastic windscreens outperform glass by protecting the pilot's eyes from UV radiation and preserve color vision by transmitting more long-wavelength visible light.

Optical transmittance can have a major affect on a windscreen material's ability to both protect the pilot's ocular tissues and influence his or her visual performance. To better understand its importance, the environmental stressors present in the aviation environment need to be defined. Nighttime aviation activities require the windscreen to transmit as much visible light as possible

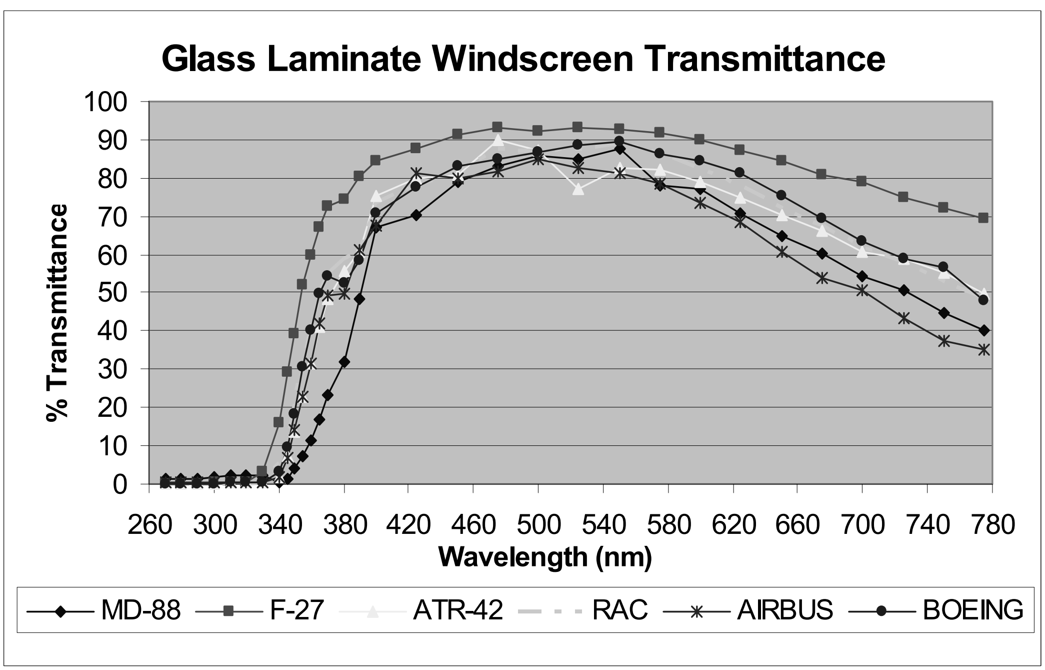

Figure 5. UV and visible light transmittance of individual glass windscreens.

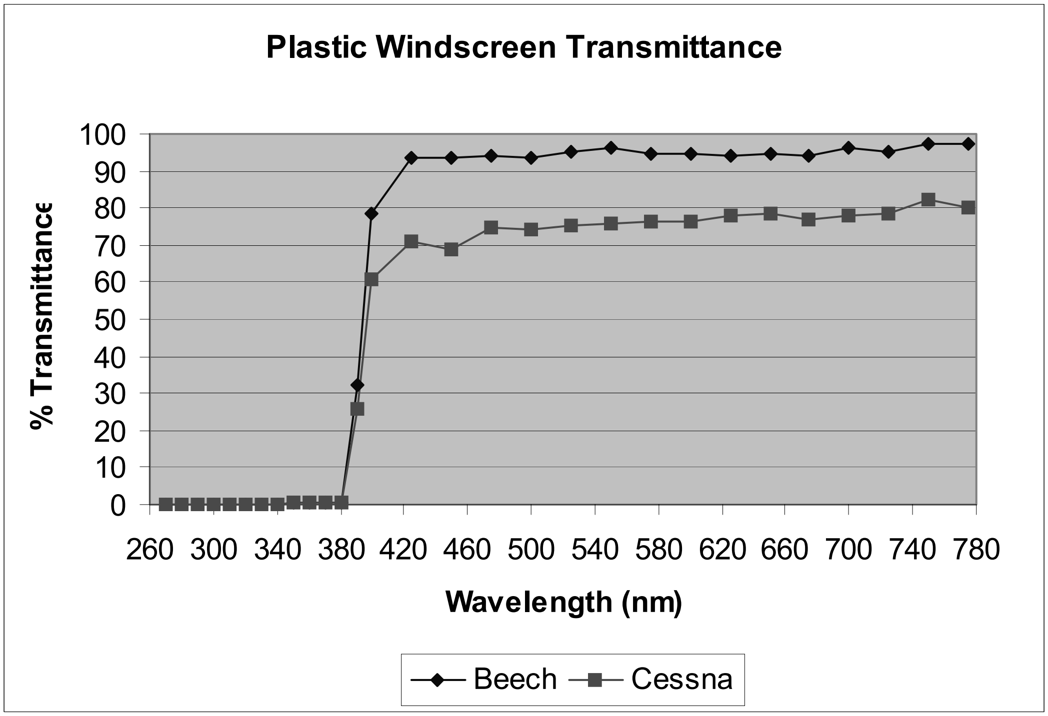

Figure 6: UV and visible light transmittance of individual plastic windscreens.

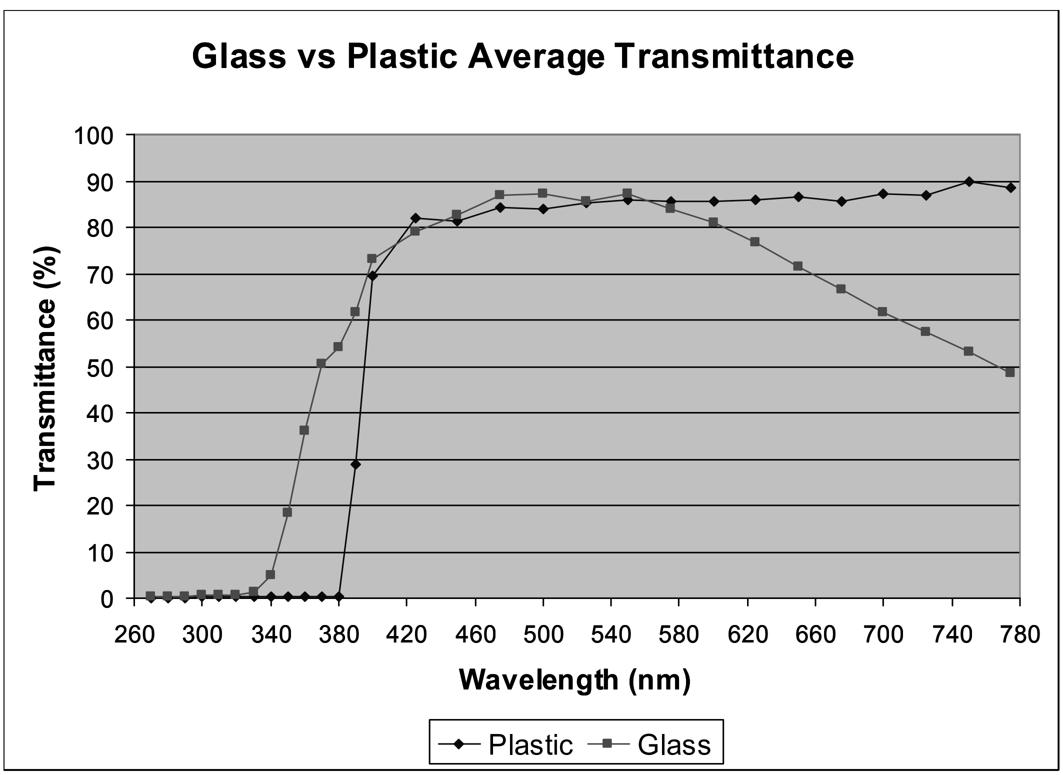

Figure 7: Average UV and visible light transmittance for glass and plastic windscreens.

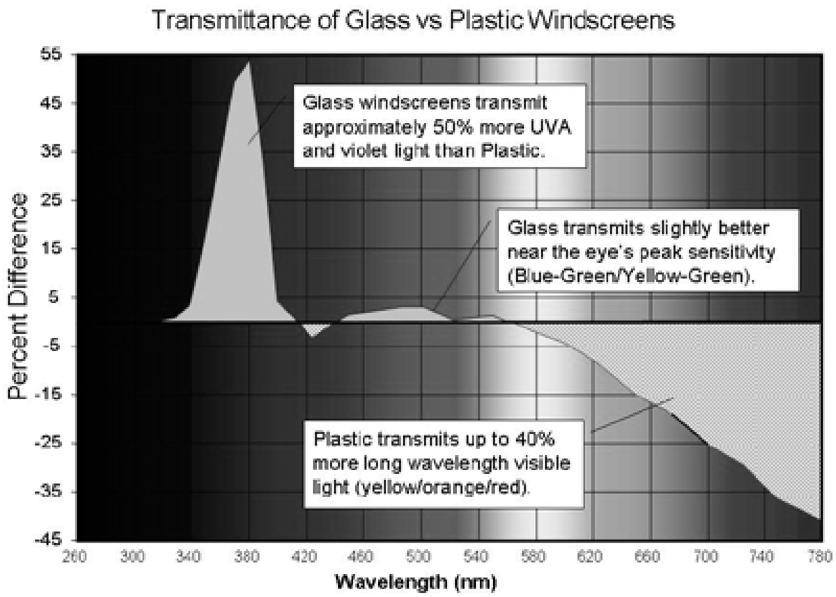

Figure 8: This chart shows the relative difference in transmittance between glass laminate and plastic windscreen materials by wavelength for UV radiation and visible light.

Figure 9: Glare from airport ramp lighting.

without significantly distorting the pilot's view of the outside scene. Since no artificial sources of UV radiation have been identified as hazardous to a pilot's vision at night, protection from such effects is not a concern in the absence of sunlight. However, intense sources of artificial broad-bandwidth light (i.e., approach and runway lights, apron lights, aircraft strobes and landing lights, airport temporary construction/detour lighting, spotlights, entertainment lasers, etc.) have been known to cause adverse visual effects (such as glare, flashblindess, and afterimage) when a pilot's eyes are adapted to low-light (Figure 9).

A recent study found that over the past two decades, visual difficulties caused by nighttime exposure to bright lights were contributing factors in at least 58 aviation accidents and incidents (5). The study also reviewed another 153 anonymous reports describing similar problems that contributed to unsafe conditions for nighttime aviation activities. While the response to visual effects is subjective, their intensity can be exacerbated by the transmittance of the windscreen and its overall physical condition. For example, windscreens that attenuate the short-wavelength (violet and blue) visible light may help to minimize some of the effects of glare. Violet and blue wavelengths are scattered more efficiently than other wavelengths. The sky looks blue, not violet, because our eyes are more sensitive to blue light, and the Sun emits more energy as blue light than it does as violet. Rayleigh's Law describes how blue light is more prone to scatter in air due to a strong wavelength versus particle size dependence, while the scattering of longer wavelengths is attributed to larger atmospheric particles, such as water molecules, rain drops, dust, smoke, and haze (6,7). Both types of scattering can contribute to visual noise, i.e., light rays that do not contribute to transmitting visual information. Figure 7 suggests that both windscreen materials block some violet and blue light; however, both windscreen materials allow approximately the same 71 to 86% transmission of violet and blue light, respectively. Once light is incident on the transparency surface, additional scattering may occur within the windscreen itself. Plastic is a relatively soft material with a tendency to scratch and pit. As these tiny irregularities build up over time, light scattering within the windscreen increases. Although glass can also become scratched and pitted, the process takes longer due to its harder, more durable surface.

Exposure to laser radiation during night operations has been a topic of concern to both pilots and the FAA for more than a decade. Illumination by a laser can be extremely disruptive to a flight crewmember trying to land an aircraft (Figure 10) and in rare instances, has resulted in lingering visual problems. A recent example of such an incident involved a Delta Air Lines First Officer (FO) who was struck with a green laser beam while flying into Salt Lake City in September 2004. The plane was tracked by the laser for about six seconds at 2,400 feet above ground level (AGL) and at an estimated range of 4,000-4,500 feet.

The FO stated he saw spots in his right eye and had problems with depth perception, but he managed to safely land the plane. In the days that followed, he reportedly saw black spots in his field of view and

Figure 10: Illumination of pilot during simulator tests using a 50 μW/cm^2 exposure from a frequency-doubled Nd:YAG green (532 nm) laser.

got intense headaches. An eye doctor found his retina was swollen, leaving him unable to fly. The problem cleared up after two weeks, and he was allowed to fly again about 10 days later (8).

A study conducted at the FAA Mike Monroney Aeronautical Center in Oklahoma City, OK, demonstrated that visual and operational performance were only slightly diminished by 5 $\mu W/cm^2$ exposure to a 532 nm green laser beam while performing typical nighttime flight operations in the Critical Flight Zone (> 2000 ft. AGL) (9). However, at this same wavelength, exposures as low as 0.5 $\mu W/cm^2$ at 100 ft. above the runway were found to seriously compromise some pilots' ability to land the aircraft safely (10). Another FAA study examined the incidence of aircraft laser illumination events over a 13-month period from January 1, 2004 to January 31, 2005 (11). This study found 90 nighttime aircraft illuminations, with 53 of those involving commercial transport aircraft and 41 resulting in cockpit illuminations. Unfortunately, with the increased availability of hand-held lasers, regulatory action alone cannot stop such incidents from occurring, and no known optical device or windscreen treatment can eliminate the risk of laser light exposure without seriously compromising the pilot's ability to see at night. However, the proper maintenance of a windscreen can help to reduce the severity of the threat to a pilot's state of dark adaptation by decreasing scattering caused by dirt, poor maintenance practices, and excessive wear.

The transmittance measurements found for the windscreens tested in this study would allow all but approximately 15% of green (525-575 nm) laser radiation to be transmitted to the pilot's eye. Glass laminate windscreens, however, would provide some additional protection by attenuating 25-45% of the radiation from red (625-675 nm) lasers. On the other hand, this difference in transmission may be negated, since the human eye's inherent sensitivity favors green light over red (Figure 11). Unfortunately, there is no easy solution for protecting pilots from exposure to artificial light sources that are orders of magnitude greater than the light level to which their eyes are adapted. Currently available laser eye protection could protect a pilot from excessive exposure but would likely interfere with aviation operations by limiting the pilot's ability to see color displays and aviation signal lights. Further research on the applicability of laser eye protection in the civil aviation environment is needed before a recommendation on its use can be formulated.

UV radiation from the Sun is the primary hazard to a pilot's ocular health during daylight flight operation. Fortunately, the UV-absorbing atmospheric ozone layer that resides in a region of the stratosphere (50,000 to 165,000 ft. above sea level) protects us from this hazard. Although it is the most dangerous type in terms of its potential to harm life on Earth, UV-C is so strongly absorbed by ozone that it does not reach Earth's surface. However, as the wavelength increases through UV-B and into UV-A, ozone absorption becomes weaker until it is

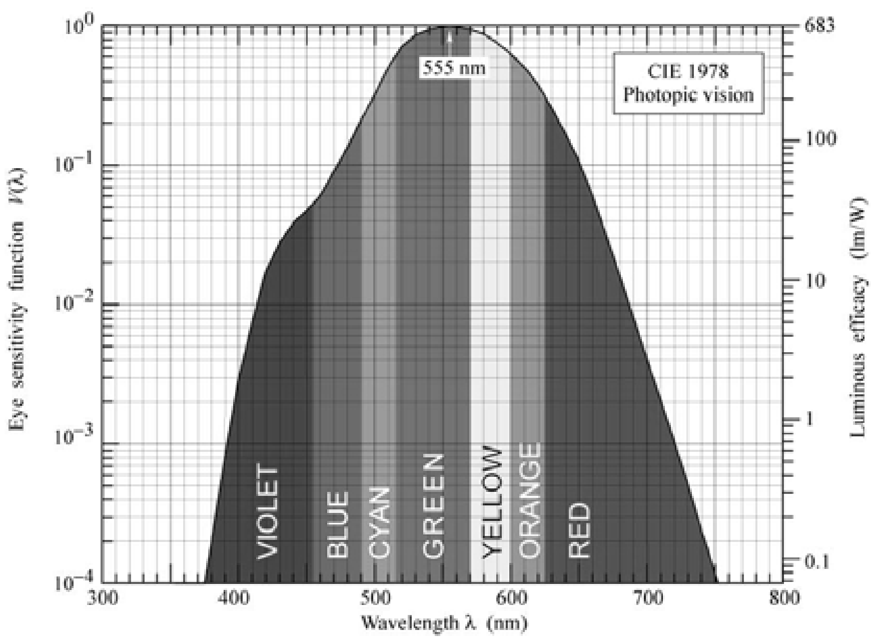

Figure 11: Luminous efficacy of the human eye by wavelength.

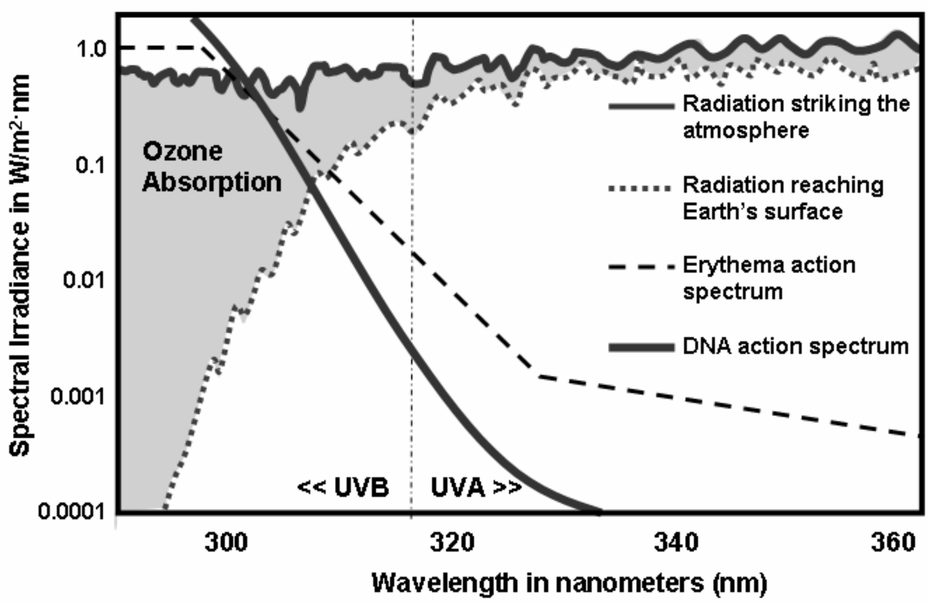

Figure 12: Ozone absorption of UV radiation with erythema and DNA action spectra.

undetectable above about 340 nm. Figure 12 represents the variation of ozone absorption with wavelength. It shows the spectrum of solar radiation striking the Earth's atmosphere and also the spectrum of solar radiation measured at ground level on a clear day in mid-June at noon. The ground level spectrum below 325 nm is reduced mostly due to ozone absorption and attenuation by air molecules and background aerosols. It also should be noted that, in general, there is a great deal of variability in ground level UV radiation due to the Sun's angle of incidence, clouds, aerosols, and other atmospheric constituents, as well as geographic location and altitude.

Studies have indicated that commercial airline pilots are at an increased risk for nuclear cataracts and some cancers (12). In addition, a study among astronauts showed an association between the incidence of cataracts and radiation exposure levels comparable to those of commercial pilots (13). These findings are of concern to pilots considering the 15% increase in the intensity of UV radiation for every additional 3,000 ft. of altitude above sea level. (Note: Between 31,000 and 41,000 ft., where most commercial aircraft fly, UV radiation exposure doubles.) Additionally, the destruction of stratospheric ozone (by chlorofluorocarbons and other pollutants) may increase UV radiation exposure. This is especially true close to the equator and both poles due to the thinning of the ozone layer in these regions (14).

Biological changes due to UV radiation exposure can be expressed in a variety of ways. An action spectrum expresses the relative efficiency for radiation of a specific wavelength to produce a particular biological effect. For erythema (sunburn) the action spectrum adopted by most international organizations is the one shown in Figure 12 (15). The erythema action spectrum indicates that skin is most vulnerable to UV-B exposure. Fortunately, ozone absorbs more than 50% of the UV-B radiation that strikes Earth's atmosphere, thus preventing it from reaching the surface. Figure 12 also shows the generalized DNA-damage action spectrum, which includes any biological effect that is a consequence of damage to the DNA molecule (16,17). Similarly, the action spectrum for cataracts has been created (18) using pig lenses (Figure 13), where it was found that very high radiant exposure levels from wavelengths longer than 315 nm (UV-A) are needed to induce subcapsular lesions in vitro; this is in agreement with another study (19) that found radiant exposures above 320 nm need to be quite high to have an effect on in vivo rabbit lenses. While the cataract action spectrum appears inverted with respect to the first two (erythema and DNA-damage) action spectra, it actually describes a similar trend with respect to radiation-induced biological response. The difference is that Figure 13 includes the probability of biological damage based on the rate of exposure. What these studies have in common is that

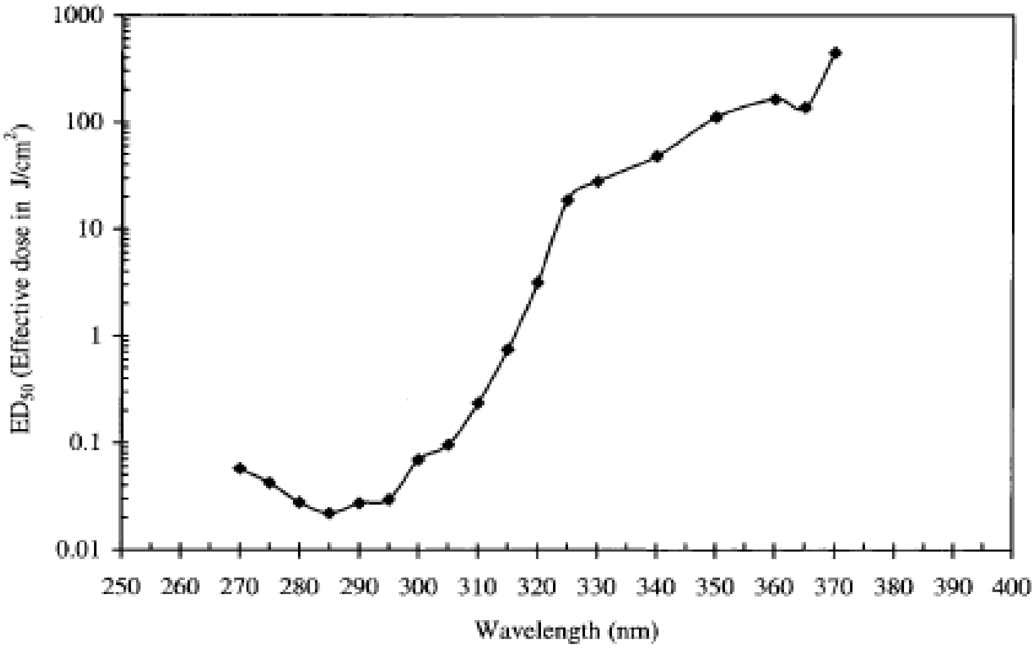

Figure 13. Plot of radiant exposure with 50% damage probability (ED_{50}) verses wavelengths showing the action spectrum for in vitro UV cataract formation.

they all show that biological change due to UV radiation exposure is more likely with exposure to UV-B than it is for UV-A exposure; or rather, UV-A exposures must be of longer duration (or more intense) to cause a similar biological change to that from exposure to UV-B.

The acute affect of excessive UV exposure to the eye is often seen as "welder's flash" or "snow blindness" (i.e., photokeratitis or keratoconjunctivitis) (20). Solar retinitis, with an accompanying central blind spot resulting from staring at the Sun, is referred to as "eclipse blindness" and associated with a retinal burn (21). Only in recent decades has it become known that solar retinitis (or photoretinitis) was the result of a photochemical injury mechanism following exposure of the retina to short-wavelength visible light (violet and blue) and not due to thermal burn as was previously speculated.

Cataract formation due to UV radiation damage to the crystalline lens has been documented by a number of epidemiologic studies. The strongest association links UV-B exposure and cortical cataract formation. Both the Beaver Dam Eye Study and a population-based survey of Maryland watermen found this association (22,23). In contrast to cataract, macular degeneration does not seem to be related to UV exposure. However, macular degeneration may be associated with excessive exposure to "visible light." In the Maryland watermen study, advanced macular degeneration was more common in men exposed to increased levels of blue light, but not in those with increased levels of UV (22). Similarly, the Beaver Dam Eye Study found that exposure to visible light was associated with age-related macular degeneration in men. No association between sunlight and macular degeneration was found in women in that study, but the authors suggest that the women studied had less sunlight exposure (3,23).

Fortunately, the windscreens tested in this study block almost all of the most disruptive short-wavelength UV radiation below 340 nm. On the other hand, since pilots are repeatedly exposed to higher levels of both UV-A and UV-B than those found at sea level, and for long periods, the cumulative effects of UV exposure are still of concern. For a pilot, hazardous exposure to naturally occurring UV and visible radiation is most likely to occur when flying over a thick cloud layer or a snow field with the Sun at its zenith. Snow reflects 85% of visible and UV radiation, while clouds can reflect up to 80%. In such conditions, sunglasses with a closely fitting wrap-around frame design are best since UV-blocking lenses are useless if radiation is allowed to enter the eye from the sides of the frame. A gray, neutral density filter to block 70-85% of all visible light is recommended to preserve color discrimination and enhance the ability to quickly adapt to lower light levels.

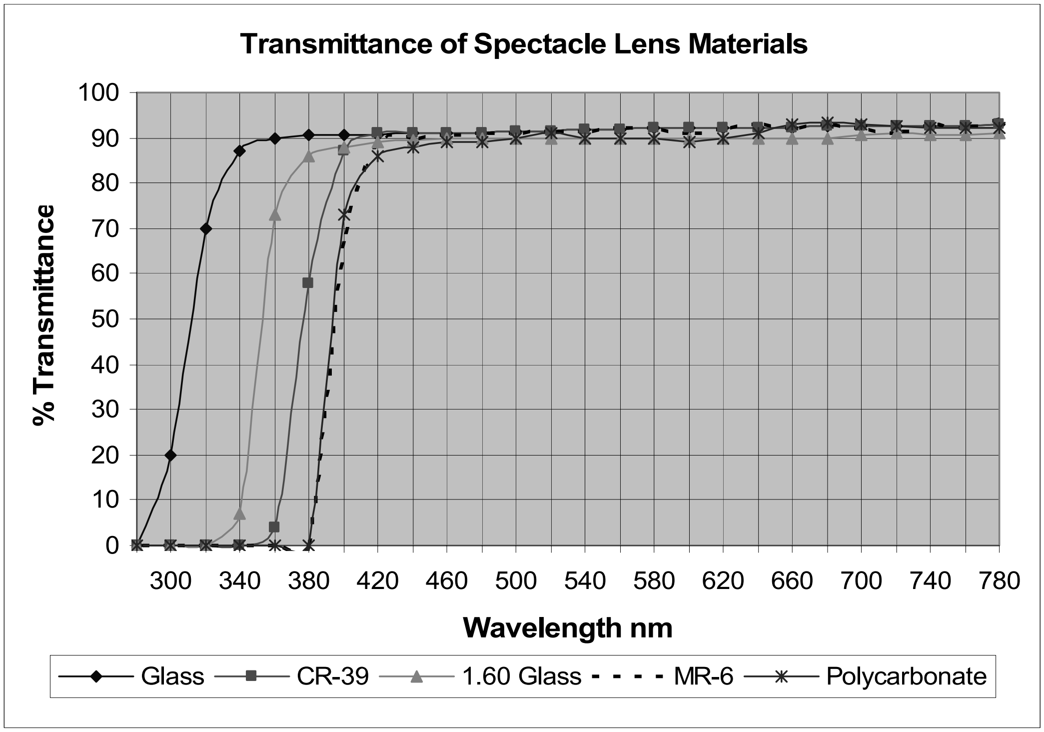

Figure 14. Transmittance of selected glass and plastic ophthalmic lens materials.

All prescription ophthalmic lens materials absorb at least some UV radiation. Transmittance data from five clear lens samples are plotted in Figure 14 (24). As this chart illustrates, high-index plastic (MR-6) and polycarbonate plastic absorb all UV radiation below 380 nm, satisfying internationally recognized standards for UV blockage for sunglasses without the need for UV coatings. These materials also result in thinner, lighter, and more shatter-resistant lenses for those requiring higher levels of refractive correction. Crown glass provides the least UV protection, transmitting 50% of UV-B at 310 nm to 90% of UV-A at 380 nm. High-index (n=1.60) glass does marginally better, blocking all UV-B but transmitting UV-A above 320 nm to approximately 85% at 380 nm. CR-39® plastic begins transmitting UV-A at 350 nm, increasing to approximately 55% transmittance at 380 nm. While there are no UV radiation standards for clear prescription lens materials, the American Optometric Association recommends that sunglasses block at least 99% of solar UV radiation below 400 nm. Without UV treatments, clear glass and CR-39® lenses fall short of this mark.

The American National Standard Institute (ANSI) and the U.S. Food and Drug Administration (FDA) recommend standards for lenses and labeling for sunglasses. ANSI standard Z80.3-2001 includes limits on UV radiation transmittance and divides sunglasses into three groups:

- Cosmetic: sunglasses that block at least 70% of UV-B and up to 60% UV-A.
- General purpose: sunglasses that block at least 95% of UV-B and a minimum of 60% UV-A.
- Special purpose: sunglasses that block at least 99% of UV-B and 60% UV-A.

The FDA requires that sunglasses intended for driving meet the International Standards Organization (ISO-14889), section 4.5, or ANSI Z80.3-2001, section 4.6.3, or carry a caution label. Sunglasses that simply filter visible radiation can actually increase UV exposure to the crystalline lens by stimulating the iris to dilate. In addition, ANSI 80.3 requires sunglasses to have a minimum transmittance of 8% for red and 6% for yellow and green to allow for proper traffic signal recognition, except for special purpose sunglasses.

UV-absorbing contact lenses are available to shield the cornea, but offer no protection to the conjunctiva, sclera, or eyelids. People often equate sunglasses with UV radiation protection. Lens tints or color, however, are not indicative of the UV blocking ability of a lens. Therefore, it is important when purchasing non-prescription, over-the-counter sunglasses to be sure they are accompanied by proper labeling and/or documentation describing their UV protection properties.

CONCLUSIONS

This study found that, of the windscreens that were tested, the laminated glass commercial aircraft windscreens transmitted substantial UV radiation below 380 nm, while the polycarbonate general aviation aircraft windscreens were more effective UV blockers. The polycarbonate windscreens transmitted almost no radiation below 380 nm. Visible light transmittance near the human eye's peak sensitivity for both dark- and light-adapted vision was slightly better for the glass windscreens; however, the glass also exhibited increased attenuation of longer wavelength light that may alter color perception, particularly for individuals with color vision deficits. Proper cleaning can maintain optimal performance by reducing glare and prolong the service life of the transparency, particularly for the (softer) plastic materials. Since the commercial aircraft windscreens that were tested did not block all harmful UV radiation, professional pilots who routinely fly at higher altitudes for longer periods of time than private pilots should take special precautions to protect their vision from UV exposure. Aircrew members should always wear lenses that provide adequate UV protection and appropriate filtering of visible light when flying during daylight hours. Further research is recommended to determine whether the transmittance values measured for this small sample of windscreens are indicative of the windscreens currently used for commercial and general aviation aircraft.

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